Features

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

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1. OVERVIEW
The CS5463 is a CMOS monolithic power measurement device with a computation engine and an energy-to-frequency pulse output. The CS5463 combines a programmable gain amplifier, two $\Delta \Sigma$ 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. E1, E2, and E3 are designed to interface to a microprocessor.
2. PIN DESCRIPTION

<table>
<thead>
<tr>
<th>Pin Description</th>
<th>Pin Numbers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Out</td>
<td>XOUT 1, 24</td>
<td>XIN Crystal In – 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.</td>
</tr>
<tr>
<td>CPU Clock Output</td>
<td>CPUCLOCK 2</td>
<td>CPUCLK – Output of on-chip oscillator which can drive one standard CMOS load.</td>
</tr>
<tr>
<td>Positive Digital Supply</td>
<td>VD+ 3</td>
<td>E2 Energy Output 2</td>
</tr>
<tr>
<td>Digital Ground</td>
<td>DGND 4</td>
<td>E1 Energy Output 1</td>
</tr>
<tr>
<td>Serial Clock</td>
<td>SCLK 5</td>
<td>INT Interrupt</td>
</tr>
<tr>
<td>Serial Data Output</td>
<td>SDO 6</td>
<td>RESET Reset</td>
</tr>
<tr>
<td>Chip Select</td>
<td>CS 7</td>
<td>E3 High Frequency Energy Output</td>
</tr>
<tr>
<td>Mode Select</td>
<td>MODE 8</td>
<td>PFMON Power Fail Monitor</td>
</tr>
<tr>
<td>Differential Voltage Input</td>
<td>VIN+ 9</td>
<td>IIN+ Differential Current Input</td>
</tr>
<tr>
<td>Differential Voltage Input</td>
<td>VIN- 10</td>
<td>IIN- Differential Current Input</td>
</tr>
<tr>
<td>Voltage Reference Output</td>
<td>VREFOUT 11</td>
<td>VA+ Positive Analog Supply</td>
</tr>
<tr>
<td>Voltage Reference Input</td>
<td>VREFIN 12</td>
<td>AGND Analog Ground</td>
</tr>
</tbody>
</table>

**Clock Generator**

- **XOUT, XIN** – The output and input of an inverting amplifier. Oscillation occurs when connected to a crystal, providing an on-chip system clock. Alternatively, an external clock can be supplied to the XIN pin to provide the system clock for the device.

**Control Pins and Serial Data I/O**

- **SCLK** – A Schmitt-trigger input pin. Clocks data from the SDI pin into the receive buffer and out of the transmit buffer onto the SDO pin when CS is low.
- **SDO** – Serial port data output pin. SDO is forced into a high-impedance state when CS is high.
- **CS** – Low, activates the serial port interface.
- **MODE** - High, enables the "auto-boot" mode. The mode pin has an internal pull-down resistor.
- **E3, E1, 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.

**Reset**

- **RESET** – A Schmitt-trigger input pin. Low activates Reset, all internal registers (some of which drive output pins) are set to their default states.

**Interrupt**

- **INT** - Low, indicates that an enabled event has occurred.

**Serial Data Input**

- **SDI** - Serial port data input pin. Data will be input at a rate determined by SCLK.

**Analog Inputs/Outputs**

- **VIN+, VIN-** – Differential analog input pins for the voltage channel.
- **IIN+, IIN-** – Differential analog input pins for the current channel.
- **VREFOUT** – The on-chip voltage reference output. The voltage reference has a nominal magnitude of 2.5 V and is referenced to the AGND pin on the converter.
- **VREFIN** – The input to this pin establishes the voltage reference for the on-chip modulator.

**Power Supply Connections**

- **VD+** – The positive digital supply.
- **DGND** – Digital Ground.
- **VA+** – The positive analog supply.
- **AGND** – Analog ground.
- **PFMON** – The power fail monitor pin monitors the analog supply. If the analog supply does not meet or falls below PFMON’s voltage threshold, a Low-supply Detect (LSD) event is set in the status register.
## 3. CHARACTERISTICS & SPECIFICATIONS

### RECOMMENDED OPERATING CONDITIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Positive Digital Power Supply</td>
<td>VD+</td>
<td>3.135</td>
<td>5.0</td>
<td>5.25</td>
<td>V</td>
</tr>
<tr>
<td>Positive Analog Power Supply</td>
<td>VA+</td>
<td>4.75</td>
<td>5.0</td>
<td>5.25</td>
<td>V</td>
</tr>
<tr>
<td>Voltage Reference</td>
<td>VREFIN</td>
<td>-</td>
<td>2.5</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>Specified Temperature Range</td>
<td>TA</td>
<td>-40</td>
<td>-</td>
<td>+85</td>
<td>°C</td>
</tr>
</tbody>
</table>

### 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 TA = 25 °C.
- VA+ = VD+ = 5 V ±5%; AGND = DGND = 0 V; VREFIN = +2.5 V. All voltages with respect to 0 V.
- MCLK = 4.096 MHz.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Symbol</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Unit</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Active Power (Note 1)</td>
<td>PActive</td>
<td>-</td>
<td>±0.1</td>
<td>-</td>
<td>%</td>
</tr>
<tr>
<td>Average Reactive Power (Note 1 and 2)</td>
<td>QAvg</td>
<td>-</td>
<td>±0.2</td>
<td>-</td>
<td>%</td>
</tr>
<tr>
<td>Power Factor (Note 1 and 2)</td>
<td>PF</td>
<td>-</td>
<td>±0.2</td>
<td>-</td>
<td>%</td>
</tr>
<tr>
<td>Current RMS (Note 1)</td>
<td>IRMS</td>
<td>-</td>
<td>±0.2</td>
<td>-</td>
<td>%</td>
</tr>
<tr>
<td>Voltage RMS (Note 1)</td>
<td>VRMS</td>
<td>-</td>
<td>±0.1</td>
<td>-</td>
<td>%</td>
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<tr>
<td>Analog Inputs (Both Channels)</td>
<td>CMRR</td>
<td>80</td>
<td>-</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Common Mode + Signal</td>
<td>VA+</td>
<td>-0.25</td>
<td>-</td>
<td>VA+</td>
<td>V</td>
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<td>Analog Inputs (Current Channel)</td>
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<tr>
<td>Differential Input Range (Gain = 10)</td>
<td>IIN</td>
<td>-</td>
<td>500</td>
<td>-</td>
<td>mVP-P</td>
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<tr>
<td>Total Harmonic Distortion (Gain = 50)</td>
<td>THD</td>
<td>80</td>
<td>94</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Crosstalk with Voltage Channel at Full Scale (Gain = 50)</td>
<td>-115</td>
<td>-</td>
<td>-</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Input Capacitance (Gain = 10)</td>
<td>IC</td>
<td>-</td>
<td>32</td>
<td>-</td>
<td>pF</td>
</tr>
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<td>Effective Input Impedance</td>
<td>EII</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>kΩ</td>
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<tr>
<td>Noise (Referred to Input) (Gain = 10)</td>
<td>N_i</td>
<td>-</td>
<td>22.5</td>
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<td>µVmms</td>
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<td>Offset Drift (Without the High Pass Filter)</td>
<td>OD</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>µV/°C</td>
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<tr>
<td>Gain Error (Note 3)</td>
<td>GE</td>
<td>-</td>
<td>±0.4</td>
<td>-</td>
<td>%</td>
</tr>
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</table>

