PM4106APDA Application Note: Evaluation Module for SA4106A

PM4106APDA

FEATURES

- Compatible with shunt resistor or current transformer current sensing elements
- Operation from either a single 5V supply or a dual 2.5V supply
- Connection of various current sensing elements, mains voltage and power supply by means of screw terminals
- On-board LED indicators for pulse output, direction and anti-creep state
- On-board optically isolated pulse output for direct connection to test equipment
- On-board precision calibration network by means of an analog trimpot
- Connection of stepper motor counter or impulse counter by means of screw terminals
- Easily accessible jumpers for setting up all possible device options

DESCRIPTION

The PM4106APDA evaluation module is designed to demonstrate the functionality and performance of the SA4106A energy metering device. A complete single phase energy meter can be built up and evaluated using this module, allowing the performance of the SA4106A to be evaluated in an end user application. The required current sensing element, a power supply as well as a stepper motor counter or an impulse counter can be connected by means of screw terminals.

The on-board calibration network is based on a trimpot and allows accurate calibration of the energy meter. The various device options can be selected by means of on-board jumpers, while all device outputs have been equipped with LED indicators for easy evaluation. An opto-isolated pulse output is available for direct connection to any energy meter test equipment.

This application note should be used in conjunction with the datasheet for the SA4106A energy metering device.

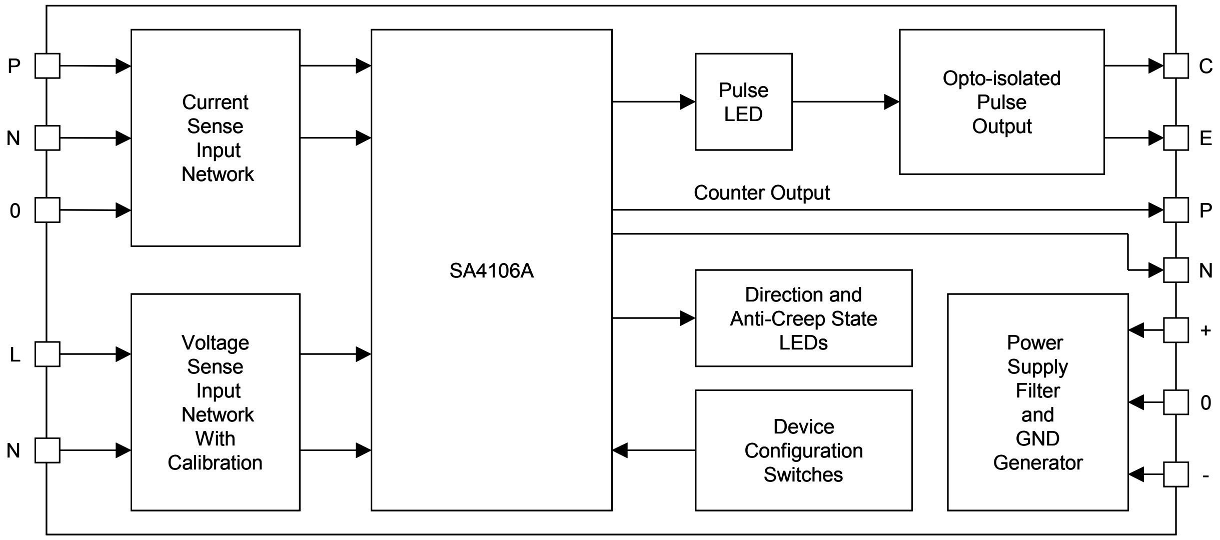

Figure 1: Functional block diagram

ANALOG INPUTS

The most important external circuitry required for the SA4106A are the voltage sense input and current sense input networks. These circuits translate the mains voltage and load current into signals that can be sensed by the energy metering device. These networks should be constructed using good quality resistors and capacitors to ensure adequate immunity to temperature and noise.

The functions of the current and voltage input networks are the following:

- to sense the load current and mains voltage and convert them to signals that are appropriate for the SA4106A,
- to allow calibration of the meter,
- to compensate for any phase shift present when a current transformer is used for current sensing and
- to filter all high frequency noise and other disturbances in the current and voltage signals in order to maintain adequate accuracy when electromagnetic disturbances are applied to the energy meter.

Current Sense Input Network

A typical single phase energy metering system can use either a shunt resistor or a current transformer (CT) as current sensing element. The PM4106APDA has therefore been designed to be used with either a shunt or a current transformer.

The PM4106APDA evaluation module has been set up for a meter with an I_{MAX} of 40A and using a shunt resistor with a resistance of 320μΩ. The current input network can easily be reconfigured for any other I_{MAX} or any other shunt resistor by simply changing the current input resistors (R3, R4, R5 and R6) as required. The evaluation module can also be adapted to use a current transformer by adding the burden resistors (R1 and R2) and changing the current input resistors.

Using a Shunt Resistor

Figure 2 shows the circuit diagram of the current sense input network when using a shunt resistor to sense the line current as it is implemented on the PM4106APDA. The shunt is connected externally.

The shunt resistor should be selected so that the voltage drop generated at maximum rated mains current (I_{MAX}) is larger than $10mV_{RMS}$ and smaller than $100mV_{RMS}$. At maximum rated mains current the current input network should be designed to supply an input current of $16μA_{RMS}$ to the current sense inputs (IIP and IIN) of the SA4106A. The current sense inputs saturate at an input current of $\pm 17.6μA_{RMS}$ ($\pm 25μA_{PEAK}$), so this allows about 10% headroom until saturation occurs. Referring to Figure 2, the resistors R3 to R6 define the current flowing into the energy metering device. The optimum input network is achieved by setting the input resistors equal, i.e. setting R3 = R4 = R5 = R6. Noting that the energy metering device creates a virtual short circuit between the differential current sense inputs (IIP and IIN) the value for the current input resistors can be calculated as follows:

$$R3 = R4 = R5 = R6 = \frac{V_{MAX}}{4 \times 16\mu A} = R_C$$

where V_{MAX} is the voltage drop across the shunt resistor at maximum rated mains current. Assuming a 320μΩ shunt and an I_{MAX} of 40A the V_{MAX} of the shunt is $12.8mV_{RMS}$ and therefore the current input resistors need to be R_C = 200Ω.

