ADS131M08 Metrology Evaluation Module

TEXAS INSTRUMENTS

Description

The ADS131M08MET evaluation module (EVM) uses the ADS131M08 and the MSPM0G1506SRHB to realize class 0.1 three-phase energy measurements based on IEC-62053, EN 50470 and ANSI C12 test methods. The ADS131M08 samples at 8kHz to measure the output of current transformers (CT) or Rogowski Coils (RC) along with a high-voltage resistive divider to measure the current and voltage of up to three phases. The EVM achieves high accuracy across a wide input current range (0.1A–100A) and AC voltage up to 270V. The metrology software is implemented in the MSPM0-SDK and can be compiled with Code Composer Studio™ for further customization.

Getting Started and Next Steps

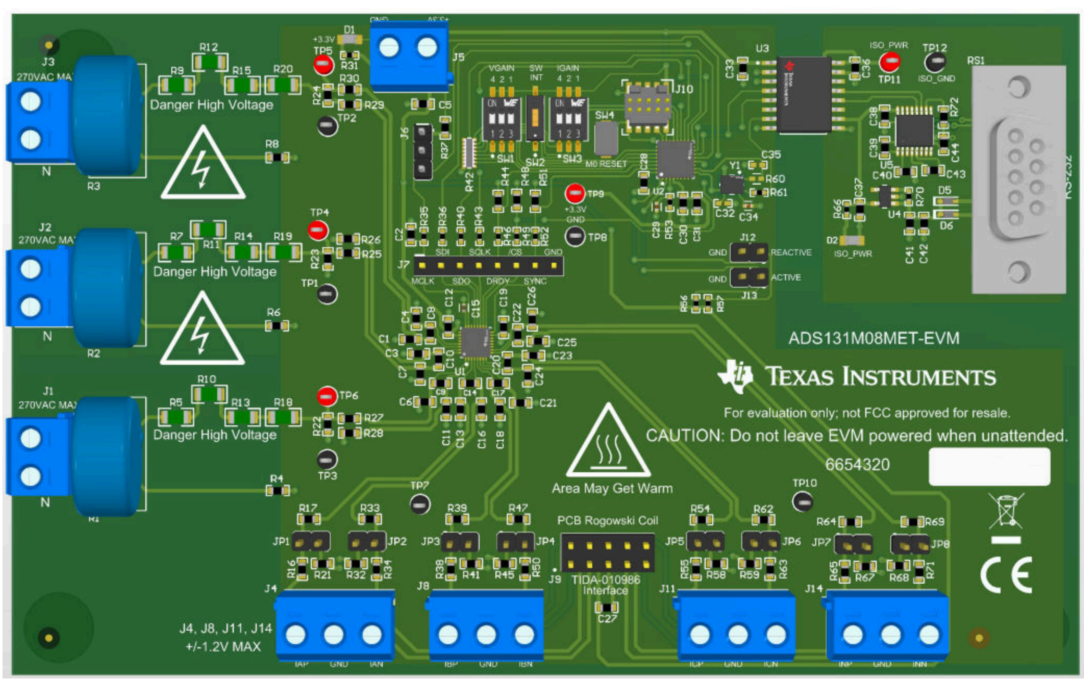
1. Order the ADS131M08MET-EVM
2. Download and install the MSPM0 SDK
3. Download and install drivers for the USB to Serial Cable

Features

- Three-phase metrology EVM that supports class 0.1 accuracy
- Active and reactive energy and power, root mean square (RMS) current and voltage, power factor, and line-frequency calculations
- Isolated RS-232 with 5kV$_{RMS}$ isolation
- Tested across 100mA to 100A and 90V to 270V input range
- Software for energy metrology and displaying results on a Microsoft® Windows® PC GUI

Applications

- Electricity meter
- Industrial circuit breaker (MCCB, ACB, VCB)
- AC charging (pile) station
- UPS - three phase
- Solar charge controller



ADS131M08MET-EVM Hardware PCB

1 Evaluation Module Overview

1.1 Introduction

This user's guide describes the characteristics, operation, and use of the ADS131M08MET evaluation module (EVM). The ADS131M08MET-EVM is an evaluation platform for the ADS131M08 along with the MSPM0G1506 microcontroller and the MSPM0 metrology software. The EVM eases the evaluation of the ADS131M08 and MSPM0G1506 with hardware, software, and computer connectivity through the universal serial bus (USB) interface. This user's guide includes complete circuit descriptions, schematic diagrams, and a bill of materials (BOM). Throughout this document, the terms evaluation module and EVM are synonymous with the ADS131M08MET-EVM.

1.2 Kit Contents

The ADS131M08MET-EVM includes a USB-to-UART cable to connect to a PC for RS-232 communication. Three 2-terminal connectors are provided for connecting voltage inputs to the ADS131M08. There are four 3-terminal connectors provided to allow user-supplied current transformers or Rogowski coils. The EVM includes two 3-position SPST switches for adjusting the voltage and current gain from 1 to 128. There is also a switch provided to implement software integration for Rogowski coils through the metrology software running on the MSPM0G1506.

1.3 Block Diagram

Figure 1-1 depicts the overall block diagram of the ADS131M08MET-EVM along with the various connections for voltage, current sensors, and communication with the PC.

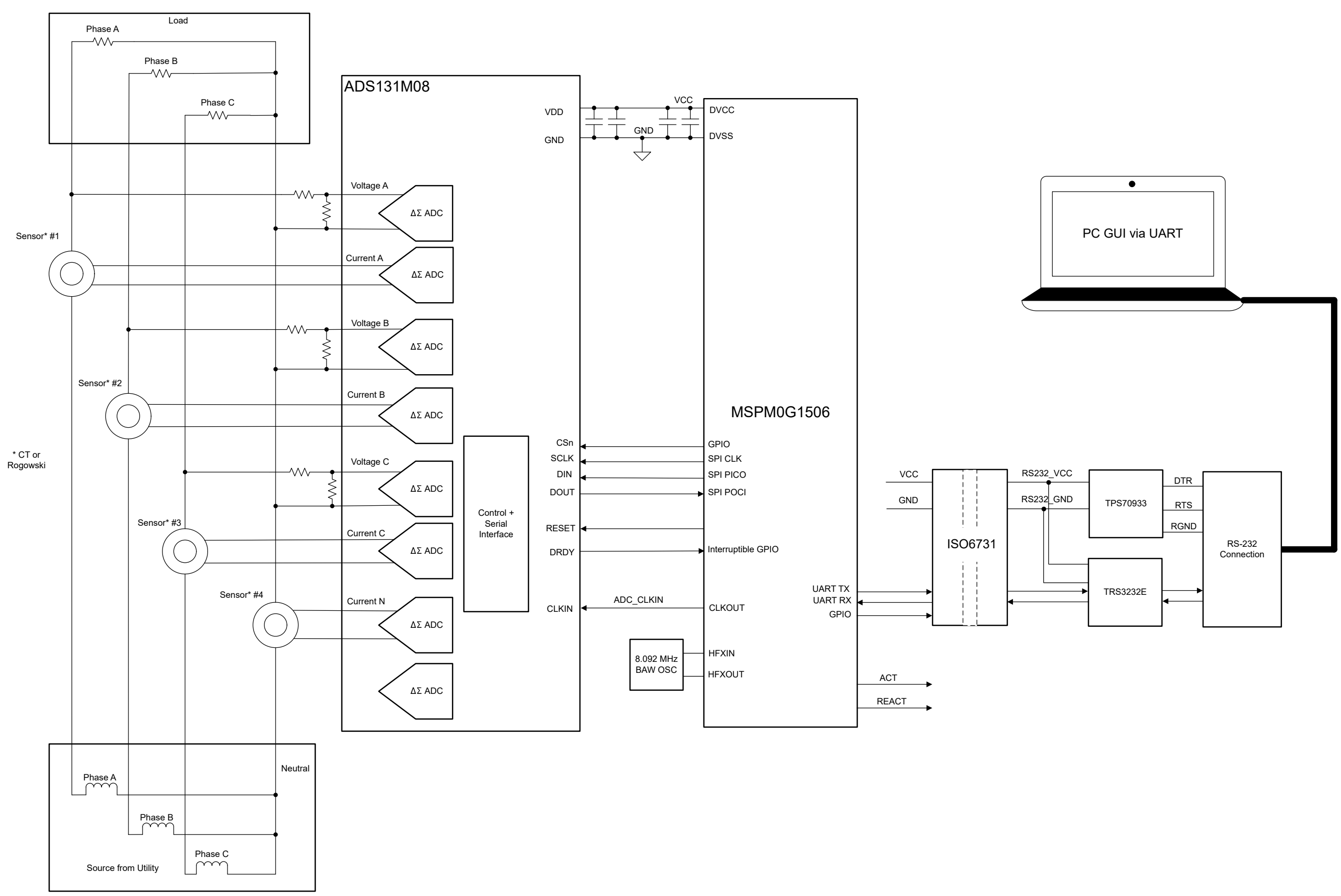


Figure 1-1. Block Diagram

1.4 Device Information

The ADS131M08 is an eight-channel, simultaneously sampling, 24-bit, delta-sigma (ΔΣ), analog-to-digital converter (ADC) that offers wide dynamic range, low power, and energy-measurement-specific features, making the device an excellent fit for energy metering, power metrology, and circuit breaker applications. The ADC inputs can be directly interfaced to a resistor divider network or a power transformer to measure voltage or to a current transformer or a Rogowski coil to measure current.

The MSPM0G1506 microcontroller (MCU) is part of the MSP highly integrated, ultra-low-power 32-bit MCU family based on the enhanced Arm® Cortex®-M0+ 32-bit core platform operating at up to 80MHz frequency. These cost-optimized MCUs offer high-performance analog peripheral integration, support extended temperature ranges from –40°C to 125°C, and operate with supply voltages ranging from 1.62V to 3.6V.

The TRS3232E device consists of two line drivers, two-line receivers, and a dual charge-pump circuit with ±15kV IEC ESD protection pin to pin (serial-port connection pins, including GND). The device meets the requirements of TIA/EIA-232-F and provides the electrical interface between an asynchronous communication controller and the serial-port connector.

The ISO6731 device is a triple-channel digital isolator that is an excellent choice for cost-sensitive applications requiring up to $5000V_{RMS}$ isolation ratings per UL 1577. The ISO6731 device provides high electromagnetic immunity and low emissions at low power consumption, while isolating CMOS or LVCMOS digital I/Os.

The TPS709 series of linear regulators are ultra-low, quiescent current devices designed for power-sensitive applications. A precision band-gap and error amplifier provides 2% accuracy over temperature.

The CDC6CE008192 is a high-precision Bulk-Acoustic Wave (BAW) oscillator with micro-resonator technology integrated directly into a package allowing for low jitter clock circuitry.

2 Hardware

2.1 Power Requirements

The ADS131M08MET-EVM requires an external 3.3V supply to power the ADS131M08 and the MSPM0G1506. The two-terminal connector J5 is provided for an easy means to connect an isolated +3.3V source to the PCB. The RS-232 connection to the PC is isolated from the main circuitry on the EVM by means of an ISO6731. Power for the TRS3232E and low side of the ISO6731 are provided by a TPS70933 +3.3V regulator and the RS-232 DTR and RTS lines as shown in the *schematic* section of this document.

2.2 Header Information

An eight pin header (J7) is provided as a means to monitor the various connections to the ADS121M08. This header allows access to the modulator clock, SDI, SDO, SCLK, DRDY, $\overline{CS}$ and the SYNC/RESET input.

J9 is a 5-pin dual row header that allows users to use the TIDA-010986 reference design with the ADS131M08MET-EVM. This reference design implements a hardware integration scheme for use with PCB based Rogowski coils. More details are found in the TIDA-010986 design guide.

J10 is a 5-pin two row JTAG header that allows further customization of the firmware that is loaded into the MSPM0G1506. Further details and access to the CCS project used for the ADS131M08MET-EVM is found in the MSPM0-SDK documentation.

