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SA9603B

SINGLE PHASE BIDIRECTIONAL POWER/ENERGY METERING IC WITH SERIAL SPI INTERFACE

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
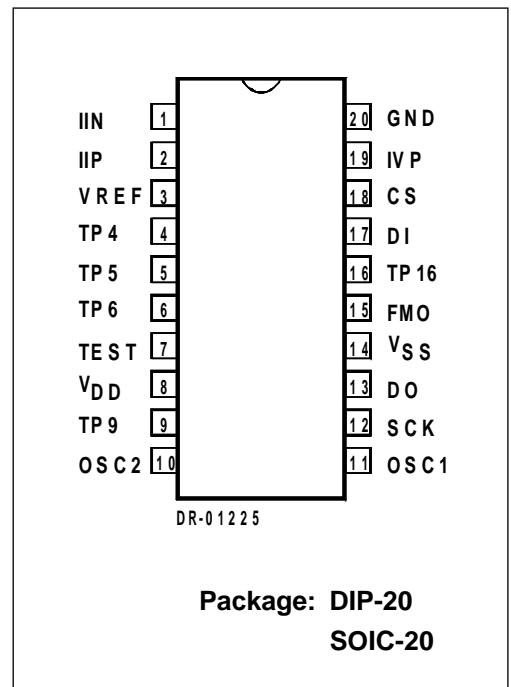
- Precision Voltage Reference on-chip

DESCRIPTION

The SAMES SA9603B Bidirectional Single Phase Power/Energy metering integrated circuit has a serial interface, ideal for use with a µ-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 accessable through the SPI bus as 24 bit values.
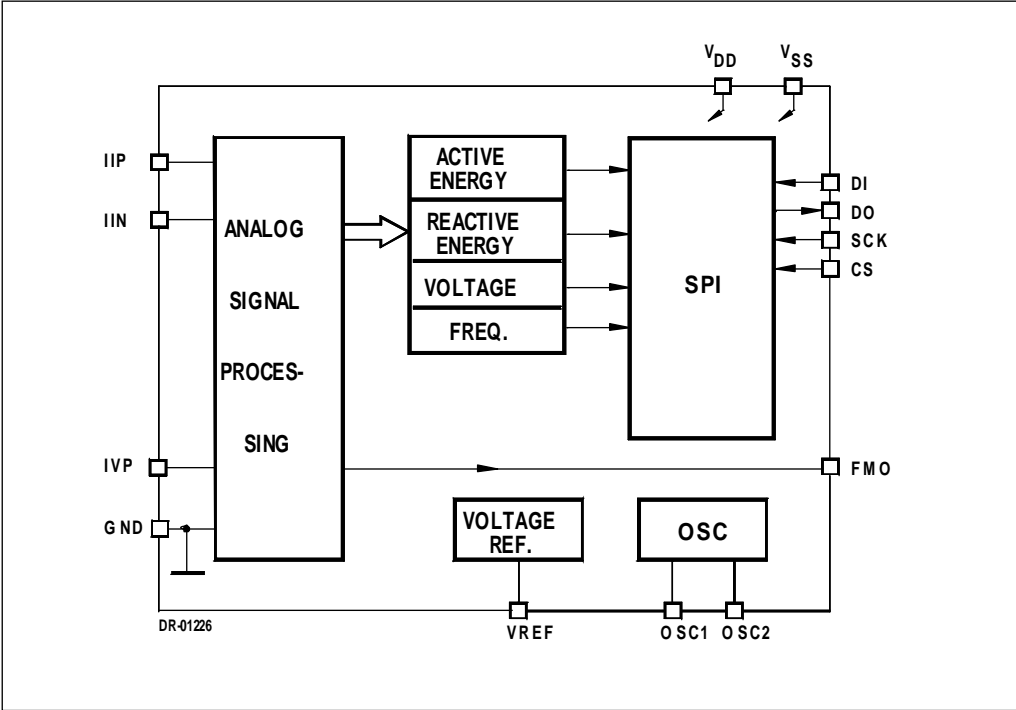
This innovative universal single phase power/energy metering integrated circuit is ideally suited for energy calculations in applications such as electricity dispensing systems (ED's), residential municipal metering and factory energy metering and control.

