A Two Wire Single Phase Tamper Resistant Energy Meter Based on the SA9903B

RM9903BSEA

sames

FEATURES

- Meets the accuracy requirement of the IEC 62053-21 and IS 13779 specifications
- Reverse energy flow detection
- Full and partial earth loop tamper detection
- Missing neutral detect metering
- TOD metering with 6 time zones
- Maximum demand
- Software calibration
- IEC 1107 and isolated RS232 interface
- LCD
- Real Time Clock

INTRODUCTION

This application note describes a low cost energy meter design based on the SA9903B. The meter is designed for the followingmeasurements in a 2-wire single-phase system.

- Active Energy (kWh)
- Maximum demand (kW)

The SA9903B is a single-phase bi-directional energy metering integrated circuit that is designed to measure active, reactive energy, RMSmains voltage and frequency.

The SA9903B has an integrated serial peripheral interface (SPI) for communication with a micro-controller. Data is available from the SA9903B's internal 24-bit registers via its SPI interface. The SA9903B includes all the required functions for power and energy measurement such as over-sampling A/D converters for the voltage and current sense inputs, power calculation and energy integration.

The RM9903BSEA meter incorporates anti-tamper features and utilises a micro-controller and LCD to perform and display the various functions. The anti-tamper features allow for the continuous measurement of energy under full or partial tamper to earth and under neutral cut conditions.

This design complies with the accuracy requirements of both the IEC 62053-21 and the IS 13779 (Indian Standard) *Alternating Current Static Watt Hour Meters for Active Energy.* Table 1 shows the accuracy requirements for the meter in accordance with IEC 62053-21.

Meter rating:

Rated Voltage	240V (+20%, -40%)
Frequency	50 Hz (±5%)
I_b	10A
I_{MAX}	60A
Meter Constant	1000 pulses/kWh

By changing some component values on the meter, these stated ratings can be adapted for other energy metering applications.

Current Range[2]	pf[3] Class 1	%Error limits[1]
$0.05I_b \le I < 0.1I_b$	1	± 1.5
$0.1I_b \le I \le I_{MAX}$	1	± 1.0
$0.1I_b \le I < 0.2I_b$	0.5 Lag 0.8 Lead	± 1.5 ± 1.5
$0.2 I_b \le I \le I_{MAX}$	0.5 Lag 0.8 Lead	± 1.0 ± 1.0

Table 1: Percentage error limits for class 1 single-phase meters.

1 $$\text{Percentage error} = \frac{\text{Energy registered by meter} - \text{True Energy}}{\text{True Energy}} \times 100$$

2 *Basic current (I_b): Value of current in accordance with which the relevant performance of a direct connected meter is fixed. Maximum current (I_{Max}) is defined to be the power meter'smaximum rated current.*

3 *Power factor (pf): Phase relationship between the input voltage and current and is defined as pf = cos(Φ) where Φ is the phase difference between the voltage and the current.*

The meter is designed to detect and correctly register energy under any of the following tamper conditions:

- Reversal of phase and neutral terminals
- The neutral is disconnected
- Full or partial load to earth

***Note:This energymeter has not been subjected to any environmental testing**

FUNCTIONAL DESCRIPTION

The diagram in figure 1 shows the implementation of a single phase energy meter using the SA9903B together with a micro-controller. This design uses three current transformers (CT's). Two CT's are used as the current sensing elements, while the third CT is used for generating an auxiliary power supply which is required when the meter's neutral line is disconnected. Both the phase and neutral lines pass through the third CT as shown in figure 1. The line voltage is supplied to the SA9903B by means of a voltage divider network. Should the neutral line be disconnected a replacement voltage signal is generated and energy measurement continues. The RM9903BSEA meter performs the power calculation by using this voltage signal together with the larger of the two current channels.

The meter can be digitally calibrated via the IR interface or the isolated RS232 interface and using the supplied software.

The following parameters are displayed on the LCD :

- Date
- Time
- Cumulative kWh
- kWMaximum demand

The RM9903BSEA meter has three operating conditions associated with it: normal operation, tamper to earth and missing neutral. The RM9903BSEA meter will accurately record energy consumption during any of these three conditions.

Normal Operation

During normal operation the meter senses the load current through the CT in the phase line and uses this together with the phase voltage to register the correct energy consumption.

Tamper to Earth

During this condition the meter's neutral is disconnected and either earthed (full earth loop tamper) or connected via a load to earth (partial earth loop tamper). The meter will sense the current flow in both the phase and neutral lines and use the larger of the two for the power calculation.

Missing Neutral

During this condition the meter's neutral is completely disconnected and current will flow in the meter's phase connection only. In a standard meter this condition would cause the meter to cease operating as no return path exists for the meter's power supply. The RM9903BSEA meter uses the active current line (phase or neutral) to generate an auxiliary power supply to power the meter's circuitry. This is achieved via the third CT which has a turns ration of 3:300. Additional circuitry has been implemented to generate a voltage signal to emulate the missing phase voltage. The meter uses this signal in conjunction with the current signal from the phase line to record the energy consumption. The additional voltage circuitry has been calibrated to simulate a unity power factor / constant phase voltage of 240V.

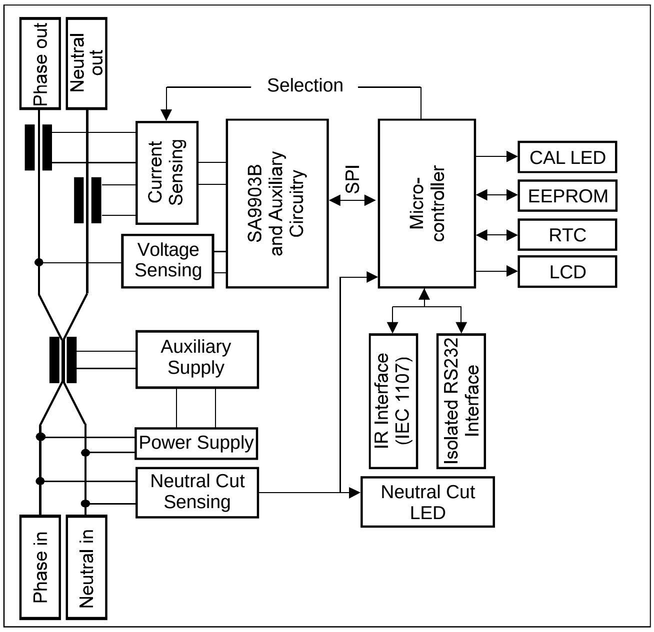


Figure 1: RM9903BSEA functional block diagram

CIRCUIT DESIGN

Analog Inputs

Current sensing resistors are used on the inputs to the SA9903B. The resistor's placement and quality is crucial for excellent performance of the meter.

Current Sense Input (IIN and IIP)

CT_1 and CT_2 are used for current measurement in the phase and neutral lines. Both CT_1 and CT_2 are terminated with 24.9 ohm resistors that result in a voltage signal of ~200mV_{RMS} over the terminating resistor at I_{MAX}. The effect of the leakage current of the CMOS switch (U_1) is reduced by using this signal amplitude.

The CMOS switch (U_1) is controlled by the on-board micro-controller. The controller switches between the two CTs periodically and determines the larger energy signal. The largest signal is then used to calculate the energy consumption.

The selected CT channel is connected to the input series resistors R_3 and R_4. These resistors define the current level into the SA9903B's current sense inputs. The resistor values are selected for a maximum input current of 16µA_{RMS}.

As per the equation described in the "Current Sense Inputs" section of the SA9903B datasheet:

$$R3 = R4 = \frac{IL}{16\mu A} \times \frac{RSH}{2} \quad \text{............ (1)}$$

$$= \frac{\left(\frac{60A}{7000}\right)}{16\mu A} \times \left(\frac{24.9}{2}\right)$$

$$= 6k8$$

Where:

$$I_L = \frac{\text{Max Line Current}}{\text{CT Ratio}} \quad \text{............ (2)}$$

R_{SH} = CT Terminating Resistor Value

The CTs used for current sensing each have a turns-ratio of 1:7000.

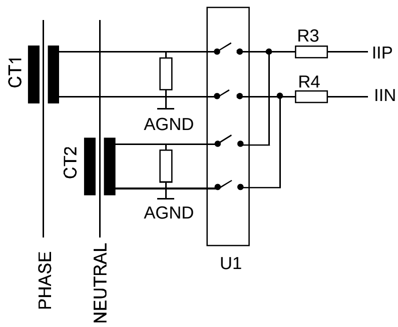


Figure 2: CT_1 used for phase line and CT_2 for neutral line monitoring. The larger of the two signals switched with U1 (4066).

