CS5463

Single Phase, Bi-directional Power/Energy IC

Features

- Energy Data Linearity: ±0.1% of Reading over 1000:1 Dynamic Range
- On-chip Functions:
  - Instantaneous Voltage, Current, and Power
  - I_{RMS} and V_{RMS}, Apparent, Reactive, and Active (Real) Power
  - Active Fundamental and Harmonic Power
  - Reactive Fundamental, Power Factor, and Line Frequency
  - Energy-to-pulse Conversion
  - System Calibrations and Phase Compensation
  - Temperature Sensor
- Meets accuracy spec for IEC, ANSI, JIS.
- Low Power Consumption
- Current Input Optimized for Sense Resistor.
- GND-referenced Signals with Single Supply
- On-chip 2.5 V Reference (25 ppm/°C typ)
- Power Supply Monitor
- Simple Three-wire Digital Serial Interface
- "Auto-boot" Mode from Serial E^2PROM
- Power Supply Configurations:
  VA+ = +5 V; AGND = 0 V; VD+ = +3.3 V to +5 V

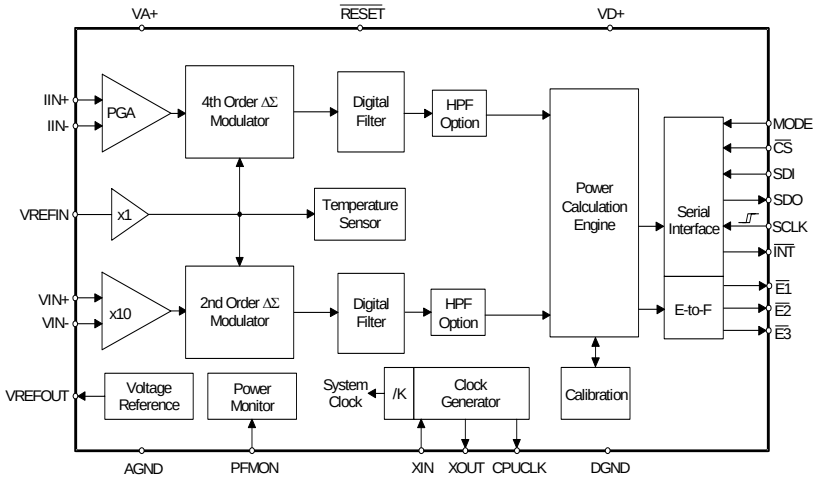
Description

The CS5463 is an integrated power measurement device which combines two ΔΣ analog-to-digital converters, power calculation engine, energy-to-frequency converter, and a serial interface on a single chip. It is designed to accurately measure instantaneous current and voltage, and calculate V_{RMS}, I_{RMS}, instantaneous power, apparent power, active power, and reactive power for single-phase, 2- or 3-wire power metering applications.

The CS5463 is optimized to interface to shunt resistors or current transformers for current measurement, and to resistive dividers or potential transformers for voltage measurement.

The CS5463 features a bi-directional serial interface for communication with a processor and a programmable energy-to-pulse output function. Additional features include on-chip functionality to facilitate system-level calibration, temperature sensor, voltage sag detection, and phase compensation.

ORDERING INFORMATION:
See Page 44.



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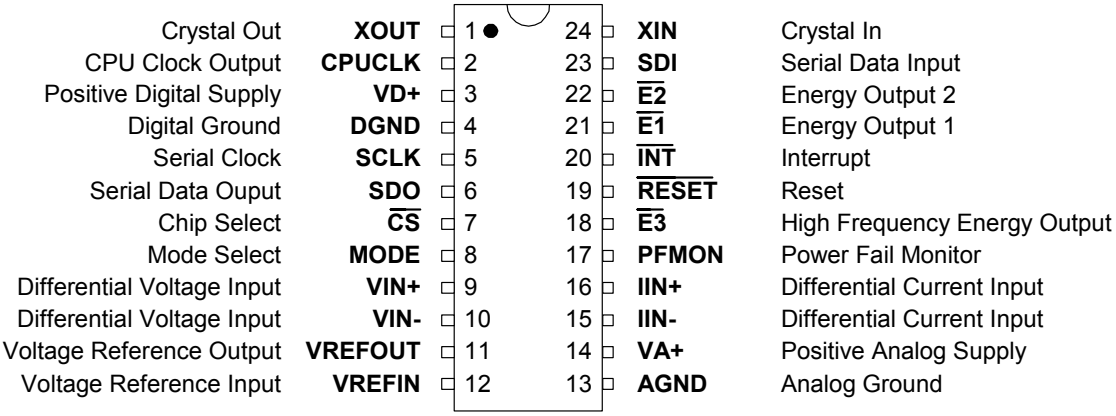
1. OVERVIEW

The CS5463 is a CMOS monolithic power measurement device with a computation engine and an energy-to-frequency pulse output. The CS5463 combines a programmable gain amplifier, two ΔΣ Analog-to-Digital Converters (ADCs), system calibration and a computation engine on a single chip.

The CS5463 is designed for power measurement applications and is optimized to interface to a current sense resistor or transformer for current measurement, and to a resistive divider or potential transformer for voltage measurement. The current channel provides programmable gains to accommodate various input levels from a multitude of sensing elements. With single +5 V supply on VA+/AGND, both of the CS5463's input channels can accommodate common mode plus signal levels between (AGND - 0.25 V) and VA+.

The CS5463 also is equipped with a computation engine that calculates instantaneous power, I_{RMS}, V_{RMS}, apparent power, active (real) power, reactive power, harmonic active power, active and reactive fundamental power, and power factor. The CS5463 additional features include line frequency, current and voltage sag detection, zero-cross detection, positive-only accumulation mode, and three programmable pulse output pins. To facilitate communication to a microprocessor, the CS5463 includes a simple three-wire serial interface which is SPI™ and Microwire™ compatible. The CS5463 provides three outputs for energy registration. $\overline{E1}$, $\overline{E2}$ and $\overline{E3}$ are designed to interface to a microprocessor.

2. PIN DESCRIPTION



Clock Generator		
Crystal Out **Crystal In**	1,24	**XOUT, XIN** - The output and input of an inverting amplifier. Oscillation occurs when connected to a crystal, providing an on-chip system clock. Alternatively, an external clock can be supplied to the XIN pin to provide the system clock for the device.
CPU Clock Output	2	**CPUCLK** - Output of on-chip oscillator which can drive one standard CMOS load.
Control Pins and Serial Data I/O		
Serial Clock Input	5	**SCLK** - A Schmitt-Trigger input pin. Clocks data from the SDI pin into the receive buffer and out of the transmit buffer onto the SDO pin when $\overline{CS}$ is low.
Serial Data Output	6	**SDO** -Serial port data output pin.SDO is forced into a high-impedance state when $\overline{CS}$ is high.
Chip Select	7	**$\overline{CS}$** - Low, activates the serial port interface.
Mode Select	8	**MODE** - High, enables the “auto-boot” mode. The mode pin has an internal pull-down resistor.
Energy Output	18,21,22	**$\overline{E3}$, $\overline{E1}$, $\overline{E2}$** - Active-low pulses with an output frequency proportional to the selected power. Configurable outputs for active, apparent, and reactive power, negative energy indication, zero cross detection, and power failure monitoring. $\overline{E1}$, $\overline{E2}$, $\overline{E3}$ outputs are configured in the Operational Modes Register.
Reset	19	**$\overline{RESET}$** - A Schmitt-Trigger input pin. Low activates Reset, all internal registers (some of which drive output pins) are set to their default states.
Interrupt	20	**$\overline{INT}$** - Low, indicates that an enabled event has occurred.
Serial Data Input	23	**SDI** - Serial port data input pin. Data will be input at a rate determined by SCLK.
Analog Inputs/Outputs		
Differential Voltage Inputs	9,10	**VIN+, VIN-** - Differential analog input pins for the voltage channel.
Differential Current Inputs	15,16	**IIN+, IIN-** - Differential analog input pins for the current channel.
Voltage Reference Output	11	**VREFOUT** - The on-chip voltage reference output. The voltage reference has a nominal magnitude of 2.5 V and is referenced to the AGND pin on the converter.
Voltage Reference Input	12	**VREFIN** - The input to this pin establishes the voltage reference for the on-chip modulator.
Power Supply Connections		
Positive Digital Supply	3	**VD+** - The positive digital supply.
Digital Ground	4	**DGND** - Digital Ground.
Positive Analog Supply	14	**VA+** - The positive analog supply.
Analog Ground	13	**AGND** - Analog ground.
Power Fail Monitor	17	**PFMON** - The power fail monitor pin monitors the analog supply. If the analog supply does not meet or falls below PFMON’s voltage threshold, a Low-supply Detect (LSD) event is set in the status register.

3. CHARACTERISTICS & SPECIFICATIONS

RECOMMENDED OPERATING CONDITIONS

Parameter	Symbol	Min	Typ	Max	Unit
Positive Digital Power Supply	VD+	3.135	5.0	5.25	V
Positive Analog Power Supply	VA+	4.75	5.0	5.25	V
Voltage Reference	VREFIN	-	2.5	-	V
Specified Temperature Range	T_A	-40	-	+85	°C

ANALOG CHARACTERISTICS

- Min / Max characteristics and specifications are guaranteed over all Operating Conditions.
- Typical characteristics and specifications are measured at nominal supply voltages and TA = 25 °C.
- VA+ = VD+ = 5 V ±5%; AGND = DGND = 0 V; VREFIN = +2.5 V. All voltages with respect to 0 V.
- MCLK = 4.096 MHz.

Parameter		Symbol	Min	Typ	Max	Unit
Accuracy						
Active Power (Note 1)	All Gain Ranges Input Range 0.1% - 100%	P_{Active}	 -	 ±0.1	 -	 %
Average Reactive Power (Note 1 and 2)	All Gain Ranges Input Range 0.1% - 100%	Q_{Avg}	 -	 ±0.2	 -	 %
Power Factor (Note 1 and 2)	All Gain Ranges Input Range 1.0% - 100% Input Range 0.1% - 1.0%	PF	 - -	 ±0.2 ±0.27	 - -	 % %
Current RMS (Note 1)	All Gain Ranges Input Range 1.0% - 100% Input Range 0.1% - 1.0%	I_{RMS}	 - -	 ±0.1 ±0.17	 - -	% % %
Voltage RMS (Note 1)	All Gain Ranges Input Range 5% - 100%	V_{RMS}	 -	 ±0.1	 -	 %
Analog Inputs (Both Channels)						
Common Mode Rejection	(DC, 50, 60 Hz)	CMRR	80	-	-	dB
Common Mode + Signal	All Gain Ranges		-0.25	-	VA+	V
Analog Inputs (Current Channel)						
Differential Input Range [(IIN+) - (IIN-)]	(Gain = 10) (Gain = 50)	IIN	- -	500 100	- -	mV_{P-P} mV_{P-P}
Total Harmonic Distortion	(Gain = 50)	THD	80	94	-	dB
Crosstalk with Voltage Channel at Full Scale	(50, 60 Hz)		-	-115	-	dB
Input Capacitance	(Gain = 10) (Gain = 50)	IC	- -	32 52	- -	pF pF
Effective Input Impedance		EII	30	-	-	kΩ
Noise (Referred to Input)	(Gain = 10) (Gain = 50)	N_I	- -	- -	22.5 4.5	μV_{rms} μV_{rms}
Offset Drift (Without the High Pass Filter)		OD	-	4.0	-	µV/°C
Gain Error	(Note 3)	GE	-	±0.4		%

Notes: 1. Applies when the HPF option is enabled.

2. Applies when the line frequency is equal to the product of the Output Word Rate (OWR) and the value of epsilon (ε).

ANALOG CHARACTERISTICS (Continued)

Parameter	Symbol	Min	Typ	Max	Unit
Analog Inputs (Voltage Channel)					
Differential Input Range [(VIN+) - (VIN-)]	VIN	-	500	-	mV_{P-P}
Total Harmonic Distortion	THD	65	75	-	dB
Crosstalk with Current Channel at Full Scale (50, 60 Hz)		-	-70	-	dB
Input Capacitance All Gain Ranges	IC	-	0.2	-	pF
Effective Input Impedance	EII	2	-	-	MΩ
Noise (Referred to Input)	N_V	-	-	140	μV_{rms}
Offset Drift (Without the High Pass Filter)	OD	-	16.0	-	µV/°C
Gain Error (Note 3)	GE	-	±3.0		%
Temperature Channel					
Temperature Accuracy	T	-	±5	-	°C
Power Supplies					
Power Supply Currents (Active State) I_{A+}	PSCA	-	1.3	-	mA
I_{D+} (VA+ = VD+ = 5 V)	PSCD	-	2.9	-	mA
I_{D+} (VA+ = 5 V, VD+ = 3.3 V)	PSCD	-	1.7	-	mA
Power Consumption Active State (VA+ = VD+ = 5 V)	PC	-	21	29	mW
(Note 4) Active State (VA+ = 5 V, VD+ = 3.3 V)		-	11.6	17.5	mW
Stand-by State		-	8	-	mW
Sleep State		-	10	-	µW
Power Supply Rejection Ratio (50, 60 Hz)			-	-	
(Note 5) Voltage Channel	PSRR	45	65	-	dB
Current Channel		70	75	-	dB
PFMON Low-voltage Trigger Threshold (Note 6)	PMLO	2.3	2.45	-	V
PFMON High-voltage Power-on Trip Point (Note 7)	PMHI	-	2.55	2.7	V

Notes:
3. Applies before system calibration.
4. All outputs unloaded. All inputs CMOS level.
5. Definition for PSRR: VREFIN tied to VREFOUT, VA+ = VD+ = 5 V, a 150 mV (zero-to-peak) (60 Hz) sinewave is imposed onto the +5 V DC supply voltage at VA+ and VD+ pins. The "+" and "-" input pins of both input channels are shorted to AGND. Then the CS5463 is commanded to continuous conversion acquisition mode, and digital output data is collected for the channel under test. The (zero-to-peak) value of the digital sinusoidal output signal is determined, and this value is converted into the (zero-to-peak) value of the sinusoidal voltage (measured in mV) that would need to be applied at the channel's inputs, in order to cause the same digital sinusoidal output. This voltage is then defined as Veq. PSRR is then (in dB):

$$PSRR = 20 \cdot \log\left[\frac{150}{V_{eq}}\right]$$

6. When voltage level on PFMON is sagging, and LSD bit is at 0, the voltage at which LSD bit is set to 1.
7. If the LSD bit has been set to 1 (because PFMON voltage fell below PMLO), this is the voltage level on PFMON at which the LSD bit can be permanently reset back to 0.

VOLTAGE REFERENCE

Parameter		Symbol	Min	Typ	Max	Unit
Reference Output						
Output Voltage		VREFOUT	+2.4	+2.5	+2.6	V
Temperature Coefficient	(Note 8)	TC_{VREF}	-	25	60	ppm/°C
Load Regulation	(Note 9)	ΔV_R	-	6	10	mV
Reference Input						
Input Voltage Range		VREFIN	+2.4	+2.5	+2.6	V
Input Capacitance			-	4	-	pF
Input CVF Current			-	25	-	nA

Notes: 8. The voltage at VREFOUT is measured across the temperature range. From these measurements the following formula is used to calculate the VREFOUT Temperature Coefficient:.

$$TC_{VREF} = \left(\frac{(VREFOUT_{MAX} - VREFOUT_{MIN})}{VREFOUT_{AVG}}\right)\left(\frac{1}{T_{A}MAX - T_{A}MIN}\right)\left(1.0 \times 10^{6}\right)$$

9. Specified at maximum recommended output of 1 µA, source or sink.

DIGITAL CHARACTERISTICS

- Min / Max characteristics and specifications are guaranteed over all Operating Conditions.
- Typical characteristics and specifications are measured at nominal supply voltages and TA = 25 °C.
- VA+ = VD+ = 5V ±5%; AGND = DGND = 0 V. All voltages with respect to 0 V.
- MCLK = 4.096 MHz.