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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
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<th>Typ</th>
<th>Max</th>
<th>Unit</th>
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<td>Analog Inputs (Voltage Channel)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Range</td>
<td>[(VIN+) - (VIN-)]</td>
<td>VIN</td>
<td>-</td>
<td>500</td>
<td>-</td>
</tr>
<tr>
<td>Total Harmonic Distortion</td>
<td>THD</td>
<td>VIN</td>
<td>65</td>
<td>75</td>
<td>-</td>
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<tr>
<td>Crosstalk with Current Channel at Full Scale (50, 60 Hz)</td>
<td>-</td>
<td>-</td>
<td>-70</td>
<td>-</td>
<td>dB</td>
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<tr>
<td>Input Capacitance</td>
<td>All Gain Ranges</td>
<td>IC</td>
<td>-</td>
<td>0.2</td>
<td>-</td>
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<td>Noise (Referred to Input)</td>
<td>N&lt;sub&gt;V&lt;/sub&gt;</td>
<td>EII</td>
<td>-</td>
<td>140</td>
<td>-</td>
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<td>Offset Drift (Without the High Pass Filter)</td>
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<td>-</td>
<td>16.0</td>
<td>-</td>
<td>µV/°C</td>
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<tr>
<td>Gain Error</td>
<td>(Note 3)</td>
<td>GE</td>
<td>-</td>
<td>±3.0</td>
<td>-</td>
</tr>
<tr>
<td>Temperature Channel</td>
<td></td>
<td>T</td>
<td>-</td>
<td>±5</td>
<td>-</td>
</tr>
<tr>
<td>Power Supplies</td>
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<tr>
<td>Power Supply Currents (Active State)</td>
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<td>PSCA</td>
<td>-</td>
<td>1.1</td>
<td>-</td>
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<td></td>
<td></td>
<td>PSCD</td>
<td>-</td>
<td>2.9</td>
<td>-</td>
</tr>
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<td></td>
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<td>PC</td>
<td>-</td>
<td>21</td>
<td>29</td>
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<tr>
<td>Power Consumption</td>
<td></td>
<td>-</td>
<td>11.6</td>
<td>17.5</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>µW</td>
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<tr>
<td>Power Supply Rejection Ratio</td>
<td>(Note 5)</td>
<td>PSRR</td>
<td>45</td>
<td>65</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>70</td>
<td>75</td>
<td>-</td>
<td>dB</td>
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<tr>
<td>PFMON Low-voltage Trigger Threshold</td>
<td>(Note 6)</td>
<td>PMLO</td>
<td>2.3</td>
<td>2.45</td>
<td>-</td>
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<tr>
<td>PFMON High-voltage Power-on Trip Point</td>
<td>(Note 7)</td>
<td>PMHI</td>
<td>-</td>
<td>2.55</td>
<td>2.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Voltage</td>
<td>VREFOUT</td>
<td>+2.4</td>
<td>+2.5</td>
<td>+2.6</td>
<td>V</td>
</tr>
<tr>
<td>Temperature Coefficient</td>
<td>TC&lt;sub&gt;VREF&lt;/sub&gt;</td>
<td>-</td>
<td>25</td>
<td>60</td>
<td>ppm/°C</td>
</tr>
<tr>
<td>Load Regulation</td>
<td>ΔV&lt;sub&gt;R&lt;/sub&gt;</td>
<td>-</td>
<td>6</td>
<td>10</td>
<td>mV</td>
</tr>
</tbody>
</table>

Reference Input

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage Range</td>
<td>VREFIN</td>
<td>+2.4</td>
<td>+2.5</td>
<td>+2.6</td>
<td>V</td>
</tr>
<tr>
<td>Input Capacitance</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>pF</td>
<td></td>
</tr>
<tr>
<td>Input CVF Current</td>
<td>-</td>
<td>25</td>
<td>-</td>
<td>nA</td>
<td></td>
</tr>
</tbody>
</table>

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:

\[
TC_{VREF} = \left( \frac{V_{REFOUT_{MAX}} - V_{REFOUT_{MIN}}}{V_{REFOUT_{AVG}}} \right) \left( \frac{1}{T_{MAX} - T_{MIN}} \right) \left( 1.0 \times 10^6 \right)
\]

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

DIGITAL CHARACTERISTICS

- Min / Max characteristics and specifications are guaranteed over all `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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Clock Frequency Internal Gate Oscillator (Note 11)</td>
<td>MCLK</td>
<td>2.5</td>
<td>4.096</td>
<td>20</td>
<td>MHz</td>
</tr>
<tr>
<td>Master Clock Duty Cycle</td>
<td>-</td>
<td>40</td>
<td>-</td>
<td>60</td>
<td>%</td>
</tr>
<tr>
<td>CPUCLK Duty Cycle (Note 12 and 13)</td>
<td>-</td>
<td>40</td>
<td>-</td>
<td>60</td>
<td>%</td>
</tr>
</tbody>
</table>

Filter Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase Compensation Range (Voltage Channel, 60 Hz)</td>
<td>-2.8</td>
<td>-</td>
<td>+2.8</td>
<td>°</td>
<td></td>
</tr>
<tr>
<td>Input Sampling Rate</td>
<td>DCLK = MCLK/K</td>
<td>-</td>
<td>DCLK/8</td>
<td>-</td>
<td>Hz</td>
</tr>
<tr>
<td>Digital Filter Output Word Rate (Both Channels)</td>
<td>OWR</td>
<td>-</td>
<td>DCLK/1024</td>
<td>-</td>
<td>Hz</td>
</tr>
<tr>
<td>High-pass Filter Corner Frequency</td>
<td>-3 dB</td>
<td>-</td>
<td>0.5</td>
<td>-</td>
<td>Hz</td>
</tr>
<tr>
<td>Full-scale DC Calibration Range (Referred to Input) (Note 14)</td>
<td>FSCR</td>
<td>25</td>
<td>-</td>
<td>100</td>
<td>%F.S.</td>
</tr>
<tr>
<td>Channel-to-channel Time-shift Error (Note 15)</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>μs</td>
<td></td>
</tr>
</tbody>
</table>

Input/Output Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-level Input Voltage</td>
<td>V&lt;sub&gt;IH&lt;/sub&gt;</td>
<td>0.6 VD+</td>
<td>-</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>All Pins Except XIN and SCLK and RESET XIN</td>
<td>(VD+) - 0.5</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>SCLK and RESET</td>
<td>0.8 VD+</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Low-level Input Voltage (VD = 5 V)</td>
<td>V&lt;sub&gt;IL&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>0.8</td>
<td>V</td>
</tr>
<tr>
<td>All Pins Except XIN and SCLK and RESET XIN</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>SCLK and RESET</td>
<td>0.2 VD+</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>
### CS5463