Voltage Sense Input (IVP)

The voltage sensing front end for the meter is made up of two resistive networks. The one is used for normal and tamper to earth operating conditions and the other is used when the meter is under a neutral cut condition.

Figure 3 illustrates the circuit used in the design of the meter's voltage channel.

The current into the voltage sense inputs should be set to 14µA_{RMS} for the nominal rated mains voltage (240V). This has been done since the meter has to operate accurately from 144V (-40%) to 288V (+20%), which translates to 8.4µA_{RMS} and 16.8µA_{RMS} on the SA9903B voltage inputs. The IVP inputs on the SA9903B will saturate with currents larger than 17µA_{RMS}. The line voltage is divided down via the voltage divider of R_6, R_7, R_8 and R_9 to 14V_{RMS}. Resistor R_{10} sets the current to 14µA_{RMS} for the voltage sense input, while R_{11} sets the correct input current under missing neutral conditions. Please refer to the SA9903B datasheet for a detailed explanation on calculating the values for R_6, R_7, R_8 and R_9.

Capacitor C is used for phase compensation between the voltage and current inputs. The phase compensation is required since the CTs cause a phase shift due to their inductive properties.

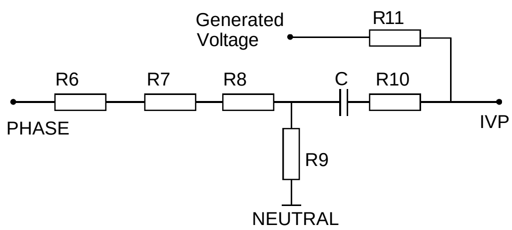


Figure 3: Voltage input used under normal and neutral cut operation.

The CTs used in this design generate a phase shift of approximately 0.41 degrees. The value of the compensation capacitor(s) can be calculated as follows:

$$C = \frac{1}{2\pi \times f_{mains} \times R \times \tan(\Phi)} \quad \text{............ (3)}$$

Substituting R_{10} into equation 3 yields C = 444 nF

Standard value

C = 440nF

This is implemented by placing C_2 = C_3 = 220nF in parallel on PCB.

POWER SUPPLY

Main Supply

Under normal operating conditions the meter is powered via a switch mode power supply, based on the LNK304-1 off-line switcher IC. Using the buck topology a triple output non-isolated supply that generates ±2.5V and 5V is implemented. The ±2.5V is centered around Neutral (AGND) and is used to power the SA9903B and peripheral circuitry in the RM9903BSEA meter. The 5V is reserved for the LCD's backlight.

This supply works over the required voltage range of 144 to 288V and consumes less than 1W and 4VA.

Auxiliary Supply

As stated before this meter includes a third CT that is used as a power supply under the neutral cut condition. The output from this CT is (full wave) rectified and diode OR'ed into the Main Supply, using its TL431's to provide ±2.5V outputs. Since the CT's output is proportional to the phase current, this supply is only capable of powering the RM9903BSEA if the phase current is more than 5A.

PCB DESIGN LAYOUT

1. The current sense resistors on the current input (R_3, R_4) must be located as close to the SA9903B input pins as possible This also holds true for R_9, R_{10}, R_{11} and the biasing resistor R_5.

2. The supply bypass capacitors C_5, C_6 and C_7 must be positioned as close as possible to the supply pins of the SA9903B and connected to a solid ground plane.

3. A ground plane surrounds the SA9903B to minimise the influence of noise on the sensing inputs. This ground plane is connected to the digital and power supply ground plane via a single ferrite bead to help isolate the sensitive measurement parts.

4. The power supply routing and placement is also a very important aspect to consider. The power supply must be placed as far away from the analog side of the SA9903B as possible, so as not to interfere with the sensing functions. The routing must be done in such a way that all other devices are serviced before the SA9903B. This will ensure that all the noise (spikes and power demands) are put on the supply line before it gets to the SA9903B. Most of the noise will then be filtered out by the supply bypass capacitors.

5. The meter is protected from high transients on the mains voltage input by means of a metal oxide varistor (MOV).

The RM9903BSEA meter provides the following secondary functionality:

Maximum Demand

The maximum demand (active and apparent power) for each month and TOD zone is logged. The integration period is thirty minutes, synchronised to the real time clock. If the meter is switched on and there is between five and twenty nine minutes before the next thirty minutes on the RTC, the meter will calculate the first MD with a smaller integration period.

Tamper Management

The number of tamper counts is stored in non-volatile memory with date/time stamping of the 1st occurrence and last restoration.

Windows Interface

The Windows interface connects a PC to the RM9903BSEA meter through either the optical interface or hardwired RS232 port.

The software has been tested on Windows 98, NT and XP. For more information on using the software, refer to the help function.

The windows interface software "RM9903.EXE" can be obtained with a request to email: support@sames.co.za. The file is also available on our website for downloading.

METER CALIBRATION

The meter can be calibrated via the isolated RS232 or IEC1107 optical ports, using the supplied Windows software (RM9903.EXE).

Single point calibration centred at I_B is used, i.e. the user should ensure that the meter senses U_{nom} (240V) and a load equal to I_B (10A). Both phase and neutral lines should be connected to the meter, the Windows software will choose a specific line during calibration.

The explanation that follows is presented based on the user choosing the optical port for calibration, the same procedure is employed for the RS232 port.

To start calibration of the meter, open the “RM9903.EXE” Windows program and go to the Calibration page.

To put the meter in calibration mode, click on the “Mode” button on the bottom of the page (this button will show the current mode of operation “Normal Mode” / ”CalibrationMode”).

UPF Calibration Procedure (pf=1.0)

- Click on “Pulse onActive Energy”
- Click on “Switch on CT1”
- Enter zero for the active calibration factors and click on “Transmit Data". Measure the percentage error for the particular phase
- Enter the percentage error for the measured phase (including sign) and click on “Transmit Data”
- Re-measure the error and adjust the percentage error if necessary
- Repeat the above steps for CT2

Neutral Cut Calibration

- Connect only the Phase line to the meter
- Disconnect the neutral voltage
- Enter zero for the neutral cut calibration factor and click on "Transmit Data"
- Measure the percentage error for the neutral cut condition
- Enter the percentage error (including sign) and click on "Transmit Data"
- Re-measure the error and adjust the percentage error if necessary
- Under neutral cut conditions the meter simulates a unity power factor, thus there is no re-active calibration

FIRMWARE DOWNLOAD

The micro-controller is programmed via JP_3 using the controller's ISCP (in circuit serial programming) capability, as described in the relevant MICROCHIP datasheet. If the intention is to program the micro using MICROCHIP'S PICSTART PLUS programmer a buffer needs to be inserted in the V_{DD} line to boost the programmer's output capability (see figure 7). Furthermore it is also required to remove jumpers J_2 and J_3 to reduce the capacitive loading on the programmer.

The firmware source code can be obtained with a request to email: support@sames.co.za. The files are also available in our website for downloading.