To reconfigure the PM4106APDA for a different I_{MAX} or a different shunt value the current input resistors should be changed.

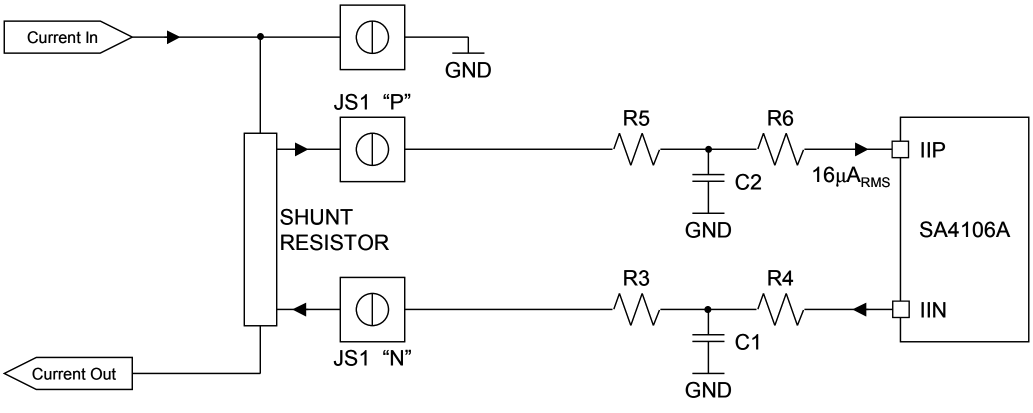

Figure 2: Current input network on the PM4106APDA when using a shunt resistor as current sensing element

Using a Current Transformer

Figure 3 shows the circuit diagram of the current sense input network when using a current transformer (CT) to sense the line current as it is implemented on the PM4106APDA. The CT is connected externally.

At maximum rated mains current (I_{MAX}) the current input network should be designed to supply an input current of $16\mu A_{RMS}$ to the current sense inputs (IIP and IIN) of the SA4106A. The current sense inputs saturate at an input current of $\pm 17.6\mu A_{RMS}$ ($\pm 25\mu A_{PEAK}$), so this allows about 10% headroom until saturation occurs. Referring to Figure 3, the resistors R1 and R2 form the current transformers termination resistor. The reference level is connected in the centre of the termination resistor to achieve purely differential input currents. The voltage drop across the current transformer termination resistors at maximum rated mains current should be in the order of $100mV_{RMS}$. The value of the termination resistors R1 and R2 is therefore

$$R1 = R2 = 100mV \times \frac{N_{CT}}{I_{MAX}} \times \frac{1}{2} = R_B$$

where N_{CT} is the current transformer ratio and I_{MAX} is the maximum rated mains current.

The resistors R3 to R6 define the current flowing into the energy metering device. The optimum input network is achieved by setting the input resistors equal, i.e. setting R3 = R4 = R5 = R6. Noting that the energy metering device creates a virtual short circuit between the differential current sense inputs (IIP and IIN) the value for the input resistors can be calculated as follows:

$$R3 = R4 = R5 = R6 = \frac{I_{MAX}}{N_{CT}} \times \frac{R_B}{2 \times 16\mu A} = R_C\ .$$

If, for example, N_{CT} = 2500 and I_{MAX} = 40A then $R_B \approx 3\Omega$ and therefore $R_C = 1.5k\Omega$.

To reconfigure the PM4106APDA for a different I_{MAX} or a different CT turns ratio typically only the current transformer burden resistors need to be changed. This will then not affect any other characteristics of the current input networks. The new value for the burden resistors can be calculated using

$$R1 = R2 = 2 \times 16\mu A \times R_C \times \frac{N_{CT}}{I_{MAX}}$$

The values of the burden resistors for some typical values of I_{MAX} when using current transformers with a turns ratio of 1:2500 (N_{CT} = 2500) and assuming $R_C = 1.5k\Omega$ are shown in Table 1, rounded to the nearest available resistor value.

Table 1: Current transformer burden resistors required for some common values of I_{MAX} when using current transformers with a turns ratio of 1:2500 and $R_C = 1.5k\Omega$

I_{MAX} (A)	Value of Burden Resistors (Ω)
6	20
10	12
20	6.2
25	4.7
30	3.9
40	3
50	2.4
60	2
80	1.5
100	1.2
120	1

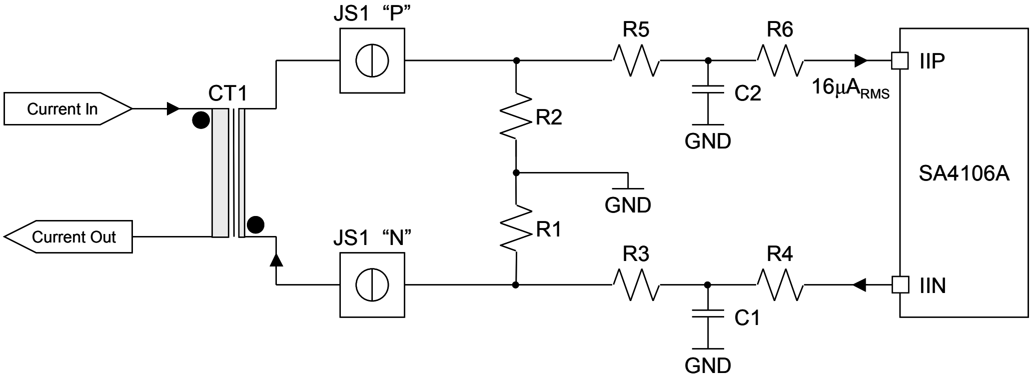

Figure 3: Current input network on the PM4106APDA when using a current transformer as current sensing element

