

# Single Phase Bidirectional Power/Energy Metering IC with Serial SPI Interface



**sames**

## SA9603B

### FEATURES

- Performs bidirectional active and reactive power/energy measurement
- Voltage and frequency measurement
- SPI communication bus
- Meets the IEC 521/1036 Specification requirements for Class 1 AC Watt hour meters
- Protected against ESD
- Total power consumption rating below 25mW
- Adaptable to different current sensor technologies
- Operates over a wide temperature range
- Precision Voltage Reference on chip.

### DESCRIPTION

The SAMES SA9603B Bidirectional Single Phase Power / Energy metering integrated circuit has a serial interface, ideal for use with a  $\mu$ -Controller. The SA9603B performs the calculation for active and reactive power, mains voltage sense and frequency.

The integrated values for active and reactive energy, the mains voltage and frequency information are accessible through the SPI bus as 24 bit values.

This innovative universal single phase power / energy metering integrated circuit is ideally suited for energy calculations in applications such as electricity dispensing systems (Ed's), residential municipal metering and factory energy metering and control.

The SA9603B integrated circuit is available in both 20 pin dual-in-line plastic (DIP20), as well as 20 pin small outline (SOIC20) package types.

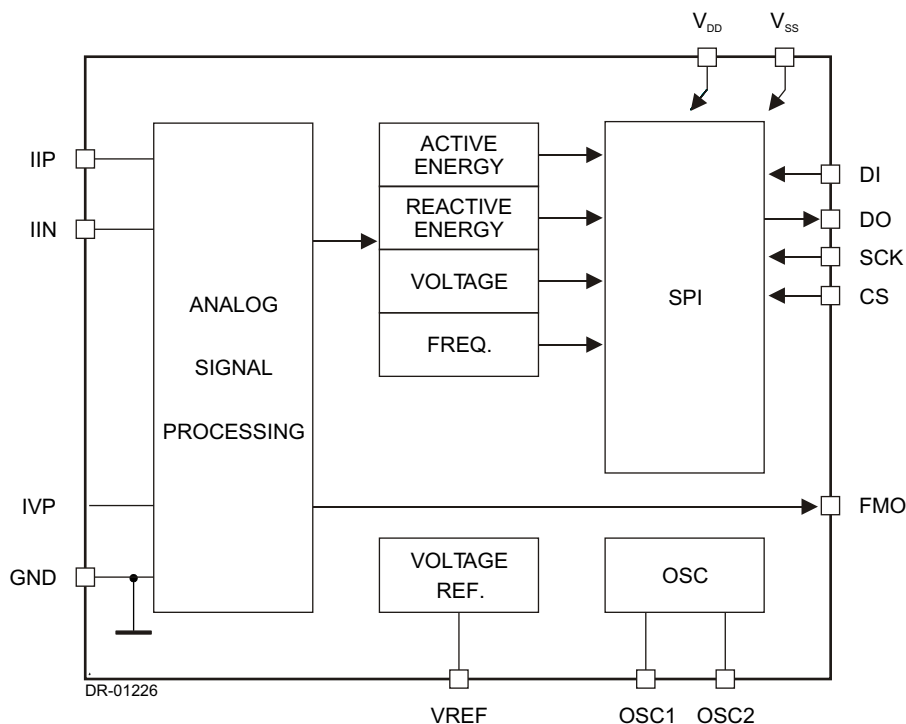


Figure 1: Block diagram

**ELECTRICAL CHARACTERISTICS**(V<sub>DD</sub> = 2.5V, V<sub>SS</sub> = -2.5V, over the temperature range -10°C to +70°C<sup>#</sup>, unless otherwise specified.)

