

# Single Channel Single Phase Energy Metering IC



## SA4104A / SA4104B ICDC - a division of SAMES

### FEATURES

- Meets the IEC62053, CBIP-88 and IS137799-1999 specification requirements for Class 1 AC static watt-hour meters for active energy
- Motor drive outputs (MOP, MON) provide average active power information and can drive an electro-mechanical counter or an impulse counter directly
- LED pulse output for calibration purposes supplies average active power information
- Configurable for different meter ratings
- Precision on-chip oscillator (70ppm/°C drift)
- Precision on-chip voltage reference (10ppm/°C drift)
- On-chip anti-creep function (0.01% of  $F_{MAX}$  on SA4104A or 0.004% of  $F_{MAX}$  on SA4104B)
- Low power consumption (<20mW typical)
- Measures AC inputs only

### DESCRIPTION

The SAMES SA4104A/B is an accurate single phase power/energy metering integrated circuit providing a single chip solution for single phase energy meters. Very few external components are required and the chip includes a direct drive capability for electro-mechanical counters. The SA4104A/B does not require an external crystal or voltage reference. A precision oscillator and a precision voltage reference to supply the circuitry with a stable frequency and stable reference currents are integrated on the chip.

The SA4104A/B metering integrated circuit generates a pulse output, the frequency of which is proportional to the active power consumption.

Programmable inputs allow the meter manufacturer to configure the SA4104A/B for different meter maximum currents ( $I_{MAX}$ ) and nominal voltages ( $V_{NOM}$ ) without having to change the stepper motor counter or impulse counter gear ratio.

The LED pulse output follows the average active power consumption measured and is intended for meter calibration purposes. In fast calibration mode this output provides a high frequency pulse rate following the average active power consumption and can be used for fast calibration or to interface with a micro-controller.

The SA4104A/B includes an anti-creep feature preventing any creep effects in the meter under no-load conditions. Two versions of the device are available, namely the SA4104A and SA4104B. The only difference between the two versions is the anti-creep threshold. The anti-creep threshold is set to 0.01% of  $F_{MAX}$  on the SA4104A and 0.004% of  $F_{MAX}$  on the SA4104B.

The SA4104A/B integrated circuit is available in a 16-pin small outline (SOIC16) RoHS compliant package.

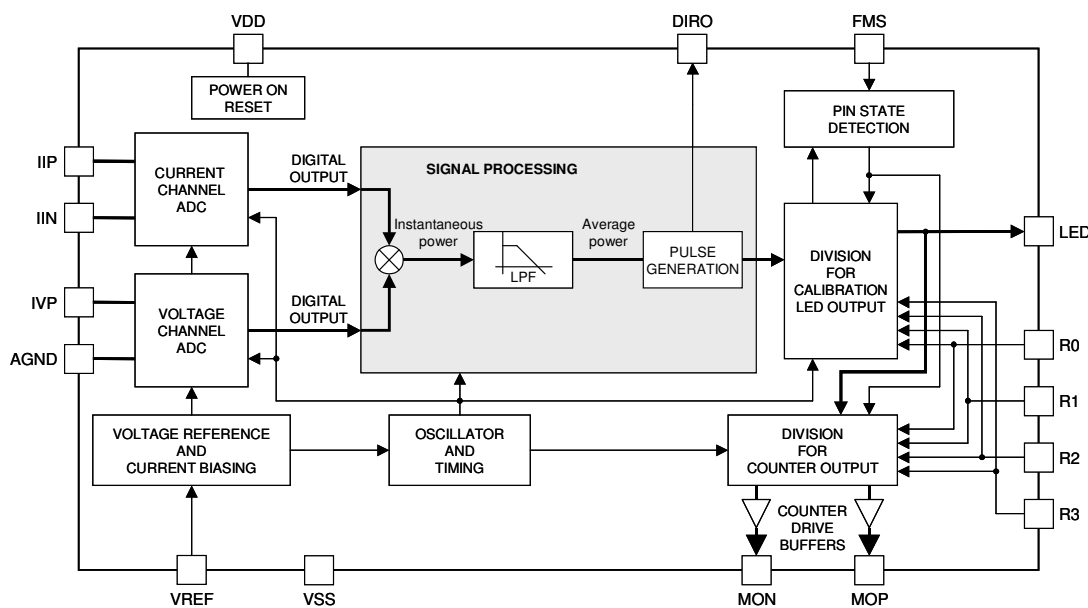


Figure 1: Block diagram

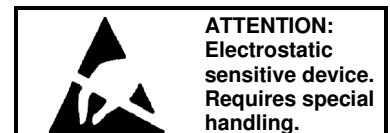
**ELECTRICAL CHARACTERISTICS**

( $V_{DD} - V_{SS} = 5V \pm 10\%$ , over the temperature range  $-40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise specified. Refer to Figure 2 “Test circuit for electrical characteristics”.)

Parameter	Symbol	Min	Typ	Max	Unit	Condition
<b>General</b>						
Supply Voltage: Positive	$V_{DD}$	2.25	2.5	2.75	V	With respect to AGND
Supply Voltage: Negative	$V_{SS}$	-2.75	-2.5	-2.25	V	With respect to AGND
Supply Current: Positive	$I_{DD}$		3.6	4.6	mA	
Supply Current: Negative	$I_{SS}$		-3.6	-4.6	mA	
<b>Analog Inputs</b>						
<b>Current Sensor Inputs (Differential)</b>						
Input Current Range	$I_{RIIP}, I_{RIIN}$	-25		25	$\mu A$	Peak value
Offset Voltage	$V_{OIIIP}, V_{OIIIN}$	-4		4	mV	With $R = 4.7k\Omega$ connected to AGND
<b>Voltage Sensor Inputs (Asymmetrical)</b>						
Input Current Range	$I_{RIVP}$	-25		25	$\mu A$	Peak value
Offset Voltage	$V_{OIVP}$	-4		4	mV	With $R = 4.7k\Omega$ connected to AGND
<b>Digital Inputs</b>						
Pull-up/down Current on FMS*	$I_{PUD}$	1.5		5.5	mA	
State Change Detection Time for Digital Inputs	$T_{ST}$			10	ms	
R0, R1, R2, R3, FMS Input High Voltage	$V_{IH}$	$V_{DD}-1$			V	
Input Low Voltage	$V_{IL}$			$V_{SS}+1$	V	
<b>Digital Outputs</b>						
LED Output Frequency in FAST Mode	$F_{MAX}$	4.5	5	5.5	kHz	$16\mu A_{RMS}$ input current per channel
LED, DIRO Output High Voltage	$V_{OH}$	$V_{DD}-1$			V	$I_{SOURCE} = 5mA$
Output Low Voltage	$V_{OL}$			$V_{SS}+1$	V	$I_{SINK} = 5mA$
MOP, MON Output High Voltage	$V_{OH}$		$V_{DD}-1$		V	$I_{SOURCE} = 10mA$
Output Low Voltage	$V_{OL}$		$V_{SS}+1$		V	$I_{SINK} = 10mA$

\* This is the actual pull-up/down current during pin state scanning which is active for  $70\mu s$  every 10ms. The average pull-up/down current is therefore between  $10\mu A$  and  $40\mu A$ .

During manufacturing, testing and shipment we take great care to protect our products against potential external environmental damage such as Electrostatic Discharge (ESD). Although our products have ESD protection circuitry, permanent damage may occur on products subjected to high-energy electrostatic discharges accumulated on the human body and/or test equipment that can discharge without detection. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality during product handling.





**ELECTRICAL CHARACTERISTICS (continued)**

(V<sub>DD</sub> - V<sub>SS</sub> = 5V ± 10%, over the temperature range -40°C to +85°C, unless otherwise specified. Refer to Figure 2 “Test circuit for electrical characteristics”.)