Parameter		Symbol	Min	Typ	Max	Unit
Master Clock Characteristics						
Master Clock Frequency	Internal Gate Oscillator (Note 11)	MCLK	2.5	4.096	20	MHz
Master Clock Duty Cycle			40	-	60	%
CPUCLK Duty Cycle	(Note 12 and 13)		40	-	60	%
Filter Characteristics						
Phase Compensation Range	(Voltage Channel, 60 Hz)		-2.8	-	+2.8	°
Input Sampling Rate	DCLK = MCLK/K		-	DCLK/8	-	Hz
Digital Filter Output Word Rate	(Both Channels)	OWR	-	DCLK/1024	-	Hz
High-pass Filter Corner Frequency	-3 dB		-	0.5	-	Hz
Full-scale DC Calibration Range (Referred to Input)	(Note 14)	FSCR	25	-	100	%F.S.
Channel-to-channel Time-shift Error	(Note 15)			1.0		µs
Input/Output Characteristics						
High-level Input Voltage		V_{IH}				
All Pins Except XIN and SCLK and $\overline{\text{RESET}}$			0.6 VD+	-	-	V
XIN			(VD+) - 0.5	-	-	V
SCLK and $\overline{\text{RESET}}$			0.8 VD+	-	-	V
Low-level Input Voltage (VD = 5 V)		V_{IL}				
All Pins Except XIN and SCLK and $\overline{\text{RESET}}$			-	-	0.8	V
XIN			-	-	1.5	V
SCLK and $\overline{\text{RESET}}$			-	-	0.2 VD+	V

Parameter	Symbol	Min	Typ	Max	Unit
Low-level Input Voltage (VD = 3.3 V)	V_{IL}				
All Pins Except XIN and SCLK and $\overline{\text{RESET}}$		-	-	0.48	V
XIN		-	-	0.3	V
SCLK and $\overline{\text{RESET}}$		-	-	0.2 VD+	V
High-level Output Voltage I_{out} = +5 mA	V_{OH}	(VD+) - 1.0	-	-	V
Low-level Output Voltage I_{out} = -5 mA	V_{OL}	-	-	0.4	V
Input Leakage Current	I_{in}	-	±1	±10	µA
3-state Leakage Current	I_{OZ}	-	-	±10	µA
Digital Output Pin Capacitance	C_{out}	-	5	-	pF

Notes: 10. All measurements performed under static conditions.

11. If a crystal is used, then XIN frequency must remain between 2.5 MHz - 5.0 MHz. If an external oscillator is used, XIN frequency range is 2.5 MHz - 20 MHz, but K must be set so that MCLK is between 2.5 MHz - 5.0 MHz.
12. If external MCLK is used, then the duty cycle must be between 45% and 55% to maintain this specification.
13. The frequency of CPUCLK is equal to MCLK.
14. The minimum FSCR is limited by the maximum allowed gain register value. The maximum FSCR is limited by the full-scale signal applied to the channel input.
15. Configuration Register bits PC[6:0] are set to “0000000”.

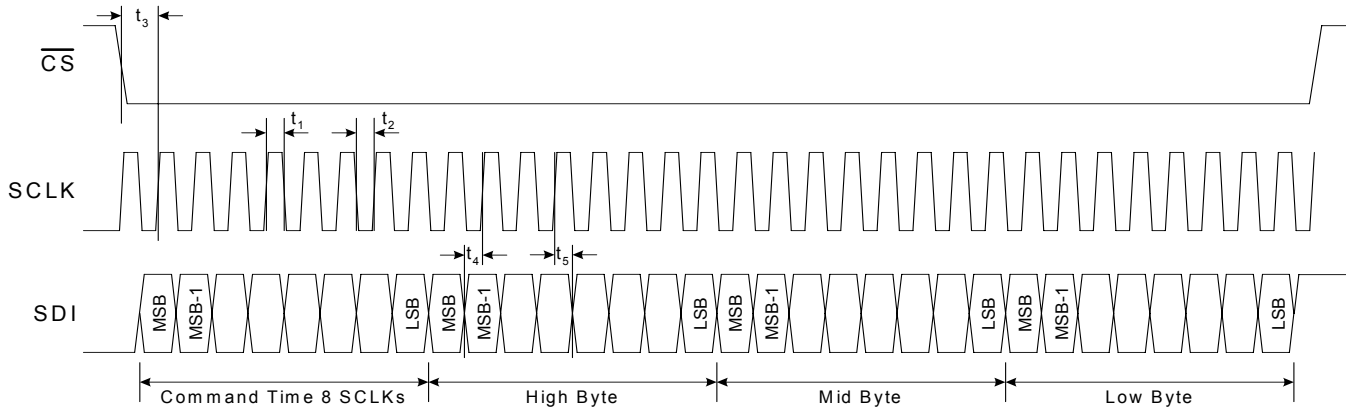
SWITCHING CHARACTERISTICS

- Min / Max characteristics and specifications are guaranteed over all Operating Conditions.
- Typical characteristics and specifications are measured at nominal supply voltages and TA = 25 °C.
- VA+ = 5 V ±5% VD+ = 3.3 V ±5% or 5 V ±5%; AGND = DGND = 0 V. All voltages with respect to 0 V.
- Logic Levels: Logic 0 = 0 V, Logic 1 = VD+.

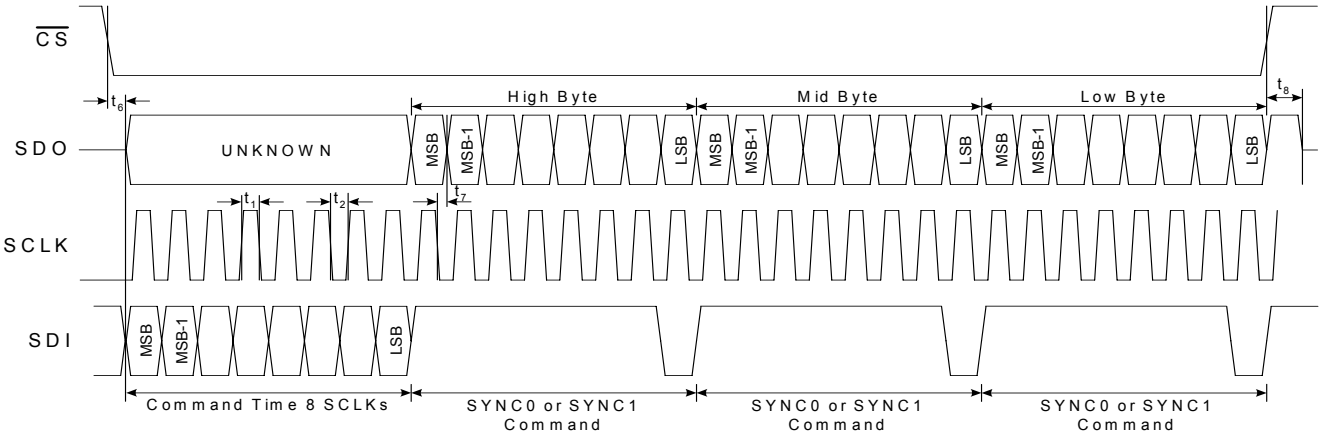
Parameter		Symbol	Min	Typ	Max	Unit
Rise Times	Any Digital Input Except SCLK	t_{rise}	-	-	1.0	µs
(Note 16)	SCLK		-	-	100	µs
	Any Digital Output		-	50	-	ns
Fall Times	Any Digital Input Except SCLK	t_{fall}	-	-	1.0	µs
(Note 16)	SCLK		-	-	100	µs
	Any Digital Output		-	50	-	ns
Start-up						
Oscillator Start-up Time	XTAL = 4.096 MHz (Note 17)	t_{ost}	-	60	-	ms
Serial Port Timing						
Serial Clock Frequency		SCLK	-	-	2	MHz
Serial Clock	Pulse Width High	t_1	200	-	-	ns
	Pulse Width Low	t_2	200	-	-	ns
SDI Timing						
$\overline{CS}$ Falling to SCLK Rising		t_3	50	-	-	ns
Data Set-up Time Prior to SCLK Rising		t_4	50	-	-	ns
Data Hold Time After SCLK Rising		t_5	100	-	-	ns
SDO Timing						
$\overline{CS}$ Falling to SDI Driving		t_6	-	20	50	ns
SCLK Falling to New Data Bit (hold time)		t_7	-	20	50	ns
$\overline{CS}$ Rising to SDO Hi-Z		t_8	-	20	50	ns
Auto-Boot Timing						
Serial Clock	Pulse Width Low	t_9		8		MCLK
	Pulse Width High	t_{10}		8		MCLK
MODE setup time to $\overline{RESET}$ Rising		t_{11}	50			ns
$\overline{RESET}$ rising to $\overline{CS}$ falling		t_{12}	48			MCLK
$\overline{CS}$ falling to SCLK rising		t_{13}	100	8		MCLK
SCLK falling to $\overline{CS}$ rising		t_{14}		16		MCLK
$\overline{CS}$ rising to driving MODE low (to end auto-boot sequence).		t_{15}	50			ns
SDO guaranteed setup time to SCLK rising		t_{16}	100			ns

Notes: 16. Specified using 10% and 90% points on waveform of interest. Output loaded with 50 pF.

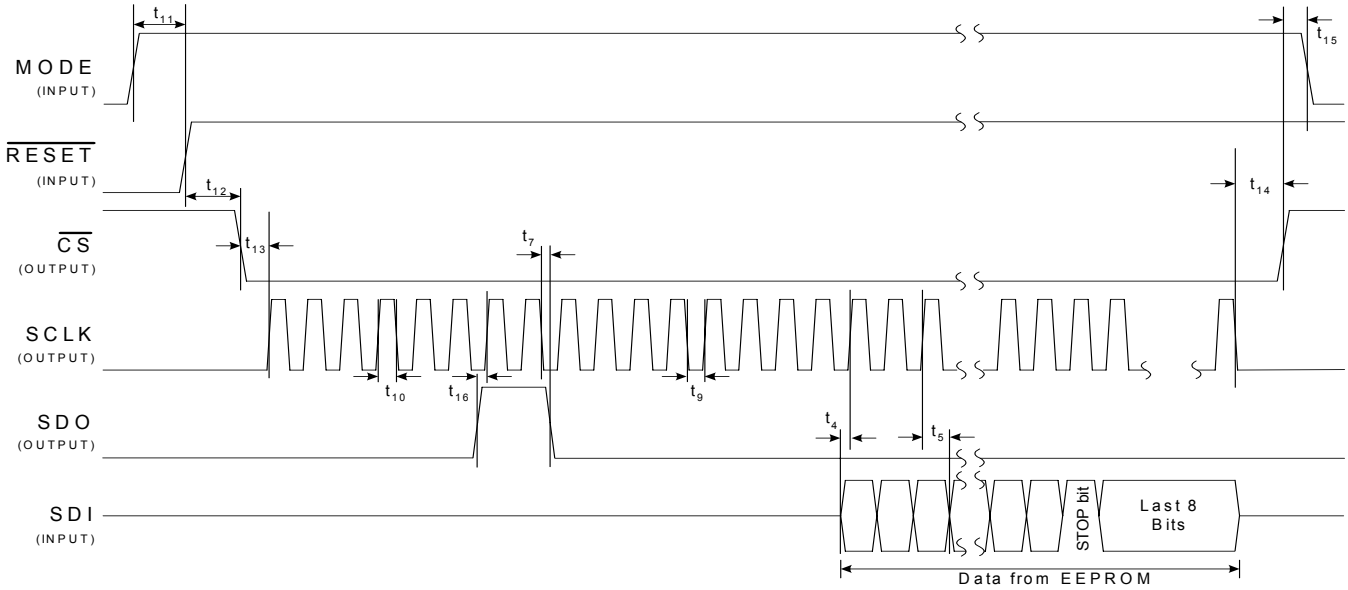
17. Oscillator start-up time varies with crystal parameters. This specification does not apply when using an external clock source.



SDI Write Timing (Not to Scale)



SDO Read Timing (Not to Scale)



Auto-boot Sequence Timing (Not to Scale)

Figure 1. CS5463 Read and Write Timing Diagrams

SWITCHING CHARACTERISTICS (Continued)

Parameter	Symbol	Min	Typ	Max	Unit
$\overline{E1}$, $\overline{E2}$ and $\overline{E3}$ Timing (Note 18 and 19)					
Period	t_{period}	250	-	-	µs
Pulse Width	t_{pw}	244	-	-	µs
Rising Edge to Falling Edge	t_3	6	-	-	µs
$\overline{E2}$ Setup to $\overline{E1}$ and/or $\overline{E3}$ Falling Edge	t_4	1.5	-	-	µs
$\overline{E1}$ Falling Edge to $\overline{E3}$ Falling Edge	t_5	248	-	-	µs

Notes: 18. Pulse output timing is specified at MCLK = 4.096 MHz, E2MODE = 0 and E3MODE1:0 = 0. Refer to Section 5.5 *Energy Pulse Output* on page 17 for more information on pulse output pins.

19. Timing is proportional to the frequency of MCLK.

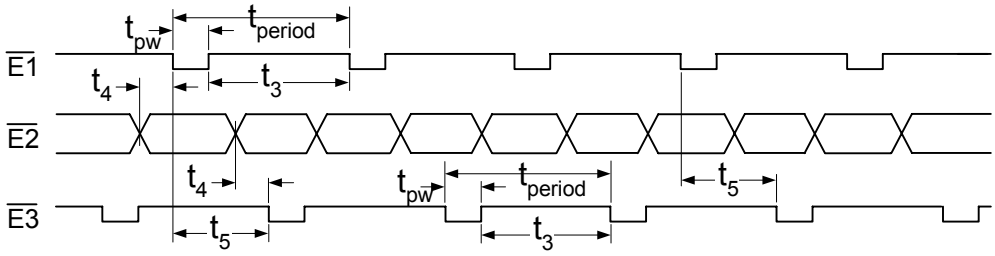


Figure 2. Timing Diagram for $\overline{E1}$, $\overline{E2}$ and $\overline{E3}$

ABSOLUTE MAXIMUM RATINGS

WARNING: Operation at or beyond these limits may result in permanent damage to the device. Normal operation is not guaranteed at these extremes.

Parameter		Symbol	Min	Typ	Max	Unit
DC Power Supplies	(Notes 20 and 21)					
Positive Digital		VD+	-0.3	-	+6.0	V
Positive Analog		VA+	-0.3	-	+6.0	V
Input Current, Any Pin Except Supplies	(Notes 22, 23, 24)	I_{IN}	-	-	±10	mA
Output Current, Any Pin Except VREFOUT		I_{OUT}	-	-	100	mA
Power Dissipation	(Note 25)	P_D	-	-	500	mW
Analog Input Voltage	All Analog Pins	V_{INA}	- 0.3	-	(VA+) + 0.3	V
Digital Input Voltage	All Digital Pins	V_{IND}	-0.3	-	(VD+) + 0.3	V
Ambient Operating Temperature		T_A	-40	-	85	°C
Storage Temperature		T_{stg}	-65	-	150	°C

Notes: 20. VA+ and AGND must satisfy [(VA+) - (AGND)] ≤ + 6.0 V.