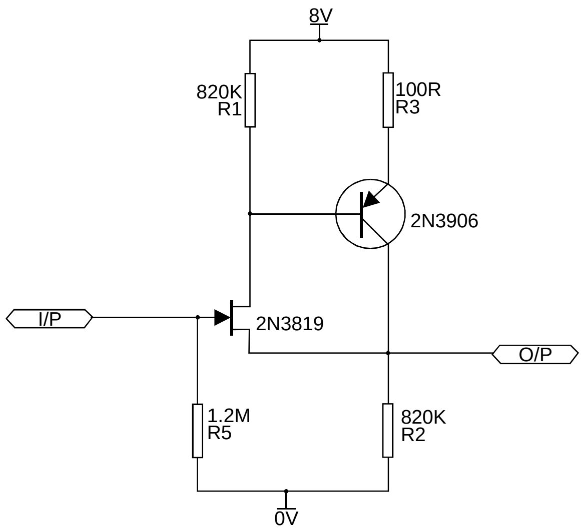
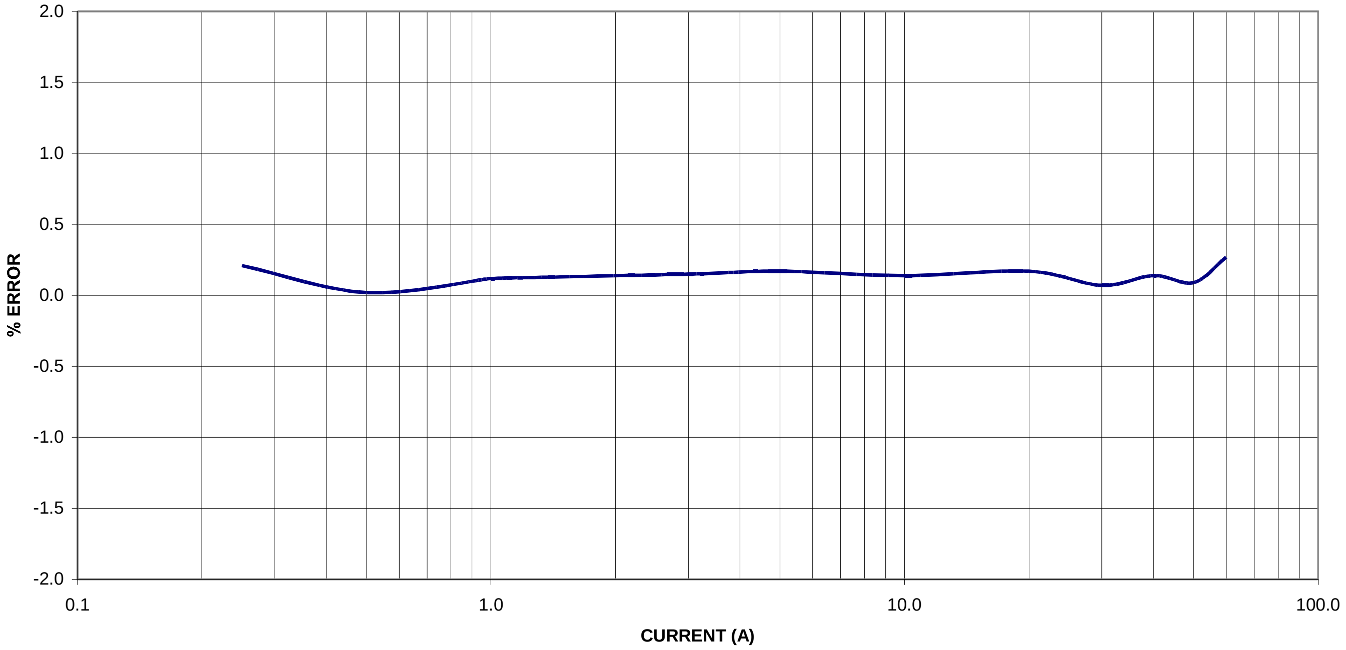


Figure 7: Typical buffer circuit

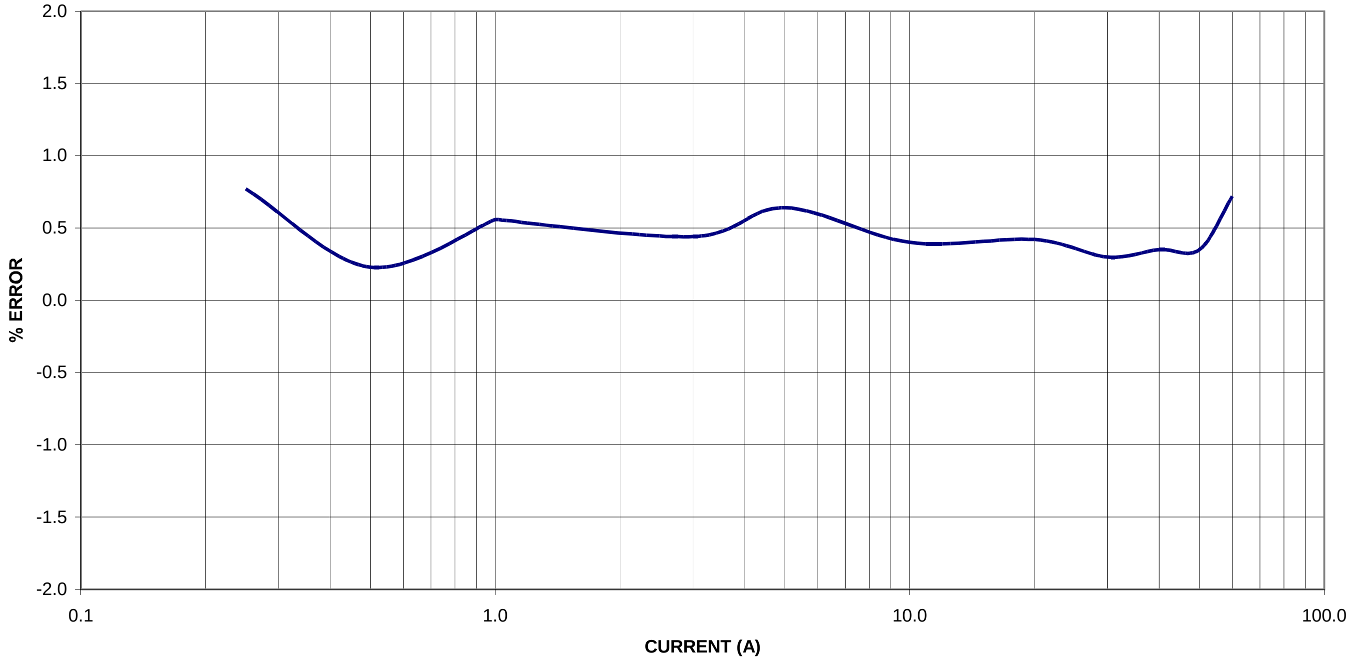
TYPICAL PERFORMANCE CURVES

The following curves show the typical results obtained with the RM9903BSEA meter.

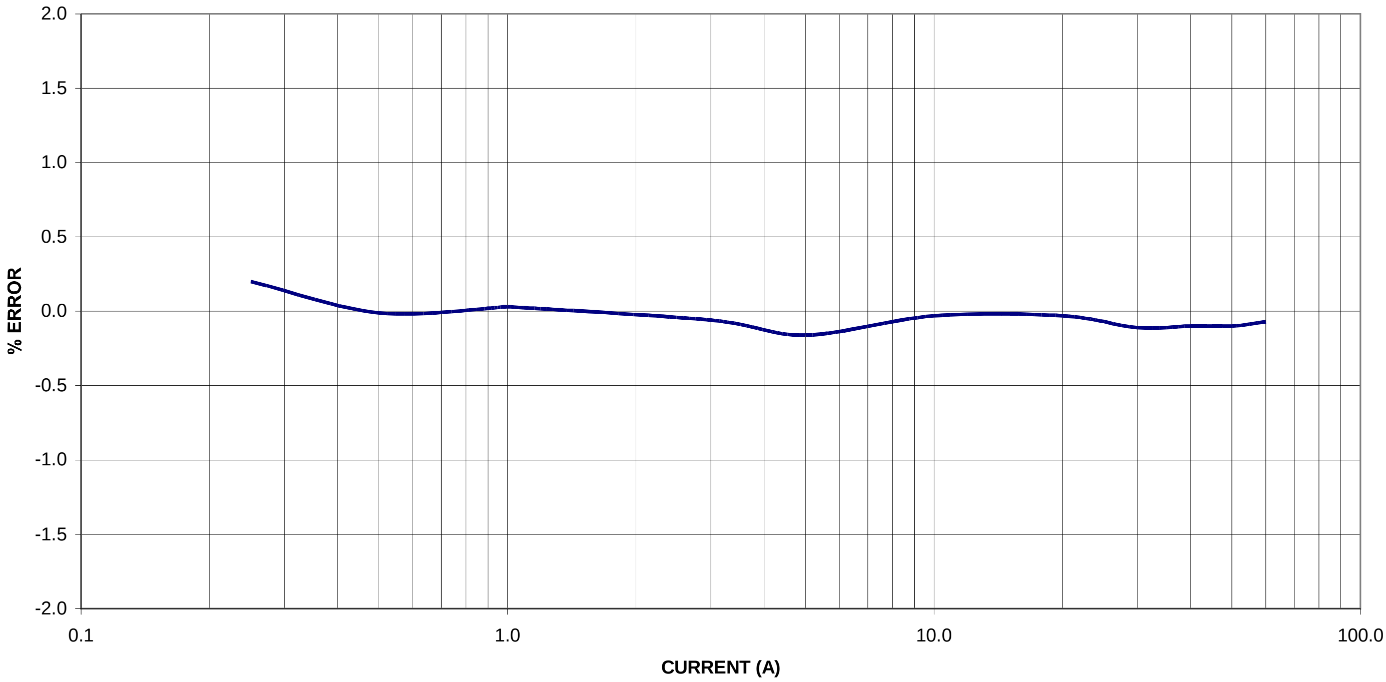
PHASE PF = 1
(NEUTRAL PATH OPEN)



