

# Single Phase, Bi-directional Power/Energy IC

## Features

- Energy Data Linearity:  $\pm 0.1\%$  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/ $^{\circ}$ C typ)
- Power Supply Monitor
- Simple Three-wire Digital Serial Interface
- "Auto-boot" Mode from Serial E<sup>2</sup>PROM
- Power Supply Configurations:  
VA+ = +5 V; AGND = 0 V; VD+ = +3.3 V to +5 V

## Description

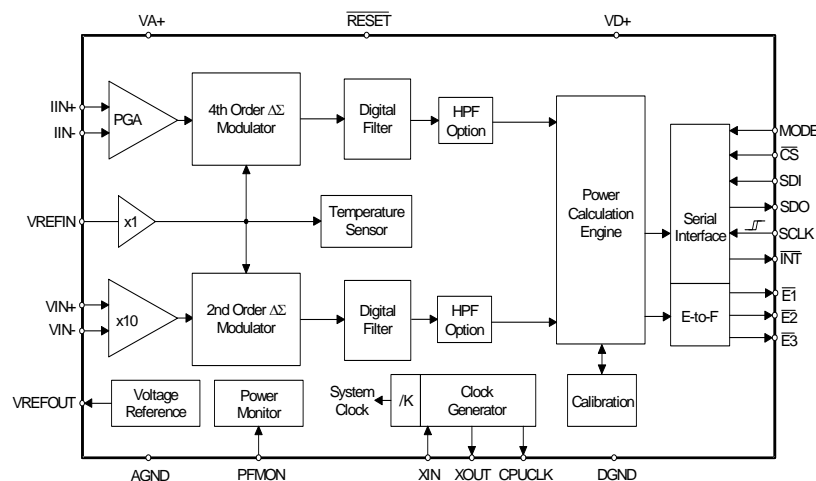
The CS5463 is an integrated power measurement device which combines two  $\Delta\Sigma$  analog-to-digital converters, power calculation engine, energy-to-frequency converter, and a serial interface on a single chip. It is designed to accurately measure instantaneous current and voltage, and calculate  $V_{RMS}$ ,  $I_{RMS}$ , 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 45](#).



**TABLE OF CONTENTS**

<b>1. Overview</b>	<b>5</b>
<b>2. Pin Description</b>	<b>6</b>
<b>3. Characteristics &amp; Specifications</b>	<b>7</b>
<b>4. Theory of Operation</b>	<b>14</b>
4.1 Digital Filters	14
4.2 Voltage and Current Measurements	14
4.3 Power Measurements	14
4.4 Linearity Performance	15
<b>5. Functional Description</b>	<b>16</b>
5.1 Analog Inputs	16
5.1.1 Voltage Channel	16
5.1.2 Current Channel	16
5.2 IIR Filters	16
5.3 High-pass Filters	16
5.4 Performing Measurements	16
5.5 Energy Pulse Output	17
5.5.1 Active Energy	17
5.5.2 Apparent Energy Mode	18
5.5.3 Reactive Energy Mode	18
5.5.4 Voltage Channel Sign Mode	18
5.5.5 PFMON Output Mode	19
5.5.6 Design Example	19
5.6 Sag and Fault Detect Feature	19
5.7 No Load Threshold	19
5.8 On-chip Temperature Sensor	19
5.9 Voltage Reference	20
5.10 System Initialization	20
5.11 Power-down States	20
5.12 Oscillator Characteristics	20
5.13 Event Handler	21
5.13.1 Typical Interrupt Handler	21
5.14 Serial Port Overview	21
5.14.1 Serial Port Interface	21
5.15 Register Paging	22
5.16 Commands	23
5.16.1 Start Conversions	23
5.16.2 SYNC0 and SYNC1	23
5.16.3 Power-up/Halt	23
5.16.4 Power-down and Software Reset	23
5.16.5 Register Read/Write	24
5.16.6 Calibration	25
<b>6. Register Description</b>	<b>26</b>
6.1 Page 0 Registers	26
6.1.1 Configuration Register ( Config )	26
6.1.2 Current and Voltage DC Offset Register ( $I_{DCoff}$ , $V_{DCoff}$ )	27
6.1.3 Current and Voltage Gain Register ( $I_{gn}$ , $V_{gn}$ )	27
6.1.4 Cycle Count Register ( Cycle Count )	27
6.1.5 PulseRateE Register ( PulseRateE )	27
6.1.6 Instantaneous Current, Voltage, and Power Registers ( I , V , P )	28

6.1.7 Active (Real) Power Register ( $P_{Active}$ )	28
6.1.8 RMS Current & Voltage Registers ( $I_{RMS}$ , $V_{RMS}$ )	28
6.1.9 Epsilon Register ( $\epsilon$ )	28
6.1.10 Power Offset Register ( $P_{off}$ )	29
6.1.11 Status Register and Mask Register ( Status , Mask )	29
6.1.12 Current and Voltage AC Offset Register ( $V_{ACoff}$ , $I_{ACoff}$ )	30
6.1.13 Operational Mode Register ( Mode )	30
6.1.14 Temperature Register ( T )	31
6.1.15 Average and Instantaneous Reactive Power Register ( $Q_{AVG}$ , Q )	31
6.1.16 Peak Current and Peak Voltage Register ( $I_{peak}$ , $V_{peak}$ )	31
6.1.17 Reactive Power Register ( $Q_{Trig}$ )	32
6.1.18 Power Factor Register ( PF )	32
6.1.19 Apparent Power Register ( S )	32
6.1.20 Control Register ( Ctrl )	33
6.1.21 Harmonic Active Power Register ( $P_H$ )	33
6.1.22 Fundamental Active Power Register ( $P_F$ )	33
6.1.23 Fundamental Reactive Power Register ( $Q_H$ )	34
6.1.24 Page Register	34
6.2 Page 1 Registers	35
6.2.1 Energy Pulse Output Width ( PulseWidth )	35
6.2.2 No Load Threshold ( Load <sub>Min</sub> )	35
6.2.3 Temperature Gain Register ( $T_{Gain}$ )	35
6.2.4 Temperature Offset Register ( $T_{Off}$ )	35
6.3 Page 3 Registers	36
6.3.1 Voltage Sag & Current Fault Duration Registers	36
6.3.2 Voltage Sag & Current Fault Level Registers	36
<b>7. System Calibration</b>	<b>37</b>
7.1 Channel Offset and Gain Calibration	37
7.1.1 Calibration Sequence	37
7.1.1.1 Duration of Calibration Sequence	37
7.1.2 Offset Calibration Sequence	37
7.1.2.1 DC Offset Calibration Sequence	37
7.1.2.2 AC Offset Calibration Sequence	38
7.1.3 Gain Calibration Sequence	38
7.1.3.1 AC Gain Calibration Sequence	38
7.1.3.2 DC Gain Calibration Sequence	39
7.1.4 Order of Calibration Sequences	39
7.2 Phase Compensation	39
7.3 Active Power Offset	39
<b>8. Auto-boot Mode Using E<sup>2</sup>PROM</b>	<b>40</b>
8.1 Auto-boot Configuration	40
8.2 Auto-boot Data for E <sup>2</sup> PROM	40
8.3 Which E <sup>2</sup> PROMs Can Be Used?	40
<b>9. Basic Application Circuits</b>	<b>41</b>
<b>10. Package Dimensions</b>	<b>44</b>
<b>11. Ordering Information</b>	<b>45</b>
<b>12. Environmental, Manufacturing, &amp; Handling Information</b>	<b>45</b>
<b>13. Revision History</b>	<b>46</b>

**LIST OF FIGURES**

Figure 1. CS5463 Read and Write Timing Diagrams.....	12
Figure 2. Timing Diagram for $\overline{E1}$ , $\overline{E2}$ , and $\overline{E3}$ .....	13
Figure 3. Data Measurement Flow Diagram. ....	14
Figure 4. Power Calculation Flow. ....	15
Figure 5. Active and Reactive Energy Pulse Outputs .....	17
Figure 6. Apparent Energy Pulse Outputs .....	18
Figure 7. Voltage Channel Sign Pulse outputs .....	18
Figure 8. PFMON Output to Pin $\overline{E3}$ .....	19
Figure 9. Sag and Fault Detect .....	19
Figure 10. Oscillator Connection.....	20
Figure 11. CS5463 Memory Map.....	22
Figure 12. Calibration Data Flow .....	37
Figure 13. System Calibration of Offset .....	37
Figure 14. System Calibration of Gain. ....	38
Figure 15. Example of AC Gain Calibration .....	38
Figure 16. Example of AC Gain Calibration .....	38
Figure 17. Typical Interface of E <sup>2</sup> PROM to CS5463.....	40
Figure 18. Typical Connection Diagram ( <i>Single-phase, 2-wire</i> ).....	41
Figure 20. Typical Connection Diagram ( <i>Single-phase, 3-wire</i> ).....	42
Figure 19. Typical Connection Diagram ( <i>Single-phase, 2-wire – Isolated from Power Line</i> ).....	42
Figure 21. Typical Connection Diagram ( <i>Single-phase, 3-wire – No Neutral Available</i> ).....	43

**LIST OF TABLES**

Table 1. Current Channel PGA Setting .....	16
Table 2. $\overline{E2}$ Pin Configuration .....	17
Table 3. $\overline{E3}$ Pin Configuration .....	17
Table 4. Interrupt Configuration .....	21

## 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  $\Delta\Sigma$  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.  $\bar{E}1$ ,  $\bar{E}2$ , and  $\bar{E}3$  are designed to interface to a microprocessor.