21. VD+ and AGND must satisfy [(VD+) - (AGND)] ≤ + 6.0 V.

22. Applies to all pins including continuous over-voltage conditions at the analog input pins.

23. Transient current of up to 100 mA will not cause SCR latch-up.

24. Maximum DC input current for a power supply pin is ±50 mA.

25. Total power dissipation, including all input currents and output currents.

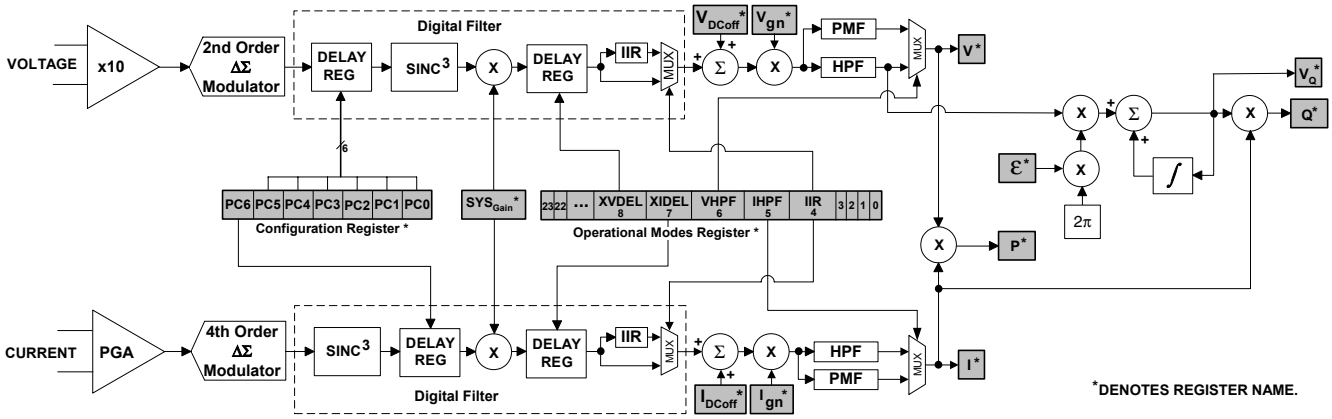


Figure 3. Data Measurement Flow Diagram.

4. THEORY OF OPERATION

The CS5463 is a dual-channel analog-to-digital converter (ADC) followed by a computation engine that performs power calculations and energy-to-pulse conversion. The data flow for the voltage and current channel measurement and the power calculation algorithms are depicted in Figure 3 and 4, respectively.

The analog inputs are structured with two dedicated channels, voltage and current, then optimized to simplify interfacing to various sensing elements.

The voltage-sensing element introduces a voltage waveform on the voltage channel input VIN± and is subject to a gain of 10x. A second-order delta-sigma modulator samples the amplified signal for digitization.

Simultaneously, the current sensing element introduces a voltage waveform on the current channel input IIN± and is subject to the two selectable gains of the programmable gain amplifier (PGA). The amplified signal is sampled by a fourth-order delta-sigma modulator for digitization. Both converters sample at a rate of MCLK/8, the over-sampling provides a wide dynamic range and simplified anti-alias filter design.

4.1 Digital Filters

The decimating digital filters on both channels are $Sinc^3$ filters followed by 4th-order IIR filters. The single-bit data is passed to the low-pass decimation filter and output at a fixed word rate. The output word is passed to an optional IIR filter to compensate for the magnitude roll-off of the low-pass filtering operation.

An optional digital high-pass filter (*HPF* in Figure 3) removes any DC component from the selected signal path. By removing the DC component from the voltage and/or the current channel, any DC content will also be removed from the calculated active power as well. With both HPFs enabled the DC component will be removed from the calculated V_{RMS} and I_{RMS} as well as the apparent power.

When the optional HPF in either channel is disabled an all-pass filter (APF) is implemented. The APF has an amplitude response that is flat within the channel bandwidth and is used for matching phase in systems where one HPF is engaged.

4.2 Voltage and Current Measurements

The digital filter output word is then subject to a DC offset adjustment and a gain calibration (See Section 7. *System Calibration* on page 36). The calibrated measurement is available by reading the instantaneous voltage and current registers

The Root Mean Square (*RMS* in Figure 4) calculations are performed on N instantaneous voltage and current samples, V_n and I_n respectively (where N is the cycle count), using the formula:

$$I_{RMS} = \sqrt{\frac{\sum_{n=0}^{N-1} I_n}{N}}$$

and likewise for V_{RMS}, using V_n. I_{RMS} and V_{RMS} are accessible by register reads, which are updated once every cycle count (referred to as a computational cycle).

4.3 Power Measurements

The instantaneous voltage and current samples are multiplied to obtain the instantaneous power (see Figure 3). The product is then averaged over N conversions to compute active power and is used to drive energy pulse outputs $\overline{E1}$. Energy output $\overline{E2}$ is selectable, providing an energy sign or a pulse output that is proportional to the apparent power. Energy output $\overline{E3}$

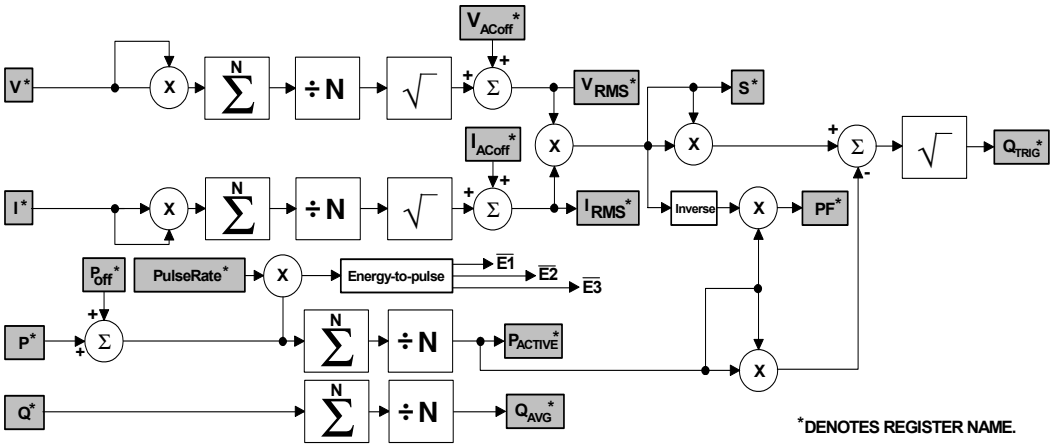


Figure 4. Power Calculation Flow.

provides a pulse output that is proportional to the reactive power or apparent power. Output $\overline{E3}$ can also be set to display the sign of the voltage applied to the voltage channel or the PFMON comparator output.

The apparent power (S) is the combination of the active power and reactive power, without reference to an impedance phase angle, and is calculated by the CS5463 using the following formula:

$$S = V_{RMS} \times I_{RMS}$$

Power Factor (PF) is the active power (P_{Active}) divided by the apparent power (S)

$$PF = \frac{P_{Active}}{S}$$

The sign of the power factor is determined by the active power.

The CS5463 calculates the reactive power, Q_{Trig} utilizing trigonometric identities, giving the formula

$$Q_{Trig} = \sqrt{S^2 - P_{Active}^2}$$

Average reactive power, Q_{Avg} is generated by averaging the voltage multiplied by the current with a 90° phase shift difference between them. The 90° phase shift is realized by applying an IIR digital filter in the voltage channel to obtain quadrature voltage (see Figure 3). This filter will give exactly -90° phase shift across all frequencies, and utilizes epsilon (ε) to achieve unity gain at the line frequency.

The instantaneous quadrature voltage (V_Q) and current (I) samples are multiplied to obtain the instantaneous quadrature power (Q). The product is then averaged over N conversions, utilizing the formula

$$Q_{Avg} = \frac{\sum_{n=1}^{N} Q_n}{N}$$

Fundamental active (P_F) and reactive (Q_F) power is calculated by performing a discrete Fourier transform (DFT) at the relevant frequency on the instantaneous voltage (V) and current (I). Epsilon is used to set the frequency of the internal sine (imaginary component) and cosine (real component) waveform generator. The harmonic active power (P_H) is calculated by subtracting the fundamental active power (P_F) from the active power (P_{Active}).

The peak current (I_{peak}) and peak voltage (V_{peak}) are the instantaneous current and voltage, respectively, with the greatest magnitude detected during the last computation cycle. Active, apparent, reactive and fundamental power are updated every computation cycle.

4.4 Linearity Performance

The linearity of the V_{RMS}, I_{RMS}, active, reactive and power-factor power measurements (before calibration) will be within ±0.1% of reading over the ranges specified, with respect to the input voltage levels required to cause full-scale readings in the I_{RMS} and V_{RMS} registers. Refer to *Accuracy Specifications* on page 7.

Until the CS5463 is calibrated, the *accuracy* of the CS5463 (with respect to a reference line-voltage and line-current level on the power mains) is not guaranteed to within ±0.1%. (See Section 7. *System Calibration* on page 36.) The accuracy of the internal calculations can often be improved by selecting a value for the Cycle Count Register that will cause the time duration of one computation cycle to be equal to (or very close to) a whole number of power-line cycles (and N must be greater than or equal to 4000).

5. FUNCTIONAL DESCRIPTION

5.1 Analog Inputs

The CS5463 is equipped with two fully differential input channels. The inputs VIN± and IIN± are designated as the voltage and current channel inputs, respectively. The full-scale differential input voltage for the current and voltage channel is ±250 mV_P.

5.1.1 Voltage Channel

The output of the line voltage resistive divider or transformer is connected to the VIN+ and VIN- input pins of the CS5463. The voltage channel is equipped with a 10x fixed gain amplifier. The full-scale signal level that can be applied to the voltage channel is ±250 mV. If the input signal is a sine wave the maximum RMS voltage at a gain 10x is:

$$\frac{250\,mV_P}{\sqrt{2}} \cong 176.78\,mV_{RMS}$$

which is approximately 70.7% of maximum peak voltage. The voltage channel is also equipped with a *Voltage Gain Register*, allowing for an additional programmable gain of up to 4x.

5.1.2 Current Channel

The output of the current sense resistor or transformer is connected to the IIN+ and IIN- input pins of the CS5463. To accommodate different current sensing elements the current channel incorporates a Programmable Gain Amplifier (PGA) with two programmable input gains. *Configuration Register* bit Igain (see Table 1) defines the two gain selections and corresponding maximum input signal level.

Igain	Maximum Input Range	
0	±250 mV	10x
1	±50 mV	50x

Table 1. Current Channel PGA Setting

For example, if Igain=0, the current channel's PGA gain is set to 10x. If the input signals are pure sinusoids with zero phase shift, the maximum peak differential signal on the current or voltage channel is ±250 mV_P. The input signal levels are approximately 70.7% of maximum peak voltage producing a full-scale energy pulse registration equal to 50% of absolute maximum energy pulse registration. This will be discussed further in See Section 5.5 *Energy Pulse Output* on page 17.

The Current Gain Register also allows for an additional programmable gain of up to 4x. If an additional gain is applied to the voltage and/or current channel, the maximum input range should be adjusted accordingly.

5.2 IIR Filters

The current and voltage channel are equipped with a 4th-order IIR filter, that is used to compensate for the magnitude roll-off of the low-pass decimation filter. *Operational Mode Register* bit $\overline{IIR}$ engages the IIR filters in both the voltage and current channel.

5.3 High-pass Filters

By removing the offset from either channel, no error component will be generated at DC when computing the active power. By removing the offset from both channels, no error component will be generated at DC when computing V_{RMS}, I_{RMS} and apparent power. *Operational Mode Register* bits VHPF and IHPF activate the HPF in the voltage and current channel respectively. When a high-pass filter is engaged in only one channel, an all-pass filter (APF) is applied to the other channel.

5.4 Performing Measurements

The CS5463 performs measurements of instantaneous voltage (V_n) and current (I_n), and calculates instantaneous power (P_n) at an Output Word Rate (OWR) of

$$OWR = \frac{(MCLK/K)}{1024}$$

where K is the clock divider selected in the *Configuration Register*.

The RMS voltage (V_{RMS}), RMS current (I_{RMS}) and active power (P_{active}) are computed, using N instantaneous samples of V_n, I_n and P_n respectively, where N is the value in the *Cycle Count Register* and is referred to as a "*computation cycle*". The apparent power (S) is the product of V_{RMS} and I_{RMS}. A computation cycle is derived from the master clock (MCLK), with frequency:

$$\text{Computation Cycle} = \frac{OWR}{N}$$

Under default conditions and with K = 1, N = 4000, and MCLK = 4.096 MHz – the OWR = 4000 Hz and the Computation Cycle = 1 Hz.

All measurements are available as a percentage of full scale. The format for *signed* registers is a two's complement, normalized value between -1 and +1. The format

for *unsigned* registers is a normalized value between 0 and 1. A register value of

$$\frac{(2^{23}-1)}{2^{23}} = 0.99999988$$

represents the maximum possible value.

At each instantaneous measurement, the CRDY bit will be set in the *Status Register*, and the $\overline{INT}$ pin will become active if the CRDY bit is unmasked in the *Mask Register*. At the end of each computation cycle, the DRDY bit will be set in the *Status Register*, and the $\overline{INT}$ pin will become active if the DRDY bit is unmasked in the *Mask Register*. When these bits are asserted, they must be cleared before they can be asserted again.

If the *Cycle Count Register* (N) is set to 1, all output calculations are instantaneous, and DRDY, like CRDY, will indicate when instantaneous measurements are finished. Some calculations are inhibited when the cycle count is less than 2.

Epsilon (ε) is the ratio of the input line frequency (f_i) to the sample frequency (f_s) of the ADC.

$$\varepsilon = f_i / f_s$$

where f_s = MCLK / (K*1024). With MCLK = 4.096 MHz and clock divider K = 1, f_s = 4000 Hz. For the two most-common line frequencies, 50 Hz and 60 Hz

$$\varepsilon = 50\ Hz / 4000\ Hz = 0.0125$$

and

$$\varepsilon = 60\ Hz / 4000\ Hz = 0.015$$

respectively. Epsilon is used to set the frequency of the internal sine/cosine reference for the fundamental active and reactive measurements, and the gain of the 90° phase shift (IIR) filter for the average reactive power.

