RM2102DSE Application Note:
Reference Meter
Watt-Hour Energy Meter Based on the SA2102D
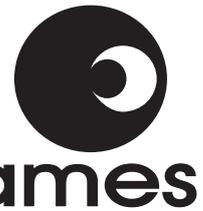
RM2102DSE

FEATURES

■ Exceeds the IEC 61036 accuracy requirements for class 1 active energy measurement

■ Uni-directional and Bi-directional power and energy measurement

■ Selectable rated conditions, LED pulse rates and counter resolutions

■ On-board precision calibration

■ Direct drive capability for both stepper motor and impulse counters

■ Opto-isolated output for connection to measurement equipment

INTRODUCTION

This application note describes the SAMES reference design for a low cost, watt-hour energy meter based on the SAMES SA2102D integrated circuit. It is advisable to use this application note in conjunction with the SA2102D datasheet, which provides detailed information on the functionality of the SA2102D.

The SA2102D is a single chip solution for accurate bi-directional power / energy measurement. It incorporates an on-chip oscillator, and has direct motor drive capabilities for stepper motors. A fast calibration LED output is made available to the meter manufacturer to ensure convenient and fast calibration of the meter. The normal calibration model at a lower frequency provides for accurate and stable energy / power measurement. The device can be configured to measure either positive or negative energy, or to measure energy irrespective of the direction.

METER SPECIFICATIONS

The International Standards IEC 61036 (Alternating current static watt-hour meters for active energy) was used as the primary specification for this design.

The dynamic range of the meter is 800, and the meter not only easily meets this specification but exceeds the IEC 61036 specification over this range.

A basic meter design using the SA2102D is shown in figure 1. This design uses a shunt as the current sensing element, while the voltage is supplied to the device by means of a voltage divider circuit. Calibration is done by means of a precision resistive network. The measured power is displayed on either a stepper-motor driven counter, or a mechanical impulse counter. An opto-isolator and LED is connected to the output for visual inspection, or use with an optical pick-up or measurement equipment.

I_{Max}, I_B, V_{nom} as well as the pulse motor constants can be chosen by the meter designer. Two examples are given later on in this document for illustration.

CIRCUIT DESIGN
ANALOG INPUT

The selection and positioning of the current and voltage sense resistors, as well as the selection and positioning of the resistor used for setting the bias are very important to ensure the correct operation of the SA2102D. The most important external components for the SA2102D integrated circuit are the current and voltage sense resistors, as well as the bias setting resistors. These resistors must be of the same type as specified in the parts list to ensure that the temperature effects and noise susceptibility are minimized.

VOLTAGE INPUT IVP

A signal of $14\mu A_{RMS}$ must be applied to the voltage input of the SA2102D for the nominal rated mains voltage. Please note that this input will saturate with currents bigger than approximately $17\mu A_{RMS}$ ($25\mu A$ max), which translates into a 20% overdrive capability. This also ensures that the device will not saturate with a 10% variance in mains voltage. The mains voltage is divided down via a resistor network (see Figure 2) to 14V. This voltage is fed to a $1M\Omega$ resistor (R18) to realize the $14\mu A_{RMS}$

Ignoring jumpers J3...J10 results in the following equations:

$$RA = R1 + R2 + Rtrim$$
$$RB = R18 \| R14$$

Where $Rtrim = R4 + R5 + R6 + R7 + R10 + R11 + R12 + R13$

Combining the two equations result in:
$$(RA + RB) / 220V = RB / 14V$$

Values for resistors $R14 = 24k\Omega$, $R18 = 1M\Omega$ are chosen.
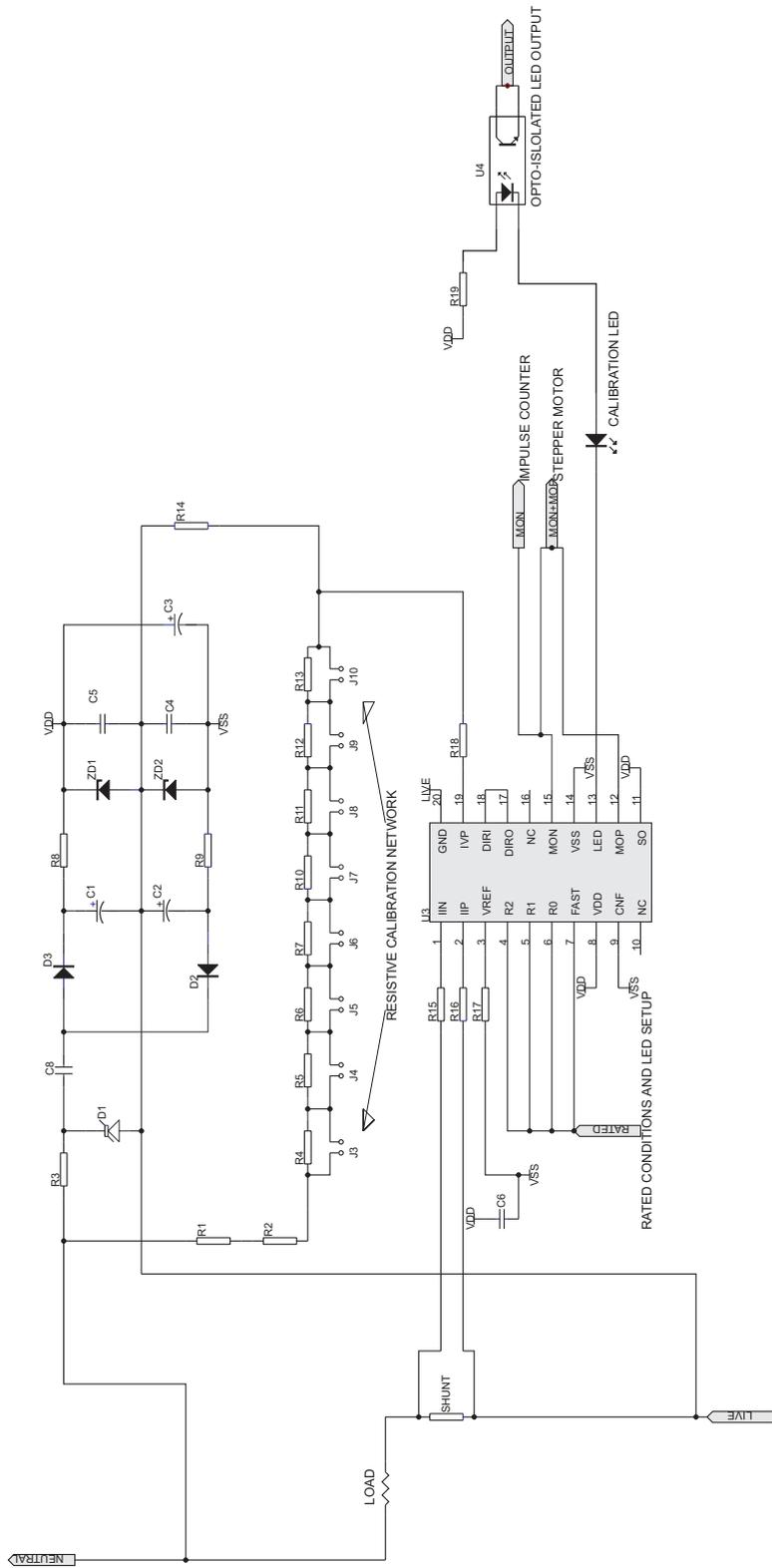
*Figure 1: Basic design of a watt-hour meter based on the SA2102D*
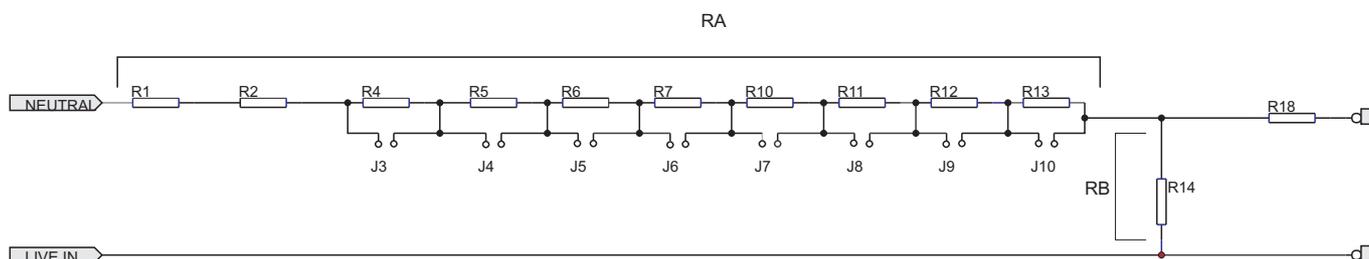
Figure 2: Voltage divider circuit and Resistive Calibration Network