## 2. PIN DESCRIPTION

Crystal Out	<b>XOUT</b>	1 ●	24	<b>XIN</b>	Crystal In
CPU Clock Output	<b>CPUCLK</b>	2	23	<b>SDI</b>	Serial Data Input
Positive Digital Supply	<b>VD+</b>	3	22	<b>E2</b>	Energy Output 2
Digital Ground	<b>DGND</b>	4	21	<b>E1</b>	Energy Output 1
Serial Clock	<b>SCLK</b>	5	20	<b>INT</b>	Interrupt
Serial Data Output	<b>SDO</b>	6	19	<b>RESET</b>	Reset
Chip Select	<b>CS</b>	7	18	<b>E3</b>	High Frequency Energy Output
Mode Select	<b>MODE</b>	8	17	<b>PFMON</b>	Power Fail Monitor
Differential Voltage Input	<b>VIN+</b>	9	16	<b>IIN+</b>	Differential Current Input
Differential Voltage Input	<b>VIN-</b>	10	15	<b>IIN-</b>	Differential Current Input
Voltage Reference Output	<b>VREFOUT</b>	11	14	<b>VA+</b>	Positive Analog Supply
Voltage Reference Input	<b>VREFIN</b>	12	13	<b>AGND</b>	Analog Ground

### Clock Generator

<b>Crystal Out</b>	1,24	<b>XOUT, XIN</b> – 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.
<b>Crystal In</b>		
<b>CPU Clock Output</b>	2	<b>CPUCLK</b> – Output of on-chip oscillator which can drive one standard CMOS load.

### Control Pins and Serial Data I/O

<b>Serial Clock Input</b>	5	<b>SCLK</b> – 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.
<b>Serial Data Output</b>	6	<b>SDO</b> – Serial port data output pin. SDO is forced into a high-impedance state when $\overline{CS}$ is high.
<b>Chip Select</b>	7	$\overline{CS}$ – Low, activates the serial port interface.
<b>Mode Select</b>	8	<b>MODE</b> - High, enables the “auto-boot” mode. The mode pin has an internal pull-down resistor.
<b>Energy Output</b>	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. E1, E2, E3 outputs are configured in the Operational Modes Register.
<b>Reset</b>	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.
<b>Interrupt</b>	20	$\overline{INT}$ - Low, indicates that an enabled event has occurred.
<b>Serial Data Input</b>	23	<b>SDI</b> - Serial port data input pin. Data will be input at a rate determined by SCLK.

### Analog Inputs/Outputs

<b>Differential Voltage Inputs</b>	9,10	<b>VIN+, VIN-</b> – Differential analog input pins for the voltage channel.
<b>Differential Current Inputs</b>	15,16	<b>IIN+, IIN-</b> – Differential analog input pins for the current channel.
<b>Voltage Reference Output</b>	11	<b>VREFOUT</b> – 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.
<b>Voltage Reference Input</b>	12	<b>VREFIN</b> – The input to this pin establishes the voltage reference for the on-chip modulator.

### Power Supply Connections

<b>Positive Digital Supply</b>	3	<b>VD+</b> – The positive digital supply.
<b>Digital Ground</b>	4	<b>DGND</b> – Digital Ground.
<b>Positive Analog Supply</b>	14	<b>VA+</b> – The positive analog supply.
<b>Analog Ground</b>	13	<b>AGND</b> – Analog ground.
<b>Power Fail Monitor</b>	17	<b>PFMON</b> – 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 <sub>A</sub>	-40	-	+85	°C

#### ANALOG CHARACTERISTICS

- Min / Max characteristics and specifications are guaranteed over all *Recommended Operating Conditions*.
- Typical characteristics and specifications are measured at nominal supply voltages and T<sub>A</sub> = 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	
<b>Accuracy</b>						
Active Power (Note 1)	All Gain Ranges Input Range 0.1% - 100%	P <sub>Active</sub>	-	±0.1	-	%
Average Reactive Power (Note 1 and 2)	All Gain Ranges Input Range 0.1% - 100%	Q <sub>Avg</sub>	-	±0.2	-	%
Power Factor (Note 1 and 2)	All Gain Ranges Input Range 1.0% - 100%	PF	-	±0.2	-	%
	Input Range 0.1% - 1.0%		-	±0.27	-	%
Current RMS (Note 1)	All Gain Ranges Input Range 0.2% - 100%	I <sub>RMS</sub>	-	±0.2	-	%
	Input Range 0.1% - 0.2%		-	±1.5	-	%
Voltage RMS (Note 1)	All Gain Ranges Input Range 5% - 100%	V <sub>RMS</sub>	-	±0.1	-	%
<b>Analog Inputs (Both Channels)</b>						
Common Mode Rejection	(DC, 50, 60 Hz)	CMRR	80	-	-	dB
Common Mode + Signal	All Gain Ranges		-0.25	-	VA+	V
<b>Analog Inputs (Current Channel)</b>						
Differential Input Range [(IIN+) - (IIN-)]	(Gain = 10)	IIN	-	500	-	mV <sub>P-P</sub>
	(Gain = 50)		-	100	-	mV <sub>P-P</sub>
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)	IC	-	32	-	pF
	(Gain = 50)		-	52	-	pF
Effective Input Impedance		EII	30	-	-	kΩ
Noise (Referred to Input)	(Gain = 10)	N <sub>I</sub>	-	22.5	-	μV <sub>rms</sub>
	(Gain = 50)		-	4.5	-	μV <sub>rms</sub>
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	
<b>Analog Inputs (Voltage Channel)</b>						
Differential Input Range [(VIN+) - (VIN-)]	VIN	-	500	-	mV <sub>P-P</sub>	
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 <sub>V</sub>	-	140	-	μV <sub>rms</sub>	
Offset Drift (Without the High Pass Filter)	OD	-	16.0	-	μV/°C	
Gain Error (Note 3)	GE	-	±3.0		%	
<b>Temperature Channel</b>						
Temperature Accuracy	T	-	±5	-	°C	
<b>Power Supplies</b>						
Power Supply Currents (Active State)	I <sub>A+</sub>	PSCA	-	1.1	-	mA
	I <sub>D+</sub> (VA+ = VD+ = 5 V)	PSCD	-	2.9	-	mA
	I <sub>D+</sub> (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. Measurement method 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 V<sub>eq</sub>. 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 = 0, the voltage at which LSD 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
<b>Reference Output</b>					
Output Voltage	VREFOUT	+2.4	+2.5	+2.6	V
Temperature Coefficient (Note 8)	TC <sub>VREF</sub>	-	25	60	ppm/°C
Load Regulation (Note 9)	ΔV <sub>R</sub>	-	6	10	mV
<b>Reference Input</b>					
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:

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

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

**DIGITAL CHARACTERISTICS**

- Min / Max characteristics and specifications are guaranteed over all *Recommended 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
<b>Master Clock Characteristics</b>					
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	%
<b>Filter Characteristics</b>					
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
<b>Input/Output Characteristics</b>					
High-level Input Voltage All Pins Except XIN and SCLK and $\overline{\text{RESET}}$	V <sub>IH</sub>	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) All Pins Except XIN and SCLK and $\overline{\text{RESET}}$	V <sub>IL</sub>	-	-	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) All Pins Except XIN and SCLK and RESET	$V_{IL}$	-	-	0.48	V
XIN		-	-	0.3	V
SCLK and 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 (Note 16)	$I_{in}$	-	$\pm 1$	$\pm 10$	$\mu A$
3-state Leakage Current	$I_{OZ}$	-	-	$\pm 10$	$\mu A$
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".
16. The MODE pin is pulled low by an internal resistor.

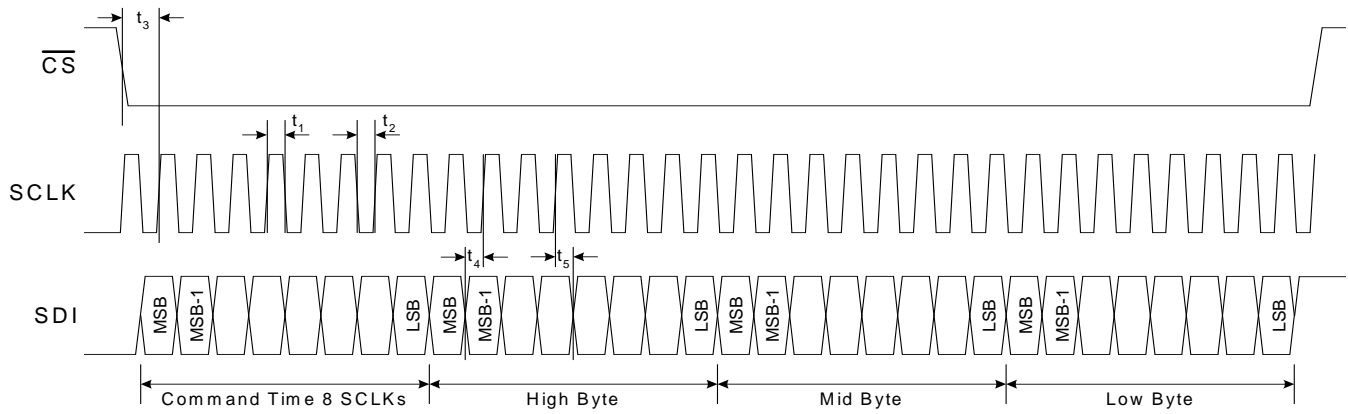
**SWITCHING CHARACTERISTICS**

- Min / Max characteristics and specifications are guaranteed over all *Recommended 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+.