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-level Input Voltage (VD = 3.3 V)</td>
<td>V&lt;sub&gt;IL&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>0.48</td>
<td>V</td>
</tr>
<tr>
<td>All Pins Except XIN and SCLK and RESET</td>
<td>V&lt;sub&gt;XIN&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>V</td>
</tr>
<tr>
<td>SCLK and RESET</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.2 VD+</td>
<td>V</td>
</tr>
<tr>
<td>High-level Output Voltage</td>
<td>V&lt;sub&gt;OH&lt;/sub&gt;</td>
<td>(VD+) - 1.0</td>
<td>-</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>Low-level Output Voltage</td>
<td>V&lt;sub&gt;OL&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
<td>V</td>
</tr>
<tr>
<td>Input Leakage Current</td>
<td>I&lt;sub&gt;in&lt;/sub&gt;</td>
<td>-</td>
<td>±1</td>
<td>±10</td>
<td>µA</td>
</tr>
<tr>
<td>3-state Leakage Current</td>
<td>I&lt;sub&gt;OZ&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>±10</td>
<td>µA</td>
</tr>
<tr>
<td>Digital Output Pin Capacitance</td>
<td>C&lt;sub&gt;out&lt;/sub&gt;</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>pF</td>
</tr>
</tbody>
</table>

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+.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
</table>
| Rise Times (Note 17)                                  | ts
times      |      | -   | -   | 1.0  | µs   |
| Any Digital Input Except SCLK SCLK Any Digital Output |            |     |     |     |      |      |
| Fall Times (Note 17)                                  | tf
tall      | -   | -   | -   | 1.0  | µs   |
| Any Digital Input Except SCLK SCLK Any Digital Output |            |     |     |     |      |      |

Start-up

Oscillator Start-up Time XTAL = 4.096 MHz (Note 18) t
tost      | - | 60 | - | ms |

Serial Port Timing

Serial Clock Frequency SCLK t1 | 200 | - | - | ns |
Pulse Width High t2 200 - - ns
Serial Clock Pulset Width Low

SDI Timing

CS Falling to SCLK Rising t3 | 50 | - | - | ns |
Data Set-up Time Prior to SCLK Rising t4 | 50 | - | - | ns |
Data Hold Time After SCLK Rising t5 | 100 | - | - | ns |

SDO Timing

CS Falling to SDI Driving t6 | - | 20 | 50 | ns |
SCLK Falling to New Data Bit (hold time) t7 | - | 20 | 50 | ns |
CS Rising to SDO Hi-Z t8 | - | 20 | 50 | ns |

Auto-Boot Timing

Serial Clock Pulse Width Low t9 8 | 8 | MCLK |
Pulse Width High t10 - | MCLK |
MODE setup time to RESET Rising t11 | 50 | ns |
RESET rising to CS falling t12 | 48 | MCLK |
CS falling to SCLK rising t13 | 100 | 8 | MCLK |
SCLK falling to CS rising t14 | 16 | MCLK |
CS rising to driving MODE low (to end auto-boot sequence) t15 | 50 | ns |
SDO guaranteed setup time to SCLK rising t16 | 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.
Figure 1. CS5463 Read and Write Timing Diagrams
SWITCHING CHARACTERISTICS (Continued)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E1, E2, and E3 Timing</strong> (Note 19 and 20)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>t&lt;sub&gt;period&lt;/sub&gt;</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>μs</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>t&lt;sub&gt;pw&lt;/sub&gt;</td>
<td>244</td>
<td>-</td>
<td>-</td>
<td>μs</td>
</tr>
<tr>
<td>Rising Edge to Falling Edge</td>
<td>t&lt;sub&gt;3&lt;/sub&gt;</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>μs</td>
</tr>
<tr>
<td>E2 Setup to E1 and/or E3 Falling Edge</td>
<td>t&lt;sub&gt;4&lt;/sub&gt;</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>μs</td>
</tr>
<tr>
<td>E1 Falling Edge to E3 Falling Edge</td>
<td>t&lt;sub&gt;5&lt;/sub&gt;</td>
<td>248</td>
<td>-</td>
<td>-</td>
<td>μs</td>
</tr>
</tbody>
</table>

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.

![Diagram](image)

Figure 2. Timing Diagram for E<sub>1</sub>, E<sub>2</sub>, and E<sub>3</sub>

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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Power Supplies (Notes 21 and 22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive Digital</td>
<td>VD+</td>
<td>-0.3</td>
<td>-</td>
<td>+6.0</td>
<td>V</td>
</tr>
<tr>
<td>Positive Analog</td>
<td>VA+</td>
<td>-0.3</td>
<td>-</td>
<td>+6.0</td>
<td>V</td>
</tr>
<tr>
<td>Input Current, Any Pin Except Supplies (Notes 23, 24, 25)</td>
<td>I&lt;sub&gt;IN&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>±10</td>
<td>mA</td>
</tr>
<tr>
<td>Output Current, Any Pin Except VREFOUT</td>
<td>I&lt;sub&gt;OUT&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>Power Dissipation (Note 26)</td>
<td>P&lt;sub&gt;D&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>500</td>
<td>mW</td>
</tr>
<tr>
<td>Analog Input Voltage All Analog Pins</td>
<td>V&lt;sub&gt;INA&lt;/sub&gt;</td>
<td>-0.3</td>
<td>-</td>
<td>(VA+) + 0.3</td>
<td>V</td>
</tr>
<tr>
<td>Digital Input Voltage All Digital Pins</td>
<td>V&lt;sub&gt;IND&lt;/sub&gt;</td>
<td>-0.3</td>
<td>-</td>
<td>(VD+) + 0.3</td>
<td>V</td>
</tr>
<tr>
<td>Ambient Operating Temperature</td>
<td>T&lt;sub&gt;A&lt;/sub&gt;</td>
<td>-40</td>
<td>-</td>
<td>85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>T&lt;sub&gt;stg&lt;/sub&gt;</td>
<td>-65</td>
<td>-</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>

Notes: 21. VA+ and AGND must satisfy [(VA+) - (AGND)] ≤ + 6.0 V.
22. VD+ and AGND must satisfy [(VD+) - (AGND)] ≤ + 6.0 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 ±50 mA.
26. Total power dissipation, including all input currents and output currents.
4. THEORY OF OPERATION

The CS5463 is a dual-channel analog-to-digital converter (ADC) followed by a computation engine that performs power calculations and energy-to-pulse conversion. The data flow for the voltage and current channel measurement and the power calculation algorithms are depicted in Figure 3 and 4, respectively. The analog inputs are structured with two dedicated channels, Voltage and Current, then optimized to simplify interfacing to various sensing elements.

