Three phase multi function Energy Meter based on SA9904B

RM9904BSEB

INTRODUCTION

This Application Note describes an accurate 3-phase multi function energy meter based on the SA9904B. The meter is designed for the measurement of **Active Energy (kWh), Apparent Energy (kVAh) and Maximum Demand (MD) in 3-phase , 4-wire balanced /unbalanced loads.**

The SA9904B is a 3-phase bi-directional energy/power metering integrated circuit that has been designed to measure **active and reactive energy, RMS mains voltage and frequency**. The SA9904B has an integrated **SPI serial interface** for communication with a micro-controller. Measured values for active and reactive energy, the mains voltage and frequency for each phase are accessible through the SPI interface from 24 bit registers. The SA9904B includes all the required functions for 3-phase power and energy measurement such as over sampling A/D converters for the voltage and current sense inputs, power calculation and energy integration.

DESIGN OBJECTIVE

The meter has been designed for class 1 accuracy requirements in accordance to the International IEC 62053-21 and Indian IS 13779/1999 specifications.

The meter rating is as follows:

Rated voltage	3x 240V (+20%, -40%)
Frequency	50 Hz (±5%)
I_b	10A
I_{MAX}	40A
Meter constant	1000 pulses/kWh

The meter detects and correctly registers energy under the following tamper conditions:

- Missing potential
- Potential Imbalance
- Current Unbalance
- Current Reversal
- Current short circuit

The meter can be calibrated via the IEC1107 optical interface/ RS232 andWindows software.

Figure 1 shows how the SA9904B is used together with a micro controller to make the 3-phase energy meter. This design uses current transformers as the current sensing elements and voltage divider networks as voltage sensing elements. The micro controller performs all the required tasks and interacts with the other components - the SA9904B energy metering IC, the real time clock (RTC), the LCD, the optical interface, the buttons to operate the meter, and to control the calibration and tamper indication LED's. The measured power and other relevant data is displayed on the LCD.

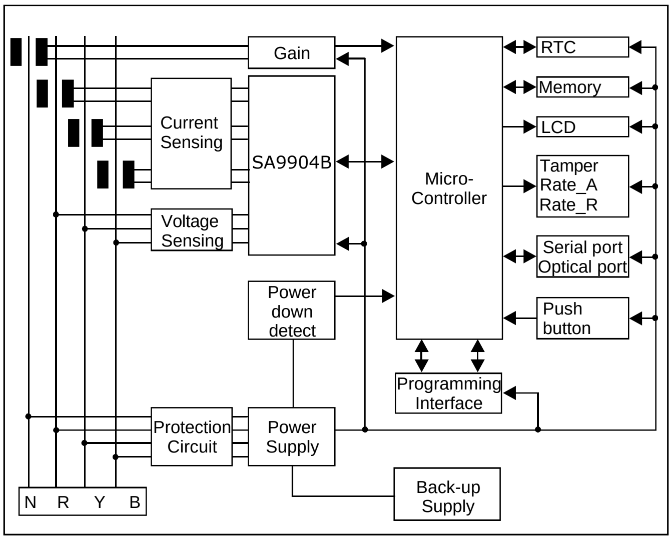

Figure 1: Functional block diagram of the RM9904BSEB three-phase energy meter

CIRCUIT DESCRIPTION

Analog Inputs

The front end of the meter is made up of three pairs of voltage and current sensing input networks.

Current sensing network

The primary function of the current sensing network is to sense the load current and convert it to the input current signal required by the SA9904B. The current sensing network is shown in Figure2.

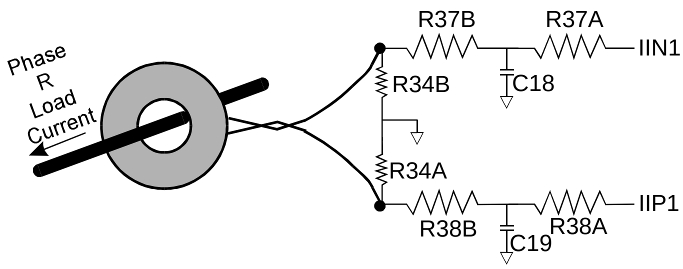

Figure 2: Circuit diagram of the current sensing network

The amplitude of the input current into the SA9904B at maximum current (I_{MAX}) should be set as close as possible to 16µA$_{RMS}$. The current input of the device saturates at 25µA peak current, so the 16µA$_{RMS}$ input current (22.62µA peak) allows for an over-current up to 110% I_{MAX} before saturation occurs. The SA9904B can be used with most available CTs. To ensure proper current sensing it is advisable to use a CT termination resistor that will give a minimum voltage drop of at least 10mV at maximum current. The internal current feedback present on the inputs IIN and IIP of the SA9904B creates a virtual short circuit between these two input pins. This means that the resistor value required to generate the correct input current can be calculated using:

$$R37A = R37B = R38A = R38B = \frac{I_{max} \times Rsh}{16 \times 10^{-6}} \times \frac{1}{4} \times \frac{1}{CT} = Rc \quad (1)$$

