

EVM User's Guide: AMC-ADC-3PH-EVM

ADC 3-Phase Evaluation Module



Description

The ADC 3-Phase EVM (AMC-ADC-3PH-EVM) implements Class 0.2S three-phase energy measurement using an isolated high-performance, multichannel analog-to-digital converter (ADC), which samples shunt current sensors at 4kHz to measure the current and voltage of each leg of the AC Mains. The reference design achieves high accuracy across a wide input current range (0.05A–100A) and supports higher sampling frequencies necessary for power quality features such as individual harmonic analysis. Faster ADC sampling rates of up to 16ksps can be supported when using a TI Arm® Cortex®-M0+ host microcontroller for calculating the metrology parameters. The necessary software functionality is implemented in [MSPM0-SDK](#) and can be compiled with TI's Code Composer Studio™.

Get Started

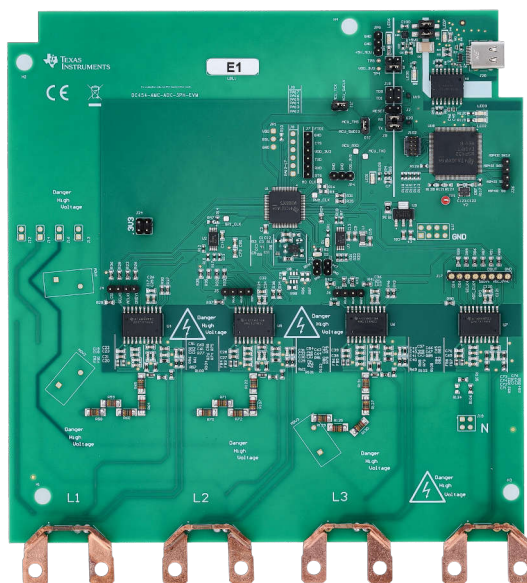
1. Order the [AMC-ADC-3PH-EVM](#)
2. Download the [Energy Metrology Library software](#) and [Microsoft®Windows® PC GUI](#)
3. Evaluate performance on the bench

Features

- Three-phase metrology for electricity meters that meets class 0.2S active energy accuracy requirements across 1000:1 input range
- Support for three-phase four-wire (3P4W) or three-phase three-wire (3P3W) systems with shunts
- Active and reactive energy and power, root mean square (RMS) current and voltage, power factor, and line-frequency calculations
- Isolated USB Type-C™ with onboard XDS110 debug probe with 5kV_{RMS} isolation, tested across 100mA to 100A input range and 100V to 270V
- Capable of detecting magnetic tampering using a linear 3D Hall-effect sensor
- Software for energy metrology with pulsed outputs to a reference test system and displaying results on a Microsoft® Windows® PC GUI

Applications

- [Electricity meter](#)
- [Power quality meter](#)
- [Power quality analyzer](#)
- [AC charging \(pile\) station](#)



1 Evaluation Module Overview

1.1 Introduction

Throughout this document, the abbreviation *EVM* and the term *evaluation module* are synonymous with the AMC-ADC-3PH-EVM. This document includes how to set up and evaluate the EVM, the printed circuit board (PCB) layout, schematics, and bill of materials (BOM).

1.2 Kit Contents

The contents included in the AMC-ADC-3PH-EVM kit are:

- (1) AMC-ADC-3PH-EVM

1.3 System Description

The AMC-ADC-3PH-EVM has the properties described in [Section 1.3.1](#) through [Section 1.3.3](#).

1.3.1 Key System Specifications

FEATURES	DESCRIPTION
Number of phases	3 phase (current measured through a SHUNT), voltage through a resistor divider
Accuracy class	0.2S
Dynamic range	1:10000 (accuracy tested for 1:2000 or 50mA–100A)
Current Sensor	SHUNT
Tested current range	0.05–100A
Tested voltage range	100V to 270V
AMC131M03 CLKIN frequency	8.192MHz
Oversampling ratio (OSR)	1024
Digital filter output sample rate	4000 samples per second (default) (adjustable per register setting)
Phase compensation implementation	Software
Selected central processing unit (CPU) clock frequency	79.87MHz
System nominal frequency	50Hz or 60Hz
Measured parameters	• Active, reactive, apparent power and energy • Root mean square (RMS) current and voltage • Power factor • Line frequency
Update rate for measured parameters	Approximately equal to 1 second
Communication options	PC graphical user interface (GUI) with a universal asynchronous receiver-transmitter (UART)
Utilized light emitting diodes (LED)	2 LEDs: Active energy and reactive energy
Board power supply	• USB-C • 3.3 to 16V External Power

1.3.2 End Equipment

[Electricity meters](#) and [power quality meters](#) are two popular system designs for accurate energy measurement in compliance with International Electrotechnical Commission (IEC), European Standard (EN), and American National Standards Institute (ANSI) standards with a common functionality for calculating the most relevant metrology parameters such as total and per-phase active (kWh), reactive (kvarh), and apparent energy (kVAh). Multiple power quality parameters in a polyphase energy measurement system can be also calculated, including:

- Per-phase voltage total harmonic distortion (THD)
- Per-phase current THD
- Voltage phase-to-phase angle
- Per-phase zero crossing

1.3.3 Electricity Meter

Utility providers and customers require more features from electricity meters. As the accuracy requirements and amount of processing expected from electricity meters rapidly increases, solving these issues with a single metrology system-on-chip (SoC) becomes increasingly more difficult.

A common answer is to utilize a standalone ADC with a host microcontroller (MCU) to simultaneously overcome the processing and accuracy limitations of electricity meter SoCs. With this dual-chip approach, system designers can mix and match the most appropriate devices for ADC and for MCU, and optimize the system for cost or performance. Using an accurate state-of-the-art standalone ADC with integrated power and data isolation, such as the AMC131M03, has the following advantages:

- Enables meeting the most stringent of accuracy requirements
- Enables meeting minimum sample rate requirements (without compromising on accuracy) that is sometimes not obtainable with application-specific products or metrology SoCs
- Enables flexibility in selecting the host MCU, as the device only has to meet the application requirements. These requirements include the following:
 - Processing capability in MIPS
 - Minimum RAM and flash area
 - The number of communications modules (for example, serial-peripheral interface (SPI), universal asynchronous receiver-transmitter (UART), and I2C), DMA and CRC modules and some other peripherals, like security features for providing meter data integrity and security

To properly measure energy consumption, voltage and current sensors translate Mains voltage and current to a voltage range that an ADC can sense. When a multiphase power distribution system is used, the current sensors must be isolated from phase-to-phase, so the sensors can properly detect the current drawn from the two or three or four different lines (when Neutral is measured) without damaging the ADCs. This design uses either 2 or 3 or 4 cost-effective shunt sensors, which are immune to magnetic tampering, and enables the implementation of electricity meters for three-phase STAR configuration with optional Neutral line measurement.

1.3.4 Power Quality Meter, Power Quality Analyzer

Except being used for [electricity meters](#), this single or multiphase ADC architecture applies also for [power quality analyzers](#) and [power quality meters](#), and [EV chargers](#) or [AC-chargers](#) (also known as wallboxes). This end equipment is used to help utilities and industrial enterprises monitor and control power quality by measuring certain power quality parameters, such as voltage harmonics, current harmonics, supply voltage dips, supply voltage swells, and more. For all equipment, a lot of computation is required for calculating the power quality parameters. Also, meeting the accuracy requirements for the different power quality parameters is important. The requirement for high accuracy and computation power is something well supported by having a standalone ADC and separate host MCU or microprocessor unit (MPU) device, as is done in this design.

A couple of the parameters commonly measured by power quality meters and power quality analyzers are voltage and current harmonics. Implement coherent sampling for the most accurate harmonic calculations. One way of implementing coherent sampling is to dynamically vary the sampling clock based on the measured Mains frequency and thus keep the sampling rate an exact multiple of the line frequency. The standalone ADCs in this design have the ability to take in a varying clock so the design can support coherent sampling. Although the clock to the standalone ADCs in this design can be varied, this design has no support for coherent sampling

because the sampling clock from the host MCU to the standalone ADC cannot be varied with the proper fine resolution.

1.4 Device Information

The AMC-ADC-3PH-EVM is designed to provide ease-of-use and high accuracy electricity metering. The AMC131M03 is an isolated ADC intended for e-metering applications with reinforced isolation and an integrated DC/DC converter. This isolated ADC has two channels that can measure voltage and current for a single phase. This EVM also features a low cost MSPM0G3507 with metrology firmware, as well as other TI components for clocking (LMK6C and CDC6CE) and power regulation (TLV76133).

2 Hardware

2.1 System Overview

2.1.1 Block Diagram

Figure 2-1 depicts the MSPM0G3507 and AMC131M03-based three-phase energy measurement application block diagram.

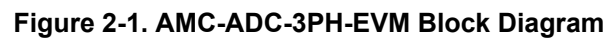
On each phase (or line) the line-to-neutral voltage is directly measured, as well as the current for each line (3 phases) and through the N (Neutral) wire; hence, both *3-phase, 3-wire (3P3W)* or *3-phase, 4-wire with Neutral (3P4W)* configurations are supported by default. By not using some phases, this reference design can also be used in a split-phase (leave open Phase C) or single-phase (leave open Phase B and C) configuration. In the TIDA-010244 block diagram, shunt sensors connect to each of the 3 phases for the current measurement while a simple voltage divider is used for dividing down the corresponding voltage of each line. The selection of the shunt is made based on the current range required for the energy measurements, while minimizing power dissipation in the shunt at high currents. Values in the range of 150 $\mu\Omega$ to 200 $\mu\Omega$ are common, assuming up to 100A or 120A maximum current per phase are to be measured.

In this design, the four AMC131M03 or AMC131M02 devices interact with the MSPM0+ MCU in the following manner:

- Three different clock signals are fed to a 4-channel output LVCMOS buffer LMK1C1104 to obtain 4 identical in-phase clock signals CLKIN1 through CLKIN4, making sure all ADCs run and collect data samples synchronized to each other.
 - TI BAW oscillator CDC6C provides a high-precision clock signal with 8.192MHz to both LMK1C1104 and MSPM0G3507 devices (default option).
 - An external 16.384MHz crystal oscillator (XTAL) supplies the MSPM0G3507 HFXIN and HFXOUT pins and runs through an internal divider by 2 to create the M0_CLKOUT signal at 8.192MHz (when TI BAW is not populated). M0_CLKOUT is then connected to the LMK1C1104 clock buffer.
 - A PWM signal from the MSPM0G3507 can be used to supply the clock buffers for evaluation purposes. To enable the PWM signal one of the previously mentioned clock devices needs to be connected to HFXIN and HFXOUT (optional).
- The 4 outputs of LMK1C1104 are fed to the four CLKIN1 through CLKIN4 input pins (one per ADC device).
- Each of the four AMC131M03 or AMC131M02 devices divides the CLKIN input by 2 and uses that value as the delta-sigma modulation clock.
- The SPI_SCK (SPU Bus clock) signal (output from the MCU being the SPI controller) is input to a second 4-channel output LVCMOS buffer LMK1C1104 to obtain four identical in-phase clock signals for the SPI data transfer.
- The four SPI_SCK lines SCLK1 through SCLK4 are fed to the SCLK input of each ADC, making sure all ADCs run synchronously on the shared SPI bus.
- Four separate $\overline{CS}$ lines are used, these are automatically generated and controlled by the SPI peripheral of the MSPM0+ MCU.
- When new ADC samples are ready, each **AMC131M03** asserts the $\overline{DRDY}$ output pin ($\overline{DRDY1}$ through $\overline{DRDY4}$), which alerts the MCU that new data samples are available.
- After detecting the $\overline{DRDY}$ falling edge, the MSPM0+ MCU uses one SPI and two of the DMA channels in the DMA module to read in the voltage and current samples from each AMC131M0X device. The four standalone ADCs generate the four $\overline{DRDY}$ signals simultaneously but because the ADCs share the same SPI bus, the ADCs are being read out sequentially by the MCU.
- The MCU also communicates to a PC GUI through the USB Type-C interface over the XDS110 debugger on the board or an external FTDI connector.
- ACT and REACT output signals from the MCU represent the active and reactive energy pulses used for accuracy measurement and calibration. Both are key signals needed for calibrating the electricity meter against a reference meter.