The voltage-sensing element introduces a voltage waveform on the voltage channel input VIN± and is subject to a gain of 10x. A second-order delta-sigma modulator samples the amplified signal for digitization. Simultaneously, the current-sensing element introduces a voltage waveform on the current channel input IIN± and is subject to 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 \(V_{RMS}\) 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:

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

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 E1. Energy output E2 is selectable, providing an energy sign or a pulse output that is proportional to the apparent power. Energy output E3
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:

\[ S = V_{\text{RMS}} \times I_{\text{RMS}} \]

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

\[ \text{PF} = \frac{P_{\text{Active}}}{S} \]

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

\[ Q_{\text{Trig}} = \sqrt{S^2 - P_{\text{Active}}^2} \]

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 (\( \varepsilon \)) 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

\[ Q_{\text{Avg}} = \frac{\sum_{n=1}^{N} Q_n}{N} \]

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

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

### 4.4 Linearity Performance

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

Until the CS5463 is calibrated, the accuracy of the CS5463 (with respect to a reference line-voltage and line-current level on the power mains) is not guaranteed to within ±0.1%. (See Section 7. System Calibration on page 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 VIN± and IIN± are designated as the voltage and current channel inputs, respectively. The full-scale differential input voltage for the current and voltage channel is ±250 mVp.

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

\[
\frac{250\text{mV}_p}{\sqrt{2}} = 176.78\text{mV}_\text{RMS}
\]

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 IIN+ and IIN- input pins of the CS5463. To accommodate different current sensing elements the current channel incorporates a programmable gain amplifier (PGA) with two programmable input gains. Configuration Register bit Igain (see Table 1) defines the two gain selections and corresponding maximum input-signal level.

<table>
<thead>
<tr>
<th>Igain</th>
<th>Maximum Input Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>±250 mV</td>
</tr>
<tr>
<td>1</td>
<td>±50 mV</td>
</tr>
</tbody>
</table>

Table 1. Current Channel PGA Setting

For example, if Igain=0, the current channel's PGA gain is set to 10x. If the input signals are pure sinusoids with zero phase shift, the maximum peak differential signal on the current or voltage channel is ±250 mVp. 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 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 VHPF and IHPF 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 (Vn) and current (In), and calculates instantaneous power (Pn) 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 Vn, In, and Pn 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 MCLK = 4.096 MHz – the OWR = 4000 Hz and the Computation Cycle = 1 Hz.

All measurements are available as a percentage of full scale. The format for signed registers is a two’s complement, normalized value between -1 and +1. The format
for unsigned registers is a normalized value between 0 and 1. A register value of

\[
\frac{2^{23} - 1}{2^{23}} = 0.99999988
\]

represents the maximum possible value.

At each instantaneous measurement, the CRDY bit will be set in the Status Register, and the INT pin will become active if the CRDY bit is unmasked in the Mask Register. At the end of each computation cycle, the DRDY bit will be set in the Status Register, and the 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 (\(\varepsilon\)) is the ratio of the input line frequency (\(f_i\)) to the sample frequency (\(f_s\)) of the ADC.

\[
\varepsilon = \frac{f_i}{f_s}
\]

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

\[
\begin{align*}
\varepsilon &= 50\ \text{Hz}/4000\ \text{Hz} = 0.0125 \\
\varepsilon &= 60\ \text{Hz}/4000\ \text{Hz} = 0.015
\end{align*}
\]

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 page 13.) 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.

<table>
<thead>
<tr>
<th>E2MODE</th>
<th>E2 Output Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sign of Energy</td>
</tr>
<tr>
<td>1</td>
<td>Apparent Energy</td>
</tr>
</tbody>
</table>

Table 2. E2 Pin Configuration

The 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.

<table>
<thead>
<tr>
<th>E3MODE1</th>
<th>E3MODE0</th>
<th>E3 OutPut Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Reactive Energy</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>PFMON</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Voltage Channel Sign</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Apparent Energy</td>
</tr>
</tbody>
</table>

Table 3. E3 Pin Configuration

The pulse output frequency of E1, E2, and 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:

\[
t_{pw} (\text{sec}) = \frac{1}{\text{MCLK/K}} / 1024
\]

If MCLK = 4.096 MHz, \(K = 1\), and PulseWidth = 1, then \(t_{pw} \approx 0.25\) ms.

5.5.1 Active Energy

The E1 pin produces active-low pulses with an output frequency proportional to the active power. The E2 pin is the energy direction indicator. Positive energy is represented by E1 pin falling while the E2 is high. Negative energy is represented by the E1 pin falling while the E2 is low. The E1 and E2 switching characteristics are specified in Figure 2. Timing Diagram for E1, E2, and E3 on page 13.

Figure 5 illustrates the pulse output format with positive active energy and negative reactive energy.
The pulse output frequency of $E_1$ is directly proportional to the active power calculated from the input signals. To calculate the output frequency of $E_1$, the following transfer function can be utilized:

$$FREQ_{p} = \frac{V_{IN} \times V\text{GAIN} \times I_{IN} \times I\text{GAIN} \times PF \times PulseRate}{V\text{REFIN}^2}$$

Where:
- $FREQ_p$ = Average frequency of active energy $E_1$ pulses [Hz]
- $V_{IN}$ = rms voltage across V$IN+$ and V$IN-$ [V]
- $V\text{GAIN}$ = Voltage channel gain
- $I_{IN}$ = rms voltage across I$IN+$ and I$IN-$ [V]
- $I\text{GAIN}$ = Current channel gain
- $PF$ = Power Factor
- $PulseRate$ = PulseRateE x (MCLK/K)/2048 [Hz]
- $V\text{REFIN}$ = 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 $E_1$ pin is (MCLK/K)/2048.

### 5.5.2 Apparent Energy Mode

Pin $E_2$ outputs apparent energy pulses when the Operational Mode Register bit $E2\text{MODE} = 1$. Pin $E_3$ outputs apparent energy pulses when the Operational Mode Register bits $E3\text{MODE}[1:0] = 3$ (11b). Figure 6 illustrates the pulse output format with apparent energy on $E_2$ ($E2\text{MODE} = 1$ and $E3\text{MODE}[1:0] = 0$)

![Figure 6. Apparent energy pulse outputs](image)

The pulse output frequency of $E_2$ (and/or $E_3$) 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 $E_2$ (and/or $E_3$):

$$FREQ_Q = \frac{V_{IN} \times V\text{GAIN} \times I_{IN} \times I\text{GAIN} \times PQ \times PulseRate}{V\text{REFIN}^2}$$

Where:
- $FREQ_Q$ = Average frequency of reactive energy $E_3$ pulses [Hz]
- $V_{IN}$ = rms voltage across V$IN+$ and V$IN-$ [V]
- $V\text{GAIN}$ = Voltage channel gain
- $I_{IN}$ = rms voltage across I$IN+$ and I$IN-$ [V]
- $I\text{GAIN}$ = Current channel gain
- $PQ = \sqrt{1 - PF^2}$
- $PulseRate$ = PulseRateE x (MCLK/K)/2048 [Hz]
- $V\text{REFIN}$ = 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 $E_2$ (and/or $E_3$) pin is (MCLK/K)/2048. The $E_2$ (and/or $E_3$) pin outputs apparent energy, but has no energy direction indicator.