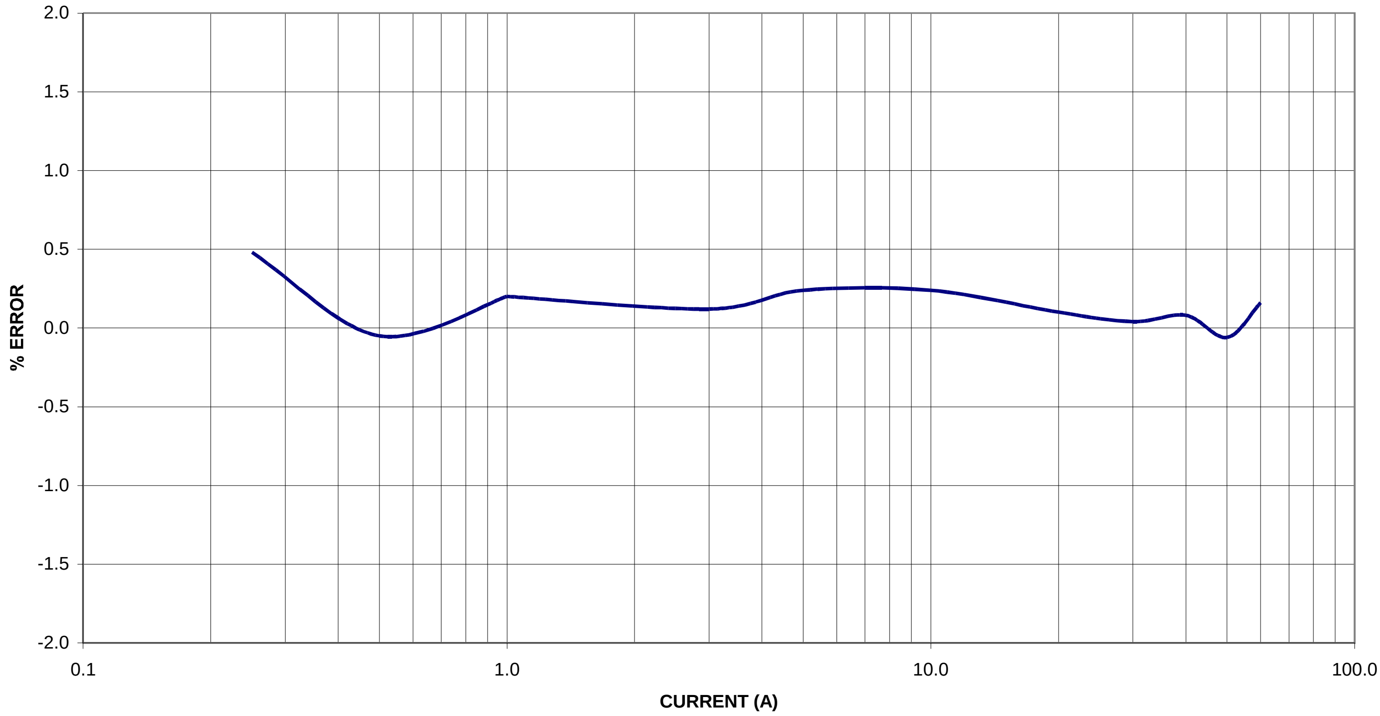
PHASE PF = 0.5 INDUCTIVE
(NEUTRAL PATH OPEN)