The MSPM0+ MCU has internal Power-on reset (POR) and BOR as well as Brownout reset (BOR) supply monitor with four configurable threshold voltages.

This reference design also comes with two options of transmitting the metrology parameters data over Bluetooth using either the CC2340 Bluetooth® low energy subsystem with all passives (discrete implementation) or a CC2340-based Bluetooth module.



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2.1.2 Design Considerations

While [AMC131M03](#) is used four times on the PCB, the 2-channel version [AMC131M02](#) suffices, in case only current and voltage are to be measured. The 3rd channel in [AMC131M03](#) (not present in [AMC131M02](#)) can support a temperature measurement at the shunt sensor, if required.

The choice of voltage divider resistors for the voltage channel is selected to make sure the main voltage is divided down to adhere to the normal input range of the [AMC131M03](#) device. Since this stand-alone ADC has a large dynamic range but only a small range is needed to measure voltage, the voltage front-end circuitry is purposely selected so that the maximum voltage present at the inputs of the voltage channel ADCs are only a fraction of the full-scale voltage. By reducing the voltage fed to the [AMC131M03](#) voltage input channels, voltage-to-current crosstalk, which actually affects metrology accuracy more than voltage ADC accuracy, is reduced at the cost of voltage accuracy, thereby resulting in more accurate energy measurements at lower currents.

2.1.2.1 Voltage Measurement - Analog Front End

The nominal voltage from the Mains in many regions of the world varies from 100V to 270V so the voltage needs to be scaled down to be sensed by an ADC. [Figure 2-2](#) shows the analog front end used for this voltage scaling, voltage is applied at the Shunt for each phase.

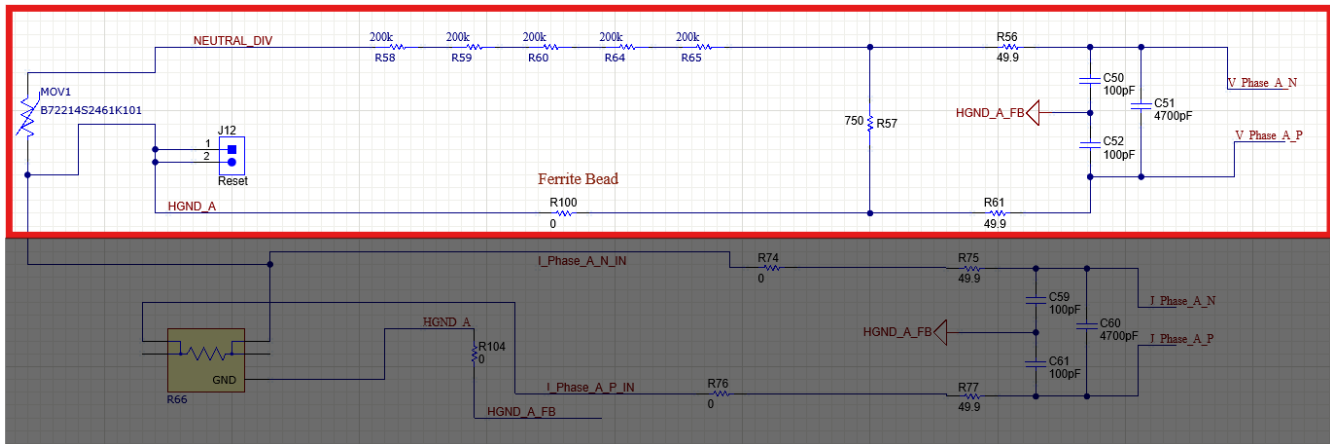


Figure 2-2. Analog Front End for Voltage Input

The analog front end for voltage input has a footprint for an optional ferrite bead (R100), voltage divider network (R57, R58, R59, R60, R64, and R65), and RC low-pass filter (R56, R61, C50, C51, and C52), as shown in [Figure 2-2](#).

If offset calibration is not performed, the voltage-to-current crosstalk affects active energy accuracy much more than voltage accuracy when the current is low. To maximize the accuracy at lower currents, in this design the entire ADC range is not used for the voltage channel. The reduced ADC range for the voltage channels in this design still provide 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.

$$V_{\text{ADC Swing, Voltage}} = \pm V_{\text{RMS}} \times \sqrt{2} \left(\frac{R_{57}}{R_{57} + R_{58} + R_{59} + R_{60} + R_{64} + R_{65}} \right) \quad (1)$$

Based on this formula and the selected resistor values in [Equation 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 $\pm 127.18\text{mV}$ ($89.93\text{mV}_{\text{RMS}}$). 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 $\pm 243.77\text{mV}$ ($172.37\text{mV}_{\text{RMS}}$). The $\pm 127.18\text{mV}$ and the $\pm 243.77\text{mV}$ voltage ranges are both well within the -1.3V to $+2.7\text{V}$ range (for GAIN = 1, see the *recommended operating conditions* section of the [AMC131M03 3-Channel, 64-kSPS, Simultaneous-Sampling, 24-Bit, Reinforced Isolated Delta-Sigma ADC With Integrated DC/DC Converter](#) datasheet), that can be sensed by the ADC.

2.1.2.2 Current Measurement - Analog Front End

Figure 2-3 shows that the analog front end for current inputs is different from the analog front end for the voltage inputs.

This design has a 300μΩ shunt populated on the board for each phase and neutral. If desired the shunt can be replaced with another by desoldering the populated shunt and connecting the positive and negative leads from the new SHUNT sensor to the solder points.

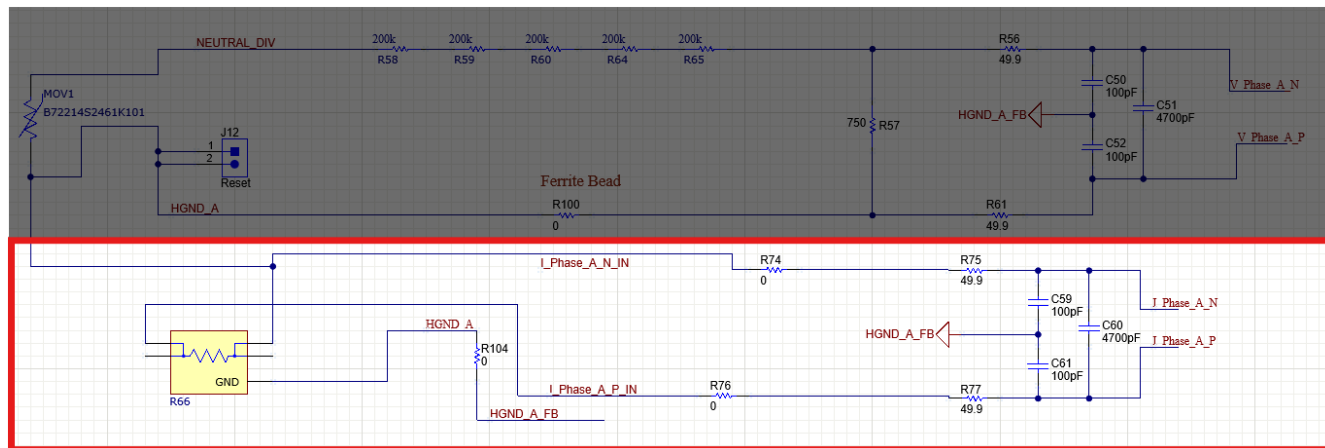


Figure 2-3. Analog Front End for Current Input

The analog front end for current consists of footprints for electromagnetic interference filter beads (R74, R76, and R104), and an RC low-pass filter (R75, R77, C59, C60, and C61) that functions as an anti-aliasing filter.

Equation 2 shows how to calculate the range of differential voltages fed to the current ADC channel for a given maximum current.

$$V_{\text{ADC Swing, Current, Shunt}} = \pm \sqrt{2} R_{\text{shunt}} I_{\text{RMS, max}} \quad (2)$$

Using the populated SHUNT value of 300μΩ, the input signal to the current ADC has a voltage swing of ±42.43mV when the maximum current rating of the meter, for example 100A, is applied. This relatively low voltage, when using GAIN = 16 is well within the required *Full Scale Range* of ±75mV, see the *Full-Scale Range* table in the [AMC131M03 3-Channel, 64-kSPS, Simultaneous-Sampling, 24-Bit, Reinforced Isolated Delta-Sigma ADC With Integrated DC/DC Converter](#) datasheet.

Table 2-1. Full-Scale Range

GAIN SETTING	FSR
1	±1.2V
2	±600mV
4	±300mV
8	±150mV
16	±75mV
32	±37.5mV
64	±18.75mV
128	±9.375mV

2.1.2.3 Input Voltage

Figure 2-4 shows the input power supply to meet a wider input power rail from the main controller, this design uses a linear voltage regulator TLV76133, which supports 2.5V to 16V input voltage and provides a stable 3.3V output to MSPM0, TMAG5273, and AMC131M03 devices.

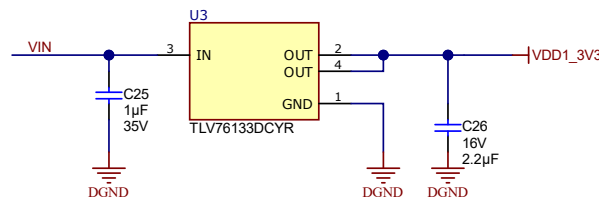


Figure 2-4. Input Power Supply

2.1.2.4 XDS110 Emulator

This design comes with an onboard XDS110 emulator. The XDS110 emulator must already be programmed. This emulator is implemented in the MSP432E401Y device which includes a UART-to-USB translator and is also responsible for programming both the MSPM0 device. To program the MSP432E401Y MCU device with the XDS110 emulator software, connect the jumper to enable the 5V to the board and a PC through the USB Type-C connector. Download the XDS110 software onto the PC from the [XDS Emulation Software \(EMUPack\) Download](#) page and follow the instructions mentioned in the [XDS110 Isolated Plug-in Board User's Guide](#) to flash the MSP432 MCU. After successfully flashing the device, the blue LED 3 lights up and two COM ports become visible in the device manager.

To flash the MSPM0 chip, see the dedicated chapter on *Jumper Settings*.

2.1.2.5 Magnetic Tamper Detection With TMAG5273 Linear 3D Hall-Effect Sensor (Not Populated on EVM)

One common nonintrusive way to steal electricity is to apply a strong permanent magnet or an AC magnet near the electricity meter, thus tampering with the meter. A permanent magnet or an AC magnetic field can affect meter components like current transformer current sensors, shunt current sensors (shunts are only affected by AC magnets), or any power supply transformer. As a result of the weaknesses of these components to magnetic tampering, utility customers can be undercharged for energy consumption, thereby allowing consumers to essentially steal electricity.