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

PIN CONNECTIONS

IIN	1	20	GND
IIP	2	19	IVP
VREF	3	18	CS
TP 4	4	17	DI
TP 5	5	16	TP 16
TP 6	6	15	FMO
TEST	7	14	V_{SS}
V_{DD}	8	13	DO
TP 9	9	12	SCK
OSC2	10	11	OSC1

DR-01225

Package: DIP-20

SOIC-20

BLOCK DIAGRAM

V_{DD} V_{SS}

IIP

IIN

ANALOG

SIGNAL

PROCES-

SING

IVP

GND

ACTIVE ENERGY

REACTIVE ENERGY

VOLTAGE

FREQ.

SPI

DI

DO

SCK

CS

FMO

VOLTAGE REF.

OSC

DR-01226

VREF

OSC1 OSC2

ABSOLUTE MAXIMUM RATINGS*

Parameter	Symbol	Min	Max	Unit
Supply Voltage	V_{DD} -V_{SS}	-0.3	6.0	V
Current on any pin	I_{PIN}	-150	+150	mA
Storage Temperature	T_{STG}	-40	+125	°C
Operating Temperature	T_{O}	-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.

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ELECTRICAL CHARACTERISTICS

(V_{DD} = 2.5V, V_{SS} = -2.5V, over the temperature range -10°C to +70°C[#], unless otherwise specified.)

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Operating temp. range	T_O	-25		+85	°C	
Supply Voltage: Positive	V_{DD}	2.25		2.75	V	
Supply Voltage: Negative	V_{SS}	-2.75		-2.25	V	
Supply Current: Positive	I_{DD}		5	6	mA	
Supply Current: Negative	I_{SS}		5	6	mA	
Current Sensor Inputs (Differential)						
Input Current Range	I_{II}	-25		+25	µA	Peak value
Voltage Sensor Input (Asymetrical)						
Input Current Range	I_{IV}	-25		+25	µA	Peak value

Pin DO
    Low Voltage
    High Voltage
	V_{OL}
	V_{OH}
		
		V_{DD}-1
				V_{SS}+1
				
					V
					V
						I_{OL} = 5mA
						I_{OH} = -2mA

Pin DI
    High Voltage
    Low Voltage
	V_{IH}
	V_{IL}
		V_{DD}-1
		
				V_{SS}+1
					V
					V	

Pin SCK
    High Voltage
    Low Voltage
	V_{IH}
	V_{IL}
		V_{DD}-1
		
				V_{SS}+1
					V
					V	

	f_{SCK} t_{LO} t_{HI}	 0.6 0.6		800 	kHz µs µs	

Pin CS
    High Voltage
    Low Voltage
	V_{IH}
	V_{IL}
		V_{DD}-1
		
				V_{SS}+1
					V
					V	

Pin FMO
    Low Voltage
    High Voltage
	V_{OL}
	V_{OH}
		
		V_{DD}-1
				V_{SS}+1
				
					V
					V
						I_{OL} = 5mA
						I_{OH} = -2mA

Oscillator	Recommended crystal: TV colour burst crystal f = 3.5795 MHz					

Pin VREF
        Ref. Current
        Ref. Voltage
	
	$-I_R$
	V_R
		
		45
		1.1
			
			50
			
				55
				1.3
					
					µA
					V
						With R = 24kΩ
						connected to V_{SS}
						Reference to V_{SS}

[#] Extended Operating Temperature Range available on request.

PIN DESCRIPTION

Pin	Designation	Description
20	GND	Ground
8	V_{DD}	Positive Supply Voltage
14	V_{SS}	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
10	OSC2	(OSC1 = Input; OSC2 = Output)
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 V_{SS} for normal operation)
4	TP4	Manufacturer's Test Pin (leave unconnected)
5	TP5	
6	TP6	
9	TP9	
16	TP16	

FUNCTIONAL DESCRIPTION

The SA9603B is a CMOS mixed signal Analog/Digital Integrated Circuit, which performs the measuerement 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 accessable 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 µ-Controller to synchronise with internal timing for data aquisition. 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.

1. Power calculation

In the Application Circuit (Figure 1), the voltage drop across the shunt will be between 0 and $16mV_{RMS}$ (0 to 80A through a shunt resistor of 200µΩ). This voltage is converted to a current of between 0 and $16µA_{RMS}$, by means of resistors R_1 and R_2.

The current sense input saturates at an input current of ±25µA peak.

For the voltage sensor input, the mains voltage (230V AC) is divided down through a divider to 14V. The resulting current into the A/D Converter input is $14µA_{RMS}$ at nominal voltage, via resistor R4 (1MΩ).