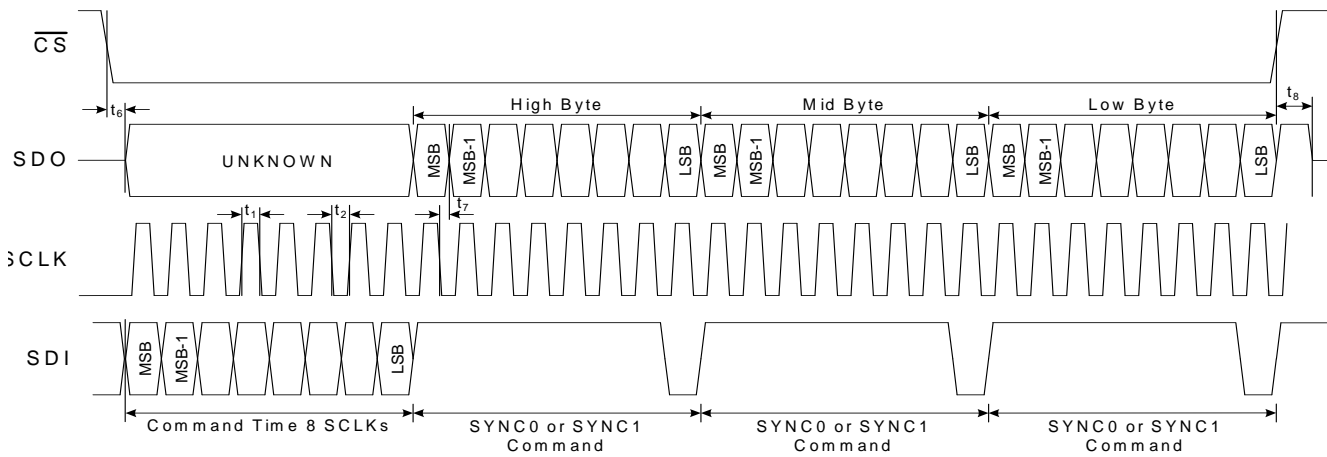
Parameter	Symbol	Min	Typ	Max	Unit	
Rise Times (Note 17)	Any Digital Input Except SCLK	t <sub>rise</sub>	-	-	1.0	µs
	SCLK	-	-	100	µs	
	Any Digital Output	-	50	-	ns	
Fall Times (Note 17)	Any Digital Input Except SCLK	t <sub>fall</sub>	-	-	1.0	µs
	SCLK	-	-	100	µs	
	Any Digital Output	-	50	-	ns	
<b>Start-up</b>						
Oscillator Start-up Time	XTAL = 4.096 MHz (Note 18)	t <sub>ost</sub>	-	60	-	ms
<b>Serial Port Timing</b>						
Serial Clock Frequency	SCLK	-	-	2		MHz
Serial Clock	Pulse Width High	t <sub>1</sub>	200	-	-	ns
	Pulse Width Low	t <sub>2</sub>	200	-	-	ns
<b>SDI Timing</b>						
CS Falling to SCLK Rising	t <sub>3</sub>	50	-	-		ns
Data Set-up Time Prior to SCLK Rising	t <sub>4</sub>	50	-	-		ns
Data Hold Time After SCLK Rising	t <sub>5</sub>	100	-	-		ns
<b>SDO Timing</b>						
CS Falling to SDI Driving	t <sub>6</sub>	-	20	50		ns
SCLK Falling to New Data Bit (hold time)	t <sub>7</sub>	-	20	50		ns
CS Rising to SDO Hi-Z	t <sub>8</sub>	-	20	50		ns
<b>Auto-Boot Timing</b>						
Serial Clock	Pulse Width Low	t <sub>9</sub>		8		MCLK
	Pulse Width High	t <sub>10</sub>		8		MCLK
MODE setup time to RESET Rising	t <sub>11</sub>	50				ns
RESET rising to CS falling	t <sub>12</sub>	48				MCLK
CS falling to SCLK rising	t <sub>13</sub>	100	8			MCLK
SCLK falling to CS rising	t <sub>14</sub>		16			MCLK
CS rising to driving MODE low (to end auto-boot sequence)	t <sub>15</sub>	50				ns
SDO guaranteed setup time to SCLK rising	t <sub>16</sub>	100				ns

Notes: 17. Specified using 10% and 90% points on waveform of interest. Output loaded with 50 pF.

18. 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)**

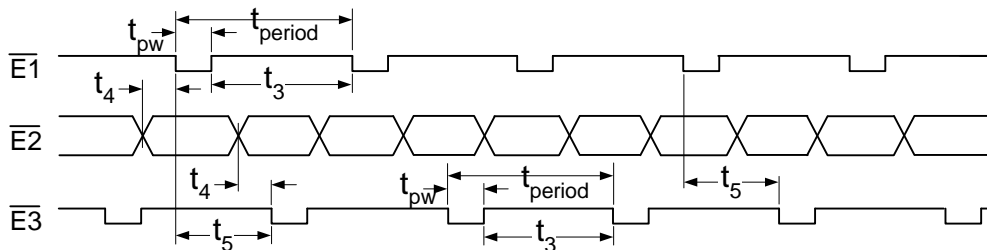
**Figure 1. CS5463 Read and Write Timing Diagrams**

**SWITCHING CHARACTERISTICS** (Continued)

Parameter	Symbol	Min	Typ	Max	Unit
<b><math>\overline{E1}</math>, <math>\overline{E2}</math>, and <math>\overline{E3}</math> Timing</b> (Note 19 and 20)					
Period	$t_{\text{period}}$	250	-	-	$\mu\text{s}$
Pulse Width	$t_{\text{pw}}$	244	-	-	$\mu\text{s}$
Rising Edge to Falling Edge	$t_3$	6	-	-	$\mu\text{s}$
$\overline{E2}$ Setup to $\overline{E1}$ and/or $\overline{E3}$ Falling Edge	$t_4$	1.5	-	-	$\mu\text{s}$
$\overline{E1}$ Falling Edge to $\overline{E3}$ Falling Edge	$t_5$	248	-	-	$\mu\text{s}$

Notes: 19. Pulse output timing is specified at MCLK = 4.096 MHz, E2MODE = 0, and E3MODE[1:0] = 0. Refer to [Section 5.5 Energy Pulse Output](#) on page 17 for more information on pulse output pins.

20. 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 21 and 22)					
Positive Digital	VD+	-0.3	-	+6.0	V
Positive Analog	VA+	-0.3	-	+6.0	V
Input Current, Any Pin Except Supplies (Notes 23, 24, 25)	$I_{\text{IN}}$	-	-	$\pm 10$	mA
Output Current, Any Pin Except VREFOUT	$I_{\text{OUT}}$	-	-	100	mA
Power Dissipation (Note 26)	$P_{\text{D}}$	-	-	500	mW
Analog Input Voltage All Analog Pins	$V_{\text{INA}}$	- 0.3	-	(VA+) + 0.3	V
Digital Input Voltage All Digital Pins	$V_{\text{IND}}$	-0.3	-	(VD+) + 0.3	V
Ambient Operating Temperature	$T_{\text{A}}$	-40	-	85	$^{\circ}\text{C}$
Storage Temperature	$T_{\text{stg}}$	-65	-	150	$^{\circ}\text{C}$

Notes: 21. VA+ and AGND must satisfy  $[(\text{VA}+) - (\text{AGND})] \leq + 6.0 \text{ V}$ .

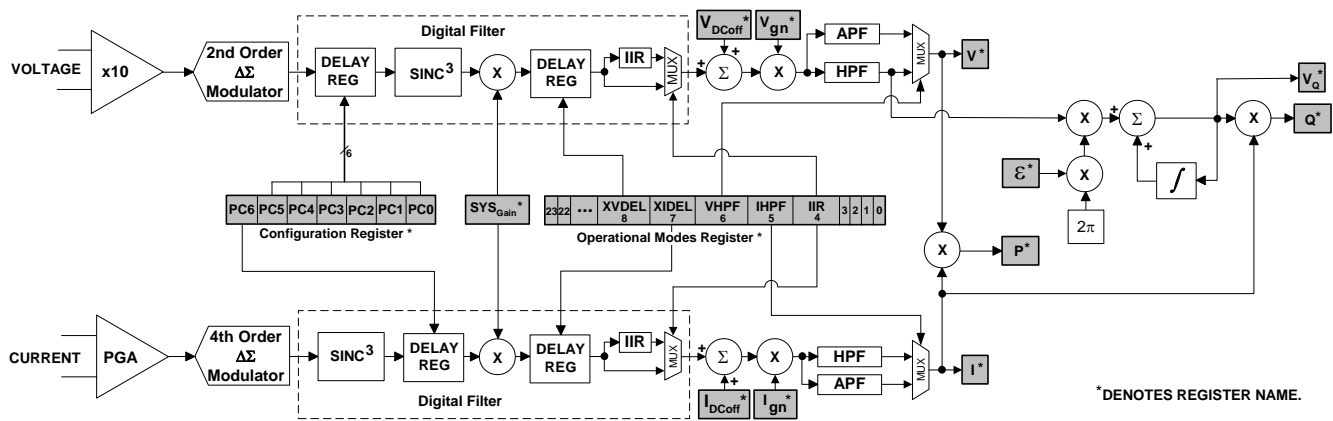
22. VD+ and AGND must satisfy  $[(\text{VD}+) - (\text{AGND})] \leq + 6.0 \text{ V}$ .

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

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

25. Maximum DC input current for a power supply pin is  $\pm 50 \text{ mA}$ .

26. 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  $V_{IN\pm}$  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  $I_{IN\pm}$  and is subject to 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 only 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 37). The calibrated measurement is available by reading the instantaneous voltage and current registers.