2.3 Jumper Information

Eight 2-pin headers are provided to manage burden resistors for CTs connected to screw terminals J4, J8, J11, and J14. Remove the shunts located on these headers to connect a Rogowski coil.

2.4 Slide Switches and Push Buttons

Push button switch SW4 is provided as a means to reset the MSPM0G1506. If there are any changes made to the gain switches SW1 and SW3, or if the software integration switch SW2 is enabled, the MSPM0G1506 needs to be reset for the changes to take effect.

2.5 Test Points

Various test points are provided on the ADS131M08 to monitor voltage and power supply inputs. See the *schematic* pages for details.

2.6 Cautions and Warnings

If the ADS131M08MET-EVM is connected to AC Mains, there is a risk of exposure to high voltages. The use of Personal Protective Equipment (PPE) such as rubber insulating gloves, electrical hazard rated footwear and goggles is recommended when performing energized testing. TI recommends using the EVM in a protective safety enclosure that disables high-voltage potential when the enclosure is opened.

WARNING

Hot Surface! Contact can cause burns. Do not touch. Take the proper precautions when operating.

CAUTION

High Voltage! Electric shocks are possible when connecting the board to live wires. The board must be handled with care by a professional. For safety, use of isolated test equipment with overvoltage or overcurrent protection is highly recommended.

2.7 Analog Inputs

The analog inputs to the ADS131M08MET-EVM are divided into two categories; voltage inputs and current sensor inputs. The following sections provide additional details.

2.7.1 Voltage Inputs

The voltage inputs to the ADS131M08 are located on two-terminal screw connectors J1, J2, and J3. The inputs are fed to the ADC through resistive dividers consisting of four 330kΩ resistors and a 1kΩ resistor to ground. Figure 2-1 depicts the input structure common to all three voltage inputs.

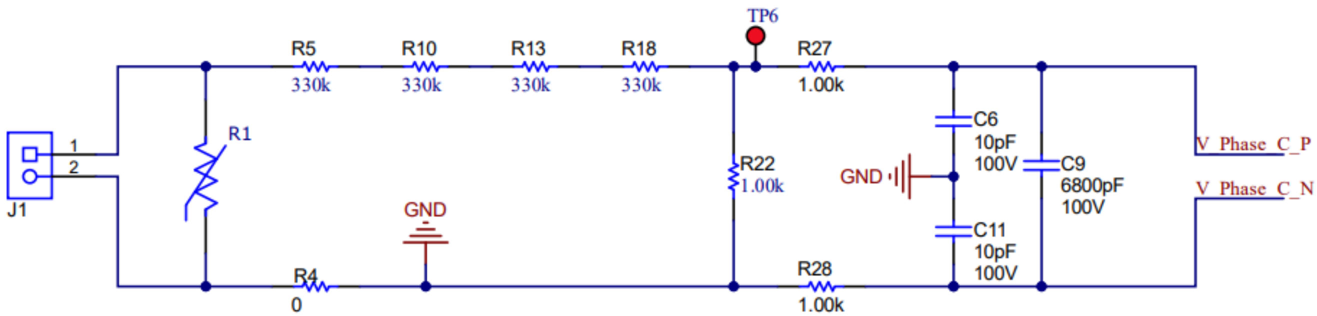


Figure 2-1. Voltage Inputs

2.7.1.1 Voltage Measurement Analog Front End

The nominal voltage from the Mains is from 100V–240V so the voltage needs to be scaled down to be sensed by an ADC. Figure 2-1 shows the analog front end used for this voltage scaling. J1 is where the voltage is applied for Phase C, similar circuitry is used for each of the Phases A and C.

In the analog front end for voltage, there is a spike protection varistor (R1), a voltage divider network (R5, R10, R13, R18 and R22), and an RC low-pass filter (R27, R28, C6, C11, and C9).

At lower currents, voltage-to-current crosstalk affects active energy accuracy much more than voltage accuracy, if power offset calibration is not performed. To maximize the accuracy at these lower currents, in this design only a small part of the full ADC range is used for voltage channels. Since the ADCs of the ADS131M08 device are high-accuracy ADCs, using the reduced ADC range for the voltage channels in this design still provides more than enough accuracy for measuring voltage. Equation 1 shows how to calculate the range of differential voltages fed to the voltage ADC channel for a given Mains voltage and selected voltage divider resistor values.

$$V_{ADC\_Swing,\,Voltage} = \pm V_{RMS} \times \sqrt{2}\left(\frac{R_{22}}{R_{22} + R_5 + R_{10} + R_{13} + R_{18}}\right) \quad (1)$$

Based on this formula and the selected resistor values in Figure 2-1, for a mains voltage of 120V (as measured between the line and neutral), the input signal to the voltage ADC has a voltage swing of ±128mV (91mV$_{RMS}$). For a mains voltage of 230V (as measured between the line and neutral), the 230V input to the front-end circuit produces a voltage swing of ±245.33mV (173.48mV$_{RMS}$). The ±128mV and the ±245.33mV voltage ranges are both well within the ±1.2V input voltage that can be sensed by the ADS131M08 device for the default PGA gain value of 1 that is used for the voltage channels.

2.7.2 Current Sensor Inputs

The current sensor inputs to the ADS131M08 are located on three-terminal screw connectors J4, J8, J11, and J14. Figure 2-2 depicts the input structure common to all four current sensor inputs.

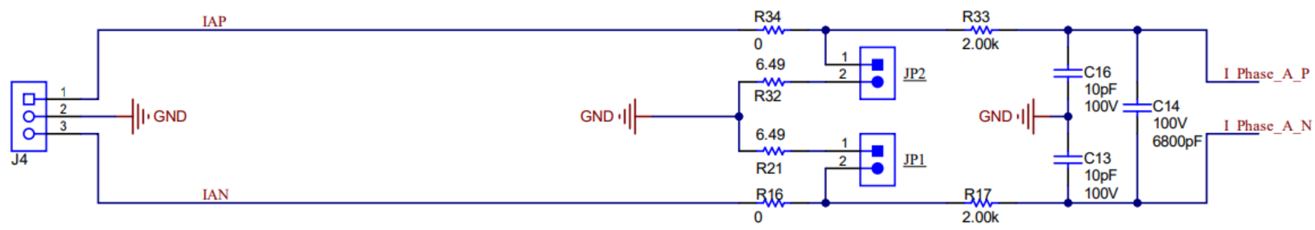


Figure 2-2. Current Sensor Inputs

The shunt jumpers on JP1 through JP8 must be installed to provide a burden resistor when using current transformers. Rogowski coils can also be connected to these inputs in which case the shunt jumpers need to be removed as no burden resistor is needed when using this type of current sensor. Figure 2-3 provides additional detail.

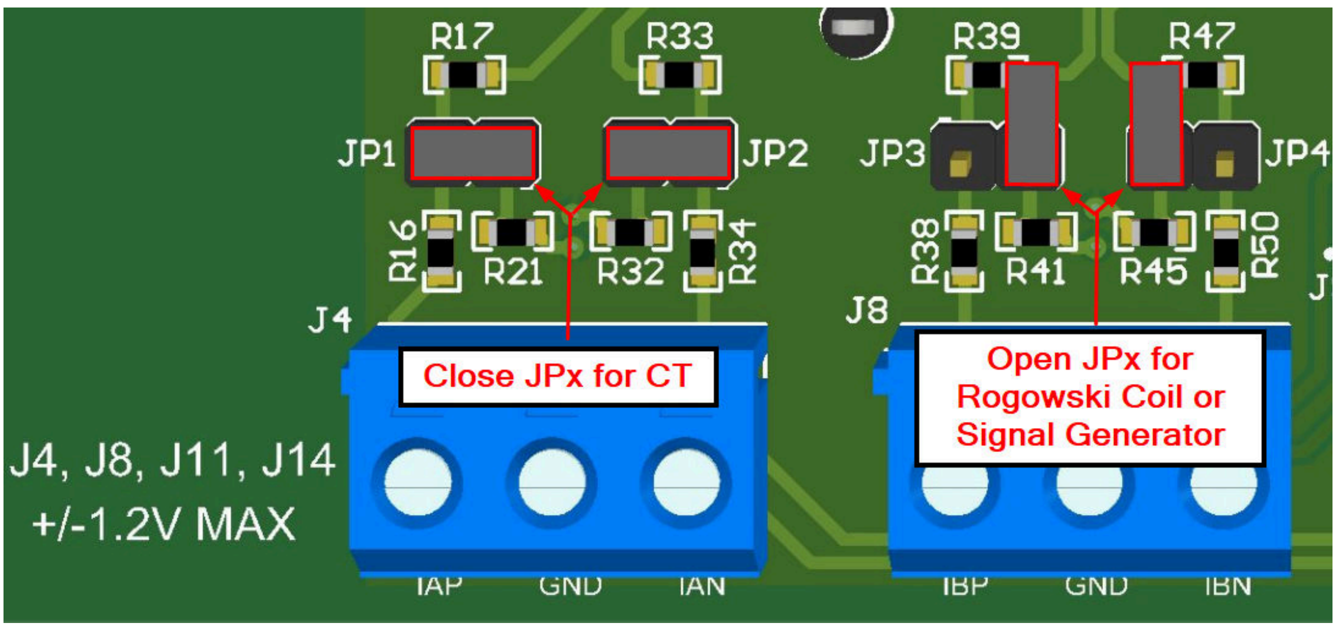


Figure 2-3. Shunt Jumpers for Current Sensor Options

2.7.2.1 Current Measurement Analog Front End

The analog front end for current inputs is different from the analog front end for the voltage inputs. Figure 2-2 shows the analog front end used for a current channel, where the positive and negative leads from a CT for Phase A are connected to pins 1 and 3 of header J4. Again, identical circuitry is used for the CTs on each of the Phases B, C, and neutral.

The analog front end for current consists of footprints for electromagnetic interference filter beads (R34 and R16), burden resistors for current transformers (R32 and R21), and an RC low-pass filter (R33, R17, C13, C16, and C14) that functions as an anti-alias filter.

As Figure 2-2 shows, resistors R32 and R21 are the burden resistors, which are in series with each other. For best Total Harmonic Distortion (THD) performance, instead of using one burden resistor, two identical burden resistors in series are used with the common point being connected to GND. This split-burden resistor configuration makes sure that the waveforms fed to the positive and negative terminals of the ADC are 180 degrees out of phase with each other, which provides the best THD results with this ADC. The total burden resistance is selected based on the current range used and the turns ratio specification of the CT (this EVM used 100A CTs with a turns ratio of 2500:1). The total value of the burden resistor for this design is 12.98Ω.

Equation 2 shows how to calculate the range of differential voltages fed to the current ADC channel for a given maximum current, CT turns ratio, and burden resistor value.

$$V_{ADC\_Swing, Current} = \pm \frac{\sqrt{2}(R_{32}+R_{21})I_{RMS, max}}{CT_{TURNS\_RATIO}} \quad (2)$$

Based on the maximum CT current of 100A, turns ratio of 2500:1, and burden resistor of 12.98Ω, the input signal to the current ADC has a voltage swing of ±918mV maximum (649mV_{RMS}) when the maximum current rating of 100A is applied. This ±918mV maximum input voltage is well within the ±1.2V input range of the ADS131M08 for the default PGA gain of 1 that is used for the current channels.

2.7.2.1.1 Rogowski Coil Inputs

When using Rogowski coils as the current sensor inputs, the shunt jumpers on JP1 through JP8 must be removed. Depending on the sensitivity of the coil, additional gain on the current input channels can be added as described in Section 2.7.3.

The MSPM0G1506 on the EVM is capable of performing software integration. To enable software integration, switch SW2 (see Figure 2-4) must be switched to the ON position followed by pressing the push-button switch SW4. TI reference design TIDA-010986 is an optional PCB design which incorporates hardware integration for up to three current inputs. The TIDA-010986 reference PCB can be plugged directly onto the ADS131M08MET-EVM through J9.

