Three Phase Power / Energy IC with SPI Interface

SA9904A

FEATURES

- Bi-directional active and reactive power/energy measurement
- RMS Voltage and frequency measurement
- Individual Phase information
- SPI communication bus
- Meets the IEC 521/1036 Specification requirements for Class 1 AC Watt hour meters
- Meets the IEC 1268 Specification requirements for VAR hour meters
- Protected against ESD
- Total power consumption rating below 60mW
- Uses current transformers for current sensing
- Operates over a wide temperature range
- Precision voltage reference on-chip

DESCRIPTION

The SAMES SA9904A is a three phase bi-directional energy/power metering integrated circuit that performs measurement of active and reactive power, mains voltage and mains frequency.

The SA9904A is pin compatible to the SA9604A. New features include, RMS mains voltage and accurate reactive power measurements.

Measured values for active and reactive energy, the mains voltage and frequency for each phase are accessible through a SPI bus from 24 bit registers.

This innovative universal three 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 SA9904A 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.

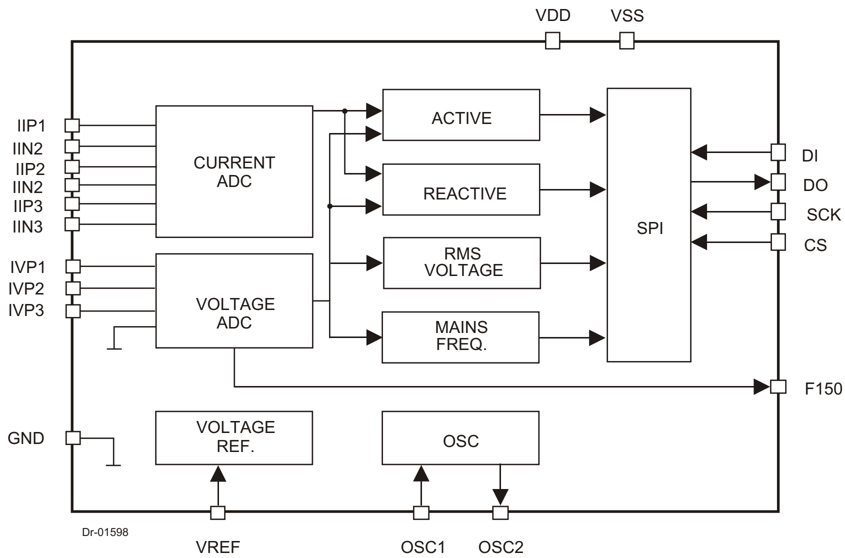


Figure 1: Block diagram

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}		9.5	11	mA	
Supply Current: Negative	I_{SS}		9.5	11	mA	
Current Sensor Inputs (Differential)						
Input Current Range	I_{II}	-25		+25	µA	Peak value
Voltage Sensor Input (Asymmetrical)						
Input Current Range	I_{IV}	-25		+25	µA	Peak value
Pins 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	
Pins CS, DI High Voltage Low Voltage	V_{IH} V_{IL}	V_{DD}-1		V_{SS}+1	V V	
Pins F150, DO 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	23 1.1	25	27 1.3	µA V	With R = 47k connected to V_{SS} Reference to V_{SS}

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.