Due to the susceptibility of meters to magnetic tampering, magnetic sensors are often used in electricity meters to detect external magnetic fields to take appropriate action, such as disconnecting services to the meter or applying a penalty fee for magnetic tampering. In this design, magnetic tamper detection is done with the TMAG5273 linear 3D Hall-effect sensor, which has the following advantages compared to other magnetic sensing devices and designs:

- **Ease of assembly:** Hall sensors in general are not as fragile as reed switches, the latter of which can break during assembly.
- **Only one surface mount IC needed:** Sensing in three directions with the TMAG5273 requires only one surface mount IC for 3D linear Hall-effect sensors instead of the three ICs in the case of 1D Hall-effect sensors. 3D linear Hall-effect sensors enable a more compact printed-circuit board (PCB) layout. In addition, having a surface mount-only implementation can reduce PCB manufacturing costs compared to a 1D Hall-effect sensor implementation that can require through-hole sensors for detecting some of the directions.
- **Flexibility for defining magnetic tampering threshold:** Since 3D linear Hall-effect sensors provide information about the actual sensed magnetic flux density value, selecting the magnetic tampering threshold of each axis to anything within the magnetic sensing range of the 3D linear Hall-effect sensor is also possible. This enables configuring how to define what is tampering, which can vary between designs since the magnetic flux density sensed depends on the distance from the magnet to the sensor as well as the characteristics of the external magnets to be detected. This type of flexibility is not possible for Hall-effect switches with fixed magnetic operating point (B_{OP}) thresholds. Finding the appropriate tamper threshold definition can be done by using a [magnetic calculation tool](#) to determine what is the resulting magnetic flux density seen for the different magnet-to-sensor distances and magnet types that must be detected. The magnetic threshold can be then set to something lower than the magnetic flux density seen by the sensor when exposed to the desired tamper conditions. Typically, the best practice is to set the threshold to be small enough to detect tamper magnets but also large enough so that the system does not see any false positives from any nearby equipment that causes a magnetic field that does not affect the functionality of the meter. The magnet-to-sensor distance depends on where the sensor is placed on the PCB as well as the dimensions of the e-Meter case. For small-sized systems, the magnetic sensor can be placed near the center of the board for symmetrical sensing coverage across the meter case, or the sensor can be placed near any

components that are affected by magnetic tampering. For large-sized systems like certain polyphase meters, one magnetic sensor to sense tampering across the entire meter surface is sometime not enough, so multiple 3D Hall sensors can be used and placed spread out with respect to each other on the PCB to cover a large sensing area. The TMAG5273 has four sets of device orderables that are factory programmed with different I2C addresses, which enable multiple devices to share the same I2C bus.

- **Ability to change between multiple device power modes:** The TMAG5273 supports switching between multiple power modes, depending upon if reducing system current consumption is desired. The TMAG5273 has an active mode for taking measurements, a sleep mode for minimizing current consumption, and a duty-cycle mode that automatically switches between active and sleep modes. Typical use-cases of the different power modes for electricity meters are described in the following:
 - Active mode is used for taking measurements and requires the most power out of the different power modes. An example scenario where active mode is typically used is when the Mains are available and the meter is running off the AC/DC power supply. When running off the AC/DC power supply, the relatively high active mode current consumption (2.3mA) of the TMAG5273 is negligible.
 - In duty cycle mode, the device takes measurements and then automatically goes to sleep for a user-specified amount of time. Duty-cycle mode is good for minimizing current consumption while still detecting magnetic tampering, such as when low-speed magnetic tamper detection is necessary when running off a backup battery. To reduce average current consumption in duty cycle mode, select a long sleep time. When selecting the sleep time, set the sleep time to be less than the desired response time for magnetic measurements. As an example, to sense magnetic tampering every 2ms using wakeup and sleep mode, set the sleep time to 1ms instead of 1second.
 - In sleep mode, the device does not take any magnetic measurements. An alternative to wakeup and sleep mode is to have the MCU manually set the sensor to sleep mode and then manually set the sensor to wake up after the desired sleep time has passed. This requires more overhead from the MCU; however, this option can reduce the system current consumption if the MCU is going to have a wakeup and sleep mode that allows the MCU to reconfigure the TMAG5273 during each wakeup and sleep mode cycle. For systems that do not require detecting magnetic tampering when running off a backup battery, the TMA5273 can just be put in sleep mode to reduce system current consumption when running off a battery and then put back in active mode when the system is able to run off the AC/DC power supply again.
- **GPIO pin interrupts when magnetic tampering detected (depends on device):** The TMAG5273 has the ability to set an interrupt pin when the sensed magnetic flux density of any axis goes beyond a user-defined magnetic switching threshold. To detect tampering, the user can set the magnetic switching point for interrupts to the desired magnetic tampering threshold. Since the interrupt pin of the Hall-effect sensor can wake up the microcontroller when the MCU is in low-power mode, and since the microcontroller does not have to read the Hall-effect sensor to determine magnetic tampering, the MCU can go to low-power mode when running off a backup power supply until woken up by the interrupt pin of the Hall-effect sensor. Used simultaneously, the general-purpose input/output (GPIO) pin interrupt feature and duty-cycle power mode can reduce system current consumption and extend the lifetime of the backup power supply. Once the GPIO pin of the Hall-effect sensor wakes up the microcontroller, the MCU can then retrieve the value of the sensed magnetic field reading that caused the interrupt and then enable wakeup and sleep mode with GPIO interrupts again.
- **Detection of AC magnets:** AC magnets do not only affect current transformers. AC magnets can also affect shunt and Rogowski coil current sensors. To detect AC magnets, a linear 3D Hall sensor can also be used. Detecting AC magnets requires a fast-enough effective sampling period and a small enough sleep time to properly capture enough samples along a cycle of the AC magnet waveform, as [Figure 2-5](#) shows. The effective sampling period corresponds to the time needed to get one set of samples, which is dependent on the internal sampling rate of the device. Since linear Hall sensors provide information on the actual sensed magnetic flux densities, the sensors are better able to detect AC magnets than a low-sample rate Hall switch.

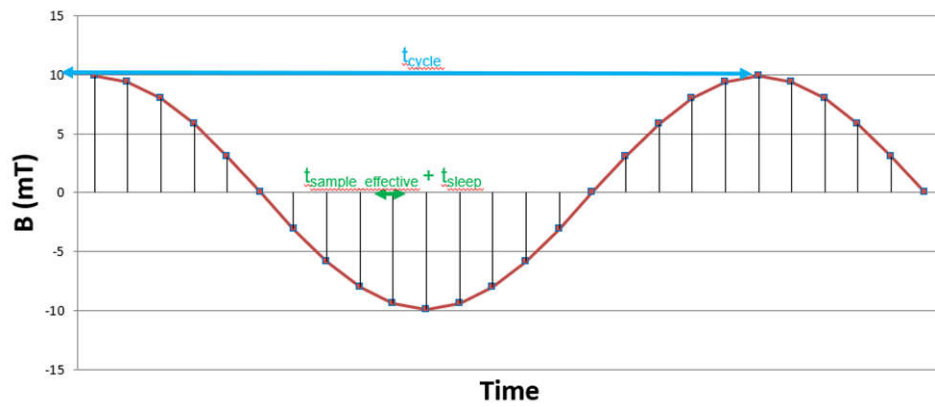


Figure 2-5. Detection AC Magnets

3 Software

The metrology software used for testing the AMC-ADC-3PH EVM is delivered as a middleware example in the latest [MSPM0 SDK](#) (Same SW as the TIDA-010244). This middleware contains hardware abstraction layers which enable communication between the standalone ADCs and an Arm Cortex-M0+ MCU and a library of metrology calculations for energy measurements. A Microsoft Windows PC GUI software is used to display metrology parameters from the EVM and is also part of the [MSPM0 SDK](#), see directory C:\ti\mspm0_sdk_2_03_00_07\tools\metrology_gui.

The MSPM0G3507 resource utilization of AMC-ADC-3PH-EVM middleware code examples are (CCS Version 12.8.1.00005 with TI Clang v3.2.2.LTS compiler):

- 32,912 Bytes FLASH for application code
- 256 Bytes FLASH for calibration data
- 9,742 Bytes RAM memory

3.1 Metrology Overview

3.1.1 Metrology Formulas

This section briefly describes the formulas used for the voltage, current, power, and energy calculations. As previously described, voltage and current samples are obtained at a sampling rate of 4kHz. All of the samples that are taken in approximately one second frames are kept and used to obtain the RMS values for voltage and current. The RMS values are obtained with the following formulas.

$$V_{RMS,ph} = K_{v,ph} \times \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} V_{ph}(n) \times V_{ph}(n)}{\text{Sample Count}}} - V_{\text{offset},ph} \quad (3)$$

$$I_{RMS,ph} = K_{i,ph} \times \sqrt{\frac{\sum_{n=1}^{\text{Sample count}} I_{ph}(n) \times I_{ph}(n)}{\text{Sample Count}}} - I_{\text{offset},ph} \quad (4)$$

where

- $V_{ph}(n)$ = Voltage sample at a sample instant n
- $V_{\text{offset},ph}$ = Offset used to subtract effects of the additive white Gaussian noise from the voltage converter
- $I_{ph}(n)$ = Each current sample at a sample instant n
- $I_{\text{offset},ph}$ = Offset used to subtract effects of the additive white Gaussian noise from the current converter
- Sample count = Number of samples within the present frame
- $K_{v,ph}$ = Scaling factor for voltage
- $K_{i,ph}$ = Scaling factor for current

Power and energy are calculated for active and reactive energy samples of one frame. These samples are phase-corrected and passed on to the foreground process, which uses the number of samples (sample count) to calculate phase active and reactive powers through the following formulas:

$$P_{ACT,ph} = K_{ACT,ph} \frac{\sum_{n=1}^{\text{Sample count}} V_{ph}(n) \times I_{ph}(n)}{\text{Sample Count}} - P_{ACT\text{Offset},ph} \quad (5)$$

$$P_{REACT,ph} = K_{REACT,ph} \frac{\sum_{n=1}^{\text{Sample count}} V_{90,ph}(n) \times I_{ph}(n)}{\text{Sample Count}} - P_{REACT\text{Offset},ph} \quad (6)$$

$$P_{APP,ph} = \sqrt{P_{ACT,ph}^2 + P_{REACT,ph}^2} \quad (7)$$

where

- $V_{90}(n)$ = Voltage sample at a sample instant n shifted by 90°
- $K_{ACT,ph}$ = Scaling factor for active power
- $K_{REACT,ph}$ = Scaling factor for reactive power
- $P_{ACT_offset,ph}$ = Offset used to subtract effects of crosstalk on the active power measurements

- $P_{\text{REACT_offset,ph}}$ = Offset used to subtract effects of crosstalk on the reactive power measurements

Note

For reactive energy, the 90° phase shift approach is used for two reasons:

1. This approach allows accurate measurement of the reactive power for very small currents
2. This approach conforms to the measurement method specified by IEC and ANSI standards

The calculated mains frequency is used to calculate the 90 degrees-shifted voltage sample. Because the frequency of the mains varies, the mains frequency is first measured accurately to phase shift the voltage samples accordingly.

To get an exact 90° phase shift, interpolation is used between two samples. For these two samples, a voltage sample slightly more than 90 degrees before the most recent voltage sample and a voltage sample slightly less than 90 degrees before the most recent voltage sample are used. The phase shift implementation of the application consists of an integer part and a fractional part. The integer part is realized by providing an N samples delay. The fractional part is realized by a one-tap FIR filter. In the test software, a lookup table provides the filter coefficients that are used to create the fractional delays.