Current Input Filtering

For best immunity to electromagnetic disturbances the SA4106A requires low-pass filters on the current sense inputs. Referring to Figure 2 and Figure 3, these filters are realized by means of the capacitors C1 and C2. The typical cut-off frequency of these filters should be between 10kHz and 20kHz. The equivalent resistance associated with each capacitor is $R_C/2$ so the capacitor value should be in the order of

$$C1 = C2 = \frac{1}{\pi f_{CI} R_C} = C_C$$

where f_{CI} is the required cut-off frequency of the low-pass filters of the current input networks.

The current input network on the PM4106APDA has been set up for a shunt with input resistors R_C = 200Ω. The filtering capacitors have been set to C_C = 100nF for simplicity. The resulting cut-off frequency is 15.9kHz.

Voltage Sense Input Network

The voltage input network on the PM4106APDA has been designed for operation at both 220V and 110V mains voltage. The mains voltage is selected by means of a jumper (J1). The voltage input network attenuates the mains voltage signal to a lower voltage by means of a voltage divider. A trimpot is used to tap this voltage divider at different levels to effect calibration.

Figure 4 shows the voltage sense input network as implemented on the PM4106APDA. The voltage sense input of the SA4106A saturates at an input current of ±17.6μA_{RMS} (±25μA_{PEAK}). The current into the voltage sense input should therefore be set between 11μA_{RMS} and 12μA_{RMS} at nominal mains voltage (V_{NOM}) to allow for a mains voltage variation of up to +30% and –50% without saturating the voltage sense input.

The input resistor R12 sets the current input into the device. This resistor should not be too large else the capacitor for the low-pass filter will be quite small. This could cause inaccurate phase shift due to parasitic capacitances and affect the performance of the energy meter at low power factor. Therefore R12 = 100kΩ is chosen. For the purpose of the evaluation module a very large tuning range on the trimpot is selected, so let R11 and P1 be 1kΩ each and the voltage over the combination of R11 and P1 be 1.76V. This allows the input currents on the voltage sense inputs of the device to be scaled from 17.6μA_{RMS} down to 8.8μA_{RMS}.

The following equations can be used to obtain the remaining resistor values:

$$1.76\text{V} = 220\text{V}\frac{2\text{k}\Omega}{R7 + R8 + R9 + R10 + 2\text{k}\Omega}$$

and

$$1.76\text{V} = 110\text{V}\frac{2\text{k}\Omega}{R7 + R8 + 2\text{k}\Omega}$$

This results in R7 + R8 = 123kΩ and R9 + R10 = 125kΩ and the values are chosen as R7 = 75kΩ, R8 = 47kΩ and R9 = R10 = 62kΩ. The effect of R12 can be ignored in the above equations, given the fact that R12 is significantly larger than the combination of P1 and R11.

A low-pass filter is required on the voltage sense input to remove any high frequency signals that could affect the performance of the SA4106A. If a current transformer is used as a current sensing element then this low pass filter is used to compensate for the phase shift of the current transformer as well by purposefully increasing the cut-off frequency.

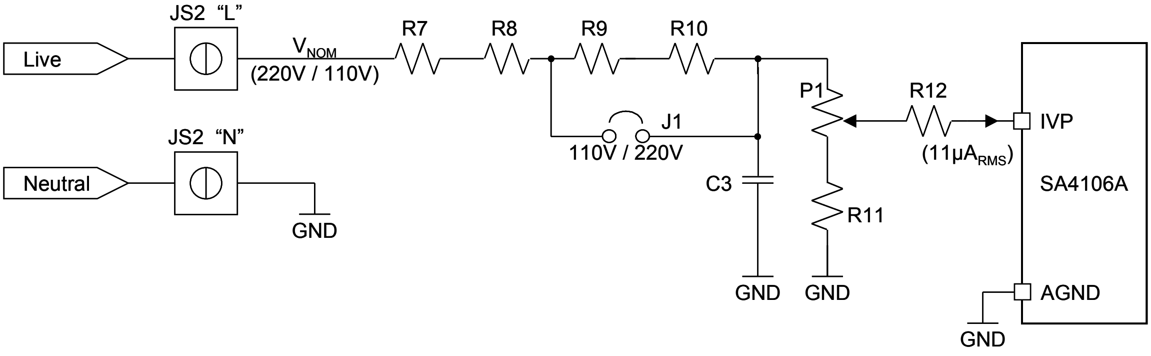

Figure 4: Voltage input network on the PM4106APDA

Referring to Figure 4, the capacitor C3 is used to both implement the high frequency filtering as well as compensating for any phase shift caused by the current sensing element. The cut-off frequency of the filter is adjusted so that the phase shift of the voltage input network is identical to the sum of the phase shifts of the current sensing element and the current input network. The PM4106APDA module has been set up to use a shunt resistor so no compensation for the current sensing element has been included. The phase compensation can be changed by simply replacing the capacitor C3.