PIN DESCRIPTION

PIN	Designation	Description
16	GND	Analog Ground. The supply voltage to this pin should be mid-way between V_{DD} and V_{SS}.
6	V_{DD}	Positive Supply voltage. The voltage to this pin is typically +2.5V if a shunt resistor is used for current sensing or in the case of a current transformer a +5V supply can be applied.
14	V_{SS}	Negative Supply Voltage. The voltage to this pin is typically -2.5V if a shunt resistor is used for current sensing or in the case of a current transformer a 0V supply can be applied.
17, 20, 3	IVP1, IVP2, IVP3	Analog Input for Voltage Phase 1, Phase 2 and Phase 3. The current into the A/D converter should be set at 14µA_{RMS} at nominal mains voltage. The voltage sense input saturates at an input current of ±25µA peak.
18, 19, 1, 2, 4, 5	IIP1, IIN1, IIP2, IIN2, IIP3, IIN3	Inputs for current sensors. The shunt resistor voltage from each channel is converted to a current of 16µA_{RMS} at rated conditions. The current sense input saturates at an input current of ±25µA peak.
15	VREF	This pin provides the connection for the reference current setting resistor. A 47k resistor connected to sets the optimum operating condition.
10, 11	OSC1, OSC2	Connections for a crystal or ceramic resonator. (OSC1 = input; OSC2 = Output)
8	SCK	Serial clock in. This pin is used to strobe data in and out of the SA9904A
9	DO	Serial data out. Data from the SA9904A is strobed out on this pin. DO is only driven when CS is active.
7	F150	Voltage zero crossover. The F150 output generates a 1ms pulse, on every rising edge of the mains voltage for each phase.
12	DI	Serial data in. Data is only accepted during an active chip select (CS).
13	CS	Chip select. The CS pin is active high.

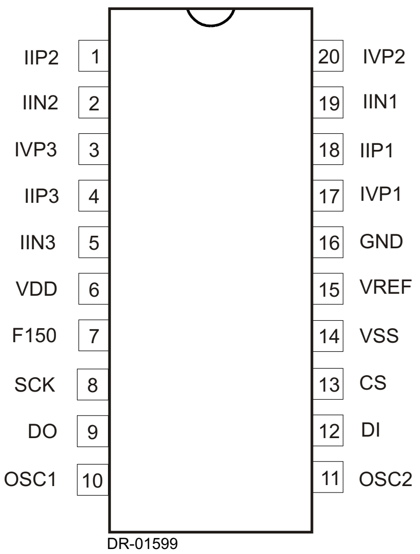


Figure 2: Pin connections: Package: DIP-20, SOIC-20

ORDERING INFORMATION

Part Number	Package
SA9904APA	DIP-20
SA9904ASA	SOIC-20

FUNCTIONAL DESCRIPTION

The SA9904A is a CMOS mixed signal Analog/Digital integrated circuit, which performs the measurement of active power, reactive power, RMS voltage and mains frequency. The integrated circuit includes all the required functions for three-phase power and energy measurement such as oversampling A/D converters for the voltage and current sense inputs, power calculation and energy integration.

The SA9904A integrates instantaneous active and reactive power into 24 bit integrators. RMS voltage and frequency are continuously measured and stored in the respective registers. The mains voltage zero crossover is available on the F150 output.

The SPI interface of the SA9904A has a tri-state output that allows connection of more than one metering device on a single SPI bus.

INPUT SIGNALS

Analog Input Configuration

The input circuitry of the current and voltage sensor inputs is 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 duplications of the input currents are generated for the analog signal processing circuitry. The current and voltage sense inputs are identical. Both inputs are differential current driven up to ±25µA peak. One of the voltage sense amplifier input terminals is internally connected to GND. This is possible because the voltage sense input is much less sensitive to externally induced parasitic signals compared to the current sense inputs.

Current Sense Inputs (IIN1, IIP1, IIN2, IIP2, IIN3, IIP3)

At rated current the resistor values should be selected for input currents of $16µA_{RMS}$. Referring to figure 8, the resistors R1 and R2 on current channel 1, resistors R3 and R4 on current channel 2 and resistors R5 and R6 on current channel 3, define the current level into the current sense inputs of the SA9904A. The current sense inputs saturates at an input current of ±25µA peak. Resistors R25, R26 and R27 are the current transformer termination resistors. The voltage drop across the termination resistors should be at least 16mV at rated conditions. Values for the current sense inputs are calculated as follows:

$R_1 = R_2 = (I_L / 16µA_{RMS}) \times RSH / 2$
$R_3 = R_4 = (I_L / 16µA_{RMS}) \times RSH / 2$
$R_5 = R_6 = (I_L / 16µA_{RMS}) \times RSH / 2$

Where:
I_L = Line current/CT-ratio

RSH = Shunt resistor or termination resistor (R25, R26, R27).

