CONFORMS TO IEE WIRING REGULATIONS BS 7671:2001 (INCORPORATING AMENDMENTS 1:2002 & 2:2004)

ADVANCED

ELECTRICAL INSTALLATION WORK

TREVOR LINSLEY

Matched to the requirements of the 2330 Level 3 Certificate in Electrotechnical Technology from City & Guilds - Installation Route

FOURTH EDITION

ELSEVIER

Newnes

Advanced Electrical Installation Work

Fourth Edition

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CONTENTS

Preface *vii*

1 Health and safety and electrical principles 1
Introduction 1
Health and safety at work ***1***
The Health and Safety At Work Act 1974 2
The Management of Health and Safety at Work Regulations 1999 4
Provision and Use of Work Equipment Regulations 1998 4
The Control of Substances Hazardous to Health Regulations 1988 4
Personal Protective Equipment (PPE) at Work Regulations 1992 5
RIDDOR 7
The Control of Major Accidents and Hazards (COMAH) Regulations 1999 8
Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) 8
The Construction (Design and Management) Regulations 1994 (CDM) 8
The Construction (Health, Safety and Welfare) Regulations 1996 9
Building Regulations – Part P 2005 9
The Electricity Safety, Quality and Continuity Regulations 2002 10
The Electricity at Work Regulations 1989 (EWR) 11
The IEE Wiring Regulations to BS 7671:2001 11
Environmental laws and regulations ***12***
Environmental Protection Act 1990 12
Pollution Prevention and Control Regulations 2000 13
Clean Air Act 1993 13
Controlled Waste Regulations 1998 13
Waste Electrical and Electronic Equipment (WEEE) EU Directive 2005 14
Radioactive Substances Act 1993 (RSA) 15
Dangerous Substances and Preparations and Chemical Regulations 2000 15
Noise Regulations 15
The Noise and Statutory Nuisance Act 1993 16
Noise Act 1996 16
Noise at Work Regulations 1989 16
The Environmental Health Officer 17
Laws protecting people ***18***
Employment Rights Act 1996 18
Health and Safety (First Aid) Regulations 1981 20
Data Protection Act 1998 20
Prejudice and discrimination 21
The Race Relations Act 1976 (RRA) and Amendment Act 2000 22
Sex Discrimination Act 1975 (SDA) 22
Disability Discrimination Act 1995 (DDA) 22
The Human Rights Act 1998 (HRA) 23
Enforcement Law Inspectors 23
In-house Safety Representatives 24
Safe and effective working practices ***25***
Quality systems 25
Investors in People (IiP) 27
Health and safety applications 27
VDU operation hazards 32
Manual handling 35
Personal Protective Equipment 36
Safety signs 38
Accidents at work 39
Fire control 40
First aid 42

Accident reports 45
Secure electrical isolation 46
Permit-to-work system 49
The world of work 50
Good customer relationships 50
Changing work patterns 51
Electrical principles ***52***
Ohm's law 52
Resistivity 53
Temperature coefficient 54
Resistors 54
Power and energy 58
Alternating waveforms 60
Magnetism 61
Electromagnetism 62
Electrostatics 67
Alternating current theory 73
Electrical machines ***86***
Direct current motors 86
Three-phase a.c. motors 90
Single-phase a.c. motors 94
Motor starters 95
Remote control of motors 97
Installation of motors 97
Motor maintenance 99
Power factor correction 100
Transformers 102
Transformer losses 103
Transformer efficiency 103
Transformer construction 104
Instrument transformers 106
Voltage transformers 106
Current transformers 106
Electricity supply systems ***108***
Low-voltage supply system 112
Industrial wiring systems ***117***
Cables 119
Installing cables 122
Protection of structures against lightning (BS 6651) 132
Exercises *136*

2 Inspection, testing and commissioning 146
The construction industry 146
The building team 146
The electrical team 147
Designing an electrical installation 148
Legal contracts 148
Management systems 150
On-site communications 155
Construction site – safe working practice 164
Electrical safety systems ***165***
Direct contact protection 165
Earth fault protection 167
Residual current protection 168
Isolation and switching 168
Overcurrent protection 169
Semi-enclosed fuses (BS 3036) 170
Cartridge fuses (BS 1361) 171
Miniature circuit breakers (BS 3871) 172
Fusing factor 173
Position of protective devices 173
Disconnection time calculations 174
Time/current characteristics of protective devices 175
Discrimination 175
Earth fault loop impedance Z_s 176
Size of protective conductor 178
Cable selection/calculation 179
Electrical testing ***182***
Moving coil instruments 182
Moving iron instruments 184
Damping 185
Making measurements 185
Range extension 187
Dynamometer wattmeter 189
Measurement of power in a three-phase circuit 189
Energy meter 190
Tong tester 191
Phase sequence testers 191
Test equipment used by electricians 191
Test procedures 193
Live testing 194
Isolation of supply 194
Inspection and testing techniques 194
Certification and reporting 206
Safe working procedures when testing 206
Portable appliance testing (PAT) 207
Commissioning electrical systems 211
Exercises *211*

3 Fault diagnosis and rectification 217
Symptoms of an electrical fault 217
Causes of electrical faults 217
Fault diagnosis 219
Wiring circuits 219
Designing out faults 227

Finding the electrical fault 227
Safe working procedures 227
Live testing 227
Secure isolation of electrical supply 227
Faulty equipment – to repair or replace? 229
Selecting test equipment 229
Special situations 230
Antistatic precautions 231
Avoiding shutdown of IT equipment 232
Damage to electronic devices by 'overvoltage' 233
Risks associated with high frequency or large capacitive circuits 234
Presence of storage batteries 235
Safe removal of waste 236
Exercises *238*

4 Electronic components **239**
Electronic circuit symbols 239
Resistors 239
Capacitors 243
Inductors and transformers 247
Electromagnetic relays 248
Overcurrent protection 248
Packaging electronic components 248
Obtaining information and components 249
Semiconductor devices 249
Voltage divider 261
Rectification of a.c. 263
Smoothing 264
Stabilized power supplies 266
Electronic circuit assembly ***266***
Safety precautions 267
Hand-tools 267
Soldering irons and guns 267
Soldering 269
Desoldering 272
Circuit boards 272
Breadboards 275
Interconnection methods 275
Fault finding 277
Electronic test equipment ***277***
Test instruments 277
Analogue and digital displays 279
The multimeter 279
The ohmmeter 279
The cathode ray oscilloscope 281
Signal generators 283
Power supply unit 283
Mains electricity supply 284
Insulation tester 284
Logic gates and digital electronics ***284***
The AND logic gate 285
The OR gate 285
The exclusive-OR gate 286
The NOT gate 286
The NOR gate 287
The NAND gate 287
Buffers 287
Logic networks 287
Logic families 290
Working with logic 291
British Standard symbols 292
Exercises *292*

Solutions to exercises *294*
Appendices *296*
Glossary *315*
Index *325*

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PREFACE

The fourth edition of *Advanced Electrical Installation Work* has been written as a complete textbook for the City and Guilds 2330 Level 3 Certificate in Electrotechnical Technology and the City and Guilds 2356 Level 3 NVQ in Installing Electrotechnical Systems. The book meets the combined requirements of these courses, that is the core units and the electrical installation occupational units and therefore students need purchase only this one textbook for all subjects in the Level 3 examinations.

The book will also assist students taking the SCOTVEC and BTEC Electrical and Utilization units at levels II and III and many taking engineering NVQ and Modern Apprentiship courses.

Although the text is based upon the City and Guilds syllabus, the book also provides a sound basic knowledge and comprehensive guide for other professionals in the construction and electrotechnical industries.

Modern regulations place a greater responsibility upon the installing electrician for safety and the design of an installation. The latest regulations governing electrical installations are the 16th edition of the IEE Wiring Regulations (BS 7671: 2001). The fourth edition of this book has been revised and updated to incorporate the requirements and amendments of the 16th edition of the IEE Wiring Regulations BS7671:2001.

The City and Guilds examinations comprise assignments and multiple-choice papers. For this reason multiple-choice questions can be found at the end of each chapter. More traditional questions are included as an aid to private study and to encourage a thorough knowledge of the subject.

I would like to acknowledge the assistance given by the following manufacturers and organizations in the preparation of this book:

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The Institution of Electrical Engineers
The British Standards Institution
The City & Guilds of London Institute

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Trevor Linsley

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1

HEALTH AND SAFETY AND ELECTRICAL PRINCIPLES

Introduction

This first chapter of Advanced Electrical Installation work covers all of the core skills required by the City & Guilds Level 3 Certificate in Electrotechnical Technology. That is the Health and Safety Laws and Regulations and the electrical science that underpins the electrotechnical industry.

Health and Safety at Work

Let me begin by looking at the background to the modern Health and Safety Regulations and the electricity supply and wiring regulations.

Electricity generation as we know it today began when Michael Faraday conducted the famous ring experiment in 1831. This experiment, together with many other experiments of the time, made it possible for Lord Kelvin and Sebastian de Ferranti to patent in 1882 the designs for an electrical machine called the Ferranti–Thompson dynamo, which enabled the generation of electricity on a commercial scale.

In 1887 the London Electric Supply Corporation was formed with Ferranti as chief engineer. This was one of many privately owned electricity generating stations supplying the electrical needs of the UK. As the demand for electricity grew, more privately owned generating stations were built until eventually the government realized that electricity was a national asset which would benefit from nationalization.

In 1926 the Electricity Supply Act placed the responsibility for generation in the hands of the Central Electricity Board. In England and Wales the Central Electricity Generating Board (CEGB) had the responsibility for the generation and transmission of electricity on the Supergrid. In Scotland, generation was the joint responsibility of the North of Scotland Hydro-Electricity Board and the South of Scotland Electricity Board. In Northern Ireland electricity generation was the responsibility of the Northern Ireland Electricity Service.

In 1988 Cecil Parkinson, the Secretary of State for Energy in the Conservative government, proposed the denationalization of the electricity supply industry; this became law in March 1991, thereby returning the responsibility for generation, transmission and distribution to the private sector. It was anticipated that this action, together with new legislation over the security of supplies, would lead to a guaranteed quality of provision, with increased competition leading eventually to cheaper electricity.

During the period of development of the electricity services, particularly in the early days, poor design and installation led to many buildings being damaged by fire and the electrocution of human beings and livestock. It was the insurance companies which originally drew up a set of rules and guidelines of good practice in the interest of reducing the number of claims made upon them. The first rules were made by the American Board of Fire Underwriters and were quickly followed by the Phoenix Rules of 1882. In the same year the first edition of the Rules and Regulations for the Prevention of Fire Risk arising from Electrical Lighting was issued by the Institute of Electrical Engineers.

The current edition of these regulations is called the Requirements for Electrical Installations, IEE Wiring Regulations (BS 7671:2001), and since January 1993 we have been using the 16th edition. All the rules have been revised, updated and amended at regular intervals to take account of modern developments, and the 16th edition brought the UK Regulations into harmony with those of the rest of Europe.

The laws and regulations affecting the electrotechnical industry have steadily increased over the years. A further huge amount of legislation from the European law-makers in Brussels reached the UK in January 2005. These laws and regulations will permeate each and every sector of the electrotechnical industry and reform and modify our future work patterns and behaviour.

In this section I want to deal with the laws and regulations that affect our industry under three general headings because there are a large number of them, and it may help us to appreciate the reasons for them. First of all I want to look at the laws concerned with health and safety at work, making the working environment safe. Then I want to go on to the laws that protect our environment from, for example, industrial waste and pollution and finally, I will look at employment legislation and the laws which protect us as individual workers, people and citizens.

The Health and Safety at Work Act 1974

Many governments have passed laws aimed at improving safety at work but the most important recent legislation has been the Health and Safety at Work Act 1974. The purpose of the Act is to provide the legal framework for stimulating and encouraging high standards of health and safety at work; the Act puts the responsibility for safety at work on both workers and managers.

The Health and Safety at Work Act is an 'Enabling Act' that allows the Secretary of State to make further laws, known as regulations, without the need to pass another Act of Parliament. Regulations are law, passed by Parliament and are usually made under the Health and Safety at Work Act 1974. This applies to regulations based on European directives as well as new UK regulations. The way it works is that the Health and Safety at Work Act established the Health and Safety Commission (HSC) and gave it the responsibility of drafting new regulations and enforcing them through its executive arm known as the Health and Safety Executive (HSE) or through the local Environmental Health Officers (EHO). The Health and Safety Commission has equal representation from employers, trade unions and special interest groups. Their role is to set out the regulations as goals to be achieved. They describe what must be achieved in the interests of safety, but not how it must be done.

Under the Health and Safety at Work Act an employer has a duty to care for the health and safety of employees (Section 2 of the Act). To do this he must ensure that:

- the working conditions and standard of hygiene are appropriate;
- the plant, tools and equipment are properly maintained;
- the necessary safety equipment – such as personal protective equipment, dust and fume extractors and machine guards – are available and properly used;
- the workers are trained to use equipment and plant safely.

Employees have a duty to care for their own health and safety and that of others who may be affected by their actions (Section 7 of the Act). To do this they must:

- take reasonable care to avoid injury to themselves or others as a result of their work activity;
- co-operate with their employer, helping him or her to comply with the requirements of the Act;
- not interfere with or misuse anything provided to protect their health and safety.

Failure to comply with the Health and Safety at Work Act is a criminal offence and any infringement of the law can result in heavy fines, a prison sentence or both.

ENFORCEMENT

Laws and rules must be enforced if they are to be effective. The system of control under the Health and Safety at Work Act comes from the HSE which is charged with enforcing the law. The HSE is divided into a number of specialist inspectorates or sections which operate from local offices throughout the UK. From the local offices the inspectors visit individual places of work.

The HSE inspectors have been given wide-ranging powers to assist them in the enforcement of the law. They can:

1 enter premises unannounced and carry out investigations, take measurements or photographs;
2 take statements from individuals;
3 check the records and documents required by legislation;
4 give information and advice to an employee or employer about safety in the workplace;
5 demand the dismantling or destruction of any equipment, material or substance likely to cause immediate serious injury;
6 issue an improvement notice which will require an employer to put right, within a specified period of time, a minor infringement of the legislation;
7 issue a prohibition notice which will require an employer to stop immediately any activity likely to result in serious injury, and which will be enforced until the situation is corrected;
8 prosecute all persons who fail to comply with their safety duties, including employers, employees, designers, manufacturers, suppliers and the self-employed.

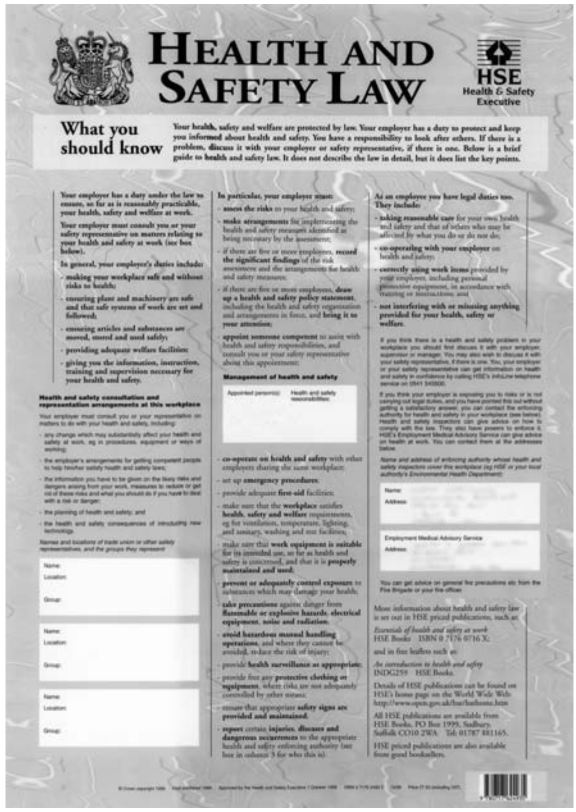


Fig. 1.1 New Health and Safety Law poster. Source: HSE © Crown copyright material is reproduced with the permission of the Controller of HMSO and Her Majesty's Stationery Office, Norwich.

SAFETY DOCUMENTATION

Under the Health and Safety at Work Act, the employer is responsible for ensuring that adequate instruction and information is given to employees to make them safety-conscious. Part 1, section 3 of the Act instructs all employers to prepare a written health and safety policy statement and to bring this to the notice of all employees. Your employer must let you know who your safety representatives are and the new health and safety poster shown in Fig. 1.1 has a blank section into which the names and contact information of your specific representatives can be added. This is a large laminated poster, 595×415 mm suitable for wall or notice board display.

All workplaces employing five or more people must display the type of poster shown in Fig. 1.1 after 30th June 2000.

To promote adequate health and safety measures the employer must consult with the employees' safety representatives. In companies which employ more than 20 people this is normally undertaken by forming a safety committee which is made up of a safety officer and employee representatives, usually nominated by a trade union. The safety officer is usually employed full-time in that role. Small companies might employ a safety supervisor, who will have other duties within the company, or alternatively they could join a 'safety group'. The safety group then shares the cost of employing a safety adviser or safety officer, who visits each company in rotation. An employee who identifies a dangerous situation should initially report to his site safety representative. The safety representative should then bring the dangerous situation to the notice of the safety committee for action which will remove the danger. This may mean changing company policy or procedures or making modifications to equipment. All actions of the safety committee should be documented and recorded as evidence that the company takes seriously its health and safety policy.

The Management of Health and Safety at Work Regulations 1999

The Health and Safety at Work Act 1974 places responsibilities on employers to have robust health and safety systems and procedures in the workplace. Directors and managers of any company who employ more than five employees can be held personally responsible for failures to control health and safety.

The Management of Health and Safety at Work Regulations 1999 tell us that employers must systematically examine the workplace, the work activity and the management of safety in the establishment through a process of '*risk assessments*'. A record of all significant risk assessment findings must be kept in a safe place and be available to an HSE inspector if required. Information based on these findings must be communicated to relevant staff and if changes in work behaviour patterns are recommended in the interests of safety, then they must be put in place. The process of risk assessment is considered in detail later in this chapter.

Risks, which may require a formal assessment in the electrotechnical industry, might be:

- working at heights;
- using electrical power tools;
- falling objects;
- working in confined places;
- electrocution and personal injury;
- working with 'live' equipment;
- using hire equipment;
- manual handling: pushing, pulling, lifting;
- site conditions: falling objects, dust, weather, water, accidents and injuries.

And any other risks which are particular to a specific type of work place or work activity.

Provision and Use of Work Equipment Regulations 1998

These regulations tidy up a number of existing requirements already in place under other regulations such as the Health and Safety at Work Act 1974, the Factories Act 1961 and the Offices, Shops and Railway Premises Act 1963.

The Provision and Use of Work Equipment Regulations 1998 places a general duty on employers to ensure minimum requirements of plant and equipment. If an employer has purchased good quality plant and equipment, which is well maintained, there is little else to do. Some older equipment may require modifications to bring it in line with modern standards of dust extraction, fume extraction or noise, but no assessments are required by the regulations other than those generally required by the Management Regulations 1999 discussed previously.

The Control of Substances Hazardous to Health Regulations 1988

The original COSHH Regulations were published in 1988 and came into force in October 1989. They were re-enacted in 1994 with modifications and improvements, and the latest modifications and additions came into force in 2002.

The COSHH Regulations control people's exposure to hazardous substances in the workplace. Regulation 6 requires employers to assess the risks to health from working with hazardous substances, to train employees in techniques which will reduce the risk and provide personal protective equipment (PPE) so that employees will not endanger themselves or others through exposure to hazardous substances. Employees should also know what cleaning, storage and disposal procedures are required and what emergency procedures to follow. The necessary information must be available to anyone using hazardous substances as well as to visiting HSE inspectors.

Hazardous substances include:

1. any substance which gives off fumes causing headaches or respiratory irritation;
2. man-made fibres which might cause skin or eye irritation (e.g. loft insulation);
3. acids causing skin burns and breathing irritation (e.g. car batteries, which contain dilute sulphuric acid);

4 solvents causing skin and respiratory irritation (strong solvents are used to cement together PVC conduit fittings and tube);
5 fumes and gases causing asphyxiation (burning PVC gives off toxic fumes);
6 cement and wood dust causing breathing problems and eye irritation;
7 exposure to asbestos – although the supply and use of the most hazardous asbestos material is now prohibited, huge amounts were installed between 1950 and 1980 in the construction industry and much of it is still in place today. In their latest amendments the COSHH Regulations focus on giving advice and guidance to builders and contractors on the safe use and control of asbestos products. These can be found in Guidance Notes EH 71.

Where personal protective equipment is provided by an employer, employees have a duty to use it to safeguard themselves.

Personal Protective Equipment (PPE) at Work Regulations 1992

PPE is defined as all equipment designed to be worn, or held, to protect against a risk to health and safety. This includes most types of protective clothing, and equipment such as eye, foot and head protection, safety harnesses, life jackets and high-visibility clothing.

Under the Health and Safety at Work Act, employers must provide free of charge any personal protective equipment and employees must make full and proper use of it. Safety signs such as those shown at Fig. 1.2 are useful reminders of the type of PPE to be used in a particular area. The vulnerable parts of the body which may need protection are the head, eyes, ears, lungs, torso, hands and feet and, additionally, protection from falls may need to be considered. Objects falling from a height present the major hazard against which head protection is provided. Other hazards include striking the head against projections and hair becoming entangled in machinery. Typical methods of protection include helmets, light duty scalp protectors called 'bump caps' and hairnets.

The eyes are very vulnerable to liquid splashes, flying particles and light emissions such as ultraviolet light, electric arcs and lasers. Types of eye protectors include safety spectacles, safety goggles and face shields. Screen based workstations are being used increasingly in industrial and commercial locations by all types of personnel. Working with VDUs (visual display units) can cause eye strain and fatigue and, therefore, this hazard is the subject of a separate section later in this chapter headed VDU operation hazards.

Fig. 1.2 Safety signs showing type of PPE to be worn.

Noise is accepted as a problem in most industries and surprisingly there has been very little control legislation. The Health and Safety Executive have published a 'Code of Practice' and 'Guidance Notes' HSG 56 for reducing the exposure of employed persons to noise. A continuous exposure limit of below 90 dB for an 8-hour working day is recommended by the code.

Noise may be defined as any disagreeable or undesirable sound or sounds, generally of a random nature, which do not have clearly defined frequencies. The usual basis for measuring noise or sound level is the decibel scale. Whether noise of a particular level is harmful or not also depends upon the length of exposure to it. This is the basis of the widely accepted limit of 90 dB of continuous exposure to noise for 8 hours per day.

A peak sound pressure of above 200 pascals or about 120 dB is considered unacceptable and 130 dB is the threshold of pain for humans. If a person has to shout to be understood at, 2 m the background noise is about 85 dB. If the distance is only 1 m, the noise level is about 90 dB. Continuous noise at work causes deafness, makes people irritable, affects concentration, causes fatigue and accident proneness and may mask sounds which need to be heard in order to work efficiently and safely.

It may be possible to engineer out some of the noise, for example, by placing a generator in a separate sound-proofed building. Alternatively, it may be possible to provide job rotation, to rearrange work locations or provide acoustic refuges.

Where individuals must be subjected to some noise at work it may be reduced by ear protectors. These may be disposable ear plugs, re-usable ear plugs or ear muffs. The chosen ear protector must be suited to the user and suitable for the type of noise and individual personnel should be trained in its correct use.

Breathing reasonably clean air is the right of every individual, particularly at work. Some industrial processes produce dust which may present a potentially serious hazard. The lung disease asbestosis is caused by the inhalation of asbestos dust or particles and the coal dust disease pneumoconiosis, suffered by many coal miners, has made people aware of the dangers of breathing in contaminated air.

Some people may prove to be allergic to quite innocent products such as flour dust in the food industry or wood dust in the construction industry. The main effect of inhaling dust is a measurable impairment of lung function. This can be avoided by wearing an appropriate mask, respirator or breathing apparatus as recommended by the company's health and safety policy and indicated by local safety signs such as those shown in Fig. 1.3.

Fig. 1.3 Breathing protection signs.

A worker's body may need protection against heat or cold, bad weather, chemical or metal splash, impact or penetration and contaminated dust. Alternatively, there may be a risk of the worker's own clothes causing contamination of the product, as in the food industry. Appropriate clothing will be recommended in the company's health and safety policy. Ordinary working clothes and clothing provided for food hygiene purposes are not included in the Personal Protective Equipment at Work Regulations. Figure 1.4 shows typical safety signs to be found in the food industry.

Hands and feet may need protection from abrasion, temperature extremes, cuts and punctures, impact or skin infection. Gloves or gauntlets provide protection from most industrial processes but should not be worn when operating machinery because they may become entangled in it. Care in selecting the appropriate protective device is required; for example, barrier creams provide only a limited protection against infection.

Boots or shoes with in-built toe caps can give protection against impact or falling objects and, when fitted with a mild steel sole plate, can also provide protection from sharp objects penetrating through the sole. Special slip resistant soles can also be provided for employees working in wet areas.

Whatever the hazard to health and safety at work, the employer must be able to demonstrate that he or she has carried out a risk analysis, made recommendations which will reduce that risk and communicated these recommendations to the workforce. Where there is a need for PPE to protect against personal injury and to

Fig. 1.4 PPE and safety signs to be found in the food industry.

create a safe working environment, the employer must provide that equipment and any necessary training which might be required and the employee must make full and proper use of such equipment and training.

RIDDOR

RIDDOR stands for Reporting of Injuries, Diseases and Dangerous Occurrences Regulation 1995, which is sometimes referred to as RIDDOR 95, or just RIDDOR for short. The HSE requires employers to report some work related accidents or diseases so that they can identify where and how risks arise, investigate serious accidents and publish statistics and data to help reduce accidents at work.

What needs reporting? Every work related death, major injury, dangerous occurrence, disease or any injury which results in an absence from work of over 3 days.

Where an employee or member of the public is killed as a result of an accident at work the employer or his representative must report the accident to the Environmental Health Department of the local authority by telephone that day and give brief details. Within 10 days this must be followed up by a complete accident report form (Form No. F2508). Major injuries sustained as a result of an accident at work include amputations, loss of sight (temporary or permanent), fractures to the body other than to fingers, thumbs or toes and any other serious injury. Once again, the Environmental Health Department of the local authority must be notified by telephone on the day that the serious injury occurs and the telephone call followed up by a completed Form F2508 within 10 days. Dangerous occurrences are listed in the regulations and include the collapse of a lift, an explosion or injury caused by an explosion, the collapse of a scaffold over five metres high, the collision of a train with any vehicle, the unintended collapse of a building and the failure of fairground equipment.

Depending upon the seriousness of the event, it may be necessary to immediately report the incident to the local authority. However, the incident must be reported within 10 days by completing Form F2508. If a doctor notifies an employer that an employee is suffering from a work related disease then form F2508A must be completed and sent to the local authority. Reportable diseases include certain poisonings, skin diseases, lung disease, infections and occupational cancer. The full list is given within the pad of report forms.

An accident at work resulting in an over 3 day injury, that is, an employee being absent from work for over three days as a result of an accident at work, requires that accident report form F2508 be sent to the local authority within 10 days.

An over 3 day injury is one which is not major but results in the injured person being away from work for more than 3 days not including the day the injury occurred.

Who are the reports sent to? They are sent to the Environmental Health Department of the local authority or the area HSE offices (See the Appendix L of this book for area office addresses). Accident report forms F2508 can also be obtained from them or by ringing the HSE Infoline or by ringing the Incident contact centre on telephone number 0845 300 9923.

For most businesses, a reportable accident, dangerous occurrence or disease is a very rare event. However, if a report is made, the company must keep a record of the occurrence for 3 years after the date on which the incident happened. The easiest way to do this would probably be to file a photocopy of the completed accident report form F2508, but a record may be kept in any form which is convenient.

The Control of Major Accidents and Hazards (COMAH) Regulations 1999

The COMAH Regulations came into force on the 1st April 1999. Their main aim is to prevent any major accidents involving dangerous substances such as chlorine, liquefied petroleum gas (LPG), explosives and arsenic pentoxide that would cause serious harm to people or damage the environment. The COMAH Regulations regard risks to the environment just as seriously as harm to people.

These regulations apply mainly to the chemical industry but also apply to some storage facilities and nuclear sites.

Operators who fall within the scope of these regulations must 'take all measures necessary to prevent major accidents and limit their consequences to people and the environment'. This sets high standards of control but by requiring operators to put in place measures for both prevention and mitigation, which means to make less serious, there is the recognition that all risks cannot be completely eliminated. Operators must, therefore, be able to show that they have taken 'all measures necessary' to prevent an accident occurring.

The COMAH Regulations are enforced by the Health and Safety Executive (HSE) and the Environment Agency.

Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)

The DSEAR Regulations came into force on the 9th December 2002 and complement the Management of Health and Safety at Work Regulations 1999. They are designed to implement the safety requirements of the Chemical Agents and Explosive Atmospheres Directive.

DSEAR deals with any dangerous substance that has the potential to create a risk to persons from energetic or energy releasing events such as fires or explosions. Dangerous substances include petrol, liquefied petroleum gas (LPG), paint, solvents and combustible or explosive dust produced in machining and sanding operations, flour mills and distilleries.

Many of these substances will also create a health risk, for example, solvents are toxic as well as being flammable. However, DSEAR does not address the health risk, only the fire and explosion risk. The potential health risk is dealt with under the COSHH Regulations discussed earlier in this Chapter.

The DSEAR Regulations follow the modern risk assessment based approach. Technical and organizational measures are required to eliminate or reduce risks as far as is reasonably practicable. There is a requirement to provide equipment and procedures to deal with accidents and emergencies and also to provide information and training for employees.

So what sort of industries does DSEAR apply to? DSEAR is concerned with the harmful effects from burns, pressure injuries from explosions and asphyxiation arising from fires and explosions. Typical industries might be those concerned with the storage of petrol as a fuel for vehicles, agricultural and horticultural storage and the movement of bulk powders for the food industry, the storing of waste dust in a range of manufacturing industries, dust produced in the mining of coal, storage and transportation of paint and LPG.

The Construction (Design and Management) Regulations 1994 (CDM)

The CDM Regulations are aimed at improving the overall management of health, safety and welfare throughout all stages of the construction project.

The person requesting that construction work commence, the client, must first of all appoint a 'duty holder', someone who has a duty of care for health, safety and welfare matters on site. This person will be called a 'planning supervisor'. The planning supervisor must produce a 'pre-tender' health and safety plan and co-ordinate and manage this plan during the early stages of construction.

The client must also appoint a principal contractor who is then required to develop the health and safety plan made by the planning supervisor, and keep it up to date during the construction process to completion.

The degree of detail in the health and safety plan should be in proportion to the size of the construction project and recognize the health and safety risks involved on that particular project. Small projects will require simple straightforward plans, large projects, or those involving significant risk, will require more detail. The CDM Regulations will apply to most large construction projects but they do not apply to the following:

- Construction work, other than demolition work, that does not last longer than 30 days and does not involve more than four people.
- Construction work carried out inside commercial buildings such as shops and offices, which does not interrupt the normal activities carried out on those premises.
- Construction work carried out for a domestic client.
- The maintenance and removal of pipes or lagging which forms a part of a heating or water system within the building.

The Construction (Health, Safety and Welfare) Regulations 1996

An electrical contractor is a part of the construction team, usually as a subcontractor, and therefore the regulations particularly aimed at the construction industry also influence the daily work procedures and environment of an electrician. The most important recent piece of legislation are the Construction Regulations.

The temporary nature of construction sites makes them one of the most dangerous places to work. These regulations are made under the Health and Safety at Work Act 1974 and are designed specifically to promote safety at work in the construction industry. Construction work is defined as any building or civil engineering work, including construction, assembly, alterations, conversions, repairs, upkeep, maintenance or dismantling of a structure.

The general provision sets out minimum standards to promote a good level of safety on site. Schedules specify the requirements for guardrails, working platforms, ladders, emergency procedures, lighting and welfare facilities. Welfare facilities set out minimum provisions for site accommodation: washing facilities, sanitary conveniences and protective clothing. There is now a duty for all those working on construction sites to wear head protection, and this includes electricians working on site as subcontractors.

Building Regulations – Part P 2005

The Building Regulations lay down the design and build standards for construction work in buildings in a series of Approved Documents. The scope of each Approved Document is given below:

Part A	structure
Part B	fire safety
Part C	site preparation and resistance to moisture
Part D	toxic substances
Part E	resistance to the passage of sound
Part F	ventilation
Part G	hygiene
Part H	drainage and waste disposal
Part J	combustion appliances and fuel storage systems
Part K	protection from falling, collision and impact.
Part L	conservation of fuel and power
Part M	access and facilities for disabled people
Part N	glazing – safety in relation to impact, opening and cleaning
Part P	electrical safety

Part P of the Building Regulations was published on the 22nd July 2004, bringing domestic electrical installations in England and Wales under building regulations control. This means that anyone carrying out domestic electrical installation work from 1st January 2005 must comply with Part P of the Building Regulations.

If the electrical installation meets the requirements of the IEE Regulations BS 7671, then it will also meet the requirements of Part P of the Building Regulations, so no change there. What is going to change under Part P is this new concept of 'notification' to carry out electrical work.

NOTIFIABLE ELECTRICAL WORK

Any work to be undertaken by a firm or individual who is *not* registered under an 'approved competent person scheme' must be notified to the Local Authority Building Control Body before work commences. That is, work that involves:

- the provision of at least one new circuit,
- work carried out in kitchens,
- work carried out in bathrooms,
- work carried out in special locations such as swimming pools and hot air saunas.

Upon completion of the work, the Local Authority Building Control Body will test and inspect the electrical work for compliance with Part P of the Building Regulations.

NON-NOTIFIABLE ELECTRICAL WORK

Work carried out by a person or firm registered under an authorized Competent Persons Self-Certification Scheme or electrical installation work that does not include the provision of a new circuit. This includes work such as:

- replacing accessories such as socket outlets, control switches and ceiling roses;
- replacing a like for like cable for a single circuit which has become damaged by, for example, impact, fire or rodent;
- re-fixing or replacing the enclosure of an existing installation component providing the circuits protective measures are unaffected;
- providing mechanical protection to existing fixed installations;
- adding lighting points (light fittings and switches) to an existing circuit, provided that the work is not in a kitchen, bathroom or special location;
- installing or upgrading the main or supplementary equipotential bonding provided that the work is not in a kitchen, bathroom or special location.

All replacement work is non-notifiable even when carried out in kitchens, bathrooms and special locations, but certain work carried out in kitchens, bathrooms and special locations may be notifiable, even when carried out by an authorized competent person. The IEE propose to publish a guide early in 2005 called the *Electricians Guide* to the Building Regulations which will bring clarity to this subject. In specific cases the Local Authority Building Control Officer or an approved Inspector will be able to confirm whether Building Regulations apply.

Failure to comply with the Building Regulations is a criminal offence and Local Authorities have the power to require the removal or alteration of work that does not comply with these requirements.

Electrical work carried out by DIY home-owners will still be permitted after the introduction of Part P. Those carrying out notifiable DIY work must first submit a building notice to the Local Authority before the work begins. The work must then be carried out to the standards set by the IEE Wiring Regulations BS 7671 and a building control fee paid for such work to be inspected and tested by the Local Authority.

COMPETENT PERSONS SCHEME

The Competent Persons Self-Certification Scheme is aimed at those who carry out electrical installation work as the primary activity of their business. The Government has approved schemes to be operated by BRE Certification Ltd., British Standards Institution, ELECSA Ltd., NICEIC Certification Services Ltd., and Napit Certification Services Ltd. All the different bodies will operate the scheme to the same criteria and will be monitored by the Office of the Deputy Prime Minister.

Those individuals or firms wishing to join the Competent Persons Scheme will need to demonstrate their competence, if necessary, by first undergoing training. The work of members will then be inspected at least once each year. There will be an initial registration and assessment fee and then an annual membership and inspection fee.

The Electricity Safety, Quality and Continuity Regulations 2002

The Electricity Safety, Quality and Continuity Regulations replaces the Electricity Supply Regulations 1988. They are statutory regulations which are enforceable by the laws of the land. They are designed to ensure a proper and safe supply of electrical energy up to the consumer's terminals.

These regulations impose requirements upon the regional electricity companies regarding the installation and use of electric lines and equipment. The regulations are administered by the Engineering

Inspectorate of the Electricity Division of the Department of Energy and will not normally concern the electrical contractor except that it is these regulations which lay down the earthing requirement of the electrical supply at the meter position.

The regional electricity companies must declare the supply voltage and maintain its value between prescribed limits or tolerances.

The government agreed on 1 January 1995 that the electricity supplies in the United Kingdom would be harmonized with those of the rest of Europe. Thus the voltages used previously in low-voltage supply systems of 415 and 240 V have become 400 V for three-phase supplies and 230 V for single-phase supplies. The permitted tolerances to the nominal voltage have also been changed from ±6% to +10% and −6%. This gives a voltage range of 216 to 253 V for a nominal voltage of 230 and 376 V to 440 V for a nominal supply voltage of 400 V.

The next change will come in 2005, when the tolerance levels will be adjusted to ±10% of the declared nominal voltage.

The frequency is maintained at an average value of 50 Hz over 24 hours so that electric clocks remain accurate.

Regulation 29 gives the area boards the power to refuse to connect a supply to an installation which in their opinion is not constructed, installed and protected to an appropriately high standard. This regulation would only be enforced if the installation did not meet the requirements of the IEE Regulations for Electrical Installations.

The Electricity at Work Regulations 1989 (EWR)

This legislation came into force in 1990 and replaced earlier regulations such as the Electricity (Factories Act) Special Regulations 1944. The Regulations are made under the Health and Safety at Work Act 1974, and enforced by the Health and Safety Executive. The purpose of the Regulations is to 'require precautions to be taken against the risk of death or personal injury from electricity in work activities'.

Section 4 of the EWR tells us that 'all systems must be constructed so as to prevent danger …, and be properly maintained.… Every work activity shall be carried out in a manner which does not give rise to danger.… In the case of work of an electrical nature, it is preferable that the conductors be made dead before work commences'.

The EWR do not tell us specifically how to carry out our work activities and ensure compliance, but if proceedings were brought against an individual for breaking the EWR, the only acceptable defence would be 'to prove that all reasonable steps were taken and all diligence exercised to avoid the offence' (Regulation 29).

An electrical contractor could reasonably be expected to have 'exercised all diligence' if the installation was wired according to the IEE Wiring Regulations (see below). However, electrical contractors must become more 'legally aware' following the conviction of an electrician for manslaughter at Maidstone Crown Court in 1989. The Court accepted that an electrician had caused the death of another man as a result of his shoddy work in wiring up a central heating system. He received a 9 month suspended prison sentence. This case has set an important legal precedent, and in future any tradesman or professional who causes death through negligence or poor workmanship risks prosecution and possible imprisonment.

The IEE Wiring Regulations to BS 7671:2001

REQUIREMENTS FOR ELECTRICAL INSTALLATIONS

The Institution of Electrical Engineers Requirements for Electrical Installations (the IEE Regulations) are non-statutory regulations. They relate principally to the design, selection, erection, inspection and testing of electrical installations, whether permanent or temporary, in and about buildings generally and to agricultural and horticultural premises, construction sites and caravans and their sites. Paragraph 7 of the introduction to the Electricity at Work Regulations (EWR) says: 'the IEE Wiring Regulations is a code of practice which is widely recognized and accepted in the United Kingdom and compliance with them is likely to achieve compliance with all relevant aspects of the Electricity at Work Regulations'. The IEE Wiring Regulations only apply to installations operating at a voltage up to 1000 V a.c. They do not apply to electrical installations in mines and quarries, where special regulations apply because of the adverse conditions experienced there.

The current edition of the IEE Wiring Regulations, is the 16th edition incorporating amendment number 1:2002 and 2:2004. The main reason for incorporating the IEE Wiring Regulations into British Standard BS 7671 was to create harmonization with European standards.

To assist electricians in their understanding of the Regulations a number of guidance notes have been published. The guidance notes which I will frequently make reference to in this book are those contained in the *On Site Guide*. Seven other guidance notes booklets are also currently available. These are:

- *Selection and Erection*;
- *Isolation and Switching*;
- *Inspection and Testing*;
- *Protection against Fire*;
- *Protection against Electric Shock*;
- *Protection against Overcurrent*;
- *Special Locations.*

These guidance notes are intended to be read in conjunction with the Regulations.

The IEE Wiring Regulations are the electricians bible and provide the authoritative framework of information for anyone working in the electrotechnical industry.

Environmental Laws and Regulations

Environmental laws protect the environment in which we live by setting standards for the control of pollution to land, air and water.

If a wrong is identified in the area in which we now think of as 'environmental' it can be of two kinds.

1. An offence in common law which means damage to property, nuisance or negligence leading to a claim for damages.
2. A statutory offence against one of the laws dealing with the protection of the environment. These offences are nearly always 'crimes' and punished by fines or imprisonment rather than by compensating any individual.

The legislation dealing with the environment has evolved for each part – air, water, land noise, radioactive substances – and we will now look at some of the regulations and try to see the present picture at the beginning of the new millennium.

Environmental Protection Act 1990

In the context of Environmental Law, the Environmental Protection Act 1990 was a major piece of legislation. The main sections of the Act are:

Part 1 Integrated pollution control by HM Inspectorate of Pollution, and air pollution control by Local Authorities
Part 2 Wastes on land
Part 3 Statutory nuisances and clean air
Part 4 Litter
Part 5 Radioactive Substances Act 1960
Part 6 Genetically Modified Organisms
Part 7 Nature Conservation
Part 8 Miscellaneous, including contaminated land.

The Royal Commission of 1976 identified that a reduction of pollutant to one medium, air, water or land, then lead to an increase of pollutant to another. It, therefore, stressed the need to take an integrated approach to pollution control. The processes subject to an integrated pollution control are:

- air emissions;
- processes which give rise to significant quantities of special waste, that is, waste defined in law in terms of its toxicity or flammability;
- processes giving rise to emissions to sewers or 'Red List' substances. These are 23 substances including mercury, cadmium and many pesticides, which are subject to discharge consent to the satisfaction of the Environment Agency.

Where a process is under integrated control the Inspectorate is empowered to set conditions to ensure that the best practicable environmental option (BPEO) is employed to control pollution. This is the cornerstone of the Environmental Protection Act.

Pollution Prevention and Control Regulations 2000

The system of Pollution Prevention and Control is replacing that of Integrated Pollution Control established by the Environmental Protection Act 1990, thus bringing Environmental Law into the new millennium and implementing the European Directive (EC/96/61) on integrated pollution prevention and control. The new system will be fully implemented by 2007.

Pollution Prevention and Control is a regime for controlling pollution from certain industrial activities. This regime introduces the concept of Best Available Technique (BAT) for reducing and preventing pollution to an acceptable level.

Industrial activities are graded according to their potential to pollute the environment:

- A(1) installations are regulated by the Environment Agency.
- A(2) installations are regulated by the Local Authorities.
- Part B installations are also regulated by the Local Authority.

All three systems require the operators of certain industrial installations to obtain a permit to operate. Once an operator has submitted a permit application, the regulator then decides whether to issue a permit. If one is issued it will include conditions aimed at reducing and preventing pollution to acceptable levels. A(1) installations are generally perceived as having the greatest potential to pollute the environment. A(2) installations and Part B installations would have the least potential to pollute.

The industries affected by these regulations are those dealing with petrol vapour recovery, incineration of waste, mercury emissions from crematoria, animal rendering, non-ferrous foundry processes, surface treating of metals and plastic materials by powder coating, galvanizing of metals and the manufacture of certain specified composite wood based boards.

Clean Air Act 1993

We are all entitled to breathe clean air but until quite recently the only method of heating houses and workshops was by burning coal, wood or peat in open fires. The smoke from these fires created air pollution and the atmosphere in large towns and cities was of poor quality. On many occasions in the 1950s the burning of coal in London was banned because the city was grinding to a halt because of the combined effect of smoke and fog, called smog. Smog was a very dense fog in which you could barely see more than a metre in front of you and which created serious breathing difficulties. In the new millennium we are no longer dependent upon coal and wood to heat our buildings, smokeless coal has been created and the gaseous products of combustion are now diluted and dispersed by new chimney design regulations. Using well engineered combustion equipment together with the efficient arrestment of small particles in commercial chimneys of sufficient height, air pollution has been much reduced. This is what the Clean Air Act set out to achieve and it has been largely successful.

The Clean Air Act applied to all small and medium sized companies operating furnaces, boilers, or incinerators. Compliance with the Act does not require an application for authorization and so companies must make sure that they do not commit an offence. In general the emission of dark smoke from any chimney is unacceptable. The emission of dark smoke from any industrial premises is also unacceptable. This might be caused by, for example, the burning of old tyres or old cable.

In England, Scotland and Wales it is not necessary for the Local Authority to have witnessed the emission of dark smoke before taking legal action. Simply the evidence of burned materials, which potentially give rise to dark smoke when burned, is sufficient. In this way the law aims to stop people creating dark smoke under the cover of darkness.

A public nuisance is ‘an act unwarranted by law or an omission to discharge a legal duty which materially affects the life, health, property, morals or reasonable comfort or convenience of Her Majesty’s subjects’. This is a criminal offence and Local Authorities can prosecute, defend or appear in proceedings that affect the inhabitants of their area.

Controlled Waste Regulations 1998

Under these Regulations we have a ‘Duty of Care to handle, recover and dispose of all waste responsibly’.

This means that all waste must be handled, recovered and disposed of by individuals or businesses that are authorized to do so under a system of signed Waste Transfer Notes.

The Environmental Protection (Duty of Care) Regulations 1991 state that as a business you have a duty to ensure that any waste you produce is handled safely and in accordance with the law. This is the 'Duty of Care' and applies to anyone who produces, keeps, carries, treats or disposes of waste from business or industry.

You are responsible for the waste that you produce, even after you have passed it on to another party such as a Skip Hire company, a Scrap Metal merchant, recycling company or local council. The Duty of Care has no time limit and extends until the waste has either been finally and properly disposed of or fully recovered.

So what does this mean for your company?

- Make sure that waste is only transferred to an authorized company.
- Make sure that waste being transferred is accompanied by the appropriate paperwork showing what was taken, where it was to be taken and by whom.
- Segregate the different types of waste that your work creates.
- Label waste skips and waste containers so that it is clear to everyone what type of waste goes into that skip.
- Minimize the waste that you produce and do not leave waste behind for someone else to clear away. Remember there is no time limit on your Duty of Care for waste.

Occupiers of domestic properties are exempt from the Duty of Care for the household waste that they produce. However, they do have a Duty of Care for the waste produced by, for example, a trades person working at a domestic property.

Special waste is covered by the Special Waste Regulations 1996 and is waste that is potentially hazardous or dangerous and which may, therefore, require special precautions during handling, storage, treatment or disposal. Examples of special waste are asbestos, lead-acid batteries, used engine oil, solvent based paint, solvents, chemical waste and pesticides. The disposal of special waste must be carried out by a competent person, with special equipment and a licence.

Electrotechnical companies produce relatively small amounts of waste and even smaller amounts of special waste. Most companies buy in the expertise of specialist waste companies these days and build these costs into the contract.

Waste Electrical and Electronic Equipment (WEEE) EU Directive 2005

Early in the year 2005 the Department for Trade and Industry (DTI) and the Department for Environment, Food and Rural Affairs (DEFRA) are due to publish regulations to ensure that Britain complies with its EU obligation to recycle waste from electrical products. The Regulation will come into effect in August 2005 and from that date any company which makes, distributes or trades in electrical or electronic goods such as household appliances, sports equipment and even torches and toothbrushes will have to make arrangements for recycling these goods at the end of their useful life. Batteries will be covered separately by yet another forthcoming EU directive.

Producers of electrical and electronic equipment must have their plans in place by the first quarter of 2005 for dealing with the return and recycling of equipment after August 2005. As I write this section in December 2004 it is not yet clear with whom companies must register, but as the new year gets under way, much more publicity will become available.

Some sectors are better prepared for the new regulations than others. Mobile phone operators, O2, Orange, Virgin and Vodaphone, along with retailers such as Currys and Dixons, have already joined together to recycle their mobile phones collectively. In Holland the price of a new car now includes a charge for the recycling costs.

If the WEEE Regulations are likely to affect your company from August 2005, you need to look out for the Government supported awareness campaign that will help businesses understand how they will be responsible for the recovery of their equipment under the new EU Directive. Information is also available on the DTI and DEFRA website under WEEE.

Radioactive Substances Act 1993 (RSA)

These regulations apply to the very low ionizing radiation sources used by specialized industrial contractors. The radioactive source may be sealed or unsealed. Unsealed sources are added to a liquid in order to trace the direction or rate of flow of that liquid. Sealed radioactive sources are used in radiography for the non-destructive testing of materials or in liquid level and density gauges.

This type of work is subject to the Ionising Radiations Regulations 1999 (IRR), which impose comprehensive duties on employers to protect people at work against exposure to ionizing radiation. These regulations are enforced by the Health and Safety Executive, while the Radioactive Substances Act is enforced by the Environmental Agency.

The RSA 1993 regulates the keeping, use, accumulation and disposal of radioactive waste, while the IRR 1999 regulates the working and storage conditions when using radioactive sources. The requirements of RSA 1993 are in addition to and separate from IRR 1999 for any industry using radioactive sources. These regulations also apply to offshore installations and to work in connection with pipelines.

Dangerous Substances and Preparations and Chemicals Regulations 2000

Chemical substances that are classified as carcinogenic, mutagenic or toxic, or preparations which contain those substances, constitute a risk to the general public because they may cause cancer, genetic disorders and birth defects, respectively.

These Regulations were introduced to prohibit the supply of these dangerous drugs to the general public, to protect consumers from contracting fatal diseases through their use.

The Regulations require that new labels be attached to the containers of these drugs which identify the potential dangers and indicate that they are restricted to professional users only.

The Regulations implement Commission Directive 99/43/EC, known as the 17th Amendment, which brings the whole of Europe to an agreement that these drugs must not be sold to the general public, this being the only way of offering the highest level of protection for consumers.

The Regulations will be enforced by the Local Authority Trading Standards Department.

Noise Regulations

Before 1960 noise nuisance could only be dealt with by common law as a breach of the peace under various Acts or local by-laws. In contrast, today there are many statutes, Government circulars, British Standards and European Union Directives dealing with noise matters. Environmental noise problems have been around for many years. During the eighteenth century, in the vicinity of some London hospitals, straw was put on the roads to deaden the sound of horses' hooves and the wheels of carriages. Today we have come a long way from this self-regulatory situation.

In the context of the *Environmental Protection Act 1990*, noise or vibration is a statutory nuisance if it is prejudicial to health or is a nuisance. However, nuisance is not defined and has exercised the minds of lawyers, magistrates and judges since the concept of nuisance was first introduced in the 1936 Public Health Act. There is a wealth of case law but a good working definition might be 'A statutory nuisance must materially interfere with the enjoyment of one's dwelling. It is more than just irritating or annoying and does not take account of the undue sensitivity of the receiver'.

The line that separates nuisance from no nuisance is very fine and non-specific. Next door's intruder alarm going off at 3 a.m. for an hour or more is clearly a statutory nuisance, whereas one going off a long way from your home would not be a nuisance. Similarly, an all night party with speakers in the garden would be a nuisance, whereas an occasional party finishing at say midnight would not be a statutory nuisance.

At Stafford Crown Court on the 1st November 2004, Alton Towers, one of the country's most popular Theme Parks, was ordered by a judge to reduce noise levels from its 'white knuckle' rides. In the first judgment of its kind, the judge told the Park's owners that neighbouring residents must not be interrupted by noise from rides such as Nemesis, Air, Corkscrew, Oblivion or from loudspeakers or fireworks.

The owners of Alton Towers, Tussauds Theme Parks Ltd., were fined the maximum sum of £5000 and served with a Noise Abatement Order for being guilty of breaching the 1990 Environmental Protection Act. Mr Richard Buxton, for the prosecution, said that the £5000 fine reflected the judge's view that Alton Towers had made little or no effort to reduce the noise nuisance.

Many nuisance complaints under the Act are domestic and are difficult to assess and investigate. Barking dogs, stereos turned up too loud, washing machines running at night to use 'low-cost' electricity, television, DIY activities are all difficult to assess precisely as statutory nuisance. Similarly, sources of commercial noise complaints are also varied and include deliveries of goods during the night, general factory noises, refrigeration units, noise from public houses and clubs are all common complaints.

Industrial noise can be complex and complaints difficult to resolve both legally and technically. Industrial noise assessment is aided by BS 4142 but no guidance exists for other noise nuisance. The Local Authority has a duty to take reasonable steps to investigate all complaints and to take appropriate action.

The Noise and Statutory Nuisance Act 1993

This Act extended the statutory nuisance provision of the Environmental Protection Act 1990 to cover noise from vehicles, machinery or equipment in the streets. The definition of equipment includes musical instruments but the most common use of this power is to deal with car alarms and house intruder alarms being activated for no apparent reason and which then continue to cause a nuisance for more than 1 hour.

In the case of a car alarm a notice is fixed to the vehicle and an officer from the Local Authority spends 1 hour trying to trace the owner with help from the Police and their National Computer system. If the alarm is still sounding at the end of this period, then the Local Authority Officer can break into the vehicle and silence the alarm. The vehicle must be left as secure as possible but if this cannot be done then it can be removed to a safe compound after the Police have been notified. Costs can be recovered from the registered keeper.

Home intruder alarms that have been sounding for 1 hour can result in a 'Notice' being served on the occupier of the property, even if he or she is absent from the property at the time of the offence. The Notice can be served by putting it through a letterbox. A Local Authority Officer can then immediately silence the alarm without going into the property. However, these powers are *adoptive* and some Local Authorities have indicated that they will not adopt them because Sections 7 to 9 of the Act makes provision for incorporating the 'Code of Practice relating to Audible Intruder Alarms' into the statute. The two key points of the Code are the installation of a 20 minute cut-off of the external sounder and the notification to the Police and Local Authority of two key holders who can silence the alarm.

Noise Act 1996

This Act clarifies the powers which may be taken against work which is in default under the nuisance provision of the Environmental Protection Act 1990. It provides a mechanism for permanent deprivation, return of seized equipment and charges for storage.

The Act also includes an *adoptive* provision making night time noise between 2300 and 0700 hours a criminal offence if the noise exceeds a certain level to be prescribed by the Secretary of State. If a notice is not complied with, a fixed penalty may be paid instead of going to court.

Noise at Work Regulations 1989

The Noise at Work Regulations, unlike the previous vague or limited provisions, apply to all work places and require employers to carry out assessments of the noise levels within their premises and to take appropriate action where necessary. The 1989 Regulations came into force on the 1st January 1990 implementing in the United Kingdom the EC Directive 86/188/EEC 'The Protection of Workers from Noise'.

Three action levels are defined by the Regulations:

1 The first action level is a daily personal noise exposure of 85 decibels, expressed as 85 dB(A).
2 The second action level is a daily personal noise exposure of 90 dB(A).
3 The third defined level is a peak action level of 140 dB(A) or 200 pascals of pressure which is likely to be linked to the use of cartridge operated tools, shooting guns or similar loud explosive noises. This action level is likely to be most important where workers are subjected to a small number of loud impulses during an otherwise quiet day.

The Noise at Work Regulations are intended to reduce hearing damage caused by loud noise. So, what is a loud noise? If you cannot hear what someone is saying when they are 2 m away from you or if they have to shout to make themselves heard, then the noise level is probably above 85 dB and should be measured by a competent person.

At the first action level an employee must be provided with ear protection (ear muffs or ear plugs) on request. At the second action level the employer must reduce, so far as is reasonably practicable, other than by providing ear protection, the exposure to noise of that employee.

Hearing damage is cumulative, it builds up, leading eventually to a loss of hearing ability. Young people, in particular, should get into the routine of avoiding noise exposure before their hearing is permanently damaged. The damage can also take the form of permanent tinnitus (ringing noise in the ears) and an inability to distinguish words of similar sound such as bit and tip.

Vibration is also associated with noise. Direct vibration through vibrating floors or from vibrating tools, can lead to damage to the bones of the feet or hands. A condition known as 'vibration white finger' is caused by an impaired blood supply to the fingers, associated with vibrating hand tools.

Employers and employees should not rely too heavily on ear protectors. In practice, they reduce noise exposure far less than is often claimed, because they may be uncomfortable or inconvenient to wear. To be effective, ear protectors need to be worn all the time when in noisy places. If left off for even a short time, the best protectors cannot reduce noise exposure effectively.

Protection against noise is best achieved by controlling it at source. Wearing ear protection must be a last resort. Employers should:

- design machinery and processes to reduce noise and vibration (mounting machines on shock absorbing materials can dampen out vibration);
- when buying new equipment, where possible, choose quiet machines. Ask the supplier to specify noise levels at the operators working position;
- enclose noisy machines in sound absorbing panels;
- fit silencers on exhaust systems;
- install motor drives in a separate room away from the operator;
- inform workers of the noise hazard and get them to wear ear protection;
- reduce a worker's exposure to noise by job rotation or provide a noise refuge.

New regulations will be introduced in 2006 which will reduce the first action level to 80 dB(A) and the second level to 85 dB(A) with a peak action level of 98 dB(A) or 140 pascals of pressure. Every employer must make a 'noise' assessment and provide workers with information about the risks to hearing if the noise level approaches the first action level. He must do all that is reasonably practicable to control the noise exposure of his employees and clearly mark ear protection zones. Employees must wear personal ear protection whilst in such a zone.

The Environmental Health Officer

The responsibilities of the Environmental Health Officer are concerned with reducing risks and eliminating the dangers to human health associated with the living and working environment. They are responsible for monitoring and ensuring the maintenance of standards of environmental and public health, including food safety, workplace health and safety, housing, noise, odour, industrial waste, pollution control and communicable diseases in accordance with the law. Although they have statutory powers with which to enforce the relevant regulations, the majority of their work involves advising and educating in order to implement public health policies.

The majority of Environmental Health Officers are employed by Local Authorities, who are the agencies concerned with the protection of public health. Increasingly, however, Officers are being employed by the private sector, particularly those concerned with food, such as large hotel chains, airlines and shipping companies.

Your Local Authority Environmental Health Officer would typically have the responsibility of enforcing the environmental laws discussed above. Their typical work activities are to:

- ensure compliance with the Health and Safety at Work Act 1974, the Food Safety Act 1990 and the Environmental Protection Act 1990;
- carry out Health and Safety investigations, food hygiene inspections and food standards inspections;
- investigate public health complaints such as illegal dumping of rubbish, noise complaints and inspect contaminated land;
- investigate complaints from employees about their workplace and carry out accident investigations;
- investigate food poisoning outbreaks;
- obtain food samples for analysis where food is manufactured, processed or sold;
- visit housing and factory accommodation to deal with specific incidents such as vermin infestation and blocked drains;
- test recreational water, such as swimming pool water and private water supplies in rural areas;
- inspect and licence pet shops, animal boarding kennels, riding stables and zoos;
- monitor air pollution in heavy traffic area and remove abandoned vehicles;
- work in both an advisory capacity and as enforcers of the law, educating managers of premises on issues which affect the safety of staff and members of the public.

In carrying out these duties, Officers have the right to enter any workplace without giving notice, although notice may be given if they think it appropriate. They may also talk to employees, take photographs and samples and serve an Improvement Notice, detailing the work which must be carried out if they feel that there is a risk to health and safety that needs to be dealt with.

Laws Protecting People

We have now looked at some of the major pieces of legislation that affect our working environment and some of the main pieces of environmental law. Let us now look at some of the laws and regulations that protect and affect us as individuals, and our human rights and responsibilities.

Employment Rights Act 1996

If you work for a company you are an employee and you will have a number of legal rights under the Employment Rights Act 1996.

As a trainee in the electrotechnical industry you are probably employed by a company and, therefore, are an employee. There are strict guidelines regarding those who are employed and those who are self-employed. Indicators of being employed are listed below:

- You work wholly or mainly for one company and work is centred upon the premises of the company.
- You do not risk your own money.
- You have no business organization such as a storage facility or stock in trade.
- You do not employ anyone.
- You work a set number of hours in a given period and are paid by the hour and receive a weekly or monthly wage or salary.
- Someone else has the right to control what you do at work even if such control is rarely practised.

Indicators of being self-employed are as follows:

- You supply the materials, plant and equipment necessary to do the job.
- You give a price for doing a job and will bear the consequences if your price is too low or something goes wrong.
- You have the right to hire other people who will answer to you and are paid by you to do a job.
- You may be paid an agreed amount for a job regardless of how long it takes or be paid according to some formula, for example, a fee to 'first fix' a row of houses.
- Within an overall deadline, you have the right to decide how and when the work will be done.

The titles 'employed' or 'self-employed' are not defined by statute but have emerged through cases coming before the courts. The above points will help in deciding the precise nature of the working relationship.

Home working is a growing trend which prompts the question as to whether home workers are employed or self-employed. As in any circumstance, it will depend upon the specific conditions of employment, and the points mentioned above may help to decide the question.

The Inland Revenue look with concern at those people who claim to be self-employed but do all or most of their work for one company. There is a free leaflet available from local Inland Revenue Offices, IR 56 – titled 'Employed or Self-Employed' – which will give further guidance if required.

If you are an employee you have a special relationship in law with your employer which entitles you to the following benefits:

- A written statement of the particulars of your employment. It is clearly in the interests of both parties to understand at the outset of their relationship the terms and conditions of employment. The legal relationship between employer and employee is one of contract. Both parties are bound by the agreed terms but the contract need not necessarily be in writing, although contracts of apprenticeship must be in writing.
- The date your employment started.
- The continuity of service, that is, whether employment with a previous employer is to count as part of an employee's continuous service. Continuous service is normally with one employer but there are exceptions, for example, if a business is transferred or taken over or there is a change of partners or trustees. This is important because many employees rights depend on the need to show that he or she has worked for the 'appropriate period' and this is known as '**continuous service**'.
- The job title.
- The normal place from which you work.
- A brief description of your work.
- The hours to be worked.
- Holiday entitlement and holiday pay.
- Sick pay entitlement.
- Pension scheme arrangements.
- The length of notice which an employee is obliged to give and is entitled to receive to terminate his contract of employment.
- Where the employment is not intended to be permanent, the period for which it is expected to continue and the date when it is to end.
- Disciplinary and grievance procedures.
- The rate of pay and frequency, weekly or monthly.
- An itemized pay statement showing
  - (i) the gross amount of the wage or salary.
  - (ii) the amounts of any deductions and the purpose for which they have been made. This will normally be tax and National Insurance contributions, but may also include payments to professional bodies or Trade Unions.
  - (iii) The net amount of salary being paid.

An **employer** has responsibilities to all employees. Even if the responsibilities are not written down in the contract of employment, they are implied by law. Case histories speak of a relationship of trust, confidence and respect. These responsibilities include:

- The obligation to pay an employee for work done.
- The obligation to treat an employee fairly.
- The obligation to take reasonable care of an employee's health and safety.
- An obligation to provide equal treatment both for men and women.

An **employee** also has responsibilities to his employer. These include:

- Carrying out the tasks for which you are employed with all reasonable skill and care.
- Conducting yourself in such way as would best serve your employer's interests.
- Carrying out all reasonable orders.

An employee is not expected to carry out any order that is plainly illegal or unreasonable. 'Illegal' is quite easy to define – anything which is against the law, for example, driving a vehicle for which you do not hold a licence or falsifying documents or accounts. 'Unreasonable' is more difficult to define, what is reasonable to one person may be quite unreasonable to another person.

Finally, employees are under a general duty not to disclose confidential information relating to their employer's affairs that they might obtain in the course of their work. Employees are also under a general duty not to assist a competitor of their employer. This is one aspect of the employee's duty to ensure that the relationship between employer and employee is one of trust. Even when an employee has left an employer, confidential information is not to be disclosed.

Health and Safety (First Aid) Regulations 1981

People can suffer an injury or become ill whilst at work. It does not matter whether the injury or illness is caused by the work they do or not, what is important is that they are able to receive immediate attention by a competent person or that an ambulance is called in serious cases. First aid at work covers the arrangements that an employer must make to ensure that this happens. It can save lives and prevent a minor incident becoming a major one.

The Health and Safety (First Aid) Regulations 1981 requires employers to provide '**adequate**' and '**appropriate**' equipment, facilities and personnel to enable first aid to be given to employees if they are injured or become ill at work. What is adequate and appropriate will depend upon the type of work being carried out by the employer. The minimum provision is a suitably stocked first aid box and a competent person to take charge of first aid arrangements.

Employers must consider:

- How many people are employed and, therefore, how many first aid boxes will be required.
- What is the pattern of working hours, shift work, night work, is a 'first aider' available for everyone at all times.
- How many trained 'first aiders' will be required.
- Where will first aid boxes be made available.
- Do employees travel frequently or work alone.
- Will it be necessary to issue personal first aid boxes if employees travel or work away from the company's main premises.
- How hazardous is the work being done – what are the risks.
- Are different employees at different levels of risk.
- What has been the accident or sickness record of staff in the past.

Although there is no legal responsibility for employers to make provision for non-employees, the HSE strongly recommends that they are included in any first aid provision.

We will look at the first aid box contents and the number of first aid boxes required a little later in this chapter when we look at the application of first aid in relation to particular injuries.

Data Protection Act 1998

The right to privacy is a fundamental human right and one that many of us take for granted. Most of us, for instance, would not want our medical records freely circulated, and many people are sensitive about revealing their age, religious beliefs, family circumstances or academic qualifications. In the UK, even the use of name and address files for mail shots is often felt to be an invasion of privacy.

With the advent of large computerized databases it is now possible for sensitive personal information to be stored without the individual's knowledge and accessed by, say, a prospective employer, credit card company or insurance company in order to assess somebody's suitability for employment, credit or insurance.

The Data Protection Act 1984 grew out of public concern about personal privacy in the face of rapidly developing computer technology.

The Act covers 'personal data' which is 'automatically processed'. It works in two ways, giving individuals certain rights whilst requiring those who record and use personal information on computer, to be open about that use and to follow proper practices.

The Data Protection Act 1998 was passed in order to implement a European Data Protection Directive. This Directive sets a standard for data protection throughout all the countries of the European Union, and the new Act was brought into force is March 2000. The Act gives the following useful definitions:

Data subjects: the individuals to whom the personal data relate – we are all data subjects.

Data users: those who control the contents and use of a collection of personal data. They can be any type of company or organization, large or small, within the public or private sector.

Personal data: information about living, identifiable individuals. Personal data does not have to be particularly sensitive information and can be as little as a name and address.

Automatically processed: processed by computer or other technology such as document image processing systems. The Act does not currently cover information which is held on manual records, for example, in ordinary paper files.

Registered data users must comply with the eight Data Protection principles of good information handling practice contained in the Act. Broadly these state that data must be:

1 obtained and processed fairly and lawfully;
2 held for the lawful purposes described in the data users' register entry;
3 used for the purposes and disclosed only to those people described in the register entry;
4 adequate, relevant and not excessive in relation to the purposes for which they are held;
5 accurate and, where necessary, kept up to date;
6 held no longer than is necessary for the registered purpose;
7 accessible to the individual concerned who, where appropriate, has the right to have information about themselves corrected or erased;
8 surrounded by proper security.

EXEMPTIONS FROM THE ACT

- The Act does not apply to payroll, pensions and accounts data, nor to names and addresses held for distribution purposes.
- Registration may not be necessary if the data is for personal, family, household or recreational use.
- Data subjects do not have a right to access data if the sole aim of collecting it is for statistical or research purposes.
- Data can be disclosed to the data subject's agent (e.g. lawyer or accountant), to persons working for the data user, and in response to urgent need to prevent injury or damage to health.

Additionally, there are exemptions for special categories, including data held:

- in connection with national security,
- for prevention of crime,
- for the collection of tax or duty.

THE RIGHTS OF DATA SUBJECTS

The Data Protection Act allows individuals to have access to information held about themselves on computer and where appropriate to have it corrected or deleted.

As an individual you are entitled, on making a written request to a data user, to be supplied with a copy of any personal data held about yourself. The data user may charge a fee of up to £10 for each register entry for supplying this information but in some cases it is supplied free.

Usually the request must be responded to within 40 days. If not, you are entitled to complain to the Registrar or apply to the courts for correction or deletion of the data.

Apart from the right to complain to the Registrar, data subjects also have a range of rights which they may exercise in the civil courts. These are:

- Right to compensation for unauthorized disclosure of data.
- Right to compensation for inaccurate data.
- Right of access to data and to apply for rectification or erasure where data is inaccurate.
- Right to compensation for unauthorized access, loss or destruction of data.

For more information see www.dataprotection.gov.uk

Prejudice and discrimination

It is because we are all different to each other that life is so interesting and varied. Our culture is about the way of life that we have, the customs, ideas and experiences that we share and the things that we find acceptable and unacceptable. Different groups of people have different cultures. When people have a certain attitude towards you, or the group of people to which you belong, or a belief about you that is based upon lack of knowledge, understanding or myth, this is prejudice.

When prejudice takes form or action it becomes discrimination and this often results in unfair treatment of people. Regardless of our age, ability, sex, religion, race or sexuality we should all be treated equally and with respect. If we are treated differently because of our differences, we are being discriminated against.

If you are being discriminated against or you see it happening to someone else, you do not have to put up with it. Stay calm and do not retaliate but report it to someone, whoever is the most appropriate person, your supervisor, trainer or manager. If you are a member of a Trade Union you may be able to get help from them if it is an employment related matter.

There are three areas covered by legislation at the moment, these are race, sex and disability. In the next few years the law will change to make it unlawful to discriminate in the training or workplace on the grounds of sexual orientation, religious belief and age.

The Race Relations Act 1976 (RRA) and Amendment Act 2000

The 1976 RRA made employers liable for acts of racial discrimination committed by their employees in the course of their employment. However, police officers are office holders, not employees, and, therefore, Chief Officers of the police were not liable under the 1976 Act for acts of racial discrimination. The Commission for Racial Equality proposed that the Act be extended to include all public services and the amendment came into force in 2000.

It is illegal to discriminate against someone because of their race, colour, nationality, citizenship or ethnic origin.

Institutional racism is when the policies or practices of an organization or institution results in its failure to provide an appropriate service to people because of their colour, culture or ethnic origin. It may mean that the organization or institution does, or does not do something, or that someone is treated less favourably. This includes public services as well as educational institutions.

There are some exceptions in the RRA. It does not apply to certain jobs where people from a certain ethnic or racial background are required for authenticity. These are known as 'genuine occupational qualifications' and might apply to actors and restaurants.

The Commission for Racial Equality website can be found on www.cre.gov.uk

Sex Discrimination Act 1975 (SDA)

'Sexism' takes place every time a person, usually a woman, is discriminated against because of their sex. The Sex Discrimination Act of 1975 makes it unlawful to discriminate against people on sexual grounds in areas relating to recruitment, promotion or training. Job advertisements must not discriminate in their language but they can make it clear that they are looking for people of a particular sex. If, though, a person of either sex applies then they must be treated equally and fairly.

There are some exceptions in the SDA known as '**genuine occupational qualifications**' that might apply to artists, models, actors and some parts of the priesthood in the church. Some exceptions can also apply when appointing people to occupations where 'decency' is required, for example, in changing room attendants in swimming pools, gymnasiums etc., and women are not allowed to work underground.

Sex discrimination is when someone is treated less favourably because of sex or marital status. It includes sexual harassment and unfavourable treatment because a woman is pregnant. Employers fear a high level of absenteeism, often unjustified, from a mother who is trying to juggle the conflicting demands of work and motherhood. This is known as 'direct sex discrimination'.

'Indirect sex discrimination' occurs when a condition of the job is applied to both sexes but excludes or disadvantages a larger proportion of one sex and is not justifiable. For example, an unnecessary height requirement of 180 cm (5′ 10″) would discriminate against women because less women would be able to meet this requirement.

The Equal Opportunities Commission has published a Code of Practice that gives guidance on best practice in the promotion of equality of opportunity in employment. Further information can be found on the SDA website at www.eoc.org.uk

Disability Discrimination Act 1995 (DDA)

There are more than 8.5 million disabled people in the United Kingdom. The DDA makes it unlawful to discriminate against a disabled person in the areas of employment, access to goods and services and buying or renting land or property.

It is now unlawful for employers of more than 15 people to discriminate against employees or job applicants on the grounds of disability. Reasonable adjustments must be made for people with disabilities and employers must ensure that discrimination does not occur in the workplace.

Under Part 111 of the DDA, from 1st October 2004, service providers will have to take reasonable steps to remove, alter or provide reasonable means of avoiding physical features that make it impossible or unreasonably difficult for disabled people to use their services. The duty requires service providers to make '**reasonable**' adjustments to their premises so that disabled people can use the service and are not restricted by physical barriers. If this is not possible then the service should be provided by means of a reasonable alternative such as bringing goods to the disabled person or helping the person to find items.

All organizations which provide goods, facilities or services to the public are covered by the DDA including shops, offices, public houses, leisure facilities, libraries, museums, banks, cinemas, churches and many more, in fact there are few exemptions.

Some service providers will need to incur significant capital expenditure in order to comply with the DDA. What is '**reasonable**' will depend upon the state and condition of the service provider's premises. A subjective standard will apply when determining what is reasonable under the circumstances at a given location. Whether or not an adjustment is reasonable will ultimately be a question of fact for the courts.

Further information can be found on the DDA website at www.disability.gov.uk

The Human Rights Act 1998 (HRA)

The Human Rights Act 1998 came into force on the 2nd October 2000 bringing the European Convention on Human Rights into UK law. It means that if you think your human rights have been violated, you can take action through the British court system, rather than taking it to the European Court of Human Rights. The Act makes it unlawful for a '**Public Authority**' to act in a way that goes against any of the rights laid down in the convention unless an Act of Parliament meant that it could not have acted differently. The basic human rights in the Human Rights Act are:

- the right to life,
- the right to a fair trial,
- the right to respect for your private and family life,
- the right to marry,
- the right to liberty and security,
- prohibition of torture,
- prohibition of slavery and forced labour,
- prohibition of discrimination,
- prohibition of the abuse of rights,
- freedom of thought, conscience and religion,
- freedom of expression,
- freedom of assembly and association,
- no punishment without law.

If you feel that your human rights have been violated, you should seek advice from a solicitor. Rights under the Act can only be used against a public authority such as the Police or a Local Authority. They cannot be used against a private company. For more information see www.humanrights.gov.uk

Enforcement Law Inspectors

If the laws relating to work, the environment and people are to be effective, they must be able to be enforced. The system of control under the Health and Safety at Work Act comes from the Health and Safety Executive (HSE) or the Local Authority. Local authorities are responsible for retail and service outlets such as shops, garages, offices, hotels, public houses and clubs. The HSE are responsible for all other work premises including the Local Authorities themselves. Both groups of inspectors have the same powers. They are allowed to:

- enter premises, accompanied by a police officer if necessary;
- examine, investigate and require the premises to be left undisturbed;
- take samples and photographs as necessary, dismantle and remove equipment;
- require the production of books or documents and information;
- seize, destroy or render harmless any substance or article;
- issue enforcement notices and initiate prosecutions.

There are two types of enforcement notices, an '**improvement notice**' and a '**prohibition notice**'.

An **improvement notice** identifies a contravention of the law and specifies a date by which the situation is to be put right. An appeal may be made to an Employment Tribunal within 21 days.

A **prohibition notice** is used to stop an activity which the inspector feels may lead to serious injury. The notice will identify which legal requirement is being contravened and the notice takes effect as soon as it is issued. An appeal may be made to the Employment Tribunal but the notice remains in place and work is stopped during the appeal process.

Cases may be heard in the Magistrates or Crown Courts.

Magistrates Court (Summary Offences) for Health and Safety offences, employers may be fined up to £20 000 and employees or individuals up to £5000. For failure to comply with an enforcement notice or a court order, anyone may be imprisoned for up to 6 months.

Crown Court (Indictable Offences) for failure to comply with an enforcement notice or a court order, fines are unlimited in the Crown Court and may result in imprisonment for up to 2 years.

Actions available to an inspector upon inspection of premises:

- take no action – the law is being upheld;
- give verbal advice – minor contraventions of the law identified;
- give written advice – omissions have been identified and a follow up visit will be required to ensure that they have been corrected;
- serve an improvement notice – a contravention of the law has, or is taking place and the situation must be remedied by a given date. A follow up visit will be required to ensure that the matter has been corrected;
- serve a prohibition notice – an activity has been identified which may lead to serious injury. The law has been broken and the activity must stop immediately;
- prosecute – the law has been broken and the employer prosecuted.

On any visit one or more of the above actions may be taken by the inspector.

In-house Safety Representatives

The Health and Safety Executive and the Environmental Health Officers are the Health and Safety professionals. The day that one of these inspectors arrives to look at the Health and Safety systems and procedures that your company has in place is a scary day! Most companies are very conscientious about their health and safety responsibilities and want to comply with the law. Many of the regulations demand that the health and safety systems and procedures are regularly reviewed and monitored and that employees are informed and appropriately trained. To meet the requirements there is a need for 'competent persons' to be appointed to the various roles within the company structure to support the company directors in their management of the Health and Safety Policy. The number of people involved, and whether health and safety is their only company role, will depend upon the size of the company and the type of work being carried out. To say that 'everyone is responsible for health and safety' is very misleading and would definitely not impress a visiting HSE inspector. There is no equality of responsibility under the law between those who provide direction and create policy and those who are employed to carry out instructions. Company directors and employers have substantially more responsibilities than employees as far as the Health and Safety at Work Act is concerned. There therefore needs to be an appropriate structure and nominated 'competent persons' within the company to manage Health and Safety at Work.

At the top of the Health and Safety structure there will need to be a senior manager. Like all management functions, establishing control and maintaining it day in day out is crucial to effective Health and Safety management. Senior managers must take proactive responsibility for controlling issues that could lead to ill health or injury. A nominated senior manager at the top of the organization must oversee policy implementation and monitoring.

Health and Safety responsibilities must then be assigned to line managers and health and safety expertise must be available to them to help them achieve the requirements of the Health and Safety at Work Act and the regulations made under the Act. The purpose of a Health and Safety organization within a company is to harness the collective enthusiasm, skill and effort of the whole workforce, with managers taking key responsibility and providing clear direction. The prevention of accidents and ill health through management systems of control then becomes the focus rather than looking for individuals to blame after an accident has happened. Two key personnel in this type of system might hold the job title 'Safety Officer' and 'Safety Representative'.

The Safety Officer will be the specialist member of staff, having responsibility for Health and Safety within the company. He or she will report to the senior manager responsible for Health and Safety and together they will develop strategies for implementing and maintaining the company Health and Safety policies.

The Safety Officer will probably hold a Health and Safety qualification such as NEBOSH (National Examination Board in Occupational Safety and Health) and will:

- monitor the internal Health and Safety systems,
- carry out risk assessments,
- maintain accident reports and records,
- arrange or carry out in-house training,
- update systems as Regulations change.

If an accident occurs, the Safety Officer would lead the investigation, identify the cause and advise the senior manager responsible for health and safety on possible improvements to the system.

The Safety Representative will be the person who represents a small section of the workforce on the Safety Committee. The role of the Safety Representative will be to bring to the Safety Committee the health and safety concerns of colleagues and to take back to colleagues, information from the Committee. The office of Safety Representative is often held by the Trade Union representative, since it is a similar role, representing colleagues on management committees. If the company does not have a Safety Committee then the Safety Representative will liase with the Safety Officer, informing him of the training and other health and safety requirements of colleagues.

The Safety Officer and Safety Representative hold important positions within a company, informing both employers and employees on health and safety matters and helping the company meet its obligation to 'consult with employees' under the Health and Safety Regulations.

Regular monitoring and reviewing of systems and procedures is an essential part of any health and safety system. Similarly, monitoring and evaluating systems systematically is an essential part of many quality management systems. In the next section I want to look at quality systems.

Safe and Effective Working Practices

Quality systems

When purchasing goods and services these days the customer is increasingly looking for good performance and reliability. Good performance means that a product will do what the customer wants it to do and reliability means that it will perform well for an acceptable period of time. Poor product reliability has been identified as one of the chief causes of customer dissatisfaction. Customers also look for durability and quality. Durability is closely linked to reliability and is a measure of the amount of use a customer receives from the product before it deteriorates.

Quality generally refers to the level of excellence, but in the business sense it means meeting the customer's expectations regarding performance, reliability and durability. Quality is also a customer's subjective impression of a product or service which has been formed by images, advertisements, brand names or reputation. It is inferred from various tangible and intangible aspects of the product or service and may, in part, be due to the reputation built up by the particular company. Marks & Spencer, for example, have built up a formidable reputation from providing good-quality products and services.

In the early 1950s a motorcycle made in Japan was considered inferior to one made in Britain. Today the opposite is true. Japanese companies have used quality to become the leading producers of cars, televisions, photocopiers, radios, watches and cameras. After watching the Japanese capture the major share of these world markets, European and American companies have finally responded to the challenge and introduced the quality standards used so successfully by Japanese industry.

The customer's impression of quality is difficult to pin down but companies can work towards providing a quality product or service by introducing quality systems. There are four fundamental approaches to managing quality: quality control, quality assurance, total quality control and total quality management.

QUALITY CONTROL

Post-production inspection is the traditional form of quality control. It was introduced in the 1920s to improve the quality of mass-produced goods. Statistical sampling of the finished product took place, where, for example, one part in every hundred was tested. If the sample was found to be faulty then all 100 parts would be scrapped. If the sample was found to be acceptable it was assumed that all 100 parts were satisfactory. The problem with quality control is that the focus of attention is on the finished product rather than on the manufacturing process. Quality control never deals with the cause of the problem and, as a result, many defective products roll off the assembly line. Also, any scrapped products become built-in costs which reduce company profits and increase the product price in the shops. Defects and malfunctions have become acceptable within certain tolerance limits, but how often these days do we buy a faulty video, television or camera? Hardly ever, because Japanese industry has moved to a 'zero defects' quality management system.

QUALITY ASSURANCE

Unlike quality control, which focuses upon post-production inspection, quality assurance emphasizes defect prevention through statistical quality control and by monitoring processes to eliminate the production of bad parts.

Each part of a process has procedures written down which have been found to be the most effective. The procedures and standard forms of documentation are followed implicitly to ensure product conformity. These written procedures, used in conjunction with one of the recognized quality standards such as BS 5750 or ISO 9000, have become synonymous with quality assurance.

TOTAL QUALITY CONTROL

Total quality control attempts to expand the quality assurance philosophy to encompass all company activities. It focuses upon the elimination of waste and views the continuous improvement of systems and procedures as essential to an organization's survival. It was slow to be adopted by Western companies because it did not easily fit the organizational structures. Typically, European companies had strong vertical management structures with little opportunity for the workers' voice to be heard. Also, managers themselves tended to work independently of each other and, as a result, efforts to address company-wide issues such as quality were often met with indifference or resistance by the individuals involved.

This attitude is in sharp contrast to that of the Japanese people. They embraced the word 'total' and introduced quality assurance throughout their organizations. They have also introduced a new term 'company-wide quality control' which seeks to achieve continuous quality improvements throughout the entire organization. In the West, this company-wide quality management philosophy is known as 'total quality management'.

TOTAL QUALITY MANAGEMENT

Total quality management makes quality a way of life. It is no longer 'inspected in', 'built in' or even 'organized in': quality is 'managed in' at all levels. It is based upon four principles: meeting the customer's requirements; striving to do error-free work; managing by prevention; and measuring the cost of non-quality.

Meeting the customer's requirements is the simple driving force behind total quality management. Many companies focus on meeting the needs of external customers, that is, those who buy the product or service, but this system accords equal importance to internal customers: other workers, supervisors, salesmen and managers all depend upon each other to provide a quality product or service.

Striving to do error-free work means providing a quality product or service first time, every time. A total quality management company strives to create an environment which seeks perfection at all levels of the operation, a corporate attitude which encourages the workforce to ask why an error has occurred, to track down the root cause and then take action to prevent it from happening again.

Managing by prevention means that workers at all levels must be encouraged to anticipate problems and be given the power to make permanent changes to procedures to prevent future errors. As the emphasis on preventing errors grows, the ability to meet a customer's requirements first time, every time, increases.

The cost of non-quality is the money a company would otherwise spend on detecting, correcting and preventing errors. The real benefits of a total quality management system are to be found in the education and training of the individuals, the improvement in contentment expressed by the workforce and the quality of the finished product or service.

BRITISH STANDARD QUALITY

British Standard 5750 (published in 1979) and the ISO 9000 series, the world standard for quality assurance (published in 1987), have become synonymous with quality assurance and are at the heart of most quality management systems in Europe. They specify the organizational framework for the quality management of systems, for product design, development, production, installation and servicing.

A BS 5750/ISO 9000 certificate provides a framework for a company to establish quality procedures and identify ways of improving its particular product or service. An essential part of any quality system is accurate record-keeping and detailed documentation which ensures that procedures are being followed and producing the desired results.

Many electrotechnical companies are now accredited to ISO 9001 which means all of the company's standard systems and procedures have been documented into an approved quality management system. All procedures are internally audited throughout the year on a rolling programme to make sure that they are working effectively. Once a year an external audit of the systems takes place by an inspector nominated by ISO 9001. If the inspector is assured that the system is being operated effectively, then the company continues to use the quality system for a further year and is entitled to display the Quality Management ISO 9001 logo on vehicles and stationery. This says to potential customers 'we are a serious professional company working to the best standards of our industry and providing a quality service'.

Another quality system dedicated to improving a company's performance through the development of its employees is 'Investors in People'.

Investors in People (IiP)

Most people would agree that the people an organization employs are the most valuable asset of the business. Conscientious workers are hard to find and difficult to keep. For any business to succeed, everyone must perform to the best of their ability from the youngest trainee to the Managing Director.

Investors in People is a National Quality Standard that focuses on the needs of the people working within an organization.

It recognizes that a company or business is investing some of its profits in its workforce in order to improve the efficiency and performance of the organization. The objective is to create an environment where what people can do and are motivated to do, matches what the company needs them to do to improve.

The IiP standard lays down a set of 'principles' and 'indicators' of good practice which the participating organization must meet. The IiP standards are the same for all types of organization, large and small, and recognizes that each company must find its own way of achieving success through the development of its employees.

The IiP was started in 1990 and was driven by a partnership between leading businesses and organizations such as the Confederation of British Industry (CBI), Trade Union Councils (TUC), the Institute of Personnel and Development and the National Training Task Force. It is now a nationally recognized quality standard with over 36 000 qualifying organizations able to display the coveted 'Investors in People' UK Charter mark on their vehicles and stationery.

For more information on IiP go to www.investorsinpeople.co.uk

Health and Safety Applications

OPERATOR SAFETY

The principles which were laid down in the many Acts of Parliament and the Regulations that we have already looked at in this Chapter, control our working environment. They make our workplace safer, but despite all this legislation, workers continue to be injured and killed at work.

In the year 2004 the HSE statistics show that 235 employed people died as a result of a work related injury. The number of people who died in 2004 was increased by the unfortunate accident in February of that year, when 21 cockle pickers died in one single night in the Morecambe Bay tragedy. In 2003, 228 people died as a result of a work related injury. The number of deaths has consistently averaged about 200 each year for the past 8 years. These figures only relate to employees. If you include the self-employed and members of the public killed in work related accidents, the numbers almost double.

In addition to the deaths, about 28 000 people have major accidents at work and about 130 000 people each year, receive minor work related injuries which keep them off work for more that 3 days.

It is a mistake to believe that these things only happen in dangerous occupations such as deep sea diving, mining and quarrying, fishing industry, tunnelling and fire-fighting or that it only happens in exceptional circumstances such as would never happen in your workplace. This is not the case. Some basic thinking and acting beforehand, could have prevented most of these accident statistics, from happening.

The most common causes of accidents are:

- slips, trips and falls;
- manual handling, that is moving objects by hand;
- using equipment, machinery or tools;
- storage of goods and materials which then become unstable;
- fire;
- electricity;
- mechanical handling.

To control the risk of an accident we usually:

- eliminate the cause;
- substitute a procedure or product with less risk;
- enclose the dangerous situation;
- put guards around the hazard;
- use safe systems of work;
- supervise, train and give information to staff;
- if the hazard cannot be removed or minimized then provide PPE.

Let us now look at the application of some of the procedures that make the workplace a safer place to work but first of all I want to explain what I mean when I use the words hazard and risk.

HAZARD AND RISK

A hazard is something with the 'potential' to cause harm, for example, chemicals, electricity or working above ground.

A risk is the 'likelihood' of harm actually being done.

Competent persons are often referred to in the Health and Safety at Work Regulations, but who is 'competent'? For the purposes of the Act, a competent person is anyone who has the necessary technical skills, training and expertise to safely carry out the particular activity. Therefore, a competent person dealing with a hazardous situation reduces the risk.

Think about your workplace and at each stage of what you do, think about what might go wrong. Some simple activities may be hazardous. Here are some typical activities where accidents might happen.

Typical activity	Potential hazard
Receiving materials	Lifting and carrying
Stacking and storing	Falling materials
Movement of people	Slips, trips and falls
Building maintenance	Working at heights or in confined spaces
Movement of vehicles	Collisions

How high are the risks? Think about what might be the worst result, is it a broken finger or someone suffering permanent lung damage or being killed? How likely is it to happen? How often is that type of work carried out and how close do people get to the hazard? How likely is it that something will go wrong?

How many people might be injured if things go wrong. Might this also include people who do not work for your company?

Employers of more than five people must document the risks at work and the process is known as Hazard Risk Assessment.

HAZARD RISK ASSESSMENT – THE PROCESS

The Management of Health and Safety at Work Regulations 1999 tells us that employers must systematically examine the workplace, the work activity and the management of safety in the establishment through a process of risk assessments. A record of all significant risk assessment findings must be kept in a safe place and be made available to an HSE Inspector if required. Information based on the risk assessment findings must be communicated to relevant staff and if changes in work behaviour patterns are recommended in the interests of safety, then they must be put in place.

So risk assessment must form a part of any employer's robust policy of health and safety. However, an employer only needs to 'formally' assess the significant risks. He is not expected to assess the trivial and minor types of household risks. Staff are expected to read and to act upon these formal risk assessments and they are unlikely to do so enthusiastically if the file is full of trivia. An assessment of risk is nothing more than a careful examination of what, in your work, could cause harm to people. It is a record that shows whether sufficient precautions have been taken to prevent harm.

The HSE recommends five steps to any risk assessment.

Step 1
Look at what might reasonably be expected to cause harm. Ignore the trivial and concentrate only on significant hazards that could result in serious harm or injury. Manufacturers data sheets or instructions can also help you spot hazards and put risks in their true perspective.

Step 2
Decide who might be harmed and how. Think about people who might not be in the workplace all the time – cleaners, visitors, contractors or maintenance personnel. Include members of the public or people who share the workplace. Is there a chance that they could be injured by activities taking place in the workplace.

Step 3
Evaluate what is the risk arising from an identified hazard. Is it adequately controlled or should more be done? Even after precautions have been put in place, some risk may remain. What you have to decide, for each significant hazard, is whether this remaining risk is low, medium or high. First of all, ask yourself if you have done all the things that the law says you have got to do. For example, there are legal requirements on the prevention of access to dangerous machinery. Then ask yourself whether generally accepted industry standards are in place, but do not stop there – think for yourself, because the law also says that you must do what is reasonably practicable to keep the workplace safe. Your real aim is to make all risks small by adding precautions, if necessary.

If you find that something needs to be done, ask yourself:

(a) Can I get rid of this hazard altogether?
(b) If not, how can I control the risk so that harm is unlikely?

Only use personal protective equipment (PPE) when there is nothing else that you can reasonably do.

If the work that you do varies a lot, or if there is movement between one site and another, select those hazards which you can reasonably foresee, the ones that apply to most jobs and assess the risks for them. After that, if you spot any unusual hazards when you get on site, take what action seems necessary.

Step 4
Record your findings and say what you are going to do about risks that are not adequately controlled. If there are fewer than five employees you do not need to write anything down but if there are five or more employees, the significant findings of the risk assessment must be recorded. This means writing down the more significant hazards and assessing if they are adequately controlled and recording your most important conclusions. Most employers have a standard risk assessment form which they use such as that shown in Fig. 1.5 but any format is suitable. The important thing is to make a record.

There is no need to show how the assessment was made, providing you can show that:

1 a proper check was made,
2 you asked those who might be affected,
3 you dealt with all obvious and significant hazards,
4 the precautions are reasonable and the remaining risk is low,
5 you informed your employees about your findings.

Risk assessments need to be *suitable* and *sufficient*, not perfect. The two main points are:

1 Are the precautions reasonable?
2 Is there a record to show that a proper check was made?

File away the written Assessment in a dedicated file for future reference or use. It can help if an HSE Inspector questions the company's precautions or if the company becomes involved in any legal action. It shows that the company has done what the law requires.

Step 5
Review the assessments from time to time and revise them if necessary.

COMPLETING A RISK ASSESSMENT

When completing a risk assessment such as that shown in Fig. 1.5, do not be over complicated. In most firms in the commercial, service and light industrial sector,

HAZARD RISK ASSESSMENT	FLASH-BANG ELECTRICAL CO.
For Company name or site: .... Address:	Assessment undertaken by: .... Signed: .... Date: ....
STEP 5 Assessment review date:	
STEP 1 List the hazards here	STEP 2 Decide who might be harmed
STEP 3 Evaluate (what is) the risk – is it adequately controlled? State risk level as low, medium or high	STEP 4 Further action – what else is required to control any risk identified as medium or high?

Fig. 1.5 Hazard risk assessment standard form.

the hazards are few and simple. Checking them is commonsense but necessary.

Step 1
List only hazards which you could reasonably expect to result in significant harm under the conditions prevailing in your workplace. Use the following examples as a guide:

- Slipping or tripping hazards (e.g. from poorly maintained or partly installed floors and stairs).
- Fire (e.g. from flammable materials you might be using, such as solvents).
- Chemicals (e.g. from battery acid).
- Moving parts of machinery (e.g. blades).
- Rotating parts of handtools (e.g. drills).
- Accidental discharge of cartridge operated tools.
- High pressure air from airlines (e.g. air powered tools).
- Pressure systems (e.g. steam boilers).
- Vehicles (e.g. fork lift trucks).
- Electricity (e.g. faulty tools and equipment).
- Dust (e.g. from grinding operations or thermal insulation).
- Fumes (e.g. from welding).
- Manual handling (e.g. lifting, moving or supporting loads).
- Noise levels too high (e.g. machinery).
- Poor lighting levels (e.g. working in temporary or enclosed spaces).
- Low temperatures (e.g. working outdoors or in refrigeration plant).
- High temperatures (e.g. working in boiler rooms or furnaces).

Step 2
Decide who might be harmed, do not list individuals by name. Just think about groups of people doing similar work or who might be affected by your work:

- Office staff
- Electricians
- Maintenance personnel
- Other contractors on site
- Operators of equipment
- Cleaners
- Members of the public.

Pay particular attention to those who may be more vulnerable, such as

- staff with disabilities
- visitors
- young or inexperienced staff
- people working in isolation or enclosed spaces.

Step 3
Calculate what is the risk – is it adequately controlled? Have you already taken precautions to protect against the hazards which you have listed in Step 1. For example,

- have you provided adequate information to staff,
- have you provided training or instruction.

Do the precautions already taken

- meet the legal standards required,
- comply with recognized industrial practice,
- represent good practice,
- reduce the risk as far as is reasonably practicable.

If you can answer 'yes' to the above points then the risks are adequately controlled, but you need to state the precautions you have put in place. You can refer to company procedures, company rules, company practices etc., in giving this information. For example, if we consider there might be a risk of electric shock from using electrical power tools, then the risk of a shock will be *less* if the company policy is to PAT test all power tools each year and to fit a label to the tool showing that it has been tested for electrical safety. If the stated company procedure is to use battery drills whenever possible, or 110 V drills when this is not possible, and to *never* use 230 V drills, then this again will reduce the risk. If a policy such as this is written down in the company Safety Policy Statement, then you can simply refer to the appropriate section of the Safety Policy Statement and the level of risk will be low. (Note: PAT testing is described in Chapter 2 of *Advanced Electrical Installation Work*.)

Step 4
Further action – what more could be done to reduce those risks which were found to be inadequately controlled?

You will need to give priority to those risks that affect large numbers of people or which could result in serious harm. Senior managers should apply the principles below when taking action, if possible in the following order:

1. Remove the risk completely.
2. Try a less risky option.
3. Prevent access to the hazard (e.g. by guarding).

4 Organize work differently in order to reduce exposure to the hazard.
5 Issue PPE.
6 Provide welfare facilities (e.g. washing facilities for removal of contamination and first aid).

Any hazard identified by a risk assessment as *high risk* must be brought to the attention of the person responsible for health and safety within the company. Ideally, in Step 4 of the Risk Assessment you should be writing, 'No further action is required. The risks are under control and identified as low risk'.

The assessor may use as many standard Hazard Risk Assessment forms, such as that shown in Fig. 1.5, as the assessment requires. Upon completion they should be stapled together or placed in a plastic wallet and stored in the dedicated file.

You might like to carry out a risk assessment on a situation you are familiar with at work, using the standard form of Fig. 1.5, or your employer's standard forms. Alternatively you might like to complete the VDU workstation risk assessment checklist given in the next section.

We all use computers, and you might find it interesting to carry out a risk assessment of the computer workstation you use most, either at home, work or college, just for fun and to get an idea of how to carry out a risk assessment.

VDU operation hazards

Those who work at Supermarket checkouts, assemble equipment or components, or work for long periods at a visual display unit (VDU) and keyboard can be at risk because of the repetitive nature of the work. The hazard associated with these activities is a medical condition called 'upper limb disorders'. The term covers a number of related medical conditions.

HEALTH AND SAFETY (DISPLAY SCREEN EQUIPMENT) REGULATIONS 1992

To encourage employers to protect the health of their workers and reduce the risks associated with VDU work, the Health and Safety Executive (HSE) have introduced the Health and Safety (Display Screen Equipment) Regulations 1992. The Regulations came into force on the 1st January 1993, and employers who use standard office VDUs must show that they have taken steps to comply with the regulations.

So who is affected by the regulations? The regulations identify employees who use VDU equipment as 'users' if they:

- use a VDU more or less continuously on most days;
- use a VDU more or less continuously for periods of an hour or more each day;
- need to transfer information quickly to or from the screen;
- need to apply high levels of attention or concentration to information displayed on a screen;
- are very dependent upon VDUs or have little choice about using them.

All VDU users must be trained to use the equipment safely and protect themselves from upper limb disorders, temporary eyestrain, headaches, fatigue and stress.

To comply with the regulations an employer must:

- train users of VDU equipment and those who will carry out a risk assessment;
- carry out a workstation risk assessment;
- plan changes of activities or breaks for users;
- provide eye and eyesight testing for users;
- make sure new workstations comply with the regulations in the future;
- give users information on the above.

User training

Good user training will normally cover the following topics:

- the operating hazards and risks as describe above;
- the importance of good posture and changing position as shown in Fig. 1.6;
- how to adjust furniture to avoid risks;
- how to organize the workstation to avoid awkward or repeated stretching movements;
- how to avoid reflections and glare on the monitor screen;
- how to adjust and clean the monitor screen;
- how to organize working routines so that there is a change of activity or a break;
- how a user might contribute to a workstation risk assessment;
- who to contact if problems arise.

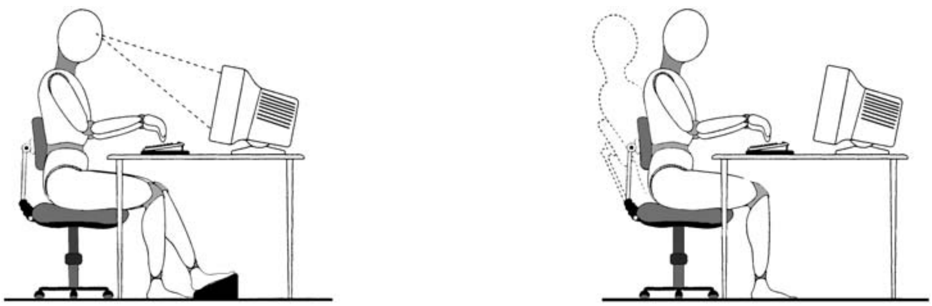


Fig. 1.6 Examples of good posture when using VDU equipment.

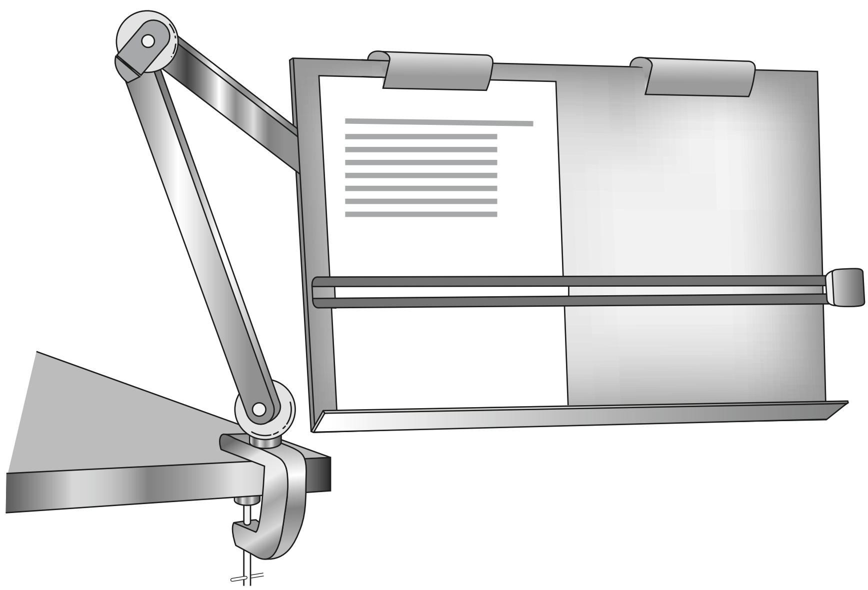


Fig. 1.7 A document holder typically used by a word processing VDU operator.

When carrying out user training, the trainer might want to consider using a video, a computer based training programme, discussions or seminars or the HSE employee leaflet *Working with VDUs* which can be obtained from the address given in Appendix B.

Workstation risk assessment

A simple way to carry out a workstation risk assessment is to use a checklist such as that shown later in this section. Users can work through the checklist themselves. They know what the problems at their workstation are and whether they are comfortable or not. A trainer/assessor should then check the completed checklist and resolve the problems which the user cannot solve. For example, users may not know how the adjustment mechanism actually operates on their chair – a shorter user may benefit from a footrest as shown in Fig. 1.6, or document holder may be more convenient for word processing users as shown in Fig. 1.7.

Breaks

Breaking up long spells of display screen work helps to prevent fatigue and upper limb problems. Where possible encourage VDU users to carry out other tasks such as taking telephone calls, filing and photocopying.

Otherwise, plan for users to take breaks away from the VDU screen if possible. The length of break required is not fixed by the law; the time will vary depending upon the work being done. Breaks should be taken before users become tired and short frequent breaks are better than longer infrequent ones.

Eye and eyesight testing

VDU users and those who are to become users of VDU equipment can request an eye and eyesight test that is free of charge to them. If the test shows that they need glasses specifically to carry out their VDU work, then their employer must pay for a basic pair of frames and lenses. Users are also entitled to further tests at regular intervals but if the user's normal glasses are suitable for VDU work, then the employer is not required to pay for them.

Workstations

Make sure that new workstations comply with the regulations when:

- major changes to the workstation display screen equipment, furniture or software are made;
- new users start work or change workstations;
- workstations are re-sited;
- the nature of the work changes considerably.

Users, trainers and assessors should focus on those aspects which have changed. For example:

- If the location of the workstation has changed, is the lighting adequate, is lighting or sunlight now reflecting off the display unit?
- Different users have different needs – replacing a tall user with a short user may mean that a footrest is required.
- Users working from a number of source documents will need more desk space than users who are word processing.

A risk assessment should always be carried out on a new workstation or when a new operator takes over a workstation. Some questions cannot be answered until a user has had an opportunity to try the workstation. For example, does the user find the layout comfortable to operate, are there reflections on the screen at different times of the day as the sun moves around the building?

To be comfortable the operator should adjust the chair and equipment so that:

- Arms are horizontal and eyes are roughly at the height of the top of the VDU casing.
- Hands can rest on the work surface in front of the keyboard with fingers outstretched over the keys.
- Feet are placed flat on the floor – too much pressure on the backs of legs and knees may mean that a footrest is needed.
- The small of the back is supported by the chair. The back should be held straight with the shoulders relaxed.

The arms on the chair or obstructions under the desk must not prevent the user from getting close enough to the keyboard comfortably.

Information

Good employers, who comply with the Display Screen Equipment Regulations, should let their employees know what care has been taken to reduce the risk to their health and safety at work. Users should be given information on:

- the health and safety relating to their particular workstations;
- the risk assessments carried out and the steps taken to reduce risks;
- the recommended break times and changes in activity to reduce risks;
- the company procedures for obtaining eye and eyesight tests.

This information might be communicated to workers by:

- telling staff, for example, as part of an induction programme;
- circulating a booklet or leaflet to relevant staff;
- putting the information on a noticeboard;
- using a computer based information system, providing staff are trained in their use.

VDU WORKSTATION RISK ASSESSMENT CHECKLIST

Using a checklist such as that shown below or the more extensive checklist shown in the HSE book '*VDUs, an Easy Guide to the Regulations*' is one way to assess workstation risks. You do not have to, but many employers find it a convenient method.

Risk factors are grouped under five headings and to each question the user should initially give a simple yes/no response. A 'yes' response means that no further action is necessary but a 'no' response will indicate that further follow-up action is required to reduce or eliminate risks to a user.

1. Is the display screen image clear?
1.1 Are the characters readable? Y/N
1.2 Is the image free of flicker and movement? Y/N
1.3 Are brightness and contrast adjustable? Y/N
1.4 Does the screen swivel and tilt? Y/N
1.5 Is the screen free from glare and reflections? Y/N

2. Is the keyboard comfortable?
2.1 Is the keyboard tiltable? Y/N
2.2 Can you find a comfortable keyboard position? Y/N
2.3 Is there enough space to rest your hands in front of the keyboard? Y/N
2.4 Are the characters on the keys easily readable? Y/N

3. Does the furniture fit the work and user?
3.1 Is the work surface large enough? Y/N
3.2 Is the surface free of reflections? Y/N
3.3 Is the chair stable? Y/N
3.4 Do the adjustment mechanisms work? Y/N
3.5 Are you comfortable? Y/N

4. Is the surrounding environment risk free?
4.1 Is there enough room to change position and vary movement? Y/N
4.2 Are levels of light, heat and noise comfortable? Y/N
4.3 Does the air feel comfortable in terms of temperature and humidity? Y/N

5. Is the software user friendly?
5.1 Can you comfortably use the software? Y/N
5.2 Is the software suitable for the work task? Y/N
5.3 Have you had enough training? Y/N

A copy of all risk assessments carried out should be placed in a dedicated file which can then be held by the trainer/assessor or other responsible person.

A copy of the full checklist can be found in the publication '*VDUs, an Easy Guide to the Regulations*'. Other relevant publications include '*Display Screen Equipment Work and Guidance on Regulations L26*' and '*Industry Advisory (General) Leaflet IND(G) 36(L) 1993 Working with VDUs*'. These and other Health and Safety Publications are available from the HSE; the address is given in Appendix L.

Manual handling

Manual handling is lifting, transporting or supporting loads by hand or by bodily force. The load might be any heavy object, a printer, a visual display unit, a box of tools or a stepladder. Whatever the heavy object is, it must be moved thoughtfully and carefully, using appropriate lifting techniques if personal pain and injury are to be avoided. Many people hurt their back, arms and feet, and over one third of all 3 day reported injuries submitted to the HSE each year are the result of manual handling.

When lifting heavy loads, correct lifting procedures must be adopted to avoid back injuries. Figure 1.8 demonstrates the technique. Do not lift objects from

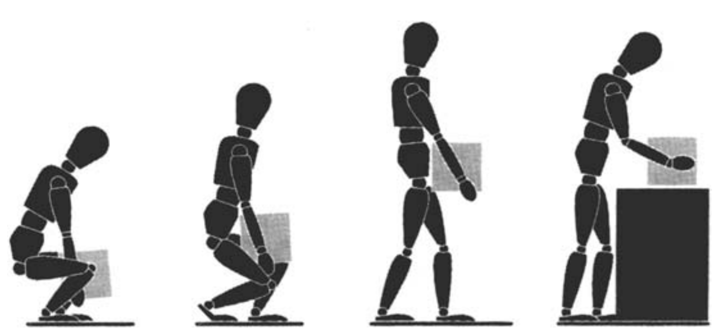


Fig. 1.8 Correct manual lifting and carrying procedure.

the floor with the back bent and the legs straight as this causes excessive stress on the spine. Always lift with the back straight and the legs bent so that the powerful leg muscles do the lifting work. Bend at the hips and knees to get down to the level of the object being lifted, positioning the body as close to the object as possible. Grasp the object firmly and, keeping the back straight and the head erect, use the leg muscles to raise in a smooth movement. Carry the load close to the body. When putting the object down, keep the back straight and bend at the hips and knees, reversing the lifting procedure. A bad lifting technique will result in sprains, strains and pains. There have been too many injuries over the years resulting from bad manual handling techniques. The problem has become so serious that the Health and Safety Executive has introduced new legislation under the Health and Safety at Work Act 1974, the Manual Handling Operations Regulations 1992. Publications such as *Getting to Grips with Manual Handling* can be obtained from HSE Books; the address and Infoline are given in Appendix L.

Where a job involves considerable manual handling, employers must now train employees in the correct lifting procedures and provide the appropriate equipment necessary to promote the safe manual handling of loads.

Consider some 'good practice' when lifting loads:

- Do not lift the load manually if it is more appropriate to use a mechanical aid. Only lift or carry what you can easily manage.
- Always use a trolley, wheelbarrow or truck such as those shown in Fig. 1.9 when these are available.
- Plan ahead to avoid unnecessary or repeated movement of loads.
- Take account of the centre of gravity of the load when lifting – the weight acts through the centre of gravity.
- Never leave a suspended load unsupervised.
- Always lift and lower loads gently.
- Clear obstacles out of the lifting area.
- Use the manual lifting techniques described above and avoid sudden or jerky movements.
- Use gloves when manual handling to avoid injury from rough or sharp edges.
- Take special care when moving loads wrapped in grease or bubble-wrap.
- Never move a load over other people or walk under a suspended load.

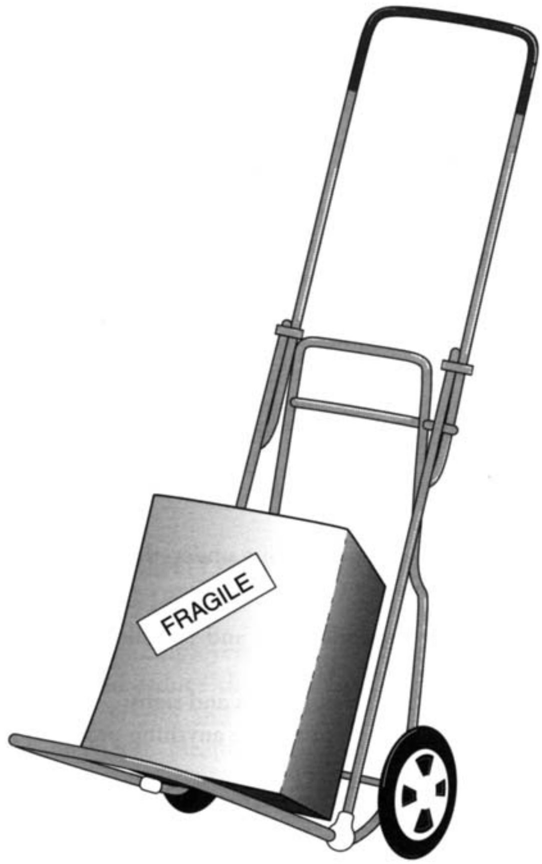


Fig. 1.9 Always use a mechanical aid to transport a load when available.

Personal Protective Equipment

PPE is defined as all equipment designed to be worn, or held, to protect against a risk to health and safety. This includes most types of protective clothing, and equipment such as eye, foot and head protection, safety harnesses, life jackets and high visibility clothing.

Under the Health and Safety at Work Act, employers must provide free of charge any personal protective equipment and employees must make full and proper use of it. Safety signs such as those shown at Fig. 1.10 are useful reminders of the type of PPE to be used in a particular area. The vulnerable parts of the body which may need protection are the head, eyes, ears, lungs, torso, hands and feet and, additionally, protection from falls may need to be considered. Objects falling from a height present the major hazard against which head protection is provided. Other

Fig. 1.10 Safety signs showing type of PPE to be worn.

hazards include striking the head against projections and hair becoming entangled in machinery. Typical methods of protection include helmets, light duty scalp protectors called 'bump caps' and hairnets.

The eyes are very vulnerable to liquid splashes, flying particles and light emissions such as ultraviolet light, electric arcs and lasers. Types of eye protectors include safety spectacles, safety goggles and face shields. Screen based workstations are being used increasingly in industrial and commercial locations by all types of personnel. Working with VDUs (visual display units) can cause eye strain and fatigue and, therefore, this hazard was the subject of a separate section earlier in this chapter headed VDU operation hazards.

Noise is accepted as a problem in most industries and we looked in some detail at the Noise Regulations a little earlier in this chapter under the Environmental Laws section.

Noise may be defined as any disagreeable or undesirable sound or sounds, generally of a random nature, which do not have clearly defined frequencies. The usual basis for measuring noise or sound level is the decibel scale. Whether noise of a particular level is harmful or not also depends upon the length of exposure to it. This is the basis of the widely accepted limit of 85 dB of continuous exposure to noise for 8 hours per day.

Where individuals must be subjected to some noise at work it may be reduced by ear protectors. These may be disposable ear plugs, re-usable ear plugs or ear muffs. The chosen ear protector must be suited to the user and suitable for the type of noise and individual personnel should be trained in its correct use.

Fig. 1.11 Breathing protection signs.

Breathing reasonably clean air is the right of every individual, particularly at work. Some industrial processes produce dust which may present a potentially serious hazard. The lung disease asbestosis is caused by the inhalation of asbestos dust or particles and the coal dust disease pneumoconiosis, suffered by many coal miners, has made people aware of the dangers of breathing in contaminated air.

Some people may prove to be allergic to quite innocent products such as flour dust in the food industry or wood dust in the construction industry. The main effect of inhaling dust is a measurable impairment of lung function. This can be avoided by wearing an appropriate mask, respirator or breathing apparatus as recommended by the company's health and safety policy and indicated by local safety signs such as those shown in Fig. 1.11.

A worker's body may need protection against heat or cold, bad weather, chemical or metal splash, impact or penetration and contaminated dust. Alternatively, there may be a risk of the worker's own clothes causing contamination of the product, as in the food industry. Appropriate clothing will be recommended in the company's health and safety policy. Ordinary working clothes and clothing provided for food hygiene purposes are not included in the Personal Protective Equipment at Work Regulations.

Hands and feet may need protection from abrasion, temperature extremes, cuts and punctures, impact or skin infection. Gloves or gauntlets provide protection from most industrial processes but should not be worn when operating machinery because they may become entangled in it. Care in selecting the appropriate protective device is required; for example, barrier creams provide only a limited protection against infection.

Boots or shoes with in-built toe caps can give protection against impact or falling objects and, when fitted with a mild steel sole plate, can also provide protection from sharp objects penetrating through the sole. Special slip resistant soles can also be provided for employees working in wet areas.

Whatever the hazard to health and safety at work, the employer must be able to demonstrate that he or she has carried out a risk analysis, made recommendations which will reduce that risk and communicated these recommendations to the workforce. Where there is a need for PPE to protect against personal injury and to create a safe working environment, the employer must provide that equipment and any necessary training which might be required and the employee must make full and proper use of such equipment and training.

Safety signs

The rules and regulations of the working environment are communicated to employees by written instructions, signs and symbols. All signs in the working environment are intended to inform. They should give warning of possible dangers and must be obeyed. At first there were many different safety signs but British Standard BS 5378 Part 1 (1980) and the Health and Safety (Signs and Signals) Regulations 1996 have introduced a standard system which gives health and safety information with the minimum use of words. The purpose of the regulations is to establish an internationally understood system of safety signs and colours which draw attention to equipment and situations that do, or could, affect health and safety. Text-only safety signs became illegal from 24th December 1998. From that date, all safety signs have had to contain a pictogram or symbol such as those shown in Fig. 1.12. Signs fall into four categories: prohibited activities; warnings; mandatory instructions and safe conditions.

Fig. 1.12 Text only safety signs do not comply.

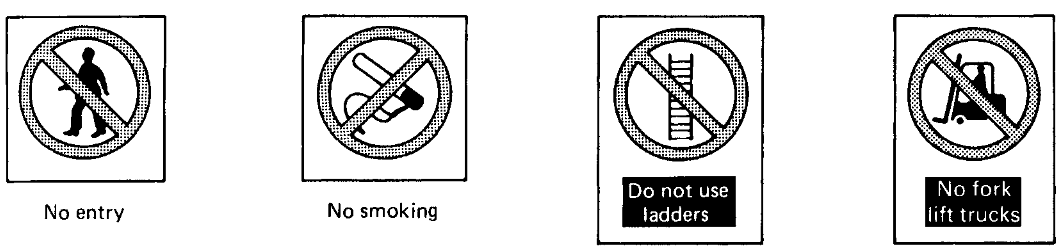


Fig. 1.13 Prohibition signs.

PROHIBITION SIGNS

These are circular white signs with a red border and red cross bar, and are given in Fig. 1.13. They indicate an activity which *must not* be done.

WARNING SIGNS

These are triangular yellow signs with a black border and symbol, and are given in Fig. 1.14. They *give warning* of a hazard or danger.

MANDATORY SIGNS

These are circular blue signs with a white symbol, and are given in Fig. 1.15. They *give instructions* which must be obeyed.

SAFE CONDITION SIGNS

These are square or rectangular green signs with a white symbol, and are given in Fig. 1.16. They *give information* about safety provision.

Accidents at work

Despite new legislation, improved information, education and training, accidents at work do still happen. An accident may be defined as an uncontrolled event causing injury or damage to an individual or property. An accident can nearly always be avoided if correct procedures and methods of working are followed. Any accident which results in an absence from work for more than 3 days, causes a major injury or death,

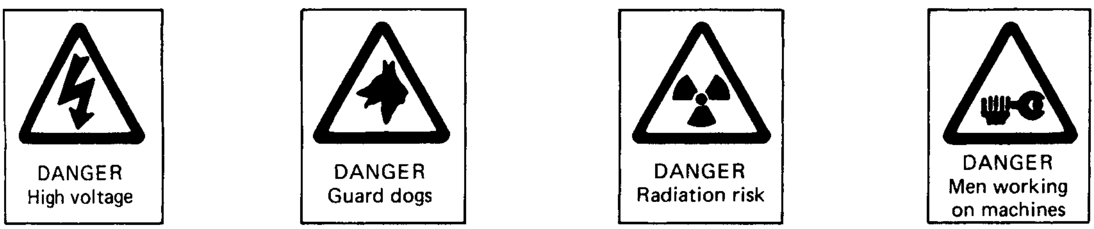


Fig. 1.14 Warning signs.

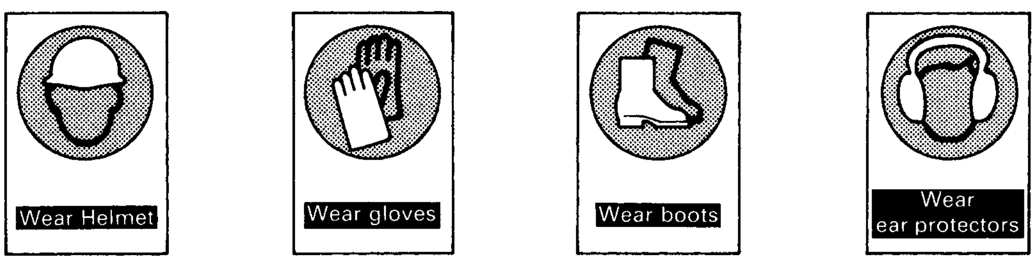


Fig. 1.15 Mandatory signs.

Fig. 1.16 Safe condition signs.

is notifiable to the HSE. There are more than 160 000 accidents reported to the HSE each year which occur as a result of some work-related activity. To avoid having an accident you should:

1 follow all safety procedures (e.g. fit safety signs when isolating supplies and screen off work areas from the general public);
2 not misuse or interfere with equipment provided for health and safety;
3 dress appropriately and use personal protective equipment (PPE) when appropriate;
4 behave appropriately and with care;
5 avoid over-enthusiasm and foolishness;
6 stay alert and avoid fatigue;
7 not use alcohol or drugs at work;
8 work within your level of competence;
9 attend safety courses and read safety literature;
10 take a positive decision to act and work safely.

If you observe a hazardous situation at work, first make the hazard safe, using an appropriate method, or screen it off, but only if you can do so without putting yourself or others at risk, then report the situation to your safety representative or supervisor.

Fire control

A fire is a chemical reaction which will continue if fuel, oxygen and heat are present. To eliminate a fire *one* of these components must be removed. This is often expressed by means of the fire triangle shown in Fig. 1.17; all three corners of the triangle must be present for a fire to burn.

FUEL

Fuel is found in the construction industry in many forms: petrol and paraffin for portable generators and heaters; bottled gas for heating and soldering. Most solvents are flammable. Rubbish also represents a source of fuel: off-cuts of wood, roofing felt, rags, empty solvent cans and discarded packaging will all provide fuel for a fire.

To eliminate fuel as a source of fire, all flammable liquids and gases should be stored correctly, usually in an outside locked store. The working environment should be kept clean by placing rags in a metal bin with a lid. Combustible waste material should be removed from the work site or burned outside under controlled conditions by a competent person.

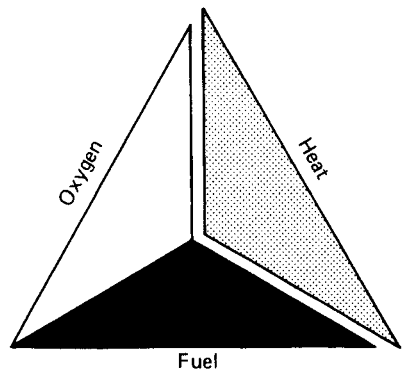


Fig. 1.17 The fire triangle.

OXYGEN

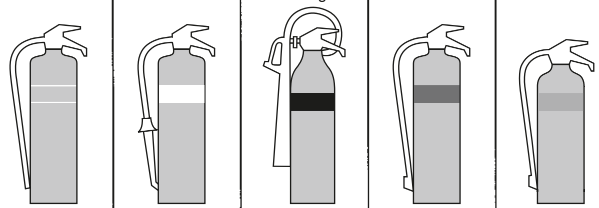
Oxygen is all around us in the air we breathe, but can be eliminated from a small fire by smothering with a fire blanket, sand or foam. Closing doors and windows but not locking them will limit the amount of oxygen available to a fire in a building and help to prevent it spreading.

Most substances will burn if they are at a high enough temperature and have a supply of oxygen. The minimum temperature at which a substance will burn is called the 'minimum ignition temperature' and for most materials this is considerably higher than the surrounding temperature. However, a danger does exist from portable heaters, blow torches and hot air guns which provide heat and can cause a fire by raising the temperature of materials placed in their path above the minimum ignition temperature. A safe distance must be maintained between heat sources and all flammable materials.

HEAT

Heat can be removed from a fire by dousing with water, but water must not be used on burning liquids since the water will spread the liquid and the fire. Some fire extinguishers have a cooling action which removes heat from the fire.

Fires in industry damage property and materials, injure people and sometimes cause loss of life.



Type of fire extinguisher / Type of fire	Water (Signal red flash on red)	Foam (Pale cream flash on red)	Carbon dioxide gas (Black flash on red)	Dry powder (French blue flash on red)	Vapourizing foam (Emerald green flash on red)
CLASS A. Paper, Wood and Fabric	✓ Yes	✓ Yes	✗ No	✓ Yes	✓ Yes
CLASS B. Flammable Liquids	✗ No	✓ Yes	✓ Yes	✓ Yes	✓ Yes
CLASS C. Flammable Gases	✗ No	✗ No	✓ Yes	✓ Yes	✓ Yes
Electrical fires	✗ No	✗ No	✓ Yes	✓ Yes	✓ Yes
Motor vehicle protection	✗ No	✓ Yes	✗ No	✓ Yes	✓ Yes

Fig. 1.18 Fire extinguishers and their applications (colour codes to BS EN3:1996). The base colour of all fire extinguishers is red, with a different coloured flash to indicate the type.

Everyone should make an effort to prevent fires, but those which do break out should be extinguished as quickly as possible.

In the event of fire you should:

- raise the alarm;
- turn off machinery, gas and electricity supplies in the area of the fire;
- close doors and windows but without locking or bolting them;
- remove combustible materials and fuels away from the path of the fire, if the fire is small, and if this can be done safely;
- attack small fires with the correct extinguisher.

Only attack the fire if you can do so without endangering your own safety in any way. Always leave your own exit from the danger zone clear. Those not involved in fighting the fire should walk to a safe area or assembly point.

Fires are divided into four classes or categories:

- Class A are wood, paper and textile fires.
- Class B are liquid fires such as paint, petrol and oil.
- Class C are fires involving gas or spilled liquefied gas.
- Class D are very special types of fire involving burning metal.

Electrical fires do not have a special category because, once started, they can be identified as one of the four above types.

Fire extinguishers are for dealing with small fires, and different types of fire must be attacked with a different type of extinguisher. Using the wrong type of extinguisher could make matters worse. For example, water must not be used on a liquid or electrical fire. The normal procedure when dealing with electrical fires is to cut off the electrical supply and use an extinguisher which is appropriate to whatever is burning. Figure 1.18 shows the correct type of extinguisher to be used on the various categories of fire. The colour coding shown is in accordance with BS EN3:1996.

First aid

Despite all the safety precautions taken in the workplace to prevent injury to the workforce, accidents do happen and *you* may be the only other person able to take action to assist a workmate. If you are not a qualified first aider limit your help to obvious commonsense assistance and call for help *but* do remember that if a workmate's heart or breathing has stopped as a result of an accident he has only minutes to live unless you act quickly. The Health and Safety (First Aid) Regulations 1981 and relevant approved codes of practice and guidance notes place a duty of care on all employers to provide *adequate* first aid facilities appropriate to the type of work being undertaken. Adequate facilities will relate to a number of factors such as:

- How many employees are employed?
- What type of work is being carried out?
- Are there any special or unusual hazards?
- Are employees working in scattered and/or isolated locations?
- Is there shift work or 'out of hours' work being undertaken?
- Is the workplace remote from emergency medical services?
- Are there inexperienced workers on site?
- What were the risks of injury and ill health identified by the company's Hazard Risk Assessment?

The regulations state that:

> Employers are under a duty to provide such numbers of suitable persons as is *adequate and appropriate in the circumstances* for rendering first aid to his employees if they are injured or become ill at work. For this purpose a person shall not be suitable unless he or she has undergone such training and has such qualifications as the Health and Safety Executive may approve.

This is typical of the way in which the health and safety regulations are written. The regulations and codes of practice do not specify numbers, but set out guidelines in respect of the number of first aiders needed, dependent upon the type of company, the hazards present and the number of people employed.

Let us now consider the questions 'what is first aid?' and 'who might become a first aider?' The regulations give the following definitions of first aid. '*First aid* is the treatment of minor injuries which would otherwise receive no treatment or do not need treatment by a doctor or nurse' *or* 'In cases where a person will require help from a doctor or nurse, first aid is treatment for the purpose of preserving life and minimizing the consequences of an injury or illness until such help is obtained.' A more generally accepted definition of first aid might be as follows: *first aid* is the initial assistance or treatment given to a casualty for any injury or sudden illness before the arrival of an ambulance, doctor or other medically qualified person.

Now having defined first aid, who might become a first aider? A *first aider* is someone who has undergone a training course to administer first aid at work and holds a current first aid certificate. The training course and certification must be approved by the HSE. The aims of a first aider are to preserve life, to limit the worsening of the injury or illness and to promote recovery.

A first aider may also undertake the duties of an *appointed person*. An *appointed person* is someone who is nominated to take charge when someone is injured or becomes ill, including calling an ambulance if required. The appointed person will also look after the first aid equipment, including re-stocking the first aid box.

Appointed persons should not attempt to give first aid for which they have not been trained but should limit their help to obvious commonsense assistance and summon professional assistance as required. Suggested numbers of first aid personnel are given in Table 1.1. The actual number of first aid personnel must take into account any special circumstances such as remoteness from medical services, the use of several separate buildings and the company's hazard risk assessment. First aid personnel must be available at all times when people are at work, taking into account shift working patterns and providing cover for sickness absences.

Every company must have at least one first aid kit under the regulations. The size and contents of the kit will depend upon the nature of the risks involved in the particular working environment and the number of employees. Table 1.2 gives a list of the contents of any first aid box to comply with the HSE Regulations.

Table 1.1 Suggested numbers of first aid personnel

Category of risk	Numbers employed at any location	Suggested number of first aid personnel
Lower risk		
e.g. shops and offices, libraries	Fewer than 50	At least one appointed person
	50–100	At least one first aider
	More than 100	One additional first aider for every 100 employed
Medium risk		
e.g. light engineering and assembly	Fewer than 20	At least one appointed person
work, food processing, warehousing	20–100	At least one first aider for every 50 employed (or part thereof)
	More than 100	One additional first aider for every 100 employed
Higher risk		
e.g. most construction, slaughterhouses,	Fewer than five	At least one appointed person
chemical manufacture, extensive work	5–50	At least one first aider
with dangerous machinery or sharp instruments	More than 50	One additional first aider for every 50 employed

Table 1.2 Contents of first aid boxes

Item	Number of employees				
	1–5	6–10	11–50	51–100	101–150
Guidance card on general first aid	1	1	1	1	1
Individually wrapped sterile adhesive dressings	10	20	40	40	40
Sterile eye pads, with attachment (Standard Dressing No. 16 BPC)	1	2	4	6	8
Triangular bandages	1	2	4	6	8
Sterile covering for serious wounds (where applicable)	1	2	4	6	8
Safety pins	6	6	12	12	12
Medium sized sterile unmedicated dressings (Standard Dressings No. 9 and No. 14 and the Ambulance Dressing No. 1)	3	6	8	10	12
Large sterile unmedicated dressings (Standard Dressings No. 9 and No. 14 and the Ambulance Dressing No. 1)	1	2	4	6	10
Extra large sterile unmedicated dressings (Ambulance Dressing No. 3)	1	2	4	6	8

Where tap water is not available, sterile water or sterile normal saline in disposable containers (each holding a minimum of 300 ml) must be kept near the first aid box. The following minimum quantities should be kept:

Number of employees	1–10	11–50	51–100	101–150
Quantity of sterile water	1 × 300 ml	3 × 300 ml	6 × 300 ml	6 × 300 ml

There now follows a description of some first aid procedures which should be practised under expert guidance before they are required in an emergency.

Bleeding

If the wound is dirty, rinse it under clean running water. Clean the skin around the wound and apply a plaster, pulling the skin together.

If the bleeding is severe apply direct pressure to reduce the bleeding and raise the limb if possible. Apply a sterile dressing or pad and bandage firmly before obtaining professional advice.

To avoid possible contact with hepatitis or the AIDS virus, when dealing with open wounds, first aiders should avoid contact with fresh blood by wearing plastic or rubber protective gloves, or by allowing the casualty to apply pressure to the bleeding wound.

Burns

Remove heat from the burn to relieve the pain by placing the injured part under clean cold water. Do not remove burnt clothing sticking to the skin. Do not apply lotions or ointments. Do not break blisters or attempt to remove loose skin. Cover the injured area with a clean dry dressing.

Broken bones

Make the casualty as comfortable as possible by supporting the broken limb either by hand or with padding. Do not move the casualty unless by remaining in that position he is likely to suffer further injury. Obtain professional help as soon as possible.

Contact with chemicals

Wash the affected area very thoroughly with clean cold water. Remove any contaminated clothing. Cover the affected area with a clean sterile dressing and seek expert advice. It is a wise precaution to treat all chemical substances as possibly harmful; even commonly used substances can be dangerous if contamination is from concentrated solutions. When handling dangerous substances it is also good practice to have a neutralizing agent to hand.

Disposal of dangerous substances must not be into the main drains since this can give rise to an environmental hazard, but should be undertaken in accordance with Local Authority Regulations.

Exposure to toxic fumes

Get the casualty into fresh air quickly and encourage deep breathing if conscious. Resuscitate if breathing has stopped. Obtain expert medical advice as fumes may cause irritation of the lungs.

Sprains and bruising

A cold compress can help to relieve swelling and pain. Soak a towel or cloth in cold water, squeeze it out and place it on the injured part. Renew the compress every few minutes.

Breathing stopped

Remove any restrictions from the face and any vomit, loose or false teeth from the mouth. Loosen tight clothing around the neck, chest and waist. To ensure a good airway, lay the casualty on his back and support the shoulders on some padding. Tilt the head backwards and open the mouth. If the casualty is faintly breathing, lifting the tongue clear of the airway may be all that is necessary to restore normal breathing. However, if the casualty does not begin to breathe, open your mouth wide and take a deep breath, close the casualty's nose by pinching with your fingers, and, sealing your lips around his mouth, blow into his lungs until the chest rises. Remove your mouth and watch the casualty's chest fall. Continue this procedure at your natural breathing rate. If the mouth is damaged or you have difficulty making a seal around the casualty's mouth, close his mouth and inflate the lungs through his nostrils. Give artificial respiration until natural breathing is restored or until professional help arrives.

Heart stopped beating

This sometimes happens following a severe electric shock. If the casualty's lips are blue, the pupils of his eyes widely dilated and the pulse in his neck cannot be felt, then he may have gone into cardiac arrest. Act quickly and lay the casualty on his back. Kneel down beside him and place the heel of one hand in the centre of his chest. Cover this hand with your other hand and interlace the fingers. Straighten your arms and press down on his chest sharply with the heel of your hands and then release the pressure. Continue to do this 15 times at the rate of one push per second. Check the casualty's pulse. If none is felt, give two breaths of artificial respiration and then a further 15 chest compressions. Continue this procedure until the heartbeat is restored and the artificial respiration until normal breathing returns. Pay close attention to the condition of the casualty while giving heart massage. When a pulse is restored the blueness around the mouth will quickly go away and you should stop the heart massage. Look carefully at the rate of breathing.

When this is also normal, stop giving artificial respiration. Treat the casualty for shock, place him in the recovery position and obtain professional help.

Shock

Everyone suffers from shock following an accident. The severity of the shock depends upon the nature and extent of the injury. In cases of severe shock the casualty will become pale and his skin become clammy from sweating. He may feel faint, have blurred vision, feel sick and complain of thirst. Reassure the casualty that everything that needs to be done is being done. Loosen tight clothing and keep him warm and dry until help arrives. *Do not* move him unnecessarily or give him anything to drink.

Accident reports

Every accident must be reported to an employer and minor accidents reported to a supervisor, safety officer or first aider and the details of the accident and treatment given suitably documented. A first aid logbook or Accident book such as that shown in Fig. 1.19 containing first aid treatment record sheets could be used to effectively document accidents which occur in the workplace and the treatment given. Failure to do so may influence the payment of compensation at a later date if an injury leads to permanent disability. To comply with the Data Protection Regulations, from the 31st December 2003 all First Aid Treatment Logbooks or Accident Report books must contain perforated sheets which can be removed after completion and filed away for personal security.

Fig. 1.19 First aid logbook/Accident book with data protection compliant removable sheets.

If the accident results in death, serious injury or an injury that leads to an absence from work of more than 3 days, then your employer must report the accident to the local office of the HSE (Health and Safety Executive). The quickest way to do this is to call the Incident Control Centre on 0845 300 9923. They will require the following information:

- The name of the person injured.
- A summary of what happened.
- A summary of events prior to the accident.
- Information about the injury or loss sustained.
- Details of witnesses.
- Date and time of accident.
- Name of the person reporting the incident.

The Incident Control Centre will forward a copy of every report they complete to the employer for them to check and hold on record. However, good practice would recommend an employer or his representative make an extensive report of any serious accident that occurs in the workplace. In addition to recording the above information, the employer or his representative should:

- Sketch diagrams of how the accident occurred, where objects were before and after the accident, where the victim fell etc.
- Take photographs or video that show how things were after the accident, for example, broken stepladders, damaged equipment, etc.
- Collect statements from witnesses. Ask them to write down what they saw.
- Record the circumstances surrounding the accident. Was the injured person working alone – in the dark – in some other adverse situation or condition – was PPE being worn – was PPE recommended in that area?

The above steps should be taken immediately after the accident has occurred and after the victim has been sent for medical attention. The area should be made safe and the senior management informed so that any actions to prevent a similar occurrence can be put in place. Taking photographs and obtaining witnesses statements immediately after an accident happens, means that evidence may still be around and memories still sharp.

Secure electrical isolation

Electric shock occurs when a person becomes part of the electrical circuit. The level or intensity of the shock will depend upon many factors, such as age, fitness and the circumstances in which the shock is received. The lethal level is approximately 50 mA, above which muscles contract, the heart flutters and breathing stops. A shock above the 50 mA level is therefore fatal unless the person is quickly separated from the supply. Below 50 mA only an unpleasant tingling sensation may be experienced or you may be thrown across a room or shocked enough to fall from a roof or ladder, but the resulting fall may lead to serious injury.

To prevent people receiving an electric shock accidentally, all circuits contain protective devices. All exposed metal is earthed, fuses and miniature circuit breakers (MCBs) are designed to trip under fault conditions and residual current devices (RCDs) are designed to trip below the fatal level as described in Chapter 2.

Construction workers and particularly electricians do receive electric shocks, usually as a result of carelessness or unforeseen circumstances. As an electrician working on electrical equipment you must always make sure that the equipment is switched off or electrically isolated before commencing work. Every circuit must be provided with a means of isolation (IEE Regulation 130–06–01). When working on portable equipment or desktop units it is often simply a matter of unplugging the equipment from the adjacent supply. Larger pieces of equipment, and electrical machines may require isolating at the local isolator switch before work commences. To deter anyone from re-connecting the supply while work is being carried out on equipment, a sign 'Danger – Electrician at Work' should be displayed on the isolator and the isolation 'secured' with a small padlock or the fuses removed so that no one can re-connect whilst work is being carried out on that piece of equipment. The Electricity at Work Regulations 1989 are very specific at Regulation 12(1) that we must ensure the disconnection and separation of electrical equipment from every source of supply and that this disconnection and separation is secure. Where a test instrument or voltage indicator is used to prove the supply dead, Regulation 4(3) of the Electricity at Work Regulations 1989 recommends that the following procedure is adopted.

1 First connect the test device such as that shown in Fig. 1.20 to the supply which is to be isolated. The test device should indicate mains voltage.

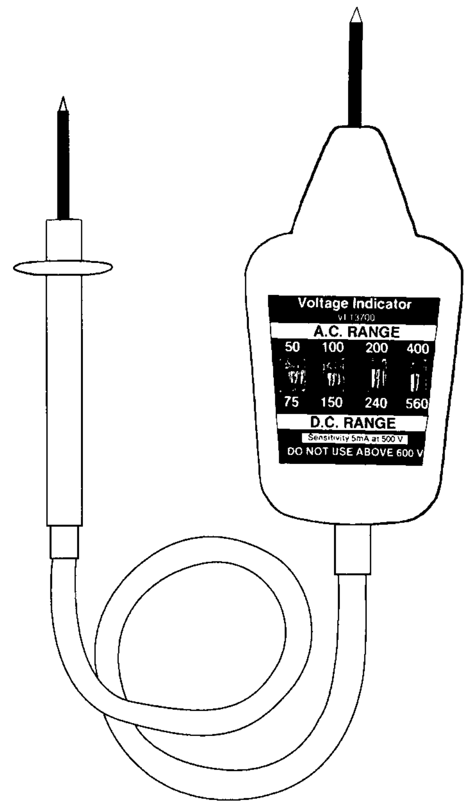


Fig. 1.20 Typical voltage indicator.

2 Next, isolate the supply and observe that the test device now reads zero volts.
3 Then connect the same test device to a known live supply or proving unit such as that shown in Fig. 1.21 to 'prove' that the tester is still working correctly.
4 Finally secure the isolation and place warning signs; only then should work commence.

The test device being used by the electrician must incorporate safe test leads which comply with the Health and Safety Executive Guidance Note 38 on electrical test equipment. These leads should incorporate barriers to prevent the user touching live terminals when testing and incorporating a protective fuse and be well insulated and robust, such as those shown in Fig. 1.22.