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

2. Analog Input Configuration

The input circuitry of the current and voltage sensor inputs are illustrated below.

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.

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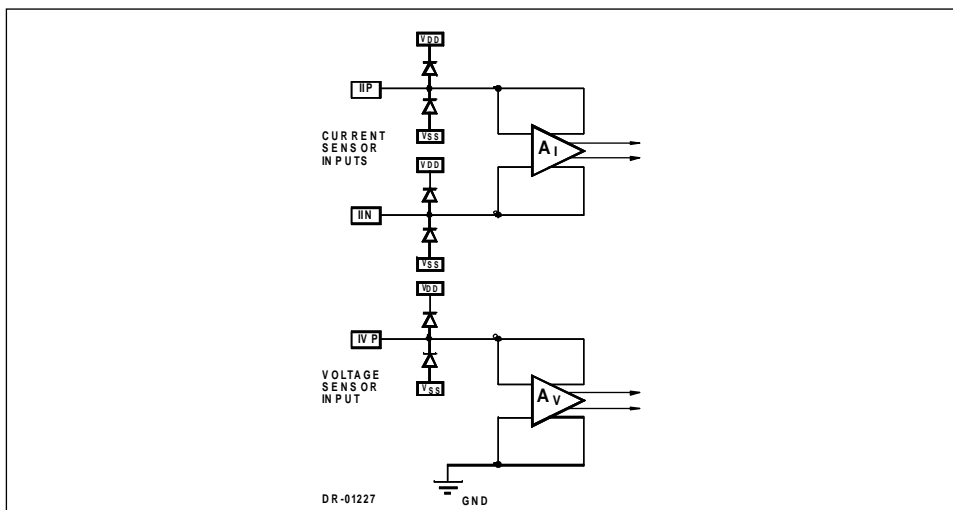
3. Electrostatic Discharge (ESD) Protection
The SA9603B Integrated Circuits inputs/outputs are protected against ESD.

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

5. SPI - INTERFACE

5.1 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.

5.2 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 subsequent registers will be output on the DO pin. Transfer will continue until CS is brough 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.

5.3 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.

5.4 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.
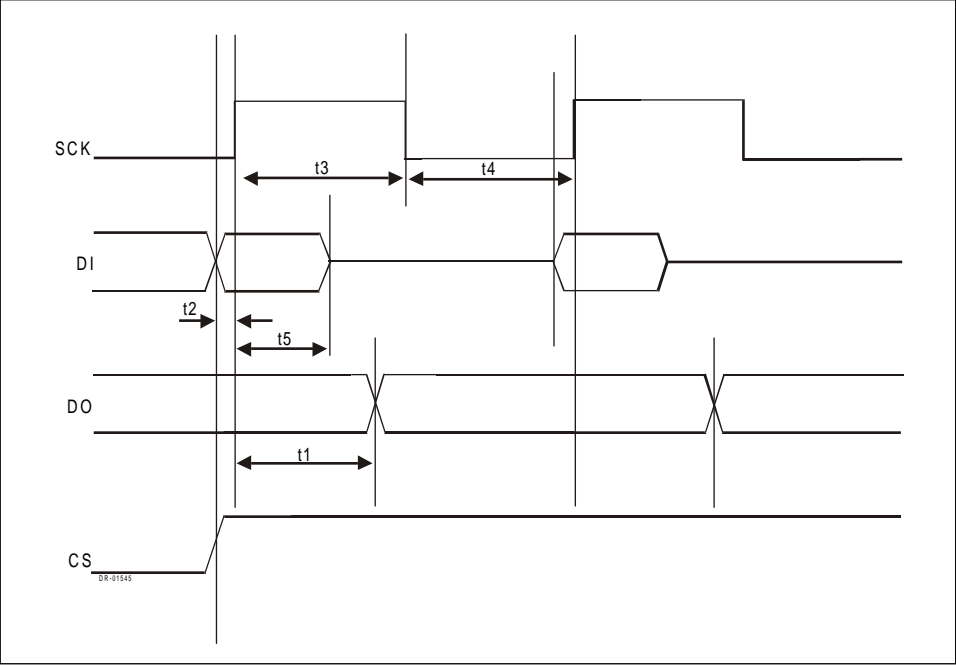
Bits D16, D20, D21, D22 and D23 are not used.