Where
Rsh = R34B + R34A
CT = CT turns ratio

A secondary function of the current sense network is to attenuate all high frequency components that could disrupt the accuracy of the SA9904B. These high frequency components may occur due to high frequency surges (fast transient burst), may be induced through strong electric fields or may simply be noise on the power lines. Certain high frequency components, typically those close to integer multiples of the sampling frequency of the analog to digital converters will be mapped close to 50 Hz once sampled (a process known as aliasing) and will distort the accuracy of the converters. This can be prevented by adequately attenuating all high frequency signal components. The typical oscillator frequency is 3.58MHz and the analog to digital converters of the SA9904B operate at one half of this frequency, so sufficient attenuation should be present at 1.79MHz. This can readily be achieved by placing a single order RC low pass filter on each current input as shown in Figure 2. The capacitors cannot be placed directly on the input pins IIN and IIP because no differential voltage signal exists between these pins due to the virtual short circuit created by the input network of the SA9904B. The input resistance is therefore split into two equal resistors (R37B/R38B and R37A/R38A) and the capacitor is placed between these resistors. Now a differential voltage can appear across the capacitors and hence filter high frequencies. The lowest -3dB cut-off frequency is achieved when all four input resistors are equal (R38A = R37B = R38B = R37A = Rc). The current input networks must be balanced so both capacitors C18 and C19 must also be equal (C18 = C19 = Cc). In this case the equivalent resistance associated with each capacitor is ½Rc and the -3dB cut-off frequency is:

$$F_{c.3db} = \frac{1}{\pi RcCc} \quad (2)$$

This frequency should be somewhere between 10kHz and 20kHz to ensure both adequate attenuation at integer multiplies of the analog to digital converters sampling frequency, and very low phase shift at mains frequency and its harmonics.

Voltage sensing network

The voltage sensing network performs similar functions to the current sensing network. It senses the mains voltage and converts it to the input current signal required by theSA9904B. It also filters all unwanted signals and prevents them from distorting the performance of the SA9904B. The voltage sensing network is shown in Figure 3. The voltage sensing network is composed of an adjustable voltage divider (resistors R21, R24, R27) and the current input resistor that generates the required current input signal for the SA9904B. The first consideration when designing the voltage sensing network is that the -3dB cut-off frequency has to be very closely matched to that of the current sensing network. This is important to ensure that the phase shift experienced by the voltage and current signals is identical. If this is not the case the energy meter will have poor performance under non unity power factor load conditions. The high cut-off frequency of the input network filters does ensure that this matching does not have to be extremely precise. This allows component tolerances to be accommodated without seriously affecting the performance of the meter. The best matching between the cut-off frequencies is achieved by using identical capacitors on both the current and voltage sensing networks, so C13 should be equal to C18 and C19 plus additional value to compensate for the phase shift induced by the measuring CTs. The IVP input is a virtual short circuit to analog ground (AGND) so the equivalent resistance associated with C13 is:

$$Requ\text{-}C13 = R30 \,||\, R31 \,||\, Rx \quad (3)$$

Where Rx is the series combination for R21, R24 and R27. If both Rx and R31 are designed to be significantly larger than R30 then

$$Requ\text{-}C13 = R30 \quad (4)$$

To match the -3dB cut-off frequency of the Current Sensing Network R30 should therefore equal ½Rc which is the value of the current sense network equivalent resistance. This ensures balanced phase shifts on the current and voltage input networks so the performance of the meter at non-unity power factors will not be affected. The voltage input IVP of the SA9904B has to be driven with a current of 11µA_{RMS} at the nominal rated mains voltage. This input also saturates at 25µApeak current, so the 11µA_{RMS} input current allows for 50% overdrive capability while maintaining linearity. This ensures that the device will not saturate with a ±20% variation in mains voltage. The simplest method is to set the input resistor R31 at 100 times the value of R30, so it will not significantly affect the -3dB cut-off frequency of the voltage sense network. Setting

$$R31 = 100 \times R30 = 50Rc \quad (5)$$

Sets the required output voltage on the voltage divider to

$$V = 11 \times 10^{-6} \times 100 \times R30 \quad (6)$$

because the IVP pin has a virtual short to ground. Given that R31 and Rx are large compared to R30

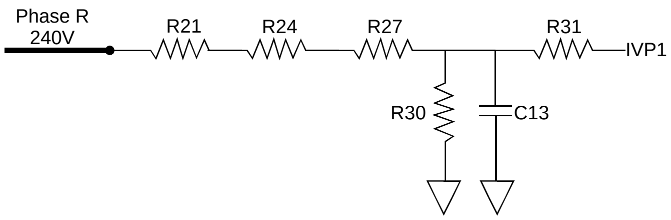

Figure 3: Circuit diagram of the voltage sensing network

Power Supply

A power supply that will work over a voltage range of 144V to 288V is required. In addition the IEC 62053-21 specifies the voltage circuits to have a mean power consumption of 2W and 10VA, the Indian Standards IS 13779/1999 specification for the power supply is 1.5W and 8VA per phase. To meet this voltage range and power consumption specifications this design uses a switched mode power supply. Refer to figure 17 for the power supply schematic.