To isolate a piece of equipment or individual circuit successfully, competently, safely and in accordance

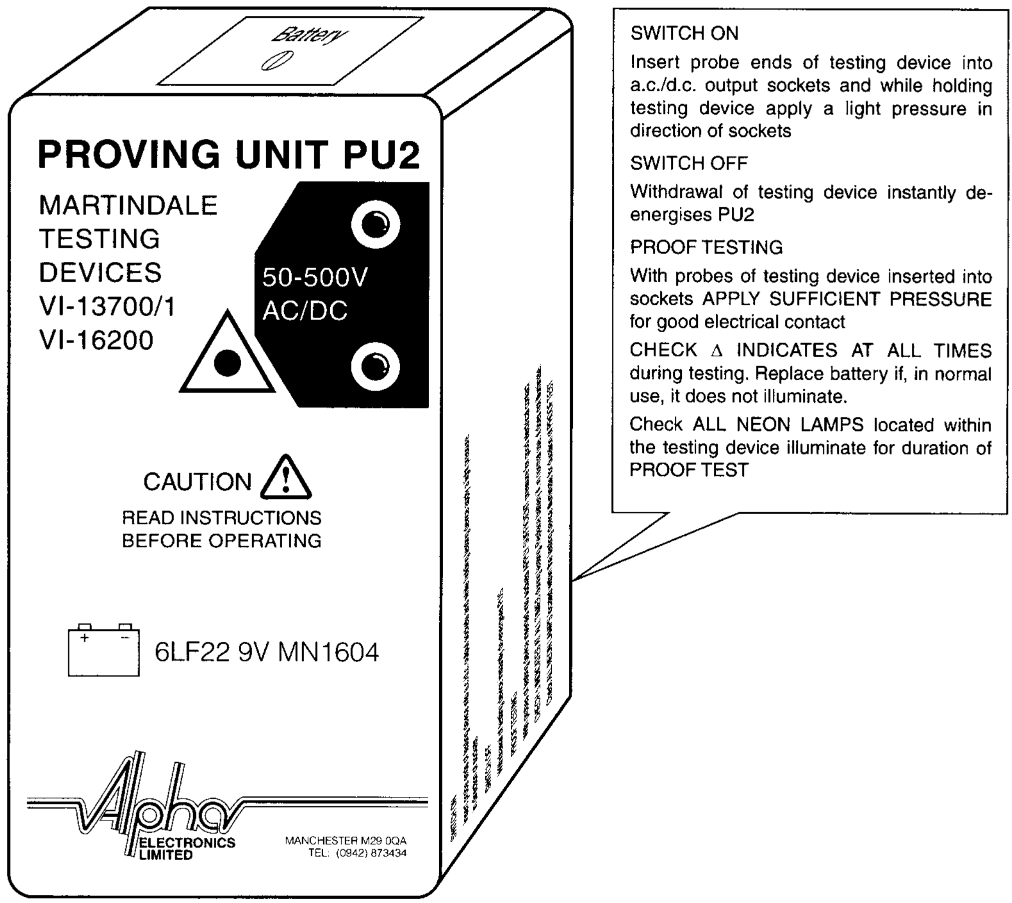


Fig. 1.21 Voltage proving unit.

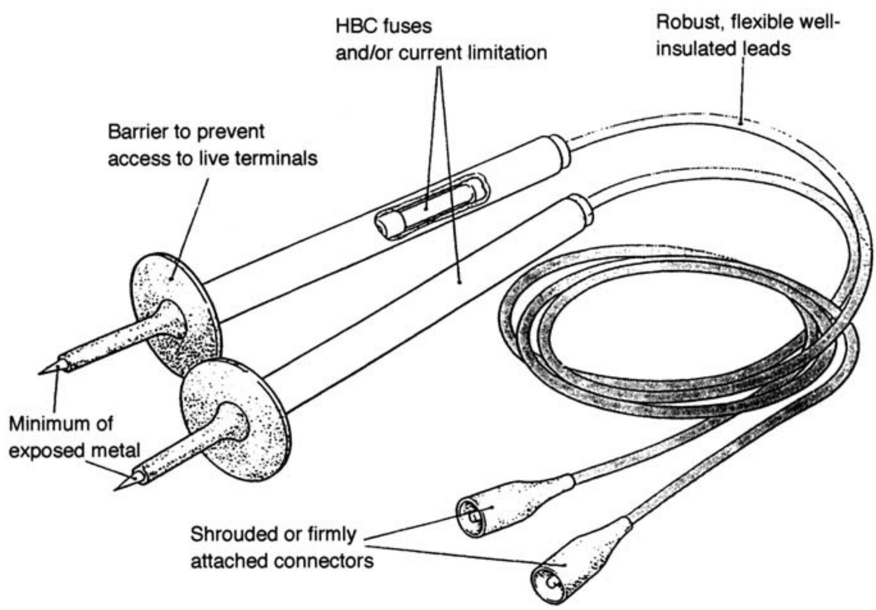


Fig. 1.22 Recommended type of test probe and leads.

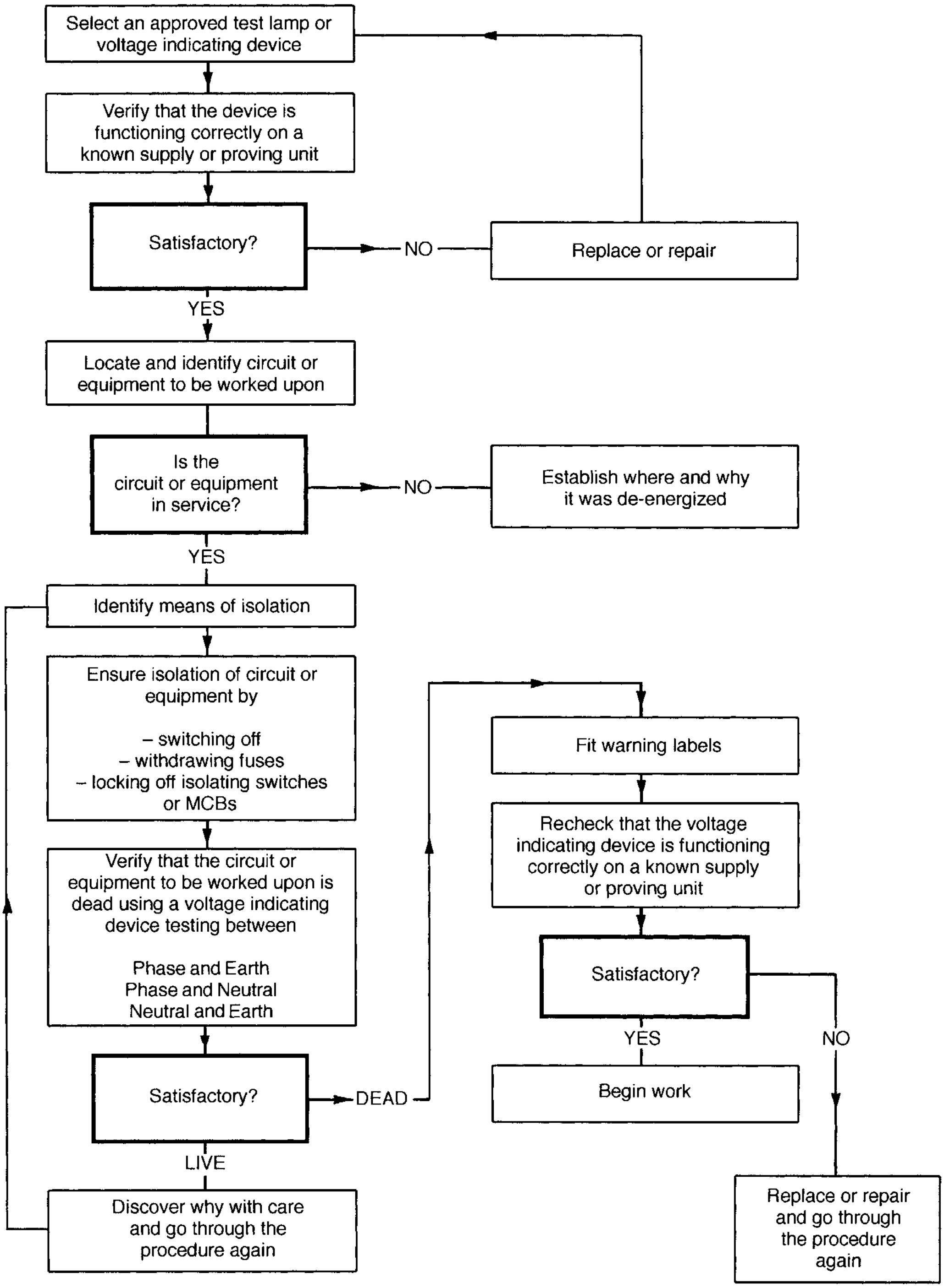


Fig. 1.23 Flowchart for a secure isolation procedure.

with all the relevant regulations, we must follow a procedure such as that given by the flow diagram of Fig. 1.23. Start at the top and work down the flow diagram. When the heavy outlined boxes are reached, pause and ask yourself whether everything is satisfactory up to this point. If the answer is 'yes', move on. If the answer is 'no', go back as indicated by the diagram.

LIVE TESTING

The Electricity at Work Regulations 1989 at Regulation 4(3) tell us that it is preferable that supplies be made dead before work commences. However, it does acknowledge that some work, such as fault finding and testing, may require the electrical equipment to remain energized. Therefore, if the fault finding and testing can only be successfully carried out live then the person carrying out the fault diagnosis must:

- be trained so that they understand the equipment and the potential hazards of working live and can, therefore, be deemed 'competent' to carry out that activity;
- only use approved test equipment;
- set up appropriate warning notices and barriers so that the work activity does not create a situation dangerous to others.

While live testing may be required by workers in the electrotechnical industries in order to find the fault, live repair work must not be carried out. The individual circuit or piece of equipment must first be isolated before work commences in order to comply with the Electricity at Work Regulations 1989.

Permit-to-work system

The permit-to-work procedure is a type of 'safe system to work' procedure used in specialized and potentially dangerous plant process situations. The procedure was developed for the chemical industry, but the principle is equally applicable to the management of complex risk in other industries or situations. For example:

- Working on part of an assembly line process where goods move through a complex, continuous process from one machine to another (e.g. the food industry).
- Repairs to railway tracks, tippers and conveyors.
- Working in confined spaces (e.g. vats and storage containers).
- Working on or near overhead crane tracks.
- Working underground or in deep trenches.
- Working on pipelines.
- Working near live equipment or unguarded machinery.
- Roof work.
- Working in hazardous atmospheres (e.g. the petroleum industry).
- Working near or with corrosive or toxic substances.

All the above situations are high risk working situations that should be avoided unless you have received special training and will probably require the completion of a permit-to-work. Permits to work must adhere to the following eight principles:

1. Wherever possible the hazard should be eliminated so that the work can be done safely without a permit to work.
2. The Site Manager has overall responsibility for the permit to work even though he may delegate the responsibility for its issue.
3. The permit must be recognized as the master instruction, which, until it is cancelled, overrides all other instructions.
4. The permit applies to everyone on site, other trades and sub-contractors.
5. The permit must give detailed information, for example: (i) which piece of plant has been isolated and the steps by which this has been achieved (ii) what work is to be carried out (iii) the time at which the permit comes into effect.
6. The permit remains in force until the work is completed and is cancelled by the person who issued it.
7. No other work is authorized. If the planned work must be changed, the existing permit must be cancelled and a new one issued.
8. Responsibility for the plant must be clearly defined at all stages because the equipment that is taken out of service is released to those who are to carry out the work.

The people doing the work, the people to whom the permit is given, take on the responsibility of following and maintaining the safeguards set out in the permit, which will define what is to be done (no other work is permitted) and the time scale in which it is to be carried out.

The permit-to-work system must help communication between everyone involved in the process or type of work. Employers must train staff in the use of such permits and ideally, training should be designed by the company issuing the permit, so that sufficient emphasis can be given to particular hazards present and the precautions which will be required to be taken. For further details see Permit to Work @ www.hse.gov.uk

The world of work

TEAM WORKING

Team working is about working with other people, probably with other employees from the company you work for. Working together, helping each other, sharing the load in order to get the job done to a good standard of workmanship in the time allowed. All the separate parts of the job have to be finished and eventually brought together at completion. The team can also be much larger than just those people who work for the same company. We are often dependent on other trades completing their work before we can start ours. The ceiling fitters must install the suspended ceiling before we can drop the recessed modular fluorescent fittings in place and connect them. So, in this case, two different trades are interdependent, working as a team to complete a suspended ceiling job.

A lot of research has been done over the years about what makes a good team and how the relationship of individual members of a team develop over time. One such model is called ‘Forming, Storming, Norming and Performing’.

Forming is the first stage of the developing team where the separate individuals come together. They behave as individuals, their responsibility to the team is unclear and they feel confused about what they should be doing. At this stage the team leader will be telling everyone what to do for the collective good because they are all acting as individuals.

Storming is the stage where people begin to see a role for themselves within the team. They will challenge other team members and the team leader, who must become less dominant and more encouraging.

Norming is the stage where team members have generally reached an agreement upon their individual roles and responsibilities to the group. They discuss together and reach agreement upon the best way to perform a task together. The team may share the leadership role.

Performing is the final stage of the development of the team. Everyone knows what they are doing and how their input fits into everyone else’s work in the team. The team leaders role is to oversee the project. There is no requirement for instruction or assistance because everyone knows what they have to do to be successful. The individual members support each other, jollying each other along if necessary, giving help when required and generally looking after each other. They have a shared vision and goal.

Good customer relationships

Remember that it is the customers who actually pay the wages of everyone employed in your company. You should always be polite and listen carefully to their wishes. They may be elderly or of a different religion or cultural background than you. In a domestic situation, the playing of loud music on a radio may not be approved of. Treat the property in which you are working with the utmost care. When working in houses, shops and offices use dust sheets to protect floor coverings and furnishings. Clean up periodically and make a special effort when the job is completed.

Dress appropriately: an unkempt or untidy appearance will encourage the customer to think that your work will be of poor quality.

The electrical installation in a building is often carried out alongside other trades. It makes good sense to help other trades where possible and to develop good working relationships with other employees. The customer will be most happy if the workers give an impression of working together as a team for the successful completion of the project.

Finally, remember that the customer will probably see more of the electrician and the electrical trainee than of the managing director of your firm and, therefore, the image presented by you will be assumed to reflect the policy of the company. You are, therefore, your company’s most important representative. Always give the impression of being capable and in command of the situation, because this gives customers confidence in the company’s ability to meet their needs. However, if a problem does occur which is outside your previous experience and you do not feel confident to solve it successfully, then contact your supervisor for professional help and guidance. It is not unreasonable for a young member of the company’s team to seek help and guidance from those employees with more experience. This approach would be preferred by most companies rather than having to meet the cost of an expensive blunder.

Changing work patterns

The elctrotechnical industries cover a large range of activities and occupations from panel building, instrumentation, maintenance, cable jointing, highway electrical systems to motor re-winding, alarm and security systems, building management systems and computer installations. Electricians are often employed in the electrical contracting industry, installing wiring systems and equipment in houses, hospitals, schools, shops and offices. Electricians are also employed directly by factories, local councils, large commercial organizations, hospitals and the armed services where their skills are in demand. Employment opportunities for electrically trained people are enormous. There were 21 000 electrical contracting companies registered in the United Kingdom in 2004. These companies employ from less than 10 people to the big multi-national companies, although the majority are small companies of less than 10 people. Then there are the small self-employed electrical businesses and those who work for the local authority, hospitals or armed forces who do not get counted as electrical personnel but as blue collar workers or soldiers.

The new technology of recent times has created many new opportunities for electrically competent personnel from installing satellite dishes, computer networks, extension telephone sockets for Internet connections to dichroic reflector miniature spotlight installations, intruder alarms and external illumination of garden areas.

New editions of the Regulations create work opportunities in domestic and public buildings bringing them up to the latest safety requirements.

A structured apprenticeship gives a broad range of experience opportunities and the achievement of the appropriate City and Guilds qualifications will lead to qualified electrician status with good electrical core skills.

New technologies present new opportunities to build on these core skills. New editions of the Regulations present new training opportunities. The acquisition of new skills gives the opportunity to transfer these new skills to new employers. Flexible workers with a range of skills can work in different disciplines in different parts of the electrotechnical industry in different parts of the country. Flexible workers are an attractive proposition to a prospective employer.

Electricians trained in the installation of conduit systems can easily transfer their skills to those we think of as belonging to a plumber or heating engineer. For those employed in the maintenance of fluid systems, this may present opportunities of further responsibility or an increase in salary or status within a company.

Maintenance work demands that a craftsman has a range of skills and the flexibility to use them. If an electric motor was found to be faulty, then to replace it would require mechanical engineering and fitting skills as well as electrical skills and the one man who can do that job has multiple skills and can demand more pay.

Increased leisure opportunities have seen a huge increase in fitness centres containing lots of electrical equipment. The overuse and misuse of equipment means that it breaks down more frequently. When does it break down? At the most inconvenient time of course! The fitness centre manager wants the equipment fixed reasonably quickly, even if it is Sunday. They are at work so why isn't the electrician!

I live close to a seaside resort. All the people involved in the holiday seasonal work, work hard long hours, usually from Easter until the end of the summer. Everything then closes down and they then get on with their planned maintenance work. However, things also go wrong during the holiday season and the electrician is expected to support them when they need him.

This leads to a demand for flexible working hours or a flexible working week. Some of the small electrical companies have a rota system so that at least one member of staff is on cover for breakdowns and emergencies over a weekend. If the rota is shared out, then each individual only need cover, say one in four weekends, and as a result receives extra pay.

The foreseeable future for those employed in the electrotechnical industries is that they will require a firm practical and academic foundation. New technologies will require that we continue to learn new skills and new ideas will create new business opportunities for electrical companies. Regulations and laws will be updated to improve health and safety and to meet the demands of industry along with new training opportunities for employees to keep up to date with new requirements. Employees will also need to be flexible, not only in relation to what they can do but when they can do it. Very few people these days work regular fixed hours.

Electrical Principles

All matter is made up of atoms which arrange themselves in a regular framework within the material. The atom is made up of a central, positively charged nucleus, surrounded by negatively charged electrons. The electrical properties of a material depend largely upon how tightly these electrons are bound to the central nucleus.

A *conductor* is a material in which the electrons are loosely bound to the central nucleus and are, therefore, free to drift around the material at random from one atom to another, as shown in Fig. 1.24(a). Materials which are good conductors include copper, brass, aluminium and silver.

An *insulator* is a material in which the outer electrons are tightly bound to the nucleus and so there are no free electrons to move around the material. Good insulating materials are PVC, rubber, glass and wood.

If a battery is attached to a conductor as shown in Fig. 1.24(b), the free electrons drift purposefully in one direction only. The free electrons close to the positive plate of the battery are attracted to it since unlike charges attract, and the free electrons near the negative plate will be repelled from it. For each electron entering the positive terminal of the battery, one will be ejected from the negative terminal, so the number of electrons in the conductor remains constant.

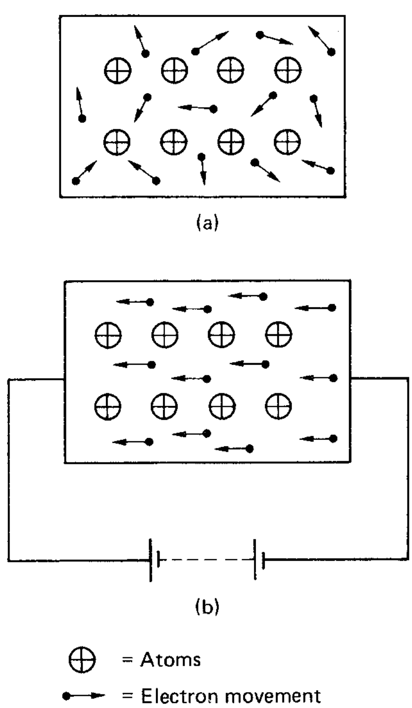


Fig. 1.24 Atoms and electrons on a material.

This drift of electrons within a conductor is known as an electric *current*, measured in amperes and given the symbol *I*. For a current to continue to flow, there must be a complete circuit for the electrons to move around. If the circuit is broken by opening a switch, for example, the electron flow and therefore the current will stop immediately.

To cause a current to flow continuously around a circuit, a driving force is required, just as a circulating pump is required to drive water around a central heating system. This driving force is the *electromotive force* (abbreviated to emf). Each time an electron passes through the source of emf, more energy is provided to send it on its way around the circuit.

An emf is always associated with energy conversion, such as chemical to electrical in batteries and mechanical to electrical in generators. The energy introduced into the circuit by the emf is transferred to the load terminals by the circuit conductors. The *potential difference* (abbreviated to p.d.) is the change in energy levels measured across the load terminals. This is also called the volt drop or terminal voltage, since emf and p.d. are both measured in volts. Every circuit offers some opposition to current flow, which we call the circuit *resistance*, measured in ohms (symbol Ω), to commemorate the famous German physicist George Simon Ohm, who was responsible for the analysis of electrical circuits.

Ohm's law

In 1826, George Ohm published details of an experiment he had done to investigate the relationship between the current passing through and the potential difference between the ends of a wire. As a result of this experiment, he arrived at a law, now known as Ohm's law, which says that *the current passing through a conductor under constant temperature conditions is proportional to the potential difference across the conductor*. This may be expressed mathematically as

$$V = I \times R \text{ (V)}$$

Transposing this formula, we also have

$$I = \frac{V}{R} \text{ (A)} \quad \text{and} \quad R = \frac{V}{I} \text{ } (\Omega)$$

EXAMPLE 1

An electric heater, when connected to a 230 V supply, was found to take a current of 4 A. Calculate the element resistance.

$$R = \frac{V}{I}$$

$$\therefore\ R = \frac{230\ \text{V}}{4\ \text{A}} = 57.5\ \Omega$$

EXAMPLE 2

The insulation resistance measured between phase conductors on a 400 V supply was found to be 2 MΩ. Calculate the leakage current.

$$I = \frac{V}{R}$$

$$\therefore I = \frac{400\ \text{V}}{2 \times 10^6\ \Omega} = 200 \times 10^{-6}\ \text{A} = 200\ \mu\text{A}$$

EXAMPLE 3

When a 4 Ω resistor was connected across the terminals of an unknown d.c. supply, a current of 3 A flowed. Calculate the supply voltage.

$$V = I \times R$$

$$\therefore\ V = 3\ \text{A} \times 4\ \Omega = 12\ \text{V}$$

Resistivity

The resistance or opposition to current flow varies for different materials, each having a particular constant value. If we know the resistance of, say, 1 m of a material, then the resistance of 5 m will be five times the resistance of 1 m.

The *resistivity* (symbol ρ – the Greek letter 'rho') of a material is defined as the resistance of a sample of unit length and unit cross-section. Typical values are given in Table 1.3. Using the constants for a particular material we can calculate the resistance of any length and thickness of that material from the equation.

$$R = \frac{\rho l}{a}\ (\Omega)$$

where
ρ = the resistivity constant for the material (Ω m)
l = the length of the material (m)
a = the cross-sectional area of the material (m^2).

Table 1.3 gives the resistivity of silver as $16.4 \times 10^{-9}\ \Omega\text{m}$, which means that a sample of silver 1 m long and 1 m in cross-section will have a resistance of $16.4 \times 10^{-9}\ \Omega$.

Table 1.3 Resistivity values

Material	Resistivity (Ω m)
Silver	16.4×10^{-9}
Copper	17.5×10^{-9}
Aluminium	28.5×10^{-9}
Brass	75.0×10^{-9}
Iron	100.0×10^{-9}

EXAMPLE 1

Calculate the resistance of 100 m of copper cable of 1.5 mm^2 cross-sectional area if the resistivity of copper is taken as $17.5 \times 10^{-9}\ \Omega\text{m}$.

$$R = \frac{\rho l}{a}\ (\Omega)$$

$$\therefore R = \frac{17.5 \times 10^{-9}\ \Omega \times 100\ \text{m}}{1.5 \times 10^{-6}\ \text{m}^2} = 1.16\ \Omega$$

EXAMPLE 2

Calculate the resistance of 100 m of aluminium cable of 1.5 mm^2 cross-sectional area if the resistivity of aluminium is taken as $28.5 \times 10^{-9}\ \Omega\text{m}$.

$$R = \frac{\rho l}{a}\ (\Omega)$$

$$\therefore R = \frac{28.5 \times 10^{-9}\ \Omega\text{m} \times 100\ \text{m}}{1.5 \times 10^{-6}\ \text{m}^2} = 1.9\ \Omega$$

The above examples show that the resistance of an aluminium cable is some 60% greater than a copper conductor of the same length and cross-section. Therefore, if an aluminium cable is to replace a copper cable, the conductor size must be increased to carry the rated current as given by the tables in Appendix 4 of the IEE Regulations and Appendix 6 of the *On Site Guide.*

The other factor which affects the resistance of a material is the temperature, and we will consider this next.

Temperature coefficient

The resistance of most materials changes with temperature. In general, conductors increase their resistance as the temperature increases and insulators decrease their resistance with a temperature increase. Therefore, an increase in temperature has a bad effect upon the electrical properties of a material.

Each material responds to temperature change in a different way, and scientists have calculated constants for each material which are called the *temperature coefficient of resistance* (symbol α – the Greek letter 'alpha'). Table 1.4 gives some typical values.

Table 1.4 Temperature coefficient values

Material	Temperature coefficient (Ω/Ω°C)
Silver	0.004
Copper	0.004
Aluminium	0.004
Brass	0.001
Iron	0.006

Using the constants for a particular material and substituting values into the following formulae the resistance of a material at different temperatures may be calculated. For a temperature increase from 0°C

$$R_t = R_0(1 + \alpha t)\ (\Omega)$$

where
R_t = the resistance at the new temperature t°C
R_0 = the resistance at 0°C
α = the temperature coefficient for the particular material.

For a temperature increase between two intermediate temperatures above 0°C

$$\frac{R_1}{R_2} = \frac{(1 + \alpha t_1)}{(1 + \alpha t_2)}$$

where
R_1 = the resistance at the original temperature
R_2 = the resistance at the final temperature
α = the temperature coefficient for the particular material.

If we take a 1 Ω resistor of, say, copper, and raise its temperature by 1°C, the resistance will increase by 0.004–1.004 Ω. This increase of 0.004 Ω is the temperature coefficient of the material.

EXAMPLE 1

The field winding of a d.c. motor has a resistance of 100 Ω at 0°C. Determine the resistance of the coil at 20°C if the temperature coefficient is 0.004 Ω/Ω°C.

$$R_t = R_0\,(1 + \alpha t)\ (\Omega)$$
$$\therefore R_t = 100\,\Omega\ (1 + 0.004\,\Omega/\Omega°\text{C} \times 20°\text{C})$$
$$R_t = 100\,\Omega\ (1 + 0.08)$$
$$R_t = 108\,\Omega$$

EXAMPLE 2

The field winding of a shunt generator has a resistance of 150 Ω at an ambient temperature of 20°C. After running for some time the mean temperature of the generator rises to 45°C. Calculate the resistance of the winding at the higher temperature if the temperature coefficient of resistance is 0.004 Ω/Ω°C.

$$\frac{R_1}{R_2} = \frac{(1 + \alpha t_1)}{(1 + \alpha t_2)}$$
$$\frac{150\,\Omega}{R_2} = \frac{1 + 0.004\,\Omega/\Omega°\text{C} \times 20°\text{C}}{1 + 0.004\,\Omega/\Omega°\text{C} \times 45°\text{C}}$$
$$\frac{150\,\Omega}{R_2} = \frac{1.08}{1.18}$$
$$\therefore R_2 = \frac{150\,\Omega \times 1.18}{1.08} = 164\,\Omega$$

It is clear from the last two sections that the resistance of a cable is affected by length, thickness, temperature and type of material. Since Ohm's law tells us that current is inversely proportional to resistance, these factors must also influence the current carrying capacity of a cable. The tables of current ratings in Appendix 4 of the IEE Regulations and Appendix 6 of the *On Site Guide* contain correction factors so that current ratings may be accurately determined under defined installation conditions. Cable selection is considered in Chapter 2.

Resistors

In an electrical circuit resistors may be connected in series, in parallel, or in various combinations of series and parallel connections.

SERIES-CONNECTED RESISTORS

In any series circuit a current I will flow through all parts of the circuit as a result of the potential difference supplied by a battery V_T. Therefore, we say that in a series circuit the current is common throughout that circuit.

When the current flows through each resistor in the circuit, R_1, R_2 and R_3 for example in Fig. 1.25, there will be a voltage drop across that resistor whose value will be determined by the values of I and R, since from Ohm's law $V = I \times R$. The sum of the individual voltage drops, V_1, V_2 and V_3 for example in Fig. 1.25, will be equal to the total voltage V_T.

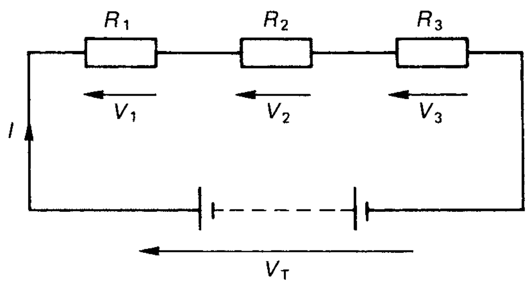


Fig. 1.25 A series circuit.

We can summarize these statements as follows. For any series circuit, I is common throughout the circuit and

$$V_T = V_1 + V_2 + V_3 \qquad (1)$$

Let us call the total circuit resistance R_T. From Ohm's law we know that $V = I \times R$ and therefore

$$\begin{aligned} \text{total voltage } V_T &= I \times R_T \\ \text{voltage drop across } R_1 \text{ is } V_1 &= I \times R_1 \\ \text{voltage drop across } R_2 \text{ is } V_2 &= I \times R_2 \qquad (2) \\ \text{voltage drop across } R_3 \text{ is } V_3 &= I \times R_3 \end{aligned}$$

We are looking for an expression for the total resistance in any series circuit and, if we substitute Equations (2) into Equation (1) we have

$$V_T = V_1 + V_2 + V_3$$

$$\therefore I \times R_T = I \times R_1 + I \times R_2 + I \times R_3$$

Now, since I is common to all terms in the equation, we can divide both sides of the equation by I. This will cancel out I to leave us with an expression for the circuit resistance:

$$R_T = R_1 + R_2 + R_3$$

Note that the derivation of this formula is given for information only. Craft students need only state the expression $R_T = R_1 + R_2 + R_3$ for series connections.

PARALLEL-CONNECTED RESISTORS

In any parallel circuit, as shown in Fig. 1.26, the same voltage acts across all branches of the circuit. The total current will divide when it reaches a resistor junction, part of it flowing in each resistor. The sum of the individual currents, I_1, I_2 and I_3 for example in Fig. 1.26, will be equal to the total current I_T.

We can summarize these statements as follows. For any parallel circuit, V is common to all branches of the circuit and

$$I_T = I_1 + I_2 + I_3 \qquad (3)$$

Let us call the total resistance R_T.

From Ohm's law we know, that $I = \dfrac{V}{R}$, and therefore

$$\begin{aligned} \text{the total current } I_T &= \frac{V}{R_T} \\ \text{the current through } R_1 \text{ is } I_1 &= \frac{V}{R_1} \\ \text{the current through } R_2 \text{ is } I_2 &= \frac{V}{R_2} \qquad (4) \\ \text{the current through } R_3 \text{ is } I_3 &= \frac{V}{R_3} \end{aligned}$$

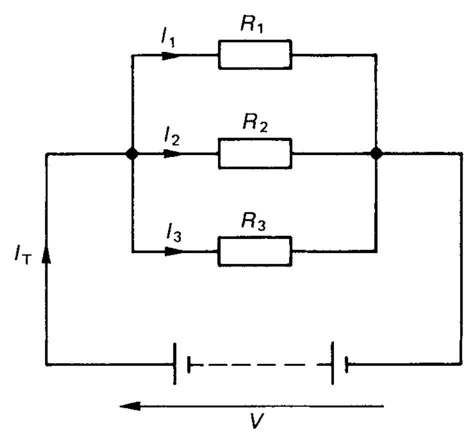


Fig. 1.26 A parallel circuit.

We are looking for an expression for the equivalent resistance R_T in any *parallel* circuit and, if we substitute Equations (4) into Equation (3) we have

$$I_T = I_1 + I_2 + I_3$$

$$\therefore \frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Now, since V is common to all terms in the equation, we can divide both sides by V, leaving us with an expression for the circuit resistance

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Note that the derivation of this formula is given for information only. Craft students need only state the expression $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$ for parallel connections.

EXAMPLE

Three 6 Ω resistors are connected (a) in series (see Fig. 1.27), and (b) in parallel (see Fig. 1.28), across a 12 V battery. For each method of connection, find the total resistance and the values of all currents and voltages.

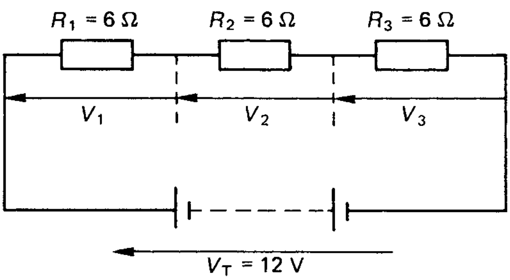


Fig. 1.27 Resistors in series.

For any series connection

$$R_T = R_1 + R_2 + R_3$$
$$\therefore R_1 = 6\,\Omega + 6\,\Omega + 6\,\Omega = 18\,\Omega$$

$$\text{Total current } I_T = \frac{V}{R_T}$$

$$\therefore I_T = \frac{12\,\text{V}}{18\,\Omega} = 0.67\,\text{A}$$

The voltage drop across R_1 is

$$V_1 = I \times R_1$$
$$\therefore V_1 = 0.67\,\text{A} \times 6\,\Omega = 4\,\text{V}$$

The voltage drop across R_2 is

$$V_2 = I \times R_2$$
$$\therefore V_2 = 0.67\,\text{A} \times 6\,\Omega = 4\,\text{V}$$

The voltage drop across R_3 is

$$V_3 = I \times R_3$$
$$\therefore V_3 = 0.67\,\text{A} \times 6\,\Omega = 4\,\text{V}$$

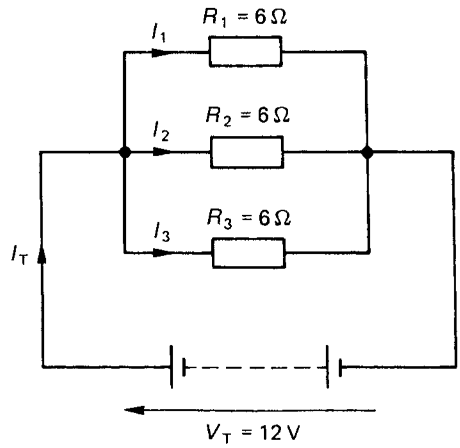


Fig. 1.28 Resistors in parallel.

For any parallel connection

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\therefore \frac{1}{R_T} = \frac{1}{6\,\Omega} + \frac{1}{6\,\Omega} + \frac{1}{6\,\Omega}$$

$$\frac{1}{R_T} = \frac{1+1+1}{6\,\Omega} = \frac{3}{6\,\Omega}$$

$$R_T = \frac{6\,\Omega}{3} = 2\,\Omega$$

$$\text{Total current } I_T = \frac{V}{R_T}$$

$$\therefore I_T = \frac{12\,\text{V}}{2\,\Omega} = 6\,\text{A}$$

The current flowing through R_1 is

$$I_1 = \frac{V}{R_1}$$

$$\therefore I_1 = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

The current flowing through R_2 is

$$I_2 = \frac{V}{R_2}$$

$$\therefore I_2 = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

The current flowing through R_3 is

$$I_3 = \frac{V}{R_3}$$

$$\therefore I_3 = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

SERIES AND PARALLEL COMBINATIONS

The most complex arrangement of series and parallel resistors can be simplified into a single equivalent resistor by combining the separate rules for series and parallel resistors.

EXAMPLE 1

Resolve the circuit shown in Fig. 1.29 into a single resistor and calculate the potential difference across each resistor.

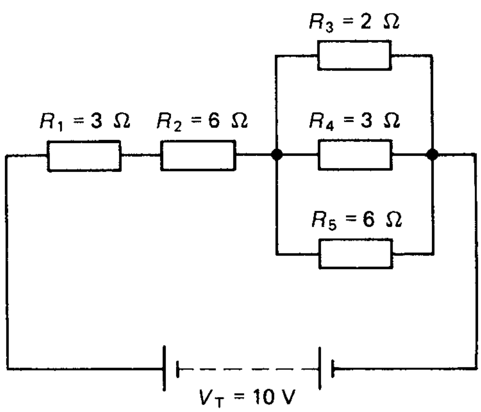


Fig. 1.29 A series/parallel circuit.

By inspection, the circuit contains a parallel group consisting of R_3, R_4 and R_5 and a series group consisting of R_1 and R_2 in series with the equivalent resistor for the parallel branch.

Consider the parallel group. We will label this group R_P. Then

$$\frac{1}{R_P} = \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_P} = \frac{1}{2\,\Omega} + \frac{1}{3\,\Omega} + \frac{1}{6\,\Omega}$$

$$\frac{1}{R_P} = \frac{3+2+1}{6\,\Omega} = \frac{6}{6\,\Omega}$$

$$R_P = \frac{6\,\Omega}{6} = 1\,\Omega$$

Figure 1.29 may now be represented by the more simple equivalent shown in Fig. 1.30

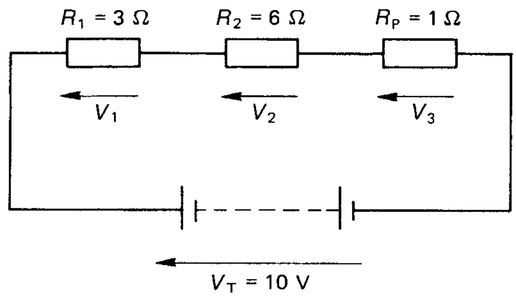


Fig. 1.30 Equivalent series circuit.

Since all resistors are now in series,

$$R_T = R_1 + R_2 + R_P$$
$$\therefore R_T = 3\,\Omega + 6\,\Omega + 1\,\Omega = 10\,\Omega$$

Thus, the circuit may be represented by a single equivalent resistor of value 10 Ω as shown in Fig. 1.31. The total current flowing in the circuit may be found by using Ohm's law

$$I_T = \frac{V_T}{R_T} + \frac{10\,\text{V}}{10\,\Omega} = 1\,\text{A}$$

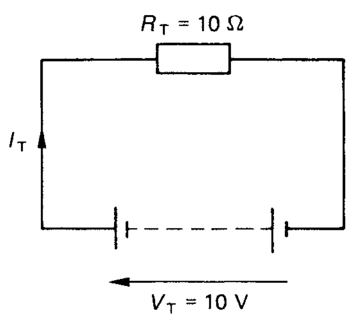


Fig. 1.31 Single equivalent resistor for Fig. 1.29.

The potential differences across the individual resistors are

$$V_1 = I \times R_1 = 1\,\text{A} \times 3\,\Omega = 3\,\text{V}$$
$$V_2 = I \times R_2 = 1\,\text{A} \times 6\,\Omega = 6\,\text{V}$$
$$V_P = I \times R_P = 1\,\text{A} \times 1\,\Omega = 1\,\text{V}$$

Since the same voltage acts across all branches of a parallel circuit the same p.d. of 1 V will exist across each resistor in the parallel branch R_3, R_4 and R_5.

EXAMPLE 2

Determine the total resistance and the current flowing through each resistor for the circuit shown in Fig. 1.32.

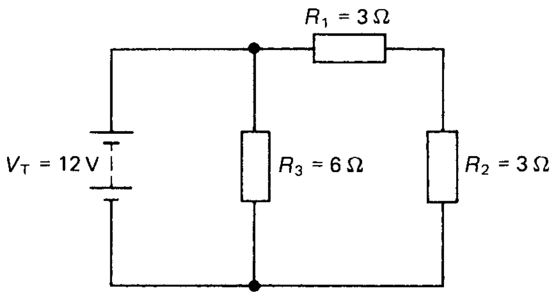


Fig. 1.32 A series/parallel circuit for Example 2.

By inspection, it can be seen that R_1 and R_2 are connected in series while R_3 is connected in parallel across R_1 and R_2. The circuit may be more easily understood if we redraw it as in Fig. 1.33.

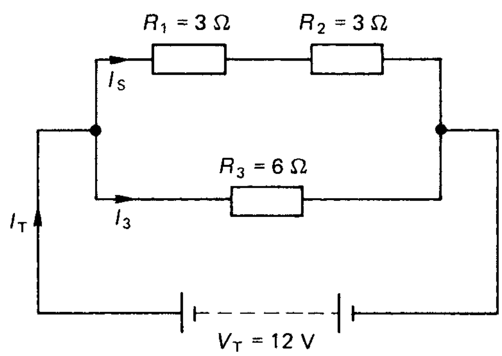


Fig. 1.33 Equivalent circuit for Example 2.

For the series branch, the equivalent resistor can be found from

$$R_S = R_1 + R_2$$
$$\therefore R_S = 3\,\Omega + 3\,\Omega = 6\,\Omega$$

Figure 1.33 may now be represented by a more simple equivalent circuit, as in Fig. 1.34.

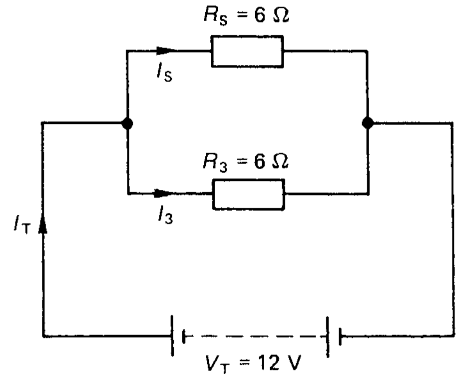


Fig. 1.34 Simplified equivalent circuit for Example 2.

Since the resistors are now in parallel, the equivalent resistance may be found from

$$\frac{1}{R_T} = \frac{1}{R_S} + \frac{1}{R_3}$$
$$\therefore \frac{1}{R_T} = \frac{1}{6\,\Omega} + \frac{1}{6\,\Omega}$$
$$\frac{1}{R_T} = \frac{1+1}{6\,\Omega} = \frac{2}{6\,\Omega}$$
$$R_T = \frac{6\,\Omega}{2} = 3\,\Omega$$

The total current is

$$I_T = \frac{V}{R_T} = \frac{12\,\text{V}}{3\,\Omega} = 4\,\text{A}$$

Let us call the current flowing through resistor R_3 I_3.

$$\therefore I_3 = \frac{V}{R_3} = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

Let us call the current flowing through both resistors R_1 and R_2, as shown in Fig. 1.33, I_S.

$$\therefore I_S = \frac{V}{R_S} = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

Power and energy

POWER

Power is the rate of doing work and is measured in watts.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} \text{ (W)}$$

In an electrical circuit

$$\text{Power} = \text{Voltage} \times \text{Current (W)} \qquad (5)$$

Now from Ohm's law

$$\text{Voltage} = I \times R\text{(V)} \qquad (6)$$

$$\text{Current} = \frac{V}{R} \text{ (A)} \qquad (7)$$

Substituting Equation (6) into Equation (5), we have

$$\text{Power} = (I \times R) \times \text{Current} = I^2 \times R \text{ (W)}$$

and substituting Equation (7) into Equation (5), we have

$$\text{Power} = \text{Voltage} \times \frac{V}{R} = \frac{V^2}{R} \text{ (W)}$$

We can find the power of a circuit by using any of the three formulae

$$P = V \times I, \quad P = I^2 \times R, \quad P = \frac{V^2}{R}$$

ENERGY

Energy is a concept which engineers and scientists use to describe the ability to do work in a circuit or system

$$\begin{aligned} \text{Energy} &= \text{Power} \times \text{Time} \\ \text{but, since Power} &= \text{Voltage} \times \text{Current} \\ \text{then Energy} &= \text{Voltage} \times \text{Current} \times \text{Time} \end{aligned}$$

The SI unit of energy is the joule, where time is measured in seconds. For practical electrical installation circuits this unit is very small and therefore the kilowatt-hour (kWh) is used for domestic and commercial installations. Electricity Board meters measure 'units' of electrical energy, where each 'unit' is 1 kWh. So

$$\begin{aligned} \text{Energy in joules} &= \text{Voltage} \times \text{Current} \\ &\quad \times \text{Time in seconds} \end{aligned}$$

$$\text{Energy in kWh} = \text{kW} \times \text{Time in hours}$$

EXAMPLE 1

A domestic immersion heater is switched on for 40 minutes and takes 15 A from a 200 V supply. Calculate the energy used during this time.

$$\text{Power} = \text{Voltage} \times \text{Current}$$
$$\text{Power} = 200\text{ V} \times 15\text{ A} = 3000\text{ W or } 3\text{ kW}$$
$$\text{Energy} = \text{kW} \times \text{Time in hours}$$

$$\text{Energy} = 3\text{ kW} \times \frac{40\text{ min}}{60\text{ min/h}} = 2\text{ kWh}$$

This immersion heater uses 2 kWh in 40 minutes, or 2 'units' of electrical energy every 40 minutes.

EXAMPLE 2

Two 50 Ω resistors may be connected to a 200 V supply. Determine the power dissipated by the resistors when they are connected (a) in series, (b) each resistor separately connected and (c) in parallel.

For (a), the equivalent resistance when resistors are connected in series is given by

$$R_T = R_1 + R_2$$
$$\therefore R_T = 50\,\Omega + 50\,\Omega = 100\,\Omega$$
$$\text{Power} = \frac{V^2}{R_T} \text{ (W)}$$
$$\therefore \text{Power} = \frac{200\text{ V} \times 200\text{ V}}{100\,\Omega} = 400\text{ W}$$

For (b), each resistor separately connected has a resistance of 50 Ω.

$$\text{Power} = \frac{V^2}{R} \text{ (W)}$$
$$\therefore \text{Power} = \frac{200\text{ V} \times 200\text{ V}}{50\,\Omega} = 800\text{ W}$$

For (c), the equivalent resistance when resistors are connected in parallel is given by

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$\therefore \frac{1}{R_T} = \frac{1}{50\,\Omega} + \frac{1}{50\,\Omega}$$
$$\frac{1}{R_T} = \frac{1+1}{50\,\Omega} = \frac{2}{50\,\Omega}$$
$$R_T = \frac{50\,\Omega}{2} = 25\,\Omega$$

$$\text{Power} = \frac{V^2}{R_T} \text{ (W)}$$

$$\therefore \text{Power} = \frac{200\text{ V} \times 200\text{ V}}{25\,\Omega} = 1600\text{ W}$$

This example shows that by connecting resistors together in different combinations of series and parallel connections, we can obtain various power outputs: in this example, 400, 800 and 1600 W. This theory finds a practical application in the three heat switch used to control a boiling ring.

Alternating waveforms

The supply which we obtain from a car battery is a unidirectional or d.c. supply, whereas the mains electricity supply is alternating or a.c. (see Fig. 1.35).

Most electrical equipment makes use of alternating current supplies, and for this reason a knowledge of alternating waveforms and their effect upon resistive, capacitive and inductive loads is necessary for all practising electricians.

When a coil of wire is rotated inside a magnetic field a voltage is induced in the coil. The induced voltage follows a mathematical law known as the sinusoidal law and, therefore, we can say that a sine wave has been generated. Such a waveform has the characteristics displayed in Fig. 1.36.

In the UK we generate electricity at a frequency of 50 Hz and the time taken to complete each cycle is given by

$$T = \frac{1}{f}$$

$$\therefore T = \frac{1}{50\text{ Hz}} = 0.02\text{ s}$$

An alternating waveform is constantly changing from zero to a maximum, first in one direction, then

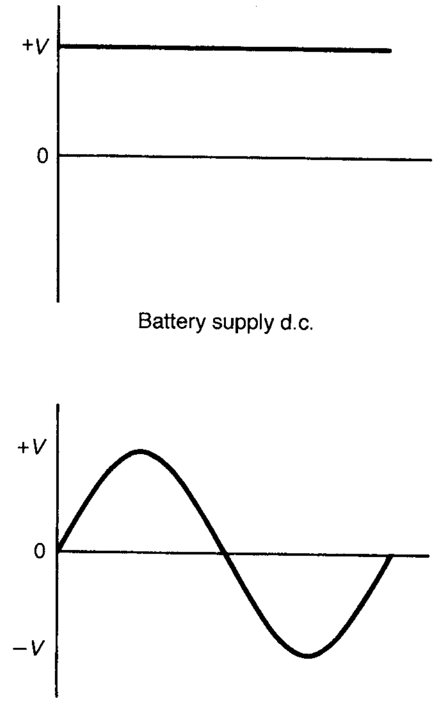


Fig. 1.35 Unidirectional and alternating supply.

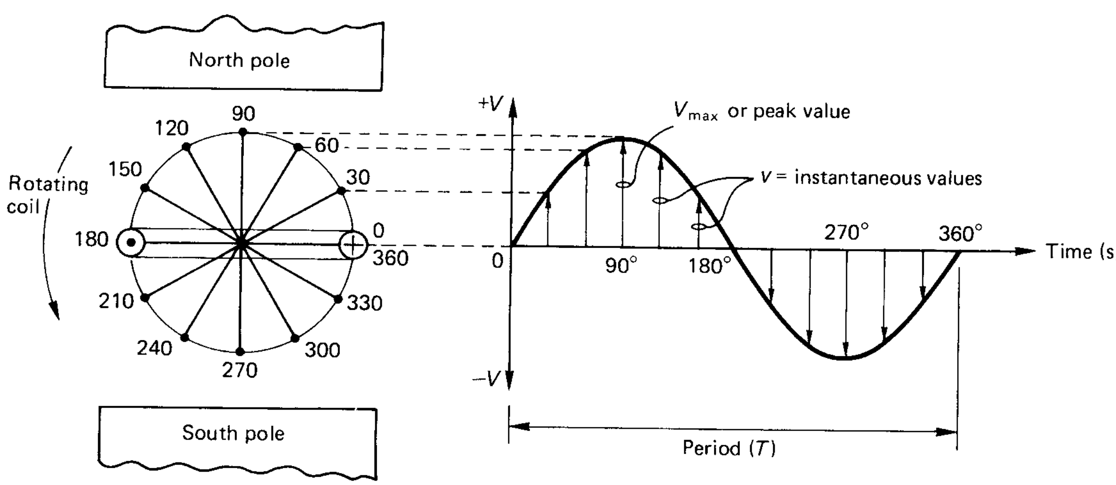


Fig. 1.36 Characteristics of a sine wave.

in the opposite direction, and so the instantaneous values of the generated voltage are always changing. A useful description of the electrical effects of an a.c. waveform can be given by the maximum, average and rms values of the waveform.

The maximum or peak value is the greatest instantaneous value reached by the generated waveform. Cable and equipment insulation levels must be equal to or greater than this value.

The average value is the average over one half-cycle of the instantaneous values as they change from zero to a maximum and can be found from the following formula applied to the sinusoidal waveform shown in Fig. 1.37:

$$V_{av} = \frac{V_1 + V_2 + V_3 + V_4 + V_5 + V_6}{6} = 0.637 V_{max}$$

For any sinusoidal waveform the average value is equal to 0.637 of the maximum value.

The rms value is the square root of the mean of the individual squared values and is the value of an a.c. voltage which produces the same heating effect as a d.c. voltage. The value can be found from the following formula applied to the sinusoidal waveform shown in Fig. 1.37.

$$V_{rms} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + V_5^2 + V_6^2}{6}} = 0.7071\ V_{max}$$

For any sinusoidal waveform the rms value is equal to 0.7071 of the maximum value.

EXAMPLE

The sinusoidal waveform applied to a particular circuit has a maximum value of 325.3 V. Calculate the average and rms value of the waveform.

$$\text{Average value } V_{av} = 0.637 \times V_{max}$$
$$\therefore V_{av} = 0.637 \times 325.3 = 207.2\text{ V}$$
$$\text{rms value } V_{rms} = 0.7071 \times V_{max}$$
$$V_{rms} = 0.7071 \times 325.3 = 230\text{ V}$$

When we say that the main supply to a domestic property is 230 V we really mean 230 V rms. Such a waveform has an average value of about 207.2 V and a maximum value of almost 325.3 V but because the rms value gives the d.c. equivalent value we almost always give the rms value without identifying it as such.

Magnetism

The Greeks knew as early as 600 BC that a certain form of iron ore, now known as magnetite or lodestone, had the property of attracting small pieces of iron. Later, during the Middle Ages, navigational compasses were made using the magnetic properties of lodestone. Small pieces of lodestone attached to wooden splints floating in a bowl of water always came to rest pointing in a north–south direction. The word lodestone is derived from an old English word meaning 'the way', and the word magnetism is derived from Magnesia, the place where magnetic ore was first discovered.

Iron, nickel and cobalt are the only elements which are attracted strongly by a magnet. These materials are said to be *ferromagnetic*. Copper, brass, wood, PVC and glass are not attracted by a magnet and are, therefore, described as *non-magnetic*.

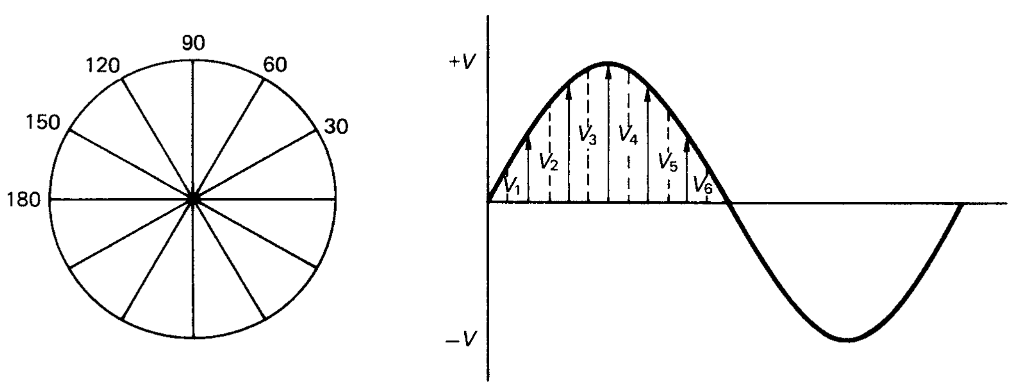


Fig. 1.37 Sinusoidal waveform showing instantaneous values of voltage.

SOME BASIC RULES OF MAGNETISM

1 Lines of magnetic flux have no physical existence, but they were introduced by Michael Faraday (1791–1867) as a way of explaining the magnetic energy existing in space or in a material. They help us to visualize and explain the magnetic effects. The symbol used for magnetic flux is the Greek letter Φ (phi) and the unit of magnetic flux is the weber (symbol Wb), pronounced 'veber', to commemorate the work of the German physicist Wilhelm Weber (1804–1891).
2 Lines of magnetic flux always form closed loops.
3 Lines of magnetic flux behave like stretched elastic bands, always trying to shorten themselves.
4 Lines of magnetic flux never cross over each other.
5 Lines of magnetic flux travel along a magnetic material and always emerge out of the 'north pole' end of the magnet.
6 Lines of magnetic flux pass through space and non-magnetic materials undisturbed.
7 The region of space through which the influence of a magnet can be detected is called the *magnetic field* of that magnet.
8 The number of lines of magnetic flux within a magnetic field is a measure of the flux density. Strong magnetic fields have a high flux density. The symbol used for flux density is B, and the unit of flux density is the tesla (symbol T), to commemorate the work of the Croatian-born American physicist Nikola Tesla (1857–1943).
9 The places on a magnetic material where the lines of flux are concentrated are called the magnetic poles.
10 Like poles repel; unlike poles attract. These two statements are sometimes called the 'first laws of magnetism' and are shown in Fig. 1.39.

EXAMPLE

The magnetizing coil of a radio speaker induces a magnetic flux of 360 μWb in an iron core of cross-sectional area 300 mm^2. Calculate the flux density in the core.

$$\text{Flux density } B = \frac{\Phi}{\text{area}} \text{ (tesla)}$$

$$B = \frac{360 \times 10^{-6} \text{ (Wb)}}{300 \times 10^{-6} \text{ (m}^2\text{)}}$$

$$B = 1.2 \text{ T}$$

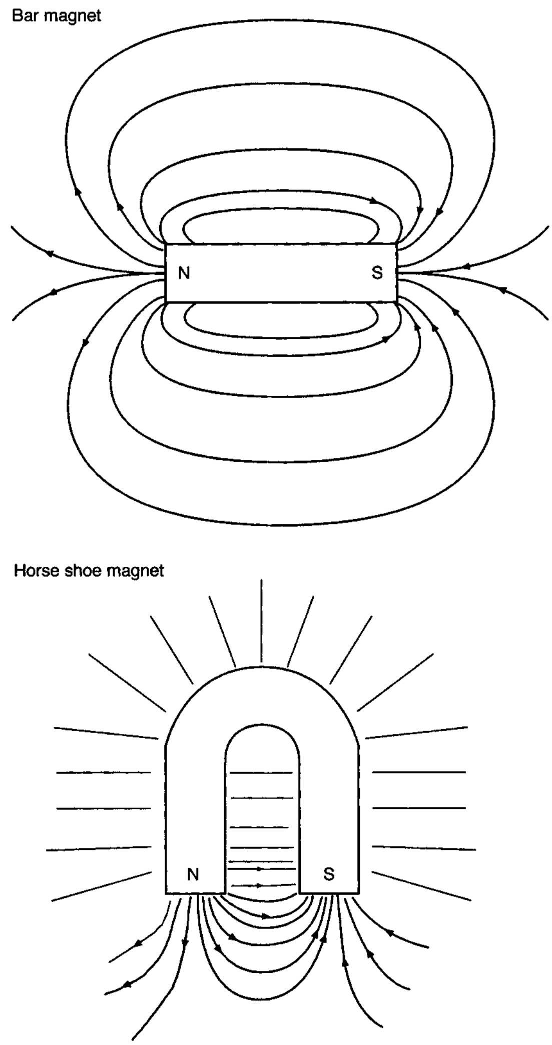


Fig. 1.38 Magnetic fields around a permanent magnet.

MAGNETIC FIELDS

If a permanent magnet is placed on a surface and covered by a piece of paper, iron filings can be shaken on to the paper from a dispenser. Gently tapping the paper then causes the filings to take up the shape of the magnetic field surrounding the permanent magnet. The magnetic fields around a permanent magnet are shown in Figs 1.38 and 1.39.

Electromagnetism

Electricity and magnetism have been inseparably connected since the experiments by Oersted and Faraday in

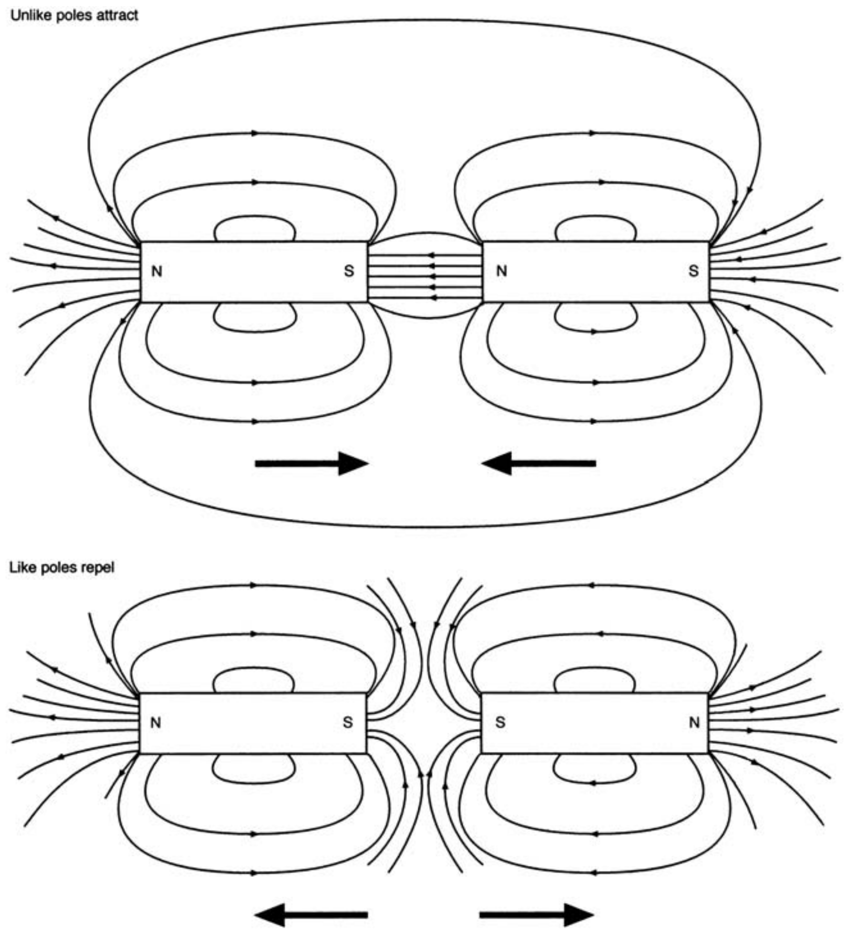


Fig. 1.39 The first laws of magnetism.

the early nineteenth century. An electric current flowing in a conductor produces a magnetic field 'around' the conductor which is proportional to the current. Thus a small current produces a weak magnetic field, while a large current will produce a strong magnetic field. The magnetic field 'spirals' around the conductor, as shown in Fig. 1.40 and its direction can be determined by the 'dot' or 'cross' notation and the 'screw rule'. To do this, we think of the current as being represented by a dart or arrow inside the conductor. The dot represents current coming towards us when we would see the point of the arrow or dart inside the conductor. The cross represents current going away from us when we would see the flights of the dart or arrow. Imagine a corkscrew or screw being turned so that it will move in the direction of the current. Therefore, if the current was coming out of the paper, as shown in Fig. 1.40(a), the magnetic field would be spiralling anticlockwise around the conductor.

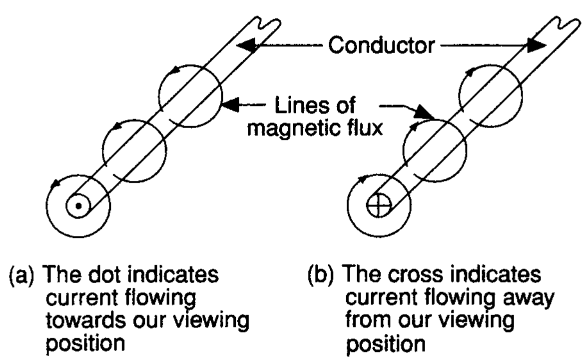


Fig. 1.40 Magnetic fields around a current carrying conductor.

If the current was going into the paper, as shown in Fig. 1.40(b), the magnetic field would spiral clockwise around the conductor.

A current flowing in a *coil* of wire or solenoid establishes a magnetic field which is very similar to that of a bar magnet. Winding the coil around a soft iron core increases the flux density because the lines of magnetic flux concentrate on the magnetic material. The advantage of the electromagnet when compared with the permanent magnet is that the magnetism of the electromagnet can be switched on and off by a functional switch controlling the coil current. This effect is put to practical use in the electrical relay as used in a motor starter or alarm circuit. Figure 1.41 shows the structure and one application of the solenoid.

A current carrying conductor maintains a magnetic field around the conductor which is proportional to the current flowing. When this magnetic field interacts with another magnetic field, forces are exerted which describe the basic principles of electric motors. This is further discussed later in this chapter and demonstrated by the diagrams shown in Fig. 1.70.

Michael Faraday demonstrated on 29 August 1831 that electricity could be produced by magnetism. He stated that '*When a conductor cuts or is cut by a magnetic field an emf is induced in that conductor. The amount of induced emf is proportional to the rate or speed at which the magnetic field cuts the conductor*'. This basic principle laid down the laws of present-day electricity generation where a strong magnetic field is rotated inside a coil of wire to generate electricity.

This law can be translated into a formula as follows

$$\text{Induced emf} = Blv \text{ (V)}$$

where B is the magnetic flux density, measured in tesla, to commemorate Nikola Tesla (1856–1943) a famous Yugoslav who invented the two-phase and three-phase alternator and motor; l is the length of conductor in the magnetic field, measured in metres; and v is the velocity or speed at which the conductor cuts the magnetic flux (measured in metres per second).

EXAMPLE

A 15 cm length of conductor is moved at 20 m/s through a magnetic field of flux density 2 T. Calculate the induced emf.

$$\text{emf} = Blv \text{ (V)}$$
$$\therefore \text{emf} = 2\,\text{T} \times 0.15 \times 20\,\text{m/s}$$
$$\text{emf} = 6\,\text{V}$$

INDUCTANCE

If a coil of wire is wound on to an iron core as shown in Fig. 1.42, a magnetic field will become established in the core when a current flows in the coil due to the switch being closed.

When the switch is opened the current stops flowing and, therefore, the magnetic flux collapses. The collapsing magnetic flux induces an emf into the coil and this

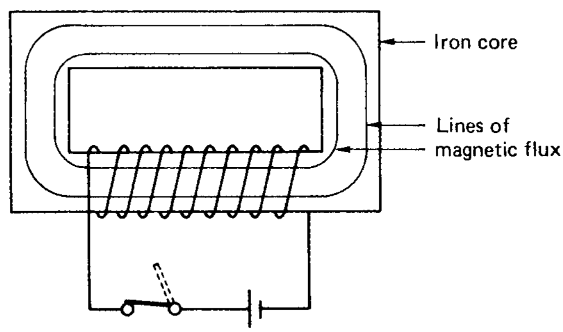


Fig. 1.42 An inductive coil or choke.

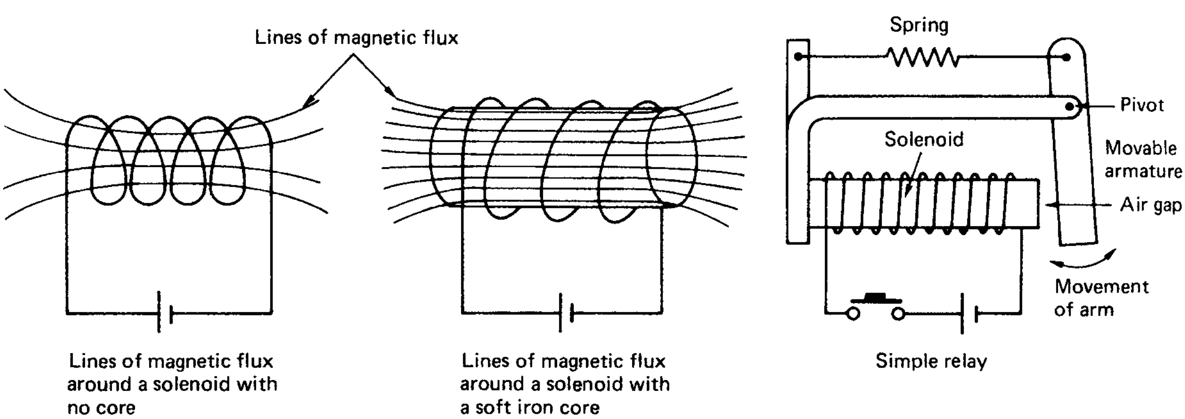


Fig. 1.41 The solenoid and one practical application: the relay.

voltage appears across the switch contacts. The effect is known as *self-inductance*, or just *inductance*, and is one property of any coil. The unit of inductance is the henry (symbol H), to commemorate the work of the American physicist Joseph Henry (1797–1878), and a circuit is said to possess an inductance of 1 henry when an emf of 1 volt is induced in the circuit by a current changing at the rate of 1 ampere per second.

Fluorescent light fittings contain a choke or inductive coil in series with the tube and starter lamp. The starter lamp switches on and off very quickly, causing rapid current changes which induce a large voltage across the tube electrodes sufficient to strike an arc in the tube.

When two separate coils are placed close together, as they are in a transformer, a current in one coil produces a magnetic flux which links with the second coil. This induces a voltage in the second coil and is the basic principle of the transformer action which is described later in this chapter. The two coils in this case are said to possess *mutual inductance*, as shown by Fig. 1.43. A mutual inductance of 1 henry exists between two coils when a uniformly varying current of 1 ampere per second in one coil produces an emf of 1 volt in the other coil.

The emf induced in the right hand coil of Fig. 1.43 is dependent upon the rate of change of magnetic flux and the number of turns on the coil. The average induced emf is, therefore, given by:

$$\text{emf} = \frac{-(\Phi_2 - \Phi_1)}{t} \times N\ (V)$$

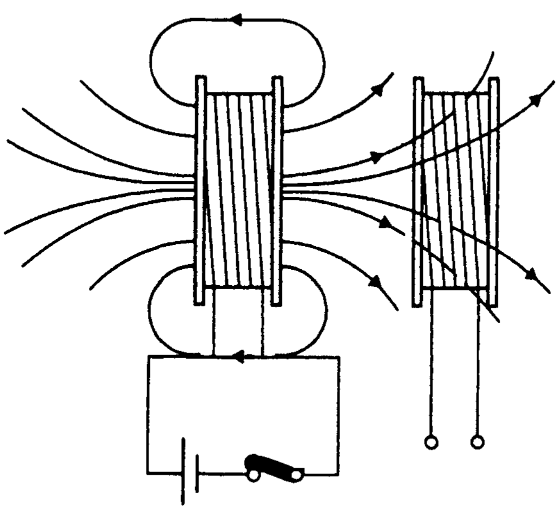


Fig. 1.43 Mutual induction between two coils.

where Φ is the magnetic flux measured in webers, to commemorate the work of the German physicist, Wilhelm Weber (1804–1891), t is the time in seconds and N the number of turns. The minus sign indicates that the emf is a back emf opposing the rate of change of current as described later by Lenz's law.

EXAMPLE

The magnetic flux linking 2000 turns of electromagnetic relay changes from 0.6 to 0.4 mWb in 50 ms. Calculate the average value of the induced emf.

$$\text{emf} = -\frac{(\Phi_2 - \Phi_1)}{t} \times N\ (V)$$

$$\therefore \text{emf} = -\frac{(0.6 - 0.4) \times 10^{-3}}{50 \times 10^{-3}} \times 2000$$

$$\text{emf} = -8\ \text{V}$$

ENERGY STORED IN A MAGNETIC FIELD

When we open the switch of an inductive circuit such as that shown in Fig. 1.42 the magnetic flux collapses and produces an arc across the switch contacts. The arc is produced by the stored magnetic energy being discharged across the switch contacts. The stored magnetic energy (symbol W) is expressed in joules and given by the following formula

$$\text{Energy} = W = \tfrac{1}{2} LI^2\ (\text{J})$$

where L is the inductance of the coil in henrys and I is the current flowing in amperes.

EXAMPLE

The field windings of a motor have an inductance of 3 H and carry a current of 2 A. Calculate the magnetic energy stored in the coils.

$$W = \tfrac{1}{2} LI^2\ (\text{J})$$

$$W = \tfrac{1}{2} \times 3\,\text{H} \times (2\,\text{A})^2$$

$$W = 6\,\text{J}$$

MAGNETIC HYSTERESIS

There are many different types of magnetic material and they all respond differently to being magnetized.

Some materials magnetize easily, and some are difficult to magnetize. Some materials retain their magnetism, while others lose it. The properties of a magnetic sample may be examined in detail if we measure the flux density (B) of the material with increasing and then decreasing values of magnetic field strength (H). The result will look like the graphs shown in Fig. 1.44 and are called *hysteresis loops*.

The hysteresis effect causes the magnetic material to retain some of its magnetism after the magnetic field strength has been removed. The flux density remaining when H is zero is called the *residual flux density*.

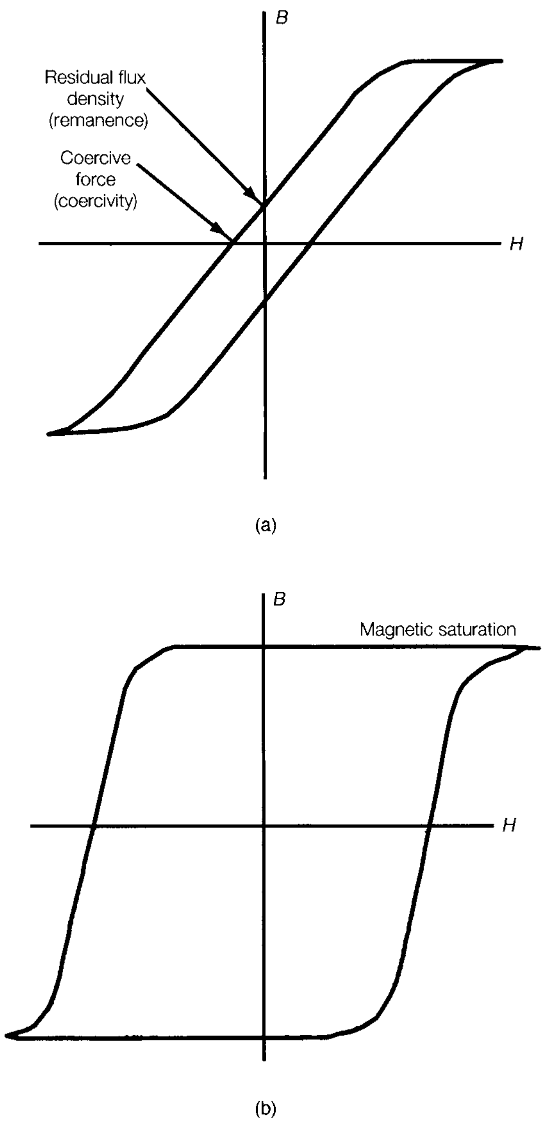


Fig. 1.44 Magnetic hysteresis loops: (a) electromagnetic material; (b) permanent magnetic material.

This residual flux density can be reduced to zero by applying a negative magnetic field strength ($-H$). The value of this demagnetizing force is called the *coercive force*.

When the material has been worked to magnetic saturation – that is, B_{max} and H_{max} the residual flux density is called *remanence* and the coercive force is called the *coercivity*. The value of coercivity varies enormously for different materials, being about 40 000 A/m for Alnico (an alloy of iron, aluminium and nickel, used for permanent magnets) and about 3 A/m for Mumetal (an alloy of nickel and iron).

Materials from which permanent magnets are made should have a high value of residual flux density and coercive force and, therefore, display a wide hysteresis loop, as shown by loop (b) in Fig. 1.44.

The core of an electromagnet is required to magnetize easily, and to lose its magnetism equally easily when switched off. Suitable materials will, therefore, have a low value of residual flux density and coercive force and, therefore, display a narrow hysteresis loop, as shown by loop (a) in Fig. 1.44.

The hysteresis effect causes an energy loss whenever the magnetic flux changes. This energy loss is converted to heat in the iron. The energy lost during a complete cycle of flux change is proportional to the area enclosed by the hysteresis loop.

When an iron core is subjected to alternating magnetization, as in a transformer, the energy loss occurs at every cycle and so constitutes a continuous power loss, and, therefore, for applications such as transformers, a material with a narrow hysteresis loop is required.

FLEMING'S RIGHT-HAND RULE

We have seen that electricity and magnetism are connected together by Faraday's laws of electromagnetic induction, which say that forces are exerted on current carrying conductors placed within a magnetic field and that conductors moving in a magnetic field have an emf induced in them. These laws have applications to electric motors and generators. When carrying out his experiments many years later, it occurred to Fleming that the thumb and first two fingers of the right hand could be used to predict the direction of the induced emf and so he formulated the following rule. Extend the thumb, first finger and second finger of the right hand so that they are all at right angles to each other. If the first finger is pointed in the direction of the magnetic field (north to south) and the thumb in the direction of the motion, then the second finger will point in the direction of the induced emf and current flow. This is shown by Fig. 1.45.

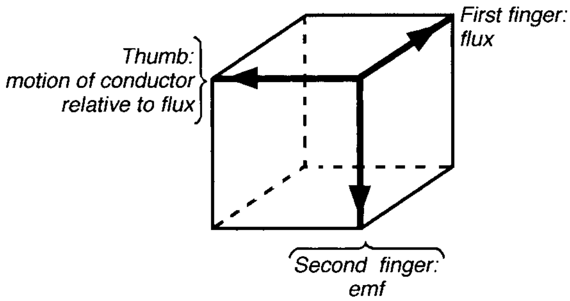


Fig. 1.45 Fleming's right-hand rule.

LENZ'S LAW

After the publication of Faraday's work on the production of electricity from magnetism in 1831, scientists in other countries repeated the experiments and built upon the basic principles adding to the total knowledge.

In Russia, Heinrich Lenz was able to publish another law of electromagnetic induction in 1834. This states that the direction of the induced emf always sets up a current opposing the motion which induced the emf.

This leads us to the concept of the back emf in a motor and the reason for the negative sign in the previous calculation on induced emf in the coil shown in Fig. 1.42.

Electrostatics

If a battery is connected between two insulated plates, the emf of the battery forces electrons from one plate to another until the p.d. between the plates is equal to the battery emf.

The electrons flowing through the battery constitute a current, I (in amperes), which flows for a time, t (in seconds). The plates are then said to be charged.

The amount of charge transferred is given by

$$Q = It \text{ (coulomb [Symbol C])}$$

Figure 1.46 shows the charges on a capacitor's plates.

When the voltage is removed the charge Q is trapped on the plates, but if the plates are joined together, the same quantity of electricity, $Q + It$, will flow back from one plate to the other, so discharging them. The property of a pair of plates to store an electric charge is called its *capacitance*.

By definition, a capacitor has a capacitance (C) of one farad (symbol F) when a p.d. of one volt maintains a charge of one coulomb on that capacitor, or

$$C = \frac{Q}{V} \text{ (F)}$$

Collecting these important formulae together, we have

$$Q = It = CV$$

CAPACITORS

A capacitor consists of two metal plates, separated by an insulating layer called the dielectric. It has the ability

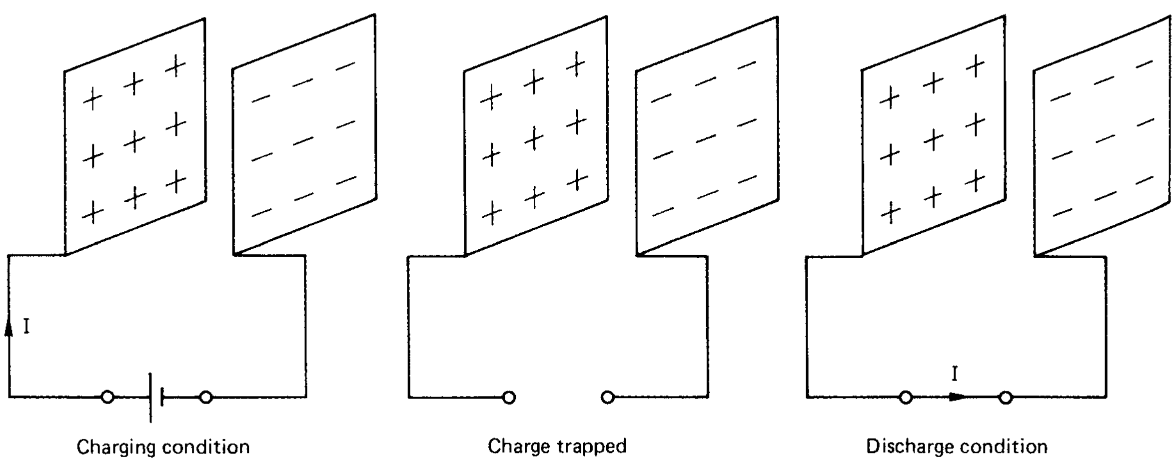


Fig. 1.46 The charge on a capacitor's plates.

of storing a quantity of electricity as an excess of electrons on one plate and a deficiency on the other.

EXAMPLE

A 100 μF capacitor is charged by a steady current of 2 mA flowing for 5 seconds. Calculate the total charge stored by the capacitor and the p.d. between the plates.

$$Q = It \text{ (C)}$$
$$\therefore Q = 2 \times 10^{-3}\text{ A} \times 5\text{ s} = 10\text{ mC}$$
$$Q = CV$$
$$\therefore V = \frac{Q}{C} \text{ (V)}$$
$$V = \frac{10 \times 10^{-3}\text{ C}}{100 \times 10^{-6}\text{ F}} = 100\text{ V}$$

The p.d. which may be maintained across the plates of a capacitor is determined by the type and thickness of the dielectric medium. Capacitor manufacturers usually indicate the maximum safe working voltage for their products.

Capacitors are classified by the type of dielectric material used in their construction. Figure 1.47 shows the general construction and appearance of some capacitor types to be found in installation work.

Air-dielectric capacitors

Air-dielectric capacitors are usually constructed of multiple aluminium vanes of which one section moves to make the capacitance variable. They are often used for radio tuning circuits.

Mica-dielectric capacitors

Mica-dielectric capacitors are constructed of thin aluminium foils separated by a layer of mica. They are expensive, but this dielectric is very stable and has low dielectric loss. They are often used in high-frequency electronic circuits.

Paper-dielectric capacitors

Paper-dielectric capacitors usually consist of thin aluminium foils separated by a layer of waxed paper. This

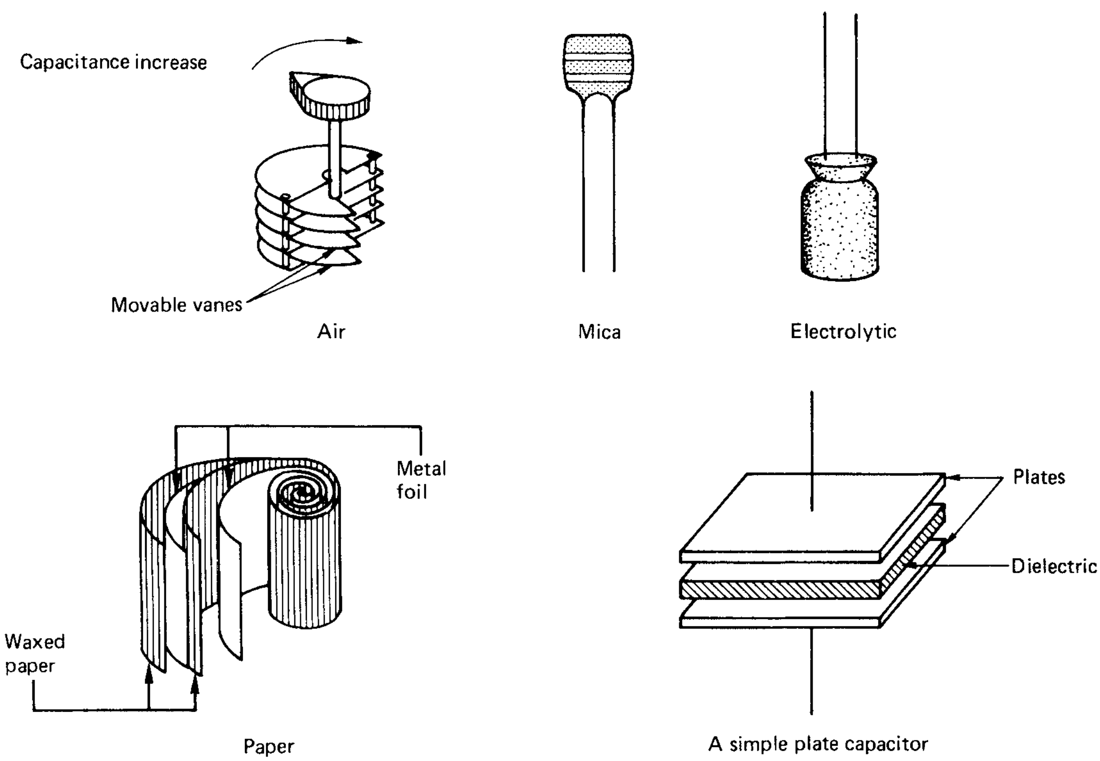


Fig. 1.47 Construction and appearance of capacitors.

paper–foil sandwich is rolled into a cylinder and usually contained in a metal cylinder. These capacitors are used in fluorescent lighting fittings and motor circuits.

Electrolytic capacitors

The construction of these is similar to that of the paper-dielectric capacitors, but the dielectric material in this case is an oxide skin formed electrolytically by the manufacturers. Since the oxide skin is very thin, a large capacitance is achieved for a small physical size, but if a voltage of the wrong polarity is applied, the oxide skin is damaged and the gas inside the sealed container explodes. For this reason electrolytic capacitors must be connected to the correct voltage polarity. They are used where a large capacitance is required from a small physical size and where the terminal voltage never reverses polarity.

CAPACITORS IN COMBINATION

Capacitors, like resistors, may be joined together in various combinations of series or parallel connections (see Fig. 1.48). The equivalent capacitance, C_T, of a number of capacitors is found by the application of similar formulae to those used for resistors and discussed earlier in this chapter. *Note* that the form of the formulae is the opposite way round to that used for series and parallel resistors.

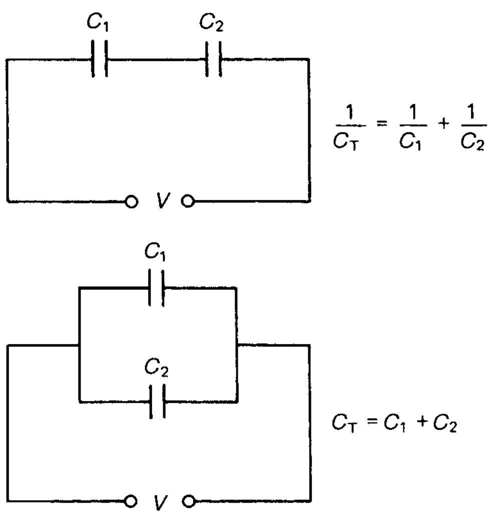


Fig. 1.48 Connection of and formulae for series and parallel capacitors.

The most complex arrangement of capacitors may be simplified into a single equivalent capacitor by applying the separate rules for series or parallel capacitors in a similar way to the simplification of resistive circuits.

EXAMPLE

Capacitors of 10 and 20 μF are connected first in series, and then in parallel, as shown in Figs 1.49 and 1.50. Calculate the effective capacitance for each connection. For connection in series,

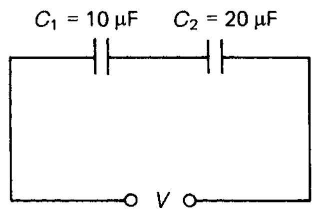


Fig. 1.49 Series capacitors.

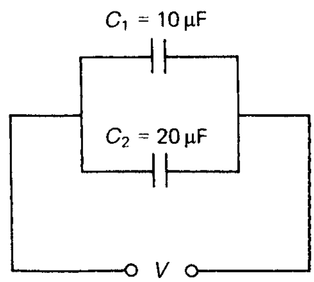


Fig. 1.50 Parallel capacitors.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_T} = \frac{1}{10\,\mu F} + \frac{1}{20\,\mu F}$$

$$\frac{1}{C_T} = \frac{2+1}{20\,\mu F} = \frac{3}{20\,\mu F}$$

$$\therefore C_T = \frac{20\,\mu F}{3} = 6.66\,\mu F$$

For connection in parallel,

$$C_T = C_1 + C_2$$

$$C_T = 10\,\mu F + 20\,\mu F = 30\,\mu F$$

Therefore, when capacitors of 10 and 20 μF are connected in series their combined effect is equivalent to a capacitor of 6.66 μF. But, when the same capacitors are connected in parallel their combined effect is equal to a capacitor of 30 μF.

The practical considerations of capacitors and the use of colour codes to determine capacitor values are dealt within Chapter 4.

Energy stored in a capacitor

Following a period of charge, the capacitor will store a small amount of energy as an electrostatic charge which, we will see later, can be made to do work. The energy stored (symbol *W*) in a capacitor is expressed in joules and given by the formula

$$\text{Energy} = W = \tfrac{1}{2}CV^2 \text{ (J)}$$

where *C* is the capacitance of the capacitor and *V* is the applied voltage.

EXAMPLE 1

A 60 μF capacitor is used for power-factor correction in a fluorescent luminaire. Calculate the energy stored in the capacitor when it is connected to the 230 V mains supply.

$$\text{Energy} = W = \tfrac{1}{2}CV^2 \text{ (J)}$$
$$\therefore\ W = \tfrac{1}{2} \times 60 \times 10^{-6}\ \text{F} \times (230\ \text{V})^2$$
$$W = 3.17\ \text{J}$$

EXAMPLE 2

The energy stored in a certain capacitor when connected across a 400 V supply is 0.3 J. Calculate (a) the capacitance and (b) the charge on the capacitor.

For (a)

$$W = \tfrac{1}{2}CV^2 \text{ (J)}$$

Transposing,

$$C = \frac{2W}{V^2} \text{ (F)}$$
$$\therefore\ C = \frac{2 \times 0.3\ \text{J}}{(400\ \text{V})^2}$$
$$C = 3.75\ \mu\text{F}$$

For (b), the charge is given by

$$Q = CV \text{ (C)}$$
$$\therefore\ Q = 3.75 \times 10^{-6}\ \text{F} \times 400\ \text{V}$$
$$Q = 1500\ \mu\text{C}$$

CR CIRCUITS

As we have discussed earlier in this chapter, connecting a voltage to the plates of a capacitor causes it to charge up to the potential of the supply. This involves electrons moving around the circuit to create the necessary charge conditions and, therefore, this action does not occur instantly, but takes some time, depending upon the size of the capacitor and the resistance of the circuit. Such circuits are called capacitor–resistor (CR) circuits, and have many applications in electronics as timers and triggers and for controlling the time base sweeps of a cathode ray oscilloscope.

Figure 1.51 shows the circuit diagram for a simple CR circuit and the graphs drawn from the meter readings. It can be seen that:

(a) initially the current has a maximum value and decreases slowly to zero as the capacitor charges and
(b) initially the capacitor voltage rises rapidly but then slows down, increasing gradually until the capacitor voltage is equal to the supply voltage when fully charged.

The mathematical name for the shape of these curves is an *exponential* curve and, therefore, we say that the capacitor voltage is growing exponentially while the current is decaying exponentially during the charging period. The *rate* at which the capacitor charges is dependent upon the *size* of the capacitor and resistor.

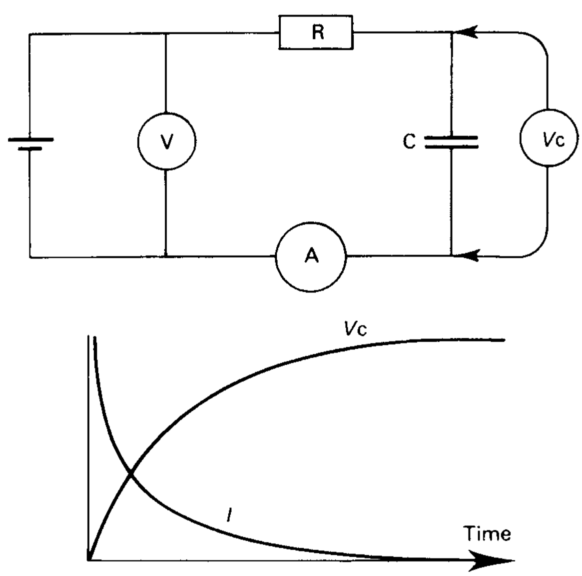


Fig. 1.51 A CR circuit.

The bigger the values of C and R, the longer it will take to charge the capacitor. The time taken to charge a capacitor by a *constant* current is given by the time constant of the circuit which is expressed mathematically as $T = CR$, where T is the time in seconds.

EXAMPLE 1

A 60 μF capacitor is connected in series with a 20 kΩ resistor across a 12 V supply. Determine the time constant of this circuit.

$$T = CR \text{ (s)}$$
$$\therefore\ T = 60 \times 10^{-6}\ \text{F} \times 20 \times 10^{3}\ \Omega$$
$$T = 1.2\,\text{s}$$

We have already seen that in practice the capacitor is not charged by a *constant* current but, in fact, charges exponentially. However, it can be shown by experiment that in one time constant the capacitor will have reached about 63% of its final steady value, taking about five times the time constant to become fully charged. Therefore, in 1.2 s the 60 μF capacitor of Example 1 will have reached about 63% of 12 V and after 5 T, that is 6 seconds, will be fully charged at 12 V.

Graphical derivation of CR circuit

The exponential charging and discharging curves of the CR circuit described in Example 1 may also be drawn to scale by following the procedure described below and shown in Fig. 1.52.

1 We have calculated the time constant for the circuit (T) and found it to be 1.2 seconds.
2 We know that the maximum voltage of the fully charged capacitor will be 12 V because the supply voltage is 12 V.
3 To draw the graph we must first select suitable scales: 0 to 12 on the voltage axis would be appropriate for this example and 0 to 6 seconds on the time axis because we know that the capacitor must be fully charged in five time constants.
4 Next draw a horizontal dotted line along the point of maximum voltage, 12 V in this example.
5 Along the time axis measure off one time constant (T), distance OA in Fig. 1.52. This corresponds to 1.2 seconds because in this example T is equal to 1.2 seconds.
6 Draw the vertical dotted line AB.
7 Next, draw a full line OB; this is the start of the charging curve.
8 Select a point C, somewhere convenient and close to O along line OB.
9 Draw a horizontal line CD equal to the length of the time constant (T).
10 Draw the dotted vertical line DE.
11 Draw in the line CE, the second line of our charging curve.

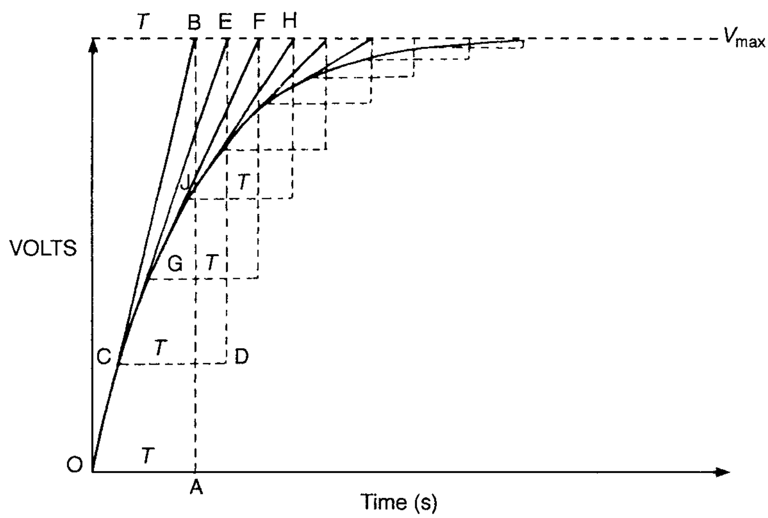


Fig. 1.52 Graphical derivation of CR growth curve.

12 Select another point G close to C along line CE and repeat the procedures 9 to 12 to draw lines GF, JH and so on as shown in Fig. 1.52.

13 Finally, join together with a smooth curving line the points OCGJ etc., and we have the exponential growth curve of the voltage across the capacitor.

Switching off the supply and discharging the capacitor through the 20 kΩ resistor will produce the exponential decay of the voltage across the capacitor which will be a mirror image of the growth curve. The decay curve can be derived graphically in the same way as the growth curve and is shown in Fig. 1.53.

SELECTING A CAPACITOR

There are two broad categories of capacitor, the non-polarized and the polarized type.

The non-polarized type is often found is electrical installation work for power-factor correction. A paper dielectric capacitor is non-polarized and can be connected either way round.

The polarized type must be connected to the polarity indicated otherwise the capacitor will explode. Electrolytic capacitors are polarized and are used where a large value of capacitance is required in a relatively small package. We therefore find polarized capacitors in electronic equipment such as smoothing or stabilized supplies, emergency lighting and alarm systems, so be careful when working on these systems.

When choosing a capacitor for a particular application, three factors must be considered: value, working voltage and leakage current.

The unit of capacitance is the *farad* (symbol F), to commemorate the name of the English scientist Michael Faraday. However, for practical purposes the farad is much too large and in electrical installation work and electronics we use fractions of a farad as follows:

$$1 \text{ microfarad} = 1\,\mu\text{F} = 1 \times 10^{-6}\,\text{F}$$
$$1 \text{ nanofarad} = 1\,\text{nF} = 1 \times 10^{-9}\,\text{F}$$
$$1 \text{ picofarad} = 1\,\text{pF} = 1 \times 10^{-12}\,\text{F}$$

The p.f. correction capacitor used in a domestic fluorescent luminaire would typically have a value of 8 μF at a working voltage of 400 V. In an electronic filter circuit a typical capacitor value might be 100 pF at 63 V.

One microfarad is 1 million times greater than one picofarad. It may be useful to remember that

$$1000\,\text{pF} = 1\,\text{nF, and } 1000\,\text{nF} = 1\,\mu\text{F}$$

The working voltage of a capacitor is the *maximum* voltage that can be applied between the plates of the capacitor without breaking down the dielectric insulating material. This is a d.c. rating and, therefore, a capacitor with a 200 V rating must only be connected across a maximum of 200 V d.c. Since a.c. voltages are usually given as rms values, a 200 V a.c. supply would

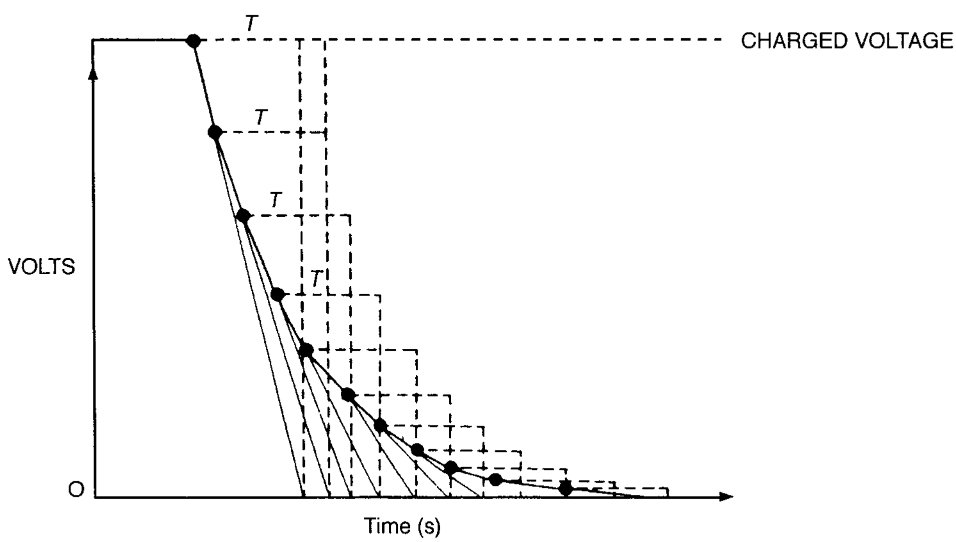


Fig. 1.53 Graphical derivation of CR decay curve.

have a maximum value of about 283 V which would damage the 200 V capacitor. When connecting a capacitor to the 230 V mains supply we must choose a working voltage of about 400 V because 230 V rms is approximately 325 V maximum. The 'factor of safety' is small and, therefore, the working voltage of the capacitor must not be exceeded.

An ideal capacitor which is isolated will remain charged for ever, but in practice no dielectric insulating material is perfect, and the charge will slowly *leak* between the plates, gradually discharging the capacitor. The loss of charge by leakage through it should be very small for a practical capacitor. However, the capacitors used in electrical installation work for power-factor correction are often fitted with a high-value discharge resistor to encourage the charge to leak away safely when not in use.

Alternating current theory

Earlier in this chapter at Figs 1.36 and 1.37 we looked at the generation of an a.c. waveform and the calculation of average and rms values. In this chapter we will first of all consider the theoretical circuits of pure resistance, inductance and capacitance acting alone in an a.c. circuit before going on to consider the practical circuits of resistance, inductance and capacitance acting together. Let us first define some of our terms of reference.

RESISTANCE

In any circuit, *resistance* is defined as opposition to current flow. From Ohm's law

$$R = \frac{V_R}{I_R} \ (\Omega)$$

However, in an a.c. circuit, resistance is only part of the opposition to current flow. The inductance and capacitance of an a.c. circuit also cause an opposition to current flow, which we call *reactance*.

Inductive reactance (X_L) is the opposition to an a.c. current in an inductive circuit. It causes the current in the circuit to lag behind the applied voltage, as shown in Fig. 1.54. It is given by the formula

$$X_L = 2\pi f L \ (\Omega)$$

where
π = 3.142 a constant
f = the frequency of the supply
L = the inductance of the circuit

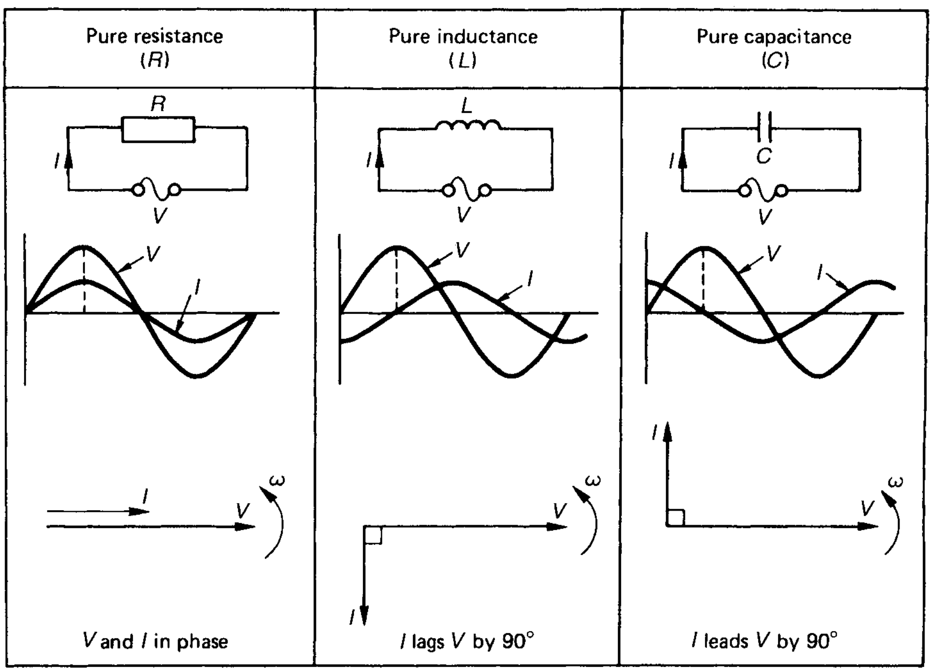


Fig. 1.54 Voltage and current relationships in resistive, capacitive and inductive circuits.

or by

$$X_L = \frac{V_L}{I_L}$$

Capacitive reactance (X_C) is the opposition to an a.c. current in a capacitive circuit. It causes the current in the circuit to lead ahead of the voltage, as shown in Fig. 1.54. It is given by the formula

$$X_C = \frac{1}{2\pi f C} \ (\Omega)$$

where π and f are defined as before and C is the capacitance of the circuit. It can also be expressed as

$$X_C = \frac{V_C}{I_C}$$

EXAMPLE

Calculate the reactance of a 150 μF capacitor and a 0.05 H inductor if they were separately connected to the 50 Hz mains supply.
For capacitive reactance

$$X_C = \frac{1}{2\pi f C}$$

where $f = 50$ Hz and $C = 150\ \mu F = 150 \times 10^{-6}$ F.

$$\therefore\ X_C = \frac{1}{2 \times 3.142 \times 50\ \text{Hz} \times 150 \times 10^{-6}} = 21.2\ \Omega$$

For inductive reactance

$$X_L = 2\pi f L$$

where $f = 50$ Hz and $L = 0.05$ H.

$$\therefore X_L = 2 \times 3.142 \times 50\ \text{Hz} \times 0.05\ \text{H} = 15.7\ \Omega$$

IMPEDANCE

The total opposition to current flow in an a.c. circuit is called impedance and given the symbol Z. Thus impedance is the combined opposition to current flow of the resistance, inductive reactance and capacitive reactance of the circuit and can be calculated from the formula

$$Z = \sqrt{R^2 + X^2} \ (\Omega)$$

or

$$Z = \frac{V_T}{I_T}$$

EXAMPLE 1

Calculate the impedance when a 5 Ω resistor is connected in series with a 12 Ω inductive reactance.

$$Z = \sqrt{R^2 + X_L^2} \ (\Omega)$$
$$\therefore\ Z = \sqrt{5^2 + 12^2}$$
$$Z = \sqrt{25 + 144}$$
$$Z = \sqrt{169}$$
$$Z = 13\ \Omega$$

EXAMPLE 2

Calculate the impedance when a 48 Ω resistor is connected in series with a 55 Ω capacitive reactance.

$$Z = \sqrt{R^2 + X_C^2} \ (\Omega)$$
$$\therefore\ Z = \sqrt{48^2 + 55^2}$$
$$Z = \sqrt{2304 + 3025}$$
$$Z = \sqrt{5329}$$
$$Z = 73\ \Omega$$

RESISTANCE, INDUCTANCE AND CAPACITANCE IN AN a.c. CIRCUIT

When a resistor only is connected to an a.c. circuit the current and voltage waveforms remain together, starting and finishing at the same time. We say that the waveforms are *in phase*.

When a pure inductor is connected to an a.c. circuit the current lags behind the voltage waveform by an angle of 90°. We say that the current *lags* the voltage by 90°. When a pure capacitor is connected to an a.c. circuit the current *leads* the voltage by an angle of 90°. These various effects can be observed on an oscilloscope, but the circuit diagram, waveform diagram and phasor diagram for each circuit are shown in Fig. 1.54.

Phasor diagrams

Phasor diagrams and a.c. circuits are an inseparable combination. Phasor diagrams allow us to produce a model or picture of the circuit under consideration which helps us to understand the circuit. A phasor is a straight line, having definite length and direction, which represents to scale the magnitude and direction of a quantity such as a current, voltage or impedance.

To find the combined effect of two quantities we combine their phasors by adding the beginning of the second phasor to the end of the first. The combined effect of the two quantities is shown by the resultant phasor, which is measured from the original zero position to the end of the last phasor.

EXAMPLE

Find by phasor addition the combined effect of currents *A* and *B* acting in a circuit. Current *A* has a value of 4 A, and current *B* a value of 3 A, leading *A* by 90°. We usually assume phasors to rotate anticlockwise and so the complete diagram will be as shown in Fig. 1.55. Choose a scale of, for example, 1 A = 1 cm and draw the phasors to scale, i.e. $A = 4$ cm and $B = 3$ cm, leading *A* by 90°.

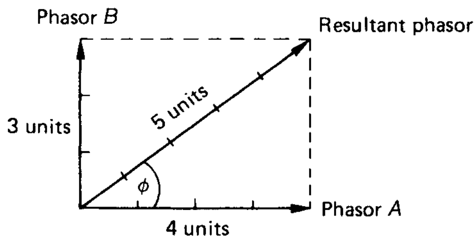


Fig. 1.55 The phasor addition of currents *A* and *B*.

The magnitude of the resultant phasor can be measured from the phasor diagram and is found to be 5 A acting at a phase angle ϕ of about 37° leading *A*. We therefore say that the combined effect of currents *A* and *B* is a current of 5 A at an angle of 37° leading *A*.

Phase angle ϕ

In an a.c. circuit containing resistance only, such as a heating circuit, the voltage and current are in phase, which means that they reach their peak and zero values together, as shown in Fig. 1.56(a).

In an a.c. circuit containing inductance, such as a motor or discharge lighting circuit, the current often reaches its maximum value after the voltage, which means that the current and voltage are out of phase with each other, as shown in Fig. 1.56(b). The phase difference, measured in degrees between the current and voltage, is called the phase angle of the circuit, and is denoted by the symbol ϕ, the lower-case Greek letter phi.

When circuits contain two or more separate elements, such as RL, RC or RLC, the phase angle between the total voltage and total current will be neither 0° nor 90° but will be determined by the relative values of resistance and reactance in the circuit. In Fig. 1.57 the phase angle between applied voltage and current is some angle ϕ.

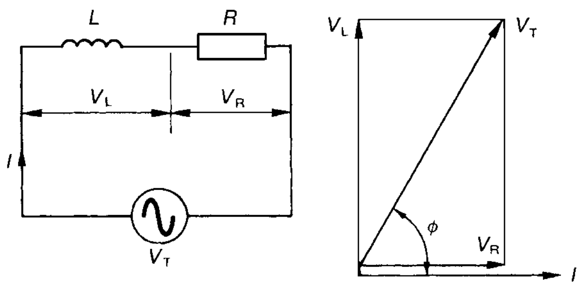


Fig. 1.57 A series RL circuit and phasor diagram.

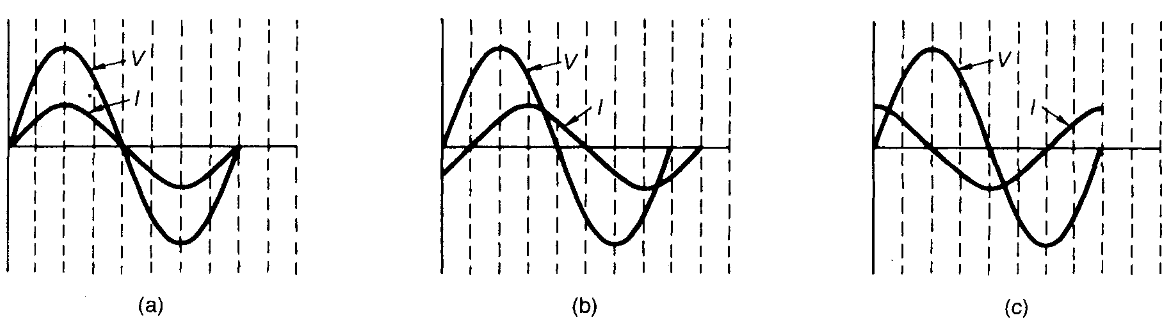


Fig. 1.56 Phase relationship of a.c. waveform: (a) *V* and *I* in phase, phase angle $\phi = 0°$ and power factor (p.f.) = $\cos \phi = 1$; (b) *V* and *I* displaced by 45°, $\phi = 45°$ and p.f. = 0.707; (c) *V* and *I* displaced by 90°, $\phi = 90°$ and p.f. = 0.

ALTERNATING CURRENT SERIES CIRCUIT

In a circuit containing a resistor and inductor connected in series as shown in Fig. 1.57, the current I will flow through the resistor and the inductor causing the voltage V_R to be dropped across the resistor and V_L to be dropped across the inductor. The sum of these voltages will be equal to the total voltage V_T but because this is an a.c. circuit the voltages must be added by phasor addition. The result is shown in Fig. 1.57, where V_R is drawn to scale and in phase with the current and V_L is drawn to scale and leading the current by 90°. The phasor addition of these two voltages gives us the magnitude and direction of V_T, which leads the current by some angle ϕ.

In a circuit containing a resistor and capacitor connected in series as shown in Fig. 1.58, the current I will flow through the resistor and capacitor causing voltage drops V_R and V_C. The voltage V_R will be in phase with the current and V_C will lag the current by 90°. The phasor addition of these voltages is equal to the total voltage V_T which, as can be seen in Fig. 1.58, is lagging the current by some angle ϕ.

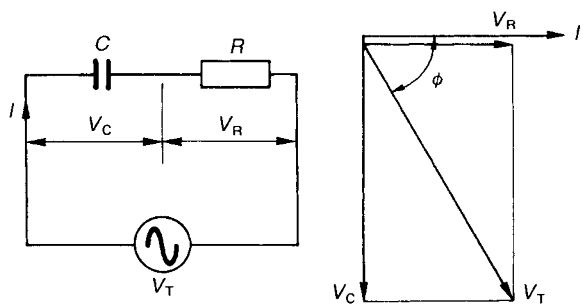


Fig. 1.58 A series RC circuit and phasor diagram.

THE IMPEDANCE TRIANGLE

We have now established the general shape of the phasor diagram for a series a.c. circuit. Figures 1.57 and 1.58 show the voltage phasors, but we know that $V_R = IR$, $V_L = IX_L$, $V_C = IX_C$ and $V_T = IZ$, and therefore the phasor diagrams (a) and (b) of Fig. 1.59 must be equal. From Fig. 1.59(b), by the theorem of Pythagoras, we have

$$(IZ)^2 = (IR)^2 + (IX)^2$$

$$I^2Z^2 = I^2R^2 + I^2X^2$$

If we now divide throughout by I^2 we have

$$Z^2 = R^2 + X^2$$

$$\text{or } Z = \sqrt{R^2 + X^2}\ \Omega$$

The phasor diagram can be simplified to the impedance triangle given in Fig. 1.59(c).

EXAMPLE 1

A coil of 0.15 H is connected in series with a 50 Ω resistor across a 100 V 50 Hz supply. Calculate (a) the reactance of the coil, (b) the impedance of the circuit, and (c) the current.

For (a)

$$X_L = 2\pi fL\ (\Omega)$$

$$\therefore X_L = 2 \times 3.142 \times 50\,\text{Hz} \times 0.15\,\text{H} = 47.1\,\Omega$$

For (b)

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$

$$\therefore\ Z = \sqrt{(50\,\Omega)^2 + (47.1\,\Omega)^2} = 68.69\,\Omega$$

For (c)

$$I = V/Z\,(\text{A})$$

$$\therefore\ I = \frac{100\,\text{V}}{68.69\,\Omega} = 1.46\,\text{A}$$

EXAMPLE 2

A 60 μF capacitor is connected in series with a 100 Ω resistor across a 230 V 50 Hz supply. Calculate (a) the reactance of the capacitor, (b) the impedance of the circuit, and (c) the current.

For (a)

$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$

$$\therefore\ X_C = \frac{1}{2\pi \times 50\,\text{Hz} \times 60 \times 10^{-6}\,\text{F}} = 53.05\,\Omega$$

For (b)

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$

$$\therefore\ Z = \sqrt{(100\,\Omega)^2 + (53.05\,\Omega)^2} = 113.2\,\Omega$$

For (c)

$$I = V/Z\,(\text{A})$$

$$\therefore\ I = \frac{230\,\text{V}}{113.2\,\Omega} = 2.03\,\text{A}$$

POWER AND POWER FACTOR

Power factor (p.f.) is defined as the cosine of the phase angle between the current and voltage

$$\text{p.f.} = \cos\phi$$

If the current lags the voltage as shown in Fig. 1.57, we say that the p.f. is lagging, and if the current leads the voltage as shown in Fig. 1.58, the p.f. is said to be leading. From the trigonometry of the impedance triangle shown in Fig. 1.59, p.f. is also equal to

$$\text{p.f.} = \cos\phi = \frac{R}{Z} = \frac{V_R}{V_T}$$

The electrical power in a circuit is the product of the instantaneous values of the voltage and current. Figure 1.60 shows the voltage and current waveform for a pure inductor and pure capacitor. The power waveform is obtained from the product of V and I at every instant in the cycle. It can be seen that the power waveform reverses every quarter cycle, indicating that energy is alternately being fed into and taken out of the inductor and capacitor. When considered over one complete cycle, the positive and negative portions are equal, showing that the average power consumed by a pure inductor or capacitor is zero. This shows that inductors and capacitors store energy during one part of the voltage cycle and feed it back into the supply later in the cycle. Inductors store energy as a magnetic field and capacitors as an electric field.

In an electric circuit more power is taken from the supply than is fed back into it, since some power is dissipated by the resistance of the circuit, and therefore

$$P = I^2R \text{ (W)}$$

In any d.c. circuit the power consumed is given by the product of the voltage and current, because in a d.c. circuit voltage and current are in phase. In an a.c. circuit the power consumed is given by the product of the current and that part of the voltage which is in phase with the current. The in-phase component of the voltage is given by $V\cos\phi$, and so power can also be given by the equation

$$P = VI\cos\phi \text{ (W)}$$

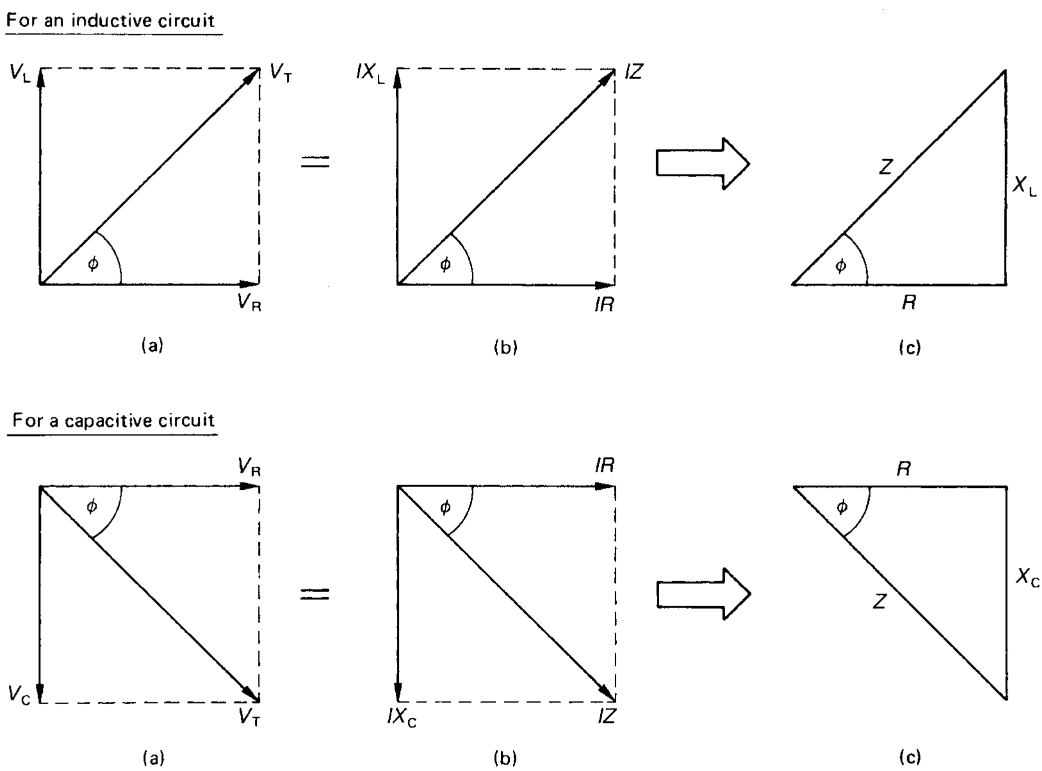


Fig. 1.59 Phasor diagram and impedance triangle.

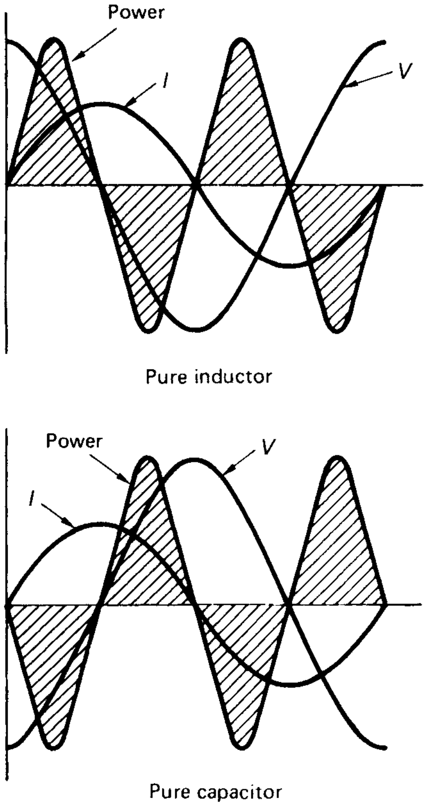


Fig. 1.60 Waveform for the a.c. power in purely inductive and purely capacitive circuits.

EXAMPLE 1

A coil has a resistance of 30 Ω and a reactance of 40 Ω when connected to a 250 V supply. Calculate (a) the impedance, (b) the current, (c) the p.f., and (d) the power.

For (a)

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$
$$\therefore\ Z = \sqrt{(30\ \Omega)^2 + (40\ \Omega)^2} = 50\ \Omega$$

For (b)

$$I = V/Z(\text{A})$$
$$\therefore\ I = \frac{250\ \text{V}}{50\ \Omega} = 5\ \text{A}$$

For (c)

$$\text{p.f.} = \cos\phi = \frac{R}{Z}$$
$$\therefore\ \text{p.f.} = \frac{30\ \Omega}{50\ \Omega} = 0.6\ \text{lagging}$$

For (d)

$$P = VI\cos\phi\ (\text{W})$$
$$\therefore P = 250\ \text{V} \times 5\ \text{A} \times 0.6 = 750\ \text{W}$$

EXAMPLE 2

A capacitor of reactance 12 Ω is connected in series with a 9 Ω resistor across a 150 V supply. Calculate (a) the impedance of the circuit, (b) the current, (c) the p.f., and (d) the power.

For (a)

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$
$$\therefore\ Z = \sqrt{(9\ \Omega)^2 + (12\ \Omega)^2} = 15\ \Omega$$

For (b)

$$I = V/Z(\text{A})$$
$$\therefore\ I = \frac{150\ \text{V}}{15\ \Omega} = 10\ \text{A}$$

For (c)

$$\text{p.f.} = \cos\phi = \frac{R}{Z}$$
$$\therefore\ \text{p.f.} = \frac{9\ \Omega}{15\ \Omega} = 0.6\ \text{leading}$$

For (d)

$$P = VI\cos\phi\ (\text{W})$$
$$\therefore P = 150\ \text{V} \times 10\ \text{A} \times 0.6 = 900\ \text{W}$$

The power factor of most industrial loads is lagging because the machines and discharge lighting used in industry are mostly inductive. This causes an additional magnetizing current to be drawn from the supply, which does not produce power, but does need to be supplied, making supply cables larger.

EXAMPLE 3

A 230 V supply feeds three 1.84 kW loads with power factors of 1, 0.8 and 0.4. Calculate the current at each power factor.

The current is given by

$$I = \frac{P}{V\cos\phi}$$

where $P = 1.84\ \text{kW} = 1840\ \text{W}$ and $V = 230\ \text{V}$. If the p.f. is 1, then

$$I = \frac{1840\ \text{W}}{230\ \text{V} \times 1} = 8\ \text{A}$$

For a p.f. of 0.8,

$$I = \frac{1840\ \text{W}}{230\ \text{V} \times 0.8} = 10\ \text{A}$$

For a p.f. of 0.4,

$$I = \frac{1840\ \text{W}}{230\ \text{V} \times 0.4} = 20\ \text{A}$$

It can be seen from these calculations that a 1.84 kW load supplied at a power factor of 0.4 would require a 20 A cable, while the same load at unity power factor could be supplied with an 8 A cable. There may also be the problem of higher voltage drops in the supply cables. As a result, the supply companies encourage installation engineers to improve their power factor to a value close to 1 and sometimes charge penalties if the power factor falls below 0.8.

Power-factor improvement

Most installations have a low power factor because of the inductive nature of the load. A capacitor has the opposite effect of an inductor, and so it seems reasonable to add a capacitor to a load which is known to have a lower power factor.

Figure 1.61(a) shows an industrial load with a low power factor. If a capacitor is connected in parallel with the load, the capacitor current I_C leads the applied voltage by 90°. When this current is added to the load current the resultant current has a much improved power factor, as can be seen in Fig. 1.61(b).

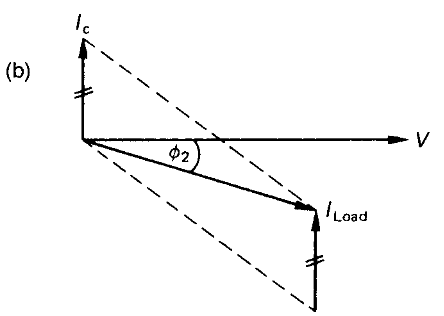


Fig. 1.61 Power-factor improvement using capacitors.

Capacitors may be connected across the main busbars of industrial loads in order to provide power-factor improvement, but smaller capacitors may also be connected across an individual piece of equipment, as is the case for fluorescent light fittings.

RESISTANCE, INDUCTANCE AND CAPACITANCE IN SERIES

The circuit diagram and phasor diagram are shown in Fig. 1.62. The voltages across the components are represented by V_R, V_L and V_C, which have the directions shown. Since V_L leads I by 90° and V_C lags by 90° the phasors are in opposition and the combined result is given by $V_L - V_C$ as shown.

Applying the theorem of Pythagoras to the phasor diagram of Fig. 7.9, we have

$$V_T^2 = V_R^2 + (V_L - V_C)^2$$

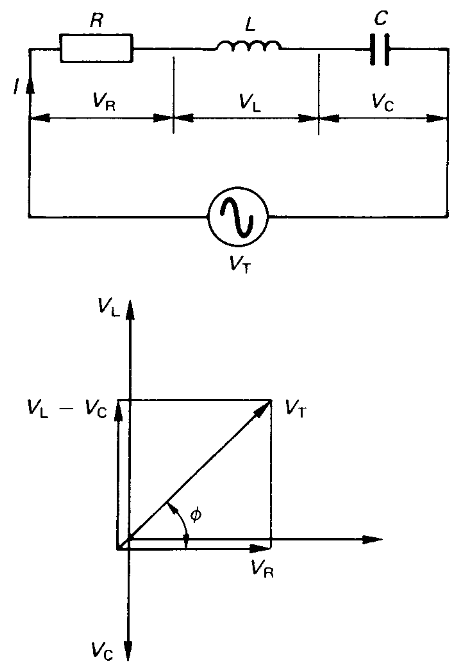


Fig. 1.62 A series RLC circuit and phasor diagram.

Since $V_T = IZ$, $V_R = IR$, $V_L = IX_L$ and $V_C = IX_C$, this equation may also be expressed thus:

$$(IZ)^2 = (IR)^2 + (IX_L - IX_C)^2$$

Cancelling out the common factors, we have

$$Z^2 = R^2 + (X_L - X_C)^2$$

$$\therefore\ Z = \sqrt{R^2 + (X_L - X_C)^2}\ (\Omega)$$

Note that the derivation of this equation is not required by craft students, but the equation should be remembered and applied in appropriate cases.

EXAMPLE 1

A coil of resistance 5 Ω and inductance 10 mH is connected in series with a 75 μF capacitor across a 200 V 100 Hz supply. Calculate (a) the impedance of the circuit, (b) the current and (c) the p.f.

For (a)

$$X_L = 2\pi fL\ (\Omega)$$
$$\therefore X_L = 2 \times 3.142 \times 100\text{ Hz} \times 10 \times 10^{-3}\text{ H}$$
$$X_L = 6.28\ \Omega$$
$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$
$$\therefore X_C = \frac{1}{2 \times 3.142 \times 100\text{ Hz} \times 75 \times 10^{-6}\text{ F}}$$
$$X_C = 21.22\ \Omega$$
$$Z = \sqrt{R^2 + (X_L - X_C)^2}\ (\Omega)$$
$$\therefore Z = \sqrt{(5\ \Omega)^2 + (6.28\ \Omega - 21.22\ \Omega)^2}$$
$$Z = 15.75\ \Omega$$

For (b)

$$I = V/Z\,(\text{A})$$
$$\therefore I = \frac{200\text{ V}}{15.75\ \Omega} = 12.69\text{ A}$$

For (c)

$$\text{p.f.} = \cos\phi = \frac{R}{Z}$$
$$\therefore \text{p.f.} = \frac{5}{15.7} = 0.317\text{ leading}$$

EXAMPLE 2

A 200 μF capacitor is connected in series with a coil of resistance 10 Ω and inductance 100 mH to a 230 V 50 Hz supply. Calculate (a) the impedance, (b) the current and (c) the voltage dropped across each component.

For (a)

$$X_L = 2\pi fL\ (\Omega)$$
$$\therefore X_L = 2 \times 3.142 \times 50\text{ Hz} \times 100 \times 10^{-3}\text{ H}$$
$$X_L = 31.42\ \Omega$$
$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$
$$\therefore X_C = \frac{1}{2 \times 3.142 \times 50\text{ Hz} \times 200 \times 10^{-6}\text{ F}}$$
$$X_C = 15.9\ \Omega$$
$$Z = \sqrt{R^2 + (X_L - X_C)^2}\ (\Omega)$$
$$\therefore Z = \sqrt{(10\ \Omega)^2 + (31.42\ \Omega - 15.9\ \Omega)^2}$$
$$Z = 18.46\ \Omega$$

For (b)

$$I = V/Z\,(\text{A})$$
$$\therefore I = \frac{230\text{ V}}{18.46\ \Omega} = 12.46\text{ A}$$

For (c)

$$V_R = I \times R\ (\text{V})$$
$$\therefore V_R = 12.46\text{ A} \times 10\ \Omega = 124.6\text{ V}$$
$$V_L = I \times X_L\ (\text{V})$$
$$\therefore V_L = 12.46\text{ A} \times 31.42\ \Omega = 391.49\text{ V}$$
$$V_C = I \times X_C\ (\text{V})$$
$$\therefore V_C = 12.46\text{ A} \times 15.9\ \Omega = 198.1\text{ V}$$

The phasor diagram of this circuit would be similar to that shown in Fig. 7.9.

SERIES RESONANCE

At resonance the circuit responds sympathetically. Therefore, the condition of resonance is used extensively in electronic and communication circuits for frequency selection and tuning. The current and reactive components of the circuit are at a maximum and so resonance is usually avoided in power applications to prevent cables being overloaded and cable insulation being broken down.

A circuit can be tuned to resonance either by varying the capacitance of the circuit or by adjusting the supply frequency. At low frequencies the circuit is mainly capacitative and at high frequencies the inductive effect predominates. At some intermediate frequency a point exists where the capacitative effect exactly cancels the inductive effect. This is the point of resonance and occurs when

$$V_L = V_C$$
$$\therefore IX_L = IX_C$$

If we cancel the common factor we have

$$X_L = X_C$$
$$\therefore\ 2\pi fL = \frac{1}{2\pi fC}$$

Collecting terms,

$$f^2 = \frac{1}{4\pi^2 LC}$$

Taking square roots,

$$\text{Resonant frequency} = f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}\ \text{(Hz)}$$

Note that the resonant frequency is given the symbol f_0. The derivation of the formula is not required by craft students.

At resonance the circuit is purely resistive, $Z = R$, the phase angle is zero and therefore the supply voltage and current must be in phase. These effects are shown in Fig. 1.63.

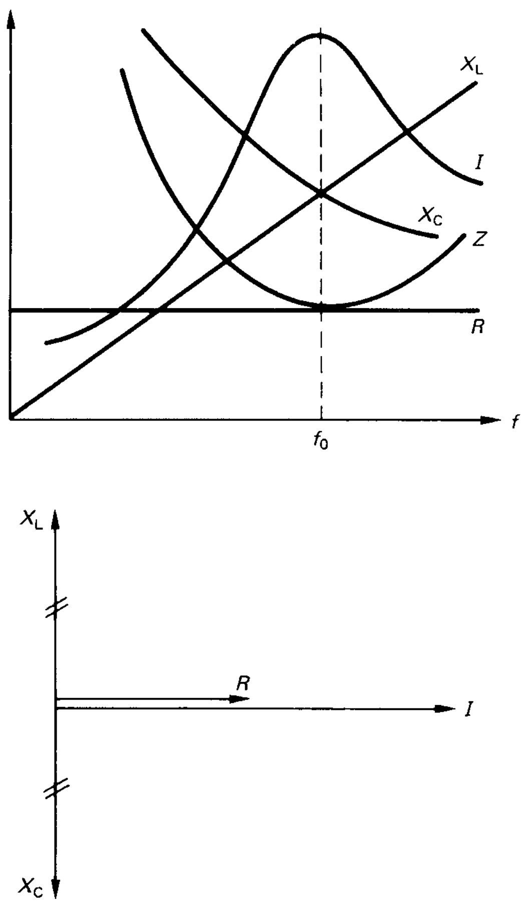


Fig. 1.63 Series resonance conditions in an RLC circuit.

EXAMPLE 1

A capacitor is connected in series with a coil of resistance 50 Ω and inductance 168.8 mH across a 50 Hz supply. Calculate the value of the capacitor to produce resonance in this circuit.

$$X_L = 2\pi fL\ (\Omega)$$
$$\therefore X_L = 2 \times 3.142 \times 50\ \text{Hz} \times 168.8 \times 10^{-3}\ \text{H}$$
$$X_L = 53.03\ \Omega$$

At resonance $X_L = X_C$, therefore $X_C = 53.03\ \Omega$

$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$

Transporting for C

$$C = \frac{1}{2\pi f X_C}\ \text{(F)}$$
$$\therefore C = \frac{1}{2 \times 3.142 \times 50\ \text{Hz} \times 53.03\ \Omega}$$
$$C = 60\ \mu\text{F}$$

EXAMPLE 2

Calculate the resonant frequency of a circuit consisting of a 25.33 mH inductor connected in series with a 100 μF capacitor.

The resonant frequency is given by:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}\ \text{(Hz)}$$
$$\therefore f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{25.33 \times 10^{-3}\ \text{H} \times 100 \times 10^{-6}\ \text{F}}}$$
$$f_0 = 100\ \text{Hz}$$

PARALLEL CIRCUITS

In practice, most electrical installations consist of a number of circuits connected in parallel to form a network. The branches of the parallel network may consist of one component or two or more components connected in series. You should now have an appreciation of series circuits and we will now consider two branch parallel circuits. In a parallel circuit the supply voltage is applied to each of the network branches. Voltage is used as the reference when drawing phasor diagrams and the currents are added by phasor addition.

In a parallel circuit containing a pure resistor and inductor as shown in Fig. 1.64, the current flowing through the resistive branch will be in phase with the voltage and the current flowing in the inductive branch will be 90° lagging the voltage. The phasor addition of these currents will give the total current drawn from the supply and its phase angle as shown in the phasor diagram of Fig. 1.64.

In a parallel circuit containing a pure resistor and capacitor connected in parallel, as shown in Fig. 1.65, the current flowing through the resistive branch will be in phase with the voltage and the current in the capacitive branch will lead the voltage by 90°. The phasor addition of these currents will give the total current and its phase angle, as shown in Fig. 1.65.

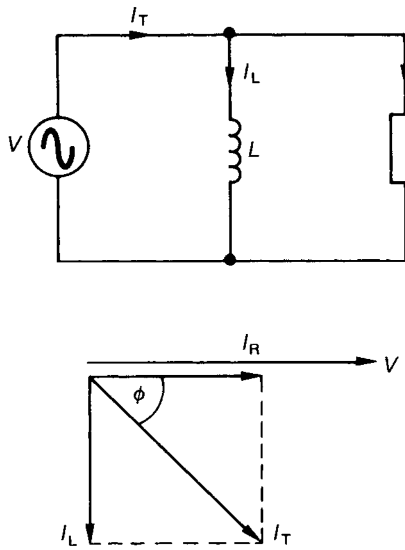


Fig. 1.64 A parallel RLC circuit and phasor diagram.

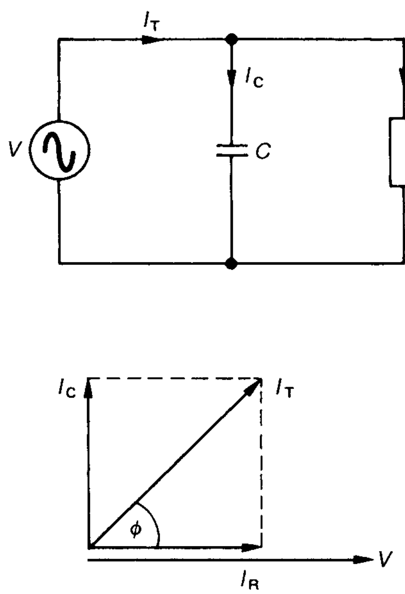


Fig. 1.65 A parallel RC circuit and phasor diagram.

EXAMPLE 1

A pure inductor of 100 mH is connected in parallel with a 30 Ω resistor to a 230 V 50 Hz supply. Calculate the branch currents and the supply current.

$$I_R = \frac{V}{R} \text{ (A)}$$

$$\therefore\ I_R = \frac{230\text{ V}}{30\ \Omega} = 7.67\text{ A}$$

$$X_L = 2\pi fL\ (\Omega)$$

$$\therefore\ X_L = 2 \times 3.142 \times 50\text{ Hz} \times 100 \times 10^{-3}\text{ H}$$

$$X_L = 31.42\ \Omega$$

$$I_L = \frac{V}{X_L} \text{ (A)}$$

$$\therefore\ I_L = \frac{230\text{ V}}{31.42\ \Omega} = 7.32\text{ A}$$

From the trigonometry of the phasor diagram in Fig. 7.11, the total current is given by

$$I_T = \sqrt{I_R^2 + I_L^2} \text{ (A)}$$

$$\therefore\ I_T = \sqrt{(7.67\text{ A})^2 + (7.32\text{ A})^2}$$

$$I_T = 10.60\text{ A.}$$

EXAMPLE 2

A pure capacitor of 60 μF is connected in parallel with a 40 Ω resistor across a 230 V 50 Hz supply. Calculate the branch currents and the supply currents.

$$I_R = \frac{V}{R} \text{ (A)}$$

$$\therefore\ I_R = \frac{230\text{ V}}{40\ \Omega} = 5.75\text{ A}$$

$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$

$$\therefore\ X_C = \frac{1}{2 \times 3.142 \times 50\ \text{Hz} \times 60 \times 10^{-6}\ \text{F}}$$

$$X_C = 53.05\ \Omega$$

$$I_C = \frac{V}{X_C}\ \text{(A)}$$

$$\therefore\ I_C = \frac{230\ \text{V}}{53.05\ \Omega} = 4.34\ \text{A}$$

From the trigonometry of the phasor diagram in Fig. 7.12, the total current is given by

$$I_T = \sqrt{I_C^2 + I_R^2}\ \text{(A)}$$

$$\therefore\ I_T = \sqrt{(5.75\ \text{A})^2 + (4.34\ \text{A})^2}$$

$$I_T = 7.2\ \text{A}$$

In considering these two examples we have assumed the capacitor and inductor to be pure. In practice the inductor will contain some resistance and the network may, therefore, be considered as a series RL branch connected in parallel with a capacitor as shown in Fig. 1.66.

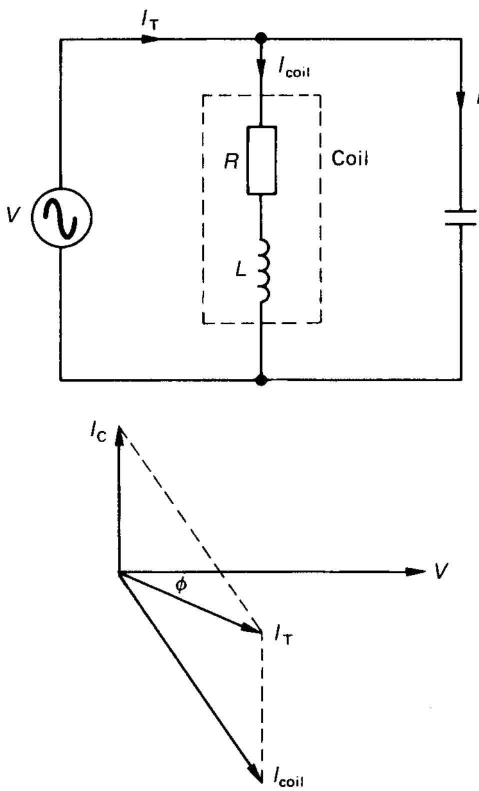


Fig. 1.66 A parallel circuit and phasor diagram.

EXAMPLE 3

A coil having a resistance of 50 Ω and inductance 318 mH is connected in parallel with 20 μF capacitor across a 230 V 50 Hz supply. Calculate the branch currents and the supply network. The circuit diagram for this network is shown in Fig. 1.66.

$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$

$$\therefore\ X_C = \frac{1}{2 \times 3.142 \times 50\ \text{Hz} \times 20 \times 10^{-6}\ \text{F}}$$

$$X_C = 159.2\ \Omega$$

$$I_C = \frac{V}{X_C}\ \text{(A)}$$

$$\therefore\ I_C = \frac{230\ \text{V}}{159.2\ \Omega} = 1.45\ \text{A}$$

$$X_L = 2\pi f L\ (\Omega)$$

$$\therefore\ X_L = 2 \times 3.142 \times 50\ \text{Hz} \times 318 \times 10^{-3}\ \text{H}$$

$$X_L = 100\ \Omega$$

$$Z_{coil} = \sqrt{R^2 + X_L^2}\ (\Omega)$$

$$\therefore\ Z_{coil} = \sqrt{(50\ \Omega)^2 + (100\ \Omega)^2}$$

$$Z_{coil} = 111.8\ \Omega$$

$$I_{coil} = \frac{V}{Z}\ \text{(A)}$$

$$\therefore\ I_{coil} = \frac{230\ \text{V}}{111.8\ \Omega} = 2.06\ \text{A}$$

The capacitor current will lead the supply voltage by 90°. The coil current will lag the voltage by an angle given by:

$$\phi_{coil} = \cos^{-1} \frac{R}{Z}$$

$$\therefore\ \phi_{coil} = \cos^{-1} \frac{50\ \Omega}{111.8\ \Omega} = 63.4°$$

The coil and capacitor currents can now be drawn to scale as shown in Fig. 1.67. The total current is the phasor addition of these currents and is found to be 1.0 A at 20° lagging from the phasor diagram.