5.5 SPI Waveforms

The waveforms to perform a read cycle are shown below:

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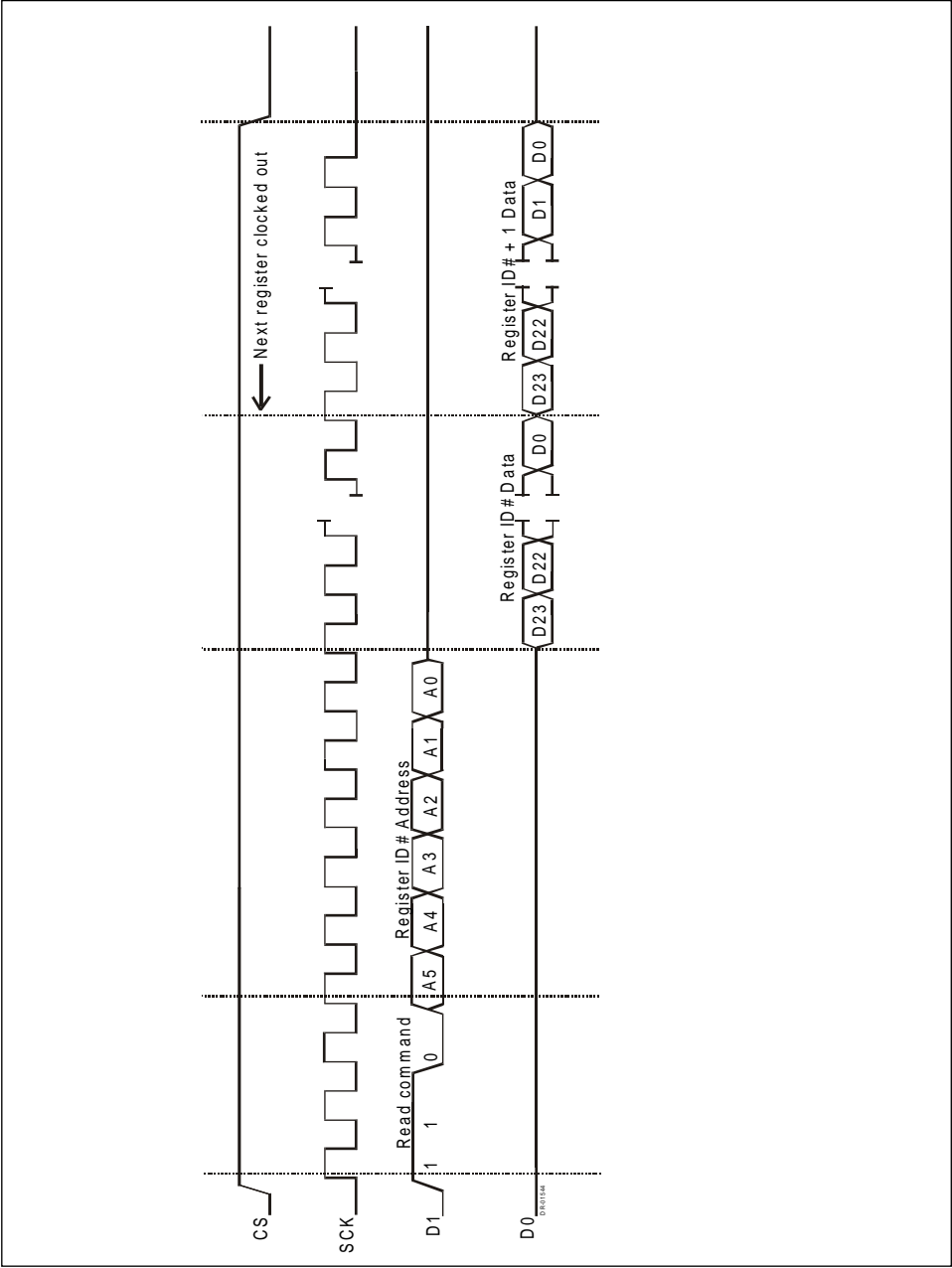
SPI TIMING

Parameter	Description	Min	Max
t1	SCK rising edge to DO valid	625µs	1,160µs
t3	SCK min high time	625µs	
t4	SCK min low time	625µs	
t2	Setup time for DI and CS before the rising edge of SCK	20µs	
t5	DI hold time	625µs	

5.6 Synchronised Reading of Registers

The SA9603B integrated circuit updates the registers on a continual basis. The SA9603B register content in 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 of 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: microcontroller) 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).