Parameter	Symbol	Min	Typ	Max	Unit	Condition
<b>On-chip Voltage Reference</b>						
Reference Voltage	V <sub>R</sub>	1.15	1.20	1.25	V	
Reference Current	-I <sub>R</sub>	24.4	25.5	26.6	μA	With R = 47kΩ connected to V <sub>SS</sub>
Temperature Coefficient	TC <sub>R</sub>		10	70	ppm/°C	
<b>On-chip Oscillator</b>						
Oscillator Frequency	f <sub>OSC</sub>	3.15	3.57	4.00	MHz	
Temperature Coefficient	TC <sub>OSC</sub>		70	200	ppm/°C	

**ABSOLUTE MAXIMUM RATINGS\***

Parameter	Symbol	Min	Max	Unit
Supply Voltage	V <sub>DD</sub> - V <sub>SS</sub>		6	V
Current on any Pin	I <sub>PIN</sub>	-150	150	mA
Storage Temperature	T <sub>STG</sub>	-60	+125	°C
Specified Operating Temperature Range	T <sub>O</sub>	-40	+85	°C
Limit Range of Operating Temperature	T <sub>limit</sub>	-40	+85	°C

\*Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only. Functional operation of the device at these or any other condition above those indicated in the operational sections of this specification, is not implied. Exposure to Absolute Maximum Ratings for extended periods may affect device reliability.

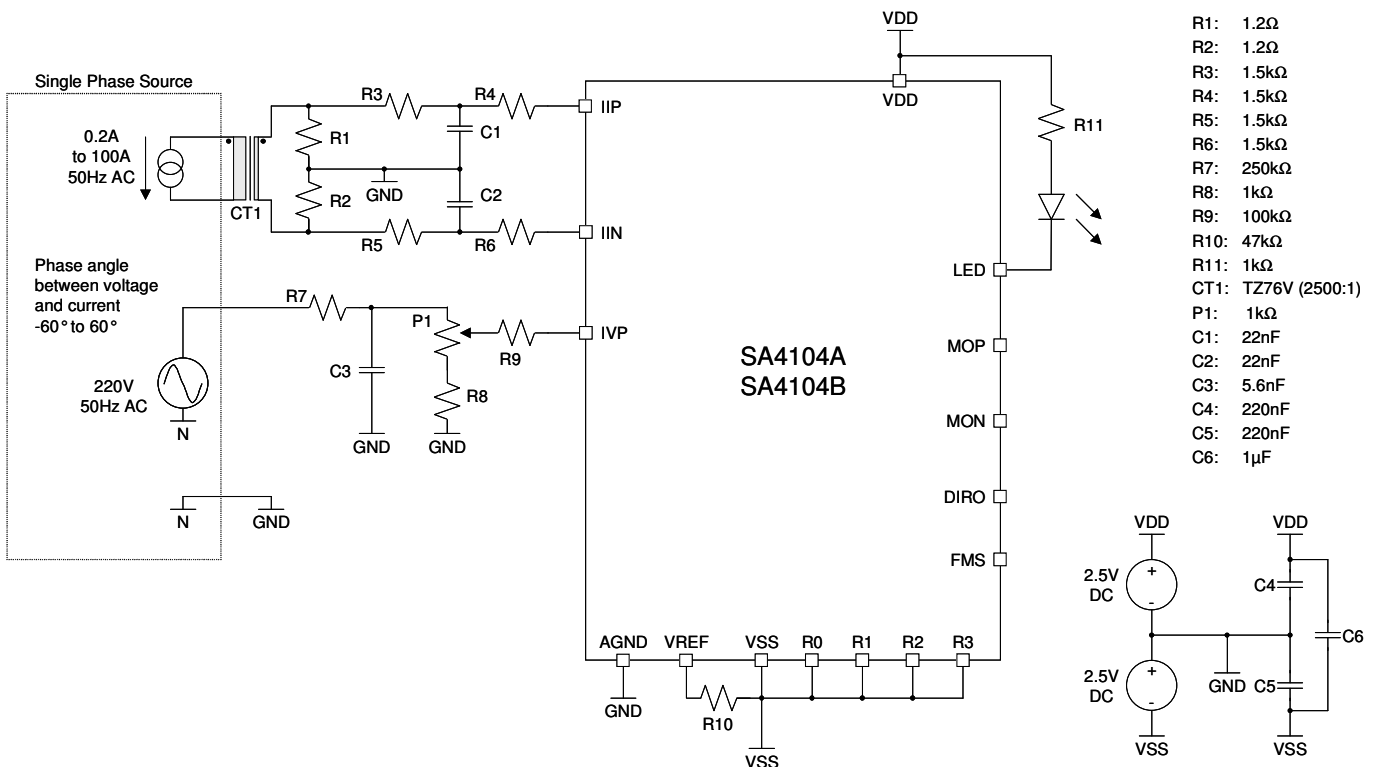


Figure 2: Test circuit for electrical characteristics

**PIN DESCRIPTION**

Designation	Pin No.	Description
AGND	16	Analog Ground. This is the reference pin for the current and voltage signal sensing networks. The supply voltage to this pin should be mid-way between $V_{DD}$ and $V_{SS}$ .
$V_{DD}$	8	Positive Supply Voltage. The voltage to this pin should be $+2.5V \pm 10\%$ with respect to AGND.
$V_{SS}$	12	Negative Supply Voltage. The voltage to this pin should be $-2.5V \pm 10\%$ with respect to AGND.
IVP	15	Analog Input for Voltage. The maximum current into the voltage sense input IVP should be set at $16\mu A_{RMS}$ . The voltage sense input saturates at an input current of $\pm 25\mu A$ peak.
IIP, IIN	2, 1	Analog Inputs for Current. The maximum current into the current sense inputs IIP/IIN should be set at $16\mu A_{RMS}$ . The current sense inputs saturate at an input current of $\pm 25\mu A$ peak.
VREF	3	This pin provides the connection for the reference current setting resistor. A $47k\Omega$ resistor connected to $V_{SS}$ sets the optimum operating conditions.
R0, R1, R2, R3	6, 5, 4, 9	Rated Condition Select inputs. These input pins are used for selecting between the different rated condition configurations. Refer to the Rated Condition Select section.
FMS	7	Fast Mode Select input. This three state input is used to select between STANDARD and FAST mode and provides an extended selection of meter constants. Refer to the Rated Condition Select and Fast Mode Select sections.
DIRO	14	Direction Indicator output. This output indicates the direction of energy flow.
LED	11	Calibration LED output. Refer to the Rated Condition Select section for the pulse rate output options.
MON, MOP	13, 10	Motor pulse outputs. These outputs can drive an electro-mechanical counter directly. Refer to the Rated Condition Select section for the pulse rate output options.

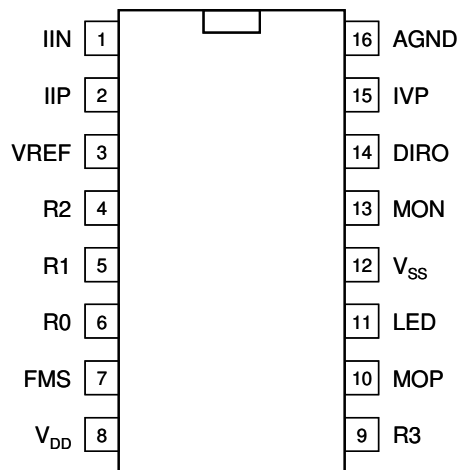


Figure 3: Pin connections

**ORDERING INFORMATION**

Part Number	Device	Package
SA4104ASAR	SA4104A	SOIC16 (RoHS compliant)
SA4104BSAR	SA4104B	SOIC16 (RoHS compliant)



## TERMINOLOGY

### Anti-Creep Threshold

The anti-creep threshold is defined as the minimum energy threshold below which no energy is registered and therefore no pulses are generated on the LED or motor drive outputs.