2.7.3 Analog Gain Setting

The three voltage inputs and four current sensor inputs use the PGA inside the ADS131M08 with a gain setting of 1 by default. SW1 sets the gain for the voltage inputs and SW3 sets the gain for the current sensor inputs. All three voltage channels use the same gain set by SW1. All four current sensors use the same gain set by SW3. To change the gain, move the slide switches shown in Figure 2-4 to the ON position. To set the PGA for a gain of 2, for example, move slide switch 3 to the ON position. The three switch positions provide gains of 1, 2, 4, 8, 16, 32, 64, and 128. For the new gain setting to take effect, press the push-button switch SW4 to reset the MSPM0G1506.

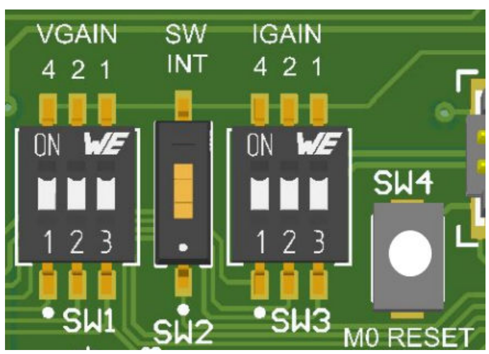


Figure 2-4. Analog Input Gain Options

Table 2-1. Switch Settings for Gain

Setting	Gain
000 (default, all switches in the off position)	1
001	2
010	4
011	8
100	16
101	32
110	64
111	128

3 Software Installation

To use the ADS131M08MET-EVM, two pieces of software must be installed on the PC being used to evaluate the EVM. If using the USB to RS-232 cable provided with the EVM, the drivers for the cable must be installed. Download the U209-000-R cable drivers from the EATON serial adapter cable link.

The second piece of software needed is the MSPM0-SDK. The SDK package includes the CCS project file that is used to create the firmware loaded into the MSPM0G1506 as well as the Energy Metrology GUI.

3.1 GUI Operation

Before running the ADS131M08MET-EVM GUI, plug the USB to RS-232 cable into the PC and verify the COM port used. On a Microsoft Windows PC, open the Device Manager and scroll down to Ports (COM and LPT). Find the Prolific PL2303GS USB Serial COM Port and note the port used. The COM ports being used are enclosed in parentheses as shown in Figure 3-1.

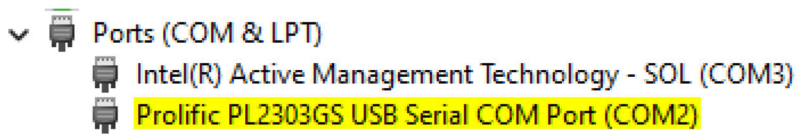


Figure 3-1. PC COM Port

Open the folder on the PC that contains the metrology GUI. By default, the GUI is located in C:\ti\mspm0_sdk_(version)\tools\metrology_gui. Before running the calibrator.exe file, open and edit the calibration-config.xml file. Open the calibration-config.XML file with a text editor and search for *<meter position="1">*. The line following the meter position must use the same COM port that is associated with the PL2303GS COM port as shown in Figure 3-2. Be sure to save any changes before running the calibrator.exe file.

```
<meter position="1">
  <port name="com2" speed="9600"/>
</meter>
```

Figure 3-2. XML COM Port

3.2 Launch the Metrology Software

Using the provided USB to serial cable, plug the USB end into the PC and connect the 9-pin *D* connector into the RS-232 port on the EVM. Apply 3.3V to J5 and run the calibrator executable file. LEDs D1 and D2 illuminate and the following screen appears on the PC.

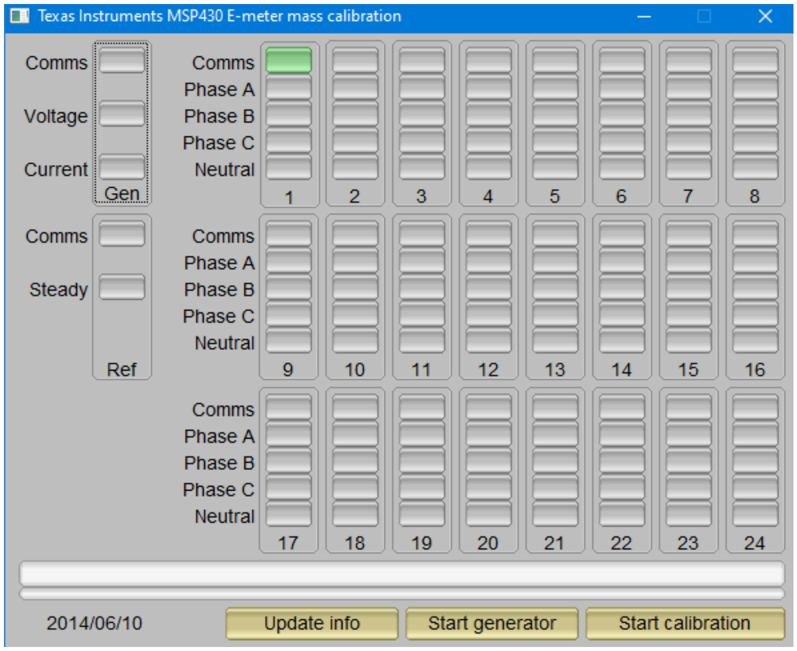


Figure 3-3. GUI Start-up

If the COMMS button does not turn green, verify there is +3.3V applied to J5 and double-check the COM port settings in both the Device Manager and calibrator-config.XML file. Press the COMMS button to launch the metering GUI. The screen in Figure 3-4 showing the meter status becomes active on the computer.

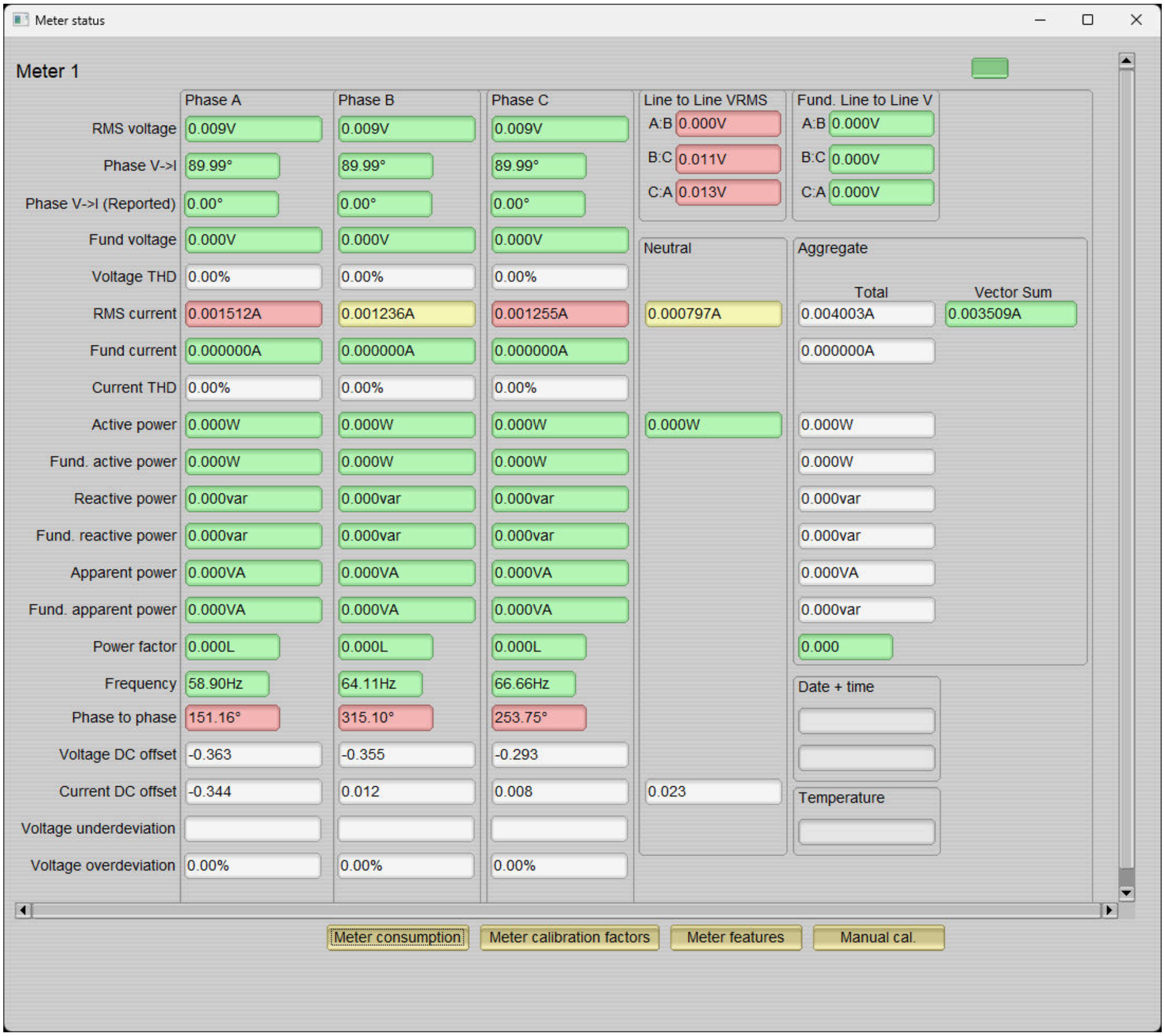


Figure 3-4. Initial Meter Status

4 Energy Metrology Software Overview

4.1 Using the ADS131M08MET-EVM

The MSPM0G1506 found on the ADS131M08REF-EVM is flashed with the necessary firmware to implement the various metering functions found within the energy measurement library. The Energy Measurement software is divided three layers. The MSPM0 DriverLib layer consists of all the peripherals defined and is configured using SysConfig. The module layer contains four modules; Hardware Abstraction Layer (HAL) module, Analog front end converter (ADS131M0x) module, Metrology module, and a Communication module. The HAL module provides Application Programming Interfaces (APIs) to manipulate and configure MCU pins and peripherals. The Analog front end module provides Application Programming Interfaces (APIs) related to configuration of ADS131M0x and SPI communication. The metrology module provides the APIs to process the sampled data and do the mathematical calculations. The communication module is used to receive commands from the GUI and send the computation results to the GUI. Documentation describing the functions and formulas used are installed with the MSPM0-SDK package.

The GUI does not support direct programming of the ADS131M08, other than gain and software integration which takes effect upon reset of the controller. The MSPM0G1506 determines the state of the *VGAIN*, *IGAIN*, and *SW INT* switches as part of an initialization process on start-up. The MSPM0G1506 configures the ADS131M08 through 4-wire SPI communication to operate with a 4.096MHz SCLK with 512 oversampling ratio (OSR) and a data rate of 8kSPS.

4.1.1 Measuring Voltage and Current

It is not necessary to apply AC Mains voltage to the EVM to evaluate the basic performance of the hardware and software. A dual-channel signal generator can safely be used to verify operation and get the basic metrology aspect of the EVM working. For example, the voltage inputs can be applied directly to test points 4, 5, and 6. With the shunt jumpers removed from JP1 through JP8, the voltage that is generated over the CT burden resistor can be applied directly to screw terminals J4, J8, J11, and J14.

With the voltage divider used on each of the three voltage input terminals, Mains voltage of 120V (as measured between the line and neutral) applied to J3, the voltage at TP5 is ±128mV (91mV_{RMS}). For a mains voltage of 230V (as measured between the line and neutral), the 230V input to the front-end circuit produces a voltage swing of ±245.33mV (173.48mV_{RMS}). The ±128mV and the ±245.33mV voltage ranges are both well within the ±1.2V input voltage that can be sensed by the ADS131M08 device for the default PGA gain value of 1 that is used for the voltage channels.