FM0 OUTPUT

Voltage

FM0

+5V
0V (Vss)

Any sequence of 8 pulse's is equal to 1 measurement cycle

D-0-1498
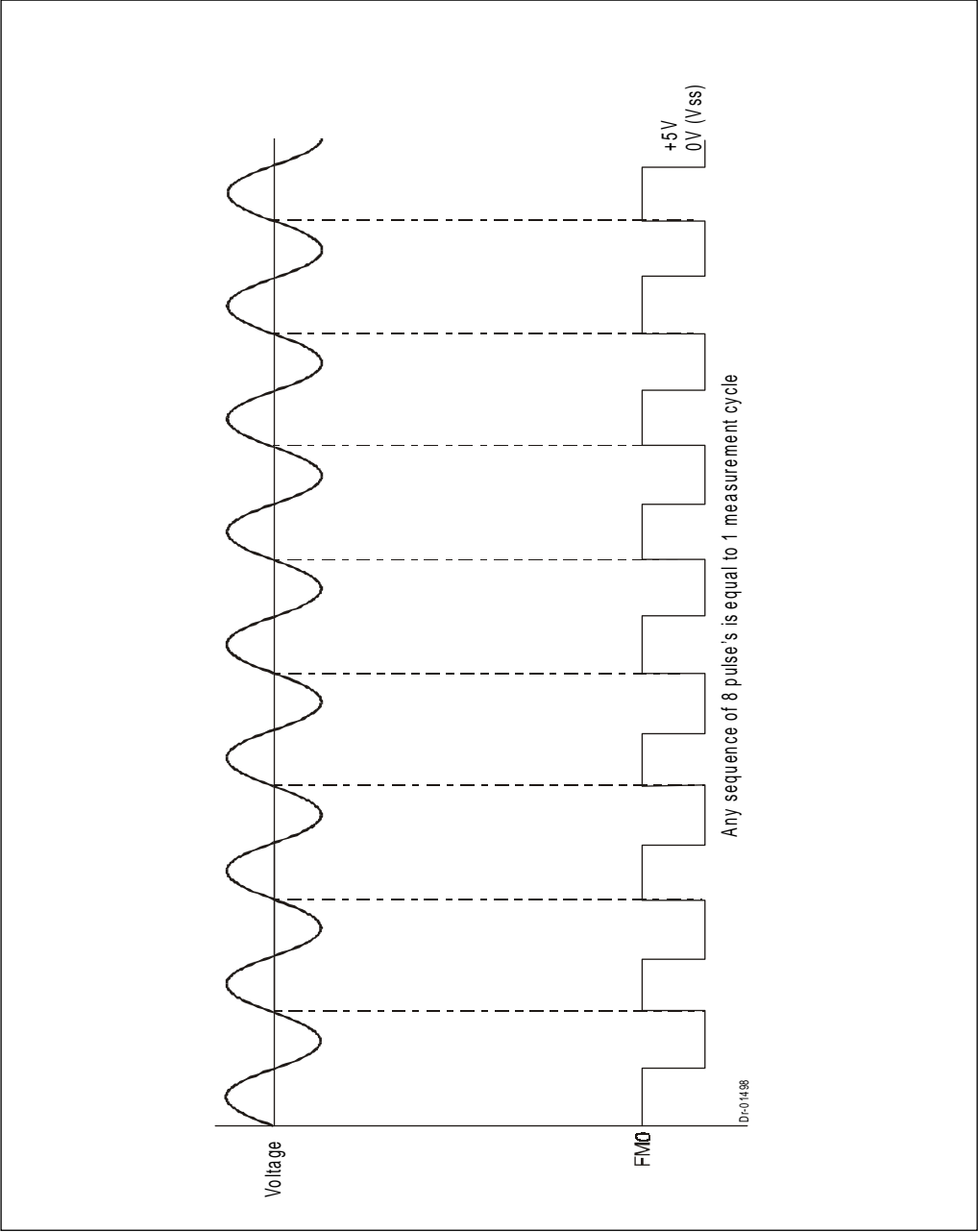
6.   Register Values

The 24 bit registers are up/down counters, which increment or decrement at a rate of 640k/s (640k*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:
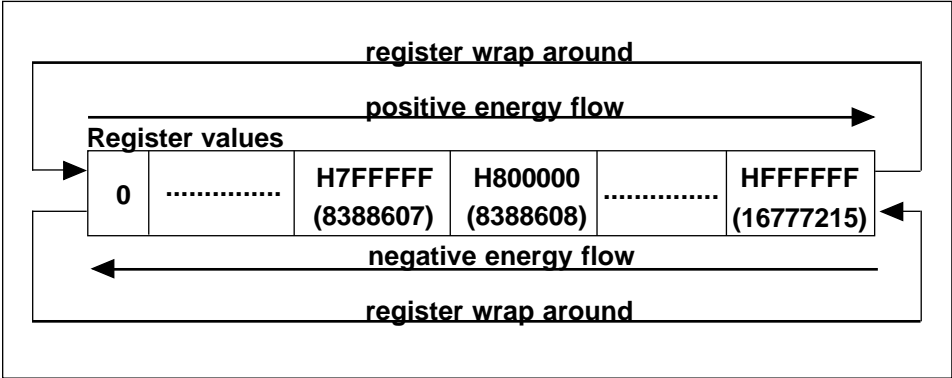
At power-up the register values are underfined and for this reason the msb of the **delta value** (delta value = present register value - previous register value) should be regarded as an indication of the measured energy direction. (0 = positive, 1 = negative).

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 16777215 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:

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

$$\text{Where} \quad V \quad = \text{Rated Voltage}$$
$$I \quad = \text{Current } (I_{max})$$
$$K \quad = 640\,000 \quad \text{for Active Energy}$$
$$\dfrac{640\,000 * 2}{\pi} \quad \text{for Reactive Energy}$$

Example:

V = 230V

I = 80A

Active Power   =   230V x 80A x (n/t)/640000

Reactive Power =   230V x 80A (n/t)/(640000 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:

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

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:

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

7. CALIBRATION

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

7.1 Active energy

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

Active Measured = Active_Register_Value x Ka

7.2 Reactive Energy

With a pf close to 1 establish the phase error:

PhaseError = arctan (VARMeaured / ActiveMeasured)

For **each measurement** calculate the following:

VA   = $\sqrt{\text{ActiveMeasured}^2 + \text{VARmeasured}^2}$

PHIcalibrated =   arctan (VARmeasured / ActiveMeasured)

PHICorrected =   PHIcalibrated - PhaseError

VARtrue   =   VA * sin(PHICorrected)

TYPICAL APPLICATIONS

In the Application Circuits (Figures 1 and 2), the components required for power metering applications are shown.

In Figure 1 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 2, when using a current transformer for current sensing, a +5V, 0V DC supply is sufficient for the circuit.

The 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 element 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 16µA$_{RMS}$ into the SA9603B at rated line current.

Values for RSH of less than 200µΩ should be avoided.

$R_1 = R_2 = (I_L/16µA_{RMS}) * RSH/2$

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 14µA$_{RMS}$.

R_7 defines all on-chip bias and reference currents. With R_7 = 24kΩ, optimum conditions are set.

R_7 defines all on-chip bias and reference currents. With R_7 = 24kΩ, optimum conditions are set. R_7 may be varied by up to ± 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.