5.5 Energy Pulse Output

The CS5463 provides three output pins for energy registration. By default, $\overline{E1}$ registers active energy, $\overline{E3}$ registers reactive energy, and $\overline{E2}$ indicates the sign of both active and reactive energy. (See Figure 2. *Timing Diagram for E1, E2 and E3* on page13.) The $\overline{E1}$ pulse output is designed to register the Active Energy. The $\overline{E2}$ pin can be set to register Apparent Energy. Table 2 defines the pulse output mode, which is controlled by bit E2MODE in the *Operational Mode Register.*

E2MODE	$\overline{E2}$ Output Mode
0	Sign of Energy
1	Apparent Energy

Table 2. $\overline{E2}$ Pin Configuration

The $\overline{E3}$ pin can be set to register, Reactive Energy (default), PFMON, Voltage Channel Sign, or Apparent Energy. Table 3 defines the pulse output format, which is controlled by bits E3MODE[1:0] in the *Operational Mode Register.*

E3MODE1	E3MODE0	$\overline{E3}$ OutPut Mode
0	0	Reactive Energy
0	1	PFMON
1	0	Voltage Channel Sign
1	1	Apparent Energy

Table 3. $\overline{E3}$ Pin Configuration

The pulse output frequency of $\overline{E1}$, $\overline{E2}$, and $\overline{E3}$ is directly proportional to the power calculated from the input signals. The value contained in the *PulseRateE Register* is the ratio of the energy-output-pulse per samples at full scale, which defines the average frequency for the output pulses. The pulse width, t_{pw} in Figure 2, is an integer multiple of MCLK cycles approximately equal to:

$$t_{pw}(sec) \cong \frac{1}{(MCLK/K)/1024}$$

If MCLK = 4.096 MHz and K = 1 then $t_{pw} \cong 0.25$ ms.

5.5.1 Active Energy

The $\overline{E1}$ pin produces active-low pulses with an output frequency proportional to the active power. The $\overline{E2}$ pin is the energy direction indicator. Positive energy is represented by $\overline{E1}$ pin falling while the $\overline{E2}$ is high. Negative energy is represented by the $\overline{E1}$ pin falling while the $\overline{E2}$ is low. The $\overline{E1}$ and $\overline{E2}$ switching characteristics are specified in Figure 2. *Timing Diagram for E1, E2 and E3* on page13.

Figure 5 illustrates the pulse output format with positive active energy and negative reactive energy.

Figure 5. Active and Reactive energy pulse outputs

The pulse output frequency of $\overline{E1}$ is directly proportional to the active power calculated from the input signals. To calculate the output frequency on $\overline{E1}$, the following transfer function can be utilized:

$$FREQ_P = \frac{VIN \times VGAIN \times IIN \times IGAIN \times PF \times PulseRate}{VREFIN^2}$$

$FREQ_P$ = Average frequency of active energy $\overline{E1}$ pulses [Hz]
VIN = rms voltage across VIN+ and VIN- [V]
VGAIN = Voltage channel gain
IIN = rms voltage across IIN+ and IIN- [V]
IGAIN = Current channel gain
PF = Power Factor
PulseRate = PulseRateE x (MCLK/K)/2048 [Hz]
VREFIN = Voltage at VREFIN pin [V]

With MCLK = 4.096 MHz, PF = 1 and default settings, the pulses will have an average frequency equal to the frequency specified by *PulseRate* when the input signals applied to the voltage and current channels cause full-scale readings in the instantaneous voltage and current registers. The maximum pulse frequency from the $\overline{E1}$ pin is (MCLK/K)/2048.

5.5.2 Apparent Energy Mode

Setting bit E2MODE = 1 in the *Operational Mode Register* outputs apparent energy pulses on pin $\overline{E2}$. Setting bit E3MODE1:0 = 3 in the *Operational Mode Register* outputs apparent energy pulses on pin $\overline{E3}$. Figure 6 illustrates the pulse output format with apparent energy on $\overline{E2}$ (E2MODE = 1 and E3MODE1:0 = 0)

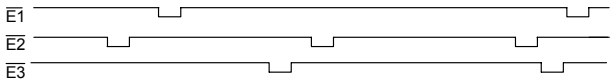


Figure 6. Apparent energy pulse outputs

The pulse output frequency of $\overline{E2}$ (and/or $\overline{E3}$) is directly proportional to the apparent power calculated from the input signals. Since apparent power is without reference to an impedance phase angle, the following transfer function can be utilized to calculate the output frequency on $\overline{E2}$ (and/or $\overline{E3}$).

$$FREQ_S = \frac{VIN \times VGAIN \times IIN \times IGAIN \times PulseRate}{VREFIN^2}$$

$FREQ_S$ = Average frequency of apparent energy $\overline{E2}$ and/or $\overline{E3}$ pulses [Hz]
VIN = rms voltage across VIN+ and VIN- [V]
VGAIN = Voltage channel gain
IIN = rms voltage across IIN+ and IIN- [V]
IGAIN = Current channel gain
PulseRate = PulseRateE x (MCLK/K)/2048 [Hz]
VREFIN = Voltage at VREFIN pin [V]

With MCLK = 4.096 MHz and default settings, the pulses will have an average frequency equal to the frequency specified by *PulseRate* when the input signals applied to the voltage and current channels cause full-scale readings in the instantaneous voltage and current registers. The maximum pulse frequency from the $\overline{E2}$ (and/or $\overline{E3}$) pin is (MCLK/K)/2048. The $\overline{E2}$ (and/or $\overline{E3}$) pin outputs apparent energy, but has no energy direction indicator.

5.5.3 Reactive Energy Mode

Reactive energy pulses are output on pin $\overline{E3}$ by setting bit E3MODE1:0 = 0 (default) in the *Operational Mode Register*. Positive reactive energy is registered by $\overline{E3}$ falling when $\overline{E2}$ is high. Negative reactive energy is registered by $\overline{E3}$ falling when $\overline{E2}$ is low. Figure 5 on page 17 illustrates the pulse output format with negative reactive energy output on pin $\overline{E3}$ and the sign of the energy on $\overline{E2}$. The $\overline{E3}$ and $\overline{E2}$ pulse output switching characteristics are specified in Figure 2 on page 13.

The pulse output frequency of $\overline{E3}$ is directly proportional to the reactive power calculated from the input signals. To calculate the output frequency on $\overline{E3}$, the following transfer function can be utilized:

$$FREQ_Q = \frac{VIN \times VGAIN \times IIN \times IGAIN \times PQ \times PulseRate}{VREFIN^2}$$

$FREQ_Q$ = Average frequency of reactive energy $\overline{E3}$ pulses [Hz]
VIN = rms voltage across VIN+ and VIN- [V]
VGAIN = Voltage channel gain
IIN = rms voltage across IIN+ and IIN- [V]
IGAIN = Current channel gain
PQ = $\sqrt{1 - PF^2}$
PulseRate = PulseRateE x (MCLK/K)/2048 [Hz]
VREFIN = Voltage at VREFIN pin [V]

With MCLK = 4.096 MHz, PF = 0 and default settings, the pulses will have an average frequency equal to the frequency specified by *PulseRate* when the input signals applied to the voltage and current channels cause full-scale readings in the instantaneous voltage and current registers. The maximum pulse frequency from the $\overline{E1}$ pin is (MCLK/K)/2048.

5.5.4 Voltage Channel Sign Mode

Setting bit E3MODE1:0 = 2 in the *Operational Mode Register* outputs the sign of the voltage channel on pin $\overline{E3}$. Figure 7 illustrates the output format with voltage channel sign on $\overline{E3}$

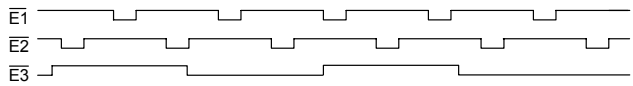


Figure 7. Voltage Channel Sign Pulse outputs

Output pin $\overline{E3}$ is high when the line voltage is positive and pin $\overline{E3}$ is low when the line voltage is negative.

5.5.5 PFMON Output Mode

Setting bit E3MODE1:0 = 1 in the *Operational Mode Register* outputs the PFMON comparator on pin $\overline{E3}$. Figure 8 illustrates the output format with PFMON on $\overline{E3}$

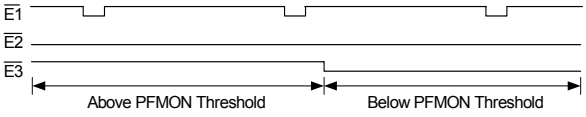


Figure 8. PFMON output to pin $\overline{E3}$

When PFMON is greater then the threshold, pin $\overline{E3}$ is high and when PFMON is less then the threshold pin $\overline{E3}$ is low.

5.5.6 Design Example

EXAMPLE #1:

The maximum rated levels for a power line meter are 250 V rms and 20 A rms. The required number of pulses-per-second on $\overline{E1}$ is 100 pulses per second (100 Hz), when the levels on the power line are 220 V rms and 15 A rms.

With a 10x gain on the voltage and current channel the maximum input signal is 250 mV_P. (See Section 5.1 *Analog Inputs* on page 16.) To prevent over-driving the channel inputs, the maximum rated rms input levels will register 0.6 in V_{RMS} and I_{RMS} by design. Therefore the voltage level at the channel inputs will be 150 mV rms when the maximum rated levels on the power lines are 250 V rms and 20 A rms.

Solving for *PulseRate* using the transfer function:

$$\text{PulseRate} = \frac{\text{FREQ}_P \times \text{VREFIN}^2}{\text{VIN} \times \text{VGAIN} \times \text{IIN} \times \text{IGAIN} \times \text{PF}}$$

Therefore with PF = 1 and:

$$\text{VIN} = 220\text{V} \times ((150\text{mV})/(250\text{V})) = 132\text{mV}$$

$$\text{IIN} = 15\text{A} \times ((150\text{mV})/(20\text{A})) = 112.5\text{mV}$$

the pulse rate is:

$$\text{PulseRate} = \frac{100 \times 2.5^2}{0.132 \times 10 \times 0.1125 \times 10} = 420.8754\text{Hz}$$

and the *PulseRateE Register* is set to:

$$\text{PulseRateE} = \frac{\text{PulseRate}}{(\text{MCLK}/\text{K})/2048} = 0.2104377$$

with MCLK = 4.096 MHz and K = 1.

5.6 Sag and Fault Detect Feature

Status bit VSAG and IFAULT in the *Status Register,* indicates a sag occurred in the power line voltage and current, respectively. For a sag condition to be identified, the absolute value of the instantaneous voltage or current must be less than the sag level for more then half of the sag duration (see Figure 9).

To activate Voltage Sag detect, a voltage sag level must be specified in the *Voltage Sag Level Register* (VSAGLevel), and a voltage sag duration must be specified in the *Voltage Sag Duration Register* (VSAGDuration). To activate Current Fault detect, a current sag level must be specified in the *Current Fault Level Register* (ISAGLevel), and a current sag duration must be specified in the *Current Fault Duration Register* (ISAGDuration). The voltage and current sag levels are specified as the average of the absolute instantaneous voltage and current, respectively. Voltage and current sag duration is specified in terms of ADC cycles.

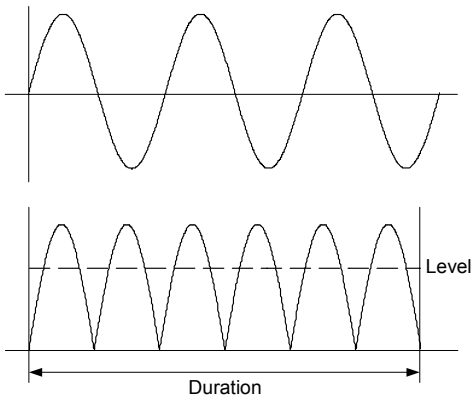


Figure 9. Sag and Fault Detect

5.7 On-chip Temperature Sensor

The on-chip temperature sensor is designed to assist in characterizing the measurement element over a desired temperature range. Once a temperature characterization is performed, the temperature sensor can then be utilized to assist in compensating for temperature drift.

Temperature measurements are performed during continuous conversions and stored in the *Temperature Register*. The *Temperature Register* (T) default is Celsius scale (°C). The *Temperature Gain Register* (T_{gain}) and *Temperature Offset Register* (T_{off}) are constant values allowing for temperature scale conversions.

The temperature update rate is a function of the number of ADC samples. With MCLK = 4.096 MHz and K = 1 the update rate is:

$$\frac{2240 \text{ samples}}{(MCLK/K)/1024} = 0.56 \text{ sec}$$

The *Cycle Count Register* (N) must be set to a value greater then one. Status bit TUP in the *Status Register,* indicates when the *Temperature Register* is updated.

The *Temperature Offset Register* sets the zero-degree measurement. To improve temperature measurement accuracy, the zero-degree offset may need to be adjusted after the CS5463 is initialized. Temperature offset calibration is achieved by adjusting the *Temperature Offset Register* (T_{off}) by the differential temperature (ΔT) measured from a calibrated digital thermometer and the CS5463 temperature sensor. A one degree adjustment to the *Temperature Register* (T) is achieved by adding 2.737649×10^{-4} to the *Temperature Offset Register* (T_{off}). Therefore,

$$T_{off} = T_{off} + (\Delta T \times 2.737649 \cdot 10^{-4})$$

if T_{off} = -0.09104831 and ΔT = -7.0 (ºC), then

$$T_{off} = -0.09104831 + (-7.0 \times 2.737649 \cdot 10^{-4}) = -0.09296466$$

or 0xF419BC (2's compliment notation) is stored in the *Temperature Offset Register* (T_{off}).

To convert the *Temperature Register* (T) from a Celsius scale (ºC) to a Fahrenheit scale (ºF) utilize the formula

$$^{o}F = \frac{9}{5}(^{o}C + 17.7778)$$

Applying the above relationship to the CS5461A temperature measurement algorithm

$$T\langle^{o}F\rangle = \left(\frac{9}{5} \times T_{gain}\right)\left[T\langle^{o}C\rangle + \left(T_{off} + (17.7778 \times 2.737649 \cdot 10^{-4})\right)\right]$$

If T_{off} = -0.09296466 and T_{gain} = 23.799 for a Celsius scale, then the modified values are T_{off} = -0.08809772 (0xF4B937) and T_{gain} = 42.8382 (0x55AD29) for a Fahrenheit scale.

5.8 Voltage Reference

The CS5463 is specified for operation with a +2.5 V reference between the VREFIN and AGND pins. To utilize the on-chip 2.5 V reference, connect the VREFOUT pin to the VREFIN pin of the device. The VREFIN can be used to connect external filtering and/or references.

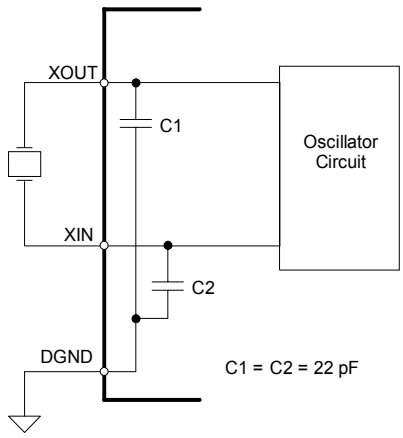


Figure 10. Oscillator Connection

5.9 System Initialization

Upon powering up, the digital circuitry is held in reset until the analog voltage reaches 4.0 V. At that time, an eight XIN clock period delay is enabled to allow the oscillator to stabilize. The CS5463 will then initialize.

A hardware reset is initiated when the $\overline{\text{RESET}}$ pin is asserted with a minimum pulse width of 50 ns. The $\overline{\text{RESET}}$ signal is asynchronous, with a Schmitt Trigger input. Once the $\overline{\text{RESET}}$ pin is de-asserted, an eight XIN clock period delay is enabled.

A software reset is initiated by writing the command 0x80. After a hardware or software reset, the internal registers (some of which drive output pins) will be reset to their *default* values. Status bit DRDY in the *Status Register,* indicates the CS5463 is in its *active* state and ready to receive commands.