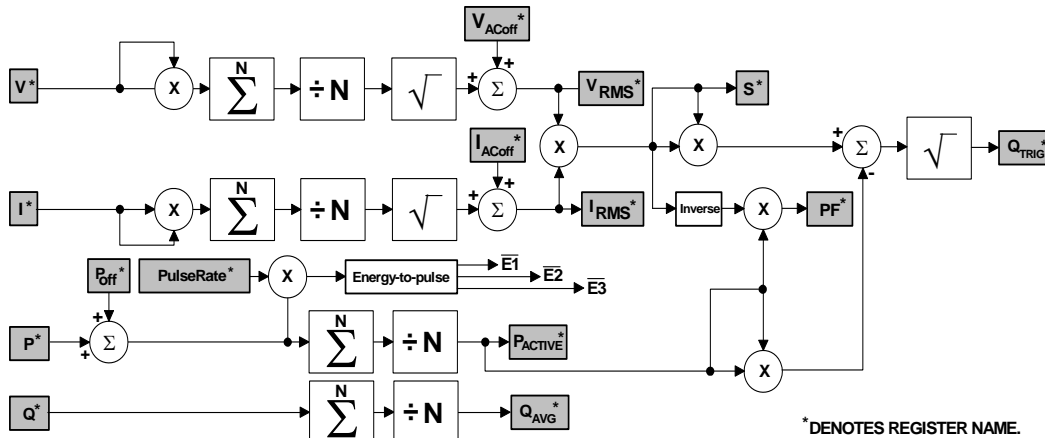
The Root Mean Square (RMS in Figure 4) calculations are performed on N instantaneous voltage and current samples,  $V_n$  and  $I_n$ , respectively (where N is the cycle count), using the formula:

$$I_{RMS} = \sqrt{\frac{\sum_{n=0}^{N-1} I_n^2}{N}}$$

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 output  $\overline{E1}$ . 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 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 ( $\epsilon$ ) 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  $\pm 0.1\%$  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  $\pm 0.1\%$ . (See Section 7. [System Calibration](#) on page 37.) 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  $V_{IN\pm}$  and  $I_{IN\pm}$  are designated as the voltage and current channel inputs, respectively. The full-scale differential input voltage for the current and voltage channel is  $\pm 250$  mV<sub>P</sub>.

#### 5.1.1 Voltage Channel

The output of the line voltage resistive divider or transformer is connected to the  $V_{IN+}$  and  $V_{IN-}$  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  $\pm 250$  mV. If the input signal is a sine wave the maximum RMS voltage at a gain 10x is:

$$\frac{250\text{mV}_P}{\sqrt{2}} \cong 176.78\text{mV}_{\text{RMS}}$$

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  $I_{IN+}$  and  $I_{IN-}$  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  $I_{\text{gain}}$  (see Table 1) defines the two gain selections and corresponding maximum input-signal level.

$I_{\text{gain}}$	Maximum Input Range	
0	$\pm 250$ mV	10x
1	$\pm 50$ mV	50x

**Table 1. Current Channel PGA Setting**

For example, if  $I_{\text{gain}}=0$ , 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  $\pm 250$  mV<sub>P</sub>. 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 facilitates 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  $IIR$  engages the IIR filters in both the voltage and current channels.

### 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  $V_{\text{RMS}}$ ,  $I_{\text{RMS}}$ , and apparent power. *Operational Mode Register* bits  $V_{\text{HPF}}$  and  $I_{\text{HPF}}$  activate the HPF in the voltage and current channel respectively. When a high-pass filter is active in only one channel, an all-pass filter (APF) is applied to the other channel. The APF has an amplitude response that is flat within the channel bandwidth and is used for matching phase in systems where only one HPF is engaged.

### 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

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

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

The RMS voltage ( $V_{\text{RMS}}$ ), RMS current ( $I_{\text{RMS}}$ ), and active power ( $P_{\text{active}}$ ) 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  $V_{\text{RMS}}$  and  $I_{\text{RMS}}$ . A computation cycle is derived from the master clock (MCLK), with frequency:

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

Under default conditions and with  $K = 1$ ,  $N = 4000$ , and  $\text{MCLK} = 4.096$  MHz – the  $\text{OWR} = 4000$  Hz and the  $\text{Computation Cycle} = 1$  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  $\overline{\text{CRDY}}$  bit will be set in the *Status Register*, and the  $\overline{\text{INT}}$  pin will become active if the CRDY bit is unmasked in the *Mask Register*. At the end of each computation cycle, the  $\overline{\text{DRDY}}$  bit will be set in the *Status Register*, and the  $\overline{\text{INT}}$  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 ( $\epsilon$ ) is the ratio of the input line frequency ( $f_i$ ) to the sample frequency ( $f_s$ ) of the ADC.

$$\epsilon = f_i / f_s$$

where  $f_s = \text{MCLK} / (K \cdot 1024)$ . 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

$$\epsilon = 50 \text{ Hz} / 4000 \text{ Hz} = 0.0125$$

and

$$\epsilon = 60 \text{ Hz} / 4000 \text{ Hz} = 0.015$$

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, E1 registers active energy, E3 registers reactive energy, and E2 indicates the sign of both active and reactive energy. (See Figure 2. [Timing Diagram for E1, E2, and E3](#) on page13.) The E1 pulse output is designed to register the Active Energy. The 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	$\overline{\text{E2}}$ Output Mode
0	Sign of Energy
1	Apparent Energy

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

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

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

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

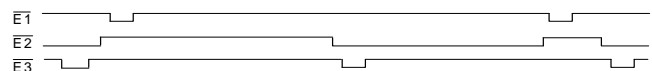
$$t_{pw}(\text{sec}) \cong \text{PulseWidth} \cdot \frac{1}{(\text{MCLK}/K) / 1024}$$

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

### 5.5.1 Active Energy

The  $\overline{\text{E1}}$  pin produces active-low pulses with an output frequency proportional to the active power. The  $\overline{\text{E2}}$  pin is the energy direction indicator. Positive energy is represented by  $\overline{\text{E1}}$  pin falling while the  $\overline{\text{E2}}$  is high. Negative energy is represented by the  $\overline{\text{E1}}$  pin falling while the  $\overline{\text{E2}}$  is low. The  $\overline{\text{E1}}$  and  $\overline{\text{E2}}$  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 of  $\overline{E1}$ , the following transfer function can be utilized:

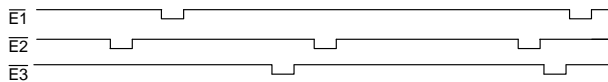
$$FREQ_P = \frac{VIN \times VGAIN \times IIN \times IGAIN \times PF \times PulseRate}{VREFIN^2}$$

$FREQ_P$  = 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  
 $PulseRate$  =  $PulseRateE \times (MCLK/K)/2048$  [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

Pin  $\overline{E2}$  outputs apparent energy pulses when the *Operational Mode Register* bit  $E2MODE = 1$ . Pin  $\overline{E3}$  outputs apparent energy pulses when the *Operational Mode Register* bits  $E3MODE[1:0] = 3$  (11b). Figure 6 illustrates the pulse output format with apparent energy on  $\overline{E2}$  ( $E2MODE = 1$  and  $E3MODE[1:0] = 0$ )



**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  
 $PulseRate$  =  $PulseRateE \times (MCLK/K)/2048$  [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  $E3MODE[1:0] = 0$  (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:

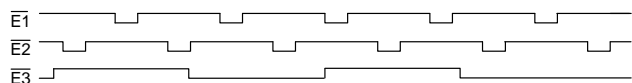
$$FREQ_Q = \frac{VIN \times VGAIN \times IIN \times IGAIN \times PQ \times PulseRate}{VREFIN^2}$$

$FREQ_Q$  = 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  
 $PQ = \sqrt{1 - PF^2}$   
 $PulseRate$  =  $PulseRateE \times (MCLK/K)/2048$  [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 bits  $E3MODE[1:0] = 2$  (10b) 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  $\overline{E3}$

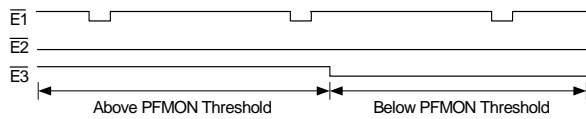


**Figure 7. Voltage Channel Sign Pulse outputs**

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

### 5.5.5 PFMON Output Mode

Setting bit  $E3MODE[1:0] = 1$  (01b) in the *Operational Mode Register* outputs the state of 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 than the threshold, pin  $\overline{E3}$  is high and when PFMON is less than 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<sub>p</sub>. (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:

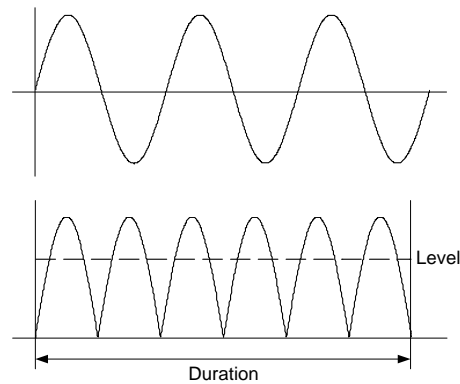
$$\text{PulseRateE} = \frac{\text{PulseRate}}{(\text{MCLK}/\text{K}) / 2048} = 0.2104377$$

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 than half of the sag duration (see Figure 9).

To activate voltage sag detection, 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 detection, 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 No Load Threshold

The *No Load Threshold* register ( $\text{Load}_{\text{Min}}$ ) is used to disable the active energy pulse output when the magnitude of the  $P_{\text{Active}}$  register is less than the value in the  $\text{Load}_{\text{Min}}$  register.

### 5.8 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* ( $T_{\text{gain}}$ ) and *Temperature Offset Register* ( $T_{\text{off}}$ ) 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:

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

The *Cycle Count Register* (N) must be set to a value greater than 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* ( $T_{\text{off}}$ ) by the differential temperature ( $\Delta T$ ) measured from a calibrated digital thermometer and the CS5463 temperature sensor. A one-degree adjustment to the *Temperature Register* (T) is achieved by adding  $2.737649 \times 10^{-4}$  to the *Temperature Offset Register* ( $T_{\text{off}}$ ). Therefore,

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

if  $T_{\text{off}} = -0.0951126$  and  $\Delta T = -2.0$  ( $^{\circ}\text{C}$ ), then

$$T_{\text{off}} = [-0.0951126 + (-2.0 \times 2.737649 \cdot 10^{-4})] = -0.09566$$

or 0xF3C168 (2's complement notation) is stored in the *Temperature Offset Register* ( $T_{\text{off}}$ ).