PCB DESIGN CONSIDERATIONS

There are numerous PCB design aspects to consider when designing a power/energy meter, but only a few crucial aspects will be discussed here.

1. The sense resistors on the current inputs (R37, R38, R39, R40, R41 and R42) must be located as close to the SA9904B input pins as possible. This also holds true for the 1M resistors (R31, R32 and R33), as well as the biasing resistor (R43).

2. The supply bypass capacitors C20, C21 and C22 must be positioned as close as possible to the supply pins of the SA9904B and connected to a solid ground plane.

3. A ground plane surrounds the SA9904B to minimise the influence of noise on the sensing inputs.

4. Two different ground planes are used. The one plane should be used only for the analog section of the PCB, the other containing the power supply and digital signals.

5. The analog ground plane must be kept as quiet as possible, i.e. free from high frequency signals, and away from high voltages and currents.

6. For EMC considerations, the two ground planes must only be connected at one point, preferably at the device ground pin.

7. 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 SA9904B 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 SA9904B. This will ensure that all the noise (spikes and power demands) are put on the supply line before it gets to the SA9904B. Most of the noise will then be filtered out by the supply bypass capacitors.

8. The meter is protected from high transients on the main voltage input by means of a metal oxide varistor. These MOVs will clamp high transients with a sufficiently long rise time when measured with respect to neutral.

METER CONNECTIONS
Figure 4 shows the electrical connections to the RM9904BSEB meter. All three phase voltages and currents are connected to the front of the meter by way of a eight-way standard screw terminal connector.

METER CALIBRATION THROUGHOPTICAL INTERFACE
For optical communication with the meter, the cover must be open and the probe (SOP-232 or similar) used.

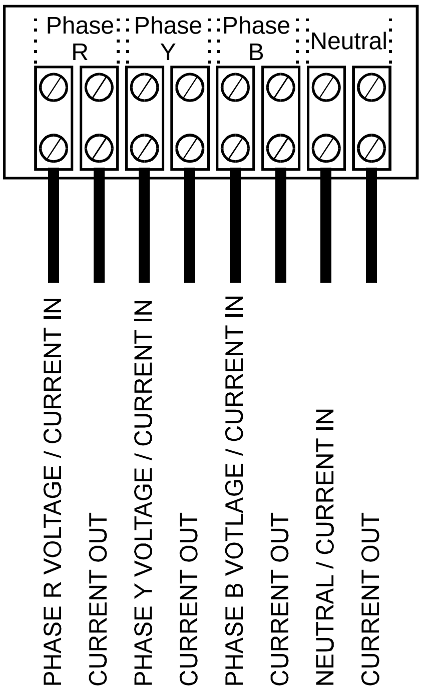

Figure 4: Electrical connections

Open the “RM9904BSEB.EXE”Windows program and click on “Receive Data” to establish communication with themeter.

See help file for more detail on usingWindows program as well as other functions of meter.

UPF Calibration Procedure (pf=1.0)
- Ensure that the voltages for all phases are switched on
- Enter zero for all 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 each phase

ZPF Calibration Procedure (pf=0.0)
- Ensure that the voltages for all phases are switched on
- Enter zero for all the reactive 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 each phase