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Operating temp. Range	T <sub>O</sub>	-25		+85	°C	
Supply Voltage: Positive	V <sub>DD</sub>	2.25		2.75	V	
Supply Voltage: Negative	V <sub>SS</sub>	-2.75		-2.25	V	
Supply Current: Positive	I <sub>DD</sub>		5	6	mA	
Supply Current: Negative	I <sub>SS</sub>		5	6	mA	
<b>Current Sensor Inputs (Differential)</b>						
Input Current Range	I <sub>II</sub>	-25		+25	µA	Peak value
<b>Voltage Sensor Input (Asymmetrical)</b>						
Input Current Range	I <sub>IV</sub>	-25		+25	µA	Peak value
<b>Pin VREF</b>						
Ref. Current	-I <sub>R</sub>	45	50	55	µA	With R = 24k connected to V <sub>SS</sub> Reference to V <sub>SS</sub>
Ref. Voltage	V <sub>R</sub>	1.1		1.3	V	
<b>Digital I/O</b>						
Pin DO High Voltage Low Voltage	V <sub>OH</sub> V <sub>OL</sub>	V <sub>DD</sub> -1		V <sub>SS</sub> +1	V V	I <sub>OL</sub> = 5mA I <sub>OH</sub> = -2mA
Pin DI High Voltage Low Voltage	V <sub>IH</sub> V <sub>IL</sub>	V <sub>DD</sub> -1		V <sub>SS</sub> +1	V V	
Pin SCK High Voltage Low Voltage	V <sub>IH</sub> V <sub>IL</sub>	V <sub>DD</sub> -1		V <sub>SS</sub> +1	V V	
	F <sub>SK</sub> t <sub>LO</sub> t <sub>HI</sub>			800	kHz µs µs	
Pin CS High Voltage Low Voltage	V <sub>IH</sub> V <sub>IL</sub>	V <sub>DD</sub> -1		V <sub>SS</sub> +1	V V	
Pin FMO High Voltage Low Voltage	V <sub>OH</sub> V <sub>OL</sub>	V <sub>DD</sub> -1		V <sub>SS</sub> +1	V V	I <sub>OL</sub> = 5mA I <sub>OH</sub> = -2mA
Oscillator	Recommended crystal: TV colour burst crystal f= 3.5795 MHz					

#Extended Operating Temperature Range available on request.

**ABSOLUTE MAXIMUM RATINGS\***

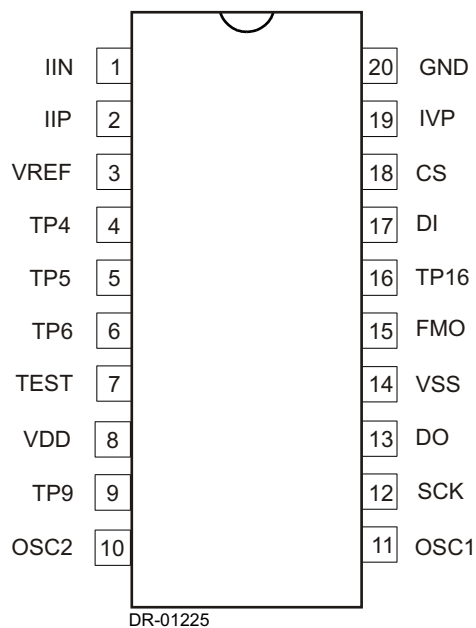
Parameter	Symbol	Min	Max	Unit
Supply Voltage	V <sub>DD</sub> -V <sub>SS</sub>	-0.3	6.0	V
Current on any pin	I <sub>PIN</sub>	-150	+150	mA
Storage Temperature	T <sub>STG</sub>	-40	+125	°C
Operating Temperature	T <sub>O</sub>	-40	+85	°C

\*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.



### PIN DESCRIPTION

Pin	Designation	Description
20	GND	Ground
8	VDD	Positive Supply Voltage
14	VSS	Negative Supply Voltage
19	IVP	Analog input for Voltage
1	IIN	Inputs for current sensor
2	IIP	
11	OSC1	Connections for crystal or ceramic resonator (OSC1 = Input ; OSC2 = Output)
10	OSC2	
13	DO	Serial Data Out
17	DI	Serial Data In
12	SCK	Serial Clock In
18	CS	Chip Select (Active High)
15	FMO	Voltage Sense Zero Crossover
3	VREF	Connection for current setting resistor
7	TEST	Manufacturer's Test Pin (connect to VSS for normal operation)
4	TP4	Manufacturer's Test Pin (leave unconnected)
5	TP5	
6	TP6	
9	TP9	
16	TP16	



### ORDERING INFORMATION

Part Number	Package
SA9603BPA	DIP20
SA9603BSA	SOIC20

Figure 2: Pin connections: Package: DIP20, SOIC20

## FUNCTIONAL DESCRIPTION

The SA9603B is a CMOS mixed signal Analog / Digital Integrated Circuit, which performs the measurement of active power, reactive power, voltage and frequency.

Internal offsets are eliminated through the use of cancellation procedures. The SA9603B integrates the measured active and reactive power consumption and the average mains voltage into 24 bit integrators, which are accessible via the SPI bus. The mains frequency is also available as a 24 bit register value.

The zero crossover of the voltage sense input is signalled on the FMO (pin 15) output. This output will allow monitoring by a  $\mu$ -Controller to synchronise with internal timing for data acquisition. Refer to 5.6 for further information.

The SA9603B has tristate output to allow connection of more than one metering device on a single SPI bus.