The phase shift of the current input network is

$$\phi_{II} = -\arctan(\pi R_C C_C \times 50\text{Hz}).$$

The phase shift required on the voltage input network is therefore

$$\phi_{IV} = \phi_{II} + \phi_{CS}$$

where ϕ_{CS} is the phase shift of the current sensing element. This is typically between about 0.05 degrees and 0.5 degrees for a good quality current transformer and negligibly small for a good quality shunt resistor. Neglecting R7, R8, R9, R10 and R12 because all these resistors are significantly larger than P1 and R11, the capacitance required to correctly compensate the voltage input network is

$$C3 = \frac{|\tan \phi_{IV}|}{2\pi(P1 + R11) \times 50\text{Hz}}$$

resulting in a cut-off frequency of

$$f_{CV} = \frac{1}{2\pi(P1 + R11) \times C3}.$$

As mentioned previously the PM4106APDA has been set up to operate with a shunt resistor, so no phase compensation for the current sensing element has been included ($\phi_{CS} = 0$). Using the values of $R_C = 200\Omega$ and $C_C = 100\text{nF}$ the phase shift of the current input network is $\phi_{II} = -0.18°$ and therefore $C3 \approx 4.7\text{nF}$. This sets the cut-off frequency of the voltage input network to 16.9kHz.

The value of the cut-off frequency of the voltage input network is less critical than that of the current input network because the dynamic range of the voltage input is small. A cut-off frequency between 10kHz and 25kHz is acceptable.

POWER SUPPLY

The PM4106APDA has an on-board filtered voltage divider to allow the evaluation board to be used with a single 5V supply. The ground level GND which represents the reference level of the meter can be generated by the on-board voltage divider. This level is also connected to the AGND pin of the energy metering device. If the module is used in conjunction with a dual 2.5V supply then the on-board voltage divider is simply overdriven by the external supply. The centre point of the split supply is the reference level of the energy meter.

REFERENCE VOLTAGE

The on-chip reference currents of the SA4106A are determined by the bias resistor R13. This resistor must be 47kΩ to set optimum bias conditions for the analog circuits of the energy metering device.

LED OUTPUTS

The PM4106APDA is equipped with LEDs to display the various outputs of the SA4106A. These are the pulse output, the direction output and the state of the anti-creep circuit. The LEDs can be disconnected if not required.

TEST POINTS

Test points for several signals are located on the PM4106APDA evaluation board. These test points allow certain critical signals on the current and voltage input networks to be measured. Test points for the meter reference level (GND) and the power supplies are also present.

CALIBRATING THE PM4106APDA

The PM4106APDA is best calibrated using the following procedure:

1. Connect the module to the test system and set up the rated conditions, energy metering mode and anti-creep threshold. Selecting the required meter constant is fully described in the datasheet of the SA4106A.
2. Power up the module.
3. Apply the mains voltage and required load current.
4. Calibrate the module by means of P1 until the error is zero.
5. The module is now calibrated.

SETTING UP THE PM4106APDA

The PM4106APDA evaluation board can be set up for the various functionality of the SA4106A through jumpers. The function of each jumper is described in Table 2. The connection of the jumpers corresponds to the markings on the evaluation board.

Table 2: Jumper functionality for the PM4106APDA

Jumper	Description
J1	Mains Voltage Selection: This jumper is used to select the mains voltage of the system. It should be left open when the mains voltage is 220V and should be closed when 110V mains voltage is used.
J2	R0 Selection: This jumper is used to set the value of the R0 pin to V_{SS} (“0”) or to V_{DD} (“1”).
J3	R1 Selection: This jumper is used to set the value of the R1 pin to V_{SS} (“0”) or to V_{DD} (“1”).
J4	R2 Selection: This jumper is used to set the value of the R2 pin to V_{SS} (“0”) or to V_{DD} (“1”).
J5	R3 Selection: This jumper is used to set the value of the R3 pin to V_{SS} (“0”) or to V_{DD} (“1”).
J6	FMS Selection: This jumper is used to set the value of the FMS pin to V_{SS} (“0”) or to V_{DD} (“1”). It can also be left open to set FMS to a floating condition to enable FAST mode on the SA4106A.
J7	ACSEL Selection: This jumper is used to set the value of the ACSEL pin to V_{SS} (“0”) or to V_{DD} (“1”). It must be left open to set ACSEL to a floating condition.
J8, J9	DIRI Selection: These jumpers can be used to set the state of the DIRI pin. Setting J9 to “A” will connect DIRI to DIRO to enable bi-directional metering. If J9 is set to “B” the uni-directional metering mode will be enabled. In this case setting J8 to “0” will set the DIRI pin to V_{SS} while setting J8 to “1” will set DIRI to V_{DD}.
J11	LED Enable: This jumper can be used to disable the pulse output of the evaluation board. Leaving it open will disable the PULSE LED as well as the PULSE opto-isolated output (JS5).
J13, J14	Counter Enable: These jumpers can be used to disable and configure the external energy counter that is connected to the COUNTER output (JS4). Leaving both jumpers open disconnects the counter from the energy metering device. Closing J13 and setting J14 to “A” configures the COUNTER output to accommodate a stepper motor counter by connecting the COUNTER terminal to MON and MOP of the energy metering device. Closing J13 and setting J14 to “B” configures the COUNTER output to accommodate an impulse counter by connecting the COUNTER terminal to MON of the energy metering device and V_{SS}.
J16	DIR Enable: This jumper can be used to disable the direction output of the evaluation board. Leaving it open will disable the DIR LED.
J18	ACST Enable: This jumper can be used to disable the anti-creep state output of the evaluation board. Leaving it open will disable the ACST LED.