TYPICAL PERFORMANCE GRAPHS FOR RM9904BSEB

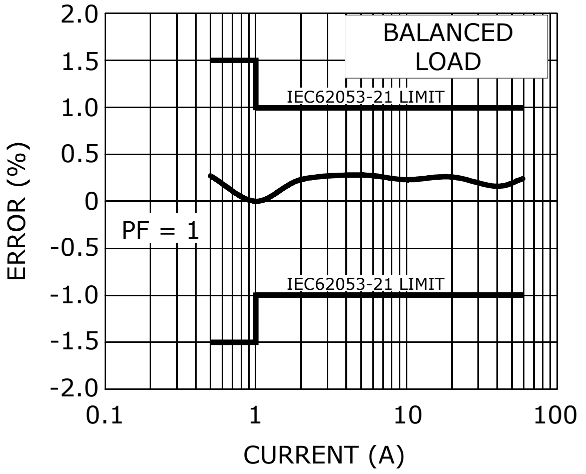

Figure 5: Balanced Load at UPF

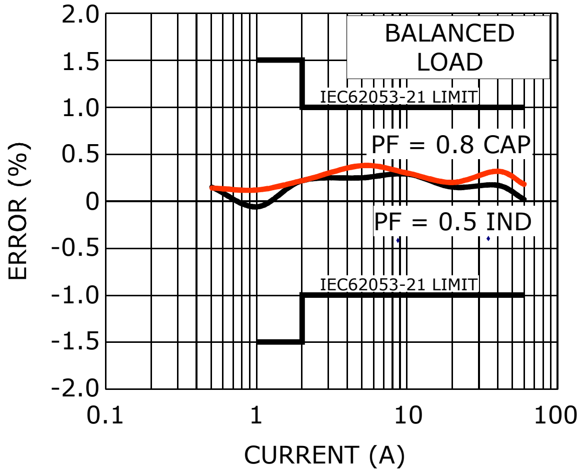

Figure 6: Balanced Load at 0.5 inductive and 0.8 capacitive

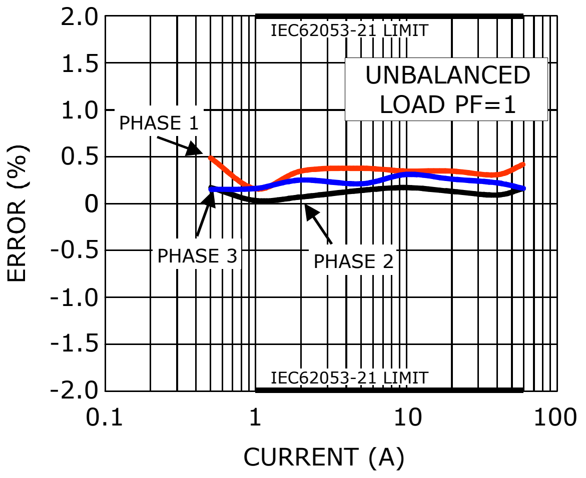

Figure 7: Unbalanced Load at UPF

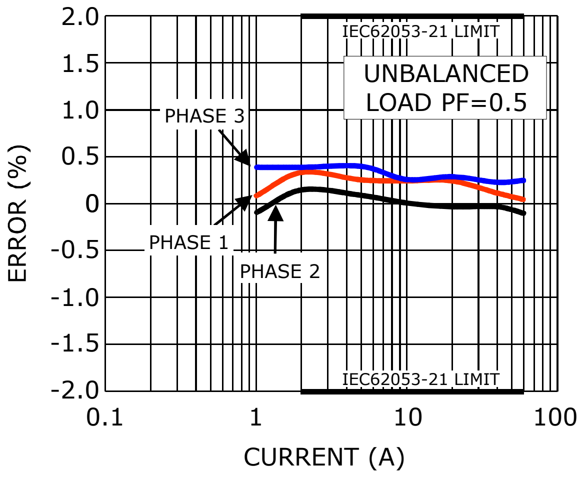

Figure 8: Unbalanced Load at 0.5 inductive

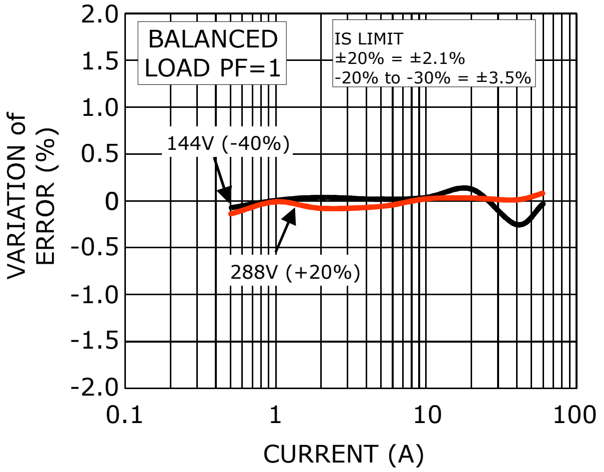

Figure 9: Indian Standard Voltage Variation -40% to+20% from 240V at UPF

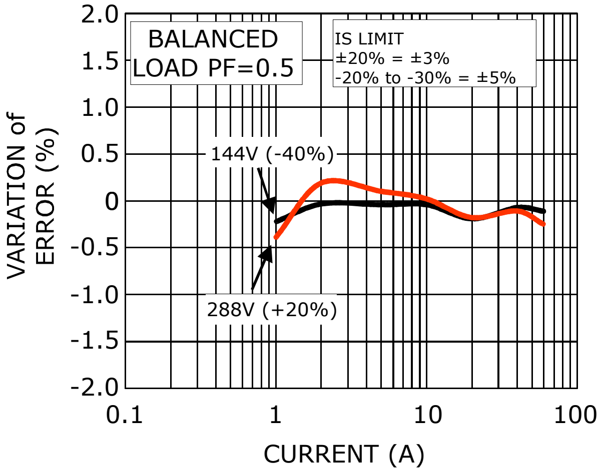

Figure 10: Indian Standard Voltage Variation -40% to+20% from 240V at 0.5 inductive