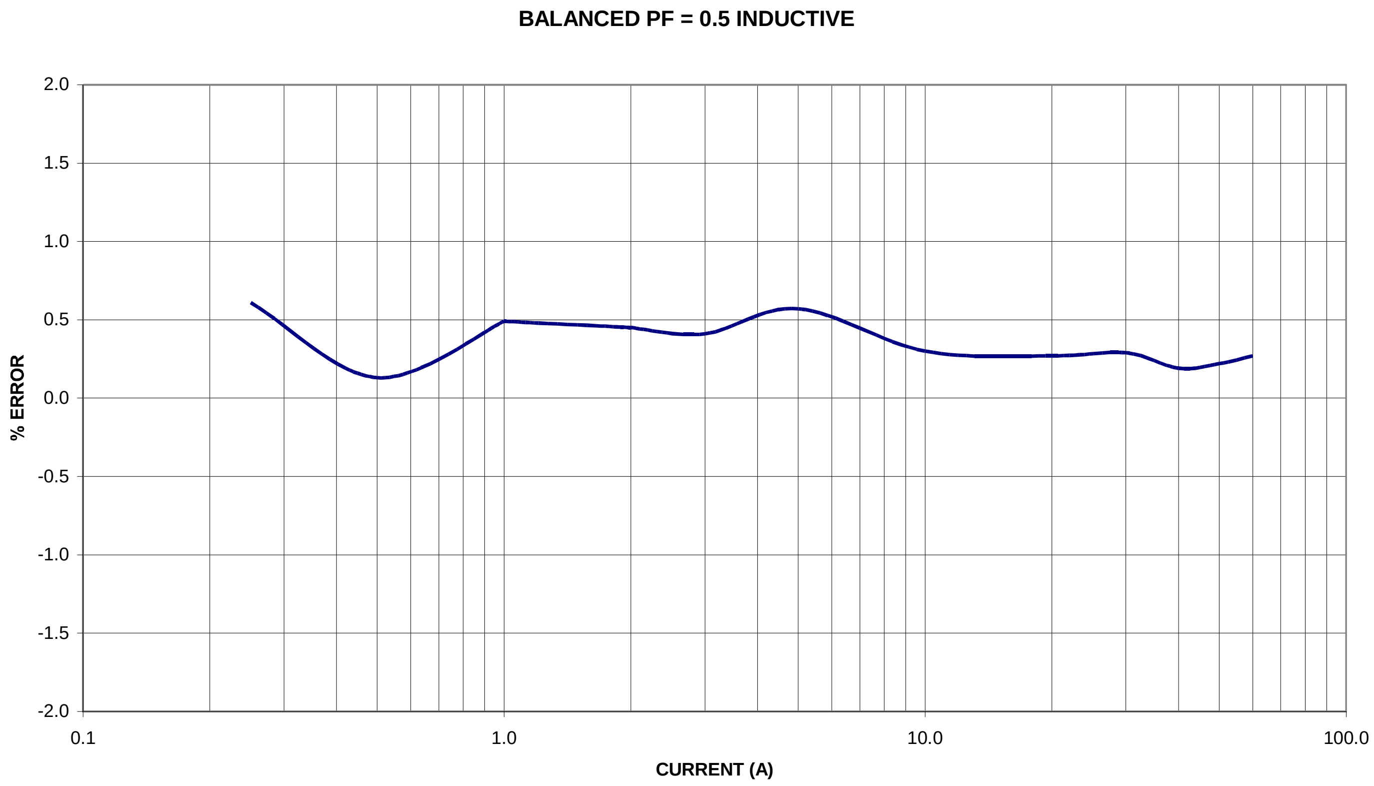


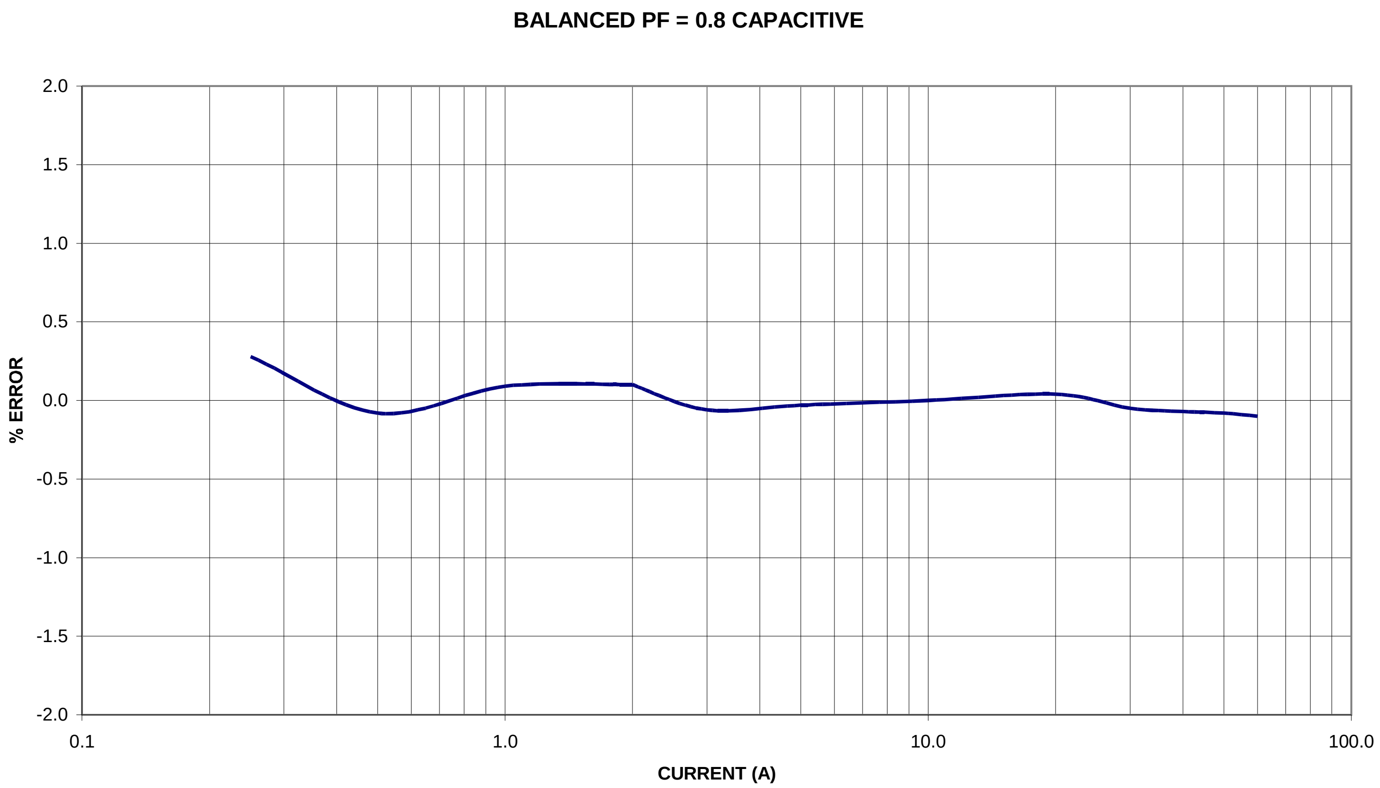
PHASE PF = 0.8 CAPACITIVE
(NEUTRAL PATH OPEN)