### 5.5.3 Reactive Energy Mode

Reactive energy pulses are output on pin $E_3$ by setting bit $E3\text{MODE}[1:0] = 0$ (default) in the Operational Mode Register. Positive reactive energy is registered by $E_3$ falling when $E_2$ is high. Negative reactive energy is registered by $E_3$ falling when $E_2$ is low. Figure 5 on page 17 illustrates the pulse output format with negative reactive energy output on pin $E_3$ and the sign of the energy on $E_2$. The $E_3$ and $E_2$ pulse output switching characteristics are specified in Figure 2 on page 13.

The pulse output frequency of $E_3$ is directly proportional to the reactive power calculated from the input signals. To calculate the output frequency on $E_3$, the following transfer function can be utilized:

$$FREQ_Q = \frac{V_{IN} \times V\text{GAIN} \times I_{IN} \times I\text{GAIN} \times PQ \times PulseRate}{V\text{REFIN}^2}$$

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 $E_1$ pin is (MCLK/K)/2048.

### 5.5.4 Voltage Channel Sign Mode

Setting bits $E3\text{MODE}[1:0] = 2$ (10b) in the Operational Mode Register outputs the sign of the voltage channel on pin $E_3$. Figure 7 illustrates the output format with voltage channel sign on $E_3$.

![Figure 7. Voltage Channel Sign Pulse outputs](image)
Output pin 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 E3. Figure 8 illustrates the output format with PFMON on E3.

![Figure 8. PFMON output to pin E3](image)

When PFMON is greater than the threshold, pin E3 is high and when PFMON is less than the threshold pin 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 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 mVp. (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 VRMS and IRMS 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:

\[
PulseRate = \frac{FREQ_p \times VREFIN^2}{VIN \times VGAIN \times IIN \times IGAIN \times PF}
\]

Therefore with PF = 1 and:

- \(VIN = 220V \times \left(\frac{(150mV)}{(250V)}\right) = 132mV\)
- \(IIN = 15A \times \left(\frac{(150mV)}{(20A)}\right) = 112.5mV\)

the pulse rate is:

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

and the PulseRateE Register is set to:

\[
PulseRateE = \frac{PulseRate}{(MCLK/K) \times 2048} = 0.2104377
\]

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](image)

5.7 No Load Threshold

The No Load Threshold register (LoadMin) is used to disable the active energy pulse output when the magnitude of the \(P_{Active}\) register is less than the value in the LoadMin 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 \(^\circ C\). The Temperature Gain Register \((T_{gain})\) and Temperature Offset Register \((T_{off})\) are constant values allowing for temperature scale conversions.
The temperature update rate is a function of the number of ADC samples. With MCLK = 4.096 MHz and K = 1, the update rate is:

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

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** (Toff) 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** (Toff). Therefore,

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

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

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

or 0xF3C168 (2’s compliment notation) is stored in the **Temperature Offset Register** (Toff).

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

\[
^\circ\text{F} = \frac{9}{5} \times ^\circ\text{C} + 17.7778
\]

Applying the above relationship to the CS5461A temperature measurement algorithm

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

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.

### 5.10 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 **RESET** pin is asserted with a minimum pulse width of 50 ns. The **RESET** signal is asynchronous, with a Schmitt-trigger input. Once the **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

\[C1 = C2 = 22 \text{ pF}\]
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 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 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 INT pin is controlled by the IMODE and IINV bits of the Configuration Register.

<table>
<thead>
<tr>
<th>IMODE</th>
<th>IINV</th>
<th>INT Pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Active-low Level</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Active-high Level</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Low Pulse</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>High Pulse</td>
</tr>
</tbody>
</table>

Table 4. Interrupt Configuration

If the interrupt output signal format is set for either falling or rising edge, the duration of the 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 0xFFFFFFF 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 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 CS pin high, then low.
- Hardware Reset (drive RESET pin low for at least 10 µs).
- Issue the Serial Port Initialization Sequence, which is 3 (or more) SYNC1 command bytes (0xFF) followed by one SYNC0 command byte (0xFE).

If a re-synchronization is necessary, it is best to re-initialize the part either by hardware or software reset (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.

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

Figure 11. CS5463 Memory Map
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

<table>
<thead>
<tr>
<th>B7 B6 B5 B4 B3 B2 B1 B0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 1 0 C3 0 0 0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>B7 B6 B5 B4 B3 B2 B1 B0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>

The serial port can be initialized by asserting 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

<table>
<thead>
<tr>
<th>B7 B6 B5 B4 B3 B2 B1 B0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 1 0 0 0 0 0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>B7 B6 B5 B4 B3 B2 B1 B0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 0 S1 S0 0 0 0</td>
</tr>
</tbody>
</table>

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

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

\[
\begin{array}{cccccccc}
B_7 & B_6 & B_5 & B_4 & B_3 & B_2 & B_1 & B_0 \\
0 & W/R & RA_4 & RA_3 & RA_2 & RA_1 & RA_0 & 0
\end{array}
\]