### Positive Energy

Positive energy is defined when the phase difference between the input signals IIP and IVP is less than 90 degrees (-90..90 degrees).

### Negative Energy

Negative energy is defined when the phase difference between the input signals IIP and IVP is greater than 90 degrees (90..270 degrees).

### Percentage Error\*

Percentage error is given by the following formula:

$$\%Error = \frac{\text{Energy registered by device} - \text{True Energy}}{\text{True Energy}} \times 100$$

NOTE: Since the true value cannot be determined, it is approximated by a value with a stated uncertainty that can be traced to standards agreed upon between manufacturer and user or to national standards.

### Rated Operating Conditions\*

Set of specified measuring ranges for performance characteristics and specified operating ranges for influence quantities, within which the variations or operating errors of a meter are specified and determined.

### Specified Measuring Range\*

Set of values of a measured quantity for which the error of a meter is intended to lie within specified limits.

### Specified Operating Range\*

A range of values of a single influence quantity, which forms a part of the rated operating conditions.

### Limit Range of Operation\*

Extreme conditions which an operating meter can withstand without damage and without degradation of its metrological characteristics when it is subsequently operated under its rated operating conditions.

### Maximum Rated Mains Current ( $I_{MAX}$ )

Maximum rated mains current is the specified maximum current flowing through the energy meter at rated operating conditions.

### Constant\*

Value expressing the relation between the active energy registered by the meter and the corresponding value of the test output. If this value is a number of pulses, the constant should be either pulses per kilowatt-hour (imp/kWh) or watt-hours per pulse (Wh/imp).

### Nominal Mains Voltage ( $V_{NOM}$ )

Nominal mains voltage ( $V_{NOM}$ ) is the voltage specified for the energy meter at rated operating conditions.

### Maximum Output Frequency ( $F_{MAX}$ )

The maximum output frequency ( $F_{MAX}$ ) is the output frequency in FAST mode when  $16\mu A_{RMS}$  input current with zero phase shift are applied to the voltage and current inputs. Both the voltage and current inputs saturate at an input current magnitude of  $25\mu A$ , or at  $17.68\mu A_{RMS}$  when using sine waves. The maximum input current on each channel is therefore defined to be  $16\mu A_{RMS}$ , which leaves about 10% headroom to the saturation point. In FAST mode the nominal maximum output frequency of 5kHz is achieved under such conditions.

### Repeatability of Error Test\*\*

This test shall be carried out at 0.05lb and lb at UPF load under reference test conditions. Twenty error samples shall be taken at time intervals of 30 minutes. Identical test conditions shall be maintained throughout the test. For an acceptance test six error tests may be carried out at time intervals of at least 5 minutes.

\* IEC 62052-11, 2003. Electricity Metering Equipment (AC) – General Requirements, Test and Test Conditions – Part 11: Metering Equipment

\*\* IS13779-1999 Indian Standard AC Static Watt-hour Meters Class 1 and 2 Specification Rev 1



PERFORMANCE GRAPHS

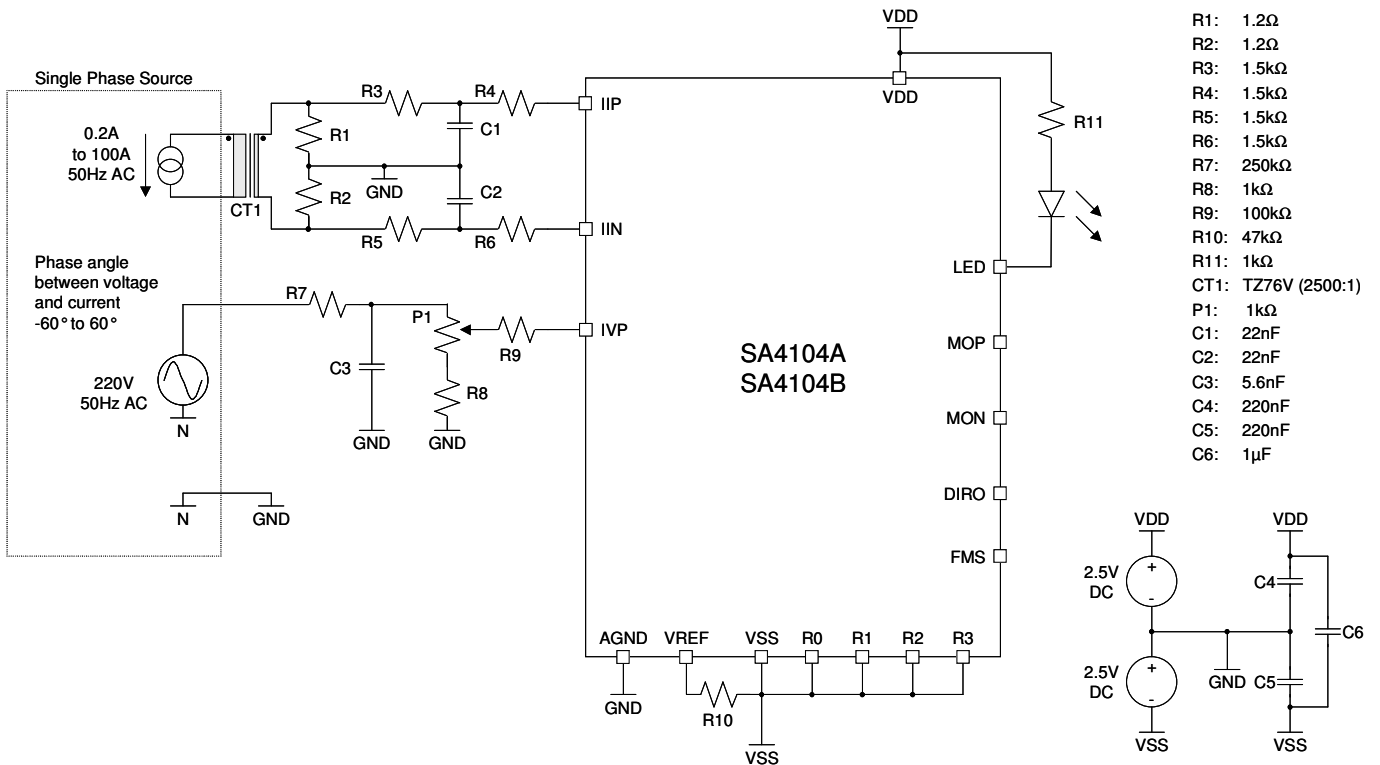
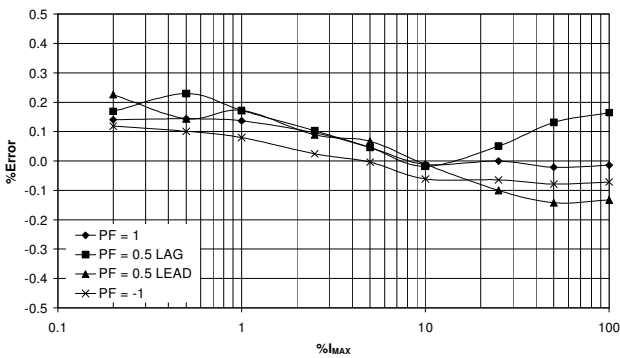
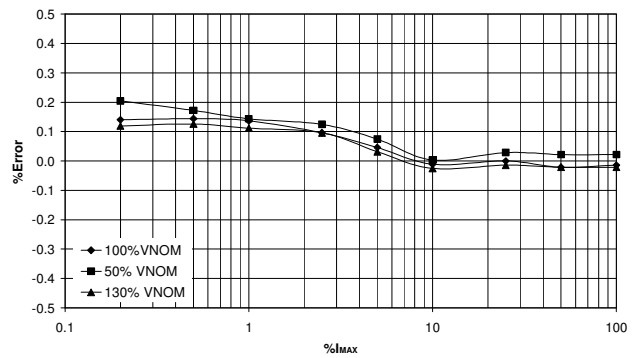