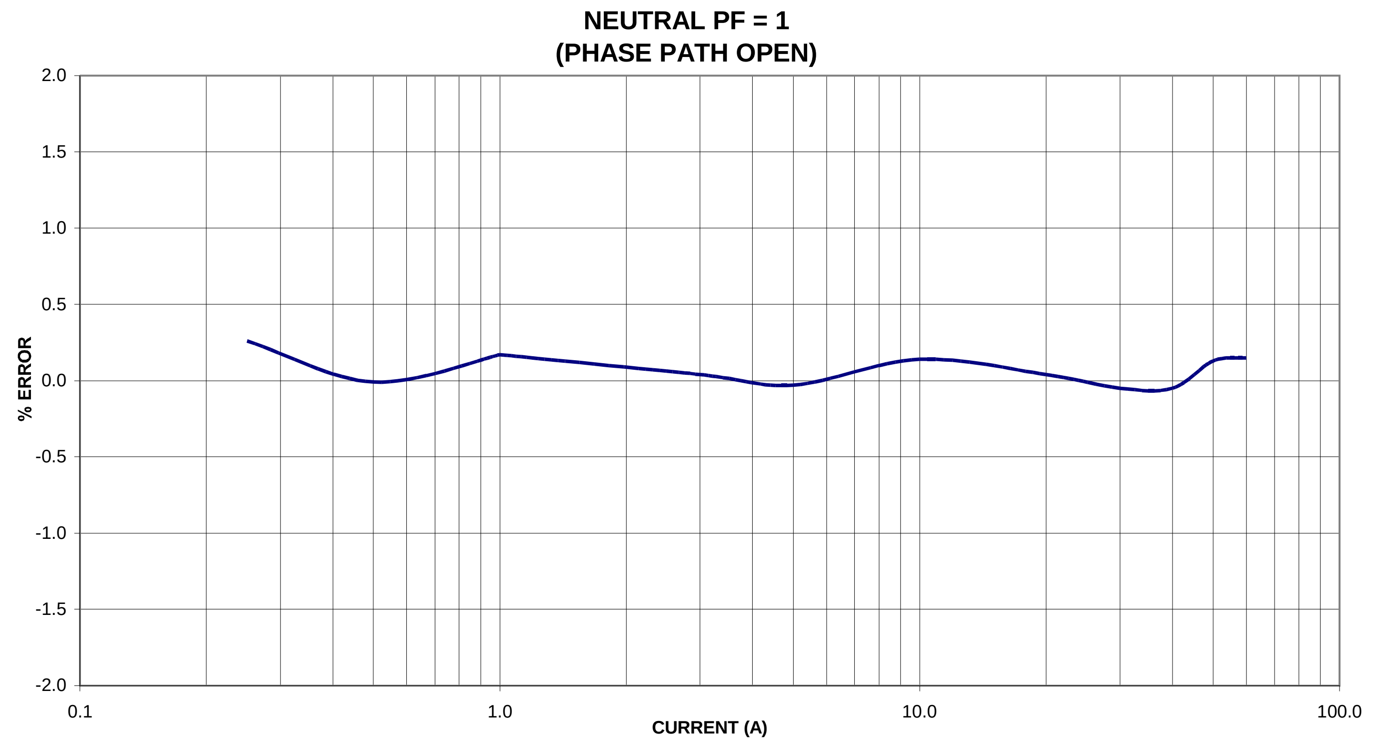


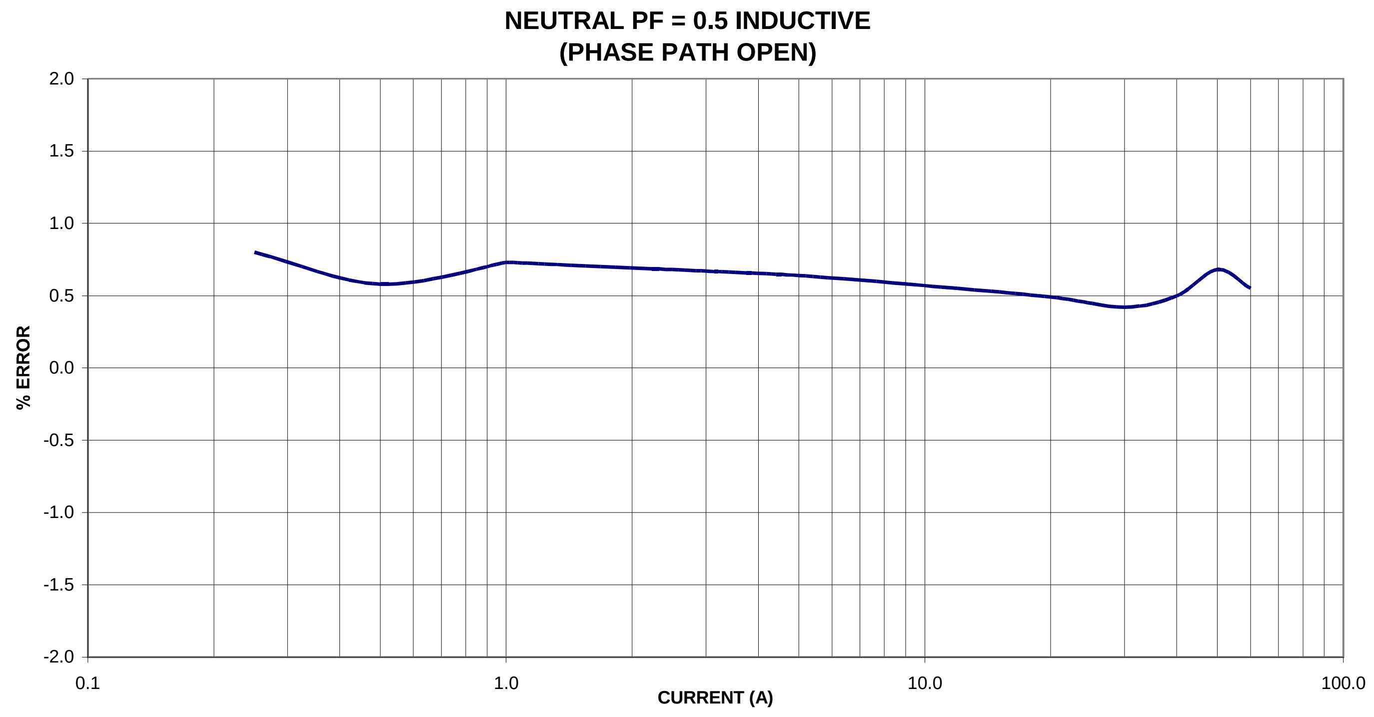
BALANCED PF = 1

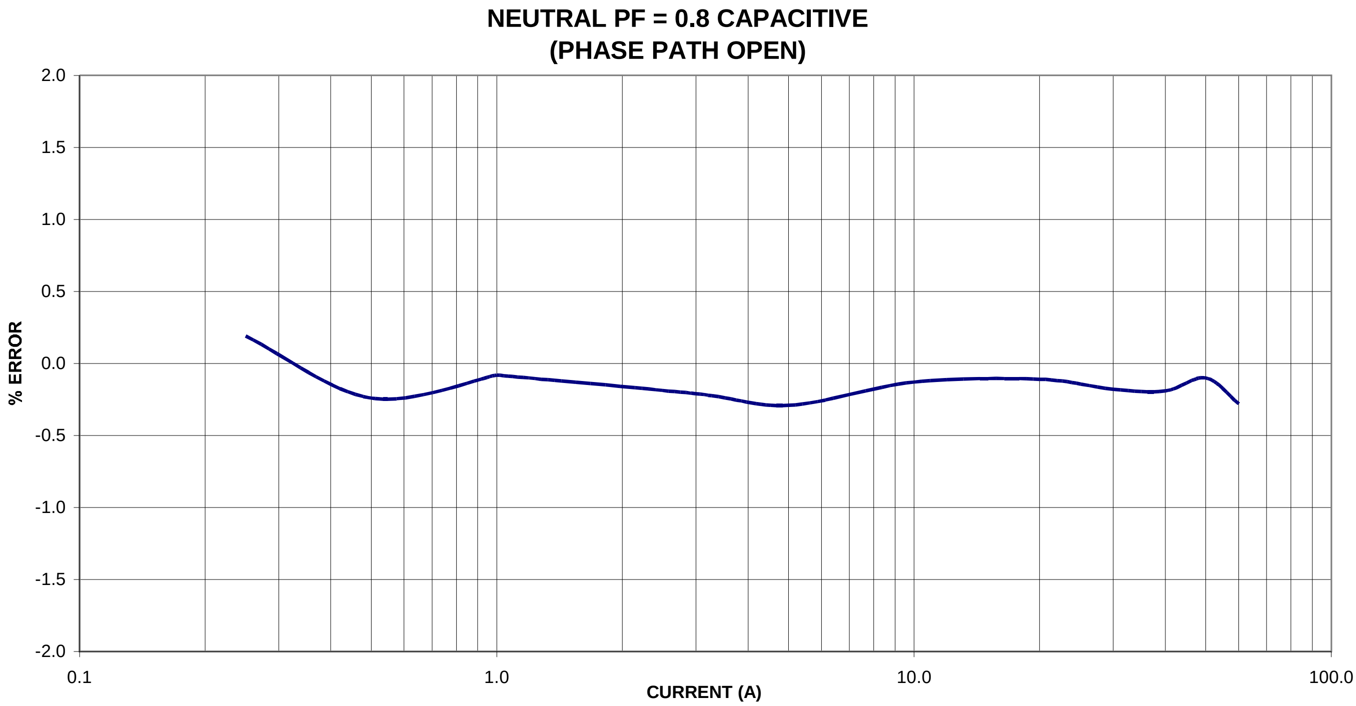



BALANCED PF = 0.5 INDUCTIVE
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
% ERROR
0.1
1.0
10.0
100.0
CURRENT (A)


BALANCED PF = 0.8 CAPACITIVE
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
% ERROR
0.1
1.0
10.0
100.0
CURRENT (A)


NEUTRAL PF = 1
(PHASE PATH OPEN)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
% ERROR
0.1
1.0
10.0
100.0
CURRENT (A)


NEUTRAL PF = 0.5 INDUCTIVE
(PHASE PATH OPEN)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
% ERROR
0.1
1.0
10.0
100.0
CURRENT (A)


NEUTRAL PF = 0.8 CAPACITIVE
(PHASE PATH OPEN)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
% ERROR
0.1
1.0
10.0
100.0
CURRENT (A)