Using the calculated powers, energies are calculated with the following formulas:

$$E_{\text{ACT,ph}} = P_{\text{ACT,ph}} \times \text{Sample Count} \quad (8)$$

$$E_{\text{REACT,ph}} = P_{\text{REACT,ph}} \times \text{Sample Count} \quad (9)$$

$$E_{\text{APP,ph}} = P_{\text{APP,ph}} \times \text{Sample Count} \quad (10)$$

The calculated energies are then accumulated into buffers that store the total amount of energy consumed since system reset. These energies are different from the working variables used to accumulate energy for outputting energy pulses. There are three sets of buffers that are available: one for each V-I mapping. Within each set of buffers, the following energies are accumulated:

1. Active import energy (active energy when active power ≥ 0)
2. Active export energy (active energy when active power < 0)
3. Fundamental active import energy (fundamental active energy when fundamental active power ≥ 0)
4. Fundamental active export energy (fundamental active energy when fundamental active power < 0)
5. React. Quad I energy (reactive energy when reactive power ≥ 0 and active power ≥ 0 ; inductive load)
6. React. Quad II energy (reactive energy when reactive power ≥ 0 and active power < 0 ; capacitive generator)
7. React. Quad III energy (reactive energy when reactive power < 0 and active power < 0 ; inductive generator)
8. React. Quad IV energy (reactive energy when reactive power < 0 and active power ≥ 0 ; capacitive load)
9. Apparent import energy (apparent energy when active power ≥ 0)
10. Apparent export energy (apparent energy when active power < 0)

The background process also calculates the frequency in terms of samples-per-mains cycle. The foreground process then converts this samples-per-mains cycle to Hertz with [Equation 11](#):

$$\text{Frequency (Hz)} = \frac{\text{Sample Rate (samples/second)}}{\text{Frequency (sample/cycle)}} \quad (11)$$

After the active power and apparent power have been calculated, the absolute value of the power factor is calculated. In the internal representation of power factor of the system, a positive power factor corresponds to a capacitive load; a negative power factor corresponds to an inductive load. The sign of the internal representation of power factor is determined by whether the current leads or lags voltage, which is determined in the background process. Therefore, the internal representation of power factor is calculated with [Equation 12](#):

$$\text{Internal Representation of Power Factor} = \begin{cases} \frac{P_{\text{ACT}}}{P_{\text{APP}}}, & \text{if capacitive load} \\ -\frac{P_{\text{ACT}}}{P_{\text{APP}}}, & \text{if inductive load} \end{cases} \quad (12)$$

3.1.2 UART for PC GUI Communication

The MSPM0+ MCU is configured to communicate to the PC GUI through a UART interface through the USB Type-C interface over J9. Alternatively, a FTDI interface for the UART communication can be used instead of the FTDI pin header J7 (this requires a SysCfg file change as another UART port is utilized).

The PC GUI polls data from the MSPM0G3507 using a UART module configured for 115200 baud with 8N1. The UART protocol for formatting the UART data is named DLT-645 and the UART module utilizes two DMA Channels: Channel 2 for data receive and Channel 3 for data transmit. More details on the DLT-645 protocol is found in the [MSP430AFE253 Test Report for China State Grid Specification](#) and [Single Phase and DC Embedded Metering \(Power Monitor\) Using MSP430I2040](#) application notes.

The UART driver supports bidirectional DMA transfer (two channels, one for transmit and one for receive) with a minimum interrupt load. UART data is processed in the HAL_startUARTDMAReceive() function, by setting a trigger at 14 bytes, as this is the byte which codes the packet length (which can change dynamically from packet to packet). After decoding byte 14, the UART DMA transfer length value gets updated to a new length, which is covering the rest of the DLT-645 protocol packet, transmitted by the PC GUI.

Table 3-1 shows the multiple UART ports in MSPM0G3507.

Table 3-1. UART Interface Assignments

OPTION	MSPM0G3507 UART PORT	PINS	HEADER
USB Type-C (default)	UART1	RX: PA8 TX: PA9	J9
FTDI device	UART3	RX: PB13 TX: PB12	J7
Bluetooth low energy chip	UART2	RX: PB18 TX: PB17	JP9

3.1.3 Direct Memory Access (DMA)

The MCU DMA module transfers packets between the MSPM0G3507 MCU and the four AMC131M03 devices with minimal hardware resources and timing overhead over the shared SPI bus. Two DMA channels are utilized: DMA Channel 0 is used to send SPI data (0x00) to the ADCs and DMA Channel 1 is used simultaneously to receive the measurements data from all ADCs over the shared SPI bus. Once a complete SPI data packet is received from the first ADC, an DMA Ready interrupt is generated and the CRC16 verification of the data packet starts. After the CRC16 check is successful, the data packet is disassembled into voltage and current values per each phase line. Then the second, third, and the fourth ADC devices are accessed time-multiplexed one after the other to read out the data samples for each phase and neutral. For the neutral line data from AMC131M03 only the current value gets processed. AMC131M03 transfers 15 bytes of packets.

3.1.4 ADC Setup

The AMC131M03 device registers must be initialized to deliver proper measurement data on all relevant analog input channels. This initialization process is followed at every start of the metrology application as well as each time the metrology calibration procedure is run.

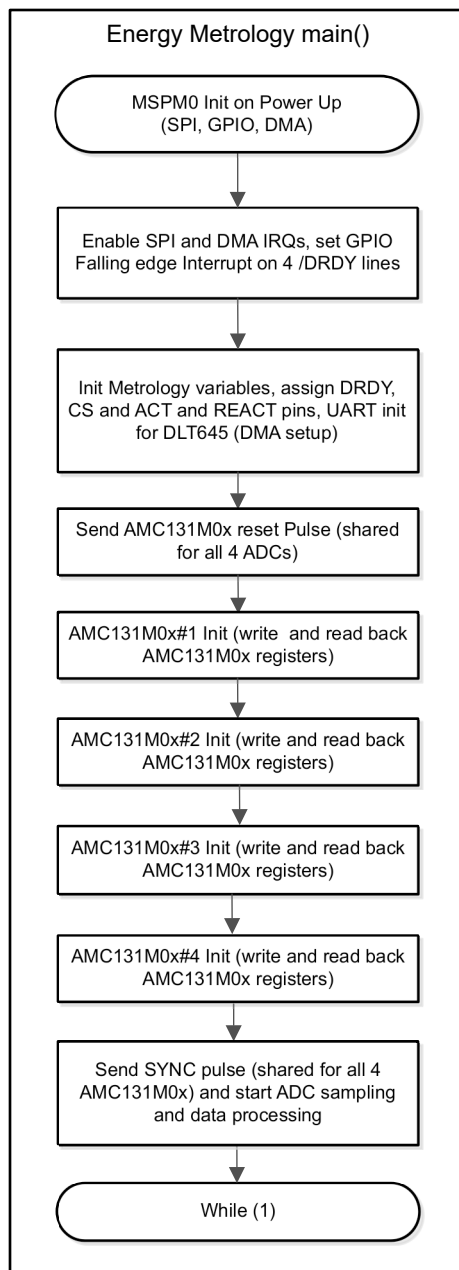


Figure 3-1. Energy Metrology Initialization Sequence in TIDA-010244 Firmware

The SPI module of the MSPM0+ MCU is configured as a controller device that uses 4-wire mode (the four chip-select signals CS0, CS1, CS2, and CS3 are automatically asserted high and low by the SPI hardware module). After the SPI module is set up, all interrupts are disabled and a reset pulse on the SYNC_RESET line is sent from the MSPM0+ MCU. Interrupts are then re-enabled and the MSPM0+ MCU sends SPI write commands to the ADCs (first to AMC131M03 for Phase A, then the AMC131M03 for Phase B, then AMC131M03 for Phase C, and finally to AMC131M03 for Neutral) to configure the registers:

- MODE register settings: 16-bit CCITT CRC used, 24-bit length for each word in the AMC31M03 data packet, the *DRDY* signal is asserted on the most lagging enabled channel, *DRDY* is asserted high when the conversion value is not available, *DRDY* is asserted low when the conversion values are ready.
- GAINx register settings: PGA gain = 1 used for all three channels, measuring the line-to-neutral voltage on each AMC device
- GAINy register settings: PGA gain = 32 is used for all four current measurement channels (SHUNT channels)
- CHx_CNG register settings (where x is the channel number)

- 3-phase mode: All seven ADC channel inputs connected to external ADC pins and the channel phase delay set to 0 for each channel (the software phase compensation in the SDK Middleware is used instead of AMC131M03 hardware phase compensation).
- CLOCK register settings: 1024 OSR, all channels enabled, and high-resolution modulator power mode

The MSPM0+ MCU is configured at start-up to generate a port interrupt whenever a falling edge occurs on any of the four *DRDY* pins, which indicate that new measurement samples are available.

The ADC modulator clock is derived from the clock fed to the CLKIN pin which gets internally divided by two, to generate the ADC modulator clock. The sampling frequency of the ADC is therefore defined as shown in Equation 13.

$$f_S = \frac{f_M}{\text{OSR}} = \frac{f_{\text{CLKIN}}}{2 \times \text{OSR}} \quad (13)$$

where

- f_S is the sampling rate
- f_M is the modulator clock frequency
- f_{CLKIN} is the clock fed to the AMC131M03 CLKIN pin
- OSR is the selected oversampling ratio

In this design, the M0_CLKOUT signal of the MSPM0+ MCU has a frequency of 8.192MHz. The oversampling ratio is selected to be 1024 with the appropriate register setting. As a result, the ADC modulator clock for all four ADCs is set to 4.096MHz and the sample rate is set to 4000 samples per second.

For a 3-phase system where each line-to-neutral voltage is measured, at least three AMC devices are necessary to independently measure three voltages and three currents and isolate between any two phases. In this design, the following ADC channel mappings are used in software for the 3-phase configuration:

- AIN0P and AIN0N of AMC131M03 (U4) → Current I1 (Phase A Current)
- AIN1P and AIN1N of AMC131M03 (U4) → Voltage V1 (Phase A Line-to-Neutral Voltage)
- AIN0P and AIN0N of AMC131M03 (U5) → Current I2 (Phase B Current)
- AIN1P and AIN1N of AMC131M03 (U5) → Voltage V2 (Phase B Line-to-Neutral Voltage)
- AIN0P and AIN0N of AMC131M03 (U6) → Current I3 (Phase C Current)
- AIN1P and AIN1N of AMC131M03 (U6) → Voltage V3 (Phase C Line-to-Neutral Voltage)
- AIN0P and AIN0N of AMC131M03 (U7) → Current N (Neutral Current)

3.1.5 Foreground Process

The foreground process includes the initial setup of the MSPM0+ MCU hardware and software and AMC130M03 registers immediately after a device RESET. Figure 3-2 shows the flow chart for this process

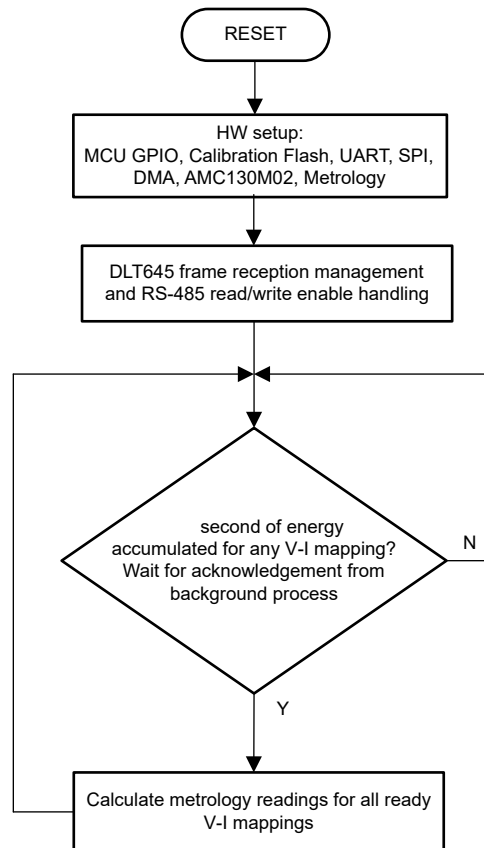


Figure 3-2. Foreground Process

The initialization routines involve the setup of the MSPM0G3507:

- General purpose input/output (GPIO) port pins
- Clock system (MCLK or CPU clock, RTC clock, SPI clock, CLK_OUT pin)
- 2 UART port
- 4 AMC130M02 registers
- DMA channels, for SPI and UART
- Metrology variables

After the hardware is set up, any received frames from the GUI are processed. Next, the foreground process checks whether the background process has notified the foreground process to calculate new metrology parameters for any voltage-current mappings. This notification is accomplished through the assertion of the PHASE_STATUS_NEW_LOG status flag whenever a frame of data is available for processing. The data frame consists of the processed dot products that are accumulated for CYCLES_PER_COMPUTATION number of cycles of data. The value for CYCLES_PER_COMPUTATION is 10 cycles when the nominal frequency setting in the software is 50Hz and 12 cycles when the nominal frequency setting in the software is set to 60Hz. When the measured line frequency is equal to the nominal frequency of the design, this is equivalent to 200ms of accumulated data.