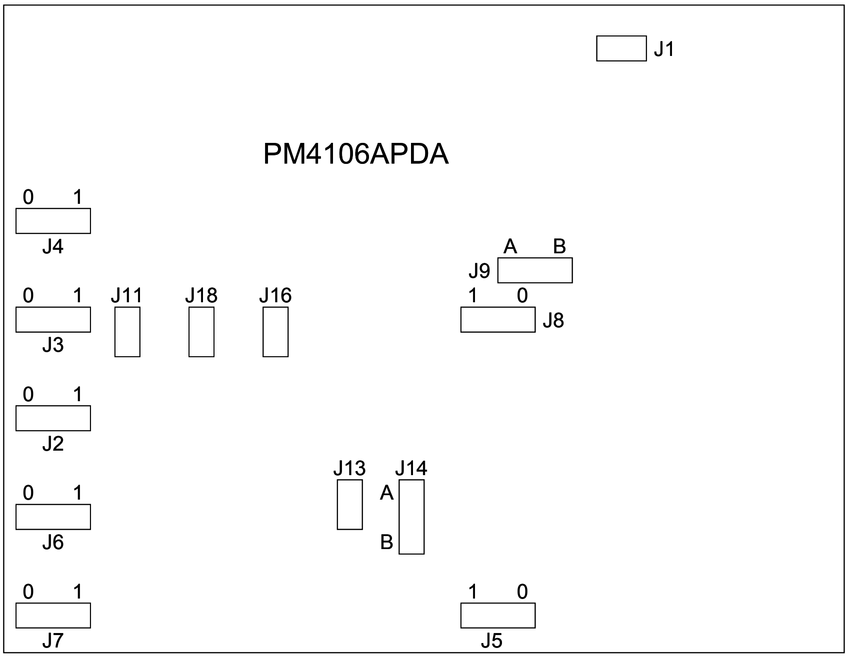

Figure 5: Layout of jumpers on the PM4106APDA

EXTERNAL CONNECTIONS TO THE PM4106APDA

The PM4106APDA evaluation board has external connectors to connect the various equipment required to evaluate the SA4106A in an end user application. The external connectors are described in the Table 3. The connection points correspond to the markings on the evaluation board. Figure 6 and Figure 7 illustrate the connection of the PM4106APDA for a shunt and current transformer application respectively.

Table 3: External connectors on the PM4106APDA

Connector	Description
JS1	Connection Point for Current Sensor: Connect the shunt resistor or the current transformer to this connector. The current sensor should be connected in such a way that a positive current flows "in" on terminal "P" and "out" on terminal "N". The connector also has a reference terminal "0" which can be used to connect the reference of the shunt resistor.
JS2	Connection Point for Mains Voltage: The mains voltage must be connected on this connector. The "N" terminal is the reference level of the module and the "L" terminal is the potential input. In the case of a current transformer the NEUTRAL line is typically the reference level of the meter and therefore NEUTRAL is connected to "N" and LIVE to "L". When a shunt resistor is used to sense the current in the LIVE line, the LIVE line acts as the reference of the meter. In this case LIVE should be connected to "N" while the NEUTRAL line is connected to the "L" terminal.
JS3	Connection Point for Power Supply: The power supply to the PM4106APDA should be connected at this connector. A single 5V supply can be connected between the "+" and "-" terminals or a dual 2.5V supply can be connected to the "+", "0" and "-" terminals.
JS4	Connection Point of Energy Counter: A stepper motor counter or impulse counter can be connected to this connection point to register the energy measured by the SA4106A. When an impulse counter is used the positive and negative terminals of the counter should be connected to the "P" and "N" terminals respectively.
JS5	Connection Point for Pulse Output: This connector is used to access the opto-isolated pulse output. The emitter and collector output terminals of the opto-coupler are marked "E" and "C" respectively. No pull-up resistor is present on the PM4106APDA. The pulse output is primarily used for performance evaluation and calibration of the SA4106A.
J10	LED Output: This connector contains the LED output of the device (centre terminal) as well as the V_{DD} ("1") and V_{SS} ("0") power supply voltages of the PM4106APDA. This terminal is useful when interfacing the pulse output to external circuitry.
J12	Motor Output: This connector contains the MON ("N") and MOP ("P") outputs of the device as well as the V_{DD} ("1") and V_{SS} ("0") power supply voltages of the PM4106APDA. This terminal is useful when interfacing the motor output to external circuitry.
J15	Direction Output: This connector contains the DIRO output of the device (centre terminal) as well as the V_{DD} ("1") and V_{SS} ("0") power supply voltages of the PM4106APDA.
J17	Anti-Creep State Output: This connector contains the ACST output of the device (centre terminal) as well as the V_{DD} ("1") and V_{SS} ("0") power supply voltages of the PM4106APDA.