To convert the *Temperature Register* (T) from a Celsius scale ( $^{\circ}\text{C}$ ) to a Fahrenheit scale ( $^{\circ}\text{F}$ ) utilize the formula

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

Applying the above relationship to the CS5461A temperature measurement algorithm

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

If  $T_{\text{off}} = -0.09566$  and  $T_{\text{gain}} = 23.507$  for a Celsius scale, then the modified values are  $T_{\text{off}} = -0.09079$  (0xF460E1) and  $T_{\text{gain}} = 42.3132$  (0x54A05E) for a Fahrenheit scale.

## 5.9 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.

## 5.10 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.

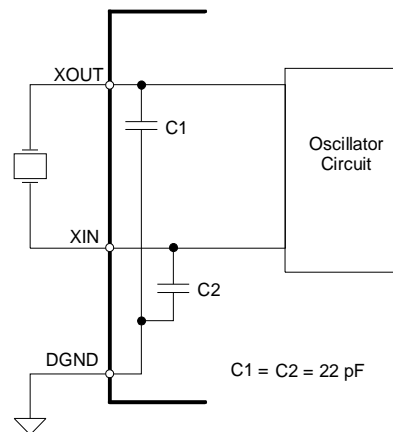
## 5.11 Power-down States

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 5.10 *System Initialization* on page 20).

## 5.12 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



**Figure 10. Oscillator Connection**





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, DCLK will equal 3 MHz, which is a valid value for DCLK.

### 5.13 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).

#### 5.13.1 Typical Interrupt Handler

The steps below show how interrupts can be handled.

##### INITIALIZATION:

- 1) All Status bits are cleared by writing 0xFFFFF 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.

### 5.14 Serial Port Overview

The CS5463 incorporates a serial port transmit and receive buffer with a command decoder that interprets one-byte (8-bit) commands as they are received. There are four types of commands: instructions, synchronizing, register writes, and register reads (See Section 5.16 *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 for writing to and reading from the serial port receive and transmit buffer, respectively. While reading data from the serial port, commands and data can be written simultaneously. 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.

#### 5.14.1 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 (logic 0). 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. Therefore, the serial port interface must then be re-initialized by one of the following actions:

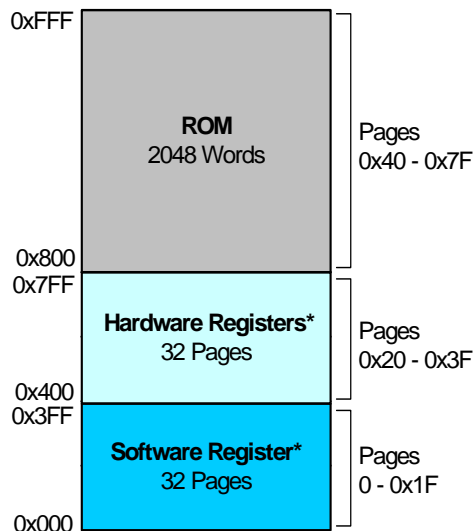
- Drive the  $\overline{CS}$  pin high, then low.
- Hardware Reset (drive  $\overline{RESET}$  pin low for at least 10  $\mu$ s).
- Issue the *Serial Port Initialization Sequence*, which is 3 (or more) SYNC1 command bytes (0xFF) followed by one SYNC0 command byte (0xFE).

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

### 5.15 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.



\* Accessed using register read/write commands.

**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



## 5.16 Commands

All commands are 8 bits in length. Any command byte value 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.

### 5.16.1 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

### 5.16.2 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.

### 5.16.3 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.

### 5.16.4 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

### 5.16.5 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 24<sup>th</sup> SCLK.

W/ $\bar{R}$             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 $\bar{A/D}$ conversions used in one computation cycle (N).
6	00110	PulseRateE	Sets the $\bar{E}1$ , $\bar{E}2$ and $\bar{E}3$ 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	$\epsilon$ (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	10110	$I_{Peak}$	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**

<u>Address</u>	<u>RA[4:0]</u>	<u>Name</u>	<u>Description</u>
0	00000	PulseWidth	Energy Pulse Output Width
1	00001	Load <sub>Min</sub>	No Load Threshold
2	00010	T <sub>Gain</sub>	Temperature Sensor Gain
3	00011	T <sub>off</sub>	Temperature Sensor Offset

**Register Page 3**

<u>Address</u>	<u>RA[4:0]</u>	<u>Name</u>	<u>Description</u>
6	00110	VSAG <sub>Duration</sub>	Voltage sag sample interval
7	00111	VSAG <sub>Level</sub>	Voltage sag level
10	01010	ISAG <sub>Duration</sub>	Current fault sample interval
11	01011	ISAG <sub>Level</sub>	Current fault level

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

**5.16.6 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

<b>23</b>	<b>22</b>	<b>21</b>	<b>20</b>	<b>19</b>	<b>18</b>	<b>17</b>	<b>16</b>
PC6	PC5	PC4	PC3	PC2	PC1	PC0	lgain
<b>15</b>	<b>14</b>	<b>13</b>	<b>12</b>	<b>11</b>	<b>10</b>	<b>9</b>	<b>8</b>
EWA	-	-	IMODE	IINV	-	-	-
<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
-	-	-	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 39 for more information.

**lgain** 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  $-1.0 \leq I_{DCoff}, V_{DCoff} < 1.0$ , with the binary point to the right of the MSB. See Section 7.1.2.1 [DC Offset Calibration Sequence](#) on page 37 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  $0.0 \leq I_{gn}, V_{gn} < 3.9999$ , 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 =  $(MCLK \times PulseRateE) / 2048$  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  $-1.0 \leq PulseRateE < 1.0$ , 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  $-1.0 \leq I, V, P < 1.0$ , with the binary point to the right of the MSB.

### 6.1.7 Active (Real) Power Register ( P<sub>Active</sub> )

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<sub>Active</sub>). The value will be within in the range of  $-1.0 \leq P_{Active} < 1.0$ . 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<sub>RMS</sub> , V<sub>RMS</sub> )

Address: 11 (I<sub>RMS</sub>); 12 (V<sub>RMS</sub>)

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<sub>RMS</sub> and V<sub>RMS</sub> 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  $0.0 \leq I_{RMS}, V_{RMS} < 1.0$ , with the binary point to the left of the MSB.

### 6.1.9 Epsilon Register ( ε )

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 (ε) 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  $-1.0 \leq \epsilon < 1.0$ , 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  $-1.0 \leq P_{off} < 1.0$ , 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 = 0x800001 (*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 its 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 <i>Instantaneous Current Register</i> overflows.
VOR	Voltage Out of Range. Set when the <i>Instantaneous Voltage Register</i> overflows.
IROR	$I_{RMS}$ Out of Range. Set when the <i><math>I_{RMS}</math> Register</i> overflows.
VROR	$V_{RMS}$ Out of Range. Set when the <i><math>V_{RMS}</math> Register</i> overflows.
EOR	Energy Out of Range. Set when $P_{ACTIVE}$ overflows.
IFault	Indicates a current fault has occurred. See Section 5.6 <a href="#">Sag and Fault Detect Feature</a> on page 19.
VSAG	Indicates a voltage sag has occurred. See Section 5.6 <a href="#">Sag and Fault Detect Feature</a> on page 19.
TUP	Temperature Updated. Indicates the <i>Temperature Register</i> 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 oscil-



lates 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 (PML0), 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).
- FUP Epsilon Updated. Indicates completion of a line frequency measurement and update of Epsilon.
- $\overline{IC}$  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)

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

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  $-1.0 \leq V_{ACoff}, I_{ACoff} < 1.0$ , with the binary point to the right of the MSB

### 6.1.13 Operational Mode Register ( *Mode* )

Address: 18

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

Default = 0x000000

- E2MODE  $\overline{E2}$  Output Mode  
0 = Energy Sign (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 (VHPF) Enables the high-pass filter on the current (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.

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

E3MODE[1:0]  $\overline{\text{E3}}$  Output Mode  
 00 = Reactive Power (default)  
 01 = PFMON  
 10 = Voltage sign  
 11 = Apparent Power

POS Positive Energy Only. Negative energy pulses on  $\overline{\text{E1}}$  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 (°C). The value is represented in two's complement notation and in the range of  $-128.0 \leq T < 128.0$ , 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 Current) 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  $-1.0 \leq I_{peak}, V_{peak} < 1.0$ , with the binary point to the right of the MSB.

**6.1.17 Reactive Power Register (  $Q_{Trig}$  )**

Address: 24

<b>MSB</b>														<b>LSB</b>	
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  $0 \leq S < 1.0$ , with the binary point to the right of the MSB.

**6.1.18 Power Factor Register (  $PF$  )**

Address: 25

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

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  $-1.0 \leq PF < 1.0$ , with the binary point to the right of the MSB.

**6.1.19 Apparent Power Register (  $S$  )**

Address: 27

<b>MSB</b>														<b>LSB</b>	
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  $0 \leq S < 1.0$ , with the binary point to the right of the MSB.

**6.1.20 Control Register ( Ctrl )**

Register Address: 28

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

Default = 0x000000

- STOP            Terminates the auto-boot sequence.  
 0 = Normal (default)  
 1 = Stop sequence
- INTOD           Converts  $\overline{\text{INT}}$  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<sub>H</sub> )**

Address: 29

<b>MSB</b>														<b>LSB</b>	
-(2 <sup>0</sup> )	2 <sup>-1</sup>	2 <sup>-2</sup>	2 <sup>-3</sup>	2 <sup>-4</sup>	2 <sup>-5</sup>	2 <sup>-6</sup>	2 <sup>-7</sup>	.....	2 <sup>-17</sup>	2 <sup>-18</sup>	2 <sup>-19</sup>	2 <sup>-20</sup>	2 <sup>-21</sup>	2 <sup>-22</sup>	2 <sup>-23</sup>

The Harmonic Active Power (P<sub>H</sub>) 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  $-1.0 \leq P_H < 1.0$ , with the binary point to the right of the MSB.