The processed dot products include the V_{RMS} , I_{RMS} , active power, reactive power, fundamental voltage, fundamental active power, and fundamental reactive power. These dot products are used by the foreground process to calculate the corresponding metrology readings in real-world units. All the processed dot products are accumulated in separate 64-bit registers to further process and obtain the RMS and mean values. The apparent power is calculated using the calculated values of active and reactive power of the foreground process.

Similarly, using the calculated values of the foreground for the fundamental voltage, fundamental reactive power, and fundamental active power, the fundamental current, fundamental apparent power – voltage THD, and current THD are calculated. Additionally, voltage underdeviation and voltage overdeviation are calculated using the value of the calculated RMS voltage and the defined nominal voltage of the design. The frequency (in Hz) and power factor are also calculated using parameters calculated by the background process using the formulas in [Section 3.1.1](#).

3.1.6 Background Process

Figure 3-3 shows the different events that occur when sampling voltage and current, where the items in green are done by the MSPM0G3507 hardware modules.

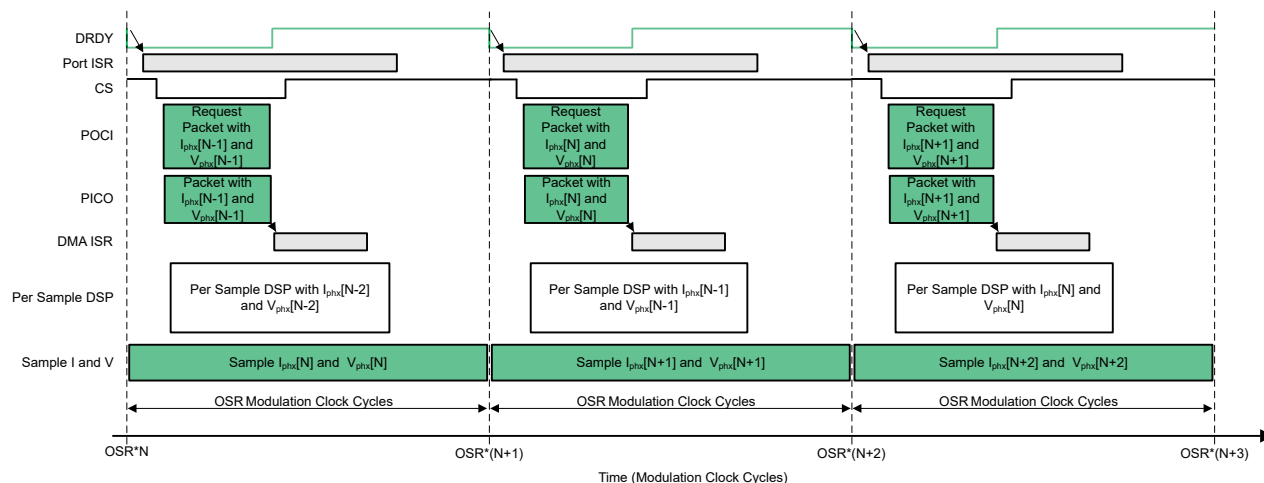


Figure 3-3. Voltage and Current Sampling Events

New current samples for each phase are ready every OSR, or 1024 modulation clock cycles for this design, thus resulting in 4000 samples per second over the SPI bus to MSPM0+ MCU. Once new samples are ready, the DRDY pin causes a GPIO interrupt on the MSPM0+ MCU, which triggers the Port ISR, and the background process is run within the Port ISR.

Figure 3-4 shows the background process, which mainly deals with timing-critical events in the test software.

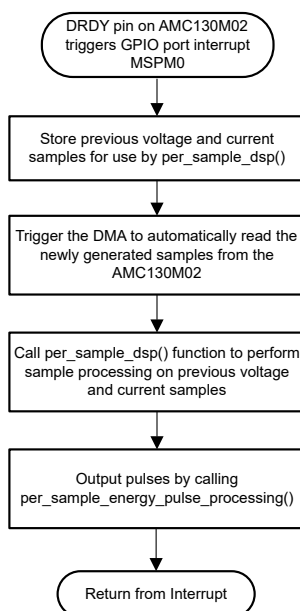


Figure 3-4. Background Process

3.1.7 Software Function *per_sample_dsp* ()

Figure 3-5 shows the flowchart for the *per_sample_dsp*() function. The *per_sample_dsp*() function is used to calculate intermediate dot product results that are fed into the foreground process for the calculation of metrology readings. Both voltage and current samples are processed and accumulated in dedicated 64-bit registers. Per-phase active power and reactive power are also accumulated in 64-bit registers.

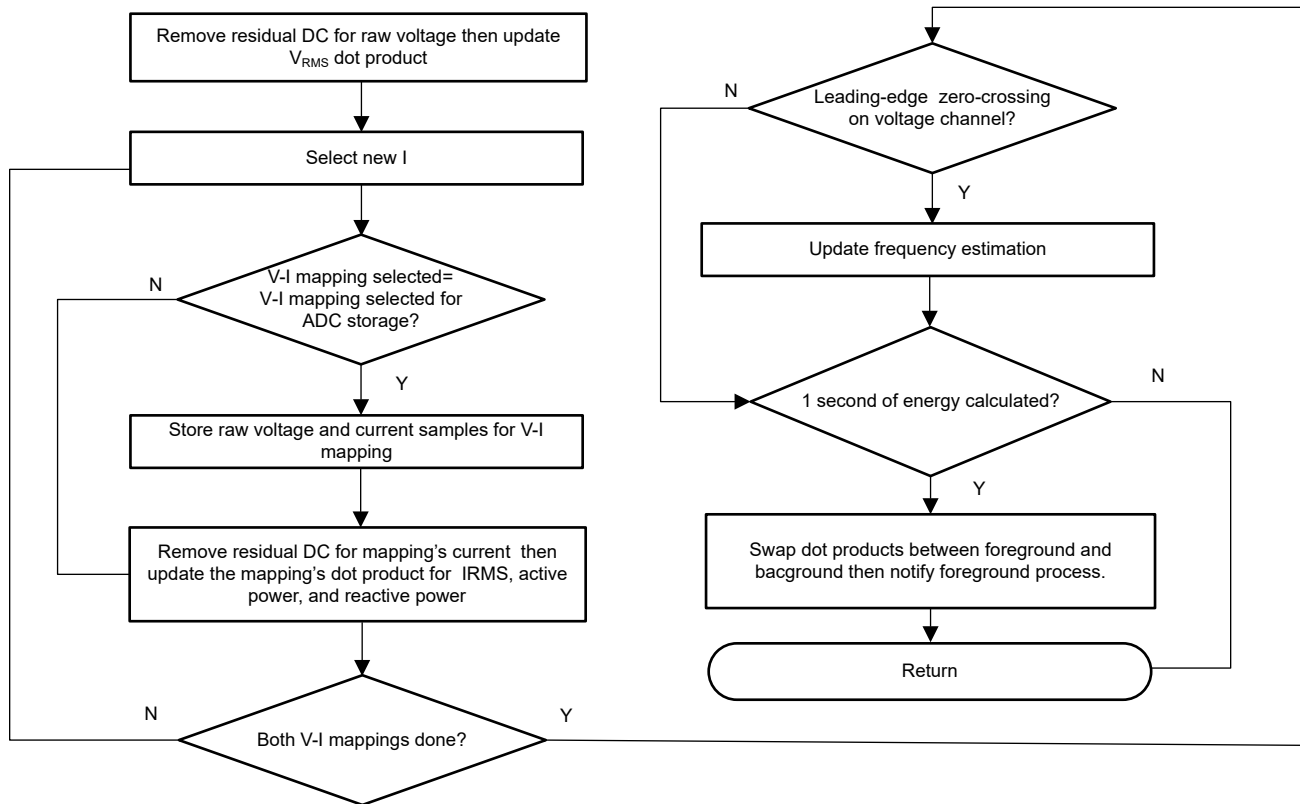


Figure 3-5. *per_sample_dsp* () Function

3.1.8 Frequency Measurement and Cycle Tracking

The instantaneous voltage, currents, active powers, and reactive powers are accumulated in 64-bit registers. A cycle tracking counter keeps track of the number of cycles accumulated. When *CYCLES_PER_COMPUTATION* number of cycles have been accumulated, the background process stores these accumulation registers and notifies the foreground process to produce the average results, such as RMS and power values. Cycle boundaries are used to trigger the foreground averaging process because this process produces very stable results.

For frequency measurements, a straight line interpolation is used between the zero crossing voltage samples. Because noise spikes can also cause errors, the application uses a rate-of-change check to filter out the possible erroneous signals and make sure that the two points are interpolated from genuine zero crossing points. For example, with two negative samples, a noise spike can make one of the samples positive, thereby making the negative and positive pair appear as if there is a zero crossing.

The resultant cycle-to-cycle timing goes through a weak low-pass filter to further smooth out any cycle-to-cycle variations. This filtering results in a stable and accurate frequency measurement that is tolerant of noise.

3.1.9 LED Pulse Generation

In electricity meters, the energy consumption of the load is normally measured in a fraction of kilowatt-hour (kWh) pulses. This information can be used to accurately calibrate any meter for accuracy measurement. Typically, the measuring element (the MSPM0+ MCU) is responsible for generating pulses proportional to the energy consumed.

This application uses average power to generate these energy pulses. The average power accumulates at every DRDY port ISR interrupt, thereby spreading the accumulated energy from the previous one-second time frame evenly for each interrupt in the current one-second time frame. This accumulation process is equivalent to converting power to energy. When the accumulated energy crosses a threshold, a pulse is generated. The amount of energy above this threshold is kept and a new energy value is added on top of the threshold in the next interrupt cycle. Because the average power tends to be a stable value, this way of generating energy pulses is very steady and free of jitter.

The threshold determines the energy tick specified by meter manufacturers and is a constant. The tick is typically defined in pulses-per-kWh or just in kWh. One pulse must be generated for every energy tick. For example, in this application, the number of pulses generated per kWh is set to 6400 for active and reactive energies. The energy tick in this case is 1kWh / 6400. Energy pulses are generated and available on the ACT and REACT pin headers and also through light-emitting diodes (LEDs) on the board. GPIO pins are used to produce the ACT and REACT energy pulses.

Figure 3-6 shows the flow diagram for pulse generation with a pulse constant of 6400, though TI recommends reducing this value to 3600 or even lower if the energy meter supports currents beyond 80A.

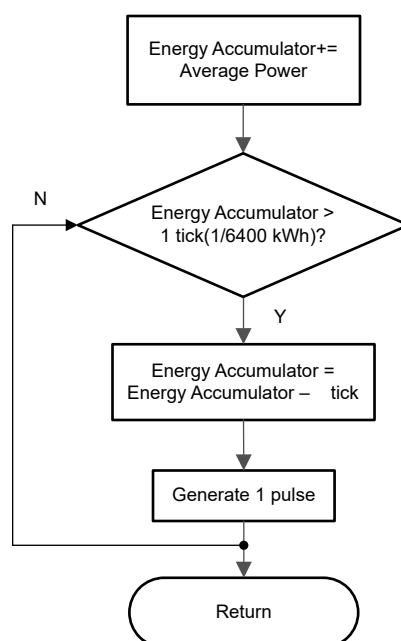


Figure 3-6. Pulse Generation for Energy Indication

The average power is in units of 0.001W and a 1kWh threshold is defined in Equation 14.

$$1\text{kWh threshold} = \frac{1}{0.001} \times 1\text{kW} \times (\text{Number of interrupts per second}) \times (\text{Number of seconds in one hour} = 1000000 \times 8000 \text{ (14)} \\ \times 3600 = 0x1A3185C50000)$$

4 Implementation Results

4.1 Evaluation Procedure

To evaluate the function of the board, TI recommends to run a test procedure - [Section 4.1.2](#).