Substituting the values result in:
RB = 23.437kΩ
RA = RB x (220V / 14V -1)
RA = 396.34kΩ

Standard resistor values of 100kΩ are chosen for R1 and 180kΩ for R2. The value of Rtrim is chosen to cover ±20% of RA. The values in the resistor ladder are used so that the resistor value halves with the next value. This results in using only two values in the E96 resistor range.

CURRENT SENSE INPUT

Resistors R15 and R16 (figure 3) define the current level into the current sense inputs of the SA2102D. The PM2102DP meter can be used with most available shunts. The explanation in this text is given for a 625µΩ shunt with an I_{MAX} of 80A and 50mV at I_{MAX}. To ensure proper current sensing it is advisable to use a shunt that will give a voltage drop of at least 20mV at rated conditions. The resistor values are calculated for an input of 16µA$_{RMS}$ on the current sense inputs at rated conditions. The design equation is as follows:

R15 = R16 = (I_L / 16µA) x R_{SH} / 2

I_L = Line current
R_{SH} = Shunt value

Also see the section on **DESIGN EXAMPLES**.

REFERENCE VOLTAGE
The on chip reference current is derived from a 47kΩ resistor

connected between pin 3 of the device and VSS.

Analog Ground (GND)
The GND pin of the SA2102D is connected to the live phase, which is halfway between V_{DD} and V_{SS}.

PM2102DP METER SETUP
External Connectors
The PM2102DP meter can be connected directly to live and neutral at terminals 3 and 4 on the meter-box. These terminals are internally connected to J1 on the PCB. The current must be connected to terminals 1 and 2 on the meter-box, which is internally connected to J2.
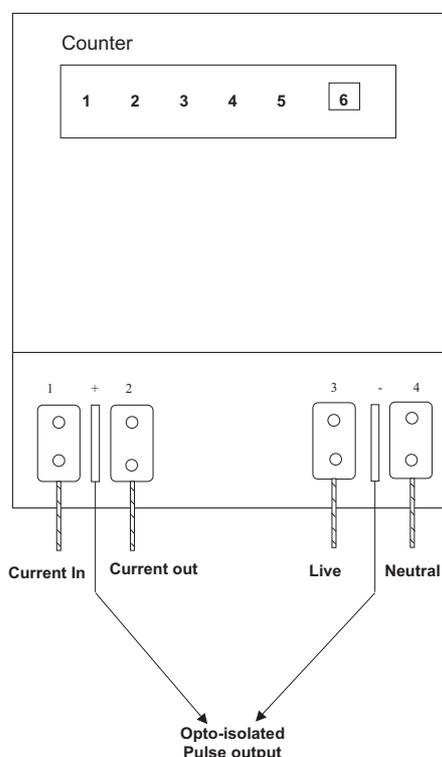

Figure 4: Current and mains voltage connection diagram

Figure 3: Current sensing using a shunt

Name	Function Description
1	Live Current In
2	Neutral Current Out
3	Live
4	Neutral
+ and -	Optical-isolated output. Connect to measurement equipment

Table 1: External connector descriptions

The connections are made as is shown in figure 4. Also see Table 1.

The optical-isolated pulse output is taken to the + and - terminals on the meter-box.

A mechanical counter can also be connected to J21 on the PCB in place of the stepper motor counter that is currently connected to J20 on the PCB.

Please take note that the meter is referenced to live, and care must be taken when connecting test equipment to the meter.