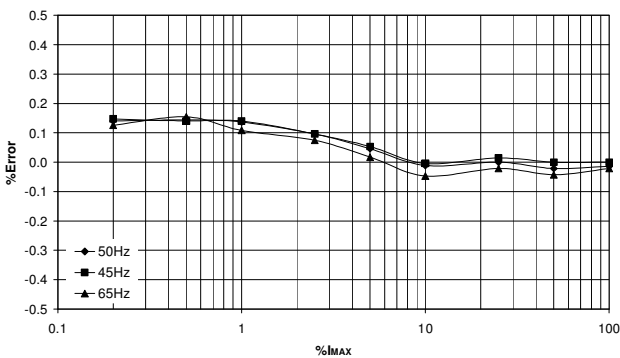
Figure 4: Test circuit for performance graphs



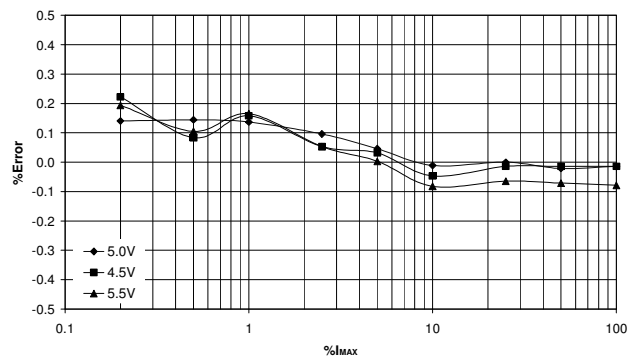
GRAPH 1 - Freq = 50Hz,  $V_{NOM}$ , Temp = 25 °C,  $V_{DD}-V_{SS} = 5.0V$



GRAPH 2 - PF = 1, Freq = 50Hz, Temp = 25 °C,  $V_{DD}-V_{SS} = 5.0V$



GRAPH 3 - PF = 1,  $V_{NOM}$ , Temp = 25 °C,  $V_{DD}-V_{SS} = 5.0V$



GRAPH 4 - PF = 1, Freq = 50Hz,  $V_{NOM}$ , Temp = 25 °C



## FUNCTIONAL DESCRIPTION

### Theory of Operation

The SA4104A/B includes all the required functions for single channel single phase power and energy measurement. Two AD converters sample the voltage and current input signals. The two digital signals, accurately representing the voltage and current inputs, are multiplied using digital multiplication. The output of the multiplier represents the instantaneous power, which is subsequently low pass filtered and integrated over time to remove the instantaneous components forming the averaged instantaneous energy. This energy is accumulated over time to form the outputs of the device.

For given voltage and current signals the instantaneous power is calculated by:

$$p(t) = v(t) \times i(t)$$

$$p(t) = V_M \cos(\omega t + \theta) \times I_M \cos(\omega t + \psi)$$

$$\text{Let } \phi = \theta - \psi, \text{ and } V_{RMS} = \frac{V_M}{\sqrt{2}} \text{ and } I_{RMS} = \frac{I_M}{\sqrt{2}} \text{ then}$$

$$p(t) = V_M \cos(\omega t + \theta) \times I_M \cos(\omega t + \theta - \phi)$$

$$p(t) = V_{RMS} I_{RMS} (\cos \phi - \cos(2(\omega t + \theta) - \phi))$$

where

$p(t)$  is the instantaneous power,

$v(t)$  is the instantaneous voltage signal,

$i(t)$  is the instantaneous current signal,

$V_M$  is the amplitude of the voltage signal,

$I_M$  is the amplitude of the current signal,

$\theta$  is the phase angle of the voltage signal and

$\psi$  is the phase angle of the current signal.

The instantaneous power is low pass filtered to remove the double mains frequency component  $\cos(2(\omega t + \theta) - \phi)$  and is then integrated over time to provide the average power information

$$P = \frac{1}{T} \int_0^T p(t) dt$$

$$P = V_{RMS} I_{RMS} \cos \phi$$

where

$P$  is the average power and

$\cos \phi$  is the power factor.

### Linearity

The SA4104A/B is a CMOS integrated circuit, which performs power/energy calculations across a dynamic range of 500:1 to an accuracy that exceeds the IEC62053 specification.

### Analog Inputs

The input circuitry of the current and voltage sensor inputs is illustrated in Figure 5. These inputs are protected against electrostatic discharge through clamping diodes. The feedback loops from the outputs of the amplifiers  $A_I$  and  $A_V$  generate virtual short circuits between IIP and IIN as well as IVP and AGND. The current sense inputs (IIP and IIN) are identical and balanced. The AD converters convert the signals on the voltage and current sense inputs to a digital format for further processing. All internal offsets are eliminated through the use of various cancellation techniques.

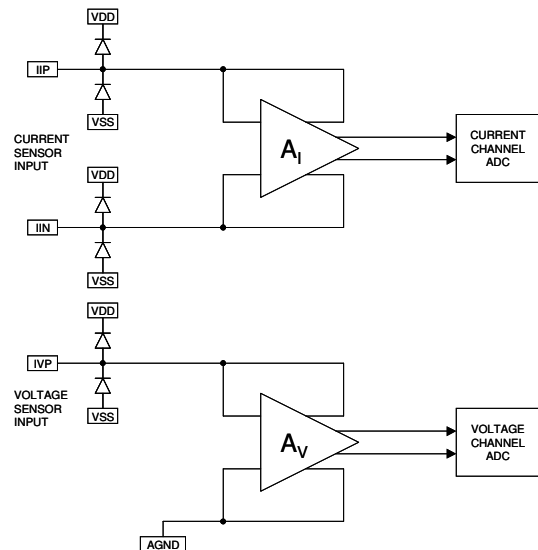


Figure 5: Analog input configuration

### Digital Outputs

The calculations required for power and energy are performed and converted to pulses on the LED, MON and MOP outputs. The complimentary output pins MON and MOP are provided for driving a stepper motor counter directly. The output frequency on the LED output is, in both STANDARD and FAST mode, proportional to the average active power consumption measured. The FAST mode is intended for fast meter calibration and verification purposes or for interfacing the SA4104A/B to a micro-controller.

### Anti-Creep Threshold

An integrated anti-creep function prevents any output pulses on the LED output and the MON/MOP motor drive outputs when the level of measured energy is below the anti-creep threshold. This threshold is set to 0.01% of  $F_{MAX}$  on the SA4104A and 0.004% of  $F_{MAX}$  on the SA4104B, where  $F_{MAX}$  is the output frequency in FAST mode when the input currents are  $IVP_{MAX} = 16\mu A_{RMS}$  and  $IIP_{MAX} = 16\mu A_{RMS}$ .



**Reverse Energy Flow Indication**

The SA4104A/B assesses the phase difference between the voltage channel signal and the current channel signal. If this phase difference is greater than 90 degrees then the DIRO signal will become active. This facility is designed to detect the wrongful connection of the meter. This operation is fully described in the Output Signals section.

**Starting Current**

The SA4104A/B generates pulses on the LED and MON/MOP outputs for an input power greater than 0.01% or 0.004% of F<sub>MAX</sub> depending on whether version A or version B of the device is used. This is to comply with the IEC requirement where the meter is required to generate pulses for currents greater than 0.4%lb.