To verify the current channel inputs without using a current transformer or Rogowski coil, the second signal generator channel can be applied directly to J4 at the IAP and IAN terminals. Remove the shunts from JP1 and JP2 and inject a 60Hz sine wave of up to ±1V. The typical voltage found on the current channel inputs depends on the turns ratio of the CTs used or the sensitivity of the Rogowski coil. As an example, a current input of 100A and CT turns ratio of 2500:1, with the burden resistor of 12.98Ω used on this EVM, the input signal to the current channels has a voltage swing of ±918mV maximum (649mV_{RMS}). Verify the current in the meter status panel. Figure 4-1 provides an example of using a low-voltage signal source to emulate 120V_{RMS} and 10A inputs on Phase A.

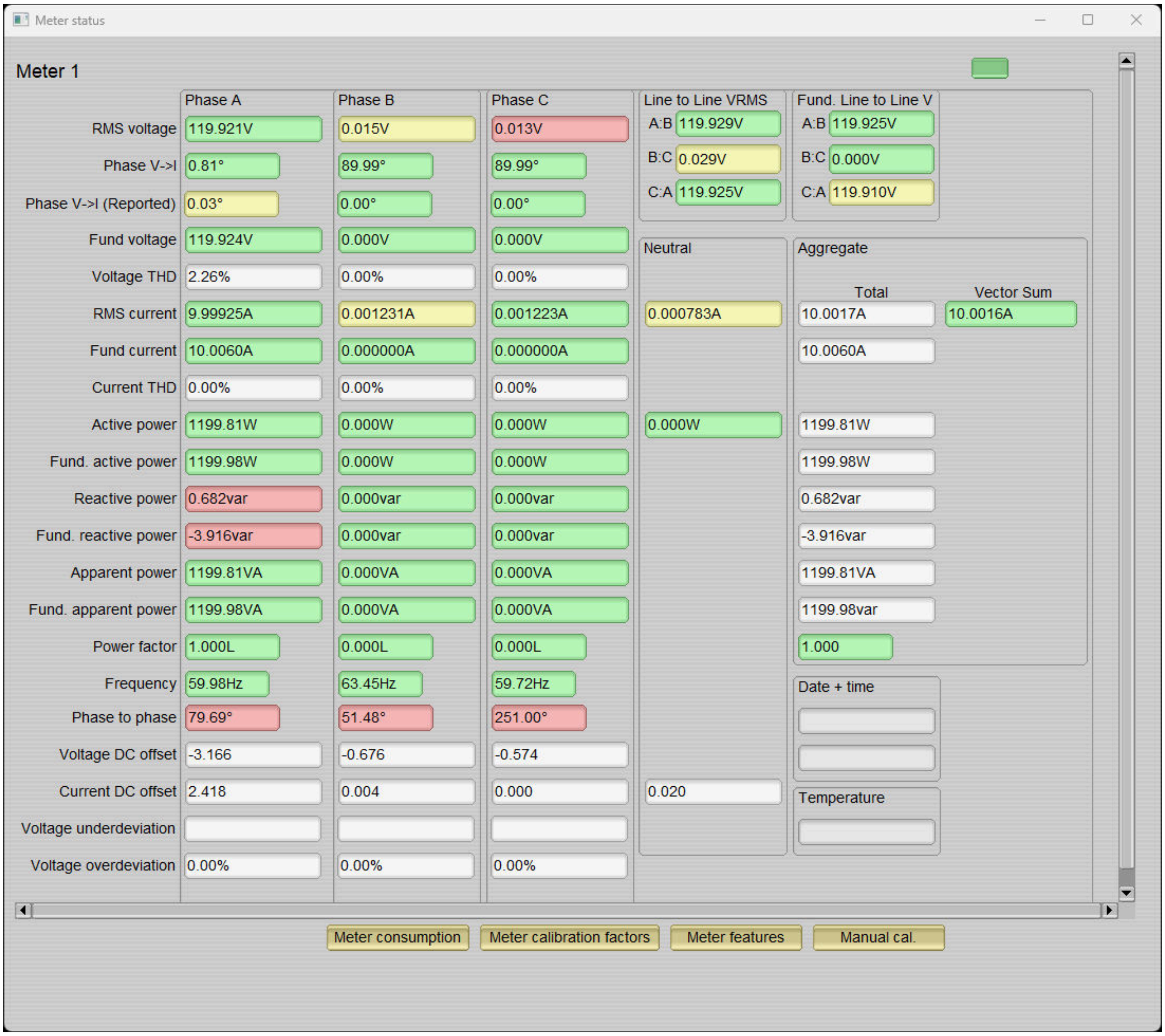


Figure 4-1. Voltage and Current Inputs

4.1.1.1 Calibration Procedure

Full calibration requires the use of an accurate generator meter or reference meter such as the PTS3.3C from MTE. Calibration can be initiated by clicking on the *Manual Cal* button in the bottom left corner of the meter status window shown in Figure 4-1.

4.1.1.1.1 Gain Calibration

Gain correction for voltage and current can be done simultaneously for all phases. However, energy accuracy (%) from the reference meter for each individual phase is required for gain correction for active power. Also, when performing active power calibration for any given phase, the other phases must be turned OFF by turning off the current but leaving the other voltages enabled.

4.1.1.1.2 Voltage and Current Gain Calibration

To calibrate the voltage and current readings, perform the following steps:

1. Connect the GUI to view results for voltage, current, active power, and the other metering parameters.
2. Configure the test source to supply the desired voltage and current for all phases. Make sure that these are the voltage and current calibration points with a zero-degree phase shift between each phase voltage and current. For example, for 120V, 10A, 0° (PF = 1). Typically, these values are the same for every phase.
3. Click on the *Manual cal.* button in Figure 4-1. The screen in Figure 4-2 pops up:

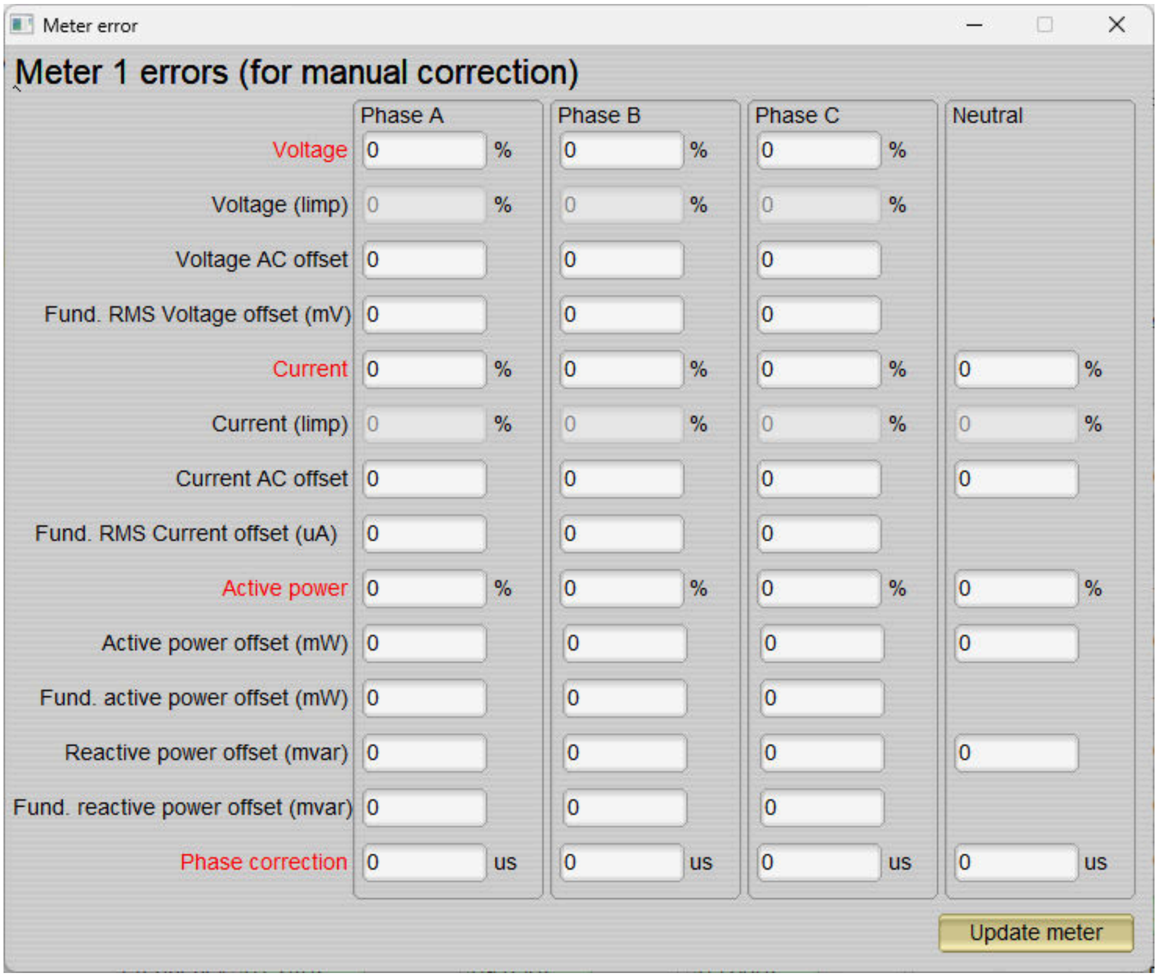


Figure 4-2. Manual Calibration Window

4. Calculate the correction values for each voltage and current. The correction values that must be entered for the voltage and current fields are calculated using Equation 3:

$$\text{Correction (\%)} = \left(\frac{\text{value}_{\text{observed}}}{\text{value}_{\text{desired}}} - 1 \right) \times 100 \tag{3}$$

   where

   - $\text{value}_{\text{observed}}$ is the value measured by the TI meter
   - $\text{value}_{\text{desired}}$ is the calibration point configured in the AC test source
5. After calculating for all voltages and currents, input these values as (±) correction factors for the fields *Voltage and Current* for the corresponding phases.
6. Click on the *Update meter* button and the observed values for the voltages and currents on the GUI settle immediately to the desired voltages and currents.

4.1.1.1.3 Active Power Gain Calibration

Note

This section is an example for one phase. Repeat these steps for the other two phases.

After performing gain correction for voltage and current, complete *gain correction* for active power. Gain correction for active power is done differently in comparison to voltage and current. Although, conceptually, calculating the active energy % error as is done with voltage and power can be done, avoid using this method because the method is not the most accurate.

The best option to get the *Correction (%)* is directly from the reference meters measurement error of the active power. This error is obtained by feeding energy pulses to the reference meter. To perform active power calibration, complete the following steps:

1. Turn off the system and connect the energy pulse output of the system to the reference meter. Configure the reference meter to measure the active power error based on these pulse inputs.
2. Turn on the AC test source.
3. Repeat step 1 to step 3 from Voltage and Current Gain Calibration with the identical voltages, currents, and 0° phase shift that are used in the same section.
4. Obtain the % error in measurement from the reference meter. A negative value is possible here.
5. Enter the error obtained in step 4 into the *Active Power* field under the corresponding phase in the GUI window. This error is already the value and does not require calculation.
6. Click the *Update meter* button and the error values on the reference meter immediately settle to a value close to zero.

4.1.1.1.4 Offset Calibration

After performing gain calibration, if the accuracy at low currents is not acceptable, perform offset calibration. Offset calibration removes any crosstalk, such as the crosstalk to the current channels of a phase from the line voltages.

To perform active power offset calibration for a phase, simply add the offset to be subtracted from the active power reading (in units of mW) to the current value of the active power offset (labeled *Voltage AC off* in Figure 4-3) and then enter this new value in the *Voltage AC offset* field in the *Manual Calibration* window. As an example, if the *Voltage AC off* has a value of 200 (0.2W) in Figure 4-3, and the desire is to subtract an additional 0.300mW, then enter a value of 500 in the *Voltage AC offset* field in the *Manual Calibration* window. After entering the value in the *Voltage AC offset* field in the *Manual Calibration* window, press the *Update meter* button for the changes to take effect.