The PM2102DP meter is equipped with several solderable selectors[1], which will allow the user / meter manufacturer to set the meter up to their own specifications. Table 2 describes the various jumper options. This table should be used in conjunction with figure 5, which will make it easier to locate the jumper in question.
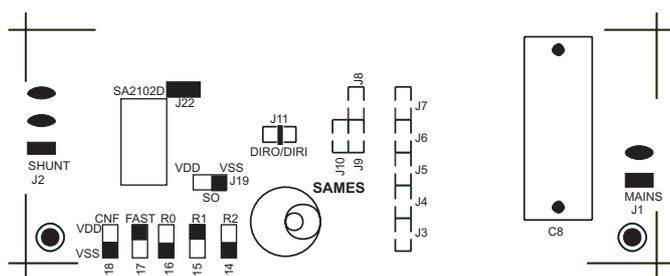

Figure 5: Solderable selector positions and default setup. This default setup enables fast mode output, with the pulse stability circuitry enabled, for the measurement of bi-directional

DESIGN EXAMPLES

Selection Of R1, R2 And R0 For Different Rated Conditions

The following equations and tables state the basic pulse constants and motor constants obtainable with the PM2102DP meter.

The Output pulse equation is:

LED p/kWh =
1160p/sec x (1/DF_LED) x [3600 / ((Vnom x IMAX) / 1000)]

And the motor constant equation is:

MOTOR p/kWh = LED p/kWh / DF MO

where dividing factors **DF_LED** and **DF_MO** are described in Table 3 (R2, R1 and R0 are input pins for SA2102D).

Please note that the MOTOR and PULSE outputs are related to each other, thus changing the one will change the other.

Example 1

Rated voltage: 220V
Rated current: 80A
Sensing element: SHUNT (80A, 50mV, 625µΩ)
Pulse constant: 800 imp/kWh
Motor constant: 100 imp/kWh

Calculate R15 and R16:

$R15 = R16 = (I_L / 16µA) x R_{SH} / 2$
$= 80A / 16µA x 625µΩ / 2.$
$= 1.5625 kΩ$

A standard value of 1k6 is chosen.

The pulse constant is derived from the equation below:

LED p/kWh = 1160p/sec x (1 / DF_LED) x [3600/((Vnom x Imax)/1000)]
= 1160 p/sec x (1 / DF_LED) x [3600 / (220 x 80) / 1000]
800 = 1160 p/sec x (1 / DF_LED) x 204.54
1 / DF_LED = 0.0033717
DF_LED = 296

MOTOR p/kWh = LED p/kWh / DF_MO
100 = 800 / DF_MO
DF_MO = 8

Notes

[1]. Solderable selectors are two pads that can be connected together by means of solder to act as a jumper.

SOLDERABLE SELECTOR SELECTION

Name	Option	Description
J3 to J10	Closed	These jumpers are used for calibration purposes. Also see "Calibrating the meter". Closing a jumper will bypass the resistor in the resistor ladder.
	Open	Leaving a jumper open will enable the resistor in the resistor ladder.
J11	VSS	Connecting to VSS will allow only negative energy to be measured.
	VDD	Connecting to VDD will allow only positive energy to be measured.
	DIRO / DIRI	Connecting to jumper DIRO / DIRI will allow bi-directional energy measurement. (Bi-directional is where both positive and negative energy is measured)
J14	VDD (+) VSS	Used to select the required rated conditions. See table 3 and 4 as well as figure 5 for further details on the various settings available.
J15	VDD (+) VSS	Used to select the required rated conditions. See table 3 and 4 as well as figure 5 for further details on the various settings available.
J16	VDD (+) VSS	Used to select the required rated conditions. See table 3 and 4 as well as figure 5 for further details on the various settings available.
J17	VSS	Used to select between fast and normal pulse output mode on the calibration LED output. When connected to VSS the normal pulse output mode is selected.
	VDD (+)	Connecting to VDD selects the fast output pulse mode.
J18	VSS	This selects the IC manufacturer's test mode. For normal metering connect to VSS.
J19	VSS (-)	When fast mode is selected this input can be used to enable or disable the internal pulse stability circuitry for the LED output pulses. Connecting to VSS disables this circuitry.
	VDD (+)	Connecting to VDD enables this circuitry.

Table 2: Jumper options

R2	R1	R0	DF_LED	DF_MO
0	0	0	322	64
0	0	1	322	32
0	1	0	322	16
0	1	1	322	8
1	0	0	536	64
1	0	1	214	16
1	1	0	214	8

Table 3: DF_LED and DF_MO factors for SA2102D

Thus using table 3, it is seen that the closest value could be R0 = 1, R1 = 1 and R2 = 0

In the above table a "1" implies that the selector is connected to V_{DD}.

Example 2

Rated voltage: 220V
Rated current: 20A
Sensing element: SHUNT (80A, 50mV, 625μΩ)
Pulse constant: 3200 imp/kWh
Motor constant: 100 imp/kWh

Calculate R15 and R16:

$$R15 = R16 = (I_L / 16\mu A) \times R_{SH} / 2$$
$$= 20A / 16\mu A \times 625\mu\Omega / 2.$$
$$= 390.625\,\Omega$$

A standard value of 390Ω is chosen.

The pulse constant is derived from the equation below:

LED p/kWh = 1160p/sec x (1 / DF_LED) x [3600/((Vnom x Imax)/1000)]

= 1160 p/sec x (1 / DF_LED) x[3600 / (220 x 20) / 1000]

3200 = 1160 p/sec x (1 / DF_LED) x 818.18

1 / DF_LED = 0,003371

DF_LED = 296

MOTOR p/kWh = LED p/kWh / DF_MO

100 = 3200 / DF_MO

DF_MO = 32

Thus using table 3, it is seen that the closest value could be R0 = 1, R1 = 0, and R2 = 0.

Standard meter constants for various rated conditions

The following table list the most common and frequently used pulse and motor constants for different rated conditions. Table 4 serves as an easy reference for meter manufacturers, and constants not listed can be calculated by using the equations provided in the previous examples.

R2	R1	R0	Rated Condition (V / I)	LED Output (p/kWh)	MON, MOP (p/kWh)
0	0	0	220/10A	6400	100
0	0	1	220/20A	3200	100
0	1	0	220/40A	1600	100
0	1	1	220/80A	800	100
1	0	0	220/6A	6400	100
1	0	1	220/30A	3200	100
1	1	0	220/60A	1600	100

Table 4: Different meter constants

CALIBRATING THE METER

The meter is calibrated by means of a resistive ladder connected to the voltage input of the SA2102D.