## POWER CALCULATION

In the Application Circuit (Figure 6), the voltage drop across the shunt will be between 0 and  $16\text{mV}_{\text{RMS}}$  (0 to 80A through a shunt resistor of  $200\mu$  ). This voltages is converted to a current of between 0 and  $16\mu\text{A}_{\text{RMS}}$ , by means of resistors  $R_1$  and  $R_2$ .

The current sense input saturates at an input current of  $\pm 25\mu\text{A}$  peak.

For the voltage sensor input, the mains voltage (230VAC) is divided down through a divider to 14V. The resulting current into the A/D Converter input is  $14\mu\text{A}_{\text{RMS}}$  at nominal voltage, via resistor  $R_4$  (1M ).

In this configuration, with a mains voltage of 230V and a current of 80A, the SA9603B functions at its optimum conditions.

## ANALOG INPUT CONFIGURATION

The input circuitry of the current and voltage sensor inputs are illustrated in Figure 3. 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 shorts on the signal inputs. Exact copies of the input currents are generated for the following analog signal processing circuitry.

## ELECTROSTATIC DISCHARGE (ESD) PROTECTION

The SA9603B Integrated Circuits inputs / outputs are protected against ESD.

## POWER CONSUMPTION

The power consumption rating of the SA9603B integrated circuit is less than 25mW.

## SPI - INTERFACE

### Register Access

The serial peripheral interface (SPI) is a synchronous bus for data transfer and is used when interfacing the SA9603B with any micro-controller. Four pins are used for the SPI. The four pins are DO (Serial Data Out), DI (Serial Data In), CE (Chip Enable), and SCK (Serial Clock). The SA9603B is the slave device in an SPI application, with the micro-controller being the master. The DI and DO pins are the serial data input and output pins for the SA9603B, respectively. The CE input is used to initiate and terminate a data transfer. The SCK pin is used to synchronize data movement between the master (micro-controller) and the slave (SA9603B) devices.

The serial clock (SCK) is generated by the micro-controller.

### Register Access

There are four registers which can be read: active, reactive, voltage and frequency. Any of these registers may be chosen as the initial register to read. If the SCK clock input continues after the first register has been read, the contents of

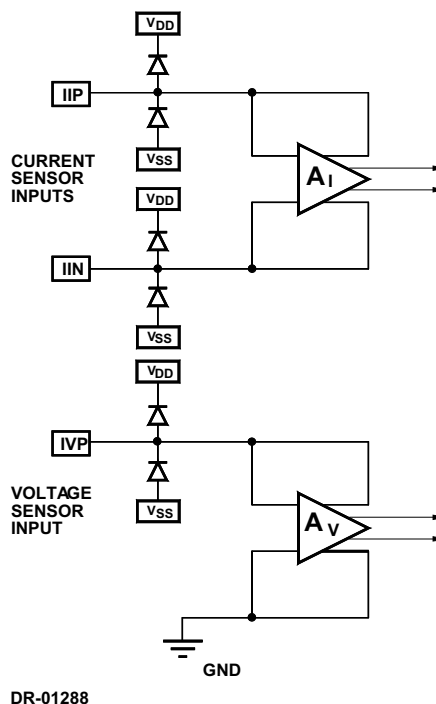


Figure 3: Analog Input Internal Configuration



## SA9603B

subsequent registers will be output on the DO pin. Transfer will continue until CS is brought inactive.

To enable registers for reading, the sequence 1 1 0 ( $6_{HEX}$ ) must precede the 6 bit address of the register being accessed.

The various register addresses are shown in the table below:

ID	REGISTER	A5	A4	A3	A2	A1	A0
1	Active	X	X	0	0	0	0
2	Reactive	X	X	0	0	0	1
3	Voltage	X	X	0	0	1	0
4	Frequency	X	X	0	0	1	1

Address locations A5 and A4 are included for compatibility with future developments. When CS is HIGH, data input on pin DI is clocked into the device on the rising edge of SCK. The data clocked into DI will comprise of 1 1 0 A5 A4 A3 A2 A1 A0, in this order.

### Data Output

After the least significant digit of the address has been entered on the rising edge of SCK, the output DO goes low with falling edge of SCK. Each subsequent falling edge transaction on the SCK pin will validate data of the register contents on pin DO.

The contents of each register consists of 24 bits of data output on pin D0, starting with the most significant digit, D23.

### Frequency Register

For the frequency register only bits D15 ... D0 are used for calculations. The upper seven bits (D23 ... D17) must still be clocked out, as important frequency information can be derived from these data bits.