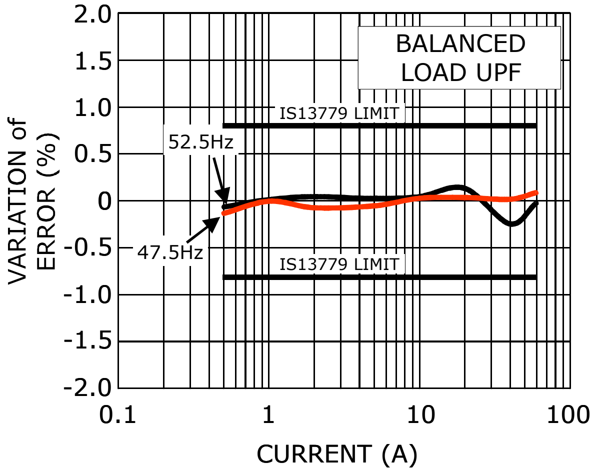

Figure 11: Indian Standard Frequency Variation ±5% from 50Hz at UPF

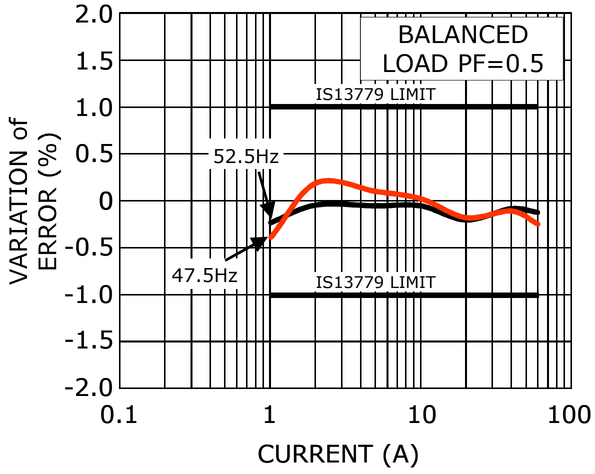

Figure 12: Indian Standard Frequency Variation ±5% from 50Hz at 0.5 inductive

PCB LAYOUT

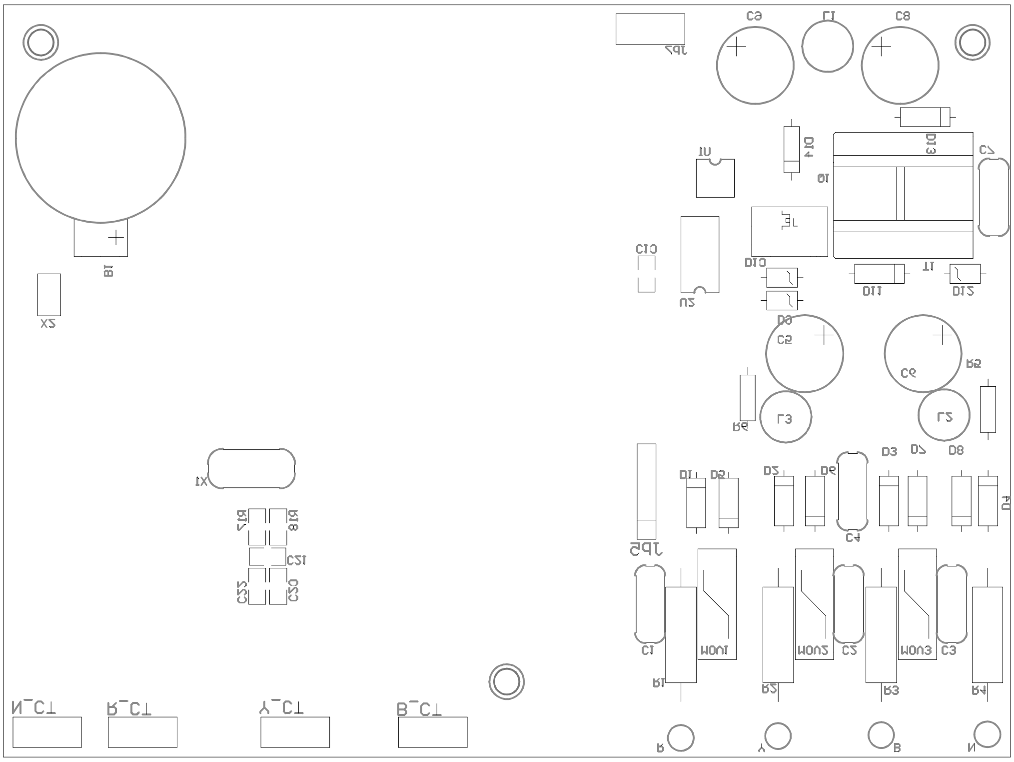

Figure 13: Bottom overlay (Scale 1:1)