The 8 resistor values are available to choose the maximum calibration range, while the 8 jumpers provide 256 possible combinations for precise tuning. Soldering a particular selector closed will short-circuit the corresponding resistor. This will in effect remove the resistor from the voltage divider, and thus provide a higher voltage at the input of R18, which is connected to the voltage input of the device. The ideal is to have $14V_{RMS}$ at the input of R18 (1MΩ) that supply a 14μA current to the device. It is possible to over-drive this setting by plus or minus 20% and this will enable or disable the resistors in the resistor ladder to achieve the precise PULSE and MOTOR constants required.

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 input (R15 and R16) must be located as close to the SA2102D-input pins as possible. This also holds true for the 1MΩ resistor (R18), and the biasing resistor (R17). 2. The supply bypass capacitors C4, C5 and C6 must be positioned as close as possible to the supply pins of the SA2102D, and connected to a solid ground plane.

3. It is advisable to keep the ground plane surrounding the device clear of noise that may influence the sensing signals.

4. Make use of two different ground planes. 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. These two planes can also be connected via a ferrite bead that will help to suppress transients and high frequency interference from the digital to the analog plane.

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 device as possible, so as not to interfere with the sensing functions. The routing must be done in such a way that all other jumpers and devices are serviced before the SA2102D device. This will ensure that all the noise (spikes and power demands) are put on the supply line before it gets to the device. Most of the noise will then be filtered out by the supply bypass capacitors that are situated as close as possible to the device.

8. The meter is protected from high transients on the main voltage input by means of a **M**etal **O**xide **V**aristor. These MOVs will clamp high transients with a sufficiently long rise time when measured with respect to neutral.

Power supply

1. The onboard power supply consists of a simple capacitive divider configuration. Where the output voltage is rectified by a diode pair, and held constant by means of a pair of TL431 shunt regulators.

2. The maximum current available from the supply is approximately 20mA.

3. Please take note that the meter is fitted with a 470nF/250VAC X3 type capacitor for 220VAC mains supply. This capacitor must be changed to 1µF/150VAC X3 type when the mains supply voltage is changed to a 110VAC network.

DESIGN RESULTS

Figure 6 shows the schematic of the complete meter design.

This meter is designed to meet the IEC 61036 accuracy requirements for a Class 1 meter. The IEC specifications are summarized in table 5.

Current Value	Power Factor	Percentage Error Limits	
		Class 1	**Class 2**
0.05Ib ≤ I < 0.1Ib	1	± 1.5%	± 2.5%
0.1Ib ≤ I ≤ Imax	1	± 1.0%	± 2.0%
0.1Ib ≤ I < 0.2Ib	0.5 inductive	± 1.5%	± 2.5%
0.1Ib ≤ I < 0.2Ib	0.8 capacitive	± 1.5%	N/A
0.2Ib ≤ I < Imax	0.5 inductive	± 1.0%	± 2.0%
0.2Ib ≤ I < Imax	0.8 capacitive	± 1.0%	N/A

Table 5: IEC 61036 Specifications

Figure 6: Complete design
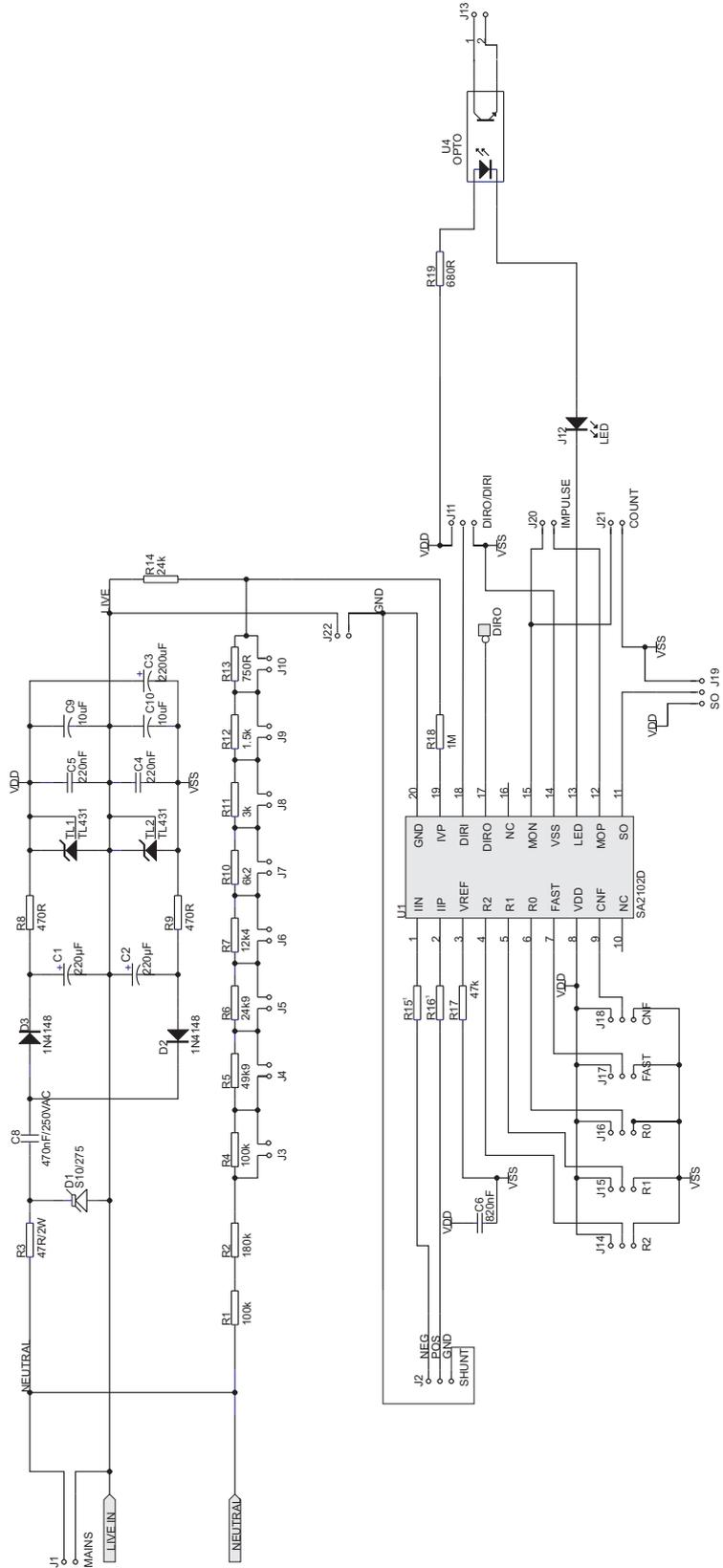
Note:
1 **To be calculated for each meter**

TYPICAL PERFORMANCE CURVES

The following performance curves show typical measurement results for instantaneous power using the SA2102D reference meter. The results are representative of the performance curves that can be obtained with test equipment equipped with a Class 0.2 reference and a stable single-phase source.