In case a current transformer is used for current sensing the value of RSH should be less than the resistance of the CT's secondary winding.

Voltage Sense Input (IVP1, IVP2, IVP3)

The current into the voltage sense inputs (virtual ground) should be set to $14µA_{RMS}$ at rated voltage conditions. The individual mains voltages are divided down to $14V_{RMS}$ per phase. The resistor R8, R9 and R10 set the current for the voltage sense inputs. The voltage sense inputs saturate at an input current of ±25µA peak.

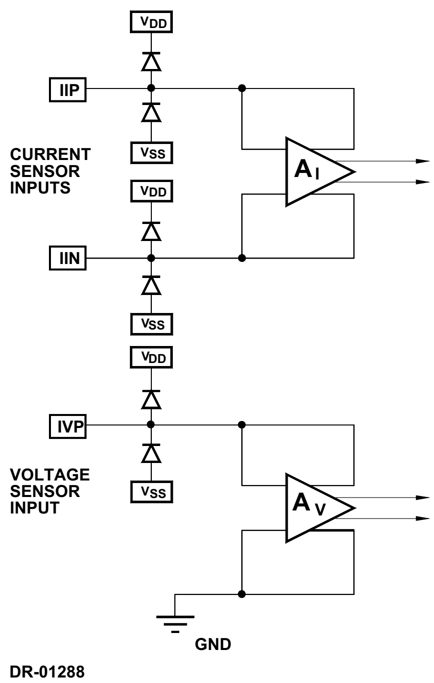


Figure 3: Analog input internal configuration

Reference Voltage (VREF)

The VREF pin is the reference for the bias resistor. With a bias resistor of 47k optimum conditions are set.

Serial Clock (SCK)

The SCK pin is used to synchronize data interchange between the micro controller and the SA9904A. The clock signal on this pin is generated by the micro controller and determines the data transfer rate of the DO and DI pins.

Serial Data In (DI)

The DI pin is the serial data input pin for the SA9904A. Data will be input at a rate determined by the Serial Clock (SCK). Data will be accepted only during an active chip select (CS).

Chip Select (CS)

The CS input is used to address the SA9904A. An active high on this pin enables the SA9904A to initiate data exchange.

OUTPUT SIGNALS

SERIAL DATA OUT (DO)

The DO pin is the serial data output pin for the SA9904A. The Serial Clock (SCK) determines the data output rate. Data is only transferred during on active chip select (CS). This output is tri-state when CS is low.

MAINS VOLTAGE SENSE ZERO CROSSOVER (F150)

The F150 output generates a signal, which follows the mains voltage zero crossings, see figure 4. The micro controller may use the F150 to extract mains timing.

ELECTROSTATIC DISCHARGE (ESD) PROTECTION

The SA9904A Integrated Circuit's inputs/outputs are protected against ESD.

POWER CONSUMPTION

The power consumption rating of the SA9904A integrated circuit is less than 60mW.