4.1.1 Equipment Setup

Figure 4-1 shows the location of various components of the reference design on the top layer of the PCB. The bottom layer has no soldered components.

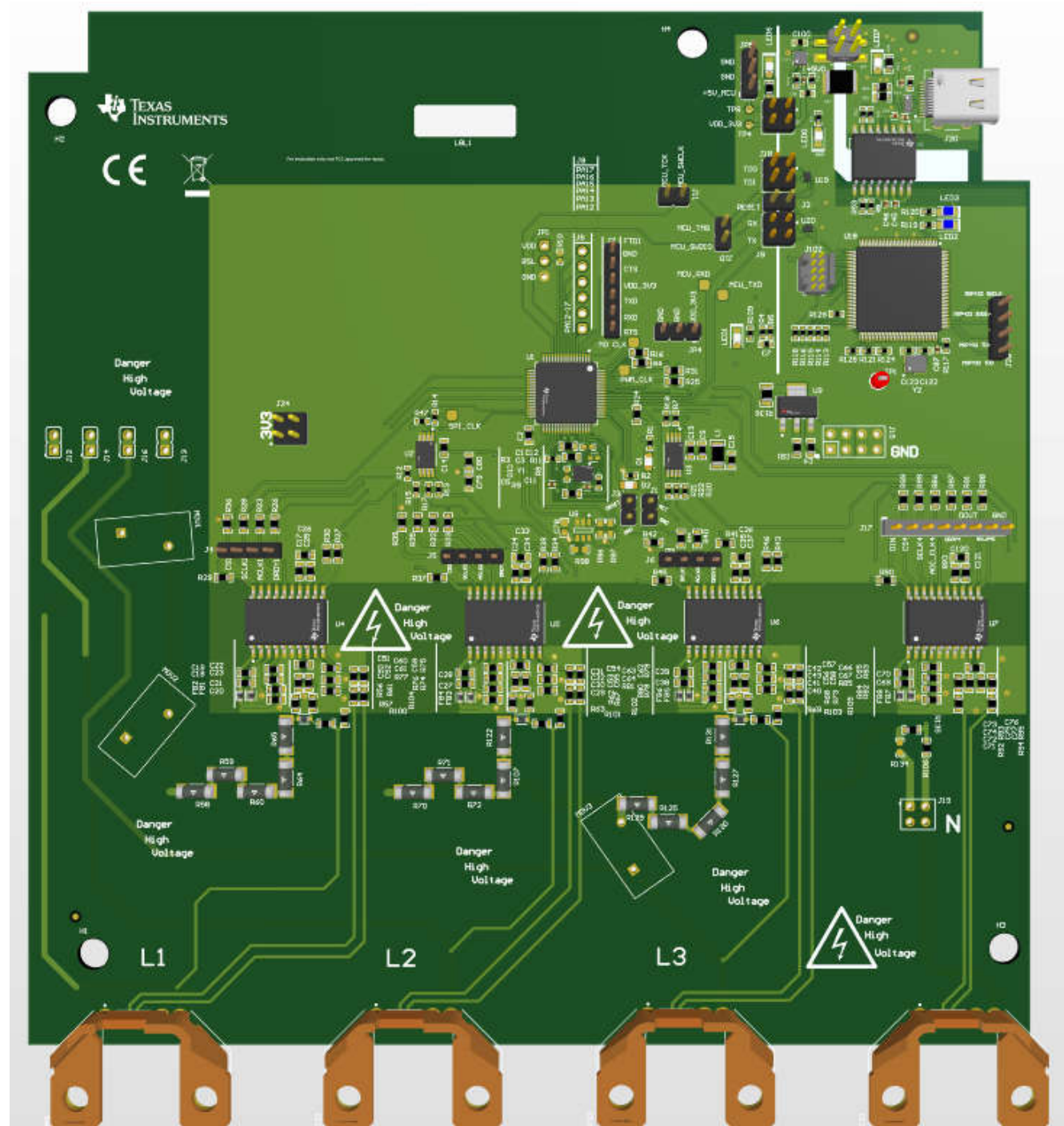


Figure 4-1. AMC-ADC-3PH-EVM Hardware 3D View

4.1.1.1 Jumper Settings for LED and UART

To run the TIDA-010244 board use the following steps:

1. Power settings

The default power source is over the USB Type-C connection. To power the board, place jumpers at JP3 and J18. The following LEDs indicate proper functionality:

- LED0: 3.3V for the XDS110 emulator
- LED1: 3.3V for the MSPM0 MCU
- LED3: Proper functionality of the XDS110 emulator
- LED6: 5V available at for the MSPM0 MCU
- LED7: 5V are available over the USB connector

Other power options are listed in [Power Supply Options and Jumper Settings](#).

2. Communication settings

The default communication is over the onboard USB Type-C interface. The interface allows programming and data can be sent from the MSPM0. To program the MSPM0 device, place the following jumpers:

- J6: MCU_TMS to MCU_SWDIO
- J7: MCU_TCK to MCU_SWCLK

The UART communication provides the results calculated by the energy metrology library. The data can be transferred through the USB Type-C interface or an FTDI device through a pin-header

The default setting is a data transfer through the USB Type-C interface. To enable this, place jumpers at J9 to RX and TX.

The second option is through an external FTDI chip on header J7. Place the FTDI cable translation device at the header and make sure to change the hardware configuration using the SysConfig file of the CCS project. See also the [UART for PC GUI Communication](#) section.

4.1.1.2 Power Supply Options and Jumper Settings

The M0+ MCU, the four stand-alone ADCs, and the rest of TIDA-010244 board are powered from an external power supply by connecting a 3.3V external power and GND. The J7 jumper is an FTDI standard 6-pin header, where an off-the-shelf FTDI UART-to-USB cable can be attached to supply external 3V3, GND, and also a UART port for communication to the PC GUI.

Various jumper headers and jumper settings are present to add to the flexibility of the board. Some of these headers require that jumpers be placed appropriately for the board to function properly. The [Section 4.1.1.1](#) section documents the functionality of each jumper on the board.

A 5V supply can be provided over the USB Type-C port by placing the Jumper on JP3, in such a case the USB interface isolation is no longer available. The 5V supply from USB is converted by an onboard LDO down to 3.3V.

The external 3.3V supply can be connected through different headers on the board. The following header can be taken to power the board directly with 3.3V:

- J7, P3
- J24, P1
- JP1, P1
- JP2, P4
- JP4, P1–4

Ground connection is found at:

- J7, P1
- J25, P1–4
- JP1, P3
- JP4, P2–3
- JP5, P2–3

LED0 indicates the 3V3 level within the USB Type-C isolation. LED1 indicates the 3V3 voltage level for the MSPM0 MCU and LED6 shows if the 5V level is applied to the board.

Additionally, the design has jumper header (J19, J20, J22, J23) connections to provide access to the high-voltage phases to connect an external power converter (like a flyback converter) to supply the board with 3.3V.

Note

In [Table 4-1](#), the headers with **(WARNING)** text in the *MAIN FUNCTIONALITY* column are not isolated, so do not use measuring equipment on those headers when running off the Mains. This applies, unless either isolators external to the board of this design are used to connect at the headers, if the equipment is battery powered and does not connect to Mains, or if AC Mains are isolated.

Table 4-1. Header Names and Jumper Settings

HEADER OR HEADER OPTION NAME	TYPE	MAIN FUNCTIONALITY	VALID USE CASE	COMMENTS
J1	2-pin header	Active energy pulses (WARNING)	Probe here for cumulative active energy pulses. This header has two pins: GND and ACT, which is where the active energy pulses are actually output.	This header is not isolated from AC Mains, so do not connect measuring equipment here. See the <i>ISO_ACT</i> pin of J2 instead, which is isolated. If testing the active power pulses is desired, use the <i>ISO_ACT</i> pin of J2 instead since this pin is isolated.
J3	2-pin header	Reactive energy pulses (WARNING)	Probe here for cumulative reactive energy pulses. This header has two pins: GND and REACT, which is where the reactive energy pulses are actually output.	This header is not isolated from AC Mains, so do not connect measuring equipment here. If testing the reactive power pulses is desired, use the <i>ISO_REACT</i> pin of J2 instead since this pin is isolated.
J102	10-pin, 2-row connector	Neutral Connection (WARNING)	Connect the XDS110 Debug Probe to this connector to program and debug the MSPM0G1106 MCU.	The XDS110 Debug Probe is used to program the MSPM0G35073 device. The MSPM0 MCU must be powered externally for programming. XDS110 also provides power. Since this header and the XDS110 are not isolated, do not connect to this header when running off Mains and Mains is not isolated.
J7	6-pin header	FTDI UART and power (WARNING)	Use FTDI cable and UART link while debugging with <i>no Mains</i> connected.	Provides UART link through a PC USB port. Since this header is not isolated, do not connect to this header when running off Mains and Mains is not isolated.
J4, J5, J6	4-pin header	AMC131M03 MSPM0G3507 communication header (WARNING)	Probe here for connections to the 4-wire SPI signals, RST signal, CLKIN signal, and DRDY signal of the respective AMC131M03 device.	The RST pin resets the AMC131M03, driven by MSPM0G3507 during initialization of all ADCs. The DRDY pin of each AMC131M03 device is used to alert the MSPM0+ MCU that new current samples are available. The CLKIN pin is fed from the M0_CLKOUT clock output through the LMK clock buffer of the MSPM0+ MCU to the AMC131M03 device, which divides the clock down to produce the used modulator clock. (WARNING) This header is <i>not</i> isolated from AC Mains, so do <i>not</i> connect measuring equipment when running from Mains unless isolators external to the reference design are available. The pin mappings on this header are as follows: - Pin 1: $\overline{CS}$ pin - Pin 2: SPI CLK - Pin 3: AMC131M03 CLKIN pin - Pin 4: AMC131M03 $\overline{DRDY}$ pin
J17	8-pin header	AMC131M03 MSPM0G3507 full communication header (WARNING)	Probe here for connections to the 4-wire SPI signals, RST signal, CLKIN signal, and DRDY signal of the AMC131M03 device.	The Header has the same functionality like J4, J5 and J6. The header is extended to give access to the SPI data lines. The pin mappings on this header are as follows: - Pin 1: AMC131M03 DIN - Pin 2: AMC131M03 $\overline{CS}$ - Pin 3: AMC131M03 SCLK - Pin 4: CLKIN - Pin 5: AMC131M03 $\overline{DRDY}$ pin - Pin 6: AMC131M03 DOUT - Pin 7: AMC131M03 SYNC, RESET pin - Pin 8: GND

Table 4-1. Header Names and Jumper Settings (continued)

HEADER OR HEADER OPTION NAME	TYPE	MAIN FUNCTIONALITY	VALID USE CASE	COMMENTS
J18	4-pin terminal block	MCU TDO and TDI		
J2	2-pin header	Reset pin		
J9	4-pin terminal block	UART XDS to MSPM0 connection	Debugging of the UART signal or connection for an external MCU.	If an external MCU is evaluated connect here an external MCU to send the data over the USB Type-C port.
J12, J13, J14, J16, J19	4-pin terminal block	Power connection to mount an external power converter (WARNING)	Provide the board with power over the three measured phases. Warning: High-voltage applied.	
J8	6-pin header	Unused GPIO pins of the MSPM0	This header is used to enable further signals from the MSPM0.	Enable these GPIO header pins as desired in the SysConfig tool.
J24	4-pin header block	3V3 header, GND Connector	Use this header for external power supply.	
J15	8-pin header block	Split External VIN and GND header	Use this header for an external supply connection up to 16V in	Left 4 pins are External VIN, Right 4 pins are GND
J26	4-pin header	MSP432 JTAG interface	This is a backup connection to program the MSP432 device. The default is through USB Type-C.	
JP1	3-pin jumper header	Pullup or pulldown through R110 = 47k Ω for BSL_invoke line on MSPM0G3507	Place a jumper at either 1-2 or 2-3 positions depending if BSL_INVOKE is VDD_3V3 or GND, respectively.	
JP2	4-pin header block	5V and 3V3 connections	5V and 3V3 connections. Place this header to connect the 5V to the board.	
JP5	3-pin header	External 5V connection		

4.1.2 Test Procedure**Note**

Verify that the outputs of the connected supplies are disabled before connecting or disconnecting equipment.