SA2102D METER Linearity: PF=1
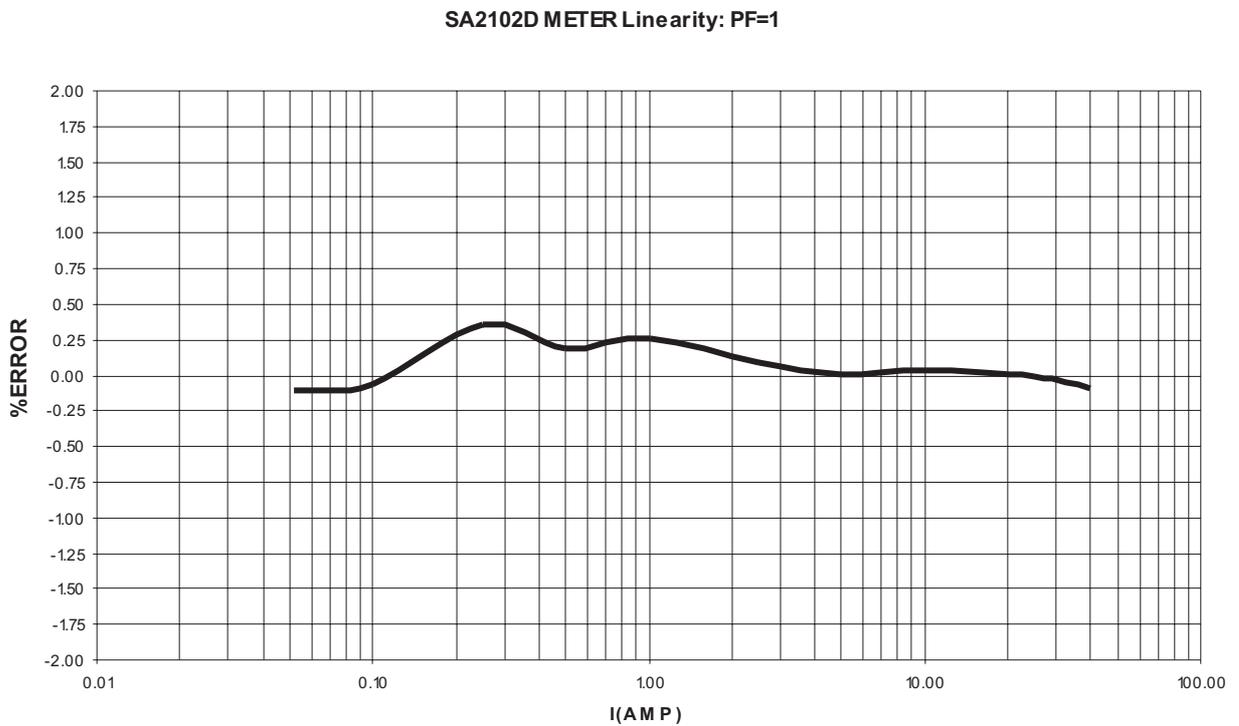
*Figure 7: Linearity over a dynamic range of 800 for PF = 1*

SA2102D METER Linearity: PF=+0.5
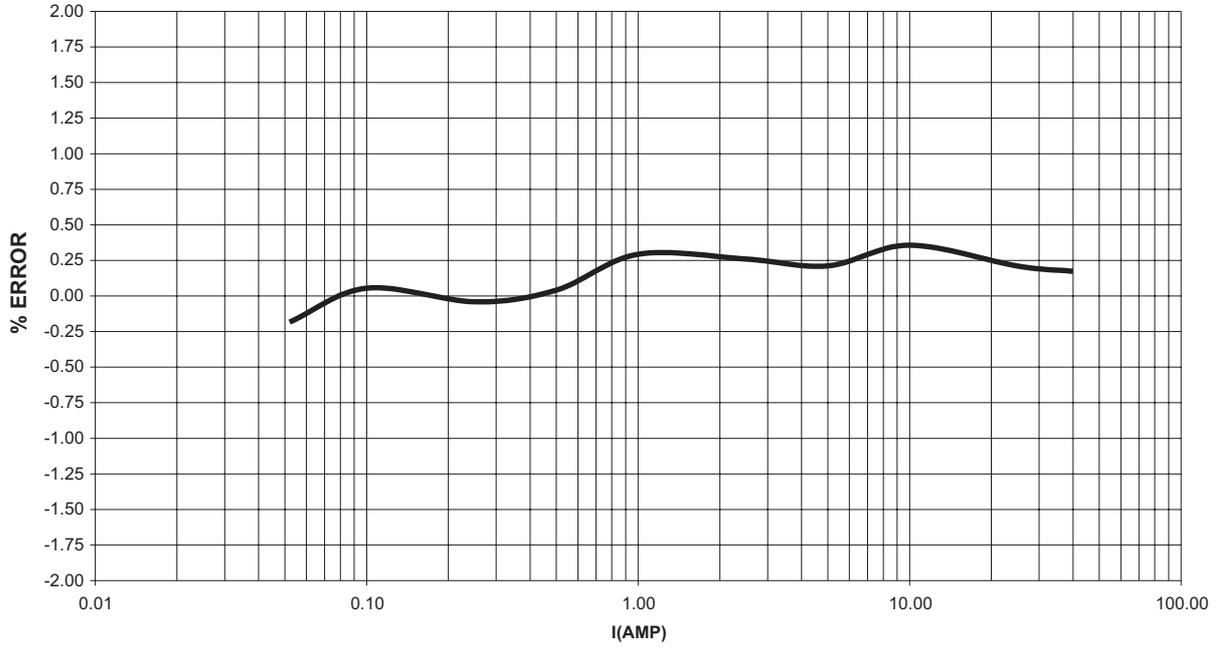
*Figure 8: Linearity at PF = +0.5*