W/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

<table>
<thead>
<tr>
<th>Address</th>
<th>RA[4:0]</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>000000</td>
<td>Config</td>
<td>Configuration</td>
</tr>
<tr>
<td>1</td>
<td>00001</td>
<td>I_{DCoff}</td>
<td>Current DC Offset</td>
</tr>
<tr>
<td>2</td>
<td>00010</td>
<td>I_{gn}</td>
<td>Current Gain</td>
</tr>
<tr>
<td>3</td>
<td>00011</td>
<td>V_{DCoff}</td>
<td>Voltage DC Offset</td>
</tr>
<tr>
<td>4</td>
<td>00100</td>
<td>V_{gn}</td>
<td>Voltage Gain</td>
</tr>
<tr>
<td>5</td>
<td>00101</td>
<td>Cycle Count</td>
<td>Number of A/D conversions used in one computation cycle (N)).</td>
</tr>
<tr>
<td>6</td>
<td>00110</td>
<td>PulseRateE</td>
<td>Sets the E1, E2 and E3 energy-to-frequency output pulse rate.</td>
</tr>
<tr>
<td>7</td>
<td>00111</td>
<td>I</td>
<td>Instantaneous Current</td>
</tr>
<tr>
<td>8</td>
<td>01000</td>
<td>V</td>
<td>Instantaneous Voltage</td>
</tr>
<tr>
<td>9</td>
<td>01001</td>
<td>P</td>
<td>Instantaneous Power</td>
</tr>
<tr>
<td>10</td>
<td>01010</td>
<td>P_{Active}</td>
<td>Active (Real) Power</td>
</tr>
<tr>
<td>11</td>
<td>01011</td>
<td>I_{RMS}</td>
<td>RMS Current</td>
</tr>
<tr>
<td>12</td>
<td>01100</td>
<td>V_{RMS}</td>
<td>RMS Voltage</td>
</tr>
<tr>
<td>13</td>
<td>01101</td>
<td>\epsilon \text{ (Epsilon)}</td>
<td>Ratio of line frequency to output word rate (OWR)</td>
</tr>
<tr>
<td>14</td>
<td>01110</td>
<td>P_{off}</td>
<td>Power Offset</td>
</tr>
<tr>
<td>15</td>
<td>01111</td>
<td>Status</td>
<td>Status</td>
</tr>
<tr>
<td>16</td>
<td>10000</td>
<td>I_{ACoff}</td>
<td>Current AC (RMS) Offset</td>
</tr>
<tr>
<td>17</td>
<td>10001</td>
<td>V_{ACoff}</td>
<td>Voltage AC (RMS) Offset</td>
</tr>
<tr>
<td>18</td>
<td>10010</td>
<td>Mode</td>
<td>Operation Mode</td>
</tr>
<tr>
<td>19</td>
<td>10011</td>
<td>T</td>
<td>Temperature</td>
</tr>
<tr>
<td>20</td>
<td>10100</td>
<td>Q_{AVG}</td>
<td>Average Reactive Power</td>
</tr>
<tr>
<td>21</td>
<td>10101</td>
<td>Q</td>
<td>Instantaneous Reactive Power</td>
</tr>
<tr>
<td>22</td>
<td>10110</td>
<td>I_{Peak}</td>
<td>Peak Current</td>
</tr>
<tr>
<td>23</td>
<td>10111</td>
<td>V_{Peak}</td>
<td>Peak Voltage</td>
</tr>
<tr>
<td>24</td>
<td>11000</td>
<td>Q_{Trig}</td>
<td>Reactive Power calculated from Power Triangle</td>
</tr>
<tr>
<td>25</td>
<td>11001</td>
<td>PF</td>
<td>Power Factor</td>
</tr>
<tr>
<td>26</td>
<td>11010</td>
<td>Mask</td>
<td>Interrupt Mask</td>
</tr>
<tr>
<td>27</td>
<td>11011</td>
<td>S</td>
<td>Apparent Power</td>
</tr>
<tr>
<td>28</td>
<td>11100</td>
<td>Ctrl</td>
<td>Control</td>
</tr>
<tr>
<td>29</td>
<td>11101</td>
<td>P_h</td>
<td>Harmonic Active Power</td>
</tr>
<tr>
<td>30</td>
<td>11110</td>
<td>P_f</td>
<td>Fundamental Active Power</td>
</tr>
<tr>
<td>31</td>
<td>11111</td>
<td>Q_f</td>
<td>Fundamental Reactive Power / Page</td>
</tr>
</tbody>
</table>

Note: For proper operation, do not attempt to write to unspecified registers.
Register Page 1

<table>
<thead>
<tr>
<th>Address</th>
<th>RA[4:0]</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>00000</td>
<td>PulseWidth</td>
<td>Energy Pulse Output Width</td>
</tr>
<tr>
<td>1</td>
<td>00001</td>
<td>LoadMin</td>
<td>No Load Threshold</td>
</tr>
<tr>
<td>2</td>
<td>00010</td>
<td>TGain</td>
<td>Temperature Sensor Gain</td>
</tr>
<tr>
<td>3</td>
<td>00011</td>
<td>Toff</td>
<td>Temperature Sensor Offset</td>
</tr>
</tbody>
</table>

Register Page 3

<table>
<thead>
<tr>
<th>Address</th>
<th>RA[4:0]</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>00110</td>
<td>VSAGDuration</td>
<td>Voltage sag sample interval</td>
</tr>
<tr>
<td>7</td>
<td>00111</td>
<td>VSAGLevel</td>
<td>Voltage sag level</td>
</tr>
<tr>
<td>10</td>
<td>01010</td>
<td>ISAGDuration</td>
<td>Current fault sample interval</td>
</tr>
<tr>
<td>11</td>
<td>01011</td>
<td>ISAGLevel</td>
<td>Current fault level</td>
</tr>
</tbody>
</table>

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

5.16.6 Calibration

<table>
<thead>
<tr>
<th>B7</th>
<th>B6</th>
<th>B5</th>
<th>B4</th>
<th>B3</th>
<th>B2</th>
<th>B1</th>
<th>B0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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

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.

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

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

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^{20})</td>
<td>2^{0}</td>
</tr>
<tr>
<td>2^{-1}</td>
<td>2^{-2}</td>
</tr>
<tr>
<td>2^{-3}</td>
<td>2^{-4}</td>
</tr>
<tr>
<td>2^{-5}</td>
<td>2^{-6}</td>
</tr>
<tr>
<td>2^{-7}</td>
<td>.....</td>
</tr>
<tr>
<td>2^{-17}</td>
<td>2^{-18}</td>
</tr>
<tr>
<td>2^{-19}</td>
<td>2^{-20}</td>
</tr>
<tr>
<td>2^{-21}</td>
<td>2^{-22}</td>
</tr>
<tr>
<td>2^{-23}</td>
<td></td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2^{1}</td>
<td>2^{0}</td>
</tr>
<tr>
<td>2^{-1}</td>
<td>2^{-2}</td>
</tr>
<tr>
<td>2^{-3}</td>
<td>2^{-4}</td>
</tr>
<tr>
<td>2^{-5}</td>
<td>2^{-6}</td>
</tr>
<tr>
<td>2^{-7}</td>
<td>.....</td>
</tr>
<tr>
<td>2^{-16}</td>
<td>2^{-17}</td>
</tr>
<tr>
<td>2^{-18}</td>
<td>2^{-19}</td>
</tr>
<tr>
<td>2^{-20}</td>
<td>2^{-21}</td>
</tr>
<tr>
<td>2^{-22}</td>
<td></td>
</tr>
</tbody>
</table>

Default = 0x400000 = 1.00

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

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2^{23}</td>
<td>2^{22}</td>
</tr>
<tr>
<td>2^{21}</td>
<td>2^{20}</td>
</tr>
<tr>
<td>2^{19}</td>
<td>2^{18}</td>
</tr>
<tr>
<td>2^{17}</td>
<td>2^{16}</td>
</tr>
<tr>
<td>.....</td>
<td>2^{6}</td>
</tr>
<tr>
<td>2^{5}</td>
<td>2^{4}</td>
</tr>
<tr>
<td>2^{3}</td>
<td>2^{2}</td>
</tr>
<tr>
<td>2^{1}</td>
<td>2^{0}</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^{20})</td>
<td>2^{0}</td>
</tr>
<tr>
<td>2^{-1}</td>
<td>2^{-2}</td>
</tr>
<tr>
<td>2^{-3}</td>
<td>2^{-4}</td>
</tr>
<tr>
<td>2^{-5}</td>
<td>2^{-6}</td>
</tr>
<tr>
<td>2^{-7}</td>
<td>.....</td>
</tr>
<tr>
<td>2^{-17}</td>
<td>2^{-18}</td>
</tr>
<tr>
<td>2^{-19}</td>
<td>2^{-20}</td>
</tr>
<tr>
<td>2^{-21}</td>
<td>2^{-22}</td>
</tr>
<tr>
<td>2^{-23}</td>
<td></td>
</tr>
</tbody>
</table>