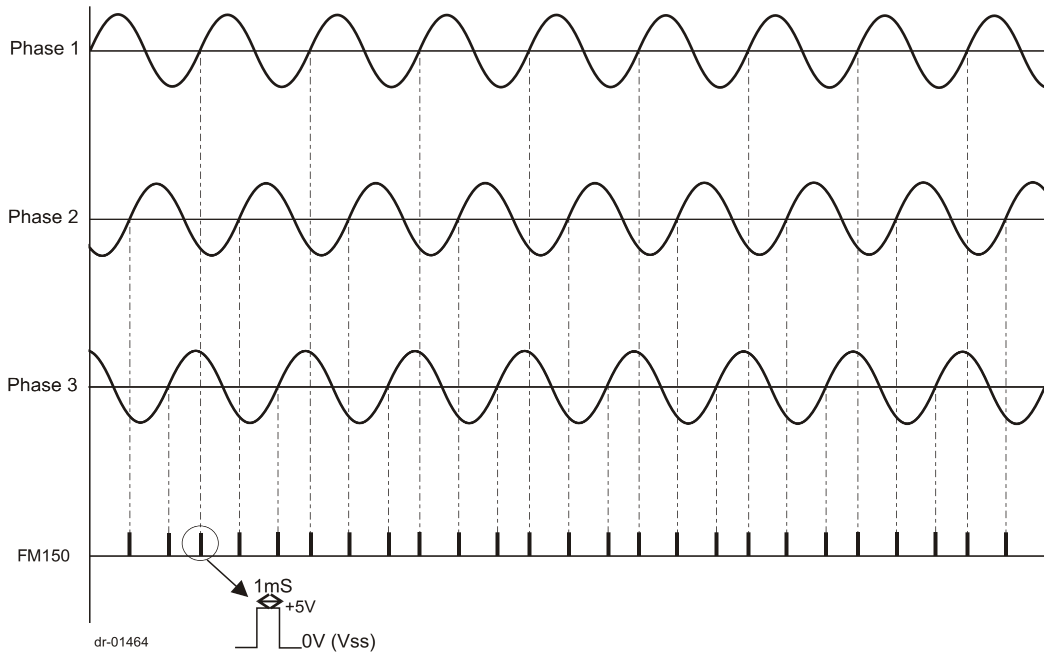


Figure 4: Mains voltage zero crossover pin FMO

SPI - INTERFACE

DESCRIPTION

A serial peripheral interface bus (SPI) is a synchronous bus used for data transfers between a micro controller and the SA9904A. The pins DO (Serial Data Out), DI (Serial Data In), CS (Chip Select), and SCK (Serial Clock) are used in the bus implementation. The SA9904A is the slave device with the micro controller being bus master. The CS input initiates and terminates data transfers. A SCK signal (generated by the micro controller) strobes data between the micro-controller and the SCK pin of the SA9904A device. The DI and DO pins are the serial data input and output pins for the SA9904A, respectively.

REGISTER ACCESS

The SA9904A contains four 24 bit registers for each phase. The content represents active energy, reactive energy, mains voltage and mains frequency. The register addresses are shown in the following table:

ID	Register	Header bits			A5	A4	A3	A2	A1	A0
1	Active Phase 1	1	1	0	X	X	0	0	0	0
2	Reactive Phase 1	1	1	0	X	X	0	0	0	1
3	Voltage Phase 1	1	1	0	X	X	0	0	1	0
4	Frequency Phase 1	1	1	0	X	X	0	0	1	1
5	Active Phase 2	1	1	0	X	X	0	1	0	0
6	Reactive Phase 2	1	1	0	X	X	0	1	0	1
7	Voltage Phase 2	1	1	0	X	X	0	1	1	0
8	Frequency Phase 2	1	1	0	X	X	0	1	1	1
9	Active Phase 3	1	1	0	X	X	1	0	0	0
10	Reactive Phase 3	1	1	0	X	X	1	0	0	1
11	Voltage Phase 3	1	1	0	X	X	1	0	1	0
12	Frequency Phase 3	1	1	0	X	X	1	0	1	1

The sequence 110 (0x06) must precede the 6-bit address of the register being accessed. When CS is HIGH, data on pin DI is clocked into the SA9904A on the rising edge of SCK. Figure 5 shows the data clocked into DI comprising of 1 1 0 A5 A4 A3 A2 A1 A0.

Address locations A5 and A4 are included for compatibility with future developments.

Registers may be read individually and in any order. After a register has been read, the contents of the next register value will be shifted out on the DO pin with every SCK clock cycle. Data output on DO will continue until CS is inactive.