SA2102D METER Linearity: PF=-0.5
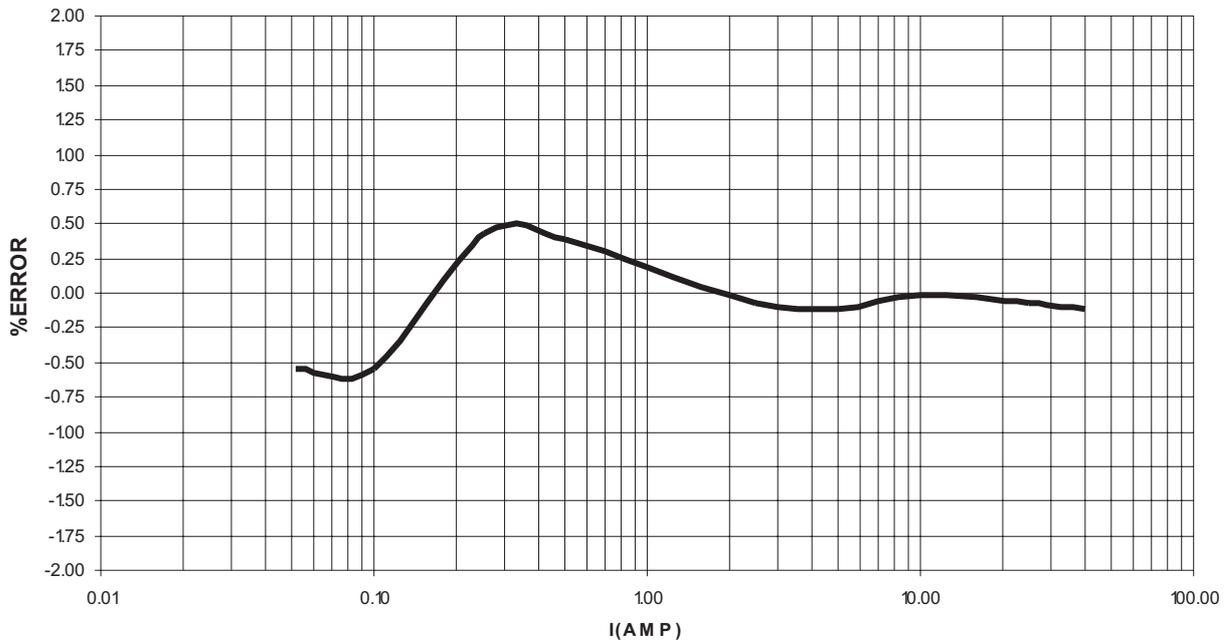
Figure 9: Linearity at PF = -0.5

SA2102D METER Linearity: PF=+0.8
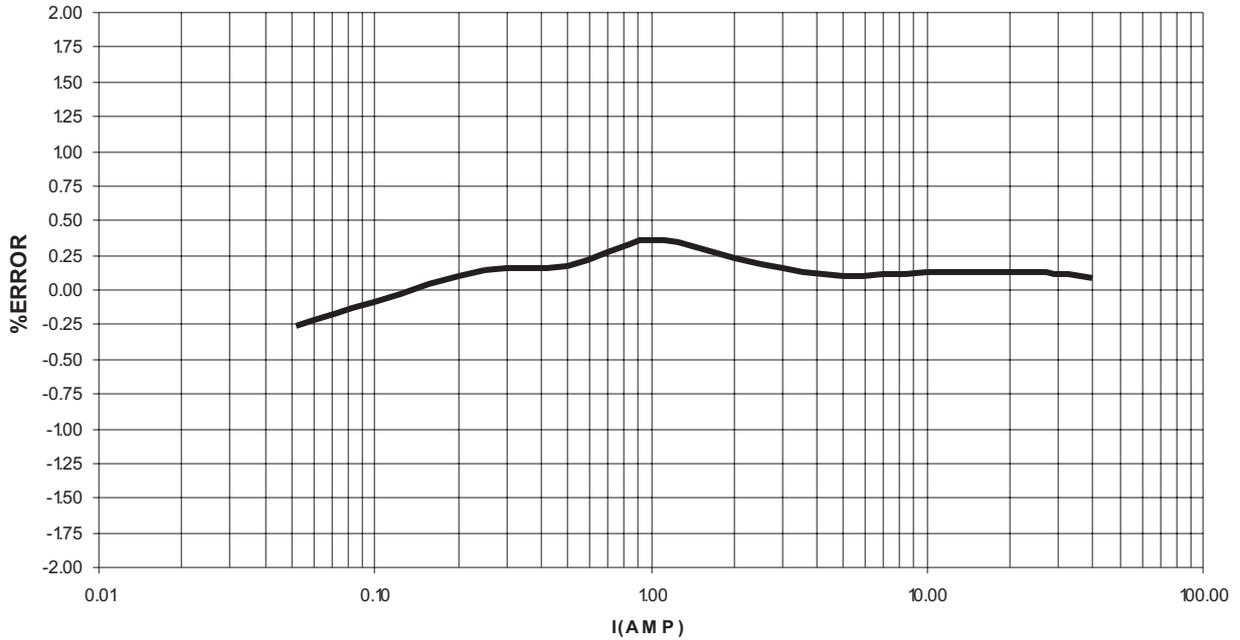
Figure 10: Linearity at PF = +0.8