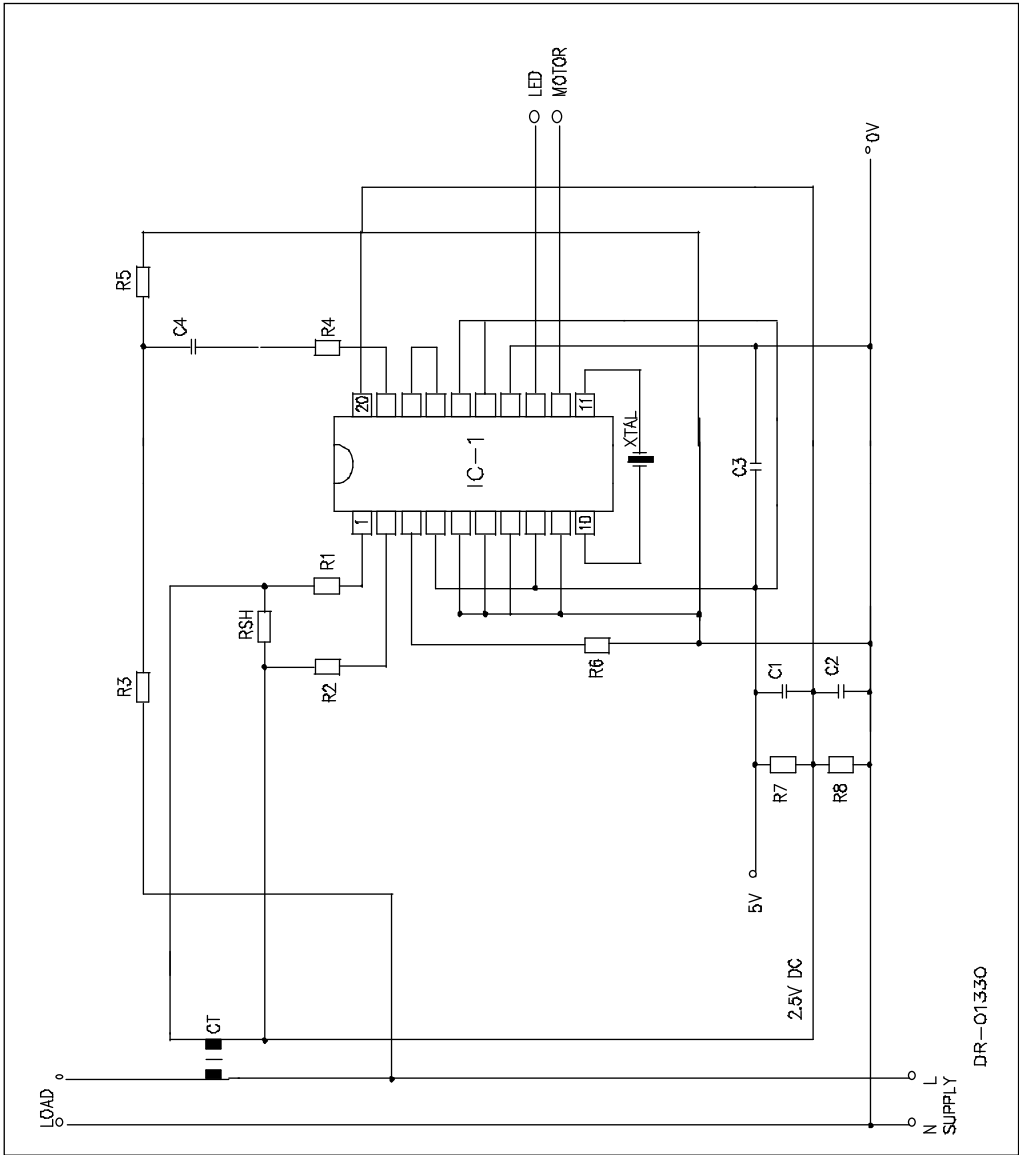**Figure 1: Application Circuit using a Shunt Resistor for