**Calibration and Repeatability**

The SA4104A/B provides an output (LED) that is used for calibration of the meter. The meter is calibrated by comparing the energy reading of the meter under test with the energy reading of the reference meter. The reference meter should have a considerably higher pulse rate than the meter under test. The accuracy to which the meter has to be calibrated will dictate how much higher the reference meter pulse rate has to be. The SA4104A/B can be calibrated to specification with a minimum of two pulses on the LED output whilst in STANDARD mode and utilizing an

appropriate reference meter. This reading is independent of time and will be repeatable so as to consistently achieve the required accuracy for the full input current range that needs to be measured to IEC62053 accuracy. In Figure 6 the reference meter pulses are counted between two pulses of the meter under test. The meter under test is then adjusted so as to reflect the expected number of counted reference meter pulses. A worst-case scenario is for measurements obtained for only two pulses of the meter under test and N pulses from the reference meter. In this case the measurement resolution will be:

$$\text{Measurement Resolution (\%)} = \frac{1}{N} \times 100$$

The corresponding calibration and repeatability results can never be more accurate than this measurement resolution.

**Power-On Reset**

The SA4104A/B has a power-on reset circuitry that activates whenever the voltage between V<sub>DD</sub> and V<sub>SS</sub> is less than 3.6V ± 8%.

**Power Consumption**

The power consumption of the SA4104A/B integrated circuit is less than 30mW.

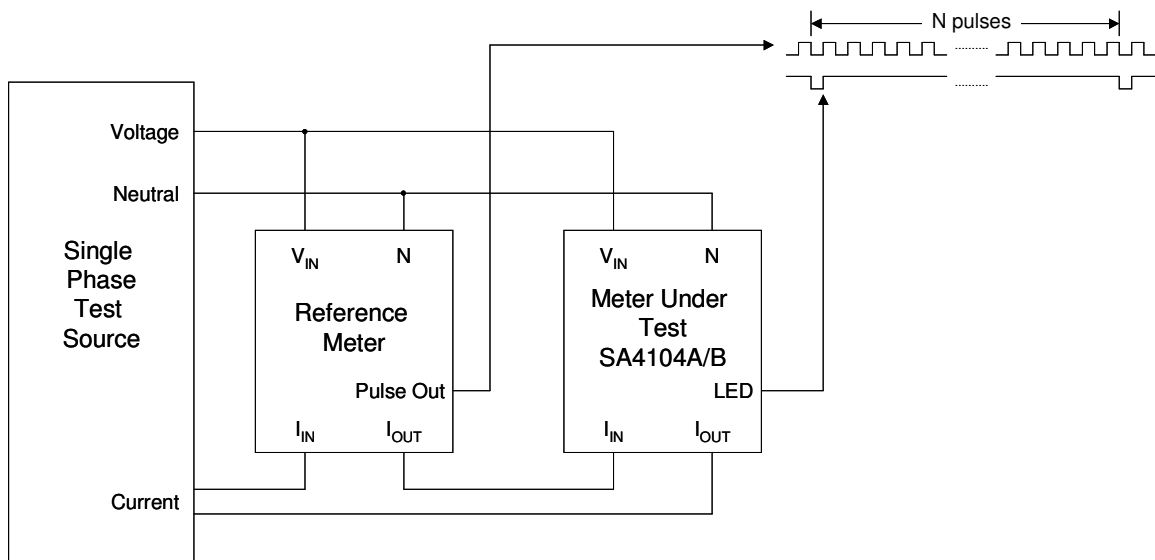


Figure 6: Calibration and repeatability setup





## INPUT SIGNALS

### Voltage Reference (VREF)

A bias resistor of 47kΩ sets optimum bias and reference conditions on chip. Calibration of the SA4104A/B should be done on the voltage input and not on the VREF input.

### Current Sense Inputs (IIP and IIN)

Figure 7 shows the typical connections for the current sensor input when using a shunt or a current transformer as a current sensing element. At maximum rated mains current ( $I_{MAX}$ ) the resistor values should be selected for an input current of  $16\mu A_{RMS}$ . 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.

The resistor RSH is the shunt resistor. The voltage drop across RSH as maximum rated mains current ( $I_{MAX}$ ) should not be less than  $5mV_{RMS}$  and not exceed  $100mV_{RMS}$ .

The resistors RA and RB 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 termination resistors at maximum rated mains current ( $I_{MAX}$ ) should be in the order of  $100mV_{RMS}$ . The termination resistance should also be significantly smaller than the DC resistance of the current transformers secondary winding.

The resistors R1 to R4 define the current flowing into the device. For best performance the SA4104A/B requires anti-alias filters on the current sense inputs. 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 optimum input network is achieved by setting the input resistors equal, i.e. setting  $R1 = R2 = R3 = R4 = R_C$ . This sets the equivalent resistance associated with each capacitor to  $R_C/2$ .

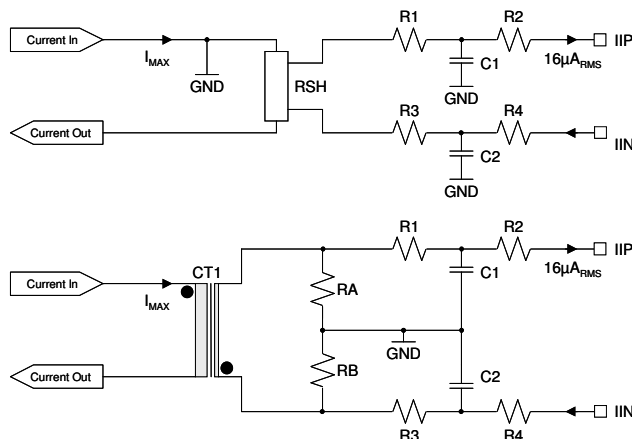


Figure 7: Current sense input configuration

### Voltage Sense Input (IVP)

Figure 8 shows the voltage sense input configuration. The voltage sense input saturates at an input current of  $\pm 17.6\mu A_{RMS}$  ( $\pm 25\mu A_{PEAK}$ ). The current into the voltage sense input should therefore be set between  $11\mu A_{RMS}$  and  $12\mu A_{RMS}$  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. Typical  $V_{NOM}$  values and the corresponding IVP input currents are shown in the following table.

Table 1: IVP input current for typical values of  $V_{NOM}$

$V_{NOM}$ (V)	IVP Input Current ( $\mu A_{RMS}$ )
110 / 220	11
115 / 230	11.5
120 / 240	12

For best performance the SA4104A/B also requires an anti-alias filter on the voltage sense input. Referring to Figure 8, the capacitor C1 is used to implement the anti-alias filter. If a current transformer is used as a current sensing element then C1 is also used to compensate for any phase shift caused by the current transformer. The resistor R4 defines the input current into the device. The optimum input network is achieved by setting R4 smaller than  $100k\Omega$ . If R4 is made too large the capacitor C1 will be very small and the phase shift of the input network could be affected by stray capacitances. The potentiometer P1 is used for calibration purposes.

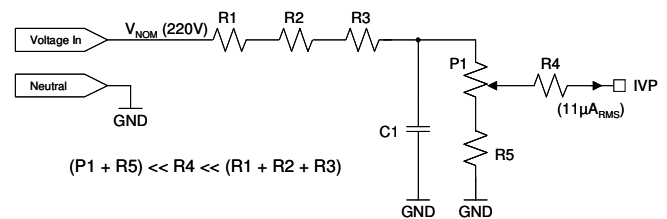


Figure 8: Voltage sense input configuration

### Fast Mode Select (FMS)

The Fast Mode Select input (FMS) is used to select between STANDARD and FAST mode as well as to select between a multitude of meter constants and motor drive dividing ratios. Connecting this pin to  $V_{DD}$  or  $V_{SS}$  enables the STANDARD mode of operation while leaving this pin floating enables the FAST mode of operation. When STANDARD mode is enabled the LED output pulses at a low frequency. This low frequency allows a longer accumulation period and the output pulse rate is therefore proportional to the average power consumption measured.