Bit D17 changes with every rising edge of the mains voltage

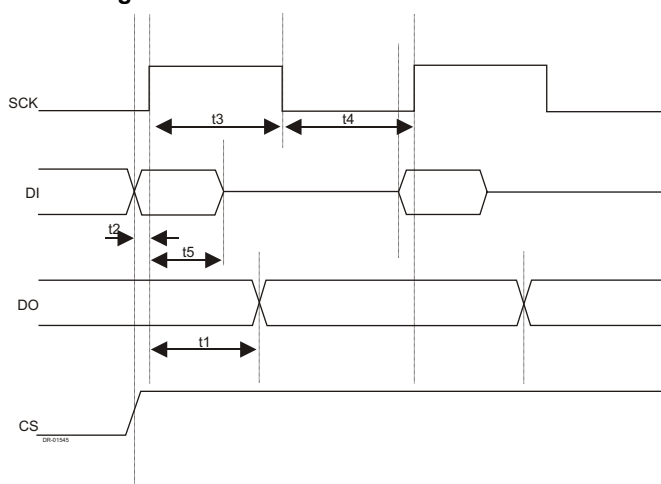
(25Hz square wave for 50Hz mains system). Bit D18 displays a frequency of D17/2 and D19 displays a frequency of D17/4.

Bits D16, D20, D21, D22 and D23 are not used.

### SPI Waveforms

The waveforms to perform a read cycle are shown in Figure 4:

#### SPI Timing



Parameter	Description	Min	Max
t1	SCK rising edge to DO valid	625µs	1.160µs
t3	SCK min high time	625µs	
t2	SCK min low time	625µs	
t2	Setup time for DI and CS before the rising edge of SCK	20µs	
t5	DI hold time	625µs	

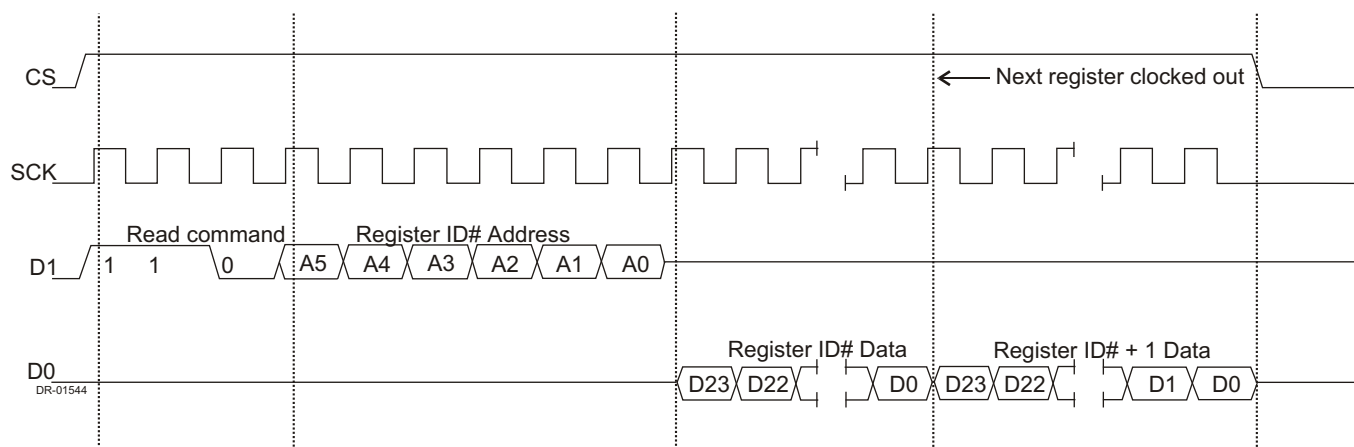


Figure 4: SPI Waveforms



### Synchronised Reading of Registers

The SA9603B integrated circuit updates the registers on a continual basis. The SA9603B register content is latched onto the SPI interface as soon as a read command has been detected or the next register is addressed during continual access. The registers can be accessed at any time however for maximum stability the time between readings must be in multiples of 8 mains cycles. The internal offset cancellation procedure requires 8 mains cycles to complete. The registers are not reset after access, so in order to determine the correct register value the previous value read must be subtracted from the current reading. This methodology holds true for Active, Reactive and Voltage registers. The data read from the registers represents the active power, reactive power and voltage integrated over time. The increase or decrease between readings is the energy consumption. The registers are not affected during access. No error is possible during read, because all control signals are generated on chip. The registers can be accessed in any sequence at any time without problems.

The voltage sense zero crossing (approx. 50% duty cycle pulse) is available on Fm0, (Pin 15). This information allows a supervisor (ie: micro-controller) to monitor when the next read operation should be performed. Another approach could be to monitor the upper bits of the frequency register (18, 19). A measurement cycle is completed when these bits change to the same state again (00..00 or 01..01 or 10..10 or 11..11).