**6.1.22 Fundamental Active Power Register ( P<sub>F</sub> )**

Address: 30

<b>MSB</b>														<b>LSB</b>	
-(2 <sup>0</sup> )	2 <sup>-1</sup>	2 <sup>-2</sup>	2 <sup>-3</sup>	2 <sup>-4</sup>	2 <sup>-5</sup>	2 <sup>-6</sup>	2 <sup>-7</sup>	.....	2 <sup>-17</sup>	2 <sup>-18</sup>	2 <sup>-19</sup>	2 <sup>-20</sup>	2 <sup>-21</sup>	2 <sup>-22</sup>	2 <sup>-23</sup>

The Fundamental Active Power (P<sub>F</sub>) 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  $-1.0 \leq P_H < 1.0$ , 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  $-1.0 \leq Q_H < 1.0$ , 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 Energy Pulse Output Width ( *PulseWidth* )

Address: 0

MSB														LSB	
0	2 <sup>22</sup>	2 <sup>21</sup>	2 <sup>20</sup>	2 <sup>19</sup>	2 <sup>18</sup>	2 <sup>17</sup>	2 <sup>16</sup>	.....	2 <sup>6</sup>	2 <sup>5</sup>	2 <sup>4</sup>	2 <sup>3</sup>	2 <sup>2</sup>	2 <sup>1</sup>	2 <sup>0</sup>

Default = 1

*PulseWidth* sets the duration of energy pulses ( $t_{PW}$ ). The actual pulse duration is the contents of *PulseWidth* divided by the output word rate (OWR). *PulseWidth* is an integer in the range of 1 to 8388607.

### 6.2.2 No Load Threshold ( *Load<sub>Min</sub>* )

Address: 1

MSB														LSB	
-(2 <sup>0</sup> )	2 <sup>-1</sup>	2 <sup>-2</sup>	2 <sup>-3</sup>	2 <sup>-4</sup>	2 <sup>-5</sup>	2 <sup>-6</sup>	2 <sup>-7</sup>	.....	2 <sup>-17</sup>	2 <sup>-18</sup>	2 <sup>-19</sup>	2 <sup>-20</sup>	2 <sup>-21</sup>	2 <sup>-22</sup>	2 <sup>-23</sup>

Default = 0

*Load<sub>Min</sub>* is used to set the no load threshold. When the magnitude of the  $P_{Active}$  register is less than *Load<sub>Min</sub>*, the active energy pulse output will be disabled. *Load<sub>Min</sub>* is a two's complement value in the range of  $-1.0 \leq Load_{Min} < 1.0$ , with the binary point to the right of the MSB. Negative values are not used.

### 6.2.3 Temperature Gain Register ( *T<sub>Gain</sub>* )

Address: 2

MSB														LSB	
2 <sup>6</sup>	2 <sup>5</sup>	2 <sup>4</sup>	2 <sup>3</sup>	2 <sup>2</sup>	2 <sup>1</sup>	2 <sup>0</sup>	2 <sup>-1</sup>	.....	2 <sup>-11</sup>	2 <sup>-12</sup>	2 <sup>-13</sup>	2 <sup>-14</sup>	2 <sup>-15</sup>	2 <sup>-16</sup>	2 <sup>-17</sup>

Default = 0x2F03C3 = 23.5073471

Sets the temperature channel gain. Temperature gain ( $T_{Gain}$ ) is utilized to convert from one temperature scale to another. The Celsius scale (°C) is the default. Values will be within in the range of  $0 \leq T_{Gain} < 128$ . The value is represented in unsigned notation, with the binary point to the right of bit 7th MSB. See Section 5.8 [On-chip Temperature Sensor](#) on page 19.

### 6.2.4 Temperature Offset Register ( *T<sub>Off</sub>* )

Address: 3

MSB														LSB	
-(2 <sup>0</sup> )	2 <sup>-1</sup>	2 <sup>-2</sup>	2 <sup>-3</sup>	2 <sup>-4</sup>	2 <sup>-5</sup>	2 <sup>-6</sup>	2 <sup>-7</sup>	.....	2 <sup>-17</sup>	2 <sup>-18</sup>	2 <sup>-19</sup>	2 <sup>-20</sup>	2 <sup>-21</sup>	2 <sup>-22</sup>	2 <sup>-23</sup>

Default = 0xF3D35A = -0.0951126

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  $-1.0 \leq T_{off} < 1.0$ , 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  $0 \leq VSAG_{Level} < 1.0$ , 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 5.16 [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 INT pin, then DRDY bit in the Mask Register must be set. The initial values in the AC gain and offset registers do affect the results of the calibration results.

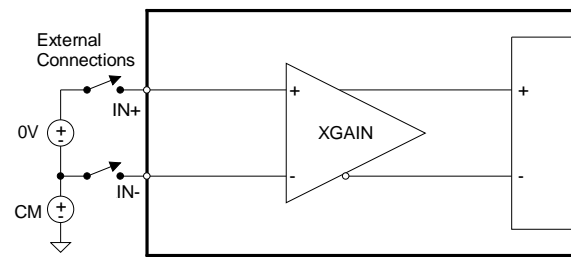
##### 7.1.1.1 Duration of Calibration Sequence

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  $V_{IN\pm}$  pins of the voltage and  $I_{IN\pm}$  pins of the current channels should be connected to their ground reference level. (see Figure 13.)

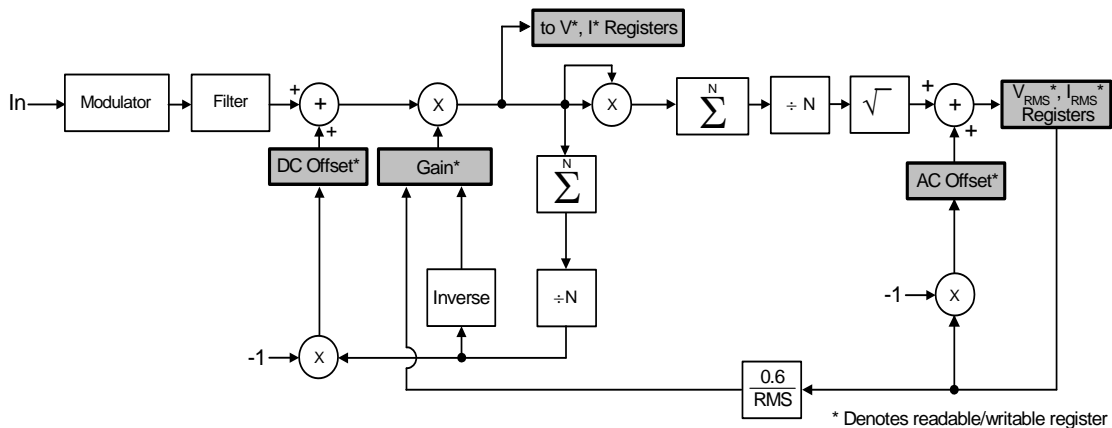


**Figure 13. System Calibration of Offset**

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 collected 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**

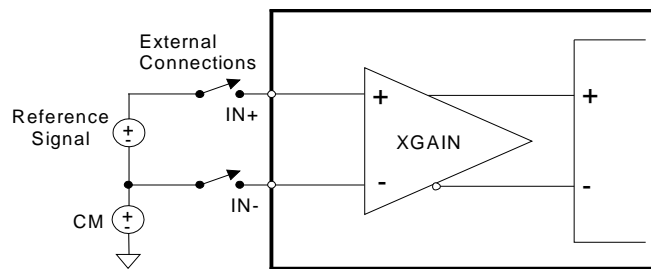
each instantaneous measurement to nullify the DC component present in the system during conversion commands.

### 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  $VIN_{\pm}$  pins of the voltage and  $IIN_{\pm}$  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.

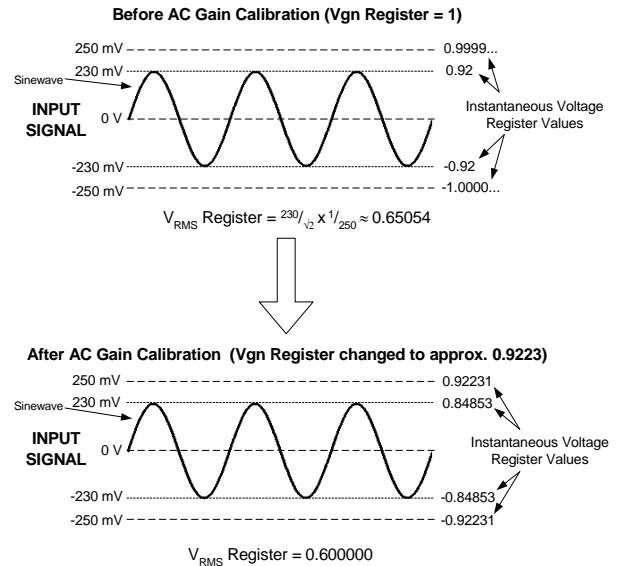
If the channel gain registers are initially set to a gain other than 1.0, AC gain calibration should be used.