THREE-PHASE a.c.

A three-phase voltage is generated in exactly the same way as a single-phase a.c. voltage. For a three-phase voltage three separate windings, each separated by 120°, are rotated in a magnetic field. The generated voltage will be three identical sinusoidal waveforms each separated by 120°, as shown in Fig. 1.68.

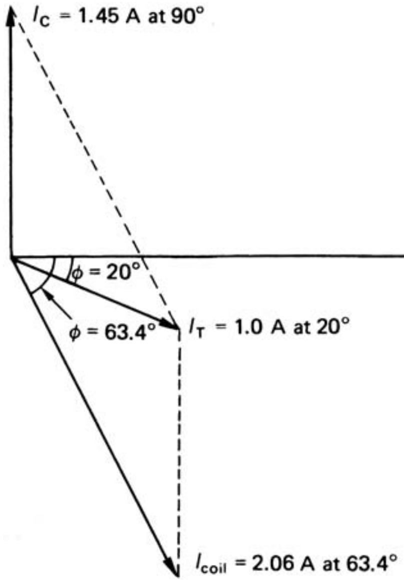


Fig. 1.67 Scale phasor diagram for Example 3.

Star and delta connections

The three phase windings may be star connected or delta connected as shown in Fig. 1.69. The important relationship between phase and line currents and voltages is also shown. The square root of 3 ($\sqrt{3}$) is simply a constant for three-phase circuits, and has a value of 1.732. The delta connection is used for electrical power transmission because only three conductors are required. Delta connection is also used to connect the windings of most three-phase motors because the phase windings are perfectly balanced and, therefore, do not require a neutral connection.

Making a star connection has the advantage that two voltages become available – a line voltage between any two phases, and a phase voltage between line and neutral which is connected to the star point.

In any star-connected system currents flow along the lines (I_L), through the load and return by the neutral conductor connected to the star point. In a *balanced* three-phase system all currents have the same value and when they are added up by phasor addition, we find the resultant current is zero. Therefore, no current flows in the neutral and the star point is at zero volts. The star point of the distribution transformer is earthed because earth is also at zero potential. A star-connected system is also called a three-phase four-wire system and allows us to connect single-phase loads to a three-phase system.

Three-phase power

We know from our single-phase theory earlier in this chapter that power can be found from the following formula:

$$\text{Power} = VI\cos\phi \text{ (W)}$$

In any balanced three-phase system, the total power is equal to three times the power in any one phase.

$$\therefore \text{ Total three-phase power} = 3V_P I_P \cos\phi \text{ (W)} \quad (1)$$

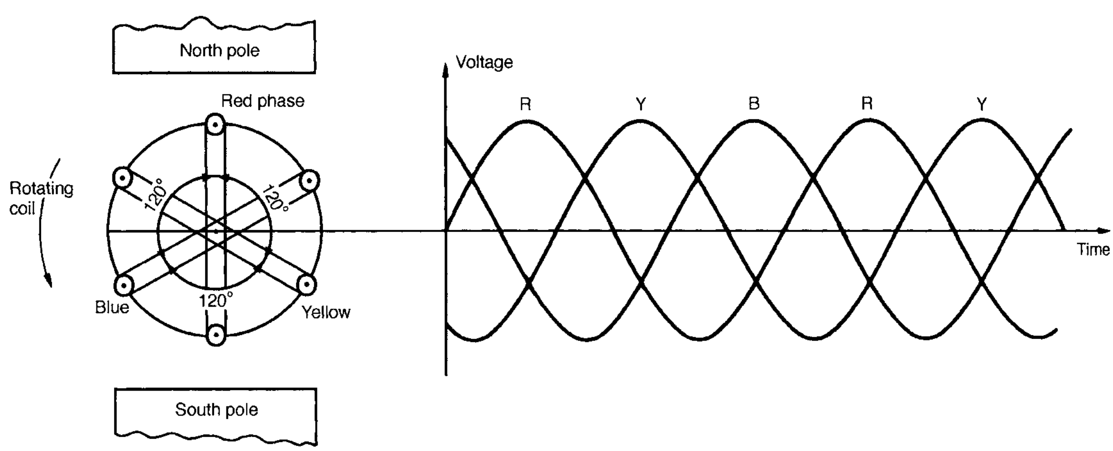


Fig. 1.68 Generation of a three-phase voltage.

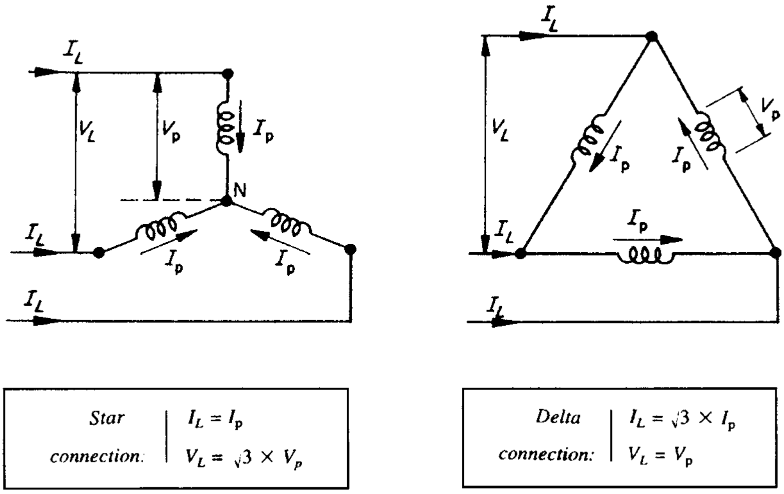


Fig. 1.69 Star and delta connections.

Now for a star connection,

$$V_P = V_L/\sqrt{3} \quad \text{and} \quad I_L = I_P \qquad (2)$$

Substituting Equation (2) into Equation (1), we have

$$\text{Total three-phase power} = \sqrt{3}\ V_L I_L \cos\phi \text{ (W)}$$

Now consider a delta connection:

$$V_P = V_L \quad \text{and} \quad I_P = I_L/\sqrt{3} \qquad (3)$$

Substituting Equation (3) into Equation (1) we have, for any balanced three-phase load,

$$\text{Total three-phase power} = \sqrt{3}\ V_L I_L \cos\phi \text{ (W)}$$

EXAMPLE 1

A balanced star-connected three-phase load of 10 Ω per phase is supplied from a 400 V 50 Hz mains supply at unity power factor. Calculate (a) the phase voltage, (b) the line current and (c) the total power consumed.

For a star connection,

$$V_L = \sqrt{3}\ V_P \quad \text{and} \quad I_L = I_P$$

For (a)

$$V_P = V_L/\sqrt{3} \text{ (V)}$$

$$V_P = \frac{400\text{ V}}{1.732} = 230.9\text{ V}$$

For (b)

$$I_L = I_P = V_P/R_P \text{ (A)}$$

$$I_L = I_P = \frac{230.9\text{ V}}{10\ \Omega} = 23.09\text{ A}$$

For (c)

$$\text{Power} = \sqrt{3}\ V_L\ I_L \cos\phi \text{ (W)}$$

$$\therefore \text{Power} = 1.732 \times 400\text{ V} \times 23.09\text{ A} \times 1 = 16\text{ kW}$$

EXAMPLE 2

A 20 kW 400 V balanced delta-connected load has a power factor of 0.8. Calculate (a) the line current and (b) the phase current.

We have that

$$\text{Three-phase power} = \sqrt{3}\ V_L\ I_L \cos\phi \text{ (W)}$$

For (a)

$$I_L = \frac{\text{Power}}{\sqrt{3}\ V_L \cos\phi} \text{ (A)}$$

$$\therefore I_L = \frac{20\,000\text{ W}}{1.732 \times 400\text{ V} \times 0.8}$$

$$I_L = 36.08 \text{ (A)}$$

For delta connection,

$$I_L = \sqrt{3}\ I_P \text{ (A)}$$

Thus, for (b),

$$I_P = I_L\sqrt{3}\ (\text{A})$$

$$\therefore I_P = \frac{36.08\ \text{A}}{1.732} = 20.83\ \text{A}$$

EXAMPLE 3

Three identical loads each having a resistance of 30 Ω and inductive reactance of 40 Ω are connected first in star and then in delta to a 400 V three-phase supply. Calculate the phase currents and line currents for each connection.

For each load,

$$Z = \sqrt{R^2 + X_L^2}\ (\Omega)$$
$$\therefore Z = \sqrt{30^2 + 40^2}$$
$$Z = \sqrt{2500}$$
$$Z = 50\ \Omega$$

For star connection,

$$V_L = \sqrt{3}\ V_P \quad \text{and} \quad I_L = I_P$$
$$V_P = V_L/\sqrt{3}\ (\text{V})$$
$$\therefore V_P = \frac{400\ \text{V}}{1.732} = 230.9\ \text{V}$$
$$I_P = V_P/Z_P\ (\text{A})$$
$$\therefore I_P = \frac{230.9\ \text{V}}{50\ \Omega} = 4.62\ \text{A}$$
$$I_P = I_L$$

therefore phase and line currents are both equal to 4.62 A.

For delta, connection,

$$V_L = V_P \quad \text{and} \quad I_L = \sqrt{3}\ I_P$$
$$V_L = V_P = 400\ \text{V}$$
$$I_P = V_P/Z_P\ (\text{A})$$
$$\therefore I = \frac{400\ \text{V}}{50\ \Omega} = 8\ \text{A}$$
$$I_L = \sqrt{3}\ I_P\ (\text{A})$$
$$\therefore I_L = 1.732 \times 8\ \text{A} = 13.86\ \text{A}$$

ELECTRICAL MACHINES

The fundamental principles of electrical machines were laid down in Chapters 2 and 3 of *Basic Electrical Installation Works* at Figs 2.39 to 2.41. In this chapter we will essentially be looking at d.c. and a.c. motors, their control equipment and maintenance and transformers.

Direct current motors

If a current carrying conductor is placed into the field of a permanent magnet as shown in Fig. 1.70(c) a force *F* will be exerted on the conductor to push it out of the magnetic field.

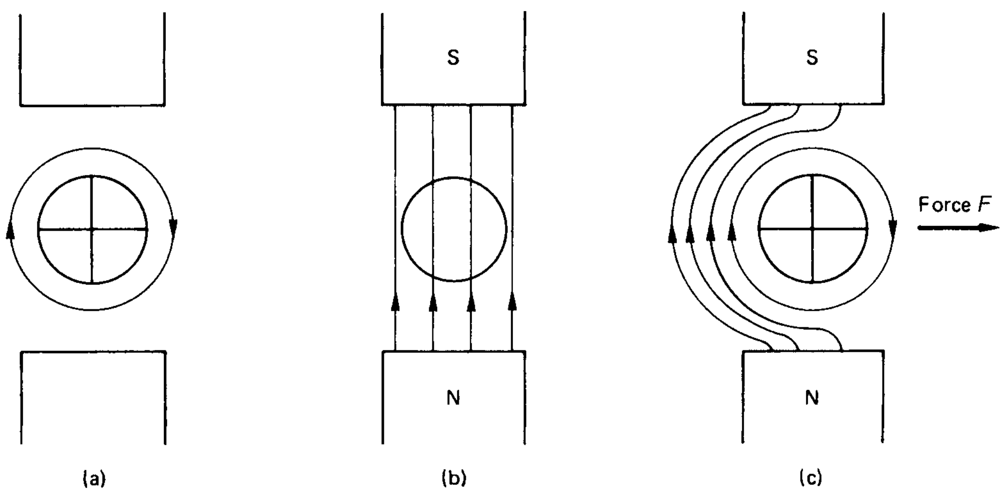


Fig. 1.70 Force on a conductor in a magnetic field.

To understand the force, let us consider each magnetic field acting alone. Figure 1.70(a) shows the magnetic field due to the current carrying conductor only. Figure 1.70(b) shows the magnetic field due to the permanent magnet in which is placed the conductor carrying no current. Figure 1.70(c) shows the effect of the combined magnetic fields which are distorted and, because lines of magnetic flux never cross, but behave like stretched elastic bands, always trying to find the shorter distance between a north and south pole, the force F is exerted on the conductor, pushing it out of the permanent magnetic field.

This is the basic motor principle, and the force F is dependent upon the strength of the magnetic field B, the magnitude of the current flowing in the conductor I and the length of conductor within the magnetic field l. The following equation expresses this relationship:

$$F = BlI \text{ (N)}$$

where B is in tesla, l is in metres, I is in amperes and F is in newtons.

EXAMPLE

A coil which is made up of a conductor some 15 m in length, lies at right angles to a magnetic field of strength 5 T. Calculate the force on the conductor when 15 A flows in the coil.

$$F = BlI \text{ (N)}$$

$$F = 5\,\text{T} \times 15\,\text{m} \times 15\,\text{A} = 1125\,\text{N}$$

PRACTICAL d.c. MOTORS

Practical motors are constructed as shown in Fig. 1.71. All d.c. motors contain a field winding wound on pole pieces attached to a steel yoke. The armature winding rotates between the poles and is connected to the commutator. Contact with the external circuit is made through carbon brushes rubbing on the commutator segments. Direct current motors are classified by the way in which the field and armature windings are connected, which may be in series or in parallel.

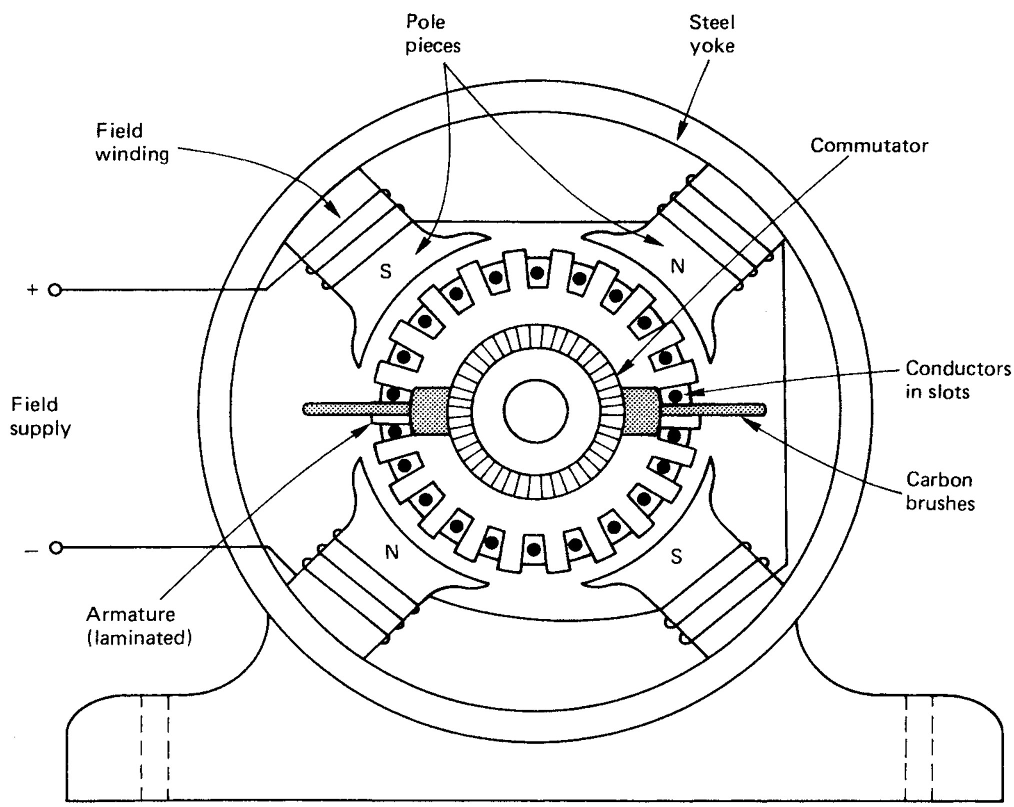


Fig. 1.71 Showing d.c. machine construction.

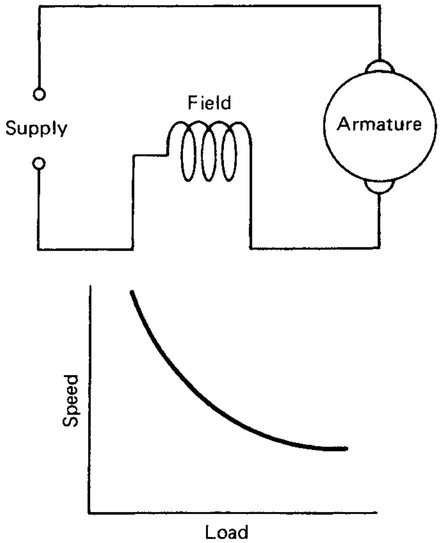


Fig. 1.72 Series motor connections and characteristics.

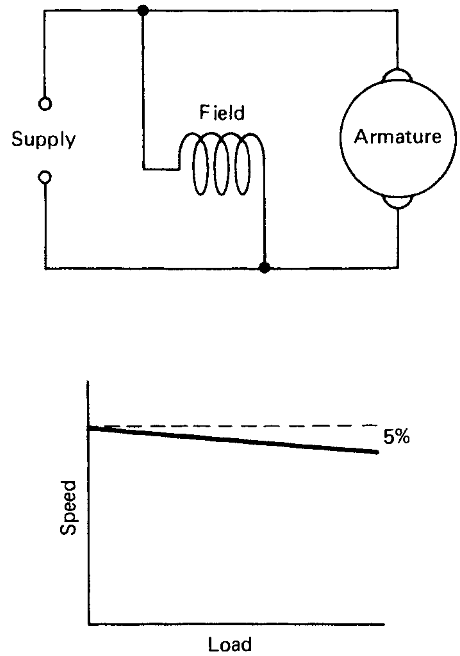


Fig. 1.73 Shunt motor connections and characteristics.

Series motor

The field and armature windings are connected in series and consequently share the same current. The series motor has the characteristics of a high starting torque but a speed which varies with load. Theoretically the motor would speed up to self-destruction, limited only by the windage of the rotating armature and friction, if the load were completely removed. Figure 1.72 shows series motor connections and characteristics. For this reason the motor is only suitable for direct coupling to a load, except in very small motors, such as vacuum cleaners and hand drills, and is ideally suited for applications where the machine must start on load, such as electric trains, cranes and hoists.

Reversal of rotation may be achieved by reversing the connections of either the field or armature windings but not both. This characteristic means that the machine will run on both a.c. or d.c. and is, therefore, sometimes referred to as a 'universal' motor.

Shunt motor

The field and armature windings are connected in parallel (see Fig. 1.73). Since the field winding is across the supply, the flux and motor speed are considered constant under normal conditions. In practice, however, as the load increases the field flux distorts and there is a small drop in speed of about 5% at full load, as shown in Fig. 1.73. The machine has a low starting torque and it is advisable to start with the load disconnected. The shunt motor is a very desirable d.c. motor because of its constant speed characteristics. It is used for driving power tools, such as lathes and drills. Reversal of rotation may be achieved by reversing the connections to either the field or armature winding but not both.

Compound motor

The compound motor has two field windings – one in series with the armature and the other in parallel. If the field windings are connected so that the field flux acts in opposition, the machine is known as a *short shunt* and has the characteristics of a series motor. If the fields are connected so that the field flux is strengthened, the machine is known as a *long shunt* and has constant speed characteristics similar to a shunt motor. The arrangement of compound motor connections is given in Fig. 1.74. The compound motor may be designed to possess the best characteristics of both series and shunt motors, that is, good starting torque together with almost constant speed. Typical applications are for electric motors in steel rolling mills, where a constant speed is required under varying load conditions.

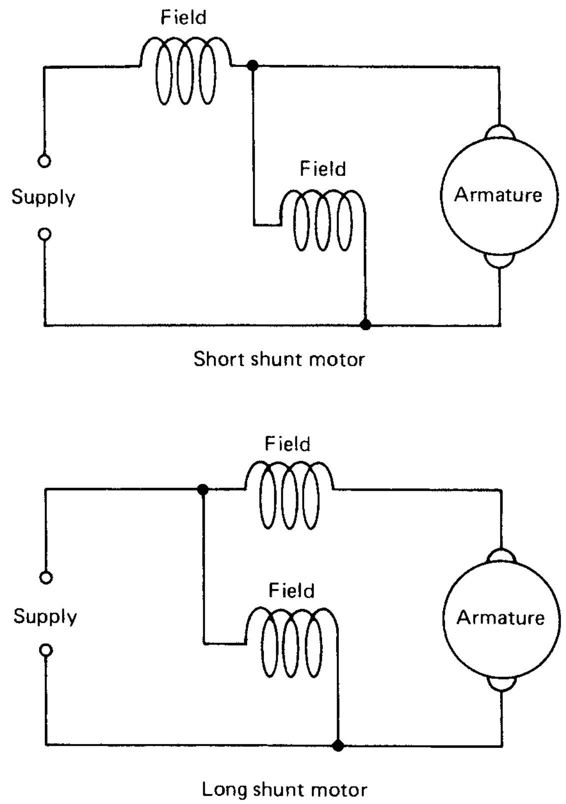


Fig. 1.74 Compound motor connections.

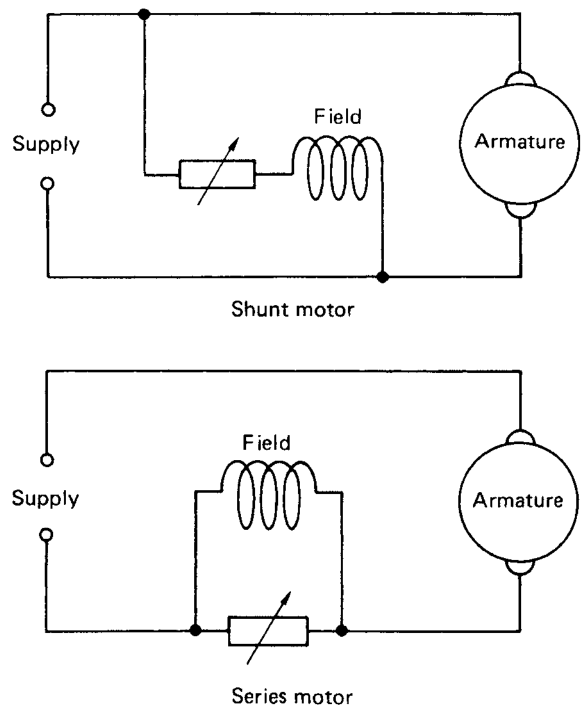


Fig. 1.75 Speed control of a d.c. motor.

SPEED CONTROL OF d.c. MACHINES

One of the advantages of a d.c. machine is the ease with which the speed may be controlled. The speed of a d.c. motor is inversely proportional to the strength of the magnetic flux in the field winding. The magnetic flux in the field winding can be controlled by the field current and, as a result, controlling the field current will control the motor speed.

A variable resistor connected into the field circuit, as shown in Fig. 1.75 provides one method of controlling the field current and the motor speed. This method has the disadvantage that much of the input energy is dissipated in the variable resistor and an alternative, when an a.c. supply is available, is to use thyristor control.

BACK emf AND MOTOR STARTING

When the armature conductors cut the magnetic flux of the main field, an emf is induced in the armature, as described earlier in this chapter at Fig. 1.43 under Inductance. This induced emf is known as the back emf, since it acts in opposition to the supply voltage. During normal running, the back emf is always a little smaller than the supply voltage, and acts as a limit to the motor current. However, when the motor is first switched on, the back emf does not exist because the conductors are stationary and so a motor starter is required to limit the starting current to a safe value. This applies to all but the very smallest of motors and is achieved by connecting a resistor in series with the armature during starting, so that the resistance can be gradually reduced as the speed builds up.

The control switch of Fig. 1.76 is moved to the start position, which connects the variable resistors in series with the motor, thereby limiting the starting current. The control switch is moved progressively over the variable resistor contacts to the run position as the motor speed builds up. A practical motor starter is designed so that the control switch returns automatically to the 'off' position whenever the motor stops, so that the starting resistors are connected when the machine is once again switched on.

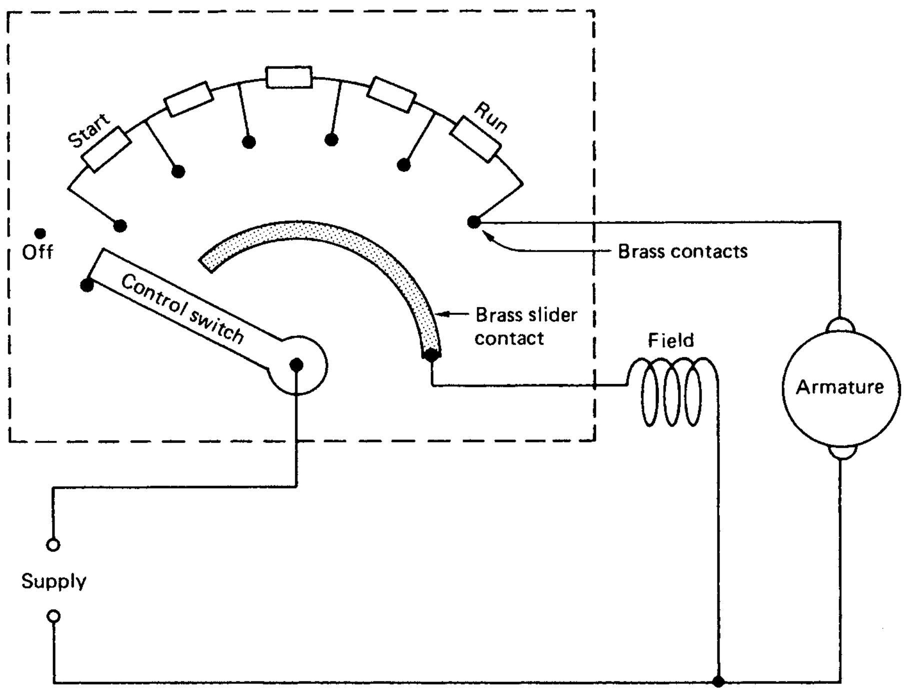


Fig. 1.76 A d.c. motor starting.

Three-phase a.c. motors

If a three-phase supply is connected to three separate windings equally distributed around the stationary part or stator of an electrical machine, an alternating current circulates in the coils and establishes a magnetic flux. The magnetic field established by the three-phase currents travels in a clockwise direction around the stator, as can be seen by considering the various intervals of time 1 to 6 shown in Fig. 1.77. The three-phase supply establishes a rotating magnetic flux which rotates at the same speed as the supply frequency. This is called synchronous speed, denoted n_S:

$$n_S = \frac{f}{P} \text{ or } N_S = \frac{60f}{P}$$

where

n_S is measured in revolutions per second
N_S is measured in revolutions per minute
f is the supply frequency measured in hertz
P is the number of pole pairs.

EXAMPLE

Calculate the synchronous speed of a four-pole machine connected to a 50 Hz mains supply.

We have

$$n_S = \frac{f}{P} \text{ (rps)}$$

A four-pole machine has two pairs of poles:

$$\therefore\ n_S = \frac{50 \text{ Hz}}{2} = 25 \text{ rps}$$

$$\text{or } N_S = \frac{60 \times 50 \text{ Hz}}{2} = 1500 \text{ rpm}$$

This rotating magnetic field is used for practical effect in the induction motor.

THREE-PHASE INDUCTION MOTOR

When a three-phase supply is connected to insulated coils set into slots in the inner surface of the stator or

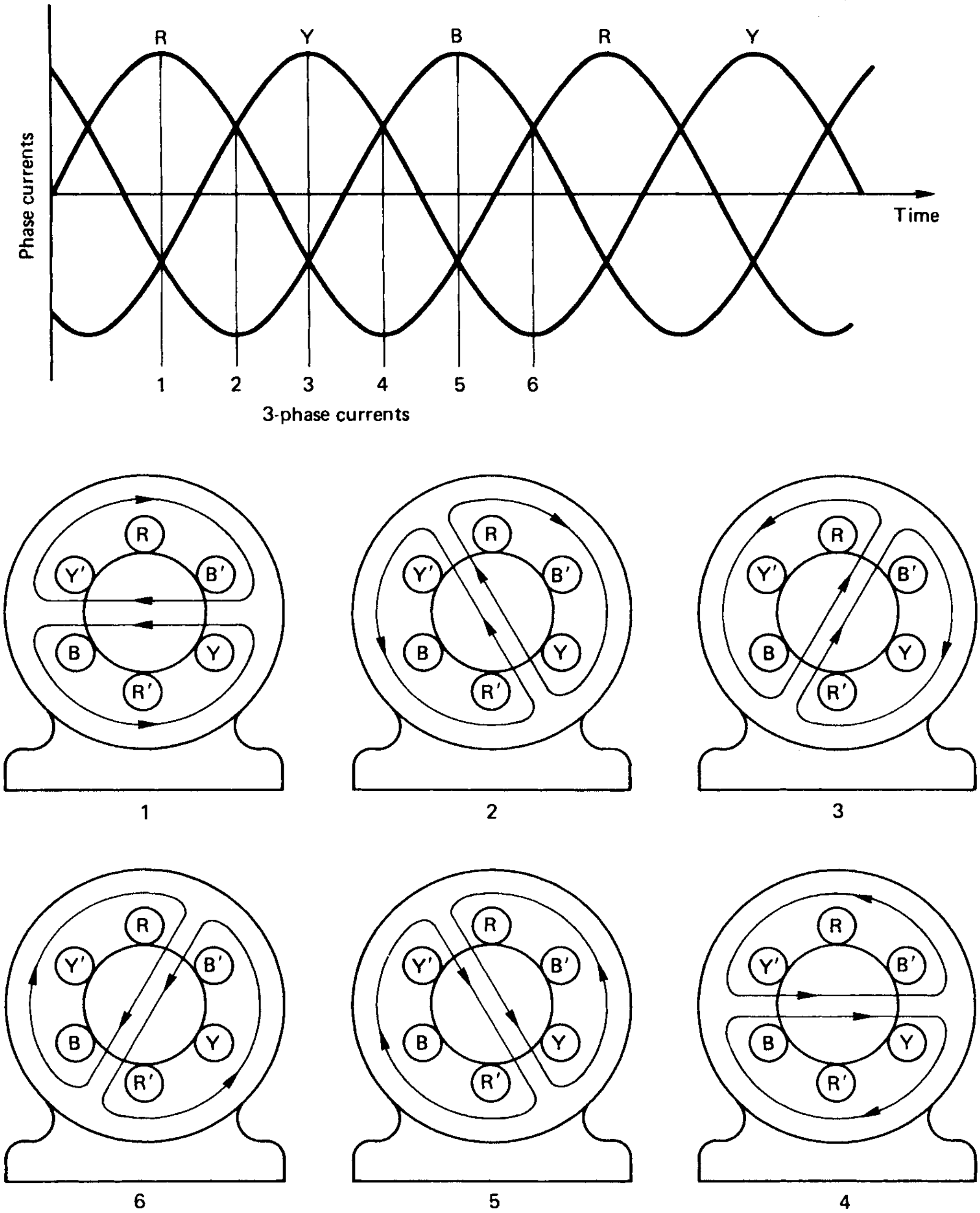


Fig. 1.77 Distribution of magnetic flux due to three-phase currents.

stationary part of an induction motor as shown in Fig. 1.78(a), a rotating magnetic flux is produced. The rotating magnetic flux cuts the conductors of the rotor and induces an emf in the rotor conductors by Faraday's law, which states that when a conductor cuts or is cut by a magnetic field, an emf is induced in that conductor, the magnitude of which is proportional to the *rate* at which the conductor cuts or is cut by the magnetic flux. This induced emf causes rotor currents to flow and establish a magnetic flux which reacts with the stator flux and causes a force to be exerted on the rotor conductors, turning the rotor as shown in Fig. 1.78(b).

The turning force or torque experienced by the rotor is produced by inducing an emf into the rotor conductors due to the *relative* motion between the

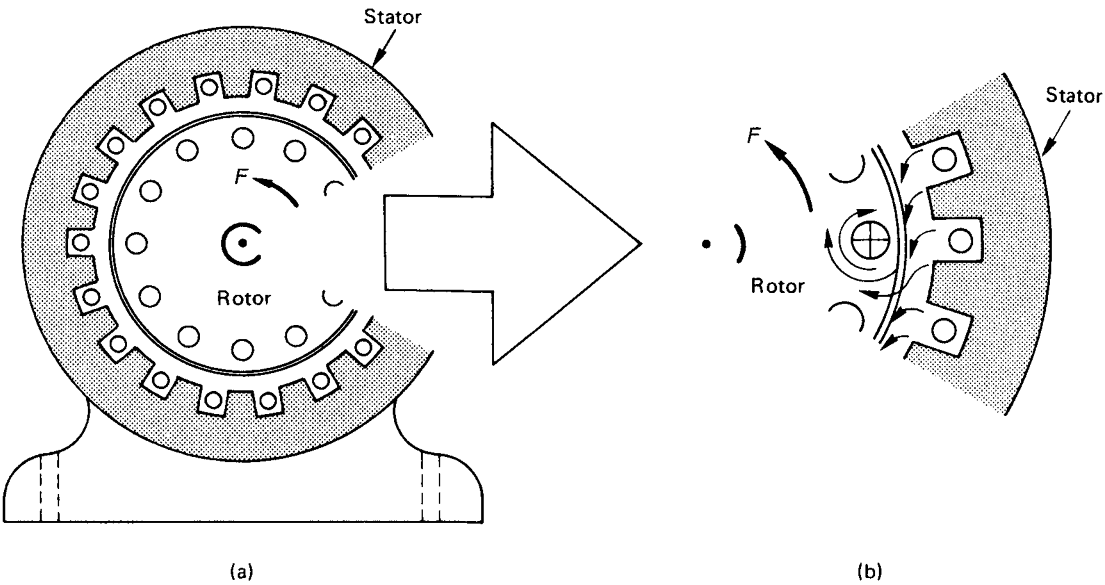


Fig. 1.78 Segment taken out of an induction motor to show turning force: (a) construction of an induction motor; (b) production of torque by magnetic fields.

conductors and the rotating field. The torque produces rotation in the same direction as the rotating magnetic field. At switch-on, the rotor speed increases until it approaches the speed of the rotating magnetic flux, that is, the synchronous speed. The faster the rotor revolves the less will be the difference in speed between the rotor and the rotating magnetic field. By Faraday's laws, this will result in less induced emf, less rotor current and less torque on the rotor. The rotor can never run at synchronous speed because, if it did so, there would be no induced emf, no current and no torque. The induction motor is called an asynchronous motor. In practice, the rotor runs at between 2% and 5% below the synchronous speed so that a torque can be maintained on the rotor which overcomes the rotor losses and the applied load.

The difference between the rotor speed and synchronous speed is called slip; the per-unit slip, denoted s, is given by

$$s = \frac{n_S - n}{n_S} = \frac{N_S - N}{N_S}$$

where
n_S = synchronous speed in revolutions per second
N_S = synchronous speed in revolutions per minute
n = rotor speed in revolutions per second
N = rotor speed in revolutions per minute.

The percentage slip is just the per-unit slip multiplied by 100.

EXAMPLE

A two-pole induction motor runs at 2880 rpm when connected to the 50 Hz mains supply. Calculate the percentage slip.

The synchronous speed is given by

$$N_S = \frac{60 \times f}{p} \text{ (rpm)}$$

$$\therefore\ N_S = \frac{60 \times 50\text{ Hz}}{1} = 3000\text{ rpm}$$

Thus the per-unit slip is

$$s = \frac{N_S - N}{N_S}$$

$$\therefore s = \frac{3000\text{ rpm} - 2880\text{ rpm}}{3000\text{ rpm}}$$

$$s = 0.04.$$

So the percentage slip is $0.04 \times 100 = 4\%$.

ROTOR CONSTRUCTION

There are two types of induction motor rotor – the wound rotor and the cage rotor. The cage rotor consists

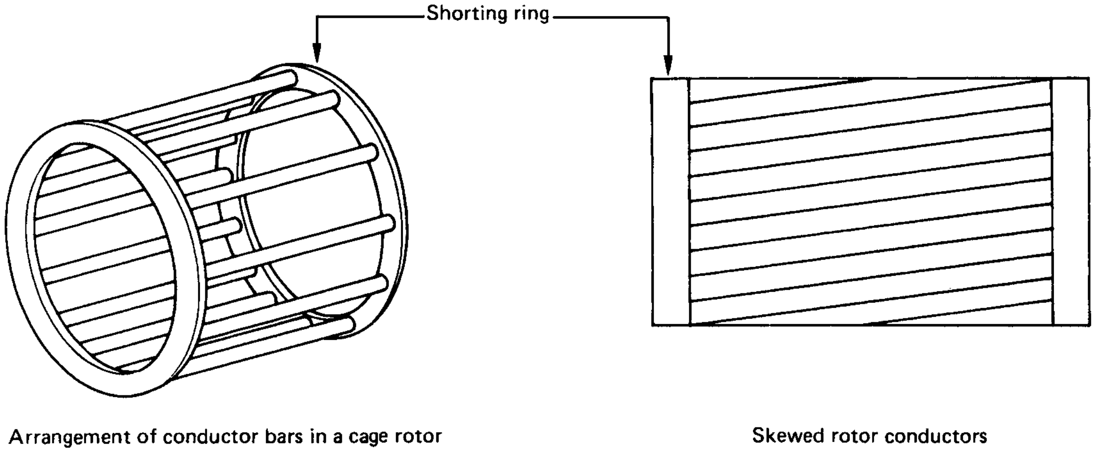


Fig. 1.79 Construction of a cage rotor.

of a laminated cylinder of silicon steel with copper or aluminium bars slotted in holes around the circumference and short-circuited at each end of the cylinder as shown in Fig. 1.79. In small motors the rotor is cast in aluminium. Better starting and quieter running are achieved if the bars are slightly skewed. This type of rotor is extremely robust and since there are no external connections there is no need for slip-rings or brushes. A machine fitted with a cage rotor does suffer from a low starting torque and the machine must be chosen which has a higher starting torque than the load, as shown by curve (b) in Fig. 1.80. A machine with the characteristic shown by curve (a) in Fig. 1.80 would not start since the load torque is greater than the machine starting torque.

Alternatively the load may be connected after the motor has been run up to full speed, or extra resistance can be added to a wound rotor through slip-rings and brushes since this improves the starting torque, as shown by curve (c) in Fig. 1.80. The wound rotor consists of a laminated cylinder of silicon steel with copper coils embedded in slots around the circumference. The windings may be connected in star or delta and the end connections brought out to slip rings mounted on the shaft. Connection by carbon brushes can then be made to an external resistance to improve starting, but once normal running speed is achieved the external resistance is short circuited. Therefore, the principle of operation for both types of rotor is the same.

The cage induction motor has a small starting torque and should be used with light loads or started

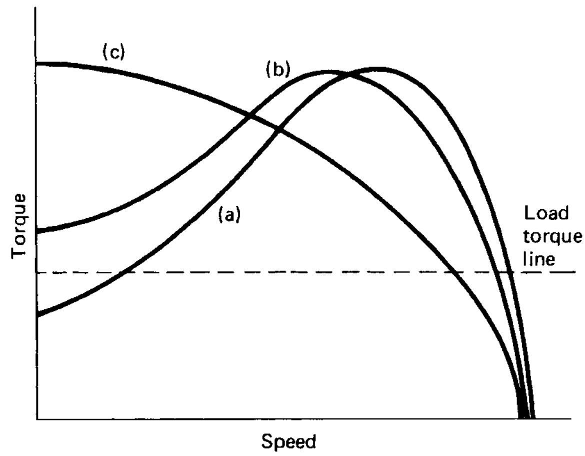


Fig. 1.80 Various speed–torque characteristics for an induction motor.

with the load disconnected. The speed is almost constant at about 5% less than synchronous speed. Its applications are for constant speed machines such as fans and pumps. Reversal of rotation is achieved by reversing any two of the stator winding connections.

THREE-PHASE SYNCHRONOUS MOTOR

If the rotor of a three-phase induction motor is removed and replaced with a simple magnetic compass, the compass needle will rotate in the same direction as the rotating magnetic field set up by the stator winding. That is, the compass needle will rotate at synchronous speed. This is the basic principle of operation of the synchronous motor.

In a practical machine, the rotor is supplied through slip-rings with a d.c. supply which sets up an electromagnet having north and south poles.

When the supply is initially switched on, the rotor will experience a force, first in one direction and then in the other direction every cycle as the stator flux rotates around the rotor at synchronous speed. Therefore, the synchronous motor is not self-starting. However, if the rotor is rotated at or near synchronous speed, then the stator and rotor poles of opposite polarity will 'lock together' producing a turning force or torque which will cause the rotor to rotate at synchronous speed.

If the rotor is slowed down and it comes out of synchronism, then the rotor will stop because the torque will be zero. The synchronous motor can, therefore, only be run at synchronous speed, which for a 50 Hz supply will be 3000, 1500, 1000 or 750 rpm depending upon the number of poles, as discussed earlier in this chapter.

A practical synchronous machine can be brought up to synchronous speed by either running it initially as an induction motor or by driving it up to synchronous speed by another motor called a 'pony motor'. Once the rotor achieves synchronous speed the pony motor is disconnected and the load applied to the synchronous motor.

With such a complicated method of starting the synchronous motor, it is clearly not likely to find applications which require frequent stopping and starting. However, the advantage of a synchronous motor is that it runs at a constant speed and operates at a leading power factor. It can, therefore, be used to improve a bad power factor while driving constant speed machines such as ventilation fans and pumping compressors.

Single-phase a.c. motors

A single-phase a.c. supply produces a pulsating magnetic field, not the rotating magnetic field produced by a three-phase supply. All a.c. motors require a rotating field to start. Therefore, single-phase a.c. motors have two windings which are electrically separated by about 90°. The two windings are known as the start and run windings. The magnetic fields produced by currents flowing through these out-of-phase windings create the rotating field and turning force required to start the motor. Once rotation is established, the pulsating field in the run winding is sufficient to maintain rotation and the start winding is disconnected by a centrifugal switch which operates when the motor has reached about 80% of the full load speed.

A cage rotor is used on single-phase a.c. motors, the turning force being produced in the way described previously for three-phase induction motors and shown in Fig. 1.78. Because both windings carry currents which are out of phase with each other, the motor is known as a 'split-phase' motor. The phase displacement between the currents in the windings is achieved in one of two ways:

- by connecting a capacitor in series with the start winding, as shown in Fig. 1.81(a), which gives a 90° phase difference between the currents in the start and run windings;
- by designing the start winding to have a high resistance and the run winding a high inductance, once again creating a 90° phase shift between the currents in each winding, as shown in Fig. 1.81(b).

When the motor is first switched on, the centrifugal switch is closed and the magnetic fields from the two coils produce the turning force required to run the rotor up to full speed. When the motor reaches about 80% of full speed, the centrifugal switch clicks open and the machine continues to run on the magnetic flux created by the run winding only.

Split-phase motors are constant speed machines with a low starting torque and are used on light loads such as fans, pumps, refrigerators and washing machines. Reversal of rotation may be achieved by reversing the connections to the start or run windings, but not both.

SHADED POLE MOTORS

The shaded pole motor is a simple, robust single-phase motor, which is suitable for very small machines with a rating of less than about 50 W. Figure 1.82 shows a shaded pole motor. It has a cage rotor and the moving field is produced by enclosing one side of each stator pole in a solid copper or brass ring, called a shading ring, which displaces the magnetic field and creates an artificial phase shift.

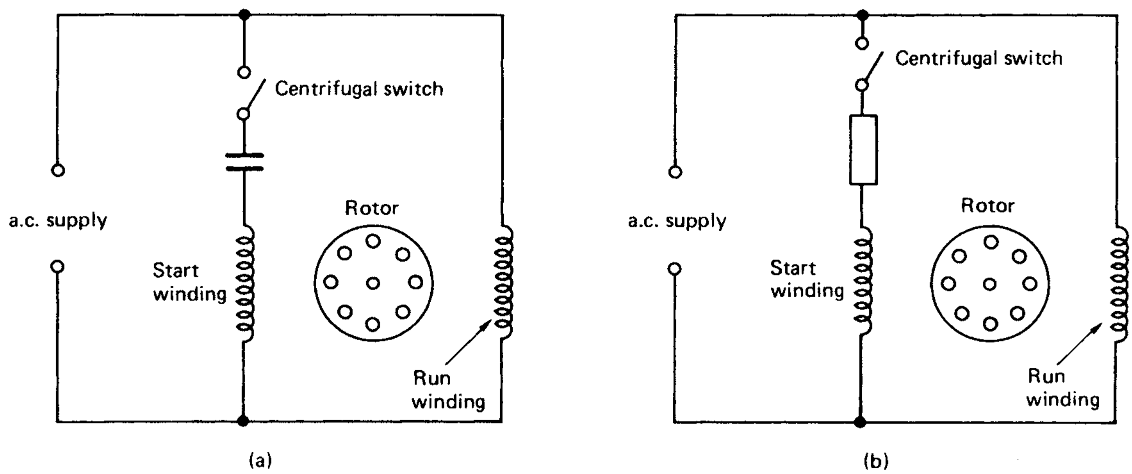


Fig. 1.81 Circuit diagram of: (a) capacitor split-phase motors; (b) resistance split-phase motors.

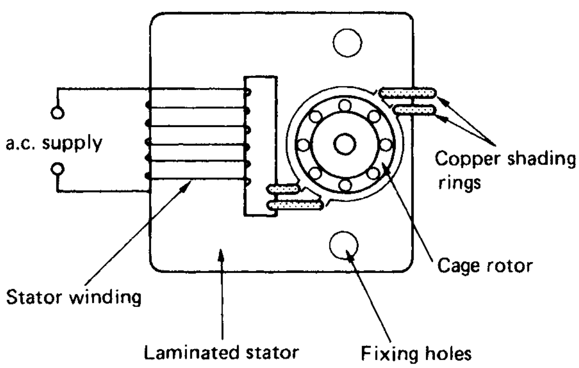


Fig. 1.82 Shaded pole motor.

Shaded pole motors are constant speed machines with a very low starting torque and are used on very light loads such as oven fans, record turntable motors and electric fan heaters. Reversal of rotation is theoretically possible by moving the shading rings to the opposite side of the stator pole face. However, in practice this is often not a simple process, but the motors are symmetrical and it is sometimes easier to reverse the rotor by removing the fixing bolts and reversing the whole motor.

There are more motors operating from single-phase supplies than all other types of motor added together. Most of them operate as very small motors in domestic and business machines where single-phase supplies are most common.

Motor starters

The magnetic flux generated in the stator of an induction motor rotates immediately the supply is switched on, and therefore the machine is self-starting. The purpose of the motor starter is not to start the machine, as the name implies, but to reduce heavy starting currents and provide overload and no-volt protection in accordance with the requirements of Regulations 552.

Thermal overload protection is usually provided by means of a bimetal strip bending under overload conditions and breaking the starter contactor coil circuit. This de-energizes the coil and switches off the motor under fault conditions such as overloading or single phasing. Once the motor has automatically switched off under overload conditions or because a remote stop/start button has been operated, it is an important safety feature that the motor cannot restart without the operator going through the normal start-up procedure. Therefore, no-volt protection is provided by incorporating the safety devices into the motor starter control circuit which energizes the contactor coil.

Electronic thermistors (thermal transistors) provide an alternative method of sensing if a motor is overheating. These tiny heat-sensing transistors, about the size of a matchstick head, are embedded in the motor windings to sense the internal temperature, and the thermistor either trips out the contactor coil as described above or operates an alarm.

All electric motors with a rating above 0.37 kW must be supplied from a suitable motor starter and we will now consider the more common types.

DIRECT ON LINE (d.o.l.) STARTERS

The d.o.l. starter switches the main supply directly on to the motor. Since motor starting currents can be seven or eight times greater than the running current, the d.o.l. starter is only used for small motors of less than about 5 kW rating.

When the start button is pressed current will flow from the red phase through the control circuit and contactor coil to the blue phase which energizes the contactor coil and the contacts close, connecting the three-phase supply to the motor, as can be seen in Fig. 1.83. If the start button is released the control circuit is maintained by the hold on contact. If the stop button is pressed or the overload coils operate, the control circuit is broken and the contractor drops out, breaking the supply to the load. Once the supply is interrupted the supply to the motor can only be reconnected by pressing the start button. Therefore this type of arrangement also provides no-volt protection.

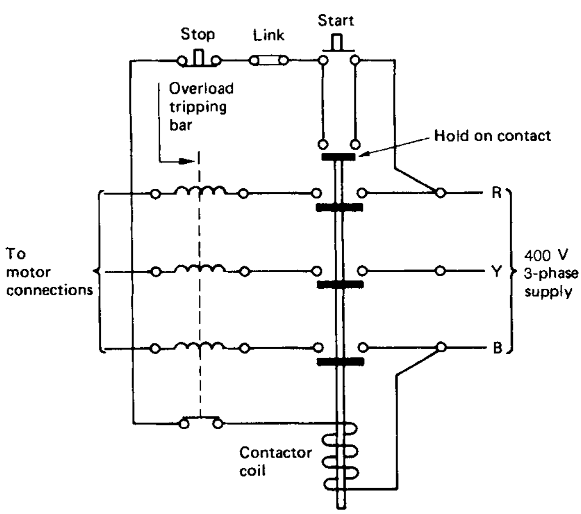


Fig. 1.83 Three-phase d.o.l. starter.

When large industrial motors have to be started, a way of reducing the excessive starting currents must be found. One method is to connect the motor to a star delta starter.

STAR DELTA STARTERS

When three loads, such as the three windings of a motor, are connected in star, the line current has only one-third of the value it has when the same load is connected in delta. A starter which can connect the motor windings in star during the initial starting period and then switch to delta connection will reduce the problems of an excessive starting current. This arrangement is shown in Fig. 1.84, where the six connections to the three stator phase windings are brought out to the starter. For starting, the motor windings are star-connected at the a–b–c end of the winding by the star making contacts. This reduces the phase voltage to about 58% of the running voltage which reduces the current and the motor's torque. Once the motor is running a double-throw switch makes the changeover from star starting to delta running, thereby achieving a minimum starting current and maximum running torque. The starter will incorporate overload and no-volt protection, but these are not shown in Fig. 1.84 in the interests of showing more clearly the principle of operation.

AUTO-TRANSFORMER STARTER

An auto-transformer motor starter provides another method of reducing the starting current by reducing the voltage during the initial starting period. Since this also reduces the starting torque, the voltage is only reduced by a sufficient amount to reduce the starting current, being permanently connected to the tapping found to be most appropriate by the installing electrician. Switching the changeover switch to the start position connects the auto-transformer windings in series with the delta-connected motor starter winding. When sufficient speed has been achieved by the motor the changeover switch is moved to the run connections which connect the three-phase supply directly on to the motor as shown in Fig. 1.85.

This starting method has the advantage of only requiring three connection conductors between the motor starter and the motor. The starter will incorporate overload and no-volt protection in addition to some method of preventing the motor being switched to the run position while the motor is stopped. These protective devices are not shown in Fig. 1.85 in order to show more clearly the principle of operation.

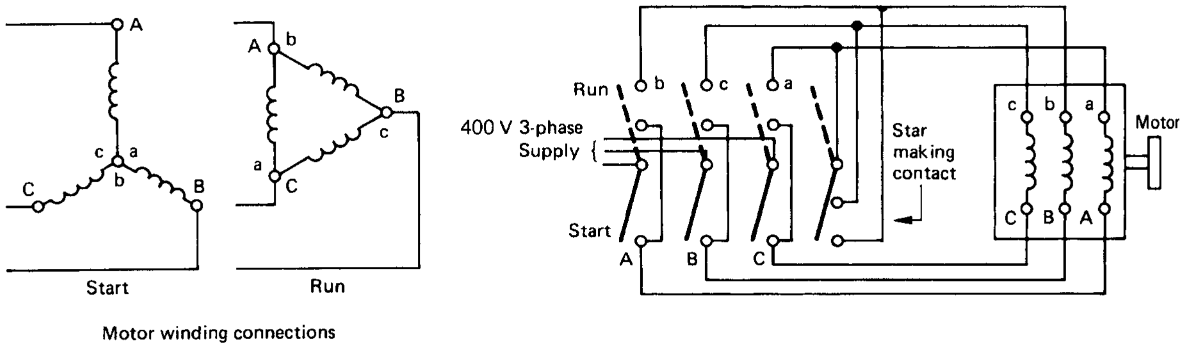


Fig. 1.84 Star delta starter.

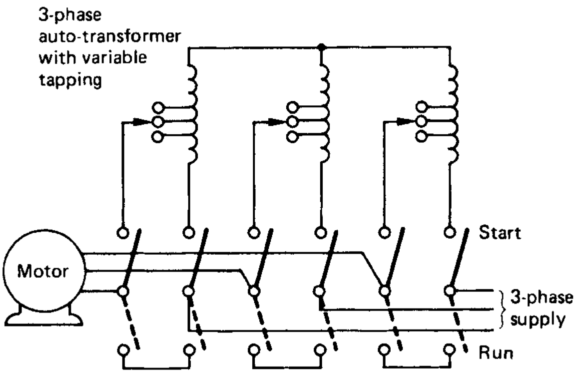


Fig. 1.85 Auto-transformer starting.

ROTOR RESISTANCE STARTER

When starting a machine on load a wound rotor induction motor must generally be used since this allows an external resistance to be connected to the rotor winding through slip-rings and brushes, which increases the starting torque as shown in Fig. 1.80 curve (c).

When the motor is first switched on the external rotor resistance is at a maximum. As the motor speed increases the resistance is reduced until at full speed the external resistance is completely cut out and the machine runs as a cage induction motor. The starter is provided with overload and no-volt protection and an interlock to prevent the machine being switched on with no rotor resistance connected, but these are not shown in Fig. 1.86 since the purpose of the diagram is to show the principle of operation.

Remote control of motors

When it is required to have stop/start control of a motor at a position other than the starter position, additional start buttons may be connected in parallel and additional stop buttons in series, as shown in Fig. 1.87 for the d.o.l. starter. This is the diagram shown in Fig. 1.83 with the link removed and a remote stop/start button connected. Additional stop and start facilities are often provided for the safety and convenience of the machine operator.

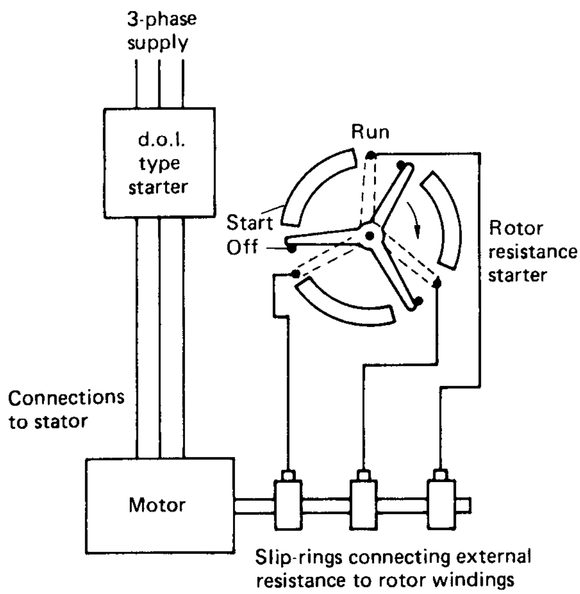


Fig. 1.86 Rotor resistance starter for a wound rotor machine.

Installation of motors

Electric motors vibrate when running and should be connected to the electrical installation through a flexible connection. This may also make final adjustments of the motor position easier. Where the final connection is made with flexible conduit, the tube

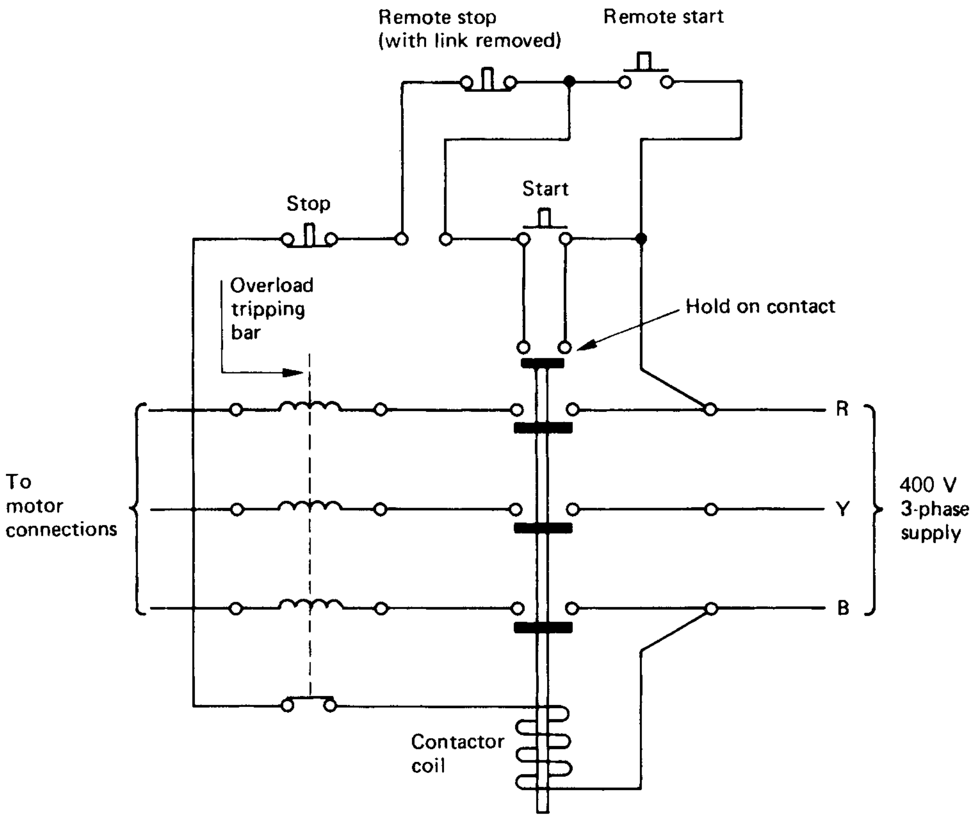


Fig. 1.87 Remote stop/start connections to d.o.l. starter.

must not be relied upon to provide a continuous earth path and a separate CPC must be run either inside or outside the flexible conduit (Regulation 543–02–01).

All motors over 0.37 kW rating must be connected to the source of supply through a suitable starter which incorporates overload protection and a device which prevents dangerous restarting of the motor following a mains failure (Regulations 552–01–02 and 03).

The cables supplying the motor must be capable of carrying at least the full load current of the motor (Regulation 552–01–01) and a local means of isolation must be provided to facilitate safe mechanical maintenance (Regulation 476–02–03).

At the supply end, the motor circuit will be protected by a fuse or MCB. The supply protection must be capable of withstanding the motor starting current while providing adequate overcurrent protection. There must also be discrimination so that the overcurrent device in the motor starter operates first in the event of an excessive motor current.

Most motors are 'continuously rated'. This is the load at which the motor may be operated continuously without overheating.

Many standard motors have class A insulation which is suitable for operating in ambient temperatures up to about 55°C. If a class A motor is to be operated in a higher ambient temperature, the continuous rating may need to be reduced to prevent damage to the motor. The motor and its enclosure must be suitable for the installed conditions and must additionally prevent anyone coming into contact with the internal live or moving parts. Many different enclosures are used, depending upon the atmosphere in which the motor is situated. Clean air, damp conditions, dust particles in the atmosphere, chemical or explosive vapours will determine the type of motor enclosure. In high ambient temperatures it may be necessary to provide additional ventilation to keep the motor cool and prevent the lubricating oil thinning. The following motor enclosures are examples of those to be found in industry.

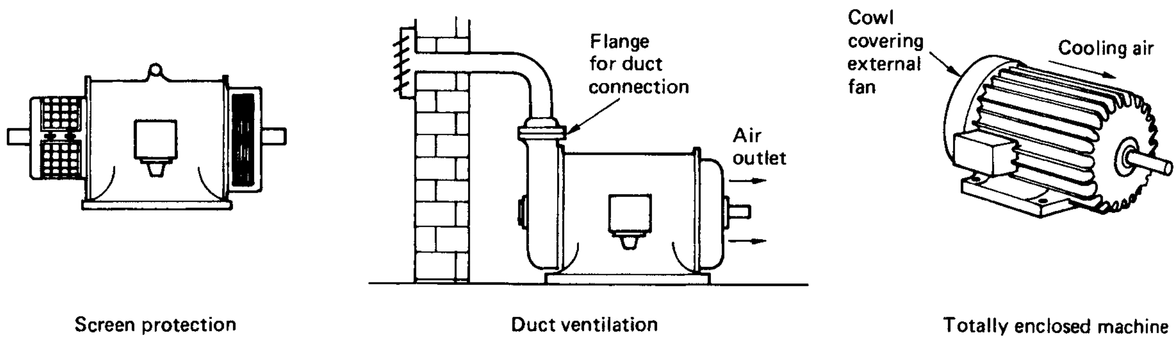


Fig. 1.88 Motor enclosures.

Screen protected enclosures prevent access to the internal live and moving parts by covering openings in the motor casing with metal screens of perforated metal or wire mesh. Air flow for cooling is not restricted and is usually assisted by a fan mounted internally on the machine shaft. This type of enclosure is shown in Fig. 1.88.

A duct ventilated enclosure is used when the air in the room in which the motor is situated is unsuitable for passing through the motor for cooling – for example, when the atmosphere contains dust particles or chemical vapour. In these cases the air is drawn from a clean air zone outside the room in which the machine is installed, as shown in Fig. 1.88.

A totally enclosed enclosure is one in which the air inside the machine casing has no connection with the air in the room in which it is installed, but it is not necessarily airtight. A fan on the motor shaft inside the casing circulates the air through the windings and cooling is by conduction through motor casing. To increase the surface area and assist cooling, the casing is surrounded by fins, and an externally mounted fan can increase the flow of air over these fins. This type of enclosure is shown in Fig. 1.88.

A flameproof enclosure requires that further modifications be made to the totally enclosed casing to prevent inflammable gases coming into contact with sparks or arcing inside the motor. To ensure that the motor meets the stringent regulations for flameproof enclosures the shaft is usually enclosed in special bearings and the motor connections contained by a wide flange junction box.

When a motor is connected to a load, either by direct coupling or by a vee belt, it is important that the shafts or pulleys are exactly in line. This is usually best achieved by placing a straight edge or steel rule across the flange coupling of a direct drive or across the flat faces of a pair of pulleys, as shown in Fig. 1.89. Since pulley belts stretch in use it is also important to have some means of adjusting the tension of the vee belt. This is usually achieved by mounting the motor on a pair of slide rails as shown in Fig. 1.90. Adjustment is carried out by loosening the motor fixing bolts, screwing in the adjusting bolts which push the motor back, and when the correct belt tension has been achieved the motor fixing bolts are tightened.

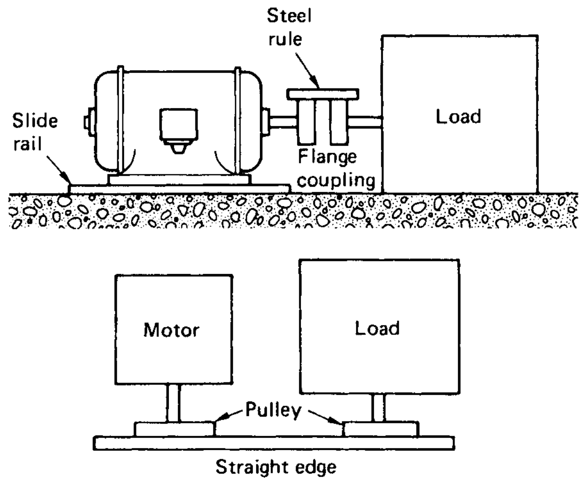


Fig. 1.89 Pulley and flange coupling arrangement.

Motor maintenance

All rotating machines are subject to wear, simply because they rotate. Motor fans which provide cooling also pull dust particles from the surrounding air into the motor enclosure. Bearings dry out, drive belts

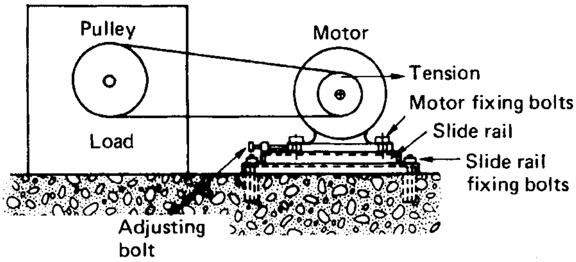


Fig. 1.90 Vee belt adjustment of slide rail mounted motor.

stretch and lubricating oils and greases require replacement at regular intervals. Industrial electric motors are often operated in a hot, dirty, dusty or corrosive environment for many years. If they are to give good and reliable service they must be suitable for the task and the conditions in which they must operate. Maintenance at regular intervals is required, in the same way that a motor car is regularly serviced.

The solid construction of the cage rotor used in many a.c. machines makes them almost indestructible, and, since there are no external connections to the rotor, the need for slip-rings and brushes is eliminated. These characteristics give cage rotor a.c. machines maximum reliability with the minimum of maintenance and make the induction motor the most widely used in industry. Often the only maintenance required with an a.c. machine is to lubricate in accordance with the manufacturer's recommendations.

However, where high torque and variable speed characteristics are required d.c. machines are often used. These require a little more maintenance than a.c. machines because the carbon brushes, rubbing on the commutator, wear down and require replacing. New brushes must be of the correct grade and may require 'bedding in' or shaping with a piece of fine abrasive cloth to the curve of the commutator.

The commutator itself should be kept clean and any irregularities smoothed out with abrasive cloth. As the commutator wears, the mica insulation between the segments must be cut back with an undercutting tool or a hacksaw blade to keep the commutator surface smooth. If the commutator has become badly worn, and a groove is evident, the armature will need to be removed from the motor, and the commutator turned in a lathe.

Motors vibrate when operating and as a result fixing bolts and connections should be checked as part of the maintenance operation. Where a motor drives a load via a pulley belt, the motor should be adjusted on the slider rails until there is about 10 mm of play in the belt.

Planning maintenance work with forethought and keeping records of work done with dates can have the following advantages:

- the maintenance is carried out when it is most convenient;
- regular simple maintenance often results in less emergency maintenance;
- regular servicing and adjustment maintain the plant and machines at peak efficiency.

The result of planned maintenance is often that fewer breakdowns occur, which result in loss of production time. Therefore, a planned maintenance programme must be a sensible consideration for any commercial operator.

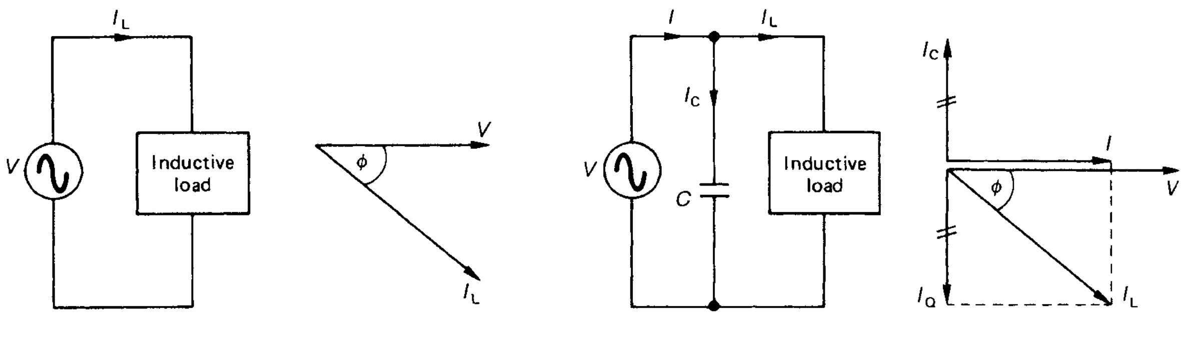
Power-factor correction

Most electrical installations have a low power factor because loads such as motors, transformers and discharge lighting circuits are inductive in nature and cause the current to lag behind the voltage. A capacitor has the opposite effect to an inductor, causing the current to lead the voltage. Therefore, by adding capacitance to an inductive circuit the bad power factor can be corrected. The load current I_L is made up of an in-phase component I and a quadrature component I_Q. The power factor can be corrected to unity when the capacitor current I_C is equal and opposite to the quadrature or reactive current I_Q of the inductive load. The quadrature or reactive current is responsible for setting up the magnetic field in an inductive circuit. Figure 1.91 shows the power factor corrected to unity, that is when $I_Q = I_C$.

A low power factor is considered a disadvantage because a given load takes more current at a low power factor than it does at a high power factor. In Chapter 7 we calculated that a 1.84 kW load at unity power factor took 8 A, but at a bad power factor of 0.4 a current of 20 A was required to supply the same load.

The supply authorities discourage industrial consumers from operating at a bad power factor because:

- larger cables and switchgear are necessary to supply a given load;



(a) Circuit and phasor diagram for an inductive load with low p.f.

(b) Circuit and phasor diagram for circuit (a) with capacitor correcting p.f. to unity

Fig. 1.91 Power-factor correction of inductive load: (a) circuit and phasor diagram for an inductive load with low p.f.; (b) circuit and phasor diagram for (a) with capacitor correcting p.f. to unity.

- larger currents give rise to greater copper losses in transmission cables and transformers;
- larger currents give rise to greater voltage drops in cables;
- larger cables may be required on the consumer's side of the electrical installation to carry the larger currents demanded by a load operating with a bad power factor.

Bad power factors are corrected by connecting a capacitor either across the individual piece of equipment or across the main busbars of the installation. When individual capacitors are used they are usually of the paper dielectric type of construction (see Fig. 1.47 earlier in this chapter). This is the type of capacitor used for power-factor correction in a fluorescent luminaire. When large banks of capacitors are required to correct the p.f. of a whole installation, paper dielectric capacitors are immersed in an oil tank in a similar type construction to a transformer, and connected on to the main busbars of the electrical installation by suitably insulated and mechanically protected cables.

The current to be carried by the capacitor for p.f. correction and the value of the capacitor may be calculated as shown by the following example.

EXAMPLE

An 8 kW load with a power factor of 0.7 is connected across a 400 V, 50 Hz supply. Calculate:

(a) the current taken by this load
(b) the capacitor current required to raise the p.f. to unity
(c) the capacitance of the capacitor required to raise the p.f. to unity.

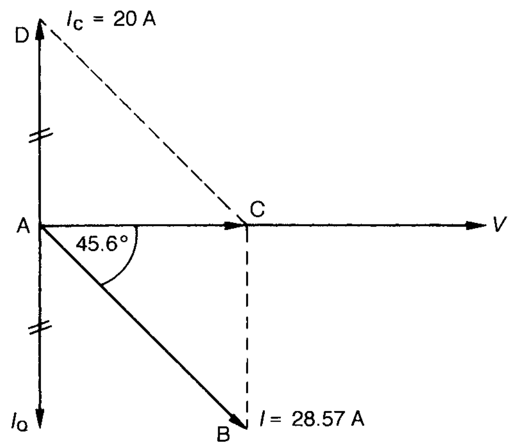


Fig. 1.92 Phasor diagram.

For (a), since $P = VI\cos\phi$ (W),

$$I = \frac{P}{V\cos\phi} \text{(A)}$$

$$\therefore\ I = \frac{8000\text{ W}}{400\text{ V} \times 0.7} = 28.57 \text{ (A)}$$

This current lags the voltage by an angle of 45.6° (since $\cos^{-1} 0.7 = 45.6°$) and can therefore be drawn to scale as shown in Fig. 1.92 and represented by line AB.

For (b) at unity p.f. the current will be in phase with the voltage, represented by line AC in Fig. 1.92. To raise the load current to this value will require a capacitor current I_c which is equal and opposite to the value of the quadrature or reactive component I_Q. The value of I_Q is measured from the phasor diagram and found to be 20 A which is the value of the capacitor current required to raise the p.f. to unity and shown by line AD in Fig. 1.92.

For (c), since

$$I_C = \frac{V}{X_C}\text{(A)} \quad \text{and} \quad X_C = \frac{V}{I_C}(\Omega)$$

$$\therefore\ X_C = \frac{400\text{ V}}{20\text{ A}} = 20\,\Omega$$

Since

$$X_C = \frac{1}{2\pi fC}\ (\Omega) \quad \text{and} \quad C = \frac{1}{2\pi fX_C}\ \text{(F)}$$

$$\therefore\ C = \frac{1}{2 \times \pi \times 50\text{ Hz} \times 20\,\Omega} = 159\ \mu\text{F}$$

A 159 μF capacitor connected in parallel with the 8 kW load would correct the power factor to unity.

Transformers

A transformer is an electrical machine which is used to change the value of an alternating voltage. They vary in size from miniature units used in electronics to huge power transformers used in power stations. A transformer will only work when an alternating voltage is connected. It will not normally work from a d.c. supply such as a battery.

A transformer, as shown in Fig. 1.93, consists of two coils, called the primary and secondary coils, or windings, which are insulated from each other and wound onto the same steel or iron core.

An alternating voltage applied to the primary winding produces an alternating current, which sets up an alternating magnetic flux throughout the core. This magnetic flux induces an emf in the secondary winding, as described by Faraday's law, which says that when a conductor is cut by a magnetic field, an emf is induced in that conductor. Since both windings are linked by the same magnetic flux, the induced emf per turn will be the same for both windings. Therefore, the emf in both windings is proportional to the number of turns. In symbols,

$$\frac{V_P}{N_P} = \frac{V_S}{N_S} \tag{1}$$

Most practical power transformers have a very high efficiency, and for an ideal transformer having 100% efficiency the primary power is equal to the secondary power:

$$\text{Primary power} = \text{Secondary power}$$

and, since

$$\text{Power} = \text{Voltage} \times \text{Current}$$

then

$$V_P \times I_P = V_S \times I_S \tag{2}$$

Combining equations (1) and (2), we have

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

EXAMPLE

A 230 V to 12 V bell transformer is constructed with 800 turns on the primary winding. Calculate the number of secondary turns and the primary and secondary currents when the transformer supplies a 12 V 12 W alarm bell.

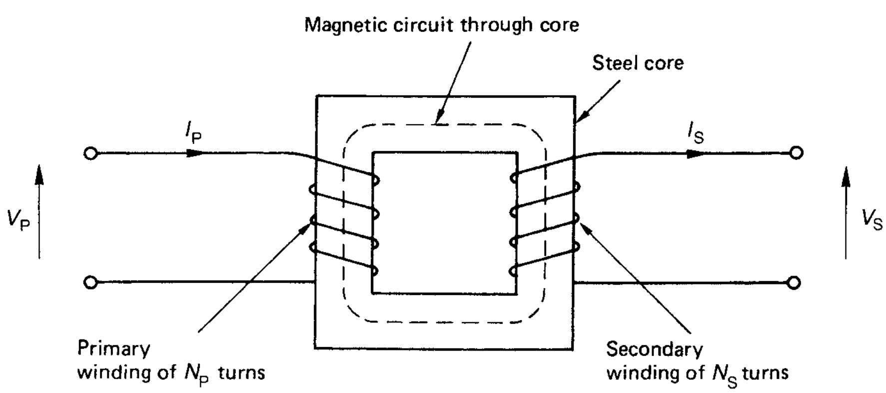


Fig. 1.93 A simple transformer.

Collecting the information given in the question into a usable form, we have

$$V_P = 230\,V$$
$$V_S = 12\,V$$
$$N_P = 800$$

Power = 12 W
Information required: N_S, I_S and I_P
Secondary turns

$$N_S = \frac{N_P V_S}{V_P}$$

$$\therefore N_S = \frac{800 \times 12\,V}{230\,V} = 42 \text{ turns}$$

Secondary current

$$I_S = \frac{\text{Power}}{V_S}$$

$$\therefore I_S = \frac{12\,W}{12\,V} = 1\,A$$

Primary current

$$I_P = \frac{I_S \times V_S}{V_P}$$

$$\therefore I_P = \frac{1\,A \times 12\,V}{230\,V} = 0.052\,A$$

Transformer losses

As they have no moving parts causing frictional losses, most transformers have a very high efficiency, usually better than 90%. However, the losses which do occur in a transformer can be grouped under two general headings: copper losses and iron losses.

Copper losses occur because of the small internal resistance of the windings. They are proportional to the load, increasing as the load increases because copper loss in an 'I^2R' loss.

Iron losses are made up of *hysteresis loss* and *eddy current loss*. The hysteresis loss depends upon the type of iron used to construct the core and consequently core materials are carefully chosen. Transformers will only operate on an alternating supply. Thus, the current which establishes the core flux is constantly changing from positive to negative. Each time there is a current reversal, the magnetic flux reverses and it is this build-up and collapse of magnetic flux in the core material which accounts for the hysteresis loss.

Eddy currents are circulating currents created in the core material by the changing magnetic flux. These are reduced by building up the core of thin slices or laminations of iron and insulating the separate laminations from each other. The iron loss is a constant loss consuming the same power from no load to full load.

Transformer efficiency

The efficiency of any machine is determined by the losses incurred by the machine in normal operation. The efficiency of rotating machines is usually in the region of 50–60% because they incur windage and friction losses; but the transformer has no moving parts so, therefore, these losses do not occur. However, the efficiency of a transformer can be calculated in the same way as for any other machine. The efficiency of a machine is generally given by:

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

(η is the Greek letter 'eta'). However, the input to the transformer must supply the output plus any losses which occur within the transformer. We can therefore say:

$$\text{Input power} = \text{Output power} + \text{Losses}$$

Rewriting the basic formula, we have:

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{Losses}}$$

EXAMPLE

A 100 kVA power transformer feeds a load operating at a power factor of 0.8. Find the efficiency of the transformer if the combined iron and copper loss at this load is 1 kW.

$$\text{Output power} = \text{kVA} \times \text{p.f.}$$
$$\therefore \text{Output power} = 100\,\text{kVA} \times 0.8$$
$$\text{Output power} = 80\,\text{kW}$$

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{Losses}}$$

$$\eta = \frac{80\,\text{kW}}{80\,\text{kW} + 1\,\text{kW}} = 0.987$$

or, multiplying by 100 to give a percentage, the transformer has an efficiency of 98.7%.

Transformer construction

Transformers are constructed in a way which reduces the losses to a minimum. The core is usually made of silicon–iron laminations, because at fixed low frequencies silicon–iron has a small hysteresis loss and the laminations reduce the eddy current loss. The primary and secondary windings are wound close to each other on the same limb. If the windings are spread over two limbs, there will usually be half of each winding on each limb, as shown in Fig. 1.94.

AUTO-TRANSFORMERS

Transformers having a separate primary and secondary winding, as shown in Fig. 1.94, are called double-wound transformers, but it is possible to construct a transformer which has only one winding which is common to the primary and secondary circuits. The secondary voltage is supplied by means of a 'tapping' on the primary winding. An arrangement such as this is called an auto-transformer.

The auto-transformer is much cheaper and lighter than a double-wound transformer because less copper and iron are used in its construction. However, the primary and secondary windings are not electrically separate and a short circuit on the upper part of the winding shown in Fig. 1.95 would result in the primary voltage appearing across the secondary terminals. For this reason auto-transformers are mostly used where only a small difference is required between the primary and secondary voltages. When installing transformers, the regulations of Section 555 must be complied with, in addition to any other regulations relevant to the particular installation.

THREE-PHASE TRANSFORMERS

Most of the transformers used in industrial applications are designed for three-phase operation. In the double-wound type construction, as shown in Fig. 1.93, three separate single-phase transformers are wound onto a common laminated silicon–steel core to form the three-phase transformer. The primary and secondary windings may be either star or delta connected but in distribution transformers the primary is usually connected in delta and the secondary in star. This has the advantage of providing two secondary voltages, typically 400 V between phases and 230 V

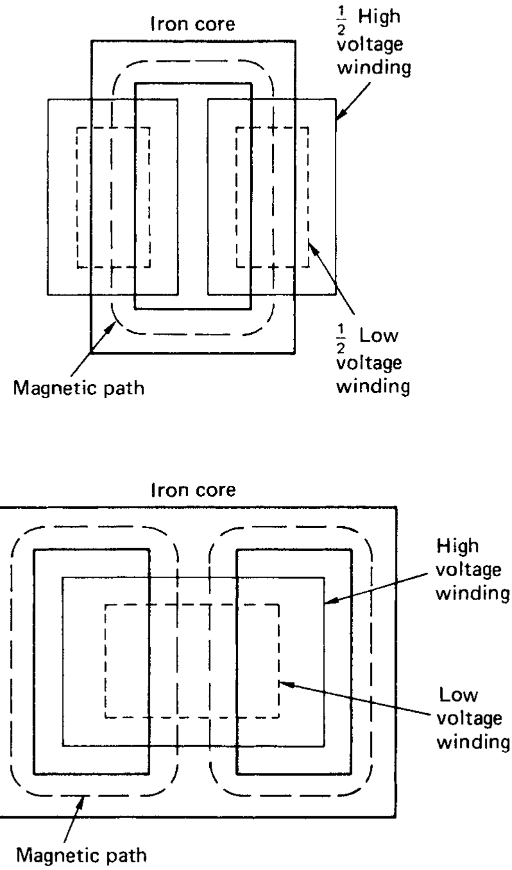


Fig. 1.94 Transformer construction.

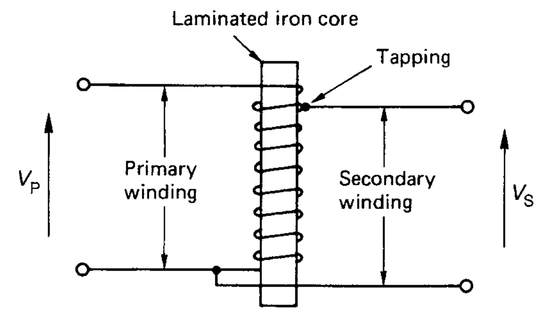


Fig. 1.95 An auto-transformer.

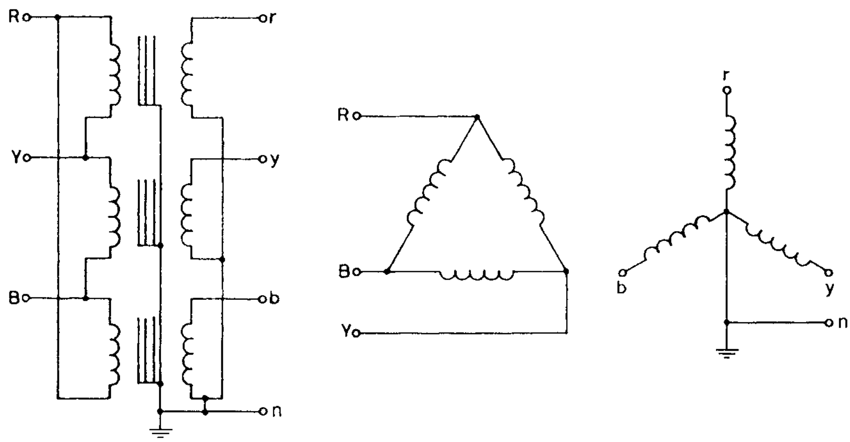


Fig. 1.96 Delta-star connected three-phase transformer.

between phase and neutral from an 11 kV primary voltage. The coil arrangement is shown in Fig. 1.96.

The construction of the three-phase transformer is the same as the single-phase transformer, but because of the larger size the core is often cooled by oil.

OIL-IMMERSED CORE

As the rating of a transformer increases so does the problem of dissipating the heat generated in the core. In power distribution transformers the most common solution is to house the transformer in a steel casing containing insulating oil which completely covers the core and the windings. The oil is a coolant and an insulating medium for the core. On load the transformer heats up and establishes circulating convection currents in the oil which flows through the external tubes. Air passing over the tubes carries the heat away and cools the transformer. Figure 1.97 shows the construction of a typical oil-filled transformer, and the arrangement is typical of a distribution transformer used in a sub-station (see Fig. 1.105).

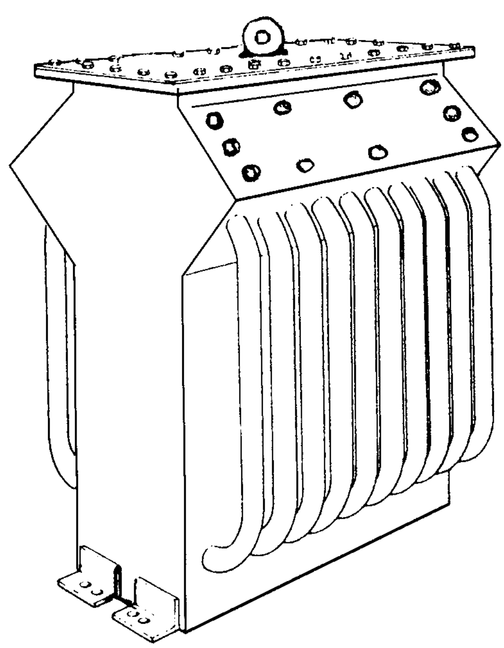


Fig. 1.97 Typical oil-filled power transformer.

TAP CHANGING

Under load conditions the secondary voltage of a transformer may fall and become less than that permitted by the Regulations. The tolerance permitted by the Regulations in 2004 is the open-circuit voltage plus 10% or minus 6%. However, this will change in 2005, when the tolerance levels will be adjusted to ±10% of the declared nominal voltage. Because the voltage of a transformer is proportional to the number of turns, one solution is to vary the number of turns on either the primary or secondary winding, to achieve the desired voltage. This process is called tap changing, and most distribution transformers are fitted with a tap changing switch on the high-voltage (HV) winding so that the number of turns can be varied. These switches are always off-load devices and, therefore, the transformer must be isolated before the tap changing operation is carried out. The switch is usually padlocked to prevent unauthorized operation.

Instrument transformers

An instrument transformer works on the same principles as a power transformer but is designed to be used specifically in conjunction with an electrical measuring instrument to extend the range of an ammeter or voltmeter. The instrument transformer carries the current or voltage to be measured and the instrument is connected to the secondary winding of the transformer. In this way the instrument measures a small current or voltage which is proportional to the main current or voltage.

The advantages of using instrument transformers are as follows:

- The secondary side of the instrument transformer is wound for low voltage which simplifies the insulation of the measuring instrument and makes it safe to handle.
- The transformer isolates the instrument from the main circuit.
- The measuring instrument can be read in a remote, convenient position connected by long leads to the instrument transformer.
- The secondary voltage or current can be standardized (usually 110 V and 5 A), which simplifies instrument changes.

Voltage transformers

The construction of a voltage transformer (VT) is similar to the power transformer dealt with earlier in this chapter. The secondary winding of the VT is connected to a voltmeter as shown in Fig. 1.98 Voltage transformers are operated as step-down transformers, the secondary voltage usually being standardized at 110 V. A large number of turns are wound on the primary and a few on the secondary since

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

The voltmeter reading must be multiplied by the turns ratio to determine the load voltage.

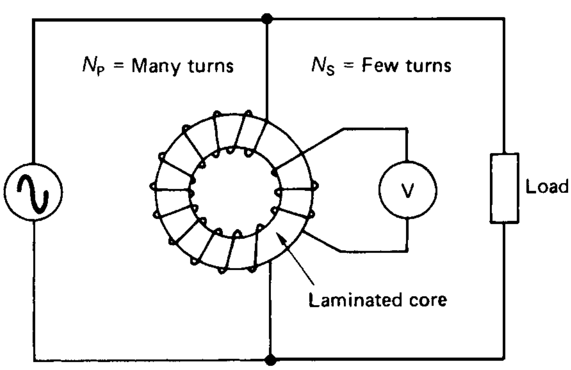


Fig. 1.98 A voltage transformer.

EXAMPLE 1

A voltmeter is connected to 50 turns on the secondary winding of a VT. The primary winding of 250 turns is connected to the main supply. Calculate the supply voltage if the voltmeter reading is 80 V.

$$\text{Primary voltage } V_P = \frac{N_P}{N_S} \times V_S$$

$$\therefore V_P = \frac{250}{50} \times 80\text{ V}$$

$$V_P = 400\text{ V.}$$

As an alternative solution we could say the turns ratio is 250:50, that is 5:1, and therefore the supply voltage is $5 \times 80 = 400$ V.

EXAMPLE 2

An electrical contractor wishes to monitor a 660 V supply with a standard 110 V voltmeter. Determine the turns ratio of the VT to perform this task.

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$\frac{660\text{ V}}{100\text{ V}} = \frac{N_P}{N_S} = \frac{6}{1}$$

The turns ratio is 6:1. This means that the number of turns on the primary side of the VT must be six times as great as the number of turns on the secondary, which is connected to the 110 V voltmeter.

Current transformers

The operation of a current transformer (CT) is different to a power transformer although the transformer principle remains the same.

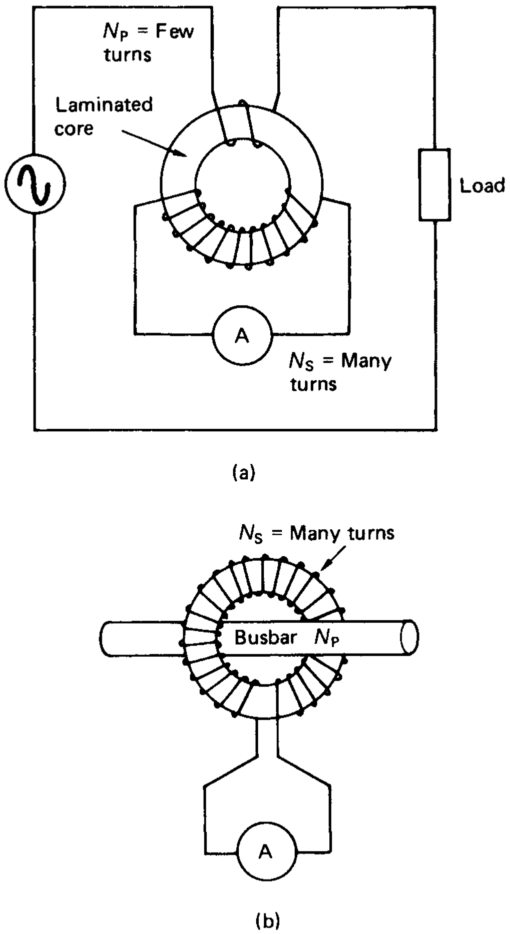


Fig. 1.99 Current transformers: (a) wound primary current transformer; (b) bar primary current transformer.

The secondary winding of the CT consists of a large number of turns connected to an ammeter as shown in Fig. 1.99 (a). The ammeter is usually standardized at 1 or 5 A and the transformer ratio chosen so that 1 or 5 A flows when the main circuit carries full load current calculated from the transformer turns ratio

$$\frac{V_P}{V_S} = \frac{I_S}{I_P}$$

The primary winding is wound with only a few turns and when heavy currents are being measured one turn on the primary may be sufficient. In this case the conductor carrying the main current or the main busbar is passed through the centre of the CT as shown in Fig. 1.99 (b). This is called a bar primary CT.

EXAMPLE 1

An ammeter having a full scale deflection of 5 A is used to measure a line current of 200 A. If the primary is wound with two turns, calculate the number of secondary turns required to give full scale deflection.

$$\frac{N_P}{N_S} = \frac{I_S}{I_P}$$

$$N_S = \frac{N_P \times I_P}{I_S}$$

$$N_S = \frac{2 \times 200\text{ A}}{5\text{ A}} = 80\text{ turns}$$

With a power transformer a secondary load is necessary to cause a primary current to flow which maintains the magnetic flux in the core at a constant value. With a CT the primary current is the main circuit current and will flow whether the secondary is connected or not.

However, the secondary current through the ammeter is necessary to stabilize the magnetic flux in the core, and if the ammeter is removed the voltage across the secondary terminals could reach a dangerously high value and cause the insulation to break down or cause excessive heating of the core. The CT must never be operated with the secondary terminals open-circuited and overload protection should not be provided in the secondary circuit (Regulation 473–01–03). If the ammeter must be removed from the CT then the terminals must first be short-circuited. This will not damage the CT and will prevent a dangerous situation arising. The rating of an instrument transformer is measured in volt amperes and is called the burden. To reduce errors, the ammeter or voltmeter connected to the CT or VT should be operated at the rated burden.

EXAMPLE 2

To determine the power taken by a single-phase motor a wattmeter is connected to the circuit through a CT and VT. The test readings obtained were:

Wattmeter reading = 300 W
Voltage transformer turns ratio = 440/110 V
Current transformer turns ratio = 150/5 A

Sketch the circuit arrangements and calculate the power taken by the motor.

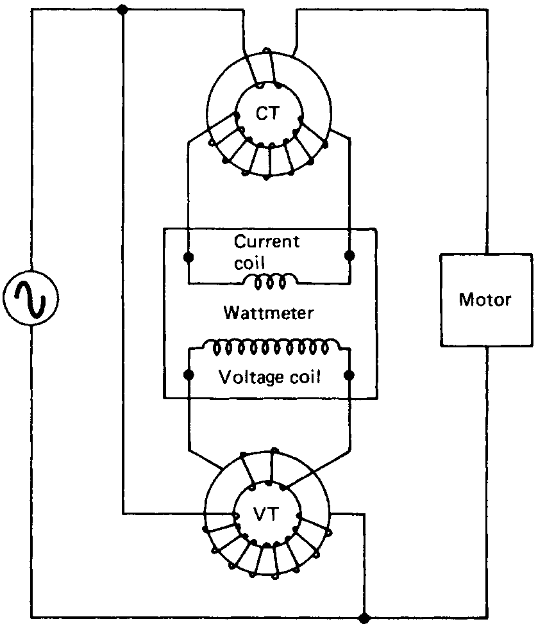


Fig. 1.100 Wattmeter connected through voltage transformer and current transformer.

The circuit arrangements are shown in Fig. 1.100.

Voltage transformer ratio = 440/110 = 4:1
Current transformer ratio = 150/5 = 30:1

$$\text{True Power} = \text{Wattmeter reading} \times \text{VT multiplier} \times \text{CT multiplier} \quad (\text{W})$$

True power = 300 W × 4 × 30 = 36 kW
The power taken by the motor is therefore 36 kW.

Electricity Supply Systems

The Generation of electricity in most modern power stations is at 25 kV, and this voltage is then transformed to 400 kV for transmission. Virtually all the generators of electricity throughout the world are three-phase synchronous generators. The generator consists of a prime mover and a magnetic field excitor. The magnetic field is produced electrically by passing a direct current through a winding on an iron core, which rotates inside three phase windings on the stator of the machine. The magnetic field is rotated by means of a prime mover which may be a steam turbine, water turbine or gas turbine. Primary sources for electricity generation are discussed in Chapter 2 of *Basic Electrical Installation Work*.

Fig. 1.101 Suspension tower.

The generators in modern power stations are rated between 500 and 1000 MW. A 2000 MW station might contain four 500 MW sets, three 660 MW sets and a 20 MW gas turbine generator or two 1000 MW sets. Having a number of generator sets in a single power station provides the flexibility required for seasonal variations in the load and for maintenance of equipment. When generators are connected to a single system they must rotate at exactly the same speed, hence the term synchronous generator.

Very high voltages are used for transmission systems because, as a general principle, the higher the voltage the cheaper is the supply. Since power in an a.c. system is expressed as $P = VI\cos\theta$, it follows that an increase in voltage will reduce the current for a given amount of power. A lower current will result in reduced cable and switchgear size and the line power losses, given by the equation $P = I^2R$, will also be reduced.

The 132 kV grid and 400 kV Supergrid transmission lines are, for the most part, steel-cored aluminium conductors suspended on steel lattice towers, since this is about 16 times cheaper than the equivalent underground cable. Figure 1.101 shows a suspension tower on the Sizewell–Sundon 400 kV transmission line. The conductors are attached to porcelain insulator strings which are fixed to the cross-members of the tower as shown in Fig. 1.102. Three conductors comprise a single circuit of a three-phase system so that towers with six arms carry two separate circuits.

Primary distribution to consumers is from 11 kV substations, which for the most part are fed from 33 kV substations, but direct transformation between 132 and 11 kV is becoming common policy in city areas where over 100 MW can be economically distributed at 11 kV from one site. Figure 1.103 shows a block diagram indicating the voltages at the various stages of the transmission and distribution system.

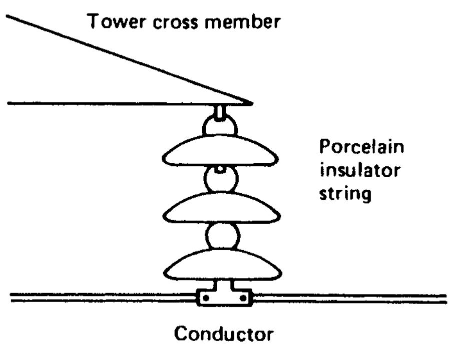


Fig. 1.102 Steel lattice tower cable supports.

Distribution systems at 11 kV may be ring or radial systems but a ring system offers a greater security of supply. The maintenance of a secure supply is an important consideration for any electrical engineer or supply authority because electricity plays a vital part in an industrial society, and a loss of supply may cause inconvenience, financial loss or danger to the consumer or the public.

The principle employed with a ring system is that any consumer's substation is fed from two directions, and by carefully grading the overload and cable protection equipment a fault can be disconnected without loss of supply to other consumers.

High-voltage distribution to primary substations is used by the electricity boards to supply small industrial, commercial and domestic consumers. This distribution method is also suitable for large industrial consumers where 11 kV substations, as shown in Fig. 1.104, may be strategically placed at load centres around the factory site. Regulation 9 of the Electricity Supply Regulations and Regulation 31 of the Factories Act require that these substations be protected by 2.44 m high fences or enclosed in some other way so that no unauthorized person may gain access to the potentially dangerous equipment required for 11 kV distribution. In towns and cities the substation equipment is usually enclosed in a brick building, as shown in Fig. 1.105.

The final connections to plant, distribution boards, commercial or domestic loads are usually by simple underground radial feeders at 400 V/230 V. These

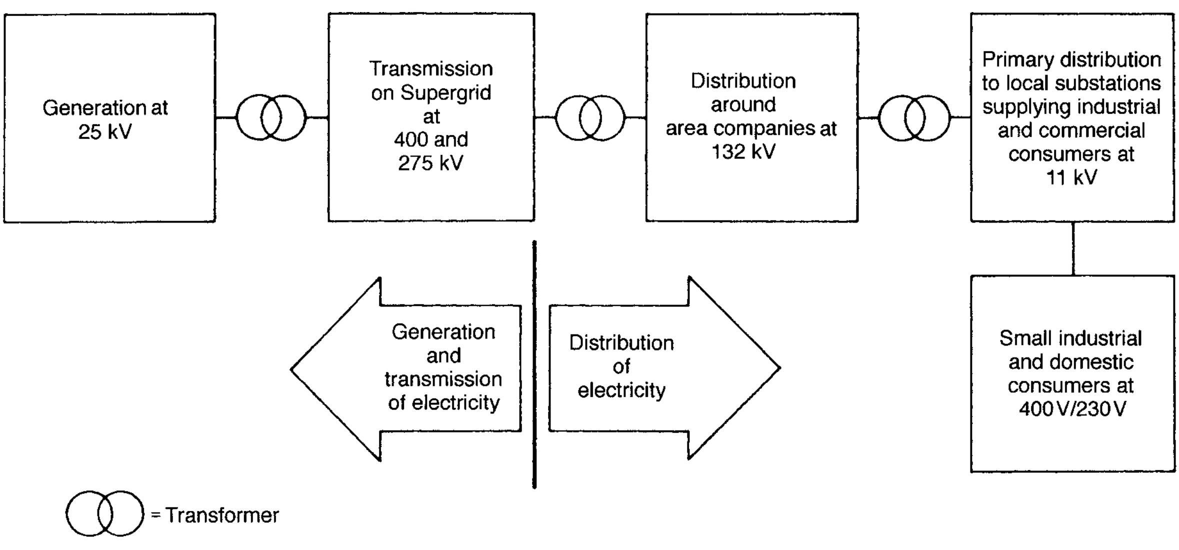


Fig. 1.103 Generation, transmission and distribution of electrical energy.

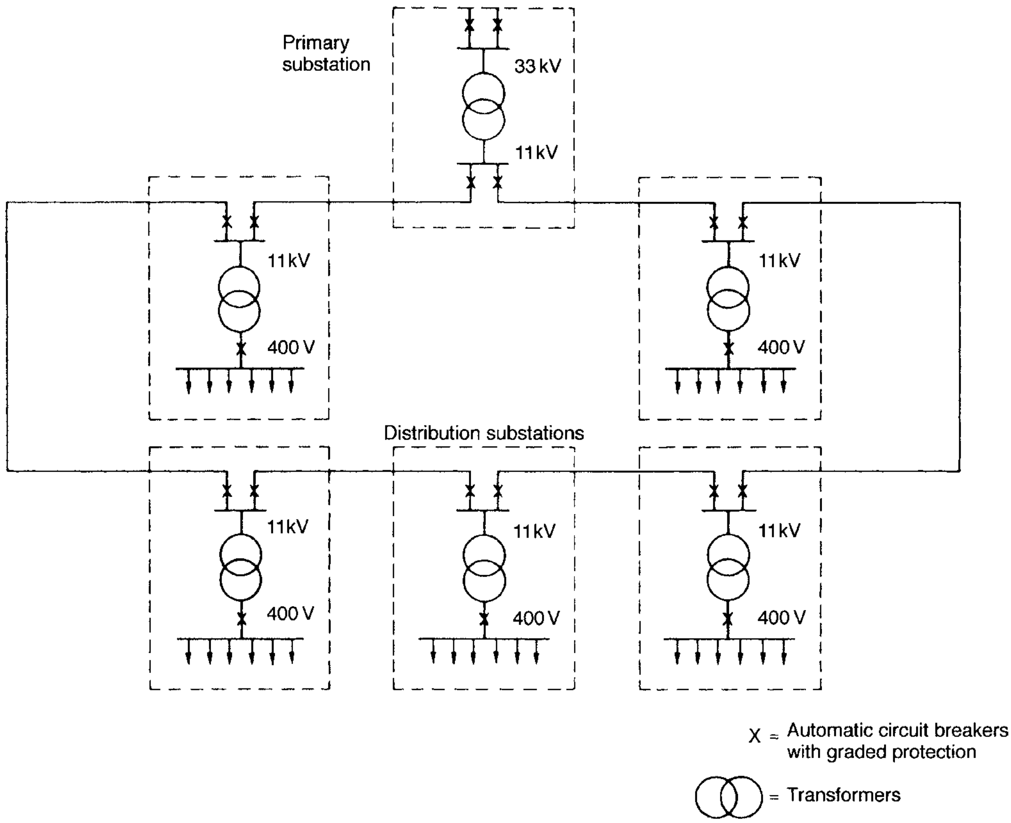


Fig. 1.104 High-voltage ring main distribution.

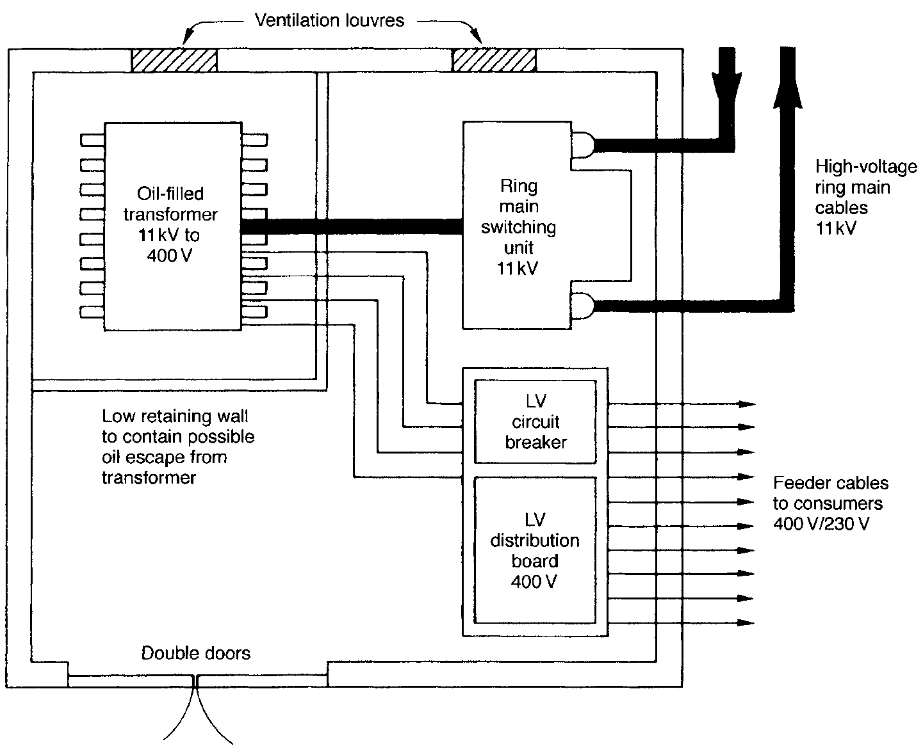


Fig. 1.105 Typical substation layout.

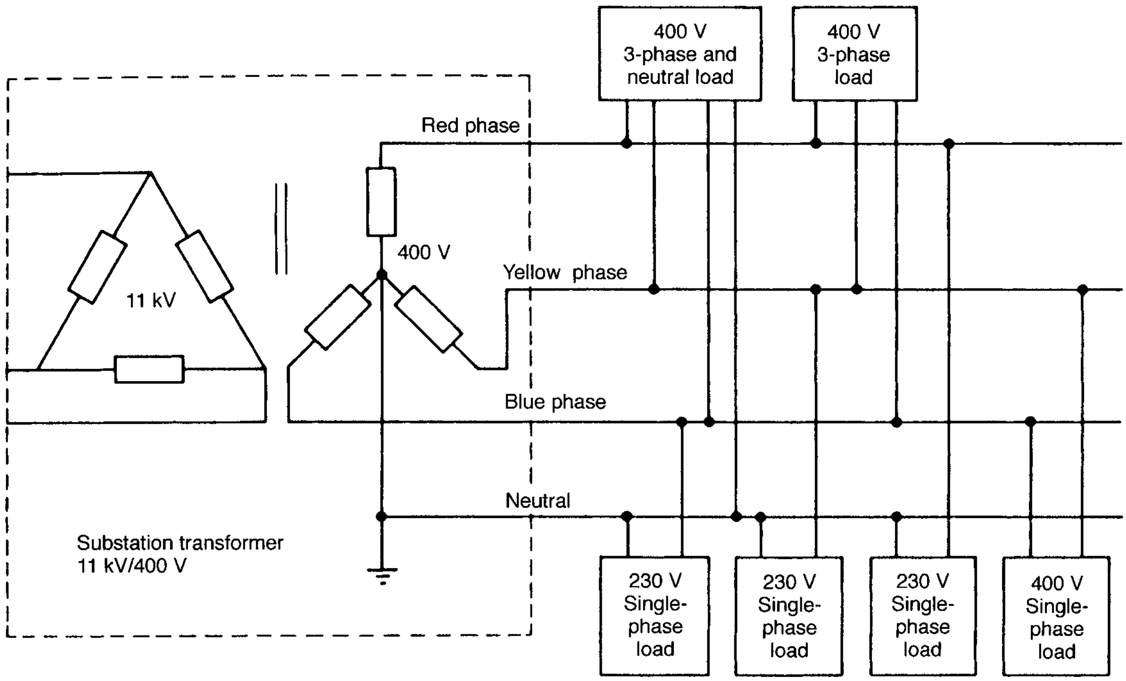


Fig. 1.106 Three-phase four-wire distribution.

outgoing circuits are usually protected by circuit breakers in a distribution board.

The 400 V/230 V is derived from the 11 kV/400 V substation transformer by connecting the secondary winding in star as shown in Fig. 1.106. The star point is earthed to an earth electrode sunk into the ground below the substation, and from this point is taken the fourth conductor, the neutral. Loads connected between phases are fed at 400 V, and those fed between one phase and neutral at 230 V. A three-phase 400 V supply is used for supplying small industrial and commercial loads such as garages, schools and blocks of flats. A single-phase 230 V supply is usually provided for individual domestic consumers.

EXAMPLE

Use a suitable diagram to show how a 400 V three-phase, four-wire supply may be obtained from an 11 kV delta-connected transformer. Assuming that the three-phase four-wire supply feeds a small factory, show how the following loads must be connected:

(a) a three-phase 400 V motor;
(b) a single-phase 400 V welder;
(c) a lighting load made up of discharge lamps arranged in a way which reduces the stroboscopic effect.
(d) State why 'balancing' of loads is desirable.
(e) State the advantages of using a three-phase four-wire supply to industrial premises instead of a single-phase supply.

Three-phase load

Figure 1.106 shows the connections of the 11–400 V supply and the method of connecting a 400 V three-phase load such as a motor and a 400 V single-phase load such as a welder.

Reducing stroboscopic effect

The stroboscopic effect may be reduced by equally dividing the lighting load across the three phases of the supply. For example, if the lighting load were made up of 18 luminaires, then six luminaires should be connected to the red phase and neutral, six to the blue phase and neutral and six to the yellow phase and neutral. (The stroboscopic effect and its elimination are discussed in some detail in Chapter 10 of this book.)

Balancing three-phase loads

A three-phase load such as a motor has equally balanced phases since the resistance of each phase winding will be the same. Therefore the current taken by each phase will be equal. When connecting single-phase loads to a three-phase supply, care should be taken to distribute the single-phase loads equally across the three phases so that each phase carries approximately the same current. Equally distributing the single-phase loads across the three-phase supply is known as 'balancing' the load. A lighting load of 18 luminaires would be 'balanced' if six luminaires were connected to each of the three phases.

Advantages of a three-phase four-wire supply

A three-phase four-wire supply gives a consumer the choice of a 400 V three-phase supply and a 230 V single-phase supply. Many industrial loads such as motors require a three-phase 400 V supply, while the lighting load in a factory, as in a house, will be 230 V. Industrial loads usually demand more power than a domestic load, and more power can be supplied by a 400 V three-phase supply than is possible with a 230 V single-phase supply for a given size of cable since power $= VI \cos \theta$ (watts).

Low-voltage supply systems

The British government agreed on 1 January 1995 that the electricity supplies in the UK would be harmonized with those of the rest of Europe. Thus the voltages used previously in low-voltage supply systems of 415 and 240 V have become 400 V for three-phase supplies and 230 V for single-phase supplies. The Electricity Supply Regulations 1988 have also been amended to permit a range of variation from the new declared nominal voltage. From January 1995 the permitted tolerance is the nominal voltage $+10\%$ or -6%. Previously it was $\pm 6\%$. This gives a voltage range of 216–253 V for a nominal voltage of 230 V and 376 V to 440 V for a nominal voltage of 400 V.

The next change comes in 2005 when the tolerance levels will be adjusted to $\pm 10\%$ of the declared nominal voltage. All EU countries will adjust their voltages to comply with a nominal voltage of 230 V single-phase and 400 V three-phase.

The low-voltage supply to a domestic, commercial or small industrial consumer's installation is usually protected at the incoming service cable position with a 100 A high breaking capacity (HBC) fuse. Other items of equipment at this position are the energy meter and the consumer's distribution unit, providing the protection for the final circuits and the earthing arrangements for the installation.

An efficient and effective earthing system is essential to allow protective devices to operate. The limiting values of earth fault loop impedance are given in Tables 41, 604 and 605 of the IEE Regulations, and Section 542 gives details of the earthing arrangements to be incorporated in the supply system to meet the requirements of the Regulations. Five systems are described in the definitions but only the TN-S, TN-C-S and TT systems are suitable for public supplies.

A system consists of an electrical installation connected to a supply. Systems are classified by a capital letter designation.

The supply earthing

Arrangements are indicated by the first letter, where T means one or more points of the supply are directly connected to earth and I means the supply is not earthed or one point is earthed through a fault-limiting impedance.

The installation earthing

Arrangements are indicated by the second letter, where T means the exposed conductive parts are connected directly to earth and N means the exposed conductive parts are connected directly to the earthed point of the source of the electrical supply.

The earthed supply conductor

Arrangements are indicated by the third letter, where S means a separate neutral and protective conductor and C means that the neutral and protective conductors are combined in a single conductor.

TN-S SYSTEM

This is one of the commonest types of supply system to be found in the UK where the electricity companies' supply is provided by underground cables. The neutral and protective conductor are separate throughout the system. The protective earth conductor (PE) is the metal sheath and armour of the underground cable, and this is connected to the consumer's main earthing terminal. All exposed conductive parts of the installation, gas pipes, water pipes and any lightning protective system are connected to the protective conductor via the main earthing terminal of the installation. The arrangement is shown in Fig. 1.107.

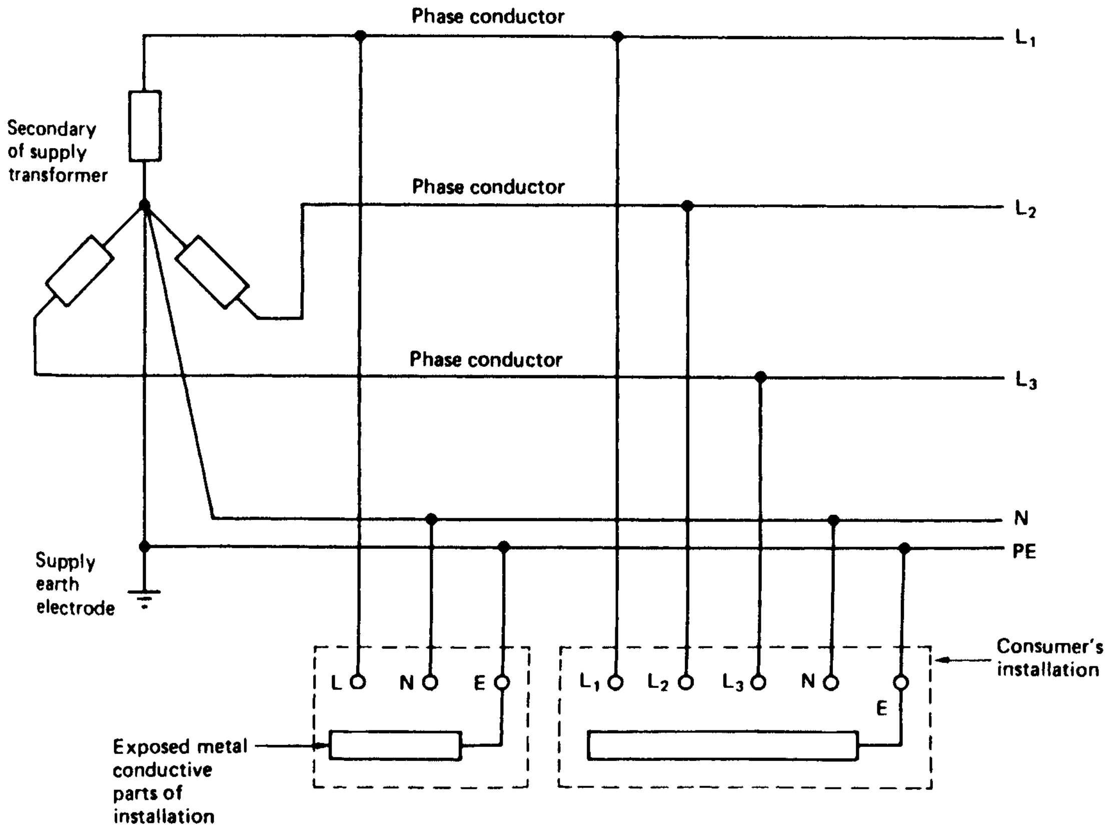


Fig. 1.107 TN-S system: separate neutral and protective conductor throughout.

TN-C-S SYSTEM

This type of underground supply is becoming increasingly popular to supply new installations in the UK. It is more commonly referred to as protective multiple earthing (PME). The supply cable uses a combined protective earth and neutral conductor (PEN conductor). At the supply intake point a consumer's main earthing terminal is formed by connecting the earthing terminal to the neutral conductor. All exposed conductive parts of the installation, gas pipes, water pipes and any lightning protective system are then connected to the main earthing terminals. Thus phase to earth faults are effectively converted into phase to neutral faults. The arrangement is shown in Fig. 1.108.

TT SYSTEM

This is the type of supply more often found when the installation is fed from overhead cables. The supply authorities do not provide an earth terminal and the installation's circuit protective conductors must be connected to earth via an earth electrode provided by the consumer. An effective earth connection is sometimes difficult to obtain and in most cases a residual current device is provided when this type of supply is used. The arrangement is shown in Fig. 1.109.

The layout of a typical domestic service position for these three supply systems is shown in Fig. 1.110. The TN-C and IT systems of supply do not comply with the supply regulations and therefore cannot be used for public supplies. Their use is restricted to private generating plants.

TN-C SYSTEM

The supply cable and the consumer's installation use a PEN conductor. All exposed conductive parts of an installation are connected to the PEN conductor. The applications of this supply system are limited to privately owned generating plants or transformers where

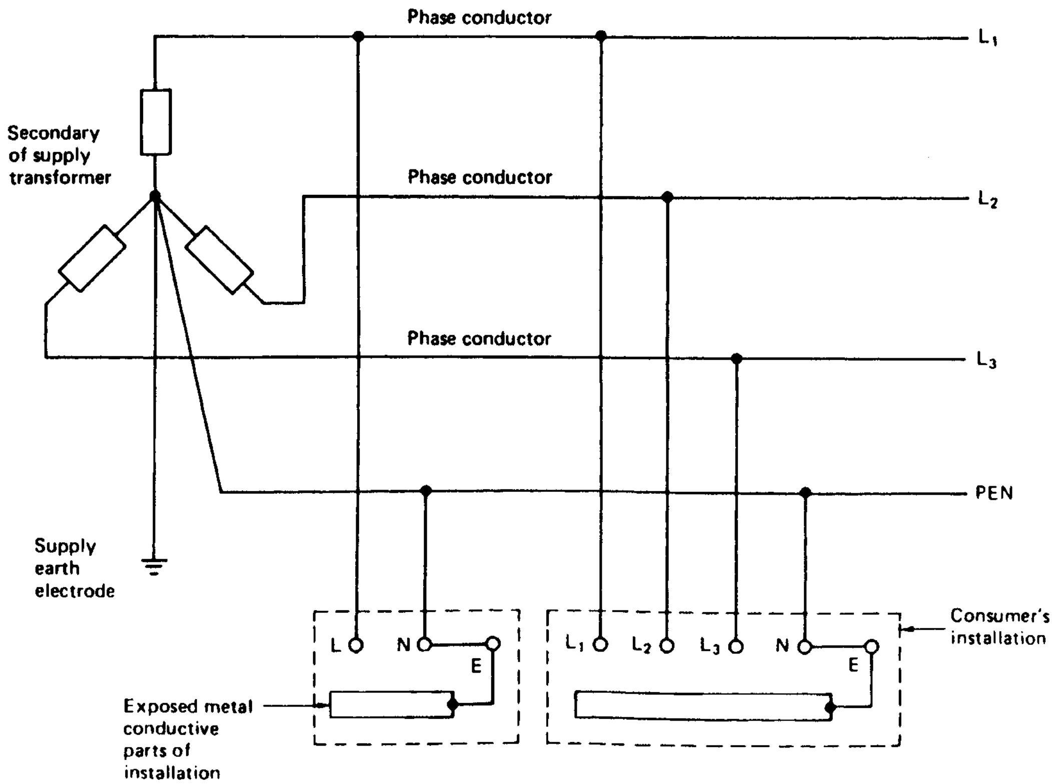


Fig. 1.108 TN-C-S system: neutral and protective functions combined in a single (PEN) conductor.

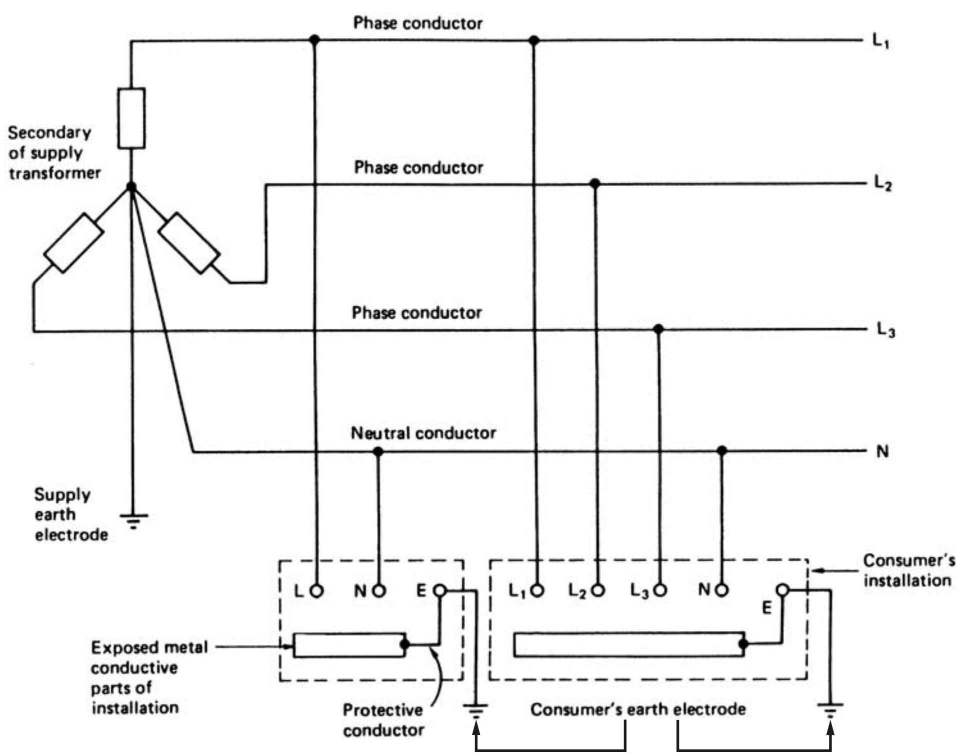


Fig. 1.109 TT systems: earthing arrangements independent of supply cable.

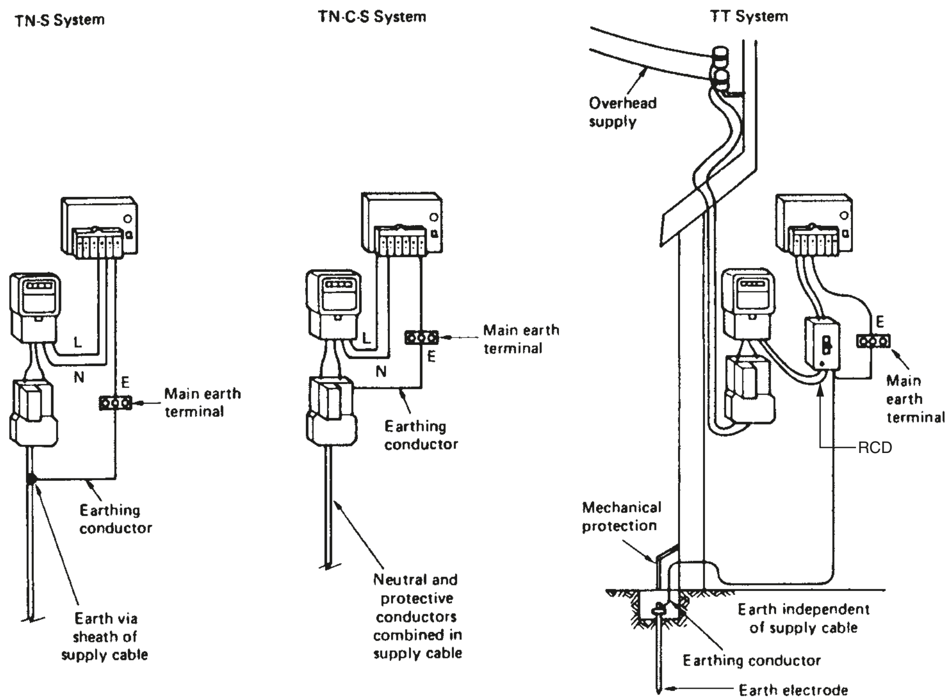


Fig. 1.110 Service arrangements for TN-S, TN-C-S and TT systems of supply.

there are no metallic connections between the TN-C system and the public supply. For this reason the arrangement is not shown here but can be seen in Part 2 of the IEE Regulations.

IT SYSTEM

The supply is isolated from earth and therefore there is no shock or fire risk involved when an earth fault occurs. Protection is afforded by monitoring equipment which gives an audible warning if a fault occurs. This type of supply is used in mines, quarries and chemical processes where interruption of the process may create a hazardous situation. The system must not be connected to a public supply, and is therefore not shown here but can be seen in Part 2 of the IEE Regulations.

LOW-VOLTAGE DISTRIBUTION IN BUILDINGS

In domestic installations the final circuits for lights, sockets, cookers, immersion heating, etc. are connected to separate fuseways in the consumer's unit mounted at the service position, as shown in Fig. 1.110.

In commercial or industrial installations a three-phase 400 V supply must be distributed to appropriate equipment in addition to supplying single-phase 230 V loads such as lighting. It is now common practice to establish industrial estates speculatively, with the intention of encouraging local industry to use individual units. This presents the electrical contractor with an additional problem. The use and electrical demand of a single industrial unit are often unknown and the electrical supply equipment will need to be flexible in order to meet a changing demand due to expansion or change of use.

Busbar chambers incorporated into cubicle switchboards or on-site assemblies of switchboards are to be found at the incoming service position of commercial and industrial consumers, since this has proved to provide the flexibility required by these consumers. This is shown in Fig. 1.111.

Distribution fuse boards, which may incorporate circuit breakers, are wired by submain cables from the service position to load centres in other parts of the building, thereby keeping the length of cable to the final circuit as short as possible. This is shown in Fig. 1.112.

When high-rise buildings such as multi-storey flats have to be wired, it is usual to provide a three-phase four-wire rising main. This may comprise vertical busbars running from top to bottom at some central

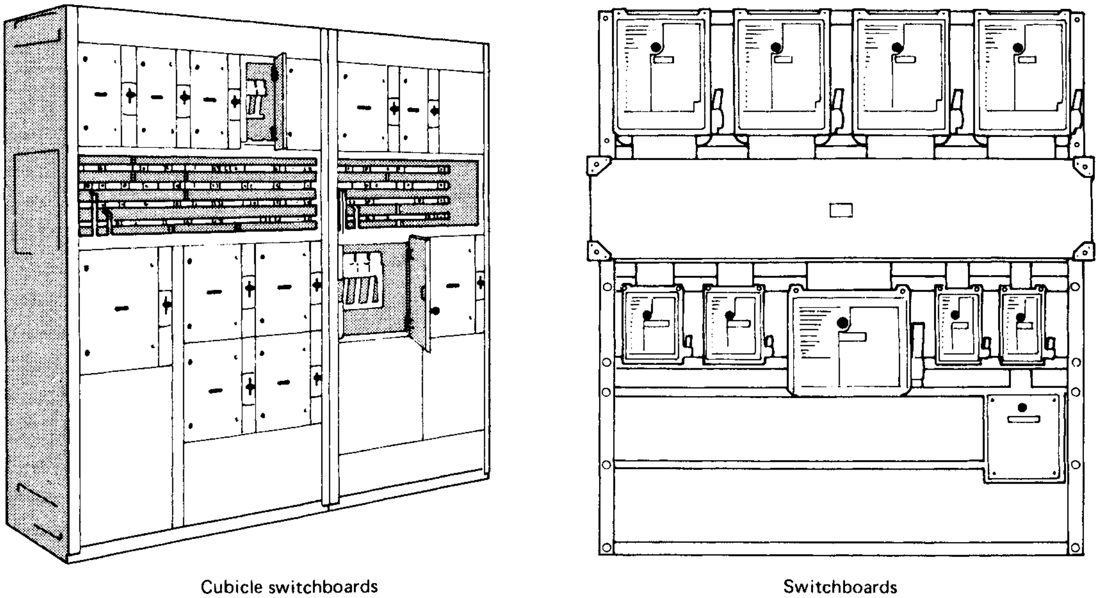


Fig. 1.111 Industrial consumer's service position equipment.

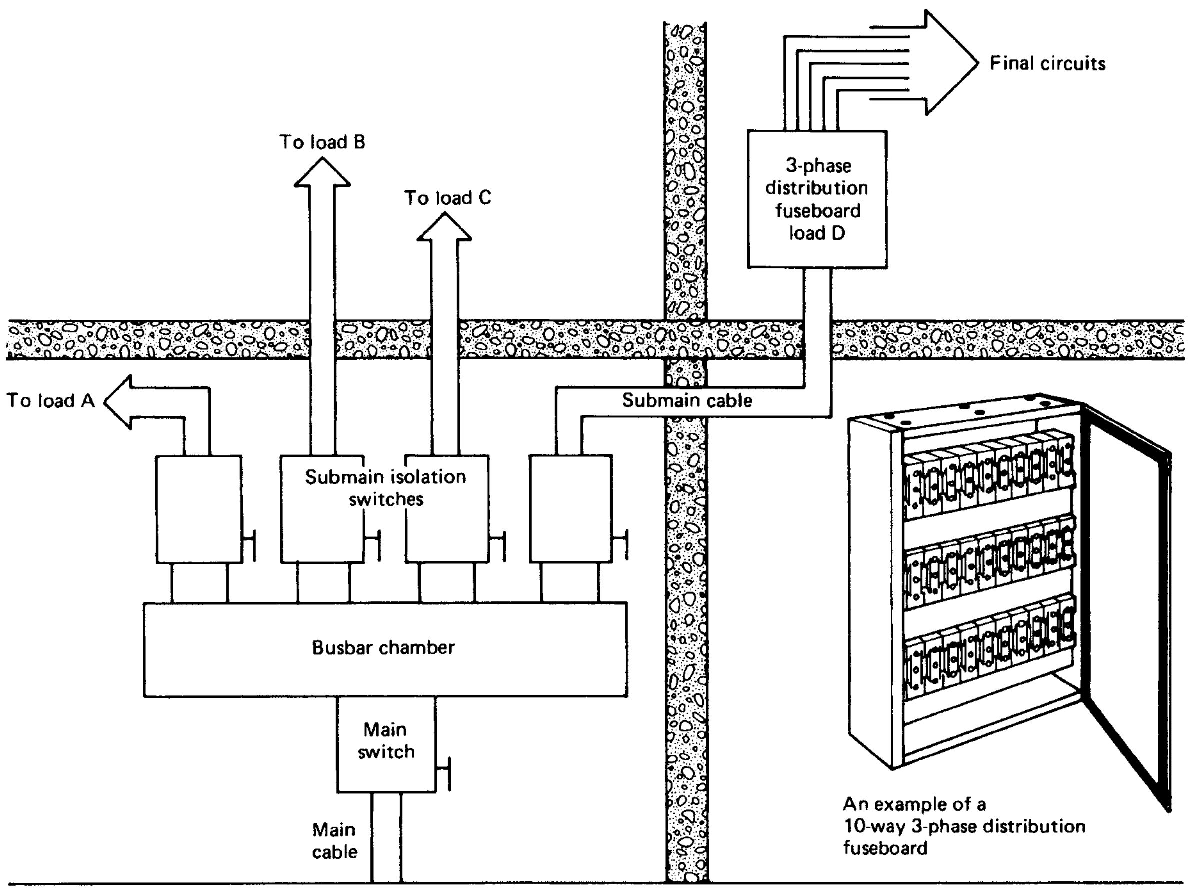


Fig. 1.112 Typical distribution in commercial or industrial building.

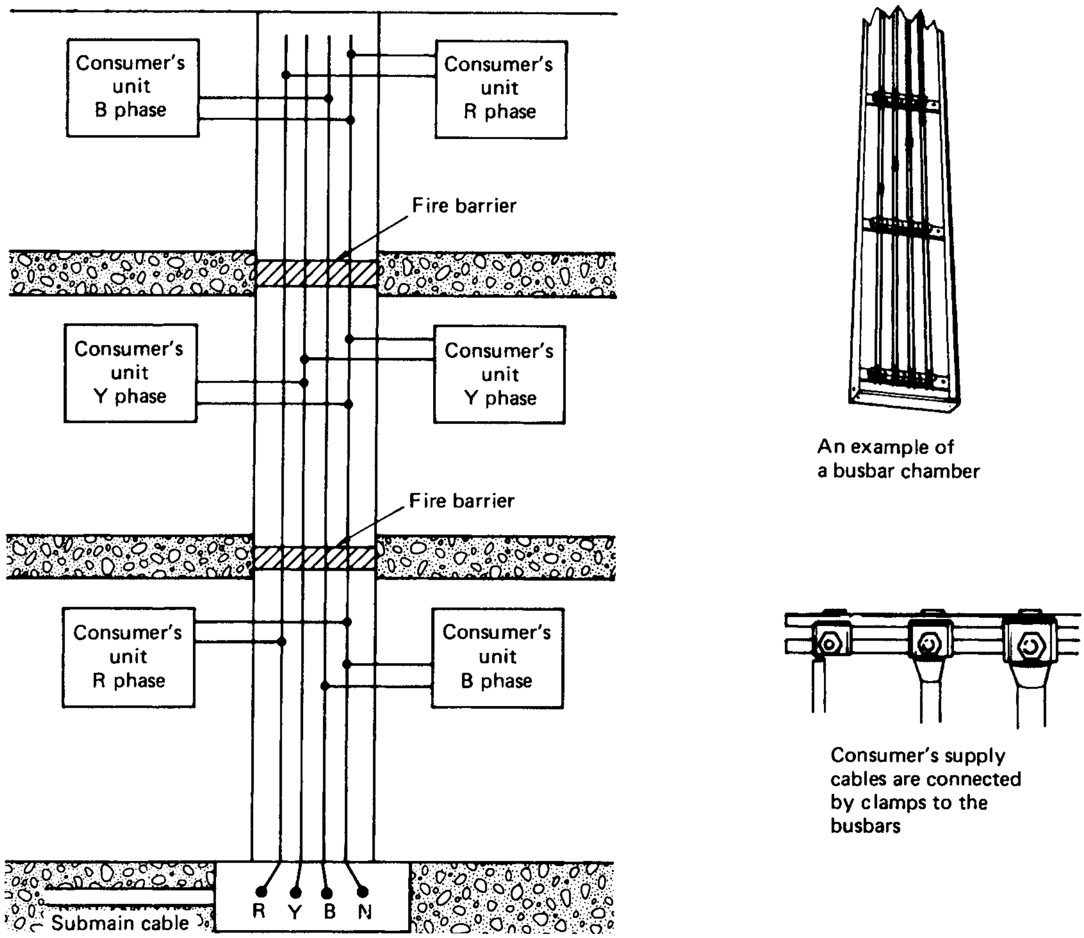


Fig. 1.113 Busbar rising main system.

point in the building. Each floor or individual flat is then connected to the busbar to provide the consumer's supply. When individual dwellings receive a single-phase supply the electrical contractor must balance the load across the three phases. Fig. 1.113 shows a rising main system. The rising main must incorporate fire barriers to prevent the spread of fire throughout the building (Regulation 527–02).

Industrial Wiring Systems

Industrial wiring systems are constructed robustly so that they can withstand some minor mechanical damage and vibration, and have the adaptability to respond to the changing needs of an industrial environment.

Cables in trunking with conduit drops or, SWA or MI cables laid on cable tray, provide a flexible, adaptable electrical installation. Compare this flexible, adaptable type of installation to the less easily adaptable fixed wiring of domestic installations where cables are buried in the finishing plaster of the walls.

Before we look at some industrial wiring systems and cables, let us first of all define some technical terms and discuss the properties of materials used in electrical wiring systems.

Conductor A material (usually a metal) which allows heat and electricity to pass easily through it.
Insulator A material (usually a non-metal) which will *not* allow heat and electricity to pass easily through it.
Ferrous A word used to describe all metals in which the main constituent is iron. The word 'ferrous' comes from the Latin word *ferrum* meaning iron. Ferrous

metals have magnetic properties. Cast iron, wrought iron and steel are all ferrous metals.

Non-ferrous Metals which *do not* contain iron are called non-ferrous. They are non-magnetic and resist rusting. Copper, aluminium, tin, lead, zinc and brass are examples of non-ferrous metals.

Alloy An alloy is a mixture of two or more metals. Brass is an alloy of copper and zinc, usually in the ratio 70–30% or 60–40%.

Corrosion The destruction of a metal by chemical action. Most corrosion takes place when a metal is in contact with moisture (see also mild steel and zinc).

Thermoplastic polymers These may be repeatedly warmed and cooled without appreciable changes occurring in the properties of the material. They are good insulators, but give off toxic fumes when burned. They have a flexible quality when operated up to a maximum temperature of 70°C but should not be flexed when the air temperature is near 0°C, otherwise they may crack. Polyvinylchloride (PVC) used for cable insulation is a thermoplastic polymer.

Thermosetting polymers Once heated and formed, products made from thermosetting polymers are fixed rigidly. Plug tops, socket outlets and switch plates are made from this material.

Rubber is a tough elastic substance made from the sap of tropical plants. It is a good insulator, but degrades and becomes brittle when exposed to sunlight.

Synthetic rubber is manufactured, as opposed to being produced naturally. Synthetic or artificial rubber is carefully manufactured to have all the good qualities of natural rubber – flexibility, good insulation and suitability for use over a wide range of temperatures.

Silicon rubber Introducing organic compounds into synthetic rubber produces a good insulating material which is flexible over a wide range of temperatures and which retains its insulating properties even when burned. These properties make it ideal for cables used in fire alarm installations such as FP200 cables.

Magnesium oxide The conductors of mineral insulated metal sheathed (MICC) cables are insulated with compressed magnesium oxide, a white chalk-like substance which is heat-resistant and a good insulator and lasts for many years. The magnesium oxide insulation, copper conductors and sheath, often additionally manufactured with various external sheaths to provide further protection from corrosion and weather, produce a cable designed for long-life and high-temperature installations. However, the magnesium oxide is very hygroscopic, which means that it attracts moisture and, therefore, the cable must be terminated with a special moisture-excluding seal, as shown in Fig. 1.116.

Copper Copper is extracted from an ore which is mined in South Africa, North America, Australia and Chile. For electrical purposes it is refined to about 98.8% pure copper, the impurities being extracted from the ore by smelting and electrolysis. It is a very good conductor, is non-magnetic and offers considerable resistance to atmospheric corrosion. Copper toughens with work, but may be annealed, or softened, by heating to dull red before quenching.

Copper forms the largest portion of the alloy brass, and is used in the manufacture of electrical cables, domestic heating systems, refrigerator tubes and vehicle radiators. An attractive soft reddish brown metal, copper is easily worked and is also used to manufacture decorative articles and jewellery.

Aluminium Aluminium is a grey-white metal obtained from the mineral bauxite which is found in the USA, Germany and the Russian Federation. It is a very good conductor, is non-magnetic, offers very good resistance to atmospheric corrosion and is notable for its extreme softness and lightness. It is used in the manufacture of power cables. The overhead cables of the National Grid are made of an aluminium conductor reinforced by a core of steel. Copper conductors would be too heavy to support themselves between the pylons. Lightness and resistance to corrosion make aluminium an ideal metal for the manufacture of cooking pots and food containers.

Aluminium alloys retain the corrosion resistance properties of pure aluminium with an increase in strength. The alloys are cast into cylinder heads and gearboxes for motorcars, and switch-boxes and luminaires for electrical installations. Special processes and fluxes have now been developed which allow aluminium to be welded and soldered.

Brass Brass is a non-ferrous alloy of copper and zinc which is easily cast. Because it is harder than copper or aluminium it is easily machined. It is a good conductor and is highly resistant to corrosion. For these reasons it is often used in the electrical and plumbing trades. Taps, valves, pipes, electrical terminals, plug top pins and terminal glands for steel wire armour (SWA) and MI cables are some of the many applications.

Brass is an attractive yellow metal which is also used for decorative household articles and jewellery. The combined properties of being an attractive metal which is highly resistant to corrosion make it a popular metal for ships' furnishings.

Cast steel Cast steel is also called tool steel or high carbon steel. It is an alloy of iron and carbon which is melted in airtight crucibles and then poured into moulds to form ingots. These ingots are then rolled or pressed into various shapes from which the finished products are made. Cast steel can be hardened and tempered and is therefore ideal for manufacturing tools (see also Chapter 5). Hammer heads, pliers, wire cutters, chisels, files and many machine parts are also made from cast steel.

Mild steel Mild steel is also an alloy of iron and carbon but contains much less carbon than cast steel. It can be filed, drilled or sawn quite easily and may be bent when hot or cold, but repeated cold bending may cause it to fracture. In moist conditions corrosion takes place rapidly unless the metal is protected. Mild steel is the most widely used metal in the world, having considerable strength and rigidity without being brittle. Ships, bridges, girders, motorcar bodies, bicycles, nails, screws, conduit, trunking, tray and SWA are all made of mild steel.

Zinc Zinc is a non-ferrous metal which is used mainly to protect steel against corrosion and in making the alloy brass. Mild steel coated with zinc is sometimes called *galvanized steel*, and this coating considerably improves steel's resistance to corrosion. Conduit, trunking, tray, steel wire armour, outside luminaires and electricity pylons are made of galvanized steel.