To perform reactive power offset calibration for a phase, a similar process is followed as the process used to perform active power offset calibration. Add the offset to be subtracted from the reactive power reading (in units of mvar) to the current value of the reactive power offset (labeled *Current AC offset* in Figure 4-3) and then enter the value in the *Current AC offset* field in the *Manual Calibration* window. After entering the value in the *Current AC offset* field in the *Manual Calibration* window, press the *Update meter* button.

4.1.1.1.5 Phase Calibration

After performing power gain correction, perform the phase calibration. Similar to active power gain calibration, to perform phase correction on one phase, the other two phases must be disabled. To perform phase correction calibration, complete the following steps:

1. If the AC test source has been turned OFF or reconfigured, perform step 1 to step 3 from Voltage and Current Gain Calibration using the identical voltages and currents used in that section.
2. Disable all other phases that are not currently being calibrated by setting the current of these phases to 0A.
3. Modify only the phase-shift to a non-zero value; typically, +60° is chosen. The reference meter now displays a different % error for active power measurement. This value can be negative.
4. If the error from step 3 is not close to zero, or is unacceptable, perform phase correction by following these steps:
   a. Enter a value as an update for the *Phase Correction* field for the phase that is being calibrated. Typically, a small ± integer must be entered to bring the error closer to zero. Additionally, for a phase shift

greater than 0 (for example: +60°), a positive (negative) error requires a positive (negative) number as correction.

b. Click on the *Update meter* button and monitor the error values on the reference meter.
c. If this measurement error (%) is not accurate enough, fine-tune by incrementing or decrementing by a value of 1 based on Step 4a and Step 4b. After a certain point, the fine-tuning only results in the error oscillating on either side of zero. The value that has the smallest absolute error must be selected.
d. Change the phase to −60° now, and check if this error is still acceptable. In the best case, errors must be symmetric for the same phase shift on lag and lead conditions.

After performing phase calibration, calibration is complete for one phase. Gain calibration, offset calibration, and phase calibration must be performed for the other phases.

This completes calibration of voltage, current, and power for both phases. View the new calibration factors (see Figure 4-3) by clicking the *Meter calibration factors* button of the GUI metering results window in Figure 4-1. For these displayed calibration factors, the *Voltage AC off* parameter actually represents the active power offset (in units of mW) subtracted from each measurement and the *Current AC offset* parameter actually represents the reactive power offset subtracted (in units of mvar) from reactive power readings. Also, this shows example calibration factors for a meter that uses the two-voltage configuration. If the same meter is set for one-voltage configuration, the voltage and active power scaling factors are approximately half of what is in Figure 4-1, since the line-to-line voltage measurement is used for the voltage readings of both phases instead of measuring the two line-to-neutral voltages. Under the best conditions for a split-phase system, the line-to-line voltage measurement has an RMS value that is twice each of the two line-to-neutral RMS measurements, which means that the voltage fed to the ADC is also twice as much when measuring line-to-line voltage compared to when measuring line-to-neutral voltage. As a result, for one-voltage configurations, the voltage and power readings have to be divided by an additional factor of two, which is automatically done by following the active power and voltage gain calibration steps.

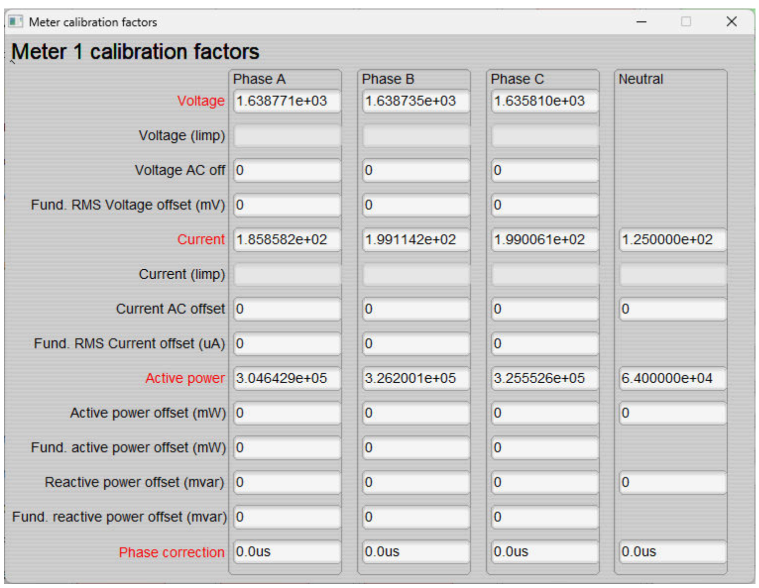


Figure 4-3. Calibration Factors Window

4.2 Test Accuracy Results

4.2.1 Current Transformer Results

For the following test results, gain and phase calibration are applied to the EVM using CR8350-2500-N current transformers from CR Magnetics Inc. In the following results, the active energy results are within 0.1% at 0° phase shift. Additionally, the active energy versus voltage results and the RMS voltage results show that good accuracy results are able to be obtained despite using only a fraction of the ADC range for the voltage channels.

The *% Error* columns in the following tables and plots are calculated as the difference between the multiple reference input values to ADS131M08MET-EVM and the measured values, shown on the PC GUI. The reference input values to ADS131M08MET-EVM are generated by a PTS3.3C source generator meter or reference meter from MTE, while the measured values calculated by the Energy Library are reported in the PC GUI.

Table 4-1. CT-Based RMS Voltage % Error Versus Voltage, 3-Phase Mode

VOLTAGE (V)	% ERROR Phase A	% ERROR Phase B	% ERROR Phase C
270	0.00555	0.01444	0.02444
260	0.00384	0.01307	0.02461
240	0.00375	0.00500	0.0112
230	0.01086	0.00304	0.01652
220	0.00863	0.01090	0.00090
200	0.00700	0.00500	0.00650
180	0.01055	0.00111	0.00388
160	0.00250	0.00687	0.01874
140	0.00214	0.00428	0.00071
120	0.00666	0.01916	0.00999
100	0.00300	0.00900	0.00200
90	0.01300	0.00922	0.00988

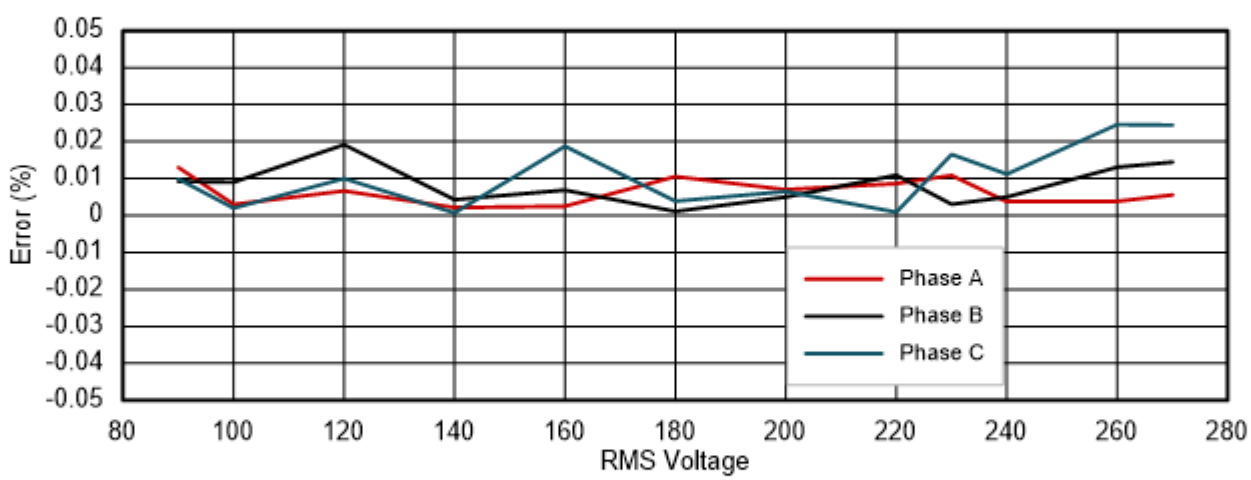


Figure 4-4. CT-Based RMS Voltage % Error Versus Voltage, 3-Phase Mode

Table 4-2. RMS Current % Error Versus Current, 3-Phase Mode

CURRENT (A)	% ERROR Phase A	% ERROR Phase B	% ERROR Phase C
0.1	0.00399	0.04498	0.00499
0.25	0.02239	0.01159	0.00200
0.50	0.00179	0.01220	0.01940
1.00	0.01999	0.01499	0.00500
2.00	0.01649	0.00449	0.00699

Table 4-2. RMS Current % Error Versus Current, 3-Phase Mode (continued)

CURRENT (A)	% ERROR Phase A	% ERROR Phase B	% ERROR Phase C
5.00	0.00539	0.01339	0.01139
10.00	0.00999	0.01000	0.00950
20.00	0.01449	0.01449	0.02570
30.00	0.03366	0.02666	0.02899
40.00	0.01124	0.02825	0.03625
50.00	0.01398	0.01019	0.01720
60.00	0.01566	0.01683	0.01166
70.00	0.00642	0.00414	0.01842
80.00	0.00749	0.00475	0.01062
90.00	0.02321	0.01988	0.00100
100.00	0.02099	0.03199	0.00120

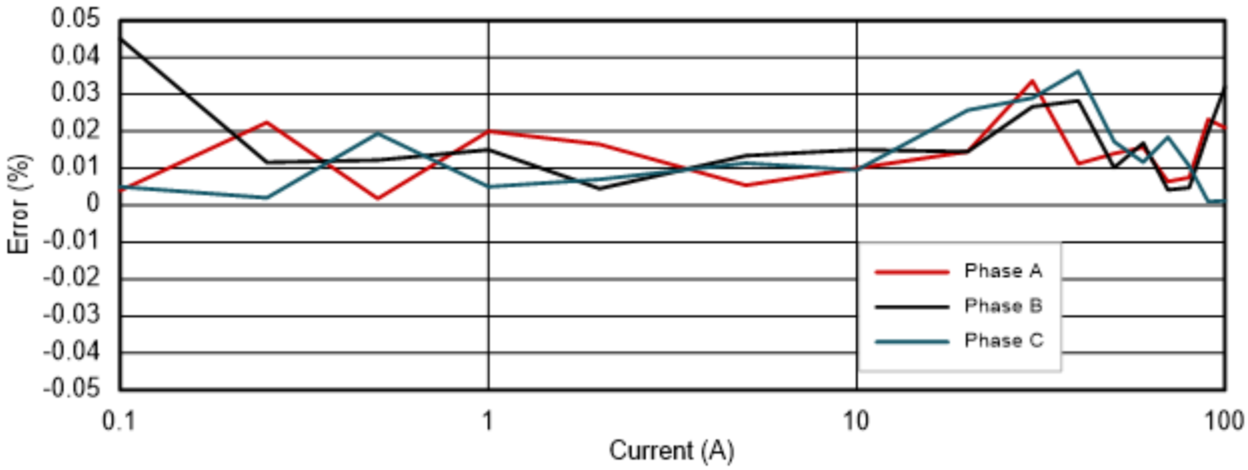


Figure 4-5. RMS Current % Error Versus Current, 3-Phase Mode

Table 4-3. Active Energy % Error Versus Current, 3 CTs With a Turns Ratio of 2500:1 Each

CURRENT (A)	AVG ERROR (%) PF = 1, cos ϕ = 0°	LIMIT (%) [CLASS 0.1] IEC 62053-22 (PF 1)	LIMIT (%) [CLASS 0.2] IEC 62053-22 (PF 1)	AVG ERROR (%) PF = 0.5i, cos ϕ = 60°	LIMIT (%) [CLASS 0.1] IEC 62053-22 (PF 0.5i|0.8c)	LIMIT (%) [CLASS 0.2] IEC 62053-22 (PF 0.5i|0.8c)	AVG ERROR (%) PF = 0.8c cos ϕ = –36.87°
1.0	0.024	±0.2	±0.4				
1.5	0.013	±0.1	±0.2				
3	0.001	±0.1	±0.2	0.093	0.25	0.5	-0.084
10	0.009	±0.1	±0.2				
15	0.005	±0.05	±0.1	0.040	0.15	0.3	-0.055
30	0.009	±0.1	±0.2				
50	0.008	±0.1	±0.2	–0.087	0.15	0.3	-0.015
75	0.027	±0.1	±0.2				
90	0.047	±0.1	±0.2				
100	0.014	±0.1	±0.2	–0.122	0.15	0.3	0.061