5.10 Power-down States

The CS5463 has two power-down states, Stand-by and Sleep. In the stand-by state all circuitry except the voltage reference and crystal oscillator is turned off. To return the device to the active state a power-up command is sent to the device.

In Sleep state all circuitry except the instruction decoder is turned off. When the power-up command is sent to the device, a system initialization is performed (See Section 5.9 *System Initialization* on page 20).

5.11 Oscillator Characteristics

XIN and XOUT are the input and output of an inverting amplifier configured as an on-chip oscillator, as shown in Figure 10. The oscillator circuit is designed to work with a quartz crystal. To reduce circuit cost, two load capacitors C1 and C2 are integrated in the device, from XIN to DGND, and XOUT to DGND. PCB trace lengths

should be minimized to reduce stray capacitance. To drive the device from an external clock source, XOUT should be left unconnected while XIN is driven by the external circuitry. There is an amplifier between XIN and the digital section which provides CMOS level signals. This amplifier works with sinusoidal inputs so there are no problems with slow edge times.

The CS5463 can be driven by an external oscillator ranging from 2.5 to 20 MHz, but the K divider value must be set such that the internal MCLK will run somewhere between 2.5 MHz and 5 MHz. The K divider value is set with the K[3:0] bits in the *Configuration Register*. As an example, if XIN = MCLK = 15 MHz, and K is set to 5, then DCLK is 3 MHz, which is a valid value for DCLK.

5.12 Event Handler

The $\overline{\text{INT}}$ pin is used to indicate that an internal error or event has taken place in the CS5463. Writing a logic 1 to any bit in the *Mask Register* allows the corresponding bit in the *Status Register* to activate the $\overline{\text{INT}}$ pin. The interrupt condition is cleared by writing a logic 1 to the bit that has been set in the *Status Register*.

The behavior of the $\overline{\text{INT}}$ pin is controlled by the IMODE and IINV bits of the *Configuration Register*.

IMODE	IINV	$\overline{\text{INT}}$ Pin	
0	0	Active-low Level	
0	1	Active-high Level	
1	0	Low Pulse	
1	1	High Pulse	

Table 4. Interrupt Configuration

If the interrupt output signal format is set for either falling or rising edge, the duration of the $\overline{\text{INT}}$ pulse will be at least one DCLK cycle (DCLK = MCLK/K).

5.12.1 Typical Interrupt Handler

The steps below show how interrupts can be handled.

INITIALIZATION:

1) All Status bits are cleared by writing 0xFFFFFF to the Status Register.
2) The condition bits which will be used to generate interrupts are then set to logic 1 in the Mask Register.
3) Enable interrupts.

INTERRUPT HANDLER ROUTINE:

4) Read the Status Register.
5) Disable all interrupts.
6) Branch to the proper interrupt service routine.
7) Clear the Status Register by writing back the read value in step 4.
8) Re-enable interrupt
9) Return from interrupt service routine.

This handshaking procedure ensures that any new interrupts activated between steps 4 and 7 are not lost (cleared) by step 7.

5.13 Serial Port Overview

The CS5463 incorporates a serial port transmit and receive buffer with a command decoder that interprets one-byte (8 bits) commands as they are received. There are four types of commands; instructions, synchronizing, register writes and register reads (See Section 5.15 *Commands* on page 23).

Instructions are one byte in length and will interrupt any instruction currently executing. Instructions do not affect register reads currently being transmitted.

Synchronizing commands are one byte in length and only affect the serial interface. Synchronizing commands do not affect operations currently in progress.

Register writes must be followed by three bytes of data. Register reads can return up to four bytes of data.

Commands and data are transferred most-significant bit (MSB) first. Figure 1 on page 12, defines the serial port timing and required sequence necessary to write to and read from the serial port receive and transmit buffer, respectively. While reading data from the serial port, commands and data can be simultaneously written. Starting a new register read command while data is being read will terminate the current read in progress. This is acceptable if the remainder of the current read data is not needed. During data reads, the serial port requires input data. If a new command and data is not sent, SYNC0 or SYNC1 must be sent.

5.13.1 Serial Port Interface

The serial port interface is a “4-wire” synchronous serial communications interface. The interface is enabled to start excepting SCLKs when $\overline{\text{CS}}$ (Chip Select) is asserted. SCLK (Serial bit-clock) is a Schmitt-trigger input that is used to strobe the data on SDI (Serial Data In) into the receive buffer and out of the transmit buffer onto SDO (Serial Data Out).

If the serial port interface becomes unsynchronized with respect to the SCLK input, any attempt to clock valid commands into the serial interface may result in unexpected operation. The serial port interface must then be re-initialized by one of the following actions:

- Drive the $\overline{CS}$ pin high, then low.
- Hardware Reset (drive $\overline{RESET}$ pin low, for at least 10 µs).
- Issue the *Serial Port Initialization Sequence*, which is 3 (or more) SYNC1 command bytes (0xFF) followed by one SYNC0 command byte (0xFE).

If a re-synchronization is necessary, it is best to re-initialize the part either by hardware or software reset (0x80), as the state of the part may be unknown.

5.14 Register Paging

Read/write commands access one of the 32 registers within a specified page. By default, Page = 0. To access registers in another page, the *Page Register* (address 0x1F) must be written with the desired page number.

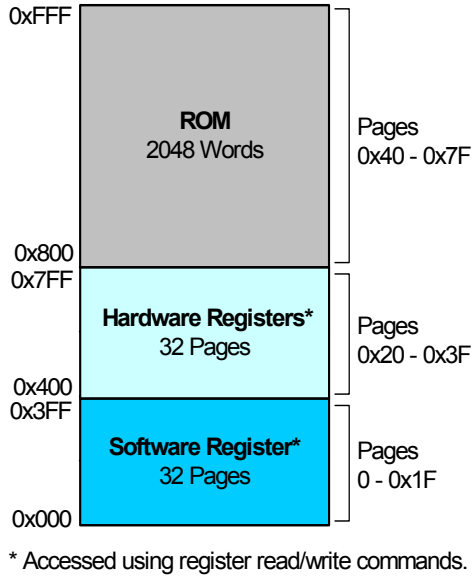


Figure 11. CS5463 Memory Map

Example:

Reading register 6 in page 3.

1. Write 3 to page register with command and data:

0x7E 0x00 0x00 0x03

2. Read register 6 with command:

0x0C 0xFF 0xFF 0xFF

5.15 Commands

All commands are 8-bits in length. Any byte that is not listed in this section is invalid. Commands that write to registers must be followed by 3 bytes of data. Commands that read data can be chained with other commands (e.g., while reading data, a new command can be sent which can execute during the original read). All commands except register reads, register writes, and SYNC0 & SYNC1 will abort any currently executing commands.

5.15.1 Start Conversions

B7	B6	B5	B4	B3	B2	B1	B0
1	1	1	0	C3	0	0	0

Initiates acquiring measurements and calculating results. The device has two modes of acquisition.

C3 — Modes of acquisition/measurement
0 = Perform a single computation cycle
1 = Perform continuous computation cycles

5.15.2 SYNC0 and SYNC1

B7	B6	B5	B4	B3	B2	B1	B0
1	1	1	1	1	1	1	SYNC

The serial port can be initialized by asserting $\overline{CS}$ or by sending three or more consecutive SYNC1 commands followed by a SYNC0 command. The SYNC0 or SYNC1 can also be sent while sending data out.

SYNC — 0 = Last byte of a serial port re-initialization sequence.
1 = Used during reads and serial port initialization.

5.15.3 Power-up/Halt

B7	B6	B5	B4	B3	B2	B1	B0
1	0	1	0	0	0	0	0

If the device is powered-down, Power-Up/Halt will initiate a power on reset. If the part is already powered-on, all computations will be halted.

5.15.4 Power-down and Software Reset

B7	B6	B5	B4	B3	B2	B1	B0
1	0	0	S1	S0	0	0	0

To conserve power the CS5463 has two power-down states. In stand-by state all circuitry, except the analog/digital clock generators, is turned off. In the sleep state all circuitry, except the command decoder, is turned off. Bringing the CS5463 out of sleep state requires more time than out of stand-by state, because of the extra time needed to re-start and re-stabilize the analog oscillator.

S[1:0] — Power-down state
00 = Software Reset
01 = Halt and enter stand-by power saving state. This state allows quick power-on
10 = Halt and enter sleep power saving state.
11 = Reserved

5.15.5 Register Read/Write

B7	B6	B5	B4	B3	B2	B1	B0
0	W/R	RA4	RA3	RA2	RA1	RA0	0

The Read/Write informs the command decoder that a register access is required. During a *read* operation, the addressed register is loaded into an output buffer and clocked out by SCLK. During a *write* operation, the data is clocked into an input buffer and transferred to the addressed register upon completion of the 24th SCLK.

W/$\overline{R}$ Write/Read control
0 = Read
1 = Write

RA[4:0] Register address bits (bits 5 through 1) of the read/write command.

Register Page 0

Address	RA[4:0]	Name	Description
0	00000	Config	Configuration
1	00001	I_{DCoff}	Current DC Offset
2	00010	I_{gn}	Current Gain
3	00011	V_{DCoff}	Voltage DC Offset
4	00100	V_{gn}	Voltage Gain
5	00101	Cycle Count	Number of A/D conversions used in one computation cycle (N)).
6	00110	PulseRateE	Sets the $\overline{E1}$, $\overline{E2}$ and $\overline{E3}$ energy-to-frequency output pulse rate.
7	00111	I	Instantaneous Current
8	01000	V	Instantaneous Voltage
9	01001	P	Instantaneous Power
10	01010	P_{active}	Active (Real) Power
11	01011	I_{RMS}	RMS Current
12	01100	V_{RMS}	RMS Voltage
13	01101	ε (Epsilon)	Ratio of line frequency to output word rate (OWR)
14	01110	P_{off}	Power Offset
15	01111	Status	Status
16	10000	I_{ACoff}	Current AC (RMS) Offset
17	10001	V_{ACoff}	Voltage AC (RMS) Offset
18	10010	Mode	Operation Mode
19	10011	T	Temperature
20	10100	Q_{AVG}	Average Reactive Power
21	10101	Q	Instantaneous Reactive Power
22	10101	I_{Peak}	Peak Current
23	10111	V_{Peak}	Peak Voltage
24	11000	Q_{Trig}	Reactive Power calculated from Power Triangle
25	11001	PF	Power Factor
26	11010	Mask	Interrupt Mask
27	11011	S	Apparent Power
28	11100	Ctrl	Control
29	11101	P_H	Harmonic Active Power
30	11110	P_F	Fundamental Active Power
31	11111	Q_F	Fundamental Reactive Power / Page

Note: For proper operation, *do not* attempt to write to unspecified registers.

Register Page 1

Address	RA[4:0]	Name	Description
2	00010	T_{Gain}	Temperature Sensor Gain
3	00011	T_{off}	Temperature Sensor Offset

Register Page 3

Address	RA[4:0]	Name	Description
6	00110	$VSAG_{Duration}$	Voltage sag sample interval
7	00111	$VSAG_{Level}$	Voltage sag level
10	01010	$ISAG_{Duration}$	Current fault sample interval
11	01011	$ISAG_{Level}$	Current fault level

Note: For proper operation, *do not* attempt to write to unspecified registers.

5.15.6 Calibration

B7	B6	B5	B4	B3	B2	B1	B0
1	1	0	CAL4	CAL3	CAL2	CAL1	CAL0

The CS5463 can perform system calibrations. Proper input signals must be applied to the current and voltage channel before performing a designated calibration.

CAL[4:0]* Designates calibration to be performed
- 01001 = Current channel DC offset
- 01010 = Current channel DC gain
- 01101 = Current channel AC offset
- 01110 = Current channel AC gain
- 10001 = Voltage channel DC offset
- 10010 = Voltage channel DC gain
- 10101 = Voltage channel AC offset
- 10110 = Voltage channel AC gain
- 11001 = Current and Voltage channel DC offset
- 11010 = Current and Voltage channel DC gain
- 11101 = Current and Voltage channel AC offset
- 11110 = Current and Voltage channel AC gain

*For proper operation, values for CAL[4:0] not specified should not be used.

6. REGISTER DESCRIPTION

1. “Default” = bit status after power-on or reset
2. Any bit not labeled is Reserved. A zero should always be used when writing to one of these bits.

6.1 Page 0 Registers

6.1.1 Configuration Register (Config)

Address: 0

23	22	21	20	19	18	17	16
PC6	PC5	PC4	PC3	PC2	PC1	PC0	Igain
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**
EWA	-	-	IMODE	IINV	-	-	-
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
-	-	-	iCPU	K3	K2	K1	K0

Default = 0x000001

PC[6:0] Phase compensation. A 2’s complement number which sets a delay in the voltage channel relative to the current channel. Default setting is 0000000 = 0.0215 degree phase delay at 60 Hz (when MCLK = 4.096 MHz). See Section 7.2 *Phase Compensation* on page 38 for more information.

I_{gain} Sets the gain of the current PGA.
0 = Gain is 10 (default)
1 = Gain is 50

EWA Allows the $\overline{E1}$ and $\overline{E2}$ pins to be configured as open-collector output pins.
0 = Normal outputs (default)
1 = Only the pull-down device of the $\overline{E1}$ and $\overline{E2}$ pins are active

IMODE, IINV Interrupt configuration bits. Select the desired pin behavior for indication of an interrupt.
00 = Active-low level (default)
01 = Active-high level
10 = High-to-low pulse
11 = Low-to-high pulse

iCPU Inverts the CPUCLK clock. In order to reduce the level of noise present when analog signals are sampled, the logic driven by CPUCLK should not be active during the sample edge.
0 = Normal operation (default)
1 = Minimize noise when CPUCLK is driving rising edge logic

K[3:0] Clock divider. A 4-bit binary number used to divide the value of MCLK to generate the internal clock DCLK. The internal clock frequency is DCLK = MCLK/K. The value of K can range between 1 and 16. Note that a value of “0000” will set K to 16 (not zero). K = 1 at reset.

6.1.2 Current and Voltage DC Offset Register (I_{DCoff} , V_{DCoff})

Address: 1 (Current DC Offset); 3 (Voltage DC Offset)

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0x000000

The DC Offset registers (I_{DCoff},V_{DCoff}) are initialized to 0.0 on reset. When DC Offset calibration is performed, the register is updated with the DC offset measured over a computation cycle. DRDY will be set at the end of the calibration. This register may be read and stored for future system offset compensation. The value is represented in two's complement notation and in the range of $-1.0 \le I_{DCoff}, V_{DCoff} < 1.0$, with the binary point to the right of the MSB. See Section 7.1.2.1 *DC Offset Calibration Sequence* on page 36 for more information.

6.1.3 Current and Voltage Gain Register (I_{gn} , V_{gn})

Address: 2 (Current Gain); 4 (Voltage Gain)

MSB															LSB
2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	.....	2^{-16}	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}

Default = 0x400000 = 1.000

The gain registers (I_{gn},V_{gn}) are initialized to 1.0 on reset. When either a AC or DC Gain calibration is performed, the register is updated with the gain measured over a computation cycle. DRDY will be set at the end of the calibration. This register may be read and stored for future system gain compensation. The value is in the range $0.0 \le I_{gn}, V_{gn} < 3.9999$, with the binary point to the right of the second MSB.