The properties of some of the materials used in the electrotechnical industries are shown in Table 1.5.

Table 1.5 Properties of materials used in electrical installation work

	PVC	Copper	Aluminium	Brass	Steel
Strength	Very poor	Poor	Poor	Good	Very good
Hardness	Very poor	Poor	Poor	Good	Good
Conductivity	None	Very good	Good	Good	Fair
Corrosion resistance	Very good	Good	Good	Good	Poor
Magnetic properties	None	None	None	None	Good

Cables

Most cables can be considered to be constructed in three parts: the *conductor* which must be of a suitable cross-section to carry the load current; the *insulation*, which has a colour or number code for identification; and the *outer sheath* which may contain some means of providing protection from mechanical damage.

The conductors of a cable are made of either copper or aluminium and may be stranded or solid. Solid conductors are only used in fixed wiring installations and may be shaped in larger cables. Stranded conductors are more flexible and conductor sizes from 4.0 mm^2 to 25 mm^2 contain seven strands. A 10 mm^2 conductor, for example, has seven 1.35 mm diameter strands which collectively make up the 10 mm^2 cross-sectional area of the cable. Conductors above 25 mm^2 have more than seven strands, depending upon the size of the cable. Flexible cords have multiple strands of very fine wire, as fine as one strand of human hair. This gives the cable its very flexible quality.

NEW WIRING COLOURS

Twenty-eight years ago the United Kingdom agreed to adopt the European colour code for flexible cords, that is, brown for live or phase conductor, blue for the neutral conductor and green combined with yellow for earth conductors. However, no similar harmonization was proposed for non-flexible cables used for fixed wiring. These were to remain as red for live or phase conductor, black for the neutral conductor and green combined with yellow for earth conductors.

On the 31st of March 2004 the IEE published Amendment No. 2 to BS 7671: 2001 which specified new cable core colours for all fixed wiring in United Kingdom electrical installations. These new core colours will 'harmonize' the United Kingdom with the practice in mainland Europe.

EXISTING FIXED CABLE CORE COLOURS

Single phase – red phase conductors, black neutral conductors and green combined with yellow for earth conductors.

Three phase – red, yellow and blue phase conductors, black neutral conductors and green combined with yellow for earth conductors.

These core colours must *not* be used after 31st of March 2006.

NEW (HARMONIZED) FIXED CABLE CORE COLOURS

Single phase – brown phase conductors, blue neutral conductors and green combined with yellow for earth conductors (just like the existing flexible cords).

Three phase – brown, black and grey phase conductors, blue neutral conductors and green combined with yellow for earth conductors.

These core colours *may* be used from 31st of March 2004.

Extensions or alterations to existing ***single phase*** installations do not require marking at the interface between the old and new fixed wiring colours. However, a warning notice must be fixed at the consumer unit or distribution fuse board which states:

> *Caution* – This installation has wiring colours to two versions of BS 7671. Great care should be taken before undertaking extensions, alterations or repair that all conductors are correctly identified.

Alterations to ***three phase*** installations must be marked at the interface L1, L2, L3 for the phases and N for the neutral. Both new and old cables must be marked. These markings are preferred to coloured tape and a caution notice is again required at the distribution board.

PVC INSULATED AND SHEATHED CABLES

Domestic and commercial installations use this cable, which may be clipped direct to a surface, sunk in plaster or installed in conduit or trunking. It is the simplest and least expensive cable. Figure 1.114 shows a sketch of a twin and earth cable.

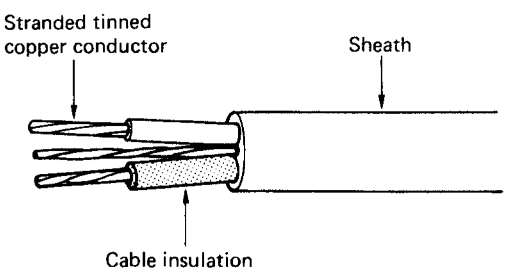


Fig. 1.114 A twin and earth PVC insulated and sheathed cable.

The conductors are covered with a colour-coded PVC insulation and then contained singly or with others in a PVC outer sheath.

PVC/SWA cable

PVC insulated steel wire armour cables are used for wiring underground between buildings, for main supplies to dwellings, rising submains and industrial installations. They are used where some mechanical protection of the cable conductors is required.

The conductors are covered with colour-coded PVC insulation and then contained either singly or with others in a PVC sheath (see Fig. 1.115). Around this sheath is placed an armour protection of steel wires twisted along the length of the cable, and a final PVC sheath covering the steel wires protects them from corrosion. The armour sheath also provides the circuit protective conductor (CPC) and the cable is simply terminated using a compression gland.

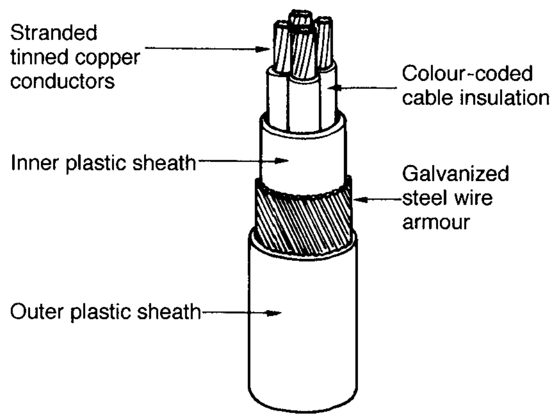


Fig. 1.115 A four-core PVC/SWA cable.

MI CABLE

A mineral insulated (MI) cable has a seamless copper sheath which makes it waterproof and fire- and corrosion-resistant. These characteristics often make it the only cable choice for hazardous or high-temperature installations such as oil refineries and chemical works, boiler-houses and furnaces, petrol pump and fire alarm installations.

The cable has a small overall diameter when compared to alternative cables and may be supplied as bare copper or with a PVC oversheath. It is colour-coded orange for general electrical wiring, white for emergency lighting or red for fire alarm wiring. The copper outer sheath provides the CPC, and the cable is terminated with a pot and sealed with compound and a compression gland (see Fig. 1.116).

The copper conductors are embedded in a white powder, magnesium oxide, which is non-ageing and non-combustible, but which is hygroscopic, which

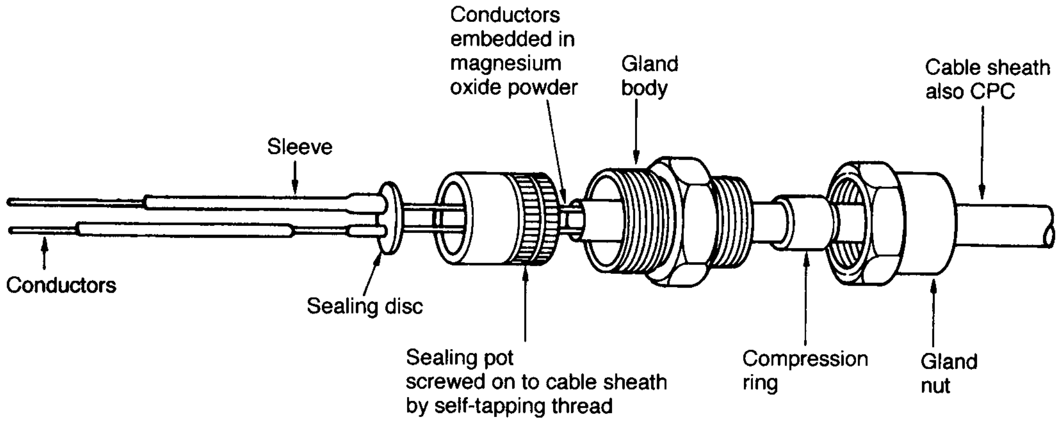


Fig. 1.116 MI cable with terminating seal and gland.

means that it readily absorbs moisture from the surrounding air, unless adequately terminated. The termination of an MI cable is a complicated process requiring the electrician to demonstrate a high level of practical skill and expertise for the termination to be successful.

FP 200 CABLE

FP 200 cable is similar in appearance to an MI cable in that it is a circular tube, or the shape of a pencil, and is available with a red or white sheath. However, it is much simpler to use and terminate than an MI cable.

The cable is available with either solid or stranded conductors that are insulated with 'insudite' a fire resistant insulation material. The conductors are then screened, by wrapping an aluminium tape around the insulated conductors, that is, between the insulated conductors and the outer sheath. This aluminium tape screen is applied metal side down and in contact with the bare circuit protective conductor.

The sheath is circular and made of a robust thermoplastic low smoke, zero halogen material.

FP 200 is available in 2, 3, 4, 7, 12 and 19 cores with a conductor size range from 1.0 mm to 4.0 mm. The core colours are: two core, red and black; three core, red, yellow and blue and four core, black, red, yellow and blue.

The cable is as easy to use as a PVC insulated and sheathed cable. No special terminations are required, the cable may be terminated through a grommet into a knock out box or terminated through a simple compression gland.

The cable is a fire resistant cable, primarily intended for use in fire alarms and emergency lighting installations or it may be embedded in plaster.

LSF CABLES

Low smoke and fume cables give off very low smoke and fumes if they are burned in a burning building. Most standard cable types are available as LSF cables.

HIGH-VOLTAGE POWER CABLES

The cables used for high-voltage power distribution require termination and installation expertise beyond the normal experience of a contracting electrician. The regulations covering high-voltage distribution are beyond the scope of the IEE Regulations for electrical installations. Operating at voltages in excess of 33 kV and delivering thousands of kilowatts, these cables are either suspended out of reach on pylons or buried in the ground in carefully constructed trenches.

HIGH-VOLTAGE OVERHEAD CABLES

Suspended from cable towers or pylons, overhead cables must be light, flexible and strong.

The cable is constructed of stranded aluminium conductors formed around a core of steel stranded conductors (see Fig. 1.117). The aluminium conductors carry the current and the steel core provides the tensile strength required to suspend the cable between pylons.

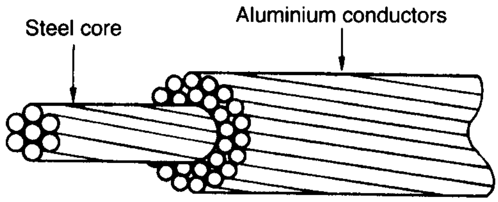


Fig. 1.117 132 kV overhead cable construction.

The cable is not insulated since it is placed out of reach and insulation would only add to the weight of the cable.

HIGH-VOLTAGE UNDERGROUND CABLES-PILCSWA

Paper insulated lead covered steel wire armour cables are only used in systems above 11 kV. Very high-voltage cables are only buried underground in special circumstances when overhead cables would be unsuitable, for example, because they might spoil a view of natural beauty. Underground cables are very expensive because they are much more complicated to manufacture than overhead cables. In transporting vast quantities of power, heat is generated within the cable. This heat is removed by passing oil through the cable to expansion points, where the oil is cooled. The system is similar to the water cooling of an internal combustion engine. Figure 1.118 shows a typical high voltage cable construction.

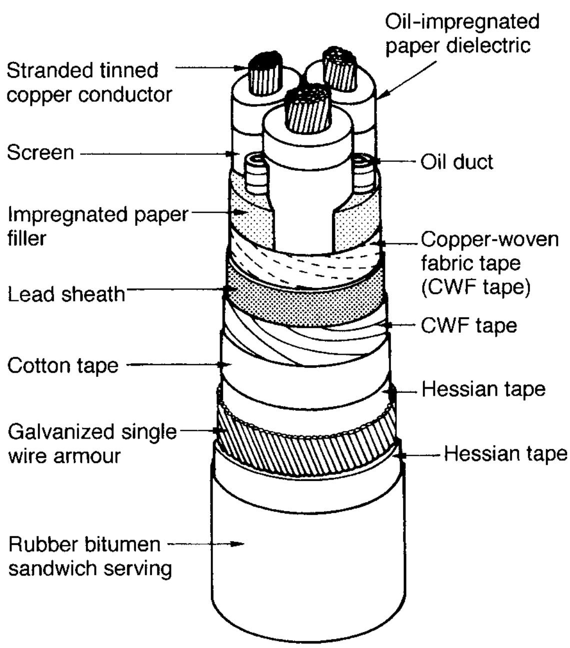


Fig. 1.118 132 kV underground cable construction.

The conductors may be aluminium or copper, solid or stranded. They are insulated with oil-impregnated brown paper wrapped in layers around the conductors. The oil ducts allow the oil to flow through the cable, removing excess heat. The whole cable within the lead sheath is saturated with oil, which is a good insulator. The lead sheath keeps the oil in and moisture out of the cable, and this is supported by the copper-woven fabric tape. The cable is protected by steel wire armouring, which has bitumen or PVC serving over it to protect the armour sheath from corrosion. The termination and installation of these cables is a very specialized job, undertaken by the supply authorities only.

Installing cables

The final choice of a wiring system must rest with those designing the installation and those ordering the work, but whatever system is employed, good workmanship and the use of proper materials is essential for compliance with the IEE Regulation 130–02–01. The necessary skills can be acquired by an electrical trainee who has the correct attitude and dedication to his craft.

PVC insulated and sheathed wiring systems are used extensively for lighting and socket installations in domestic dwellings. Mechanical damage to the cable caused by impact, abrasion, penetration, compression or tension must be minimized during installation (Regulation 522–06–01). The cables are generally fixed using plastic clips incorporating a masonry nail, which means the cables can be fixed to wood, plaster or brick with almost equal ease. Cables should be run horizontally or vertically, not diagonally, down a wall. All kinds should be removed so that the cable is run straight and neatly between clips fixed at equal distances providing adequate support for the cable so that it does not become damaged by its own weight (Regulation 522–08–04 and Table 4A of the *On Site Guide*). Where cables are bent, the radius of the bend should not cause the conductors to be damaged (Regulation 522–08–03 and Table 4E of the *On Site Guide*).

Terminations or joints in the cable may be made in ceiling roses, junction boxes, or behind sockets or switches, provided that they are enclosed in a non-ignitable material, are properly insulated and are mechanically and electrically secure (IEE Regulation 526). All joints must be accessible for inspection testing and maintenance when the installation is completed.

Where PVC insulated and sheathed cables are concealed in walls, floors or partitions, they must be provided with a box incorporating an earth terminal at each outlet position. PVC cables do not react chemically with plaster, as do some cables, and consequently PVC cables may be buried under plaster. Further protection by channel or conduit is only necessary outside of designated zones if mechanical protection from nails or screws is required. However, Regulation 522–06–07 now tells us that where PVC cables are to be embedded in wet plaster, they should be covered in mechanical protection to protect them from the plasterer's trowel and penetration by nails and screws. To identify the most probable cable routes, Regulation 522–06–06 tells us that outside a zone formed by a 150 mm border all around a wall edge, cables can only be run horizontally or vertically to a point or accessory unless they are contained in a substantial earthed enclosure, such as a conduit, which can withstand nail penetration. This is shown in Fig. 4.22 in Chapter 4 of Basic Electrical Installation Work, 4th edition.

Where cables and wiring systems pass through walls, floors and ceilings the hole should be made good with incombustible material such as mortar or plaster to prevent the spread of fire (Regulation 527–02–01). Cables passing through metal boxes should be bushed with a rubber grommet to prevent abrasion of the cable. Holes drilled in floor joists through which cables are run should be 50 mm below the top or 50 mm above the bottom of the joist to prevent damage to the cable by nail penetration (Regulation 522–06–05). PVC cables should not be installed when the surrounding temperature is below 0°C or when the cable temperature has been below 0°C for the previous 24 hours because the insulation becomes brittle at low temperatures and may be damaged during installation.

CONDUIT INSTALLATIONS

A conduit is a tube, channel or pipe in which insulated conductors are contained. The conduit, in effect, replaces the PVC outer sheath of a cable, providing mechanical protection for the insulated conductors. A conduit installation can be rewired easily or altered at any time, and this flexibility, coupled with mechanical protection, makes conduit installations popular for commercial and industrial applications. There are three types of conduit used in electrical installation work: steel, PVC and flexible.

Steel conduit

Steel conduits are made to a specification defined by BS 4568 and are either heavy gauge welded or solid drawn. Heavy gauge is made from a sheet of steel welded along the seam to form a tube and is used for most installation work. Solid drawn conduit is a seamless tube which is much more expensive and only used for special gas-tight, explosion-proof or flame-proof installations.

Conduit is supplied in 3.75 m lengths and typical sizes are 16, 20, 25 and 32 mm. Conduit tubing and fittings are supplied in a black enamel finish for internal use or hot galvanized finish for use on external or damp installations. A wide range of fittings are available and the conduit is fixed using saddles or pipe hooks, as shown in Fig. 1.119.

Metal conduits are threaded with stocks and dies and bent using special bending machines. The metal conduit is also utilized as the circuit protective conductor and, therefore, all connections must be screwed up tightly and all burrs removed so that cables will not be damaged as they are drawn into the conduit. Metal conduits containing a.c. circuits must contain phase and neutral conductors in the same conduit to prevent eddy currents flowing, which would result in the metal conduit becoming hot (Regulation 521–02–01).

PVC conduit

PVC conduit used on typical electrical installations is heavy gauge standard impact tube manufactured to BS 4607. The conduit size and range of fittings are the same as those available for metal conduit. PVC conduit is most often joined by placing the end of the conduit into the appropriate fitting and fixing with a PVC solvent adhesive. PVC conduit can be bent by hand using a bending spring of the same diameter as the inside of the conduit. The spring is pushed into the conduit to the point of the intended bend and the conduit then bent over the knee. The spring ensures that the conduit keeps its circular shape. In cold weather, a little warmth applied to the point of the

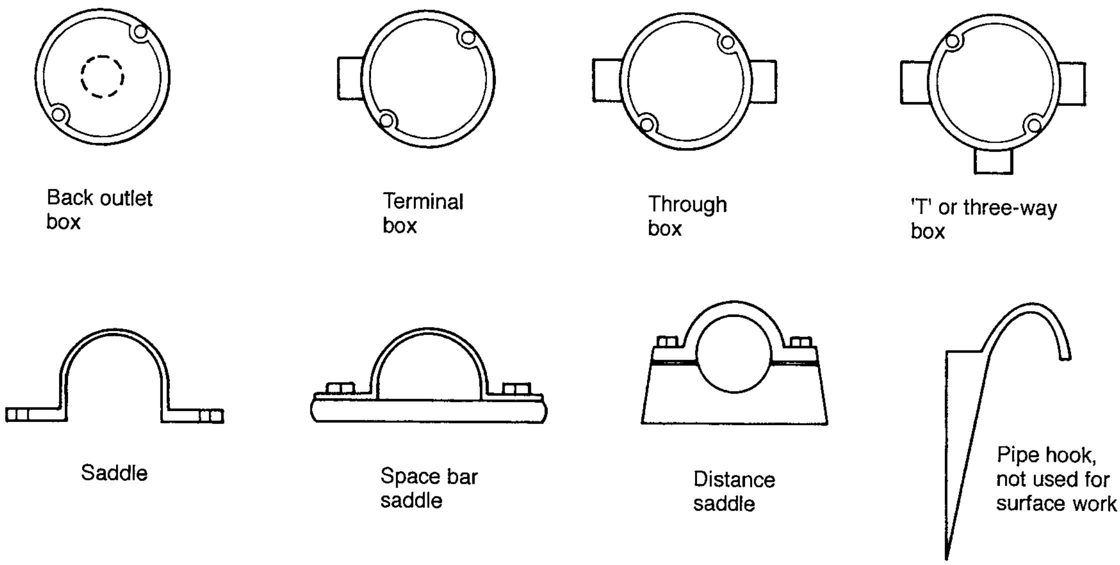


Fig. 1.119 Conduit fittings and saddles.

intended bend often helps to achieve a more successful bend.

The advantages of a PVC conduit system are that it may be installed much more quickly than steel conduit and is non-corrosive, but it does not have the mechanical strength of steel conduit. Since PVC conduit is an insulator it cannot be used as the CPC and a separate earth conductor must be run to every outlet. It is not suitable for installations subjected to temperatures below −5°C or above 60°C. Where luminaires are suspended from PVC conduit boxes, precautions must be taken to ensure that the lamp does not raise the box temperature or that the mass of the luminaire supported by each box does not exceed the maximum recommended by the manufacturer (IEE Regulation 522–01). PVC conduit also expands much more than metal conduit and so long runs require an expansion coupling to allow for conduit movement and help to prevent distortion during temperature changes.

All conduit installations must be erected first before any wiring is installed (IEE Regulation 522–080–02). The radius of all bends in conduit must not cause the cables to suffer damage, and therefore the minimum radius of bends given in Table 4E of the *On Site Guide* applies (IEE Regulation 522–08–03). All conduits should terminate in a box or fitting and meet the boxes or fittings at right angles, as shown in Fig. 1.120. Any unused conduit box entries should be blanked off and all boxes covered with a box lid, fitting or accessory to

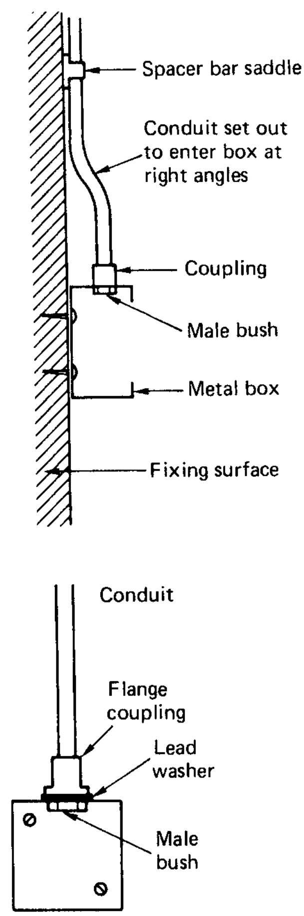


Fig. 1.120 Terminating conduits.

provide complete enclosure of the conduit system. Conduit runs should be separate from other services, unless intentionally bonded, to prevent arcing occurring from a faulty circuit within the conduit, which might cause the pipe of another service to become punctured.

When drawing cables into conduit they must first be *run off* the cable drum. That is, the drum must be rotated as shown in Fig. 1.121 and not allowed to *spiral off*, which will cause the cable to twist.

Cables should be fed into the conduit in a manner which prevents any cable crossing over and becoming twisted inside the conduit. The cable insulation must not be damaged on the metal edges of the draw-in box. Cables can be pulled in on a draw wire if the run is a long one. The draw wire itself may be drawn in on a fish tape, which is a thin spring steel or plastic tape.

A limit must be placed on the number of bends between boxes in a conduit run and the number of cables which may be drawn into a conduit to prevent the cables being strained during wiring. Appendix 5 of the *On Site Guide* gives a guide to the cable capacities of conduits and trunking.

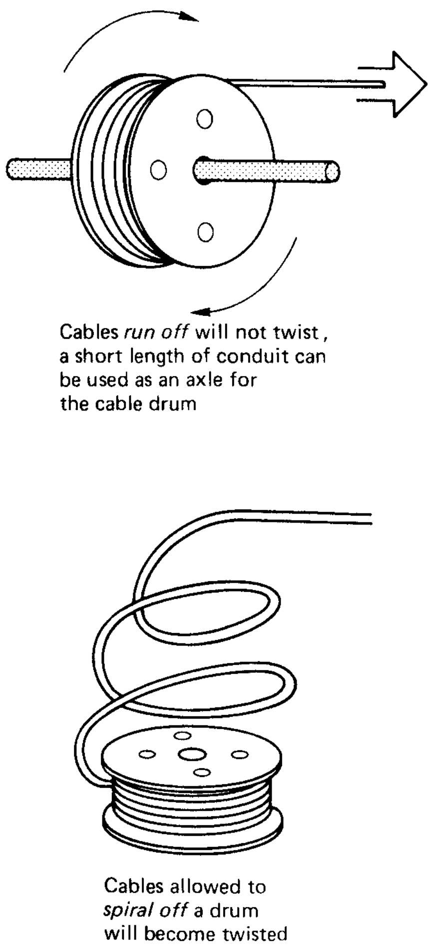


Fig. 1.121 Running off cable from a drum.

Flexible conduit

Flexible conduit is made of interlinked metal spirals often covered with a PVC sleeving. The tubing must not be relied upon to provide a continuous earth path and, consequently, a separate CPC must be run either inside or outside the flexible tube (Regulation 543–02–01).

Flexible conduit is used for the final connection to motors so that the vibrations of the motor are not transmitted throughout the electrical installation and to allow for modifications to be made to the final motor position and drive belt adjustments.

Conduit capacities

Single PVC insulated conductors are usually drawn into the installed conduit to complete the installation. Having decided upon the type, size and number of cables required for a final circuit, it is then necessary to select the appropriate size of conduit to accommodate those cables.

The tables in Appendix 5 of the *On Site Guide* describe a 'factor system' for determining the size of conduit required to enclose a number of conductors. The Tables are shown in Tables 1.6 and 1.7. The method is as follows:

- Identify the cable factor for the particular size of conductor. (This is given in Table 5A for straight conduit runs and Table 5C for cables run in conduits which incorporate bends, see Table 1.6.)
- Multiply the cable factor by the number of conductors, to give the sum of the cable factors.
- Identify the appropriate part of the conduit factor table given by the length of run and number of bends. (For straight runs of conduit less than 3 m in length, the conduit factors are given in Table 5B. For conduit runs in excess of 3 m or incorporating bends, the conduit factors are given in Table 5D, see Table 1.7.)
- The correct size of conduit to accommodate the cables is that conduit which has a factor equal to or greater than the sum of the cable factors.

EXAMPLE 1

Six 2.5 mm^2 PVC insulated cables are to be run in a conduit containing two bends between boxes 10 m apart. Determine the minimum size of conduit to contain these cables.

From Table 5C, shown in Table 1.6

The factor for one 2.5 mm^2 cable $= 30$
The sum of the cable factors $= 6 \times 30$
$= 180$

From Table 5D shown in Table 1.7, a 25 mm conduit, 10 m long and containing two bends, has a factor of 260. A 20 mm conduit containing two bends only has a factor of 141 which is less than 180, the sum of the cable factors and, therefore, 25 mm conduit is the minimum size to contain these cables.

Table 1.6 Conduit cable factors. Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

TABLE 5C
Cable factors for use in conduit in long straight runs over 3 m, or runs of any length incorporating bends

Type of conductor	Conductor cross-sectional area (mm^2)	Cable factor
Solid or stranded	1	16
	1.5	22
	2.5	30
	4	43
	6	58
	10	105
	16	145
	25	217

The inner radius of a conduit bend should be not less than 2.5 times the outside diameter of the conduit.

EXAMPLE 2

Ten 1.0 mm^2 PVC insulated cables are to be drawn into a plastic conduit which is 6 m long between boxes and contains one bend. A 4.0 mm PVC insulated CPC is also included. Determine the minimum size of conduit to contain these conductors.

From Table 5C, and shown in Table 1.6

The factor for one 1.0 mm cable $= 16$
The factor for one 4.0 mm cable $= 43$.
The sum of the cable factors $= (10 \times 16) + (1 \times 43) = 203$.

From Table 5D shown in Table 1.7, a 20 mm conduit, 6 m long and containing one bend, has a factor of 233. A 16 mm conduit containing one bend

Table 1.7 Conduit cable factors for bends and long straight runs. Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

TABLE 5D
Cable factors for runs incorporating bends and long straight runs

	Conduit diameter (mm)																			
Length of run (m)	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32
	Straight				One bend				Two bends				Three bends				Four bends			
1	Covered by				188	303	543	947	177	286	514	900	158	256	463	818	130	213	388	692
1.5					182	294	528	923	167	270	487	857	143	233	422	750	111	182	333	600
2	Tables				177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529
2.5					171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474
3	A and B				167	270	487	857	143	233	422	750	111	182	333	600				
3.5	179	290	521	911	162	263	475	837	136	222	404	720	103	169	311	563				
4	177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529				
4.5	174	282	507	889	154	250	452	800	125	204	373	667	91	149	275	500				
5	171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474				
6	167	270	487	857	143	233	422	750	111	182	333	600								
7	162	263	475	837	136	222	404	720	103	169	311	563								
8	158	256	463	818	130	213	388	692	97	159	292	529								
9	154	250	452	800	125	204	373	667	91	149	275	500								
10	150	244	442	783	120	196	358	643	86	141	260	474								

Additional factors: For 38 mm diameter use ...... 1.4 × (32 mm factor)
For 50 mm diameter use ...... 2.6 × (32 mm factor)
For 63 mm diameter use ...... 4.2 × (32 mm factor)

only has a factor of 143 which is less than 203, the sum of the cable factors and, therefore, 20 mm conduit is the minimum size to contain these cables.

TRUNKING INSTALLATIONS

A trunking is an enclosure provided for the protection of cables which is normally square or rectangular in cross-section, having one removable side. Trunking may be thought of as a more accessible conduit system and for industrial and commercial installations it is replacing the larger conduit sizes. A trunking system can have great flexibility when used in conjunction with conduit; the trunking forms the background or framework for the installation, with conduits running from the trunking to the point controlling the current using apparatus. When an alteration or extension is required it is easy to drill a hole in the side of the trunking and run a conduit to the new point. The new wiring can then be drawn through the new conduit and the existing trunking to the supply point.

Trunking is supplied in 3 m lengths and various cross-sections measured in millimetres from 50 × 50 up to 300 × 150. Most trunking is available in either steel or plastic.

Metallic trunking

Metallic trunking is formed from mild steel sheet, coated with grey or silver enamel paint for internal use or a hot-dipped galvanized coating where damp conditions might be encountered. A wide range of accessories are available, such as 45° bends, 90° bends, tee and four-way junctions, for speedy on-site assembly. Alternatively, bends may be fabricated in lengths of trunking, as shown in Fig. 1.122. This may be necessary or more convenient if a bend or set is non-standard, but it does take more time to fabricate bends than merely to bolt on standard accessories.

When fabricating bends the trunking should be supported with wooden blocks for sawing and filing, in order to prevent the sheet steel vibrating or becoming deformed. Fish plates must be made and riveted or bolted to the trunking to form a solid and secure bend. When manufactured bends are used, the continuity of the earth path must be ensured across the joint by making all fixing screw connections very tight, or fitting a separate copper strap between the trunking and the standard bend. If an earth continuity test on the trunking is found to be unsatisfactory, an insulated CPC must be installed inside the trunking. The

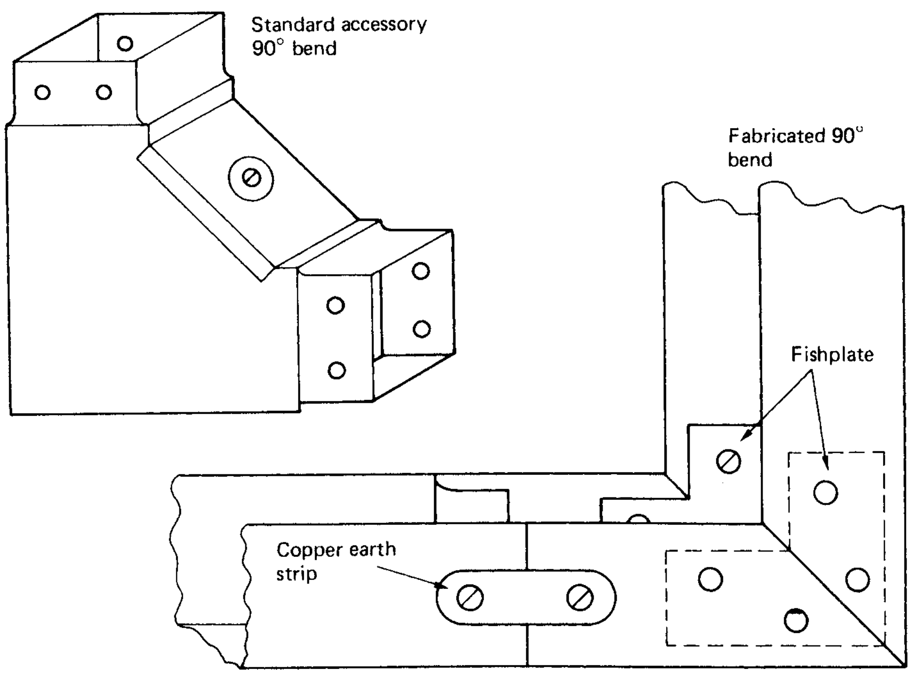


Fig. 1.122 Alternative trunking bends.

size of the protective conductor will be determined by the largest cable contained in the trunking, as described by Table 54G of the IEE Regulations.

Non-metallic trunking

Trunking and trunking accessories are also available in high-impact PVC. The accessories are usually secured to the lengths of trunking with a PVC solvent adhesive. PVC trunking, like PVC conduit, is easy to install and is non-corrosive. A separate CPC will need to be installed and non-metallic trunking may require more frequent fixings because it is less rigid than metallic trunking. All trunking fixings should use round-headed screws to prevent damage to cables since the thin sheet construction makes it impossible to countersink screw heads.

Mini-trunking

Mini-trunking is very small PVC trunking, ideal for surface wiring in domestic and commercial installations such as offices. The trunking has a cross-section of 16 mm × 16 mm, 25 mm × 16 mm, 38 mm × 16 mm or 38 mm × 25 mm and is ideal for switch drops or for housing auxiliary circuits such as telephone or audio equipment wiring. The modern square look in switches and sockets is complemented by the mini-trunking which is very easy to install (see Fig. 1.123).

Skirting trunking

A trunking manufactured from PVC or steel and in the shape of a skirting board is frequently used in commercial buildings such as hospitals, laboratories and offices. The trunking is fitted around the walls of a room and contains the wiring for socket outlets and telephone points which are mounted on the lid, as shown in Fig. 1.123.

Where any trunking passes through walls, partitions, ceilings or floors, short lengths of lid should be fitted so that the remainder of the lid may be removed later without difficulty. Any damage to the structure of the buildings must be made good with mortar, plaster or concrete in order to prevent the spread of fire. Fire barriers must be fitted inside the trunking every 5 m, or at every floor level or room dividing wall, if this is a shorter distance, as shown in Fig. 1.124(a).

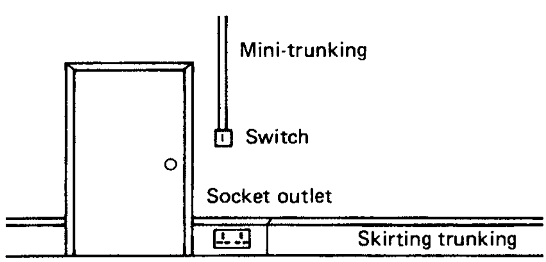


Fig. 1.123 Typical installation of skirting trunking and mini-trunking.

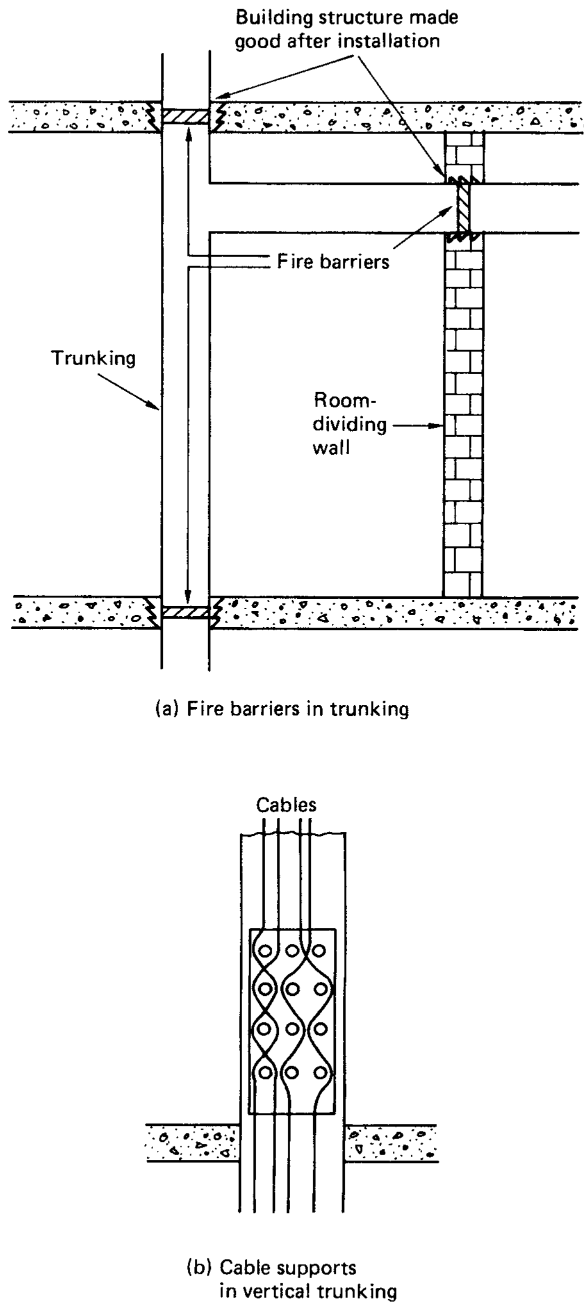


Fig. 1.124 Installation of trunking.

Where trunking is installed vertically, the installed conductors must be supported so that the maximum unsupported length of non-sheathed cable does not exceed 5 m. Figure 1.124(b) shows cables woven through insulated pin supports, which is one method of supporting vertical cables.

PVC insulated cables are usually drawn into an erected conduit installation or laid into an erected trunking installation. Table 5D of the *On Site Guide* only gives factors for conduits up to 32 mm in diameter, which would indicate that conduits larger than this are not in frequent or common use. Where a cable enclosure greater than 32 mm is required because of the number or size of the conductors, it is generally more economical and convenient to use trunking.

Trunking capacities

The ratio of the space occupied by all the cables in a conduit or trunking to the whole space enclosed by the conduit or trunking is known as the *space factor*. Where sizes and types of cable and trunking are not covered by the tables in Appendix 5 of the *On Site Guide* a space factor of 45% must not be exceeded. This means that the cables must not fill more than 45% of the space enclosed by the trunking. The tables of Appendix 5 take this factor into account.

To calculate the size of trunking required to enclose a number of cables:

- Identify the cable factor for the particular size of conductor (Table 5E). See Table 1.8.
- Multiply the cable factor by the number of conductors to give the sum of the cable factors.
- Consider the factors for trunking (Table 5F) and shown in Table 1.9. The correct size of trunking to accommodate the cables is that trunking which has a factor equal to or greater than the sum of the cable factors.

Table 1.8 Trunking, cable factors. Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

TABLE 5E

Cable factors for trunking

Type of conductor	Conductor cross-sectional area (mm^2)	PVC, BS 6004 Cable factor	Thermosetting BS 7211 Cable factor
Solid	1.5	8.0	8.6
	2.5	11.9	11.9
Stranded	1.5	8.6	9.6
	2.5	12.6	13.9
	4	16.6	18.1
	6	21.2	22.9
	10	35.3	36.3
	16	47.8	50.3
	25	73.9	75.4

Note:
(i) These factors are for metal trunking and may be optimistic for plastic trunking where the cross-sectional area available may be significantly reduced from the nominal by the thickness of the wall material.
(ii) The provision of spare space is advisable; however, any circuits added at a later date must take into account grouping. Appendix 4, BS 7671.

EXAMPLE

Calculate the minimum size of trunking required to accommodate the following single-core PVC cables:

20 × 1.5 mm solid conductors
20 × 2.5 mm solid conductors
21 × 4.0 mm stranded conductors
16 × 6.0 mm stranded conductors

From Table 5E shown in Table 1.8, the cable factors are:

for 1.5 mm solid cable – 8.0
for 2.5 mm solid cable – 11.9
for 4.0 mm stranded cable – 16.6
for 6.0 mm stranded cable – 21.2

The sum of the cable terms is:
$(20 \times 8.0) + (20 \times 11.9) + (21 \times 16.6) + (16 \times 21.2) = 1085.8$. From Table 5F shown in Table 1.9, 75 mm × 38 mm trunking has a factor of 1146 and, therefore, the minimum size of trunking to accommodate these cables is 75 mm × 38 mm, although a larger size, say 75 mm × 50 mm would be equally acceptable if this was more readily available as a standard stock item.

SEGREGATION OF CIRCUITS

Where an installation comprises a mixture of low-voltage and very low-voltage circuits such as mains lighting and power, fire alarm and telecommunication circuits, they must be separated or *segregated* to prevent electrical contact (IEE Regulation 528–01–01).

For the purpose of these regulations various circuits are identified by one of two bands and defined by

Table 1.9 Trunking cable factors Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

TABLE 5F
Factors for trunking

Dimensions of trunking (mm × mm)	Factor	Dimensions of trunking (mm × mm)	Factor
50 × 38	767	200 × 100	8572
50 × 50	1037	200 × 150	13001
75 × 25	738	200 × 200	17429
75 × 38	1146	225 × 38	3474
75 × 50	1555	225 × 50	4671
75 × 75	2371	225 × 75	7167
100 × 25	993	225 × 100	9662
100 × 38	1542	225 × 150	14652
100 × 50	2091	225 × 200	19643
100 × 75	3189	225 × 225	22138
100 × 100	4252	300 × 38	4648
150 × 38	2999	300 × 50	6251
150 × 50	3091	300 × 75	9590
150 × 75	4743	300 × 100	12929
150 × 100	6394	300 × 150	19607
150 × 150	9697	300 × 200	26285
200 × 38	3082	300 × 225	29624
200 × 50	4145	300 × 300	39428
200 × 75	6359		

Space factor – 45% with trunking thickness taken into account

Part 2 of the Regulations as follows:

Band I telephone, radio, bell, call and intruder alarm circuits, emergency circuits for fire alarm and emergency lighting.
Band II mains voltage circuits.

When Band I circuits are insulated to the same voltage as Band II circuits, they may be drawn into the same compartment.

When trunking contains rigidly fixed metal barriers along its length, the same trunking may be used to enclose cables of the separate Bands without further precautions, provided that each Band is separated by a barrier, as shown in Fig. 1.125.

Multi-compartment PVC trunking cannot provide band segregations since there is no metal screen between the Bands. This can only be provided in PVC trunking if screened cables are drawn into the trunking.

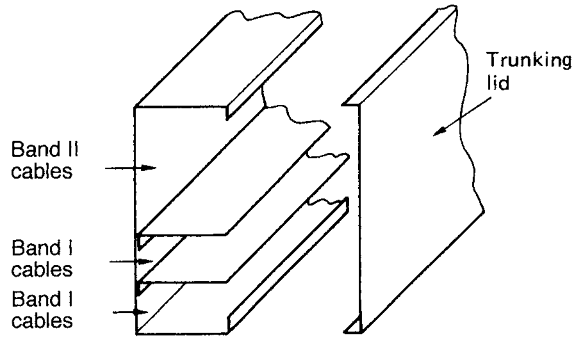


Fig. 1.125 Segregation of cables in trunking.

CABLE TRAY INSTALLATIONS

Cable tray is a sheet-steel channel with multiple holes. The most common finish is hot-dipped galvanized but PVC-coated tray is also available. It is used extensively on large industrial and commercial installations for supporting MI and SWA cables which are laid on the cable tray and secured with cable ties through the tray holes.

Cable tray should be adequately supported during installation by brackets which are appropriate for the particular installation. The tray should be bolted to the brackets with round-headed bolts and nuts, with the round head inside the tray so that cables drawn along the tray are not damaged.

The tray is supplied in standard widths from 50 mm to 900 mm, and a wide range of bends, tees and reducers are available. Figure 1.126 shows a factory-made 90° bend at B. The tray can also be bent using a cable tray bending machine to create bends such as that shown at A in Fig. 1.126. The installed tray should be securely bolted with round-headed bolts where lengths or accessories are attached, so that there is a continuous earth path which may be bonded to an electrical earth. The whole tray should provide a firm support for the cables and therefore the tray fixings must be capable of supporting the weight of both the tray and cables.

PVC/SWA CABLE INSTALLATIONS

Steel wire armoured PVC insulated cables are now extensively used on industrial installations and often laid on cable tray. This type of installation has the advantage of flexibility, allowing modifications to be made speedily as the need arises. The cable has a steel wire armouring giving mechanical protection and

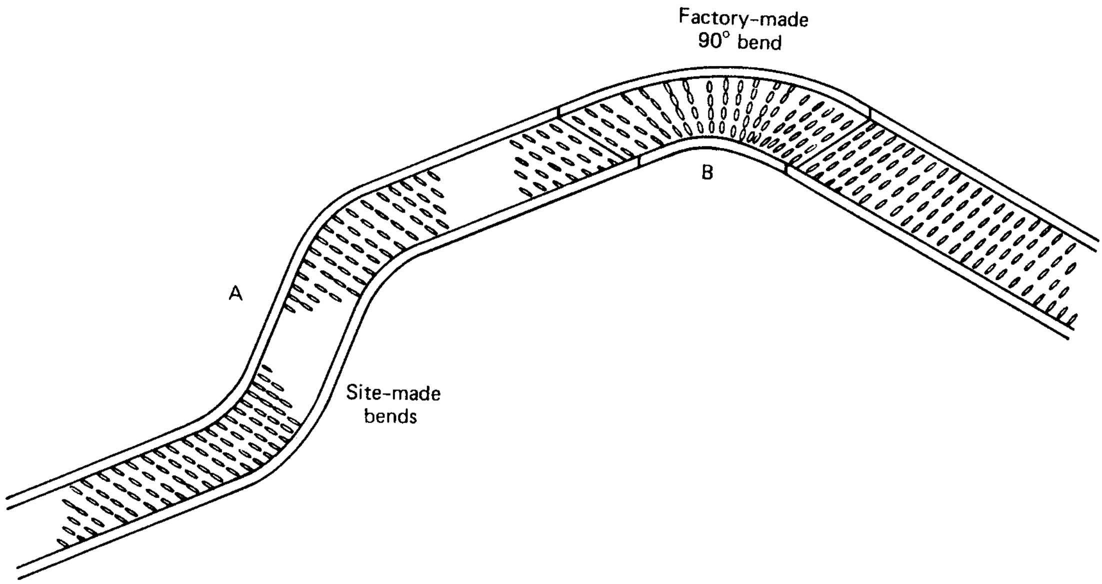


Fig. 1.126 Cable tray with bends.

permitting it to be laid directly in the ground or inducts, or it may be fixed directly or laid on a cable tray.

It should be remembered that when several cables are grouped together the current rating will be reduced according to the correction factors given in Table 4B1 of the IEE Regulations and Table 6C of the *On Site Guide.*

The cable is easy to handle during installation, is pliable and may be bent to a radius of eight times the cable diameter. The PVC insulation would be damaged if installed in ambient temperatures over 70°C or below 0°C, but once installed the cable can operate at low temperatures.

The cable is terminated with a simple gland which compresses a compression ring onto the steel wire armouring to provide the earth continuity between the switchgear and the cable.

MI CABLE INSTALLATIONS

Mineral insulated cables are available for general wiring as:

- light-duty MI cables for voltages up to 600 V and sizes from 1.0 mm^2 to 10 mm^2 and
- heavy-duty MI cables for voltages up to 1000 V and sizes from 1.0 mm^2 to 150 mm^2.

The cables are available with bare sheaths or with a PVC oversheath. The cable sheath provides sufficient mechanical protection for all but the most severe situations, where it may be necessary to fit a steel sheath or conduit over the cable to give extra protection, particularly near floor level in some industrial situations.

The cable may be laid directly in the ground, inducts, on cable tray or clipped directly to a structure. It is not affected by water, oil or the cutting fluids used in engineering and can withstand very high temperature or even fire. The cable diameter is small in relation to its current carrying capacity and it should last indefinitely if correctly installed because it is made from inorganic materials. These characteristics make the cable ideal for Band I emergency circuits, boiler-houses, furnaces, petrol stations and chemical plant installations.

The cable is supplied in coils and should be run off during installation and not spiralled off, as described in Fig. 1.121 for conduit. The cable can be work-hardened if over-handled or over-manipulated. This makes the copper outer sheath stiff and may result in fracture. The outer sheath of the cable must not be penetrated, otherwise moisture will enter the magnesium oxide insulation and lower its resistance. To reduce the risk of damage to the outer sheath during installation, cables should be straightened and formed by hammering with a hide hammer or a block of wood and a steel hammer. When bending MI cables the radius of the bend should not cause the cable to become damaged and clips should provide adequate support (Regulations 522–08–03 and 04 and Tables 4A and 4E of the *On Site Guide*).

The cable must be prepared for termination by removing the outer copper sheath to reveal the copper conductors. This can be achieved by using a rotary stripper tool or, if only a few cables are to be terminated, the outer sheath can be removed with side cutters, peeling off the cable in a similar way to peeling the skin from a piece of fruit with a knife. When enough conductor has been revealed, the outer sheath must be cut off square to facilitate the fitting of the sealing pot, and this can be done with a ringing tool. All excess magnesium oxide powder must be wiped from the conductors with a clean cloth. This is to prevent moisture from penetrating the seal by capillary action.

Cable ends must be terminated with a special seal to prevent the entry of moisture. Figure 1.116 shows a brass screw-on seal and gland assembly, which allows termination of the MI cables to standard switchgear and conduit fittings. The sealing pot is filled with a sealing compound, which is pressed in from one side only to prevent air pockets forming, and the pot closed by crimping home the sealing disc. Such an assembly is suitable for working temperatures up to 105°C. Other compounds or powdered glass can increase the working temperature up to 250°C.

The conductors are not identified during the manufacturing process and so it is necessary to identify them after the ends have been sealed. A simple continuity or polarity test, as described in Chapter 2 of this book can identify the conductors which are then sleeved or identified with coloured markers.

Connection of MI cables can be made directly to motors, but to absorb the vibrations a 360° loop should be made in the cable just before the termination. If excessive vibration is to be expected the MI cable should be terminated in a conduit through-box and the final connection made by flexible conduit.

Copper MI cables may develop a green incrustation or patina on the surface, even when exposed to normal atmospheres. This is not harmful and should not be removed. However, if the cable is exposed to an environment which might encourage corrosion, an MI cable with an overall PVC sheath should be used.

Protection of structures against lightning (BS 6651)

From the earliest times men have tended to regard the thunderstorm as a manifestation of God's anger and His power to destroy. Thunderstorms can, indeed, be dangerous but the actual danger that an individual might be exposed to whilst standing in the middle of a field in a thunderstorm is probably less than that of being caught in the middle of a pedestrian crossing during a city's 'rush hour'. Every person in Britain has a one in two million chance of being killed by lightning each year. This compares with a one in 8000 chance of being killed in a traffic accident.

Benjamin Franklin (1707–1790) is generally considered to be the father of modern lightning protection theory. His famous kite experiment, flying a kite into a thundercloud, although rather foolish, proved, for the first time, that storm clouds generate, store and discharge static electricity.

The succession of events that we know of as a thunderstorm, result from the building up to maturity and subsequent decay of a cumulo-nimbus cloud, commonly called a 'thundercloud'. A cumulo-nimbus cloud may form in the following way. On a hot sultry summer afternoon, white fluffy 'cumulus' clouds, having clearly defined curvaceous boundaries, are formed in the clear blue sky. Humid air passing over the ground warmed by a summer sun, receives heat from below, expands, grows lighter and rises. Subsequent expansion, in an atmosphere of diminishing pressure, is accomplished adiabatically (without gain or loss of heat). When the humid air reaches a certain height, known as the condensation level, the temperature falls to the dew point, and the excess water vapour content of the air condenses out in the form of tiny water droplets. A fog has been created which, from a distance, looks like fluffed out cotton wool.

In this simple cumulus cloud, condensed-out droplets of water are carried upwards with the rising draught. Some droplets may collide and join together, the bigger drops possible falling as rain.

If sufficient heat is available from the ground, cumulus clouds may grow both vertically and horizontally, indeed several may amalgamate and a thundercloud may be formed.

The cloud base may be over a mile above the ground or it may be almost touching the ground, especially if advancing over rising country. The base area may exceed 100 square miles and it may travel at more than 20 miles/hour. The height of the cloud may reach 50 miles and a large thundercloud may well contain half a million tons of ice and water.

Mason and Maybank observed in 1960 that sometimes, if water drops of a radius greater than 0.03 mm were frozen, an ice shell first formed on the surface (because the drop froze from the outside inwards). As the freezing action proceeded, the water encapsulated in the thin shell of ice, expanded and burst the shell. This broke up into small splinters carrying a positive charge. The remainder of the drop was left with a negative charge. They deduced that such splinters were also produced in the formation of soft hail pellets. Laytham and Mason, in the next 2 years, made an extensive study of the electrification of hailstones and concluded that the size of the charges fully justified the belief that here was the mechanism by which a thundercloud charged and re-charged itself.

Electric field measurements both outside and inside a thundercloud show that, when formed, the cloud contains positive and negative charges (rather like a Van der Graaf machine). Its terminals are not metallic conductors but a diffuse collection of charge, poised in space and not apparently connected to anything. So until switches are closed or the system insulation breaks down, the voltage generated will build up in proportion to the charge transferred. In fact, the cloud may charge up to 1000 MV although 100 MV is more normal.

If the voltage is sufficient, a lightning discharge will take place between the electrical centre of the cloud and some protuberance on the earth's surface. Early in its existence the lightning discharge current may be 200 000 A, with an average of 20 000 A, in fact, there may be several surges in this order. Inevitably, however, as the generator loses charge, its voltage falls and the discharge current also falls. A time soon comes when the voltage will be insufficient to re-strike and the connection between the thundercloud and the earth will be broken. The thundercloud has then handed over its charge and is free to start building another.

Tall buildings and particularly pointed spires encourage lightning discharge. In relatively flat country, such modest protuberances as haystacks or golfers may call down unwelcome attention. Compared to an area of land the size of a football pitch, a person is a relatively sharp point.

The principle effects of a lightning discharge to a structure are electrical, thermal and mechanical. These three effects are determined by the current that is discharged into the structure.

The current in any discharge is unidirectional and rises steeply to its crest value in several microseconds and decays to zero in several tens or hundreds of microseconds.

The point of strike on the lightning protective system may be raised to a high potential and, therefore, there is a risk of flashover from the lightning protective system to the metal of the structure. If such a flashover occurred, part of the lightning current would be discharged through internal installations (water-pipes, gutters, ventilation ducts) with consequent risk to the occupants and the fabric of the building as described by BS 6651: Section 14. This can be avoided by isolation or bonding.

The thermal effect of a lightning discharge is confined to the temperature rise of the conductor through which the lightning current flows. Although the amplitude of the current is high, the duration is short and, therefore, the thermal effect is usually ignored. If ignored, the fusing or welding effect that might occur locally could result in a rupture of a conductor that had previously been damaged or of inadequate cross-section. In practice the CSA of a lightning conductor is determined by mechanical considerations.

When high currents are discharged through conductors, these conductors are subjected to mechanical forces and secure mechanical fixing is required for lightning conductors.

Another mechanical effect is due to the strong pressure wave set up between the thundercloud and the lightning conductor. This is due to the air channel along which the discharge is propagated being suddenly raised to a very high temperature. The pressure wave is responsible for the lifting of roof tiles but no protection can be provided against such effect.

WHEN IS PROTECTION NECESSARY?

Structures with inherent explosive risks, for example armament factories and stores, fuel dumps and fuel tanks, usually need the highest possible degree of protection. With many other structures there will be little doubt as to the need for protection. Examples of such structures are:

- those in which large numbers of people congregate,
- those concerned with the maintenance of essential public services,
- those in areas where lightning strikes are prevalent,
- structures of historic or cultural importance.

Other factors which can be considered for determining an overall 'risk factor' might be:

- The geographical location of the structure which pinpoints the average lightning flash density (that is the number of flashes to ground per km per year) for which maps are available.

- The effective collection area of the structure. This is the projected area of the building in all directions including the structures height. The significance being that the larger the structure, the more likely it is to be struck.
- The intended use of the structure. Is it a factory, office block, church or, perhaps a hospital?
- The type of construction. Is it built of brick or concrete or does it have a steel frame or metal roof?
- What is contained within the structure? Does it contain valuable paintings or important telephone exchange equipment?
- The location of the structure. Is it located in a town, a forest area or an isolated hillside?
- The topography of the surrounding countryside. Is the structure located in generally flat terrain or mountainous region?

It is acknowledged that not all factors can be assessed logically. For example, there may be times when occupants of a building must feel 'fully protected' and in this situation the installation of a lightning protective system would be justified. The final decision can only be taken after consultation with the specialist provider, the architect and the client.

DEFINITIONS AND ABBREVIATIONS

Definitions

Lightning protective system – The whole system of conductors used to protect a structure from the effects of lightning.

Air termination or Air termination network – The part of a lightning protective system intended to intercept lightning discharges.

Down conductor – A conductor that connects an air termination to the earth termination.

Earth termination – That part of a lightning protective system that is intended to discharge lightning currents into the general mass of earth. (These consist of all parts below the lowest testing point in a down conductor.)

Earth electrode – That part of the earth terminal that makes direct electrical contact with the earth.

Bond – A conductor intended to provide electrical connection between the lightning protective system and other metalwork.

Joint – A mechanical and electrical junction between two or more portions of the lightning protective system.

Testing joint – A joint designed and situated so as to enable resistance or continuity measurements to be made.

Abbreviation

H.C. = horizontal conductor
V.C. = vertical conductor
Z.P. = zone of protection (boundary indicated by dotted lines)

Zone of protection

This term denotes the space within which a lightning conductor provides protection against a direct lightning strike by diverting the strike to itself. The protected zone is contained by a cone with its apex at the highest point of the conductor and its sides radiating out at an angle of 45° from the vertical as shown in Figure 1.127.

Installation of lightning protection

Air terminations Should be made from copper, aluminium or galvanized steel. They may consist of a vertical conductor as for a spire, a single horizontal conductor as on the ridge of a small building, or a system of horizontal conductors for the protection of roofs of large dimensions. For flat roofs an air termination along the outer perimeter of the roof is required.

No part of the roof should be more than 10 m from the nearest horizontal protective conductor (BS 6651: Section 3).

All metallic projections, chimneys, ducts, vent pipes, railings, gutters, etc. on or above the main surface of the roof structure should be bonded to and, therefore, form part of the air termination network. The method of fixing should be simple, solid and permanent.

Down conductors Should be made of aluminium or copper and the number of down conductors should be decided as follows:

- Structures with a base are not exceeding 100 m – one down conductor.

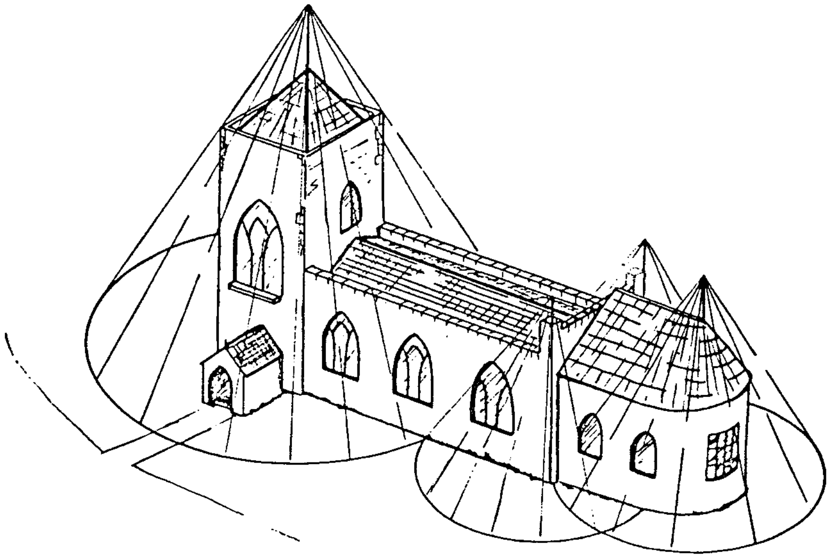


Fig. 1.127 The zone of protection for a structure is given by a cone with its apex at the highest point of the air termination.

- Structures with a base area greater than 100 m – either
  (a) one, plus one for every 300 m in excess of the first 100 m or,
  (b) one for every 30 m of perimeter – whichever is the smaller number.

The down conductor should be as straight as possible as shown in Figure 1.128 and it is very unwise to bend the rods to conform with architectural fancies. If a rod is struck by lightning (and this is the desired outcome) the inductance of a conductor that has been bent back on itself is higher than that of a straight one. The discharging current may take short cuts – seriously damaging masonry and endangering people's lives.

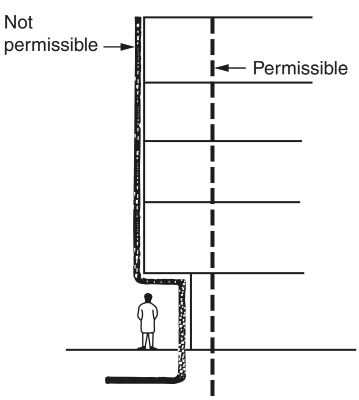


Fig. 1.128 Down conductors must always be as straight as possible to prevent flash over.

The routing of the down conductor must take account of its accessibility for inspection, testing and maintenance.

The lightning protective system should have as few joints as possible, but where necessary, these should be mechanically and electrically effective.

The cross-section of the bonds should not be less than that employed for the main conductors.

Every down conductor should be provided with a *testing joint* in such a position that, whilst not inviting unauthorized interference, is convenient for use when testing.

Earth termination There should be an earth termination to each down conductor. Each earth terminal should have a resistance to earth not exceeding 10 Ω × the number of earth terminals. The whole lightning system should have a combined resistance to earth not exceeding 10 Ω.

For example, if a system has four down conductors the maximum value for each earth terminal will be 40 Ω. This gives a total resistance for the whole system of

$$\frac{1}{R_T} = \frac{1}{40} + \frac{1}{40} + \frac{1}{40} + \frac{1}{40} = \frac{1+1+1+1}{40}$$

$$\frac{1}{R_T} = \frac{4}{40} \quad \therefore R_T = \frac{40}{4} = 10\,\Omega$$

If the value of the whole system is greater than 10 Ω a reduction can be achieved by adding to the earth electrodes or by interconnecting the individual earth terminations below ground.

Reducing the resistance to earth below 10 Ω has the advantage of reducing the potential gradient around the earth electrode when discharging lightning currents ($V = I \times R$).

As the lightning current is discharged through the earth electrode, the surrounding soil is raised for the duration of the discharge to a potential with respect to the body of the earth (similar to the ripples radiating from a pebble thrown into a pond). Such a potential difference may be lethal to a person if it exceeds a few thousand volts and to an animal if it exceeds a few hundred volts.

Earth electrodes Should be made from metal rods or strips, or a combination of both.

When rods are used they should be driven into the ground beneath or close to the structure. The length of the earth electrode is dependent on soil conditions. Section 3 of BS 6651, system design, is very informative.

Water and other service pipes are not recommended as a primary earthing connection but they may be considered as secondary terminations and in any event should be bonded together and to the lightning protective system.

Corrosion Precautions This must be taken and corrosion inhibitor must be used on all joints and bonds.

Inspection by a competent person must be made at least once a year and the following tests carried out:

- Resistance to earth
- Electrical continuity
- Visual inspection of bonds and joints.

Records must be kept on site or held by a responsible person of:

- Scale drawing – showing all components and any alterations
- Nature of soil – special earthing requirements
- Date and particulars of salting, if used
- Test conditions and results
- Name of the responsible person.

Little maintenance should be necessary but inspection and testing will indicate any maintenance required.

Particular attention should be paid to any corrosion or alterations to the structure that may affect the lightning protective system. Examples are changes in the use of the building, the installation of fuel storage tanks or the erection of radio or television or communication masts.

Further details may be obtained from the British Standard or from specialist suppliers and installers such as W.J. Furse & Co. Ltd., Wilford Road, Nottingham NG2 1EB Tel. (0115) 9643700 or www.furse.com.

Other industrial wiring systems and special installations relating to farms, caravan sites, flammable and explosive installations are described in Chapter 4 of Basic Electrical Installation Work, 4th edition.

Exercises

1 To avoid back injuries when manually lifting heavy weights from ground level a worker should:
(a) bend both legs and back
(b) bend legs but keep back straight
(c) keep legs straight but bend back
(d) keep both legs and back straight.

2 For any fire to continue to burn three components must be present. These are:
(a) fuel, wood, cardboard
(b) petrol, oxygen, bottled gas
(c) flames, fuel, heat
(d) fuel, oxygen, heat.

3 A CO_2 gas fire extinguisher, colour-coded black, is suitable on:
(a) class A fires only
(b) class A and B fires only
(c) class B and C fires only
(d) class A, B and C fires.

4 The recommended voltage for portable hand tools on construction sites is:
(a) 50 V
(b) 110 V
(c) 230 V
(d) 400 V.

5 Meeting the customer's expectations regarding performance, reliability and durability is one definition of:
(a) quality
(b) quality control
(c) quality assurance
(d) total quality management.

6 Making quality a way of life in a company is one definition of:
(a) quality

(b) quality control
(c) quality assurance
(d) total quality management.

7 Monitoring processes and procedures to eliminate defects is one definition of:
(a) quality
(b) quality control
(c) quality assurance
(d) total quality management.

8 Post-production inspection of goods is one definition of:
(a) quality
(b) quality control
(c) quality assurance
(d) total quality management.

9 The current taken by a 10 Ω resistor when connected to a 230 V supply is:
(a) 41 mA
(b) 2.3 A
(c) 23 A
(d) 230 A.

10 The resistance of an element which takes 12 A from a 230 V supply is:
(a) 2.88 Ω
(b) 5 Ω
(c) 12.24 Ω
(d) 19.16 Ω.

11 A 12 Ω lamp was found to be taking a current of 2 A at full brilliance. The voltage across the lamp under these conditions was:
(a) 6 V
(b) 12 V
(c) 24 V
(d) 240 V.

12 The resistance of 100 m of 1 mm^2 cross-section copper cable of resistivity 17.5×10^{-9} Ωm will be:
(a) 1.75 mΩ
(b) 1.75 Ω
(c) 17.5 Ω
(d) 17.5 kΩ.

13 The resistance of a motor field winding at 0°C was found to be 120 Ω. Find its new resistance at 20°C if the temperature coefficient of the winding is 0.004 Ω/Ω°C.
(a) 116.08 Ω
(b) 120.004 Ω
(c) 121.08 Ω
(d) 140.004 Ω.

14 The resistance of a motor field winding was found to be 120 Ω at an ambient temperature of 20°C. If the temperature coefficient of resistance is 0.004 Ω/Ω°C the resistance of the winding at 60°C will be approximately:
(a) 102 Ω
(b) 120 Ω
(c) 130 Ω
(d) 138 Ω.

15 A capacitor is charged by a steady current of 5 mA for 10 seconds. The total charge stored on the capacitor will be:
(a) 5 mC
(b) 50 mC
(c) 5 C
(d) 50 C.

16 When 100 V was connected to a 20 μF capacitor the charge stored was:
(a) 2 mC
(b) 5 mC
(c) 20 mC
(d) 100 mC.

17 An air dielectric capacitor is often used:
(a) for power-factor correction of fluorescents
(b) for tuning circuits
(c) when correct polarity connections are essential
(d) when only a very small physical size can be accommodated by the circuit enclosure.

18 An electrolytic capacitor:
(a) is used for power-factor correction in fluorescents
(b) is used for tuning circuits
(c) must only be connected to the correct polarity
(d) has a small capacitance for a large physical size.

19 A paper dielectric capacitor is often used:
(a) for power-factor correction in fluorescents
(b) for tuning circuits
(c) when correct polarity connections are essential
(d) when only a small physical size can be accommodated in the circuit enclosure.

20 A current flowing through a solenoid sets up a magnetic flux. If an iron core is added to the solenoid while the current is maintained at a constant value the magnetic flux will:
(a) remain constant
(b) totally collapse
(c) decrease in strength
(d) increase in strength.

21 Resistors of 6 and 3 Ω are connected in series. The combined resistance value will be:
(a) 2 Ω
(b) 3.6 Ω

(c) 6.3 Ω
(d) 9 Ω.

22 Resistors of 3 and 6 Ω are connected in parallel. The equivalent resistance will be:
(a) 2 Ω
(b) 3.6 Ω
(c) 6.3 Ω
(d) 9 Ω.

23 Three resistors of 24, 40 and 60 Ω are connected in series. The total resistance will be:
(a) 12 Ω
(b) 26.4 Ω
(c) 44 Ω
(d) 124 Ω.

24 Resistors of 24, 40 and 60 Ω are connected together in parallel. The effective resistance of this combination will be:
(a) 12 Ω
(b) 26.4 Ω
(c) 44 Ω
(d) 124 Ω.

25 Two identical resistors are connected in series across a 12 V battery. The voltage drop across each resistor will be:
(a) 2 V
(b) 3 V
(c) 6 V
(d) 12 V.

26 Two identical resistors are connected in parallel across a 24 V battery. The voltage drop across each resistor will be:
(a) 6 V
(b) 12 V
(c) 24 V
(d) 48 V.

27 A 6 Ω resistor is connected in series with a 12 Ω resistor across a 36 V supply. The current flowing through the 6 Ω resistor will be:
(a) 2 A
(b) 3 A
(c) 6 A
(d) 9 A.

28 A 6 Ω resistor is connected in parallel with a 12 Ω resistor across a 36 V supply. The current flowing through the 12 Ω resistor will be:
(a) 2 A
(b) 3 A
(c) 6 A
(d) 9 A.

29 The total power dissipated by a 6 Ω and 12 Ω resistor connected in parallel across a 36 V supply will be:
(a) 72 W
(b) 324 W
(c) 576 W
(d) 648 W.

30 Three resistors are connected in series and a current of 10 A flows when they are connected to a 100 V supply. If another resistor of 10 Ω is connected in series with the three series resistors the current carried by this resistor will be:
(a) 4 A
(b) 5 A
(c) 10 A
(d) 100 A.

31 The rms value of a sinusoidal waveform whose maximum value is 100 V will be:
(a) 63.7 V
(b) 70.71 V
(c) 100 V
(d) 100.67 V.

32 The average value of a sinusoidal alternating current whose maximum value is 10 A will be:
(a) 6.37 A
(b) 7.071 A
(c) 10 A
(d) 10.67 A.

33 Capacitors of 24, 40 and 60 μF are connected in series. The equivalent capacitance will be:
(a) 12 μF
(b) 44 μF
(c) 76 μF
(d) 124 μF.

34 Capacitors of 24, 40 and 60 μF are connected in parallel. The total capacitance will be:
(a) 12 μF
(b) 44 μF
(c) 76 μF
(d) 124 μF.

35 The core of a transformer is laminated to:
(a) reduce cost
(b) reduce copper losses
(c) reduce hysteresis loss
(d) reduce eddy current loss.

36 The transformation ratio of a step-down transformer is 20:1. If the primary voltage is 230 V the secondary voltage will be:
(a) 2.3 V

(b) 11.5 V
(c) 23 V
(d) 46 V.

37 Before an ammeter can be removed from the secondary terminals of a current transformer connected to a load, the transformer terminals must be:
(a) open-circuited
(b) short-circuited
(c) connected to the primary winding
(d) connected to earth.

38 An a.c. series circuit has an inductive reactance of 4 Ω and a resistance of 3 Ω. The impedance of this circuit will be:
(a) 5 Ω
(b) 7 Ω
(c) 12 Ω
(d) 25 Ω.

39 An a.c. series circuit has a capacitive reactance of 12 Ω and a resistance of 9 Ω. The impedance of this circuit will be:
(a) 3 Ω
(b) 15 Ω
(c) 20 Ω
(d) 108 Ω.

40 A circuit whose resistance is 3 Ω, reactance 5 Ω and impedance 5.83 Ω will have a p.f. of:
(a) 0.515
(b) 0.600
(c) 0.858
(d) 1.666.

41 A circuit whose resistance is 5 Ω, capacitive reactance 12 Ω and inductive reactance 20 Ω will have an impedance of:
(a) 9.434 Ω
(b) 21.189 Ω
(c) 23.853 Ω
(d) 32.388 Ω.

42 The inductive reactance of a 100 mH coil when connected to 50 Hz will be:
(a) 0.5 Ω
(b) 0.0318 Ω
(c) 5.0 Ω
(d) 31.416 Ω.

43 The capacitive reactance of a 100 μF capacitor connected to a 50 Hz supply will be:
(a) 0.5 Ω
(b) 5.0 mΩ
(c) 31.83 Ω
(d) 31415.93 Ω.

44 In a series resonant circuit the:
(a) current and impedance are equal
(b) current is at a minimum and the impedance a maximum
(c) current is at a maximum and the impedance a minimum
(d) current and impedance are at a maximum.

45 In a series resonant circuit the:
(a) capacitive and inductive reactances are equal
(b) capacitive and inductive reactances are at a minimum value
(c) capacitive and inductive reactances are at a maximum value
(d) capacitive and inductive reactances are equal to the resistance of the circuit.

46 A circuit containing a 100 μF capacitor in series with a 100 mH inductor will resonate at a frequency of:
(a) 3.142 Hz
(b) 50.33 Hz
(c) 316.23 Hz
(d) 10 kHz.

47 A series circuit consisting of a 25.33 mH inductor and 100 μF capacitor will have a resonant frequency of:
(a) 2.53 Hz
(b) 79.58 Hz
(c) 90 Hz
(d) 100 Hz.

48 A capacitor is connected across the supply at a fluorescent light fitting to:
(a) increase the voltage
(b) increase the current
(c) suppress radio interference
(d) improve the power factor.

49 Capacitors of 24, 40 and 60 μF are connected in series. The equivalent capacitance will be:
(a) 12 μF
(b) 44 μF
(c) 76 μF
(d) 124 μF.

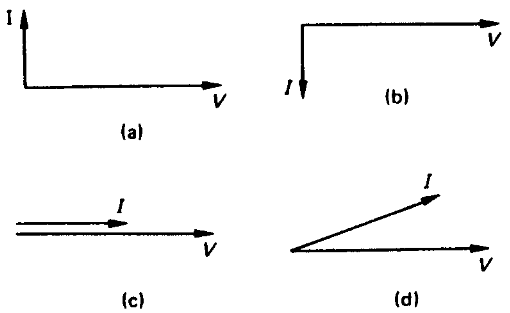
50 Capacitors of 24, 40 and 60 μF are connected in parallel. The total capacitance will be:
(a) 12 μF
(b) 44 μF
(c) 76 μF
(d) 124 μF.

51 Two a.c. voltages V_1 and V_2 have values of 20 and 30 V, respectively. If V_1 leads V_2 by 45° the

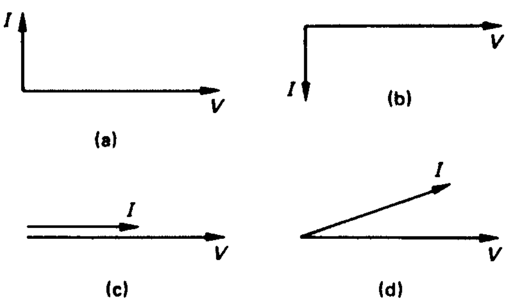
resultant voltage will be:
(a) 16 V at 24°
(b) 45 V at 90°
(c) 46 V at 18°
(d) 50 V at 45°.

52 Two parallel branch currents I_1 and I_2 are found to have values of 9 and 12 A, respectively. If I_1 leads I_2 by 90° the resultant current will be:
(a) 3 A at 21°
(b) 10.5 A at 90°
(c) 15 A at 37°
(d) 21 A at 45°.

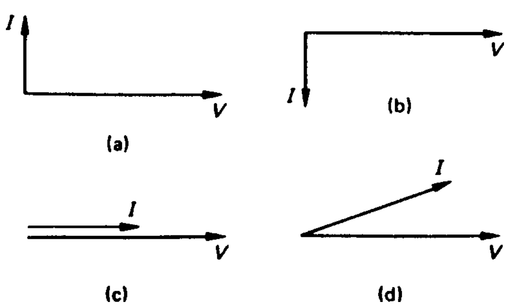
53 The phasor diagram which shows *V* and *I* at a power factor of unity is:



54 The phasor diagram for a lagging p.f. is given by:



55 The phasor diagram for a purely capacitive circuit is given by:



56 The transmission of electricity is, for the most part, by overhead conductors suspended on steel towers because:
(a) this is environmentally more acceptable than running cables underground
(b) this is very many times cheaper than running an equivalent cable underground
(c) high-voltage electricity cables cannot be buried on agricultural land
(d) more power can be carried by overhead conductors than is possible by an underground cable.

57 A ring distribution system of electrical supply:
(a) is cheaper than a radial distribution system
(b) can use smaller supply cables than a radial distribution system
(c) offers greater security of supply than a radial distribution system
(d) is safer than a radial system.

58 A TN-S system of electrical supply:
(a) uses a separate neutral and protective conductor throughout the system
(b) uses a combined protective and neutral conductor
(c) does not provide the consumer with an earth terminal and the installation's circuit protective conductors must be connected to earth by an earth electrode provided by the consumer
(d) is isolated from earth.

59 A TN-C-S system of electrical supply:
(a) uses a separate neutral and protective conductor throughout the system
(b) uses a combined protective and neutral conductor
(c) does not provide the consumer with an earth terminal and the installation's circuit protective conductors must be connected to earth by an earth electrode provided by the consumer
(d) is isolated from earth.

60 An off-peak supply is available to a consumer:
(a) for water heating purposes only
(b) during the day time only
(c) during the night time only
(d) at all times provided that peak demand does not exceed 4 hours.

61 A small blow-torch burn to the arm of a workmate should be treated by:
(a) immersing in cold water before applying a clean dry dressing

(b) pricking blisters before applying a clean dry dressing
(c) covering burned skin with cream or petroleum jelly to exclude the air before applying a clean dry dressing
(d) applying direct pressure to the burned skin to remove the heat from the burn and relieve the pain.

62 One advantage of a steel conduit installation, compared with a PVC conduit installation, is that it:
(a) may be easily rewired
(b) may be installed more quickly
(c) offers greater mechanical protection
(d) may hold more conductors for a given conduit size.

63 The earth continuity of a metallic conduit installation will be improved if:
(a) black enamel conduit is replaced by galvanized conduit
(b) the installation is painted with galvanized paint
(c) the installation is painted with bright orange paint
(d) all connections are made tight and secure during installation.

64 The earth continuity of a metallic trunking installation may be improved if:
(a) copper earth straps are fitted across all joints
(b) galvanized trunking is used
(c) all joints are painted with galvanized paint
(d) a space factor of 45% is not exceeded.

65 Circuits of Band 1 and 2 can
(a) never be installed in the same trunking
(b) only be installed in the same trunking if they are segregated by metal enclosures
(c) only be installed in the same trunking if a space factor of 45% is not exceeded
(d) only be wired in MI cables.

66 An industrial installation of PVC/SWA cables laid on cable tray offers the advantage over other types of installation of:
(a) greater mechanical protection
(b) greater flexibility in response to changing requirements
(c) higher resistance to corrosion in an industrial atmosphere
(d) flameproof installation suitable for hazardous areas.

67 The cables which can best withstand high temperatures are:
(a) MI cables
(b) PVC cables with asbestos oversleeves
(c) PVC/SWA cables
(d) PVC cables in galvanized conduit.

68 A coil is made up of 30 m of conductor and is laid within and at right angles to a magnetic field of 4 T. The force exerted upon this coil when 5 A flows will be:
(a) 1.875 N
(b) 30 N
(c) 240 N
(d) 600 N.

69 An instrument coil of 20 mm diameter is wound with 100 turns and placed within and at right angles to a magnetic field of flux density 5 T. The force exerted on this coil when 15 mA flows in the coil conductors will be:
(a) 0.15 N
(b) 0.47 N
(c) 0.628 N
(d) 1.875 N.

70 The synchronous speed N_s of a four-pole machine connected to a 50 Hz supply will be:
(a) 200 rpm
(b) 750 rpm
(c) 1500 rpm
(d) 3000 rpm.

71 A four-pole induction motor running at 1425 rpm has a percentage slip of:
(a) 2%
(b) 5%
(c) 52.5%
(d) 75%.

72 A laminated cylinder of silicon steel with copper or aluminium bars slotted into holes around the circumference and short-circuited at each end of the cylinder, is one description of:
(a) a cage rotor
(b) an electromagnet
(c) a linear motor
(d) an induction motor.

73 All electric motors with a rating above 0.37 kW must be supplied with:
(a) protection by MCB
(b) protection by HBC fuses
(c) a motor starter
(d) remote stop/start switches.

74 A star delta starter:
(a) increases the initial starting torque of the motor
(b) reduces the initial starting current of the motor
(c) gives direct connection of the main voltage to the motor during starting
(d) requires only three connecting conductors between the motor and starter.

75 An auto-transformer starter:
(a) increases the initial starting torque of the motor
(b) increases the initial starting current of the motor
(c) gives direct connection of the mains voltage to the motor during starting
(d) requires only three connecting conductors between the motor and starter.

76 When an electric motor is to be connected to a load via a vee belt, it is recommended that the motor be mounted:
(a) firmly and secured by raw bolts
(b) firmly and secured on slide rails
(c) loosely and connected by flexible conduit
(d) adjacent to the motor starter.

77 A series d.c. motor has the characteristic of:
(a) constant speed about 5% below synchronous speed
(b) start winding 90° out of phase with the run winding
(c) low starting torque but almost constant speed
(d) high starting torque and a speed which varies with load.

78 A shunt motor has the characteristic of:
(a) constant speed about 5% below synchronous speed
(b) start winding 90° out of phase with the run winding
(c) low starting torque but almost constant speed
(d) high starting torque and a speed which varies with load.

79 A three-phase induction motor has the characteristic of:
(a) constant speed about 5% below synchronous speed
(b) start winding 90° out of phase with the run winding
(c) high starting torque but almost constant speed
(d) high starting torque and a speed which varies with load.

80 A single-phase induction motor has:
(a) variable speed control operated by a centrifugal switch
(b) a start winding approximately 90° out of phase with the run winding
(c) high starting torque and almost constant speed
(d) high starting torque and a speed which varies with load.

81 One advantage of all d.c. machines is:
(a) that they are almost indestructible
(b) that starters are never required
(c) that they may be operated on a.c. or d.c. supplies
(d) the ease with which speed may be controlled.

82 One advantage of a cage rotor is:
(a) that it is almost indestructible
(b) that starters are never required
(c) that it may be operated on a.c. or d.c. supplies
(d) the ease with which speed may be controlled.

83 One advantage of a series d.c. motor is that:
(a) it is almost indestructible
(b) starters are never required
(c) it may be operated on a.c. or d.c. supplies
(d) speed is constant at all loads.

84 A shaded pole motor would normally be used for:
(a) an industrial process drive motor
(b) a portable electric drill motor
(c) a constant speed lathe motor
(d) a record turntable drive motor.

85 A d.c. shunt motor would normally be used for a:
(a) domestic oven fan motor
(b) portable electric drill motor
(c) constant speed lathe motor
(d) record turntable drive motor.

86 A d.c. series motor would normally be used for a:
(a) domestic oven fan motor
(b) portable electric drill motor
(c) constant speed lathe motor
(d) record turntable drive motor.

87 A 7.5 kW motor with a p.f. of 0.866 is connected to a 400 V 50 Hz supply. Calculate:
(a) the current taken by the motor
(b) the value of the capacitor required to correct the p.f. to unity.

88 Four 1 mm cables and four 2.5 mm cables are to be run in a metal conduit which contains one right-angle bend and one double set. The distance between the boxes is 8 m. Find the size of conduit required to enclose these cables.

89 Determine the minimum size of trunking required to contain the following stranded cables:
(a) 20×1.5 mm cables

(b) 16 × 2.5 mm cables
(c) 10 × 4.0 mm cables
(d) 20 × 6.0 mm cables.

90 Calculate the number of 1.0 mm cables which may be drawn into a 5 m straight run of 20 mm conduit.

91 Calculate the number of 2.5 mm cables which may be drawn into a 20 mm plastic conduit along with a 4.0 mm CPC if the distance between the boxes is 10 m and contains one right-angled bend.

92 Determine the size of galvanized steel conduit required to contain PVC insulated conductors if the distance between two boxes is 5 m and the conduit has two bends of 90°. The conduit must contain ten 1.5 mm cables and four 2.5 mm cables.

93 Calculate the number of PVC insulated 4.0 mm cables which may be installed in a 75 × 75 mm trunking.

94 (a) Calculate the minimum size of vertical trunking required to contain 20 × 10 mm PVC insulated cables.
(b) Explain why fire barriers are fitted in vertical trunking.
(c) Explain how and why cables are supported in vertical trunking.

95 A 10 Ω resistor is connected in series with an inductor of reactance 15 Ω across a 230 V a.c. supply. Calculate
(a) the impedance
(b) the current
(c) the voltage across each component
(d) the power factor.
Draw to scale the phasor diagram.

96 A 9 Ω resistor is connected in series with a capacitor of 265.25 μF across a 230 V 50 Hz supply. Calculate
(a) the impedance
(b) the current
(c) the voltage across each component
(d) the power factor.
Draw to scale the phasor diagram.

97 A 15 Ω resistor is connected in series with a 60 μF capacitor and a 0.1 H inductor across a 230 V 50 Hz supply. Draw the circuit diagram and calculate
(a) the impedance
(b) the current
(c) the voltage across each component
(d) the power factor.
Draw the phasor diagram to scale.

98 A pure inductor of 100 mH is connected in parallel with a 15 Ω resistor across a 230 V 50 Hz supply. Calculate the current in each branch and the total current and power factor. Sketch the phasor diagram.

99 A 60 μF capacitor is connected in parallel with a 20 Ω resistor across a 230 V 50 Hz supply. Calculate the current in each branch and the total current and power factor. Sketch the phasor diagram.

100 State the responsibilities under the Health and Safety at Work Act of:
(a) an employer to his employees
(b) an employee to his employer and fellow workers.

101 Safety signs are used in the working environment to give information and warnings. Describe the purpose of the four categories of signs and state their colour code and shape. You may use sketches to illustrate your answer.

102 A trainee electrician discovers a large well-established fire in a store-room of the building in which he is working. The building is an office block which is under construction but almost complete. There are six offices on each of six floors and the store-room and fire are in an office on the fourth floor of the building. The trainee knows that there are between 10 and 20 other construction workers somewhere in the building and that the fire alarm system is not connected. Describe the actions which the trainee should take to prevent this emergency becoming a disaster.

103 Describe the action to be taken upon finding a workmate apparently dead on the floor and connected to a live electrical supply.

104 Briefly identify the main difference between the Electricity at Work Regulations 1989 and the IEE Regulations, 16th edition (BS 7671).

105 State the requirements of the Electricity at Work Act with regard to
(a) 'live' testing and 'fault diagnosis'
(b) 'live working' to repair a fault.

106 Define 'isolation' with respect to an electrical circuit or item of equipment.

107 List a logical procedure for the isolation of an electrical circuit. Start from the point at which you choose the voltage indicating device and finish with the point at which you begin to work on the circuit.

108 Use a sketch to describe the construction of a test lead approved to HSE GS 38.

109 Write down 10 short bullet points that you think would lead to good customer relations.

110 What do people mean by 'team working'. Give an example from your own experience. Who was involved – what did each member of the team do.

111 Define what we mean by 'hazard' and 'risk'.

112 Briefly describe in no more that 100 words two quality systems often used by electrotechnical industries.

113 How does the work of the HSE Inspector and the Environmental Health Officer differ from the work of the Safety Officer and Safety Representative in a Company?

114 Very briefly describe any two of the Laws which protect people's legal rights.

115 Very briefly describe any two of the Laws which protect our environment.

116 Very briefly describe any two Regulations which protect the working environment.

117 Sketch an 11 kV ring distribution system suitable for supplying four load centres in a factory from a 33 kV primary substation. Show how the supply can be secured to all four load centres even though a fault occurs on a cable between two of the distribution substations.

118 Use a block diagram to describe the electrical equipment which should be installed in an 11 kV/400 V substation of brick construction.

119 Use a simple circuit diagram to show how a 230 and 400 V consumer may be connected to the supply company's TN-S system. Include in your diagram the supply authority's transformer.

120 Using a circuit diagram which shows the secondary winding of the supply transformer, show how a 230 and 400 V supply are connected to a TN-C-S system.

121 Show how a 230 and 400 V installation is connected to a TT system of supply. Clearly explain how an effective earth is obtained for the installation and the possible dangers in not providing an adequate earth connection.

122 Sketch the arrangements of the service position equipment at a 230 V installation supplied by:
(a) a TN-S system of supply
(b) a TN-C-S system of supply
(c) a TT system of supply.

123 A 400 V three-phase and neutral busbar rising main is to be used to provide a 230 V supply to each of eight individual flats on four floors of a building.
(a) Sketch the arrangement and describe how each flat's supply must be connected to the rising main if the total load is to be balanced.
(b) Describe the method used to prevent the spread of fire.

124 State the advantages and disadvantages of transmitting electricity:
(a) at very high voltage
(b) by overhead lines suspended on steel towers.

125 Describe with sketches the meaning of the terms *frequency* and *period* as applied to an a.c. wave-form.

126 Derive from first principles an expression for the resonant frequency of a series circuit.

127 Sketch a graph to show the variation of R, X_L, X_C, Z and I with frequency for a series a.c. circuit. Indicate the point at which resonance occurs on the graph using frequency as a base.

128 Describe, with the aid of a circuit diagram, how speed control may be achieved with:
(a) a d.c. series motor
(b) a d.c. shunt motor.

129 Describe what is meant by the back emf of an electric motor and describe the construction and operation of a d.c. motor starter.

130 With the aid of a sketch describe the construction of a cage rotor. State the advantages and disadvantages of a rotor constructed in this way.

131 With the aid of a sketch describe how the turning forces are established which rotate the cage rotor of an induction motor.

132 Describe how a rotating magnetic flux produces a turning force on the rotor conductors of an induction motor.

133 Describe, with sketches, the construction of a wound rotor and cage rotor. State one advantage and one disadvantage for each type of construction.

134 The Regulations require that motor starters incorporate overload protection and no-volt protection. Describe what is meant by overload protection and no-volt protection.

135 Sketch a three-phase direct on line motor starter and describe its operation.

136 Sketch the wiring diagram for a three-phase direct on line motor starter which incorporates remote stop/start buttons.

137 Sketch the wiring diagram for a star delta motor starter and describe its operation.

138 Sketch the wiring diagram for an auto-transformer motor starter and describe its operation.

139 Sketch the wiring diagram for a rotor resistance motor starter and describe its operation.

140 Use sketches to explain how an electric motor should be installed and connected to a load via a vee belt.

141 Use a block diagram to explain the sequence of control for an electric motor of about 5 kW.

142 Describe what is meant by the 'continuous rating' of a motor.

143 Describe three types of motor enclosure and state one typical application for each type.

144 Use a phasor diagram to explain the meaning of a 'bad power factor'. Describe two methods of correcting the bad power factor due to a number of industrial motors.

145 With the aid of neat sketches, describe the construction of:
(a) a double-wound transformer
(b) an auto-transformer
and state the losses which occur in a transformer.

146 Describe the construction and use of a voltage transformer.

147 Describe the construction and use of a bar primary current transformer.

148 Draw a circuit diagram to show an ammeter and current transformer connected to measure the current in a single-phase a.c. circuit. Explain why the secondary winding must not be open-circuited when the transformer is connected to the supply.

149 Draw a circuit diagram showing a voltmeter and voltage transformer connected to measure the voltage in a single-phase load.

150 Describe the construction of an oil-immersed transformer.

151 Describe what is meant by a tap changing transformer.

152 State three types of wiring system which would be suitable for an industrial environment.

153 Draw a metallic trunking 90° bend of the type which
(a) was supplied by a manufacturer and
(b) was made on site.

154 Describe with the aid of a sketch, how conductors in a vertical trunking are supported.

155 Describe the following parts of a lightning protective system
(a) The air termination
(b) The down conductor
(c) The earth electrode
(d) The zone of protection.

2

INSPECTION, TESTING AND COMMISSIONING

The construction industry

An electrician working for an electrical contracting company works as a part of the broader construction industry. This is a multi-million-pound industry carrying out all types of building work, from basic housing to hotels, factories, schools, shops, offices and airports. The construction industry is one of the UK's biggest employers, and carries out contracts to the value of about 10% of the UK's gross national product.

Although a major employer, the construction industry is also very fragmented. Firms vary widely in size, from the local builder employing two or three people to the big national companies employing thousands. Of the total workforce of the construction industry, 92% are employed in small firms of less than 25 people.

The yearly turnover of the construction industry is about £35 billion. Of this total sum, about 60% is spent on new building projects and the remaining 40% on maintenance, renovation or restoration of mostly housing.

In all these various construction projects the electrotechnical industries play an important role, supplying essential electrical services to meet the needs of those who will use the completed building.

The building team

The construction of a new building is a complex process which requires a team of professionals working together to produce the desired results. We can call this team of professionals the building team, and their interrelationship can be expressed by Fig. 2.1.

The client is the person or group of people with the actual need for the building, such as a new house, office or factory. The client is responsible for financing all the work and, therefore, in effect, employs the entire building team.

The architect is the client's agent and is considered to be the leader of the building team. The architect must interpret the client's requirements and produce working drawings. During the building process the architect will supervise all aspects of the work until the building is handed over to the client.

The quantity surveyor measures the quantities of labour and material necessary to complete the building work from drawings supplied by the architect.

Specialist engineers advise the architect during the design stage. They will prepare drawings and calculations on specialist areas of work.

The clerk of works is the architect's 'on-site' representative. He or she will make sure that the contractors carry out the work in accordance with the drawings and other contract documents. They can also agree general matters directly with the building contractor as the architect's representative.

The local authority will ensure that the proposed building conforms to the relevant planning and building legislation.

The health and safety inspectors will ensure that the government's legislation concerning health and safety is fully implemented by the building contractor.

The building contractor will enter into a contract with the client to carry out the construction work in

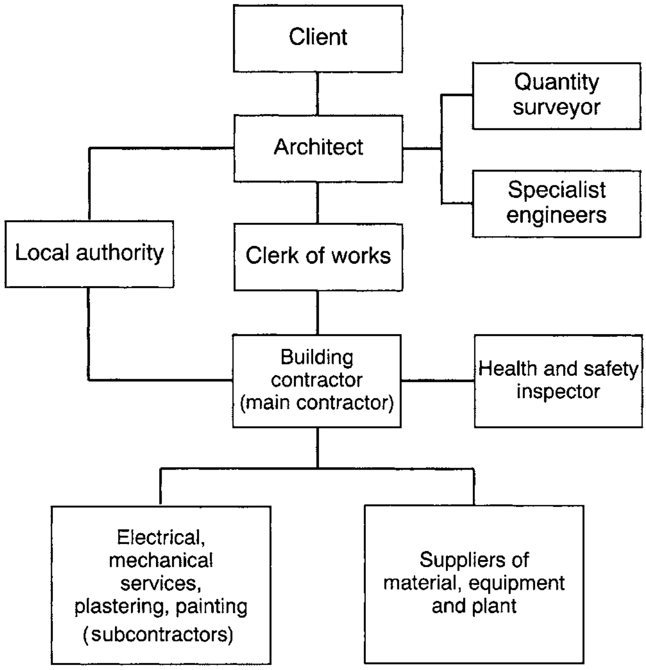


Fig. 2.1 The building team.

accordance with contract documents. The building contractor is the main contractor and he or she, in turn, may engage subcontractors to carry out specialist services such as electrical installation, mechanical services, plastering and painting.

The electrical team

The electrical contractor is the subcontractor responsible for the installation of electrical equipment within the building. An electrical contracting firm is made up of a group of individuals with varying duties and responsibilities. There is often no clear distinction between the duties of the individuals, and the responsibilities carried by an employee will vary from one employer to another. If the firm is to be successful, the individuals must work together to meet the requirements of their customers. Good customer relationships are important for the success of the firm and the continuing employment of the employee.

The customer or his representatives will probably see more of the electrician and the electrical trainee than the managing director of the firm and, therefore, the image presented by them is very important. They should always be polite and seen to capable and in command of the situation. This gives a customer confidence in the firm's ability to meet his or her needs. The electrician and his trainee should be appropriately dressed for the job in hand, which probably means an overall of some kind. Footwear is also important, but sometimes a difficult consideration for a journeyman electrician. For example, if working in a factory, the safety regulations may insist that protective footwear be worn, but rubber boots may be most appropriate for a building site. However, neither of these would be the most suitable footwear for an electrician fixing a new light fitting in the home of the managing director!

The electrical installation in a building is often carried out alongside other trades. It makes sound sense to help other trades where possible and to develop good working relationships with other employees.

The employer has the responsibility of finding sufficient work for his employees, paying government taxes and meeting the requirements of the Health and Safety at Work Act described in Chapter 1. The rates of pay and conditions for electricians and trainees are determined by negotiation between the Joint Industry Board and the Amalgamated Engineering and Electrical

Union, which will also represent their members in any disputes. Electricians are usually paid at a rate agreed for their grade as an electrician, approved electrician or technician electrician; movements through the grades are determined by a combination of academic achievement and practical experience.

The electrical team will consist of a group of professionals and their interrelationship can be expressed as shown in Fig. 2.2.

Designing an electrical installation

The designer of an electrical installation must ensure that the design meets the requirements of the IEE Wiring Regulations for electrical installations and any other regulations which may be relevant to a particular installation. The designer may be a professional technician or engineer whose job it is to design electrical installations for a large contracting firm. In a smaller firm, the designer may also be the electrician who will carry out the installation to the customer's requirements. The designer of any electrical installation is the person who interprets the electrical requirements of the customer within the regulations, identifies the appropriate types of installation, the most suitable methods of protection and control and the size of cables to be used.

A large electrical installation may require many meetings with the customer and his professional representatives in order to identify a specification of what is required. The designer can then identify the general characteristics of the electrical installation and its compatibility with other services and equipment, as indicated in Part 3 of the Regulations. The protection and safety of the installation, and of those who will use it, must be considered, with due regard to Part 4 of the Regulations. An assessment of the frequency and quality of the maintenance to be expected (Regulation 341–01–01) will give an indication of the type of installation which is most appropriate.

The size and quantity of all the materials, cables, control equipment and accessories can then be determined. This is called a 'bill of quantities'.

It is common practice to ask a number of electrical contractors to tender or submit a price for work specified by the bill of quantities. The contractor must cost all the materials, assess the labour cost required to install the materials and add on profit and overhead costs in order to arrive at a final estimate for the work. The contractor tendering the lowest cost is usually, but not always, awarded the contract.

To complete the contract in the specified time the electrical contractor must use the management skills required by any business to ensure that men and materials are on site as and when they are required. If alterations or modifications are made to the electrical installation as the work proceeds which are outside the original specification, then a variation order must be issued so that the electrical contractor can be paid for the additional work.

The specification for the chosen wiring system will be largely determined by the building construction and the activities to be carried out in the completed building.

An industrial building, for example, will require an electrical installation which incorporates flexibility and mechanical protection. This can be achieved by a conduit, tray or trunking installation.

In a block of purpose-built flats, all the electrical connections must be accessible from one flat without intruding upon the surrounding flats. A loop-in conduit system, in which the only connections are at the light switch and outlet positions, would meet this requirement.

For a domestic electrical installation an appropriate lighting scheme and multiple socket outlets for the connection of domestic appliances, all at a reasonable cost, are important factors which can usually be met by a PVC insulated and sheathed wiring system.

The final choice of a wiring system must rest with those designing the installation and those ordering the work, but whatever system is employed, good workmanship is essential for compliance with the regulations. The necessary skills can be acquired by an electrical trainee who has the correct attitude and dedication to his craft.

Legal contracts

Before work commences, some form of legal contract should be agreed between the two parties, that is, those providing the work (e.g. the subcontracting

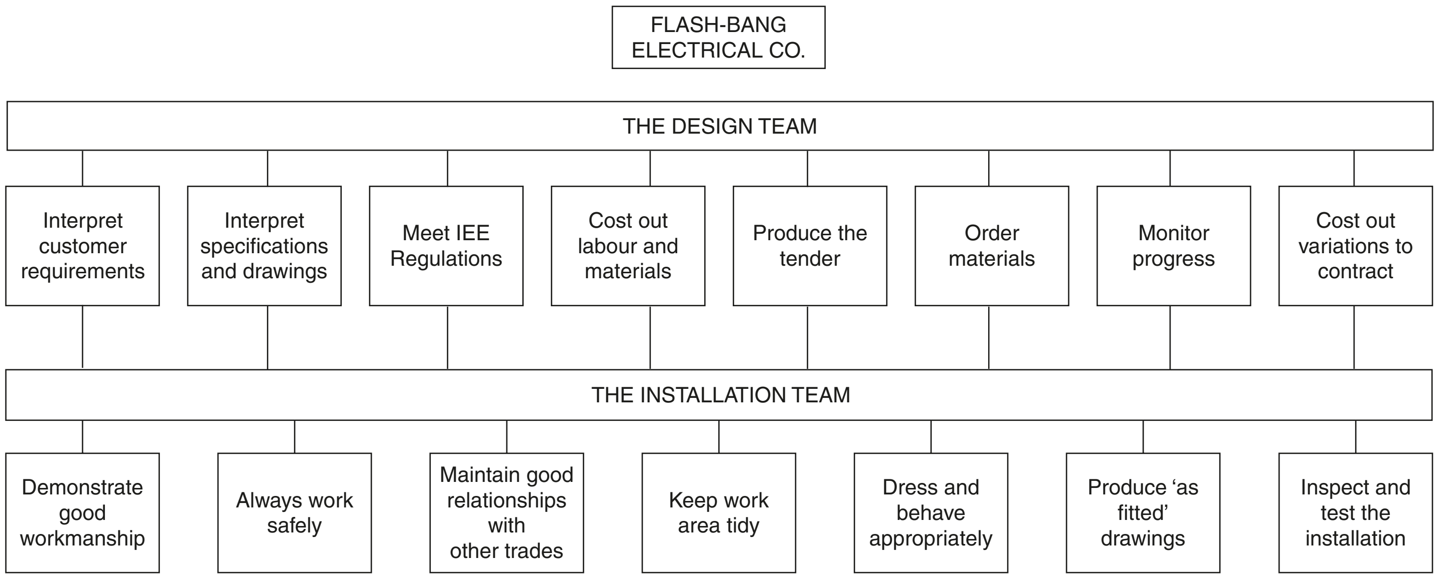


Fig. 2.2 The electrical team.

electrical company) and those asking for the work to be carried out (e.g. the main building company).

A contract is a formal document which sets out the terms of agreement between the two parties. A standard form of building contract typically contains four sections:

1 The articles of agreement – this names the parties, the proposed building and the date of the contract period.
2 The contractual conditions – this states the rights and obligations of the parties concerned, e.g. whether there will be interim payments for work completed, or a penalty if work is not completed on time.
3 The appendix – this contains details of costings, e.g. the rate to be paid for extras as daywork, who will be responsible for defects, how much of the contract tender will be retained upon completion and for how long.
4 The supplementary agreement – this allows the electrical contractor to recoup any value-added tax paid on materials at interim periods.

In signing the contract, the electrical contractor has agreed to carry out the work to the appropriate standards in the time stated and for the agreed cost. The other party, say the main building contractor, is agreeing to pay the price stated for that work upon completion of the installation.

If a dispute arises the contract provides written evidence of what was agreed and will form the basis for a solution.

For smaller electrical jobs, a verbal contract may be agreed, but if a dispute arises there is no written evidence of what was agreed and it then becomes a matter of one person's word against another's.

Management systems

Smaller electrical contracting firms will know where their employees are working and what they are doing from day to day because of the level of personal contact between the employer, employee and customer.

As a firm expands and becomes engaged on larger contracts, it becomes less likely that there is anyone in the firm with a complete knowledge of the firm's operations, and there arises an urgent need for sensible management and planning skills so that men and materials are on site when they are required and a healthy profit margin is maintained.

When the electrical contractor is told that he has been successful in tendering for a particular contract he is committed to carrying out the necessary work within the contract period. He must therefore consider:

- by what date the job must be finished;
- when the job must be started if the completion date is not to be delayed;
- how many men will be required to complete the contract;
- when certain materials will need to be ordered;
- when the supply authorities must be notified that a supply will be required;
- if it is necessary to obtain authorization from a statutory body for any work to commence.

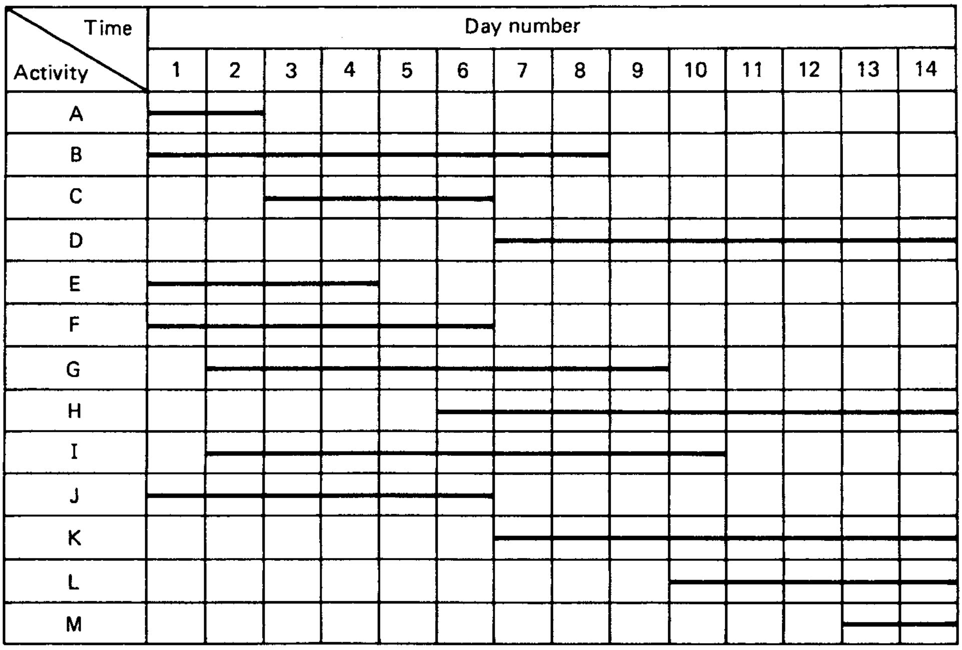
In thinking ahead and planning the best method of completing the contract, the individual activities or jobs must be identified and consideration given to how the various jobs are interrelated. To help in this process a number of management techniques are available. In this chapter we will consider only two: bar charts and network analysis. The very preparation of a bar chart or network analysis forces the contractor to think deeply, carefully and logically about the particular contract, and it is therefore a very useful aid to the successful completion of the work.

BAR CHARTS

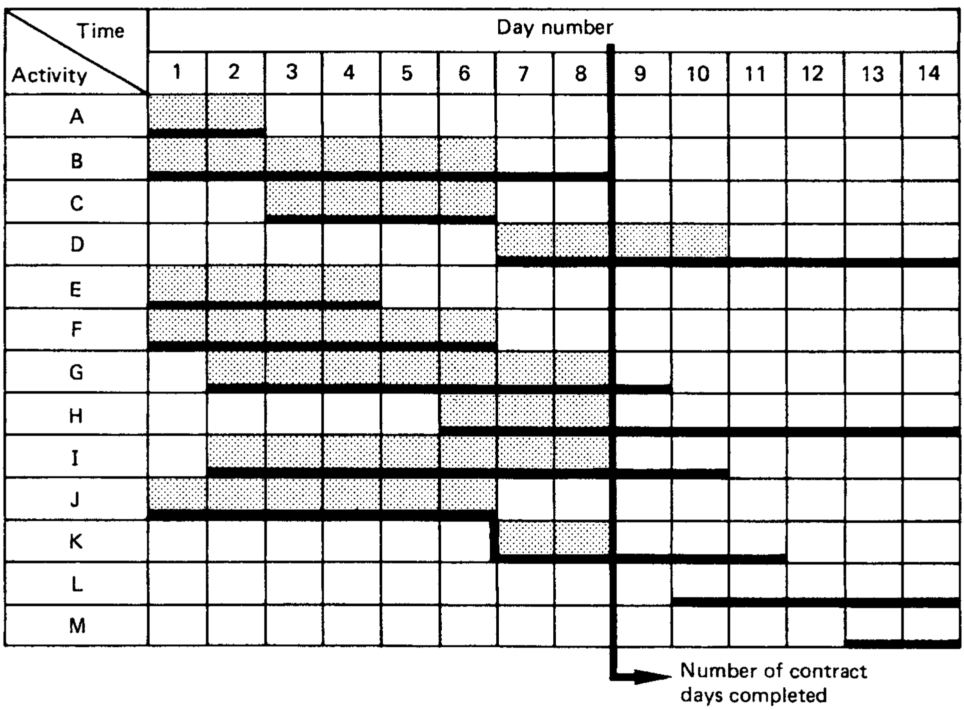
There are many different types of bar chart used by industry, but the object of any bar chart is to establish the sequence and timing of the various activities involved in the contract as a whole. They are a visual aid in the process of communication. In order to be useful they must be clearly understood by the people involved in the management of a contract. The chart is constructed on a rectangular basis, as shown in Fig. 2.3.

All the individual jobs or activities which make up the contract are identified and listed separately down the vertical axis on the left-hand side, and time flows from left to right along the horizontal axis. The unit of time can be chosen to suit the length of the particular contract, but for most practical purposes either days or weeks are used.

The simple bar chart shown in Fig. 2.3(a) shows a particular activity A which is estimated to last 2 days,



(a) A simple bar chart



(b) A modified bar chart indicating actual work completed

Fig. 2.3 Bar charts.

while activity B lasts 8 days. Activity C lasts 4 days and should be started on day 3. The remaining activities can be interpreted in the same way.

With the aid of colours, codes, symbols and a little imagination, much additional information can be included on this basic chart. For example, the actual work completed can be indicated by shading above the activity line as shown in Fig. 2.3(b) with a vertical line indicating the number of contract days completed; the activities which are on time, ahead of or behind time can easily be identified. Activity B in Fig. 2.3(b) is 2 days behind schedule, while activity D is 2 days ahead of schedule. All other activities are on time. Some activities must be completed before others can start. For example, all conduit work must be completely erected before the cables are drawn in. This is shown in Fig. 2.3(b) by activities J and K. The short vertical line between the two activities indicates that activity J must be completed before K can commence.

Useful and informative as the bar chart is, there is one aspect of the contract which it cannot display. It cannot indicate clearly the interdependence of the various activities upon each other, and it is unable to identify those activities which must strictly adhere to the time schedule if the overall contract is to be completed on time, and those activities in which some flexibility is acceptable. To overcome this limitation, in 1959 the CEGB developed the critical path network diagram which we will now consider.

NETWORK ANALYSIS

In large or complex contracts there are a large number of separate jobs or activities to be performed. Some can be completed at the same time, while others cannot be started until others are completed. A network diagram can be used to co-ordinate all the interrelated activities of the most complex project in such a way that all sequential relationships between the various activities, and the restraints imposed by one job on another, are allowed for. It also provides a method of calculating the time required to complete an individual activity and will identify those activities which are the key to meeting the completion date, called the critical path. Before considering the method of constructing a network diagram, let us define some of the terms and conventions we shall be using.

Critical path

This is the path taken from the start event to the end event which takes the longest time. This path denotes the time required for completion of the whole contract.

Float time

Float time, slack time or time in hand is the time remaining to complete the contract after completion of a particular activity.

$$\text{Float time} = \text{Critical path time} - \text{Activity time}$$

The total float time for any activity is the total leeway available for all activities in the particular path of activities in which it appears. If the float time is used up by one of the early activities in the path, there will be no float left for the remaining activities and they will become critical.

Activities

Activities are represented by an arrow, the tail of which indicates the commencement, and the head the completion of the activity. The length and direction of the arrows have no significance: they are not vectors or phasors. Activities require time, manpower and facilities. They lead up to or emerge from events.

Dummy activities

Dummy activities are represented by an arrow with a dashed line. They signify a logical link only, require no time and denote no specific action or work.

Event

An event is a point in time, a milestone or stage in the contract when the preceding activities are finished. Each activity begins and ends in an event. An event has no time duration and is represented by a circle which sometimes includes an identifying number or letter.

Time may be recorded to a horizontal scale or shown on the activity arrows. For example, the activity from event A to B takes 9 hours in the network diagram shown in Fig. 2.4.

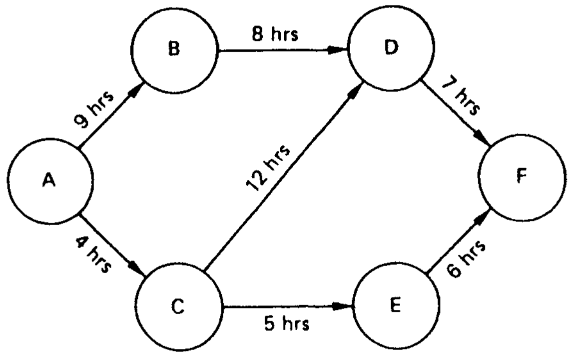


Fig. 2.4 A network diagram for Example 1.

EXAMPLE 1

Identify the three possible paths from the start event A to the finish event F for the contract shown by the network diagram in Fig. 2.4. Identify the critical path and the float time in each path.

The three possible paths are:

1 event A–B–D–F
2 event A–C–D–F
3 event A–C–E–F.

The times taken to complete these activities are:

1 path A–B–D–F = 9 + 8 + 7 = 24 hours
2 path A–C–D–F = 4 + 12 + 7 = 23 hours
3 path A–C–E–F = 4 + 5 + 6 = 15 hours.

The longest time from the start event to the finish event is 24 hours, and therefore the critical path is A–B–D–F.

The float time is given by

Float time = Critical path − Activity time

For path 1, A–B–D–F,

Float time = 24 hours − 24 hours = 0 hours

There can be no float time in any of the activities which form a part of the critical path since a delay on any of these activities would delay completion of the contract. On the other two paths some delay could occur without affecting the overall contract time. For path 2, A–C–D–F,

Float time = 24 hours − 23 hours = 1 hour

For path 3, A–C–E–F,

Float time = 24 hours − 15 hours = 9 hours

EXAMPLE 2

Identify the time taken to complete each activity in the network diagram shown in Fig. 2.5. Identify the three possible paths from the start event A to the final event G and state which path is the critical path.

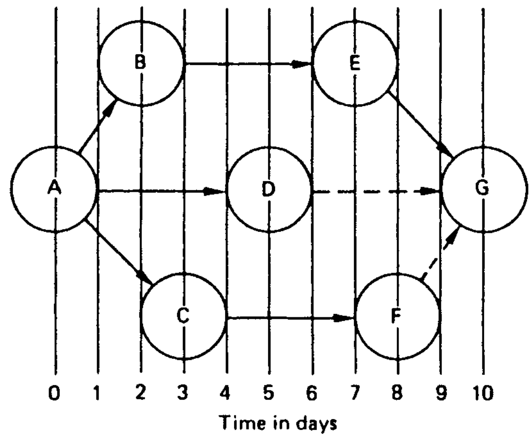


Fig. 2.5 A network diagram for Example 2.

The time taken to complete each activity using the horizontal scale is:

activity A–B = 2 days
activity A–C = 3 days
activity A–D = 5 days
activity B–E = 5 days
activity C–F = 5 days
activity E–G = 3 days
activity D–G = 0 days
activity F–G = 0 days

Activities D–G and F–G are dummy activities which take no time to complete but indicate a logical link only. This means that in this case once the activities preceding events D and F have been completed, the contract will not be held up by work associated with these particular paths and they will progress naturally to the finish event.

The three possible paths are:

1 A–B–E–G
2 A–D–G
3 A–C–F–G.

The times taken to complete the activities in each of the three paths are:

path 1, A–B–E–G = 2 + 5 + 3 = 10 days
path 2, A–D–G = 5 + 0 = 5 days
path 3, A–C–F–G = 3 + 5 + 0 = 8 days.

The critical path is path 1, A–B–E–G.

Constructing a network

The first step in constructing a network diagram is to identify and draw up a list of all the individual jobs, or activities, which require time for their completion and which must be completed to advance the contract from start to completion.

The next step is to build up the arrow network showing schematically the precise relationship of the various activities between the start and end event. The designer of the network must ask these questions:

1 Which activities must be completed before others can commence? These activities are then drawn in a similar way to a series circuit but with event circles instead of resistor symbols.
2 Which activities can proceed at the same time? These can be drawn in a similar way to parallel circuits but with event circles instead of resistor symbols.

Commencing with the start event at the left-hand side of a sheet of paper, the arrows representing the various activities are built up step by step until the final event is reached. A number of attempts may be necessary to achieve a well-balanced and symmetrical network diagram showing the best possible flow of work and information, but this time is well spent when it produces a diagram which can be easily understood by those involved in the management of the particular contract.

EXAMPLE 3

A particular electrical contract is made up of activities A to F as described below:

A = an activity taking 2 weeks commencing in week 1
B = an activity taking 3 weeks commencing in week 1
C = an activity taking 3 weeks commencing in week 4
D = an activity taking 4 weeks commencing in week 7
E = an activity taking 6 weeks commencing in week 3
F = an activity taking 4 weeks commencing in week 1.

Certain constraints are placed on some activities because of the availability of men and materials and because some work must be completed before other work can commence as follows:

Activity C can only commence when B is completed.
Activity D can only commence when C is completed.
Activity E can only commence when A is completed.
Activity F does not restrict any other activity.

(a) Produce a simple bar chart to display the activities of this particular contract.
(b) Produce a network diagram of the programme and describe each event.
(c) Identify the critical path and the total contract time.
(d) State the maximum delay which would be possible on activity E without delaying the completion of the contract.
(e) State the float time in activity F.

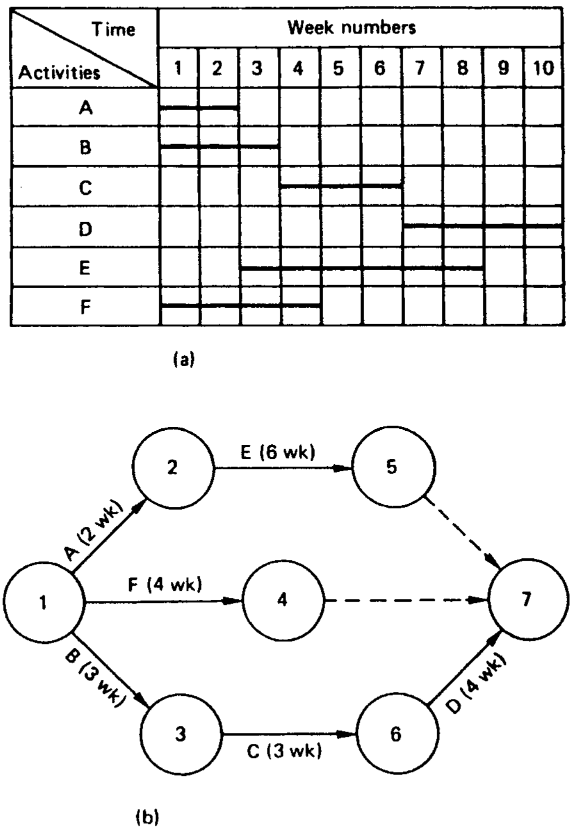


Fig. 2.6 (a) Bar chart and (b) network diagram for Example 3.

(a) A simple bar chart for this contract is shown in Fig. 2.6(a).
(b) The network diagram is shown in Fig. 2.6(b). The events may be described as follows:

Event 1 = the commencement of the contract.
Event 2 = the completion of activity A and the commencement of activity E.
Event 3 = the completion of activity B and the commencement of activity C.
Event 4 = the completion of activity F.
Event 5 = the completion of activity E.
Event 6 = the completion of activity C.
Event 7 = the completion of activity D and the whole contract.

(c) There are three possible paths:

1 via events 1–2–5–7
2 via events 1–4–7
3 via events 1–3–6–7.

The time taken for each path is:

path 1 = 2 weeks + 6 weeks = 8 weeks
path 2 = 4 weeks = 4 weeks
path 3 = 3 weeks + 3 weeks + 4 weeks = 10 weeks.

The critical path is therefore path 3, via events 1–3–6–7, and the total contract time is 10 weeks.

(d) We have that

Float time = Critical path time − Activity time

Activity E is on path 1 via events 1–2–5–7 having a total activity time of 8 weeks.

Float time = 10 weeks − 8 weeks = 2 weeks.

Activity E could be delayed for a maximum of 2 weeks without delaying the completion date of the whole contract.

(e) Activity F is on path 2 via events 1–4–7 having a total activity time of 4 weeks.

Float time = 10 weeks − 4 weeks = 6 weeks.

On-site communications

Good communication is about transferring information from one person to another. Electricians and other professionals in the construction trades communicate with each other and the general public by means of drawings, sketches and symbols in addition to what we say and do.

DRAWINGS AND DIAGRAMS

Many different types of electrical drawing and diagram can be identified: layout, schematic, block, wiring and circuit diagrams. The type of diagram to be used in any particular application is the one which most clearly communicates the desired information.

Layout drawings

These are scale drawings based upon the architect's site plan of the building and show the positions of the electrical equipment which is to be installed. The electrical equipment is identified by a graphical symbol.

The standard symbols used by the electrical contracting industry are those recommended by the British Standard BS EN 60617, *Graphical Symbols for Electrical Power, Telecommunications and Electronic Diagrams.* Some of the more common electrical installation symbols are given in Fig. 2.7.

A layout drawing is shown in Fig. 2.8 of a small domestic extension. It can be seen that the mains intake position, probably a consumer's unit, is situated in the store room which also contains one light controlled by a switch at the door. The bathroom contains one lighting point controlled by a one-way switch at the door. The kitchen has two doors and a switch is installed at each door to control the fluorescent luminaire. There are also three double sockets situated around the kitchen. The sitting room has a two-way switch at each door controlling the centre lighting point. Two wall lights with built in switches are to be wired, one at each side of the window. Two double sockets and one switched socket are also to be installed in the sitting room. The bedroom has two lighting points controlled independently by two oneway switches at the door.

The wiring diagrams and installation procedures for all these circuits can be found in Chapter 4 of *Basic Electrical Installation Work,* 4th Edition.

As-fitted drawings

When the installation is completed a set of drawings should be produced which indicate the final positions of all the electrical equipment. As the building and electrical installation progresses, it is sometimes necessary to modify the positions of equipment indicated on the layout drawing because, for example, the position of a doorway has been changed. The layout drawings indicate the original intentions for the positions of equipment, while the 'as-fitted' drawing indicates the actual positions of equipment upon completion of the job.

Detail drawings

These are additional drawings produced by the architect to clarify some point of detail. For example, a drawing might be produced to give a fuller description of the suspended ceiling arrangements.

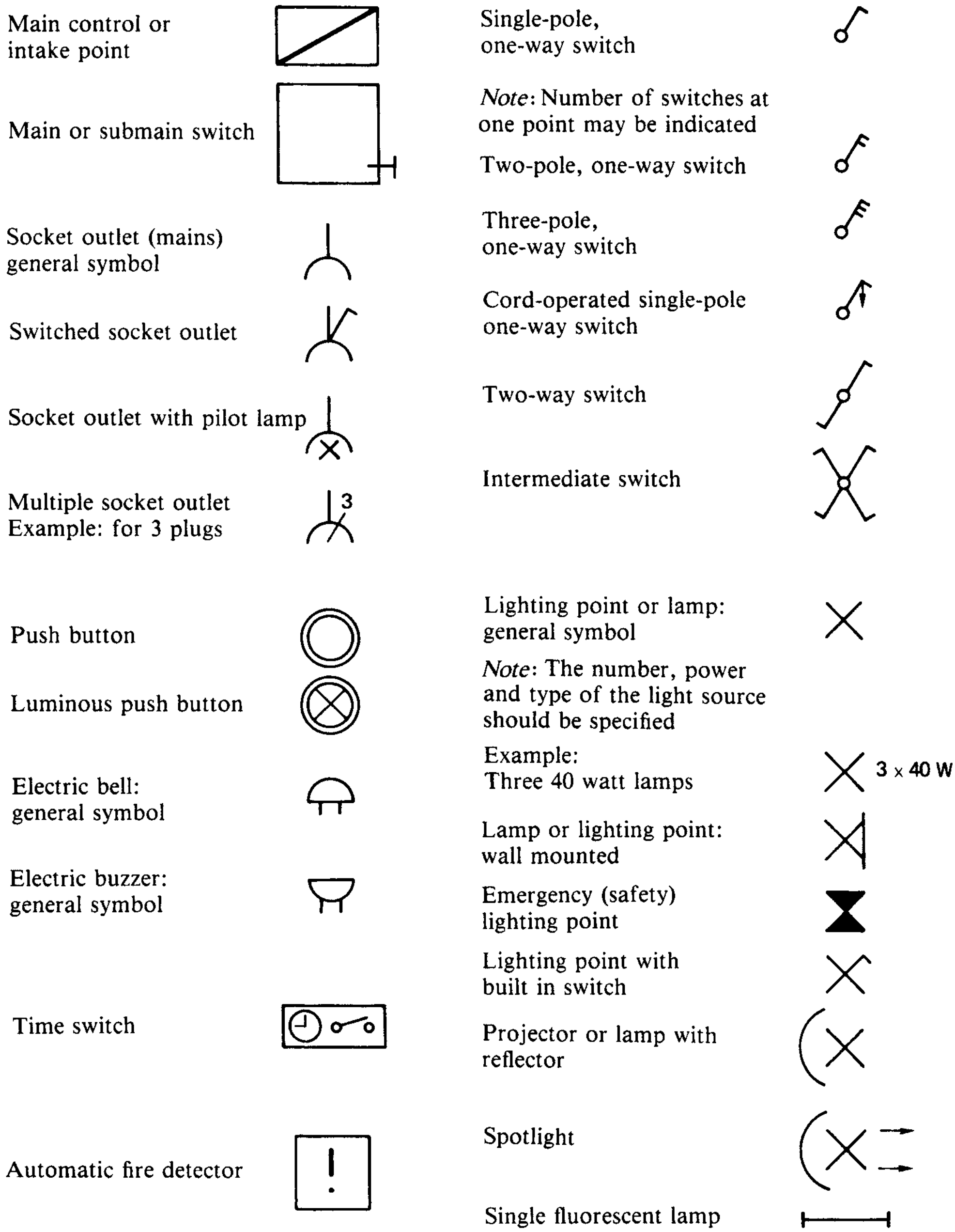


Fig. 2.7 Some BS EN 60617 installation symbols.

Schematic diagrams

A schematic diagram is a diagram in outline of, for example, a motor starter circuit. It uses graphical symbols to indicate the interrelationship of the electrical elements in a circuit. These help us to understand the working operation of the circuit.

An electrical schematic diagram looks very like a circuit diagram. A mechanical schematic diagram gives a more complex description of the individual elements in the system, indicating, for example, acceleration, velocity, position, force sensing and viscous damping.

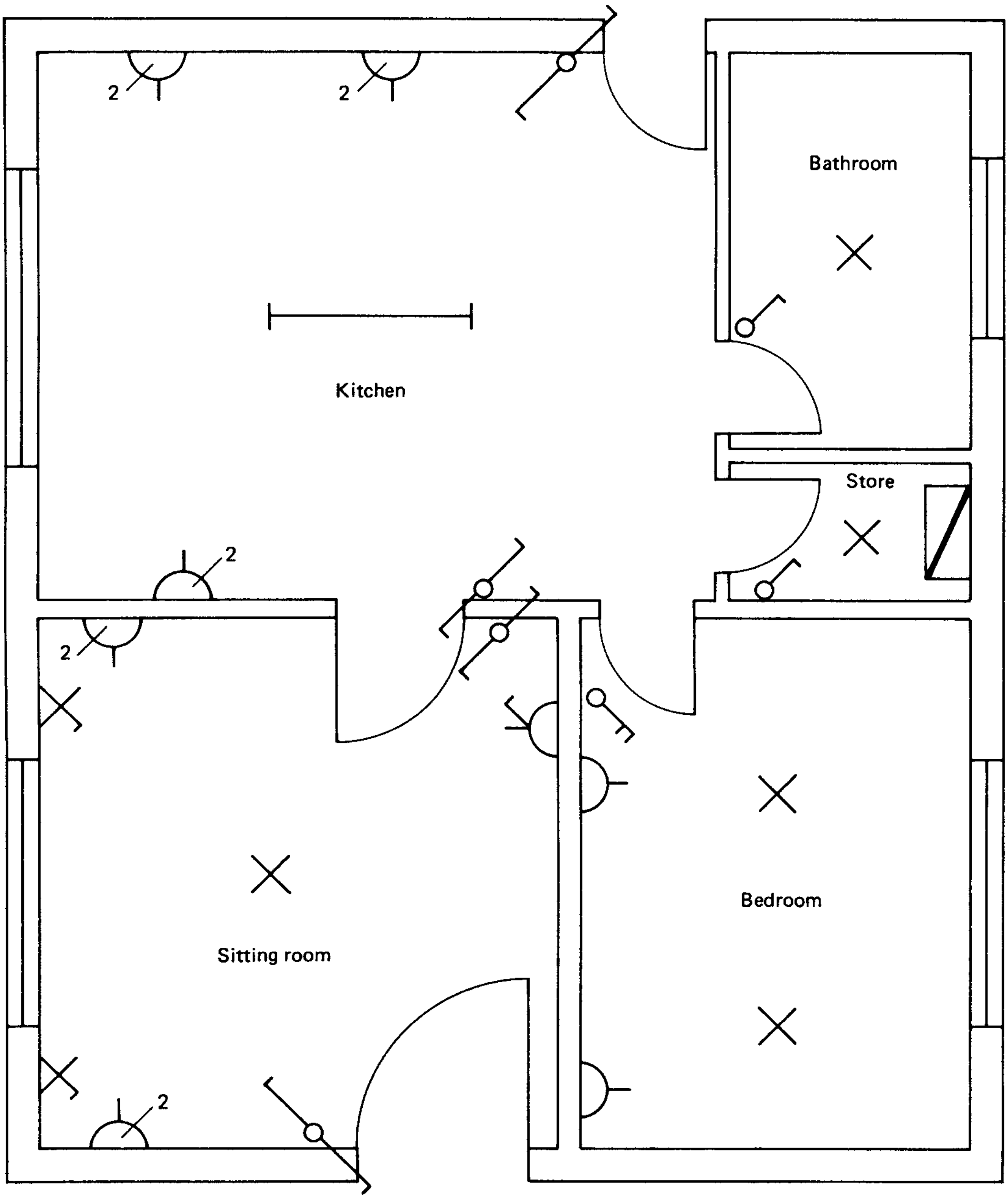


Fig. 2.8 Layout drawing for electrical installation.

Block diagrams

A block diagram is a very simple diagram in which the various items or pieces of equipment are represented by a square or rectangular box. The purpose of the block diagram is to show how the components of the circuit relate to each other and therefore the individual circuit connections are not shown. Figure 2.9 shows the block diagram of a high-voltage discharge lighting circuit.

Wiring diagrams

A wiring diagram or connection diagram shows the detailed connections between components or items of equipment. They do not indicate how a piece of

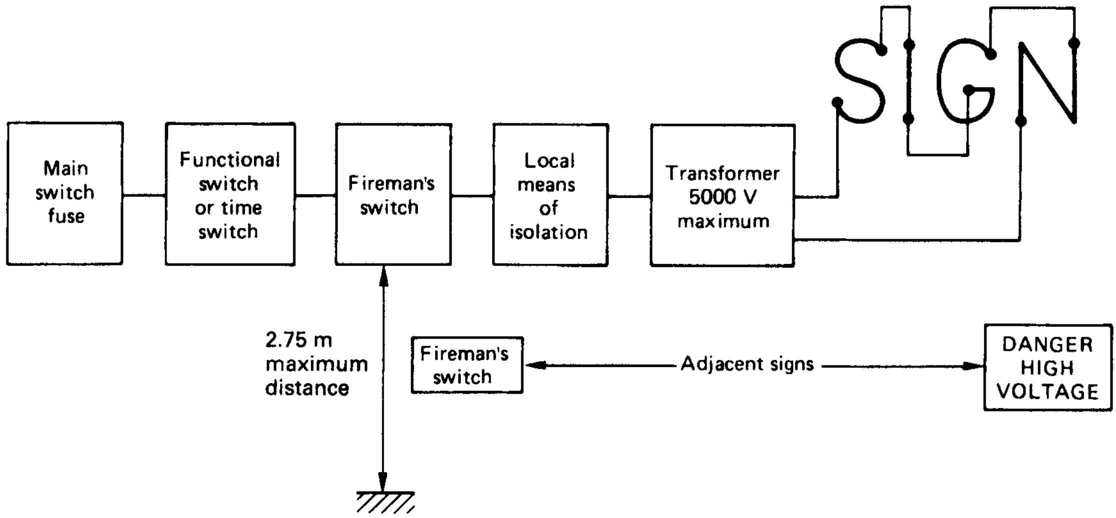


Fig. 2.9 Block diagram showing the layout of a high-volume voltage discharge lighting circuit.

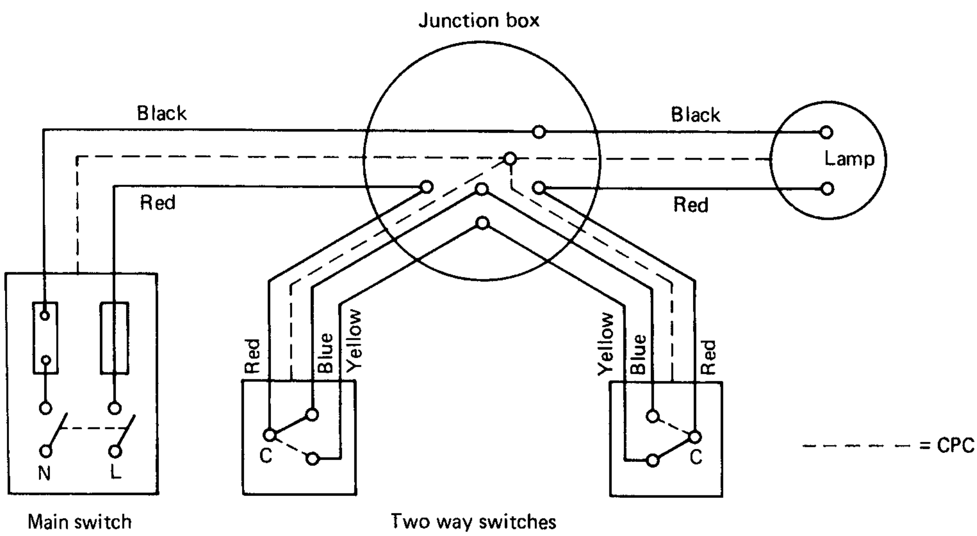


Fig. 2.10 Wiring diagram of two-way switch control.

equipment or circuit works. The purpose of a wiring diagram is to help someone with the actual wiring of the circuit. Figure 2.10 shows the wiring diagram for a two-way lighting circuit.

Circuit diagrams

A circuit diagram shows most clearly how a circuit works. All the essential parts and connections are represented by their graphical symbols. The purpose of a circuit diagram is to help our understanding of the circuit. It will be laid out as clearly as possible, without regard to the physical layout of the actual components, and therefore it may not indicate the most convenient way to wire the circuit. Figure 2.11 shows the circuit diagram of an n-p-n transistor test circuit.

TELEPHONE MESSAGES

Telephones today play one of the most important roles in enabling people to communicate with each other. The advantage of a telephone message over a

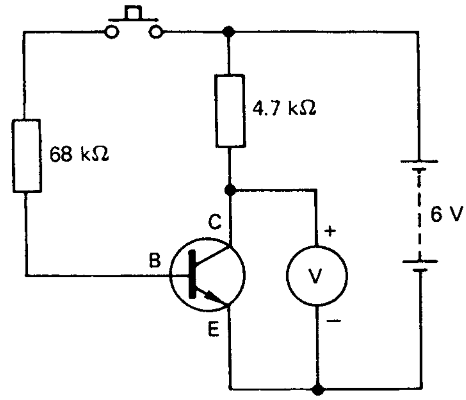


Fig. 2.11 Circuit diagram of an n-p-n transistor test circuit.

written message is its speed; the disadvantage is that no record is kept of an agreement made over the telephone. Therefore, business agreements made on the telephone are often followed up by written confirmation.

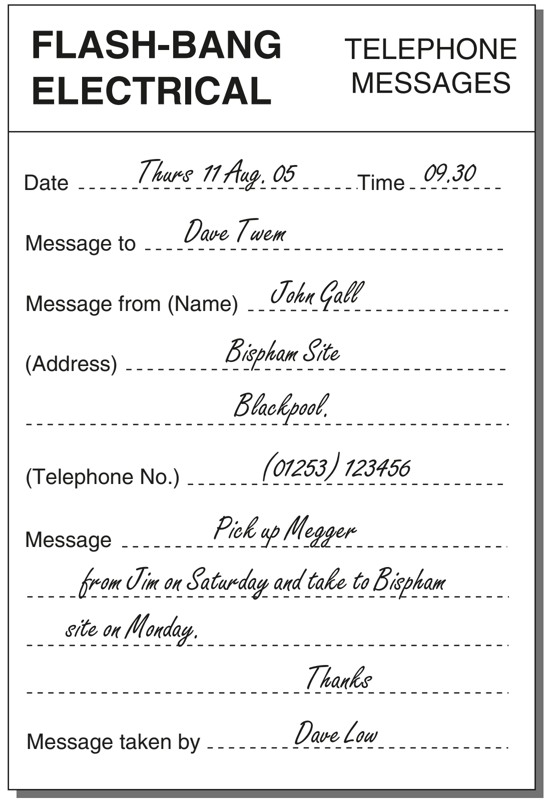
When *taking* a telephone call, remember that you cannot be seen and, therefore, gestures and facial expressions will not help to make you understood. Always be polite and helpful when answering your company's telephone – you are your company's most important representative at that moment. Speak clearly and loud enough to be heard without shouting, sound cheerful and write down messages if asked. Always read back what you have written down to make sure that you are passing on what the caller intended.

Many companies now use standard telephone message pads such as that shown in Fig. 2.12 because they prompt people to collect all the relevant information. In this case John Gall wants Dave Twem to pick up the Megger from Jim on Saturday and take it to the Bispham site on Monday. The person taking the call and relaying the message is Dave Low.

When *making* a telephone call, make sure you know what you want to say or ask. Make notes so that you have times, dates and any other relevant information ready before you make the call.

WRITTEN MESSAGES

A lot of communications between and within larger organizations take place by completing standard forms or sending internal memos. Written messages have the advantage of being 'auditable'. An auditor can follow the paperwork trail to see, for example, who was responsible for ordering certain materials.


FLASH-BANG ELECTRICAL
TELEPHONE MESSAGES

Date Thurs 11 Aug. 05 Time 09.30

Message to Dave Twem

Message from (Name) John Gall

(Address) Bispham Site
Blackpool.

(Telephone No.) (01253) 123456

Message Pick up Megger
from Jim on Saturday and take to Bispham
site on Monday.
Thanks

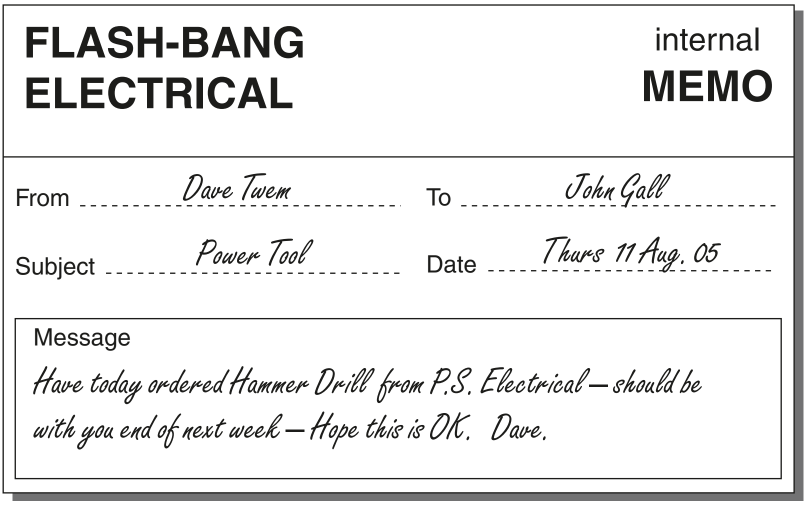
Message taken by Dave Low

Fig. 2.12 Typical standard telephone message pad.

When completing standard forms, follow the instructions given and ensure that your writing is legible. Do not leave blank spaces on the form, always specifying 'not applicable' or 'N/A' whenever necessary. Sign or give your name and the date as asked for on the form. Finally, read through the form again to make sure you have answered all the relevant sections correctly.

Internal memos are forms of written communication used within an organization; they are not normally used for communicating with customers or suppliers. Figure 2.13 shows the layout of a typical standard memo form used by Dave Twem to notify John Gall that he has ordered the hammer drill.