### Register Values

The 24 bit registers are up/down counters, which increment or decrement at a rate of  $640k \cdot 2 / PI$  for reactive) at rated conditions. The energy register values will increment for positive energy flow and decrement for negative energy flow as can be seen in the following diagram:

At power-up the register values are underfined and for this reason the msb of the **delta value** (delta value = present register value - previous register value) should be regarded as an indication of the measured energy direction. (0 = positive, 1 = negative).

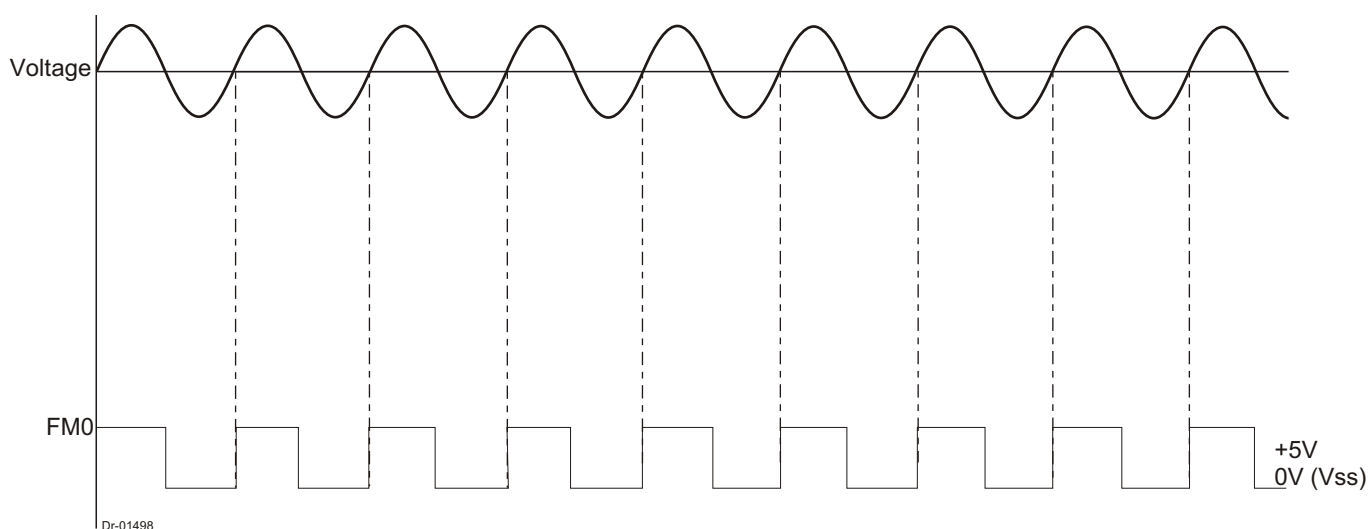
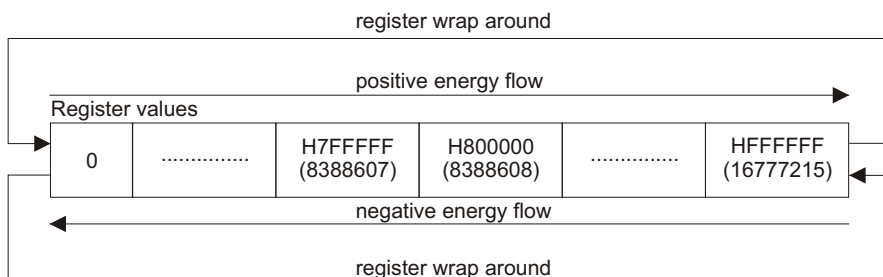


Figure 5: Fm0 Output



## SA9603B

The **delta value** for the energy registers is between 0 and 8388607 for positive energy flow and between 0 and -8388607 for negative energy flow. For voltage the maximum usable delta value is 17666215 as voltage is in a positive direction only.

When reading the registers care should be taken to check for a wrap around condition.