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

\(PulseRateE\) sets the frequency of \(E_1, E_2, E_3\) pulses. \(E_1, E_2, E_3\) 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 \(-1.0 \leq PulseRateE < 1.0\), 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)

\[
\begin{array}{cccccccccccccccccccc}
\text{MSB} & -(2^0) & 2^-1 & 2^-2 & 2^-3 & 2^-4 & 2^-5 & 2^-6 & 2^-7 & \ldots & 2^-17 & 2^-18 & 2^-19 & 2^-20 & 2^-21 & 2^-22 & 2^-23 \\
\text{LSB} & & & & & & & & & & & & & & & & &
\end{array}
\]

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 \((P_{\text{Active}})\)
Address: 10 (Active Power)

\[
\begin{array}{cccccccccccccccccccc}
\text{MSB} & -(2^0) & 2^-1 & 2^-2 & 2^-3 & 2^-4 & 2^-5 & 2^-6 & 2^-7 & \ldots & 2^-17 & 2^-18 & 2^-19 & 2^-20 & 2^-21 & 2^-22 & 2^-23 \\
\text{LSB} & & & & & & & & & & & & & & & & &
\end{array}
\]

The instantaneous power is averaged over each computation cycle (\(N\) conversions) to compute Active Power \((P_{\text{Active}})\). The value will be within in the range of \(-1.0 \leq P_{\text{Active}} < 1.0\). 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 \((I_{\text{RMS}}, V_{\text{RMS}})\)
Address: 11 (I_{\text{RMS}}); 12 (V_{\text{RMS}})

\[
\begin{array}{cccccccccccccccccccc}
\text{MSB} & 2^-1 & 2^-2 & 2^-3 & 2^-4 & 2^-5 & 2^-6 & 2^-7 & 2^-8 & \ldots & 2^-18 & 2^-19 & 2^-20 & 2^-21 & 2^-22 & 2^-23 & 2^-24 \\
\text{LSB} & & & & & & & & & & & & & & & & &
\end{array}
\]

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

6.1.9 Epsilon Register \((\varepsilon)\)
Address: 13

\[
\begin{array}{cccccccccccccccccccc}
\text{MSB} & -(2^0) & 2^-1 & 2^-2 & 2^-3 & 2^-4 & 2^-5 & 2^-6 & 2^-7 & \ldots & 2^-17 & 2^-18 & 2^-19 & 2^-20 & 2^-21 & 2^-22 & 2^-23 \\
\text{LSB} & & & & & & & & & & & & & & & & &
\end{array}
\]

Default = 0x01999A = 0.0125 sec

Epsilon \((\varepsilon)\) 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 \(-1.0 \leq \varepsilon < 1.0\), with the binary point to the right of the MSB. Negative values have no significance.
6.1.10 Power Offset Register (P\text{off})

Address: 14

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^0)</td>
<td>2^1</td>
</tr>
</tbody>
</table>

Default = 0x0000000

Power Offset (P\text{off}) is added to the instantaneous power being accumulated in the P\text{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\text{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)

<table>
<thead>
<tr>
<th>23</th>
<th>22</th>
<th>21</th>
<th>20</th>
<th>19</th>
<th>18</th>
<th>17</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRDY</td>
<td>CRDY</td>
<td>IOR</td>
<td>VOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>IROR</td>
<td>VROR</td>
<td>EOR</td>
<td>IFAULT</td>
<td>VSAG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Default = 0x8000001 (Status Register), 0x0000000 (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 INT pin. Placing a logic ‘1’ in a Mask bit will allow the corresponding bit in the Status Register to activate the INT pin when the status bit is asserted.

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

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

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

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

IROR \text{I}_{\text{RMS}} Out of Range. Set when the \text{I}_{\text{RMS}} Register overflows.

VROR \text{V}_{\text{RMS}} Out of Range. Set when the \text{V}_{\text{RMS}} Register overflows.

EOR Energy Out of Range. Set when \text{P}_{\text{ACTIVE}} overflows.

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

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

TUP Temperature Updated. Indicates the Temperature Register has updated.

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

VOD (IOD) Modulator oscillation detected on the voltage (current) channel. Set when the modulator 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 (PMLO), with respect to AGND pin. The LSD bit cannot be reset until the voltage at PFMON pin rises back above the high-voltage threshold (PMHI).

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

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)

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
</tr>
</tbody>
</table>

Default = 0x0000000

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

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>17</td>
<td>16</td>
</tr>
</tbody>
</table>

Default = 0x0000000

E2MODE
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.

IIR  Enables the IIR compensation filters.
0 = IIR compensation filters enabled (default)
1 = IIR compensation filters disabled

E3MODE[1:0]  E3 Output Mode
00 = Reactive Power (default)
01 = PFMON
10 = Voltage sign
11 = Apparent Power

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

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

6.1.14 Temperature Register (T)
Address: 19

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^1)</td>
<td>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</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^0)</td>
<td>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</td>
</tr>
</tbody>
</table>

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

6.1.16 Peak Current and Peak Voltage Register (I_{peak}, V_{peak})
Address: 22 (Peak Currect) and 23 (Peak Voltage)

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^0)</td>
<td>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</td>
</tr>
</tbody>
</table>

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

| MSB | \(2^0\) | \(2^{-1}\) | \(2^{-2}\) | \(2^{-3}\) | \(2^{-4}\) | \(2^{-5}\) | \(2^{-6}\) | \(2^{-7}\) | \(2^{-8}\) | \(2^{-9}\) | \(2^{-10}\) | \(2^{-11}\) | \(2^{-12}\) | \(2^{-13}\) | \(2^{-14}\) | \(2^{-15}\) | \(2^{-16}\) | \(2^{-17}\) | \(2^{-18}\) | \(2^{-19}\) | \(2^{-20}\) | \(2^{-21}\) | \(2^{-22}\) | \(2^{-23}\) |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

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 \(\leq Q < 1.0\), with the binary point to the right of the MSB.

6.1.18  Power Factor Register (PF)
Address: 25

| MSB | \(-2^{0}\) | \(2^{-1}\) | \(2^{-2}\) | \(2^{-3}\) | \(2^{-4}\) | \(2^{-5}\) | \(2^{-6}\) | \(2^{-7}\) | \(2^{-8}\) | \(2^{-9}\) | \(2^{-10}\) | \(2^{-11}\) | \(2^{-12}\) | \(2^{-13}\) | \(2^{-14}\) | \(2^{-15}\) | \(2^{-16}\) | \(2^{-17}\) | \(2^{-18}\) | \(2^{-19}\) | \(2^{-20}\) | \(2^{-21}\) | \(2^{-22}\) | \(2^{-23}\) |
|-----|----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

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

| MSB | 0 | \(2^{-1}\) | \(2^{-2}\) | \(2^{-3}\) | \(2^{-4}\) | \(2^{-5}\) | \(2^{-6}\) | \(2^{-7}\) | \(2^{-8}\) | \(2^{-9}\) | \(2^{-10}\) | \(2^{-11}\) | \(2^{-12}\) | \(2^{-13}\) | \(2^{-14}\) | \(2^{-15}\) | \(2^{-16}\) | \(2^{-17}\) | \(2^{-18}\) | \(2^{-19}\) | \(2^{-20}\) | \(2^{-21}\) | \(2^{-22}\) | \(2^{-23}\) |
|-----|----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|

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

<table>
<thead>
<tr>
<th>23</th>
<th>22</th>
<th>21</th>
<th>20</th>
<th>19</th>
<th>18</th>
<th>17</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **15**: STOP
- **14**: INTOD
- **13**: NOCPU
- **12**: NOOSC
- **11**: STOP
- **10**: INTOD
- **9**: NOCPU
- **8**: NOOSC

Default = 0x000000

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

- **INTOD**: Converts `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 (PH)

Address: 29

The Harmonic Active Power (PH) 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 \(-1.0 \leq PH < 1.0\), with the binary point to the right of the MSB.