Letters provide a permanent record of communications between organizations and individuals. They may be handwritten, but formal business letters give a better impression of the organization if they are typewritten. A letter should be written using simple concise language, and the tone of the letter should always be polite even if it is one of complaint. Always include the date of the correspondence. The greeting on a


FLASH-BANG ELECTRICAL

internal MEMO

From: Dave Twem
To: John Gall
Subject: Power Tool
Date: Thurs 11 Aug. 05

Message

Have today ordered Hammer Drill from P.S. Electrical — should be with you end of next week — Hope this is OK. Dave.

Fig. 2.13 Typical standard memo form.

formal letter should be 'Dear Sir/Madam' and concluded with 'Yours faithfully'. A less formal greeting would be 'Dear Mr Smith' and concluded 'Yours sincerely'. Your name and status should be typed below your signature.

DELIVERY NOTES

When materials are delivered to site, the person receiving the goods is required to sign the driver's 'delivery note'. This record is used to confirm that goods have been delivered by the supplier, who will then send out an invoice requesting payment, usually at the end of the month.

The person receiving the goods must carefully check that all the items stated on the delivery note have been delivered in good condition. Any missing or damaged items must be clearly indicated on the delivery note before signing, because, by signing the delivery note the person is saying 'yes, these items were delivered to me as my company's representative on that date and in good condition and I am now responsible for these goods'. Suppliers will replace materials damaged in transit provided that they are notified within a set time period, usually three days. The person receiving the goods should try to quickly determine their condition. Has the packaging been damaged, does the container 'sound' like it might contain broken items? Its best to check at the time of delivery if possible, or as soon as possible after delivery and within the notifiable period.

Electrical goods delivered to site should be handled carefully and stored securely until they are installed. Copies of delivery notes are sent to head office so that payment can be made for the goods received.

TIME SHEETS

A time sheet is a standard form completed by each employee to inform the employer of the actual time spent working on a particular contract or site. This helps the employer to bill the hours of work to an individual job. It is usually a weekly document and includes the number of hours worked, the name of the job and any travelling expenses claimed. Office personnel require time sheets such as that shown in Fig 2.14 so that wages can be made up.

JOB SHEETS

A job sheet or job card such as that shown in Fig 2.15 carries information about a job which needs to be done, usually a small job. It gives the name and address of the customer, contact telephone numbers, often a job reference number and a brief description of the work to be carried out. A typical job sheet work description might be:

- Job 1 Upstairs lights not working
- Job 2 Funny fishy smell from kettle socket in kitchen.

TIME SHEET

FLASH-BANG ELECTRICAL

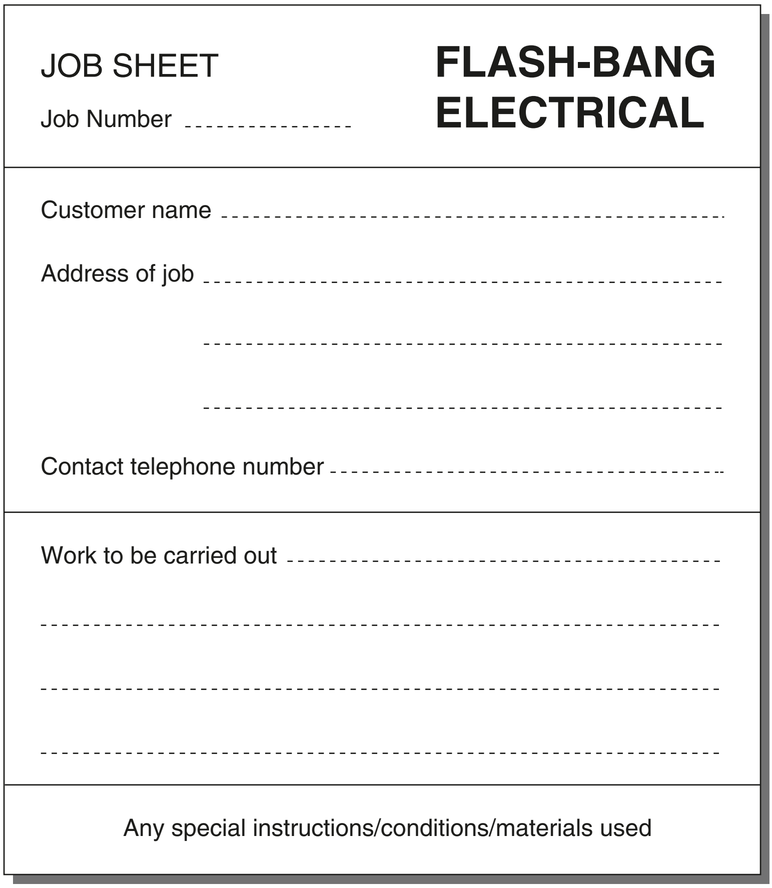
Employee's name (Print) ....

Week ending ....

Day	Job number and/or address	Start time	Finish time	Total hours	Travel time	Expenses
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
Sunday						

Employee's signature .... Date ....

Fig. 2.14 Typical time sheet.



JOB SHEET

Job Number ----------------

FLASH-BANG ELECTRICAL

Customer name --

Address of job --

Contact telephone number --

Work to be carried out --

Any special instructions/conditions/materials used

Fig. 2.15 Typical job sheet.

An electrician might typically have a 'jobbing day' where he picks up a number of job sheets from the office and carries out the work specified.

Job 1, for example, might be the result of a blown fuse which is easily rectified, but the electrician must search a little further for the fault which caused the fuse to blow in the first place. The actual fault might, for example, be a decayed flex on a pendant drop which has become shorted out, blowing the fuse. The pendant drop would be re-flexed or replaced, along with any others in poor condition. The installation would then be tested for correct operation and the customer given an account of what has been done to correct the fault. General information and assurances about the condition of the installation as a whole might be requested and given before setting off to job 2.

The kettle socket outlet at job 2 is probably getting warm and, therefore, giving off that 'fishy' bakelite smell because loose connections are causing the bakelite socket to burn locally. A visual inspection would confirm the diagnosis. A typical solution would be to replace the socket and repair any damage to the conductors inside the socket box. Check the kettle plug top for damage and loose connections. Make sure all connections are tight before reassuring the customer that all is well; then, off to the next job or back to the office.

The time spent on each job and the materials used are sometimes recorded on the job sheet, but alternatively a daywork sheet can be used. This will depend upon what is normal practice for the particular electrical company. This information can then be used to 'bill' the customer for work carried out.

DAYWORK SHEETS

Daywork is one way of recording variations to a contract, that is, work done which is outside the scope of the original contract. If daywork is to be carried out, the site supervisor must first obtain a signature from the client's representative, for example, the architect, to authorize the extra work. A careful record must then be kept on the daywork sheets of all extra time and materials used so that the client can be billed for the extra work. A typical daywork sheet is shown in Fig. 2.16.

FLASH-BANG ELECTRICAL

DAYWORK SHEET

Client name ....

Job number/REF. ....

Date	Labour	Start time	Finish time	Total hours	Office use

Materials quantity	Description	Office use

Site supervisor or Flash-Bang electrical representative responsible for carrying out work ....

Signature of person approving work and status e.g.

Client ☐ Architect ☐ Q.S. ☐ Main contractor ☐ Clerk of works ☐

Signature ....

Fig. 2.16 Typical daywork sheet.

REPORTS

On large jobs, the foreman or supervisor is often required to keep a report of the relevant events which happen on the site for example, how many people from your company are working on site each day, what goods were delivered, whether there were any breakages or accidents, and records of site meetings attended. Some firms have two separate documents, a site diary to record daily events and a weekly report which is a summary of the week's events extracted from the site diary. The site diary remains on site and the weekly report is sent to head office to keep managers informed of the work's progress.

PERSONAL COMMUNICATIONS

Remember that it is the customers who actually pay the wages of everyone employed in your company. You should always be polite and listen carefully to their wishes. They may be elderly or of a different religion or cultural background than you. In a domestic situation, the playing of loud music on a radio may not be approved of. Treat the property in which you are working with the utmost care. When working in houses, shops and offices use dust sheets to protect floor coverings and furnishings. Clean up periodically and made a special effort when the job is completed.

Dress appropriately: an unkempt or untidy appearance will encourage the customer to think that your work will be of poor quality.

The electrical installation in a building is often carried out alongside other trades. It makes good sense to help other trades where possible and to develop good working relationships with other employees. The customer will be most happy if the workers give an impression of working together as a team for the successful completion of the project.

Finally, remember that the customer will probably see more of the electrician and the electrical trainee than the managing director of your firm and, therefore, the image presented by you will be assumed to reflect the policy of the company. You are, therefore, your company's most important representative. Always give the impression of being capable and in command of the situation, because this gives customers confidence in the company's ability to meet their needs. However, if a problem does occur which is outside your previous experience and you do not feel confident to solve it successfully, then contact your supervisor for professional help and guidance. It is not unreasonable for a young member of the company's team to seek help and guidance from those employees with more experience. This approach would be preferred by most companies rather than having to meet the cost of an expensive blunder.

Construction site – safe working practice

In Chapter 1 we looked at some of the laws and regulations that affect our working environment. We looked at Safety Signs and PPE, and how to recognise and use different types of fire extinguishers. The structure of companies within the electrotechnical industry and the ways in which they communicate information by drawings, symbols and standard forms was discussed earlier in this chapter.

If your career in the electrotechnical industry is to be a long, happy and safe one, you must always wear appropriate personal protective equipment such as footwear, and head protection and behave responsibly and sensibly in order to maintain a safe working environment. Before starting work, make a safety assessment. What is going to be hazardous, will you require PPE, do you need any special access equipment. Carry out safe isolation procedures before beginning any work. You do not necessarily have to do these things formally, such as carrying out a risk assessment as described in Chapter 1, but just get into the habit of always working safely and being aware of the potential hazards around you when you are working.

Having chosen an appropriate wiring system which meets the intended use and structure of the building and satisfies the environmental conditions of the installation, you must install the system conductors, accessories and equipment in a safe and competent manner. (Various wiring systems were discussed in Chapter 1 under the sub-heading Industrial Wiring Systems).

The structure of the building must be made good if it is damaged during the installation of the wiring system. For example, where conduits and trunking are run through walls and floors.

All connections in the wiring system must be both electrically and mechanically sound. All conductors must be chosen so that they will carry the design current under the installed conditions.

If the wiring system is damaged during installation it must be made good to prevent future corrosion. For example, where galvanised conduit trunking or tray is cut or damaged by pipe vices, it must be made good to prevent localised corrosion.

All tools must be used safely and sensibly. Cutting tools should be sharpened and screwdrivers ground to a sharp square end on a grindstone.

It is particularly important to check that the plug top and cables of hand held electrically powered tools and extension leads are in good condition. Damaged plug tops and cables must be repaired before you use them. All electrical power tools of 110 and 230 V must be tested with a portable appliance tester (PAT) in accordance with the company's Health and Safety procedures, but probably at least once each year.

Tools and equipment that are left lying about in the workplace can become damaged or stolen and may also be the cause of people slipping, tripping or falling. Tidy up regularly and put power tools back in their boxes. You personally may have no control over the condition of the workplace in general, but keeping your own work area clean and tidy is the mark of a skilled and conscientious craftsman.

Finally, when the job is finished, clean up and dispose of all waste material responsibly as described in Chapter 3 of *Basic Electrical Installation Work*, 4th Edition under the heading Disposing of Waste.

Electrical Safety Systems

The provision of protective devices in an electrical installation is fundamental to the whole concept of the safe use of electricity in buildings. The electrical installation as a whole must be protected against overload or short circuit and the people using the building must be protected against the risk of shock, fire or other risks arising from their own misuse of the installation or from a fault. The installation and maintenance of adequate and appropriate protective measures is a vital part of the safe use of electrical energy. I want to look at protection against an electric shock by both direct and indirect contact, at protection by equipotential bonding and automatic disconnection of the supply, and protection against excess current.

Let us first define some of the words we will be using. Chapter 54 of the IEE Regulations describes the earthing arrangements for an electrical installation. It gives the following definitions:

Earth – the conductive mass of the earth.

Bonding Conductor – a protective conductor providing equipotential bonding.

Circuit Protective Conductor (CPC) – a protective conductor connecting exposed conductive parts of equipment to the main earthing terminal. This is the green and yellow insulated conductor in twin and earth cable.

Exposed Conductive Parts – this is the metalwork of an electrical appliance or the trunking and conduit of an electrical system which can be touched because they are not normally live, but which may become live under fault conditions.

Extraneous Conductive Parts – this is the structural steelwork of a building and other service pipes such as gas, water, radiators and sinks. They do not form a part of the electrical installation but may introduce a potential, generally earth potential, to the electrical installation.

Direct contact protection

The human body's movements are controlled by the nervous system. Very tiny electrical signals travel between the central nervous system and the muscles, stimulating operation of the muscles, which enable us to walk, talk and run and remember that the heart is also a muscle.

If the body becomes part of a more powerful external circuit, such as the electrical mains, and current flows through it, the body's normal electrical operations are disrupted. The shock current causes unnatural operation of the muscles and the result may be that the person is unable to release the live conductor causing the shock, or the person may be thrown across the room. The current which flows through the body is determined by the resistance of the human body and the surface resistance of the skin on the hands and feet.

This leads to the consideration of exceptional precautions where people with wet skin or wet surfaces are involved, and the need for special consideration in bathroom installations.

Two types of contact will result in a person receiving an electric shock. Direct contact with live parts which involves touching a terminal or phase conductor

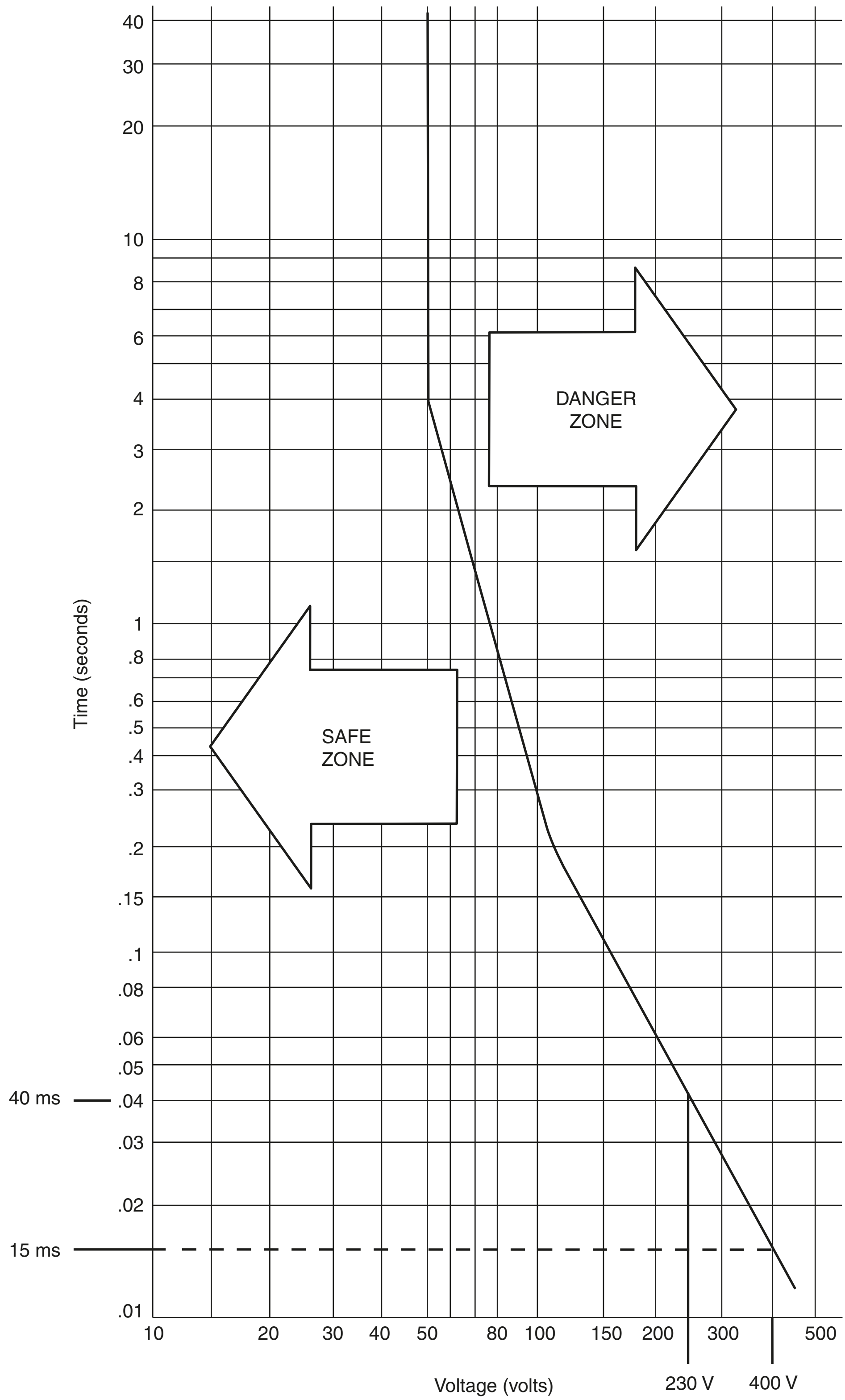


Fig. 2.17 Touch voltage curve.

that is actually live. Indirect contact results from contact with an exposed conductive part such as the metal structure of a piece of equipment that has become live as a result of a fault.

The touch voltage curve in Fig. 2.17 shows that a person in contact with 230 V must be released from this danger in 40 ms if harmful effects are to be avoided. Similarly, a person in contact with 400 V must be released in 15 ms to avoid being harmed.

In installations operating at normal mains voltage, the primary method of protections against direct contact is by insulation. All live parts are enclosed in insulating material such as rubber or plastic, which prevents contact with those parts. The insulating material must, of course, be suitable for the circumstances in which they will be used and the stresses to which they will be subjected.

Other methods of direct contact protection include the provision of barriers or enclosures which can only be opened by the use of a tool, or when the supply is first disconnected. Protection can also be provided by fixed obstacles such as a guard rail around an open switchboard or by placing live parts out of reach as with overhead lines.

Earth fault protection

In Chapter 13 of the IEE Regulations we are told that where the metalwork of electrical equipment may become charged with electricity in such a manner as to cause danger, that metalwork will be connected with earth so as to discharge the electrical energy without danger.

There are five methods of protection against contact with metalwork which has become unintentionally live, that is, indirect contact with exposed conductive parts recognized by the IEE Regulations. These are:

1 Earthed equipotential bonding coupled with automatic disconnection of the supply.
2 The use of Class II (double insulated) equipment.
3 The provision of a non-conducting location.
4 The use of earth free equipotential bonding.
5 Electrical separation.

Methods 3 and 4 are limited to special situations under the effective supervision of trained personnel.

Method 5, electrical separation, is little used but does find an application in the domestic electric shaver supply unit which incorporates an isolating transformer.

Method 2, the use of Class II insulated equipment is limited to single pieces of equipment such as tools used on construction sites, because it relies upon effective supervision to ensure that no metallic equipment or extraneous earthed metalwork enters the area of the installation.

The method which is most universally used in the United Kingdom is, therefore, Method 1 – earthed equipotential bonding coupled with automatic disconnection of the supply.

This method relies upon all exposed metalwork being electrically connected together to an effective earth connection. Not only must all the metalwork associated with the electrical installation be so connected, that is conduits, trunking, metal switches and the metalwork of electrical appliances, but Regulation 413–02–02 tells us to connect the extraneous metalwork of water service pipes, gas and other service pipes and ducting, central heating and air conditioning systems, exposed metallic structural parts of the building and lightning protective systems to the main earthing terminal. In this way the possibility of a voltage appearing between two exposed metal parts is removed. Main equipotential bonding is shown in Fig. 2.64 in Chapter 2 of *Basic Electrical Installation Work*, 4th Edition.

The second element of this protection method is the provision of a means of automatic disconnection of the supply in the event of a fault occurring that causes the exposed metalwork to become live.

The IEE Regulations recognize that the risk of an injurious shock is greater when the equipment concerned is portable and likely to be hand held, such as an electric drill, than when the equipment is fixed. The Regulations, therefore, specify that the disconnection must be effected within 0.4 seconds for circuits, which include socket outlets, but within 5.0 seconds for circuits connected to fixed equipment.

The achievement of these disconnection times is dependent upon the type of protective device used, fuse or circuit breaker, the circuit conductors to the fault and the provision of adequate equipotential bonding. The resistance, or we call it the impedance; of the earth fault loop must be less than the values given in Appendix 2 of the *On Site Guide* and Tables 41B1, 41B2 and 41D of the IEE Regulations. (Table 2.3 later in this chapter shows the maximum value of the earth fault loop impedance for circuits protected by a semi-enclosed fuse to BS 3036). We will look at this again later in this chapter under the heading 'Earth Fault Loop Impedance Z_S'. Section 542 of the IEE Regulations gives details of the earthing arrangements to be incorporated in the supply system to meet these Regulations and these were described in Chapter 1 under the heading 'Low Voltage Supply Systems' and are shown in Figs 1.106 to 1.108.

Residual current protection

The IEE Regulations recognize the particular problems created when electrical equipment such as lawnmowers, hedge-trimmers, drills and lights are used outside buildings. In these circumstances the availability of an adequate earth return path is a matter of chance. The Regulations, therefore, require that any socket intended to be used to supply equipment outside a building shall have the additional protection of a residual current device (RCD), which has a rated operating current of not more than 30 milliamperes (mA).

An RCD is a type of circuit breaker that continuously compares the current in the phase and neutral conductors of the circuit. The currents in a healthy circuit will be equal, but in a circuit that develops a fault, some current will flow to earth and the phase and neutral currents will no longer balance. The RCD detects the imbalance and disconnects the circuit. Figure 2.18 shows an RCD.

Isolation and switching

Part 4 of the IEE Regulations deals with the application of protective measures for safety and Chapter 53 with

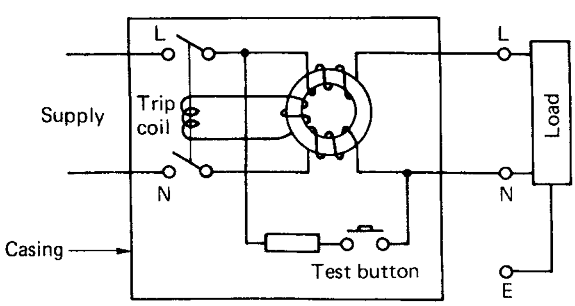


Fig. 2.18 Construction of a residual current device (RCD).

the regulations for switching devices or switchgear required for protection, isolation and switching of a consumer's installation.

The consumer's main switchgear must be readily accessible to the consumer and be able to:

- isolate the complete installation from the supply,
- protect against overcurrent,
- cut off the current in the event of a serious fault occurring.

The Regulations identify four separate types of switching: switching for isolation; switching for mechanical maintenance; emergency switching; and functional switching.

Isolation is defined as cutting off the electrical supply to a circuit or item of equipment in order to ensure the safety of those working on the equipment by making dead those parts which are live in normal service.

An isolator is a mechanical device which is operated manually and used to open or close a circuit off load. An isolator switch must be provided close to the supply point so that all equipment can be made safe for maintenance. Isolators for motor circuits must isolate the motor and the control equipment, and isolators for high-voltage discharge lighting luminaires must be an integral part of the luminaire so that it is isolated when the cover is removed (Regulations 461, 476–02 and 537–02). Devices which are suitable for isolation are isolation switches, fuse links, circuit breakers, plugs and socket outlets.

Isolation at the consumer's service position can be achieved by a double pole switch which opens or closes all conductors simultaneously. On three-phase supplies the switch need only break the live conductors with a solid link in the neutral, provided that the neutral link cannot be removed before opening the switch.

The switching for mechanical maintenance requirements is similar to those for isolation except that the control switch must be capable of switching the full load current of the circuit or piece of equipment. Switches for mechanical maintenance must not have exposed live parts when the appliance is opened, must be connected in the main electrical circuit and have a reliable on/off indication or visible contact gap (Regulations 462 and 537–03). Devices which are suitable for switching off for mechanical maintenance are switches, circuit breakers, plug and socket outlets.

Emergency switching involves the rapid disconnection of the electrical supply by a single action to remove or prevent danger. The device used for emergency switching must be immediately accessible and identifiable, and be capable of cutting off the full load current. A fireman's switch provides emergency switching for high-voltage signs, as described in Chapter 5 of *Basic Electrical Installation Work*, 4th Edition.

Electrical machines must be provided with a means of emergency switching, and a person operating an electrically driven machine must have access to an emergency switch so that the machine can be stopped in an emergency. The remote stop/start arrangement shown in Fig. 3.49 could meet this requirement for an electrically driven machine (Regulations 463, 476–03 and 537–04). Devices which are suitable for emergency switching are switches, circuit breakers and contactors. Where contactors are operated by remote control they should *open* when the coil is de-energized, that is, fail safe. Push-buttons used for emergency switching must be coloured red and latch in the stop or off position. They should be installed where danger may arise and be clearly identified as emergency switches. Plugs and socket outlets cannot be considered appropriate for emergency disconnection of supplies.

Functional switching involves the switching on or off or varying the supply of electrically operated equipment in normal service. The device must be capable of interrupting the total steady current of the circuit or appliance. When the device controls a discharge lighting circuit it must have a current rating capable of switching an inductive load. Plug and socket outlets may be used as switching devices and recent years have seen an increase in the number of electronic dimmer switches being used for the control and functional switching of lighting circuits (Regulations 537–05–01).

Where more than one of these functions is performed by a common device, it must meet the individual requirements for each function (Regulation 476–01–01).

Overcurrent protection

The consumer's mains equipment must provide protection against overcurrent; that is, a current exceeding the rated value (Regulation 431–01–01). Fuses provide overcurrent protection when situated in the live conductors; they must not be connected in the neutral conductor. Circuit breakers may be used in place of fuses, in which case the circuit breaker may also provide the means of isolation, although a further means of isolation is usually provided so that maintenance can be carried out on the circuit breakers themselves.

Overcurrent can be subdivided into overload current, and short-circuit current. An overload current can be defined as a current which exceeds the rated value in an otherwise healthy circuit. Overload currents usually occur because the circuit is abused or because it has been badly designed or modified. A short circuit is an overcurrent resulting from a fault of negligible impedance connected between conductors. Short circuits usually occur as a result of an accident which could not have been predicted before the event.

An overload may result in currents of two or three times the rated current flowing in the circuit. Short-circuit currents may be hundreds of times greater than the rated current. In both cases the basic requirements for protection are that the fault currents should be interrupted quickly and the circuit isolated safely before the fault current causes a temperature rise which might damage the insulation and terminations of the circuit conductors.

The selected protective device should have a current rating which is not less than the full load current of the circuit but which does not exceed the cable current rating. The cable is then fully protected against both overload and short-circuit faults (Regulation 433–02–01). Devices which provide overcurrent protection are:

- HBC fuses to BS 88. These are for industrial applications having a maximum fault capacity of 80 kA.
- Cartridge fuses to BS 1361. These are used for a.c. circuits on industrial and domestic installations having a fault capacity of about 30 kA.
- Cartridge fuses to BS 1362. These are used in 13 A plug tops and have a maximum fault capacity of about 6 kA.
- Semi-enclosed fuses to BS 3036. These were previously called rewirable fuses and are used mainly on domestic installations having a maximum fault capacity of about 4 kA.
- MCBs to BS 3871. These are miniature circuit breakers which may be used as an alternative to fuses for some installations. The British Standard

includes ratings up to 100 A and maximum fault capacities of 9 kA. They are graded according to their instantaneous tripping currents – that is, the current at which they will trip within 100 ms. This is less than the time taken to blink an eye.

MCB Type 1 to BS 3871 will trip instantly at between 2.7 and four times its rated current and is therefore more suitable on loads with minimal or no switching surges such as domestic or commercial installations.

MCB Type B to BS EN 60898 will trip instantly at between three and five times its rated current and is also suitable for domestic and commercial installations.

MCB Type 2 to BS 3871 will trip instantly at between four and seven times its rated current. It offers fast protection on small overloads combined with a slower operation on heavier faults, which reduces the possibility of nuisance tripping. Its characteristics are very similar to those of an HBC fuse, and this MCB is possibly best suited for general commercial and industrial use.

MCB Type C to BS EN 60898 will trip instantly at between five and ten times its rated current. It is more suitable for highly inductive commercial and industrial loads.

MCB Type 3 to BS 3871 will trip instantly at between seven and ten times its rated current. It is more suitable for protecting highly inductive circuits and is used on circuits supplying transformers, chokes and lighting banks.

MCB Type D to BS EN 69898 will trip instantly at between 10 and 25 times its rated current. It is suitable for welding and X-ray machines where large inrush currents may occur.

MCB Type 4 to BS 3871 will trip instantly between 10 and 50 times the rated current and is more suitable for special industrial applications such as welding equipment and X-ray machines.

We will now look at the construction, advantages and disadvantages of the various protective devices.

Semi-enclosed fuses (BS 3036)

The semi-enclosed fuse consists of a fuse wire, called the fuse element, secured between two screw terminals in a fuse carrier. The fuse element is connected in series with the load and the thickness of the element is sufficient to carry the normal rated circuit current. When a fault occurs an overcurrent flows and the fuse element becomes hot and melts or 'blows'.

The designs of the fuse carrier and base are also important. They must not allow the heat generated from an overcurrent to dissipate too quickly from the element, otherwise a larger current would be required to 'blow' the fuse. Also if over-enclosed, heat will not escape and the fuse will 'blow' at a lower current. This type of fuse is illustrated in Fig. 2.19. The fuse element should consist of a single strand of plain or tinned copper wire having a diameter appropriate to the current rating as given in Table 2.1.

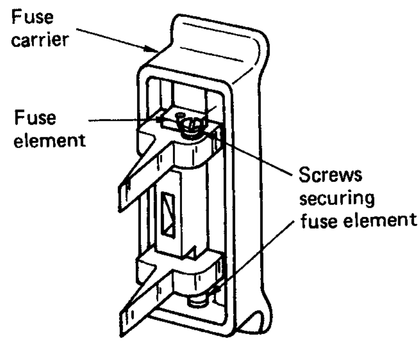


Fig. 2.19 A semi-enclosed fuse.

Table 2.1 Size of fuse element

Current rating (A)	Wire diameter (mm)
5	0.20
10	0.35
15	0.50
20	0.60
30	0.85

ADVANTAGES OF SEMI-ENCLOSED FUSES

- They are very cheap compared with other protective devices both to install and to replace.
- There are no mechanical moving parts.
- It is easy to identify a 'blown fuse'.

DISADVANTAGES OF SEMI-ENCLOSED FUSES

- The fuse element may be replaced with wire of the wrong size either deliberately or by accident.

- The fuse element weakens with age due to oxidization, which may result in a failure under normal operating conditions.
- The circuit cannot be restored quickly since the fuse element requires screw fixing.
- They have low breaking capacity since, in the event of a severe fault, the fault current may vaporize the fuse element and continue to flow in the form of an arc across the fuse terminals.
- There is a danger from scattering hot metal if the fuse carrier is inserted into the base when the circuit is faulty.

Cartridge fuses (BS 1361)

The cartridge fuse breaks a faulty circuit in the same way as a semi-enclosed fuse, but its construction eliminates some of the disadvantages experienced with an open-fuse element.

The fuse element is encased in a glass or ceramic tube and secured to end-caps which are firmly attached to the body of the fuse so that they do not blow off when the fuse operates. Cartridge fuse construction is illustrated in Fig. 2.20. With larger-size cartridge fuses, lugs or tags are sometimes brazed on to the end-caps to fix the fuse cartridge mechanically to the carrier. They may also be filled with quartz sand to absorb and extinguish the energy of the arc when the cartridge is brought into operation.

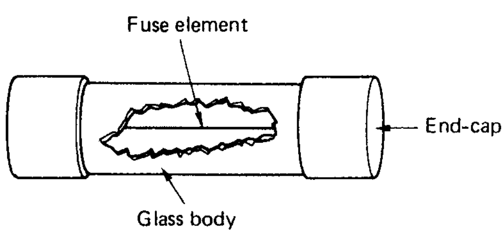


Fig. 2.20 A cartridge fuse.

ADVANTAGES OF CARTRIDGE FUSES

- They have no mechanical moving parts.
- The declared rating is accurate.
- The element does not weaken with age.
- They have small physical size and no external arcing which permits their use in plug tops and small fuse carriers.
- Their operation is more rapid than semi-enclosed fuses. Operating time is inversely proportional to the fault current.

DISADVANTAGES OF CARTRIDGE FUSES

- They are more expensive to replace than rewirable fuse elements.
- They can be replaced with an incorrect cartridge.
- The cartridge may be shorted out by wire or silver foil in extreme cases of bad practice.
- They are not suitable where extremely high fault currents may develop.

HIGH BREAKING CAPACITY FUSES (BS 88)

As the name might imply, these cartridge fuses are for protecting circuits where extremely high fault currents may develop such as on industrial installations or distribution systems.

The fuse element consists of several parallel strips of pure silver encased in a substantial ceramic cylinder, the ends of which are sealed with tinned brass end-caps incorporating fixing lugs. The cartridge is filled with silica sand to ensure quick arc extraction. Incorporated on the body is an indicating device to show when the fuse has blown. HBC fuse construction is shown in Fig. 2.21.

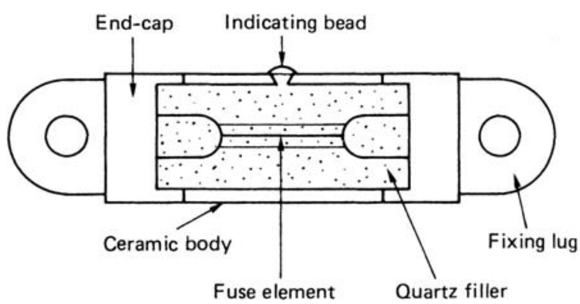


Fig. 2.21 HBC fuse.

ADVANTAGES OF HBC FUSES

- They have no mechanical moving parts.
- The declared rating is accurate.
- The element does not weaken with age.
- Their operation is very rapid under fault conditions.
- They are capable of breaking very heavy fault currents safely.

- They are capable of discriminating between a persistent fault and a transient fault such as the large starting current taken by motors.
- It is difficult to confuse cartridges since different ratings are made to different physical sizes.

DISADVANTAGES OF HBC FUSES

- They are very expensive compared to semi-enclosed fuses.

Miniature circuit breakers (BS 3871)

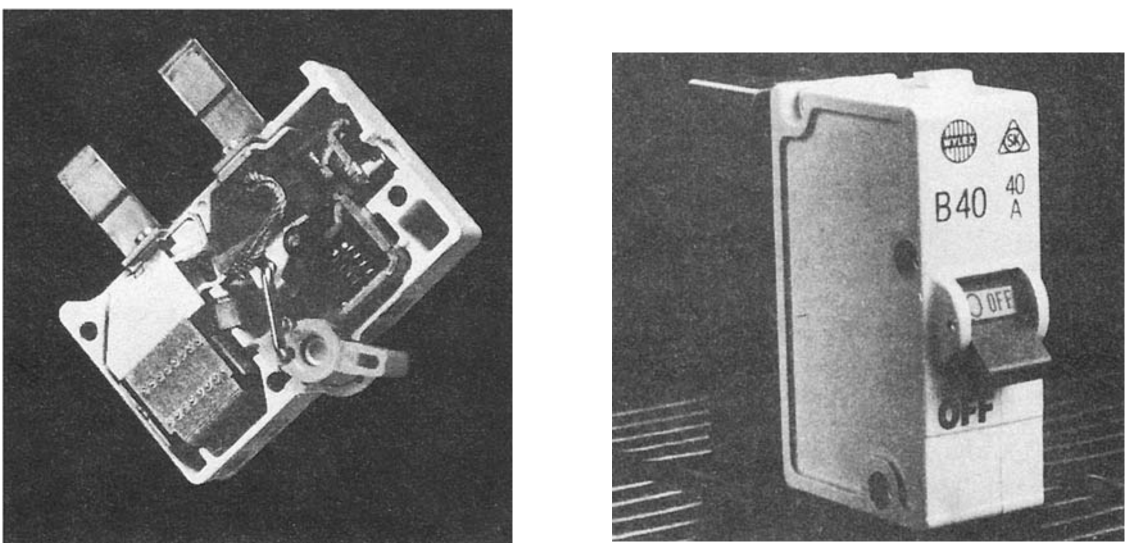
The disadvantage of all fuses is that when they have operated they must be replaced. An MCB overcomes this problem since it is an automatic switch which opens in the event of an excessive current flowing in the circuit and can be closed when the circuit returns to normal.

An MCB of the type shown in Fig. 2.22 incorporates a thermal and magnetic tripping device. The load current flows through the thermal and the electromagnetic mechanisms. In normal operation the current is insufficient to operate either device, but when an overload occurs, the bimetal strip heats up, bends and trips the mechanism. The time taken for this action to occur provides an MCB with the ability to discriminate between an overload which persists for a very short time, for example the starting current of a motor, and an overload due to a fault. The device only trips when a fault current occurs. This slow operating time is ideal for overloads but when a short circuit occurs it is important to break the faulty circuit very quickly. This is achieved by the coil electromagnetic device.

When a large fault current (above about eight times the rated current) flows through the coil a strong magnetic flux is set up which trips the mechanisms almost instantly. The circuit can be restored when the fault is removed by pressing the ON toggle. This latches the various mechanisms within the MCB and 'makes' the switch contact. The toggle switch can also be used to disconnect the circuit for maintenance or isolation or to test the MCB for satisfactory operation. The simplified diagram in Fig. 2.23 shows the various parts within an MCB.

ADVANTAGES OF MCBS

- Tripping characteristics and therefore circuit protection are set by installer.
- The circuit protection is difficult to interfere with.
- The circuit is provided with discrimination.
- A faulty circuit may be easily and quickly restored.
- The supply may be safely restored by an unskilled operator.



(a) (b)

Fig. 2.22 (a) Interior view of Wylex 'plug-in' MCB; (b) 'plug-in' MCB fits any standard Wylex consumer's unit.

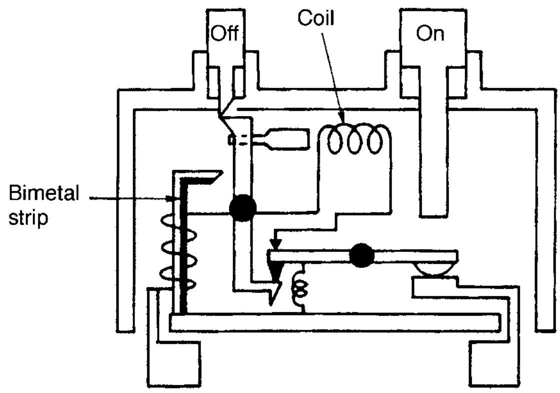


Fig. 2.23 A simplified diagram of an MCB.

DISADVANTAGES OF MCBS

- They are very expensive compared to rewirable fuses.
- They contain mechanical moving parts and therefore require regular testing to ensure satisfactory operation under fault conditions.

Fusing factor

The speed with which a protective device will operate under fault conditions gives an indication of the level of protection being offered by that device. This level of protection or fusing performance is given by the fusing factor of the device:

$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Current rating}}$$

The minimum fusing current of a device is the current which will cause the fuse or MCB to blow or trip in a given time (BS 88 gives this operating time as 4 hours). The current rating of a device is the current which it will carry continuously without deteriorating.

Thus, a 10 A fuse which operates when 15 A flows will have a fusing factor of $15 \div 10 = 1.5$.

Since the protective device must carry the rated current it follows that the fusing factor must always be greater than one. The closer the fusing factor is to one, the better is the protection offered by that device. The fusing factors of the protective devices previously considered are:

- semi-enclosed fuses: between 1.5 and 2
- cartridge fuses: between 1.25 and 1.75
- HBC fuses: less than 1.25
- MCBs: less than 1.5.

In order to give protection to the conductors of an installation:

- the current rating of the protective device must be equal to or less than the current carrying capacity of the conductor;
- the current causing the protective device to operate must not be greater than 1.45 times the current carrying capacity of the conductor to be protected.

The current carrying capacities of cables given in the tables of Appendix 4 of the IEE Regulations assume that the circuit will comply with these requirements and that the circuit protective device will have a fusing factor of 1.45 or less. Cartridge fuses, HBC fuses and MCBs do have a fusing factor less than 1.45 and therefore when this type of protection is afforded the current carrying capacities of cables may be read directly from the tables.

However, semi-enclosed fuses can have a fusing factor of 2. The wiring regulations require that the rated current of a rewirable fuse must not exceed 0.725 times the current carrying capacity of the conductor it is to protect. This factor is derived as follows:

The maximum fusing factor of a rewirable fuse is 2.

Now, if I_n = current rating of the protective device
I_z = current carrying capacity of conductor
I_2 = current causing the protective device to operate.

Then $I_2 = 2\,I_n \leqslant 1.45\,I_z$

therefore $I_n \leqslant \dfrac{1.45\,I_z}{2}$

or $I_n \leqslant 0.725\,I_z$

When rewirable fuses are used, the current carrying capacity of the cables given in the tables is reduced by a factor of 0.725, as detailed in Appendix 4 item 5 of the Regulations.

Position of protective devices

Isolation, switching and protective devices can be found at the consumers mains equipment position such as that shown in Chapter 1 at Fig. 1.111 and 1.112. The general principle to be followed is that a protective device must be placed at a point where a reduction occurs in the current carrying capacity of the circuit conductors. A reduction may occur because of a change in the size or type of conductor or because of a change in the method of installation or a change in the environmental conditions. The only exceptions to this rule are where an overload protective device opening a circuit might cause a greater danger than the overload itself – for example, a circuit feeding an overhead electromagnet in a scrapyard.

Disconnection time calculations

The overcurrent protection device protecting socket outlet circuits and any fixed equipment in bathrooms must operate within 0.4 seconds. Those protecting fixed equipment circuits in rooms other than bathrooms must operate within 5 seconds (Regulation 413–02–08 to 13 and 601).

The reason for the more rapid disconnection of the socket outlet circuits is that portable equipment plugged into the socket outlet is considered a higher risk than fixed equipment since it is more likely to be firmly held by a person. The more rapid disconnection times for fixed equipment in bathrooms take account of a possibly reduced body resistance in the bathroom environment.

The IEE Regulations permit us to assume that where an overload protective device is also intended to provide short-circuit protection, and has a rated breaking capacity greater than the prospective short-circuit current at the point of its installation, the conductors on the load side of the protective device are considered to be adequately protected against short-circuit currents without further proof. This is because the cable rating and the overload rating of the device are compatible. However, if this condition is not met or if there is some doubt, it must be verified that fault currents will be interrupted quickly before they can cause a dangerously high temperature rise in the circuit conductors. Regulation 434–03–03 provides an equation for calculating the maximum operating time of the protective device to prevent the permitted conductor temperature rise being exceeded as follows:

$$t = \frac{k^2S^2}{I^2} \text{ (seconds)}$$

where

t = duration time in seconds

S = cross-sectional area of conductor in square millimetres

I = short-circuit rms current in amperes

k = a constant dependent upon the conductor metal and type of insulation (see Table 43A of the IEE Regulations).

EXAMPLE

A 10 mm PVC insulated copper cable is short-circuited when connected to a 400 V supply. The impedance of the short-circuit path is 0.1 Ω. Calculate the maximum permissible disconnection time and show that a 50 A type 2 MCB to BS 3871 will meet this requirement:

$$I = \frac{V}{Z} \text{(A)} \qquad \therefore\ I = \frac{400\text{ V}}{0.1\ \Omega} = 4000\text{ A}$$

For copper conductor and PVC insulation, Table 43A gives a value for k of 115. So,

$$t = \frac{k^2S^2}{I^2} \text{ (s)}$$

$$\therefore\ t = \frac{115^2 \times 10^2\text{ mm}^2}{4000\text{ A}} = 82.66 \times 10^{-3}\text{ s}$$

The maximum time that a 4000 A fault current can be applied to this 10 mm^2 cable without dangerously raising the conductor temperature is 82.66 ms. Therefore, the protective device must disconnect the supply to the cable in less than 82.66 ms under short-circuit conditions. Manufacturers' information and Appendix 3 of the IEE Regulations give the operating times of protective devices at various short-circuit currents in the form of graphs, similar to those shown in Figs 2.24 and 2.25.

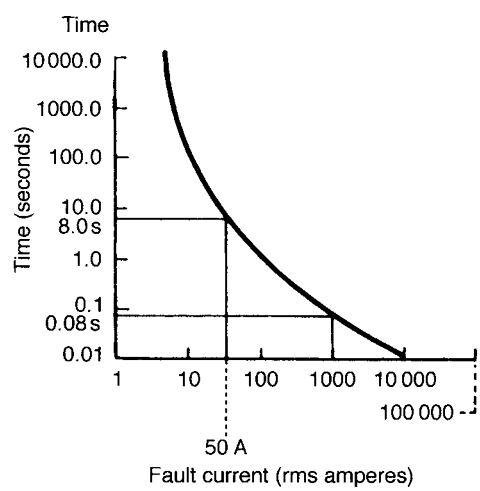


Fig. 2.24 Time/current characteristic of an overcurrent protective device.

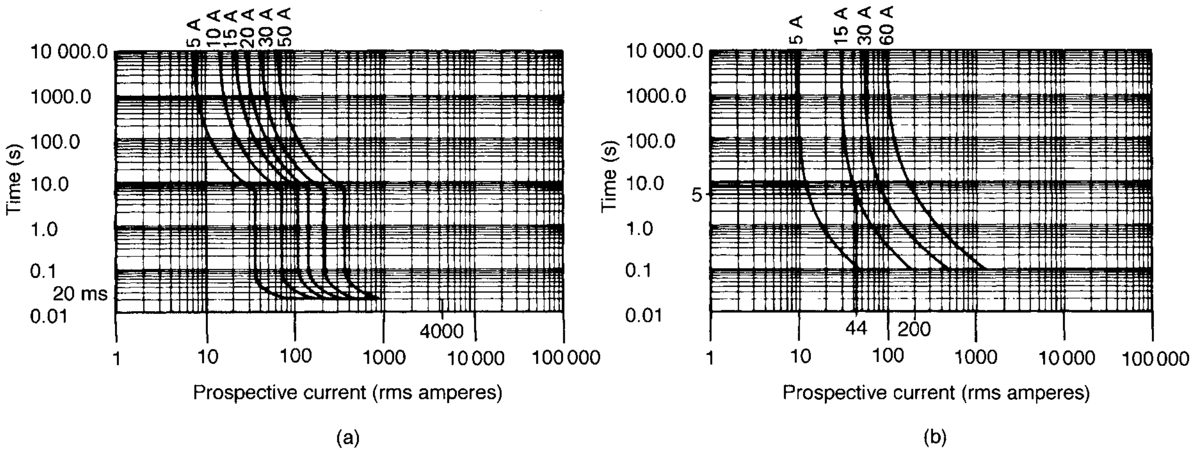


Fig. 2.25 Time/current characteristics of (a) a type 2 MCB to BS 3871; (b) semi-enclosed fuse to BS 3036.

Time/current characteristics of protective devices

Disconnection times for various overcurrent devices are given in the form of a logarithmic graph. This means that each successive graduation of the axis represents a ten times change over the previous graduation.

These logarithmic scales are shown in the graphs of Figs 2.24 and 2.25. From Fig. 2.24 it can be seen that the particular protective device represented by this characteristic will take 8 seconds to disconnect a fault current of 50 A and 0.08 seconds to clear a fault current of 1000 A.

Figure 2.25(a) shows the time/current characteristics for a type 2 MCB to BS 3871. This graph shows that a fault current of 4000 A will trip the protective device in 20 ms. Since this is quicker than 82.66 ms, the 50 A type 2 MCB will clear the fault current before the temperature of the cable is raised to a dangerous level.

Appendix 3 of the IEE Regulations gives the time/current characteristics and specific values of prospective short-circuit current for a number of protective devices.

These indicate the value of fault current which will cause the protective device to operate in the times indicated by Chapter 413 of the IEE Regulations, that is 0.4 and 5 seconds in the case of domestic socket outlet circuits and distribution circuits feeding fixed appliances.

Figures 1, 2 and 3 in Appendix 3 of the IEE Regulations deal with fuses and Figures 4 to 8 with MCBs.

It can be seen that the prospective fault current required to trip an MCB in the required time is a multiple of the current rating of the device. The multiple depends upon the characteristics of the particular devices. Thus:

- type 1 MCB to BS 3871 has a multiple of 4
- type 2 MCB to BS 3871 has a multiple of 7
- type 3 MCB to BS 3871 has a multiple of 10
- type B MCB to BS EN 60898 has a multiple of 5
- type C MCB to BS EN 60898 has a multiple of 10
- type D MCB to BS EN 60898 has a multiple of 20.

EXAMPLE

A 6 A type 1 MCB to BS 3871 used to protect a domestic lighting circuit will trip within 5 seconds when 6 A times a multiple of 4, that is 24 A, flows under fault conditions.

Therefore if the earth fault loop impedance is low enough to allow at least 24 A to flow in the circuit under fault conditions, the protective device will operate within the time required by Regulation 413–02–14.

The characteristics shown in Appendix 3 of the IEE Regulations give the specific values of prospective short-circuit current for all standard sizes of protective device.

Discrimination

In the event of a fault occurring on an electrical installation only the protective device nearest to the fault should operate, leaving other healthy circuits unaffected. A circuit designed in this way would be considered to have effective discrimination. Effective discrimination can be achieved by graded protection since the speed of operation of the protective device increases as the rating decreases. This can be seen in Fig. 2.25(b). A fault current of 200 A will cause a 15 A semi-enclosed fuse to operate in about 0.1 seconds, a 30 A semi-enclosed fuse in about 0.45 seconds and a 60 A semi-enclosed fuse in about 5.4 seconds. If a circuit is arranged as shown in Fig. 2.26 and a fault occurs on the appliance, effective discrimination will be achieved because the 15 A fuse will operate more quickly than the other protective devices if they were all semi-enclosed types fuses with the characteristics shown in Fig. 2.25(b).

Security of supply, and therefore effective discrimination, is an important consideration for an electrical engineer and is also a requirement of Regulation 533–01–06.

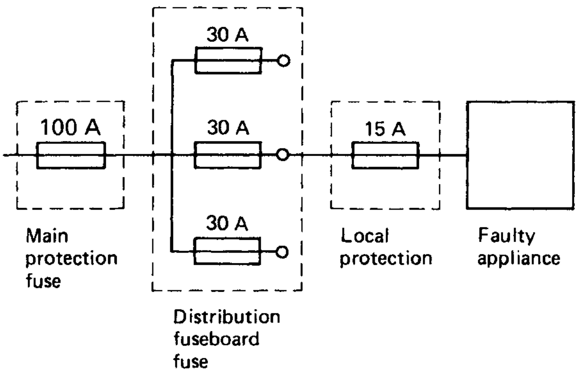


Fig. 2.26 Effective discrimination achieved by graded protection.

Earth fault loop impedance Z_S

In order that an overcurrent protective device can operate successfully, meeting the required disconnection times, of less than 0.4 seconds for socket outlets and 5.0 seconds for fixed equipment, the earth fault loop impedance value measured in ohms must be less than those values given in Appendix 2 of the *On Site Guide* and Tables 41B1 and 41B2 of the IEE Regulations for socket outlet circuits and Tables 41B2 and 41D for circuits supplying fixed equipment. The value of the earth fault loop impedance may be verified by means of an earth fault loop impedance test as described later in this chapter. The formula is:

$$Z_S = Z_E + (R_1 + R_2)\ (\Omega)$$

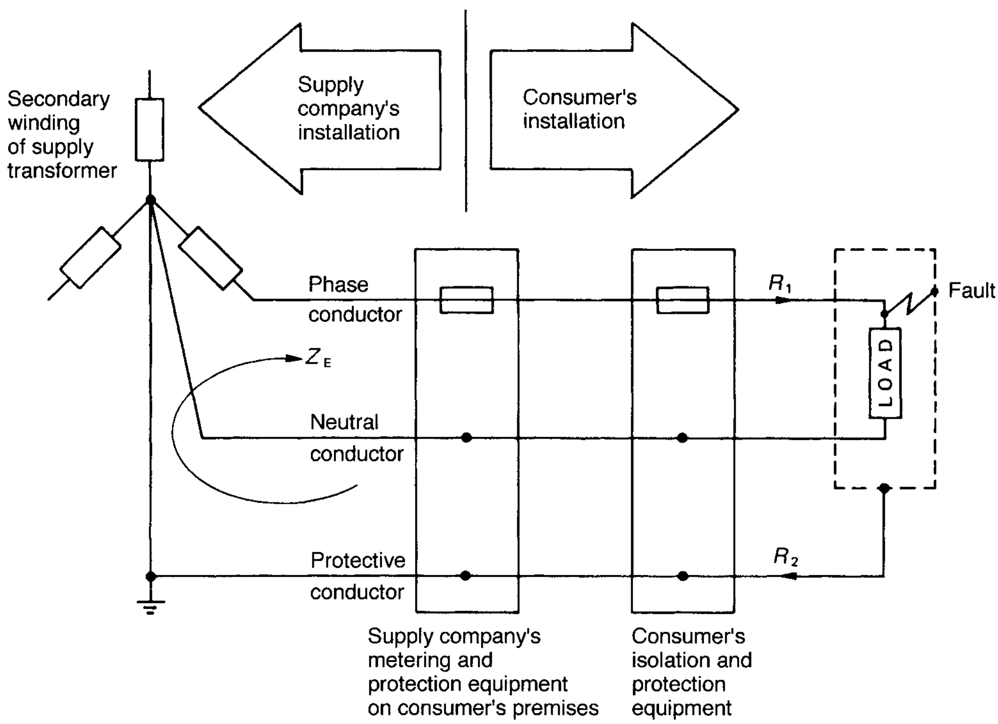


Fig. 2.27 Earth fault loop path for a TN-S system.

Here Z_E is the impedance of the supply side of the earth fault loop. The actual value will depend upon many factors: the type of supply, the ground conditions, the distance from the transformer, etc. The value can be obtained from the area electricity companies, but typical values are 0.35 Ω for TN-C-S (PME) supplies and 0.8 Ω for TN-S (cable sheath earth) supplies. Also in the above formula, R_1 is the resistance of the phase conductor and R_2 is the resistance of the earth conductor. The complete earth fault loop path is shown in Fig. 2.27.

Values of $R_1 + R_2$ have been calculated for copper and aluminium conductors and are given in Table 9A of the *On Site Guide* as shown in Table 2.2.

Table 2.2 This shows Table 9A of the IEE *On Site Guide* Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

Cross-sectional area (mm^2)		Resistance/metre or $(R_1 + R_2)$/metre (mΩ/m)	
Phase conductor	Protective conductor	Copper	Aluminium
1	—	18.10	
1	1	36.20	
1.5	—	12.10	
1.5	1	30.20	
1.5	1.5	24.20	
2.5	—	7.41	
2.5	1	25.51	
2.5	1.5	19.51	
2.5	2.5	14.82	
4	—	4.61	
4	1.5	16.71	
4	2.5	12.02	
4	4	9.22	
6	—	3.08	
6	2.5	10.49	
6	4	7.69	
6	6	6.16	
10	—	1.83	
10	4	6.44	
10	6	4.91	
10	10	3.66	
16	—	1.15	1.91
16	6	4.23	—
16	10	2.98	—
16	16	2.30	3.82
25	—	0.727	1.20
25	10	2.557	—
25	16	1.877	—
25	25	1.454	2.40
35	—	0.524	0.87
35	16	1.674	2.78
35	25	1.251	2.07
35	35	1.048	1.74
50	—	0.387	0.64
50	25	1.114	1.84
50	35	0.911	1.51
50	50	0.774	1.28

EXAMPLE

A 20 A radial socket outlet circuit is wired in 2.5 mm^2 PVC cable incorporating a 1.5 mm^2 CPC. The cable length is 30 m installed in an ambient temperature of 20°C and the consumer's protection is by semi-enclosed fuse to BS 3036. The earth fault loop impedance of the supply is 0.5 Ω. Calculate the total earth fault loop impedance Z_S, and establish that the value is less than the maximum value permissible for this type of circuit.

We have

$$Z_S = Z_E + (R_1 + R_2)\ (\Omega)$$

$$Z_E = 0.5\,\Omega \text{ (value given in the question)}$$

From the value given in Table 9A of the *On Site Guide* and reproduced in Table 2.2 a 2.5 mm phase conductor with a 1.5 mm protective conductor has an $(R_1 + R_2)$ value of $19.51 \times 10^{-3}\,\Omega/\text{m}$

$$(R_1 + R_2) = 19.51 \times 10^{-3}\,\Omega/\text{m} = 30\,\text{m} = 0.585\,\Omega$$

However, under fault conditions, the temperature and therefore the cable resistance will increase. To take account of this, we must multiply the value of cable resistance by the factor given in Table 9C of the *On Site Guide*. In this case the factor is 1.20 and therefore the cable resistance under fault conditions will be:

$$0.585\,\Omega \times 1.20 = 0.702\,\Omega$$

The total earth fault loop impedance is therefore

$$Z_S = 0.5\,\Omega + 0.702\,\Omega = 1.202\,\Omega$$

The maximum permitted value given in Table 2A of the *On Site Guide* for a 20 A fuse to BS 3036 protecting a socket outlet is 1.48 Ω as shown by Table 2.3. The circuit earth fault loop impedance is less than this value and therefore the protective device will operate within the required disconnection time of 0.4 seconds.

Size of protective conductor

The circuit protective conductor forms an integral part of the total earth fault loop impedance, so it is necessary to check that the cross-section of this conductor is adequate. If the cross-section of the circuit protective conductor complies with Table 54G of the IEE Regulations, there is no need to carry out further checks. Where phase and protective conductors are made from the same material, Table 54G tells us that:

- for phase conductors equal to or less than 16 mm^2, the protective conductor should equal the phase conductor;
- for phase conductors greater than 16 mm^2 but less than 35 mm^2, the protective conductor should have a cross-sectional area of 16 mm^2;
- for phase conductors greater than 35 mm^2, the protective conductor should be half the size of the phase conductor.

However, where the conductor cross-section does not comply with this table, then the formula given in Regulation 543–01–03 must be used:

$$S = \frac{\sqrt{I^2 t}}{k}\ (\text{mm}^2)$$

where

S = cross-sectional area in mm^2
I = value of maximum fault current in amperes
t = operating time of the protective device

Table 2.3 This shows Table 2A of the IEE *On Site Guide* Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

Table 2A Semi enclosed fuses

Maximum measured earth fault loop impedance (in ohms) overcurrent protective device is a semi-enclosed fuse to BS 3036

Protective conductor (mm^2)	Fuse rating (amperes)				
	5	15	20	30	45
(i) 0.4 second disconnection					
1.0	8.00	2.14	1.48	NP	NP
1.5	8.00	2.14	1.48	0.91	NP
2.5 to 16.0	8.00	2.14	1.48	0.91	0.50
(ii) 5 seconds disconnection					
1.0	14.80	4.46	2.79	NP	NP
1.5	14.80	4.46	3.20	2.08	NP
2.5	14.80	4.46	3.20	2.21	1.20
4.0 to 16.0	14.80	4.46	3.20	2.21	1.33

NP protective conductor, fuse combination NOT PERMITITTED.

k = a factor for the particular protective conductor (see Table 54B to 54F of the IEE Regulations).

EXAMPLE 1

A 230 V ring main circuit of socket outlets is wired in 2.5 mm single PVC copper cables in a plastic conduit with a separate 1.5 mm CPC. An earth fault loop impedance test identifies Z_S as 1.15 Ω. Verify that the 1.5 mm CPC meets the requirements of Regulation 543–01–03 when the protective device is a 30 A semi-enclosed fuse.

$$I = \text{Maximum fault current} = \frac{V}{Z_S} \text{ (A)}$$

$$\therefore I = \frac{230}{1.15} = 200 \text{ A}$$

t = Maximum operating time of the protective device for a socket outlet circuit is 0.4 seconds from Regulation 413–02–09. From Fig. 2.25(b) you can see that the time taken to clear a fault of 200 A is about 0.4 seconds.

k = 115 (from Table 54C).

$$S = \frac{\sqrt{I^2 t}}{k} (\text{mm}^2)$$

$$S = \frac{\sqrt{(200 \text{ A})^2 \times 0.4 \text{ s}}}{115} = 1.10 \text{ mm}^2$$

A 1.5 mm² CPC is acceptable since this is the nearest standard-size conductor above the minimum cross-sectional area of 1.10 mm² found by calculation.

EXAMPLE 2

A domestic immersion heater is wired in 2.5 mm² PVC insulated copper cable and incorporates a 1.5 mm² CPC. The circuit is correctly protected with a 15 A semi-enclosed fuse to BS 3036. Establish by calculation that the CPC is of an adequate size to meet the requirements of Regulation 543–01–03. The characteristics of the protective device are given in Fig. 2.25(b).

For circuits feeding fixed appliances the maximum operating time of the protective device is 5 seconds. From Fig. 2.25 it can be seen that a current of about 44 A will trip the 15 A fuse in 5 seconds. Alternatively Table 2 A in Appendix 3 of the IEE Regulations gives a value of 43 A. Let us assume a value of 43 A:

$\therefore I$ = 43 A
t = 5 seconds for fixed appliances
k = 115 (from Table 54C)

$$S = \frac{\sqrt{I^2 t}}{k} (\text{mm}^2) \text{ (from Regulation 543–01–03)}$$

$$S = \frac{\sqrt{(43 \text{ A})^2 \times 5 \text{ s}}}{115} = 0.836 \text{ mm}^2$$

The circuit protective conductor of the cable is greater than 0.836 mm² and is therefore suitable. If the protective conductor is a separate conductor, that is, it does not form part of a cable as in this example and is not enclosed in a wiring system as in Example 1, the cross-section of the protective conductor must be not less than 2.5 mm² where mechanical protection is provided or 4.0 mm² where mechanical protection is *not* provided in order to comply with Regulation 547–03–03.

Cable selection/calculation

The size of a cable to be used for an installation depends upon:

- the current rating of the cable under defined installation conditions and
- the maximum permitted drop in voltage as defined by Regulation 525–01.

The factors which influence the current rating are:

1. the design current – the cable must carry the full load current;
2. the type of cable – PVC, MICC, copper conductors or aluminium conductors;
3. the installed conditions – clipped to a surface or installed with other cables in a trunking;
4. the surrounding temperature – cable resistance increases as temperature increases and insulation may melt if the temperature is too high;
5. the type of protection – for how long will the cable have to carry a fault current?

Regulation 525–01 states that the drop in voltage from the supply terminals to the fixed current-using equipment must not exceed 4% of the mains voltage. That is, a maximum of 9.2 V on a 230 V installation. The volt drop for a particular cable may be found from

$$VD = \text{Factor} \times \text{Design current} \times \text{Length of run}$$

The factor is given in the tables of Appendix 4 of the IEE Regulations and Appendix 6 of the *On Site Guide*. (See Table 2.6).

The cable rating, denoted I_t, may be determined as follows:

$$I_t = \frac{\text{Current rating of protective device}}{\text{Any applicable correction factors}}$$

The cable rating must be chosen to comply with Regulation 433–02–01. The correction factors which may need applying are given below as:

Ca the ambient or surrounding temperature correction factor, which is given in Tables 4C1 and 4C2 of Appendix 4 of the IEE Regulations and Tables 6A1 and 6A2 of the *On Site Guide* which is shown in Table 2.4.

Cg the grouping correction factor given in Tables 4B1, 4B2 and 4B3, of the IEE Regulations and 6C of the *On Site Guide*.

Cr the 0.725 correction factor to be applied when semi-enclosed fuses protect the circuit as described in item 6.2 of the preface to Appendix 4 of the IEE Regulations.

Ci the correction factor to be used when cables are enclosed in thermal insulation. Regulation 523–04 gives us three possible correction values:

- Where one side of the cable is in contact with thermal insulation we must read the current rating from the column in the table which relates to reference method 4. (See Table 2.5).
- Where the cable is *totally* surrounded over a length greater than 0.5 m we must apply a factor of 0.5.
- Where the cable is *totally* surrounded over a short length, the appropriate factor given in Table 52A of the IEE Regulations or Table 6B of the *On Site Guide* should be applied.

Having calculated the cable rating, the smallest cable should be chosen from the appropriate table which will carry that current. This cable must also meet the voltage drop Regulation 525–01 and this should be calculated as described earlier. When the calculated value is less than 4% of the mains voltage the cable may be considered suitable. If the calculated value is greater than the 4% value, the next larger cable size must be tested until a cable is found which meets both the current rating and voltage drop criteria.

EXAMPLE

A house extension has a total load of 6 kW installed some 18 m away from the mains consumer unit. A PVC insulated and sheathed twin and earth cable will provide a submain to this load and be clipped to the side of the ceiling joists over much of its length in a roof space which is anticipated to reach 35°C in the summer and where insulation is installed up to the top of the joists. Calculate the minimum cable size if the circuit is to be protected (a) by a semi-enclosed fuse to BS 3036 and (b) by a type 2 MCB to BS 3871. Assume a TN-S supply, that is, a supply having a separate neutral and protective conductor throughout.

Let us solve this question using only the tables given in the *On Site Guide*. The tables in the Regulations will give the same values, but this will simplify the problem. Refer to Tables 2.4, 2.5 and 2.6.

$$\text{Design current } I_b = \frac{\text{Power}}{\text{Volts}} = \frac{6000\text{ W}}{240\text{ V}} = 26.09\text{ A}$$

Table 2.4 Ambient temperature correction factors. Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

Table 6A1 Ambient temperature factors

Correction factors for ambient temperature where protection is against short-circuit and overload

Type of insulation	Operating temperature	Ambient temperature (°C)								
		25	30	35	40	45	50	55	60	65
Thermoplastic (general purpose PVC)	70°C	1.03	1.0	0.94	0.87	0.79	0.71	0.61	0.50	0.35

Table 6A2 Ambient temperature factors

Correction factors for ambient temperature where the overload protective device is a semi-enclosed fuse to BS 3036

Type of insulation	Operating temperature	Ambient temperature (°C)								
		25	30	35	40	45	50	55	60	65
Thermoplastic (general purpose PVC)	70°C	1.03	1.0	0.97	0.94	0.91	0.87	0.84	0.69	0.48

Table 2.5 Current carrying capacity of cables. Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

Table 6E1 Multicore cables having thermoplastic (PVC) or thermosetting insulation (note 1), non-armoured, (COPPER CONDUCTORS)

Ambient temperature: 30°C. Conductor operating temperature: 70°C
CURRENT-CARRYING CAPACITY (amperes): BS 6004, BS 7629

Conductor cross-sectional area	Reference Method 4 (enclosed in an insulated wall, etc.)		Reference Method 3 (enclosed in conduit on a wall or ceiling, or in trunking)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray) or Reference Method 13 (free air)	
	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.
1	2	3	4	5	6	7	8	9
mm^2	A	A	A	A	A	A	A	A
1	11	10	13	11.5	15	13.5	17	14.5
1.5	14	13	16.5	15	19.5	17.5	22	18.5
2.5	18.5	17.5	23	20	27	24	30	25
4	25	23	30	27	36	32	40	34
6	32	29	38	34	46	41	51	43
10	43	39	52	46	63	57	70	60
16	57	52	69	62	85	76	94	80
25	75	68	90	80	112	96	119	101
35	92	83	111	99	138	119	148	126
50	110	99	133	118	168	144	180	153
70	139	125	168	149	213	184	232	196
95	167	150	201	179	258	223	282	238

For a fuller treatment see Appendix 4 of BS 7671 Table 4D2A.* With or without protective conductor.

Nominal current setting of the protection for this load $I_n = 30\,A$.

For (a) the correction factors to be included in this calculation are:

- Ca ambient temperature; from Table 6A2 which is shown in Table 2.4 the correction factor for 35°C is 0.97.
- Cg the grouping correction factor is not applied since the cable is to be clipped direct to a surface and not in contact with other cables.
- Cr the protection is by a semi-enclosed fuse and, therefore, a factor of 0.725 must be applied.
- Ci thermal insulation is in contact with one side of the cable and we must therefore assume installed method 4. (See Table 2.5).

The cable rating, I_t is given by

$$I_t = \frac{\text{Current rating of protective device}}{\text{The product of the correction factors}}$$

$$= \frac{30\,A}{0.97 \times 0.725} = 42.66\,A$$

From column 2 of Table 6E1, shown in Table 2.5 a 10 mm cable having a rating of 43 A is required to carry this current.

Now test for volt drop: The maximum permissible volt drop is $4\% \times 230\,V = 9.2\,V$. From Table 6E2 shown in Table 2.6 the volt drop per ampere per metre for a 10 mm cable is 4.4 mV.

Therefore, the volt drop for this cable length and load is equal to

$$4.4 \times 10^{-3}\,V/(A\,m) \times 26.09\,A \times 18\,m = 2.07\,V$$

Since this is less than the maximum permissible value of 9.2 V, a 10 mm cable satisfies the current and drop in voltage requirements and is therefore the chosen cable when semi-enclosed fuse protection is used.

For (b) the correction factors to be included in this calculation are:

- Ca ambient temperature; from Table 6A1 shown in Table 2.4 the correction factor for 35°C is 0.94.
- Cg grouping factors need not be applied.
- Cr since protection is by MCB no factor need be applied.
- Ci thermal insulation once more demands that we assume installed method 4. (See Table 2.5).

Table 2.6 Voltage drop in cables factor. Reproduced from the IEE *On site Guide* by kind permission of the Institution of Electrical Engineers

Table 6E2

Voltage drop: (per ampere per metre): Conductor operating temperature: 70°C

Conductor cross-sectional area	Two-core cable, d.c.	Two-core cable, single-phase a.c.	Three- or four-core cable, three-phase
1	2	3	4
mm^2	mV/A/m	mV/A/m	mV/A/m
1	44	44	38
1.5	29	29	25
2.5	18	18	15
4	11	11	9.5
6	7.3	7.3	6.4
10	4.4	4.4	3.8
16	2.8	2.8	2.4
		r	r
25	1.75	1.75	1.50
35	1.25	1.25	1.10
50	0.93	0.93	0.80
70	0.63	0.63	0.55
95	0.46	0.47	0.41

Note: For a fuller treatment see Appendix 4 of BS 7671 Table 4D2B.

The design current is still 26.09 A and we will therefore choose a 30 A MCB for the nominal current setting of the protective device, I_n.

$$\text{Cable rating} = I_t = \frac{30}{0.94} = 31.9\,\text{A}$$

From column 2 of Table 6E1 shown in Table 2.5, a 6 mm cable, having a rating of 32 A, is required to carry this current.

Now test for volt drop: from Table 6E2 which is shown in Table 2.6 the volt drop per ampere per metre for a 6 mm cable is 7.3 mV. So the volt drop for this cable length and load is equal to

$$7.3 \times 10^{-3}\,\text{V/(A m)} \times 26.09\,\text{A} \times 18\,\text{m} = 3.43\,\text{V}$$

Since this is less than the maximum permissible value of 9.2 V, a 6 mm cable satisfies the current and drop in voltage requirements when the circuit is protected by an MCB. From the above calculations it is clear that better protection can reduce the cable size. Even though an MCB is more expensive than a semi-enclosed fuse, the installation of a 6 mm cable with an MCB may be less expensive than 10 mm cable protected by a semi-enclosed fuse. These are some of the decisions which the electrical contractor must make when designing an installation which meets the requirements of the customer and the IEE Regulations.

If you are unsure of the standard fuse and MCB rating of protective devices, you can refer to Tables 2A, 2B, 2C and 2D of the *On Site Guide*.

Electrical Testing

The electrical contractor is charged with a responsibility to carry out a number of tests on an electrical installation and electrical equipment. The individual tests are dealt with in Part 7 of the IEE Regulations and described later in this chapter. Electrical measuring instruments are identified by the way in which the instrument movement is deflected in operation. Thus a moving coil instrument movement consists of a coil which is free to move in operation.

The connection of a test instrument into a circuit can change the circuit resistance and cause error readings. For example, some power is drawn from the test circuit to drive the instrument movement across a scale. Fortunately for electrical installation students, this is not a common problem found in power engineering, but does need consideration when testing electronic circuits. Electronic test equipment is discussed in Chapter 4. *Analogue* and *digital* meters, their advantages and disadvantages are also discussed in Chapter 4 and shown in Figs 4.74 and 4.76.

Moving coil instruments

A delicate coil is suspended on jewelled bearings between the pole pieces of a strong permanent magnet. The test current is fed to the moving coil through the spiral control springs which also return the pointer to zero after each test reading. The construction is shown in Fig. 2.28.

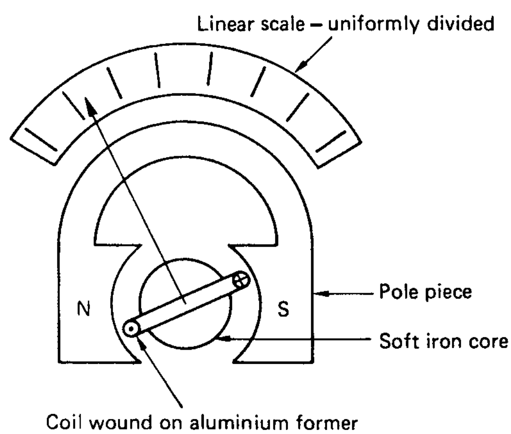


Fig. 2.28 Moving coil instrument.

When the test current flows in the moving coil, a magnetic flux is established, as shown in Fig. 2.29. This flux interacts with the magnetic flux from the permanent magnet and since lines of magnetic flux never cross, the magnetic flux is distorted and a force *F* is exerted on the coil, rotating it and moving the pointer across the scale.

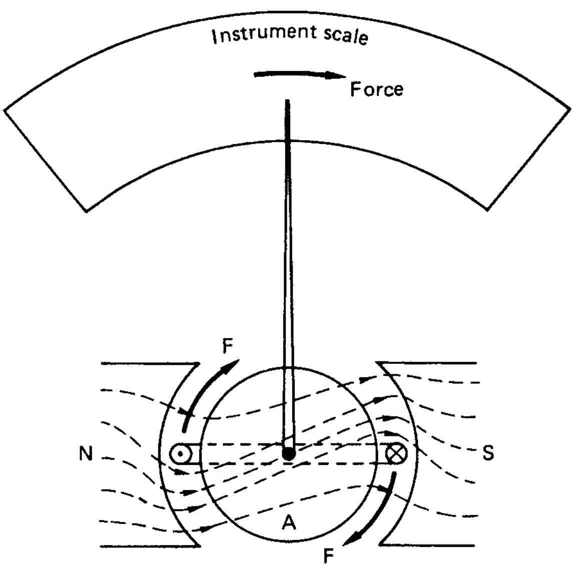


Fig. 2.29 Operation of a moving coil instrument.

The purpose of the soft iron armature A is to establish a uniform magnetic field of equal flux density for the coil's rotation. This gives the moving coil instrument the qualities of sensitivity and a uniform scale.

The basic moving coil movement will only respond satisfactorily to a d.c. supply since an a.c. supply would reverse the current and magnetic flux in the coil at the supply frequency, resulting in the pointer trembling at some useless mid-point on the scale. To overcome this disadvantage, a.c. test circuits are connected to the moving coil meter movement through a rectifier circuit, as shown in Fig. 2.30.

The moving coil instrument presents a high impedance to the test circuit and draws very little current from it. When used with the rectifier circuit, it will give accurate readings over a frequency range from 50 to 50 kHz. This makes it suitable for power or electronic circuit measurements. Many commercial multirange analogue instruments such as the AVO use the moving coil movement because of these advantages, together with a high sensitivity and linear scale. The wide range of scales achieved by the same meter movement in a commercial instrument is discussed in this chapter under the heading 'Range extension'.

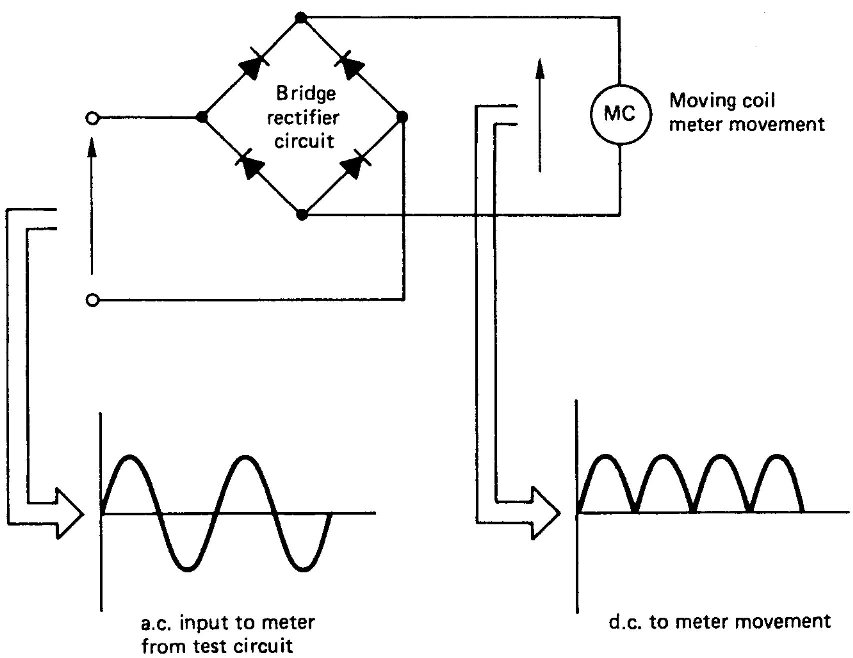


Fig. 2.30 Rectified input to moving coil meter movement.

Moving iron instruments

Moving iron instruments operate on basic magnetic principles, either attracting or repelling a piece of soft iron attached to a pointer which moves across a scale. These instruments can be used to test a.c. or d.c. supplies without the addition of a rectifier circuit.

ATTRACTION-TYPE MOVING IRON INSTRUMENTS

The construction of an attraction-type moving iron instrument is shown in Fig. 2.31(a). The test current passing through the instrument solenoid establishes a magnetic flux which attracts the soft iron towards the solenoid, moving the pointer across the scale.

The flux density of the magnetic field in which the iron disc moves varies. This creates a non-linear force on the iron as it moves through the magnetic field and therefore the scale is non-linear. This instrument is usually arranged to have gravity control, by which the force of gravity returns the pointer to zero, and it can only be operated vertically.

REPULSION-TYPE MOVING IRON INSTRUMENTS

The repulsion-type moving iron instrument is the moving iron instrument most often found today. The construction is shown in Figs 2.31(b) and 2.32.

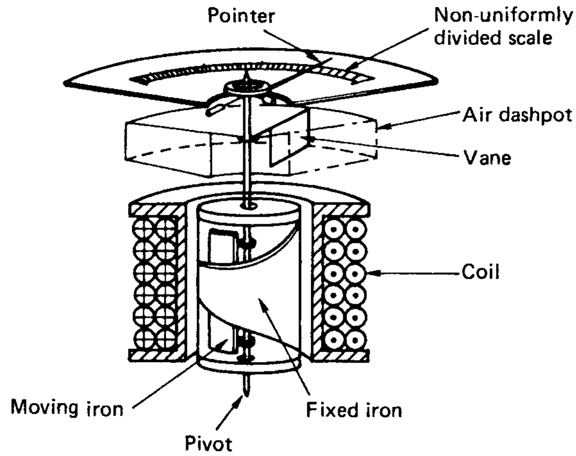


Fig. 2.32 Repulsion-type moving iron instrument (by kind permission of G. Waterworth and R.P. Phillips).

Current passing through the solenoid coil establishes a magnetic field inside the solenoid. This magnetic field magnetizes two pieces of soft iron, one fixed and the other moving, which are close to each other. Since like magnetic poles repel, the moving iron is repelled away from the fixed iron and the pointer is deflected across the scale. The forces exerted between the fixed and moving iron are proportional to the square of the current flowing in the solenoid, which results in a non-linear scale.

A linear scale is highly desirable, and to achieve an almost linear scale the manufacturers of commercial

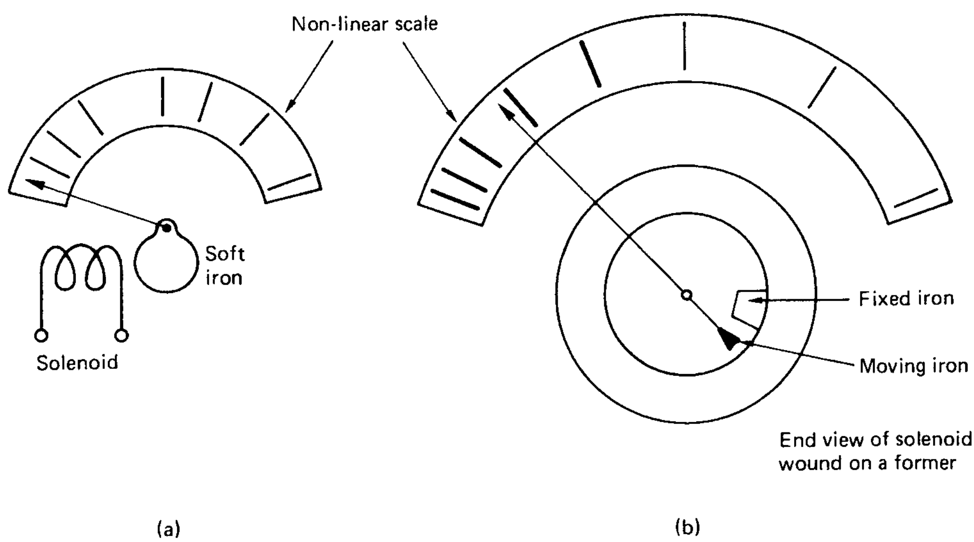


Fig. 2.31 Moving iron instruments: (a) attraction type; (b) repulsion type.

moving iron repulsion-type instruments shape the iron pieces. Rectangular moving iron pieces and fixed iron pieces in the shape of a tapered scroll have been found to give good results.

This instrument can usually be operated horizontally since the movement is supported by jewelled bearings and a spiral spring provides the control torque which returns the pointers to zero after each test reading.

Moving iron instruments present a low impedance to the test circuit and will therefore draw current from the test circuit to provide the power necessary for the deflection of the pointer. The frequency range of a moving iron instrument is restricted to between about 50 and 400 Hz, and so the applications of moving iron instruments are to be found in power circuits and electrical installations. They are not suitable for electronic circuit measurements.

Damping

If an analogue electrical measuring instrument is correctly connected to a live test circuit, the pointer will rise quite quickly and then settle on the true circuit reading, maintaining a steady value throughout the connection. This effect we take for granted, but it can only be achieved if the deflection system is critically damped.

In an undamped system the pointer would rise quickly to the true circuit reading but would then overshoot because of the inertia of the moving system. The forces exerted on the moving system would be insufficient to maintain this higher value and the pointer would fall back towards the true circuit reading, gaining momentum which would take the pointer below the true reading. The forces exerted on the moving system would force the pointer towards the true value, again gaining momentum, resulting in the pointer oscillating about the true value for some time before finally coming to rest. This effect is shown in Fig. 2.33, where A represents the true reading of the circuit, curve B the undamped system and curve C the correctly or critically damped system. Note that curve C reaches its final steady value much more quickly than the undamped system of curve B.

To achieve damping in an electrical instrument a force is provided which opposes the rise of the moving system towards the final true value. This is achieved in one of three ways: eddy current damping; air vane damping; and air piston damping.

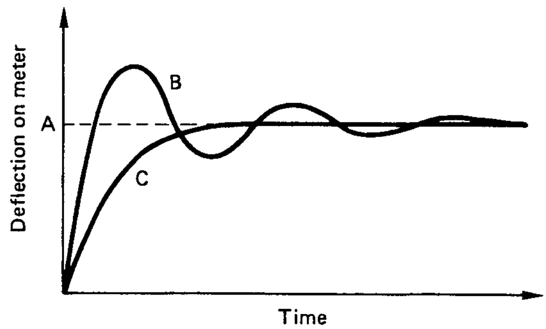


Fig. 2.33 Damping curves.

Making measurements

The electrical contractor is charged by the IEE Regulations for Electrical Installations to test all new installations and major extensions before connection to the mains supply. The contractor may also be called upon to test installations and equipment in order to identify and remove faults. These requirements imply the use of appropriate test instruments, and in order to take accurate readings consideration should be given to the following points:

- Is the instrument suitable for this test?
- Have the correct scales been selected?
- Is the test instrument correctly connected to the circuit?

Test instruments normally consume a small amount of power in order to provide the torque required to move the pointer across a scale. Most instruments are constructed in a way which makes them highly sensitive, giving full scale deflection with only very small currents, but these currents are drawn from the circuit being tested. When testing power and electrical installation circuits and equipment, the power consumed by the test instrument can often be neglected, but electronic circuits use very little power and therefore when testing electronic circuits a high impedance test instrument must be used.

EXAMPLE

A 50 Ω load is connected across a 100 V supply. A multirange meter is correctly connected to read first the current and then the voltage. As an ammeter, the instrument has a resistance of 0.1 Ω and as a voltmeter a resistance of 20 kΩ. The power loss in the instrument for each connection is as follows:

$$\text{Load current } I = \frac{V}{R} = \frac{100V}{50\,\Omega} = 2\text{ A}$$

Power loss in the load

$$= V \times I = 100\,V \times 2\text{ A} = 200\text{ W}$$

Power loss in the ammeter

$$= I^2R = (2\text{ A})^2 \times 0.1\,\Omega = 0.4\text{ W}$$

Power loss in the voltmeter

$$= \frac{V^2}{R} = \frac{(100\ V)^2}{20 \times 10^3\,\Omega} = 0.5\text{ W}$$

This instrument consumes approximately half a watt when taking the readings, which in a power or electrical installation circuit is negligible, but might destroy an electronic circuit.

EDDY CURRENT DAMPING

When a copper or aluminium disc is rotated between the poles of a permanent magnet, a current is induced into the disc, as shown in Fig. 2.34. The magnetic field due to this current sets up a force opposing the motion (Lenz's law) which produces a braking effect. The braking effect only occurs when the disc is in motion, and this type of damping is used in moving coil instruments. The delicate moving coil is wound on an aluminium former and as the moving coil moves in the magnetic field so does the aluminium former. Eddy currents are induced in the former, setting up a force to oppose the motion, and damping is achieved for the moving coil system.

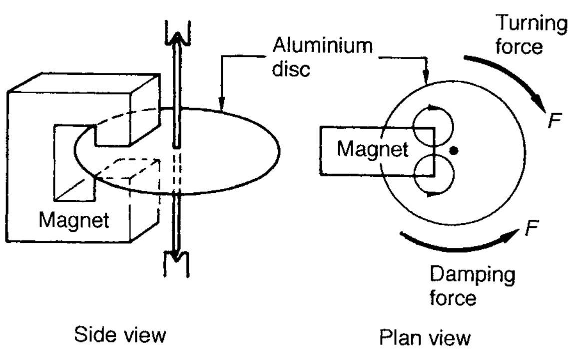


Fig. 2.34 Eddy current damping.

AIR VANE DAMPING

This is usually achieved by attaching a thin rectangle of aluminium to the spindle of the instrument movement, as shown in Fig. 2.35. When the instrument movement deflects, the aluminium rectangle or vane moves in a segment-shaped box, compressing the air, which exerts a damping force on the vane and on the instrument movement. Air vane damping is used on most moving iron instruments.

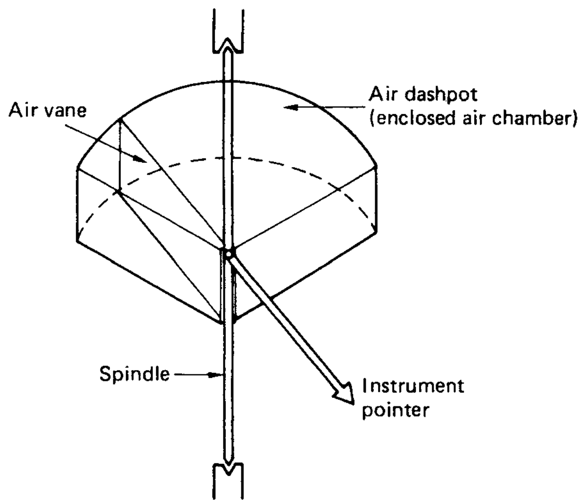


Fig. 2.35 Air vane damping.

AIR PISTON DAMPING

This is an alternative method of air damping. A piston is attached to the moving system of the instrument, as shown in Fig. 2.36. When the moving system deflects, the piston is pushed into an air chamber which compresses the air and applies a force which opposes the motion and causes damping of the meter movement.

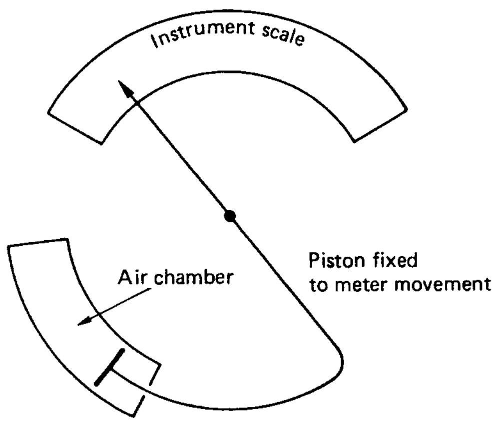


Fig. 2.36 Air piston damping.

Range extension

Moving iron instruments may be constructed to read 10, 20 or 50 A by increasing the thickness and number of solenoid conductors. However, moving coil instruments can only be constructed using a delicate lightweight coil whose maximum current carrying capacity is no more than about 75 mA. To extend the range of a moving coil instrument, shunt or series resistors are connected to it as shown in Fig. 2.37.

To extend the range of an ammeter a low-resistance shunt resistor is connected across the meter movement. This allows the majority of the circuit current to pass through the shunt and only a very small part of the current to pass through the meter movement.

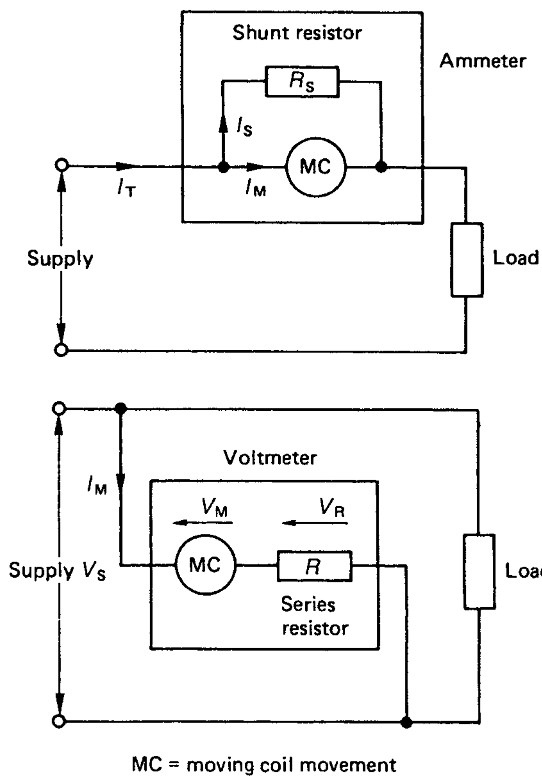


Fig. 2.37 Range extension of moving coil movement.

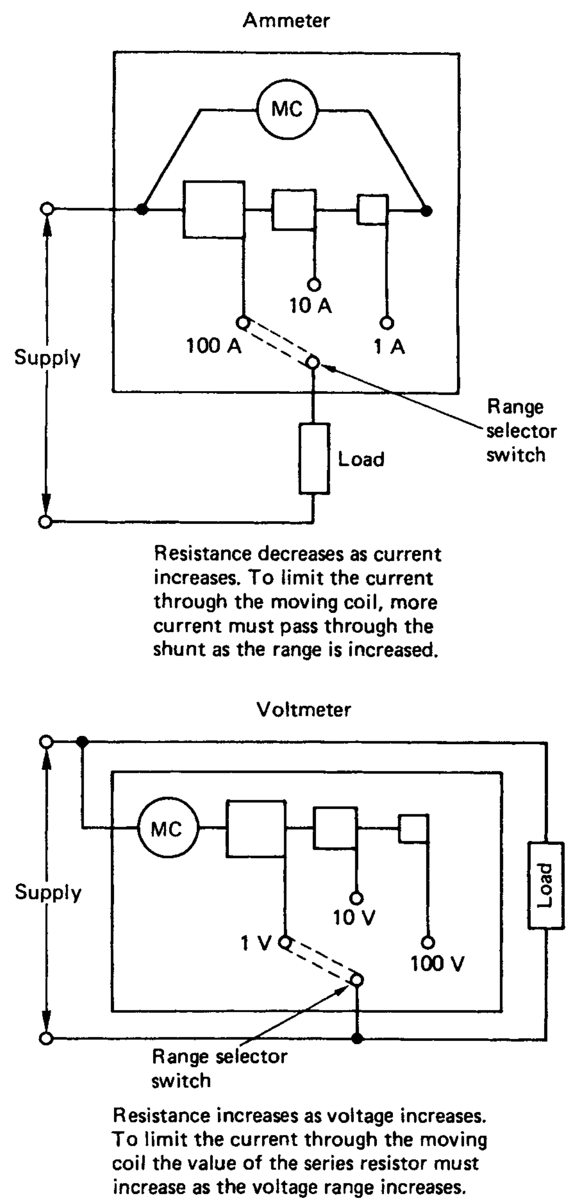


Fig. 2.38 The resistor and coil arrangements in a multirange instrument.

To extend the range of a voltmeter a high-resistance series resistor is connected to the meter movement. This limits the current flowing through the meter movement to an acceptable low value.

A multirange instrument contains a number of shunt or series resistors which are connected by a range selector switch to form the various scales of the instrument, as shown in Fig. 2.38.

EXAMPLE

A moving coil movement has a resistance of 5 Ω and gives full scale deflection when 15 mA flows in the coil. Calculate the value of the resistor which must be connected to the movement in order that the instrument may be used (a) as a 5 A ammeter and (b) as a 100 V voltmeter.

For (a),

$$I_T = I_M + I_S \text{ (A) (from Fig. 2.37)}$$
$$I_S = I_T - I_M \text{ (A)}$$
$$I_S = 5\text{ A} - 0.015\text{ A}$$
$$I_S = 4.985\text{ A}$$

The voltage dropped across the moving coil is given by

$$V_M = I_M \times R \text{ (V)}$$

where R is the resistance of moving coil

$$\therefore V_M = 15 \times 10^{-3}\text{A} \times 5\,\Omega$$
$$V_M = 75 \times 10^{-3}\text{V}$$

Since the shunt resistor is connected in parallel with the moving coil movement

$$V_M = V_S$$

where V_S is the voltage across the shunt. The shunt resistance is given by

$$R_S = \frac{V_S}{I_S}(\Omega)$$

$$\therefore\ R_S = \frac{75 \times 10^{-3}\text{V}}{4.985\text{A}}$$

$$R_S = 15.045\text{ m}\Omega$$

For (b), the voltage dropped across the moving coil is given by

$$V_M = I_M \times R \text{ (V)}$$

where R is, as before, the resistance of the moving coil

$$\therefore V_M = 15 \times 10^{-3}\text{A} \times 5\Omega$$
$$V_M = 75 \times 10^{-3}\text{V}$$

The supply voltage is given by

$$V_S = V_M + V_R \text{ (from Fig. 2.37)}$$
$$\therefore V_R = V_S - V_M$$
$$V_R = 100\text{ V} - 75 \times 10^{-3}\text{V}$$
$$V_R = 99.925\text{ V}$$

Since I_M flows through the moving coil and the series resistor the resistance of the series resistor is given by

$$R = \frac{V_R}{I_M}(\Omega)$$

$$\therefore\ R = \frac{99.925\text{ V}}{15 \times 10^{-3}\text{A}}$$

$$R = 6660\ \Omega$$

Many commercial instruments are capable of making more than one test or have a range of scales to choose from. A range selector switch is usually used to choose the appropriate scale, as shown in Fig. 2.38. A scale range should be chosen which suits the range of the current, voltage or resistance being measured. For example, when taking a reading in the 8 or 9 V range the obvious scale choice would be one giving 10 V full scale deflection. To make this reading on an instrument with 100 V full scale deflection would lead to errors, because the deflection is too small.

Ammeters must be connected in series with the load, and voltmeters in parallel across the load as shown in Fig. 2.39. The power in a resistive load may be calculated from the readings of voltage and current since $P = VI$. This will give accurate calculations on both a.c. and d.c. supplies, but when measuring the power of an a.c. circuit which contains inductance or capacitance a wattmeter must be used because the voltage and current will be out of phase.

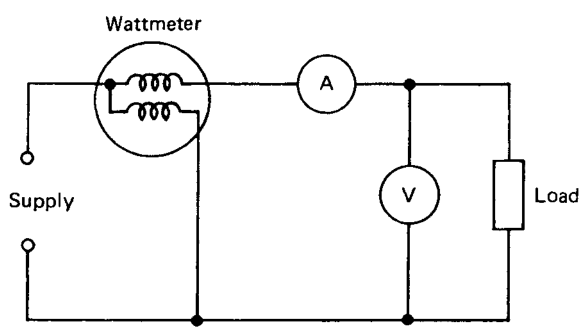


Fig. 2.39 Wattmeter, ammeter and voltmeter correctly connected to a load.

Dynamometer wattmeter

A correctly connected wattmeter will give an accurate measure of the power in any a.c. or d.c. circuit. It is essentially a moving coil instrument in which the main magnetic field is produced by two fixed current coils. The moving coil is the voltage coil and rotates within the fixed coils, being pivoted centrally between them and controlled by spiral hair springs as shown in Fig. 2.40.

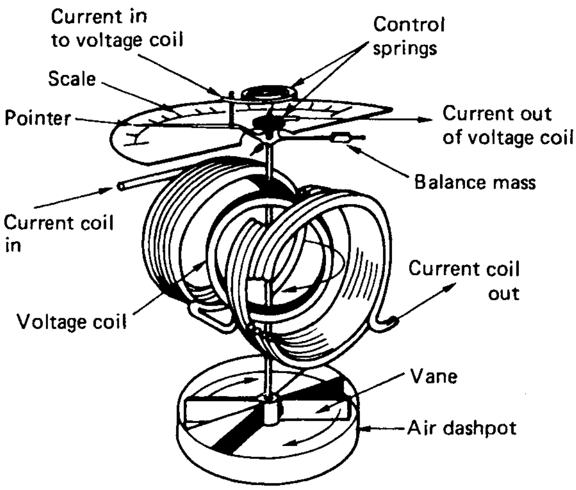


Fig. 2.40 A dynamometer wattmeter (by kind permission of G. Waterworth and R.P. Phillips).

The main magnetic field is produced by the current in the fixed coil and is proportional to it. The force rotating the moving coil is proportional to its current and the magnetic field strength produced by the fixed coils. The deflection is proportional to the product of the currents in the fixed and moving coils. Since the moving coil current depends upon the voltage and the fixed coils depend upon the current, the meter deflection is proportional to $V \times I =$ power in watts.

Any change in the direction of the current in the circuit affects both coils and the direction of deflection remains unchanged, allowing the instrument to be used on both a.c. and d.c. circuits. On a.c. circuits the deflection will be the average value of the product of the instantaneous values of current and voltage, meaning that the wattmeter will measure the true power or active power in the circuit, in which the deflection is proportional to $VI \cos \theta$ (watts). Damping is achieved by an air vane moving in a dashpot.

Measurement of power in a three-phase circuit

ONE-WATTMETER METHOD

When three-phase loads are balanced, for example in motor circuits, one wattmeter may be connected into any phase, as shown in Fig. 2.41. This wattmeter will indicate the power in that phase and since the load is balanced the total power in the three-phase circuit will be given by:

$$\text{Total power} = 3 \times \text{Wattmeter reading}$$

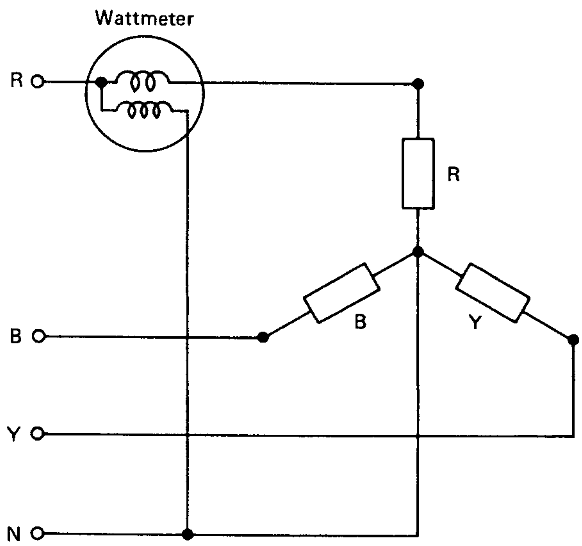


Fig. 2.41 One-wattmeter measurement of power.

TWO-WATTMETER METHOD

This is the most commonly used method for measuring power in a three-phase, three-wire system since it can be used for both balanced and unbalanced loads connected in either star or delta. The current coils are connected to any two of the lines, and the voltage coils are connected to the other line, the one without a current coil connection, as shown in Fig. 2.42. Then

$$\text{Total power} = W_1 + W_2$$

This equation is true for any three-phase load, balanced or unbalanced, star or delta connection, provided there is no fourth wire in the system.

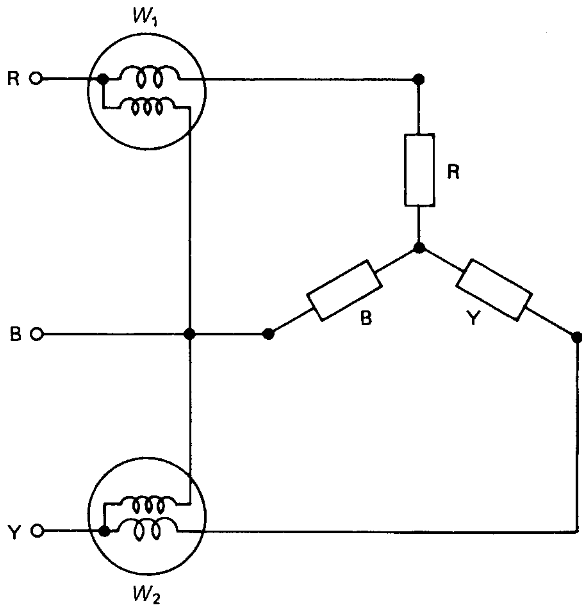


Fig. 2.42 Two-wattmeter measurement of power.

THREE-WATTMETER METHOD

If the installation is four-wire, and the load on each phase is unbalanced, then three wattmeter readings are necessary, connected as shown in Fig. 2.43. Each wattmeter measures the power in one phase and the total power will be given by

$$\text{Total power} = W_1 + W_2 + W_3$$

Energy meter

The current and voltage coils are wound on the two magnets as shown in Fig. 2.44. The current coil establishes a flux Φ_1 which is proportional to the current, and the voltage coil establishes a magnetic flux Φ_v.

The rotation of the aluminium disc is due to the interaction of these magnetic fields. The magnetic flux establishes eddy currents in the disc which produce a turning force. The force exerted is proportional to the phase angle between the voltage and current coil fluxes; maximum force occurs when they are 90° out of phase. This force is proportional to the true power $VI\cos\theta$, which is equal to the speed of rotation of the disc. The number of revolutions in a given time will give a measure of energy since energy = power × time.

The rotating disc spindle is attached through suitable gearing to a revolution counter which is calibrated to read kilowatt-hours, which is the Board of Trade unit of electric energy.

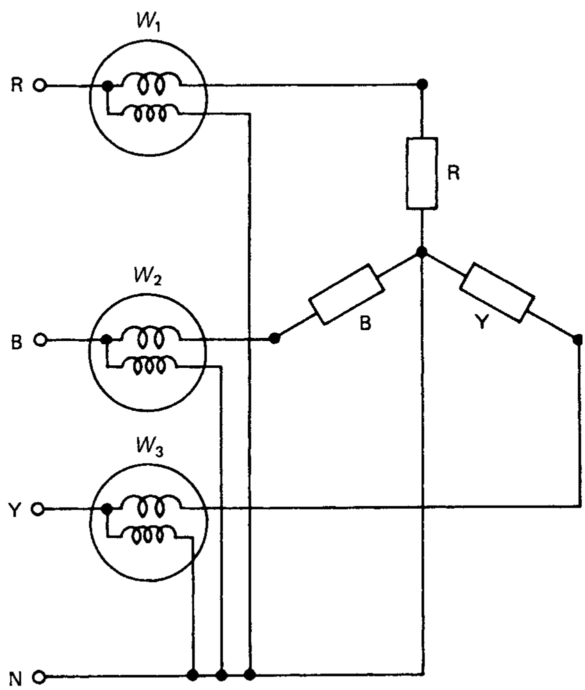


Fig. 2.43 Three-wattmeter measurement of power.

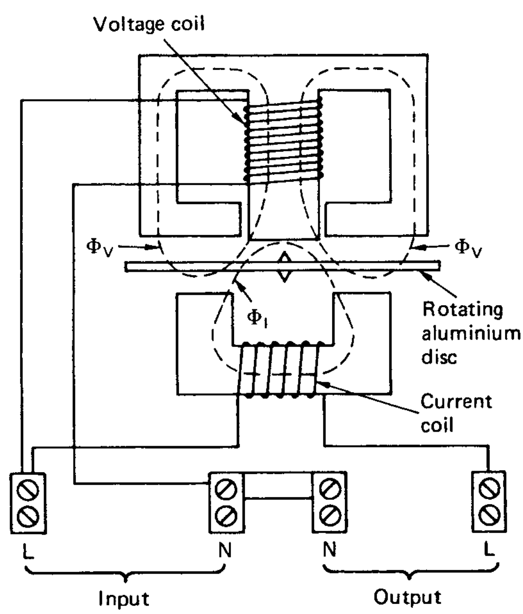


Fig. 2.44 Construction of an energy meter.

Tong tester

The tong tester or clip-on ammeter works on the same principle as the bar primary current transformer shown in Fig. 1.99(b). The laminated core of the transformer can be opened and passed over the busbar or single-core cable. In this way a measurement of the current being carried can be made without disconnection of the supply. The construction is shown in Fig. 2.45.

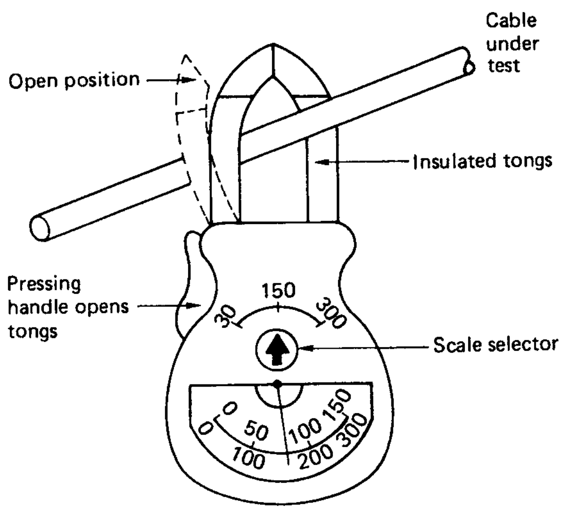


Fig. 2.45 Tong tester or clip-on ammeter.

Phase sequence testers

Phase sequence is the order in which each phase of a three-phase supply reaches its maximum value. The normal phase sequence for a three-phase supply is R–Y–B, which means that first red, then yellow and finally the blue phase reaches its maximum value.

Phase sequence has an important application in the connection of three-phase transformers. The secondary terminals of a three-phase transformer must not be connected in parallel until the phase sequence is the same.

A phase sequence tester can be an indicator which is, in effect, a miniature induction motor, with three clearly colour-coded connection leads. A rotating disc with a pointed arrow shows the normal rotation for phase sequence R–Y–B. If the sequence is reversed the disc rotates in the opposite direction to the arrow. However, an on-site phase sequence tester can be made by connecting four 230 V by 100 W lamps and a p.f. correction capacitor from a fluorescent luminaire as shown in Fig. 2.46.

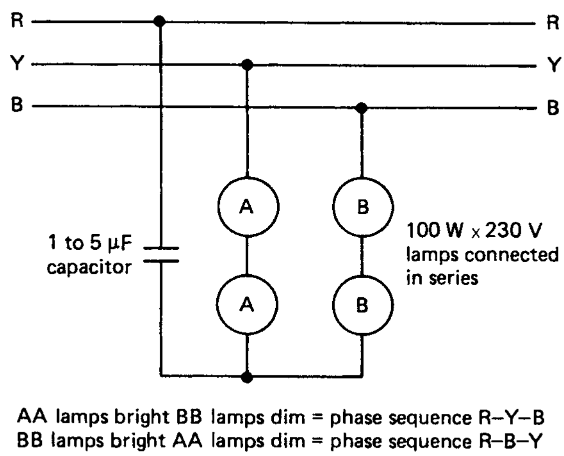


Fig. 2.46 Phase sequence test by the lamps bright, lamps dim method.

The capacitor takes a leading current which results in a phase displacement in the other two phases. The phasor addition of the voltage in the circuit results in one pair of lamps illuminating brightly while the other pair are illuminated dimly. Two lamps must be connected in series as shown in Fig. 2.46 because most of the line voltage will be across them during the test.

Test equipment used by electricians

The Health and Safety Executive has published Guidance Notes (GS 38) which advise electricians and other electrically competent people on the selection of suitable test probes, voltage indicating devices and measuring instruments. This is because they consider suitably constructed test equipment to be as vital for personal safety as the training and practical skills of the electrician. In the past, unsatisfactory test probes and voltage indicators have frequently been the cause of accidents, and therefore all test probes must now incorporate the following features:

1 The probes must have finger barriers or be shaped so that the hand or fingers cannot make contact with the live conductors under test.

2 The probe tip must not protrude more than 2 mm, and preferably only 1 mm, be spring-loaded and screened.
3 The lead must be adequately insulated and coloured so that one lead is readily distinguished from the other.
4 The lead must be flexible and sufficiently robust.
5 The lead must be long enough to serve its purpose but not too long.
6 The lead must not have accessible exposed conductors even if it becomes detached from the probe or from the instrument.
7 Where the leads are to be used in conjunction with a voltage detector they must be protected by a fuse.

A suitable probe and lead is shown in Fig. 2.47.

GS 38 also tells us that where the test is being made simply to establish the presence or absence of a voltage, the preferred method is to use a proprietary test lamp or voltage indicator which is suitable for the working voltage, rather than a multimeter. Accident history has shown that incorrectly set multimeters or makeshift devices for voltage detection have frequently caused accidents. Figure 2.48 shows a suitable voltage indicator. Test lamps and voltage indicators are not fail-safe, and therefore GS 38 recommends that they should be regularly proved, preferably before and after use, as described in the flowchart for a safe isolation procedure.

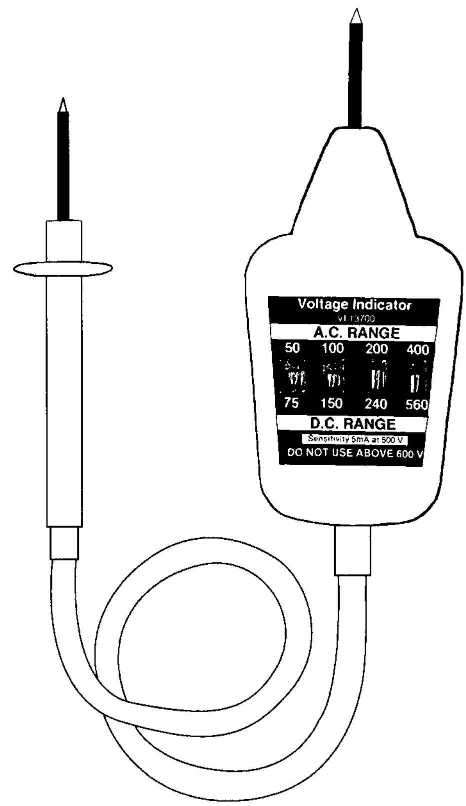


Fig. 2.48 Typical voltage indicator.

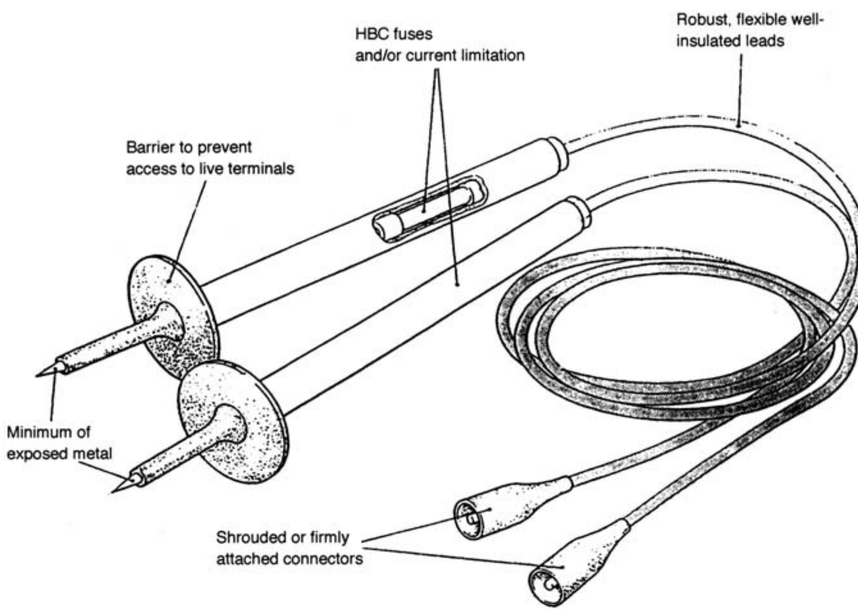


Fig. 2.47 Recommended type of test probe and leads.

Test procedures

1 The circuits must be isolated using a 'safe isolation procedure', such as that described below, before beginning to test.
2 All test equipment must be 'approved' and connected to the test circuits by recommended test probes as described by the HSE Guidance Notes GS 38. The test equipment used must also be 'proved' on a known supply or by means of a proving unit such as that shown in Fig. 2.49.
3 Isolation devices must be 'secured' in the 'off' position as shown in Fig. 2.50.
4 Warning notices must be posted.
5 All relevant safety and functional tests must be completed before restoring the supply.

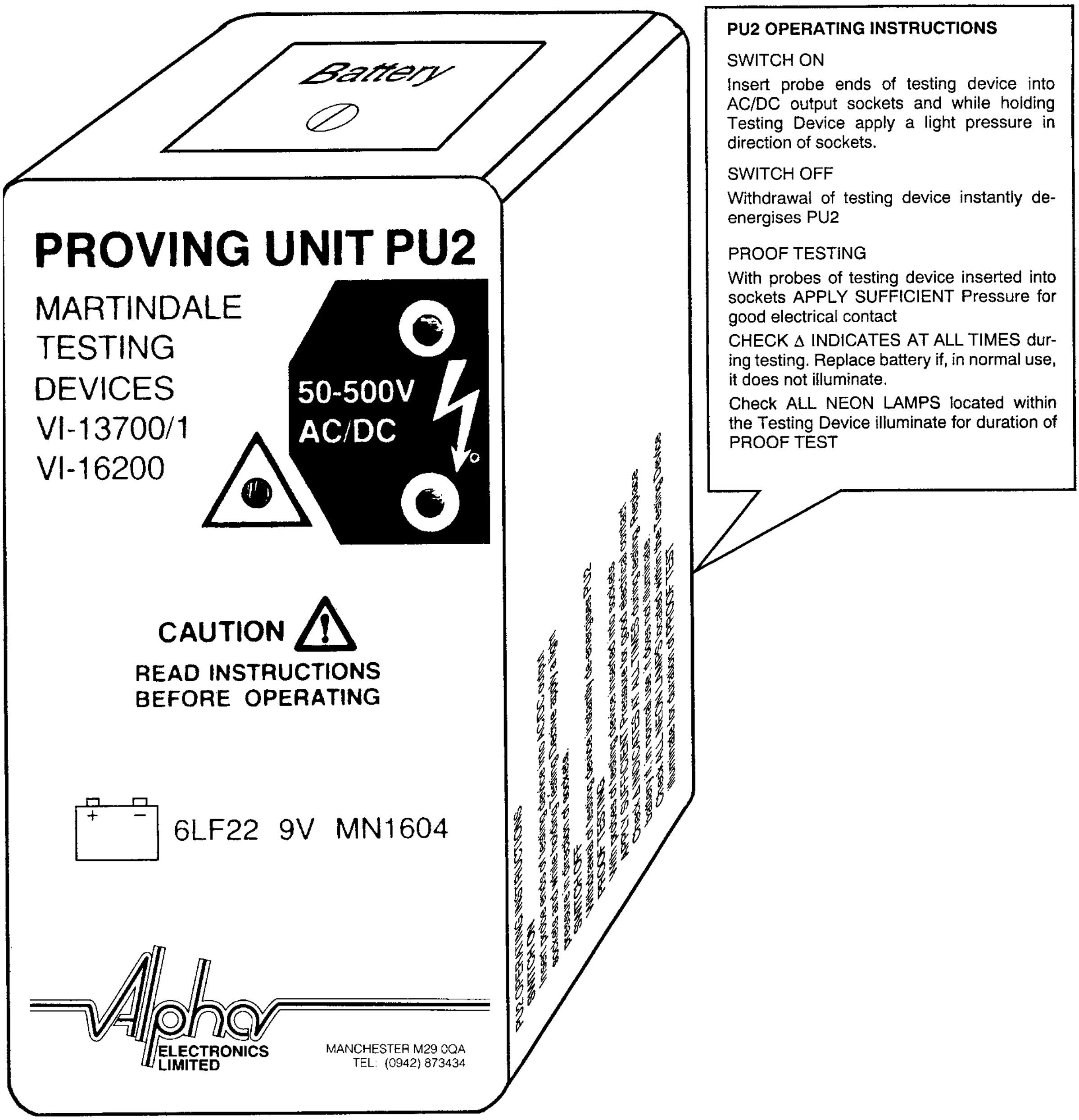


Fig. 2.49 Voltage proving unit.

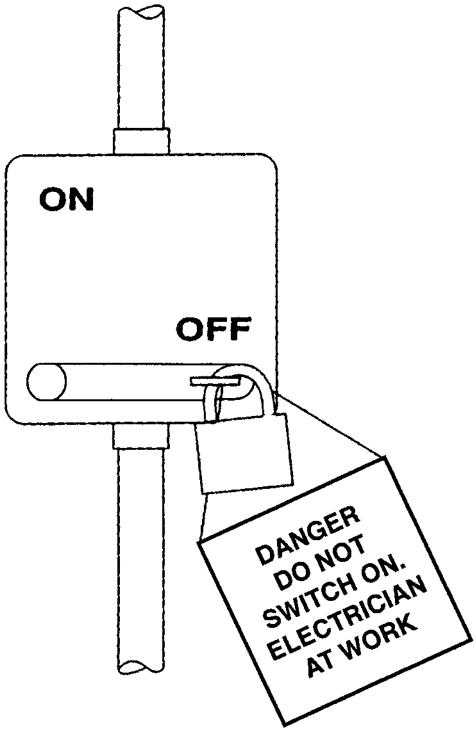


Fig. 2.50 Secure isolation of a supply.

Live testing

The Electricity at Work Act tells us that it is 'preferable' that supplies be made dead before work commences (Regulation 4(3)). However, it does acknowledge that some work, such as fault finding and testing, may require the electrical equipment to remain energized. Therefore, if the fault finding and testing can only be successfully carried out 'live', then the person carrying out the fault diagnosis must:

- be trained so that he understands the equipment and the potential hazards of working live and can, therefore, be deemed to be 'competent' to carry out the activity;
- only use approved test equipment;
- set up barriers and warning notices so that the work activity does not create a situation dangerous to others.

Note that while live testing may be required in order to find the fault, live repair work must not be carried out. The individual circuit or item of equipment must first be isolated.

Isolation of supply

The Electricity at Work Regulations are very specific in describing the procedure to be used for isolation of the electrical supply. Regulation 12(1) tells us that isolation means the disconnection and separation of the electrical equipment from every source of electrical energy in such a way that this disconnection and separation is secure. Regulation 4(3) tells us that we must also prove the conductors dead before work commences and that the test instrument used for this purpose must itself be proved immediately before and immediately after testing the conductors. To isolate an individual circuit or item of equipment successfully, competently and safely we must follow a procedure such as that given by the flow diagram in Fig. 2.51. Start at the top and work your way down the flowchart. When you get to the heavy-outlined boxes, pause and ask yourself whether everything is satisfactory up to this point. If the answer is yes, move on. If no, go back as indicated by the diagram.

Inspection and testing techniques

The testing of an installation implies the use of instruments to obtain readings. However, a test is unlikely to identify a cracked socket outlet, a chipped or loose switch plate, a missing conduit-box lid or saddle, so it is also necessary to make a visual inspection of the installation.

All new installations must be inspected and tested before connection to the mains, and all existing installations should be periodically inspected and tested to ensure that they are safe and meet the regulations of the IEE Regulations 711 to 744.

The method used to test an installation may inject a current into the system. This current must not cause danger to any person or equipment in contact with the installation, even if the circuit being tested is faulty. The test results must be compared with any relevant data, including the IEE Regulation tables, and the test procedures must be followed carefully and in the correct sequence, as indicated by Regulation 713–01–01. This ensures that the protective conductors are correctly connected and secure before the circuit is energized.

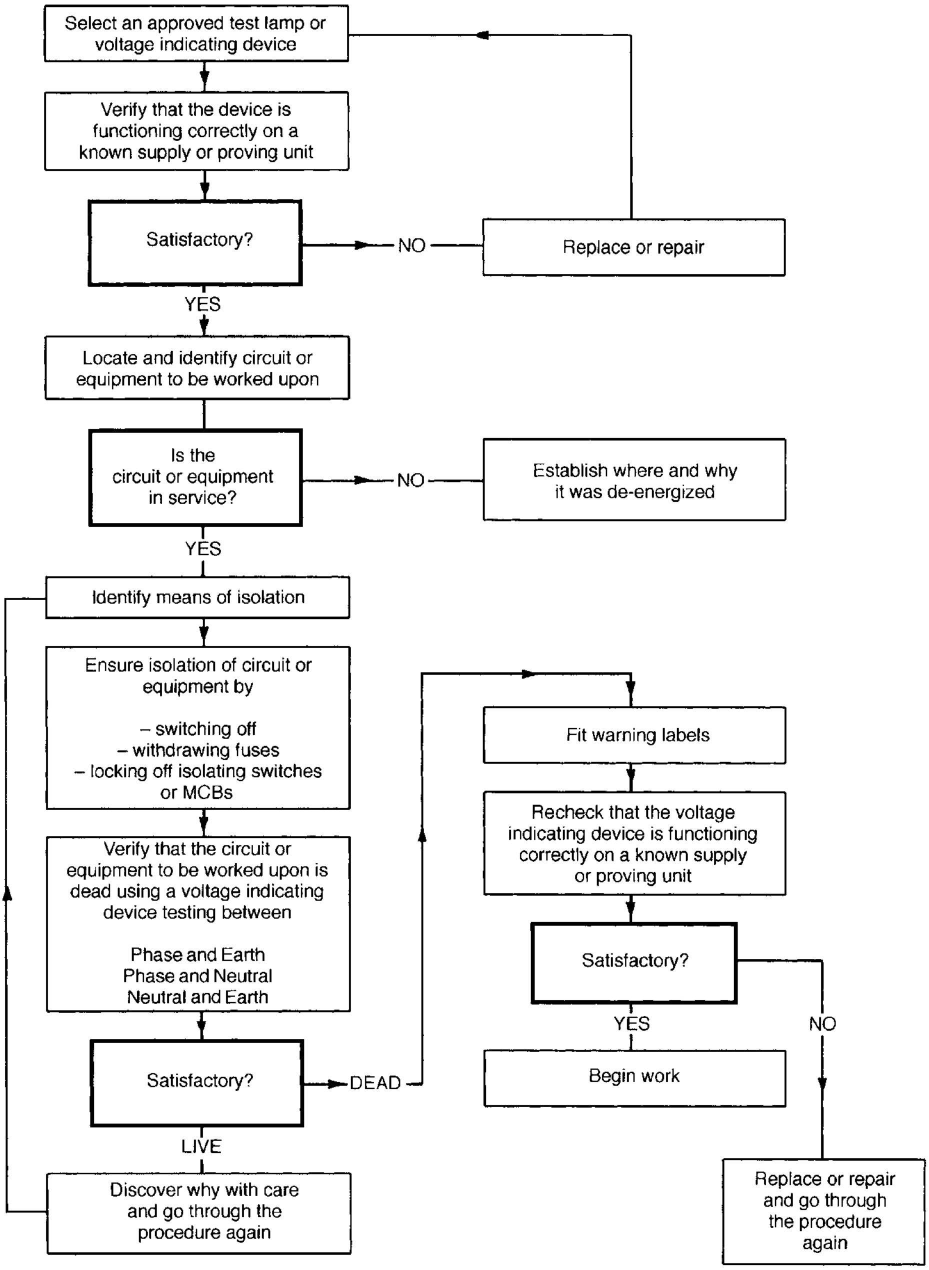


Fig. 2.51 Flowchart for a secure isolation procedure.

The installation must be visually inspected before testing begins. The aim of the visual inspection is to confirm that all equipment and accessories are undamaged and comply with the relevant British and European Standards, and also that the installation has been securely and correctly erected. Regulation 712–01–03 gives a check-list for the initial visual inspection of an installation, including:

- connection of conductors;
- identification of conductors;
- routing of cables in safe zones;
- selection of conductors for current carrying capacity and volt drop;

- connection of single-pole devices for protection or switching in phase conductors only;
- correct connection of socket outlets, lampholders, accessories and equipment;
- presence of fire barriers, suitable seals and protection against thermal effects;
- methods of protection against electric shock, including the insulation of live parts and placement of live parts out of reach by fitting appropriate barriers and enclosures;
- prevention of detrimental influences (e.g. corrosion);
- presence of appropriate devices for isolation and switching;
- presence of undervoltage protection devices;
- choice and setting of protective devices;
- labelling of circuits, fuses, switches and terminals;
- selection of equipment and protective measures appropriate to external influences;
- adequate access to switchgear and equipment;
- presence of danger notices and other warning notices;
- presence of diagrams, instructions and similar information;
- appropriate erection method.

The checklist is a guide, it is not exhaustive or detailed, and should be used to identify relevant items for inspection, which can then be expanded upon. For example, the first item on the checklist, connection of conductors, might be further expanded to include the following:

- Are connections secure?
- Are connections correct? (conductor identification)
- Is the cable adequately supported so that no strain is placed on the connections?
- Does the outer sheath enter the accessory?
- Is the insulation undamaged?
- Does the insulation proceed up to but not *into* the connection?

This is repeated for each appropriate item on the checklist.

Those tests which are relevant to the installation must then be carried out in the sequence given in Regulation 713–01–01 and Sections 9 and 10 of the *On Site Guide* for reasons of safety and accuracy. These tests are as follows:

Before the supply is connected

1 Test for continuity of protective conductors, including main and supplementary bonding.
2 Test the continuity of all ring final circuit conductors.
3 Test for insulation resistance.
4 Test for polarity using the continuity method.
5 Test the earth electrode resistance.

With the supply connected

6 Recheck polarity using a voltmeter or approved test lamp.
7 Test the earth fault loop impedance.
8 Carry out functional testing (e.g. operation of RCDs).

If any test fails to comply with the Regulations, then *all* the preceding tests must be repeated after the fault has been rectified. This is because the earlier test results may have been influenced by the fault (Regulation 713–01–01).

There is an increased use of electronic devices in electrical installation work, for example, in dimmer switches and ignitor circuits of discharge lamps. These devices should temporarily be disconnected so that they are not damaged by the test voltage of, for example, the insulation resistance test (Regulation 713–04).

APPROVED TEST INSTRUMENTS

The test instruments and test leads used by the electrician for testing an electrical installation must meet all the requirements of the relevant regulations. The Health and Safety Executive has published Guidance Notes GS 38 for test equipment used by electricians. The IEE Regulations (BS 7671) also specify the test voltage or current required to carry out particular tests satisfactorily. All testing must, therefore, be carried out using an 'approved' test instrument if the test results are to be valid. The test instrument must also carry a calibration certificate, otherwise the recorded results may be void. Calibration certificates usually last for a year. Test instruments must, therefore, be tested and recalibrated each year by an approved supplier. This will maintain the accuracy of the instrument to an acceptable level, usually within 2% of the true value.

Modern digital test instruments are reasonably robust, but to maintain them in good working order they must be treated with care. An approved test instrument costs equally as much as a good-quality camera; it should, therefore, receive the same care and consideration.

Continuity tester

To measure accurately the resistance of the conductors in an electrical installation we must use an instrument which is capable of producing an open circuit voltage of between 4 and 24 V a.c. or d.c., and deliver a short-circuit current of not less than 200 mA (Regulation 713–02). The functions of continuity testing and insulation resistance testing are usually combined in one test instrument.

Insulation resistance tester

The test instrument must be capable of detecting insulation leakage between live conductors and between live conductors and earth. To do this and comply with Regulation 713–04 the test instrument must be capable of producing a test voltage of 250, 500 or 1000 V and deliver an output current of not less than 1 mA at its normal voltage.

Earth fault loop impedance tester

The test instrument must be capable of delivering fault currents as high as 25 A for up to 40 ms using the supply voltage. During the test, the instrument does an Ohm's law calculation and displays the test result as a resistance reading.

RCD tester

Where circuits are protected by a residual current device we must carry out a test to ensure that the device will operate very quickly under fault conditions and within the time limits set by the IEE Regulations. The instrument must, therefore, simulate a fault and measure the time taken for the RCD to operate. The instrument is, therefore, calibrated to give a reading measured in milliseconds to an in-service accuracy of 10%.

If you purchase good-quality 'approved' test instruments and leads from specialist manufacturers they will meet all the Regulations and Standards and therefore give valid test results. However, to carry out all the tests required by the IEE Regulations will require a number of test instruments and this will represent a major capital investment in the region of £1000.

Let us now consider the individual tests.

1 TESTING FOR CONTINUITY OF PROTECTIVE CONDUCTORS (713–02)

The object of the test is to ensure that the circuit protective conductor (CPC) is correctly connected, is electrically sound and has a total resistance which is low enough to permit the overcurrent protective device to operate within the disconnection time requirements of Regulation 413–02–08, should an earth fault occur. Every protective conductor must be separately tested from the consumer's earthing terminal to verify that it is electrically sound and correctly connected, including any main and supplementary bonding conductors.

A d.c. test using an ohmmeter continuity tester is suitable where the protective conductors are of copper or aluminium up to 35 mm^2. The test is made with the supply disconnected, measuring from the consumer's earthing terminal to the far end of each CPC, as shown in Fig. 2.52. The resistance of the long test lead is subtracted from these readings to give the resistance value of the CPC. The result is recorded on an installation schedule such as that given in Appendix 7 of the *On Site Guide.*

Where steel conduit or trunking forms the protective conductor, the standard test described above may be used, but additionally the enclosure must be visually checked along its length to verify the integrity of all the joints.

If the inspecting engineer has grounds to question the soundness and quality of these joints then the phase earth loop impedance test described later in this chapter should be carried out.

If, after carrying out this further test, the inspecting engineer still questions the quality and soundness of the protective conductor formed by the metallic conduit or trunking then a further test can be done using an a.c. voltage not greater than 50 V at the frequency of the installation and a current approaching 1.5 times the design current of the circuit, but not greater than 25 A.

This test can be done using a low-voltage transformer and suitably connected ammeters and voltmeters, but a number of commercial instruments are available such as the Clare tester, which give a direct reading in ohms.

Because fault currents will flow around the earth fault loop path, the measured resistance values must be low enough to allow the overcurrent protective device to operate quickly. For a satisfactory test result, the resistance of the protective conductor should be consistent with those values calculated for a phase

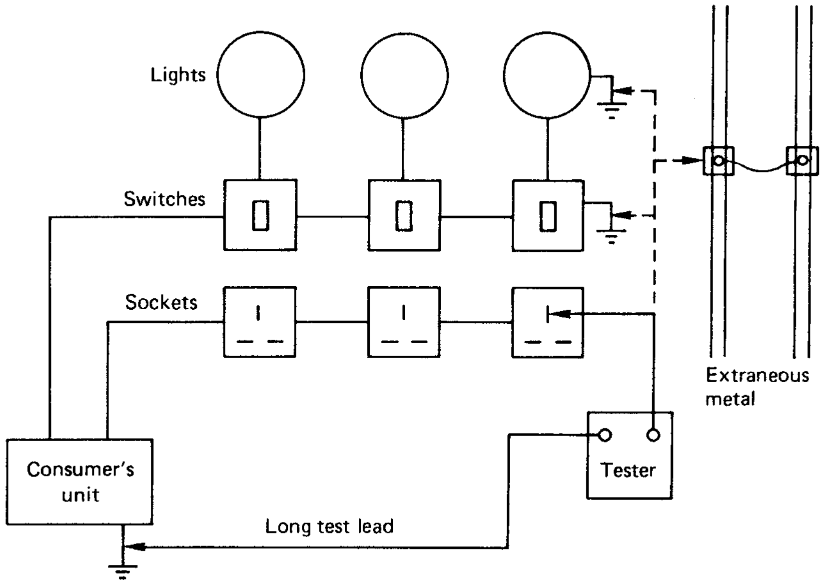


Fig. 2.52 Testing continuity of protective conductors.

conductor of similar length and cross-sectional area. Values of resistance per metre for copper and aluminium conductors are given in Table 9A of the *On Site Guide*. The resistances of some other metallic containers are given in Table 2.7.

Table 2.7 Resistance values of some metallic containers

Metallic sheath	Size (mm)	Resistance at 20°C (mΩ/m)
Conduit	20	1.25
	25	1.14
	32	0.85
Trunking	50 × 50	0.949
	75 × 75	0.526
	100 × 100	0.337

EXAMPLE

The CPC for a ring final circuit is formed by a 1.5 mm^2 copper conductor of 50 m approximate length. Determine a satisfactory continuity test value for the CPC using the value given in Table 9A of the *On Site Guide*.

From Table 9A:

Resistance/metre for a 1.5 mm^2 copper conductor $= 12.10\,\text{m}\Omega/\text{m}$

Therefore, the resistance of 50 m $= 50 \times 12.10 \times 10^{-3}$

$= 0.605\,\Omega$

The protective conductor resistance values calculated by this method can only be an approximation since the length of the CPC can only be estimated. Therefore, in this case, a satisfactory test result would be obtained if the resistance of the protective conductor was about 0.6 Ω. A more precise result is indicated by the earth fault loop impedance test which is carried out later in the sequence of tests.

2 TESTING FOR CONTINUITY OF RING FINAL CIRCUIT CONDUCTORS (713–03)

The object of the test is to ensure that all ring circuit cables are continuous around the ring, that is, that there are no breaks and no interconnections in the ring, and that all connections are electrically and mechanically sound. This test also verifies the polarity of each socket outlet.

The test is made with the supply disconnected, using an ohmmeter as follows:

Disconnect and separate the conductors of both legs of the ring at the main fuse. There are three steps to this test:

Step 1

Measure the resistance of the phase conductors (L_1 and L_2), the neutral conductors (N_1 and N_2) and the protective conductors (E_1 and E_2) at the mains position as shown in Fig. 2.53. End-to-end live and neutral conductor readings should be approximately the same (i.e. within 0.05 Ω) if the ring is continuous. The protective conductor reading will be 1.67 times as great as these readings if 2.5/1.5 mm cable is used. Record the results on a table such as that shown in Table 2.8.

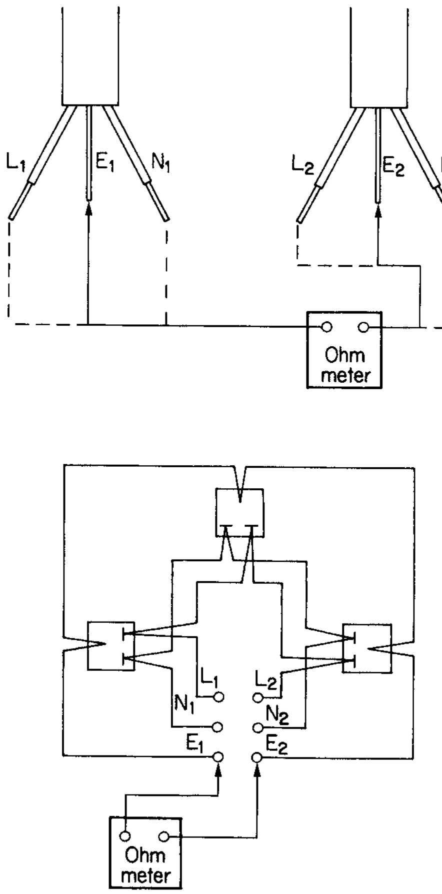


Fig. 2.53 Step 1 test: measuring the resistance of phase, neutral and protective conductors.

Table 2.8 Table which may be used to record the readings taken when carrying out the continuity of ring final circuit conductors tests according to IEE Regulation 713–02

Test	Ohmmeter connected to	Ohmmeter readings	This gives a value for
Step 1	L_1 and L_2		r_1
	N_1 and N_2		
	E_1 and E_2		r_2
Step 2	Live and neutral at each socket		
Step 3	Live and earth at each socket		$R_1 + R_2$

As a check $(R_1 + R_2)$ value should equal $(r_1 + r_2)/4$.

Step 2

The live and neutral conductors should now be temporarily joined together as shown in Fig. 2.54. An ohmmeter reading should then be taken between live and neutral at *every* socket outlet on the ring circuit. The readings obtained should be substantially the same, provided that there are no breaks or multiple loops in the ring. Each reading should have a value of approximately half the live and neutral ohmmeter readings measured in step 1 of this test. Sockets connected as a spur will have a slightly higher value of resistance because they are fed by only one cable, while each socket on the ring is fed by two cables. Record the results on a table such as that shown in Table 2.8.

Step 3

Where the circuit protective conductor is wired as a ring, for example where twin and earth cables or plastic conduit is used to wire the ring, temporarily join the live and circuit protective conductors together as shown in Fig. 2.55. An ohmmeter reading should

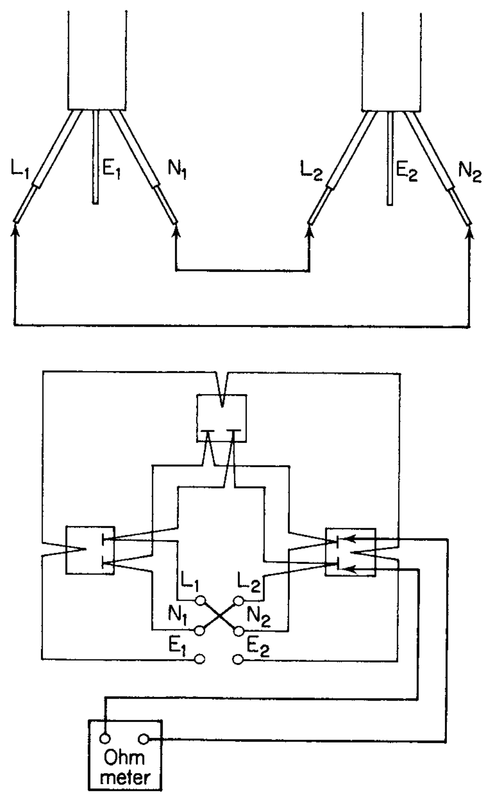


Fig. 2.54 Step 2 test: connection of mains conductors and test circuit conditions.

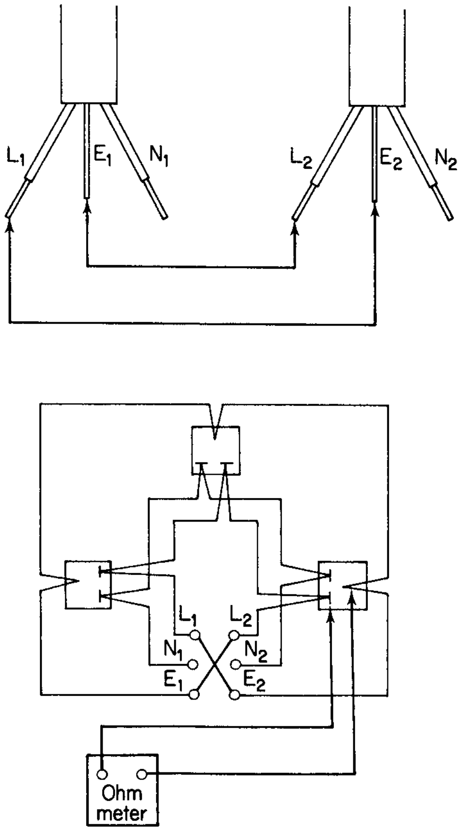


Fig. 2.55 Step 3 test: connection of mains conductors and test circuit conditions.

then be taken between live and earth at *every* socket outlet on the ring. The readings obtained should be substantially the same provided that there are no breaks or multiple loops in the ring. This value is equal to $R_1 + R_2$ for the circuit. Record the results on an installation schedule such as that given in Appendix 7 of the *On Site Guide* or a table such as that shown in Table 2.8. The step 3 value of $R_1 + R_2$ should be equal to $(r_1 + r_2)/4$, where r_1 and r_2 are the ohmmeter readings from step 1 of this test (see Table 2.8).