4.1.2.1 Working With the Metrology GUI

To view the metrology parameter values from the GUI, perform the following steps:

1. Select UART connection for communication to the PC GUI. Connect J12 to PC USB and a COM port is created on the PC. The testing is done using UART with 115200, 8N1 setting.
2. Open the GUI folder and open calibration-config.xml in a text editor.
3. Change the port name field within the meter tag to the COM port connected to the system. As Figure 4-2 shows, this field is changed to COM7.

```

260 </correction>
261 </phase>
262 <temperature/>
263 <rtc/>
264 </cal-defaults>
265 <meter position="1">
266 <port name="com7" speed="9600"/>
267 </meter>
268 <reference-meter>
269 <port name="USB0::0x0A69::0x0835::A66200101281::INSTR"/>
270 <type id="chroma-66202"/>
271 <log requests="on" responses="on"/>
272 <scaling voltage="1.0" current="1.0"/>
273 </reference-meter>

```

Figure 4-2. GUI Configuration File Changed to Communicate With Energy Measurement System

4. Run the calibrator.exe file, which is located in the GUI folder. If the COM port in the calibration-config.xml is changed in the previous step to the COM port connected to the reference design, the GUI opens (see Figure 4-3). If the GUI connects to the design properly, the top-left button is green. If there are problems with connections or if the code is not configured correctly, the button is red. Click the green button to view the results.

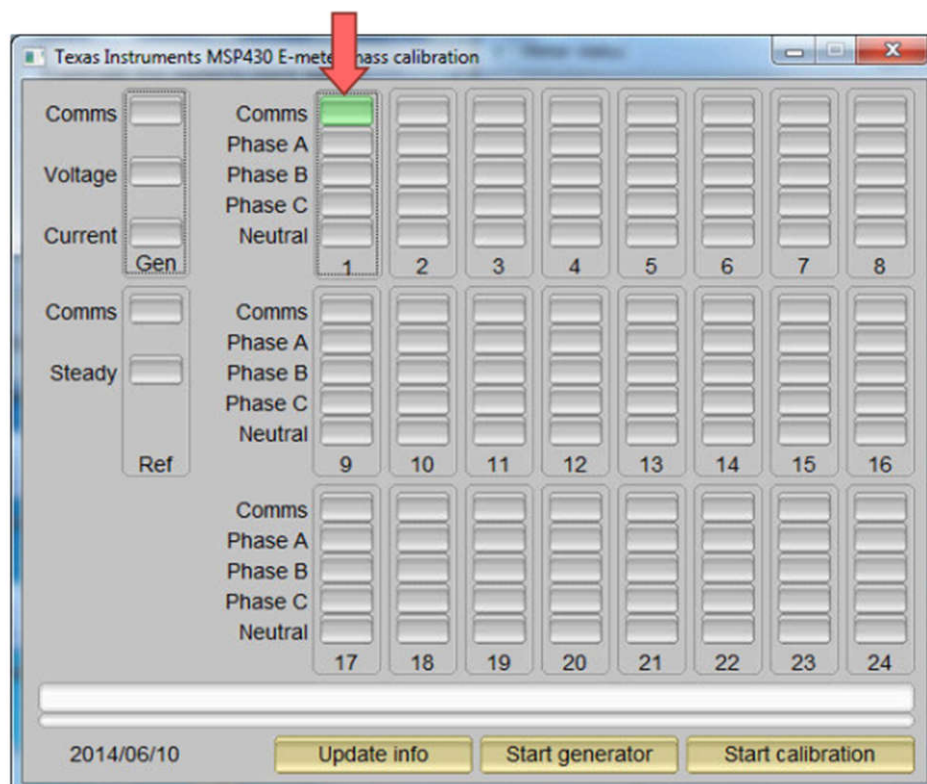


Figure 4-3. GUI Start-Up Window

The results window opens after clicking on the green button (See also Figure 4-4, All 3 Phases are expected to display values in 3PH mode).

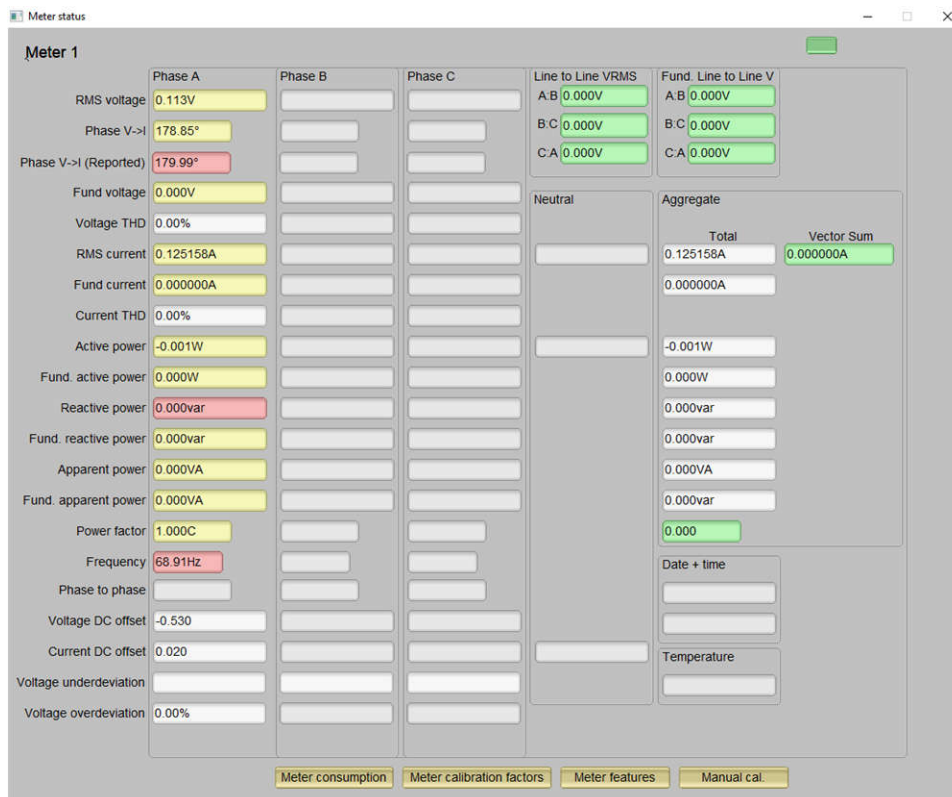


Figure 4-4. GUI Results Window

4.1.2.2 Calibration

The PC GUI (see the `c:\ti\mspm0_sdk_2_03_00_07\tools\metrology_gui` directory in [MSPM0 SDK](#)) is used for viewing results and for calibrating the energy metrology function. During calibration, parameters called calibration factors are modified in the test software to give the least error in the energy measurement.

For this meter, there are six main calibration factors for each phase: voltage scaling factor, active power offset (erroneously called voltage AC offset in the GUI), current scaling factor, reactive power offset (erroneously called current AC offset in the GUI), power scaling factor, and the phase compensation factor. The voltage, current, and power scaling factors translate measured quantities in metrology software to real-world values represented in volts, amps, and watts, respectively. The power offset is used to subtract voltage to current crosstalk, which appears as a constant power offset and causes greater inaccuracies at lower currents. The last calibration factor is the phase compensation factor, which is used to compensate any phase shifts introduced by the current sensors and other passives.

The voltage, current, and power calibration factors are independent of each other. Therefore, calibrating voltage does not affect the readings for RMS current or power. When the Energy Metrology middleware is flashed on the MSPM0+ MCU for the first time, default initial values are loaded into these calibration factors. These default values are modified through the GUI during calibration. The calibration factors are stored into a FLASH sector in the MCU; and therefore, remains the same if the hardware is restarted. Calibrating any of the scaling factors is referred to as gain correction. Calibrating the phase compensation factors is referred to as phase correction. For the entire calibration process, the AC test source must be ON and the energy pulses connected to the reference meter.

4.1.2.2.1 Voltage and Current Offset Calibration

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

1. Connect the GUI to view results for voltage and current.
2. Configure the test source to supply the desired voltage and current.
 - Using a low but non-zero value is recommended; for example, 120V and 1A.
3. Click on the *Manual cal.* button.

- Input the difference from the expected input versus what the GUI is reading into the appropriate fields.

Note

AC current offset is in microamps and AC voltage offset is in millivolts.

4.1.2.2.2 Voltage and Current Gain Calibration

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

- Connect the GUI to view results for voltage, current, active power, and the other metering parameters.
- 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.
- Click on the *Manual cal.* button as illustrated in Figure 4-4.

The screen in Figure 4-5 pops up:

	Phase A	Phase B	Phase C	Neutral
Voltage	0 %	0 %	0 %	
Voltage (limp)	0 %	0 %	0 %	
Voltage AC offset	0	0	0	
Fund. RMS Voltage offset (mV)	0	0	0	
Current	0 %	0 %	0 %	0 %
Current (limp)	0 %	0 %	0 %	0 %
Current AC offset	0	0	0	0
Fund. RMS Current offset (uA)	0	0	0	
Active power	0 %	0 %	0 %	0 %
Active power offset (mW)	0	0	0	0
Fund. active power offset (mW)	0	0	0	
Reactive power offset (mvar)	0	0	0	0
Fund. reactive power offset (mvar)	0	0	0	
Phase correction	0 us	0 us	0 us	0 us

Update meter

Figure 4-5. Manual Calibration Window

- 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 15.

$$\text{Correction (\%)} = \left(\frac{\text{value}_{\text{observed}}}{\text{value}_{\text{desired}}} - 1 \right) \times 100 \quad (15)$$

where

- value_{observed} is the value measured by the TI meter
- value_{desired} is the calibration point configured in the AC test source

4.1.2.2.3 Active Power Gain Calibration

After performing gain correction for voltage and current, gain correction for active power must be completed. 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, this 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:

- 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 steps 1 to 3 from [Section 4.1.2.2.2](#) 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.

Note

The error can be negative.

5. Enter the error obtained in 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.

4.1.2.2.4 Offset Calibration

After performing gain calibration, if the accuracy at low currents is not acceptable, offset calibration can be done. 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, 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 *Active power offset (mW)* in the meter calibration factors window) and then enter this new value in the *Active power offset (mW)* field in the *Manual Calibration* window. As an example, if the *Active power offset (mW)* has a value of 200 (0.2W) in the meter calibration window, and subtracting an additional 0.300mW is desired, then enter a value of 500 in the *Active power offset (mW)* field in the *Manual Calibration* window. After entering the value in the *Active power offset (mW)* field in the *Manual Calibration* window, press the *Update meter* button.

To perform reactive power offset calibration for a phase, a similar process is followed as the process used to perform active power offset calibration.

4.1.2.2.5 Phase Calibration

After performing power gain correction, do the phase calibration. To perform phase correction calibration, complete the following steps:

1. If the AC test source has been turned OFF or reconfigured, perform steps 1 through 3 from [Section 4.1.2.2.2](#) using the identical voltages and currents used in that section.
2. Modify only the phase-shift to a non-zero value; typically, +60° is selected. The reference meter now displays a different % error for active power measurement.

Note

This value can be negative.