Current Sensing**
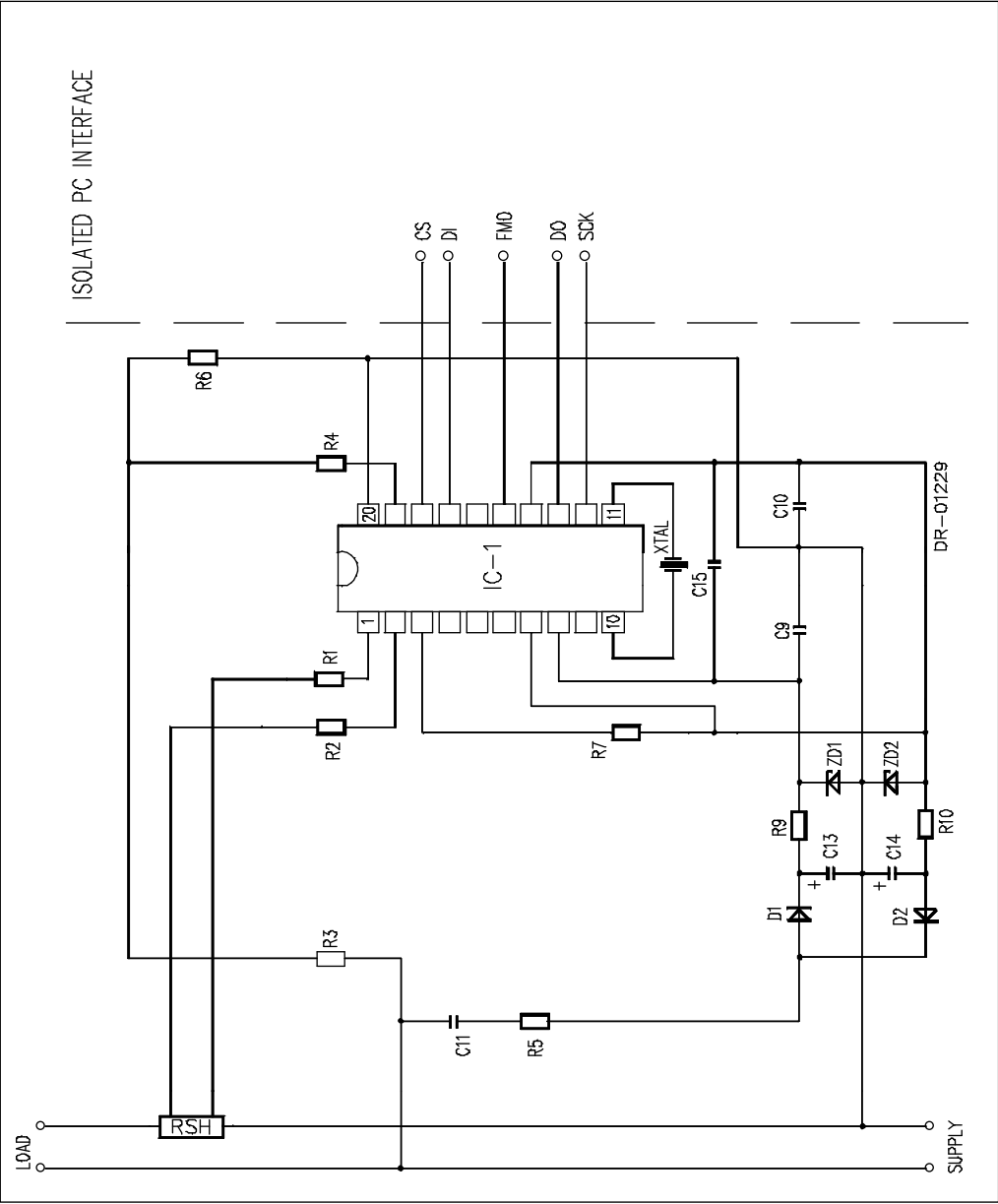
Part List for Application Circuit: Figure 1