3 TESTING INSULATION RESISTANCE (713–04)

The object of the test is to verify that the quality of the insulation is satisfactory and has not deteriorated or short-circuited. The test should be made at the consumer's unit with the mains switch off, all fuses in place and all switches closed. Neon lamps, capacitors and electronic circuits should be disconnected, since they will respectively glow, charge up or be damaged by the test.

There are two tests to be carried out using an insulation resistance tester which must supply a voltage of 500 V d.c. for 230 and 400 V installations. These are phase and neutral conductors to earth and between phase conductors. The procedures are:

Phase and neutral conductors to earth

1 Remove all lamps.
2 Close all switches and circuit breakers.
3 Disconnect appliances.
4 Test separately between the phase conductor and earth, *and* between the neutral conductor and earth, for *every* distribution circuit at the consumer's unit as shown in Fig. 2.56(a). Record the results on an installation schedule such as that given in Appendix 7 of the *On Site Guide*.

Between phase conductors

1 Remove all lamps.
2 Close all switches and circuit breakers.
3 Disconnect appliances.
4 Test between phase and neutral conductors of *every* distribution circuit at the consumer's unit as shown in Fig. 2.56(b) and record the result.

The insulation resistance readings for each test must be not less than 0.5 MΩ for a satisfactory result (IEE Regulation 713–04–02).

Where equipment is disconnected for the purpose of the insulation resistance test, the equipment itself must be insulation resistance tested between all live parts (i.e. live and neutral conductors connected together) and the exposed conductive parts. The insulation resistance of these tests should be not less than 0.5 MΩ (IEE Regulation 713–04–04).

Although an insulation resistance reading of 0.5 MΩ complies with the Regulations, the IEE Guidance Notes tell us that a reading of less than 2 MΩ might indicate a latent but not yet visible fault in the installation. In these cases each circuit should be separately tested to obtain a reading greater than 2 MΩ.

4 TESTING POLARITY (713–09)

The object of this test is to verify that all fuses, circuit breakers and switches are connected in the phase or live conductor only, and that all socket outlets are correctly

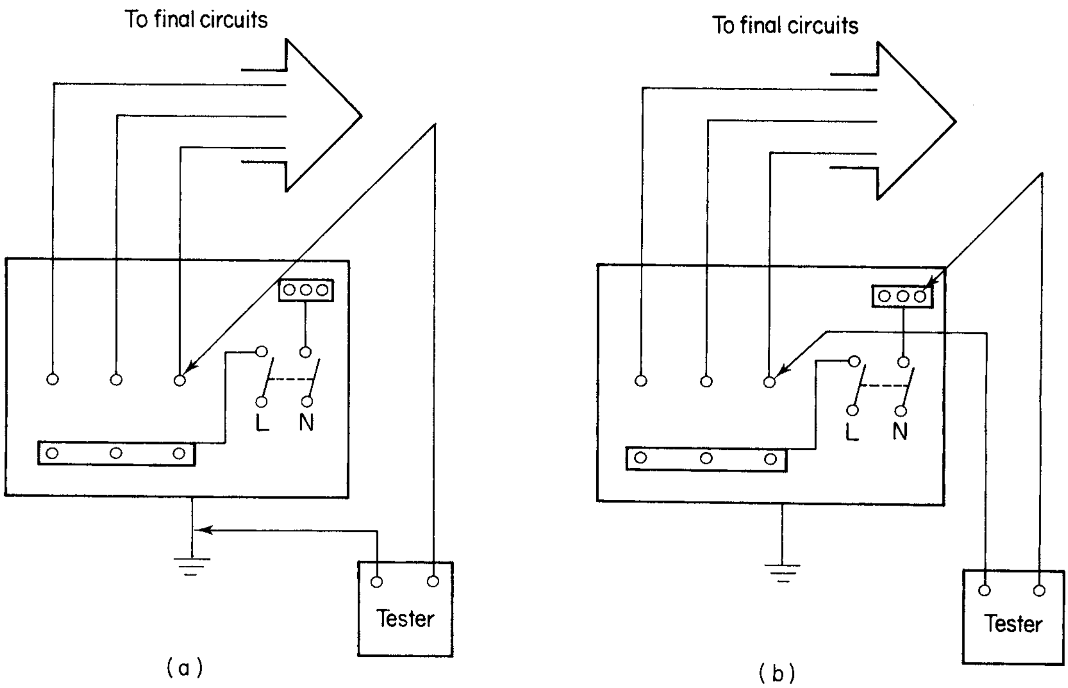


Fig. 2.56 Insulation resistance test.

wired and Edison screw-type lampholders have the centre contact connected to the live conductor. It is important to make a polarity test on the installation since a visual inspection will only indicate conductor identification.

The test is done with the supply disconnected using an ohmmeter or continuity tester as follows:

1 Switch off the supply at the main switch.
2 Remove all lamps and appliances.
3 Fix a temporary link between the phase and earth connections on the consumer's side of the main switch.
4 Test between the 'common' terminal and earth at each switch position.
5 Test between the centre pin of any Edison screw lampholders and any convenient earth connection.
6 Test between the live pin (i.e. the pin to the right of earth) and earth at each socket outlet as shown in Fig. 2.57.

For a satisfactory test result the ohmmeter or continuity meter should read approximately zero.

Remove the test link and record the results on an installation schedule such as that given in Appendix 7 of the *On Site Guide*.

5 TESTING EARTH ELECTRODE RESISTANCE (713–10)

When an earth electrode has been sunk into the general mass of earth, it is necessary to verify the resistance of the electrode. The general mass of earth can be considered as a large conductor which is at zero potential. Connection to this mass through earth electrodes provides a reference point from which all other voltage levels can be measured. This is a technique which has been used for a long time in power distribution systems.

The resistance to earth of an electrode will depend upon its shape, size and the resistance of the soil. Earth rods form the most efficient electrodes. A rod of about 1 m will have an earth electrode resistance of between 10 and 200 Ω. Even in bad earthing conditions a rod of about 2 m will normally have an earth electrode resistance which is less than 500 Ω in the United Kingdom. In countries which experience long dry periods of weather the earth electrode resistance may be thousands of ohms.

In the past, electrical engineers used the metal pipes of water mains as an earth electrode, but the recent increase in the use of PVC pipe for water mains now prevents the use of water pipes as the only means of

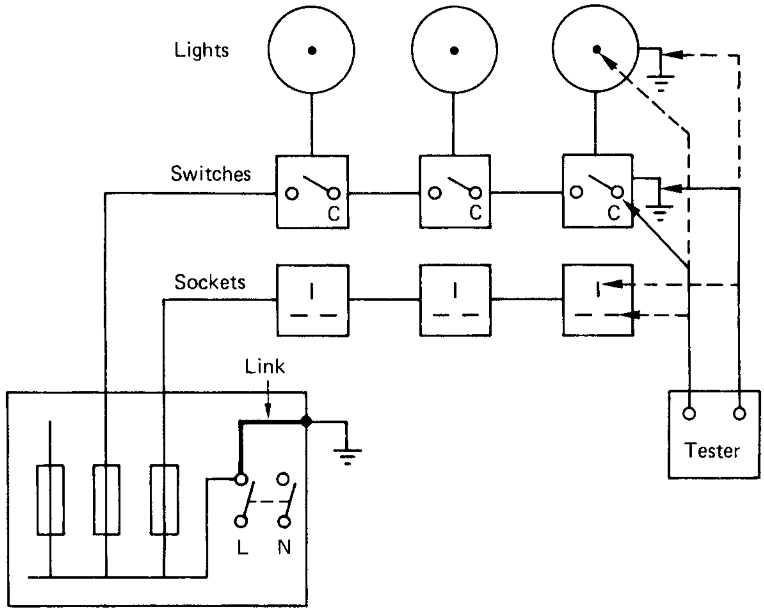


Fig. 2.57 Polarity test.

earthing in the United Kingdom, although this practice is still permitted in some countries. The IEE Regulation 542–02–01 recognizes the use of the following types of earth electrodes:

- earth rods or pipes
- earth tapes or wires
- earth plates
- earth electrodes embedded in foundations
- metallic reinforcement of concrete structures
- metal pipes
- lead sheaths or other metallic coverings of cables.

The earth electrode is sunk into the ground, but the point of connection should remain accessible (Regulation 542–04–02). The connection of the earthing conductor to the earth electrode must be securely made with a copper conductor complying with Table 54A and Regulation 542–03–03 as shown in Fig. 2.58.

The installation site must be chosen so that the resistance of the earth electrode does not increase above the required value due to climatic conditions such as the soil drying out or freezing, or from the effects of corrosion (542–02–02 and 03).

Under fault conditions the voltage appearing at the earth electrode will radiate away from the electrode like the ripples radiating away from a pebble thrown into a pond. The voltage will fall to a safe level in the

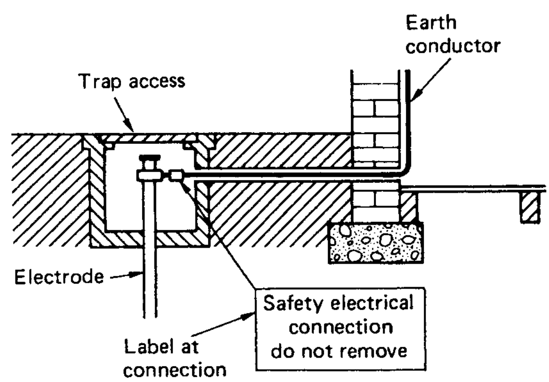


Fig. 2.58 Termination of an earth electrode.

first two or three metres away from the point of the earth electrode, as shown in Fig. 2.59.

The basic method of measuring earth electrode resistance is to pass a current into the soil through the electrode and to measure the voltage required to produce this current.

Regulation 713–11 demands that where earth electrodes are used they should be tested. To carry out the test, either a hand-operated tester or a mains energized double-wound transformer with a separate ammeter and high-resistance voltmeter is used. The test procedure is the same in both cases. The earth electrode is disconnected from all sources of the supply.

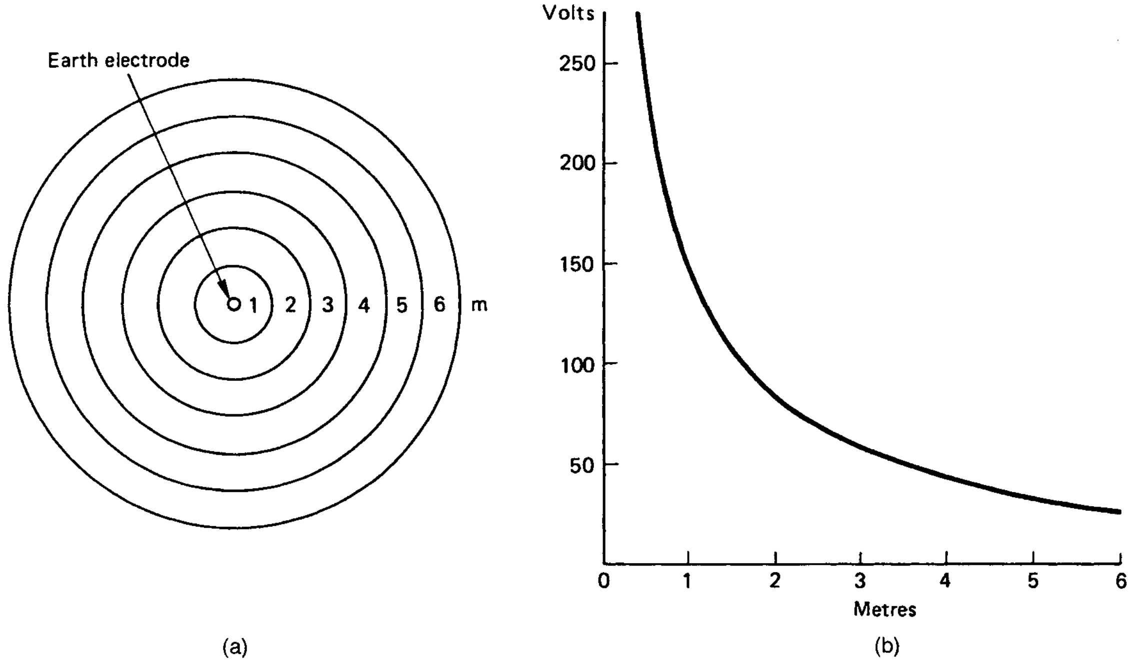


Fig. 2.59 Earth electrode voltage gradient: (a) lines of equipotential voltage; (b) voltage gradient.

An alternating current supplied by a double-wound transformer (as shown in Fig. 2.60) is passed between the earth electrode under test T and an auxiliary earth electrode T_1. The auxiliary electrode T_1 is placed at some distance from T so that the resistance areas of the two electrodes do not overlap. A second auxiliary electrode T_2 is driven into the ground half-way between T and T_1 and the voltmeter reading V tabulated. The resistance of the earth electrode is the voltmeter reading V, divided by the current flowing in the circuit and indicated on ammeter A.

To check that the resistance of the earth electrode is a true value, two further readings are taken at X and Y, with the auxiliary electrode T_2 moved 6 m further from and then 6 m nearer to T, respectively. If the readings are substantially in agreement, the mean of the three readings is taken as the resistance of the earth electrode. If there is no agreement the test must be repeated with the distance between T and T_1 increased.

The test procedure is the same if a hand-operated tester is used. The instrument is connected as shown in Fig. 2.61. The hand-operated generator is turned and the three dials rotated until null balance is indicated on the galvanometer. The value indicated by the dials gives the resistance of the earth electrode. Three readings are taken as in the previously described procedure and the average reading taken as the resistance of the earth electrode. The resistance of the earth electrode will depend upon the type of ground in which the electrode is driven. Wet, marshy land will give a lower resistance reading than rocky ground. Typical resistance readings are:

- marshy ground, 5–20 Ω
- agricultural soil, 5–50 Ω
- loam and clay, 10–150 Ω
- sandy gravel, 200–500 Ω
- rocky ground, 500–10 000 Ω.

Acceptable values of earth electrode resistance will be determined by the purpose for which the earth electrode is being used.

Lightning conductors provide a path of low resistance to lightning current, which may be many thousands of amperes. If the earth electrode forms the final connection for a lightning conductor it must have an electrode resistance of 10 Ω maximum (BS 6651). The lightning protective system must be connected to the main earthing terminal of the electrical installation (Regulation 413–02–02).

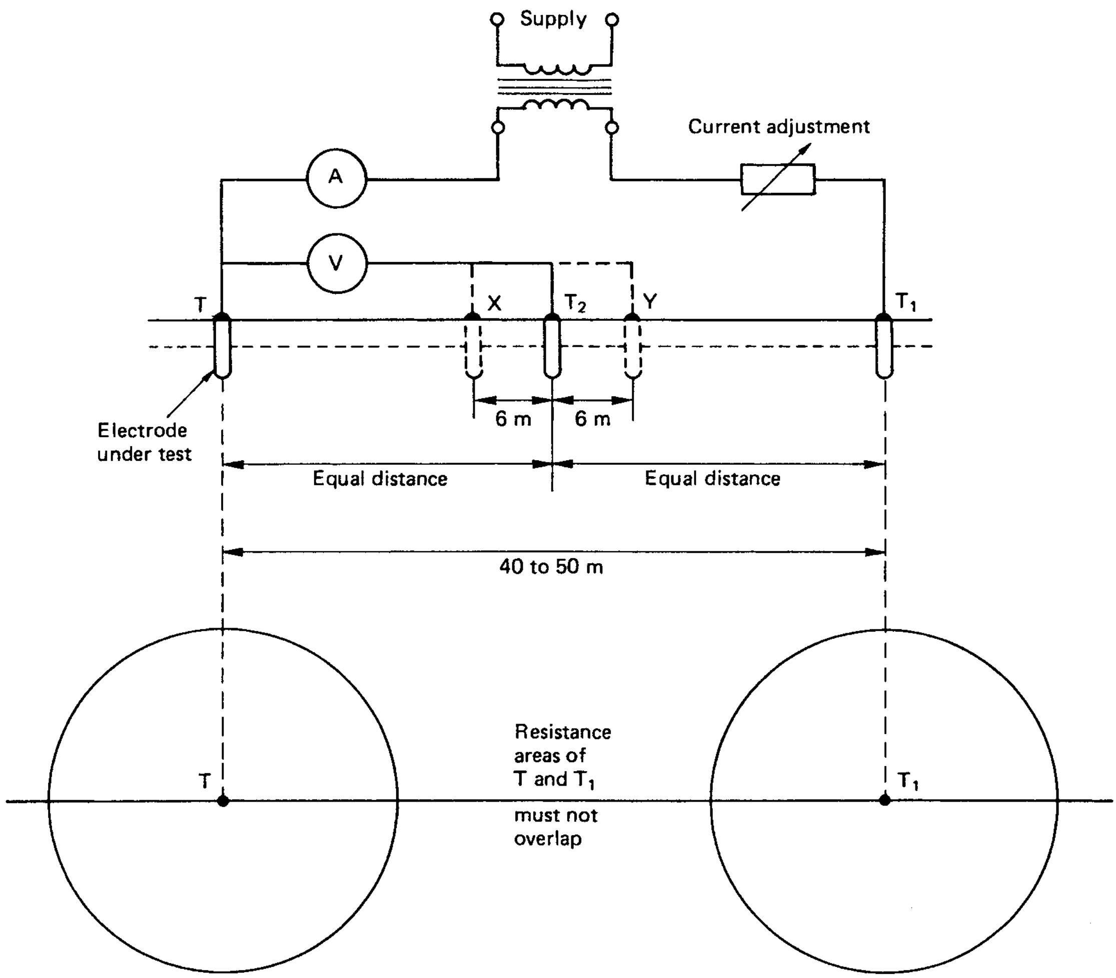


Fig. 2.60 Earth electrode resistance test using a mains-energized double-wound transformer.

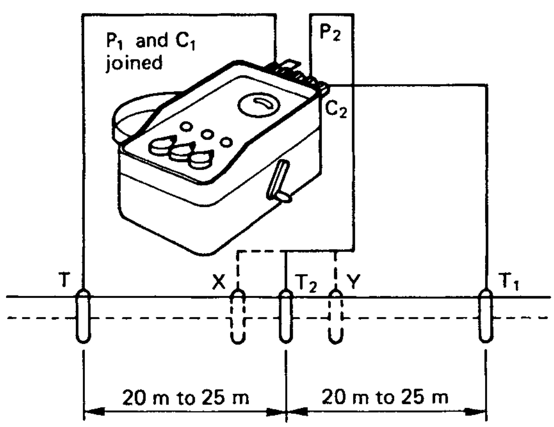


Fig. 2.61 Earth electrode resistance test using a hand-operated tester.

In order that any protective device can operate under earth fault conditions it is necessary for an earth path to exist which can carry the fault current back to the supply transformer. In most installations this earth path is provided by the sheath of the supply cable, but in some rural areas where supplies are provided by overhead cables, the metallic sheath is not available and the general mass of earth is relied upon to provide the return path. The total resistance of the whole earth loop path must be low enough to permit the protective device to disconnect the supply to the circuit in 0.4 seconds for socket outlets and 5 seconds for fixed appliances (Regulations 413–02–09 and 13). The resistance of the earth electrode will probably be the biggest individual factor in the total resistance of the consumer's earth path.

EXAMPLE

The total resistance of the complete earth path of an electrical installation supplied by a TT system is 20 Ω including the resistance of the consumer's earth electrode. Calculate the earth fault current which would flow if the supply voltage was 230 V.

$$I = \frac{V}{R}\,(\text{A})$$

$$\therefore\ I = \frac{230\ \text{V}}{20\,\Omega} = 11.5\ \text{A}$$

Under earth fault conditions only 11.5 A will flow which would not be sufficient to operate, for example, a 30 A ring main fuse, but would be sufficient to kill someone since 50 mA can be fatal.

To operate a 30 A protective device effectively would require an earth electrode resistance of about 0.5 Ω. For this reason Regulation 471–08–06 recommends that socket outlets on a TT system be protected by an RCD. Regulation 413–02–16 states that the product of the earth loop impedance and the operating current of the RCD should be less than 50.

If the electrode under test forms part of the earth return for a TT installation in conjunction with a residual current device, Section 10.3.5 of the *On Site Guide* describes the following method:

1 Disconnect the installation equipotential bonding from the earth electrode to ensure that the test current passes only through the earth electrode.
2 Switch off the consumer's unit to isolate the installation.
3 Using a phase earth loop impedance tester, test between the incoming phase conductor and the earth electrode.

Record the result on an installation schedule such as that given in Appendix 7 of the *On Site Guide*.

Section 10.3.5 of the *On Site Guide* tells us that the recommended maximum value of the earth fault loop impedance for a TT installation is 220 Ω.

Since most of the circuit impedance will be made up of the earth electrode resistance, we can say that an acceptable value for the measurement of the earth electrode resistance would be less than about 200 Ω.

Providing the first five tests were satisfactory, the supply may now be switched on and the final tests completed with the supply connected.

6 TESTING POLARITY – SUPPLY CONNECTED

Using an approved voltage indicator such as that shown at Fig. 2.48 or test lamp and probes which comply with the HSE Guidance Note GS 38, again carry out a polarity test to verify that all fuses, circuit breakers and switches are connected in the live conductor. Test from the common terminal of switches to earth, the live pin of each socket outlet to earth and the centre pin of any Edison screw lampholders to earth. In each case the voltmeter or test lamp should indicate the supply voltage for a satisfactory result.

7 TESTING EARTH FAULT LOOP IMPEDANCE (SUPPLY CONNECTED) (713–11)

The object of this test is to verify that the impedance of the whole earth fault current loop phase to earth is low enough to allow the overcurrent protective device to operate within the disconnection time requirements of Regulations 413–02–08 and 09, should an earth fault occur.

The whole earth fault current loop examined by this test is comprised of all the installation protective conductors, the earthing terminal and earth conductors, the earthed neutral point and the secondary winding of the supply transformer and the phase conductor from the transformer to the point of the fault in the installation.

The test will, in most cases, be done with a purpose-made phase earth loop impedance tester which circulates a current in excess of 10 A around the loop for a very short time, so reducing the danger of a faulty circuit. The test is made with the supply switched on, from the furthest point of *every* final circuit, including lighting, socket outlets and any fixed appliances. Record the results on an installation schedule.

Purpose-built testers give a readout in ohms and a satisfactory result is obtained when the loop impedance does not exceed the appropriate values given in Tables 2A, 2B and 2C of Appendix 2 of the *On Site Guide* or Table 41B1 and 41B2 or Table 604B2, 605B1 and 605B2 of the IEE Regulations.

(Note Table 2A of the *On Site Guide* was shown earlier in this chapter as Table 2.3).

8 FUNCTIONAL TESTING OF RCD – SUPPLY CONNECTED (713–12)

The object of the test is to verify the effectiveness of the residual current device, that it is operating with the correct sensitivity and proving the integrity of the electrical and mechanical elements. The test must simulate an appropriate fault condition and be independent of any test facility incorporated in the device.

When carrying out the test, all loads normally supplied through the device are disconnected.

Functional testing of a ring circuit protected by a general-purpose RCD to BS 4293 in a split-board consumer unit is carried out as follows:

1. Using the standard lead supplied with the test instrument, disconnect all other loads and plug in the test lead to the socket at the centre of the ring (i.e. the socket at the furthest point from the source of supply).
2. Set the test instrument to the tripping current of the device and at a phase angle of 0°.
3. Press the test button – the RCD should trip and disconnect the supply within 200 ms.
4. Change the phase angle from 0° to 180° and press the test button once again. The RCD should again trip within 200 ms. Record the highest value of these two results on an installation schedule such as that given in Appendix 7 of the *On Site Guide*.
5. Now set the test instrument to 50% of the rated tripping current of the RCD and press the test button. The RCD should *not trip* within 2 seconds. This test is testing the RCD for inconvenience *or* nuisance tripping.
6. Finally, the effective operation of the test button incorporated within the RCD should be tested to prove the integrity of the mechanical elements in the tripping device. This test should be repeated every 3 months.

If the RCD fails any of the above tests it should be changed for a new one.

Where the residual current device has a rated tripping current not exceeding 30 mA and has been installed to reduce the risk associated with direct contact, as indicated in Regulation 412–06–02, a residual current of 150 mA should cause the circuit breaker to open within 40 ms.

Certification and reporting

Following the completion of all new electrical work or additional work to an existing installation, the installation must be inspected and tested and an installation certificate issued and signed by a competent person. The 'competent person' must have a sound knowledge of the type of work undertaken, be fully versed in the inspection and testing procedures contained in the IEE Regulations (BS 7671) and employ adequate testing equipment.

A certificate and test results shall be issued to those ordering the work in the format given in Appendix 7 of the *On Site Guide* and Appendix 6 of the IEE Regulations. Those responsible for large or complex installations may provide an equivalent form of installation certificate (IEE Regulation 741–01–01).

All installations must be periodically tested and inspected and for this purpose a periodic inspection report should be issued (IEE Regulation 741–01–02). The standard format is again shown in Appendix 7 of the *On Site Guide* and Appendix 6 of the IEE Regulations.

In both cases the certificate must include the test values which verify that the installation complies with the IEE Regulations at the time of testing. Forms WR1, WR2, WR3 and WR4 make up an installation certificate and forms WR5, WR2, WR3 and WR4 make up the periodic inspection report.

Suggested periodic inspection intervals are given below:

- domestic installations – 10 years
- industrial installations – 3 years
- agricultural installations – 3 years
- caravan site installations – 1 year
- caravans – 3 years
- temporary installations on construction sites – 3 months.

Safe working procedures when testing

Whether you are carrying out the test procedure (i) as a part of a new installation (ii) upon the completion of an extension to an existing installation (iii) because you are trying to discover the cause of a fault on an installation or (iv) because you are carrying out a periodic test and inspection of a building, you must always be aware of your safety, the safety of others using the building and the possible damage which your testing might cause to other systems in the building.

For your own safety:

- Always use 'approved' test instruments and probes.
- Ensure that the test instrument carries a valid calibration certificate otherwise the results may be invalid.
- Secure all isolation devices in the 'off' position.
- Put up warning notices so that other workers will know what is happening.
- Notify everyone in the building that testing is about to start and for approximately how long it will continue
- Obtain a 'permit to work' if this is relevant.
- Obtain approval to have systems shut down which might be damaged by your testing activities. For example, computer systems may 'crash' when supplies are switched off. Ventilation and fume extraction systems will stop working when you disconnect the supplies.

For the safety of others:

- Fix warning notices around your work area.
- Use cones and highly visible warning tape to screen off your work area.
- Make an effort to let everyone in the building know that testing is about to begin. You might be able to do this while you carry out the initial inspection of the installation.
- Obtain verbal or written authorization to shut down information technology, emergency operation or stand-by circuits.

To safeguard other systems:

- Computer systems can be severely damaged by a loss of supply or the injection of a high test voltage from, for example, an insulation resistance test. Computer systems would normally be disconnected during the test period but this will generally require some organization before the testing begins. Commercial organizations may be unable to continue to work without their computer systems and, in these circumstances it may be necessary to test outside the normal working day.
- Any resistance measurements made on electronic equipment or electronic circuits must be achieved with a battery operated ohmmeter of the type described in Chapter 4 of this book, and shown in Fig. 4.74, in order to avoid damaging the electronic circuits.
- Farm animals are creatures of habit and may become very grumpy to find you testing their milking parlour equipment at milking time.
- Hospitals and factories may have emergency stand-by generators which re-energize essential circuits in the event of a mains failure. Your isolation of the circuit for testing may cause the emergency systems to operate. Discuss any special systems with the person authorizing the work before testing begins.

Portable appliance testing (PAT)

A quarter of all serious electrical accidents involve portable electrical appliances, that is, equipment which has a cable lead and plug and which is normally moved around or can easily be moved from place to place. This includes, for example, floor cleaners, kettles, heaters, portable power tools, fans, televisions, desk lamps, photocopiers, fax machines and desktop computers. There is a requirement for employers under the Health and Safety at Work Act to take adequate steps to protect users of portable appliances from the hazards of electric shock and fire. The responsibility for safety applies equally to small as well as large companies. The Electricity at Work Regulations 1989 also place a duty of care upon employers to ensure that the risks associated with the use of electrical equipment are controlled.

Against this background the Health and Safety Executive (HSE) have produced guidance notes HS(G) 107 *Maintaining Portable and Transportable Electrical Equipment* and leaflets *Maintaining Portable Electrical Equipment in Offices and Maintaining Portable Electrical Equipment in Hotels and Tourist Accommodation.* In these publications the HSE recommend that a three level system of inspection can give cost effective maintenance of portable appliances. These are:

- user checking;
- visual inspection by an appointed person;
- combined inspection and testing by a competent person or contractor.

A user visually checking equipment which they are using is probably the most important maintenance procedure. About 95% of faults or damage can be identified by just looking. A user should check for obvious damage using common sense. The use of potentially dangerous equipment can then be avoided. Possible dangers to look for are as follows:

- Damage to the power cable or lead which exposes the colours of the internal conductors, which are brown, blue and green with a yellow stripe.
- Damage to the plug top itself. The plug top pushes into the wall socket, usually a square pin 13A socket in the UK, to make an electrical connection. With the plug top removed from the socket the equipment is usually electrically 'dead'. If the bakelite plastic casing of the plug top is cracked, broken or burned, or the contact pins are bent, do not use it.
- Non-standard joints in the power cable, such as taped joints.
- Poor cable retention. The outer sheath of the power cable must be secure and enter the plug top at one end and the equipment at the other. The coloured internal conductors must not be visible at either end.
- Damage to the casing of the equipment such as cracks, pieces missing, loose or missing screws or signs of melted plastic, burning, scorching or discolouration.
- Equipment which has previously been used in unsuitable conditions such as a wet or dusty environment.

If any of the above dangers are present, the equipment should not be used until the person appointed by the company to make a 'visual inspection' has had an opportunity to do so.

A **visual inspection** will be carried out by an appointed person within a company, such person having been trained to carry out this task. In addition to the user checks described above, an inspection could include the removal of the plug top cover to check that:

- a fuse of the correct rating is being used and also that a proper cartridge fuse is being used and not a piece of wire, a nail or silver paper;
- the cord grip is holding the sheath of the cable and not the coloured conductors;
- the wires (conductors) are connected to the correct terminals of the plug top as shown in Fig. 2.62;
- the coloured insulation of each conductor wire goes right up to the terminal so that no bare wire is visible;

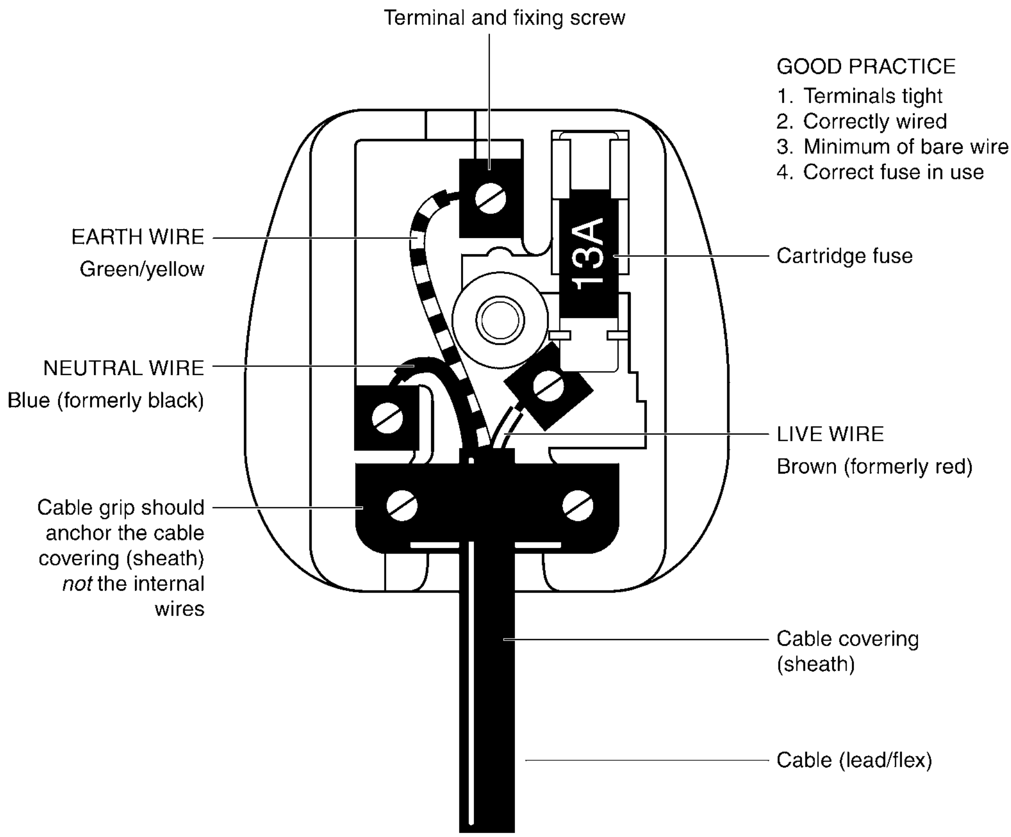


Fig. 2.62 Correct connection of plug top.

- the terminal fixing screws hold the conductor wires securely and the screws are tight;
- all the conductor wires are secured within the terminal;
- there are no internal signs of damage such as overheating, excessive 'blowing' of the cartridge fuse or the intrusion of foreign bodies such as dust, dirt or liquids.

The above inspection cannot apply to 'moulded plugs', which are moulded on to the flexible cable by the manufacturer in order to prevent some of the bad practice described above. In the case of a moulded plug top, only the fuse can be checked. The visual inspection checks described above should also be applied to extension leads and their plugs. The HSE recommends that a simple procedure be written to give guidance to the 'appointed person' carrying out the visual inspection.

Combined inspection and testing is also necessary on some equipment because some faults cannot be seen by just looking – for example, the continuity and effectiveness of earth paths. For some portable appliances the earth is essential to the safe use of the equipment and, therefore, all earthed equipment and most extension leads should be periodically tested and inspected for these faults. All portable appliance test instruments (PAT Testers) will carry out two important tests, earth bonding and insulation resistance.

Earth bonding tests apply a substantial test current, typically about 25 A, down the earth pin of the plug top to an earth probe, which should be connected to any exposed metalwork on the portable appliance being tested. The PAT Tester will then calculate the resistance of the earth bond and either give an actual reading or indicate pass or fail. A satisfactory result for this test would typically be a reading of less than 0.1 Ω. The earth bond test is, of course, not required for double insulated portable appliances because there will be no earthed metalwork.

Insulation resistance tests apply a substantial test voltage, typically 500 V, between the live and neutral bonded together and the earth. The PAT Tester then calculates the insulation resistance and either gives an actual reading or indicates pass or fail. A satisfactory result for this test would typically be a reading greater than 2 MΩ.

Some PAT Testers offer other tests in addition to the two described above. These are described below.

A flash test tests the insulation resistance at a higher voltage than the 500 V test described above. The flash test uses 1.5 kV for Class 1 portable appliances, that is earthed appliances, and 3 kV for Class 2 appliances which are double insulated. The test establishes that the insulation will remain satisfactory under more stringent conditions but must be used with caution, since it may overstress the insulation and will damage electronic equipment. A satisfactory result for this test would typically be less than 3 mA.

A fuse test tests that a fuse is in place and that the portable appliance is switched on prior to carrying out other tests. A visual inspection will be required to establish that the *size* of the fuse is appropriate for that particular portable appliance.

An earth leakage test measures the leakage current to earth through the insulation. It is a useful test to ensure that the portable appliance is not deteriorating and liable to become unsafe. It also ensures that the tested appliances are not responsible for nuisance 'tripping' of RCDs (residual current devices – see Chapter 1). A satisfactory reading is typically less than 3 mA.

An operation test proves that the preceding tests were valid (i.e. that the unit was switched on for the tests), that the appliances will work when connected to the appropriate voltage supply and not draw a dangerously high current from that supply. A satisfactory result for this test would typically be less than 3.2 kW for 230 V equipment and less than 1.8 kW for 110 V equipment.

All PAT Testers are supplied with an operating manual, giving step by step instructions for their use and pass and fail scale readings. The HSE suggested intervals for the three levels of checking and inspection of portable appliances in offices and other low risk environments is given in Table 2.9.

WHO DOES WHAT?

When actual checking, inspecting and testing of portable appliances takes place will depend upon the company's safety policy and risk assessments. In low risk environments such as offices and schools, the three level system of checking, inspection and testing recommended by the HSE should be carried out. Everyone can use common sense and carry out the user checks described earlier. Visual inspections must be carried out by a 'competent person' but that person

Table 2.9 HSE suggested intervals for checking, inspecting and testing of portable appliances in offices and other low risk environments

Equipment/environment	User checks	Formal visual inspection	Combined visual inspection and electrical testing
Battery-operated: (less than 20 V)	No	No	No
Extra low voltage: (less than 50 V a.c.) e.g. telephone equipment, low voltage desk lights	No	No	No
Information technology: e.g. desktop computers, VDU screens	No	Yes, 2–4 years	No if double insulated – otherwise up to 5 years
Photocopiers, fax machines: *not* hand-held, rarely moved	No	Yes, 2–4 years	No if double insulated – otherwise up to 5 years
Double insulated equipment: *not* hand-held, moved occasionally, e.g. fans, table lamps, slide projectors	No	Yes, 2–4 years	No
Double insulated equipment: *hand-held*, e.g. power tools	Yes	Yes, 6 months–1 year	No
Earthed equipment (Class 1): e.g. electric kettles, some floor cleaners, power tools	Yes	Yes, 6 months–1 year	Yes, 1–2 years
Cables (leads) and plugs connected to the above. Extension leads (mains voltage)	Yes	Yes, 6 months–4 years depending on the type of equipment it is connected to	Yes, 1–5 years depending on the type of equipment it is connected to

does not need to be an electrician or electronics service engineer. Any sensible member of staff who has received training can carry out this duty. They will need to know what to look for and what to do, but more importantly, they will need to be able to avoid danger to themselves and to others. The HSE recommend that the appointed person follows a simple written procedure for each visual inspection. A simple tick sheet would meet this requirement. For example:

1 Is the correct fuse fitted? Yes/No
2 Is the cord grip holding the cable sheath? Yes/No

The tick sheet should incorporate all the appropriate visual checks and inspections described earlier.

Testing and inspection require a much greater knowledge than is required for simple checks and visual inspections. This more complex task need not necessarily be carried out by a qualified electrician or electronics service engineer. However, the person carrying out the test must be trained to use the equipment and to interpret the results. Also, greater knowledge will be required for the inspection of the range of portable appliances which might be tested.

KEEPING RECORDS

Records of the inspecting and testing of portable appliances are not required by law but within the Electricity at Work Regulations 1989, it is generally accepted that some form of recording of results is required to implement a quality control system. The control system should:

- ensure that someone is nominated to have responsibility for portable appliance inspection and testing;
- maintain a log or register of all portable appliance test results to ensure that equipment is inspected and tested when it is due;
- label tested equipment with the due date for its next inspection and test as shown in Fig. 2.63.

Any piece of equipment which fails a PAT Test should be disabled and taken out of service (usually by

Fig. 2.63 Typical PAT Test labels.

cutting off the plug top), labelled as faulty and sent for repair.

The register of PAT Test results will help managers to review their maintenance procedures and the frequency of future visual inspections and testing. Combined inspection and testing should be carried out where there is a reason to suspect that the equipment may be faulty, damaged or contaminated but cannot be verified by visual inspection alone. Inspection and testing should also be carried out after any repair or modification to establish the integrity of the equipment or at the start of a maintenance system, to establish the initial condition of the portable equipment being used by the company.

Commissioning electrical systems

The commissioning of the electrical and mechanical systems within a building is a part of the 'handing-over' process of the new building by the architect and main contractor to the client or customer in readiness for its occupation and intended use. To 'commission' means to give authority to someone to check that everything is in working order. If it is out of commission, it is not in working order.

Following the completion, inspection and testing of the new electrical installation, the functional operation of all the electrical systems must be tested before they are handed over to the customer. It is during the commissioning period that any design or equipment failures become apparent, and this testing is one of the few quality controls possible on a building services installation.

This is the role of the commissioning engineer, who must assure himself that all the systems are in working order and that they work as they were designed to work. He must also instruct the client's representative, or the staff who will use the equipment, in the correct operation of the systems, as part of the handover arrangements.

The commissioning engineer must test the operation of all the electrical systems, including the motor controls, the fan and air conditioning systems, the fire alarm and emergency lighting systems. However, before testing the emergency systems, he must first notify everyone in the building of his intentions so that alarms may be ignored during the period of testing.

Commissioning has become one of the most important functions within the building projects completion sequence. The commissioning engineer will therefore have access to all relevant contract documents, including the building specifications and the electrical installation certificates as required by the IEE Regulations (BS 7671), and have a knowledge of the requirements of the Electricity at Work Act and the Health and Safety at Work Act.

The building will only be handed over to the client if the commissioning engineer is satisfied that all the building services meet the design specification in the contract documents.

Exercises

1 A meter with a moving coil movement:
(a) has a digital readout
(b) can be used on both a.c. and d.c. supplies
(c) has a linear scale
(d) can be used to measure power.

2 A meter with a moving iron movement:
(a) has a digital readout
(b) can be used on both a.c. and d.c. supplies
(c) has a linear scale
(d) can be used to measure power.

3 A dynamometer instrument:
(a) has a digital readout
(b) can only be used on electronic circuits
(c) has a linear scale
(d) can be used to measure power.

4 Damping in a moving coil instrument is achieved by:
(a) air vane
(b) air piston
(c) eddy currents
(d) spiral hair springs.

5 Instrument transformers can be used to extend the range of instruments connected to:
(a) a.c. circuits
(b) d.c. circuits
(c) 400V supplies only
(d) rectified a.c. circuits.

6 A tong test instrument can also be correctly called:
(a) a dynamometer wattmeter
(b) an insulation resistance tester
(c) an earth loop impedance tester
(d) a clip-on ammeter.

7 To reduce errors when testing electronic circuits, the test instrument should:
(a) have a very low impedance
(b) have a very high impedance
(c) have a resistance equal to the circuit impedance
(d) have a resistance approximately equal to the circuit current.

8 The two-wattmeter method is used to measure the power in a three-phase, three-wire system. The two readings obtained are 100 and 50 W and, therefore, the total power in the system is:
(a) 50 W
(b) 75 W
(c) 150 W
(d) 5 kW.

9 An acceptable earth electrode resistance test on a lightning conductor earth electrode must reveal a maximum value of:
(a) 10 Ω
(b) 100 Ω
(c) 0.5 MΩ
(d) 1 MΩ.

10 The test required by the Regulations to ascertain that the circuit protective conductor is correctly connected is:
(a) continuity of ring final circuit conductors
(b) continuity of protective conductors
(c) earth electrode resistance
(d) protection by electrical separation.

11 One objective of the polarity test is to verify that:
(a) lampholders are correctly earthed
(b) final circuits are correctly fused
(c) the CPC is continuous throughout the installation
(d) the protective devices are connected in the live conductor.

12 When testing a 230 V installation an insulation resistance tester must supply a voltage of:
(a) less than 50 V
(b) 500 V
(c) less than 500 V
(d) greater than twice the supply voltage but less than 1000 V.

13 The value of a satisfactory insulation resistance test on each final circuit of a 230 V installation must be:
(a) less than 1 Ω
(b) less than 0.5 MΩ
(c) not less than 0.5 MΩ
(d) not less than 1 MΩ.

14 The value of a satisfactory insulation resistance test on a disconnected piece of equipment is:
(a) less than 1 Ω
(b) less than 0.5 MΩ
(c) not less than 0.5 MΩ
(d) not less than 1 MΩ.

15 The maximum inspection and retest period for a general electrical installation is:
(a) 3 months
(b) 3 years
(c) 5 years
(d) 10 years.

16 A visual inspection of a new installation must be carried out:
(a) during the erection period
(b) during testing upon completion
(c) after testing upon completion
(d) before testing upon completion.

17 'To ensure that all the systems within a building work as they were intended to work' is one definition of the purpose of:
(a) testing electrical systems
(b) inspecting electrical systems
(c) commissioning electrical systems
(d) isolating electrical systems.

18 The person responsible for financing the building team is the:
(a) main contractor
(b) subcontractor
(c) client
(d) architect.

19 The person responsible for interpreting the client's requirements to the building team is the:
(a) main contractor
(b) subcontractor
(c) client
(d) architect.

20 The building contractor is also called the:
(a) main contractor
(b) subcontractor
(c) client
(d) architect.

21 The electrical contractor is also called the:
(a) main contractor
(b) subcontractor

(c) client
(d) architect.

22 The people responsible for interpreting the architect's electrical specifications and drawings are the:
(a) building team
(b) electrical design team
(c) electrical installation team
(d) construction industry.

23 The people responsible for demonstrating good workmanship and maintaining good relationships with other trades are the:
(a) building team
(b) electrical design team
(c) electrical installation team
(d) construction industry.

24 A simple bar chart can show:
(a) the activities involved in a particular contract where some flexibility is acceptable
(b) the sequence and timing of the various activities involved in a particular contract
(c) the interdependence of the various activities involved in a particular contract
(d) the total man-hours involved in a particular contract.

25 A simple network diagram can show:
(a) the actual cost of a contract
(b) the actual number of man-hours involved in a contract
(c) the interdependence of the various activities involved in a particular contract
(d) the rating of the incoming supply cable.

26 The standard symbols used by the electrical contracting industry on a layout diagram are those recommended by:
(a) the Institute of Electrical Engineers
(b) the Health and Safety at Work Act 1974
(c) the Factories Act 1961
(d) the British Standard 3939.

27 The Regulations define isolation switching as:
(a) a mechanical switching device capable of making, carrying and breaking current under normal circuit conditions
(b) cutting off an electrical installation or circuit from every source of electrical energy
(c) the rapid disconnection of the electrical supply to remove or prevent danger
(d) the switching of electrical equipment in normal service.

28 Functional switching may be defined as:
(a) a mechanical switching device capable of making, carrying and breaking current under normal circuit conditions
(b) cutting off an electrical installation or circuit from every source of electrical energy
(c) the rapid disconnection of the electrical supply to remove or prevent danger
(d) the switching of electrical equipment in normal service.

29 Emergency switching can be defined as:
(a) a mechanical switching device capable of making, carrying and breaking current under normal circuit conditions
(b) cutting off an electrical installation or circuit from every source of electrical energy
(c) the rapid disconnection of the electrical supply to remove or prevent danger
(d) the switching of electrical equipment in normal service.

30 The Regulations require that an overcurrent protective device interrupts a fault quickly and isolates the circuit before:
(a) the voltage on any extraneous conductive parts reaches 50 V
(b) the earth loop impedance reaches 0.4 Ω on circuits feeding 13 A socket outlets
(c) the fault causes damage to the circuit isolating switches
(d) the fault causes a temperature rise which might damage the insulation and terminations of the circuit conductors.

31 The maximum permissible value of the earth loop impedance of a circuit supplying fixed equipment and protected by a 30 A semi-enclosed fuse to BS 3036 is found by reference to the tables in Part 4 of the IEE Regulations to be:
(a) 1.1 Ω
(b) 1.92 Ω
(c) 2.0 Ω
(d) 2.76 Ω.

32 The earth fault loop impedance of a socket outlet circuit protected by a 30 A cartridge fuse to BS 1361 must not exceed:
(a) 0.4 Ω
(b) 1.14 Ω

(c) 1.20 Ω
(d) 2.0 Ω.

33 The $(R_1 + R_2)$ resistance of 1000 m of PVC insulated copper cable having a 4.0 mm^2 phase conductor and 2.5 mm^2 protective conductor will be found from Table 9A of the *On Site Guide* to be:
(a) 4.61 Ω
(b) 9.22 Ω
(c) 12.02 Ω
(d) 16.71 Ω.

34 The $(R_1 + R_2)$ resistance of 176 m of PVC insulated copper cable having a 2.5 mm^2 phase and protective conductor is:
(a) 2.608 Ω
(b) 7.41 Ω
(c) 14.82 Ω
(d) 19.51 Ω.

35 The value of the earth fault loop impedance Z_S of a circuit fed by 40 m of PVC insulated copper cable having a 2.5 mm^2 phase conductor and 1.5 mm^2 protective conductor connected to a supply having an impedance Z_E of 0.5 Ω under fault conditions will be
(a) 1.436 Ω
(b) 9.755 Ω
(c) 20.01 Ω
(d) 780.4 mΩ.

36 The time/current characteristics shown in Fig. 3.20 indicate that a fault current of 300 A will cause a 30 A semi-enclosed fuse to BS 3036 to operate in
(a) 0.01 s
(b) 0.1 s
(c) 0.2 s
(d) 2.0 s.

37 The time/current characteristics shown in Fig. 3.20 indicate that a fault current of 30 A will cause a 10 A type 2 MCB to BS 3871 to operate in
(a) 0.02 s
(b) 8 s
(c) 30 s
(d) 200 s.

38 'Under fault conditions the protective device nearest to the fault should operate leaving other healthy circuits unaffected'. This is one definition of:
(a) fusing factor
(b) effective discrimination
(c) a miniature circuit breaker
(d) a circuit protective conductor.

39 The overcurrent protective device protecting socket outlet circuits and any fixed equipment in bathrooms must operate within:
(a) 0.02 s
(b) 0.4 s
(c) 5 s
(d) 45 s.

40 The overcurrent protective device protecting fixed equipment in rooms other than bathrooms must operate within
(a) 0.02 s
(b) 0.4 s
(c) 5 s
(d) 45 s.

41 Explain why the maximum values of earth fault loop impedance Z_S specified by the IEE Regulations and given in Tables 41B1 and 41B2 should not be exceeded.

42 By referring to the table in the IEE Regulations (Tables 41B1, 42B2 and 41D), determine the maximum permitted earth fault loop impedance Z_S for the following circuits:
(a) a ring main of 13 A socket outlets protected by a 30 A semi-enclosed fuse to BS 3036
(b) a ring main of 13 A socket outlets protected by a 30 A cartridge fuse to BS 1361
(c) a single socket outlet protected by a 15 A type 1 MCB to BS 3871
(d) a water heating circuit protected by a 15 A semi-enclosed fuse to BS 3036
(e) a lighting circuit protected by a 6 A HBC fuse to BS 88 Part 2
(f) a lighting circuit protected by a 5 A semi-enclosed fuse to BS 3036.

43 10 mm^2 cables with PVC insulated copper conductors feed a commercial cooker connected to a 400 V supply. An earth loop impedance test indicates that Z_S has a value of 1.5 Ω. Calculate the minimum size of the protective conductor.

44 It is proposed to protect the commercial cooker circuit described in Exercise 43 with 30 A
(a) semi-enclosed fuses to BS 3036
(b) type 2 MCBs to BS 3871.

Determine the time taken for each protection device to clear an earth fault on this circuit by referring to the characteristics of Fig. 3.20.

45 A 2.5 mm^2 PVC insulated and sheathed cable is used to feed a single 13 A socket outlet from a 15 A semi-enclosed fuse in a consumer's unit connected to a 230 V supply. Calculate the minimum size of the protective conductor to comply with the Regulations, given that the value of Z_S was 0.9 Ω.

46 Calculate the design current I_b and the nominal current setting I_n of a type 1 MCB to supply a 10 kW load connected to the domestic mains.

47 State the ambient temperature correction factors for cables protected by a semi-enclosed fuse to BS 3036 and installed in the following ambient temperatures:
(a) 25°C
(b) 35°C
(c) 45°C.

48 State the correction factors to be applied for groups of cables installed according to method 1 if the circuit under consideration is run:
(a) on its own
(b) with four other cables
(c) with six other cables.

49 State the factors which must be applied to the current carrying capacity of cables when they are:
(a) protected by an MCB
(b) protected by a semi-enclosed fuse.

50 State the current rating of a three-phase 4.0 mm cable clipped direct to a wall. Neglect all other correction factors.

51 Calculate the volt drop of 30 m of 10 mm cable connected to the single-phase a.c. mains supply and carrying a design current of 32 A. Is this volt drop within that permitted by IEE Regulation 525–01?

52 A 1000 W lighting load is connected to 230 V and wired in single-core PVC cables enclosed in a conduit fixed to a wall. The circuit is protected by a 5 A semi-enclosed fuse to BS 3036 and runs 30 m through an ambient temperature of 35°C. Two other circuits are grouped within the same conduit. Calculate:
(a) the design current I_b
(b) the cable rating I_t
(c) the size of cable
(d) the volt drop.

53 The total installed load in a machine workshop connected to the 230 V mains supply is 3276 W. The load is wired in single-core PVC cables grouped with two other circuits in steel conduit fixed to a wall. The length of run is 30 m through an ambient temperature of 35°C and protection is afforded by a circuit breaker to BS 3871. Calculate:
(a) the design current I_b
(b) the cable rating I_t
(c) the cable size
(d) the volt drop.

54 Briefly describe the duties of each of the following people:
(a) the clerk of works
(b) the Health and Safety inspector
(c) the electrician
(d) the foreman electrician.

55 Describe the importance of a correct attitude towards the customer by an apprentice electrician and other members of the installation team.

56 A moving coil deflection system has a resistance of 5 Ω and gives full scale deflection when 15 mA flows through the moving coil. Calculate the value of the resistor required to make the movement into:
(a) a 10 A ammeter
(b) a 250 V voltmeter.
Draw a circuit diagram showing how the resistor would be connected to the instrument movement in both cases.

57 The CPC of a lighting final circuit is formed by approximately 70 m of 1.0 m copper conductor. Calculate a satisfactory value for a continuity test on the CPC given that the resistance per metre of 1.0 mm copper is 18.1 mΩ/m.

58 The CPC of an installation is formed by approximately 200 m of 50 mm × 50 mm trunking. Determine a satisfactory test result for this CPC, using the information given in Table 2.7. Describe briefly a suitable instrument to carry out this test.

59 Describe how a polarity test should be carried out on a domestic installation comprising eight light positions and ten socket outlets. The final circuits are to be supplied by a consumer unit.

60 Describe how to carry out a continuity test of ring final circuit conductors. State the values to be obtained for a satisfactory test.

61 Describe how to carry out an earth fault loop impedance test. Sketch a circuit diagram and indicate the test circuit path.

62 Describe how to carry out an insulation resistance test on a domestic installation. State the type of instrument to be used and the values of a satisfactory test.

63 State eight separate tasks carried out by the electrical design team.

64 State seven separate tasks carried out by the electrical installation team.

65 State the purpose of a 'variation' order.

66 State the advantages of a written legal contract as compared to a verbal contract.

67 A particular contract is made up of activities A to I as follows: Activity A takes 3 weeks commencing in week 1. Activity B takes 1 week commencing in week 1. Activity C takes 5 weeks commencing in week 2. Activity D takes 4 weeks commencing in week 7. Activity E takes 3 weeks commencing in week 3. Activity F takes 5 weeks commencing in week 4. Activity G takes 4 weeks commencing in week 9. Activity H takes 4 weeks commencing in week 6. Activity I takes 10 weeks commencing in week 3.

Due to the availability of men and materials some activities must be completed before others can commence, as follows. Activity C can only commence when B is completed. Activity D can only commence when C is completed. Activity F can only commence when A is completed. Activity G can only commence when F is completed. Activity H can only commence when E is completed. Activity I does not restrict any other activity.

(a) Draw up a bar chart to show the various activities.
(b) Assemble a network diagram for the contract.
(c) Identify the critical path.
(d) Find the time required to complete the contract.
(e) State the float time in activity F.
(f) State the float time in activity D.

68 Sketch the BS EN 60617 graphical symbols for the following equipment:

(a) a single socket outlet
(b) a double socket outlet
(c) a switched double socket outlet
(d) an electric bell
(e) a single-pole one-way switch
(f) a cord-operated single-pole one-way switch
(g) a wall-mounted lighting point
(h) a double fluorescent lamp
(i) an emergency lighting point.

69 State the requirements of the Electricity at Work Act with regard to

(a) 'live' testing and 'fault diagnosis'
(b) 'live working' to repair a fault.

70 Define 'isolation' with respect to an electrical circuit or item of equipment.

71 List a logical procedure for the isolation of an electrical circuit. Start from the point at which you choose the voltage indicating device and finish with the point at which you begin to work on the circuit.

72 Use a sketch to describe the construction of a test lead approved to HSE GS 38.

73 Describe eddy current damping.

74 Describe air vane and air piston damping.

75 Use a labelled sketch to describe the construction and operation of an energy meter.

76 Use a labelled sketch to describe the construction and operation of a tong tester.

77 Describe the construction and use of a phase sequence tester.

78 Use sketches to describe the operation of the deflection system in a moving coil instrument.

79 Explain how the basic moving coil system is modified so that a test instrument can be used on a.c. circuits.

80 Describe what is meant by damping of a system. Sketch a graph to show an overdamped, underdamped and critically damped system.

81 Describe the construction and operation of a dynamometer wattmeter.

82 Explain with the aid of a diagram how a single wattmeter can be used to measure the total power in

(a) a balanced three-phase load
(b) an unbalanced three-phase load.

3

FAULT DIAGNOSIS AND RECTIFICATION

To diagnose and find faults in electrical installations and equipment is probably one of the most difficult tasks undertaken by an electrician. The knowledge of fault finding and the diagnosis of faults can never be completely 'learned' because no two fault situations are exactly the same. As the systems we install become more complex, then the faults developed on these systems become more complicated to solve. To be successful the individual must have a thorough knowledge of the installation or piece of equipment and have a broad range of the skills and competences associated with the electrotechnical industries.

The ideal person will tackle the problem using a reasoned and logical approach, recognize his own limitations and seek help and guidance where necessary.

The tests recommended by the IEE Regulations can be used as a diagnostic tool but the safe working practices described by the Electricity at Work Act and elsewhere must always be observed during the fault-finding procedures.

If possible, fault finding should be planned ahead to avoid inconvenience to other workers and to avoid disruption of the normal working routine. However, a faulty piece of equipment or a fault in the installation is not normally a planned event and usually occurs at the most inconvenient time. The diagnosis and rectification of a fault is therefore often carried out in very stressful circumstances.

Symptoms of an electrical fault

The basic symptoms of an electrical fault may be described in one or a combination of the following ways:

1 There is a complete loss of power.
2 There is partial or localized loss of power.
3 The installation or piece of equipment is failing because of the following:
   (a) an individual component is failing;
   (b) the whole plant or piece of equipment is failing;
   (c) the insulation resistance is low;
   (d) the overload or protective devices operate frequently;
   (e) electromagnetic relays will not latch, giving an indication of undervoltage.

Causes of electrical faults

A fault is not a natural occurrence; it is an unplanned event which occurs unexpectedly. The fault in an electrical installation or piece of equipment may be caused by:

- negligence – that is, lack of proper care and attention;
- misuse – that is, not using the equipment properly or correctly;
- abuse – that is, deliberate ill-treatment of the equipment.

If the installation was properly designed in the first instance to perform the tasks required of it by the user, then the negligence, misuse or abuse must be the fault of the user. However, if the installation does not perform the tasks required of it by the user then the negligence is due to the electrical contractor in not designing the installation to meet the needs of the user.

Negligence on the part of the user may be due to insufficient maintenance or lack of general care and attention, such as not repairing broken equipment or removing covers or enclosures which were designed to prevent the ingress of dust or moisture.

Misuse of an installation or pieces of equipment may occur because the installation is being asked to do more than it was originally designed to do, because of expansion of a company, for example. Circuits are sometimes overloaded because a company grows and a greater demand is placed on the existing installation by the introduction of new or additional machinery and equipment.

WHERE DO ELECTRICAL FAULTS OCCUR?

1 Faults occur in wiring systems, but not usually along the length of the cable, unless it has been damaged by a recent event such as an object being driven through it or a JCB digger pulling up an underground cable. Cable faults usually occur at each end, where the human hand has been at work at the point of cable inter-connections. This might result in broken conductors, trapped conductors or loose connections in joint boxes, accessories or luminaires.

   All cable connections must be made mechanically and electrically secure. They must also remain accessible for future inspection, testing and maintenance (IEE Regulation 526–04–01). The only exceptions to this rule are when
   - underground cables are connected in a compound filled or encapsulated joint;
   - floor warming or ceiling warming heating systems are connected to a cold tail;
   - a joint is made by welding, brazing, soldering or compression tool.

   Since they are accessible, cable inter-connections are an obvious point of investigation when searching out the cause of a fault.
2 Faults also occur at cable terminations. The IEE Regulations require that a cable termination of any kind must securely anchor all conductors to reduce mechanical stresses on the terminal connections. All conductors of flexible cords must be terminated within the terminal connection otherwise the current carrying capacity of the conductor is reduced, which may cause local heating. Flexible cords are delicate – has the terminal screw been over-tightened, thus breaking the connection as the conductors flex or vibrate? Cables and flexible cords must be suitable for the temperature to be encountered at the point of termination or must be provided with additional insulation sleeves to make them suitable for the surrounding temperatures (IEE Regulation 522–02–02).
3 Faults also occur at accessories such as switches, sockets, control gear, motor contactors or at the point of connection with electronic equipment. The source of a possible fault is again at the point of human contact with the electrical system and again the connections must be checked as described in the first two points above. Contacts that make and break a circuit are another source of wear and possible failure, so switches and motor contactors may fail after extensive use. Socket outlets that have been used extensively and loaded to capacity in say kitchens, are another source of fault due to overheating or loose connections. Electronic equipment can be damaged by the standard tests described in the IEE Regulations and must, therefore, be disconnected before testing begins.
4 Faults occur on instrumentation panels either as a result of a faulty instrument or as a result of a faulty monitoring probe connected to the instrument. Many panel instruments are standard sizes connected to CT's or VT's and this is another source of possible faults of the types described in points 1–3.
5 Faults occur in protective devices for the reasons given in points 1–3 above but also because they may have been badly selected for the job in hand and do not offer adequate protection or discrimination as described in Chapter 2 of this book.
6 Faults often occur in luminaires (light fittings) because the lamp has expired. Discharge lighting (fluorescent fittings) also require a 'starter' to be in good condition, although many fluorescent luminaires these days use starter-less electronic control gear. The points made in 1–3 about cable and flexible cord connections are also relevant to luminaire faults.
7 Faults occur when terminating flexible cords as a result of the flexible cable being of a smaller cross section than the load demands, because it is not adequately anchored to reduce mechanical stresses on the connection or because the flexible cord is not suitable for the ambient temperature to be encountered at the point of connection. When terminating flexible cords, the insulation should be carefully removed without cutting out any flexible cord strands of wire because this effectively reduces the cross section of the conductor. The conductor

strands should be twisted together and then doubled over, if possible, and terminated in the appropriate connection. The connection screws should be opened fully so that they will not snag the flexible cord as it is eased into the connection. The insulation should go up to, but not into, the termination. The terminal screws should then be tightened.

8 Faults occur in electrical components, equipment and accessories such as motors, starters, switch gear, control gear, distribution panels, switches, sockets and luminaires because these all have points at which electrical connections are made. It is unusual for an electrical component to become faulty when it is relatively new because it will have been manufactured and tested to comply with the appropriate British Standard. Through overuse or misuse components and equipment do become faulty but most faults are caused by poor installation techniques.

Modern electrical installations using new materials can now last longer than fifty years. Therefore, they must be properly installed. Good design, good workmanship and the use of proper materials are essential if the installation is to comply with the relevant Regulations (IEE Regulations 130–01–01 and 130–02–01).

Fault diagnosis

Before an electrician can begin to diagnose the cause of a fault he must:

- have a thorough knowledge and understanding of the electrical installation or electrical equipment;
- collect information about the fault and the events occurring at or about the time of the fault from the people who were in the area at the time;
- begin to predict the probable cause of the fault using his own and other people's skills and expertise;
- test some of the predictions using a logical approach to identify the cause of the fault.

Most importantly, electricians must use their detailed knowledge of electrical circuits and equipment learned through training and experience and then apply this knowledge to look for a solution to the fault.

Let us, therefore, now look at some of the basic wiring circuits that we first considered while studying Unit 4 of the Level 2 Certificate of Electrotechnical Technology. These were first discussed in Chapter 4 of Basic Electrical Installation Work 4th Edition and are repeated here for your convenience.

Wiring circuits

LIGHTING CIRCUITS

Table 1A in Appendix 1 of the *On Site Guide* deals with the assumed current demand of points, and states that for lighting outlets we should assume a current equivalent to a minimum of 100 W per lampholder. This means that for a domestic lighting circuit rated at 5 A, a maximum of 11 lighting outlets could be connected to each circuit. In practice, it is usual to divide the fixed lighting outlets into two or more circuits of seven or eight outlets each. In this way the whole installation is not plunged into darkness if one lighting circuit fuses.

Lighting circuits are usually wired in 1.0 or 1.5 mm cable using either a loop-in or joint-box method of installation. The loop-in method is universally employed with conduit installations or when access from above or below is prohibited after installation, as is the case with some industrial installations or blocks of flats. In this method the only joints are at the switches or lighting points, the live conductors being looped from switch to switch and the neutrals from one lighting point to another.

The use of junction boxes with fixed brass terminals is the method often adopted in domestic installations, since the joint boxes can be made accessible but are out of site in the loft area and under floorboards.

All switches and ceiling roses must contain an earth connection (Regulation 471–09–02) and the live conductors must be broken at the switch position in order to comply with the polarity regulations (713–09–01). A ceiling rose may only be connected to installations operating at 250 V maximum and must only accommodate one flexible cord unless it is specially designed to take more than one (553–04–02). Lampholders must comply with Regulation 553–03–02 and be suspended from flexible cords capable of suspending the mass of the luminaire fixed to the lampholder (554–01–01).

The type of circuit used will depend upon the installation conditions and the customer's requirements. One light controlled by one switch is called one-way switch control (see Fig. 3.1). A room with two access

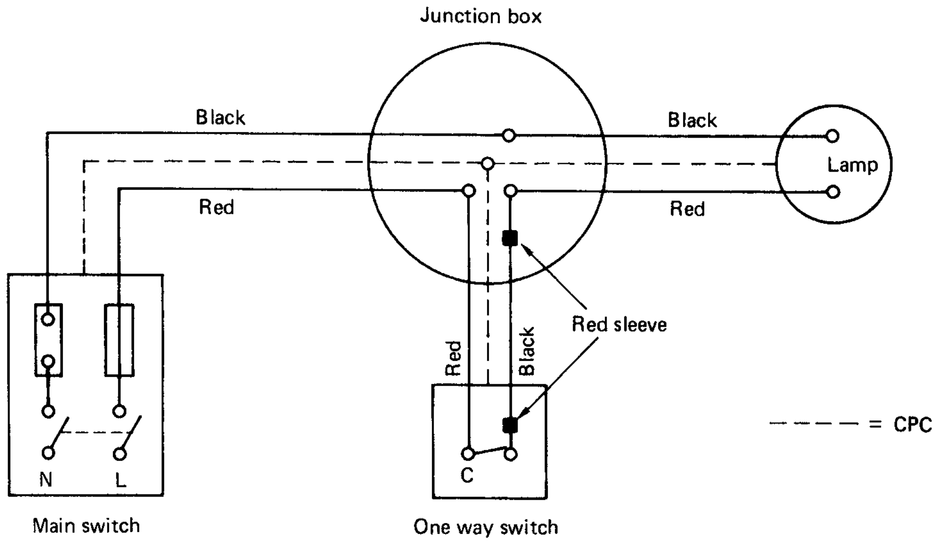


Fig. 3.1 Wiring diagram of one-way switch control.

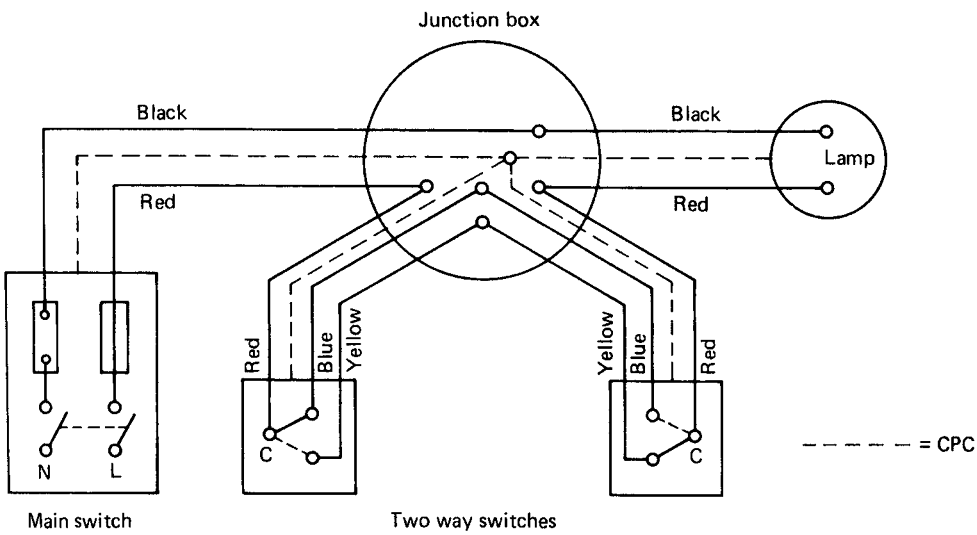


Fig. 3.2 Wiring diagram of two-way switch control.

doors might benefit from a two-way switch control (see Fig. 3.2) so that the lights may be switched on or off at either position. A long staircase with more than two switches controlling the same lights would require intermediate switching (see Fig. 3.3).

One-way, two-way or intermediate switches can be obtained as plate switches for wall mounting or ceiling mounted cord switches. Cord switches can provide a convenient method of control in bedrooms or bathrooms and for independently controlling an office luminaire.

To convert an existing one-way switch control into a two-way switch control, a three-core and earth cable is run from the existing switch position to the proposed second switch position. The existing one-way switch is replaced by a two-way switch and connected as shown in Fig. 3.4.

SOCKET OUTLET CIRCUITS

A plug top is connected to an appliance by a flexible cord which should normally be no longer than 2 m

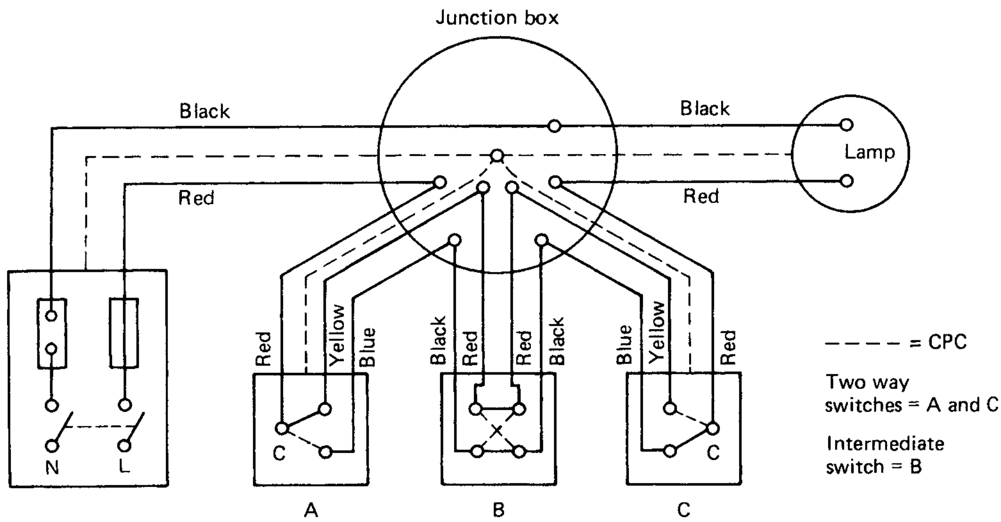


Fig. 3.3 Wiring diagram of intermediate switch control.

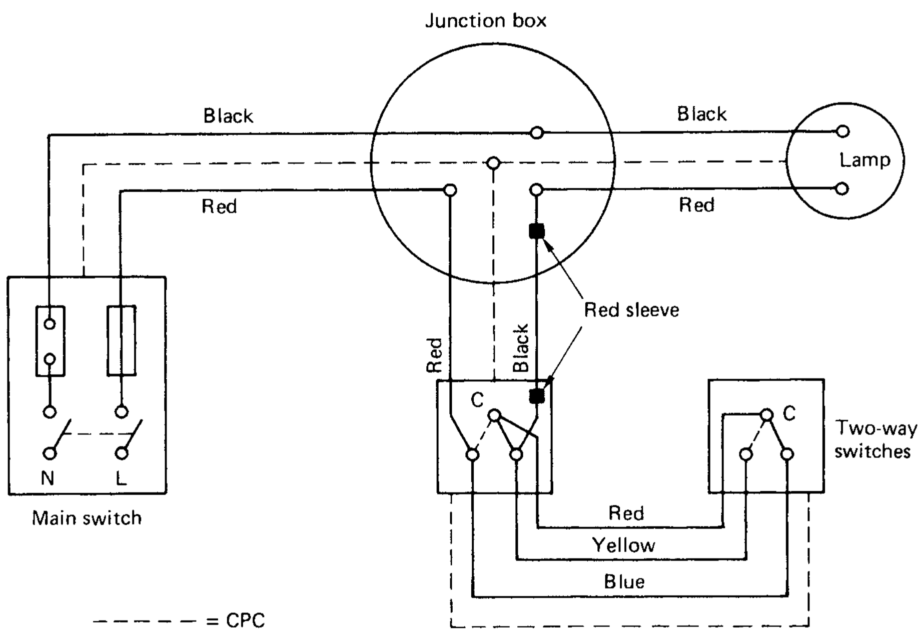


Fig. 3.4 Wiring diagram of one-way to two-way switch control.

(Regulation 553–01–07). Pressing the plug top into a socket outlet connects the appliance to the source of supply. Socket outlets therefore provide an easy and convenient method of connecting portable electrical appliances to a source of supply.

Socket outlets can be obtained in 15, 13, 5 and 2 A ratings, but the 13 A flat pin type complying with BS 1363 is the most popular for domestic installations in the United Kingdom. Each 13 A plug top contains a cartridge fuse to give maximum potential protection to the flexible cord and the appliances which it serves.

Socket outlets may be wired on a ring or radial circuit and in order that every appliance can be fed from an adjacent and convenient socket outlet, the number of sockets is unlimited provided that the floor area covered by the circuit does not exceed that given in Table 8A, Appendix 8 of the *On Site Guide.*

RADIAL CIRCUITS

In a radial circuit each socket outlet is fed from the previous one. Live is connected to live, neutral to neutral and earth to earth at each socket outlet. The fuse and cable sizes are given in Table 8A of Appendix 8 but circuits may also be expressed with a block diagram, as shown in Fig. 3.5. The number of permitted socket outlets is unlimited but each radial circuit must not exceed the floor area stated and the known or estimated load.

Where two or more circuits are installed in the same premises, the socket outlets and permanently connected equipment should be reasonably shared out among the circuits, so that the total load is balanced.

When designing ring or radial circuits special consideration should be given to the loading in kitchens which may require separate circuits. This is because the maximum demand of current-using equipment in kitchens may exceed the rating of the circuit cable and protection devices.

Ring and radial circuits may be used for domestic or other premises where the maximum demand of the current using equipment is estimated not to exceed the rating of the protective devices for the chosen circuit.

RING CIRCUITS

Ring circuits are very similar to radial circuits in that each socket outlet is fed from the previous one, but in ring circuits the last socket is wired back to the source of supply. Each ring final circuit conductor must be looped into every socket outlet or joint box which forms the ring and must be electrically continuous throughout its length. The number of permitted socket outlets is unlimited but each ring circuit must not cover more than 100 m^2 of floor area.

The circuit details are given in Table 8A, Appendix 8 of the *On Site Guide* but may also be expressed by the block diagram given in Fig. 3.6.

Spurs to ring circuits

A spur is defined in Part 2 of the Regulations as a branch cable from a ring final circuit.

Non-fused spurs

The total number of non-fused spurs must not exceed the total number of socket outlets and pieces of stationary equipment connected directly in the circuit.

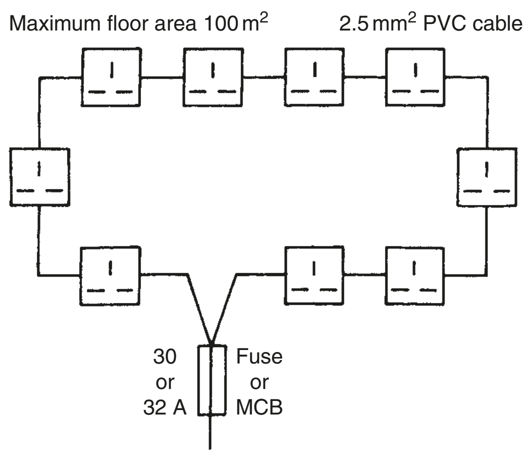


Fig. 3.6 Block diagram of ring circuits.

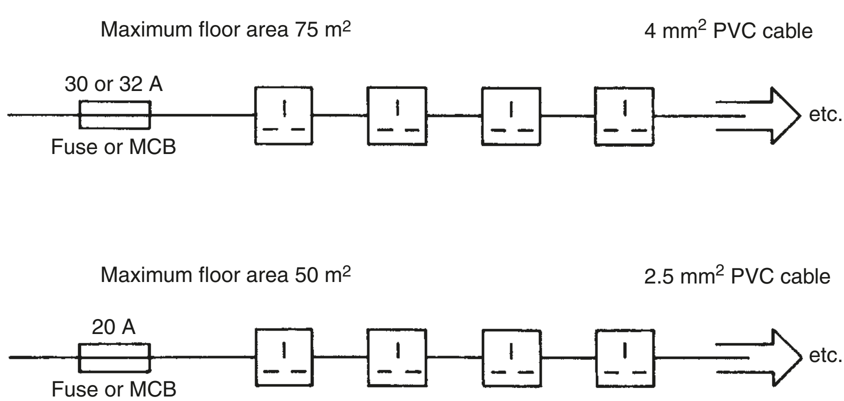


Fig. 3.5 Block diagram of radial circuits.

The cable used for non-fused spurs must not be less than that of the ring circuit. The requirements concerning spurs are given in Appendix 8 of the *On Site Guide* but the various circuit arrangements may be expressed by the block diagrams of Fig. 3.7.

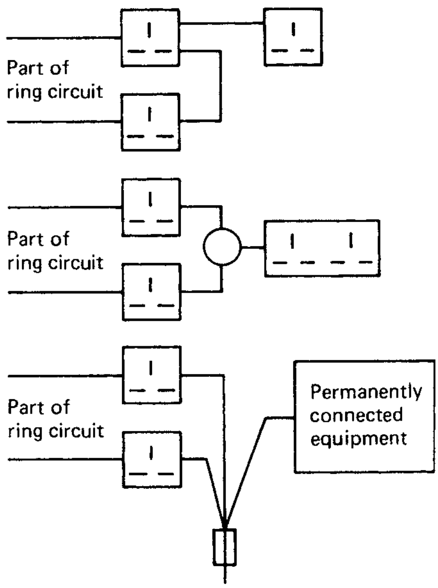


Fig. 3.7 Connection of non-fused spurs.

A non-fused spur may only feed one single or one twin socket or one permanently connected piece of equipment.

Non-fused spurs may be connected into the ring circuit at the terminals of socket outlets or at joint boxes or at the origin of the circuit.

Fused spurs

The total number of fused spurs is unlimited. A fused spur is connected to the circuit through a fused connection unit, the rating of which should be suitable for the conductor forming the spur but should not exceed 13 A. The requirements for fused spurs are also given in Appendix 8 but the various circuit arrangements may be expressed by the block diagrams of Fig. 3.8.

The general arrangement shown in Fig. 3.9 shows 11 socket outlets connected to the ring, three non-fused spur connections and two fused spur connections.

WATER HEATING CIRCUITS

A small, single-point over-sink type water heater may be considered as a permanently connected appliance and so may be connected to a ring circuit through a

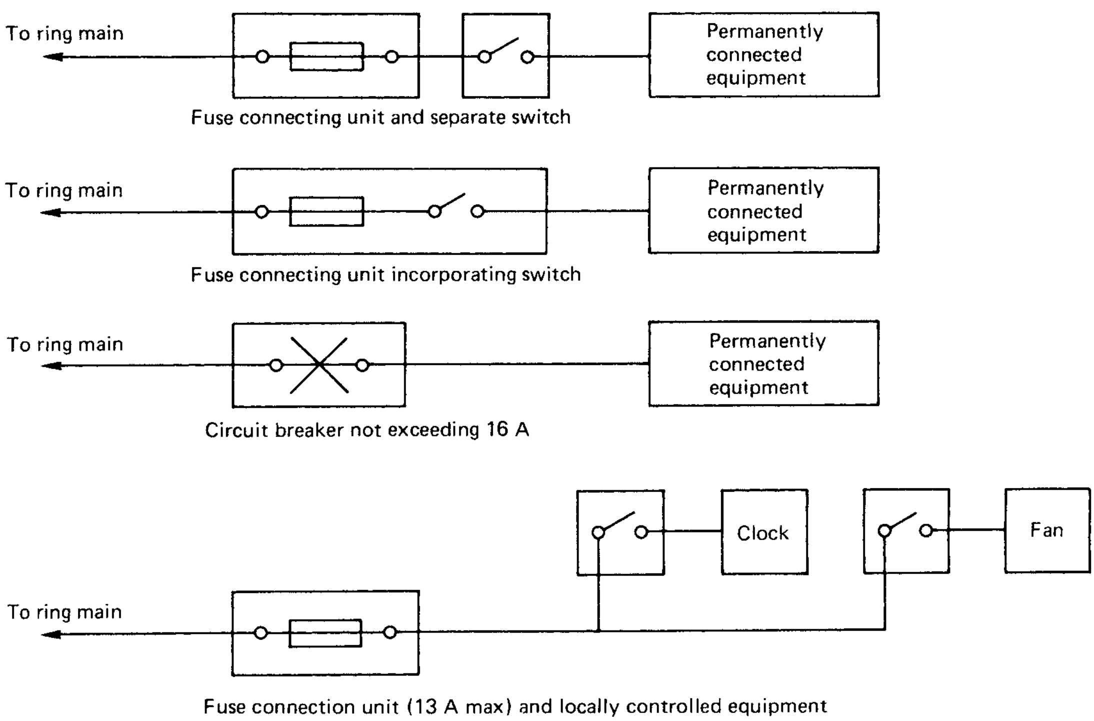


Fig. 3.8 Connection of fused spurs.

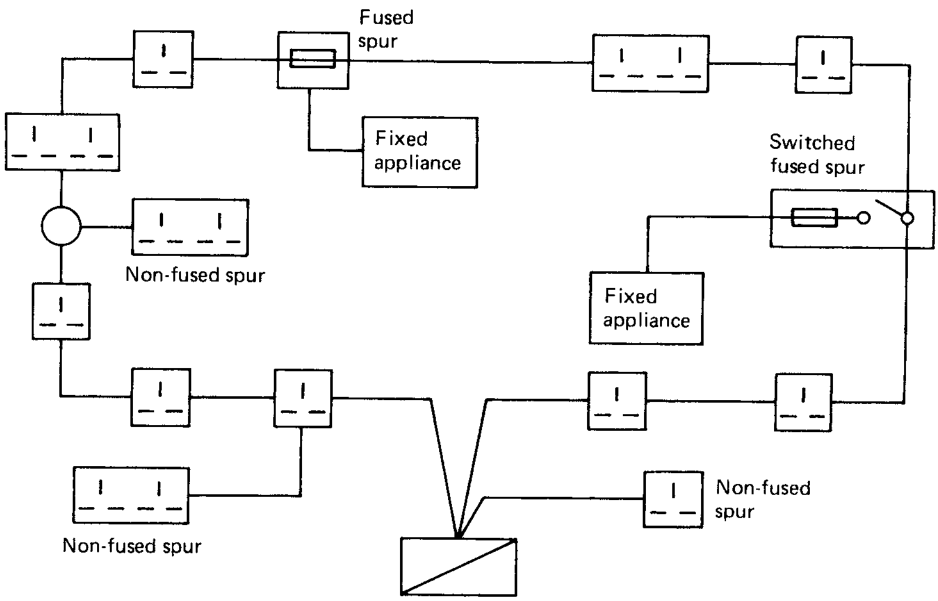


Fig. 3.9 Typical ring circuit with spurs.

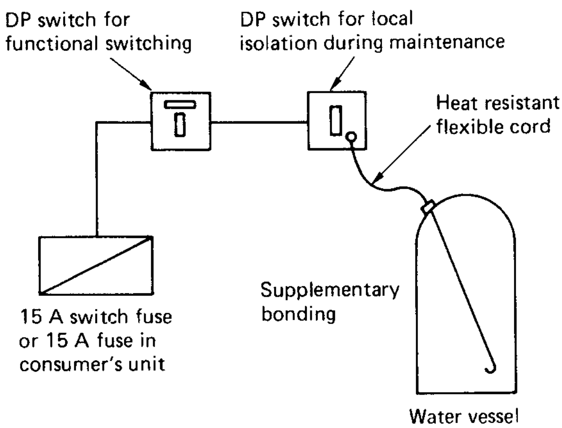


Fig. 3.10 Immersion heater wiring.

fused connection unit. A water heater of the immersion type is usually rated at a maximum of 3 kW, and could be considered as a permanently connected appliance, fed from a fused connection unit. However, many immersion heating systems are connected into storage vessels of about 150 l in domestic installations, and Appendix 8 of the *On Site Guide* states that immersion heaters fitted to vessels in excess of 15 l should be supplied by their own circuit.

Therefore, immersion heaters must be wired on a separate radial circuit when they are connected to water vessels which hold more than 15 l. Figure 3.10 shows the wiring arrangements for an immersion heater. The hot and cold water connections must be connected to an earth connection in order to meet the supplementary bonding requirements of Regulation 413–05–02. Every switch must be a double-pole (DP) switch and out of reach of anyone using a fixed bath or shower (Regulation 601–08–01) when the immersion heater is fitted to a vessel in a bathroom.

ELECTRIC SPACE HEATING CIRCUITS

Electrical heating systems can be broadly divided into two categories: unrestricted local heating and off-peak heating.

Unrestricted local heating may be provided by portable electric radiators which plug into the socket outlets of the installation. Fixed heaters that are wall-mounted or inset must be connected through a fused connection and incorporate a local switch, either on the heater itself or as a part of the fuse connecting unit, as shown in Fig. 3.8. Heating appliances where the heating element can be touched must have a double-pole switch which disconnects all conductors. This requirement includes radiators which have an element inside a silica-glass sheath (601–12–01).

Off-peak heating systems may provide central heating from storage radiators, ducted warm air or underfloor heating elements. All three systems use the

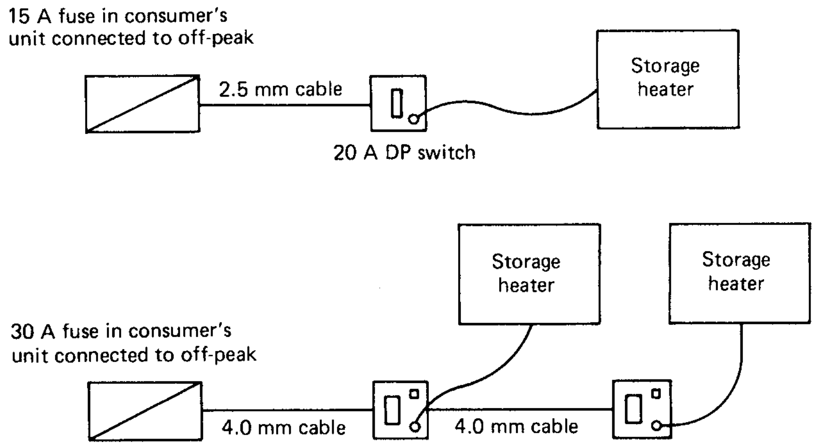


Fig. 3.11 Possible wiring arrangements for storage heaters.

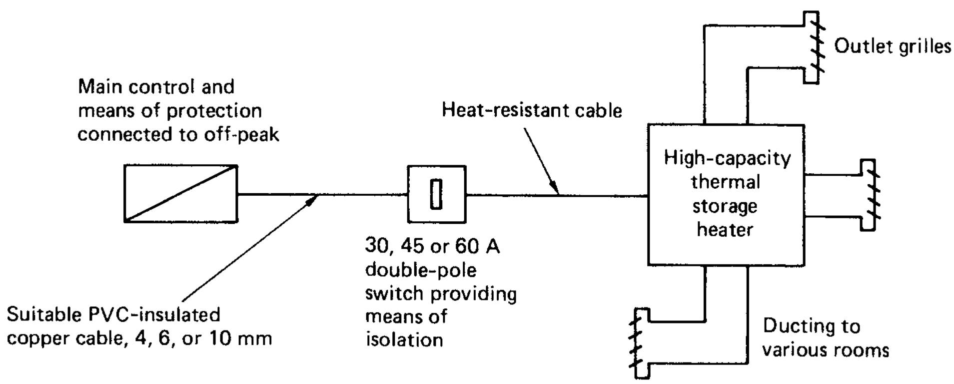


Fig. 3.12 Ducted warm air heating system.

thermal storage principle, whereby a large mass of heat-retaining material is heated during the off-peak period and allowed to emit the stored heat throughout the day. The final circuits of all off-peak heating installations must be fed from a separate supply controlled by an electricity board time clock.

When calculating the size of cable required to supply a single storage radiator, it is good practice to assume a current demand equal to 3.4 kW at each point. This will allow the radiator to be changed at a future time with the minimum disturbance to the installation. Each radiator must have a 20 A double-pole means of isolation adjacent to the heater and the final connection should be via a flex outlet. See Fig. 3.11 for wiring arrangements.

Ducted warm air systems have a centrally sited thermal storage heater with a high storage capacity. The unit is charged during the off-peak period, and a fan drives the stored heat in the form of warm air through large air ducts to outlet grilles in the various rooms. The wiring arrangements for this type of heating are shown in Fig. 3.12.

The single storage heater is heated by an electric element embedded in bricks and rated between 6 and 15 kW depending upon its thermal capacity. A radiator of this capacity must be supplied on its own circuit, in cable capable of carrying the maximum current demand and protected by a fuse or MCB of 30, 45 or 60 A as appropriate. At the heater position, a double-pole switch must be installed to terminate the fixed heater wiring. The flexible cables used for the final connection to the heaters must be of the heat-resistant type.

Floor warming installations use the thermal storage properties of concrete. Special cables are embedded in the concrete floor screed during construction. When

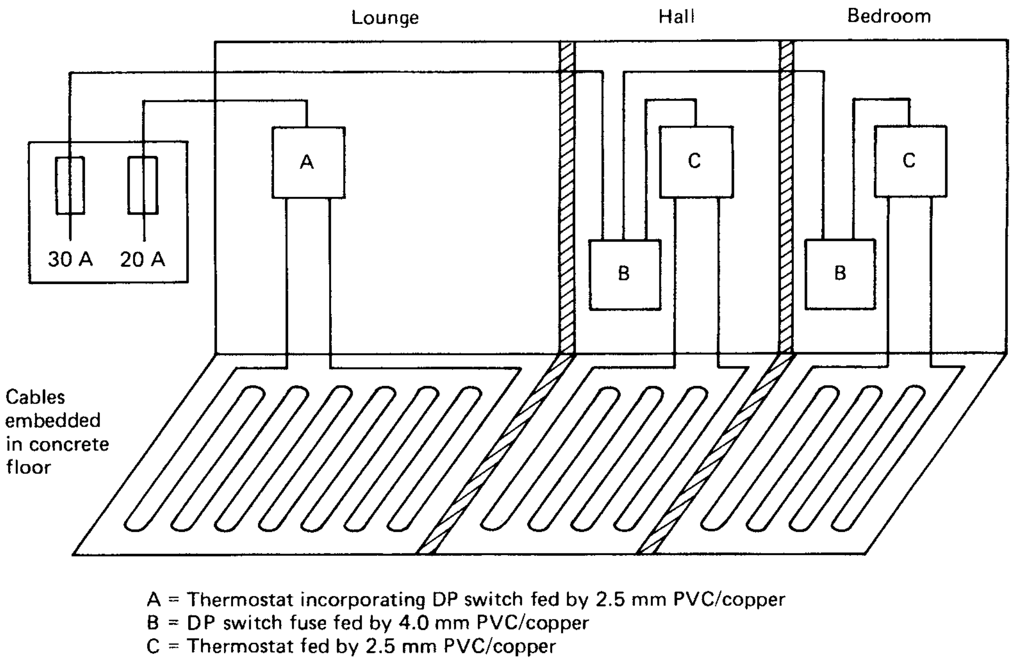


Fig. 3.13 Floor warming installations.

current is passed through the cables they become heated, the concrete absorbs this heat and radiates it into the room. The wiring arrangements are shown in Fig. 3.13. Once heated, the concrete will give off heat for a long time after the supply is switched off and is, therefore, suitable for connection to an off-peak supply.

Underfloor heating cables installed in bathrooms or shower rooms must incorporate an earthed metallic sheath or be covered by an earthed metallic grid connected to the supplementary bonding (Regulation 601–12–02).

COOKER CIRCUIT

A cooker with a rating above 3 kW must be supplied on its own circuit but since it is unlikely that in normal use every heating element will be switched on at the same time, a diversity factor may be applied in calculating the cable size, as detailed in Table 1A in Appendix 1 of the *On Site Guide.*

Consider, as an example, a cooker with the following elements fed from a cooker control unit incorporating a 13 A socket:

$$4 \times 2\,\text{kW fast boiling rings} = 8000\,\text{W}$$
$$1 \times 2\,\text{kW grill} = 2000\,\text{W}$$
$$1 \times 2\,\text{kW oven} = 2000\,\text{W}$$
$$\text{Total loading} = 12\,000\,\text{W}$$

When connected to 250 V

$$\text{Current rating} = \frac{12\,000}{250} = 48\,\text{A}.$$

Applying the diversity factor of Table 1A,

$$\text{Total current rating} = 48\,\text{A}$$
$$\text{First 10 amperes} = 10\,\text{A}$$
$$30\%\text{ of }38\,\text{A} = 11.4\,\text{A}$$
$$\text{Socket outlet} = 5\,\text{A}$$
$$\text{Assessed current demand} = 10 + 11.4 + 5 = 26.4\,\text{A}$$

Therefore, a cable capable of carrying 26.4 A may be used safely rather than a 48 A cable.

A cooking appliance must be controlled by a switch separate from the cooker but in a readily accessible position (Regulation 476–03–04). Where two cooking appliances are installed in one room, such as split-level cookers, one switch may be used to control both appliances provided that neither appliance is more than 2 m from the switch (*On Site Guide*, Appendix 8).

Designing out faults

The designer of the installation cannot entirely design out the possibility of a fault occurring but he can design in 'damage limitation' should a fault occur.

For example designing in two, three or four lighting and power circuits will reduce the damaging effect of any one circuit failing because not all lighting and power will be lost as a result of a fault. Limiting faults to only one of many circuits is good practice because it limits the disruption caused by a fault. Regulation 314–01–01 tells us to divide an installation into circuits as necessary so as to

1 avoid danger and minimise inconvenience in the event of a fault occurring and
2 facilitate safe operation, inspection testing and maintenance.

Finding the electrical fault

The steps involved in successfully finding a fault can be summarized as follows:

1 Gather *information* by talking to people and looking at relevant sources of information such as manufacturer's data, circuit diagrams, charts and schedules.
2 *Analyse* the evidence and use standard tests and a visual inspection to predict the cause of the fault.
3 *Interpret* test results and diagnose the cause of the fault.
4 *Rectify* the fault.
5 *Carry out* functional tests to verify that the installation or piece of equipment is working correctly and that the fault has been rectified.

Safe working procedures

1 The circuits must be isolated using a 'safe isolation procedure', such as that described below, before beginning to repair the fault.
2 All test equipment must be 'approved' and connected to the test circuits by recommended test probes as described by the HSE Guidance Note GS 38 which are discussed later in this chapter. The test equipment used must also be 'proved' on a known supply or by means of a proving unit such as that shown in Fig. 2.49.
3 Isolation devices must be 'secured' in the 'off' position as shown in Fig. 2.50. The key is retained by the person working on the isolated equipment.
4 Warning notices must be posted.
5 All relevant safety and functional tests must be completed before restoring the supply.

Live testing

The Electricity at Work Act tells us that it is 'preferable' that supplies be made dead before work commences (Regulation 4(3)). However, it does acknowledge that some work, such as fault finding and testing, may require the electrical equipment to remain energized. Therefore, if the fault finding and testing can only be successfully carried out 'live', then the person carrying out the fault diagnosis must:

- be trained so that he understands the equipment and the potential hazards of working live and can, therefore, be deemed to be 'competent' to carry out the activity;
- only use approved test equipment;
- set up barriers and warning notices so that the work activity does not create a situation dangerous to others.

Note that while live testing may be required in order to find the fault, live repair work must not be carried out. The individual circuit or item of equipment must first be isolated.

Secure isolation of electrical supply

The Electricity at Work Regulations are very specific in describing the procedure to be used for isolation of the electrical supply. Regulation 12(1) tells us that isolation means the disconnection and separation of the electrical equipment from every source of electrical energy in such a way that this disconnection and separation is secure. Regulation 4(3) tells us that we must also prove the conductors dead before work commences and that the test instrument used for this

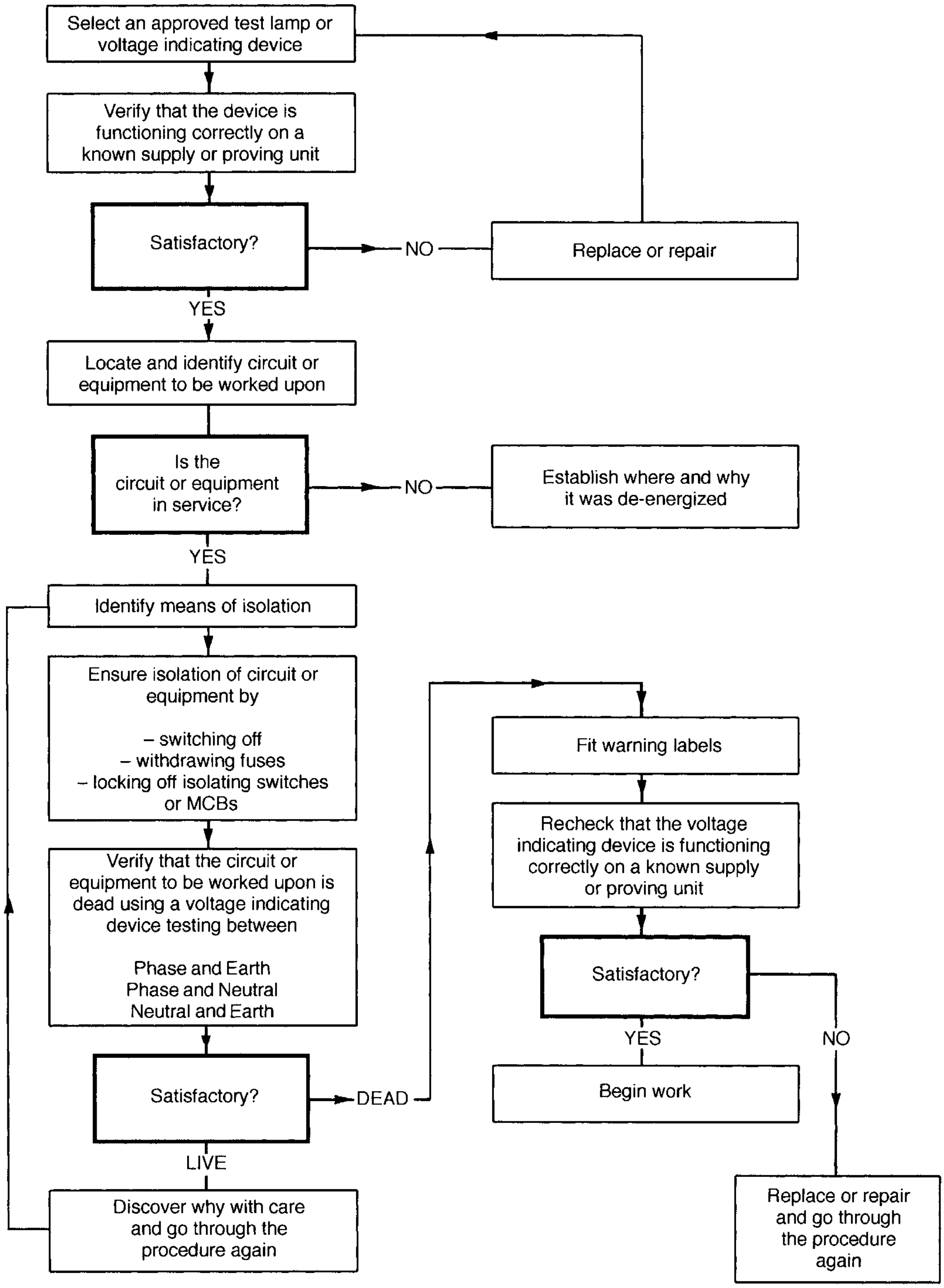


Fig. 3.14 Flowchart for a secure isolation procedure.

purpose must itself be proved immediately before and immediately after testing the conductors. To isolate an individual circuit or item of equipment successfully, competently and safely we must follow a procedure such as that given by the flow diagram in Fig. 3.14. Start at the top and work your way down the flowchart. When you get to the heavy-outlined boxes, pause and ask yourself whether everything is satisfactory up to this point. If the answer is yes, move on. If no, go back as indicated by the diagram.

Faulty equipment: to repair or replace?

Having successfully diagnosed the cause of the fault we have to decide if we are to repair or replace the faulty component or piece of equipment.

In many cases the answer will be straightforward and obvious, but in some circumstances the solution will need to be discussed with the customer. Some of the issues which may be discussed are as follows:

- What is the cost of replacement? Will the replacement cost be prohibitive? Is it possible to replace only some of the components? Will the labour costs of the repair be more expensive than a replacement? Do you have the skills necessary to carry out the repair? Would the repaired piece of equipment be as reliable as a replacement?
- Is a suitable replacement available within an acceptable time? These days, manufacturers carry small stocks to keep costs down.
- Can the circuit or system be shut down to facilitate a repair or replacement?
- Can alternative or temporary supplies and services be provided while replacements or repairs are carried out?

Selecting test equipment

The Health and Safety Executive has published Guidance Notes (GS 38) which advise electricians and other electrically competent people on the selection of suitable test probes, voltage indicating devices and measuring instruments. This is because they consider suitably constructed test equipment to be as vital for personal safety as the training and practical skills of the electrician. In the past, unsatisfactory test probes and voltage indicators have frequently been the cause of accidents, and therefore all test probes must now incorporate the following features:

1. The probes must have finger barriers or be shaped so that the hand or fingers cannot make contact with the live conductors under test.
2. The probe tip must not protrude more than 2 mm, and preferably only 1 mm, be spring-loaded and screened.
3. The lead must be adequately insulated and coloured so that one lead is readily distinguished from the other.
4. The lead must be flexible and sufficiently robust.
5. The lead must be long enough to serve its purpose but not too long.
6. The lead must not have accessible exposed conductors even if it becomes detached from the probe or from the instrument.
7. Where the leads are to be used in conjunction with a voltage detector they must be protected by a fuse.

A suitable probe and lead is shown in Fig. 2.47.

GS 38 also tells us that where the test is being made simply to establish the presence or absence of a voltage, the preferred method is to use a proprietary test lamp or voltage indicator which is suitable for the working voltage, rather than a multimeter. Accident history has shown that incorrectly set multimeters or makeshift devices for voltage detection have frequently caused accidents. Figure 2.48 shows a suitable voltage indicator. Test lamps and voltage indicators are not fail-safe, and therefore GS 38 recommends that they should be regularly proved, preferably before and after use, as described previously in the flowchart for a safe isolation procedure.

The IEE Regulations (BS 7671) also specify the test voltage or current required to carry out particular tests satisfactorily. All testing must, therefore, be carried out using an 'approved' test instrument if the test results are to be valid. The test instrument must also carry a calibration certificate, otherwise the recorded results may be void. Calibration certificates usually last for a year. Test instruments must, therefore, be tested and recalibrated each year by an approved supplier. This will maintain the accuracy of the instrument to an acceptable level, usually within 2% of the true value.

Modern digital test instruments are reasonably robust, but to maintain them in good working order they must be treated with care. An approved test instrument costs equally as much as a good-quality camera; it should, therefore, receive the same care and consideration.

CONTINUITY TESTER

To measure accurately the resistance of the conductors in an electrical installation we must use an instrument which is capable of producing an open circuit voltage of between 4 and 24 V a.c. or d.c., and deliver a short-circuit current of not less than 200 mA (Regulation 713–02). The functions of continuity testing and insulation resistance testing are usually combined in one test instrument.

INSULATION RESISTANCE TESTER

The test instrument must be capable of detecting insulation leakage between live conductors and between live conductors and earth. To do this and comply with Regulation 713–04 the test instrument must be capable of producing a test voltage of 250, 500 or 1000 V and deliver an output current of not less than 1 mA at its normal voltage.

EARTH FAULT LOOP IMPEDANCE TESTER

The test instrument must be capable of delivering fault currents as high as 25 A for up to 40 ms using the supply voltage. During the test, the instrument does an Ohm's law calculation and displays the test result as a resistance reading.

RCD TESTER

Where circuits are protected by a residual current device we must carry out a test to ensure that the device will operate very quickly under fault conditions and within the time limits set by the IEE Regulations. The instrument must, therefore, simulate a fault and measure the time taken for the RCD to operate. The instrument is, therefore, calibrated to give a reading measured in milliseconds to an in-service accuracy of 10%.

If you purchase good-quality 'approved' test instruments and leads from specialist manufacturers they will meet all the Regulations and Standards and therefore give valid test results. However, to carry out all the tests required by the IEE Regulations will require a number of test instruments and this will represent a major capital investment in the region of £1000.

The specific tests required by the IEE Regulations: BS 7671 are described in detail in Chapter 2 of this book under the sub-heading 'Inspection and Testing Techniques.'

Electrical installation circuits usually carry in excess of 1 A and often carry hundreds of amperes. Electronic circuits operate in the milliampere or even microampere range. The test instruments used on electronic circuits must have a *high impedance* so that they do not damage the circuit when connected to take readings. All instruments cause some disturbance when connected into a circuit because they consume some power in order to provide the torque required to move the pointer. In power applications these small disturbances seldom give rise to obvious errors, but in electronic circuits, a small disturbance can completely invalidate any readings taken. We must, therefore, choose our electronic test equipment with great care.

This is described in detail in Chapter 4 of this book under the sub-heading 'Electronic Test Equipment' and suitable test instruments are shown in Figs 4.74–4.76.

So far in this chapter, I have been considering standard electrical installation circuits wired in conductors and cables using standard wiring systems. However, you may be asked to diagnose and repair a fault on a system that is unfamiliar to you or outside your experience and training. If this happens to you I would suggest that you immediately tell the person ordering the work that it is beyond your knowledge and experience. I have said earlier that fault diagnosis can only be carried out successfully by someone with a broad range of experience and a thorough knowledge of the installation or equipment that is malfunctioning. The person ordering the work will not think you a fool for saying straightaway that the work is outside your experience. It is better to be respected for your honesty than to attempt something that is beyond you at the present time and which could create bigger problems and waste valuable repair time.

Let us now consider some situations where special precautions or additional skills and knowledge may need to be applied.

Special situations

OPTICAL FIBRE CABLES

The introduction of fibre-optic cable systems and digital transmissions will undoubtedly affect future cabling arrangements and the work of the electrician. Networks based on the digital technology currently being used so successfully by the telecommunications industry are very likely to become the long-term standard for computer systems. Fibre-optic systems dramatically reduce the number of cables required for control and communications systems, and this will in turn reduce the physical room required for these systems. Fibre-optic cables are also immune to electrical noise when run parallel to mains cables and, therefore, the present rules of segregation and screening may change in the future. There is no spark risk if the cable is accidentally cut and, therefore, such circuits are intrinsically safe.

Optical fibre cables are communication cables made from optical-quality plastic, the same material from which spectacle lenses are manufactured. The energy is transferred down the cable as digital pulses of laser light as against current flowing down a copper conductor in electrical installation terms. The light pulses stay within the fibre-optic cable because of a scientific principle known as 'total internal refraction' which means that the laser light bounces down the cable and when it strikes the outer wall it is always deflected inwards and, therefore, does not escape out of the cable, as shown in Fig. 3.15.

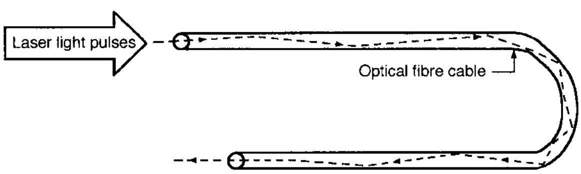


Fig. 3.15 Digital pulses of laser light down an optical fibre cable.

The cables are very small because the optical quality of the conductor is very high and signals can be transmitted over great distances. They are cheap to produce and lightweight because these new cables are made from high-quality plastic and not high-quality copper. Single-sheathed cables are often called 'simplex' cables and twin sheathed cables 'duplex', that is two simplex cables together in one sheath. Multicore cables are available containing up to 24 single fibres.

Fibre-optic cables look like steel wire armour cables (but of course are lighter) and should be installed in the same way and given the same level of protection as SWA cables. Avoid tight-radius bends if possible and kinks at all costs. Cables are terminated in special joint boxes which ensure cable ends are cleanly cut and butted together to ensure the continuity of the light pulses. Fibre-optic cables are Band I circuits when used for data transmission and must therefore be segregated from other mains cables to satisfy the IEE Regulations.

The testing of fibre-optic cables requires that special instruments be used to measure the light attenuation (i.e. light loss) down the cable. Finally, when working with fibre-optic cables, electricians should avoid direct eye contact with the low-energy laser light transmitted down the conductors.

Antistatic precautions

Static electricity is a voltage charge which builds up to many thousands of volts between two surfaces when they rub together. A dangerous situation occurs when the static charge has built up to a potential capable of striking an arc through the airgap separating the two surfaces.

Static charges build up in a thunderstorm. A lightning strike is the discharge of the thunder cloud, which might have built up to a voltage of 100 MV, to the general mass of earth which is at 0 V. Lightning discharge currents are of the order of 20 kA, hence the need for lightning conductors on vulnerable buildings in order to discharge the energy safely.

Static charge builds up between any two insulating surfaces or between an insulating surface and a conducting surface, but it is not apparent between two conducting surfaces.

A motor car moving through the air builds up a static charge which sometimes gives the occupants a minor shock as they step out and touch the door handle.

Static electricity also builds up in modern offices and similar carpeted areas. The combination of synthetic carpets, man-made footwear materials and dry air conditioned buildings contribute to the creation of static electrical charges building up on people moving about these buildings. Individuals only become aware of the charge if they touch earthed metalwork, such as a stair banister rail, before the static electricity has been dissipated. The effect is a sensation of momentary shock.

The precautions against this problem include using floor coverings that have been 'treated' to increase

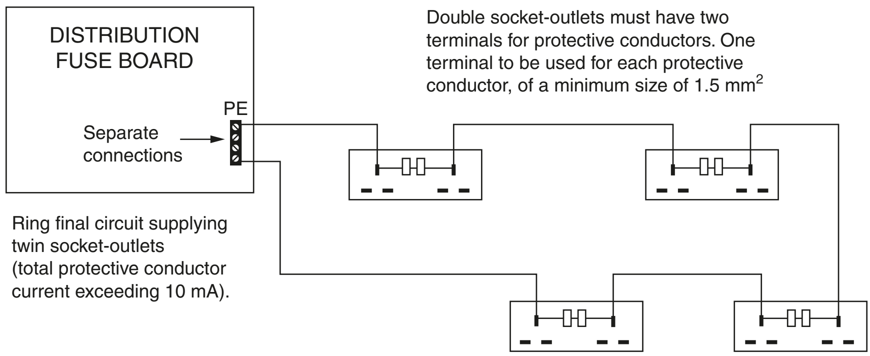


Fig. 3.16 Recommended method of connecting IT equipment to socket outlets.

their conductivity or that contain a proportion of natural fibres that have the same effect. The wearing of leather soled footwear also reduces the likelihood of a static charge persisting as does increasing the humidity of the air in the building.

A nylon overall and nylon bed sheets build up static charge which is the cause of the 'crackle' when you shake them. Many flammable liquids have the same properties as insulators, and therefore liquids, gases, powders and paints moving through pipes build up a static charge.

Petrol pumps, operating theatre oxygen masks and car spray booths are particularly at risk because a spark in these situations may ignite the flammable liquid, powder or gas.

So how do we protect ourselves against the risks associated with static electrical charges? I said earlier that a build-up of static charge is not apparent between two conducting surfaces, and this gives a clue to the solution. Bonding surfaces together with equipotential bonding conductors prevents a build-up of static electricity between the surfaces. If we use large-diameter pipes, we reduce the flow rates of liquids and powders and, therefore, we reduce the build-up of static charge. Hospitals use cotton sheets and uniforms, and use bonding extensively in operating theatres. Rubber, which contains a proportion of graphite, is used to manufacture antistatic trolley wheels and surgeons' boots. Rubber constructed in this manner enables any build-up of static charge to 'leak' away. Increasing humidity also reduces static charge because the water droplets carry away the static charge, thus removing the hazard.

Avoiding shutdown of IT equipment

Every modern office now contains computers, and many systems are linked together or networked. Most computer systems are sensitive to variations or distortions in the mains supply and many computers incorporate filters which produce high protective conductor currents of around 2 or 3 mA. This is clearly not a fault current, but is typical of the current which flows in the circuit protective conductor of IT equipment under normal operating conditions. Section 607 of the IEE Regulations deals with the earthing requirements for the installation of equipment having high protective conductor currents. IEE Guidance Note 7 recommends that IT equipment should be connected to double sockets as shown in Fig. 3.16.

CLEAN SUPPLIES

Supplies to computer circuits must be 'clean' and 'secure'. Mainframe computers and computer networks are sensitive to mains distortion or interference, which is referred to as 'noise'. Noise is mostly caused by switching an inductive circuit which causes a transient spike, or by brush gear making contact with the commutator segments of an electric motor. These distortions in the mains supply can cause computers to 'crash' or provoke errors and are shown in Fig. 3.17.

To avoid this, a 'clean' supply is required for the computer network. This can be provided by taking

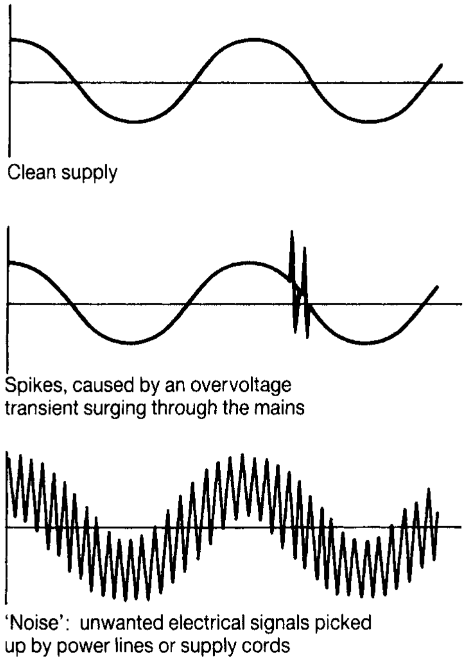


Fig. 3.17 Distortions in the a.c. mains supply.

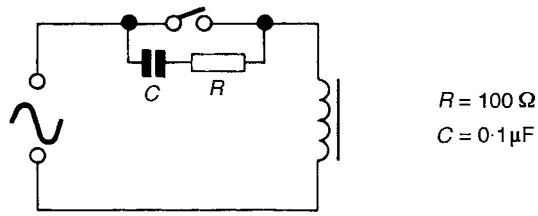


Fig. 3.18 A simple noise suppressor.

the ring or radial circuits for the computer supplies from a point as close as possible to the intake position of the electrical supply to the building. A clean earth can also be taken from this point, which is usually one core of the cable and not the armour of an SWA cable, and distributed around the final wiring circuit. Alternatively, the computer supply can be cleaned by means of a filter such as that shown in Fig. 3.18.

SECURE SUPPLIES

The mains electrical supply in the UK is extremely reliable and secure. However, the loss of supply to a mainframe computer or computer network for even a second can cause the system to 'crash', and hours or even days of work can be lost.

One solution to this problem is to protect 'precious' software systems with an uninterruptable power supply (UPS). A UPS is essentially a battery supply electronically modified to provide a clean and secure a.c. supply. The UPS is plugged into the mains supply and the computer systems are plugged into the UPS.

A UPS to protect a small network of, say, six PCs is physically about the size of one PC hard drive and is usually placed under or at the side of an operator's desk.

It is best to dedicate a ring or radial circuit to the UPS and either to connect the computer equipment permanently or to use non-standard outlets to discourage the unauthorized use and overloading of these special supplies by, for example, kettles.

Finally, remember that most premises these days contain some computer equipment and systems. Electricians intending to isolate supplies for testing or modification should first check and then check again before they finally isolate the supply in order to avoid loss or damage to computer systems.

Damage to electronic devices by 'overvoltage'

The use of electronic circuits in all types of electrical equipment has increased considerably over recent years. Electronic circuits and components can now be found in leisure goods, domestic appliances, motor starting and control circuits, discharge lighting, emergency lighting, alarm circuits and special-effects lighting systems. All electronic circuits are low voltage circuits carrying very small currents.

Electrical installation circuits usually carry in excess of 1 A and often carry hundreds of amperes. Electronic circuits operate in the milliampere or even microampere range. The test instruments used on electronic circuits must have a *high impedance* so that they do not damage the circuit when connected to take readings.

The use of an insulation resistance test as described by the IEE Regulations (described in Chapter 2 of this book), must be avoided with any electronic equipment. The working voltage of this instrument can cause total devastation to modern electronic equipment. When carrying out an insulation resistance test as part of the prescribed series of tests for an electrical installation, all electronic equipment must first be disconnected or damage will result.

Any resistance measurements made on electronic circuits must be achieved with a battery-operated ohmmeter as described in Chapter 4 of this book and shown in Fig 4.74 to avoid damaging the electronic components.

Risks associated with high frequency or large capacitive circuits

Induction heating processes use high frequency power to provide very focused heating in industrial processes.

The induction heater consists of a coil of large cross section. The work-piece or object to be heated is usually made of ferrous metal and is placed inside the coil. When the supply is switched on, eddy currents are induced into the work-piece and it heats up very quickly so that little heat is lost to conduction and convection.

The frequency and size of the current in the coil determines where the heat is concentrated in the work-piece:

- the higher the current the greater is the surface penetration;
- the longer the current is applied the deeper the penetration;
- the higher the frequency the less is the depth of heat penetration.

For shallow penetration, high frequency, high current, short time application is typically used for tool tempering. Other applications are brazing and soldering industrial and domestic gas boiler parts.

When these machines are not working they look very harmless but when they are working they operate very quietly and there is no indication of the intense heat that they are capable of producing. Domestic and commercial microwave ovens operate at high frequency. The combination of risks of high frequency and intense heating means that before any maintenance, repair work or testing is carried out, the machine must first be securely isolated and no one should work on these machines unless they have received additional training to enable them to do so safely.

Industrial wiring systems are very inductive because they contain many inductive machines and circuits, such as electric motors, transformers, welding plants and discharge lighting. The inductive nature of the industrial load causes the current to lag behind the voltage and creates a bad power factor. Power factor is the percentage of current in an alternating current circuit that can be used as energy for the intended purpose. A power factor of say 0.7 indicates that 70% of the current supplied is usefully employed by the industrial equipment.

An inductive circuit, such as that produced by an electric motor, induces an electromagnetic force which opposes the applied voltage and causes the current wave to lag the voltage wave. Magnetic energy is stored up in the load during one half cycle and returned to the circuit in the next half cycle. If a capacitive circuit is employed, the current leads the voltage since the capacitor stores energy as the current rises and discharges it as the current falls. So here we have the idea of a solution to the problem of a bad power factor created by inductive industrial loads. Power Factor and Power Factor Improvement was discussed in Chapter 1 of this book.

The power factor at which consumers take their electricity from the local electricity supply authority is outside the control of the supply authority. The power factor of the consumer is governed entirely by the electrical plant and equipment that is installed and operated within the consumer's buildings. Domestic consumers do not have a bad power factor because they use very little inductive equipment, most of the domestic load is neutral and at unity power factor.

Electricity supply authorities discourage the use of equipment and installations with a low power factor because they absorb part of the capacity of the generating plant and the distribution network to no useful effect. They, therefore, penalise industrial consumers with a bad power factor through a maximum demand tariff, metered at the consumer's intake position. If the power factor falls below a datum level of between 0.85 and 0.9 then extra charges are incurred. In this way industrial consumers are encouraged to improve their power factor.

Power factor improvement of most industrial loads is achieved by connecting capacitors to either

- individual items of equipment or
- banks of capacitors may be connected to the main bus-bars of the installation at the intake position.

The method used will depend upon the utilization of the installed equipment by the industrial or commercial consumer. If the load is constant then banks of capacitors at the mains intake position would be indicated. If the load is variable then power factor correction equipment could be installed adjacent to the machine or piece of equipment concerned.

Power factor correction by capacitors is the most popular method because of the following:

- They require no maintenance.
- Capacitors are flexible and additional units may be installed as an installation or system is extended.
- Capacitors may be installed adjacent to individual pieces of equipment or at the mains intake position. Equipment may be placed on the floor or fixed high up and out of the way.

Capacitors store charge and must be disconnected before the installation or equipment is tested in accordance with section 7 of the IEE Regulations BS 7671.

Small power factor correction capacitors as used in discharge lighting often incorporate a high value resistor connected across the mains terminals. This discharges the capacitor safely when not in use. Banks of larger capacity capacitors may require discharging to make them safe when not in use. To discharge a capacitor safely and responsibly it must be discharged slowly over a period in excess of five 'time-constants' through a suitable discharge resistor. Capacitors and time-constants were discussed earlier in this book in Chapter 1 under the sub-heading 'Electrostatics'.

Presence of storage batteries

Since an emergency occurring in a building may cause the mains supply to fail, the emergency lighting should be supplied from a source which is independent from the main supply. A battery's ability to provide its output instantly makes it a very satisfactory source of standby power. In most commercial, industrial and public service buildings housing essential services, the alternative power supply would be from batteries, but generators may also be used. Generators can have a large capacity and duration, but a major disadvantage is the delay of time while the generator runs up to speed and takes over the load. In some premises a delay of more than 5 seconds is considered unacceptable, and in these cases a battery supply is required to supply the load until the generator can take over.

The emergency lighting supply must have an adequate capacity and rating for the specified duration of time (IEE Regulation 313–02). BS 5266 states that after a battery is discharged by being called into operation for its specified duration of time, it should be capable of once again operating for the specified duration of time following a recharge period of not longer than 24 hours. The duration of time for which the emergency lighting should operate will be specified by a statutory authority but is normally 1–3 hours. BS 5266 states that escape lighting should operate for a minimum of 1 hour. Standby lighting operation time will depend upon financial considerations and the importance of continuing the process or activity. Within the premises after the mains supply has failed.

The contractor installing the emergency lighting should provide a test facility which is simple to operate and secure against unauthorized interference. The emergency lighting installation must be segregated completely from any other wiring, so that a fault on the main electrical installation cannot damage the emergency lighting installation (IEE Regulation 528–01).

The batteries used for the emergency supply should be suitable for this purpose. Motor vehicle batteries are not suitable for emergency lighting applications, except in the starter system of motor-driven generators. The fuel supply to a motor-driven generator should be checked. The battery room of a central battery system must be well ventilated and, in the case of a motor-driven generator, adequately heated to ensure rapid starting in cold weather.

BS 5266 recommends that the full load should be carried by the emergency supply for at least 1 hour in every 6 months. After testing, the emergency system must be carefully restored to its normal operative state. A record should be kept of each item of equipment and the date of each test by a qualified or responsible person. It may be necessary to produce the record as evidence of satisfactory compliance with statutory legislation to a duly authorized person.

Self-contained units are suitable for small installations of up to about 12 units. The batteries contained within these units should be replaced about every 5 years, or as recommended by the manufacturer.

Storage batteries are secondary cells. A secondary cell has the advantage of being rechargeable. If the cell is connected to a suitable electrical supply, electrical energy is stored on the plates of the cell as chemical energy. When the cell is connected to a load, the chemical energy is converted to electrical energy.

A lead-acid cell is a secondary cell. Each cell delivers about 2 V, and when six cells are connected in series a 12 V battery is formed. Figure 3.19 shows the construction of a lead-acid battery.

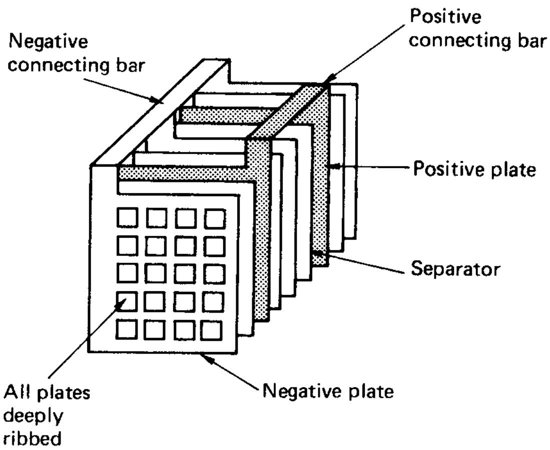


Fig. 3.19 The construction of a lead-acid battery.

A lead-acid battery is constructed of lead plates which are deeply ribbed to give maximum surface area for a given weight of plate. The plates are assembled in groups, with insulating separators between them. The separators are made of a porous insulating material, such as wood or ebonite, and the whole assembly is immersed in a dilute sulphuric acid solution in a plastic container.

BATTERY RATING

The capacity of a cell to store charge is a measure of the total quantity of electricity which it can cause to be displaced around a circuit after being fully charged. It is stated in ampere-hours, abbreviation Ah, and calculated at the 10-hour rate which is the steady load current which would completely discharge the battery in 10 hours. Therefore, a 50 Ah battery will provide a steady current of 5 A for 10 hours.

MAINTENANCE OF LEAD-ACID BATTERIES

- The plates of the battery must always be covered by the dilute sulphuric acid. If the level falls, it must be topped up with distilled water.
- Battery connections must always be tight and should be covered with a thin coat of petroleum jelly.
- The specific gravity or relative density of the battery gives the best indication of its state of charge. A discharged cell will have a specific gravity of 1.150, which will rise to 1.280 when fully charged. The specific gravity of a cell can be tested with a hydrometer.
- To maintain a battery in good condition it should be regularly trickle-charged. A rapid charge or discharge encourages the plates to buckle, and may cause permanent damage. Most batteries used for standby supplies today are equipped with constant voltage chargers. The principle of these is that after the battery has been discharged by it being called into operation, the terminal voltage will be depressed and this enables a relatively large current (1–5 A) to flow from the charger to recharge the battery. As the battery becomes more fully charged its voltage will rise until it reaches the constant voltage level where the current output from the charger will drop until it is just sufficient to balance the battery's internal losses. The main advantage of this system is that the battery controls the amount of charge it receives and is therefore automatically maintained in a fully charged condition without human intervention and without the use of any elaborate control circuitry.
- The room used to charge the emergency supply storage batteries must be well ventilated because the charged cell gives off hydrogen and oxygen, which are explosive in the correct proportions.

Safe removal of waste

Having successfully diagnosed the electrical fault and carried out the necessary repairs OR having completed any work in the electrotechnical industry, we come to the final task, leaving the site in a safe and clean condition and the removal of any waste material. This is an important part of your companies 'good customer relationships' with the client. We also know from Chapter 1 of this book that we have a 'duty of care' for the waste that we produce as an electrical company (see Chapter 1, under the sub-heading Controlled Waste Regulations 1998).

We have also said in Chapter 2 of this book that having a good attitude to health and safety, working conscientiously and neatly, keeping passageways clear and regularly tidying up the workplace is the sign of a good and competent craftsman. But what do you do with the rubbish that the working environment produces? Well, all the packaging material for electrical fittings and accessories usually goes into either your employer's skip or the skip on site designated for that purpose. All the off-cuts of conduit, trunking and tray also go into the skip. In fact, most of the general site debris will probably go into the skip and the waste disposal company will take the skip contents to a designated local council land fill area for safe disposal.

The part coils of cable and any other re-useable leftover lengths of conduit, trunking or tray will be taken back to your employer's stores area. Here it will be stored for future use and the returned quantities deducted from the costs allocated to that job.

What goes into the skip for normal disposal into a land fill site is usually a matter of common sense. However, some substances require special consideration and disposal. We will now look at asbestos and large quantities of used fluorescent tubes which are classified as 'Special waste'.

Asbestos is a mineral found in many rock formations. When separated it becomes a fluffy, fibrous material with many uses. It was used extensively in the construction industry during the 1960's and 70's for roofing material, ceiling and floor tiles, fire resistant board for doors and partitions, for thermal insulation and commercial and industrial pipe lagging.

In the buildings where it was installed some 40 years ago, when left alone, it does not represent a health hazard, but those buildings are increasingly becoming in need of renovation and modernisation. It is in the dismantling and breaking up of these asbestos materials that the health hazard increases. Asbestos is a serious health hazard if the dust is inhaled. The tiny asbestos particles find their way into delicate lung tissue and remain embedded for life, causing constant irritation and eventually, serious lung disease.

Working with asbestos materials is not a job for anyone in the electrotechnical industry. If asbestos is present in situations or buildings where you are expected to work, it should be removed by a specialist contractor before your work commences. Specialist contractors, who will wear fully protective suits and use breathing apparatus, are the only people who can safely and responsibly carry out the removal of asbestos. They will wrap the asbestos in thick plastic bags and store them temporarily in a covered and locked skip. This material is then disposed of in a special land fill site with other toxic industrial waste materials and the site monitored by the local authority for the foreseeable future.

There is a lot of work for electrical contractors in my part of the country, updating and improving the lighting in government buildings and schools. This work often involves removing the old fluorescent fittings, hanging on chains or fixed to beams and installing a suspended ceiling and an appropriate number of recessed modular fluorescent fittings. So what do we do with the old fittings? Well, the fittings are made of sheet steel, a couple of plastic lampholders, a little cable, a starter and ballast. All of these materials can go into the ordinary skip. However, the fluorescent tubes contain a little mercury and fluorescent powder with toxic elements, which cannot be disposed of in the normal land fill sites. The responsible way to dispose of fluorescent tubes is by grinding them up into small pieces using a 'lamp crusher', which looks very much like a garden waste shredder. The crushed lamp contents falls into a heavy duty plastic bag, which is sealed and disposed of along with the asbestos, material and other industrial waste in special land fill sites.

The COSHH Regulations and the Controlled Waste Regulations 1998 have encouraged specialist companies to set up businesses dealing with the responsible disposal of toxic waste material. Specialist companies have systems and procedures, which meet the relevant regulation, and they would usually give an electrical company a certificate to say that they had disposed of a particular waste material responsibly. The system is called 'Waste Transfer Notes'. The notes will identify the type of waste taken by whom and its final place of disposal. The person handing over the waste material to the waste disposal company will be given a copy of the notes and this must be filed in a safe place, probably in the job file or a dedicated file. It is the proof that your company has carried out its duty of care to dispose of the waste responsibly. The cost of this service is then passed on to the customer. These days, large employers and local authorities insist that waste is disposed of properly.

The Environmental Health Officer at your local Council Offices will always give advice and point you in the direction of specialist companies dealing with toxic waste disposal.

Exercises

1. Describe the symptoms of an electrical fault.
2. State how negligence, misuse or abuse by the installer or user may result in faults.
3. List the four logical stages of fault diagnosis.
4. List the five steps involved in finding and rectifying a fault.
5. List the safe working procedures to be applied on an electrical system before undertaking fault rectification.
6. State the requirements of the Electricity at Work Act with regard to the following:
   (**a**) 'live' testing and 'fault diagnosis',
   (**b**) 'live working' to repair a fault.
7. Define 'isolation' with respect to an electrical circuit or item of equipment.
8. List a logical procedure for the isolation of an electrical circuit. Start from the point at which you choose the voltage indicating device and finish with the point at which you begin to work on the circuit.
9. State five factors which might influence the decision to repair or replace a piece of faulty equipment.
10. Briefly explain how you might design in 'damage limitation' when planning a new installation.
11. Briefly explain what we mean by static electricity and how we would prevent it becoming a hazard in a store-room where large quantities of paint are stored on metal shelves.
12. Describe with simple sketches what we mean by a 'clean' computer supply and 'noise'.
13. Describe one method of obtaining a 'secure' supply for a computer network.
14. Describe how you would responsibly dispose of about 200 old lead-acid batteries that had previously been used as standby lighting in a cinema.
15. Explain with a sketch how digital pulses pass down fibre optic cables.

4

ELECTRONIC COMPONENTS

There are numerous types of electronic component – diodes, transistors, thyristors and integrated circuits – each with its own limitations, characteristics and designed application. When repairing electronic circuits it is important to replace a damaged component with an identical or equivalent component. Manufacturers issue comprehensive catalogues with details of working voltage, current, power dissipation etc., and the reference numbers of equivalent components, and some of this information is included in the Appendices. These catalogues of information, together with a high-impedance multi-meter as described later in this chapter and show at Fig. 4.74 should form a part of the extended tool-kit for anyone in the electrotechnical industries proposing to repair electronic circuits.

Electronic circuit symbols

The British Standard BS EN 60617 recommends that particular graphical symbols be used to represent a range of electronic components on circuit diagrams. The same British Standard recommends a range of symbols suitable for electrical installation circuits with which electricians will already be familiar. Figure 4.1 shows a selection of electronic symbols.

Resistors

All materials have some resistance to the flow of an electric current but, in general, the term *resistor* describes a conductor specially chosen for its resistive properties.

Resistors are the most commonly used electronic component and they are made in a variety of ways to suit the particular type of application. They are usually manufactured as either carbon composition or carbon film. In both cases the base resistive material is carbon and the general appearance is of a small cylinder with leads protruding from each end, as shown in Fig. 4.2(a).

If subjected to overload, carbon resistors usually decrease in resistance since carbon has a negative temperature coefficient. This causes more current to flow through the resistor, so that the temperature rises and failure occurs, usually by fracturing. Carbon resistors have a power rating of between 0.1 and 2 W which should not be exceeded.

When a resistor of a larger power rating is required a wire-wound resistor should be chosen. This consists of a resistance wire of known value wound on a small ceramic cylinder which is encapsulated in a vitreous enamel coating, as shown in Fig. 4.2(b). Wire-wound resistors are designed to run hot and have a power rating up to 20 W. Care should be taken when mounting wire-wound resistors to prevent the high operating temperature affecting any surrounding components.

A variable resistor is one which can be varied continuously from a very low value to the full rated resistance. This characteristic is required in tuning circuits to adjust the signal or voltage level for brightness, volume or tone. The most common type used in electronic work has a circular carbon track contacted by a metal wiper arm. The wiper arm can be adjusted by means of an adjusting shaft (rotary type) or by placing a screwdriver in a slot (preset type), as shown in

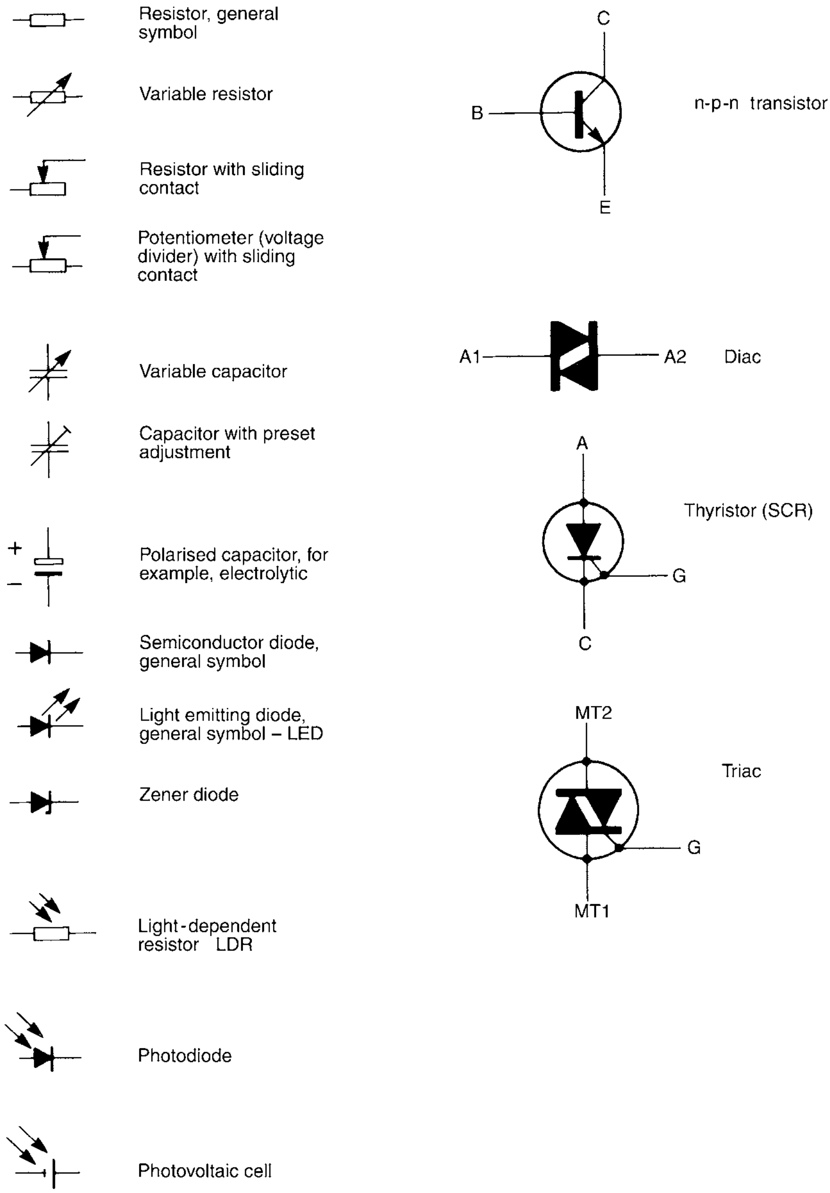


Fig. 4.1 Some BS EN 60617 graphical symbols used in electronics.

Fig. 4.3. Variable resistors are also known as potentiometers because they can be used to adjust the potential difference (voltage) in a circuit. The variation in resistance can be to either a logarithmic or a linear scale.

The value of the resistor and the tolerance may be marked on the body of the component either by direct numerical indication or by using a standard colour code. The method used will depend upon the type, physical size and manufacturer's preference, but in general the larger components have values marked directly on the body and the smaller components use the standard resistor colour code.

ABBREVIATIONS USED IN ELECTRONICS

Where the numerical value of a component includes a decimal point, it is standard practice to include the prefix for the multiplication factor in place of the

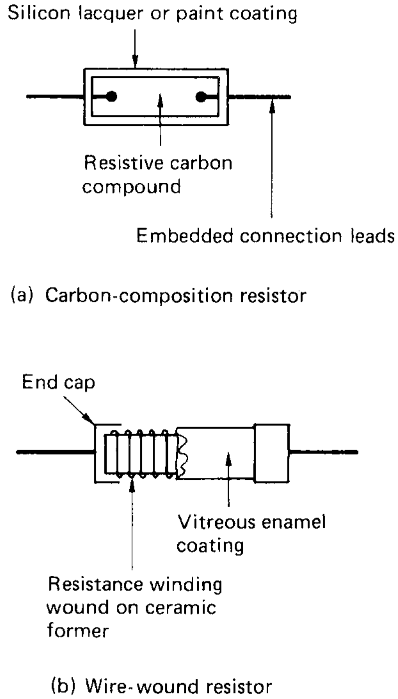


Fig. 4.2 Construction of resistors.

decimal point, to avoid accidental marks being mistaken for decimal points. Multiplication factors and prefixes are dealt with in Chapter 8.

The abbreviation R means × 1
k means × 1000
M means × 1 000 000

Therefore, a 4.7 kΩ resistor would be abbreviated to 4k7, a 5.6 Ω resistor to 5R6 and a 6.8 MΩ resistor to 6M8.

Tolerances may be indicated by adding a letter at the end of the printed code.

The abbreviation F means ±1%, G means ±2%, J means ±5%, K means ±10% and M means ±20%. Therefore a 4.7 kΩ resistor with a tolerance of 2% would be abbreviated to 4 k7G. A 5.6 Ω resistor with a tolerance of 5% would be abbreviated to 5R6J. A 6.8 MΩ resistor with a 10% tolerance would be abbreviated to 6M8K.