### 6.1.22 Fundamental Active Power Register (PF)

Address: 30

The Fundamental Active Power (PF) 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 \(-1.0 \leq PH < 1.0\), with the binary point to the right of the MSB.
6.1.23 Fundamental Reactive Power Register (Q_H)
Address: 31 (read only)

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^0)</td>
<td>2^1</td>
</tr>
<tr>
<td>2^-2</td>
<td>2^-3</td>
</tr>
<tr>
<td>2^-4</td>
<td>2^-5</td>
</tr>
<tr>
<td>2^-6</td>
<td>2^-7</td>
</tr>
<tr>
<td>.....</td>
<td>2^-17</td>
</tr>
<tr>
<td>2^-18</td>
<td>2^-19</td>
</tr>
<tr>
<td>2^-20</td>
<td>2^-21</td>
</tr>
<tr>
<td>2^-22</td>
<td>2^-23</td>
</tr>
</tbody>
</table>

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 ≤ Q_H < 1.0, with the binary point to the right of the MSB.

6.1.24 Page Register
Address: 31 (write only)

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2^6</td>
<td>2^5</td>
</tr>
<tr>
<td>2^4</td>
<td>2^3</td>
</tr>
<tr>
<td>2^2</td>
<td>2^1</td>
</tr>
<tr>
<td>2^0</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2^22</td>
</tr>
</tbody>
</table>

Default = 1

PulseWidth sets the duration of energy pulses (tPW). 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 (LoadMin)
Address: 1

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^0)</td>
<td>2^-1</td>
</tr>
</tbody>
</table>

Default = 0

LoadMin is used to set the no load threshold. When the magnitude of the PActive register is less than LoadMin, the active energy pulse output will be disabled. LoadMin is a two's complement value in the range of -1.0 ≤ LoadMin < 1.0, with the binary point to the right of the MSB. Negative values are not used.

6.2.3 Temperature Gain Register (TGain)
Address: 2

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2^6</td>
<td>2^5</td>
</tr>
</tbody>
</table>

Default = 0x2F03C3 = 23.5073471

Sets the temperature channel gain. Temperature gain (TGain) 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 ≤ TGain < 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 (TOff)
Address: 3

<table>
<thead>
<tr>
<th>MSB</th>
<th>LSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>-(2^0)</td>
<td>2^-1</td>
</tr>
</tbody>
</table>

Default = 0xF3D35A = -0.0951126

Temperature offset (Toff) 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 ≤ Toff < 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\textsubscript{Duration}, ISAG\textsubscript{Duration})
Address: 6 (Voltage Sag Duration); 10 (Current Fault Duration)

![MSB LSB Table]

Voltage Sag Duration (VSAG\textsubscript{Duration}) and Current Fault Duration (ISAG\textsubscript{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\textsubscript{Level}, ISAG\textsubscript{Level})
Address: 7 (Voltage Sag Level); 11 (Current Fault Level)

![MSB LSB Table]

Voltage Sag Level (VSAG\textsubscript{Level}) and Current Fault Level (ISAG\textsubscript{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 $0 \leq \text{VSAG}_{\text{Level}} < 1.0$, 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 VIN± pins of the voltage and IIN± pins of the current channels should be connected to their ground reference level. (see Figure 13.)

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**

**Figure 13. System Calibration of Offset**
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 $V_{IN}^{\pm}$ pins of the voltage and $I_{IN}^{\pm}$ 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 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 $V_{\text{RMS}}$ or $I_{\text{RMS}}$ calculation, then the AC offset calibration sequence should be performed.

3. Perform the gain calibration sequence.

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

### 7.2 Phase Compensation

The CS5463 is equipped with phase compensation to cancel out phase shifts introduced by the measurement element. Phase Compensation is set by bits PC[6:0] in the Configuration Register 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 ±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 MHz/(MCLK/K). For power line frequencies other than 60Hz, the values of the range and step size of the PC[6:0] bits can be determined by converting the above values from angular measurement into the time domain (seconds), and then computing the new range and step size (in degrees) with respect to the new line frequency. To calculate the phase shift induced between the voltage and the current channel use the equation:

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

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 E²PROM

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

8.1 Auto-boot Configuration

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

Figure 17. Typical Interface of E²PROM to CS5463

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

8.2 Auto-boot Data for E²PROM

Below is an example code set for an auto-boot sequence. This code is written into the E²PROM by the user. The serial data for such a sequence is shown below in single-byte 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 E²PROMs Can Be Used?

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

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

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

Figure 18 shows the CS5463 configured to measure power in a single-phase, 2-wire system while operating in a single-supply configuration. In this diagram, a shunt resistor is used to sense the line current and a voltage divider is used to sense the line voltage. In this type of shunt-resistor configuration, the common-mode level of the 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

#### INCHES | MILLIMETERS | NOTE
--- | --- | ---
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

<table>
<thead>
<tr>
<th>Model</th>
<th>Temperature</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS5463-ISZ (lead free)</td>
<td>-40 to +85 °C</td>
<td>24-pin SSOP</td>
</tr>
</tbody>
</table>

## 12. ENVIRONMENTAL, MANUFACTURING, & HANDLING INFORMATION

<table>
<thead>
<tr>
<th>Model Number</th>
<th>Peak Reflow Temp</th>
<th>MSL Rating*</th>
<th>Max Floor Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS5463-ISZ (lead free)</td>
<td>260 °C</td>
<td>3</td>
<td>7 Days</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>MAR 2005</td>
<td>Advance Release</td>
</tr>
<tr>
<td>PP1</td>
<td>AUG 2005</td>
<td>First preliminary release.</td>
</tr>
<tr>
<td>F1</td>
<td>NOV 2005</td>
<td>First final release, updated with most-current characterization data.</td>
</tr>
<tr>
<td>F2</td>
<td>APR 2008</td>
<td>Added PulseWidth &amp; LoadMin Registers.</td>
</tr>
<tr>
<td>F3</td>
<td>APR 2011</td>
<td>Removed lead-containing (Pb) device ordering information.</td>
</tr>
</tbody>
</table>

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

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