The 9 bits needed for register addressing can be padded with leading zeros when the micro-controller requires a 8 bit SPI word length. The following sequence is valid:

0000 0001 10A5A4 A3A2A1A0

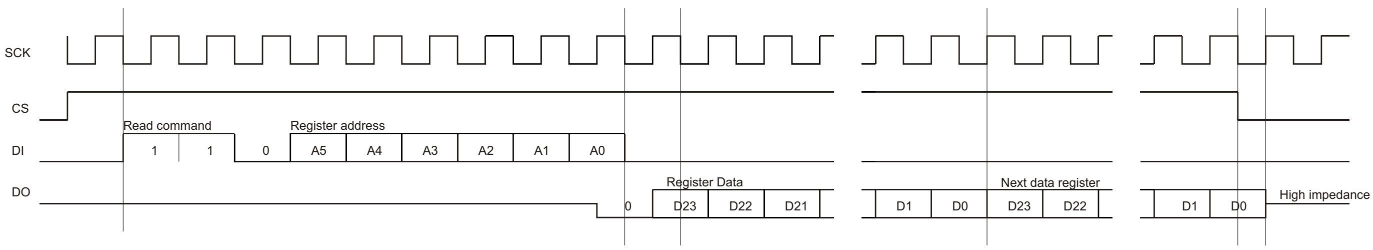
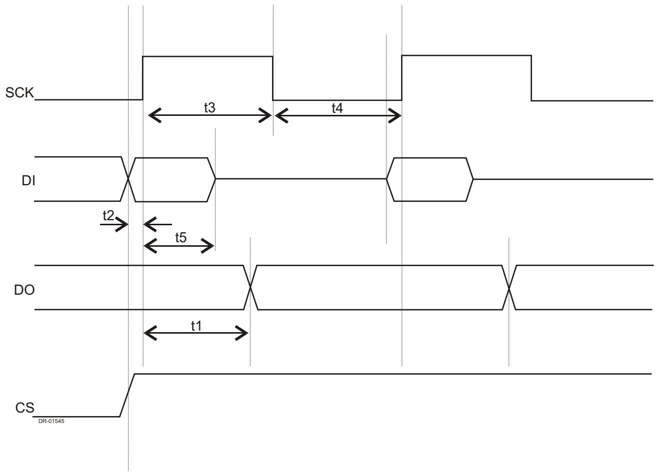


Figure 5: SPI waveforms

DATA FORMAT

Figure 5 shows the SPI waveforms. After the least significant digit of the address has been entered on the rising edge of SCK, the output DO goes low with the falling edge of SCK. Each subsequent falling edge transition on the SCK pin will validate the next data bit on the DO pin.

The content of each register consists of 24 bits of data. The MSB is shifted out first.



Parameter	Description	Min	Max
t1	SCK rising edge to DO valid	625ns	1.160µs
t3	SCK min high time	625ns	
t4	SCK min low time	625ns	
t2	Setup time for DI and CS before the rising edge of SCK	20ns	
t5	DI hold time	625ns	

Figure 6: SPI Timing diagrams

ACTIVE AND REACTIVE REGISTER VALUES

The active and reactive registers are 24 bit up/down counters, that increment or decrement at a rate of 320k samples per second at rated conditions. The register values will increment for positive energy flow and decrement for negative energy flow as indicated in figure 7. The active and reactive 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. The data read from the registers represents the active or reactive power integrated over time. The increase or decrease between readings represent the measured energy consumption.