This is the British Standard BS 1852 code which is recommended for indicating the values of resistors on circuit diagrams and components when their physical size permits.

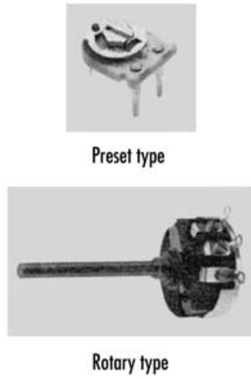
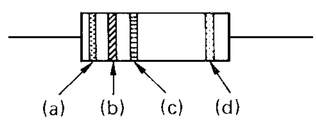


Fig. 4.3 Types of variable resistor.

THE STANDARD COLOUR CODE

Small resistors are marked with a series of coloured bands, as shown in Table 4.1. These are read according to the standard colour code to determine the resistance. The bands are located on the component towards one end. If the resistor is turned so that this end is towards the left, the bands are then read from left to right. Band (a) gives the first number of the component value, band (b) the second number, band (c) the number of zeros to be added after the first two

Table 4.1 The resistor colour code



Colour	Band (a) first number	Band (b) second number	Band (c) number of zeros	Band (d) tolerance band (%)
Black	0	0	None	–
Brown	1	1	1	1
Red	2	2	2	2
Orange	3	3	3	–
Yellow	4	4	4	–
Green	5	5	5	–
Blue	6	6	6	–
Violet	7	7	7	–
Grey	8	8	–	–
White	9	9	–	–
Gold	–	–	÷10	5
Silver	–	–	÷100	10
None	–	–	–	20

numbers and band (d) the resistor tolerance. If the bands are not clearly oriented towards one end, first identify the tolerance band and turn the resistor so that this is towards the right before commencing to read the colour code as described.

The tolerance band indicates the maximum tolerance variation in the declared value of resistance. Thus a 100 Ω resistor with a 5% tolerance will have a value somewhere between 95 and 105 Ω, since 5% of 100 Ω is 5 Ω.

EXAMPLE 1

A resistor is colour coded yellow, violet, red, gold. Determine the value of the resistor.

Band (a) – yellow has a value of 4.
Band (b) – violet has a value of 7.
Band (c) – red has a value of 2.
Band (d) – gold indicates a tolerance of 5%.

The value is therefore 4700 ± 5%.
This could be written as 4.7 kΩ ± 5% or 4k7J.

EXAMPLE 2

A resistor is colour coded green, blue, brown, silver. Determine the value of the resistor.

Band (a) – green has a value of 5.
Band (b) – blue has a value of 6.
Band (c) – brown has a value of 1.
Band (d) – silver indicates a tolerance of 10%.

The value is therefore 560 ± 10% and could be written as 560 Ω ± 10% or 560RK.

EXAMPLE 3

A resistor is colour coded blue, grey, green, gold. Determine the value of the resistor.

Band (a) – blue has a value of 6.
Band (b) – grey has a value of 8.
Band (c) – green has a value of 5.
Band (d) – gold indicates a tolerance of 5%.

The value is therefore 6 800 000 ± 5% and could be written as 6.8 MΩ ± 5% or 6M8J.

EXAMPLE 4

A resistor is colour coded orange, white, silver, silver. Determine the value of the resistor.

Band (a) – orange has a value of 3.
Band (b) – white has a value of 9.
Band (c) – silver indicates divide by 100 in this band.
Band (d) – silver indicates a tolerance of 10%.

The value is therefore 0.39 ± 10% and could be written as 0.39 Ω ± 10% or R39K.

PREFERRED VALUES

It is difficult to manufacture small electronic resistors to exact values by mass production methods. This is not a disadvantage as in most electronic circuits the value of the resistors is not critical. Manufacturers produce a limited range of *preferred* resistance values rather than an overwhelming number of individual resistance values. Therefore, in electronics, we use the preferred value closest to the actual value required.

A resistor with a preferred value of 100 Ω and a 10% tolerance could have any value between 90 and 110 Ω. The next larger preferred value which would give the maximum possible range of resistance values without too much overlap would be 120 Ω. This could have any value between 108 and 132 Ω. Therefore, these two preferred value resistors cover all possible resistance values between 90 and 132 Ω. The next preferred value would be 150 Ω, then 180, 220 Ω and so on.

There is a series of preferred values for each tolerance level, as shown in Table 4.2, so that every possible numerical value is covered. Table 4.2 indicates values between 10 and 100 but larger values can be obtained by multiplying these preferred values by some multiplication factor. Resistance values of 47 Ω, 470 Ω, 4.7 kΩ, 470 kΩ, 4.7 MΩ, etc., are available in this way.

TESTING RESISTORS

The resistor being tested should have a value close to the preferred value and within the tolerance stated by the manufacturer. To measure the resistance of a resistor which is not connected into a circuit, the leads of a suitable ohmmeter should be connected to each resistor connection lead and a reading obtained. The ohmmeter and its use are discussed later in this chapter and shown at Fig. 4.76.

Table 4.2 Preferred values

E6 series 20% tolerance	E12 series 10% tolerance	E24 series 5% tolerance
10	10	10
		11
	12	12
		13
15	15	15
		16
	18	18
		20
22	22	22
		24
	27	27
		30
33	33	33
		36
	39	39
		43
47	47	47
		51
	56	56
		62
68	68	68
		75
	82	82
		91

If the resistor to be tested is connected into an electronic circuit it is *always necessary* to disconnect one lead from the circuit before the test leads are connected, otherwise the components in the circuit will provide parallel paths, and an incorrect reading will result.

Capacitors

The fundamental principles of capacitors are discussed in Chapter 2 under the sub-heading 'Electrostatics'. In this chapter we shall consider the practical aspects associated with capacitors in electronic circuits.

A capacitor stores a small amount of electric charge; it can be thought of as a small rechargeable battery which can be quickly recharged. In electronics we are not only concerned with the amount of charge stored by the capacitor but in the way the value of the capacitor determines the performance of timers and oscillators by varying the time constant of a simple capacitor–resistor circuit.

CAPACITORS IN ACTION

If a test circuit is assembled as shown in Fig. 4.4 and the changeover switch connected to d.c. the signal lamp will only illuminate for a very short pulse as the capacitor charges. The charged capacitor then blocks any further d.c. current flow. If the changeover switch is then connected to a.c. the lamp will illuminate at full brilliance because the capacitor will charge and discharge continuously at the supply frequency. Current is *apparently* flowing through the capacitor because electrons are moving to and fro in the wires joining the capacitor plates to the a.c. supply.

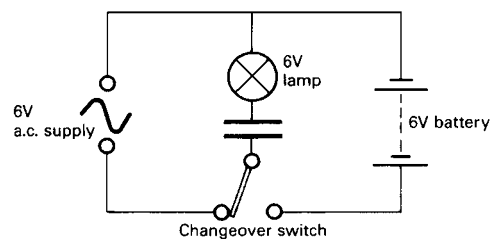


Fig. 4.4 Test circuit showing capacitors in action.

COUPLING AND DECOUPLING CAPACITORS

Capacitors can be used to separate a.c. and d.c. in an electronic circuit. If the output from circuit A, shown in Fig. 4.5(a), contains both a.c. and d.c. but only an a.c. input is required for circuit B then a *coupling* capacitor is connected between them. This blocks the d.c. while offering a low reactance to the a.c. component. Alternatively, if it is required that only d.c. be connected to circuit B, shown in Fig. 4.5(b), a *decoupling*

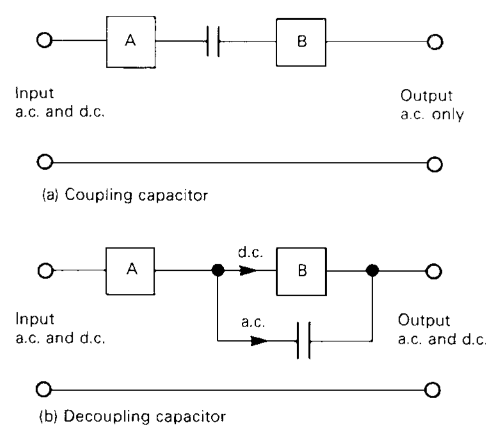


Fig. 4.5 (a) Coupling and (b) decoupling capacitors.

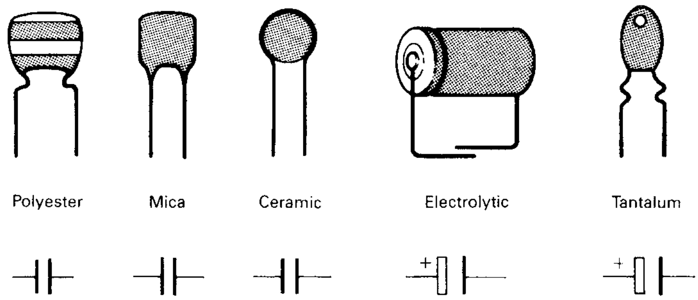


Fig. 4.6 Capacitors and their symbols used in electronic circuits.

capacitor can be connected in parallel with circuit B. This will provide a low reactance path for the a.c. component of the supply and only d.c. will be presented to the input of B. This technique is used to *filter out* unwanted a.c. in, for example, d.c. power supplies.

TYPES OF CAPACITOR

There are two broad categories of capacitor, the non-polarized and polarized type. The non-polarized type can be connected either way round, but polarized capacitors *must* be connected to the polarity indicated otherwise a short circuit and consequent destruction of the capacitor will result. There are many different types of capacitor, each one being distinguished by the type of dielectric used in its construction. Figure 4.6 shows some of the capacitors used in electronics.

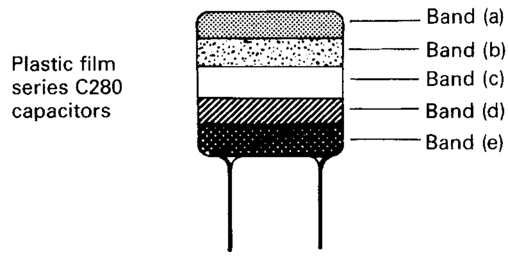
Polyester capacitors

Polyester capacitors are an example of the plastic film capacitor. Polypropylene, polycarbonate and polystyrene capacitors are other types of plastic film capacitor. The capacitor value may be marked on the plastic film, or the capacitor colour code given in Table 4.3 may be used. This dielectric material gives a compact capacitor with good electrical and temperature characteristics. They are used in many electronic circuits, but are not suitable for high-frequency use.

Mica capacitors

Mica capacitors have excellent stability and are accurate to ±1% of the marked value. Since costs usually increase with increased accuracy, they tend to be more expensive than plastic film capacitors. They are used where high stability is required, for example in tuned circuits and filters.

Table 4.3 Colour code for plastic film capacitors (values in picofarads)



Colour	Band (a) first number	Band (b) second number	Band (c) number of zeros to be added	Band (d) tolerance (%)	Band (e) maximum voltage (V)
Black	–	0	None	20	–
Brown	1	1	1	–	100
Red	2	2	2	–	250
Orange	3	3	3	–	–
Yellow	4	4	4	–	400
Green	5	5	5	5	–
Blue	6	6	6	–	–
Violet	7	7	7	–	–
Grey	8	8	8	–	–
White	9	9	9	10	–

Ceramic capacitors

Ceramic capacitors are mainly used in high-frequency circuits subjected to wide temperature variations. They have high stability and low loss.

Electrolytic capacitors

Electrolytic capacitors are used where a large value of capacitance coupled with a small physical size is required. They are constructed on the 'Swiss roll' principle as are the paper dielectric capacitors used for power-factor correction in electrical installation circuits. The electrolytic capacitors' high capacitance for very small volume is derived from the extreme thinness of the dielectric coupled with a high dielectric strength. Electrolytic capacitors have a size gain of approximately 100 times over the equivalent non-electrolytic type. Their main disadvantage is that they are polarized and must be connected to the correct polarity in a circuit. Their large capacity makes them ideal as smoothing capacitors in power supplies.

Tantalum capacitors

Tantalum capacitors are a new type of electrolytic capacitor using tantalum and tantalum oxide to give a further capacitance/size advantage. They look like a 'raindrop' or 'blob' with two leads protruding from the bottom. The polarity and values may be marked on the capacitor, or the colour code shown in Table 4.4 may be used. The voltage ratings available tend to be low, as with all electrolytic capacitors. They are also extremely vulnerable to reverse voltages in excess of 0.3 V. This means that even when testing with an ohmmeter, extreme care must be taken to ensure correct polarity.

Variable capacitors

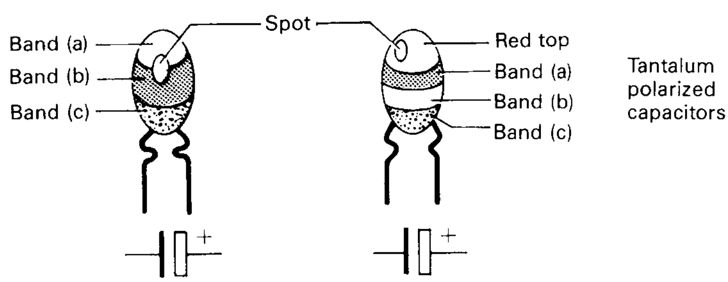
Variable capacitors are constructed so that one set of metal plates moves relative to another set of fixed metal plates as shown in Fig. 4.7. The plates are separated by air or sheet mica, which acts as a dielectric. Air dielectric variable capacitors are used to tune radio receivers to a chosen station, and small variable capacitors called *trimmers* or *presets* are used to make fine, infrequent adjustments to the capacitance of a circuit.

SELECTING A CAPACITOR

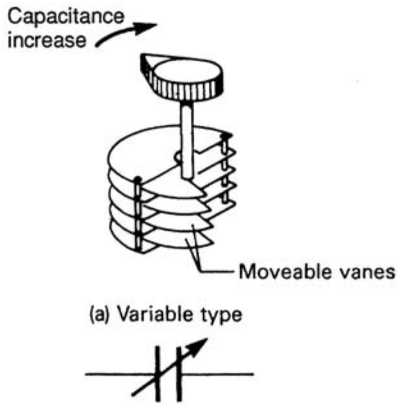
When choosing a capacitor for a particular application, three factors must be considered: value, working voltage and leakage current.

The unit of capacitance is the *farad* (symbol F), to commemorate the name of the English scientist

Table 4.4 Colour code for tantalum polarized capacitors (values in microfarads)



Colour	Band (a) first number	Band (b) second number	Spot number of zeros to be added	Band (c) maximum voltage(V)
Black	–	0	None	10
Brown	1	1	1	–
Red	2	2	2	–
Orange	3	3	–	–
Yellow	4	4	–	6.3
Green	5	5	–	16
Blue	6	6	–	20
Violet	7	7	–	–
Grey	8	8	÷100	25
White	9	9	÷1000	30
Pink				35



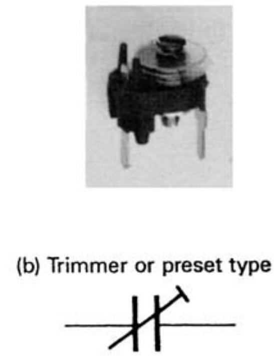


Fig. 4.7 Variable capacitors and their symbols: (a) variable type; (b) trimmer or preset type.

Michael Faraday. However, for practical purposes the farad is much too large and in electrical installation work and electronics we use fractions of a farad as follows:

$$1 \text{ microfarad} = 1\,\mu\text{F} = 1 \times 10^{-6}\,\text{F}$$
$$1 \text{ nanofarad} = 1\,\text{nF} = 1 \times 10^{-9}\,\text{F}$$
$$1 \text{ picofarad} = 1\,\text{pF} = 1 \times 10^{-12}\,\text{F}$$

The power-factor correction capacitor used in a domestic fluorescent luminaire would typically have a value of 8 μF at a working voltage of 400 V. In an electronic filter circuit a typical capacitor value might be 100 pF at 63 V.

One microfarad is one million times greater than one picofarad. It may be useful to remember that

$$1000\,\text{pF} = 1\,\text{nF}$$
$$1000\,\text{nF} = 1\,\mu\text{F}$$

The working voltage of a capacitor is the *maximum* voltage that can be applied between the plates of the capacitor without breaking down the dielectric insulating material. This is a d.c. rating and, therefore, a capacitor with a 200 V rating must only be connected across a maximum of 200 V d.c. Since a.c. voltages are usually given as rms values, a 200 V a.c. supply would have a maximum value of about 283 V, which would damage the 200 V capacitor. When connecting a capacitor to the 230 V mains supply we must choose a working voltage of about 400 V because 230 V rms. is approximately 325 V maximum. The 'factor of safety' is small and, therefore, the working voltage of the capacitor must not be exceeded.

An ideal capacitor which is isolated will remain charged forever, but in practice no dielectric insulating material is perfect, and the charge will slowly *leak* between the plates, gradually discharging the capacitor. The loss of charge by leakage through it should be very small for a practical capacitor.

Capacitor colour code

The actual value of a capacitor can be identified by using the colour codes given in Tables 4.3 and 4.4 in the same way that the resistor colour code was applied to resistors.

EXAMPLE 1

A plastic film capacitor is colour coded, from top to bottom, brown, black, yellow, black, red. Determine the value of the capacitor, its tolerance and working voltage.

From Table 4.3

Band (a) – brown has a value 1.
Band (b) – black has a value 0.
Band (c) – yellow indicates multiply by 10 000.
Band (d) – black indicates 20%.
Band (e) – red indicates 250 V.

The capacitor has a value of 100 000 pF or 0.1 μF with a tolerance of 20% and a maximum working voltage of 250 V.

EXAMPLE 2

Determine the value, tolerance and working voltage of a polyester capacitor colour-coded, from top to bottom, yellow, violet, yellow, white, yellow.

From Table 4.3

Band (a) – yellow has a value 4.
Band (b) – violet has a value 7.

Band (c) – yellow indicates multiply by 10 000.
Band (d) – white indicates 10%.
Band (e) – red indicates 400 V.

The capacitor has a value of 470 000 pF or 0.47 μF with a tolerance of 10% and a maximum working voltage of 400 V.

EXAMPLE 3

A plastic film capacitor has the following coloured bands from its top down to the connecting leads: blue, grey, orange, black, brown. Determine the value, tolerance and voltage of this capacitor.

From Table 10.3 we obtain the following:

Band (a) – blue has a value 6.
Band (b) – grey has a value 8.
Band (c) – orange indicates multiply by 1000.
Band (d) – black indicates 20%.
Band (e) – brown indicates 100 V.

The capacitor has a value of 68 000 pF or 68 nF with a tolerance of 20% and a maximum working voltage of 100 V.

CAPACITANCE VALUE CODES

Where the numerical value of the capacitor includes a decimal point, it is standard practice to use the prefix for the multiplication factor in place of the decimal point. This is the same practice as we used earlier for resistors.

The abbreviation μ means microfarad, n means nanofarad and p means picofarad. Therefore, a 1.8 pF capacitor would be abbreviated to 1p8, a 10 pF capacitor to 10p, a 150 pF capacitor to 150p or n15, a 2200 pF capacitor to 2n2 and a 10 000 pF capacitor to 10n.

$$1000\,\text{pF} = 1\,\text{nF} = 0.001\,\mu\text{F}$$

TESTING CAPACITORS

The discussion earlier in this chapter about *ideal* and *leaky* capacitors provides us with a basic principle to test for a faulty capacitor.

Non-polarized capacitors

Using an ohmmeter as shown in Fig. 4.76, connect the leads of the capacitor to the ohmmeter and observe the reading. If the resistance is less than about 1 MΩ, it is allowing current to pass from the ohmmeter and, therefore, the capacitor is leaking and is faulty. With large-value capacitors (in the microfarad range) there may be a short initial burst of current as the capacitor charges up.

Polarized capacitors

It is essential to connect the *true positive* of the ohmmeter to the positive lead of the capacitor, as shown in Fig. 4.76. When first connected, the resistance is low but rises to a steady value as the dielectric forms between the capacitor plates.

Inductors and transformers

An inductor is a coil of wire wound on a former (to give it a specific shape) having a core of air or iron. When a current flows through the coil a magnetic field is established. A transformer consists of two coils wound on a common magnetic core and, therefore, in this sense, is also an inductor. Simple transformer theory is discussed in Chapter 1. A small electronic transformer and the aerial of a radio receiver comprising a coil wound on a ferrite core are shown in Fig. 4.8.

Inductors such as the radio receiver aerial can be connected in parallel with a variable capacitor and *tuned* for maximum response so that a particular radio station can be listened to while excluding all others.

Most electronic circuits require a voltage between 5 and 12 V and the transformer provides an ideal way of initially reducing the mains voltage to a value which is suitable for the particular electronic circuit.

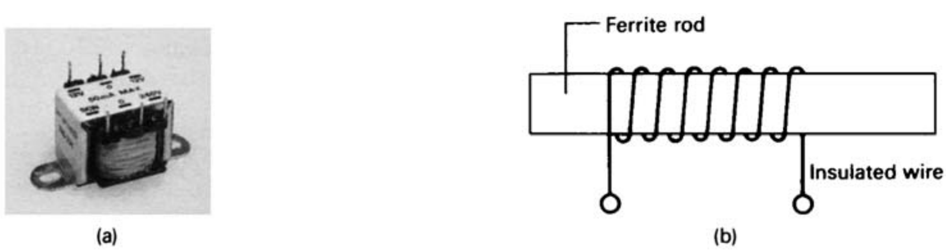


Fig. 4.8 Examples of an inductor: (a) transformer; (b) radio receiver aerial.

Compared with other individual electronic components, inductors are large. The magnetic fields produced by industrial electronic equipment such as electromagnets, relays and transformers can cut across other electronic components and cause undesirable emfs to be induced. This causes electrical interference – called *electrical noise* – and may prevent the normal operation of the electronic circuit. This interference can be avoided by magnetically *screening* the inductive components from the remaining circuits.

Electromagnetic relays

An electromagnetic relay is simply an electromagnet operating a number of switch contacts, as shown in Fig. 4.9. When a current is passed through the coil, the soft iron core becomes magnetized, attracts the iron armature and closes the switch contacts. The relay coil is electrically insulated from the switch contacts and, therefore, a relay is able to switch circuits operating at a different voltage than the coil operating voltage. The small current which energizes the coil is also able to switch larger currents at the switch contacts. The switch part of the relay may have many poles controlling several circuits at once.

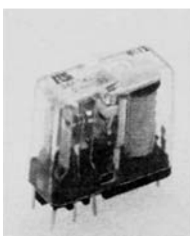


Fig. 4.9 An electromagnetic relay.

Miniature plug-in relays are popular in electronic circuits and intruder alarm circuits. However, all mechanical–electrical switches are limited in their speed of operation by the time taken physically for a movable contact to make or break a switch contact. Where extremely high-speed operations are required, the switching action must take place without physical movement. This is only possible using the properties of semiconductor materials in devices such as transistors and thyristors. They permit extremely high-speed switching without arcing and are considered later in this chapter.

Overcurrent protection

Every piece of electronic equipment must incorporate some means of overcurrent protection. The term 'overcurrent' can be subdivided into *overload* current and *short-circuit* current. An overload can be defined as a current which exceeds the rated value in an otherwise healthy circuit and a short circuit as an overcurrent resulting from a fault of negligible impedance between conductors. An overload may result in currents of two or three times the rated current flowing in the circuit, while short-circuit currents may be hundreds of times greater than the rated current. In both cases the basic requirement for safety is that the fault current should be interrupted quickly and the circuit isolated from the supply. Fuses provide overcurrent protection when connected in the live conductor; they must not be connected in the neutral conductor. Circuit breakers may be used in place of fuses and the best protection of all is obtained when the equipment is connected to a residual current device. Figure 4.10 shows a cartridge fuse holder. Protection from excess current is covered in some detail in Chapter 2.

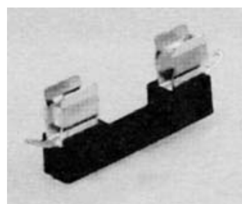


Fig. 4.10 A fuse holder for cartridge fuses up to 15 A.

Packaging electronic components

When we talk about packaging electronic components we are not referring to the parcel or box which contains the components for storage and delivery, but to the type of encapsulation in which the tiny semiconductor material is contained Figure 4.11 shows three different package outlines for just one type of discrete component, the transistor. Identification of the pin connections for different packages is given within the text as each separate or discrete component is considered, particularly later in this chapter when we discuss semiconductor devices. However, the

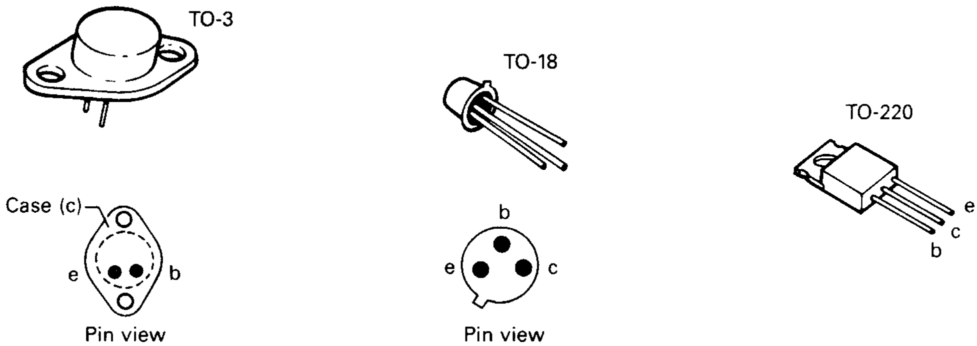


Fig. 4.11 Three different package outlines for transistors.

Appendices aim to draw together all the information on pin connections and packages for easy reference.

Obtaining information and components

Electricians use electrical wholesalers and suppliers to purchase electrical cable, equipment and accessories. Similar facilities are available in most towns and cities for the purchase of electronic components and equipment. There are also a number of national suppliers who employ representatives who will call at your workshop to offer technical advice and take your order. Some of these national companies also offer a 24-hour telephone order and mail order service. Their full-colour, fully illustrated catalogues also contain an enormous amount of technical information. The names and addresses of these national companies are given in Appendix A. For local suppliers you must consult your local phone book and *Yellow Pages*. The Appendices of this book also contain some technical reference information.

Semiconductor devices

SEMICONDUCTOR MATERIALS

Modern electronic devices use the semiconductor properties of materials such as silicon or germanium. The atoms of pure silicon or germanium are arranged in a lattice structure, as shown in Fig. 4.12. The outer

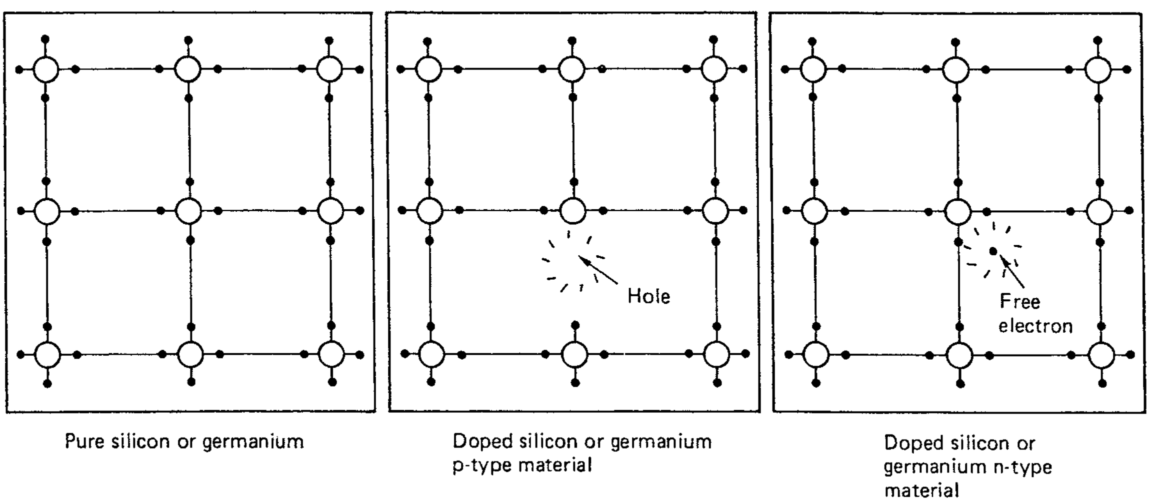


Fig. 4.12 Semiconductor material.

electron orbits contain four electrons known as *valence* electrons. These electrons are all linked to other valence electrons from adjacent atoms, forming a covalent bond. There are no free electrons in pure silicon or germanium and, therefore, no conduction can take place unless the bonds are broken and the lattice framework is destroyed.

To make conduction possible without destroying the crystal it is necessary to replace a four-valent atom with a three- or five-valent atom. This process is known as *doping*.

If a three-valent atom is added to silicon or germanium a hole is left in the lattice framework. Since the material has lost a negative charge, the material becomes positive and is known as a p-type material (p for positive).

If a five-valent atom is added to silicon or germanium, only four of the valence electrons can form a bond and one electron becomes mobile or free to carry charge. Since the material has gained a negative charge it is known as an n-type material (n for negative).

Bringing together a p-type and n-type material allows current to flow in one direction only through the p–n junction. Such a junction is called a diode, since it is the semiconductor equivalent of the vacuum diode valve used by Fleming to rectify radio signals in 1904.

SEMICONDUCTOR DIODE

A semiconductor or junction diode consists of a p-type and n-type material formed in the same piece of silicon or germanium. The p-type material forms the anode and the n-type the cathode, as shown in Fig. 4.13. If the anode is made positive with respect to the cathode, the junction will have very little resistance and current will flow. This is referred to as forward bias. However, if reverse bias is applied, that is, the anode is made negative with respect to the cathode, the junction resistance is high and no current can flow, as shown in Fig. 4.14. The characteristics for a forward and reverse bias p–n junction are given in Fig. 4.15.

It can be seen that a small voltage is required to forward bias the junction before a current can flow. This is approximately 0.6 V for silicon and 0.2 V for germanium. The reverse bias potential of silicon is about 1200 V and for germanium about 300 V. If the reverse bias voltage is exceeded the diode will break down and current will flow in both directions. Similarly, the

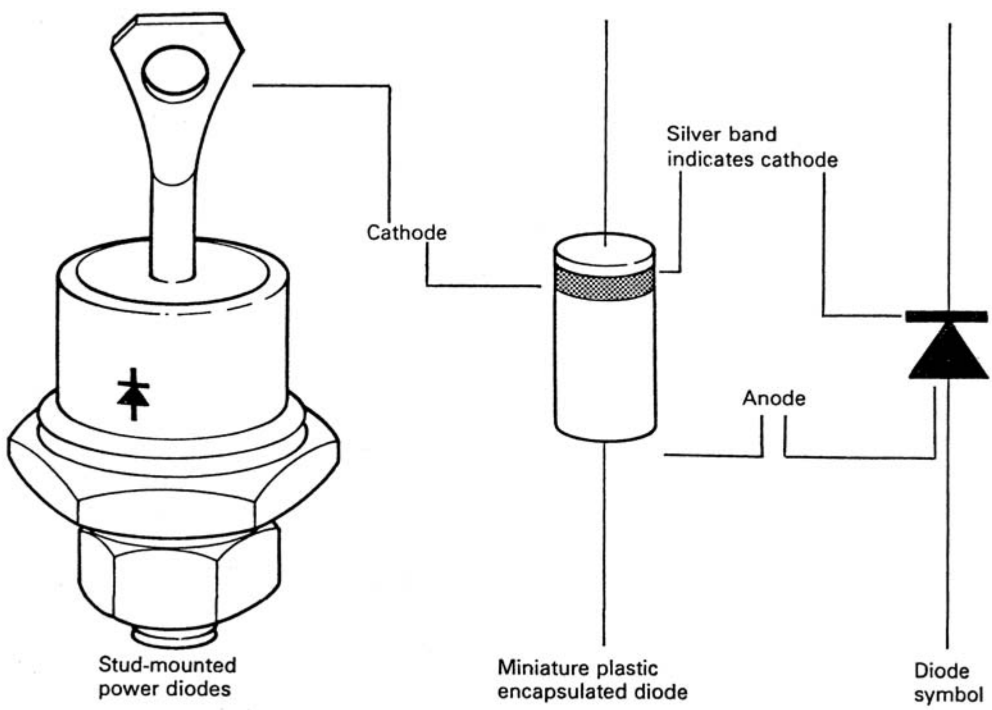


Fig. 4.13 Symbol for and appearance of semiconductor diodes.

diode will break down if the current rating is exceeded, because excessive heat will be generated. Manufacturer's information therefore gives maximum voltage and current ratings for individual diodes which must not be exceeded. However, it is possible to connect a number of standard diodes in series or parallel, thereby sharing current or voltage, as shown in Fig. 4.16, so that the manufacturers' maximum values are not exceeded by the circuit.

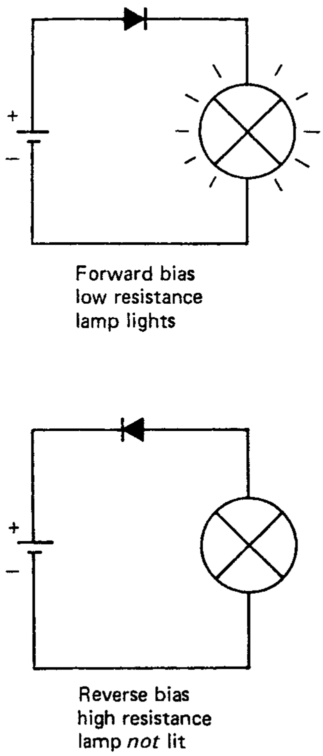


Fig. 4.14 Forward and reverse bias of a diode.

DIODE TESTING

The p–n junction of the diode has a low resistance in one direction and a very high resistance in the reverse direction.

Connecting an ohmmeter, as shown in Fig. 4.76 with the red positive lead to the anode of the junction diode and the black negative lead to the cathode, would give a very low reading. Reversing the lead connections would give a high resistance reading in a 'good' component.

ZENER DIODE

A Zener diode is a silicon junction diode but with a different characteristic than the semiconductor diode considered previously. It is a special diode with a predetermined reverse breakdown voltage, the mechanism for which was discovered by Carl Zener in 1934. Its symbol and general appearance are shown in Fig. 4.17. In its forward bias mode, that is, when the

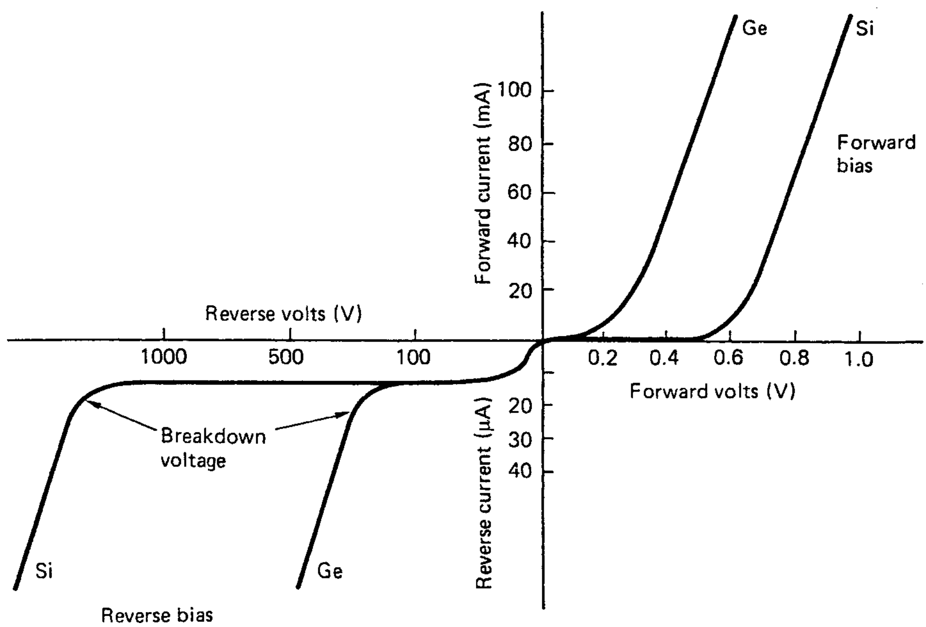


Fig. 4.15 Forward and reverse bias characteristic of silicon and germanium.

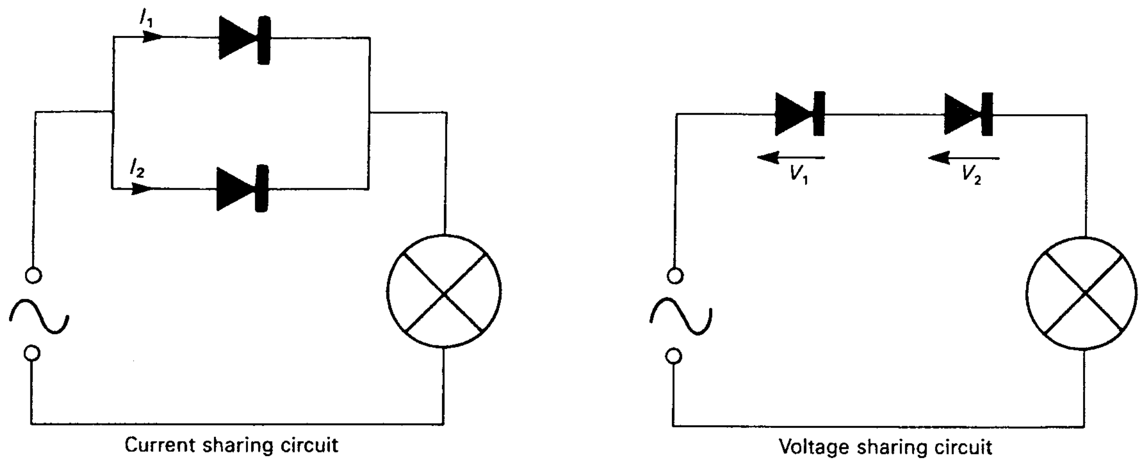


Fig. 4.16 Using two diodes to reduce the current or voltage applied to a diode.

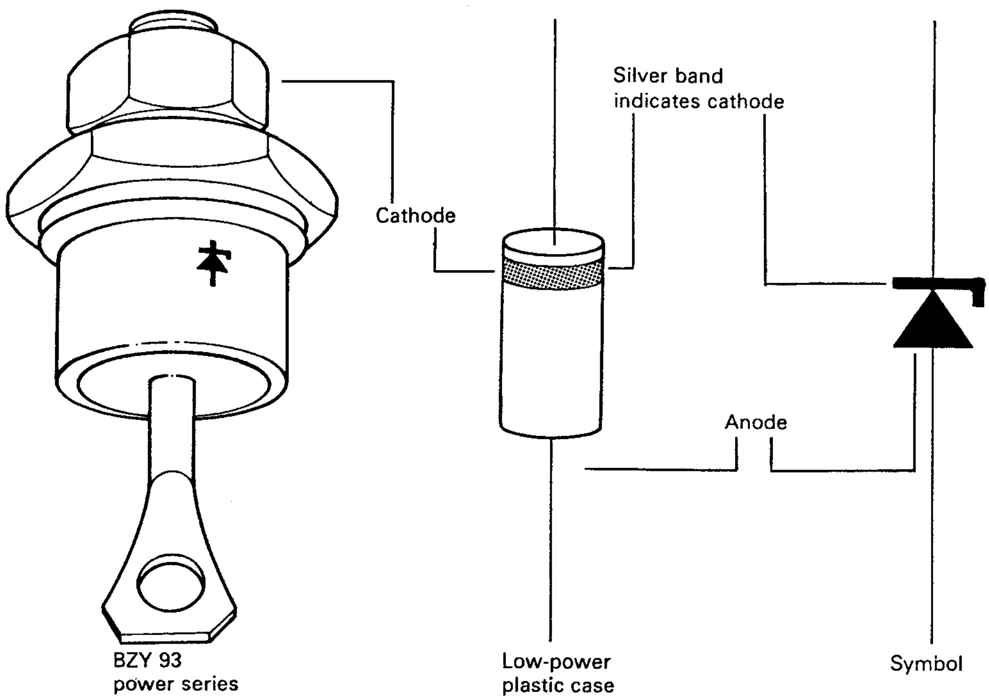


Fig. 4.17 Symbol for and appearance of Zener diodes.

anode is positive and the cathode negative, the Zener diode will conduct at about 0.6 V, just like an ordinary diode, but it is in the reverse mode that the Zener diode is normally used. When connected with the anode made negative and the cathode positive, the reverse current is zero until the reverse voltage reaches a predetermined value, when the diode switches on, as shown by the characteristics given in Fig. 4.18. This is called the Zener voltage or reference voltage. Zener diodes are manufactured in a range of preferred values, for example, 2.7, 4.7, 5.1, 6.2, 6.8, 9.1, 10, 11 V, 12 V, etc., up to 200 V at various ratings. The diode may be damaged by overheating if the current is not limited by a series resistor, but when this is connected,

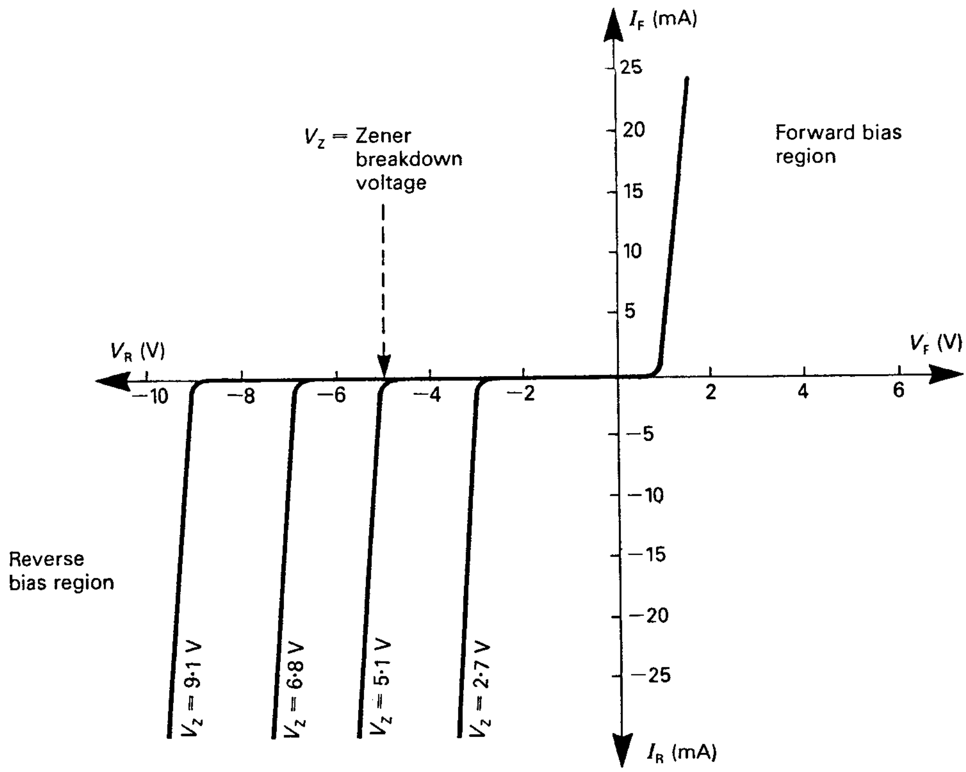
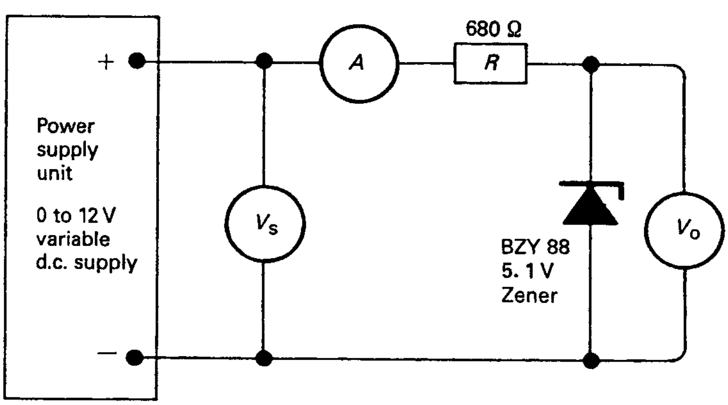


Fig. 4.18 Zener diode characteristics.

the voltage across the diode remains constant. It is this property of the Zener diode which makes it useful for stabilizing power supplies and these circuits are considered at the end of this chapter.

If a test circuit is constructed as shown in Fig. 4.19, the Zener action can be observed. When the supply is less than the Zener voltage (5.1 V in this case) no current will flow and the output voltage will be equal to the input voltage. When the supply is equal to or greater than the Zener voltage, the diode will conduct and any excess voltage will appear across the 680 Ω resistor, resulting in a very stable voltage at the output.



P.S.U. Supply Volts(V_S)	Current (A)	Output Volts (V_O)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Fig. 4.19 Experiment to demonstrate the operation of a Zener diode.

When connecting this and other electronic circuits you must take care to connect the polarity of the Zener diode as shown in the diagram. Note that current must flow through the diode to enable it to stabilize.

LIGHT-EMITTING DIODE (LED)

The light-emitting diode is a p–n junction especially manufactured from a semiconducting material which emits light when a current of about 10 mA flows through the junction.

No light is emitted when the junction is reverse biased and if this exceeds about 5 V the LED may be damaged.

The general appearance and circuit symbol are shown in Fig. 4.20.

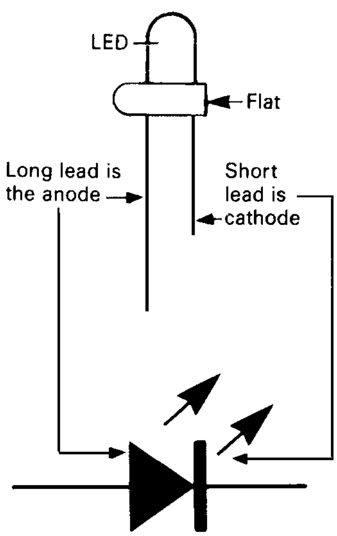


Fig. 4.20 Symbol for and general appearance of an LED.

The LED will emit light if the voltage across it is about 2 V. If a voltage greater than 2 V is to be used then a resistor must be connected in series with the LED.

To calculate the value of the series resistor we must ask ourselves what we know about LEDs. We know that the diode requires a forward voltage of about 2 V and a current of about 10 mA must flow through the junction to give sufficient light. The value of the series resistor *R* will, therefore, be given by:

$$R = \frac{\text{Supply voltage} - 2\text{ V}}{10\text{ mA}}\ \Omega$$

EXAMPLE

Calculate the value of the series resistor required when an LED is to be used to show the presence of a 12 V supply.

$$R = \frac{12\text{ V} - 2\text{ V}}{10\text{ mA}}\ \Omega$$

$$R = \frac{10\text{ V}}{10\text{ mA}} = 1\text{ k}\Omega$$

The circuit is, therefore, as shown in Fig. 4.21.

LEDs are available in red, yellow and green and, when used with a series resistor, may replace a filament lamp. They use less current than a filament lamp, are smaller, do not become hot and last indefinitely. A filament lamp, however, is brighter and emits white light. LEDs are often used as indicator lamps, to indicate the presence of a voltage. They do not, however, indicate the *precise* amount of voltage present at that point.

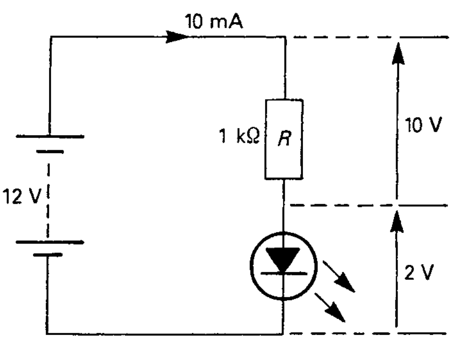


Fig. 4.21 Circuit diagram for LED example.

Another application of the LED is the seven-segment display used as a numerical indicator in calculators, digital watches and measuring instruments. Seven LEDs are arranged as a figure 8 so that when various segments are illuminated, the numbers 0 to 9 are displayed as shown in Fig. 4.22.

LIGHT-DEPENDENT RESISTOR (LDR)

Almost all materials change their resistance with a change in temperature. Light energy falling on a suitable semiconductor material also causes a change in resistance. The semiconductor material of an LDR is encapsulated as shown in Fig. 4.23 together with the circuit symbol. The resistance of an LDR in total

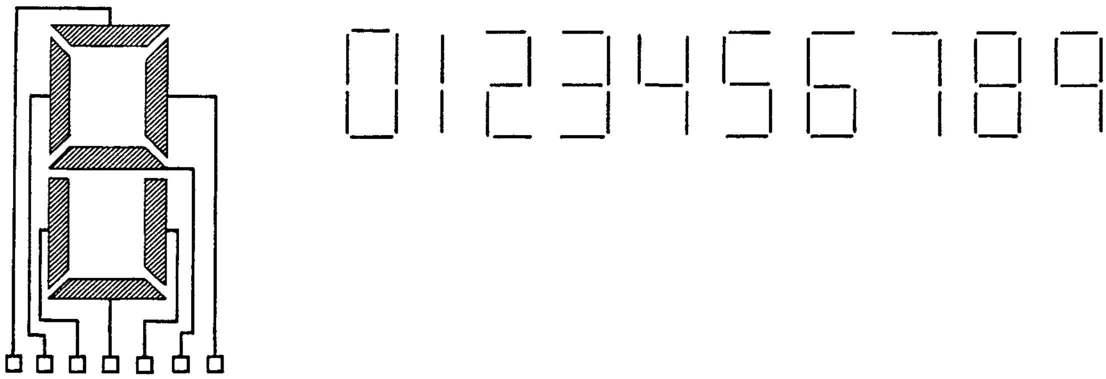


Fig. 4.22 LED used in seven-segment display.

Fig. 4.23 Symbol and appearance of a light-dependent resistor.

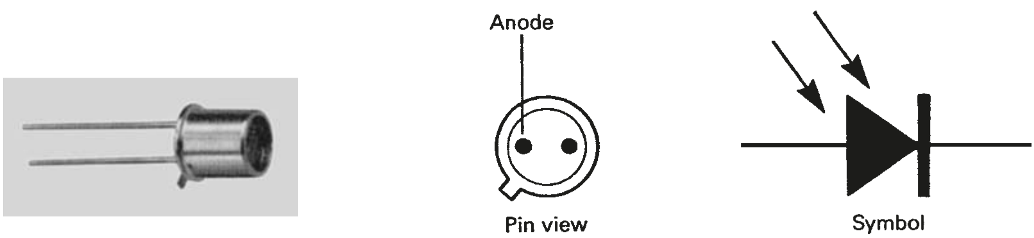


Fig. 4.24 Symbol for, pin connections of and appearance of a photodiode.

darkness is about 10 MΩ, in normal room lighting about 5 kΩ and in bright sunlight about 100 Ω. They can carry tens of milliamperes, an amount which is sufficient to operate a relay. The LDR uses this characteristic to switch on automatically street lighting and security alarms.

PHOTODIODE

The photodiode is a normal junction diode with a transparent window through which light can enter. The circuit symbol and general appearance are shown in Fig. 4.24. It is operated in reverse bias mode and the leakage current increases in proportion to the amount of light falling on the junction. This is due to the light energy breaking bonds in the crystal lattice of the semiconductor material to produce holes and electrons.

Photodiodes will only carry microamperes of current but can operate much more quickly than LDRs and are used as 'fast' counters when the light intensity is changing rapidly.

THERMISTOR

The thermistor is a thermal resistor, a semiconductor device whose resistance varies with temperature. Its circuit symbol and general appearance are shown in Fig. 4.25. They can be supplied in many shapes and

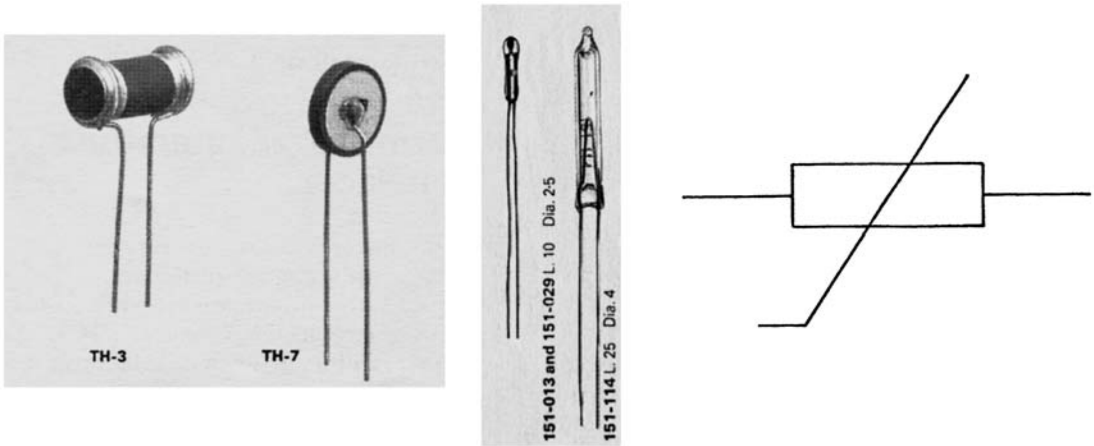


Fig. 4.25 Symbol for and appearance of a thermistor.

are used for the measurement and control of temperature up to their maximum useful temperature limit of about 300°C. They are very sensitive and because the bead of semiconductor material can be made very small, they can measure temperature in the most inaccessible places with very fast response times. Thermistors are embedded in high-voltage underground transmission cables in order to monitor the temperature of the cable. Information about the temperature of a cable allows engineers to load the cables more efficiently. A particular cable can carry a larger load in winter for example, when heat from the cable is being dissipated more efficiently. A thermistor is also used to monitor the water temperature of a motor car.

TRANSISTORS

The transistor has become the most important building block in electronics. It is the modern, miniature, semiconductor equivalent of the thermionic valve and was invented in 1947 by Bardeen, Shockley and Brattain at the Bell Telephone Laboratories in the USA. Transistors are packaged as separate or *discrete* components, as shown in Fig. 4.26.

There are two basic types of transistor, the *bipolar* or junction transistor and the *field-effect transistor* (FET).

The FET has some characteristics which make it a better choice in electronic switches and amplifiers. It uses less power and has a higher resistance and frequency response. It takes up less space than a bipolar transistor and, therefore, more of them can be packed together on a given area of silicon chip. It is, therefore, the FET which is used when many transistors are integrated on to a small area of silicon chip as in the *integrated circuit* (IC) discussed later.

When packaged as a discrete component the FET looks much the same as the bipolar transistor. Its circuit symbol and connections are given in Appendix F.

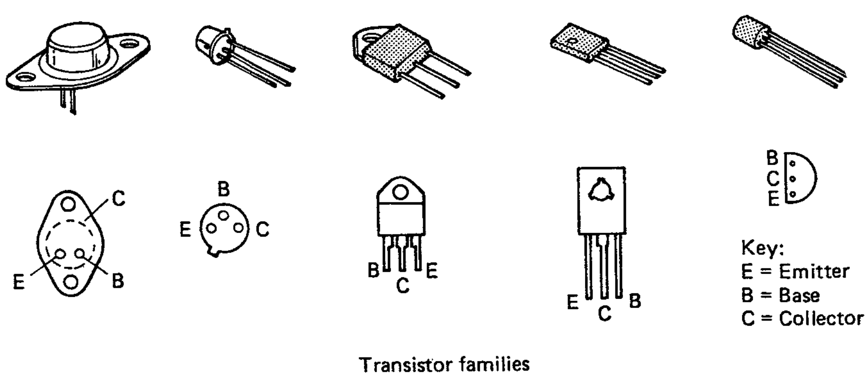


Fig. 4.26 The appearance and pin connections of the transistor family.

However, it is the bipolar transistor which is much more widely used in electronic circuits as a discrete component.

The bipolar transistor

The bipolar transistor consists of three pieces of semiconductor material sandwiched together as shown in Fig. 4.27. The structure of this transistor makes it a three-terminal device having a base, collector and emitter terminal. By varying the current flowing into the base connection a much larger current flowing between collector and emitter can be controlled. Apart from the supply connections, the n-p-n and p-n-p types are essentially the same but the n-p-n type is more common.

A transistor is generally considered a current-operated device. There are two possible current paths through the transistor circuit, shown in Fig. 4.28: the base–emitter path when the switch is closed; and the collector–emitter path. Initially, the positive battery supply is connected to the n-type material of the collector, the junction is reverse biased and, therefore, no current will flow. Closing the switch will forward bias the bass–emitter junction and current flowing through this junction causes current to flow across the collector–emitter junction and the signal lamp will light.

A small base current can cause a much larger collector current to flow. This is called the *current gain* of the transistor, and is typically about 100. When I say a much larger collector current, I mean a large current in electronic terms, up to about half an ampere.

We can, therefore, regard the transistor as operating in two ways: as a switch because the base current turns on and controls the collector current; and as a current amplifier because the collector current is greater than the base current.

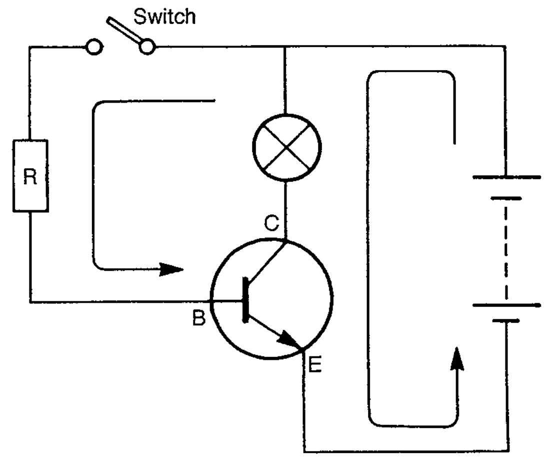


Fig. 4.28 Operation of the transistor.

We could also consider the transistor to be operating in a similar way to a relay. However, transistors have many advantages over electrically operated switches such as relays. They are very small, reliable, have no moving parts and, in particular, they can switch millions of times a second without arcing occurring at the contacts.

Transistor testing

A transistor can be thought of as two diodes connected together and, therefore, a transistor can be tested using an ohmmeter in the same way as was described for the diode.

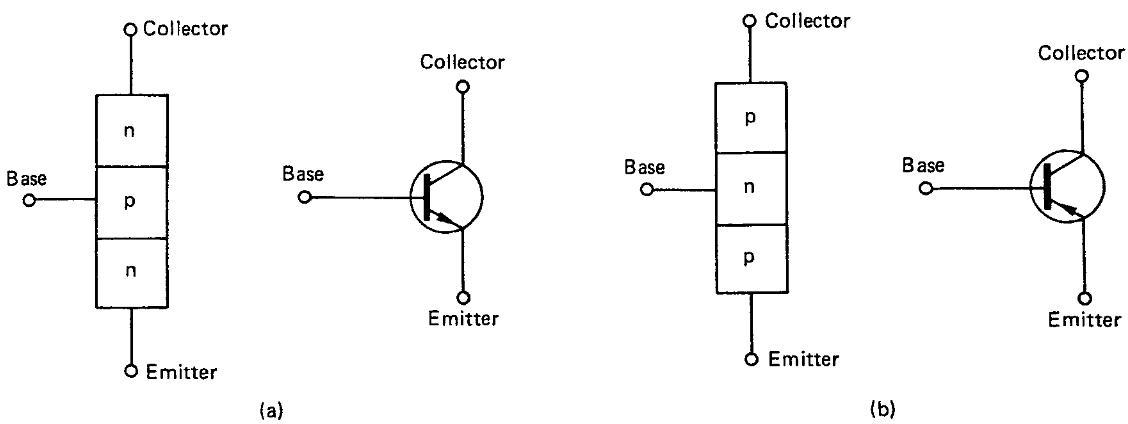


Fig. 4.27 Structure of and symbol for (a) n-p-n and (b) p-n-p transistors.

Table 4.5 Transistor testing using an ohmmeter

A 'good' n-p-n transistor will give the following readings:
Red to base and black to collector = low resistance Red to base and black to emitter = low resistance
Reversed connections on the above terminals will result in a high resistance reading, as will connections of either polarity between the collector and emitter terminals.

A 'good' p-n-p transistor will give the following readings:
Black to base and red to collector = low resistance Black to base and red to emitter = low resistance
Reversed connections on the above terminals will result in a high resistance reading, as will connections of either polarity between the collector and emitter terminals.

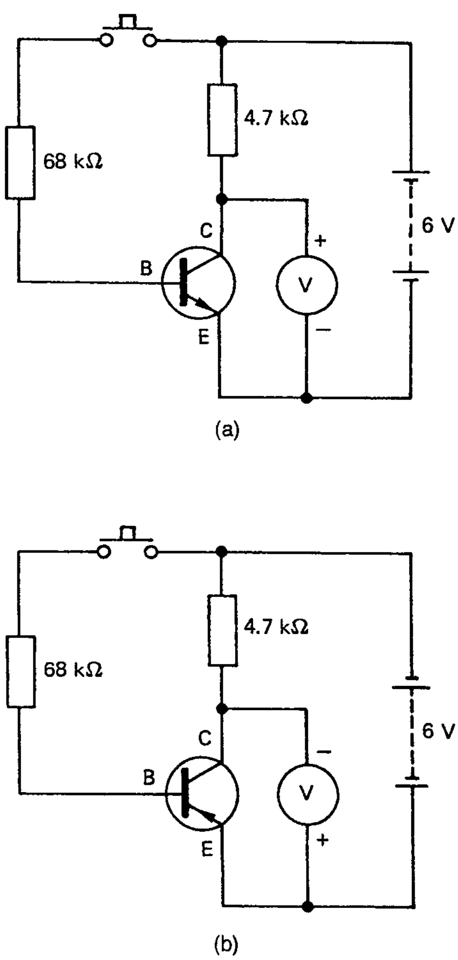


Fig. 4.29 Transistor test circuits (a) n-p-n transistor test; (b) p-n-p transistor test.

Assuming that the red lead of the ohmmeter is positive, as described in Fig. 4.76 the transistor can be tested in accordance with Table 4.5 overpage.

When many transistors are to be tested, a simple test circuit can be assembled as shown in Fig. 4.29.

With the circuit connected, as shown in Fig. 4.29 a 'good' transistor will give readings on the voltmeter of 6 V with the switch open and about 0.5 V when the switch is made. The voltmeter used for the test should have a high internal resistance, about ten times greater than the value of the resistor being tested – in this case 4.7 kΩ – and this is usually indicated on the back of a multirange meter or in the manufacturers' information supplied with a new meter.

INTEGRATED CIRCUITS

Integrated circuits (ICs) were first developed in the 1960s. They are densely populated miniature electronic circuits made up of hundreds and sometimes thousands of microscopically small transistors, resistors, diodes and capacitors, all connected together on a single chip of silicon no bigger than a baby's fingernail. When assembled in a single package, as shown in Fig. 4.30, we call the device an integrated circuit.

There are two broad groups of integrated circuit: digital ICs and linear ICs. Digital ICs contain simple switching-type circuits used for logic control and calculators, discussed at the end of this chapter. Linear ICs incorporate amplifier-type circuits which can respond to audio and radio frequency signals. The most versatile linear IC is the operational amplifier which has applications in electronics, instrumentation and control.

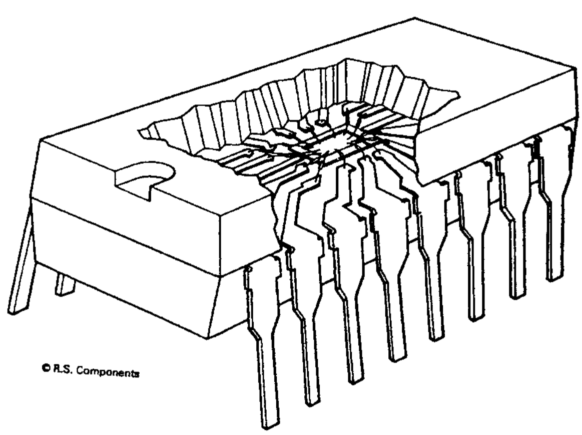


Fig. 4.30 Exploded view of an integrated circuit.

The integrated circuit is an electronic revolution. ICs are more reliable, cheaper and smaller than the same circuit made from discrete or separate transistors, and electronically superior. One IC behaves differently than another because of the arrangement of the transistors within the IC.

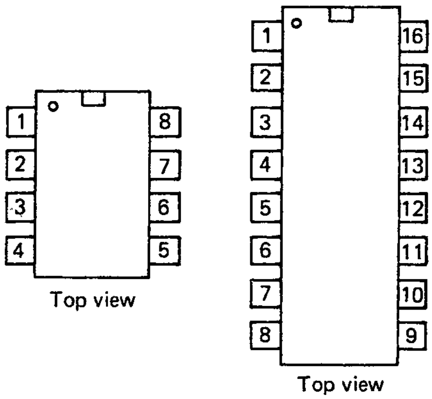


Fig. 4.31 IC pin identification.

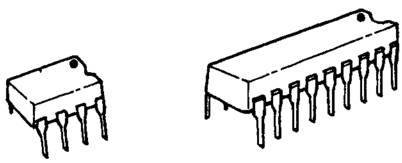


Fig. 4.32 DIL packaged integrated circuits.

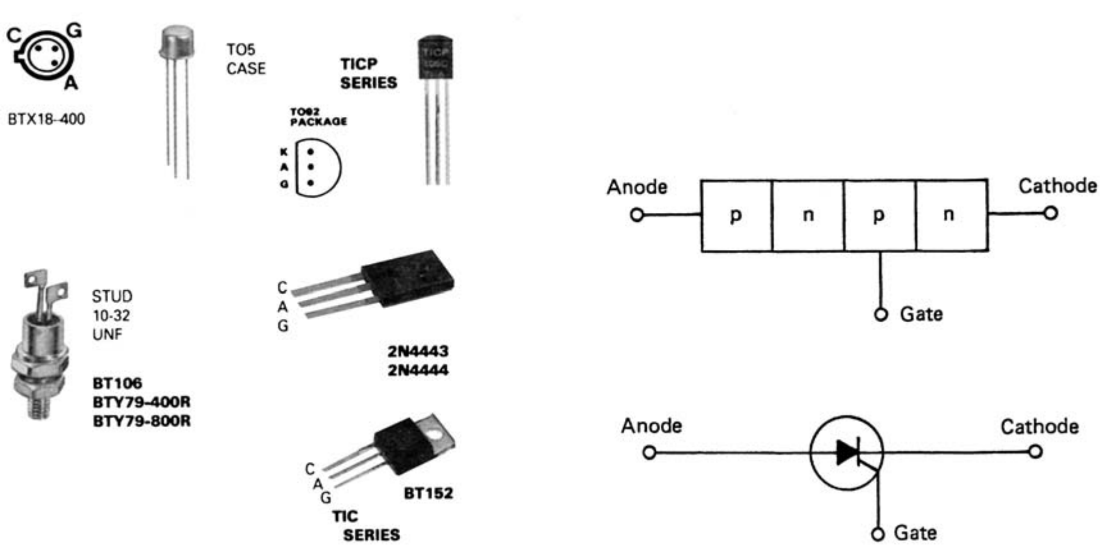


Fig. 4.33 Symbol for and structure and appearance of a thyristor.

Manufacturers' data sheets describe the characteristics of the different ICs, which have a reference number stamped on the top.

When building circuits, it is necessary to be able to identify the IC pin connection by number. The number 1 pin of any IC is indicated by a dot pressed into the encapsulation; it is also the pin to the left of the cutout (Fig. 4.31). Since the packaging of ICs has two rows of pins they are called DIL (dual in-line) packaged integrated circuits and their appearance is shown in Fig. 4.32.

Integrated circuits are sometimes connected into DIL sockets and at other times are soldered directly into the circuit. The testing of ICs is beyond the scope of a practising electrician, and when they are suspected of being faulty an identical or equivalent replacement should be connected into the circuit, ensuring that it is inserted the correct way round, which is indicated by the position of pin number 1 as described earlier.

THE THYRISTOR

The *thyristor* was previously known as a 'silicon controlled rectifier' since it is a rectifier which controls the power to a load. It consists of four pieces of semiconductor material sandwiched together and connected to three terminals, as shown in Fig. 4.33.

The word thyristor is derived from the Greek word *thyra* meaning door, because the thyristor behaves like a door. It can be open or shut, allowing or preventing

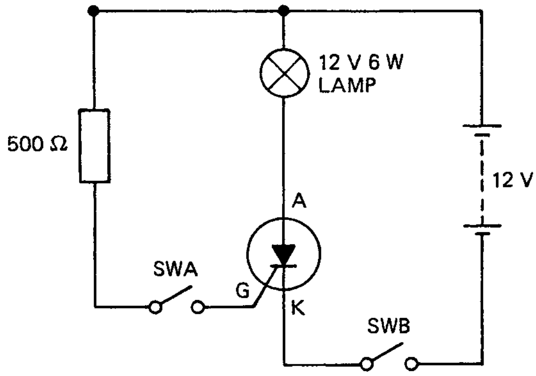


Fig. 4.34 Thyristor test circuit.

current flow through the device. The door is opened – we say the thyristor is triggered – to a conducting state by applying a pulse voltage to the gate connection. Once the thyristor is in the conducting state, the gate loses all control over the devices. The only way to bring the thyristor back to a non-conducting state is to reduce the voltage across the anode and cathode to zero or apply reverse voltage across the anode and cathode.

We can understand the operation of a thyristor by considering the circuit shown in Fig. 4.34. This circuit can also be used to test suspected faulty components.

When SWB only is closed the lamp will not light, but when SWA is also closed, the lamp lights to full brilliance. The lamp will remain illuminated even when SWA is opened. This shows that the thyristor is operating correctly. Once a voltage has been applied to the gate the thyristor becomes forward conducting, like a diode, and the gate loses control.

A thyristor may also be tested using an ohmmeter as described in Table 4.6, assuming that the red lead of the ohmmeter is positive as described in Chapter 12.

The thyristor has no moving parts and operates without arcing. It can operate at extremely high speeds, and the currents used to operate the gate are very small. The most common application for the thyristor is to control the power supply to a load, for example, lighting dimmers and motor speed control.

The power available to an a.c. load can be controlled by allowing current to be supplied to the load during only a part of each cycle. This can be achieved by supplying a gate pulse automatically at a chosen point in each cycle, as shown by Fig. 4.35. Power is reduced by triggering the gate later in the cycle.

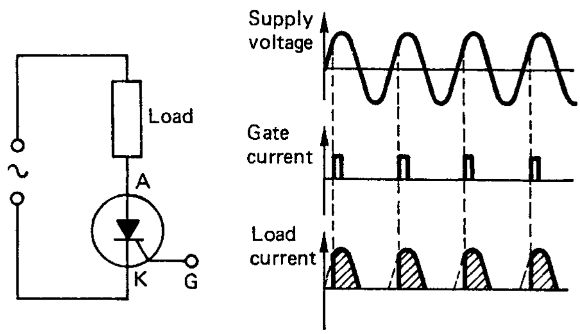


Fig. 4.35 Waveforms to show the control effect of a thyristor.

The thyristor is only a half-wave device (like a diode) allowing control of only half the available power in an a.c. circuit. This is very uneconomical, and a further development of this device has been the triac which is considered next.

Table 4.6 Thyristor testing using an ohmmeter

A 'good' thyristor will give the following readings:
Black to cathode and red on gate = low resistance Red to cathode and black on gate = a higher resistance value
The value of the second reading will depend upon the thyristor, and may vary from only slightly greater to very much greater.
Connecting the test instrument leads from cathode to anode will result in a very high resistance reading, whatever polarity is used.

THE TRIAC

The triac was developed following the practical problems experienced in connecting two thyristors in parallel, to obtain full wave control, and in providing two separate gate pulses to trigger the two devices.

The triac is a single device containing a back-to-back, two-directional thyristor which is triggered on both halves of each cycle of the a.c. supply by the same gate signal. The power available to the load can, therefore, be varied between zero and full load.

Its symbol and general appearance are shown in Fig. 4.36. Power to the load is reduced by triggering the gate later in the cycle, as shown by the waveforms of Fig. 4.37.

The triac is a three-terminal device, just like the thyristor, but the terms anode and cathode have no

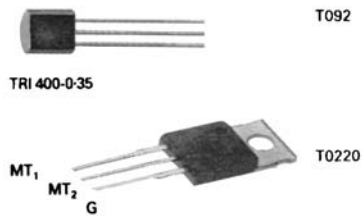
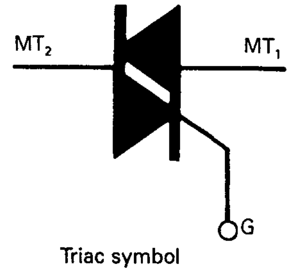


Fig. 4.36 Appearance of a triac.



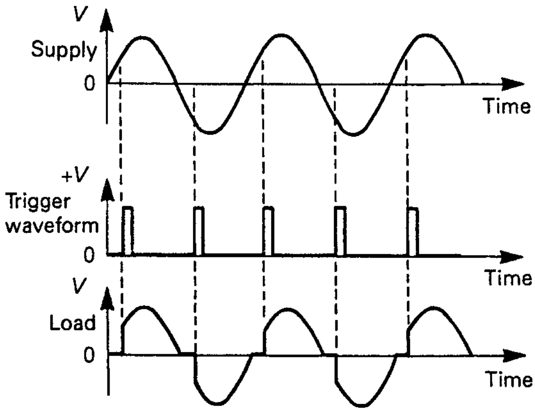


Fig. 4.37 Waveforms to show the control effect of a triac.

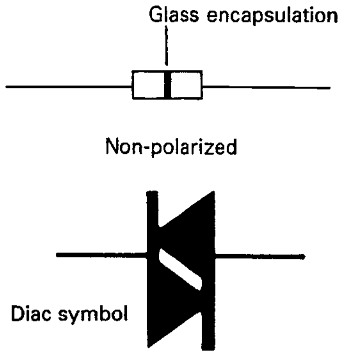


Fig. 4.38 Symbol for and appearance of a diac used in triac firing circuits.

meaning for a triac. Instead, they are called main terminal one (MT_1) and main terminal two (MT_2). The device is triggered by applying a small pulse to the gate (G). A gate current of 50 mA is sufficient to trigger a triac switching up to 100 A. They are used for many commercial applications where control of a.c. power is required, for example, motor speed control and lamp dimming.

THE DIAC

The diac is a two-terminal device containing a two-directional Zener diode. It is used mainly as a trigger device for the thyristor and triac. The symbol is shown in Fig. 4.38.

The device turns on when some predetermined voltage level is reached, say 30 V, and, therefore, it can be used to trigger the gate of a triac or thyristor each time the input waveform reaches this predetermined value. Since the device contains back-to-back Zener diodes it triggers on both the positive and negative half cycles.

Voltage divider

In Chapter 1 we considered the distribution of voltage across resistors connected in series. We found that the supply voltage was divided between the series resistors in proportion to the size of the resistor. If two identical resistors were connected in series across a 12 V supply, as shown in Fig. 4.39(a), both common sense and a simple calculation would confirm that 6 V would be measured across the output. In the circuit shown in Fig. 4.39(b), the 1 and 2 kΩ resistors divide the input voltage into three equal parts. One part, 4 V, will appear across the 1 kΩ resistor and two parts, 8 V, will appear across the 2 kΩ resistor. In Fig. 4.39(c) the situation is reversed and, therefore, the voltmeter will read 4 V. The division of the voltage is proportional to the ratio of the two resistors and, therefore, we call this simple circuit a *voltage divider* or *potential divider*. The values of the resistors R_1 and R_2 determine the output voltage as follows:

$$V_{OUT} = V_{IN} \times \frac{R_2}{R_1 + R_2} \text{ (V)}$$

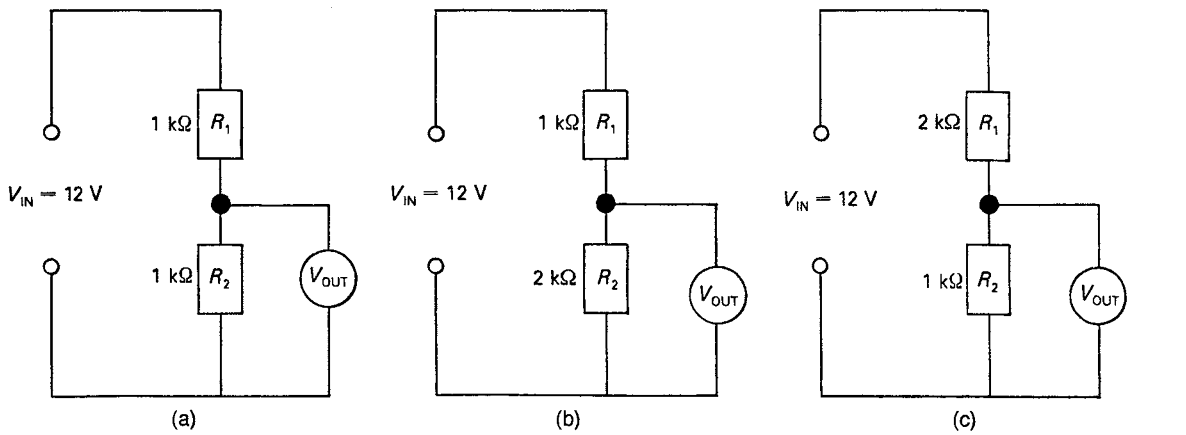


Fig. 4.39 Voltage divider circuit.

For the circuit shown in Fig. 4.39(b),

$$V_{OUT} = 12\text{ V} \times \frac{2\text{ k}\Omega}{1\text{ k}\Omega + 2\text{ k}\Omega} = 8\text{ V}$$

For the circuit shown in Fig. 4.39(c),

$$V_{OUT} = 12\text{V} \times \frac{1\text{ k}\Omega}{2\text{ k}\Omega + 1\text{ k}\Omega} = 4\text{V}$$

EXAMPLE 1

For the circuit shown in Fig. 4.40, calculate the output voltage.

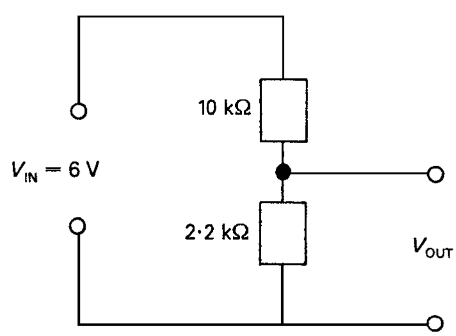


Fig. 4.40 Voltage divider circuit for Example 1.

$$V_{OUT} = 6\text{ V} \times \frac{2.2\text{ k}\Omega}{10\text{ k}\Omega + 2.2\text{ k}\Omega} = 1.08\text{ V}$$

EXAMPLE 2

For the circuit shown in Fig. 4.41(a), calculate the output voltage.

We must first calculate the equivalent resistance of the parallel branch:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_T} = \frac{1}{10\text{ k}\Omega} + \frac{1}{10\text{ k}\Omega} = \frac{1+1}{10\text{ k}\Omega} = \frac{2}{10\text{ k}\Omega}$$

$$R_T = \frac{10\text{ k}\Omega}{2} = 5\text{ k}\Omega$$

The circuit may now be considered as shown in Fig. 4.41(b):

$$V_{OUT} = 6\text{ V} \times \frac{10\text{ k}\Omega}{5\text{ k}\Omega + 10\text{ k}\Omega} = 4\text{ V}$$

Voltage dividers are used in electronic circuits to produce a reference voltage which is suitable for operating transistors and integrated circuits. The volume control in a radio or the brightness control of a cathode-ray oscilloscope requires a continuously variable voltage divider and this can be achieved by connecting a variable resistor or potentiometer, as shown in Fig. 4.42. With the wiper arm making a connection at the bottom of the resistor, the output would be zero. When connection is made at the centre, the voltage would be 6 V, and at the top of the resistor the voltage would be 12 V. The voltage is continuously variable between 0 and 12 V simply by moving the wiper arm of a suitable variable resistor such as those shown in Fig. 4.3.

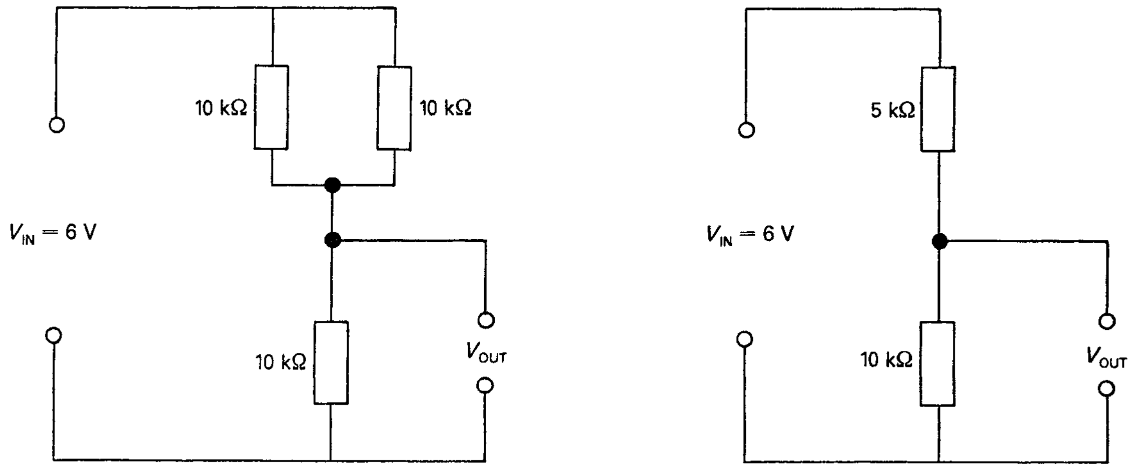


Fig. 4.41 (a) Voltage divider circuit for Example 2; (b) Equivalent circuit for example 2.

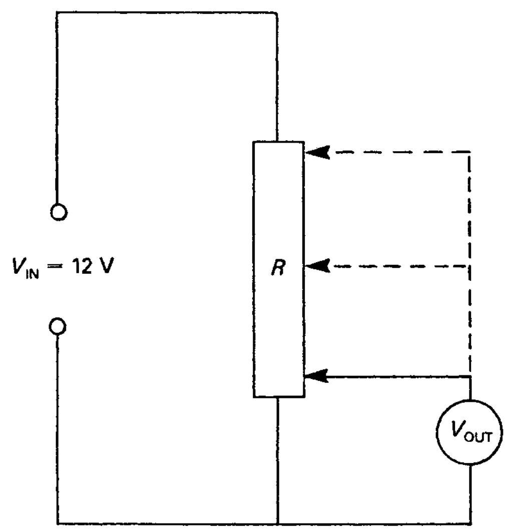


Fig. 4.42 Constantly variable voltage divider circuit.

When a load is connected to a voltage divider it 'loads' the circuit, causing the output voltage to fall below the calculated value. To avoid this, the resistance of the load should be at least ten times as great as the value of the resistor across which it is connected. For example, the load connected across the voltage divider shown in Fig. 4.39(b) must be greater than 20 kΩ and across 4.39(c) greater than 10 kΩ. This problem of loading the circuit also occurs when taking voltage readings, as discussed later in this chapter under the subheading Instrument Errors.

Rectification of a.c.

When a d.c. supply is required, batteries or a rectified a.c. supply can be provided. Batteries have the advantage of portability, but a battery supply is more expensive than using the a.c. mains supply suitably rectified. Rectification is the conversion of an a.c. supply into a unidirectional or d.c. supply. This is one of the many applications for a diode which will conduct in one direction only, that is when the anode is positive with respect to the cathode.

HALF-WAVE RECTIFICATION

The circuit is connected as shown in Fig. 4.43. During the first half cycle the anode is positive with respect to the cathode and, therefore, the diode will conduct. When the supply goes negative during the second half cycle, the anode is negative with respect to the cathode and, therefore, the diode will not allow current to flow. Only the positive half of the waveform will be available at the load and the lamp will light at reduced brightness.

FULL-WAVE RECTIFICATION

Figure 4.44 shows an improved rectifier circuit which makes use of the whole a.c. waveform and is, therefore, known as a full-wave rectifier. When the four diodes

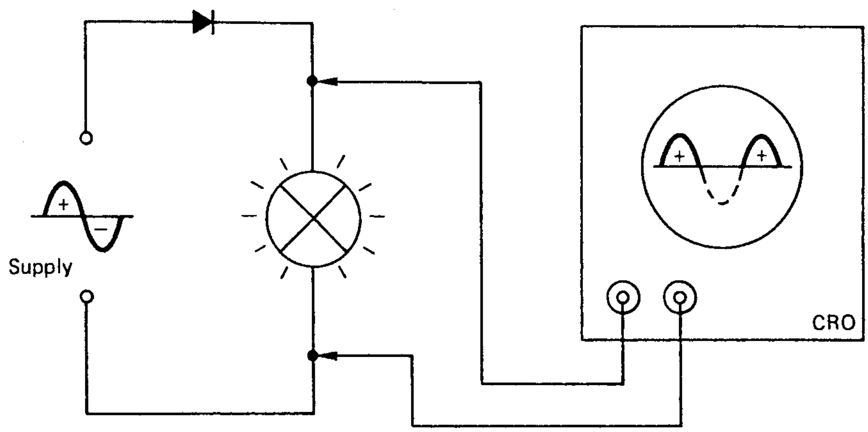


Fig. 4.43 Half-wave rectification.

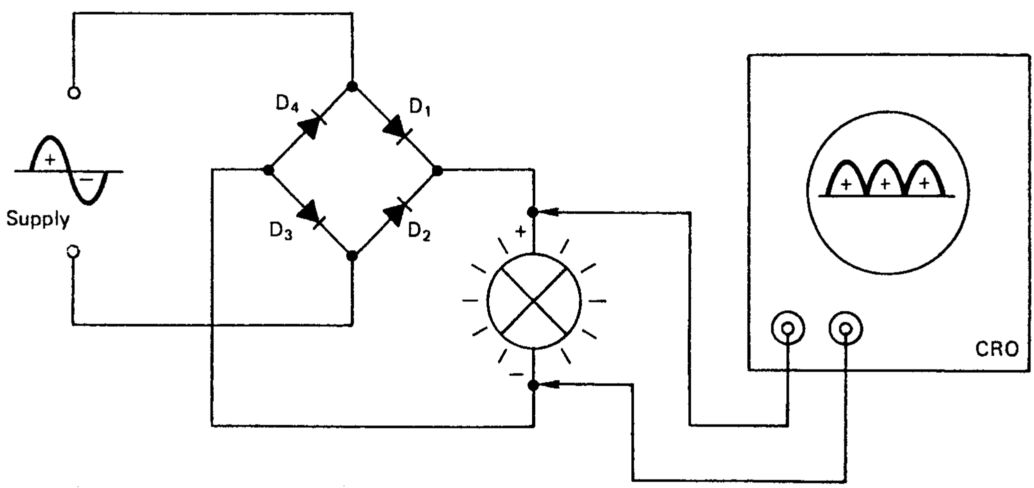


Fig. 4.44 Full-wave rectification using a bridge circuit.

are assembled in this diamond-shaped configuration, the circuit is also known as a *bridge rectifier*. During the first half cycle diodes D_1 and D_3 conduct, and diodes D_2 and D_4 conduct during the second half cycle. The lamp will light to full brightness.

Full-wave and half-wave rectification can be displayed on the screen of a CRO and will appear as shown in Figs 4.43 and 4.44.

Smoothing

The circuits of Figs 4.43 and 4.44 convert an alternating waveform into a waveform which never goes negative, but they cannot be called continuous d.c. because they contain a large alternating component. Such a waveform is too bumpy to be used to supply electronic equipment but may be used for battery charging. To be useful in electronic circuits the output must be smoothed. The simplest way to smooth an output is to connect a large-value capacitor across the output terminals as shown in Fig. 4.45.

When the output from the rectifier is increasing, as shown by the dotted lines of Fig. 4.46, the capacitor charges up. During the second quarter of the cycle, when the output from the rectifier is falling to zero, the capacitor discharges into the load. The output voltage falls until the output from the rectifier once again charges the capacitor. The capacitor connected to the full-wave rectifier circuit is charged up twice as often as the capacitor connected to the half-wave

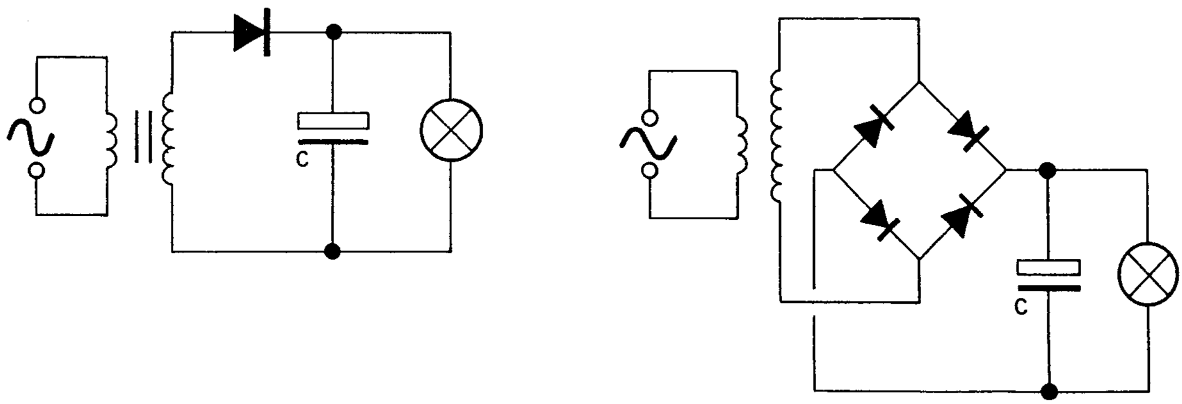


Fig. 4.45 Rectified a.c. with smoothing capacitor connected.

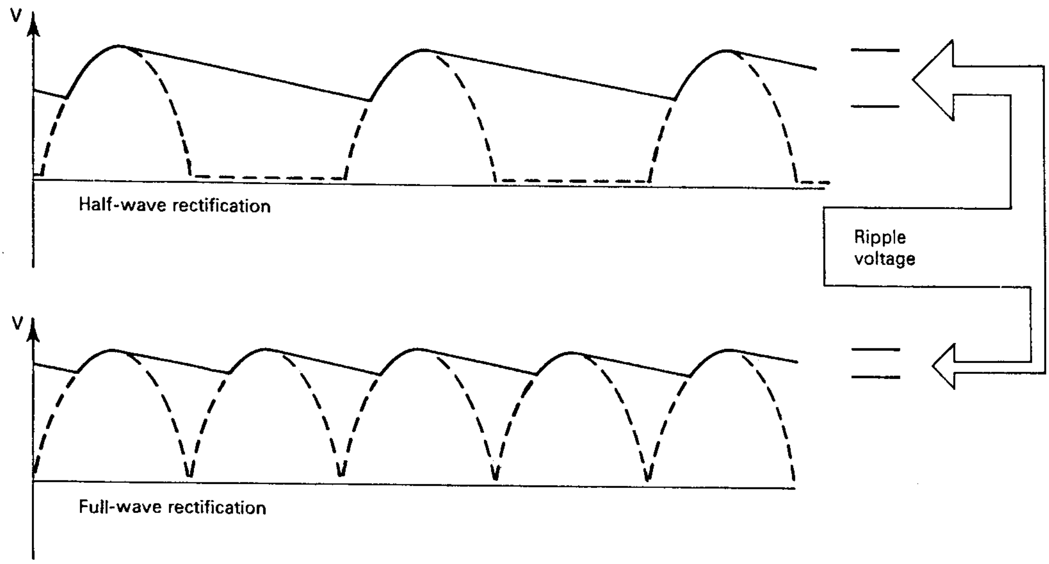


Fig. 4.46 Output waveforms with smoothing showing reduced ripple with full wave.

circuit and, therefore, the output ripple on the full-wave circuit is smaller, giving better smoothing. Increasing the current drawn from the supply increases the size of the ripple. Increasing the size of the capacitor reduces the amount of ripple.

LOW-PASS FILTER

The ripple voltage of the rectified and smoothed circuit shown in Fig. 4.45 can be further reduced by adding a low-pass filter, as shown in Fig. 4.47. A low-pass filter allows low frequencies to pass while blocking higher frequencies. Direct current has a frequency of zero hertz, while the ripple voltage of a full-wave rectifier has a frequency of 100 Hz. Connecting the low-pass filter will allow the d.c. to pass while blocking the ripple voltage, resulting in a smoother output voltage.

The low-pass filter shown in Fig. 4.47 does, however, increase the output resistance, which encourages the voltage to fall as the load current increases. This can be reduced if the resistor is replaced by a choke, which has a high impedance to the ripple voltage but a low resistance, which reduces the output ripple without increasing the output resistance.

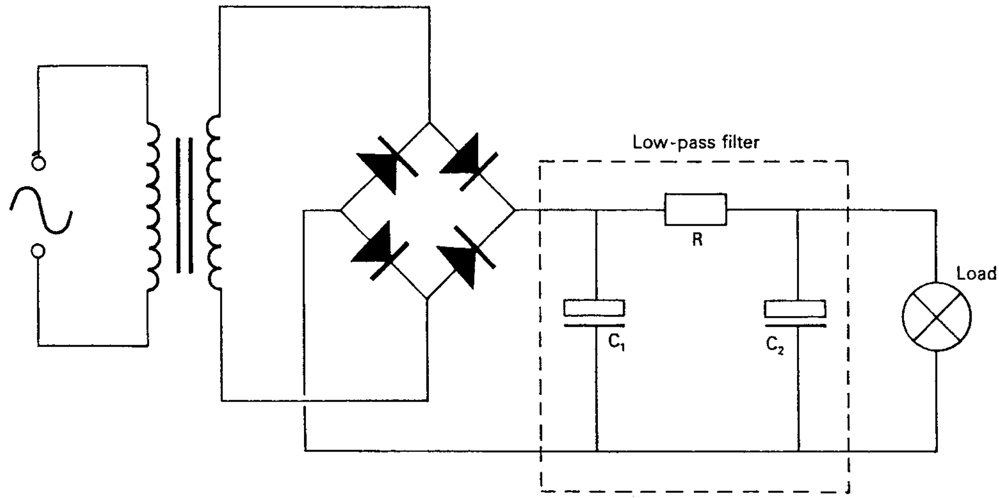


Fig. 4.47 Rectified a.c.with low-pass filter connected.

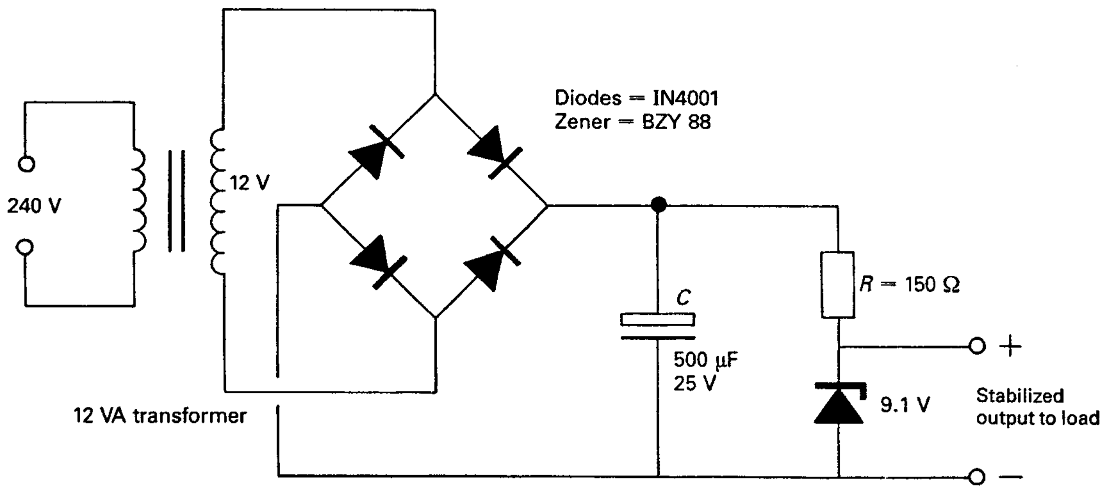


Fig. 4.48 Stabilized d.c. supply.

Stabilized power supplies

The power supplies required for electronic circuits must be ripple-free, stabilized and have good regulation, that is the voltage must not change in value over the whole load range. A number of stabilizing circuits are available which, when connected across the output of the circuit shown in Fig. 4.45, give a constant or stabilized voltage output. These circuits use the characteristics of the Zener diode which was described by the experiment in Fig. 4.19.

Figure 4.48 shows an a.c. supply which has been rectified, smoothed and stabilized. You could build and test this circuit using the circuit assembly and testing skills described next in this chapter.

Electronic Circuit Assembly

To get a 'feel' for electronics you should take the opportunity to build some of the simple circuits described up to now in this chapter using the constructional methods which will be considered now. Practical electronics can be carried out with very few tools and limited resources. A kitchen table, suitably protected, or a small corner of the electrical workshop is all that is required. The place chosen should be well lit, have a flat and dry area of about 1 m × 1 m and have access to a three-pin socket.

Working with others can also be a valuable source of inspiration and encouragement. Many technical colleges and evening institutes offer basic electronics courses which give someone new to electronics courses which give someone new to electronics an opportunity to use the tools and equipment under guidance and at little cost. The City and Guilds of London offer many electronics examinations which are particularly suitable for electricians and those in the electrotechnical industries who require a formal qualification in electronics.

Safety precautions

Electricity can be dangerous. It can give a serious shock and it does cause fires. For maximum safety, the sockets being used for the electronic test and assembly should be supplied by a residual current circuit breaker. These sense fault currents as low as 30 mA so that a faulty circuit or piece of equipment can be isolated before the lethal limit to human beings of about 50 mA is reached. Plug-in RCDs of the type shown in Fig. 4.49 can now be bought very cheaply from any good electrical supplier or DIY outlet. All equipment should be earthed and fitted with a 2 A or 5 A fuse, which is adequate for most electronics equipment. Larger fuses reduce the level of protection.

Fig. 4.49 A plug-in RCD for safe electrical assembly.

Another source of danger in electronic assembly is the hot soldering iron, which may cause burns or even start a fire. The soldering iron should always be placed in a soldering iron stand when not being used. The chances of causing a fire or burning yourself can be reduced by storing the soldering iron in its stand at the back of the workspace so that you do not have to lean over it when working.

So far we have been discussing the sensible safety precautions which everyone working with electricity should take. However, you or someone else in your workplace may receive an electric shock and Chapter 1 offers some guidance under the sub-heading First Aid.

Hand-tools

Tools extend the physical capabilities of the human body. Good-quality, sharp tools are important to any craftsman. An electrician or electronic service engineer is no less a craftsman than a wood carver. Each must work with a high degree of skill and expertise and each must have sympathy and respect for the materials which they use. The basic tools required by anyone working with electrical equipment are those used to strip, cut and connect conductors and components. The tools required for successful electronic assembly are wire strippers, diagonal cutters or snips, long-nose pliers and ordinary or combination pliers (Fig. 4.50). Electricians and those in the electrotechnical industries have traditionally chosen insulated hand-tools.

Soldering irons and guns

An electric soldering iron with the correct-size bit is essential for making good-quality, permanent connections in electronic circuits. A soldering iron consists of a heat-insulated handle, supporting a heating element of between 15 and 25 W. The bit is inserted into this element and heats up to a temperature of about 210°C by conduction. Various sizes of bits are available and they are interchangeable.

Copper bits can be filed clean or rubbed with emery cloth until the tip is a bright copper colour. *Ironclad* bits must *not* be cleaned with a file or emery cloth but should be rubbed clean when they are hot, using a damp cloth or wet sponge.

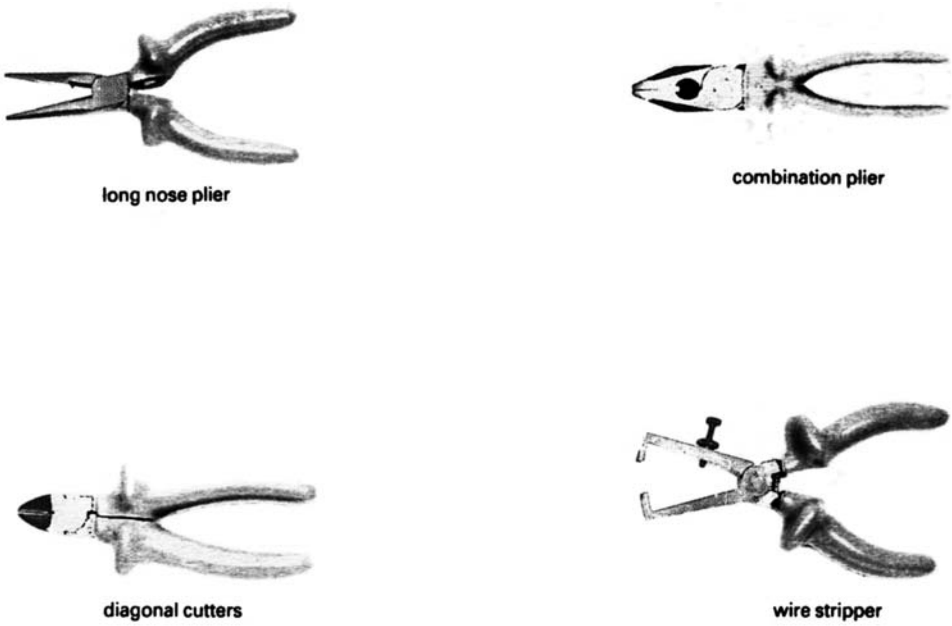


Fig. 4.50 Basic tools required for electronic assembly.

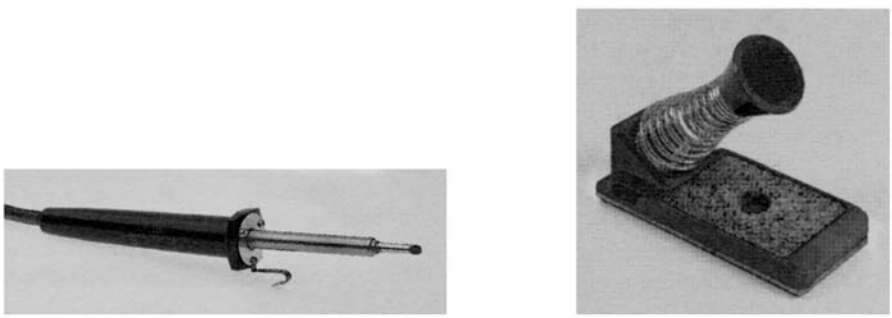


Fig. 4.51 Electronic soldering iron and stand.

Before the soldering iron can be used to make electrical connections, the bit must be *tinned* as follows:

- First, clean the bit as described above.
- Plug in the soldering iron and allow it to heat up.
- Apply cored solder to the clean hot bit.
- Wipe off the excess solder with a damp cloth or damp sponge.

This will leave the soldering iron brightly 'tinned' and ready to be used. Figure 4.51 shows a 230 V general-purpose soldering iron and stand suitable for use in electronic assembly.

Soldering guns of the type shown in Fig. 4.52 are trigger-operated soldering irons. Within 10 seconds of pressing the trigger the bit is at the working temperature of 315°C. The working temperature can be

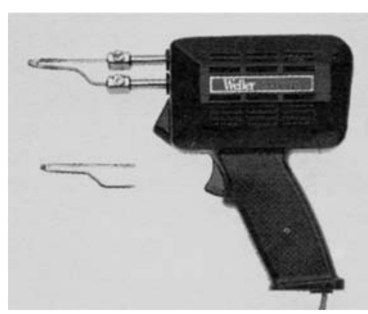


Fig. 4.52 Instant soldering gun.

arrived at even more quickly with constant use. The plastic case holds a 230 V transformer having an isolated low-voltage high-current secondary circuit which is completed by the copper soldering bit. The bits are interchangeable and should be tinned and used in the same way as the general-purpose iron considered above.

Butane gas-powered soldering irons are also available. In appearance they are very similar to the general-purpose soldering iron shown in Fig. 4.51, but without the mains cable. The handle acts as the fuel tank, various sizes of soldering bits are available and a protective cap is supplied to cover the hot end of the tool when not in use. The advantage of a gas soldering iron is that it can be used when a mains supply is not easily available.

The final choice of soldering iron will be influenced by many factors, frequency of use, where used, personal preference and cost. In 2004 the relevant costs were approximately £13 for the general-purpose iron, £30 for the soldering gun, £65 for the gas soldering iron and about £250 for a low-voltage temperature-controlled iron.

Soldering

There are many ways of making suitable electrical connections and in electrical installation work a screwed terminal is the most common method. In electronics, the most common method of making permanent connections is by soldering the components into the circuit. Good soldering can only be achieved by effort and practice and you should, therefore, take the opportunity to practise the technique before committing your skills to the 'real' situation.

Soldering is an alloying process, whereby a small amount of soft metal (the solder) is made to run between the two metals to be joined, therefore mixing or alloying them. Solder can be used to join practically any metals or alloys except those containing large amounts of chromium or aluminium, which must be welded or hard-soldered.

SOFT SOLDERS

Soft solders are so called because they are made up of the rather soft metals tin and lead in the proportion 40 to 60. Solders containing tin will adhere very firmly to most metals, providing that the surfaces of the metals to be joined are clean. Solder will not adhere to a tarnished or oxidized metal surface. This is because solder adheres by forming an alloy with the metal of the connection and this alloy cannot form if there is a film of oxide in the way.

FLUXES

Fluxes are slightly acid materials which dissolve an oxide film, leaving a perfectly clean surface to which the solder can firmly adhere. There are two types of flux in common use – salt flux and rosin flux. Salt fluxes are rather corrosive and are therefore used when joining iron, steel, nickel and stainless steel, which oxidize easily when hot. Rosin fluxes are less corrosive, and, when used in the form of a sticky paste, are the preferred fluxes for soldering tin, copper and brass; they are thus the most suitable for electrical and electronic work. In electronics it is not convenient to apply the flux and solder separately, so they are combined as flux-cored solder wire. This is solder wire with a number of cores of flux running the whole length of the wire. The multicore construction shown in Fig. 4.53 ensures the correct proportions of flux for each soldered joint.

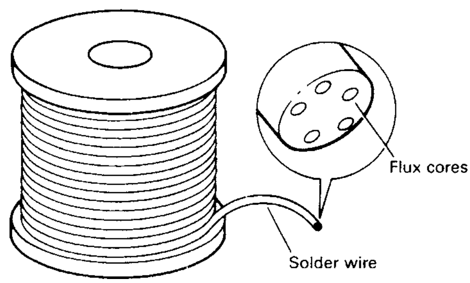


Fig. 4.53 Construction of flux-cored solder wire.

SOLDERING TECHNIQUES

As already mentioned, when soldering with an iron it is important to choose an iron with a suitable bit size. A 1.5 or 2.0 mm bit is suitable for most electronic connections, but a 1.0 mm bit is better when soldering dual-in-line IC packages. The bit should be clean and freshly 'tinned'. The materials to be soldered must be free from grease and preferably pretinned. Electronic

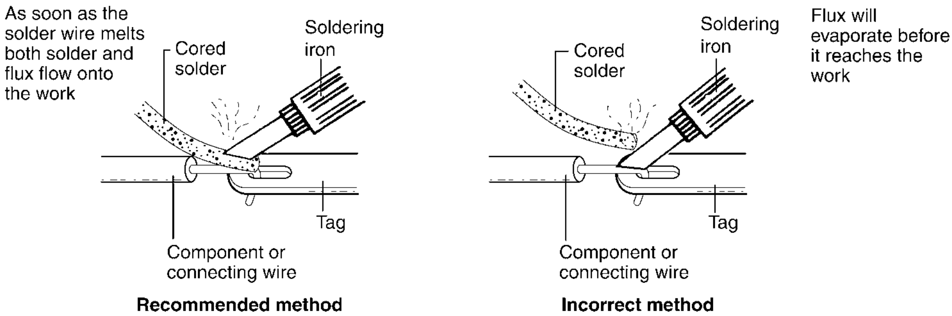


Fig. 4.54 Soldering technique with multicore solders.

components should not need more cleaning than a wipe to remove dust or grease. The purpose of the soldering iron is to apply heat to the joint. If solder is first melted on to the bit, which is then used to transfer the solder to the joint, the active components of the flux will evaporate before the solder reaches the joint, and an imperfect or 'dry' joint will result. Also applying the iron directly to the joint oxidizes the component surfaces, making them more difficult to solder effectively. The best method of making a 'good' soldered joint is to apply the cored solder to the joint and then melt the solder with the iron. This is the most efficient way of heating the termination, letting the solder and the flux carry the heat from the soldering bit on to the termination, as shown in Fig. 4.54.

While the termination is heating up, the solder will appear dull, and then quite suddenly the solder will become bright and fluid, flowing around and 'wetting' the termination. Apply enough solder to cover the termination before removing the solder and then the iron. The joint should be soldered quickly. If attempts are made to improve the joint merely by continued heating and applying more flux and solder, the component or the cable insulation will become damaged by the heat and the connection will have excessive solder on it. The joint must not be moved or blown upon until the solder has solidified. A good soldered joint will appear smooth and bright, a bad connection or *dry joint* will appear dull and the solder may be in a 'blob' or appear spiky.

Dry joints

Dry joints may occur because the components or termination are dirty or oxidized, or because the soldering temperature was too low, or too little flux was used.

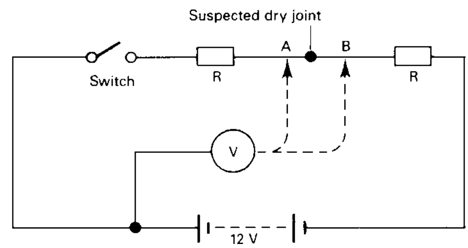


Fig. 4.55 Testing a suspected dry joint.

Dry joints do not always make an electrical connection, or the connection will have a high resistance which deteriorates with time and may cause trouble days or weeks later. A suspected dry joint can be tested as shown in Fig. 4.55. If the joint is dry the voltmeter will read 12 V at position B, just to the right of the joint, and 0 V at position A, to the left. If the joint is found to be dry, the connection must be remade.

COMPONENT ASSEMBLY AND SOLDERING

Soft solder is not as strong as other metals and, therefore, the electronic components must be shaped at the connection site to give extra strength. This can be done by bending the connecting wires so that they hook together or by making the joint area large. Special *lead-forming* or *wire-shaping* tools are available which both cut and shape the components' connecting wires ready for soldering. Figure 4.56 shows a suitable tag terminal connection, Fig. 4.57 a suitable pin terminal connection and Fig. 4.58 a suitable stripboard connection.

All wires must be cut to length before assembly because it is often difficult to trim them after soldering. Also the strain of cutting after soldering may weaken the joint and encourage dry joints. If the wires must be

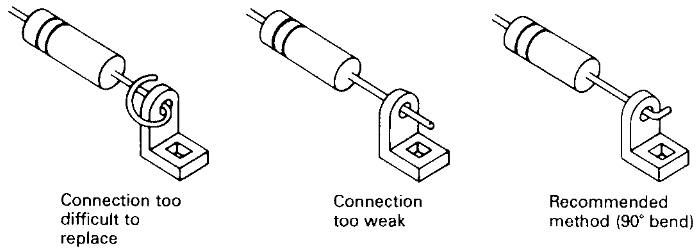


Fig. 4.56 Shaping conductors to give strength to electrical connections to tag terminals.

cut after soldering, cutters with a shearing action should be used, as shown in Fig. 4.59. Side cutters have a pinching action and the shock of the final pinch-through, identified by a sharp click, may fracture the soldered joint or damage the component.

Most electronic components are very sensitive and are easily damaged by excess heat. Soldered joints must not, therefore, be made close to the body of the component or the heat transferred from the joint may cause some damage. When components are being soldered into a circuit the heat from the soldering iron at the connection must be diverted or 'shunted' away from the body of the component. This can be done by placing a pair of long-nosed pliers or a crocodile clip

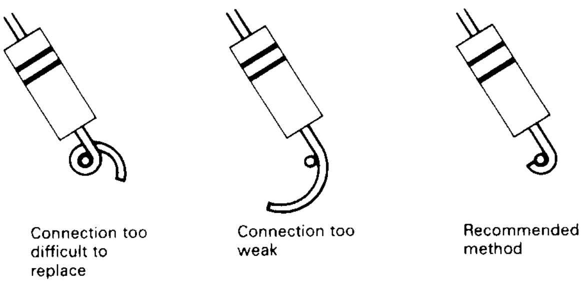


Fig. 4.57 Shaping conductors to give strength to electrical connections to pin terminals (plan view).

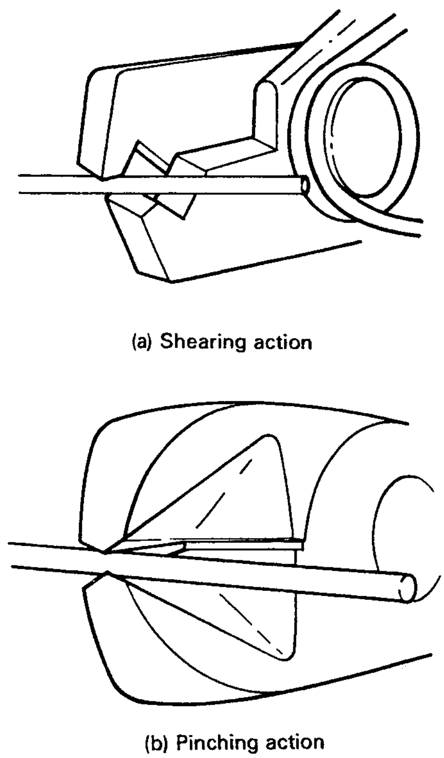


Fig. 4.59 Wire cutting.

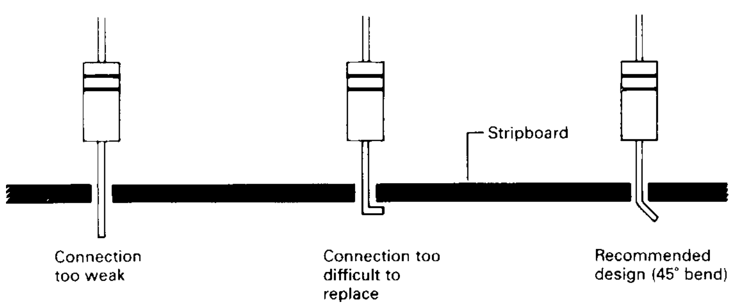


Fig. 4.58 Shaping conductors to give strength to electrical connections to stripboard.

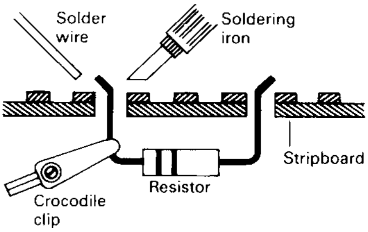


Fig. 4.60 Using a crocodile clip as a heat shunt.

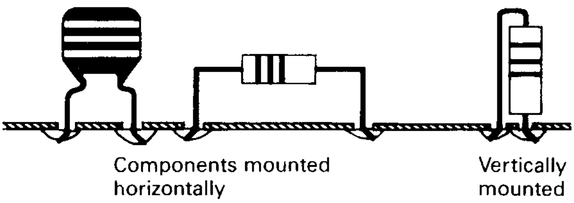


Fig. 4.61 Vertical and horizontal mounting of components.

between the soldered joint and the body of the component, as shown in Fig. 4.60.

Components such as resistors, capacitors and transistors are usually cylindrical, rectangular or disc-shaped, with round wire terminations. They should be shaped, mounted and soldered into the circuit as previously described and shown in Fig. 4.61. A small clearance should be left between the body of the component and the circuit board, to allow convection currents to circulate, which encourages cooling. The vertical mounting method permits many more components to be mounted on the circuit board but the horizontal method gives better mechanical support to the component.

Desoldering

If it is necessary to replace an electronic component, the old, faulty component must first be removed from the circuit board. To do this the solder of the old joint is first liquefied by applying a hot iron to the joint. The molten solder is then removed from the joint with a desoldering tool. The desoldering tool works like a bicycle pump in reverse and is shown in Fig. 4.62. The tool is made ready by compressing the piston down on to a latch position which holds it closed. The nozzle is then placed into the pool of molten solder and the latch release button pressed.

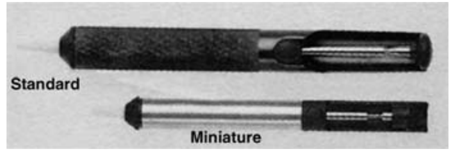


Fig. 4.62 A desoldering tool.

This releases the plunger which shoots out, sucking the molten solder away from the joint and into the body of the desoldering tool.

REMOVING FAULTY TRANSISTORS

First identify the base, collector and emitter connections so that the new component can be correctly connected into the circuit. Remove the solder from each leg with the soldering iron and desoldering tool before removing the faulty transistor. Then, with the aid of a pair of long-nosed pliers, pull the legs of the transistor out of the circuit board. An alternative method is to cut the three legs with a pair of side cutters before desoldering and then remove the individual legs with a pair of long-nosed pliers.

REMOVING FAULTY INTEGRATED CIRCUITS (CHIPS)

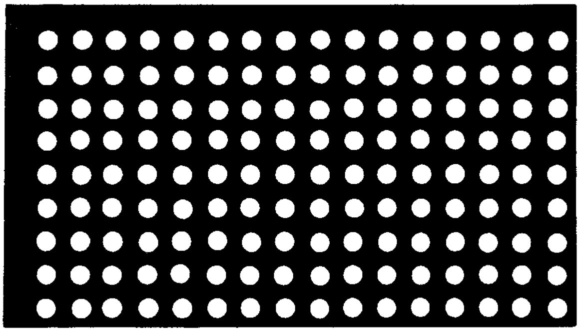
Remove the solder from each leg of the IC with the soldering iron and desoldering tool and then pull the IC clear of the circuit board. If it has been firmly established that the IC is faulty, it may be removed from the circuit board by cutting the body from the connecting pins before desoldering and removing the individual pins with a pair of long-nosed pliers.

Circuit boards

Permanent circuits require that various discrete components be soldered together on some type of insulated board. Three types of board can be used – matrix, strip and printed circuit board – the base material being synthetic resin bonded paper (SRBP).

MATRIX BOARDS

Matrix boards have a matrix of holes on 0.1 inch centres as shown in Fig. 4.63. Boards are available in



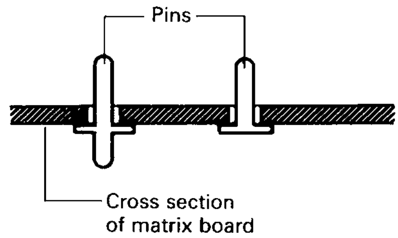
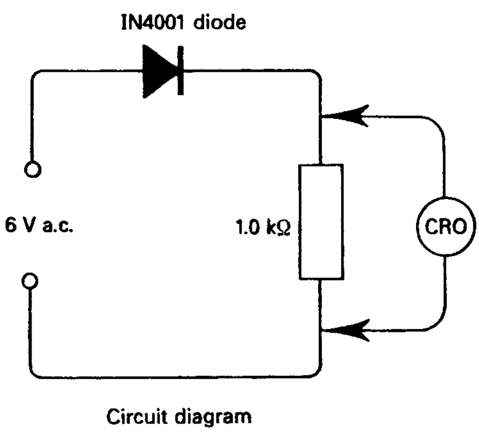


Fig. 4.63 Matrix board and double-sided and single-sided pin inserts.

various sizes: the 149 × 114 mm board is pierced with 58 × 42 holes and the 104 × 65 mm board has 39 × 25 holes. Matrix pins press into any of the holes in the board and provide a terminal post to which components and connecting wires can be soldered. Single-sided or double-sided matrix pins are available. Double-sided pins have the advantage that connections can be made on the underside of the board as well as on the top. The hole spacing of 0.1 inch makes the board compatible with many electronic components. Plug-in relays, DIL integrated circuits and many sockets and connectors all use 0.1 inch spacing at their connections.

Matrix board is probably the easiest and cheapest way to build simple electronic circuits. It is recommended that inexperienced circuit builders construct the circuit on the matrix board using a layout which is very similar to the circuit diagram to reduce the possibility of mistakes.

Suppose, for example, that we intend to build the very simple circuit shown in Fig. 4.64. First we would insert four pins into the matrix board as shown. The diode would then be connected between pins A and B, taking care that the anode was connected to pin A. The resistor would be connected between pins B and C and a wire linked between pins C and D. The a.c. supply from a signal generator would be connected to pins A and D by 'flying' leads and the oscilloscope leads to pins B and C. This circuit would show half-wave rectification. When planning the conversion of circuit diagrams into a matrix board layout it helps to have a positional reference system so that we know where to push the pins in the matrix board.



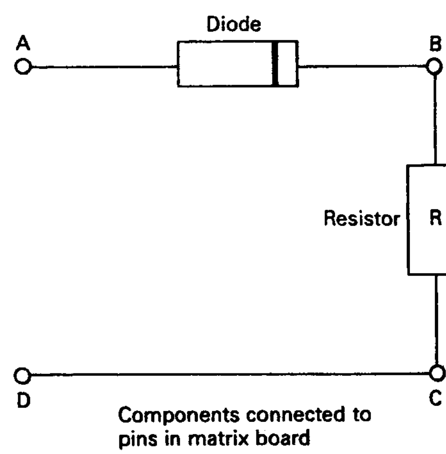


Fig. 4.64 Circuit diagram converted to a component layout.

The positional reference system

The positional reference system used with matrix boards uses a simple grid reference system to identify holes on the board. This is achieved by counting along the columns at the top of the board, starting from the left and then counting down the rows. For example, the position reference point 4:3 would be 4 holes from the left and 3 holes down. The board should be prepared as follows:

- Turn the matrix board so that a manufactured straight edge is to the top and left-hand side.
- Use a felt tip pen to mark the holes in groups of five along the top edge and down the left-hand edge as shown in Fig. 4.65.

The pins can then be inserted as required. Figure 4.65 shows a number of pin reference points. Counting from the left-hand side of the board there are 3:3, 3:16, 10:11, 18:3, 18:11, 25:3 and 25:16.

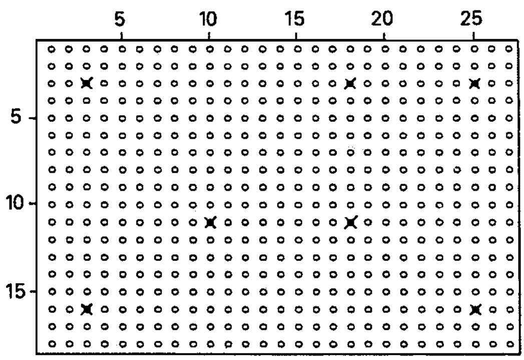


Fig. 4.65 Matrix board pin reference system.

STRIPBOARD OR VEROBOARD

Stripboard or Veroboard is a matrix board with a continuous copper strip attached to one side by adhesive. The copper strip links together rows of holes so that connections can be made between components inserted into holes on a particular row, as shown in Fig. 4.66. The components are assembled on the plain board side with the component leads inserted through the holes and soldered in place to the copper strip.

The copper strips are continuous but they can be broken using a strip cutter or small drill. The drill or cutter is placed on the hole where the break is to be made and then rotated a few turns between the fingers until the very thin copper strip is removed leaving a circle, as shown in Fig. 4.66.

Stripboard is very useful because the copper strips take the place of the wire links required with plain matrix boards. Components can easily be mounted vertically on stripboard, which leads to high-density small-area circuits being assembled. It is, however, more expensive than matrix board because of the additional cost of the copper, most of which is not used in the circuit. Also some translation of the circuit diagram is required before it can be assembled on the stripboard. Excessive heat from the soldering iron can melt the adhesive and cause the copper to peel from the insulating board. Heat should only be applied long enough to melt the solder and secure the component.

PRINTED CIRCUIT BOARDS

Printed circuit boards (PCBs) are produced by chemically etching a copper-clad epoxy glass board so that a copper pattern is engraved on one side of the board. The pattern provides the copper conducting paths

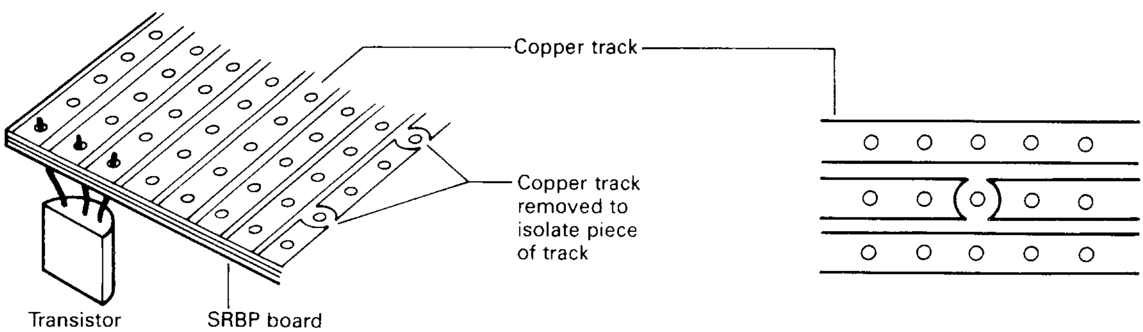


Fig. 4.66 Stripboard or Veroboard.

making connections to the various components of the circuit. After etching, small holes are drilled for the components which are inserted from the plain side of the board and soldered on to the copper conductor. The copper pattern replaces the lengths of wire used to connect components on to the matrix board.

The copper foil is very thin and is attached to the board with an adhesive. Excessive heat from the soldering iron can melt the adhesive and cause the track to peel from the insulating board. The board should not be flexed, otherwise hairline cracks may appear but go unnoticed until intermittent faults occur in the circuit later.

The process of designing and making a PCB is quite simple but does require specialized equipment, and for that reason we will not consider it further here.

Breadboards

Breadboarding is the name given to solderless temporary circuit building by pressing wires and component leads into holes in the prototype board. This method is used for building temporary circuits for testing or investigation.

THE S-DEC

The S-DeC prototype board is designed for interconnecting discrete components. The hole spacing and hole connections do not suit DIL IC packages. Each board has 70 phosphor-bronze contact points arranged in two sections, each of which has seven parallel rows of five connected contact points. The case is formed in high-impact polystyrene and the individual boards may be interlocked to create a larger working area. The S-DeC can be supplied with a vertical bracket for mounting switches or variable resistors, as shown in Fig. 4.67.

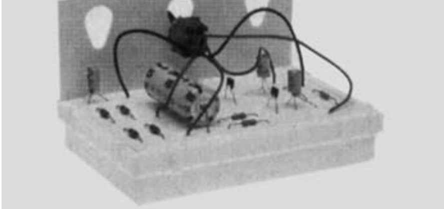


Fig. 4.67 S-DeC prototype board used for temporary circuit building.

THE PROFESSIONAL

The professional prototype board is designed for the interconnection of many different types of component. The hole spacing of 0.1 inch allows DIL IC packages to be plugged directly into the board. Each board has 47 rows of five interconnected nickel–silver contacts each side of a central channel and a continuous row at the top and bottom which may be used as power supply rails. The case is formed in high-impact thermoplastic and the individual boards may be interlocked to create a larger working area. A vertical side bracket is also supplied for mounting switches or variable resistors, as shown in Fig. 4.68.

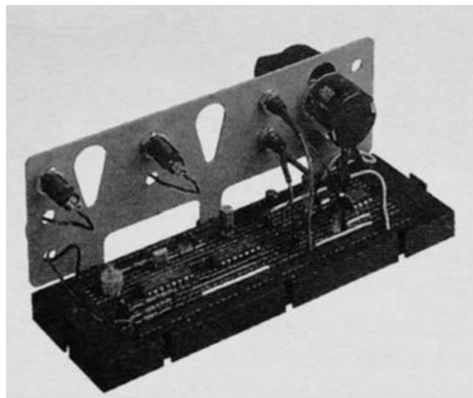


Fig. 4.68 Professional prototype board used for temporary circuit building.

Interconnection methods

A plug and socket provide an ideal method of connecting or isolating components and equipment which cannot be permanently connected. In electrical installation work we usually need to make plug and socket connections between three conductors on single-phase circuits and five conductors on three-phase systems. In electronics we often need to make multiple connections between circuit boards or equipment. However, the same principles apply, that is, the plug and socket must be capable of separation, but while connected they must make a good electrical contact. Also the plug and socket must incorporate some method of preventing reverse connection.

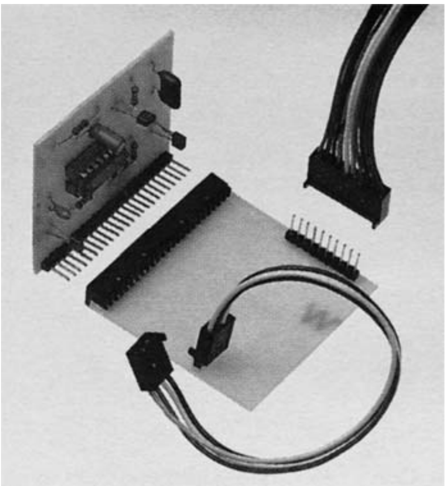


Fig. 4.69 PCB edge connectors.

PCB EDGE CONNECTORS

A range of connectors are available which make direct contact to printed circuit boards, as shown in Fig. 4.69. Multiple connectors are available with a contact pitch of 0.1 inch so that they can be soldered into circuit boards. The plug and socket can then be used as edge connectors to make board-to-board and cable-to-board connections.

RIBBON CABLE CONNECTORS

A ribbon cable is a multicore cable laid out as flat strip or ribbon strip. A range of connectors is made to connect ribbon cable, as shown in Fig. 4.70, which is used for making board-to-board interconnections and to connect computer peripherals such as VDUs and printers.

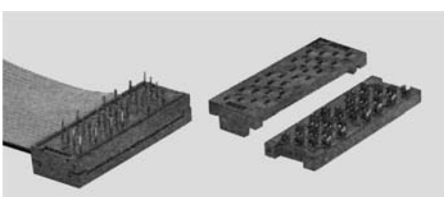


Fig. 4.70 Ribbon cable connector.

DIN CONNECTORS

DIN-style audio connectors are available for making up to eight connections, as shown in Fig. 4.71, and used when frequent connection and disconnection is required between a small number of contacts.

Fig. 4.71 DIN-style audio connectors.

JACK CONNECTORS

Jack connectors are used when frequent connections are to be made between two or three poles on, for example, headphones or microphones. They are available in three sizes: subminiature (2.5 mm), miniature (3.5 mm) and commercial (0.25 inch). Examples are shown in Fig. 4.72.

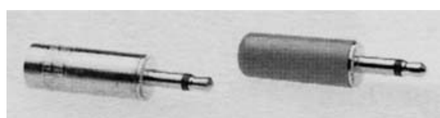


Fig. 4.72 Jack connectors.

All the above connectors may be terminated on to the cable end by a soldered, crimped or cable displacement method. When a soldered connection is to be made the cable end must be stripped of its insulation, tinned and then terminated. A crimped connection also requires that the insulation be removed and the prepared cable end inserted into a lug, which is then crimped using an appropriate tool. The insulation displacement method of connection is much quicker to make because the cable ends do not require stripping or preparing. The connection is made by pressing insulation piercing tines or prongs into the cable which displaces the insulation to make an electrical connection with the conductor. This method is used extensively when terminating ribbon cable and for making rapid connections to the existing wiring system of motor vehicles.

Fault finding

The best way to avoid problems in electronic circuit assembly is to be always alert while working, to think about what you are doing and to try always to be neat. If, despite your best efforts, the circuit does not work as it should when tested, then follow a logical test procedure which will usually find the faults in the shortest possible time. First carry out a series of visual tests:

1. Is the battery or supply correctly connected?
2. Is the battery flat or the supply switched off?
3. Is the circuit constructed *exactly* as it should be according to the circuit diagram?
4. Are all the components in place?
5. Check the values of all the components.
6. Are all the components such as diodes, capacitors, transistors and ICs connected the correct way round?
7. Have all connections and links been made?
8. Have all the necessary breaks been made in the stripboard?
9. Are all the soldered joints good?
10. Are any of the components hot or burnt?
    If the fault has not been identified by the first ten tests, ask someone else to carry them out. You may have missed something which will be obvious to a fresh pair of eyes. If the visual tests have failed to identify the fault, then further meter tests are called for as follows:
11. Check the input voltage and the output voltage. Check the mid-point voltage between components which are connected in series with the supply.
12. Variable resistors may suffer from mechanical wear. Check the voltage at the wiper as well as across the potentiometer.
13. Check the coil voltage on relays; if this is low, the coil contacts may not be making.
14. Is the diode connected correctly? Short circuit the diode momentarily with a wire link to see if the circuit works. If it does the diode is open-circuit.
15. Check capacitor–resistor circuits by momentarily shorting out the capacitor and then observing the charging voltage. If it does not charge, the resistor may be open-circuit. If it charges instantly, the resistor may be short-circuit. Check the polarity of electrolytic capacitors. Check the capacitor leads for breaks where the lead enters the capacitor body.
16. Check the base–emitter voltage of the transistor. A satisfactory reading would be between 0.6 and 1.0 V. Temporarily connect a 1 kΩ resistor between the positive supply and the base connection. If the transistor works, the base feed is faulty. If it does not work, the transistor is faulty.
17. Short out the anode and cathode of the thyristor. If the load operates, the thyristor or the gate pulse is faulty. If the load does not operate, the load is faulty.

The testing of capacitors, resistors and discrete semiconductor components was dealt with earlier in this chapter.

Electronic Test Equipment

The use of electronic circuits in all types of electrical equipment has increased considerably over recent years. Electronic circuits and components can now be found in leisure goods, domestic appliances, motor starting and control circuits, discharge lighting, emergency lighting, alarm circuits and special-effects lighting systems. There is, therefore, a need for the installation electrician and all those involved in the electrotechnical industries to become familiar with some basic electronic test equipment, which is the aim of this section.

Test instruments

Electrical installation circuits usually carry in excess of 1 A and often carry hundreds of amperes. Electronic circuits operate in the milliampere or even microampere range. The test instruments used on electronic circuits must have a *high impedance* so that they do not damage the circuit when connected to take readings.

All instruments cause some disturbance when connected into a circuit because they consume some power in order to provide the torque required to move the pointer. In power applications these small disturbances seldom give rise to obvious errors, but in electronic circuits, a small disturbance can completely invalidate any readings taken. We must, therefore, choose our electronic test equipment with great care. Let us consider some of the problems.

Let me first of all define what is meant by the terms 'error' and 'accuracy' used in this chapter. When the term *error* is used it means the *deviation of the meter reading from the true value* and *accuracy* means the *closeness of the meter reading to the true value*.

INSTRUMENT ERRORS

Consider a voltmeter of resistance 100 kΩ connected across the circuit shown in Fig. 4.73(a).

Connection of the meter loads the circuit by effectively connecting a 100 kΩ resistor in parallel with the circuit resistor as shown in Fig. 4.73(b), which changes the circuit to that shown in Fig. 4.73(c).

Common sense tells us that the voltage across each resistor will be 100 V but the meter would read about 67 volts because connection of the meter has changed the circuit. This loading effect can be reduced by choosing instruments which have a very high impedance. Such instruments impose less load on the circuit and give an indication much closer to the true value.

Test instruments used to measure a.c. supplies are also frequency dependent. The important practical consideration is the *frequency range* of the test instrument. This is the range of frequencies over which the instrument may be considered free from frequency errors and is indicated on the back of the instrument or in the manufacturer's information. Frequency limitations are not a normal consideration for an electrician since electrical installations operate at the fixed mains frequency of 50 Hz.

The scale calibration of an instrument assumes a sinusoidal supply unless otherwise stated. Non-sinusoidal or complex waveforms contain harmonic frequencies which may be outside the instrument frequency range. The chosen instrument must, therefore, be suitable for the test circuit waveform.

The maximum permissible errors for various instruments and their applications are indicated in British Standard 89. When choosing an instrument for

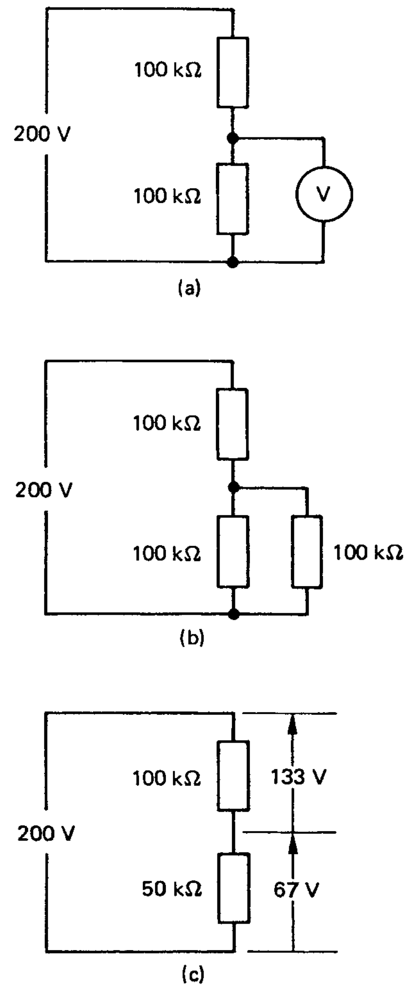


Fig. 4.73 Circuit disturbances caused by the connection of a voltmeter.

electronic testing an electrician or service engineer will probably be looking for an instrument with about a 2% maximum error, that is, 98% accurate. Instrument manufacturers will provide detailed information for their products.

OPERATOR ERRORS

Errors are not restricted to the instrument being used; operators can cause errors, too. Operator errors are errors such as misreading the scale, recording the measurement incorrectly or reading the wrong scale on a multirange instrument. The test instrument must be used on the most appropriate scale: do not try to read 12 V on a 250 V scale, the reading will be much more accurate if the 25 V scale is used.

Analogue and digital displays

The type of instrument to be purchased for general use is a difficult choice because there are so many different types on the market and every manufacturer's representative is convinced that his company's product is the best. However, most instruments can be broadly grouped under two general headings: those having *analogue* and those with *digital* displays.

ANALOGUE METERS

These meters have a pointer moving across a calibrated scale. They are the only choice when a general trend or variation in value is to be observed. Hi-fi equipment often uses analogue displays to indicate how power levels vary with time, which is more informative than a specific value. Red or danger zones can be indicated on industrial instruments. The fuel gauge on a motor car often indicates full, half full or danger on an analogue display which is much more informative than an indication of the exact number of litres of petrol remaining in the tank.

These meters are only accurate when used in the calibrated position – usually horizontally.

Most meters using an analogue scale incorporate a mirror to eliminate parallax error. The user must look straight at the pointer on the scale when taking readings and the correct position is indicated when the pointer image in the mirror is hidden behind the actual pointer. A good-quality analogue multimeter suitable for electronic testing is shown in Fig. 4.76.

The input impedance of this type of instrument is typically 1000 Ω per volt or 20 000 Ω per volt, depending upon the scale chosen.

DIGITAL METERS

These provide the same functions as analogue meters but they display the indicated value using a seven-segment LED (see Fig. 4.22) to give a numerical value of the measurement. Modern digital meters use semiconductor technology to give the instrument a very high input impedance, typically about 10 MΩ and, therefore, they are ideal for testing most electronic circuits.

The choice between an analogue and a digital display is a difficult one and must be dictated by specific circumstances. However, if you are an electrician or working in any sector of the electrotechnical industry intending to purchase a new instrument which would be suitable for electronic testing, I think on balance that a good-quality digital multimeter such as that shown in Fig. 4.74 would be best. Having no moving parts, digital meters tend to be more rugged and, having a very high input impedance, they are ideally suited to testing electronic circuits.

Fig. 4.74 Digital multimeter suitable for testing electronic circuits.

The multimeter

Multimeters are designed to measure voltage, current or resistance. Before taking measurements the appropriate volt, ampere or ohm scale should be selected. To avoid damaging the instrument it is good practice first to switch to the highest value on a particular scale range. For example, if the 10 A scale is first selected and a reading of 2.5 A is displayed, we then know that a more appropriate scale would be the 3 or 5 A range. This will give a more accurate reading which might be, say, 2.49 A. When the multimeter is used as an ammeter to measure current it must be connected in series with the test circuit, as shown in Fig. 4.75(a). When used as a voltmeter the multimeter must be connected in parallel with the component, as shown in Fig. 4.75(b).

The ohmmeter

When using a commercial multirange meter as an ohmmeter for testing electronic components, care must be exercised in identifying the positive terminal.