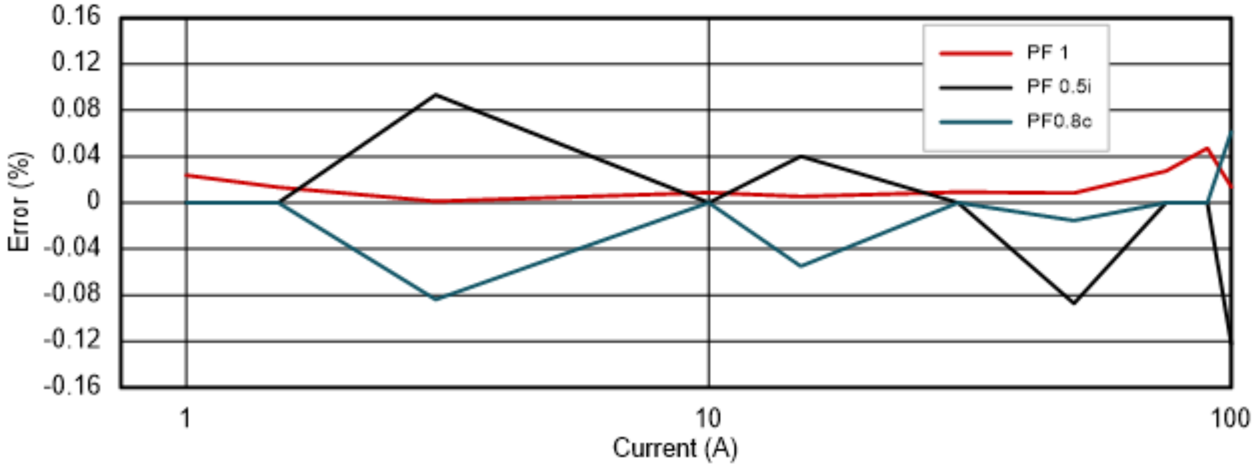


Figure 4-6. Active Energy % Error

Table 4-4. Starting Load Test, cos ϕ = 1i (0°) 0.5A

VOLTAGE (V)	AVERAGE ERROR (%)	Test Current (A)
90	–2.062	0.05

Table 4-5. Variation of Voltage, cos ϕ = 1i (0°)

VOLTAGE (V)	TEST CURRENT (A)	AVERAGE ERROR (%)	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]
120	1.5	0.075	REF	REF
108	1.5	0.072	±0.1	±0.2
235	1.5	0.074	±0.1	±0.2
270	1.5	0.071	±0.1	±0.2
297	1.5	0.069	±0.1	±0.2
120	15	0.053	REF	REF
108	15	0.053	±0.1	±0.2
235	15	0.055	±0.1	±0.2
270	15	0.052	±0.1	±0.2
297	15	0.052	±0.1	±0.2

Table 4-6. Phase Sequence Reversal

CIRCUIT	TEST CURRENT (A)	AVERAGE ERROR (%)	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]
ABC	1.5	0.048	REF	REF
CBA	1.5	0.041	±0.1	±0.3
ABC	15	0.026	REF	REF
CBA	15	0.018	±0.1	±0.3

Table 4-7. Equality of Current Circuits

CIRCUIT	TEST CURRENT (A)	AVERAGE ERROR (%)	LIMIT(%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]
All	1.5	0.056	REF	REF
Circuit A	1.5	0.034	±0.15	±0.3
Circuit B	1.5	0.066	±0.15	±0.3
Circuit C	1.5	0.042	±0.15	±0.3
All	15	0.032	REF	REF
Circuit A	15	0.011	±0.15	±0.3
Circuit B	15	0.046	±0.15	±0.3
Circuit C	15	0.030	±0.15	±0.3

4.2.2 Rogowski Coil Results

For the test results in Table 4-8, gain and phase calibration are applied to the EVM using PA3209NL Rogowski Coils from Pulse Electronics and software integration with the MSPM0G1506. In the following results, the active energy results are within class 0.1%.

Table 4-8. Active Energy % Error Versus Current, 3 Rogowski Coils

CURRENT (A)	AVG ERROR (%) PF = 1, cos ϕ = 0°	LIMIT (%) [CLASS 0.1] IEC 62053-22 (PF 1)	LIMIT (%) [CLASS 0.2] IEC 62053-22 (PF 1)	AVG ERROR (%) PF = 0.5i, cos ϕ = 60°	LIMIT (%) [CLASS 0.1] IEC 62053-22 (PF 0.5i|0.8c)	LIMIT (%) [CLASS 0.2] IEC 62053-22 (PF 0.5i|0.8c)	AVG ERROR (%) PF = 0.8c, cos ϕ = –36.87°
1.0	-0.062	±0.2	±0.4				
1.5	-0.032	±0.1	±0.2				
3	-0.001	±0.1	±0.2	-0.011	0.25	0.5	0.033
10	0.029	±0.1	±0.2				
15	-0.010	±0.05	±0.1	-0.012	0.15	0.3	0.049
30	0.008	±0.1	±0.2				
50	0.002	±0.1	±0.2	-0.076	0.15	0.3	0.030
75	0.005	±0.1	±0.2				
90	-0.014	±0.1	±0.2				
100	-0.029	±0.1	±0.2	-0.088	0.15	0.3	0.018

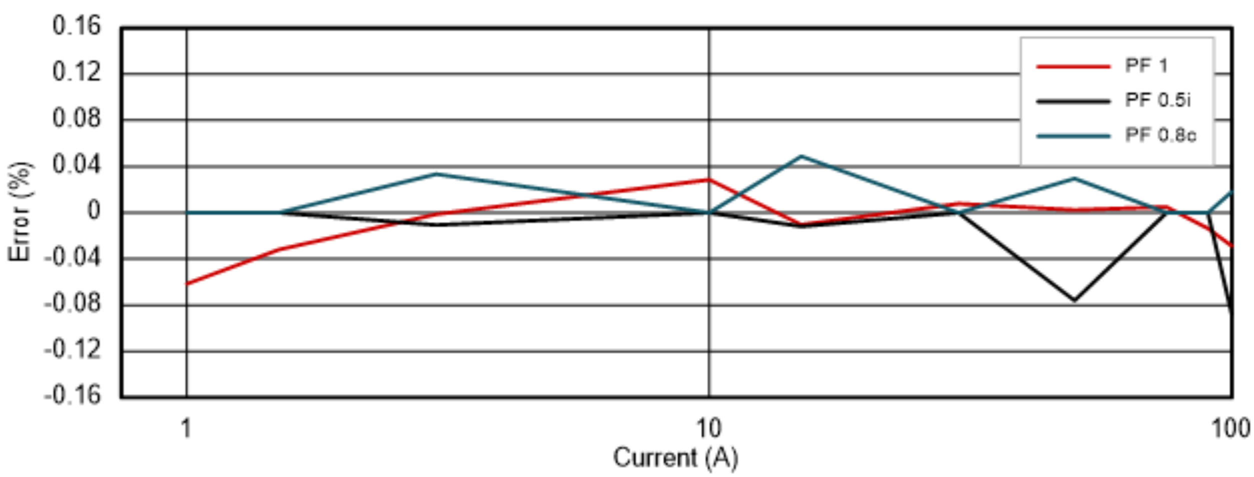


Figure 4-7. Active Energy % Error

Table 4-9. Starting Load Test, cos ϕ = 1i (0°) 1.5A

VOLTAGE (V)	AVERAGE ERROR (%)	Test Current (A)
90	1.049	0.05

Table 4-10. Variation of Voltage, cos ϕ = 1i (0°)

VOLTAGE (V)	TEST CURRENT (A)	AVERAGE ERROR (%)	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]
120	1.5	-0.047	REF	REF
108	1.5	-0.055	±0.1	±0.2
235	1.5	-0.049	±0.1	±0.2
270	1.5	-0.065	±0.1	±0.2
297	1.5	-0.070	±0.1	±0.2
120	15	-0.015	REF	REF
108	15	-0.015	±0.1	±0.2
235	15	-0.008	±0.1	±0.2
270	15	-0.011	±0.1	±0.2
297	15	-0.016	±0.1	±0.2

Table 4-11. Equality of Current Circuits

CIRCUIT	TEST CURRENT (A)	AVERAGE ERROR (%)	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]
All	1.5	-0.045	REF	REF
Circuit A	1.5	-0.112	±0.15	±0.3
Circuit B	1.5	0.090	±0.15	±0.3
Circuit C	1.5	0.037	±0.15	±0.3
All	15	-0.007	REF	REF
Circuit A	15	-0.088	±0.15	±0.3
Circuit B	15	0.014	±0.15	±0.3
Circuit C	15	0.047	±0.15	±0.3

Table 4-12. Phase Sequence Reversal

CIRCUIT	TEST CURRENT (A)	AVERAGE ERROR (%)	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]
ABC	1.5	-0.047	REF	REF
CBA	1.5	-0.052	±0.1	±1.0
ABC	15	-0.008	REF	REF
CBA	15	-0.015	±0.1	±0.3

The TIDA-010986 reference design is a three-phase signal conditioning circuit for Rogowski coils, targeting enhanced accuracy for current measurement in E-meters, circuit breakers, protection relays, and EV chargers. This op amp-based active integrator design covers a wide dynamic current range with bandwidth, stability, and adjustable gain. The design is optimized for three-phase systems and interfaces with the ADS131M08MET-EVM via J5. The design aims to achieve current transformer accuracy at a cost similar to shunt-based designs.

4.3 Developing an Application

The information needed to develop a customized version of the firmware loaded into the MSPM0G1506 is installed on the PC with the MSPM0-SDK package. The default installation directory is C:>ti>mspm0_sdk_(current version)>docs>english (or Chinese) >middleware>energy_metrology as noted in Figure 4-8.

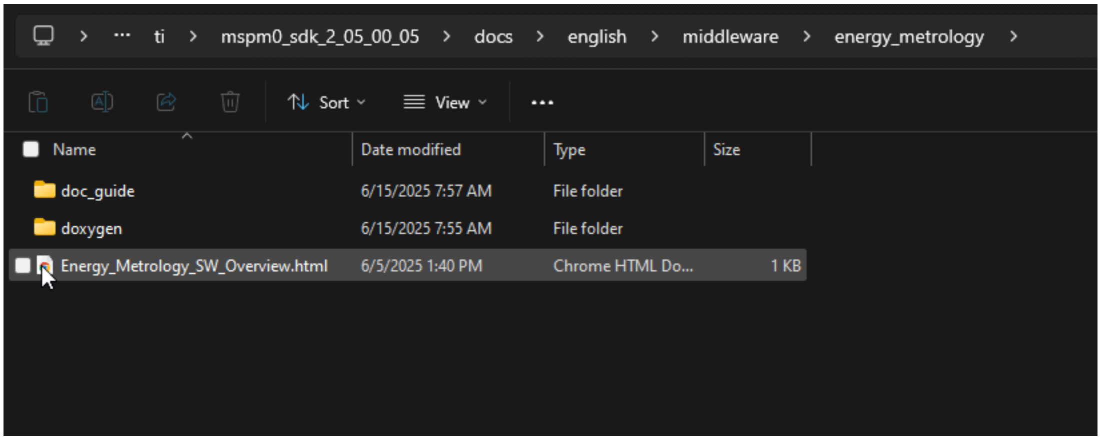


Figure 4-8. Energy Metrology Documentation

Click on the *Energy_Metrology_SW_Overview.html* file to gain access to details on using the *CCS User's Guide*, the *Energy Library User's Guide* as well as the various background and foreground process that are used with the various metrology aspects of the CCS project used to create the firmware loaded onto the ADS131M08MET-EVM.