6.1.4 Cycle Count Register (Cycle Count)

Address: 5

MSB															LSB
2^{23}	2^{22}	2^{21}	2^{20}	2^{19}	2^{18}	2^{17}	2^{16}	.....	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Default = 0x000FA0 = 4000

Cycle Count, denoted as N, determines the length of one *computation cycle*. During continuous conversions, the computation cycle frequency is (MCLK/K)/(1024∗N). A one second computational cycle period occurs when MCLK = 4.096 MHz, K = 1, and N = 4000.

6.1.5 PulseRateE Register (PulseRateE)

Address: 6

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0x800000 = 1.00 (2 kHz @ 4.096 MHz MCLK)

PulseRateE sets the frequency of $\overline{E1}$, $\overline{E2}$, & $\overline{E3}$ pulses. $\overline{E1}$, $\overline{E2}$, $\overline{E3}$ frequency = (MCLK x PulseRateE) / 2048 at full scale. For a 4 khz sample rate, the maximum pulse rate is 2 khz. The value is represented in two's complement notation and in the range is $-1.0 \le$ PulseRateE < 1.0, with the binary point to the right of the MSB. Negative values have the same effect as positive. See Section 5.5 *Energy Pulse Output* on page 17 for more information.

6.1.6 Instantaneous Current, Voltage, and Power Registers (I , V , P)

Address: 7 (Instantaneous Current); 8 (Instantaneous Voltage); 9 (Instantaneous Power)

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

I and V contain the instantaneous measured values for current and voltage, respectively. The instantaneous voltage and current samples are multiplied to obtain Instantaneous Power (P). The value is represented in two's complement notation and in the range of $-1.0 \le I, V, P < 1.0$, with the binary point to the right of the MSB.

6.1.7 Active (Real) Power Register (P_{Active})

Address: 10 (Active Power)

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

The instantaneous power is averaged over each computation cycle (N conversions) to compute Active Power (P_{Active}). The value will be within in the range of $-1.0 \le P_{Active} < 1.0$. The value is represented in two's complement notation, with the binary point to the right of the MSB.

6.1.8 RMS Current & Voltage Registers (I_{RMS} , V_{RMS})

Address: 11 (I_{RMS}); 12 (V_{RMS})

MSB															LSB
2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	.....	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}	2^{-24}

I_{RMS} and V_{RMS} contain the Root Mean Square (RMS) values of I and V, calculated each computation cycle. The value is represented in unsigned binary notation and in the range of $0.0 \le I_{RMS}, V_{RMS} < 1.0$, with the binary point to the left of the MSB.

6.1.9 Epsilon Register ($\mathcal{E}$)

Address: 13

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0x01999A = 0.0125 sec

Epsilon ($\mathfrak{E}$) is the ratio of the input line frequency to the sample frequency of the ADC (See Section 5.4 *Performing Measurements* on page 16). Epsilon is either written to the register, or measured during conversions. The value is represented in two's complement notation and in the range of $-1.0 \le \mathfrak{E} < 1.0$, with the binary point to the right of the MSB. Negative values have no significance.

6.1.10 Power Offset Register (P_{off})

Address: 14

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0x000000

Power Offset (P_{off}) is added to the instantaneous power being accumulated in the P_{active} register, and can be used to offset contributions to the energy result that are caused by undesirable sources of energy that are inherent in the system. The value is represented in two's complement notation and in the range of $-1.0 \le P_{off} < 1.0$, with the binary point to the right of the MSB.

6.1.11 Status Register and Mask Register (Status , Mask)

Address: *15* (*Status Register*)*; 26 (Mask Register)*

23	22	21	20	19	18	17	16
DRDY			CRDY			IOR	VOR
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**
	IROR	VROR	EOR	IFAULT	VSAG		
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
TUP	TOD		VOD	IOD	LSD	FUP	$\overline{IC}$

Default = 0x000001 (Status Register), 0x000000 (Mask Register)

The Status Register indicates status within the chip. In normal operation, writing a '1' to a bit will cause the bit to reset. Writing a '0' to a bit will not change it's current state.

The Mask Register is used to control the activation of the $\overline{INT}$ pin. Placing a logic '1' in a Mask bit will allow the corresponding bit in the Status Register to activate the $\overline{INT}$ pin when the status bit is asserted.

DRDY — Data Ready. During conversions, this bit will indicate the end of computation cycles. For calibrations, this bit indicates the end of a calibration sequence.

CRDY — Conversion Ready. Indicates a new conversion is ready. This will occur at the output word rate.

IOR — Current Out of Range. Set when the *Instantaneous Current Register* overflows.

VOR — Voltage Out of Range. Set when the *Instantaneous Voltage Register* overflows.

IROR — I_{RMS} Out of Range. Set when the *I_{RMS} Register* overflows.

VROR — V_{RMS} Out of Range. Set when the *V_{RMS} Register* overflows.

EOR — Energy Out of Range. Set when P_{ACTIVE} overflows.

FUP — Epsilon Updated. Indicates completion of a line frequency measurement and update of Epsilon.

IFAULT — Indicates a current fault has occurred. See Section 5.6 *Sag and Fault Detect Feature* on page 19.

VSAG — Indicates a voltage sag has occurred. See Section 5.6 *Sag and Fault Detect Feature* on page 19.

TUP — Temperature Updated. Indicates the *Temperature Register* has updated.

TOD — Modulator oscillation detected on the temperature channel. Set when the modulator oscillates due to an input above full scale.

VOD (IOD) Modulator oscillation detected on the voltage (current) channel. Set when the modulator oscillates due to an input above full scale. The level at which the modulator oscillates is significantly higher than the voltage channel's differential input voltage (current) range.

Note: *The IOD and VOD bits may be 'falsely' triggered by very brief voltage spikes from the power line. This event should not be confused with a DC overload situation at the inputs, when the IOD and VOD bits will re-assert themselves even after being cleared, multiple times.*

LSD Low Supply Detect. Set when the voltage at the PFMON pin falls below the low-voltage threshold (PMLO), with respect to AGND pin. The LSD bit cannot be reset until the voltage at PFMON pin rises back above the high-voltage threshold (PMHI).

$\overline{IC}$ Invalid Command. Normally logic 1. Set to logic 0 if an invalid command is received or the *Status Register* has not been successfully read.

6.1.12 Current and Voltage AC Offset Register (V_{ACoff} , I_{ACoff})

Address: 16 (Current AC Offset); 17 (Voltage AC Offset)

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0x000000

The AC Offset Registers (V_{ACoff}, I_{ACoff}) are initialized to zero on reset, allowing for uncalibrated normal operation. AC Offset Calibration updates these registers. This sequence lasts approximately (6N + 30) ADC cycles (where N is the value of the *Cycle Count Register*). DRDY will be asserted at the end of the calibration. These values may be read and stored for future system AC offset compensation. The value is represented in two's complement notation in the range of $-1.0 \le V_{ACoff}, I_{ACoff} < 1.0$, with the binary point to the right of the MSB

6.1.13 Operational Mode Register (Mode)

Address: 18

23	22	21	20	19	18	17	16
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**
						E2MODE	XVDEL
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
XIDEL	IHPF	VHPF	$\overline{IIR}$	E3MODE1	E3MODE0	POS	AFC

Default = 0x000000

E2MODE E2 Output Mode
0 = Sign of Active Power (default)
1 = Apparent Power

XVDEL Enables an extra sample of voltage channel delay. XVDEL and XIDEL can not be enabled at the same time.

XIDEL Enables an extra sample of current channel delay. XVDEL and XIDEL can not be enabled at the same time.

IHPF Enables the High-pass Filter on the current channel.
0 = High-pass filter disabled (default)
1 = High-pass filter enabled

VHPF — Enables the High-pass Filter on the voltage channel.
0 = High-pass filter disabled (default)
1 = High-pass filter enabled

Note: *When either IHPF or VHPF are enabled, but not both, an all pass filter is applied to the opposite channel for phase-matching.*

$\overline{IIR}$ — Enables the IIR compensation filters.
0 = IIR compensation filters enabled (default)
1 = IIR compensation filters disabled

E3MODE1:0 — E3 Output Mode
00 = Reactive Power (default)
01 = PFMON
10 = Voltage sign
11 = Apparent Power

POS — Positive Energy Only. Negative energy pulses on E1 are suppressed. However, it will NOT suppress negative P register results.

AFC — Enables automatic line frequency measurement and sets the frequency of the local sine/cosine generator used in fundamental/harmonic measurements. When AFC is enabled, the Epsilon register will be updated periodically.

6.1.14 Temperature Register (T)

Address: 19

MSB															LSB
$-(2^7)$	2^6	2^5	2^4	2^3	2^2	2^1	2^0	.....	2^{-10}	2^{-11}	2^{-12}	2^{-13}	2^{-14}	2^{-15}	2^{-16}

T contains measurements from the on-chip temperature sensor. Measurements are performed during continuous conversions, with the default the Celsius scale (^oC). The value is represented in two's complement notation and in the range of $-128.0 \le T < 128.0$, with the binary point to the right of the eighth MSB.

6.1.15 Average and Instantaneous Reactive Power Register (Q_{AVG} , Q)

Address: 20 (Average Reactive Power) and 21 (Instantaneous Reactive Power)

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

The Instantaneous Reactive Power (Q) is the product of the voltage, shifted 90 degrees, and the current. The Average Reactive Power (Q_{AVG}) is Q averaged over N samples. The results are signed values with. The value is represented in two's complement notation and in the range of $-1.0 < Q, Q_{AVG} < 1.0$, with the binary point to the right of the MSB.

6.1.16 Peak Current and Peak Voltage Register (I_{peak} , V_{peak})

Address: 22 (Peak Currect) and 23 (Peak Voltage)

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

The Peak Current (I_{peak}) and Peak Voltage (V_{peak}) registers contain the instantaneous current and voltage with the greatest magnitude detected during the last computation cycle. The value is represented in two's complement notation and in the range of $-1.0 \le I_{peak}, V_{peak} < 1.0$, with the binary point to the right of the MSB.

6.1.17 Reactive Power Register (Q_{Trig})

Address: 24

MSB															LSB
0	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

The Reactive Power (Q_{Trig}) is calculated using trigonometric identities. (See Section 4.3 *Power Measurements* on page 14). The value is represented in unsigned notation and in the range of $0 \le S < 1.0$, with the binary point to the right of the MSB.

6.1.18 Power Factor Register (PF)

Address: 25

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Power Factor is calculated by dividing the Active (Real) Power by Apparent Power. The value is represented in two's complement notation and in the range of $-1.0 \le PF < 1.0$, with the binary point to the right of the MSB.

6.1.19 Apparent Power Register (S)

Address: 27

MSB															LSB
0	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Apparent power (S) is the product of the V_{RMS} and I_{RMS}, The value is represented in unsigned notation and in the range of $0 \le S < 1.0$, with the binary point to the right of the MSB.

6.1.20 Control Register (Ctrl)

Register Address: 28

23	22	21	20	19	18	17	16
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**
							STOP
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
			INTOD		NOCPU	NOOSC	

Default = 0x000000

STOP — Terminates the auto-boot sequence.
0 = Normal (default)
1 = Stop sequence

INTOD — Converts $\overline{INT}$ output pin to an open drain output.
0 = Normal (default)
1 = Open drain

NOCPU — Saves power by disabling the CPUCLK pin.
0 = Normal (default)
1 = Disables CPUCLK

NOOSC — Saves power by disabling the crystal oscillator.
0 = Normal (default)
1 = Disabling oscillator circuit

6.1.21 Harmonic Active Power Register (P_H)

Address: 29

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

The Harmonic Active Power (P_H) is calculated by subtracting the Fundamental Active Power from the Active (Real) Power. The value is represented in two's complement notation and in the range of $-1.0 \le P_H < 1.0$, with the binary point to the right of the MSB.

6.1.22 Fundamental Active Power Register (P_F)

Address: 30

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

The Fundamental Active Power (P_F) is calculated by performing a discrete Fourier transform (DFT) at the relevant frequency on the V and I channels. The results are multiplied to yield fundamental power. The value is represented in two's complement notation and in the range of $-1.0 \le P_H < 1.0$, with the binary point to the right of the MSB.

6.1.23 Fundamental Reactive Power Register (Q_H)

Address: 31 *(read only)*

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Fundamental Reactive Power (Q_H) is calculated by performing a discrete Fourier transform (DFT) at the relevant frequency on the V and I channels. The value is represented in two's complement notation and in the range of $-1.0 \le Q_H < 1.0$, with the binary point to the right of the MSB.

6.1.24 Page Register

Address: 31 (write only)

MSB						LSB
2^6	2^5	2^4	2^3	2^2	2^1	2^0

Default = 0x00

Determines which register page the serial port will access.

6.2 Page 1 Registers

6.2.1 Temperature Gain Register (T_{Gain})

Address: 2

MSB															LSB
2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^{-1}	.....	2^{-11}	2^{-12}	2^{-13}	2^{-14}	2^{-15}	2^{-16}	2^{-17}

Default = 0x34E2E7 = 26.443169

Sets the temperature channel gain. Temperature gain (T_{Gain}) is utilized to convert from one temperature scale to another. The Celsius scale (^oC) is the default. Values will be within in the range of $0 \le T_{Gain} < 128$. The value is represented in unsigned notation, with the binary point to the right of bit 7th MSB. See Section 5.7 *On-chip Temperature Sensor* on page 19.

6.2.2 Temperature Offset Register (T_{Off})

Address: 3

MSB															LSB
$-(2^0)$	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0xF3E7D0 = -0.094488

Temperature offset (T_{off}) is used to remove the temperature channel's offset at the zero degree reading. Values are represented in two's complement notation and in the range of $-1.0 \le T_{off} < 1.0$, with the binary point to the right of the MSB.

6.3 Page 3 Registers

6.3.1 *Voltage Sag and Current Fault* Duration *Registers ($VSAG_{Duration}$, $ISAG_{Duration}$)*

Address: 6 (Voltage Sag Duration); 10 (Current Fault Duration)

MSB															LSB
0	2^{22}	2^{21}	2^{20}	2^{19}	2^{18}	2^{17}	2^{16}	.....	2^{6}	2^{5}	2^{4}	2^{3}	2^{2}	2^{1}	2^{0}

Default = 0x000000

Voltage Sag Duration ($VSAG_{Duration}$) and Current Fault Duration ($ISAG_{Duration}$) defines the number of instantaneous measurements utilized to determine a sag event. Setting these register to zero will disable this feature. The value is represented in unsigned notation. See Section 5.6 *Sag and Fault Detect Feature* on page 19.

6.3.2 *Voltage Sag and Current Fault Level Registers ($VSAG_{Level}$, $ISAG_{Level}$)*

Address: 7 (*Voltage Sag Level*); 11 (*Current Fault Level*)

MSB															LSB
0	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	.....	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}

Default = 0x000000

Voltage Sag Level ($VSAG_{Level}$) and Current Fault Level ($ISAG_{Level}$) defines the voltage level that the magnitude of input samples, averaged over the sag duration, must fall below in order to register a sag/fault condition. These value are represented in unsigned notation and in the range of $0 \le VSAG_{Level} < 1.0$, with the binary point to the right of the third MSB. See Section 5.6 *Sag and Fault Detect Feature* on page 19.