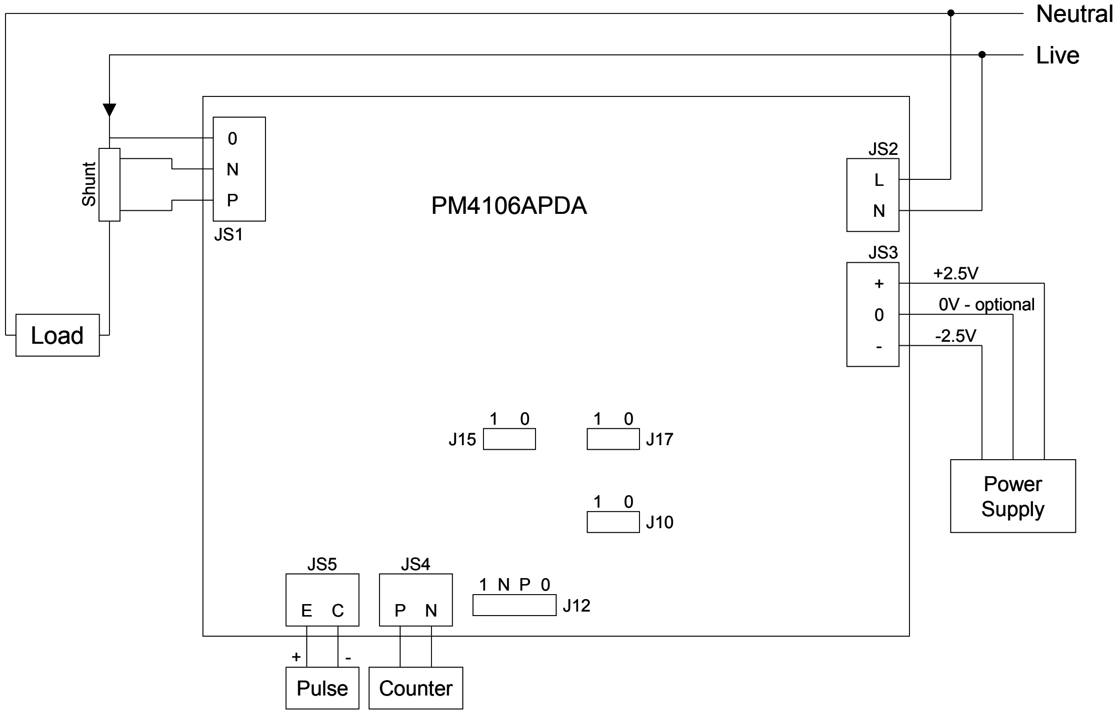

Figure 6: Connecting the PM4106APDA to test equipment with a shunt resistor as current sensing element

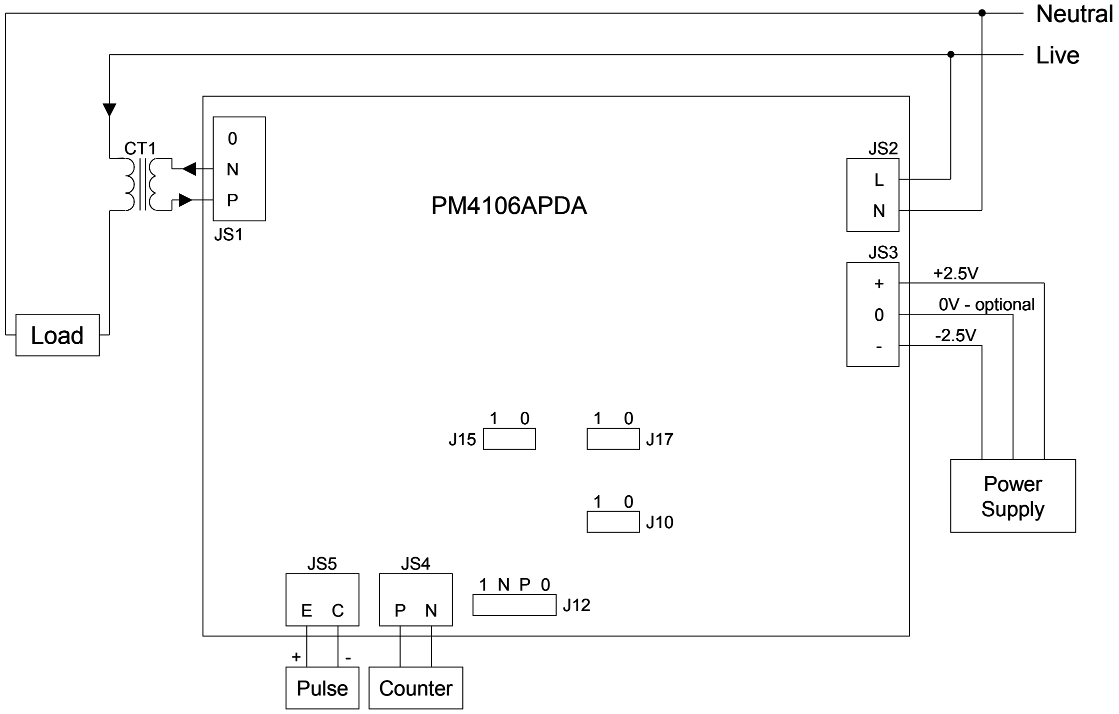

Figure 7: Connecting the PM4106APDA to test equipment with a current transformer as current sensing element