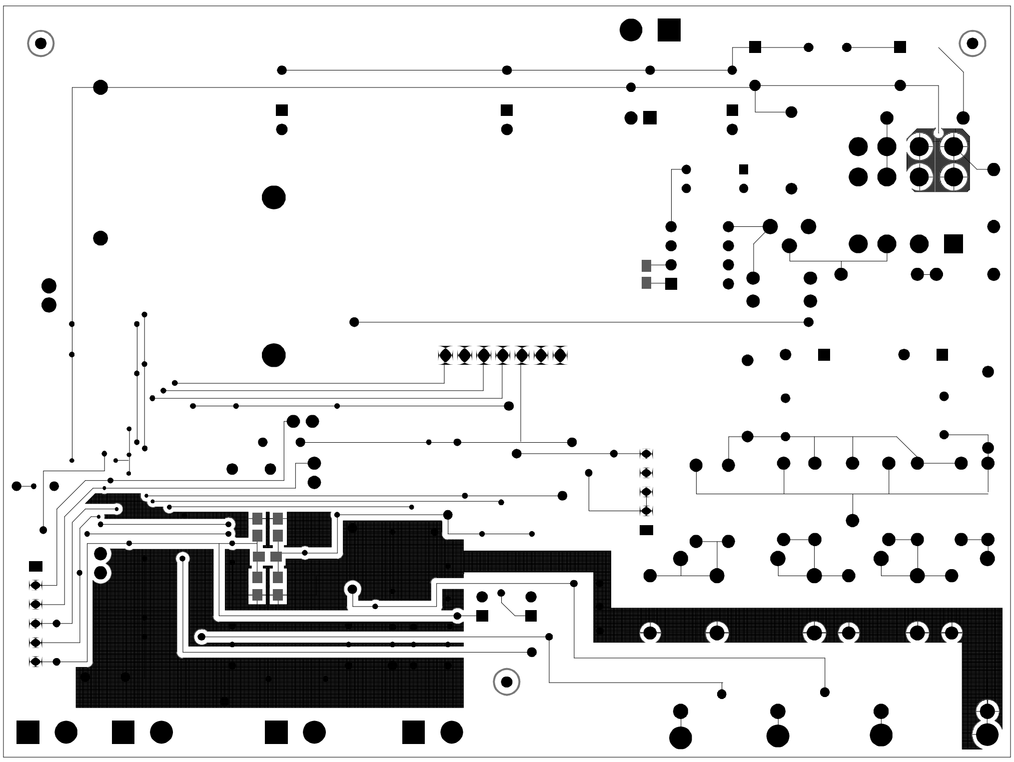

Figure 14: Bottom Layer (Scale 1:1)

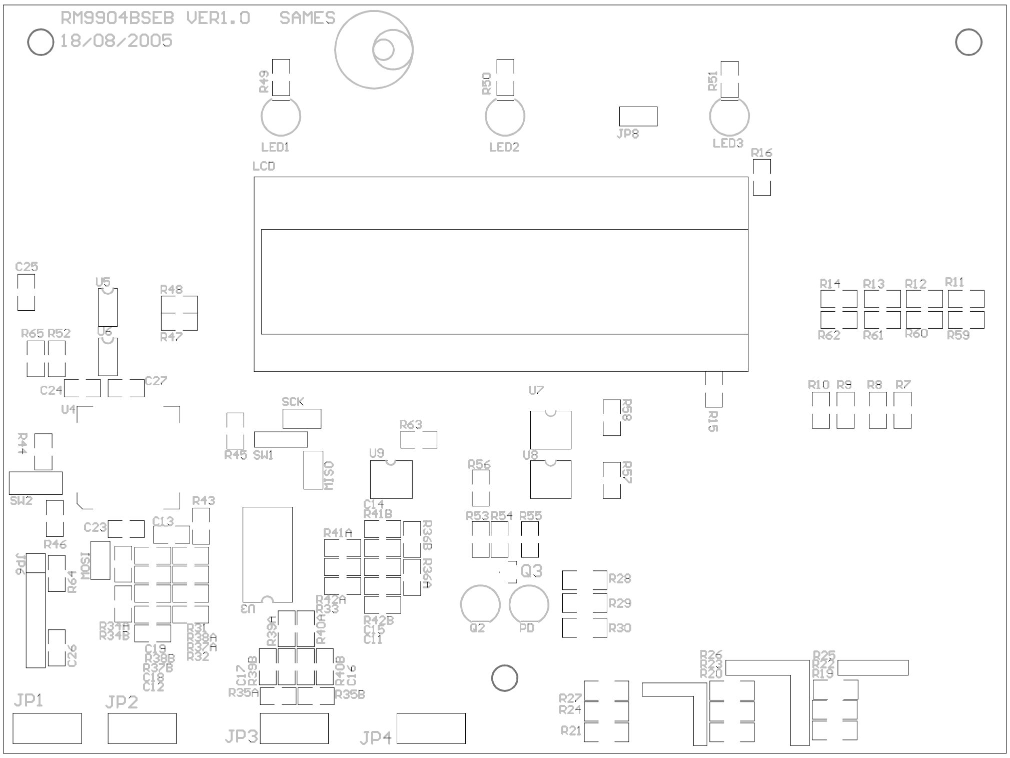

Figure 15: Top overlay (Scale 1:1)