As an example lets assume that with a constant load connected the delta value is 22260. Because of the constant load, the delta value should always be 22260 every time the register is read and the previous value subtracted (assuming the same time period between reads). However this will not be true when a wrap around occurs as the following example will demonstrate:

Previous register value = 16744955  
Present register value = 16767215  
Delta value = 16767215-16744955 = 22260

After the next read the values are as follows:

Previous register value = 16767215  
Present register value = 12260  
Delta value = 12260 - 16767215 = -16754955

Computing this delta value will result in incorrect readings, in other words a wrap around has occurred. A typical function to check for wrap around condition would be as follows:

Function Check (delta\_value);

```
Begin
Temp_delta_value = abs(delta_value); {get rid of the minus
sign for example: abs(-151) = 151}
If (Temp_delta_value) > 8388607 then
Begin
If (delta_value) > 0 then result: = (16777216-delta_value) *-1
else result : = (16777216+delta_value);
End;
End; {end function}
```

At rated conditions, the time for wrap around is as follows:  
18.6 seconds for voltage  
13 seconds for active and 21 seconds for reactive

The active and reactive energy measured per count, may be calculated by applying the following formula:

$$\text{Energy per Count} = \frac{VI}{K} \text{ Watt seconds}$$

**Where:**

V = Rated Voltage  
I = Current (I<sub>MAX</sub>)

$$K = \begin{matrix} 640\,000 & \text{for Active Energy} \\ \underline{640\,000 * 2} & \text{for Reactive Energy} \end{matrix}$$

**Example:**

V = 230V  
I = 80A  
Active Power = 230V x 80A x (n/t) / 640 000  
Reactive Power = 230V x 80A (n/t) / (640 000 x 2)/Pi  
N = Difference in register values between successive reads (delta value)  
T = Time difference between successive reads (in seconds)

To calculate the measured voltage, the following formula is applied:

$$V_{\text{measured}} = \frac{V * n}{940\,000 * t}$$

**Where:**

V = Rated Voltage  
T = Time difference between successive reads  
N = Difference in register values between successive reads

The Voltage calculated is the average voltage. The voltage measurement will give an accuracy of better than 1% for a voltage range of 50% to 115% of the rated mains voltage if the voltage is a pure sine wave.

The mains frequency may be calculated as follows:

$$\text{Frequency} = \frac{\text{Crystal frequency}}{\text{Register Value} * 2}$$

### CALIBRATION

For accurate results we would recommend the following software calibration procedure:

#### Active energy

Establish a calibration factor for active energy (Ka) at pf close to 1.

$$\text{Active Measured} = \text{Active\_Register\_Value} \times K_a$$

#### Reactive Energy

With a pf close to 1 establish the phase error:

$$\text{PhaseError} = \arctan (\text{VARMeasured} / \text{ActiveMeasured})$$

For each measurement calculate the following:

$$\begin{aligned} VA &= \sqrt{\text{ActiveMeasured}^2 + \text{VARmeasured}^2} \\ \text{PHIcalibrated} &= \arctan (\text{VARmeasured} / \text{ActiveMeasured}) \\ \text{PHICorrected} &= \text{PHIcalibrated} - \text{PhaseError} \\ \text{VARtrue} &= VA * \sin(\text{PHICorrected}) \end{aligned}$$



### TYPICAL APPLICATION

In the Application Circuits (Figure 6 and 7), the components required for power metering application are shown.

In Figure 6 a shunt resistor is used for current sensing. In this application, the circuitry requires a +2.5V, 0V, -2.5V DC supply.

In the case of Figure 7, when using a current transformer for current sensing, a +5V, 0V DC supply is sufficient for the circuit.

Two current sense input require a differential approach to cater for precisions across the dynamic range. It is, therefore, important that the PC board layout for the branches to the sensing elements are as symmetrical as possible and the loop area kept to a minimum.

The most important external components for the SA9603B integrated circuit are:

$R_2$ ,  $R_1$  and RSH are the resistors defining the current level into the current sense input. The values should be selected for an input current of  $16\mu A_{RMS}$  into the SA9603B at rated line current.

Values for RSH of less than  $200\mu$  should be avoided.

$$R_1 = R_2 = (I_L / 16\mu A_{RMS}) * RSH / 2$$

Where:

$I_L$  = Line current

RSH = Shunt resistor / termination resistor

$R_3$ ,  $R_6$  and  $R_4$  set the current for the voltage sense input. The values should be selected so that the input current into the voltage sense input (virtual ground) is set to  $14\mu A_{RMS}$ .  $R_7$  defines all on-chip bias and reference currents. With  $R_7 = 24k$ , optimum conditions area set.

$R_7$  defines all on-chip bias and reference currents. With  $R_7 = 24k$ , optimum conditions area set.  $R_7$  may be varied by up to  $\pm 10\%$  for calibration purposes. Any changes to  $R_7$  will affect the output quadratically (i.e.:  $\Delta R = +5\%$ , then  $\Delta P = +10\%$ ).

XTAL is a colour burst TV crystal ( $f = 3.5795MHz$ ) for the oscillator. The oscillator frequency is divided down to  $1.7897MHz$  on-chip to supply the A/D Converters and digital circuitry.