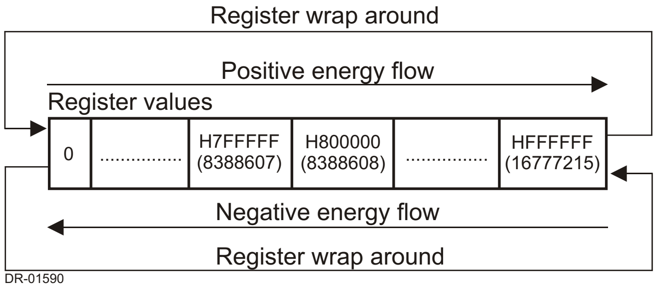


Figure 7: Register increment / decrement showing the register wrap around

At rated conditions, the active and reactive registers will wrap around every 26 seconds. The micro controller program needs to take this condition into account when calculating the difference between register values.

As an example lets assume that with a constant load connected, the delta value (delta value = present register - previous register 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:

Description	Valiable	Decimal	Hex
Present register value	new_val	16767215	0x00FFD8EF
Previous register value	old_val	16744955	0x00FF81FB
new_val - old_val =	delta_val	22260	0x000056F4
The register now wraps around so after the next read the values are as follows:			
Present register value	new_val	12259	0x00002FE4
Previous register value	old_val	16767215	0x00FFD8EF
new_val - old_val =	delta_val	-16754955	0x00FFA90B

Computing this delta value will result in incorrect calculations.

USING THE REGISTER VALUES

ACTIVE AND REACTIVE ENERGY REGISTER

The active and reactive energy measured per count can be calculated by applying the following formulae:

Energy per count = $(V_{RATED} \times I_{RATED}) / 320000$

The active and reactive power measured by the SA9904A is calculated as follows:

Power = $(V_{RATED} \times I_{RATED} \times N / INT_{TIME} / 320000$
(In watt seconds or var seconds)

Where:
V_{RATED} Rated mains voltage of meter
I_{RATED} Rated mains current of meter
N Difference in register values between successive reads (delta value)
INT_{TIME} Time difference between successive register reads (in seconds)

MAINS VOLTAGE REGISTER

The RMS voltage measurement is accurate to 1% in a range of 50% to 115% of rated mains voltage. The RMS mains voltage measured by the SA9904A is calculated as follows:

Voltage = $V_{RATED} \times V_{REGISTER\ VALUE} / 700$
V_{RATED} Rated mains voltage of meter
$V_{REGISTER\ VALUE}$ Voltage register value

MAINS FREQUENCY REGISTER

Bits D0 to D9 represents a counter value that is scaleable to the mains frequency measured.

The mains frequency measured by the SA9904A is calculated as follows:

Frequency = $F_{CRYSTAL} / 256 / F_{REGISTER\ VALUE}$
$F_{CRYSTAL}$ The external crystal frequency.
$F_{REGISTER\ VALUE}$ Bits D9 to D0 of the frequency register.

Bits D10 to D20 are not used in the frequency register.

The phase error status may be ascertained from bits D21 and D22, as shown in the following table:

Frequency data Bits D22	D21	Description
0	0	No phase error
1	0	Phase sequence error (2 phases swapped)
X	1	Missing phase

The phase error status is merged on all three frequency registers.

Bit D23 is set with a rising edge of the mains voltage and cleared after 2ms.

TYPICAL APPLICATION

In figure 8, the components required for the three phase power/energy metering section of a meter, is shown. The application uses current transformers for current sensing. The 4-wire meter section is capable of measuring 3x230V/80A with precision better than Class 1.

The most important external components for the SA9904A integrated circuit are the current sense resistors, the voltage sense resistors as well as the bias setting resistor.

BIAS RESISTOR

R7 defines all on-chip and reference currents. With R7=47k , optimum conditions are set.

CT TERMINATION RESISTOR

The voltage drop across the CT termination resistor at rated current should be at least 16mV. The CT's used have low phase shift and a ratio of 1:2500.The CT is terminated with a 2.7 resistor giving a voltage drop across the termination resistor 86.4mV at rated conditions (Imax for the meter).

CURRENT SENSE RESISTORS

The resistors R1 and R2 define the current level into the current sense inputs of phase one of the device. The resistor values are selected for an input current of 16µA on the current inputs at rated conditions.