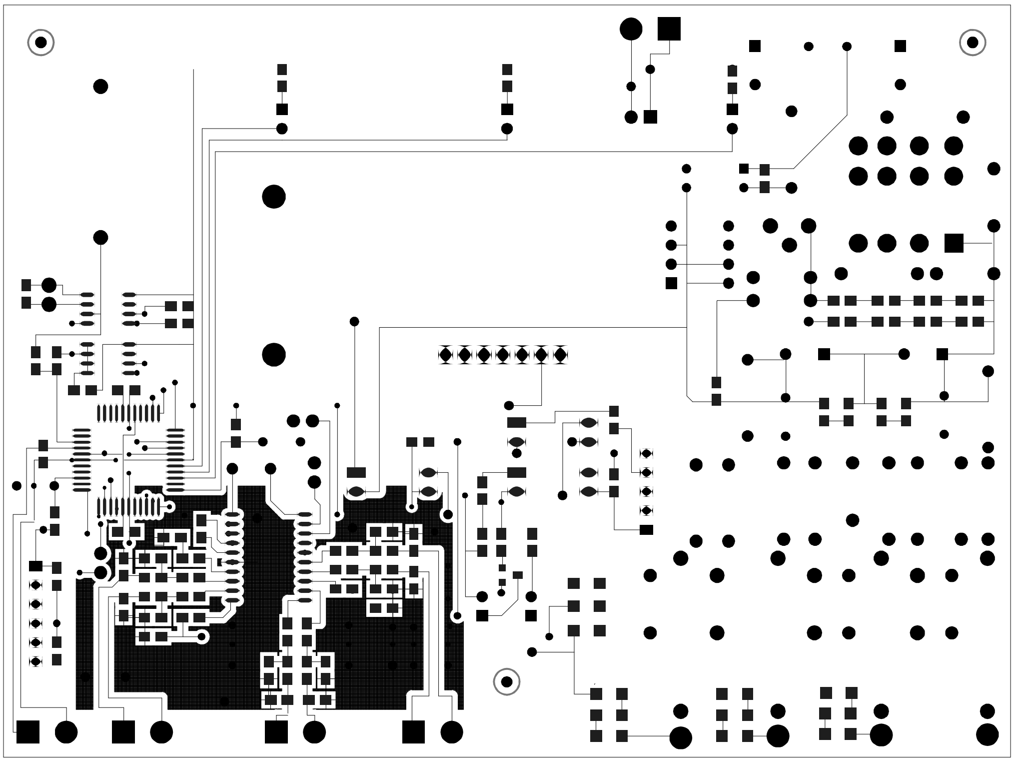

Figure 16: Top Layer (Scale 1:1)