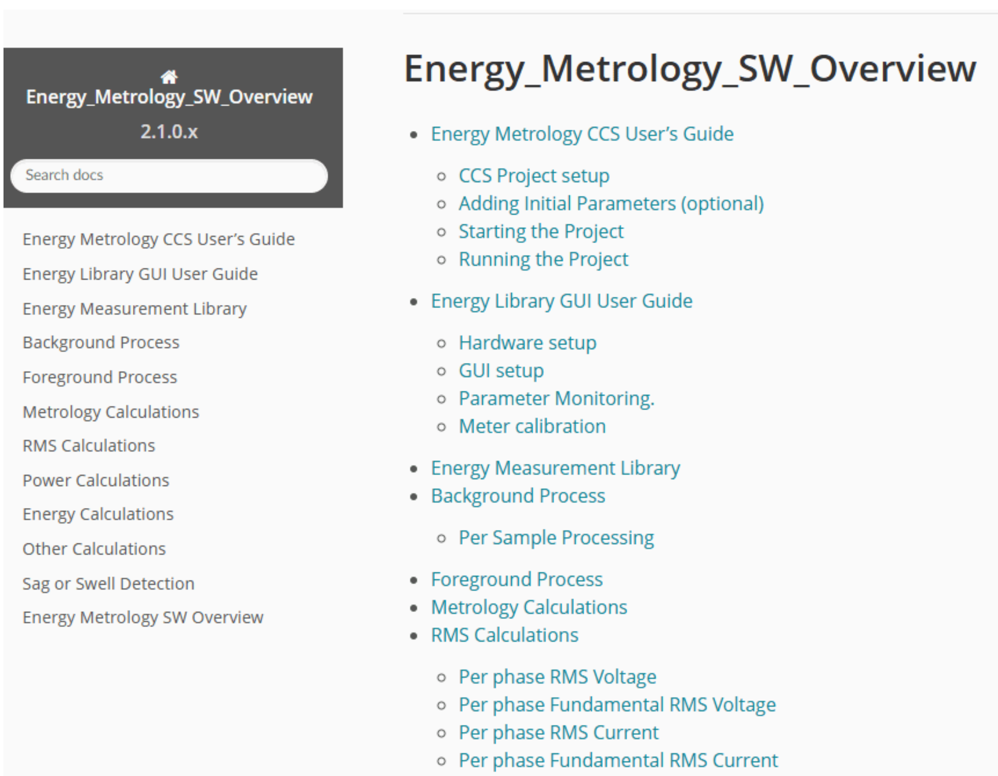


Figure 4-9. Software Overview

5 Hardware Design Files

5.1 Schematics

This section contains the full ADS131M08MET-EVM schematics. Figure 5-1 shows the analog voltage and current input circuits to the ADS131M08MET-EVM circuit board. The voltage inputs are provided through resistive dividers to attenuate the high-voltage AC line while the current sensor inputs provide low-pass filtering and a burden resistor for current transformers. The burden resistor can be bypassed through shunt jumpers for use with Rogowski coils.

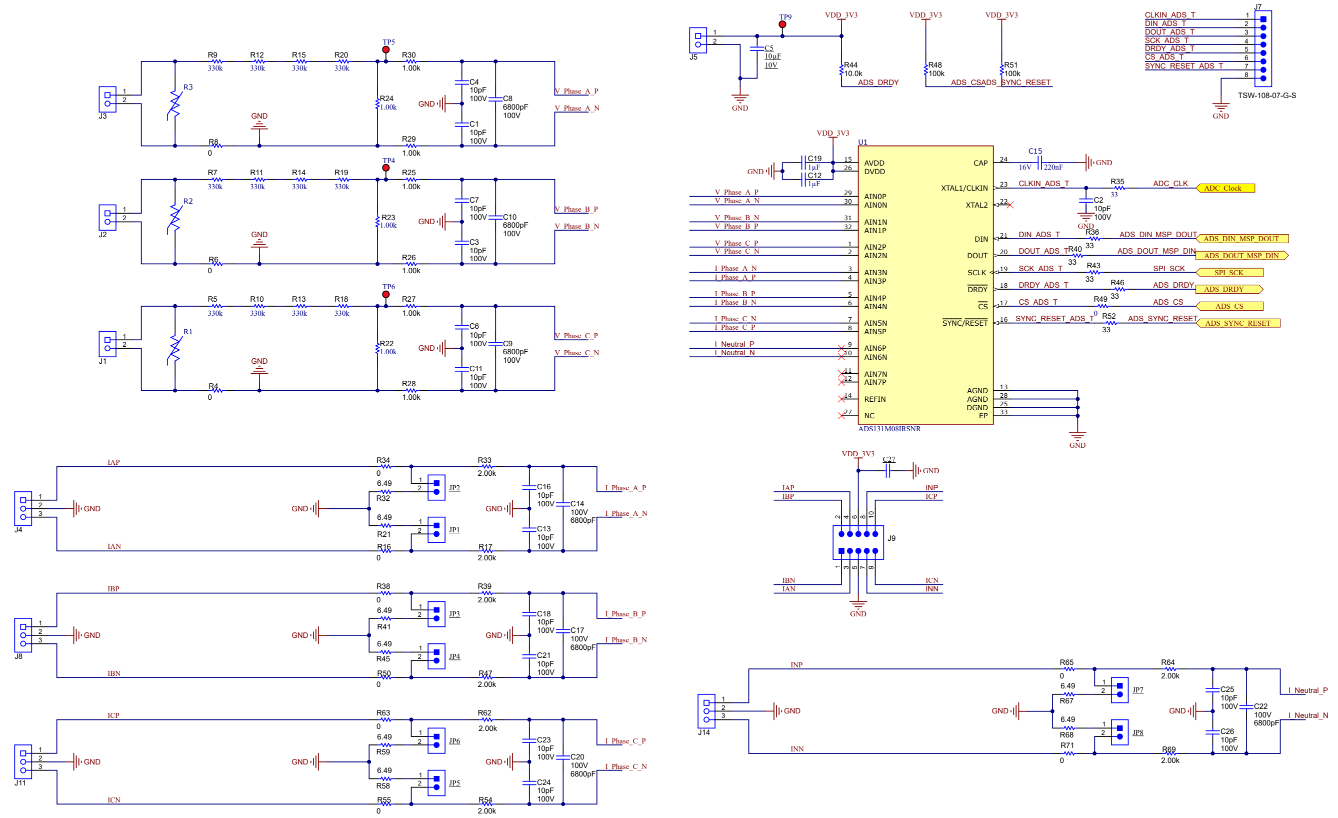


Figure 5-1. AFE and ADS131M08

[Figure 5-2](#) shows the RS-232, power supply, communication isolation, gain switches, and MSPM0G1506 details of the ADS131M03MET-EVM board.

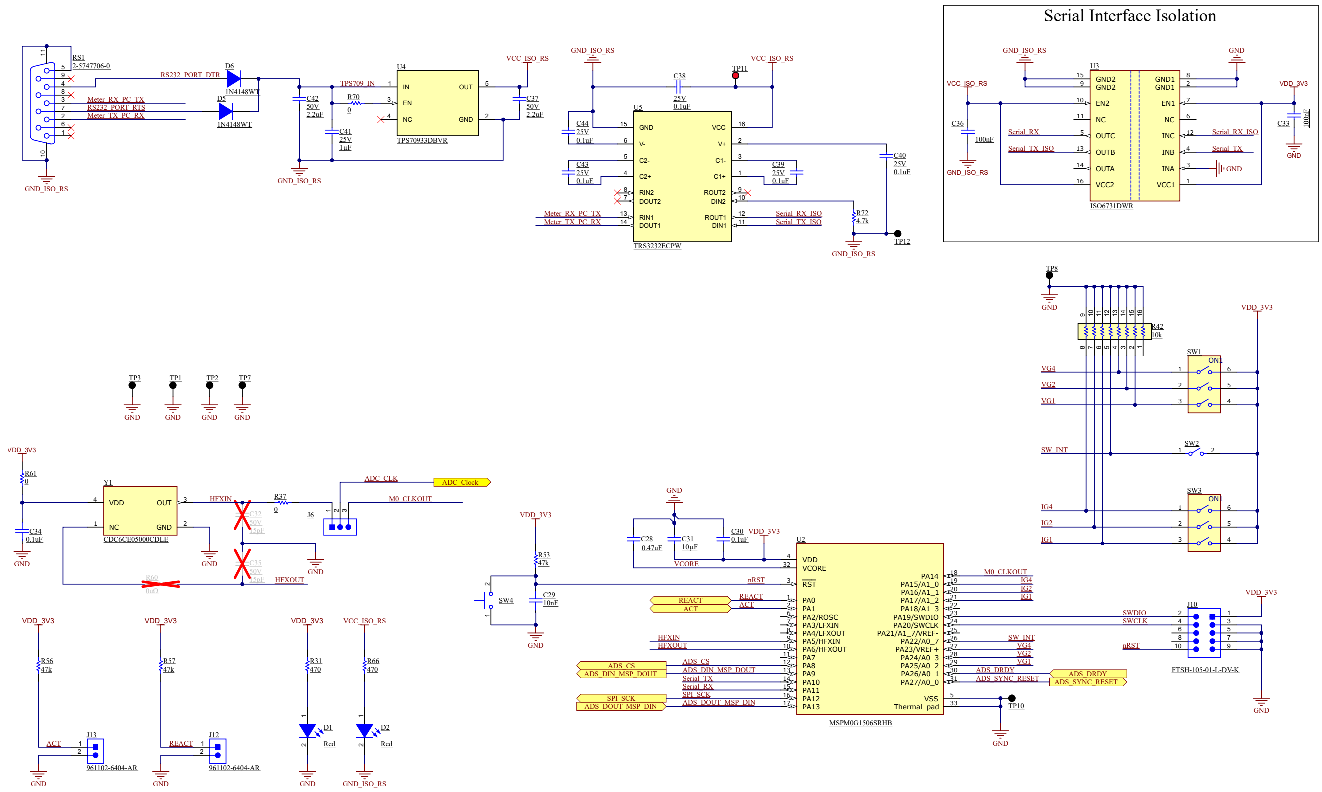


Figure 5-2. RS-232 and MSPM0G1506 Details

5.2 Bill of Materials (BOM)

REFERENCE DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
C1, C2, C3, C4, C6, C7, C11, C13, C16, C18, C21, C23, C24, C25, C26	15	10pF	CAP, CERM, 10pF, 100V, ±5%, C0G/NP0, AEC-Q200 Grade 1, 0603	0603	GCM1885C2A100JA16D	MuRata
C5, C27, C31	3	10µF	CAP, CERM, 10µF, 10V, ±10%, X5R, 0603	0603	GRM188R61A106KAALD	MuRata
C8, C9, C10	3	6800pF	CAP, CERM, 6800pF, 100V, ±5%, C0G/NP0, AEC-Q200 Grade 0, 0603	0603	CGA3EANP02A682J080AC	TDK
C12, C19	2	1µF	CAP, CERM, 1µF, 16V, ±10%, X7R, AEC-Q200 Grade 1, 0603	0603	CGA3E1X7R1C105K080AC	TDK
C14, C17, C20, C22	4	6800pF	CAP, CERM, 6800pF, 100V, ±10%, X7R, 0603	0603	GRM188R72A682KA01D	MuRata
C15	1	220nF	Cap Ceramic 220nF 16V X7R 10% Pad SMD 0402 +125°C Automotive T/R	0402	CGA2B2X7R1C224K050BE	TDK Corporation
C28	1	0.47µF	CAP, CERM, 0.47µF, 10V, ±10%, X5R, 0603	0603	GRM188R61A474KA61D	MuRata
C29	1	10nF	10000pF ±10% 25V Ceramic Capacitor X7R 0402 (1005 Metric)	0402	885012205050	Würth Electronics
C30, C38, C39, C40, C43, C44	6	0.1µF	CAP, CERM, 0.1µF, 25V, ±10%, X8R, AEC-Q200 Grade 0, 0603	0603	CGA3E2X8R1E104K080AA	TDK
C33, C36	2	0.1µF	CAP, CERM, 0.1µF, 25V, ±10%, X7R, 0603	0603	C0603X104K3RACTU	Kemet
C34	1	100nF	0.1µF ±10% 10V Ceramic Capacitor X7R 0402 (1005 Metric)	0402	885012205018	Würth Electronics
C37, C42	2	2.2µF	CAP, CERM, 2.2µF, 50V, ±10%, X5R, AEC-Q200 Grade 3, 0603	0603	GRT188R61H225KE13D	MuRata
C41	1	1µF	CAP, CERM, 1µF, 25V, ±20%, X7R, AEC-Q200 Grade 1, 0603	0603	CGA3E1X7R1E105M080AC	TDK
D1, D2	2	Red	LED, Red, SMD	2 × 1.25mm	CMD17-21SRC/TR8	Visual Communications Company, LLC