METER SCHEMATICS

Figure 8:Metering

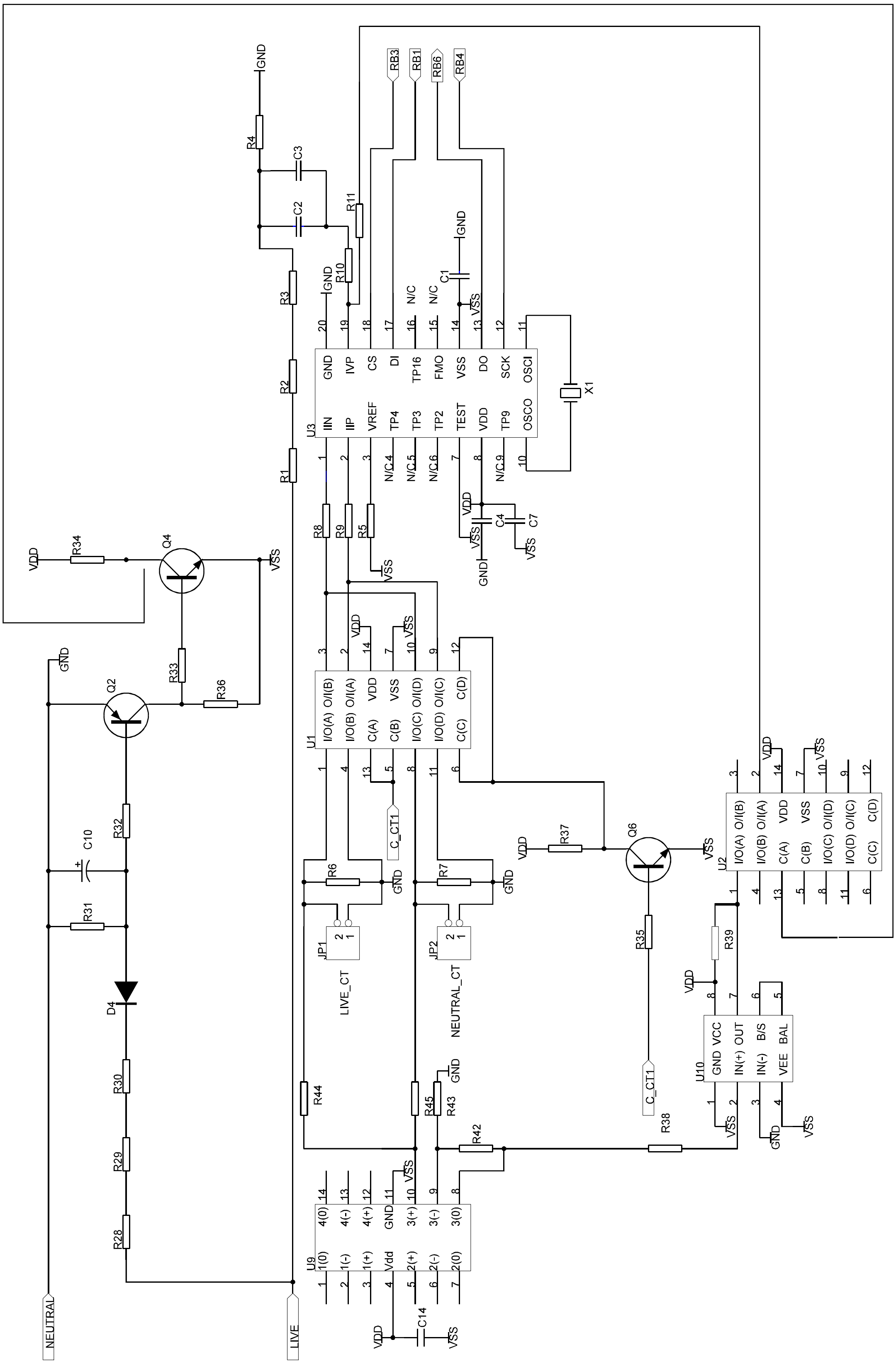


Figure 9: Digital

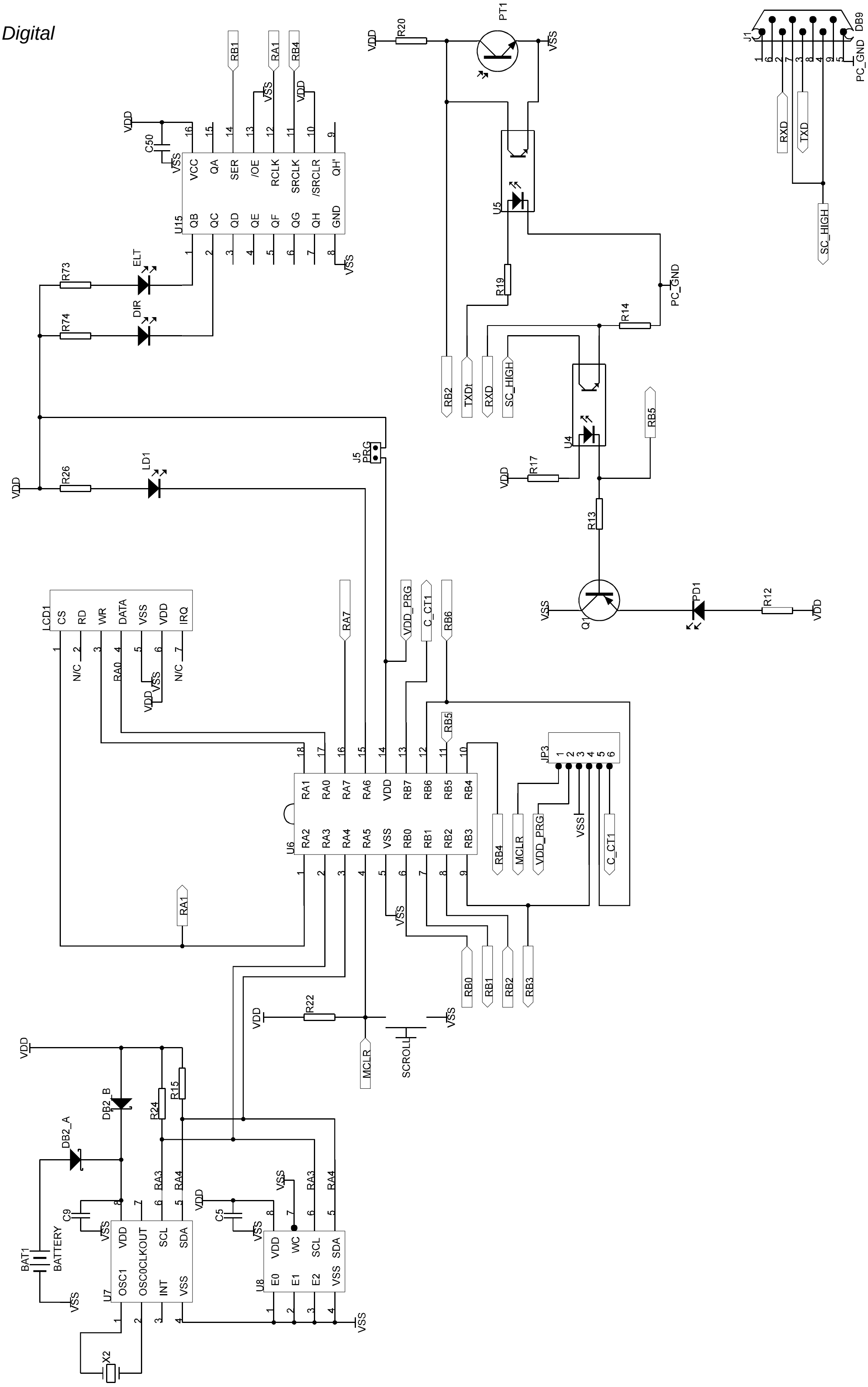
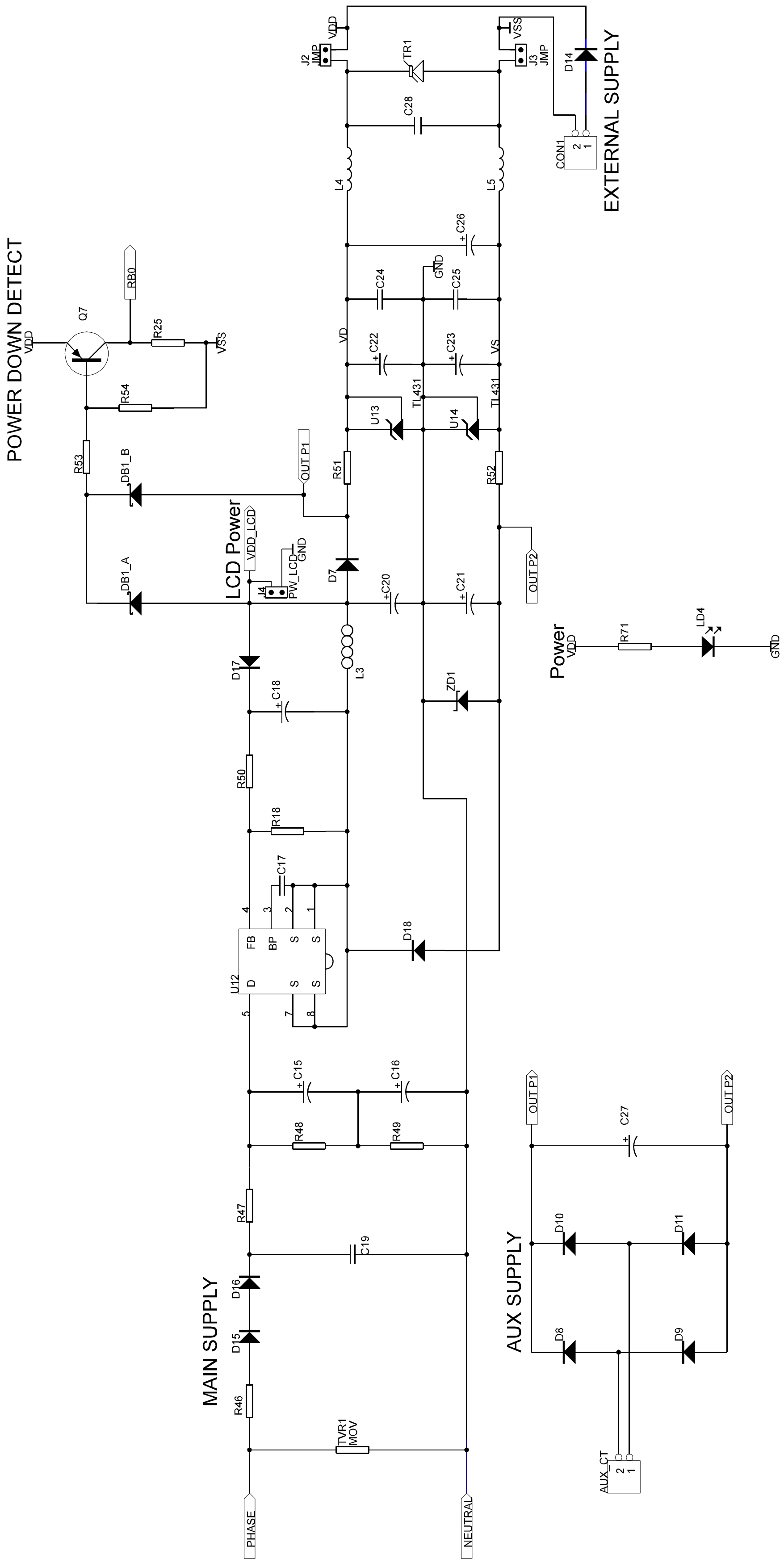
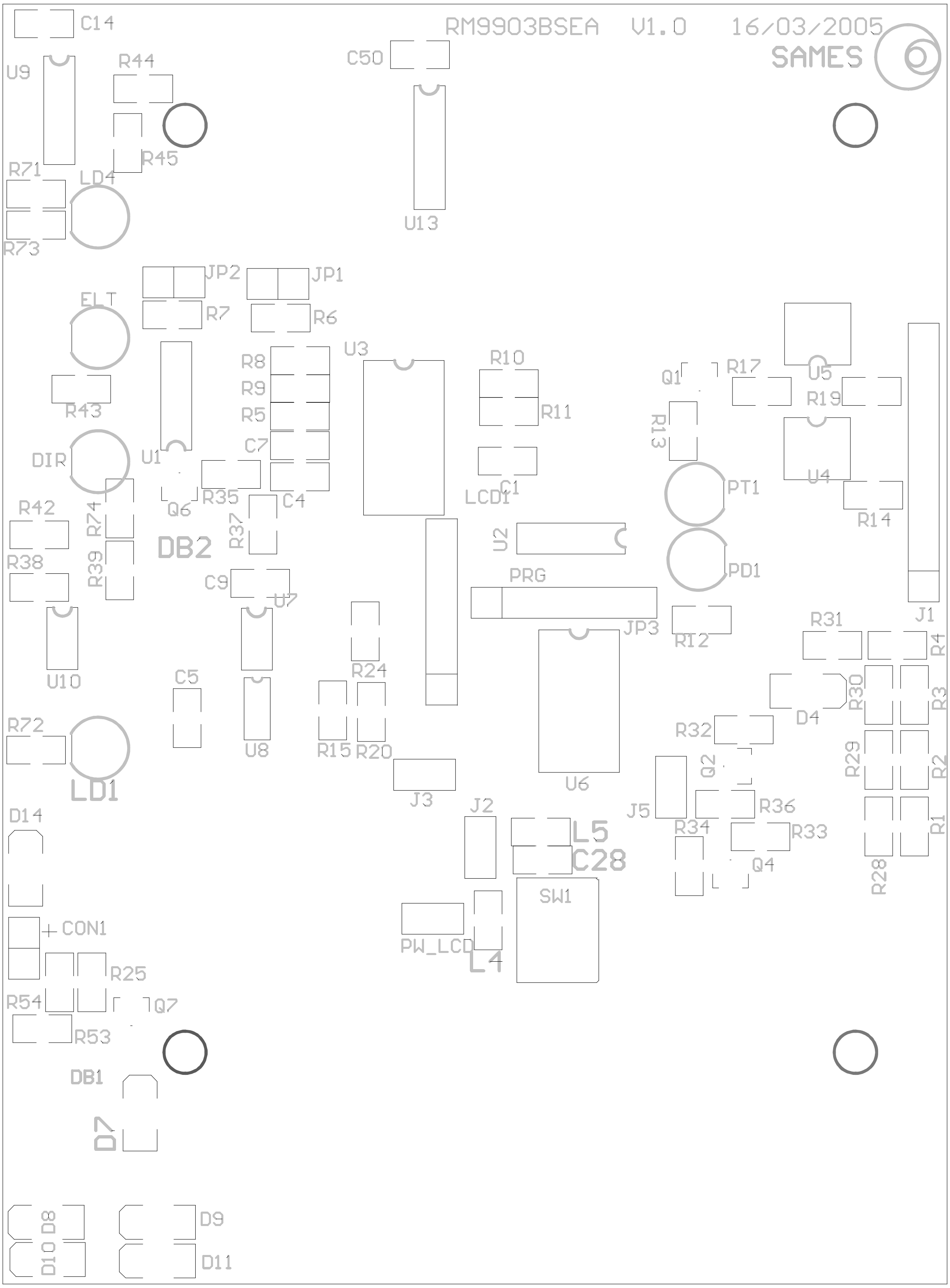