Item	Symbol	Description	Detail
1	IC-1	SA9603B	20 pin DIP/SOIC
2	D1	Diode, Silicon, 1N4148	
3	D2	Diode, Silicon, 1N4148	
4	ZD1	Diode, Zener, 2.4V, 200mW	
5	ZD2	Diode, Zener, 2,4V, 200mW	
6	XTAL	Crystal, 3,5795MHz	Colour burst TV
7	R1	Resistor, 1% metal	Note 1
8	R2	Resistor, 1% metal	Note 1
9	R3	Resistor, 390k, (230VAC), 1% metal	
10	R4	Resistor, 1M, 1/8W, 1% metal	
11	R5	Resitor, 470Ω, 2W, 5%, carbon	
12	R6	Resistor, 24k, 1/8W, 1%, metal	
13	R7	Resistor, 24k, 1/8W, 1%, metal	
14	R9	Resistor, 680Ω, 1/8W, 5%	
15	R10	Resistor, 680Ω, 1/8W, 5%	
16	C9	Capacitor, 0.47µF	
17	C10	Capacitor 0.1µF	
18	C11	Capacitor, 0.47µF, 250VAC, polyester	
19	C13	Capacitor, 100µF	
20	C14	Capacitor, 100µF	
21	RSH	Shunt Resistor	Note 2

Note 1: Resistor (R1 and R2) values are dependant upon the selected value of RSH.

Note 2: See TYPICAL APPLICATIONS when selecting the value for RSH.

Figure 2: Application Circuit using a Current Transformer for Current Sensing.

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Parts List for Application Circuit: Figure 2

Item	Symbol	Description	Detail
1	IC-1	SA9603B	20 pin DIP/SOIC
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, metal film	
8	R5	Resistor, 24k, 1/8W, metal film	
9	R6	Resistor, 24k, 1/8W, 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 APPLICATIONS when selecting the value of RSH.

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

Note 3:   Capacitors (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.

ORDERING INFORMATION

Part Number	Package
SA9603BPA	DIP-20
SA9603BSA	SOIC-20

Any sales or technical questions may be posted to our e-mail address below:
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For the latest updates on datasheets, please visit our web site:
http://www.sames.co.za

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