7. SYSTEM CALIBRATION

7.1 Channel Offset and Gain Calibration

The CS5463 provides digital DC offset and gain compensation that can be applied to the instantaneous voltage and current measurements, and AC offset compensation to the voltage and current RMS calculations.

Since the voltage and current channels have independent offset and gain registers, system offset and/or gain can be performed on either channel without the calibration results from one channel affecting the other.

The computational flow of the calibration sequences are illustrated in Figure 12. The flow applies to both the voltage channel and current channel.

7.1.1 Calibration Sequence

The CS5463 must be operating in its active state and ready to accept valid commands. Refer to Section Section 5.15 *Commands* on page 23. The calibration algorithms are dependent on the value N in the *Cycle Count Register* (see Figure 12). Upon completion, the results of the calibration are available in their corresponding register. The DRDY bit in the *Status Register* will be set. If the DRDY bit is to be output on the $\overline{\text{INT}}$ pin, then DRDY bit in the Mask Register must be set. The initial values in the calibration registers do affect the results of the calibration results.

7.1.1.1 Duration of Calibration Sequence

The value of the *Cycle Count Register* (N) determines the number of conversions performed by the CS5463 during a given calibration sequence. For DC offset and gain calibrations, the calibration sequence takes at least N + 30 conversion cycles to complete. For AC offset calibrations, the sequence takes at least 6N + 30 ADC cycles to complete, (about 6 computation cycles). As N is increased, the accuracy of calibration results will increase.

7.1.2 Offset Calibration Sequence

For DC and AC offset calibrations, the VIN± pins of the voltage and IIN± pins of the current channels should be connected to their ground reference level. (see Figure 13.)

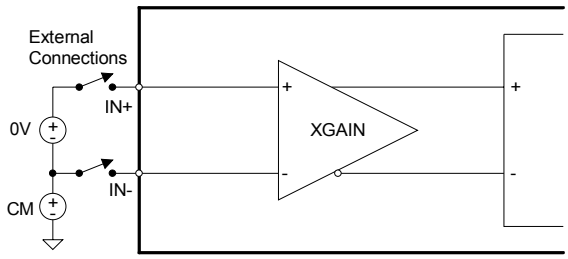


Figure 13. System Calibration of Offset

The AC offset registers must be set to the default (0x000000).

7.1.2.1 DC Offset Calibration Sequence

Channel gain should be set to 1.0 when performing DC offset calibration. Initiate a DC offset calibration. The DC offset registers are updated with the negative of the average of the instantaneous samples taken over a computational cycle. Upon completion of the DC offset calibration the DC offset is stored in the corresponding DC offset register. The DC offset value will be added to

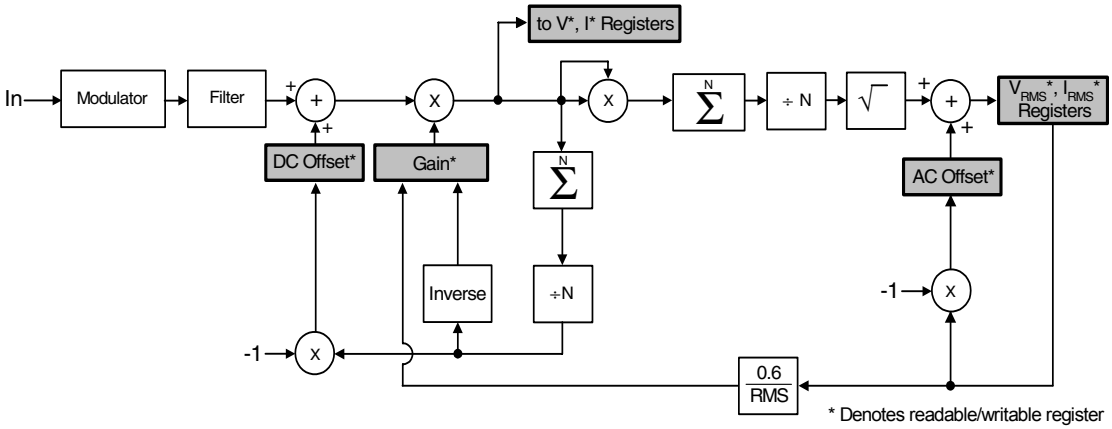


Figure 12. Calibration Data Flow

each instantaneous measurement to nullify the DC component present in the system during conversion commands.

7.1.2.2 AC Offset Calibration Sequence

Corresponding offset registers I_{ACoff} and/or V_{ACoff} should be cleared prior to initiating AC offset calibrations. Initiate an AC offset calibration.The AC offset registers are updated with an offset value that reflects the RMS output level. Upon completion of the AC offset calibration the AC offset is stored in the corresponding AC offset register. The AC offset register value is subtracted from each successive V_{RMS} and I_{RMS} calculation.

7.1.3 Gain Calibration Sequence

When performing gain calibrations, a reference signal should be applied to the VIN± pins of the voltage and IIN± pins of the current channels that represents the desired maximum signal level. Figure 14 shows the basic setup for gain calibration.

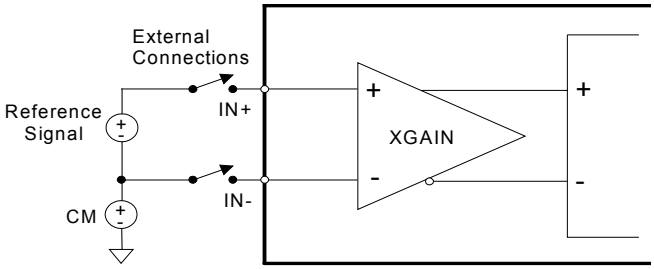


Figure 14. System Calibration of Gain.

For gain calibrations, there is an absolute limit on the RMS voltage levels that are selected for the gain calibration input signals. The maximum value that the gain registers can attain is 4. Therefore, if the signal level of the applied input is low enough that it causes the CS5463 to attempt to set either gain register higher than 4, the gain calibration result will be invalid and all CS5463 results obtained while performing measurements will be invalid.

If the channel gain registers are initially set to a gain other then 1.0, AC gain calibration should be used.

7.1.3.1 AC Gain Calibration Sequence

The corresponding gain register should be set to 1.0, unless a different initial gain value is desired. Initiate an AC gain calibration. The AC gain calibration algorithm computes the RMS value of the reference signal applied to the channel inputs. The RMS register value is then divided into 0.6 and the quotient is stored in the corresponding gain register. Each instantaneous measurement will be multiplied by its corresponding AC gain value.

A typical rms calibration value which allows for reasonable over-range margin would be 0.6 or 60% of the voltage and current channel's maximum input voltage level.

Two examples of AC gain calibration and the updated digital output codes of the channel's instantaneous data registers are shown in Figures 15 and 16. Figure 16

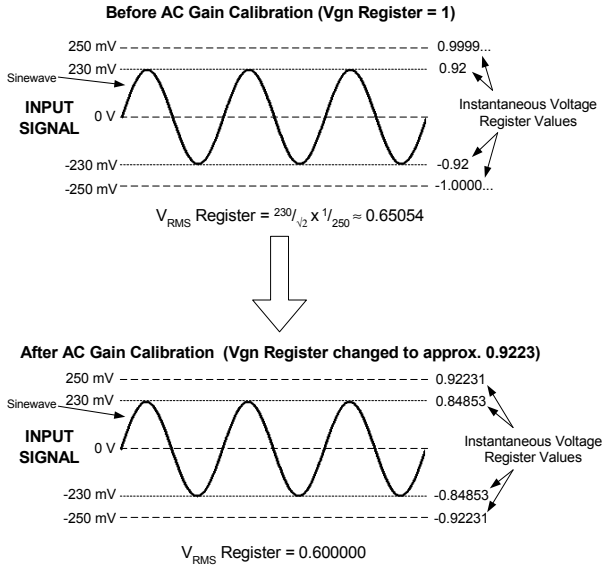


Figure 15. Example of AC Gain Calibration

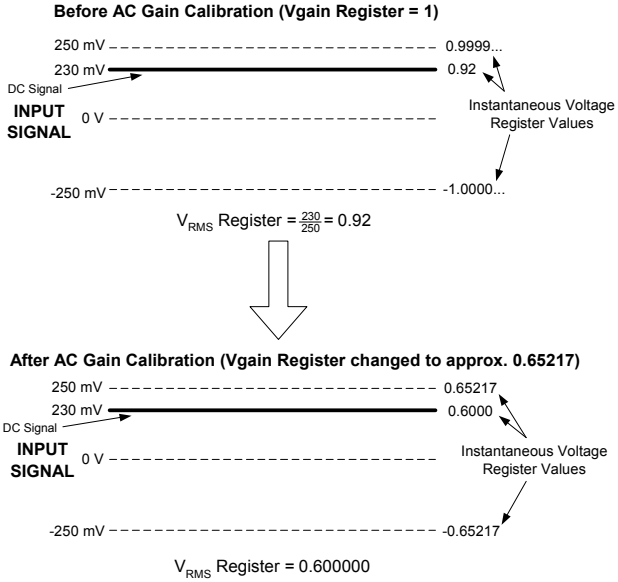


Figure 16. Example of AC Gain Calibration

shows that a positive (or negative) DC level signal can be used even though an AC gain calibration is being executed.

However, an AC signal cannot be used for DC gain calibration.

7.1.3.2 DC Gain Calibration Sequence

Initiate a DC gain calibration. The corresponding gain register is restored to default (1.0). The DC gain calibration averages the channel's instantaneous measurements over one computation cycle (N samples). The average is then divided into 1.0 and the quotient is stored in the corresponding gain register

After the DC gain calibration, the instantaneous register will read at full-scale whenever the DC level of the input signal is equal to the level of the DC calibration signal applied to the inputs during the DC gain calibration.The HPF option should not be enabled if DC gain calibration is utilized.

7.1.4 Order of Calibration Sequences

1. If the HPF option is enabled, then any DC component that may be present in the selected signal path will be removed and a DC offset calibration is not required. However, if the HPF option is disabled the DC offset calibration sequence should be performed.

   When using high-pass filters, it is recommended that the DC Offset register for the corresponding channel be set to zero. When performing DC offset calibration, the corresponding gain channel should be set to one.

2. If there is an AC offset in the V_{RMS} or I_{RMS} calculation, then the AC offset calibration sequence should be performed.
3. Perform the gain calibration sequence.
4. Finally, if an AC offset calibration was performed (step 2), then the AC offset may need to be adjusted to compensate for the change in gain (step 3). This can be accomplished by restoring zero to the AC offset register and then perform an AC offset calibration sequence. The adjustment could also be done by multiplying the AC offset register value that was calculated in step 2 by the gain calculated in step 3 and updating the AC offset register with the product.

7.2 Phase Compensation

The CS5463 is equipped with phase compensation to cancel out phase shifts introduced by the measurement element. Phase Compensation is set by bits PC[6:0] in the *Configuration Register*.

The default value of PC[6:0] is zero. With MCLK = 4.096 MHz and K = 1, the phase compensation has a range of ±2.8 degrees when the input signals are 60 Hz. Under these conditions, each step of the phase compensation register (value of one LSB) is approximately 0.04 degrees. For values of MCLK other than 4.096 MHz, the range and step size should be scaled by 4.096 MHz/(MCLK/K). For power line frequencies other than 60Hz, the values of the range and step size of the PC[6:0] bits can be determined by converting the above values from angular measurement into the time domain (seconds), and then computing the new range and step size (in degrees) with respect to the new line frequency.

7.3 Active Power Offset

The *Power Offset Register* can be used to offset system power sources that may be resident in the system, but do not originate from the power line signal. These sources of extra energy in the system contribute undesirable and false offsets to the power and energy measurement results. After determining the amount of stray power, the Power Offset Register can be set to cancel the effects of this unwanted energy.

8. AUTO-BOOT MODE USING E²PROM

When the CS5463 MODE pin is asserted (logic 1), the CS5463 *auto-boot mode* is enabled. In auto-boot mode, the CS5463 downloads the required commands and register data from an external serial E²PROM, allowing the CS5463 to begin performing energy measurements.

8.1 Auto-boot Configuration

A typical auto-boot serial connection between the CS5463 and a E²PROM is illustrated in Figure 17. In auto-boot mode, the CS5463's $\overline{CS}$ and SCLK are configured as outputs. The CS5463 asserts $\overline{CS}$ (logic 0), provides a clock on SCLK, and sends a read command to the E²PROM on SDO. The CS5463 reads the user-specified commands and register data presented on the SDI pin. The E²PROM's programmed data is utilized by the CS5463 to change the designated registers' default values and begin registering energy.

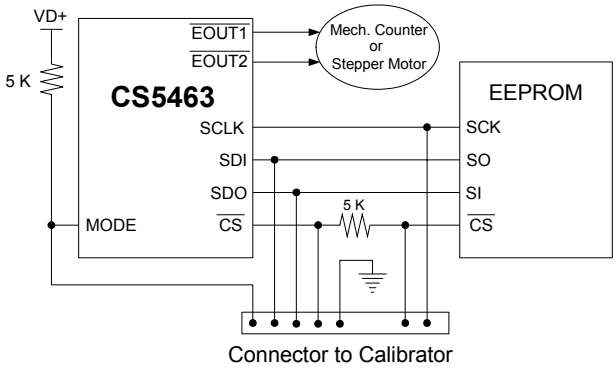


Figure 17. Typical Interface of E²PROM to CS5463

Figure 17 also shows the external connections that would be made to a calibrator device, such as a PC or custom calibration board. When the metering system is installed, the calibrator would be used to control calibration and/or to program user-specified commands and calibration values into the E²PROM. The user-specified commands/data will determine the CS5463's exact operation, when the auto-boot initialization sequence is running. Any of the valid commands can be used.

8.2 Auto-boot Data for E²PROM

Below is an example code set for an auto-boot sequence. This code is written into the E²PROM by the user. The serial data for such a sequence is shown below in single-byte hexidecimal notation:

-64 00 00 60
Write Operation Mode Register, turn high-pass filters on.
-44 7F C4 A9
Write value of 0x7FC4A9 to Current Gain Register.
-48 FF B2 53
Write value of 0xFFB253 to Voltage Gain Register.
-74 00 00 04
Unmask bit #2 (LSD) in the Mask Register.
-E8
Start continuous conversions
-78 00 01 00
Write STOP bit to Control Register, to terminate auto-boot initialization sequence.

8.3 Which E²PROMs Can Be Used?

Several industry-standard serial E²PROMs that will successfully run auto-boot with the CS5461A are listed below:

- Atmel AT25010, AT25020 or AT25040
- National Semiconductor NM25C040M8 or NM25020M8
- Xicor X25040SI

These types of serial E²PROMs expect a specific 8-bit command (00000011) in order to perform a memory read. The CS5461A has been hardware programmed to transmit this 8-bit command to the E²PROM at the beginning of the auto-boot sequence.

9. BASIC APPLICATION CIRCUITS

Figure 18 shows the CS5463 configured to measure power in a single-phase, 2-wire system while operating in a single-supply configuration. In this diagram, a shunt resistor is used to sense the line current and a voltage divider is used to sense the line voltage. In this type of shunt-resistor configuration, the common-mode level of the CS5466 must be referenced to the line side of the power line. This means that the common-mode potential of the CS5463 will track the high-voltage levels, as well as low-voltage levels, with respect to earth ground. Isolation circuitry is required when an earth-ground-referenced communication interface is connected.