REFERENCE DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
D5, D6	2	75V	Diode, Switching, 75V, 0.3A, SOD-523F	SOD-523F	1N4148WT	Fairchild Semiconductor
H1, H2, H3, H4	4		Bumpon, Hemisphere, 0.375 X 0.235, Black	Black Bumpon	SJ61A2	3M
H5	1		CABLE USB to RS232		U209-000-R	Eaton Tripp Lite
J1, J2, J3, J5	4		Terminal Block, 5.08mm, 2 × 1, Brass, TH	2 × 1 5.08mm Terminal Block	ED120/2DS	On-Shore Technology
J4, J8, J11, J14	4		Terminal Block, 5.08mm, 3 × 1, Brass, TH	3 × 1 5.08mm Terminal Block	ED120/3DS	On-Shore Technology
J6	1		Header, 2.54mm, 3 × 1, Tin, TH	Header, 2.54mm, 3 × 1, Tin, TH	22284030	Molex
J7	1		Header, 100mil, 8x1, Gold, TH	8 × 1 Header	TSW-108-07-G-S	Samtec
J9	1		Header, 100mil, 5x2, Gold, TH	5 × 2 Header	TSW-105-07-G-D	Samtec
J10	1		Header(Shrouded), 1.27mm, 5x2, Gold, SMT	Header(Shrouded), 1.27mm, 5x2, SMT	FTSH-105-01-L-DV-K	Samtec
J12, J13, JP1, JP2, JP3, JP4, JP5, JP6, JP7, JP8	10		Header, 2.54mm, 2 × 1, TH	Header, 2.54mm, 2 × 1, TH	961102-6404-AR	3M
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650 x 0.200 inch	THT-14-423-10	Brady
R1, R2, R3	3		Var MOV 460VAC/615VDC 5000A 750V Thru-Hole Radial Bulk	RADIAL	B72214S2461K101	TDK
R4, R6, R8, R16, R34, R38, R50, R55, R63, R65, R71	11	0	RES, 0, 5%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	ERJ-3GEY0R00V	Panasonic
R5, R7, R9, R10, R11, R12, R13, R14, R15, R18, R19, R20	12	330k	RES, 330 k, 0.1%, 1 W, 1206	1206	TNPV1206330KBEEN	Vishay Draloric
R17, R33, R39, R47, R54, R62, R64, R69	8	2.00k	RES, 2.00 k, 0.5%, 0.1 W, 0603	0603	RT0603DRD072KL	Yageo America
R21, R32, R41, R45, R58, R59, R67, R68	8	6.49	RES, 6.49, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW06036R49FKEA	Vishay-Dale
R22, R23, R24	3	1.00k	RES, 1.00 k, 1%, 0.1 W, 0603	0603	RC0603FR-071KL	Yageo
R25, R26, R27, R28, R29, R30	6	1.00k	RES, 1.00 k, 0.5%, 0.1 W, 0603	0603	RT0603DRD071KL	Yageo
R31, R66	2	470	RES, 470, 1%, 0.063 W, 0402	0402	RC0402FR-07470RL	Yageo America
R35, R36, R37, R40, R43, R46, R52	7	33	RES, 33, 5%, 0.063 W, 0402	0402	CRCW040233R0JNED	Vishay-Dale
R42	1	10k	RES, 10 k, 5%, 0.063 W, AEC-Q200 Grade 1, Resistor Array - 8x1	Resistor Array - 8x1	EXB2HV103JV	Panasonic
R44	1	10.0k	RES, 10.0 k, 1%, 0.1 W, 0603	0603	CRCW060310K0FKEA	Vishay-Dale
R48, R51	2	100k	RES, 100 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW0603100KFKEA	Vishay-Dale
R49	1	0	RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04020000Z0ED	Vishay-Dale
R53, R56, R57	3	47k	RES, 47 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040247K0JNED	Vishay-Dale
R61, R70	2	0	RES, 0, 5%, 0.063 W, 0402	0402	RC0402JR-070RL	Yageo America
R72	1	4.7k	RES, 4.7 k, 5%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW06034K70JNEA	Vishay-Dale
RS1	1		Receptacle, D-SUB-9, 2.74mm, Gold, TH	Receptacle, D-SUB-9, 2.74mm, TH	2-5747706-0	TE Connectivity
SH-J1, SH-JP1, SH-JP2, SH-JP3, SH-JP4, SH-JP5, SH-JP6, SH-JP7, SH-JP8	9	1 × 2	Shunt, 2mm, Gold plated, Black	2mm Shunt, Closed Top	2SN-BK-G	Samtec
SW1, SW3	2		Dip Switch SPST 3 Position Surface Mount Slide (Standard) Actuator 25mA 24VDC	SMT_SW_5MM8_4MM98	416131160803	Würth Electronics
SW2	1		Dip Switch SPST 1 Position Surface Mount Slide (Standard) Actuator 25mA 24VDC	SMT_SW_2MM40_6MM20	TDA01H0SB1R	C&K Components
SW4	1		Switch, Tactile, SPST-NO, 0.05A, 12V, SMT	Switch, 4.4 × 2 × 2.9mm	TL1015AF160QG	E-Switch
TP1, TP2, TP3, TP7, TP8, TP10, TP12	7		Test Point, Miniature, Black, TH	Black Miniature Test Point	5001	Keystone
TP4, TP5, TP6, TP9, TP11	5		Test Point, Miniature, Red, TH	Red Miniature Test Point	5000	Keystone
U1	1		8-Channel, Simultaneously-Sampling, 24-Bit, Delta-Sigma ADC	WQFN32	ADS131M08IRSNR	Texas Instruments
U2	1		Mixed-Signal Microcontrollers	VQFN32	MSPM0G1506SRHB	Texas Instruments
U3	1			SOIC16	ISO6731DWR	Texas Instruments

REFERENCE DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
U4	1		150mA, 30V, Ultra-Low I_Q, Wide Input Low-Dropout Regulator with Reverse Current Protection, DBV0005A (SOT-23-5)	DBV0005A	TPS70933DBVR	Texas Instruments
U5	1		3V to 5.5V Multichannel RS-232 Line Driver | Receiver with ±15-kV IEC ESD Protection, 0 to 70°C, 16-pin TSSOP (PW), Green (RoHS and no Sb/Br)	PW0016A	TRS3232ECPWR	Texas Instruments
Y1	1		Crystal replacement: Ultra-low-Power LVCMOS Oscillator 4-pin, VSON 3.2 × 2.5 × 0.9mm	VSON4	CDC6CE008192ADLE	Texas Instruments

5.3 PCB Layouts

Figure 5-3 and Figure 5-4 show the top and bottom PCB layout details, respectively.

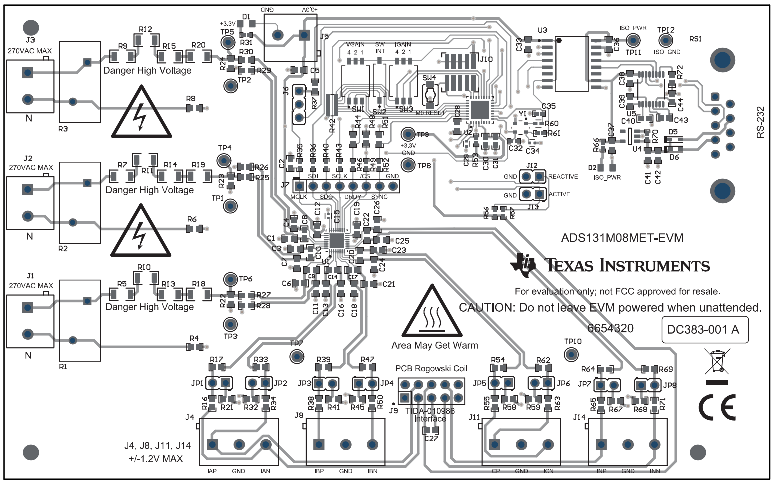


Figure 5-3. Top Layer

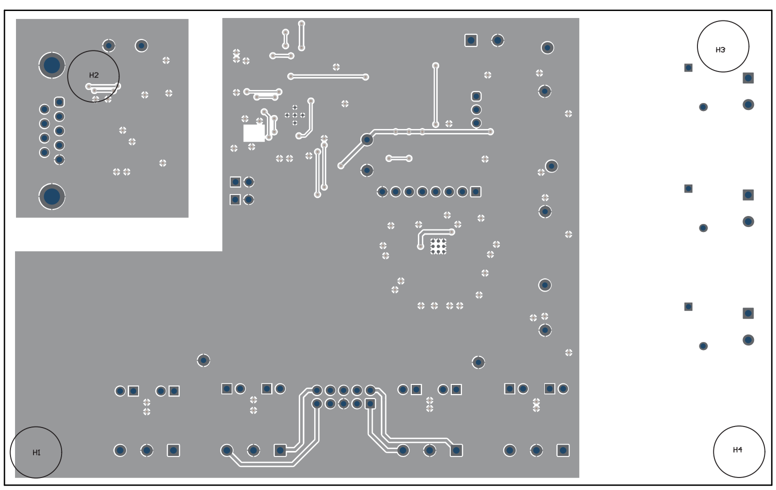


Figure 5-4. Bottom Layer

6 Design and Documentation Support

6.1 Design Files

6.1.1 PCB Layout Recommendations

The following general guidelines are followed for this evaluation module:

- Place decoupling capacitors close to the associated pins of the ADS131M08.
- Use ground planes instead of ground traces and minimize the cuts in the ground plane, especially near the ADS131M08.
- Keep the analog inputs of each ADC channel symmetrical and as close as possible to each other.
- For the ADS131M08 device, place the 0.1µF capacitor closest to the AVDD pin than the 1µF capacitor. Do the same thing also for the 0.1µF and 1µF capacitors connected to DVDD.
- Minimize the length of the traces used to connect the crystal to the microcontroller.
- Use wide traces for power-supply connections.

6.2 Tools and Software

Tools

CCSTUDIO	Code Composer Studio™ integrated development environment (IDE)
MSPM0-SDK	MSPM0 software development kit (SDK)
SYSCONFIG	System configuration tool with an intuitive graphical user interface for configuring pins, peripherals, radios, software stacks, RTOS, clock tree, and other components.

Software

MSPM0-SDK	Contains source code example for ADS131M08MET-EVM energy metrology

6.3 Documentation Support

1. Texas Instruments, *ADS131M08 8-Channel, Simultaneously-Sampling, 24-Bit, Delta-Sigma ADC Data Sheet*
2. Texas Instruments, *MSPM0G150x Mixed-Signal Microcontrollers Data Sheet*
3. Texas Instruments, *ISO6731 General-Purpose Triple-Channel Digital Isolator with Robust EMC Data Sheet*
4. Texas Instruments, *TPS709 150mA, 30V, 1µA I_Q Voltage Regulators With Enable Data Sheet*
5. Texas Instruments, *TRS3232E 3- to 5.5V Multichannel RS-232 Line Driver/Receiver With ±15kV ESD Protection Data Sheet*

6.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

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   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI’s recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI’s recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI’s instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

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4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

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