#### 7.1.3.1 AC Gain Calibration Sequence

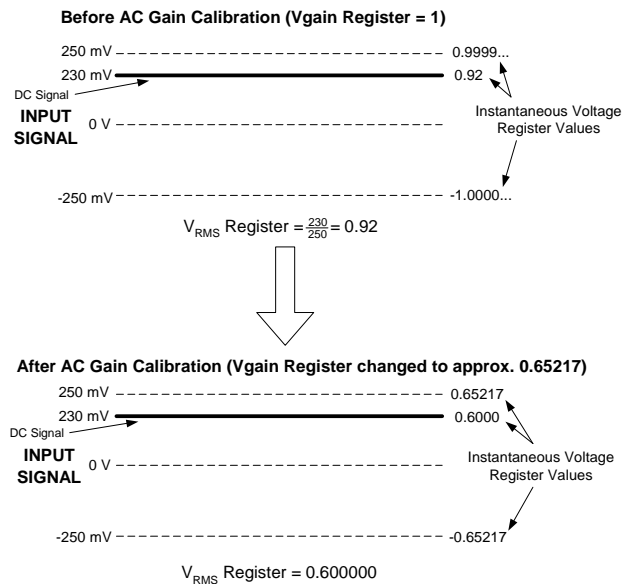
The corresponding gain register should be set to 1.0, unless a different initial gain value is desired. Initiate an AC gain calibration. The AC gain calibration algorithm computes the RMS value of the reference signal applied to the channel inputs. The RMS register value is then divided into 0.6 and 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 cal-

culated 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* and bits XVDEL and XIDEL in the *Operational Mode Register*

The default value of PC[6:0], XVDEL, and XIDEL is zero. With MCLK = 4.096 MHz and K = 1, the phase compensation has a range of  $\pm 8.1$  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  $4.096 \text{ MHz}/(\text{MCLK}/K)$ . 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. To calculate the phase shift induced between the voltage and the current channel use the equation:

$$\text{Phase} = \frac{\text{Freq} \times 360^\circ \times (\text{PC}[5:0] - (\text{PC}[6] \times 64) + (\text{XDEL} \times 128))}{(\text{MCLK}/K)/8}$$

Freq = Line Frequency [Hz]  
XDEL = XVDEL or -XIDEL

## 7.3 Active Power Offset

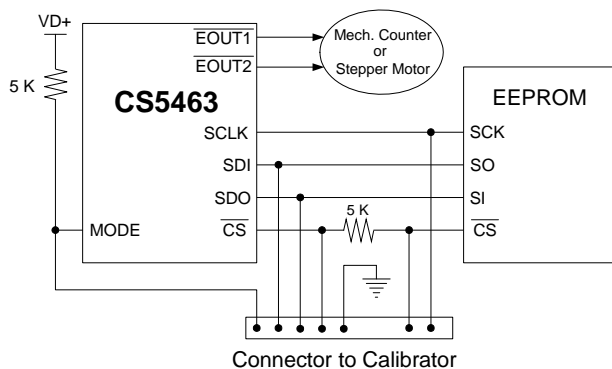
The *Power Offset Register* can be used to offset system power sources that may be resident in the system, but do not originate from the power line signal. These sources of extra energy in the system contribute undesirable and false offsets to the power and energy measurement results. After determining 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 E<sup>2</sup>PROM

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 E<sup>2</sup>PROM, allowing the CS5463 to begin performing energy measurements.

### 8.1 Auto-boot Configuration

A typical auto-boot serial connection between the CS5463 and an E<sup>2</sup>PROM 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 E<sup>2</sup>PROM on SDO. The CS5463 reads the user-specified commands and register data presented on the SDI pin. The E<sup>2</sup>PROM's programmed data is utilized by the CS5463 to change the designated registers' default values and begin registering energy.



**Figure 17. Typical Interface of E<sup>2</sup>PROM 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 E<sup>2</sup>PROM. 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 E<sup>2</sup>PROM

Below is an example code set for an auto-boot sequence. This code is written into the E<sup>2</sup>PROM by the user. The serial data for such a sequence is shown below in single-byte hexadecimal 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 E<sup>2</sup>PROMs Can Be Used?

Several industry-standard serial E<sup>2</sup>PROMs 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 E<sup>2</sup>PROMs 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 E<sup>2</sup>PROM 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 CS5463 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.

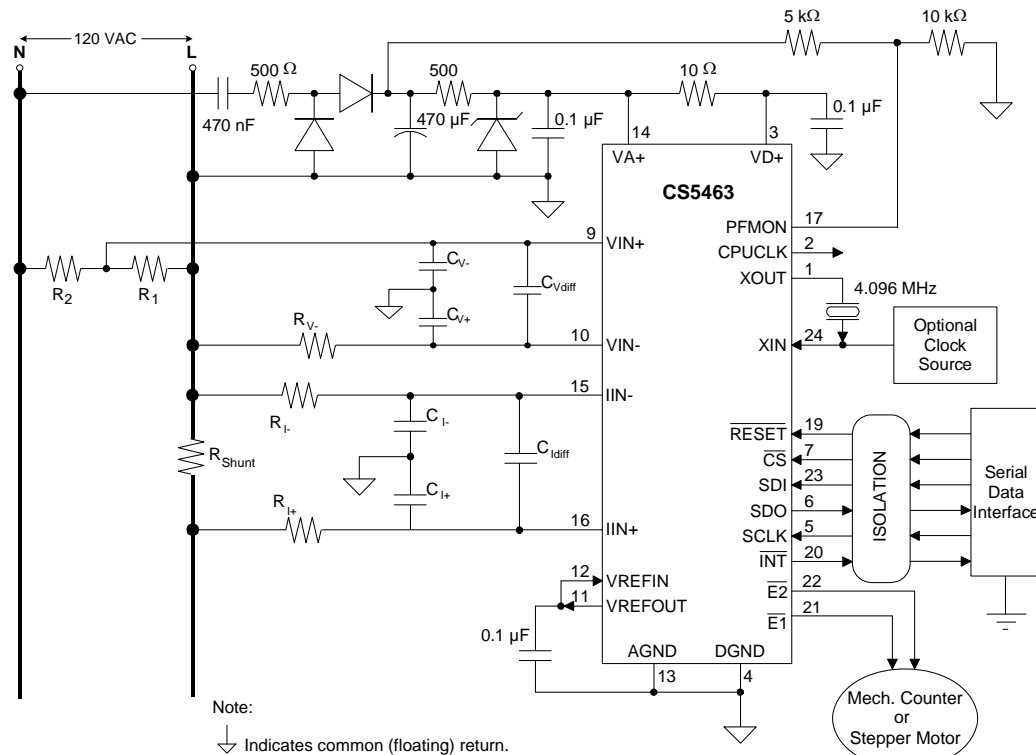
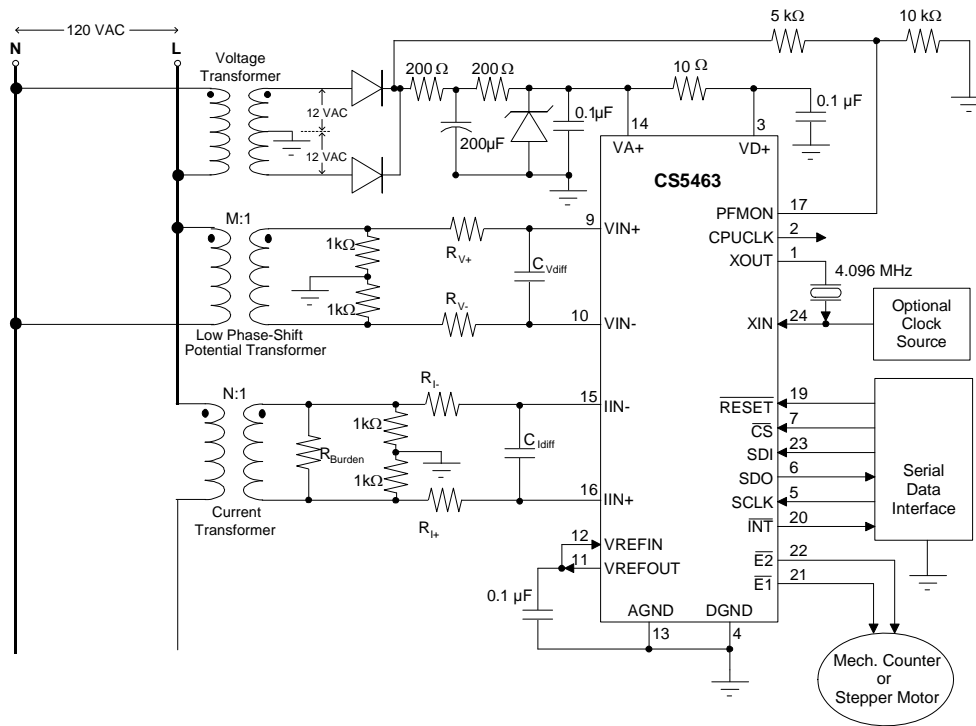
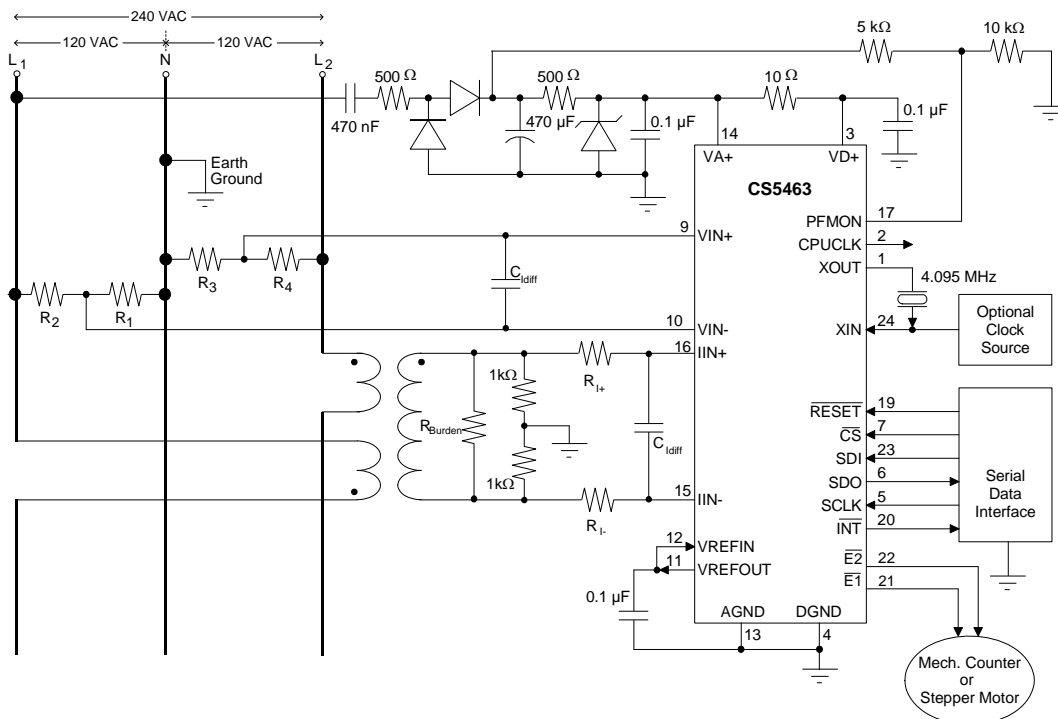