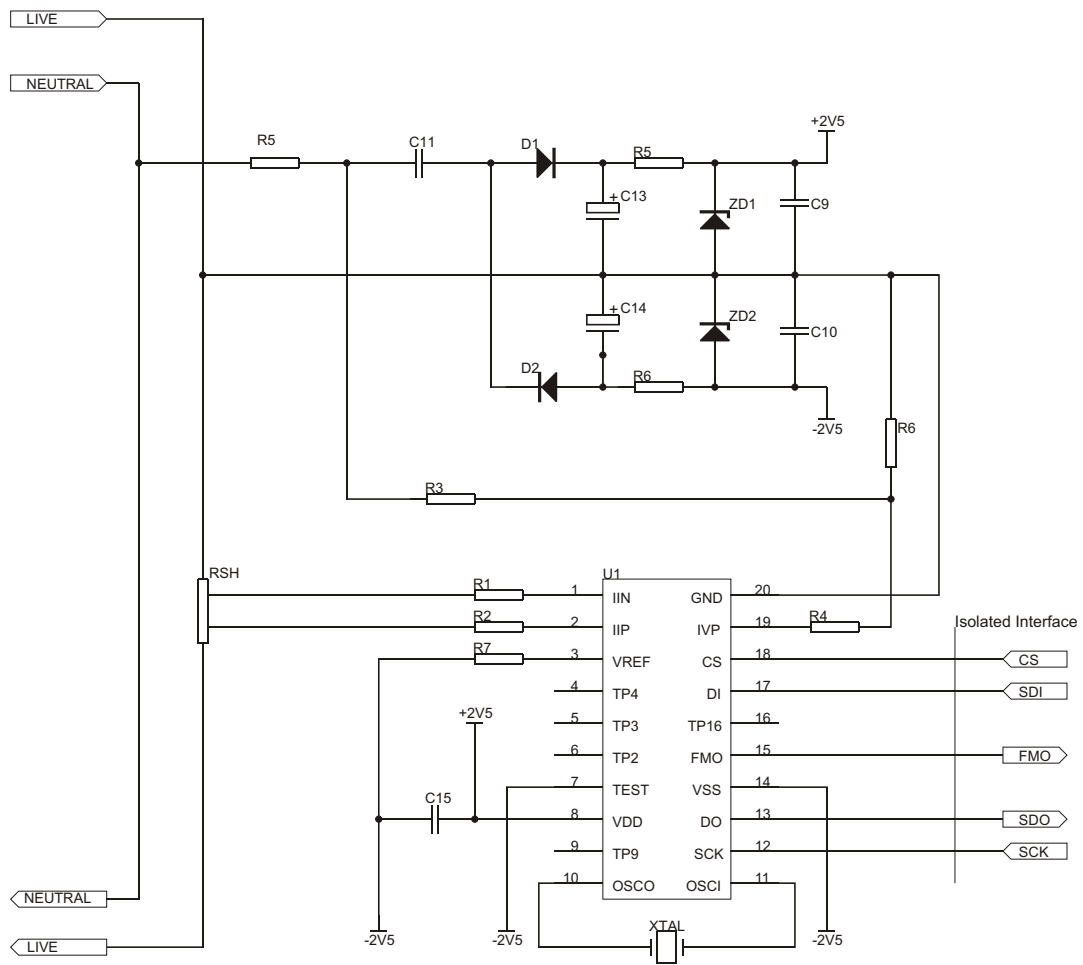


Figure 6: Application Circuit using a Shunt Resistor for Current Sensing

**Parts List for Application Circuit: Figure 6**

Item	Symbol	Description	Detail
1	IC-1	SA9603B	DIP-20/SOIC-20
2	D1	Diode, Silicon 1N4007	
3	D2	Diode, Silicon 1N4007	
4	ZD1	Diode, Zener, 2.4V, 200mW	
5	ZD2	Diode, Zener, 2.4V, 200mW	
6	XTAL	Crystal, 3.5795MHz	
7	R1	Resistor, 1%, metal	Colour burst TV
8	R2	Resistor, 1%, metal	Note 1
9	R3	Resistor, 390k, (230VAC), 1%, metal	Note 1
10	R4	Resistor, 1M, 1/8W, 1%, metal	
11	R5	Resistor, 470 , 2W, 5%, carbon	
12	R6	Resistor, 24k, 1/8W, 1%, metal	
13	R7	Resistor, 24k, 1/8W, 1%, metal	
14	R9	Resistor, 680 , 1/8W, 5%	
15	R10	Resistor, 680 , 1/8W, 5%	
16	C9	Capacitor, 0.47 $\mu$ F	
17	C10	Capacitor, 0.1 $\mu$ F	
18	C11	Capacitor, 0.47 $\mu$ F, 250VAC, poleyster	
19	C13	Capacitor, 100 $\mu$ F	
20	C14	Capacitor, 100 $\mu$ F	
21	RSH	Shunt Resistor	Note 2