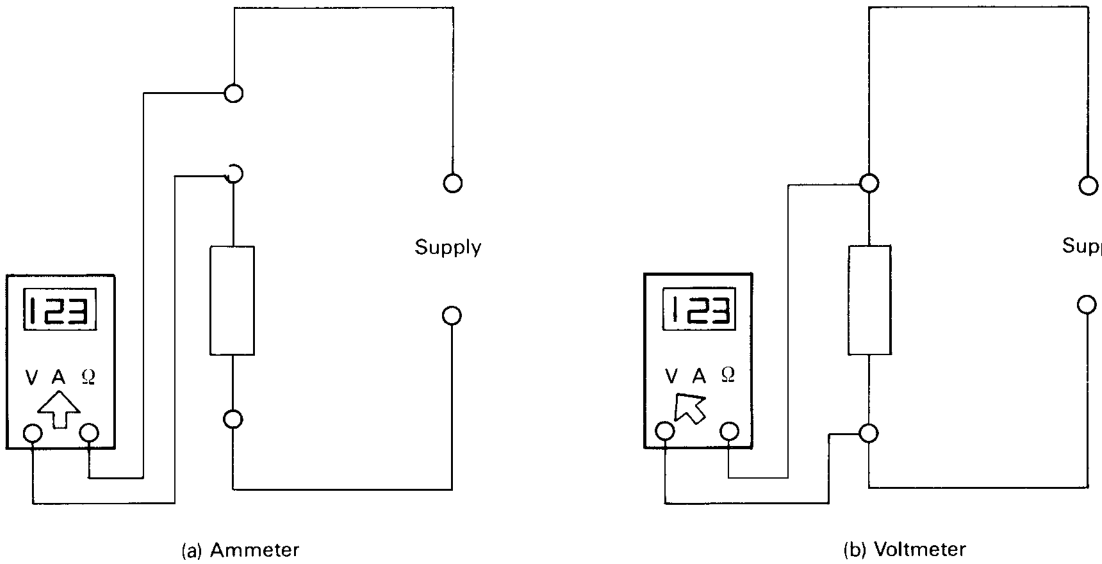


Fig. 4.75 Using a multimeter (a) as an ammeter and (b) as a voltmeter.

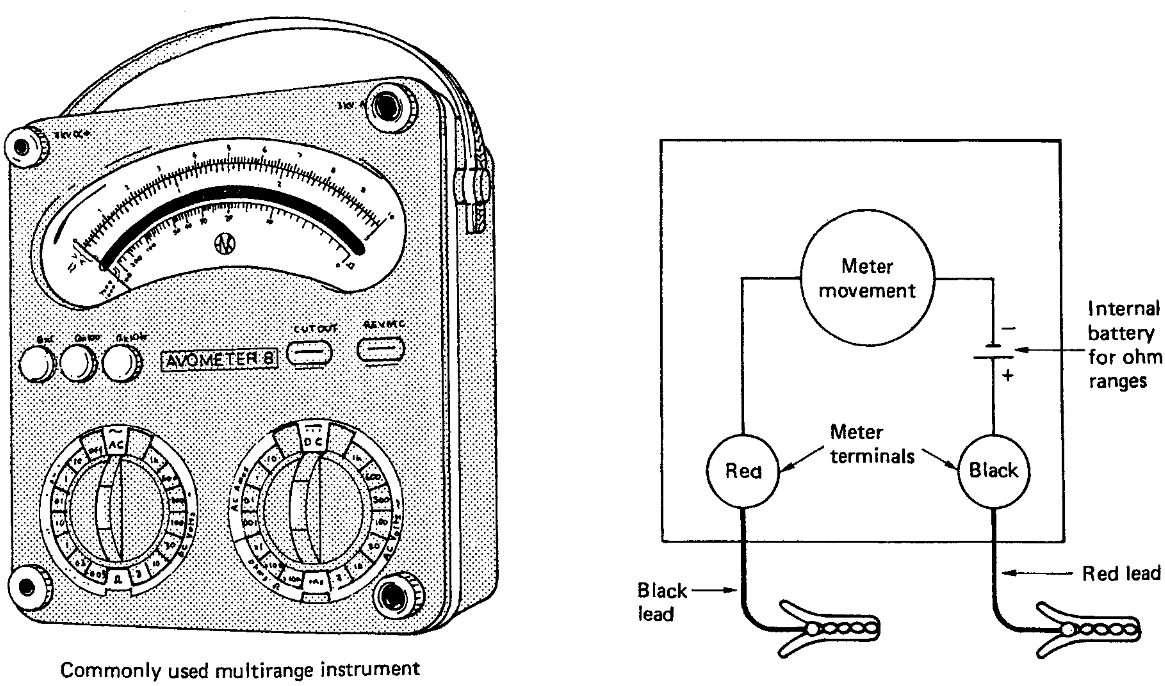


Fig. 4.76 Multirange meter used as an ohmmeter.

The red terminal of the meter, identifying the positive input for testing voltage and current, usually becomes the negative terminal when the meter is used as an ohmmeter because of the way the internal battery is connected to the meter movement. To reduce confusion when using a multirange meter as an ohmmeter it is advisable to connect the red lead to the black terminal and the black lead to the red terminal so that the red lead indicates positive and the black lead negative, as shown in Fig. 4.76. The ohmmeter can then be successfully used to test diodes, transistors and thyristors as described earlier in this chapter.

Commercial multirange instruments reading volts, amperes and ohms are usually the most convenient test instrument for an electrician or service engineer, although a cathode ray oscilloscope (CRO) can be invaluable for bench work.

The cathode ray oscilloscope

The CRO is probably one of the most familiar and useful instruments to be found in an electronic repair service workshop or college laboratory. It is a more useful instrument for two reasons: it is a high impedance voltmeter and, therefore, takes very little current from the test circuit; and it allows us to 'look into' a circuit and 'see' the waveforms present. 'Cathode ray' is the name given to a high-speed beam of electrons generated in the cathode ray tube and was first used during the Second World War as part of the *radar* system. The beam of electrons is deflected horizontally across the screen at a constant rate by the *time-base circuit* and vertically by the test voltage. The many controls on the front of the CRO are designed so that the operator can stabilize and control these signals. Figure 4.77 shows the front panel of a simple CRO. Electricians and service engineers who are unfamiliar with the CRO should not be baffled by the formidable array of knobs and switches – take them one at a time, and give yourself time to become familiar with these controls.

The single most important component in the CRO is the cathode ray tube.

CATHODE RAY TUBE

Figure 4.78 shows a simplified diagram of the cathode ray tube. This is an evacuated glass tube containing

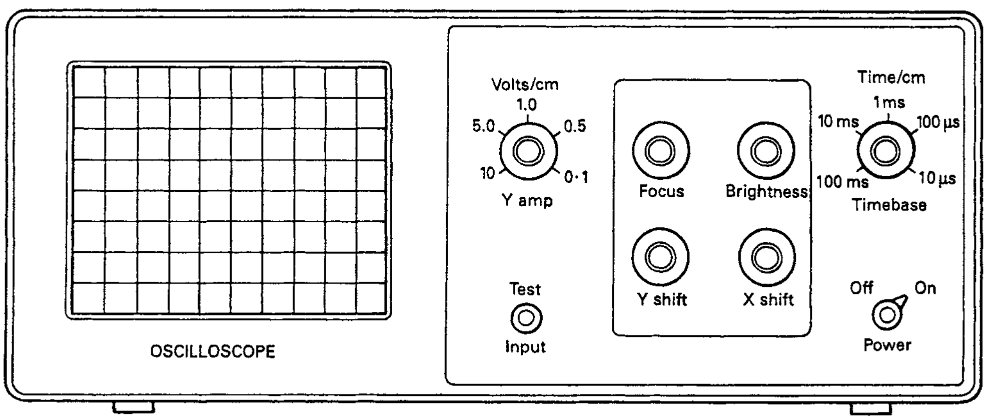


Fig. 4.77 Front panel of a simple CRO.

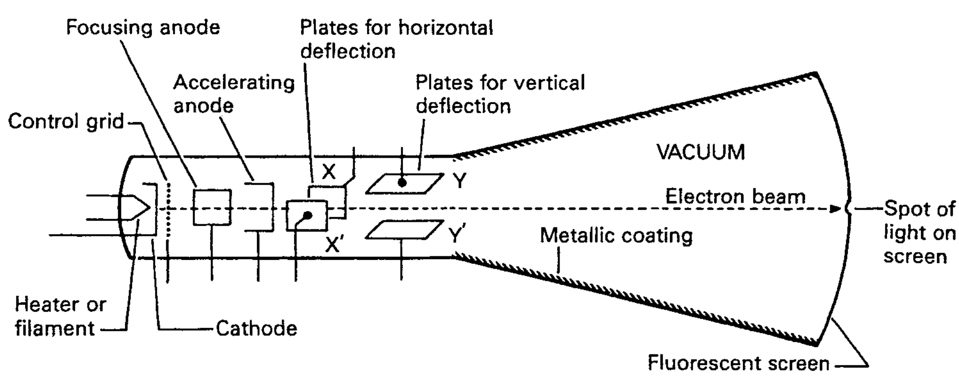


Fig. 4.78 Simplified diagram of the cathode ray tube.

the *electron gun* components on the left and the fluorescent screen, which the operator looks at, on the right. On the far left of the diagram is the wire filament through which a current is passed. This heats a metal plate called a cathode, which emits the electrons to be accelerated. The rate at which the electrons are accepted for acceleration could be modified by making changes to the temperature of the cathode, but in practice it is more convenient to have a metal control grid with a hole in it. By varying the voltage of the control grid it is possible to influence the number of electrons passing through the hole in the grid. The electrons which pass through the grid tend to be moving in various directions and the purpose of the next component therefore is to focus the beam. The electrons are then further accelerated by the accelerating anode to give them sufficient final velocity to produce a bright spot on the screen.

The electrons, on emerging through a hole in this anode, pass through two pairs of parallel plates X–X′ and Y–Y′, each pair being at right angles to the other. If an electric field is established between X and X′ the beam can be deviated horizontally, the direction and magnitude of the deflection depending upon the polarity of the plates. The negative beam of electrons is attracted towards the more positive plate. Likewise, an electric field between plates Y and Y′ produces a vertical deviation. Therefore, a suitable combination of electric fields across X–X′ and Y–Y′ directs the beam to any desired point on the screen.

Upon reaching the screen, the electrons bombard the fluorescent coating on the inside of the screen and emit visible light. The brightness of the spot depends upon the speed of the electrons and the number of electrons arriving at that point.

USE OF THE CRO

The function of the various controls is as follows:

1. Power on switch. Switch on and wait a few seconds for the instrument to warm up. An LED usually indicates a satisfactory main supply.
2. Brightness or intensity. This controls the brightness of the trace. This should be adjusted until bright, but not too brilliant, otherwise the fluorescent powder may be damaged.
3. Scale illumination. This illuminates and highlights the 1 cm square grid lines on the screen.
4. Focus. The spot or trace should be adjusted for a sharp image.
5. Gain controls. 'Adjust' for 'calibrate'.
6. X-shift. The spot or trace can be moved to the left or right and should be centralized.
7. Y-shift. The spot or trace can be moved up or down.
8. TRIG control. This allows the time base to be synchronized to the applied signal to enable a steady trace to be obtained. Set the switch to either Auto or to the Y-input which is connected to the test voltage.
9. AC/GND/DC. It is quite common for a signal to be made up of a mixture of a.c. and d.c. Select DC for all signals and AC to block out the d.c. components of a.c. signals. The GND position disconnects the signal from the Y-amplifier and connects the Y-plates to ground or earth.
10. Chop/Alt. When a double-beam oscilloscope is used, it is common practice to obtain the two X-traces from one beam by either sweeping the electron beams alternately or by sweeping a very small segment of each beam as the trace moves across the screen, leaving each trace chopped up. Use *chop* for slow time-base ranges and *alt* for fast time-base ranges.
11. Connect the test voltage to the CRO leads and adjust the calibrated Y-shift (volts/cm) and time base (time/cm) controls until a steady trace fills the screen.

USE OF THE CRO TO MEASURE VOLTAGE AND FREQUENCY

The calibrated Y-shift, time base and 1 cm grating on the tube front provide us with a method of measuring the displayed waveform.

With the test voltage connected to the Y-input, adjust all controls to the calibrate position. Adjust the X and Y tuning controls until a steady trace is obtained on the CRO screen, such as that shown in Fig. 4.79.

To measure the voltage of the signal shown in Fig. 4.79 count the number of centimetres from one peak of the waveform to the other using the centimetre grating. This distance is shown as 4 cm in Fig. 4.79. This value is then multiplied by the volts/cm indicated on the Y-amplifier control knob. If the knob was set to, say, 2 V/cm, the peak-to-peak voltage of Fig. 4.79 would be

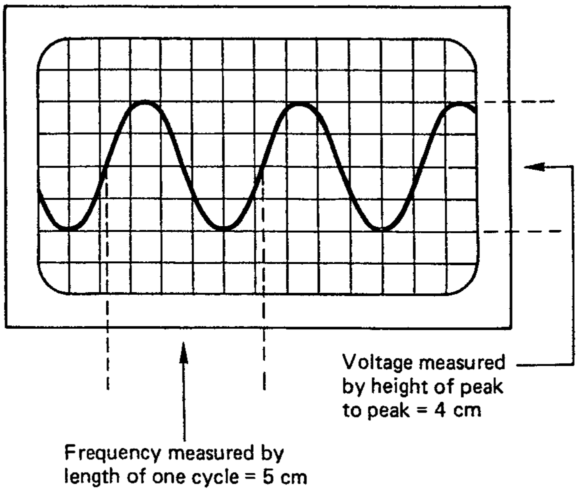


Fig. 4.79 Typical trace on a CRO screen.

4 cm × 2 V/cm = 8 V. The peak voltage would be 4 V and the rms voltage 0.7071 × 4 = 2.828 V.

To measure the frequency of the waveform shown in Fig. 4.79 count the number of centimetres for one complete cycle using the 1 cm grating. The distance is shown as 5 cm in Fig. 4.79. This value is then multiplied by the time/cm on the X-amplifier or time-base amplifier control knob. If this knob was set to 4 ms/cm the time taken to complete one cycle would be 5 cm × 4 ms/cm = 20 ms. Frequency can be found from:

$$f = \frac{1}{T} \text{ (Hz)}$$

$$\therefore f = \frac{1}{20 \times 10^{-3}} = \frac{1000}{20} = 50 \text{ Hz}$$

The waveform shown in Fig. 4.79 therefore has an rms voltage of 2.828 V at a frequency of 50 Hz. The voltage and frequency of any waveform can be found in this way. The relevant a.c. theory is covered in Chapter 1.

EXAMPLE 1

A sinusoidal waveform is displayed on the screen of a CRO as shown in Fig. 4.79. The controls on the *Y*-axis are set to 10 V/cm and the measurement from peak to peak is measured as 4 cm. Calculate the rms value of the waveform.

The peak-to-peak voltage is 4 cm × 10 V/cm = 40 V
The peak voltage is 20 V
The rms voltage is 20 V × 0.7071 = 14.14 V

EXAMPLE 2

A sinusoidal waveform is displayed on the screen of a CRO as shown in Fig. 4.79. The controls on the X-axis are set to 2 ms/cm and the measurement for one period is calculated to be 5 cm. Calculate the frequency of the waveform.

The time taken to complete one cycle (*T*) is 5 cm × 2 ms/cm = 10 ms.

$$f = \frac{1}{T} \text{ (Hz)}$$

$$\therefore f = \frac{1}{10 \times 10^{-3}} = \frac{1000}{10} = 100 \text{ Hz}$$

As you can see, the CRO can be used to calculate the values of voltage and frequency. It is not a *direct reading* instrument as were the analogue and digital instruments considered previously. It does, however, allow us to observe the quantity being measured unlike any other instrument and, therefore, makes a most important contribution to our understanding of electronic circuits.

Signal generators

A signal generator is an oscillator which produces an a.c. voltage of continuously variable frequency. It is used for serious electronic testing, fault finding and experimental work. A signal generator is shown in Fig. 4.80.

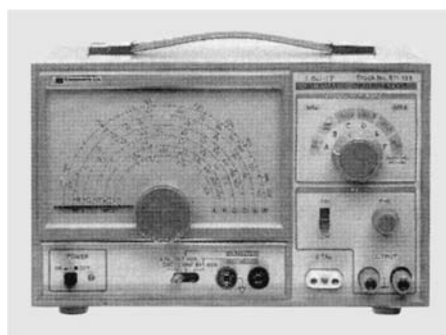


Fig 4.80 A signal generator.

Power supply unit

A bench power supply unit is a very convenient way of obtaining a variable d.c. voltage from the a.c. mains. The output is very pure, a straight line when observed on a CRO, and continuously variable from zero to usually 30 V. It provides a convenient power source for bench testing or building electronic circuits. A bench power supply unit is shown in Fig. 4.81.

Fig. 4.81 A bench power supply unit.

Mains electricity supply

The mains electricity supply can be lethal, as all electricians and all those working in the electrotechnical industries will know. It is, therefore, a sensible precaution to connect any electronic equipment being tested or repaired to a socket protected by a residual current device. Electronic equipment is protected by in-line fuses and circuit breakers and when testing suspected faulty electronic equipment, a good starting point is to establish the presence of the mains supply. A multi-range meter with the 250 V range selected would be a suitable instrument for this purpose or, alternatively, a voltage indicator as shown in Fig. 4.82 could be used.

When isolating electronic equipment from the mains supply, in order to carry out tests or repairs, the following procedure should be followed:

1 Connect the voltage indicator or voltmeter to the incoming supply of the piece of equipment to be isolated. This should indicate the mains voltage and proves the effectiveness of the test instrument.
2 Isolate the supply.
3 Again test the supply to the equipment. If 0 V is indicated the equipment is disconnected from the mains supply.
4 Finally, test the tester again on a known supply or 'proving' unit to be sure the voltage indicator is still working. If the voltage indicator is 'proved' to be working, the equipment is safe to work on.

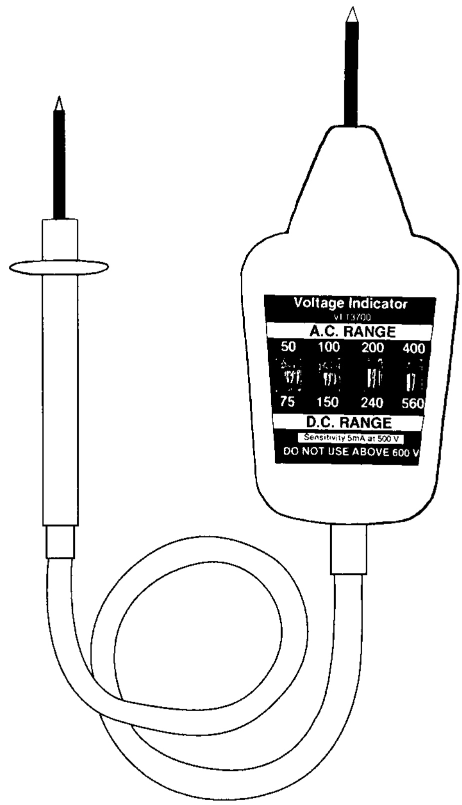


Fig. 4.82 A voltage indicator.

Insulation tester

The use of an insulation resistance test as described by the IEE Regulations must be avoided with any electronic equipment. The working voltage of this instrument can cause total devastation to modern electronic equipment. When carrying out an insulation resistance test as part of the prescribed series of tests for an electrical installation, all electronic equipment must first be disconnected or damage will result.

Any resistance measurements made on electronic circuits must be achieved with a battery-operated ohmmeter as described previously to avoid damaging the electronic components.

LOGIC GATES AND DIGITAL ELECTRONICS

Digital electronics embraces all of today's computer-based systems. These are decision-making circuits which use simple little circuits called 'gates' in applications such as industrial robots, industrial hydraulic and pneumatic systems such as programmable logic controllers (PLCs), telephone exchanges, motor vehicle and domestic appliance control systems, children's toys and their parents' personal computers and audio equipment. Digital electronics is concerned with straightforward two-state switching circuits. The simplicity and reliability of this semiconductor transistor switching has encouraged designers to look for new digital markets. Traditional applications which have analogue inputs, such as audio recordings, are now using digital techniques, with the development of analogue-to-digital converters. These convert the analogue voltage signals into digital numbers. A digital and an analogue waveform are shown in Fig. 4.83.

The digital waveform has two quite definite states, either on or off, and changes between these two states very rapidly. An analogue waveform changes its value smoothly and progressively between two extremes.

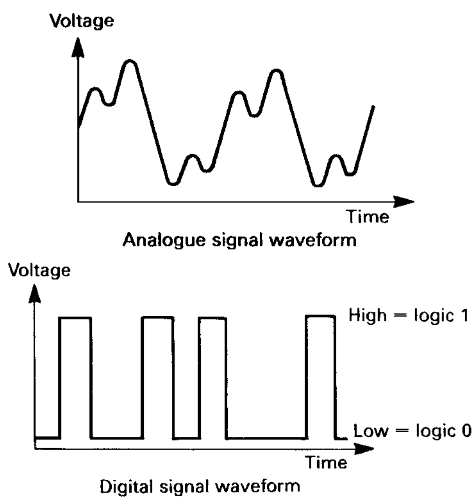


Fig. 4.83 Comparison of analogue and digital waveforms.

In an analogue system, changes in component values due to ageing and temperature can affect the circuit's performance. Digital systems are very much less susceptible to individual component changes. Another significant advantage of digital circuits is their immunity to noise and interference signals. With analogue circuitry this is a nuisance, particularly when signal levels are very small and, therefore, easily contaminated by noise. Digital signals, however, have a very large amplitude and can, therefore, be made relatively free of noise, which helps manufacturers to achieve a very high quality of sound reproduction, as anyone who listens to a compact disc recording can testify. Logic circuits have been developed to deal with these digital, two-state switching circuits. Information is expressed as *binary numbers*, that is, numbers which consist of ones and zeros. These two binary states are represented by low and high voltages, where low voltage is 0 V and high voltage is, say, +5 V. The low level is called logic 0 and the high level logic 1. When the voltage level of a digital signal is not rapidly changing it remains steady at one of these two levels. Information is processed according to rules built into circuits made up of single units called *logic gates*. These units can allow information to pass through or stop it, and behave according to rules which can be described by logical or predictable statements. A logic gate may have a number of inputs but has only one output which can only be either logic 1 or logic 0; no other value exists. The basic various types of logic gate are known by the names AND, OR, NOT, NOR and NAND.

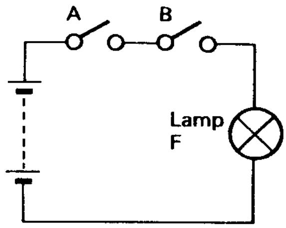
The AND logic gate

The operation of this gate can probably best be understood by drawing a simple switch-equivalent circuit, as shown in Fig. 4.84. The logic symbol is also shown. The signal lamp will only illuminate if both switch A *and* switch B are closed, or we could say the output F of the gate will only be at logic 1 if both input A and input B are both at logic 1.

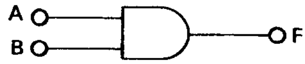
If the AND gate was operating a car handbrake warning lamp, it would only illuminate when both the handbrake and the ignition were on. The *truth table* shows the output state for all possible combinations of inputs.

The OR gate

The OR gate can be represented by parallel connected switches, as shown in Fig. 4.85 which also shows the logic symbol. In this case the signal lamp will only illuminate if switch A *or* switch B *or* both switches are closed. Alternatively, we could say that the output F will only be at logic 1 if input A or input B or both inputs are at logic 1.



(a)

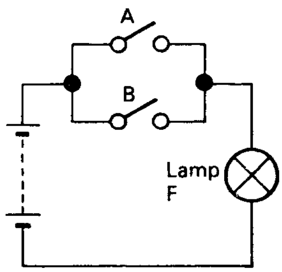


(b)

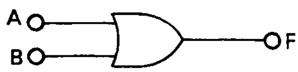
A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

(c)

Fig. 4.84 The AND gate: (a) simple switching circuit; (b) logic symbol; (c) truth table.



(a)



(b)

A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

(c)

Fig. 4.85 The OR gate: (a) simple switching circuit; (b) logic symbol; (c) truth table.

If the OR gate was operating an interior light in a motor car, it would illuminate when the nearside door was opened *or* the offside door was opened *or* when both doors were opened. The truth table shows the output state for all possible combinations of inputs.

The exclusive-OR gate

The exclusive-OR gate is an OR gate with only two inputs which will give a logic 1 output only if input A *or* input B is at logic 1, but *not* when both A and B are at logic 1. The symbol and truth table are given in Fig. 4.86.

(a)

A	B	F
0	0	0
0	1	1
1	0	1
1	1	0

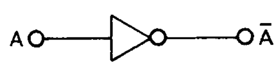
(b)

Fig. 4.86 The exclusive-OR gate: (a) logic symbol; (b) truth table.

The NOT gate

The NOT gate is a single input gate which gives an output that is the opposite of the input. For this reason it is sometimes called an *inverter* or a *negator* or simply a *sign changer*. If the input is A, the output is *not* A, which is written as $\bar{A}$ (A bar). The small circle on the output of the gate always indicates a change of sign.

If the NOT gate was operating a spin dryer motor it would only allow the motor to run when the lid was *not* open. The truth table shows the output state for all possible inputs in Fig. 4.87.



(a)

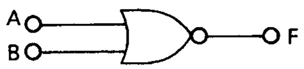
INPUT	OUTPUT
0	1
1	0

(b)

Fig. 4.87 The NOT gate: (a) logic symbol; (b) truth table.

The NOR gate

The NOR gate is a NOT gate and an OR gate combined to form a NOT–OR gate. The output of the NOR gate is the opposite of the OR gate, as can be seen by comparing the truth table for the NOR gate in Fig. 4.88 with that of the OR gate.



(a)

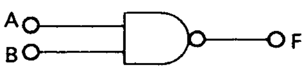
A	B	F
0	0	1
0	1	0
1	0	0
1	1	0

(b)

Fig. 4.88 The NOR gate: (a) logic symbol; (b) truth table.

The NAND gate

The NAND gate is a NOT gate and an AND gate combined to form a NOT–AND gate. The output of the NAND gate is the opposite of the AND gate, as can be seen by comparing the truth table for the NAND gate in Fig. 4.89 with that of the AND gate.



(a)

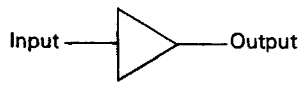
A	B	F
0	0	1
0	1	1
1	0	1
1	1	0

(b)

Fig. 4.89 The NAND gate: (a) logic symbol; (b) truth table.

Buffers

The simplest of all logic devices is the buffer. This device has only one input and one output, and its logical output is exactly the same as its logical input. Given that this device has no effect upon the logic levels within a circuit, you may be wondering what the purpose of such an apparently redundant device might be! Well, although the input and output voltage levels of the buffer are identical, the *currents* present at the input and output can be *very* different. The output current can be much greater than the input current and, therefore, buffers can be said to exhibit *current gain*. In this way, buffers can be used to interface logic circuits to other circuits which demand more current than could be supplied by an unbuffered logic circuit. The symbol used to represent a buffer is shown in Fig. 4.90.



(a)

INPUT	OUTPUT
0	0
1	1

(b)

Fig. 4.90 The buffer: (a) logic symbol; (b) truth table.

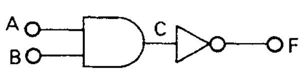
Logic networks

Individual logic gates may be interconnected to provide any desired output. The results of any combination can be found by working through each individual gate in the combination or logic system in turn, and producing the truth table for the particular network. It can also be very instructive to build up logic gate combinations on a logic simulator and to confirm the theoretical results. This facility will undoubtedly be available if the course of study is being undertaken at a technical college, training centre or evening institute.

EXAMPLE 1

Two logic gates are connected together as shown in Fig. 4.91. Complete the truth table for this particular logic network.

In considering Fig. 4.91 and working as always from left to right, we can see that an AND gate feeds a NOT gate. The whole network has two inputs, A and B, and one output F. The first step in constructing the truth table for the combined logic gates is to label the outputs of *all* the gates and prepare a blank truth table as shown in Fig. 4.84. Let us call the



(a)

A	B	C	F

(b)

Fig. 4.91 (a) Logic network and (b) blank truth table for Example 1.

output of the AND gate C (it could be any letter except A, B or F) and work our way progressively through the individual gates from left to right. For any two-input logic gate, there are four possible combinations, 00, 01, 10 and 11. When these are included on the truth table it will appear as shown in Table 4.7. The next step is to complete column C. Now, C is the output of an AND gate and can, therefore, only be at logic 1 when both A *and* B are logic 1. The truth table can, therefore, be completed as shown in Table 4.8. The final step is to complete column F, the output of a NOT gate whose input combinations are given by column C. A NOT gate is a single-input gate whose output is the opposite of the input and, therefore, the output column F must be the opposite of column C, as shown by Table 4.9. The truth table tells us that this particular combination of gates will give a logic 1 output with any input combination *except* when A and B are both at logic 1. This combination, therefore, behaves like a NAND gate, as can be confirmed by referring to Fig. 4.89.

A	B	C	F
0	0		
0	1		
1	0		
1	1		

Table 4.7 Truth table for Example 1

A	B	C	F
0	0	0	
0	1	0	
1	0	0	
1	1	1	

Table 4.8 Completed column C of truth table

A	B	C	F
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

Table 4.9 The completed truth table for Example 1

EXAMPLE 2

A NAND and NOT gate are connected together as shown in Fig. 4.92. Complete a truth table for this particular network.

The truth table for this particular combination can be constructed in exactly the same way as for Example 1. The NAND gate has two inputs P and Q and an output R. The NOT gate has an input R and output S.

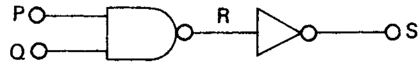


Fig. 4.92 Logic network for Example 2.

All possible combinations of inputs are shown in columns P and Q of the truth table shown in Table 4.10. A NAND gate will give a logic 1 output for *all* combinations of inputs *except* when input A *and* B are at logic 1 as shown by column R of Table 4.10. The second and final gate in this network is a NOT gate which provides an output which is the reverse of the input. The output, given by column S of the truth table, will therefore be the reverse of column R, as shown in Table 4.10.

P	Q	R	S
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

Table 4.10 Truth table for Example 2

This particular combination will, therefore, give a logic 1 output only when input P *and* input Q are at logic 1. Therefore, it can be seen that the combination of a NAND and a NOT gate produces the equivalent of an AND gate. This can be checked by referring back to Fig. 4.84.

EXAMPLE 3

A NAND gate has a NOT gate on each of its inputs as shown in Fig. 4.93. Construct a truth table for this particular network.

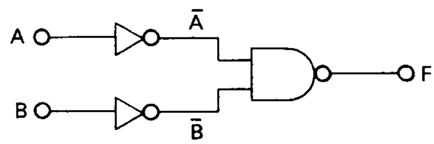


Fig. 4.93 Logic network for Example 3.

The NOT gates will invert or reverse the input. We can, therefore, call the output of these NOT gates not A and not B, written as $\bar{A}$ and $\bar{B}$. This then provides the input to the NAND gate. A NAND gate will provide a logic 1 output for any input combination *except* when both inputs are at logic 1. The truth table can, therefore, be developed as shown in Table 4.11. It can be seen by referring back to Fig. 4.85, and comparing the inputs A and B and output F, that this combination gives the network equivalent of an OR gate. That is, the output is at logic 1 if the input A *or* input B *or* both are at logic 1.

A	B	$\bar{A}$	$\bar{B}$	F
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

Table 4.11 Truth table for Example 3

EXAMPLE 4

A logic network is assembled as shown in Fig. 4.94. Develop a truth table and describe in a sentence the relationship between the input and output.

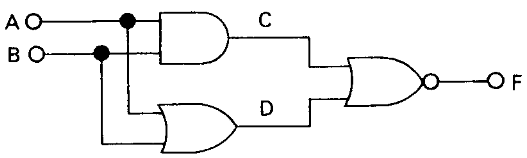


Fig. 4.94 Logic network for Example 4.

The truth table for this particular combination can be drawn up as shown in Table 4.12. There are only two inputs A and B. The output C of the AND gate and the output D of the OR gate provide the input to a NOR gate, which provides the output F.

A	B	C	D	F
0	0	0	0	1
0	1	0	1	0
1	0	0	1	0
1	1	1	1	0

Table 4.12 Truth table for Example 4

The output of an AND gate is high, that is at logic 1, only when input A *and* input B are at logic 1. Column C of the truth table shows the output of the AND gate for all combinations of input. The output of an OR gate is high when input A *or* input B *or* both are high. This is shown by column D of the truth table. The input to the final NOR gate is provided by the logic levels indicated in columns C and D and the output F is, therefore, as shown in column F. The output of this combination of logic gates is high only when input A *and* input B are low. This is equivalent to a single NOR gate.

In the examples considered until now, the inputs have been restricted to only two variables. In practice, logic gates may be constructed with many inputs and the truth tables developed as shown above. However, when there are more than three inputs the truth table becomes very cumbersome because the number of lines required for the truth table follows the law of 2^n where n is equal to the number of inputs. Therefore, a two-input gate requires 2^2 (4) lines, as can be seen in the previous examples, a three-input gate 2^3 (8) lines, a four-input gate 2^4 (16) lines, etc.

EXAMPLE 5

A logic system having three inputs is assembled as shown in Fig. 4.95. Develop a truth table and describe in a sentence the relationship between the input and output.

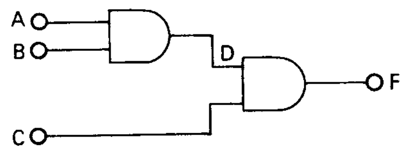


Fig. 4.95 Logic network for Example 5.

The truth table for this combination of logic gates can be drawn up as shown in Table 4.13. Three inputs mean that the truth table must have $2^3 = 8$ rows. All possible combinations of input are shown in columns A, B and C. The first AND gate will give a logic 1 output only when input A and B are both logic 1. There are two such occasions, as shown by column D. The second AND gate will give a logic 1 output only when input C and D are both logic 1. This occurs on only one occasion. That is, the output is at logic 1 only when all three inputs are at logic 1.

A	B	C	D	F
0	0	0	0	0
0	0	1	0	0
0	1	0	0	0
0	1	1	0	0
1	0	0	0	0
1	0	1	0	0
1	1	0	1	0
1	1	1	1	1

Table 4.13 Truth table for Example 5

EXAMPLE 6

A three-input logic network is assembled as shown in Fig. 4.96. Develop a suitable truth table and use this to describe the relationship between the three inputs and the output Z.

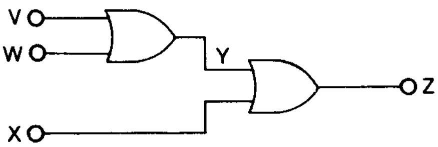


Fig. 4.96 Logic network for Example 6.

The truth table for this network can be constructed as shown in Table 4.14. All possible combinations of the input are shown in columns V, W and X.

V	W	X	Y	Z
0	0	0	0	0
0	0	1	0	1
0	1	0	1	1
0	1	1	1	1
1	0	0	1	1
1	0	1	1	1
1	1	0	1	1
1	1	1	1	1

Table 4.14 Truth table for Example 6

The first OR gate will give a logic 1 output when V *or* W *or* both are at logic 1. This occurs on all but two occasions as can be seen by considering column Y of the truth table. The second OR gate will give a logic 1 output when X *or* Y *or* both are at logic 1. This occurs on all but one occasion. Therefore, we can say that the output Z is at logic 0 *only* when all three inputs are at logic 0. If any input is at logic 1, the output Z is also at logic 1.

Logic families

The simplicity of digital electronics, with its straightforward on–off switching, means that many logic elements can be packed together in a single integrated circuit and packaged as a standard dual-in-line IC, as shown in Figs 4.30 and 4.32. Different types of semiconductor circuitry can be used to construct the logic gates. Each type is called a logic family because all members of that integrated circuit family will happily work together in a circuit.

Two main families of digital logic have emerged as the most popular with designers of general-purpose digital circuits in recent years. These are the TTL and CMOS families. The older of these is the TTL (transistor–transistor logic) family which was introduced in 1964 by Texas Instruments Ltd. The standard TTL family is designated the 7400 series. Figure 4.97 shows the internal circuitry of a TTL 7400 IC. This contains a quad 2-input NAND gate, that is, it contains four NAND gates each with two inputs and one output. Thus, with two power supply connections, the 7400 IC has 14 connections and is manufactured as the familiar 14 pin dual-in-line package. Many other combinations are available and each has its own unique number which, in this family, always begins with 74 and is followed by two other numbers. The final two numbers indicate the type of logic gate: for example, a 7432 is a quad 2-input OR gate, and a 7411 a triple 3-input AND gate. Details are given in manufacturers' data sheets.

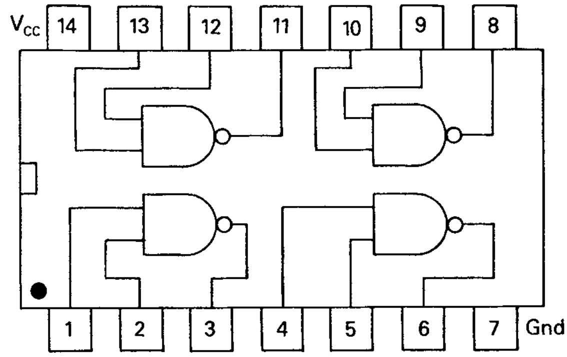


Fig. 4.97 The 7400 TTL logic family.

The CMOS family, pronounced 'see-mos', is the complementary metal oxide semiconductor family of logic ICs which was introduced in 1968. The best-known CMOS family is designated the 4000 series and, like its TTL equivalent, is housed in a 14 pin dual-in-line package. The 4011B is a quad 2-input NAND gate, as shown in Fig. 4.98. This is *similar* to the TTL 7400 shown in Fig. 4.97 but it is not identical because the pin connections differ and, therefore, a TTL package cannot replace a CMOS package.

The theory of digital logic is the same for all logic families. The differences between the families are confined to the practical aspects of the circuit design. Each logic family has its own special characteristics which make it appropriate for particular applications.

COMPARISON OF TTL AND CMOS

A CMOS device dissipates about 1 mW per logic gate, compared with about 20 mW for a standard TTL logic

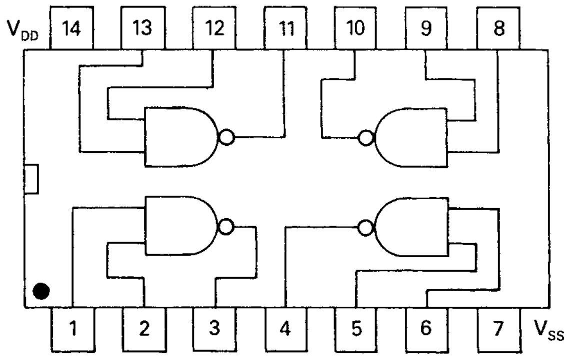


Fig. 4.98 The 4011B CMOS logic family.

Table 4.15 Properties of logic families

Property	TTL	CMOS
Power consumption	high: 20 mW	low: 1 mW
Operating current	high: mA range	low: μA range
Power supply	5 V ± 0.25 V d.c.	3 V to 15 V d.c.
Switching speeds	fast: 10 ns	slow: 100 ns
Input impedance	low	high
Fan-out	10	50

gate. Therefore, CMOS has a much lower power consumption than TTL, which is particularly important when the circuitry is to be battery-powered.

The output of a logic gate may be connected to the input of many other logic gates. The drive capability of a gate to hold its input at logic 0 or logic 1 while delivering current to the other gates in the circuit is called the *fan-out* capability. The fan-out for TTL is 10, which means that ten other TTL logic gates can take their input from one TTL output and still switch reliably before overloading occurs. A fan-out of 50 is typical for CMOS because they have a very high input impedance and low power consumption.

The power supply for TTL must be 5 V ± 0.25 V with a ripple of less than 5% peak to peak. A TTL device will be damaged if voltages in excess of these limits are applied. CMOS devices can tolerate a much wider variation of supply voltages, typically +3 V to +15 V.

Another advantage of CMOS logic circuits is that they require only about one-fiftieth of the 'floor space' on a silicon chip compared with TTL. CMOS is, therefore, ideal for complex silicon chips, such as those required by microprocessors and memories.

The switching times of any logic network are infinitesimal when compared when an electro-mechanical relay. However, the switching times for TTL logic are very much faster than for CMOS, although both are measured in nanoseconds. The properties of each family are summarized in Table 4.15.

Working with logic

ICs of the same number will always have the same function regardless of the manufacturer and any suffix or prefix which may accompany the basic gate number. Therefore, an IC package must be replaced with another of the same number. The very high input impedance of CMOS accounts for its low power consumption but it does mean that static electricity can build up on the input pins if they come into contact with plastic, nylon or the man-made fibres of workers' clothing during circuit assembly or repair. This does not happen with TTL because the low input impedance ensures that any static charges leak harmlessly away through the junctions in the IC. Static voltages on CMOS devices can destroy them; they are supplied with anti-static carriers and these should not be removed until wiring is completed. Internal protection is also provided by buffered inputs, but these cannot become effective until the supply is connected. Inputs must, therefore, be disconnected before the mains connections when disconnecting CMOS devices. Alternatively, the power supplies must be connected before the inputs when assembling CMOS chips. Input signals must not be applied until the power supply is connected and switched on.

When operating CMOS devices with normal positive logic signals V_{SS} is the common line (0 V) and V_{DD} is the positive connection, 3–15 V (inputs 7 and 14 in Fig. 4.98). Unused inputs must not be left *floating*. They must always be connected in parallel with similar used inputs, or connected to the supply rail.

Working with CMOS has created many new problems for electronic technicians. These can be overcome by:

- working on a copper plate working surface which is connected to earth.
- ensuring that all equipment is properly earthed.
- wearing a conductive wristband which is connected to the earth of the working surface.

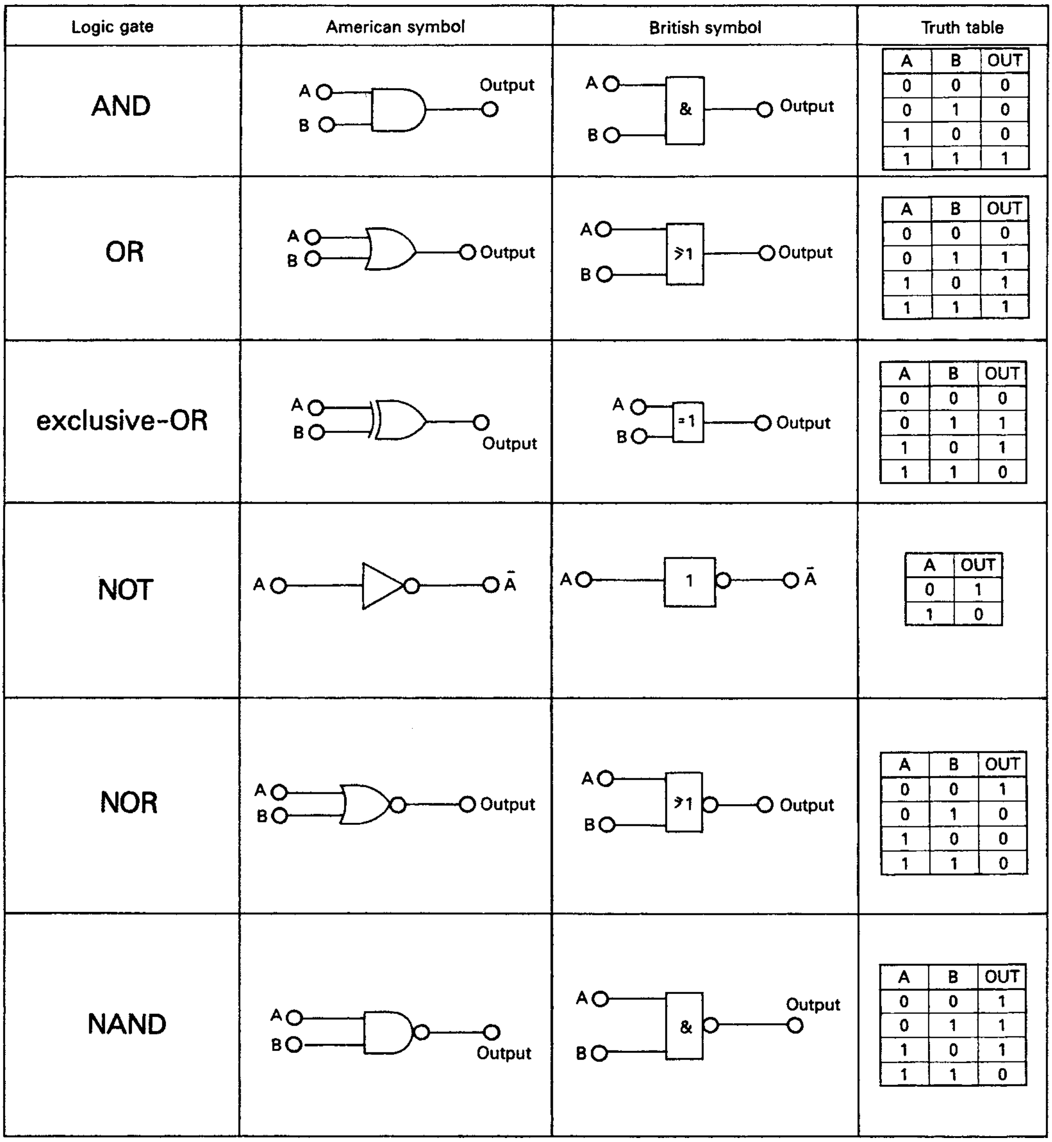


Fig. 4.99 Comparison of British and American logic gate symbols.

When these precautions are observed the problems of handling CMOS ICs can be overcome without too much difficulty.

British Standard symbols

Although the British Standards recommend symbols for logic gates, much of the manufacturers' information uses the American 'MilSpec' Standard symbols. For this reason I have reluctantly used the American standard symbols in this chapter. However, there is some pressure in the UK to adopt the BS symbols, and for this reason the British Standard and American Standard symbols are cross-referenced in Fig. 4.99.

Exercises

1 A voltage signal which changes smoothly and progressively between two extremes is called:
(a) a logical waveform
(b) an analogue waveform

(c) an interference signal
(d) a digital waveform.

2 A voltage signal which has two quite definite states, either on or off, is called:
(a) a logical waveform
(b) an analogue waveform
(c) an interference signal
(d) a digital waveform.

3 A single logic gate has two inputs X and Y and one output Z. The output Z will be at logic 1 only when input A and input B are at logic 1 if the gate is:
(a) a NOT gate
(b) an AND gate
(c) an OR gate
(d) a NOR gate.

4 Develop the truth table for an exclusive-OR gate.

5 Develop the truth table for a NOR gate.

6 For the circuit shown in Fig. 4.100 develop the truth table.

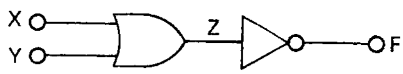


Fig. 4.100 Logic network for Exercise 6.

7 Develop the truth table for the network shown in Fig. 4.101 and describe the relationship between the inputs and output.

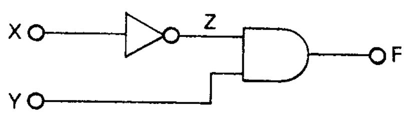


Fig. 4.101 Logic network for Exercise 7.

8 Develop the truth table for the logic system shown in Fig. 4.102 and describe the relationship between the output and inputs.

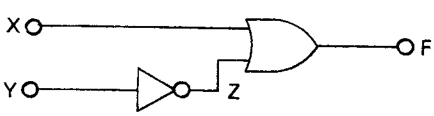


Fig. 4.102 Logic network for Exercise 8.

9 Work out the truth table for the circuit shown in Fig. 4.103. Describe in a sentence the behaviour of this circuit.

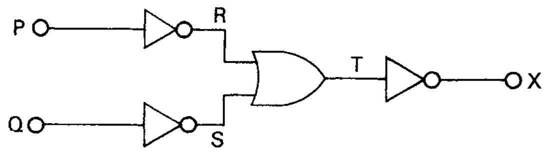


Fig. 4.103 Logic network for Exercise 9.

10 Complete the truth table for the circuit shown in Fig. 4.104 and describe the circuit behaviour.

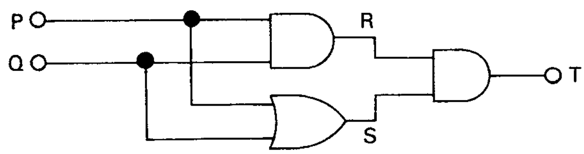


Fig. 4.104 Logic network for Exercise 10.

11 Using a truth table describe the output of the logic system shown in Fig. 4.105.

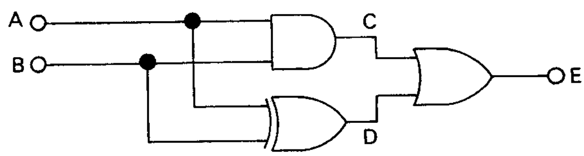


Fig. 4.105 Logic network for Exercise 11.

12 Use a truth table to describe the output of the logic network shown in Fig. 4.106.

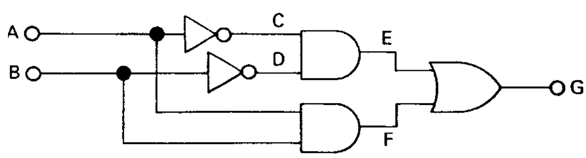


Fig. 4.106 Logic network for Exercise 12.

13 Inputs A, B and C of Fig. 4.107 are controlled by three separate key switches. Determine the sequence of key switch positions which will give an output at F.

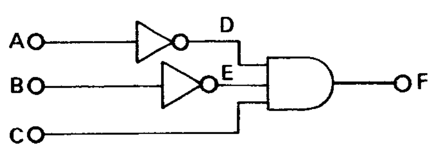


Fig. 4.107 Logic network for Exercise 13.

SOLUTIONS TO EXERCISES

CHAPTER 1

1: (b) 2: (d) 3: (c) 4: (b) 5: (a) 6: (d) 7: (c) 8: (b) 9: (c) 10: (d) 11: (c) 12: (b) 13: (c) 14: (d) 15: (b) 16: (a) 17: (b) 18: (c) 19: (a) 20: (d) 21: (d) 22: (a) 23: (d) 24: (a) 25: (c) 26: (c) 27: (a) 28: (b) 29: (b) 30: (b) 31: (b) 32: (a) 33: (a) 34: (d) 35: (d) 36: (b) 37: (c) 38: (a) 39: (b) 40: (a) 41: (a) 42: (d) 43: (c) 44: (c) 45: (a) 46: (b) 47: (d) 48: (d) 49: (a) 50: (d) 51: (c) 52: (c) 53: (c) 54: (b) 55: (a) 56: (b) 57: (c) 58: (a) 59: (b) 60: (c) 61: (a) 62: (c) 63: (d) 64: (a) 65: (b) 66: (b) 67: (a) 68: (d) 69: (b) 70: (c) 71: (b) 72: (a) 73: (c) 74: (b) 75: (d) 76: (b) 77: (d) 78: (c) 79: (a) 80: (b) 81: (d) 82: (a) 83: (c) 84: (d) 85: (c) 86: (b) 87: (a) 21.65A (b) 86.0 μF 88: 25 mm 89: 100 × 25 90: 17 91: 5 92: 25 mm 93: 155 94: (a) 75 × 25 (b) & (c) Answers in text 95: (a) 18.03 (b) 12.76 (c) 127.6, 191.35 (d) 0.55 96: (a) 15 (b) 15.33 (c) 137.97, 183.96 (d) 0.6 97: (a) 32 (b) 8.74 (c) 131.1, 274.6, 463.66 (d) 0.569 98: 15.33, 7.32, 16.99, 0.902 99: 11.55, 4.335, 12.82, 0.936 100–155: Answers in text

CHAPTER 2

1: (c) 2: (b) 3: (d) 4: (c) 5: (a) 6: (d) 7: (b) 8: (c) 9: (a) 10: (b) 11: (d) 12: (b) 13: (c) 14: (c) 15: (c) 16: (d) 17: (c) 18: (c) 19: (d) 20: (a) 21: (b) 22: (b) 23: (c) 24: (b) 25: (c) 26: (d) 27: (b) 28: (d) 29: (c) 30: (d) 31: (d) 32: (c) 33: (c) 34: (a) 35: (a) 36: (c) 37: (c) 38: (b) 39: (b) 40: (c) 41: Answer in text 42: (a) 1.14 (b) 1.20 (c) 4.0 (d) 5.58 (e) 14.1 (f) 18.15 43: 5.18 mm 44: (a) 0.25 s (b) 0.04 s 45: 1.405 mm 46: $I_b = 43.48$ A $I_n = 45.0$ A 47: (a) 1.03 (b) 0.97 (c) 0.91 48: (a) 1.0 (b) 0.6 (c) 0.54 49: (a) 1.0 (b) 0.725 50: 32 A 51: 4.224 Yes 52: (a) 4.35 A (b) 10.15 A (c) 1.0 mm (d) 5.74 V 53: (a) 14.24 A (b) 22.09 A (c) 2.5 mm (d) 7.67 V 54: Answer in text 55: Answer in text 56: (a) 7.5 mΩ (b) 16.662 kΩ 57: 1.27 Ω 58: 190 mΩ 59–66 Answers in text 67: (c) AFG (d) 12 weeks (e) None (f) 2 weeks 68–82: Answers in text

CHAPTER 3

1–15: Answers in text

CHAPTER 4

1: (b) 2: (d) 3: (b) 4: See Fig. 4.86 5: See Fig. 4.88 6: See Table S.1

X	Y	Z	F
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

Table S.1 Truth table for Exercise 6

7: See Table S.2. The output is high only when the input X is low and the input Y is high. For all other input combinations the output is low.

X	Y	Z	F
0	0	1	0
0	1	1	1
1	0	0	0
1	1	0	0

Table S.2 Truth table for Exercise 7

8: See Table S.3. The output is high for all input combinations except when input X is low and input Y is high.

X	Y	Z	F
0	0	1	1
0	1	0	0
1	0	1	1
1	1	0	1

Table S.3 Truth table for Exercise 8

9: See Table S.4. The output X is at logic 1 only when input P and input Q are at logic 1. For all other input combinations the output is logic 0.

P	Q	R	S	T	X
0	0	1	1	1	0
0	1	1	0	1	0
1	0	0	1	1	0
1	1	0	0	0	1

Table S.4 Truth table for Exercise 9

10: See Table S.5. The output T is logic 1 only when both inputs are at logic 1. For all other input combinations the output is logic 0.

P	Q	R	S	T
0	0	0	0	0
0	1	0	1	0
1	0	0	1	0
1	1	1	1	1

Table S.5 Truth table for Exercise 10

11: See Table S.6. The output E is logic 1 for all input combinations except when input A and B are both logic 0.

A	B	C	D	E
0	0	0	0	0
0	1	0	1	1
1	0	0	1	1
1	1	1	0	1

Table S.6 Truth table for Exercise 11

12: See Table S.7. The output is high when both inputs are the same.

A	B	C	D	E	F	G
0	0	1	1	1	0	1
0	1	1	0	0	0	0
1	0	0	1	0	0	0
1	1	0	0	0	1	1

Table S.7 Truth table for Exercise 12

13: See Table S.8. An output is only available at F when keys A and B are off (both at logic 0) and key C is on.

A	B	C	D	E	F
0	0	0	1	1	0
0	0	1	1	1	1
0	1	0	1	0	0
0	1	1	1	0	0
1	0	0	0	1	0
1	0	1	0	1	0
1	1	0	0	0	0
1	1	1	0	0	0

Table S.8 Truth table for Exercise 13

APPENDICES

Appendix A: Obtaining information and electronic components

For local suppliers, you should consult your local telephone directory. However, the following companies distribute electrical and electronic components throughout the UK. In most cases, telephone orders received before 5 p.m. can be dispatched the same day.

Electromail (R.S. mail order business), P.O. Box 33, Corby, Northants NN17 9EL, Telephone: 011536 204555. Website: RS www.com

Farnell Electronic Components, Canal Road, Leeds LS12 2TU, Telephone: 0113 636311. Email: Sale@farnellinone.co.uk

Maplin Electronics, Valley Road. Wombwell S73 OBS, Telephone: 01226 751155. Website: www.maplin.co.uk

Rapid Electronics Ltd, Heckworth Close, Severalls Industrial Estate, Colchester, Essex CO4 4TB, Telephone: 01206 751166. Fax: 01206 751188. Email: sales@rapidelec.co.uk

R.S. Components Ltd, P.O. Box 99, Corby, Northants NN17 9RS, Telephone: 01536 201234. Website: RS www.com

Verospeed Electronic Components, Boyatt Wood, Eastleigh, Hants SO5 4ZY, Telephone: 02380 644555.

Appendix B: Abbreviations, symbols and codes

Abbreviations used in electronics for multiples and sub-multiples

T	tera	10^{12}
G	giga	10^{9}
M	mega or meg	10^{6}
k	kilo	10^{3}
d	deci	10^{-1}
c	centi	10^{-2}
m	milli	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	pico	10^{-12}

Terms and symbols used in electronics

Term	Symbol
Approximately equal to	$\simeq$
Proportional to	$\propto$
Infinity	∞
Sum of	Σ
Greater than	$>$
Less than	$<$
Much greater than	$\gg$
Much less than	$\ll$
Base of natural logarithms	e
Common logarithms of x	$\log x$
Temperature	θ
Time constant	T
Efficiency	η
Per unit	p.u.

Electrical quantities and units

Quantity	Quantity symbol	Unit	Unit symbol
Angular velocity	ω	radian per second	rad/s
Capacitance	C	farad	F
		microfarad	μF
		picofarad	pF
Charge or quantity of electricity	Q	coulomb	C
Current	I	ampere	A
		milliampere	mA
		microampere	μA
Electromotive force	E	volt	V
Frequency	f	hertz	Hz
		kilohertz	kHz
		megahertz	MHz
Impedance	Z	ohm	Ω
Inductance, self	L	henry (plural, henrys)	H
Inductance, mutual	M	henry (plural, henrys)	H
Magnetic field strength	H	ampere per metre	A/m
Magnetic flux	θ	weber	Wb
Magnetic flux density	B	tesla	T
Potential difference	V	volt	V
		millivolt	mV
		kilovolt	kV
Power	P	watt	W
		kilowatt	kW
		megawatt	MW
Reactance	X	ohm	Ω
Resistance	R	ohm	Ω
		microohm	μΩ
		megaohm	MΩ
Resistivity	ρ	ohm metre	Ωm
Wavelength	λ	metre	m
		micrometre	μm

Capacitor values-conversion table

Capacitance (picofarad pF)	Capacitance (nanofarad nF)	Capacitance (microfarad μF)	Capacitance code
10	0.01		100
15	0.015		150
47	0.047		470
82	0.082		820
100	0.1		101
330	0.33		331
470	0.47	0.00047	471
1000	1.0	0.001	102
1500	1.5	0.0015	152
2200	2.2	0.0022	222
4700	4.7	0.0047	472
6800	6.8	0.0068	682
10 000	10	0.01	103
22 000	22	0.022	223
47 000	47	0.047	473
100 000	100	0.1	104
220 000	220	0.22	224
470 000	470	0.47	474

Capacitance code: First two digits significant figures; third is number of zeros. Value given in pF.

Suffixes used with semiconductor devices

Many semiconductor devices are available with suffix letters after the part number, that is, BC108B, C106D, TIP31C.

The suffix is used to indicate a specific parameter relevant to the device – some examples are shown below.

Thyristors, triacs, power rectifiers

Suffix indicates voltage rating, for example TIC 106D indicates device has a 400 V rating. Letters used are:

Q = 15 V	B = 200 V	M = 600 V
Y = 30 V	C = 300 V	S = 700 V
F = 50 V	D = 400 V	N = 800 V
A = 100 V	E = 500 V	

Small signal transistors

Suffix indicates h_{FE} range, for example BC108C
A = h_{FE} of 125–260
B = h_{FE} of 240–500
C = h_{FE} of 450–900

Power transistors

Suffix indicates voltage, for example TIP32C
No suffix = 40 V
A = 60 V
B = 80 V
C = 100 V
D = 120 V

Resistor and capacitor letter and digit code (BS 1852)

Resistor values are indicated as follows:

0.47 Ω	marked	R47	100 Ω	marked	100R
1 Ω		1R0	1 kΩ		1K0
4.7 Ω		4R7	10 kΩ		10 K
47 Ω		47R	10 MΩ		10 M

A letter following the value shows the tolerance.
F = ±1%; G = ±2%; J = ±5%; K = ±10%; M = ±20%;
R33 M = 0.33 Ω ±20%; 6K8F = 6.8 kΩ ± 1%.

Capacitor values are indicated as:

0.68 pF	marked	p68	6.8 nf	marked	6n8
6.8 pf		6p8	1000 nF		1 μ0
1000 pF		1n0	6.8 μF		6 μ8

Tolerance is indicated by letters as for resistors. Values up to 999 pF are marked in pF, from 1000 pf to 999 000 pF (=999 nF) as nF (1000 pF = 1 nF) and from 1000 nF (=1 μF) upwards as μF.

Some capacitors are marked with a code denoting the value in pF (first two figures) followed by a multiplier as a power of ten (3 denotes 10^3). Letters denote tolerance as for resistors but C= ±0.25 pF.
For example 123J = 12 pF × 10^3 ± 5% = 12 000 pF (or 0.12 μF).

Appendix C: Greek symbols

Greek letters used as symbols in electronics

Greek letter	Capital (used for)	Small (used for)
Alpha	–	α (angle, temperature coefficient of resistance, current amplification factor for common-base transistor)
Beta		β (current amplification factor for common-emitter transistor)
Delta	Δ (increment, mesh connection)	δ (small increment)
Epsilon	–	ϵ (permittivity)
Eta	–	η (efficiency)
Theta	–	θ (angle, temperature)
Lambda	–	λ (wavelength)
Mu	–	μ (micro, permeability, amplification factor)
Pi	–	π (circumference/diameter)
Rho	–	ρ (resistivity)
Sigma	Σ (sum of)	σ (conductivity)
Phi	Φ (magnetic flux)	ϕ (angle, phase difference)
Psi	Ψ (electric flux)	–
Omega	Ω (ohm)	ω (solid angle, angular velocity, angular frequency)

Appendix D: Battery information

1. TYPES OF BATTERY

Alkaline primary cells

These cells and batteries offer very long service life compared with Leclanché types in equipments having high current drains. In addition these cells have very low self-discharge currents and are completely sealed.

Available in sizes AAA, AA, C, D and PP3.

Silver/mercuric oxide primary cells

These button cells are suitable for use in calculators, small tools, cameras, clocks, watches, etc. They may often be used as replacements for previously fitted alkaline manganese button cell types. Supplied in boxes of individual blister packs.

Available in six of the most popular sizes.

Ni-Cad sintered cells

Applications where extreme ruggedness and/or high peak currents are required. In addition these cells offer very long service life and can be electrically misused without damage.

Available in sizes N, AAA, AA, C, D and PP9.

Ni-Cad high-temperature sintered cells

Primarily for use in emergency lighting installations these cells and batteries are particularly suitable for charging and discharging at elevated temperatures. Other applications include alarm control panels and emergency and standby areas where higher ambient temperatures are experienced.

Available as single D cells and 3 × D cell battery packs.

Note: sintered cells

Have fairly high self-discharge currents and are therefore not suitable for equipment which has to be operational without recharging after being left unattended for long periods of time.

Ni-Cad mass plate cells

Applications where small size and ruggedness are required. These cells have low self-discharge currents and are ideal in small portable equipment.

A range of sizes including PP3 is available.

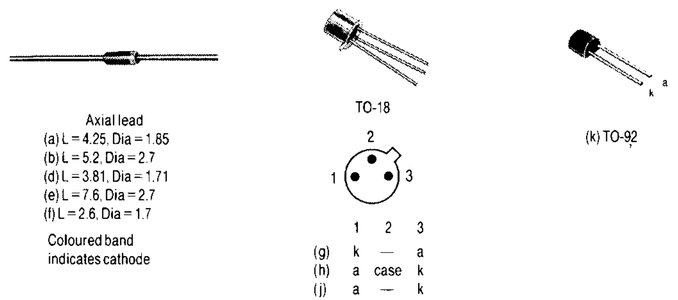
2. BATTERY RATING AND STORAGE

Battery type and Stock No.	Ratings			Storage		
	Voltage		Capacity	Shelf life (see note 1)	Storage life	Storage temp.
	Fully charged	Discharged				
Alkaline Cells						
591–657 AAA	1.50 V	0.90 V	0.7 Ah			
591–225 AA	1.50 V	0.90 V	1 Ah	24 months	24 months	−20°C−+50°C
591–231 C	1.50 V	0.90 V	4 Ah	$T_a = 20$°C	@$T_a = 20$°C	
591–247 D	1.50 V	0.90 V	8 Ah		(see note 2)	
591–792 PP3	9.00 V	5.40 V	0.4 Ah			
Silver Oxide Cells						
592–082 SR41	1.55 V	1.2 V	38 mAh	24 months	24 months	
592–098 SR43	1.55 V	1.2 V	120 mAh	$T_a = 20$°C	@$T_a = 20$°C	−10°C−+25°C
592–105 SR44	1.55 V	1.2 V	140 mAh	to 90%	to 90%	recommended
592–111 SR54	1.55 V	1.2 V	80 mAh	capacity	capacity	
Mercuric Oxide Cells						
592–127 PX/RM 625	1.35 V	0.9 V	350 mAh	24 months	24 months	
592–133 PX/RM 400	1.35 V	0.9 V	70 mAh	$T_a = 20$°C	@$T_a = 20$°C	−10°C−+25°C
				to 90%	to 90%	recommended
				capacity	capacity	
Ni-Cad Sintered Cells			(5 hr discharge rate)			
592–026 N	1.24–1.27 V	1.00 V	150 mAh			
591–146 AAA	1.24–1.27 V	1.00 V	180 mAh	120 days		
591–051 AA	1.24–1.27 V	1.00 V	500 mAh	$T_a = 0$°C		
591–045 C	1.24–1.27 V	1.00 V	2 Ah	40 days	>5 years	−40°C−+60°C
591–039 D	1.24–1.27 V	1.00 V	4 Ah	$T_a = 20$°C	(see note 2)	
591–095 PP9	8.68–8.90 V	7.00 V	1.2 Ah	11 days		
				$T_a = 40$°C		
Ni-Cad High Temp Cells			(5 hr discharge rate)			
592–032 D	1.24–1.27 V	1.00 V	4 Ah			−45°C−+65°C
592–048 3 ×D, Stick	3.72–3.81 V	3.00 V	4 Ah	55 days	>5 years	possible
592–054 3 ×D, Plate	3.72–3.81 V	3.00 V	4 Ah	$T_a = 20$°C	(see note 2)	0°C−+45°C
						recommended
Ni-Cad Mass Plate						
591–477 PCB Battery	3.72–3.81 V	3.00 V	(10 hr discharge rate)			
591–089 PP3	8.70–8.90 V	7.00 V	100 mAh	26 months		Max limits
591–168 Button Cell	1.24–1.27 V	1.00 V	110 mAh	$T_a = 0$°C	>5 years	−40°C−+50°C
591–174 Button Cell	1.24–1.27 V	1.00 V	170 mAh	10 months	(see note 2)	0°C−+45°C
591–180 Stack	8.70–8.90 V	7.00 V	280 mAh	$T_a = 20$°C		recommended
591–196 Stack	6.00–6.20 V	5.00 V	170 mAh	1 month		
			280 mAh	$T_a = 40$°C		

Note:
1. Period after which only 60% of the stated capacity is obtainable.
2. Period after which battery should be replaced with new stock.

Appendix E: Small signal diodes

Signal diodes



Application Code:

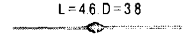
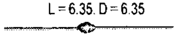
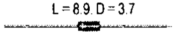
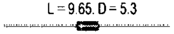
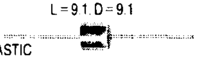
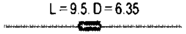
General Purpose – Switching – ● High speed
VHF Tuner – Low leakage/low capacitance

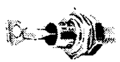
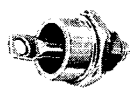
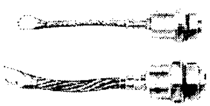
Package	V_{RRM} max (V)	I_F(AV) max (mA)	V_F max (V)	@	I_F (mA)	App'n Code	Order Code
(e)	100	140	0.8		250		AAZ15■
(e)	75	140	0.8		250		AAZ17■
(a)	30	100	1.1		100		BA317
(f)	35	100	1.2		100		BA482
(f)	125	225	1.0		200		BAS45
(a)	100	100	0.45		1		BAT41◆
(a)	30	100	0.4		10		BAT42◆
(a)	30	100	0.45		15		BAT43◆
(a)	100	150	0.45		10		BAT46◆
(a)	20	350	0.4		10		BAT47◆
(a)	40	350	0.4		10		BAT48◆
(b)	80	1000	0.42		100		BAT49◆
(f)	40	30	0.41		1	●	BAT81◆
(f)	60	30	0.41		1	●	BAT83◆
(f)	30	200	0.4		10	●	BAT85◆
(a)	60	300	1.0		200	●	BAV10
(a)	120	250	1.2		200		BAV19
(a)	200	250	1.2		200		BAV20
(a)	250	250	1.2		200		BAV21
(g)	35	50	1.0		10		BAV45
(a)	75	100	1.0		100	●	BAW62
(a)	50	75	1.0		20	●	BAX1301
(a)	150	200	1.3		100		BAX16
(a)	150	200	1.3		100		BAX1601
(a)	150	200	1.3		100		BAX16ES
(a)	100	200	1.0		100		BAY72
(a)	100	200	0.8		10		BAY73
(b)	20	1000	0.55		1000		BYV10–20◆
(b)	30	1000	0.55		1000		BYV10–30◆
(b)	40	1000	0.55		1000		BYV10–40◆
(b)	60	1000	0.7		1000		BYV10–60◆
(k)	35	10	1.5		5		JPAD100
(k)	35	10	1.5		5		JPAD50
(j)	35	50	1.5		5		PAD100
(h)	45	50	1.5		5		PAD5
(e)	30	110	0.54		130		OA47■
(e)	30	10	2.0		30	●	OA9005■
(e)	115	50	2.1		30		OA9105■
(e)	115	50	1.85		30		OA9505■
(a)	150	80	1.15		30		OA20201
(e)	400VRW	400	1.0		400		ZS104
(a)	100	75	1.0		10	●	1N914
(a)	100	75	1.0		10	●	1N916
(a)	125	200	0.8		10		1N3595
(a)	75	150	1.0		10	●	1N4148
(a)	75	200	1.0		10	●	1N4148-NSC
(a)	75	75	1.0		10	●	1N4149
(a)	50	200	0.74		10	●	1N4150
(a)	75	200	1.0		20	●	1N4446
(a)	75	150	1.0		100	●	1N4448
(a)	75	200	1.0		100	●	1N4448-NSC
(d)	40	75	1.0		10		1S44
(d)	50	200	1.2		200		1S920
(d)	100	200	1.2		200		1S921
(d)	150	200	1.2		200		1S922
(d)	200	200	1.2		200		1S923

■ Germanium ◆ Silicon schottky barrier

Appendix F: Power diodes

Power diodes

Package (Not relative size)	**IF (AV) Max Mean F'ward Current**	**VRRM**								
		50–100	**200**	**300**	**400**	**600**	**800**	**1000**	**1200**	**1600**
L = 4.6 D = 3.8  GLASS	**1A**				1N5060					
L = 5 D = 2.7  PLASTIC	**1A**	IN4001 (50 V)								
		IN4002 (100 V)	1N4003		1N4004	1N4005	1N4006	1N4007		
		1N4001TR■ (50 V)								
		1N4002TR■ (100 V)	1N4003TR■		1N4004TR■	1N4005TR■	1N4006TR■	1N4007TR■		
		1N4001GP◆ (50 V)	1N4003GP◆		1N4004GP◆	1N4005GP◆	1N4006GP◆	1N4007GP◆		
		1N4002GP◆ (100 V)								
L = 6.35 D = 6.35  GLASS	**3A**		1N5624			1N5626				
L = 8.9 D = 3.7  PLASTIC	**3A**	30S1(100 V)	30S2		30S4	30S6	30S8	30S10		
L = 9.65 D = 5.3  PLASTIC	**3A**		MR502		MR504					
		1N5401(100 V)	1N5402		1N5404	1N5406		1N5408		
L = 9.1 D = 9.1  PLASTIC	**6A**	G1750(50 V)								
		G1751(100 V)	G1752			G1756				
L = 9.5 D = 6.35  PLASTIC	**6A**	60S1D10DE (100 V)	60S2		60S4	60S6	60S8	60S10		
 TO-220	**6.5A**			BY249–300		BY249–600				

	**10A**				BYX98–300**		BYX98–600**			BYX98–1200**	
					BYX98–300R*		BYX98–600R*			BYX98–1200R*	
	12A			12F20**					12F100**		
				12FR20*							
	15A				BYX99–300**					BYX99–1200**	
10-32 UNF 2A	**16A**		M16–100**	M16–200**		M16–400**		M16–800**		M16–1200**	
			M16–100R*	M16–200R*		M16–400R*		M16–800R*		M16–1200R*	
				16F20**				16F80**	16F100**	16F120**	
									16FR100*	16FR120*	
METRIC M5 	**30A**				BYX96–300**		BYX96–600**			BYX96–1200**	BYX96–1600R**
					BYX96–300R*		BYX96–600R*			BYX96–1200R*	BYX96–1600R*
	**40A**	(A)	M41–100**	M41–200**			M41–600**				
		(A)	M41–100R*	M41–200R*			M41–600R*				
		(A)	40HF10**	40HF20**		40HF40**	40HF60**	40HF80**	40HF100**	40HF120**	
		(A)	40HFR10*	40HFR20*		40HFR40*	40HFR60*	40HFR80*	40HFR100*	40HFR120*	
	47A	(B)					BYX97–600**			BYX97–1200**	BYX97–1600**
		(B)					BYX97–600R*			BYX97–1200R*	BYX97–1600R*
(A) ¼-28 UNF 2A	**70A**	(A)	M71–100**	M71–200**		M71–400**	M71–600**	M71–800**			
(B) METRIC M6		(A)	M71–100R*	M71–200R*		M71–400R*	M71–600R*	M71–800R*			
		(A)	70HF10**	70HF20**		70HF40**	70HF60**	70HF80**	70HF100**	70HF120**	
		(A)	70HFR10*	70HFR20*		70HFR40*	70HFR60*	70HFR80*	70HFR100*	70HFR120*	
	**150A**	(A)	45L10**	45L20**		45L40**	45L60**	45L80**	45L100**	45L120**	
		(A)	45LR10*	45LR20*		45LR40*	45LR60*			45LR120*	
	250A	(B)	70U10**	70U20**		70U40**				70U120**	
(A) ½-20 UNF 2A (B) ¾-16 UNF 2A		(B)	70UR10*	70UR20*						70UR120*	

Important – Forward current ratings quoted on stud mounting devices are maximum rating. Manufacturer's data should always be consulted as in some cases devices have to be forced air cooled to obtain the maximum ratings quoted

**Denotes stud cathode
*Denotes stud anode
■ Denotes bandoliered

◆ Glass passivated hermetically sealed construction with proven reliability equal to MIL-S-19500

Appendix G: Zener diodes

Zener diodes

Mftr	Philips	SGS-Thomson	SGS-Thomson	Philips	Philips	Philips	–	Philips	Philips	Philips
Nominal Zener Voltage	**WATTAGE (All + 5% Voltage Tolerance)**									
	400 mW	**500 mW**	**1.3 W**	**1.3 W**	**2.5 W**	**3 W**	**5 W**	**6 W**	**20 W**	**75 W**
2.4 V	BZX79C2V4	BZX55C2V4								
2.7 V	BZX79C2V7	BZX55C2V7	BZX85C2V7							
3 V	BZX79C3V0	BZX55C3V0	BZX85C3V0							
3.3 V	BZX79C3V3	BZX55C3V3	BZX85C3V3				1N5333B			
3.6 V	BZX79C3V6	BZX55C3V6	BZX85C3V6				1N5334B			
3.9 V	BZX79C3V9	BZX55C3V9	BZX85C3V9				1N5335B			
4.3 V	BZX79C4V3	BZX55C4V3	BZX85C4V3				1N5336B			
4.7 V	BZX79C4V7	BZX55C4V7	BZX85C4V7				1N5337B			
5.1 V	BZX79C5V1	BZX55C5V1	BZX85C5V1	BZV85C5V1			1N5338B			
5.6 V	BZX79C5V6	BZX55C5V6	BZX85C5V6	BZV85C5V6			1N5339B			
6.2 V	BZX79C6V2	BZX55C6V2	BZX85C6V2	BZV85C6V2			1N5341B			
6.8 V	BZX79C6V8	BZX55C6V8	BZX85C6V8	BZV85C6V8			1N5342B			
7.5 V	BZX79C7V5	BZX55C7V5	BZX85C7V5	BZV85C7V5	BZX70C7V5	BZT03C7V5	1N5343B		BZY93C7V5#	BZY91C7V5
8.2 V	BZX79C8V2	BZX55C8V2	BZX85C8V2	BZV85C8V2	BZX70C8V2	BZT03C8V2	1N5344B		BZY93C8V2#	

9.1 V	BZX79C9V1	BZX55C9V1	BZX85C9V1	BZV85C9V1	BZX70C9V1	BZT03C9V1	1N5346B		BZY93C9V1#	
10 V	BZX79C10	BZX55C10	BZX85C10	BZV85C10	BZX70C10	BZT03C10	1N5347B	BZW03-C10 NEW	BZY93C 10#	BZY91C10
11 V	BZX79C11	BZX55C11	BZX85C11	BZV85C11	BZX70C11	BZT03C11	1N5348B		BZY93C11	
12 V	BZX79C12	BZX55C12	BZX85C12	BZV85C12	BZX70C12	BZT03C12	1N5349B	BZW03-C12 NEW	BZY93C12#	BZY91C12
13 V	BZX79C13	BZX55C13	BZX85C13	BZV85C13	BZX70C13	BZT03C13	1N5350B		BZY93C13#	
15 V	BZX79C15	BZX55C15	BZX85C15	BZV85C15	BZX70C15	BZT03C15	1N5352B		BZY93C15#	BZY91C15#
16 V	BZX79C16	BZX55C16	BZX85C16	BZV85C16	BZX70C16	BZT03C16	1N5353B		BZY93C16#	
18 V	BZX79C18	BZX55C18	BZX85C18	BZV85C18	BZX70C18	BZT03C18	1N5355B		BZY93C18#	BZY91C18#
20 V	BZX79C20	BZX55C20	BZX85C20	BZV85C20	BZX70C20	BZT03C20	1N5357B		BZY93C20#	BZY91C20
22 V	BZX79C22	BZX55C22	BZX85C22	BZV85C22	BZX70C22	BZT03C22	1N5358B		BZY93C22	
24 V	BZX79C24	BZX55C24	BZX85C24	BZV85C24	BZX70C24	BZT03C24	1N5359B	BZW03-C24 NEW	BZY93C24#	BZY91C24
27 V	BZX79C27	BZX55C27	BZX85C27	BZV85C27	BZX70C27	BZT03C27	1N5361B	BZW03-C27 NEW	BZY93C27#	BZY91C27
30 V	BZX79C30	BZX55C30	BZX85C30	BZV85C30	BZX70C30	BZT03C30	1N5363B		BZY93C30#	BZY91C30
33 V	BZX79C33	BZX55C33	BZX85C33	BZV85C33	BZX70C33	BZT03C33	1N5364B		BZY93C33#	BZY91C33
36 V	BZX79C36	BZX55C36	BZX85C36	BZV85C36	BZX70C36	BZT03C36	1N5365B	BZW03-C36 NEW	BZY93C36	BZY91C36
39 V	BZX79C39	BZX55C39	BZX85C39	BZV85C39	BZX70C39	BZT03C39	1N5366B		BZY93C39#	
43 V	BZX79C43	BZX55C43	BZX85C43	BZV85C43	BZX70C43	BZT03C43	1N5367B		BZY93C43	BZY91C43
47 V	BZX79C47	BZX55C47	BZX85C47	BZV85C47	BZX70C47	BZT03C47	1N5368B	BZW03-C47 NEW	BZY93C47	BZY91C47
51 V	BZX79C51	BZX55C51	BZX85C51	BZV85C51	BZX70C51	BZT03C51	1N5369B	BZW03-C51 NEW	BZY93C51	BZY91C51
56 V	BZX79C56	BZX55C56	BZX85C56	BZV85C56	BZX70C56	BZT03C56	1N5370B		BZY93C56	
62 V	BZX79C62	BZX55C62	BZX85C62	BZV85C62	BZX70C62	BZT03C62	1N5372B		BZY93C62	BZY91C62
68 V	BZX79C68	BZX55C68	BZX85C68	BZV85C68	BZX70C68	BZT03C68	1N5373B		BZY93C68	BZY91C68
75 V	BZX79C75	BZX55C75	BZX85C75	BZV85C75	BZX70C75	BZT03C75	1N5374B	BZW03-C75 NEW	BZY93C75#	BZY91C75
82 V		BZX55C82	BZX85C82			BZT03C82	1N5375B	BZW03-C82 NEW		

Zener diodes continued

Mftr	Philips	SGS-Thomson	SGS-Thomson	Philips	Philips	Philips	–	Philips	Philips	Philips
Nominal Zener Voltage	**WATTAGE (All + 5% Voltage Tolerance)**									
	400 mW	**500 mW**	**1.3 W**	**1.3 W**	**2.5 W**	**3 W**	**5 W**	**6 W**	**20 W**	**75 W**
91 V		BZX55C91	BZX85C91			BZT03C91	1N5377B			
100 V		BZX55C100	BZX85C100			BZT03C100	1N5378B			
110 V		BZX55C110	BZX85C110			BZT03C110	1N5379B			
120 V		BZX55C120	BZX85C120			BZT03C120	1N5380B			
130 V		BZX55C130	BZX85C130			BZT03C130	1N5381B			
150 V		BZX55C150	BZX85C150			BZT03C150	1N5383B			
160 V		BZX55C160	BZX85C160			BZT03C160	1N5384B			
180 V		BZX55C180	BZX85C180			BZT03C180	1N5386B			
200 V		BZX55C200	BZX85C200			BZT03C200	1N5388B			
220 V						BZT03C220				
240 V						BZT03C240				
270 V						BZT03C270				

Appendix H: Epoxy-potted bridge rectifiers

Voltage	Current	Device No.
200	2	KBPC 102
400	2	KBPC 104
600	2	KBPC 106
800	2	KBPC 108
200	4	KBU 4D
800	4	KBU 4K
200	6	KBPC 802
800	6	KBPC 808
200	12	SKB 25/02
800	12	SKB 25/08
1200	12	SKB 25/12
50	25	KBPC 25005
200	25	KBPC 2502
600	25	KBPC 2506
200	35	KBPC 3502
600	35	KBPC 3506

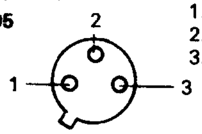
Notes:

1. The bridge assembly should be mounted on a heat sink.
2. Current ratings are for resistive loads. When the rectifier is used on a battery or capacitive load the current rating should be multiplied by 0.8.

Appendix I: Transistors

Transistor pin connections

TO18, TO5, TO39
TO205



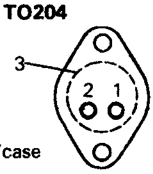
(A)
1. Emitter
2. Base
3. Collector

(B)
1. Source
2. Drain
3. Gate

(C)
1. Source
2. Gate
3. Drain

(D)
1. Drain
2. Source
3. Gate

TO3, SO55, TO204

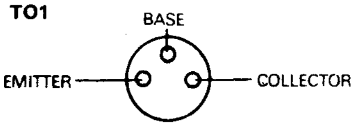


(A)
1. Base
2. Emitter
3. Collector/case

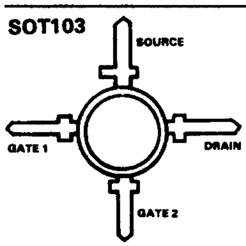
(B)
1. Gate
2. Drain
3. Source/case

(C)
1. Gate
2. Source
3. Drain/case

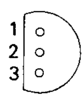
TO1



SOT103



TO92
TO237



plastic

(A)
1. Base
2. Collector
3. Emitter

(B)
1. Emitter
2. Base
3. Collector

(C)
1. Collector
2. Base
3. Emitter

(D)
1. Drain
2. Gate
3. Source

(E)
1. Gate
2. Source
3. Drain

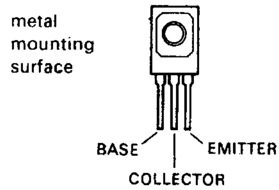
(F)
1. Gate
2. Drain
3. Source

(G)
1. Source
2. Gate
3. Drain

(H)
1. Source
2. Drain
3. Gate

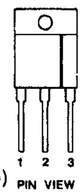
TO126, 77–03, SOT32

plastic



TAB, TO202, TO220, TO218, SOT93

plastic



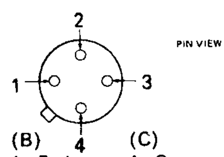
(A)
1. Base
2. Collector
3. Emitter

(AB)
1. Gate
2. Drain (tab)
3. Source

(B)
1. Source
2. Gate
3. Drain (tab)

(AC)
1. Base
2. Collector (tab)
3. Emitter

TO72



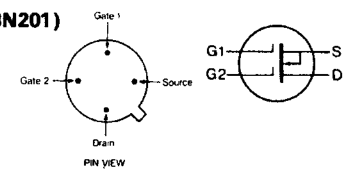
(A)
1. Base
2. Emitter
3. Collector

(B)
1. Emitter
2. Base
3. Collector

(C)
1. Source
2. Drain
3. Gate

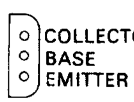
(D)
1. Source
2. Gate
3. Drain
4. Substrate

TO72 (3N201)



E Line

plastic



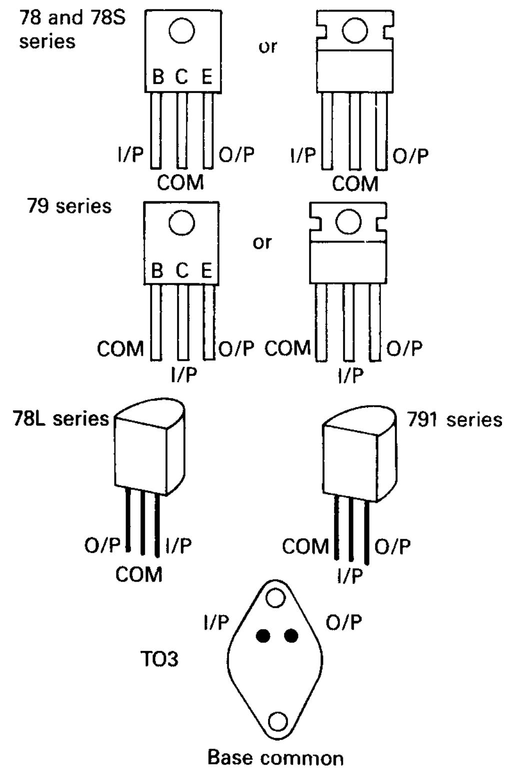
Appendix J: Voltage regulators

Voltage regulators

Fixed voltage series regulators

Description	Output		Case	Stock No.	Suitable transformer		
	Voltage	Current			Stock No.	Sec. Voltage	VA
78L05 RS309K	5 V	100 mA	T092	306–190	207–188	9(S)	6
(LM309K)	5 V	1.2 A	T03	305–614	207–122	9(S)	20
7805	5 V	1.0 A	T0220	305–888	207–122	9(S)	20
78S05	5 V	2 A	T0220	633–026	207–239	9(S)	50
78H05	5 V	5 A	T03	307–301	207–239	9(S)	50
78L12	12 V	100 mA	T092	306–207	207–217	15(P)	6
7812	12 V	1.0 A	T0220	305–894	207–267	15(P)	50
78S12	12 V	2 A	T0220	633–032	207–267	15(P)	50
78H12	12 V	5 A	T03	307–317	207–289	12(S)	100
78L15	15 V	100 mA	T092	306–213	207–217	15(P)	6
7815	15 V	1.0 A	T0220	305–901	207–267	15(P)	50
78S15	15 V	2 A	T0220	633–048	207–267	15(P)	50
78L24	24 V	100 mA	T092	306–229	207–201	24(S)	6
7824	24 V	1.0 A	T0220	305–917	207–251	24(S)	50
78S24	24 V	2 A	T0220	633–054	207–295	24(S)	100
79L05	−5 V	100 mA	T092	306–235	207–188	9(S)	6
7905	−5 V	1.2 A	T0220	306–049	207–122	9(S)	20
79L12	−12 V	100 mA	T092	306–241	207–217	15(P)	6
7912	−12 V	1.2 A	T0220	306–055	207–267	15(P)	50
79L15	−15 V	100 mA	T092	306–257	207–217	15(P)	6
7915	−15 V	1.2 A	T0220	305–923	207–267	15(P)	50
79L24	24 V	100 mA	T092	306–263	207–201	24(S)	6
7924	−24 V	1.0 A	T0220	306–184	207–251	24(S)	50

Source: RS Data Library.



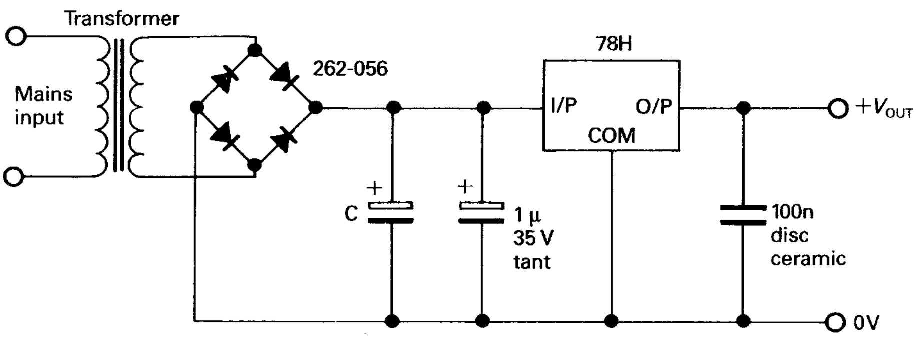
78H05 AND 78H12 FIXED HYBRID REGULATORS

Two fixed voltage hybrid regulators, housed in T03 style metal cases, capable of supplying output currents up to 5 A. The internal circuitry limits the junction temperature to a safe value and provides automatic thermal overload protection.

Safe operating protection is also incorporated making the regulators virtually damage proof.

In order to achieve maximum performance the internal power dissipation must be kept below 50 W. Transformer and heat sink selections are dependent upon the exact application.

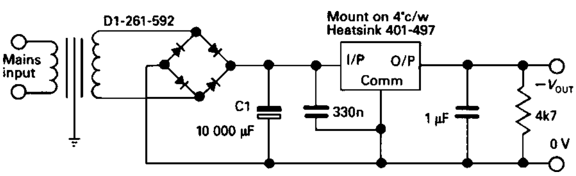
78H – BASIC CIRCUIT, FIXED VOLTAGE



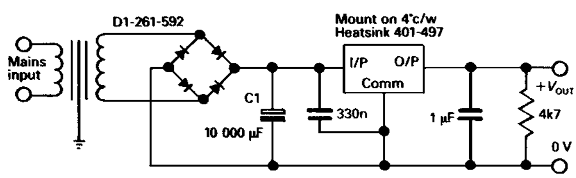
Regulator	Output voltage	Transformer	Heat sink	C
78H05	+5 V d.c.	207–239 (S)	401–807,1/1°c/w	15 000 µF 16 V
78H12	+12 V d.c.	207–289(S)	401–403,2/1°c/w	22 000 µF 25 V

Source: RS Data Library.

79 Series negative regulators

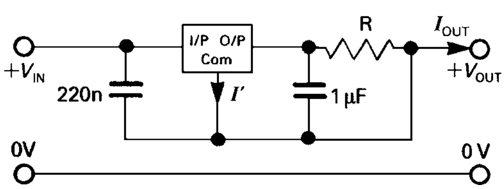


78 Series positive regulators



For T03 types $I' = 10$ mA typ.
For 78S series $I' = 8$ mA typ.
For 78/79 series $I' = 4.5$ mA typ.
For 78L/79L series $I' = 3.5$ mA typ.

Constant current generator



Source: RS Data Library.

Circuit gives constant current through load provided V_{OUT} does not exceed $V_{IN} - (V_R + 2.5)$. [$V_{IN} - (V_R + 3)$ for 78S series.] Select R to give designed constant current I_{OUT}

$$I_{OUT} = \frac{V_R}{R} + I'$$

where V_R is the basic regulator voltage.

INCREASING BASIC REGULATOR VOLTAGE

The input voltage V_{IN} should be derived from a suitable transformer, rectifier and smoothing capacitor circuit. Note V_{IN} must be greater (within maximum ratings) than $V_{OUT} + 2.5$ V.

Figure A1 gives higher output voltage than basic circuit but with reduced regulation.

$$V_{OUT} = V_R \left(1 + \frac{R_2}{R_1}\right) + I'R_2$$

$$I_{R1} \geq 5 \times I'$$

where V_R = basic regulator voltage
I' = 10 mA (T03)
= 8 mA (78S series)
= 4.5 mA (78/79 series)
= 3.5 mA (78L/79L series)

Figure A2 gives better regulation than Fig. A1.

$$V_{OUT} = V_R + V_1 + 0.6$$

$$\text{where } V_1 = \frac{R_2 V_{OUT}}{R_1 + R_2}$$

$$\text{and } \frac{R_1}{R_2} = \frac{V_R + 0.6}{V_{OUT} - (V_R + 0.6)}$$

For example, for 9 V output with 5 V regulator

$$R_1 = 5\text{k}6 \quad R_2 = 3\text{k}3$$

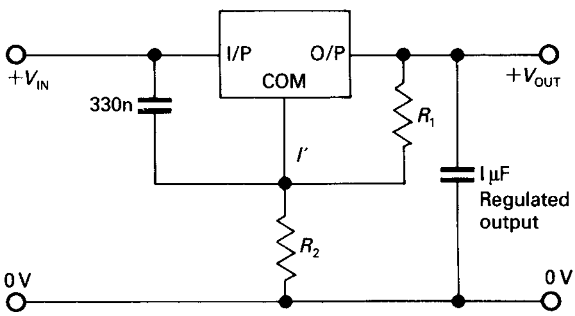


Fig. A1

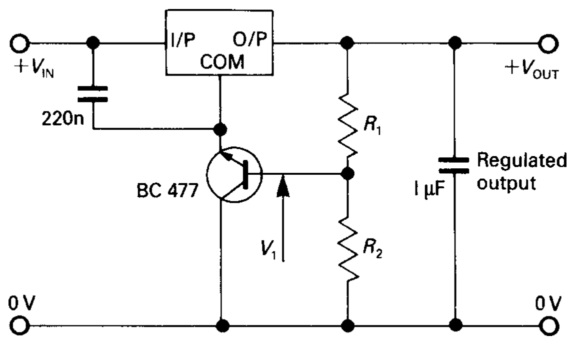
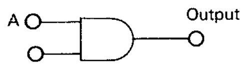
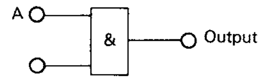
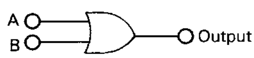
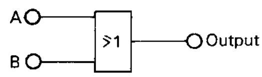
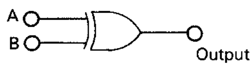
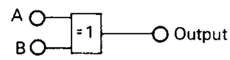
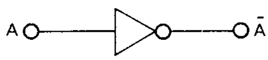
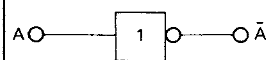
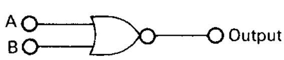
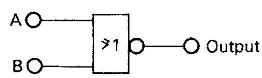
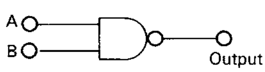
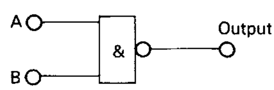


Fig. A2

Appendix K: Comparison of British and American logic gate symbols

Comparison of British and American logic gate symbols

Logic gate	American symbol	British symbol	Truth table
AND			A B OUT 0 0 0 0 1 0 1 0 0 1 1 1
OR			A B OUT 0 0 0 0 1 1 1 0 1 1 1 1
Exclusive - OR			A B OUT 0 0 0 0 1 1 1 0 1 1 1 0
NOT			A OUT 0 1 1 0
NOR			A B OUT 0 0 1 0 1 0 1 0 0 1 1 0
NAND			A B OUT 0 0 1 0 1 1 1 0 1 1 1 0

Appendix L: Health and Safety Executive (HSE) publications and information

HSE Books, Information Leaflets and Guides may be obtained from
HSE Books, P.O. Box 1999, Sudbury, Suffolk CO10 6FS

HSE Infoline – Telephone: 01541 545500 or write to
HSE Information Centre, Broad Lane, Sheffield S3 7HO

www.gov.uk link to HSE books
www.legislation.HMSO.gov.uk link to Acts and Regulations

Environmental Health Department of the Local Authority
Look in the local telephone directory under the name of the authority.

HSE AREA OFFICES

01 South West
Inter City House, Mitchell Lane, Victoria Street, Bristol BS1 6AN
Telephone: 01171 290681

02 South
Priestley House, Priestley Road,
Basingstoke RG24 9NW Telephone: 01256 473181

03 South East
3 East Grinstead House, London Road,
East Grinstead, West Sussex RH19 1RR
Telephone: 01342 326922

05 London North
Maritime House, 1 Linton Road, Barking,
Essex IG11 8HF Telephone: 0208 594 5522

06 London South
1 Long Lane London SE1 4PG
Telephone: 0207 407 8911

07 East Anglia
39 Baddow Road, Chelmsford, Essex CM2 OHL
Telephone: 01245 284661

08 Northern Home Counties
14 Cardiff Road, Luton, Beds LU1 1PP
Telephone: 01582 34121

09 East Midlands
Belgrave House, 1 Greyfriars, Northampton NN1 2BS
Telephone: 01604 21233

10 West Midlands
McLaren Building, 2 Masshouse Circus, Queensway
Birmingham B4 7NP
Telephone: 0121 200 2299

11 Wales
Brunel House, Nizalan Road, Cardiff CF2 1SH
Telephone: 02920 473777

12 Marches
The Marches House, Midway, Newcastle-under-Lyme,
Staffs ST5 1DT Telephone: 01782 717181

13 North Midlands
Brikbeck House, Trinity Square, Nottingham NG1 4AU
Telephone: 0115 470712

14 South Yorkshire
Sovereign House, 40 Silver Street, Sheffield S1 2ES
Telephone: 0114 739081

15 West and North Yorkshire
8 St Paul's Street, Leeds LS1 2LE
Telephone: 0113 446191

16 Greater Manchester
Quay House, Quay Street, Manchester M3 3JB
Telephone: 0161 831 7111

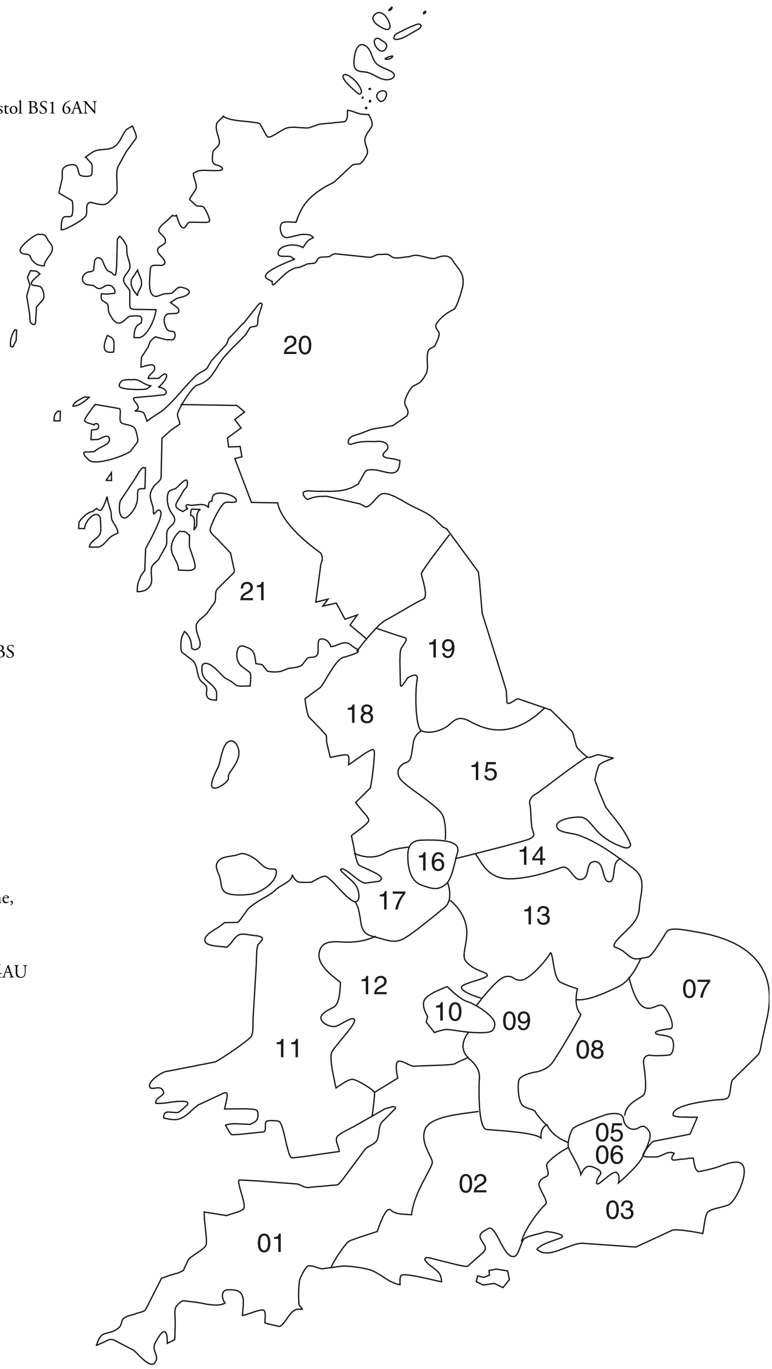
17 Merseyside
The Triad, Stanley Road, Bootle L20 3PG
Telephone: 01229 922 7211

18 North West
Victoria House, Ormskirk Road, Preston PR1 1HH
Telephone: 01772 59321

19 North East
Arden House, Regent Centre, Gosforth, Newcastle upon Tyne NE3 3JN
Telephone: 0191 284 8448

20 Scotland East
Belford House, 59 Belford Road, Edinburgh EH4 3UE
Telephone: 0181 225 1313

21 Scotland West
314 St Vincent Street, Glasgow G3 8XG
Telephone: 0141 204 2646



GLOSSARY

Adder In a computer it is a device which can form the sum of two or more numbers.

Address Information which identifies a particular location in the memory of a computer.

Aerial The part of a communication system from which energy is radiated or received.

ALGOL A symbolic language used to program computers in mathematical and engineering applications.

Alignment The adjustment of tuned circuits so that they respond in a desired way at a given frequency.

AM (amplitude modulation) A method of sending a message on a radio or light wave by varying the amplitude of the wave in response to the frequency of the message.

Amplifier A device whose output is a magnified function of its input.

Analogue signals Signals that respond to or produce a continuous range of values rather than specific values.

Analogue-to-digital converter A circuit designed to convert an analogue voltage into a binary code which can be read by a computer.

AND gate A building block in digital logic circuits.

Astable A circuit which can generate a continuous waveform with no trigger.

Atom The smallest particle of a chemical element that can exist alone or in combination with other atoms.

Attenuator A network designed to reduce the amplitude of a wave without distortion.

Audio frequency Any frequency at which the sound wave can normally be heard. The audio frequencies for most humans are those frequencies between 15 Hz and about 20 kHz.

Automation Any device or system that takes the place of humans in carrying out repetitive and boring jobs.

Band pass filter A filter that passes all frequencies between two specified frequencies.

Bandwidth The range of frequencies amplified or the range of frequencies passed by a filter.

BASIC (beginners all-purpose symbolic instruction code) An introductory high-level computer programming language.

Battery A power source made up of a number of individual cells.

Bias The current or voltage which is applied to part of a circuit to make the circuit function properly.

Binary number A number which can have just two values, 1 and 0.

Bipolar transistor A transistor that depends, for its operation, on both n-type and p-type semiconductors.

Bistable (also flip-flop) A circuit which has two stable outputs which can act as memories for data fed into its input.

Bit A unit of information content.

Boolean algebra A branch of symbolic logic in which logical operations are indicated by operators such as AND, OR and NOT signs.

Bourdon tube A pressure-measuring device made of a flexible tube formed into a C shape. Increasing pressure causes the C to straighten.

Buffer An isolating circuit used to avoid a reaction between a driver and driven circuit.

Bus One or more conductors used as a path for transmitting information from source to destination.

Byte A sequence of adjacent binary bits, usually 8.

Carrier wave A relatively high frequency wave which is suitable for transmission and modulation.

CATV (cable TV) A distribution of TV programmes by means of cables laid underground.

Cell A single source of electric potential.

Chip A small piece of silicon on which a complex miniaturized circuit, called an integrated circuit, is formed by photographic and chemical processes.

Circuit An electrical network in which there is at least one path which can be closed.

Closed loop control A control system which modifies its own behaviour according to feedback information e.g. constant speed control of an electric motor.

Closed loop gain The gain of an amplifier with feedback. Negative feedback reduces amplifier gain. Positive feedback increases amplifier gain.

CMOS (complementary metal oxide semiconductor logic) A logic family used especially in portable equipment.

Co-axial cable A cable formed from an inner and outer cylindrical conductor.

Code A system of symbols which represents information in a form which is convenient for a computer.

Colour code The values and tolerances of components such as resistors indicated by coloured bands.

Combinational logic A digital circuit, e.g. a NAND gate, that produces an output based on the combination of 0 s and 1 s presented to its input.

Communications The transmission of information by means of electromagnetic waves or by signals along conductors.

Comparator An electronic device, e.g. one based on an operational amplifier, that produces an output when the voltages of two input signals are different.

Computer A programmable device used for storing, retrieving and processing data.

CPU (central processor unit) The principal operating and controlling part of a computer, also known as its microprocessor.

Critically damped The degree of damping that provides the best compromise between the undamped response and the overdamped response.

CRO (cathode ray oscilloscope) A test and measurement instrument for showing the patterns of electrical waveforms and for measuring their frequency and other characteristics.

Cutoff frequency The 'corner frequency' of a filter. That frequency at which the signal level falls by 3 dB.

Data-handling Automatic or semi-automatic equipment which can collect, receive, transmit and store numerical data.

Decade counter A binary counter that counts up to a maximum count of ten before resetting to zero.

Decibel (dB) A unit used for comparing the strengths of two signals, such as the intensity of sound and the voltage gain of an amplifier.

Decoder A device that converts coded information, e.g. the binary code into a more readily understood code such as decimal.

Decoupling network A network designed to prevent an interaction between two electric circuits. These usually consist of RL or RC filters.

Demodulator A device for recovering information, e.g. music from a carrier wave.

DIAC Four-layer breakover device used to extend the range of control in a TRIAC circuit.

Dielectric The insulating layer between the conducting plates of a capacitor.

Difference amplifier An operational amplifier circuit that finds the difference between two input voltages.

Differential pressure flowmeter A device for measuring the flow of fluids. Depends on the drop in pressure created when a fluid flows past an obstruction or around a bend.

Differentiator An amplifier that performs the calculus operation of differentiation.

Diffusion The movement of electrons and/or holes from a region of high to low concentration.

Digital computer A system that uses gates, flip-flops, counters etc., to process information in digital form.

Digital-to-analogue converter A device that converts a digital signal into an equivalent analogue signal. DACs are widely used in computer systems for controlling the speed of motors, the brightness of lamps etc.

Digital voltmeter A voltmeter which displays the measured value as numbers composed of digits.

Doping The process of introducing minute amounts of material, the dopant, into a silicon crystal to produce n-type or p-type semiconductors in the making of transistors, integrated circuits and other devices.

Earth electrode A conductor driven into the earth and used to maintain conductors connected to it at earth potential.

Electric charge The quantity of electricity contained in or on a body, symbol Q, measured in coulombs, symbol C.

Electrolyte A substance which produces a conducting medium when dissolved in a suitable solvent.

Electrolytic capacitor A capacitor which is made from two metal plates separated by a very thin layer of aluminium oxide. Electrolytic capacitors offer a high capacitance in a small volume, but they are polarized and need connecting the right way round in a circuit.

Electromagnetic spectrum The family of radiations which all travel at the speed of light through a vacuum and include light, infrared and ultraviolet radiation.

Electron A small negatively charged particle which is one of the basic building blocks of all substances and forms a cloud round the nucleus of an atom.

Electronic ice A system of reference junction compensation used in thermocouple circuits. This is an electronic means of creating the thermocouple reference junction.

Electronics That branch of science and technology which is concerned with the study of the conduction of electricity in a vacuum and in semiconductors and with the application of devices using these phenomena.

emf (electromotive force) The electrical force generated by a cell or battery that makes electrons move through a circuit connected across the terminals of the battery.

Encoder Any device that converts information into a form suitable for transmission by electronic means.

Fan-in The number of logic gate outputs which can be connected to the input of another logic gate.

Fan-out The number of logic gate inputs which may be driven from a logic gate output.

Farad (F) The unit of electrical capacitance and equal to the charge stored in coulombs in a capacitor when the potential difference across its terminals is 1 V.

FAX (facsimile) The process of scanning fixed graphic material so that the image is converted into an electrical signal which may be used to produce a recorded likeness of the original.

Feedback The sending back to the input part of the output of a system in order to improve the performance of the system. There are two types of feedback, positive and negative.

Ferrite One of a class of magnetic materials which have a very low eddy-current loss, used for high-frequency circuit transformers and computer memories.

Ferroxcube A commercially available ferrite.

FET (field-effect transistor) A unipolar transistor that depends for its operation on either n-type or p-type semiconductor material.

Fibre optics The use of hair-thin transparent glass fibres to transmit information on a light beam that passes through the fibre by repeated internal reflections from the walls of the fibre.

Fidelity The quality or precision or the reproduction of sound.

Filter A circuit that passes only signals of a desired frequency or band of frequencies. May be high pass, low pass or band pass.

Flip-flop A device having two stable states, logic 0 or logic 1, and two input terminals corresponding to these states. The device will remain in either state until caused to change to the other by the application of an appropriate signal. In digital electronics, the bistable multivibrator circuit has earned the name ‘flip-flop’.

Float switch Level-sensing limit switch, actuated by a float on the surface of a liquid.

Floppy disc A flexible disc, usually 5.25 inches (133 mm) in diameter, made of plastic and coated with a magnetic film on which computer data can be stored and erased.

FM (frequency modulation) A method of sending information by varying the frequency of a radio or light wave in response to the amplitude of the message being sent. For high-quality radio broadcasts, FM is preferable to AM since it is affected less by interference from electrical machinery and lightning.

Force A directed effort that changes the motion of a body.

Forward bias A voltage applied across a p–n junction which causes electrons to flow across the junction.

Forward breakover voltage The voltage between anode and cathode of an SCR at which forward bias conduction will begin.

Fourier analysis A mathematical method of determining the harmonic component of a complex wave.

Gain The ratio of increase in signal level between the input and output of an amplifier.

Gauge factor The ratio of change in resistance to the change in length of a strain gauge. Approximately 2 for a bonded foil strain gauge.

Gigabyte (GB) A quantity of computer data equal to one thousand million bytes.

Gigahertz (GHz) A frequency equal to one thousand million hertz (10^9 Hz).

Half-wave rectifier A diode, or circuit based on one or more diodes, which produces a direct current from alternating current by removing one half of the a.c. waveform.

Hardware Any mechanical or electronic equipment that makes up a system.

Heat sink A relatively large piece of metal that is placed in contact with a transistor or other component to help dissipate the heat generated within the component.

Henry (H) The unit of electrical inductance.

Hertz (Hz) The unit of frequency equal to the number of complete cycles per second of an alternating waveform.

High pass filter A filter that passes all frequencies above a specified frequency.

Hole A vacancy in the crystal structure of a semiconductor that is able to attract an electron. A p-type semiconductor contains an excess of holes.

Impedance (Z) The resistance of a circuit to alternating current.

Impurity An element such as boron that is added to silicon to produce a semiconductor with desirable electrical qualities.

Inductor An electrical component, usually in the form of a coil of wire. Inductors are used as 'chokes' to reduce the possibly damaging effects of sudden surges of current, and in tuned circuits.

Information technology (IT) The gathering, processing and circulation of information by combining the data-processing power of the computer with the message-sending capability of communications.

Input/output port The electrical 'window' on most computer systems that allows the computer to send data to and receive data from an external device.

Instrumentation amplifier A difference amplifier with very high input impedances at both inputs.

Insulator A material, e.g. glass, that does not allow electricity to pass through it.

Integrated circuit (IC) An often very complex electronic circuit which has resistors, transistors, capacitors and other components formed on a single silicon chip.

Integrator An amplifier circuit that performs the calculus function of integration.

Interface A circuit or device, e.g. a modem, that enables a computer to transfer data to and from its surroundings or between computers.

Inverting amplifier An amplifier whose output is 180 degrees out of phase with its input.

Ion An atom or group of atoms that has gained or lost one or more electrons, and which therefore carries a positive charge.

Isothermal block A connecting block used with thermocouples.

Jack A connecting device which is arranged for the insertion of a plug to which the wires of a circuit may be connected.

Joule The SI unit of energy.

Junction A region of contact between two dissimilar metals (as in a thermocouple) or two dissimilar conductors (as in a diode) which has useful electrical properties.

Kilobit One thousand bits. i.e. 0 s and 1 s of data.

Kilobyte One thousand bytes of data.

Kilohertz (kHz) A frequency equal to 1000 Hz.

Large-scale integration (LSI) The process of making integrated circuits with between 100 and 5000 logic gates on a single silicon chip.

Laser A device that produces an intense and narrow beam of light of almost one particular wavelength. The light from lasers is used in optical communications systems, compact disc players and video disc players. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation.

LCD (liquid crystal display) A display that operates by controlling the reflected light from special liquid crystals, rather than by emitting light as in the light-emitting diode.

LDR (light-dependent resistor) A semiconductor device that has a resistance decreasing sharply with increasing light intensity. The LDR is used in light control and measurement systems, e.g. automatic street lights and cameras.

LED (light-emitting diode) A small semiconductor diode that emits light when current passes between its anode and cathode terminals. Red, green, yellow and blue LEDs are used in all types of display systems, e.g. hi-fi amplifiers.

Limit switch A switch that is arranged to be actuated by a workpiece.

Load The general name for a device e.g. an electric motor, that absorbs electrical energy.

Load cell A device for measuring weight. Weight resting on the device causes compression strain. Weight suspended from the device causes tensile strain. Strain is reported as a change in resistance by a coupled strain gauge.

Logic circuit An electronic circuit that carries out simple logic functions.

Logic diagram A circuit diagram showing how logic gates and other digital devices are connected together to produce a working circuit or system.

Logic gate A digital device e.g. an AND gate, that produces an output of logic 1 or 0 depending on the combination of 1 s and 0 s at its inputs.

Loudspeaker A device used to convert electrical energy into sound energy.

Low pass filter A filter that passes all frequencies below a specific frequency.

LVDT (linear variable differential transformer) A device used for position detection.

Machine code Instructions in the form of patterns of binary digits which enable a computer to carry out calculations.

Magnetic bubble memory (MBM) A device that stores data as a string of magnetic 'bubbles' in a thin film of magnetic material. The MBM can store a very large amount of data in small volume and is ideal for portable computer products such as word processors.

Magnetic reed switch A magnetically operated switch. Made of two or three magnetic leaves in a glass tube. Proximity of a magnet causes the switch to close.

Magnetic storage Magnetic tapes, floppy discs and magnetic bubble memories that store data as local changes in the strength of a magnetic field, and which can be recovered electrically.

Majority carrier The most abundant of the two charge carriers present in a conductor. The majority charge carriers in n-type material are electrons.

Man-machine interface Any hardware, e.g. a keyboard or mouse, that allows a person to exchange information with a computer or machine.

Mark-to-space ratio The ratio of the time that the waveform of a rectangular waveform is *high* to the time it is *low*.

Mass flowmeter A fluid-flow measuring device that measures the mass of the fluid instead of its velocity. Used when great accuracy is required.

Matrix A logical network in the form of a rectangular array of intersections.

Medium waves Radio waves having wavelengths in the range about 200 to 700 m, i.e. frequencies in the range 1.5 to 4.5 MHz.

Megabit A quantity of data equivalent to one million (10^6) bits.

Megabyte A quantity of binary data equal to one million (10^6) bytes. Floppy discs store approximately this amount of data.

Memory That part of a computer system used for storing data until it is needed. A microprocessor in a computer can locate and read each item of data by using an address.

Memory-mapped interface An interface system in which the input/output ports are addressed as memory locations.

Microcomputer A usually portable computer which can be programmed to perform a large number of functions quickly and relatively cheaply. Its main uses are in the home, school, laboratory and office.

Microelectronics The production and use of complex circuits on silicon chips.

Microfarad A unit of electrical capacitance equal to one millionth of a farad (10^{-6} F).

Micron (micrometre) A distance equal to one millionth of a metre. The micron is used for measuring the size and separation of components on silicon chips.

Microprocessor A complex integrated circuit manufactured on a single silicon chip. It is the 'heart' of a computer and can be programmed to perform a wide range of functions. A microprocessor is used in washing machines, cars, cookers, games and many other products.

Microswitch A small mechanically operated switch.

Microwaves Radio waves having wavelengths less than about 300 mm and used for straight line communications by British Telecom and others.

Minority carrier The least abundant of the two charge carriers present in a semiconductor. The minority charge carriers in n-type material are holes.

Modem (modulator/demodulator) A device for converting computer data in digital form into analogue signals for transmission down a telephone.

Modulator A circuit that puts a message on some form of carrier wave.

Monostable A circuit that produces a time delay when it is triggered, and then reverts back to its original, normally stable, state.

Mouse A small hand-operated device connected to a computer by a trailing wire, or by optical means, that makes a cursor move around the screen of a VDU to select operations and make decisions.

MSB (most significant bit) The left-hand binary digit in a digital word.

Multimeter An instrument for measuring current, potential difference and resistance, and used for testing and fault-finding in the design and use of electronic circuits.

Multiplexing A method of making a single communications channel carry several messages.

Multivibrator Any one of three basic types of two-stage transistor circuit in which the output of each stage is fed back to the input of the other stage using coupling capacitors and resistors, and causing the transistors to switch on and off rapidly. The multivibrator family includes the monostable, astable and bistable.

Negative feedback The feeding back to the input of a system a part of its output signal. Negative feed-back reduces the overall gain of an amplifier but increases its bandwidth and stability.

Neutron A particle in the nucleus of an atom which has no electrical charge and a mass roughly equal to that of the proton.

Noise An undesirable electrical disturbance or interference.

Noise (white) Noise which is made up of a frequency spectrum (like white light).

Node A point of zero voltage or zero current on a conductor or the point in a radio wave where the amplitude is zero.

Nucleus The central and relatively small part of an atom that is made up of protons and neutrons.

Open loop control A control system in which no self-correcting action occurs as it does in a closed loop system.

Open loop gain The gain of an amplifier without feedback.

Operational amplifier (Op amp) A very high gain amplifier that produces an output voltage proportional to the difference between its two input voltages. Op amps are widely used in instrumentation and control systems.

Optical fibre A thin glass or plastic thread through which light travels without escaping from its surface.

Opto electronics A branch of electronics dealing with the interaction between light and electricity. Light-emitting diodes and liquid crystal displays are examples of opto electronic devices.

Oscillator A circuit or device, e.g. an audio frequency oscillator, that provides a sinusoidal or square wave voltage output at a chosen frequency. An astable multivibrator is one type of oscillator.

Package The plastic or ceramic material used to cover and protect an integrated circuit.

Parabolic reflector A hollow concave reflector.

Passband The range of frequencies passed by a filter.

Passive filter A filter made of passive components: resistors, capacitors and inductors.

PCB (printed circuit board) A thin board made of electrically insulating material (usually glass fibre) on which a network of copper tracks is formed to provide connections between components soldered to the tracks.

Period The time taken for a wave to make one complete oscillation. The period of the 50 Hz mains frequency is 0.02 s.

Photodiode A light-sensitive diode that is operated in reverse bias. When light strikes the junction the diode goes into reverse breakdown and conducts. It is able to respond rapidly to changes of light.

Photoelectron An electron released from the surface of a metal by the action of light.

Photomask A transparent glass plate used in the manufacture of integrated circuits on a silicon chip.

Photon The smallest 'packet', or quantum, of light energy.

Photoresist A light-sensitive material that is spread over the surface of a silicon wafer from which silicon chips are made.

Photoresistor A transistor that responds to light and produces an amplified output signal. Like photodiodes, photoresistors respond rapidly to light changes and are used as sensors in optical communications systems.

Photovoltaic The property of responding to light with an electrical current. Photovoltaic cells are used in generating electricity from solar energy.

Picofarad (pF) An electrical capacitance equal to one millionth of a microfarad (10^{-12} F).

Piezoelectricity The electricity that crystals, such as quartz, produce when they are squeezed. Conversely, if a potential difference is applied across a piezoelectric crystal, it alters shape slightly. The piezoelectric effect is used in digital watches, hi-fi pick-ups and gas lighters.

Plasma A completely ionized gas at extremely high temperatures.

Port A place on a microcomputer to which peripherals can be connected to provide two-way communication between the computer and the outside world.

Positive displacement flowmeter A device that measures fluid flow by passing the fluid in measured increments. Usually accomplished by alternately filling and emptying a chamber.

Positive feedback The feeding back to the input of a system a part of its output signal. Positive feedback increases the overall gain of an amplifier and is used in an astable multivibrator.

Potential divider Two or more resistors connected in series through which current flows to produce potential differences dependent on the resistor values.

Potentiometer An electrical component, having three terminals, that provides an adjustable potential difference.

Power The rate of doing work. Measured in watts.

Preferred value Manufacturers' standardized component values used in resistor and capacitor values.

Programme A set of instructions used for the collation of data or for the solution of a problem.

Proton A particle that makes up the nucleus of an atom and has a positive charge equal in value to the negative charge of the electrons.

Pulse A short-lived variation of voltage or current in a circuit.

Q-factor The sharpness (or 'quality') of an electronic filter circuit, e.g. a tuned circuit, that enables it to accept or reject a particular frequency.

Quantum The smallest packet of radiant energy, e.g. a photon, that can be transmitted from place to place and described by Planck's quantum theory.

Quartz A crystalline form of silicon dioxide which has piezoelectric properties and can, therefore, be used as a pressure transducer and to provide a stable frequency in, for example, crystal clocks.

Qwerty keyboard A keyboard (e.g. a computer keyboard) that has its keys arranged in the same way as those of a standard typewriter, i.e. the first six letters of the top row spell 'QWERTY'.

Radiation Energy travelling in the form of electromagnetic waves.

Radio The use of electromagnetic waves to transmit or receive electrical signals without connecting wires.

RAM (random access memory) An integrated circuit that is used for the temporary storage of computer programs.

Rectifier A semiconductor diode that makes use of the one-way conducting properties of a p–n junction to convert a.c. to d.c.

Relay A magnetically operated switch that enables a small current to control a much larger current in a separate circuit.

Resistance The opposition offered by a component to the passage of electricity.

Resonance The build-up of large amplitude oscillations in a tuned circuit.

Response time The time required for a system to return to normal following a disturbance.

Reverse bias A voltage applied across a p–n junction (e.g. a diode) which prevents the flow of electrons across the junction.

Rheostat An adjustable resistor.

rms (root mean square) value The value of an alternating current which has the same heating effect as a steady d.c. current. 230 V is the rms value of the mains voltage.

Robot A computer-controlled device that can be programmed to perform repetitive tasks such as paintspraying, welding and machining of parts.

ROM (read-only memory) An integrated circuit that is used for holding data permanently, e.g. for storing the language and graphics symbols used by a computer.

Schmitt trigger A snap-action electronic switch which is widely used to 'sharpen up' slowly changing waveforms.

SCR (silicon-controlled rectifier) A four-layer semiconductor device used in switching circuits. Also known as a thyristor.

Semiconductor A solid material that is a better electrical conductor than an insulator but not such a good conductor as a metal. Diodes, transistors and integrated circuits are based on n-type and p-type semiconductors.

Sensor Any device which produces an electrical signal indicating a change in its surroundings.

Sequential logic A digital circuit that can store information. Sequential logic circuits are based on flip-flops and are the basis of counters and computer memories.

Servosystem An electromechanical system which uses sensors to control and monitor precisely the movement of something.

Short waves Radio waves that have wavelengths between about 2.5 and 15 MHz and which are mainly used for amateur and long-range communications.

Silicon An abundant non-metallic element used for making diodes and transistors. Silicon is doped with small amounts of impurities such as boron and phosphorus to make n-type and p-type semiconductors.

Silicon chip A small piece of silicon on which a complex miniaturized circuit (called an integrated circuit) is formed by photographic and chemical processes.

Small-scale integration (SSI) The process of making integrated circuits.

Software Instructions or programs stored in a computer system.

Solder An alloy of tin and lead that has a low melting point and is used for making electrical connections between components on a circuit board.

Solenoid A coil of copper wire in which an iron rod moves by the magnetic field produced when a current flows through the coil.

Stepping motor An electric motor with a shaft that rotates one step at a time. Stepping (or stepper) motors are used for the precise positioning of robot arms.

Strain Change in dimension of a material when force is applied.

Strain gauge A device used to measure strain. The change in electrical resistance of the strain gauge is a measure of the strain.

Summing amplifier An amplifier whose output is proportional to the sum of two or more input signals, or an amplifier used to add (sum) its input voltages.

System All the parts which make up a working whole.

Tachogenerator A device used to measure motor speed. The output is a voltage or a frequency that is proportional to motor speed.

Telex An audio frequency teleprinter system provided by the Post Office for use over telephone lines.

Tensile strain Strain caused by force pulling on a member.

Thermistor A semiconductor temperature sensor.

Thermocouple A temperature-sensing device whose output is a current or voltage which is proportional to the difference between the temperatures at two junctions of dissimilar metals.

Thermopile A system of several thermocouples in a series-aiding configuration. This configuration increases the sensitivity of the thermocouple.

Thyristor A half-wave semiconductor switching device used for motor speed control and lamp dimming. Also known as a silicon-controlled rectifier (SCR).

Time constant The time taken for the voltage across a capacitor to rise to 63% of its final voltage when it charges through a resistor connected in series with it.

Torque Twisting or rotary force, such as that delivered by a motor shaft.

Transducer A device which converts mechanical or physical quantities into electrical quantities, or a device which converts electrical quantities into physical quantities.

Transformer An electromagnetic device for converting alternating current from one voltage to another.

Transistor A semiconductor device which has three terminals and is used for switching and amplification.

Transmitter A device or equipment which converts audio or video signals into modulated radio frequency signals which are then sent (transmitted) by electromagnetic waves.

TRIAC A full-wave semiconductor switching device used for motor speed control and lamp dimming.

Truth table A list of 0 s and 1 s that shows how a digital logic circuit responds to all possible combinations of binary input signals.

TTL (transistor-transistor logic) The most common type of IC logic in use today.

Tuned circuit A circuit which contains an inductor and a capacitor and can be tuned to receive particular radio signals.

Tweeter A loudspeaker used to reproduce the higher audio frequencies (above 5 kHz).

UHF (ultra-high frequency) Radio waves that have frequencies in the range 500 to 30 000 MHz and are used for TV broadcasts.

UJT (uni-junction transistor) A type of transistor used as a relaxation oscillator in SCR control circuits.

Unipolar transistor A transistor that depends for its operation on either n-type or p-type semiconductor materials as in a field-effect transistor.

Ultrasonic waves Sound waves inaudible to the human ear that have frequencies above about 20 kHz.

Ultraviolet Radiation having wavelengths between the visible violet and the X-ray region of the electromagnetic spectrum.

VDU (video display unit) An input/output device comprising a screen and sometimes a keyboard that enables a person to communicate with a computer.

Velocity flowmeter A device that measures fluid flow directly. The most common is the turbine flowmeter.

VHF (very high frequency) Radio waves that have frequencies in the range 30 to 300 MHz and are used for high-quality radio broadcasts (FM) and TV transmission.

Viewdata An information service that enables telephone subscribers to access a wide range of information held in a database and which is displayed on a TV set coupled to the telephone line by a modem.

VMOS (vertical metal-oxide semiconductor) A type of field-effect transistor. It is a small high-power fast-acting transistor used in audio amplifiers and power switching circuits.

Voltage difference amplifier An amplifier whose output is proportional to the difference between two input voltages.

Wafer A thin disc cut from a single crystal of silicon on which hundreds of integrated circuits are made before being cut up into individual ICs for packaging.

Waveform The shape of an electrical signal, e.g. a sinusoidal waveform.

Wavelength The distance between one point on a wave and the next corresponding point.

Wheatstone bridge A network of resistors used to measure very small changes in resistance.

Woofer A loudspeaker used to reproduce the lower audio frequencies.

Word A pattern of bits (i.e. 1s and 0 s) that is handled as a single unit of information in digital systems; e.g. a byte is an 8-bit word.

Wordprocessor A computerized typewriter that allows written material to be generated, stored, edited, printed and transmitted.

X-axis deflection Horizontal deflection on the screen of a CRO, often used as the time base.

X-rays Penetrating electromagnetic radiation used in industry and in medicine for seeing below the surface of solid materials.

Y-axis deflection Vertical deflection on the screen of a CRO.

Zener diode A special semiconductor diode that is designed to conduct current in the reverse-bias direction at a particular reverse-bias voltage. Zener diodes are widely used to provide stabilized voltages in electronic circuits.

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INDEX

A.C. Parallel Circuits 81
A.C. Series Circuits 76
A.C. Theory 73
Accident Reports 45
Accidents 28
Adequate and Appropriate Precautions 42
Alternating (AC) Waveforms 60
AND Logic Gate 285
Antistatic Precautions 231
Appointed Person 42
Approved Competent Person Scheme 9
Approved Test Instruments 196
Auto-Transformers 104

Balancing Three Phase Loads 111
Bar Charts 150
Barriers and Safe Areas 206, 207
Best Available Technique (BAT) 13
Block Diagrams 157
Breadboards 275
British Standard Quality 27
BS 5750 26
BS 7671 – Wiring Regulations 11
Building Regulations – Part P 9

Cable Size Calculation 179
Cage Rotor 93
Calibration of Instruments 196
Capacitor Circuits 69
Capacitor Colour Code 246
Capacitor Selection 72
Capacitors 67, 243
Cartridge Fuse 171
Cathode Ray Oscilloscope (CRO) 281
Changing Work Patterns 51
Circuit Breakers 172
Circuit Diagrams 158
Circuits – Cooker 226
Circuits – Heating 224
Circuits – Lighting 219
Circuits – Radial 222
Circuits – Ring 222
Clean Air Act 13
Clean Computer Supplies 232
Clip-on Ammeter 191
Commissioning Electrical Systems 211
Communications on Site 155
Competent Person 24, 28
Competent Person Scheme 10
Compound Motor 88
Computer Systems Supplies 232, 233
Conductors 52
Conduit Capacities 125
Construction, Design and Management (CDM) Regulations 8
Construction, Health, Safety and Welfare Regulations 9
Continuity of Ring Conductors Test 198
Continuity Test 197
Continuous Service 19
Control of Major Accidents and Hazards (COMAH) Regulations 8
Control of Substances Hazardous to Health (COSHH) 4
Controlled Waste Regulations 13, 236
Cooker Circuits 226
Critical Path 152
Current Rating of Cables 179
Current Transformers 106

D.C. Motors 86
Damping Instruments 185
Dangerous Substances and Chemical Regulations 15
Dangerous Substances and Explosive Atmospheres (DSEAR) Regulations 8
Data Protection Act 20
Daywork Sheets 162
Delivery Notes 160
Delta and Star Connections 84
Desoldering 272
Digital Electronics 284
Direct Contact with Live Parts 165
Disability Discrimination Act 22
Disconnection Time Calculations 174
Discrimination and Prejudice 21
Discrimination of Protective Device 175
Display Screen Equipment (VDU) Hazards 34
Distribution of Electricity 109
Drawings and Diagrams 155
Duty of Care-Responsibilities 13, 42, 236
Dynamometer Wattmeter 189

Earth Electrode Resistance Test 201
Earth Fault Loop Impedance 176
Earth Fault Loop Impedance Test 205
Earth Fault Protection 167
Electric Current 52
Electrical Contractor 147
Electrical Faults 217, 227
Electrical Isolation 46
Electrical Measurement – the Process 185, 197–206, 277
Electrical Safety, Quality and Continuity Regulations 10
Electrical Symbols 156

Electrical Test Equipment 191, 229, 230, 277
Electrical Test Procedures 193, 194
Electrical Testing 182, 197–206, 227, 277
Electricity at Work (EWR) Regulations 11
Electricity Supply System 108
Electrolytic Capacitor 69
Electromagnetic Relay 248
Electromagnetism 62
Electromotive Force (emf) 52
Electronic Abbreviations 240
Electronic Circuit Assembly 266
Electronic Connectors 276
Electronic Symbols 239
Electronic Testing 277
Electrostatics 67
Employment Rights Act 18
Enabling Act 2
Energy and Power 59
Environmental Health Officers 2, 17
Environmental Protection Act 12
Environmental Regulations 12
Equal Opportunities Commission 22
Exclusive OR Logic Gate 286
Eyesight Test 34

Fault Diagnosis 219, 227
Faulty Electrical Systems 217
Fire Control 40
Fire Extinguishers 41
First Aid 42
First Aid Regulations 20
First Aider 42
Fleming's Rule 66
Fluxes and Soldering 269
Forming 50
FP 200 Cables 121
Full-wave Rectification 263
Functional Tests 195
Fuse – Cartridge 171
Fuse – HBC 171
Fuse – Semi-enclosed 170
Fusing Factor 172

Generation of Electricity 108
Good Work Relationships 50

Half-wave Rectification 263
Hazard 28
HBC Fuse 171
Health and Safety – documentation 3
Health and Safety – management of 4
Health and Safety at Work Act 2
Health and Safety Executive (HSE) 2
Heating Circuits 224
High Frequency Circuit Risks 234
High Voltage Distribution of Electricity 108
Human Rights Act 23

IEE Wiring Regulations 11
Impedance 74
Impedance Triangle 76
Improvement Notice 23
Indirect Contact with Live Parts 166
Induced emf 64
Inductance 64
Induction Motor 90
Inductors 247
Inspection and Test Certification 206
Installation of Motors 97
Installing Cable Tray 130
Installing Cables 122
Installing Conduit 123
Installing MI Cables 131
Installing Trunking 127
Instrument Errors when Testing 278
Instrument Range Extension 187
Instrument Transformers 106
Insulation Resistance Test 200
Insulators 52
Integrated Circuits 258
Investors in People (IIP) 27
ISO 9000 26
Isolation of Live Supplies 46, 168, 194, 227
Isolation of Supply 46

Job Sheets 160

Lamp Crusher 237
Large Capacitive Circuit Risks 234
Law Enforcement 23
Legal Contracts 148
Lenz's Law 67
Lifting Loads 35
Light-dependent Resistor (LDR) 254
Light-emitting Diode (LED) 254
Lighting Circuits 219
Lightning Protection 132
Live Testing 49, 194
Lock Off Procedure 168, 194, 227
Logic – Working with 291
Logic Families, TTL and CMOS 290
Logic Gates 284
Logic Networks 287
Low Pass Filter 265
Low Voltage Supply Systems 112
LSF Cables 121

Magnetic Energy 65
Magnetic Fields 62
Magnetic Hysteresis 65
Magnetism 61
Manual Handling 35
Matrix Boards 272
MCB 172
Measurement of Energy 190
Measurement of Power 189
Mechanical Aids 35
MI Cables 120
Motor – Enclosures 99
Motor – Maintenance 99
Motor Starters 95
Motor Starting 89
Motors – Installation of 97
Motors – Remote Control 97
Motors – Speed Control 89
Motors and Machines 86
Moving Coil Instruments 182
Moving Iron Instruments 184
Multimeter Instruments 279
Mutual Inductance 65

NAND Logic Gate 287
Network Analysis 152
New Wiring Colours 119
Noise Abatement Order 16
Noise and Statutory Nuisance Act 16
Noise at Work Regulations 16
Noise Regulations 6, 15
Non-Notifiable Electrical Work 10
NOR Logic Gate 287
Norming 50
NOT Logic Gate 286
Notifiable Electrical Work 9

Ohm's Law 52
Ohmmeter Testing 279
Operator Errors when Testing 278
Optical Fibre Cables 230
OR Logic Gate 285
Overcurrent Protection 169

Parallel Circuits 55
Part P – Building Regulations 9
PAT Testing 207

Performing 50
Permit to Work 49
Personal Protective Equipment (PPE) Regulations 5, 36
Phase Angle 75
Phasor Diagrams 74
Photodiode 255
PILCSWA Cables 122
Polarity Test 200, 205
Pollution Prevention and Control Regulations 13
Potential Difference (pd) 52
Power and Energy 58
Power Factor (pf) 77
Power Factor Correction 100
Power Supply Unit 283
Prejudice and Discrimination 21
Printed Circuit Board (PCB) 274
Prohibition Notice 23
Properties of Materials 118, 119
Protection – from Noise 16
Protective Conductor Size 178
Protective Device Characteristics 175
Prototype Electronic Assembly 275
Proving Unit 47
Proving Unit – for Voltage Indicators 193
Proving Unit – Voltage Indicator 47
Public Nuisance 13, 15
PVC/SWA Cables 120

Quality Assurance 26
Quality Control 26
Quality Systems 25

Race Relations Act 22
Radial Circuits 222
Radioactive Substances Act 15
RCD Functional Test 205
RCD Protection 168
Reactance 73
Rectification of A.C. 263
Remote Control of Motors 97
Reporting of Injuries, Diseases and Dangerous Occurrences (RIDDOR) Regulations 7
Resistance – Electrical 52, 54, 73, 239
Resistivity 53
Resistor Colour Code 241
Resonance 80
Ring Circuits 222
Risk Assessment 4, 28, 33

S-DEC 275
Safe Testing Procedures 206
Safe Working on Site 164
Safety Officer 25
Safety Representative 24
Safety Signs 5, 37, 38
Secure Computer Supplies 232
Secure Isolation 46
Segregation of Circuits 129
Self Employed 18
Semi-enclosed Fuse 170
Semiconductor Diode 250
Semiconductor Materials 249
Series Circuits 55
Series Motors 88
Sex Discrimination 22
Sexism 22
Shaded Pole Motor 93
Shunt Motor 88
Signal Generators 283
Single Phase – A.C. Motor 93
Sinusoidal Waveform 60
Smoothing Circuits 264
Socket Outlet Circuits 220
Soldering Techniques 269
Solders 269
Solenoid 64
Speed Control – of Motors 89
Stabilized Power Supply 266
Star and Delta Connections 84
Statutory Nuisance 15
Storage Batteries 236
Storming 50
Stripboard or Veroboard 274
Stroboscopic Effect 111
Super Grid Transmission 108
Supply Voltage Tolerance Levels 11
Switching – for Isolation 168
Switching – for Mechanical Maintenance 168
Switching – Functional 168
Switching – in an Emergency 168
Symbols 156
Synchronous Motor 93

Tap Changing 105
Team Working 50
Telephone Messages 158
Temperature Co-efficient 54
Testing 182, 197–206, 227, 277
Testing Resistors 242
Testing Transistors 257
Thermistor 255
Three Phase A.C. 83
Three Phase Motors 90
Three Phase Power 84
Thyristor 259
Time Sheets 160
TN – C – S Supply System 113
TN – S Supply System 112
Total Quality Control 26
Total Quality Management 26
Touch Voltage Curve 167
Transformer Construction 104
Transformer Efficiency 103
Transformer Losses 103
Transformers 102
Transformers – Oil Immersed 105
Transformers – Power 105
Transformers – Three Phase 104
Transistors 256
Transmission of Electricity 109
Triac 260
Trunking Capacities 129
Truth Tables 286
TT Supply System 113

UK Charter Mark 27

Vibration and Noise at Work 17
Visual Display Units (VDU) 5, 32
Visual Inspection 195
Voltage – Supply levels 112
Voltage – Supply Tolerances 112
Voltage Divider 261
Voltage Indicator 46, 192
Voltage Proving Unit 47
Voltage Transformers 106

Waste – Safe Removal 13, 236
Waste Electrical, Electronic Equipment (WEEE) Directive 14
Waste Transfer Notes 237
Wiring Diagrams 157
Wiring Regulations – BS7671 11
Work Equipment Regulations 4
Written Messages 159

Zener Diode 251
Zone of Protection 134