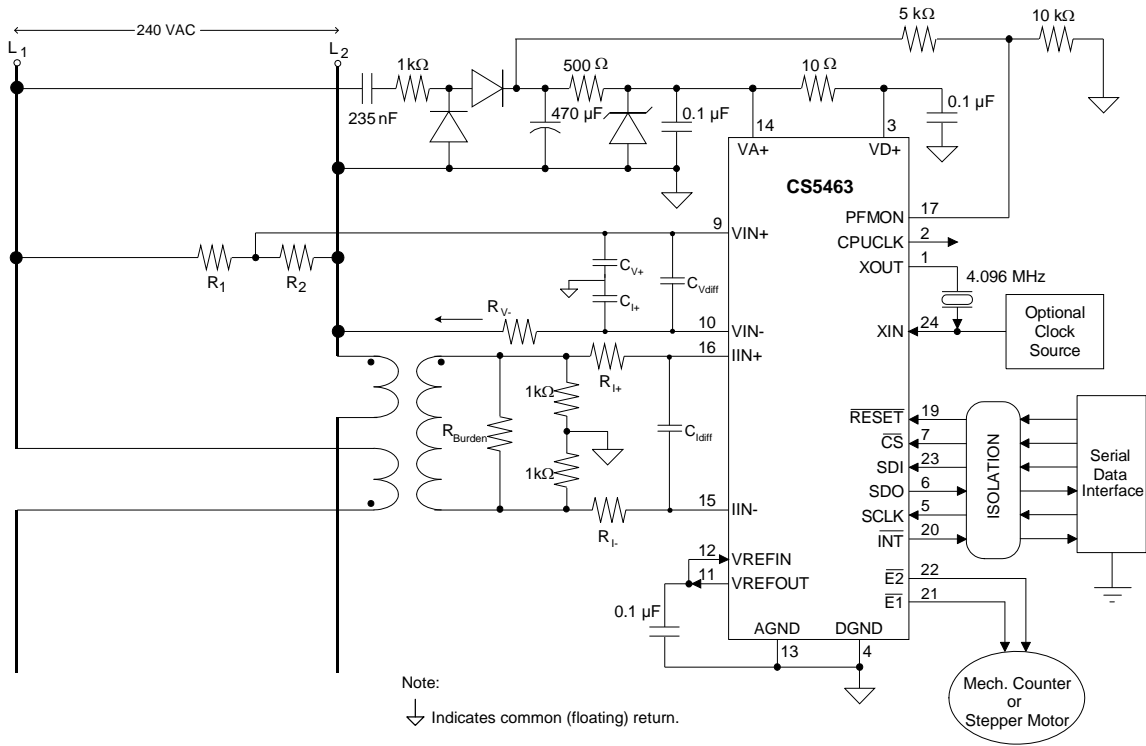
Figure 18. Typical Connection Diagram (Single-phase, 2-wire – Direct Connect to Power Line)



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

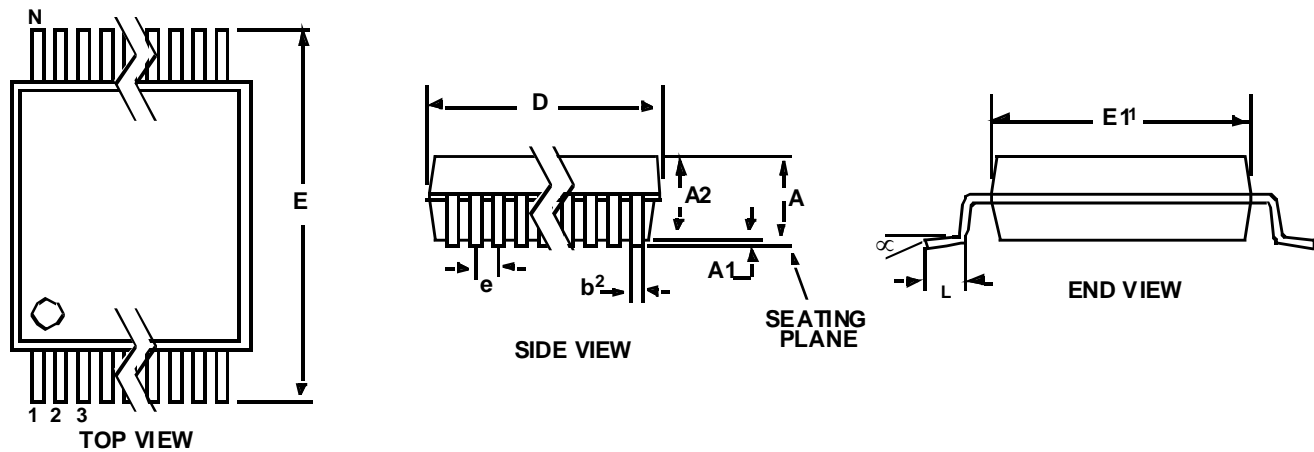


**Figure 20. Typical Connection Diagram (Single-phase, 3-wire)**



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



**10. PACKAGE DIMENSIONS**
**24L SSOP PACKAGE DRAWING**


DIM	INCHES			MILLIMETERS			NOTE
	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 include 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-ISZ (lead free)	-40 to +85 °C	24-pin SSOP

**12. ENVIRONMENTAL, MANUFACTURING, & HANDLING INFORMATION**

Model Number	Peak Reflow Temp	MSL Rating*	Max Floor Life
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.
F1	NOV 2005	First final release, updated with most-current characterization data.
F2	APR 2008	Added <i>PulseWidth</i> & <i>Load<sub>Min</sub></i> Registers.
F3	APR 2011	Removed lead-containing (Pb) device ordering information.

---

### 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](http://www.cirrus.com)

---

#### IMPORTANT NOTICE

Cirrus Logic, Inc. and its subsidiaries ("Cirrus") believe that the information contained in this document is accurate and reliable. However, the information is subject to change without notice and is provided "AS IS" without warranty of any kind (express or implied). Customers are advised to obtain the latest version of relevant information to verify, before placing orders, that information being relied on is current and complete. All products are sold subject to the terms and conditions of sale supplied at the time of order acknowledgment, including those pertaining to warranty, indemnification, and limitation of liability. No responsibility is assumed by Cirrus for the use of this information, including use of this information as the basis for manufacture or sale of any items, or for infringement of patents or other rights of third parties. This document is the property of Cirrus and by furnishing this information, Cirrus grants no license, express or implied under any patents, mask work rights, copyrights, trademarks, trade secrets or other intellectual property rights. Cirrus owns the copyrights associated with the information contained herein and gives consent for copies to be made of the information only for use within your organization with respect to Cirrus integrated circuits or other products of Cirrus. This consent does not extend to other copying such as copying for general distribution, advertising or promotional purposes, or for creating any work for resale.

CERTAIN APPLICATIONS USING SEMICONDUCTOR PRODUCTS MAY INVOLVE POTENTIAL RISKS OF DEATH, PERSONAL INJURY, OR SEVERE PROPERTY OR ENVIRONMENTAL DAMAGE ("CRITICAL APPLICATIONS"). CIRRUS PRODUCTS ARE NOT DESIGNED, AUTHORIZED OR WARRANTED FOR USE IN PRODUCTS SURGICALLY IMPLANTED INTO THE BODY, AUTOMOTIVE SAFETY OR SECURITY DEVICES, LIFE SUPPORT PRODUCTS OR OTHER CRITICAL APPLICATIONS. INCLUSION OF CIRRUS PRODUCTS IN SUCH APPLICATIONS IS UNDERSTOOD TO BE FULLY AT THE CUSTOMER'S RISK AND CIRRUS DISCLAIMS AND MAKES NO WARRANTY, EXPRESS, STATUTORY OR IMPLIED, INCLUDING THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR PARTICULAR PURPOSE, WITH REGARD TO ANY CIRRUS PRODUCT THAT IS USED IN SUCH A MANNER. IF THE CUSTOMER OR CUSTOMER'S CUSTOMER USES OR PERMITS THE USE OF CIRRUS PRODUCTS IN CRITICAL APPLICATIONS, CUSTOMER AGREES, BY SUCH USE, TO FULLY INDEMNIFY CIRRUS, ITS OFFICERS, DIRECTORS, EMPLOYEES, DISTRIBUTORS AND OTHER AGENTS FROM ANY AND ALL LIABILITY, INCLUDING ATTORNEYS' FEES AND COSTS, THAT MAY RESULT FROM OR ARISE IN CONNECTION WITH THESE USES.

Cirrus Logic, Cirrus, and the Cirrus Logic logo designs are trademarks of Cirrus Logic, Inc. All other brand and product names in this document may be trademarks or service marks of their respective owners.

SPI is a trademark of Motorola, Inc.

Microwire is a trademark of National Semiconductor Corporation.