The Rated Condition Select pins (R0, R1, R2, R3) together with the FMS pin are used to select different LED output frequencies which in turn determine the applications meter constant. Refer to Figure 9 for the LED output timing diagram. When the FAST mode is enabled the LED output generates pulses at a nominal frequency of 5kHz at I<sub>MAX</sub> and V<sub>MAX</sub>. In this mode the pulse frequency is proportional to the average power consumption measured. This mode is useful when interfacing to a micro-controller.

When FMS is floating the LED pin outputs fast mode pulses. The motor pulses occur as usual based on the last FMS before a floating condition was detected as well as the current states of R0, R1, R2 and R3. If a floating condition on FMS is detected at device start-up the motor pulses are generated based on FMS set to V<sub>SS</sub>.

**Rated Condition Select (R0, R1, R2, R3)**

The Rated Condition Select inputs (R0, R1, R2 and R3) along with the Fast Mode Select input (FMS) are used for obtaining a multitude of meter constants and motor drive ratios. The different LED and motor division factors (DF\_LED and DF\_MO) that can be selected via R0, R1, R2, R3 and FMS are shown Table 2.

To calculate the LED output pulse constant in STANDARD mode and the motor drive pulse constant for any meter rating (I<sub>MAX</sub> and V<sub>NOM</sub>) the following formulae can be used:

$$\text{LED imp/kWh} = \frac{\text{IVP}}{16} \times \frac{5000}{\text{DL\_LED}} \times \frac{1000 \times 3600}{V_{\text{NOM}} \times I_{\text{MAX}}} \quad (1)$$

where

- I<sub>MAX</sub> = maximum rated mains current,
- V<sub>NOM</sub> = nominal mains voltage,
- IVP = the analog input current on the voltage sense input at V<sub>NOM</sub> as specified in Table 1 and
- DF\_LED = the dividing factor for the LED output that is set by the combination of R0, R1, R2, R3 and FMS as specified in Table 2.

Equation 1 is based on the assumption that the input current into the IIP/IIN current sense input is set to 16μA<sub>RMS</sub> at I<sub>MAX</sub>.

$$\text{Motor imp/kWh} = \frac{\text{LED imp/kWh}}{\text{DF\_MO}} \quad (2)$$

where

- LED imp/kWh = the LED constant as calculated using Equation 1 and
- DF\_MO = the dividing factor for the motor output that is set by the combination of R0, R1, R2, R3 and FMS as specified in Table 2.

Table 3 illustrates some of the possible LED and motor constants that are achievable for some common values of I<sub>MAX</sub> using a V<sub>NOM</sub> between 220V and 240V.

Table 2: LED and motor division factors

FMS	R3	R2	R1	R0	DF_LED	DF_MO
0	0	0	0	0	220	256
0	0	0	0	1	440	128
0	0	0	1	0	880	64
0	0	0	1	1	1760	32
0	0	1	0	0	220	128
0	0	1	0	1	440	64
0	0	1	1	0	880	32
0	0	1	1	1	1760	16
0	1	0	0	0	220	64
0	1	0	0	1	440	32
0	1	0	1	0	880	16
0	1	0	1	1	1760	8
0	1	1	0	0	220	32
0	1	1	0	1	440	16
0	1	1	1	0	880	8
0	1	1	1	1	1760	4
1	0	0	0	0	1464	64
1	0	0	0	1	2928	32
1	0	0	1	0	352	64
1	0	0	1	1	704	32
1	0	1	0	0	584	32
1	0	1	0	1	1168	16
1	0	1	1	0	352	32
1	0	1	1	1	704	16
1	1	0	0	0	584	16
1	1	0	0	1	1168	8
1	1	0	1	0	352	16
1	1	0	1	1	704	8
1	1	1	0	0	292	16
1	1	1	0	1	584	8
1	1	1	1	0	234	16
1	1	1	1	1	468	8

Note: Pin values defined as follows  
 0 pin is connected to V<sub>SS</sub>  
 1 pin is connected to V<sub>DD</sub>



Table 3: LED and motor constants achievable for some common I<sub>MAX</sub> currents for V<sub>NOM</sub> = 220V to 240V

I <sub>MAX</sub> (A)	Dividing Factors		LED Output (imp/kWh)	Motor Output (imp/kWh)
	DF_LED	DF_MO		
6	1464	64	6400	100
6	2928	32	3200	100
10	220	256	25600	100
10	440	128	12800	100
10	880	64	6400	100
10	1760	32	3200	100
10	220	128	25600	200
10	440	64	12800	200
10	880	32	6400	200
10	1760	16	3200	200
10	220	64	25600	400
10	440	32	12800	400
10	880	16	6400	400
10	1760	8	3200	400
10	220	32	25600	800
10	440	16	12800	800
10	880	8	6400	800
10	1760	4	3200	800
20	220	128	12800	100
20	440	64	6400	100
20	880	32	3200	100
20	1760	16	1600	100
20	220	64	12800	200
20	440	32	6400	200
20	880	16	3200	200
20	1760	8	1600	200
20	220	32	12800	400
20	440	16	6400	400
20	880	8	3200	400
20	1760	4	1600	400
25	352	64	6400	100
25	704	32	3200	100
25	352	32	6400	200
25	704	16	3200	200
25	352	16	6400	400
25	704	8	3200	400

I <sub>MAX</sub> (A)	Dividing Factors		LED Output (imp/kWh)	Motor Output (imp/kWh)
	DF_LED	DF_MO		
30	584	32	3200	100
30	1168	16	1600	100
30	584	16	3200	200
30	1168	8	1600	200
30	292	16	6400	400
30	584	8	3200	400
40	220	64	6400	100
40	440	32	3200	100
40	880	16	1600	100
40	1760	8	800	100
40	220	32	6400	200
40	440	16	3200	200
40	880	8	1600	200
40	1760	4	800	200
50	352	32	3200	100
50	704	16	1600	100
50	352	16	3200	200
50	704	8	1600	200
60	584	16	1600	100
60	1168	8	800	100
60	292	16	3200	200
60	584	8	1600	200
80	220	32	3200	100
80	440	16	1600	100
80	880	8	800	100
80	1760	4	400	100
100	352	16	1600	100
100	704	8	800	100
120	292	16	1600	100
120	584	8	800	100
150	234	16	1600	100
150	468	8	800	100



## OUTPUT SIGNALS

### LED Output (LED)

The LED output pin provides a pulse output with a frequency proportional to the average active energy consumption measured when in STANDARD mode or FAST mode. A low pass filter is applied to the instantaneous energy output directly after multiplication. This filtering allows all instantaneous components to be removed resulting in a constant output frequency at constant energy input, even over a short period of time. The delay of this filter is about 200ms.

The LED output is primarily used for calibration purposes. The Rated Condition Select inputs (R0, R1, R2, R3) and the Fast Mode Select input (FMS) allow different nominal output frequencies to be selected. The FMS input also allows selection between STANDARD mode and FAST mode. The LED output is active low. Figure 9 shows the LED output waveform.

In FAST mode the LED pulse output is set to a nominal frequency of 5kHz at an input current of 16μA<sub>RMS</sub> on both the current and voltage channels.

The nominal output frequency of the LED pin is given by

$$f_{LED\_FAST} = 5000 \times \frac{IVP \times IIP \times |\cos \phi|}{16^2} \quad (3)$$

in FAST mode and by

$$f_{LED\_STD} = \frac{f_{LED\_FAST}}{DF\_LED} \quad (4)$$

in STANDARD mode where

IVP and IIP = the analog input currents in μA<sub>RMS</sub> on the voltage and current sense inputs,

cos φ = the phase angle between the current and voltage signals and

DF\_LED = the LED divider selected by R0, R1, R2, R3 and FMS according to Table 2.