Figure 10: Power



COMPONENT LAYOUT



The complete PCB manufacturing files (RM9903BSEA_PCB.ZIP) can be obtained with a request to email: support@sames.co.za. The files are also available on our website for downloading.

COMPONENT LIST

Designator	Part Type	Description
BAT1	CR2032	3.6V Lithium Button Cell
---	Battery holder	PCB mount
C1, C4, C5, C28	220nF	Monolithic ceramic, 0805
C2, C3	220nF	5.08mm pitch, CT Compensation
C7	1µF	Monolithic ceramic, 0805
C8, C9, C14, C50	100nF	Monolithic ceramic, 0805
C10, C18, C22, C23	10µF	Radial Electrolytic, 16V, 2.5mm pitch
C15, C16	2.2µF	Radial Electrolytic, 400V, 5.08mm pitch
C17, C24, C25	100nF	Monolithic ceramic, 5.08mm pitch
C19	1nF	Monolithic ceramic, 1kV, 7.62mm pitch
C20, C21	220µF	Radial Electrolytic, 25V, 2.5mm pitch
C26	1000µF	Radial Electrolytic, 16V, 5.08mm pitch
C27	470µF	Radial Electrolytic, 25V, 2.5mm pitch
CON1	HEADER 2	External power supply connection
D4, D7, D8, D9, D10, D11, D14	1N4148	Si Signal diode
D15, D16, D17	1N4007	
DB1, DB2	BAT74	Schottky barrier double diode
D18	1N4937	
J1	DB9	Serial port header
J2	JMP	VDD jumper
J3	JMP	VSS jumper
J4	PW_LCD	LCD back-light connection
J5	PRG	Connected
JP1	HEADER 2	Phase CT connection
JP2	HEADER 2	Neutral CT connection
JP3	PRG	Programming header
L3	1mH	Radial inductor, 150mA, 5mm pitch
L4, L5	33µH	SMD inductor, 0805
LCD1	CM01040	LCD Module, Bona Fide
LD1, LD4, ELT, DIR	LED	Red 5mm, mounted off-board
PCB	Main, FR4	77.5 x 105mm

COMPONENT LIST (continued)

Designator	Part Type	Description
PD1	TSUS520	Photo Diode, mounted off-board
PT1	BPW96	Photo Transistor, mounted off-board
Q1, Q2, Q7	PMST3906	PNP, SOT-23
Q4, Q6	PMST3904	NPN, SOT-23
R1, R28	150k	0.125W, 1%, MFR, 0805
R2, R3, R29	120k	0.125W, 1%, MFR, 0805
R4, R5, R31	24k	0.125W, 1%, MFR, 0805
R6, R7	20R	0.125W, 1%, MFR, 0805
R8, R9	6k8	0.125W, 1%, MFR, 0805
R10	1M	0.125W, 1%, MFR, 0805
R11	220k	0.125W, 1%, MFR, 0805
R12	420R	0.125W, 1%, MFR, 0805
R13, R14, R15, R19, R37	4k7	0.125W, 1%, MFR, 0805
R17	2k7	0.125W, 1%, MFR, 0805
R18	2k	0.125W, 1%, MFR, 0805
R20, R26, R33, R38 R71, R73, R74	1k	0.125W, 1%, MFR, 0805
R22, R24, R25, R34, R35, R36, R42	10k	0.125W, 1%, MFR, 0805
R30, R32	100k	0.125W, 1%, MFR, 0805
R39	22k	0.125W, 1%, MFR, 0805
R43	100R	0.125W, 1%, MFR, 0805
R44, R45	100k	0.125W, 1%, MFR, 0805
R46	1k5	3W, Wire Wound
R47	220R	¼W, 1%, MFR
R48, R49	1M	½W, 5%, Carbon Film
R50	11k	¼W, 1%, MFR
R51, R52	68R	2W, 5%, Carbon Film
R53	3k3	0.125W, 1%, MFR, 0805
R54	5k1	0.125W, 1%, MFR, 0805

COMPONENT LIST (continued)

Designator	Part Type	Description
TR1	P6KE6.8A	Transorb
TVR1	S20/275	MOV
U1, U2	CD4066B	CMOS switch, SO-14
U3	SA9903B	SAMES, SOL-20
U4, U5	KB817	Opto-Coupler, SMD
U6	PIC16F87	Microchip, SOL-18
U7	M41T00	Real Time Clock, SO-8
U8	M24256-B	External Eeprom, SO-8
U9	LM324	Op-Amp, SO-14
U10	LM311	Comparator, SO-8
U12	LNK304G	Switcher, SMD
U13, U14	TL431	Precision shunt Voltage reference
U15	74HC595	Port expander
X1	3.57MHz	Crystal Oscillator
X2	32kHz	Crystal Oscillator
ZD1	5V1	Zener Diode, 400mW

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