METER SCHEMATIC

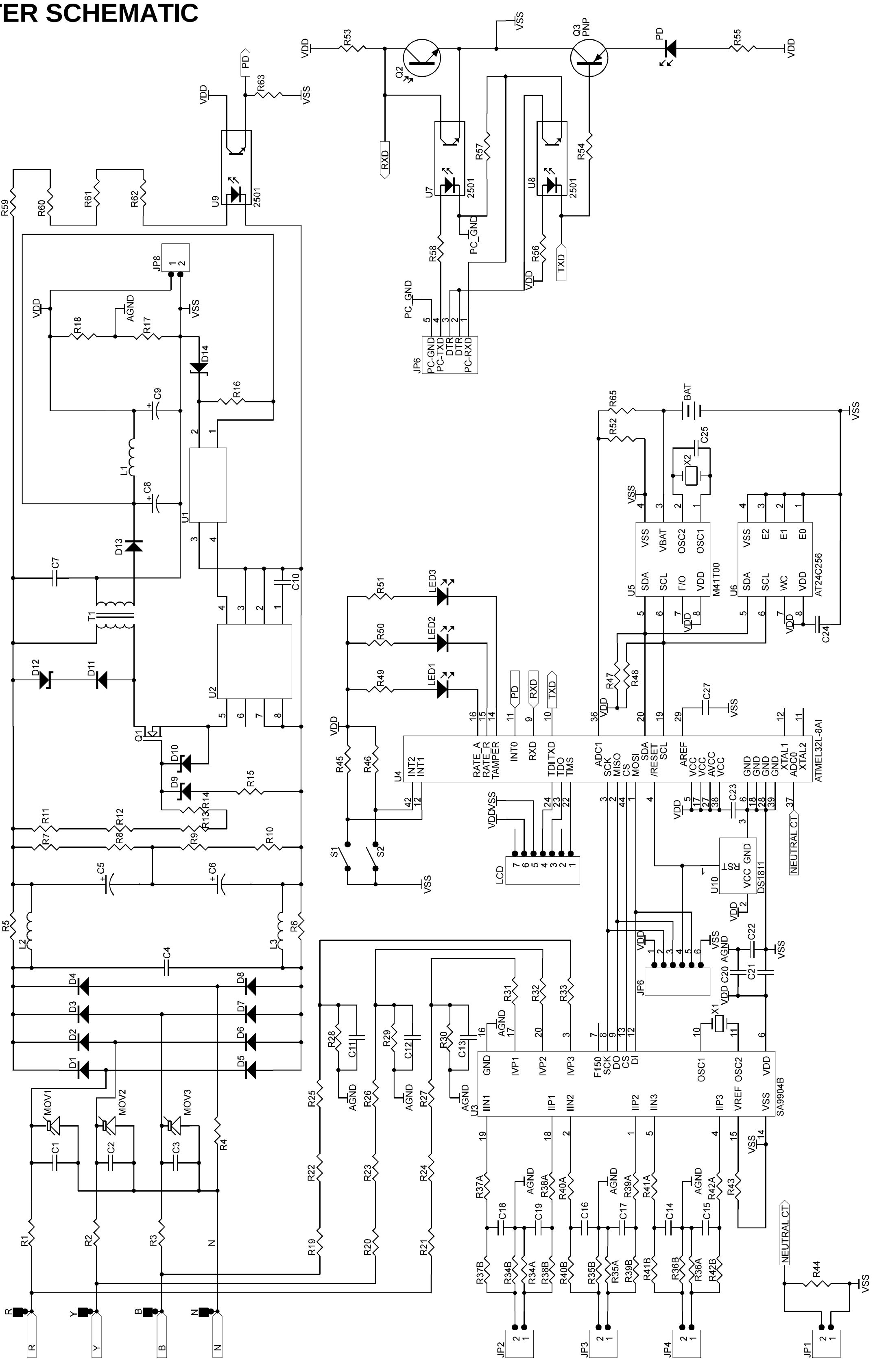

Figure 17: Meter Schematic

COMPONENT LIST

Designator	Part Type	Remarks
BAT	CR2032	3V6 Lithium button cell
C1, C2, C3, C4	1nF, 1kV Ceramic Capacitor	
C5,C6	2.2µF, 450V radial electrolytic	
C7	1nF, 250Vac Y1 class	
C8	470µF, 16V radial electrolytic	
C9	2200µF, 25V radial electrolytic	
C10, C23, C24, C27	0.1µF, 50V Ceramic	
C11, C12, C13	10nF, 50V, Ceramic	
C14, C15, C16, C17, C18, C19	47nF, 50V, Ceramic	
C20, C21, C22	1uF, 16V Ceramic	
C25		Not fitted
C26		Not fitted
D1, D2, D3, D4, D5, D6, D7, D8	1N4007 Rectifier diodes	
D9	P4KE550A Transzorb	
D10	15V, 400mW zener diode	
D11	UF4007 ultra fast rectifier	
D12	P6KE200A Transzorb	
D13	1N4935 Fast rectifier	
D14	3V9, 400mW Zener diode	
JP1, JP2, JP3, JP4, SW1, SW2	Solder joint	
JP5	Single inline pin 5 header	RS232
JP6	Single inline pin 6 header	Programming interface
L1, L2, L3	10uH, 100mA inductor	
LCD	CM01040 LCD module	
LED1, LED2, LED3	5mm Red LED	
MOV1, MOV2, MOV3	S20/K460	
PD	LD271 5mm Infra-red LED	
Q1	IRF820 MOSFET transistor	
Q2	PT331C 5mm Photo transistor	
Q3	2N3906 PNP transistor	
R1,R2,R3,R4	1k, 3W Resistor	
R5, R6	1k5, 1%, ¼ metal film resistor	
R7,R8,R9,R10,R52,R65	1M, 1% Resistor	
R11,R12,R13,R14	470k, 1% Resistor	
R31, R32, R33	68k, 1% Resistor	
R15	10R, 1% Resistor	
R16	120R, 1% Resistor	
R17,R18,R49,R50,R51,R53,R58	1k, 1% Resistor	
R19,R20,R21,R22,R23,R24,R25,R26,R27	56k, 1% Resistor	
R28,R29,R30	680R, 1% Resistor	
R34A,R34B,R35A,R35B,R36A,R36B	4R7, 1% Resistor	
R37A,R37B,R38A,R38B,R39A,R39B, R40A,R40B,R41A,R41B,R42A,R42B	1k5, 1% Resistor	

COMPONENT LIST continued

Designator	Part Type	Remarks
R43	47k, 1% Resistor	
R44	100R, 1% Resistor	
R45,R46,R47,R48,R63	10k, 1% Resistor	
R54,R57	4k7, 1% Resistor	
R55	402R, 1% Resistor	
R56	2k2, 1% Resistor	
R59,R60,R61,R62	54k, 1% Resistor	Note 1[1]
R64	Not fitted	Replace with U10
MOSI,MISO,SCK	Wire link	
T1	3phase VAR2, SMP transformer	Innovatech, Type EE1605
U1,U7,U8,U9	2501 or 817	Opto-coupler
U2	TNY253P	SMPS controller
U3	SA9904BSA	
U4	ATmega32-8A	Micro controller
U5	M41T00	RTC
U6	AT24C256	External eeprom
U10	DS1811-10	Reset IC
X1	3.57MHz Crystal	
X2	32.768MHz Crystal	

[1] 54k is a sum of three resistors of 18k each, to meet power dissipations level.

DISCLAIMER:

Any sales or technical questions may be posted to our e-mail address below:
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For the latest updates on datasheets, please visit our web site:
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