The timing values given below are based on the nominal frequency value of the internal oscillator.

$$t_L = 1/f_{LED\_FAST} \text{ in FAST mode (} f_{LED\_FAST} \text{ as per Equation 3)}$$

$$= 1/f_{LED\_STD} \text{ in STANDARD mode (} f_{LED\_STD} \text{ as per Equation 4)}$$

$$t_{LP} = 91.5\text{ms when } t_L > 183\text{ms in STANDARD mode}$$

$$= t_L/2 \text{ when } t_L < 183\text{ms in STANDARD mode}$$

$$= 69\mu\text{s in FAST mode}$$

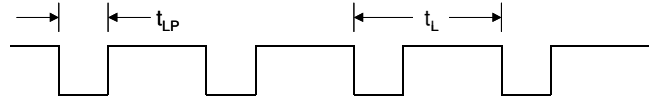


Figure 9: LED pulse output waveform

### Motor Pulse Output (MON, MOP)

The MON and MOP pins are complementary outputs with a frequency proportional to the average active power consumption measured. These active high outputs can be used to either directly drive a stepper motor counter or an electro-mechanical impulse counter. The Rated Condition Select inputs (R0, R1, R2, R3) as well as the Fast Mode Select input (FMS) allow the selection of different output frequencies corresponding to different meter constants. Figure 10 indicates the timing of these signals.

The nominal output frequency of each motor output is given by:

$$f_{MOT} = \frac{f_{LED\_STD}}{DF\_MO} \quad (5)$$

f<sub>LED\_STD</sub> = the output frequency of the LED output in STANDARD mode as per Equation 4 and

DF\_MO = the motor divider selected by R0, R1, R2, R3 and FMS according to Table 2

When connecting a stepper motor counter between MON and MOP the output pulse rate is effectively doubled because the pulses on both MON and MOP contribute to incrementing the counter.

The timing values given below are based on the nominal frequency value of the internal oscillator.

$$t_M = 1/f_{MOT} \text{ (} f_{MOT} \text{ as per Equation 5)}$$

$$t_{MP} = 220\text{ms when } t_M > 440\text{ms}$$

$$= t_M/2 \text{ when } t_M < 440\text{ms}$$

$$t_{MS} = t_M/2$$

$$t_{MSP} = t_{MS} - t_{MP} \text{ when } t_M > 440\text{ms}$$

$$= 6.7\mu\text{s when } t_M < 440\text{ms}$$

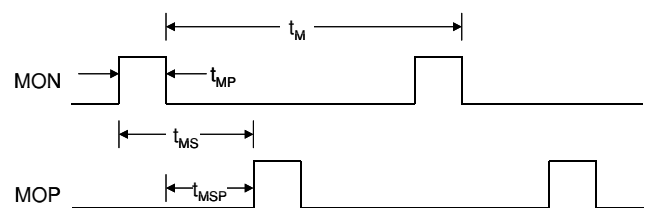


Figure 10: Motor pulse output waveform

**Direction Indicator Output (DIRO)**

The direction of the energy flow may be ascertained by monitoring the DIRO pin. A logic 0 on this pin indicates negative energy flow. Positive energy flow is indicated by a logic 1. Should the energy (either negative or positive) be less than the anti-creep threshold then this output will retain its previous state. This prevents a flickering output in the case of no or very low current flow. The DIRO pin may be used to drive an LED. The state of the DIRO pin is updated on the internal FAST mode pulses, regardless of whether the device is set to FAST or STANDARD mode. A power-on reset will set DIRO high and it will remain high until negative

energy above the anti-creep threshold is detected. Table 4 illustrates the operation of the DIRO output.

*Table 4: Operation of the DIRO output*

Energy Level	Phase Angle	State of DIRO
$< F_{MIN}$	$0^{\circ} - 360^{\circ}$	Previous State
$> F_{MIN}$	$< 90^{\circ}$	HIGH
$> F_{MIN}$	$> 90^{\circ}$	LOW

Note:  $F_{MIN}$  is the anti-creep threshold



## TYPICAL APPLICATION

The following description outlines the basic process required to design a typical single phase energy meter using the SA4104A/B and a shunt resistor as a current sensing element. The meter is capable of measuring 220V/40A/50Hz with a precision better than Class 1. It uses a stepper motor counter with 100imp/kWh and the calibration LED has a constant of 1600imp/kWh.

The most important external circuits required for the SA4104A/B are the current input network, the voltage input network as well as the bias resistor. All resistors should be 1% metal film resistors of the same type to minimize temperature effects.

### Bias Resistor

A bias resistor of  $R_{10} = 47k\Omega$  sets optimum bias and reference currents on chip. Calibration of the meter should be done using the voltage input and not by means of the bias resistor.

### Current Input Network

The voltage drop across the shunt resistor at maximum rated current should not be less than  $5mV_{RMS}$  and not exceed  $100mV_{RMS}$ . A  $320\mu\Omega$  shunt is chosen which sets the voltage drop at maximum rated current to 12.8mV and the power dissipation in the shunt to 0.5W. The voltage across the shunt resistor is converted to the required differential input currents through the current input resistors. Anti-alias filters are incorporated on these input resistors to filter any high frequency signal components that could affect the performance of the SA4104A/B.

The four current input resistors ( $R_1, R_2, R_3, R_4$ ) should be of equal size to optimize the input networks low pass filtering characteristics, so the values can be calculated as follows:

$$R_1 = R_2 = R_3 = R_4 = I_{MAX} \times \frac{R_{SH}}{4 \times 16\mu A} = 200\Omega = R_C.$$

For optimum performance the cut-off frequency of the anti-alias filter should be between 10kHz and 20kHz. The equivalent resistance associated with each capacitor is  $R_C/2$  so the capacitor values should be in the order of

$$C_1 = C_2 = \frac{1}{\pi f_{CI} R_C} = \frac{1}{\pi \times 15kHz \times 200\Omega} \approx 100nF$$

where  $f_{CI}$  is the cut-off frequency of the anti-alias filter of the current input network.

### Voltage Input Network

The voltage sense input requires an input current of  $11\mu A_{RMS}$  at  $V_{NOM}$  (220V) according to Table 1. The mains voltage is divided by means of a voltage divider to a lower voltage that is converted to the required input current by means of the input resistor. Once again an anti-alias filter is required to remove any high frequency signals that could affect the performance of the SA4104A/B. A shunt typically has no phase shift so phase compensation is not required.

The input resistor  $R_8$  sets the current input into the device. This resistor should not be too large else the capacitor for the anti-alias filter will be quite small which could cause inaccurate phase shift due to parasitic capacitances. Therefore  $R_8 = 100k\Omega$  is chosen and the voltage at the centre of the trimpot should be 1.1V ( $11\mu A \times 100k\Omega$ ). The calibration range of the voltage input network should be about  $\pm 15\%$  to ensure that all component tolerances can be catered for, so the total tuning range can be set to  $\pm 0.17V$ . Therefore the voltage across the trimpot and  $R_9$  is 1.27V. Choosing a  $1k\Omega$  trimpot results in

$$R_9 = \frac{1k\Omega}{(2 \times 0.17)} \times (1.27 - 2 \times 0.17) \approx 2.7k\Omega.$$

The effect of  $R_8$  can be ignored in the above equation, given the fact that  $R_8$  is significantly larger than  $P_1$  and  $R_9$ . Now let  $R_A = R_5 + R_6 + R_7$  and

$$R_A = (P_1 + R_9) \times \left( \frac{220V}{1.27V} - 1 \right) \approx 637k\Omega$$

so choose  $R_5 = 240k\Omega$ ,  $R_6 = 220k\Omega$  and  $R_7 = 180k\Omega$ .

The cut-off frequency of the anti-alias filter is adjusted so that it is identical to that of the current input network anti-alias filters. This ensures that the phase shift caused by the anti-alias filters is identical on the current and voltage input networks. Therefore

$$\frac{1}{\pi C_1 \times R_C} = \frac{1}{2\pi(P_1 + R_8) \times C_3}$$

and so  $C_3 = 2.7nF$ .