According to equation described in the Current Sense inputs section:

R1 = R2 = $(I_L$ / 16µA) x R_{SH} / 2
= 80A /2500 / 16µA x 2.7 / 2
= 2.7k

I_L = Line current / CT Ratio

The three current channels are identical so R1 = R2 = R3 = R4 = R5 = R6.

VOLTAGE DIVIDER

The voltage divider is calculated for a voltage drop of 14V. Equations for the voltage divider in figure 5 are:

RA = R16 + R19 + R22
RB = R8 || R13)
Combining the two equations gives:

(RA + RB) / 230V = RB / 14V

A 24k resistor is chosen for R13 and a 1M resistor is used for R8.

Substituting the values result in:
RB = 23.44k
RA = RB x (230V / 14V - 1)
RA = 361.6k.

Resistor values of R16, R19 and R22 is chosen to be 120k each.

The three voltage channels are identical so R14= R15= R16 = R17 = R18 = R19 and R20 = R21= R22.

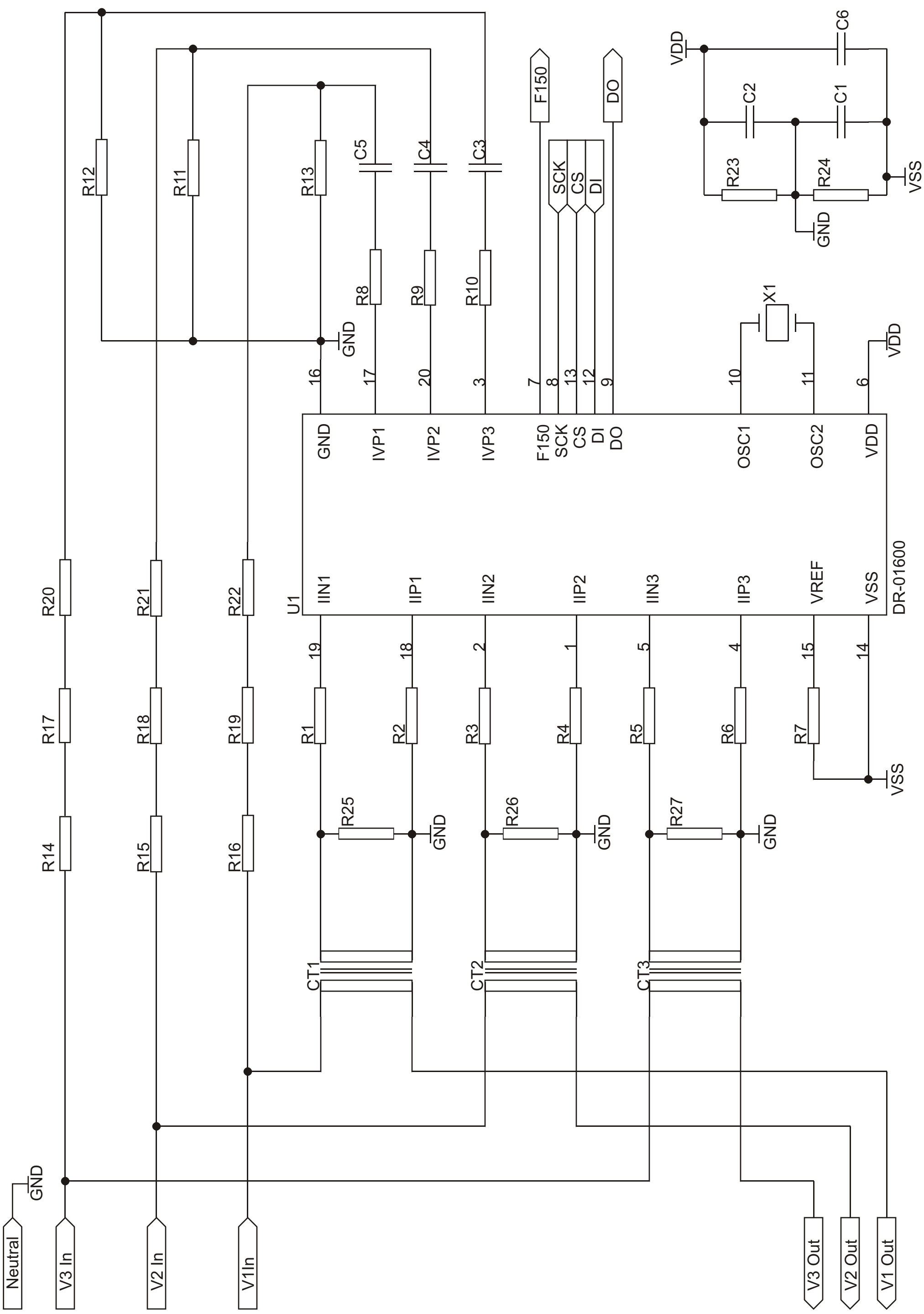


Figure 8: Typical application circuit

Parts List for Application Circuit: Figure 8

Symbol	Description	Detail
U1	SA9904A	DIP-20/SOIC-20
R1	Resistor, 2.7k, 1/4W, 1% metal	Note 1
R2	Resistor, 2.7k, 1/4W, 1% metal	Note 1
R3	Resistor, 2.7k, 1/4W, 1% metal	Note 1
R4	Resistor, 2.7k, 1/4W, 1% metal	Note 1
R5	Resistor, 2.7k, 1/4W, 1% metal	Note 1
R6	Resistor, 2.7k, 1/4W, 1% metal	Note 1
R7	Resistor, 47k, 1/4W, 1%, metal	
R8	Resistor, 1M, 1/4W, 1%, metal	
R9	Resistor, 1M, 1/4W, 1%, metal	
R10	Resistor, 1M, 1/4W, 1%, metal	