SA2102D METER Linearity: PF=-0.8
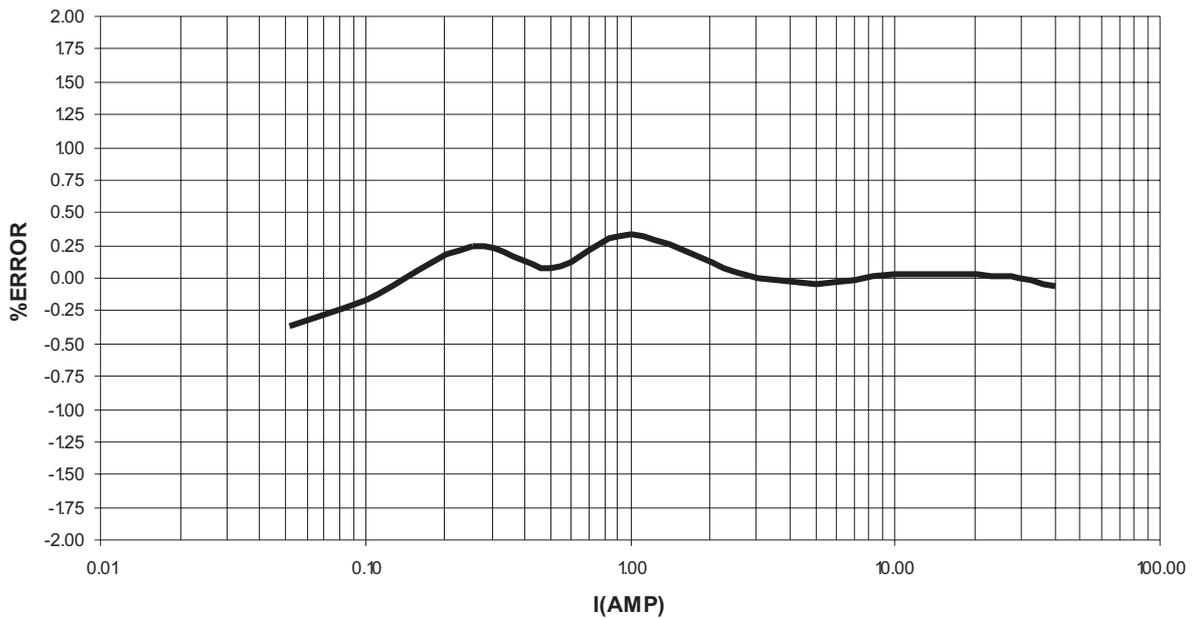
Figure 11: Linearity at PF = -0.8

EVALUATION BOARD COMPONENT LIST

Designator	Part Type	Description	Detail
U1	SA2102DSA	20 Pin SOIC	
D2, D3	1N4148	Silicon Diode	
TL1, TL2	TL431	Precision Shunt Regulator, TO-92 Package	
R1	100k	1% Resistor	
R2	180k	1% Resistor	
R3	47R	2W, 5% Wire-Wound	
R4	100k	1% Resistor	
R5	49k9	1% Resistor	
R6	24k9	1% Resistor	
R7	12k4	1% Resistor	
R8, R9	470R	1% Resistor	
R10	6k2	1% Resistor	
R11	3k	1% Resistor	
R12	1k5	1% Resistor	
R13	750R	1% Resistor	
R14	24k	1% Resistor	
R15, R16	To be calculated	1% Resistor	Note 1
R17	47k	1% Resistor	
R18	1M	1% Resistor	
R19	680R	5% Resistor	
D1	S10/275	Metal Oxide Varistor	
J12	3mm LED	Red	
U4	NEC 2501	Opto-isolator	
C4, C5	220nF	Capacitor Ceramic	
C1, C2	220µF / 16V	Capacitor Electrolytic Radial	
C8	470nF / 250VAC	Capacitor Polyester, X2 or X3	Note 2
C6	820nF / 16V	Capacitor Ceramic	
C3	2200µF / 16V	Capacitor Electrolytic Radial	
C9, C10	10µF / 16V	Capacitor Tantalum	
17	Jumpers		
2	Screws	M4 x 10mm	