Figure 19 shows the same single-phase, two-wire system with complete isolation from the power lines. This isolation is achieved using three transformers: a general purpose transformer to supply the on-board DC power; a high-precision, low-impedance voltage transformer, with very little roll-off/phase-delay, to measure voltage; and a current transformer to sense the line current.

Figure 20 shows a single-phase, 3-wire system. In many 3-wire residential power systems within the United States, only the two line terminals are available (neutral is not available). Figure 21 shows the CS5463 configured to meter a three-wire system with no neutral available.

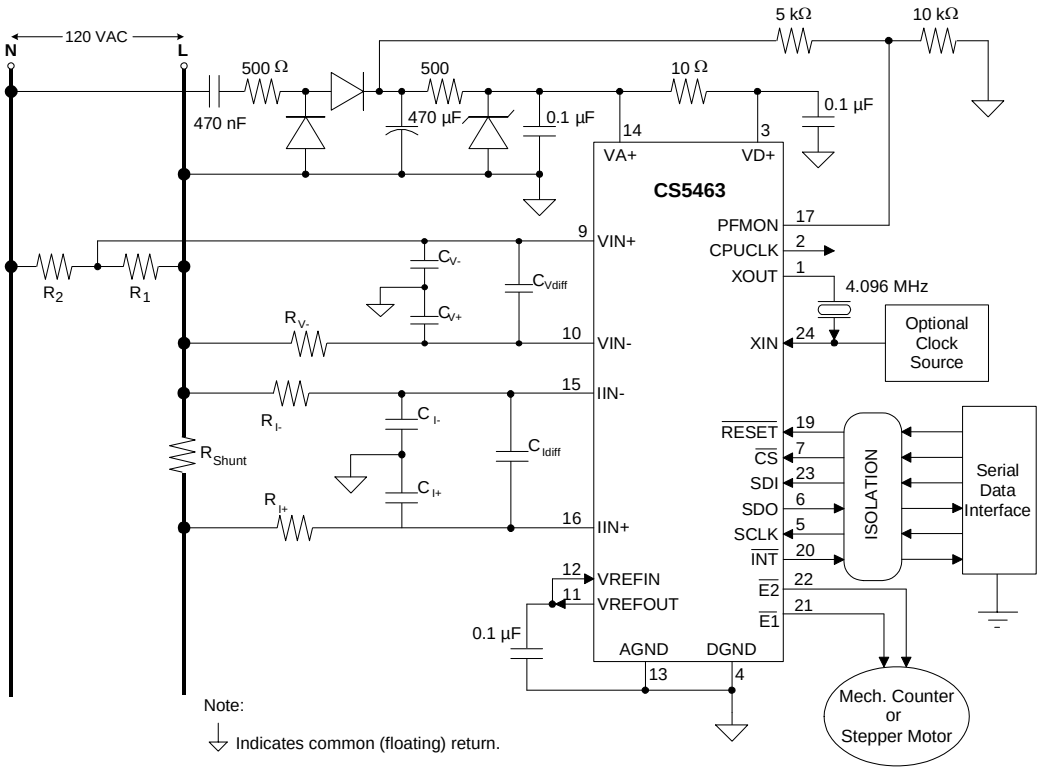


Figure 18. Typical Connection Diagram *(Single-phase, 2-wire – Direct Connect to Power Line)*

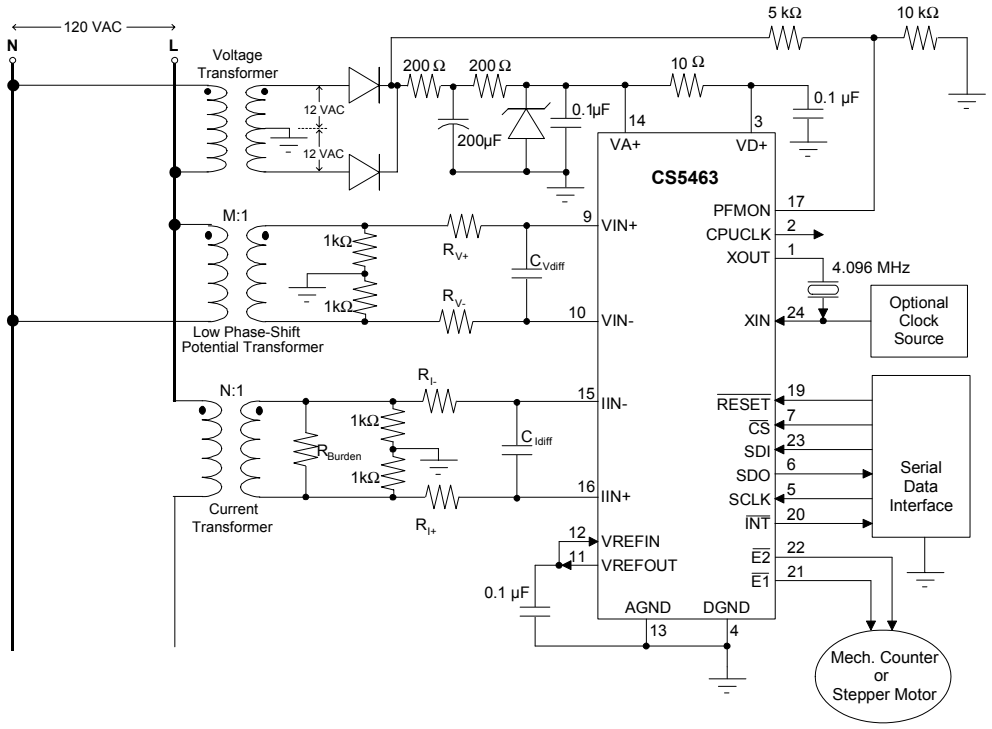


Figure 19. Typical Connection Diagram *(Single-phase, 2-wire – Isolated from Power Line)*

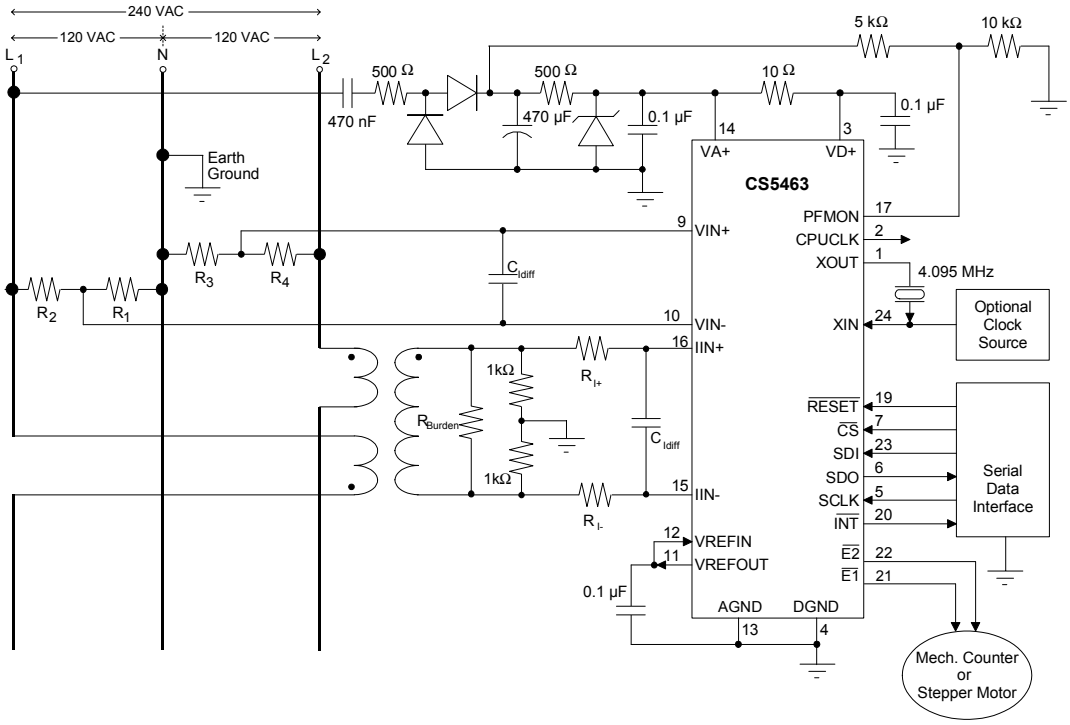


Figure 20. Typical Connection Diagram *(Single-phase, 3-wire)*

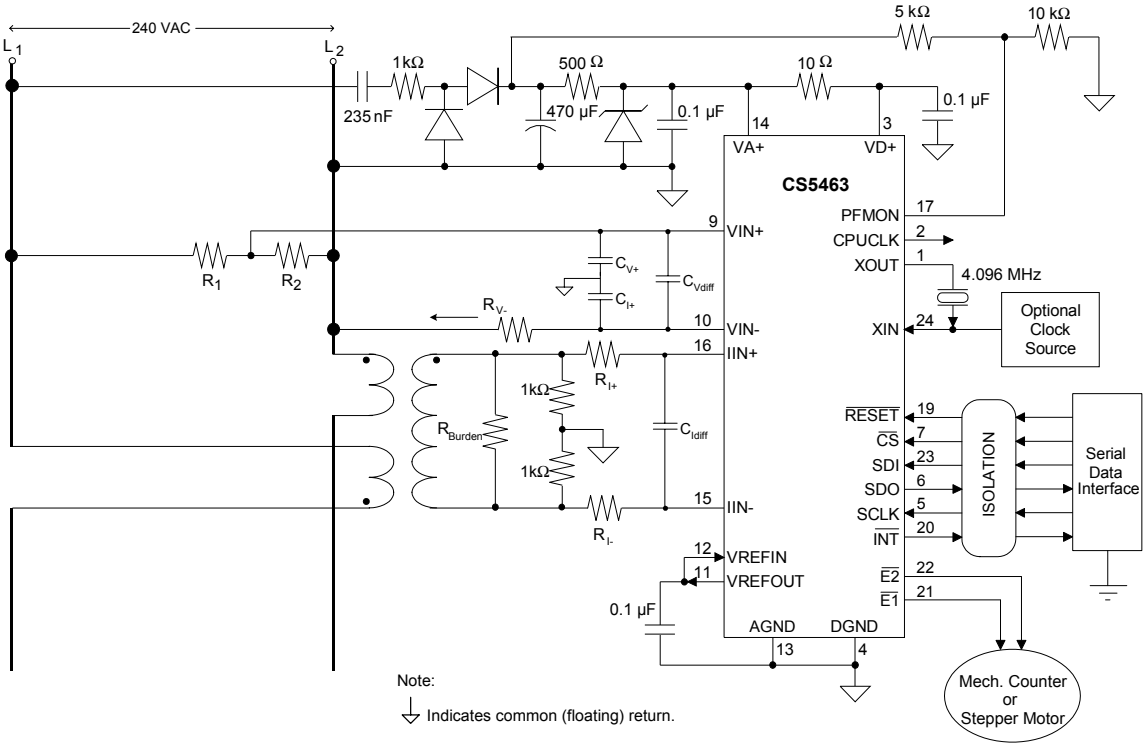
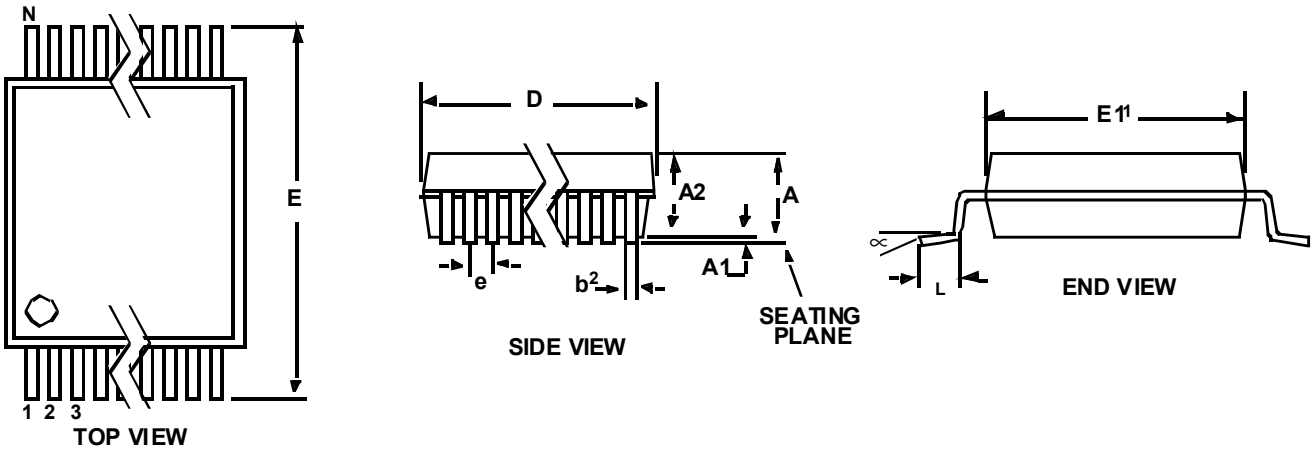


Figure 21. Typical Connection Diagram *(Single-phase, 3-wire – No Neutral Available)*

10.PACKAGE DIMENSIONS

24L SSOP PACKAGE DRAWING



	INCHES			MILLIMETERS			NOTE
DIM	MIN	NOM	MAX	MIN	NOM	MAX	
A	--	--	0.084	--	--	2.13	
A1	0.002	0.006	0.010	0.05	0.13	0.25	
A2	0.064	0.068	0.074	1.62	1.73	1.88	
b	0.009	--	0.015	0.22	--	0.38	2,3
D	0.311	0.323	0.335	7.90	8.20	8.50	1
E	0.291	0.307	0.323	7.40	7.80	8.20	
E1	0.197	0.209	0.220	5.00	5.30	5.60	1
e	0.022	0.026	0.030	0.55	0.65	0.75	
L	0.025	0.03	0.041	0.63	0.75	1.03	
∝	0°	4°	8°	0°	4°	8°	

JEDEC #: MO-150

Controlling Dimension is Millimeters.

Notes: 3. "D" and "E1" are reference datums and do not included mold flash or protrusions, but do include mold mismatch and are measured at the parting line, mold flash or protrusions shall not exceed 0.20 mm per side.

4. Dimension "b" does not include dambar protrusion/intrusion. Allowable dambar protrusion shall be 0.13 mm total in excess of "b" dimension at maximum material condition. Dambar intrusion shall not reduce dimension "b" by more than 0.07 mm at least material condition.

5. These dimensions apply to the flat section of the lead between 0.10 and 0.25 mm from lead tips.

11. ORDERING INFORMATION

Model	Temperature	Package
CS5463-IS	-40 to +85 °C	24-pin SSOP
CS5463-ISZ (lead free)		

12. ENVIRONMENTAL, MANUFACTURING, & HANDLING INFORMATION

Model Number	Peak Reflow Temp	MSL Rating*	Max Floor Life
CS5463-IS	240 °C	2	365 Days
CS5463-ISZ (lead free)	260 °C	3	7 Days

* MSL (Moisture Sensitivity Level) as specified by IPC/JEDEC J-STD-020.

13. REVISION HISTORY

Revision	Date	Changes
A1	MAR 2005	Advance Release
PP1	AUG 2005	First preliminary release, updated with most-current characterization data.

Contacting Cirrus Logic Support

For all product questions and inquiries contact a Cirrus Logic Sales Representative.

To find the one nearest to you go to www.cirrus.com