R11	Resistor, 24k, 1/4W, 1%, metal	
R12	Resistor, 24k, 1/4W, 1%, metal	
R13	Resistor, 24k, 1/4W, 1%, metal	
R14	Resistor, 120k, 1/4W, 1%, metal	
R15	Resistor, 120k, 1/4W, 1%, metal	
R16	Resistor, 120k, 1/4W, 1%, metal	
R17	Resistor, 120k, 1/4W, 1%, metal	
R18	Resistor, 120k, 1/4W, 1%, metal	
R19	Resistor, 120k, 1/4W, 1%, metal	
R20	Resistor, 120k, 1/4W, 1%, metal	
R21	Resistor, 120k, 1/4W, 1%, metal	
R22	Resistor, 120k, 1/4W, 1%, metal	
R23	Resistor, 1k, 1/4W, 1%, metal	
R24	Resistor, 1k, 1/4W, 1%, metal	
R25	Resistor, 2.7R, 1/4W, 1%, metal	Note 1
R26	Resistor, 2.7R, 1/4W, 1%, metal	Note 1
R27	Resistor, 2.7R, 1/4W, 1%, metal	Note 1
C1	Capacitor, 220nF	
C2	Capacitor, 220nF	
C3	Capacitor, 820nF	Note 2
C4	Capacitor, 820nF	Note 2
C5	Capacitor, 820nF	Note 2
C6	Capacitor, 820nF	Note 3
CT1	Current Transformer, TZ76	
CT2	Current Transformer, TZ76	
CT3	Current Transformer, TZ76	

Note 1: Resistor (R1 to R6) values are dependant on the selection of the termination resistors (R25 to R27) and CT combination.
Note 2: Capacitor values may be selected to compensate for phase errors caused by the current transformers.
Note 3: Capacitor C6 to be positioned as close as possible to supply pins V_{DD} and V_{SS} of U1 as possible.

DISCLAIMER:

Any sales or technical questions may be posted to our e-mail address below:
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