PM4106APDA CIRCUIT SCHEMATIC

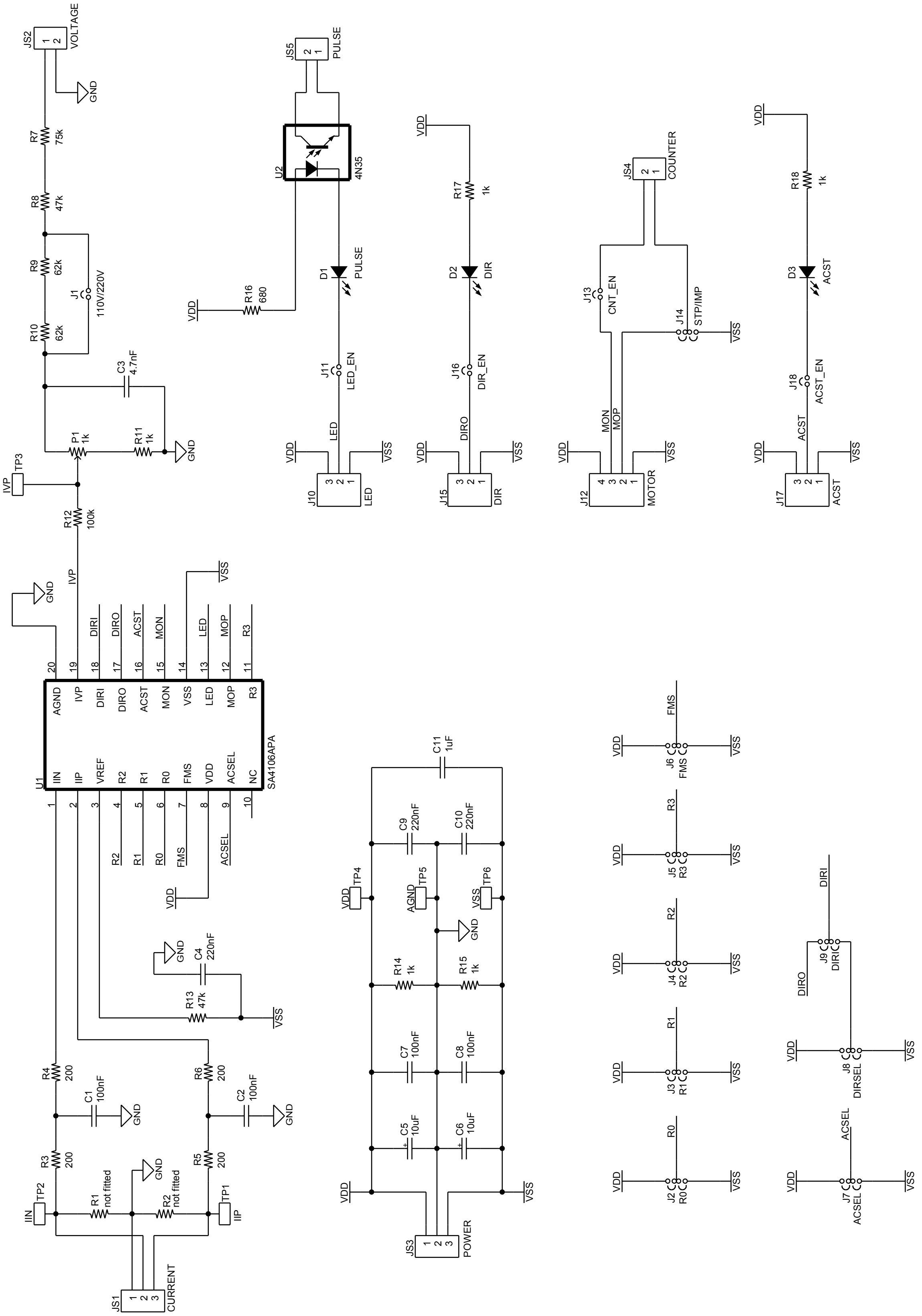

Figure 8: Circuit schematic for the PM4106APDA

PM4106APDA COMPONENT LIST

Table 4: Component list for the PM4106APDA

Symbol	Description
U1	20-pin DIP IC socket, tulip type
U1	Energy metering device from SAMES, SA4106APA
U2	6-pin DIP IC socket, tulip type
U2	Opto-coupler, 1N35
R1[1], R2[1]	Resistor, 1%, 1/4W, metal film (not fitted)
R3[2], R4[2], R5[2], R6[2]	Resistor, 200Ω, 1%, 1/4W, metal film
R7	Resistor, 75kΩ, 1%, 1/4W, metal film
R8	Resistor, 47kΩ, 1%, 1/4W, metal film
R9, R10	Resistor, 62kΩ, 1%, 1/4W, metal film
R11	Resistor, 1kΩ, 1%, 1/4W, metal film
R12	Resistor, 100kΩ, 1%, 1/4W, metal film
R13	Resistor, 47kΩ, 1%, 1/4W, metal film
R14, R15, R17, R18	Resistor, 1kΩ, 1%, 1/4W, metal film
R16	Resistor, 680Ω, 1%, 1/4W, metal film
P1	Trim-pot, 25 turns, top adjust, 1kΩ
C1, C2	Capacitor, 100nF, ceramic
C3[3]	Capacitor, 4.7nF, ceramic
C5, C6	Capacitor, 10µF, electrolytic
C7, C8	Capacitor, 100nF, ceramic
C4, C9, C10	Capacitor, 220nF, ceramic
C11	Capacitor, 1µF, ceramic
D1	3mm light emitting diode, red
D2	3mm light emitting diode, green
D3	3mm light emitting diode, yellow
JS1	3-way screw terminal
JS2	2-way screw terminal
JS3	3-way screw terminal
JS4, JS5	2-way screw terminal
J1, J11, J13, J16, J18	2 single inline pins
J2, J3, J4, J5, J6, J7	3 single inline pins
J8, J9, J10, J14, J15, J17	3 single inline pins
J12	4 single inline pins
TP1, TP2, TP3, TP4, TP5, TP6	1 single inline pin

Note 1: Resistors R1, R2 must be fitted when using a current transformer as a current sensing element

Note 2: Resistors R3, R4, R5 and R6 must be recalculated when the shunt or the I_{MAX} of the module is changed or if a current transformer is used as a current sensing element

Note 3: Capacitor C3 must be changed to change the phase compensation of the module

PCB LAYOUT

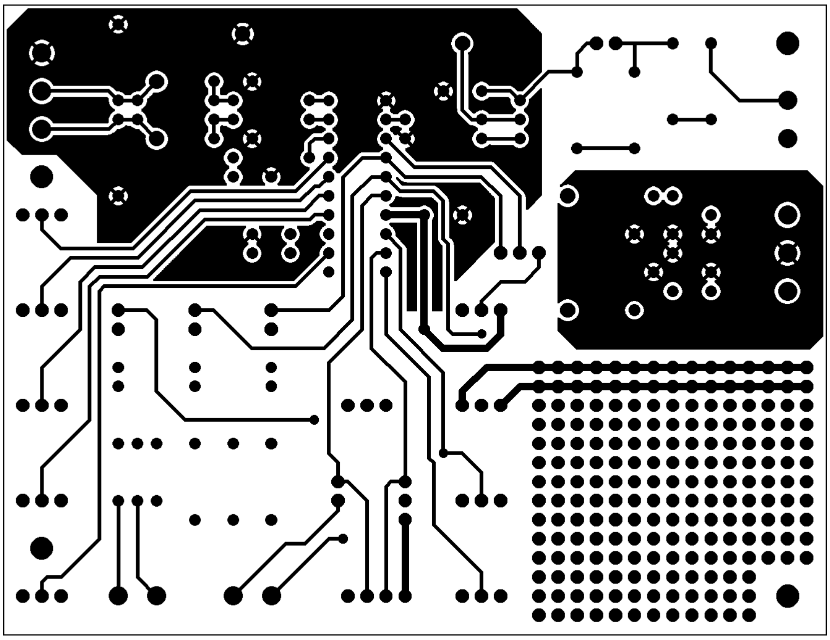

Figure 9: Top layer of PCB (scale 1:1)