**Device Setup**

The SA4104A/B has to be set to STANDARD mode. Using Equations 1 and 2 in the Rated Condition Select section the required LED and motor dividers for 1600imp/kWh and

100imp/kWh respectively are calculated as  $DF\_LED = 880$  and  $DF\_MO = 16$ . Using Table 2 the device is set up using  $FMS = V_{SS}$ ,  $R3 = V_{DD}$ ,  $R2 = V_{SS}$ ,  $R1 = V_{DD}$  and  $R0 = V_{SS}$ .

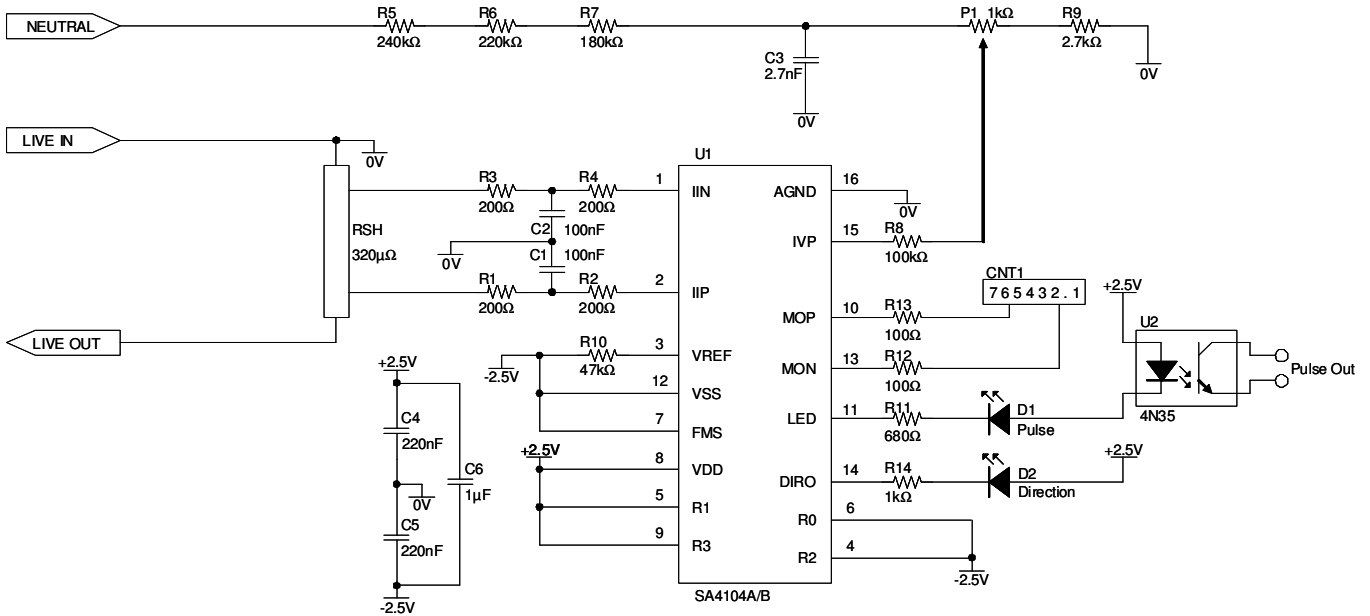


Figure 11: Typical application circuit

Table 5: Component list for typical application

Symbol	Description
U1	Energy metering device, SA4104ASAR, SA4104BSAR
U2	Opto-coupler, 1N35
RSH	Shunt Resistor, 40A, 320µΩ
R1, R2 <sup>1</sup> , R3, R4 <sup>1</sup>	Resistor, 200Ω, 1%, metal film
R5	Resistor, 240kΩ, 1%, metal film
R6	Resistor, 220kΩ, 1%, metal film
R7	Resistor, 180kΩ, 1%, metal film
R8 <sup>1</sup>	Resistor, 100kΩ, 1%, metal film
R9	Resistor, 2.7kΩ, 1%, metal film
R10 <sup>1</sup>	Resistor, 47kΩ, 1%, metal film

Symbol	Description
R11	Resistor, 680Ω, 5%, carbon film
R12, R13	Resistor, 100Ω, 5%, carbon film
R14	Resistor, 1kΩ, 5%, carbon film
P1	Trim-pot, 25 turns, 1kΩ
C1, C2	Capacitor, 100nF, ceramic
C3	Capacitor, 2.7nF, ceramic
C4 <sup>2</sup> , C5 <sup>2</sup>	Capacitor, 220nF, ceramic
C6 <sup>2</sup>	Capacitor, 1µF, ceramic
D1	3mm light emitting diode, pulse output
D2	3mm light emitting diode, energy direction output
CNT1	Stepper motor counter, 100imp/kWh

Note 1: Resistors R2, R4, R8 and R10 must be positioned as close as possible to the respective device pins

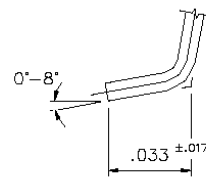
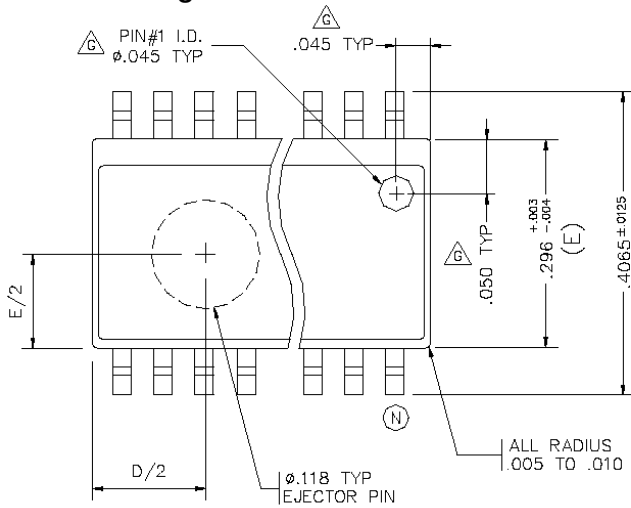
Note 2: Capacitors C4, C5 and C6 must be positioned as close as possible to the V<sub>DD</sub> and V<sub>SS</sub> power supply pins



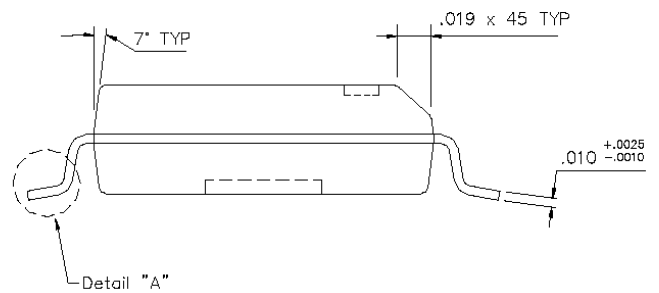
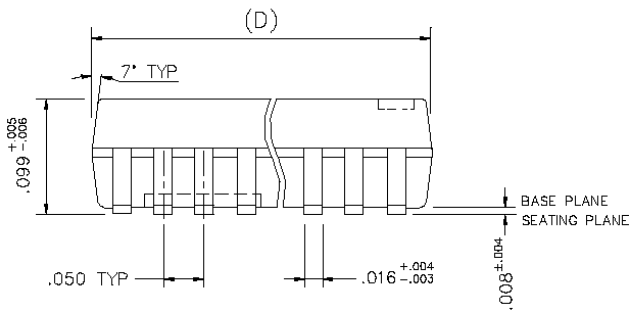
PACKAGE DIMENSIONS

SOIC16 Package

Dimensions are shown in inches



N	D VARIATIONS		
	MIN	NOM	MAX
16	.398	.405	.412
18	.449	.456	.463
20	.496	.503	.510
24	.599	.606	.613
28	.697	.704	.711







**NOTES**

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