Notes

1.   Calculate for specific shunt used and meter ratings.
2.   Use 1µF / 150VAC for 115V mains supply
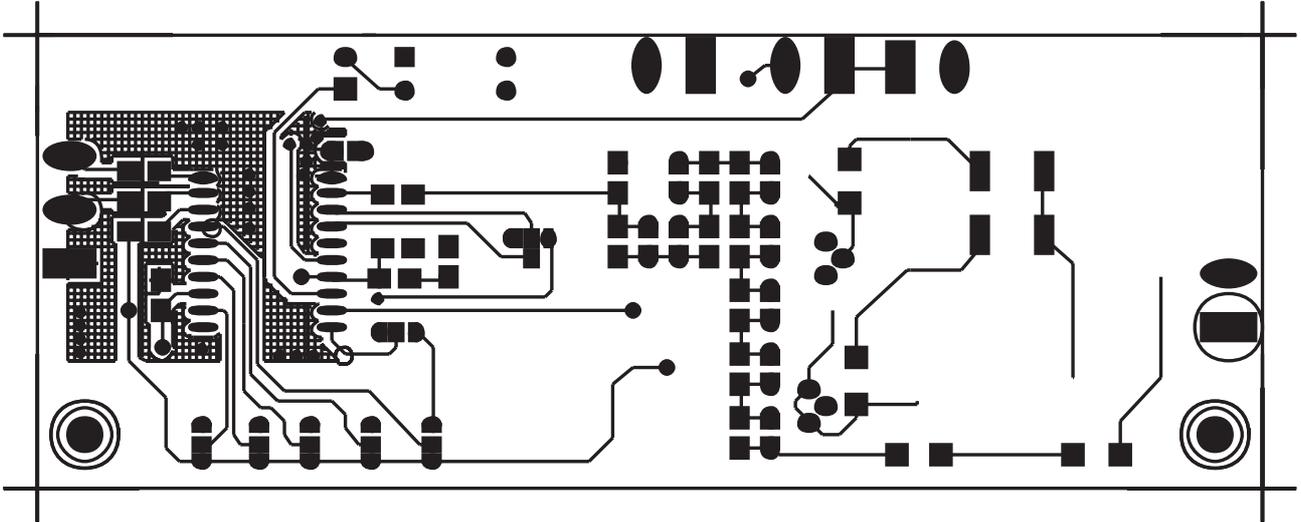
Figure 12: Top Layer
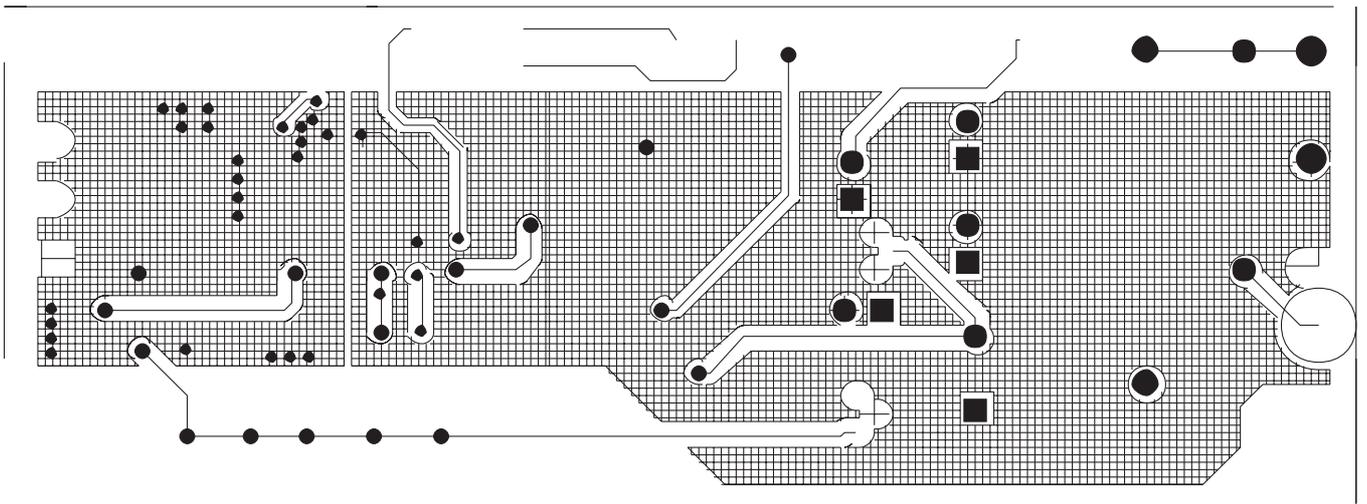
Figure 13: Bottom Layer
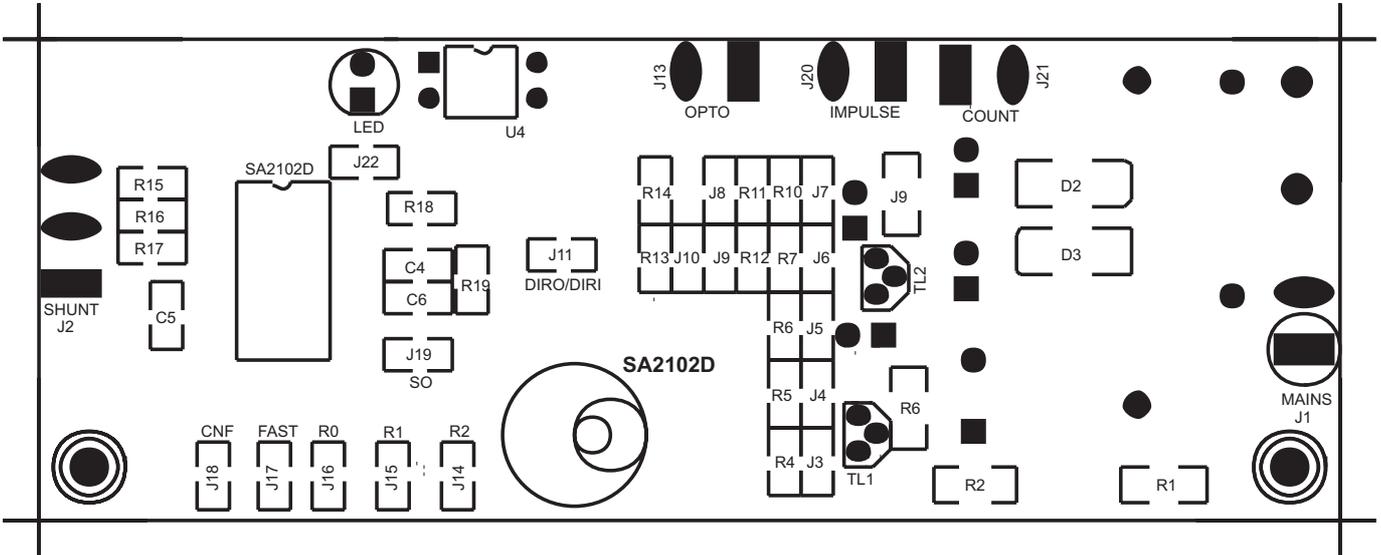
Figure 14: Top Overlay
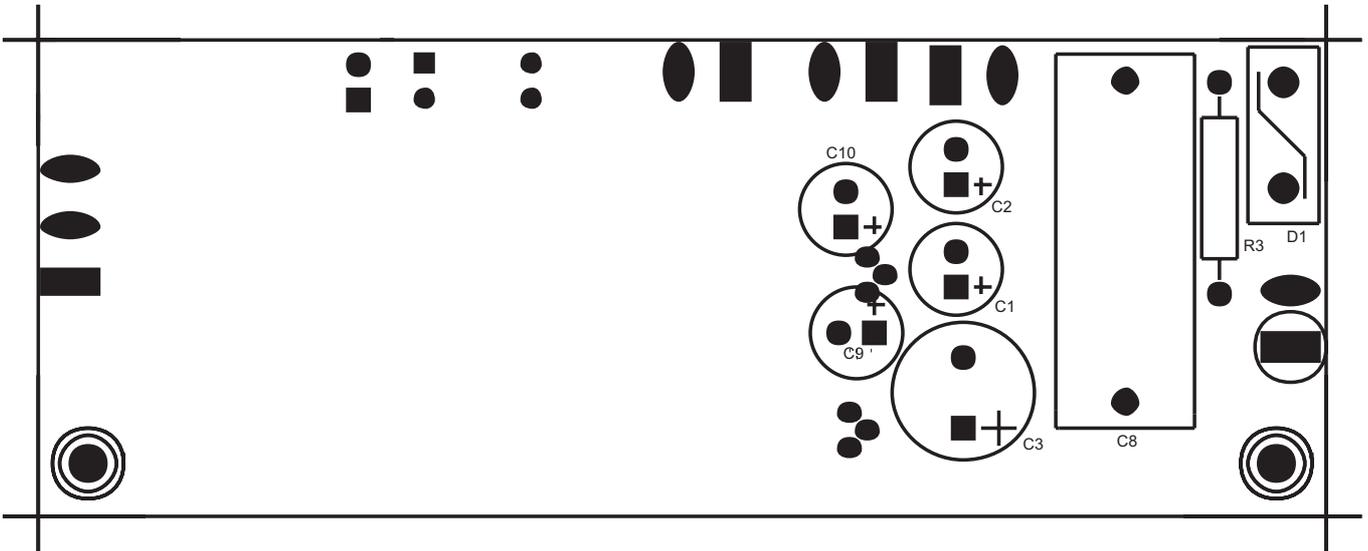
Figure 15: Bottom Overlay

NOTES:

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