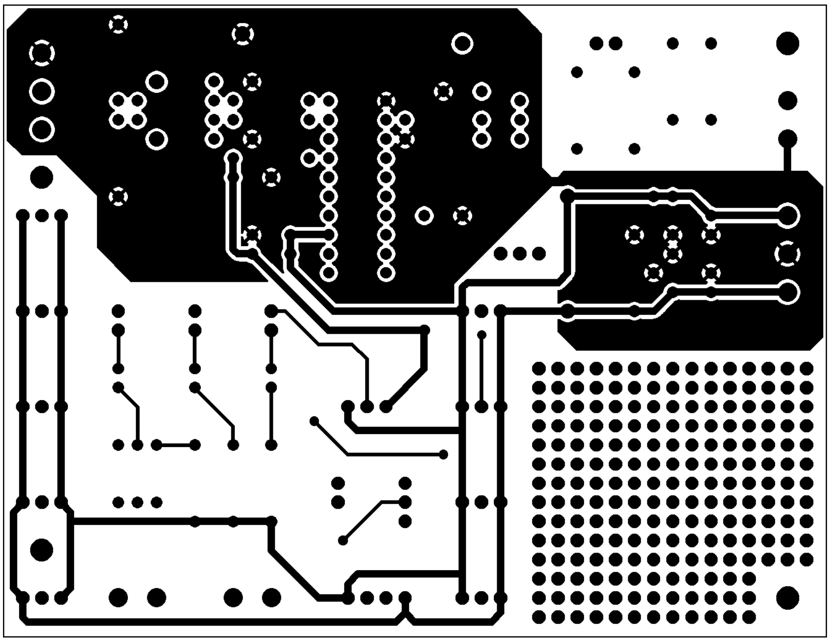

Figure 10: Bottom layer of PCB (scale 1:1)

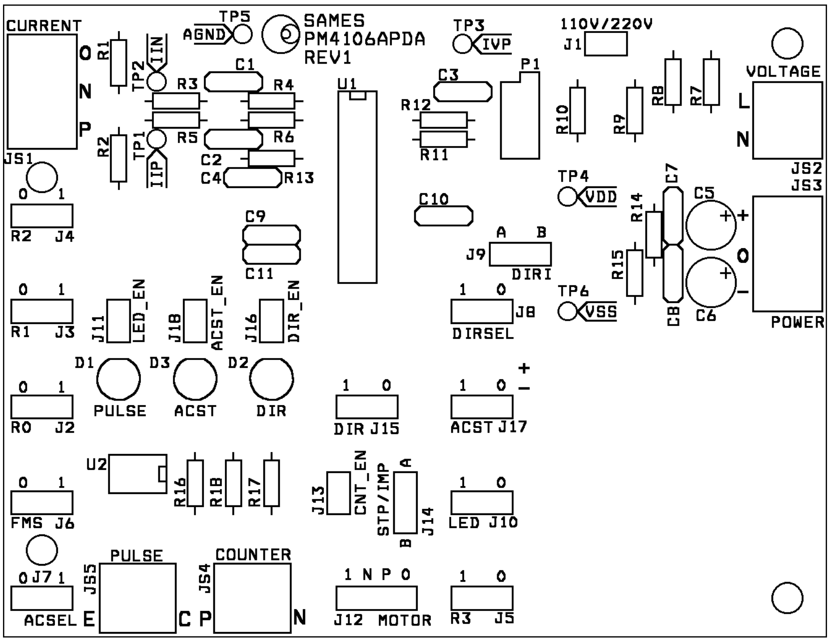

Figure 11: Top silkscreen layer of PCB (scale 1:1)

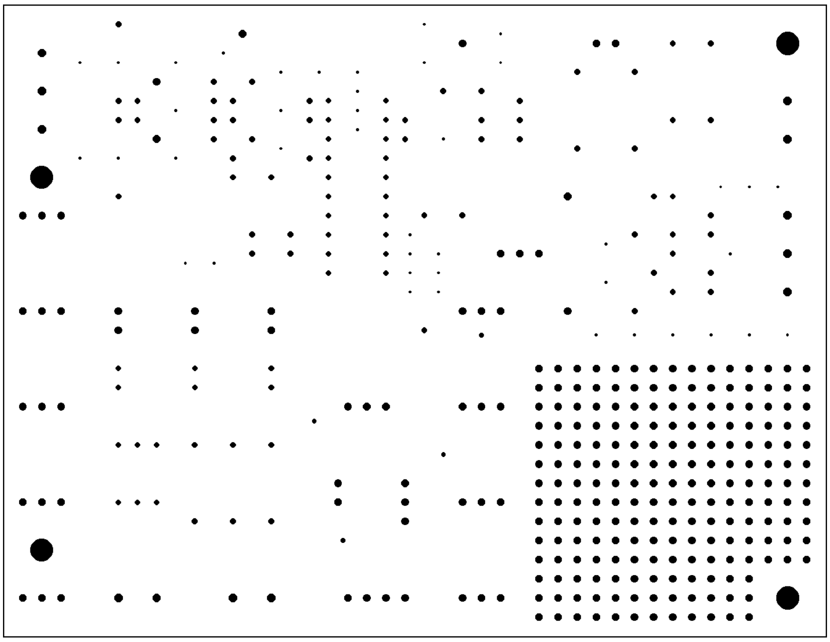

Figure 12: Drill layer of PCB (scale 1:1)

NOTES

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