**Note 1:** Resistor (R1 and R2) values are dependent upon the selected value of RSA.

**Note 2:** See TYPICAL APPLICATION when selected the value for RSH.

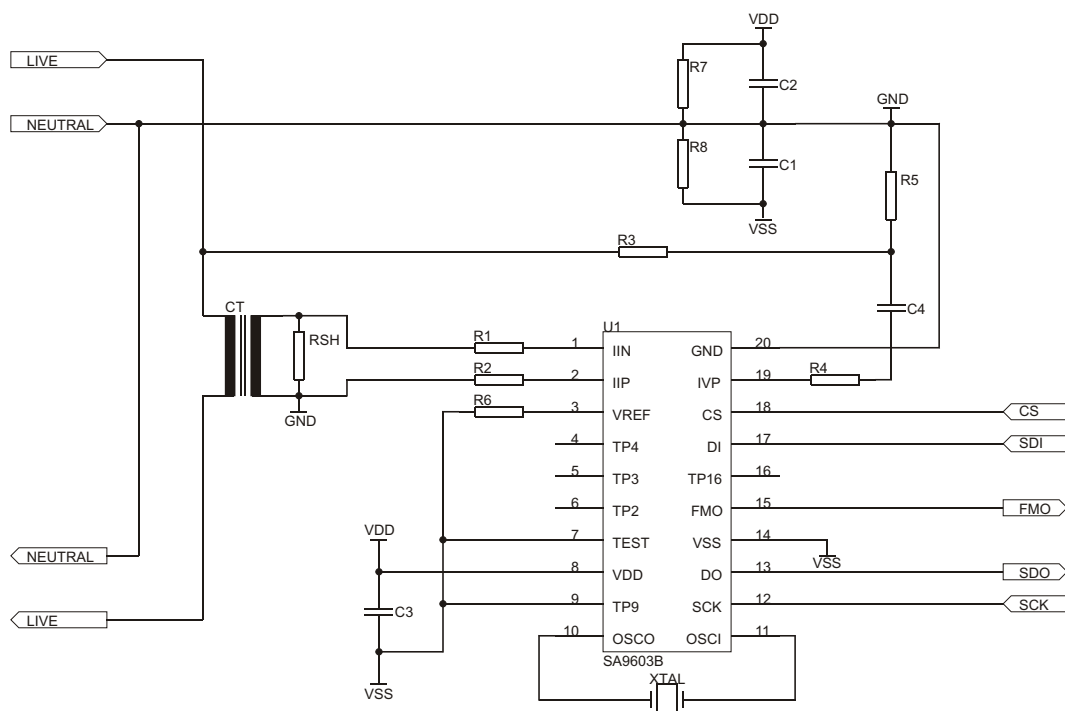


Figure 7: Application Circuit using a Current Transformer for Current Sensing

Parts List for Application Circuit: Figure 7

Item	Symbol	Description	Detail
1	IC-1	SA9603B	DIP-20/SOIC-20
2	XTAL	Crystal, 3.5795MHz	Colour burst TV
3	RSH	Resistor	Note 1
4	R1	Resistor, 1%, metal	Note 2
5	R2	Resistor, 1%, metal	Note 2
6	R3	Resistor, 390k, (230VAC), 1%, metal	
7	R4	Resistor, 1M, 1/8W, 1%, metal film	
8	R5	Resistor, 24k, 1/8W, 1%, metal film	
9	R6	Resistor, 24k, 1/8W, 1%, metal film	
10	R7	Resistor, 2.2k, 1/8W, 5%	
11	R8	Resistor, 2.2k, 1/8W, 5%	
12	C3	Capacitor, 0.47µF	Note 3
13	C1	Capacitor, 0.1µF	
14	C2	Capacitor, 0.1µF	Note 3
15	C4	Capacitor	Note 4
16	CT	Current Transformer	

**Note 1:** See TYPICAL APPLICATION when selected the value for RSH.

**Note 2:** Resistor (R1 and R2) values are dependent upon the selected value of RSH.

**Note 3:** Capacitor (C1, C2 and C3) to be positioned as close to IC-1, as possible.

**Note 4:** Capacitor (C4) selected to minimize phase error introduced by current transformer.



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