3. If the error from 2 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 $\pm$ 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 1. 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 now to -60° and check if this error is still acceptable. In best practice, errors must be symmetric for the same phase shift on lag and lead conditions.

After performing phase calibration, calibration is complete. [Figure 4-6](#) shows the new calibration factors.

Meter calibration factors

Meter 1 calibration factors

	Phase A	Phase B	Phase C	Neutral
Voltage	1.589500e+003			
Voltage (limp)				
Voltage AC off	-106			
Fund. RMS Voltage offset (mV)	0			
Current	4.493959e+001			
Current (limp)				
Current AC offset	-125000			
Fund. RMS Current offset (uA)	0			
Active power	7.237284e+004			
Active power offset (mW)	0			
Fund. active power offset (mW)	0			
Reactive power offset (mvar)	0			
Fund. reactive power offset (mvar)	0			
Phase correction	0.0us			

Figure 4-6. Calibration Factors Window

4.2 Performance Data and Results

To test for metrology accuracy in the electricity meter configuration, a source generator is used to provide the voltages and currents to AMC-ADC-3PH-EVM. In this design, a nominal voltage of 120V between the three phases and neutral, calibration current of 10A, and nominal frequency of 60Hz are used for each of the three phases, while phase calibration is done at 60°.

In the cumulative active and reactive energy testing, the sum of the energy reading of each phase is tested for accuracy. For cumulative active energy error and cumulative reactive energy error testing, current is varied from 100mA to 100A. For cumulative active energy, a phase shift of 0° (PF = 1), PF = 0.5i (inductive), and PF = 0.8c (capacitive) is applied between the voltage and current waveforms fed to the reference design. Based on the error from the active energy output pulse, a plot of active energy % error versus current is created for the three PF values.

For cumulative reactive energy error testing, a similar process is followed except that a phase shift of 90° ($\sin \phi = 1i$), $\sin \phi = 0.5i$ (inductive), and $\sin \phi = 0.8c$ (capacitive) are used, and cumulative reactive energy error is plotted.

All these tests are run using the 4ksps sample rate setting of the AMC131M03.

For the V_{RMS} accuracy test on Phase A, the voltage is varied from 10V to 270V while current is held steady at 10A. For the I_{RMS} accuracy test on Phase A, the voltage is kept steady at 120V, while current is varied from 0.025A to 100A.

The following two plots for Active and Reactive Power are per IEC 62053-22 limits for class 0.2S and 0.5S accuracy, assuming $I_{nominal} = 15A$; hence, the 5% point of $I_{nominal}$ is at 750mA.

The average error for each measurement is calculated from five test series, taken sequentially for each current value, and the maximum deviation from these five measurements is calculated (not shown in the following plots) to confirm the stability of this metrology subsystem being below 10% of the maximum error allowed.

For the following test results, gain, phase, and offset calibration are applied to the meter. At higher currents, the % error shown is dominated by shunt resistance drift caused by the increased heat generated at high currents.

The test data are recorded with calibrated value data of:

- $V_{in} = 120V$
- $I_{in} = 10A$
- Phase calibrated at 60°
- Phases = 3
- Energy Pulses for ACT and REACT = 6400
- Room temperature

4.2.1 Electricity Meter Metrology Accuracy Results

After gain, phase, and offset calibration, the test results are shown in the following tables. [Table 4-2](#) and [Figure 4-7](#) show the active energy test results.

Table 4-2. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 1, 0°)

Current	AVG Error %	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]	Limit (%) [Class 0.1]
0.25	0.0745	-0.0858	± 1.000	± 0.400	± 0.200
0.5	0.0307	-0.0420	± 1.000	± 0.400	± 0.200
1.0	0.0217	-0.0330	± 1.000	± 0.400	± 0.200
1.5	0.0053	-0.0167	± 0.500	± 0.200	± 0.100
3.0	0.0057	-0.0170	± 0.500	± 0.200	± 0.100
10.0	-0.0017	-0.0097	± 0.500	± 0.200	± 0.100
15.0	-0.0113	(REF)	± 0.200	± 0.100	± 0.050
30.0	-0.0087	-0.0027	± 0.500	± 0.200	± 0.100
50.0	-0.0108	-0.0005	± 0.500	± 0.200	± 0.100
75.0	-0.0120	0.0007	± 0.500	± 0.200	± 0.100
90.0	-0.0522	0.0408	± 0.500	± 0.200	± 0.100
100.0	-0.0983	0.0870	± 0.500	± 0.200	± 0.100

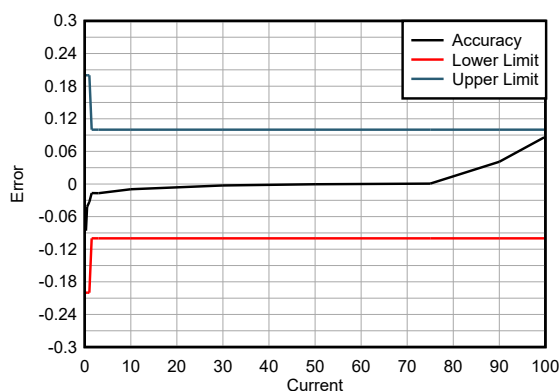


Figure 4-7. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 1, 0°)

Table 4-3. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.5i, 60°)

Current	AVG Error %	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]	Limit (%) [Class 0.1]
1.500	0.005	(REF)	NA	NA	NA
1.500	0.085	-0.079	± 1.000	± 0.500	± 0.250
15.000	-0.011	(REF)	NA	NA	NA
15.000	0.063	-0.075	± 0.600	± 0.300	± 0.150
50.000	-0.011	(REF)	NA	NA	NA
50.000	0.017	-0.027	± 0.600	± 0.300	± 0.150
100.000	-0.098	(REF)	NA	NA	NA
100.000	-0.021	-0.078	± 0.600	± 0.300	± 0.150

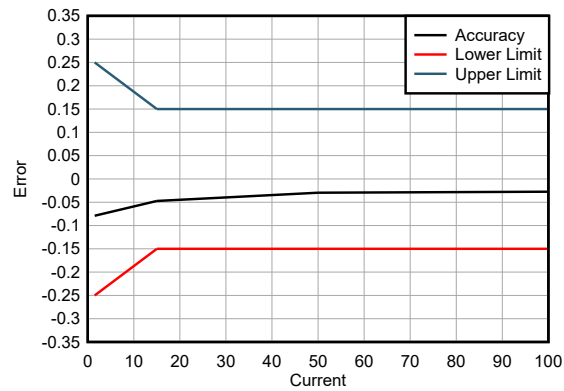


Figure 4-8. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.5i, 60°)

Table 4-4. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.8c, 323.13°)

Current	AVG Error %	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]	Limit (%) [Class 0.1]
1.500	0.005	(REF)	NA	NA	NA
1.500	0.025	-0.020	±1.000	±0.500	±0.250
15.000	-0.011	(REF)	NA	NA	NA
15.000	0.003	-0.014	±0.600	±0.300	±0.150
50.000	-0.011	(REF)	NA	NA	NA
50.000	-0.034	0.023	±0.600	±0.300	±0.150
100.000	-0.098	(REF)	NA	NA	NA
100.000	-0.100	0.002	±0.600	±0.300	±0.150

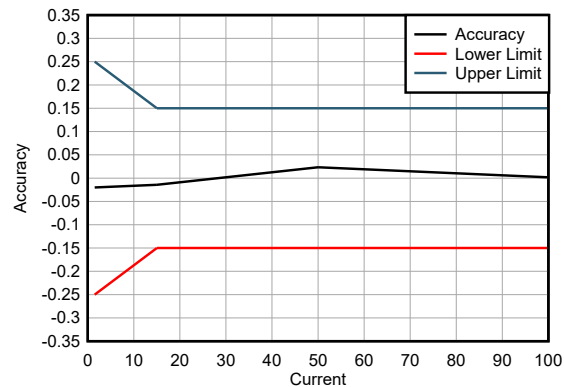


Figure 4-9. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.8c, 323.13°)

Figure 4-10 and Figure 4-11 show the reactive energy test results.

Table 4-5. Reactive Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 1i, 90°)

Current	AVG Error %	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]	Limit (%) [Class 0.1]
0.25	0.1718	-0.1167	± 1.000	± 0.400	± 0.200
0.5	0.1070	-0.0518	± 1.000	± 0.400	± 0.200
1.0	0.0852	-0.0300	± 1.000	± 0.400	± 0.200
1.5	0.0702	-0.0150	± 0.500	± 0.200	± 0.100
3.0	0.0667	-0.0115	± 0.500	± 0.200	± 0.100
10.0	0.0617	-0.0065	± 0.500	± 0.200	± 0.100
15.0	0.0552	(REF)	± 0.200	± 0.100	± 0.050
30.0	0.0685	-0.0133	± 0.500	± 0.200	± 0.100
50.0	0.0797	-0.0245	± 0.500	± 0.200	± 0.100
75.0	0.0962	-0.0410	± 0.500	± 0.200	± 0.100
90.0	0.0998	-0.0447	± 0.500	± 0.200	± 0.100
100.0	0.0833	-0.0282	± 0.500	± 0.200	± 0.100

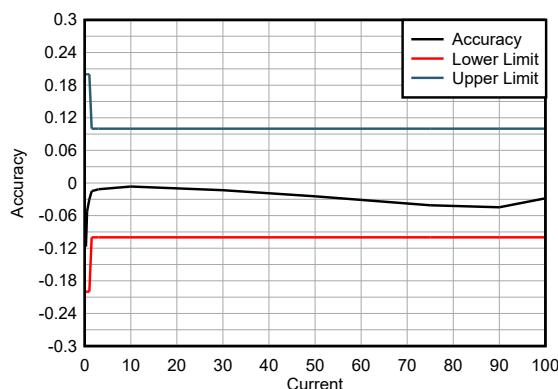


Figure 4-10. Reactive Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 1i, 90°)

Table 4-6. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.5i, 30°)

Current	AVG Error %	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]	Limit (%) [Class 0.1]
1.500	0.070	(REF)	NA	NA	NA
1.500	0.109	-0.039	± 1.000	± 0.500	± 0.250
15.000	0.055	(REF)	NA	NA	NA
15.000	0.084	-0.029	± 0.600	± 0.300	± 0.150
50.000	0.080	(REF)	NA	NA	NA
50.000	0.056	0.024	± 0.600	± 0.300	± 0.150
100.000	0.083	(REF)	NA	NA	NA
100.000	-0.002	0.085	± 0.600	± 0.300	± 0.150

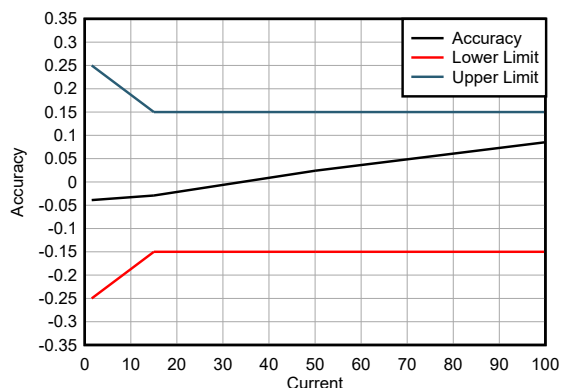


Figure 4-11. Reactive Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.5i, 30°)

Table 4-7. Active Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.8c, 306.87°)

Current	AVG Error %	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]	Limit (%) [Class 0.1]
1.500	0.070	(REF)	NA	NA	NA
1.500	0.103	-0.032	± 1.000	± 0.500	± 0.250
15.000	0.055	(REF)	NA	NA	NA
15.000	0.102	-0.047	± 0.600	± 0.300	± 0.150
50.000	0.080	(REF)	NA	NA	NA
50.000	0.109	-0.030	± 0.600	± 0.300	± 0.150
100.000	0.083	(REF)	NA	NA	NA
100.000	0.111	-0.027	± 0.600	± 0.300	± 0.150

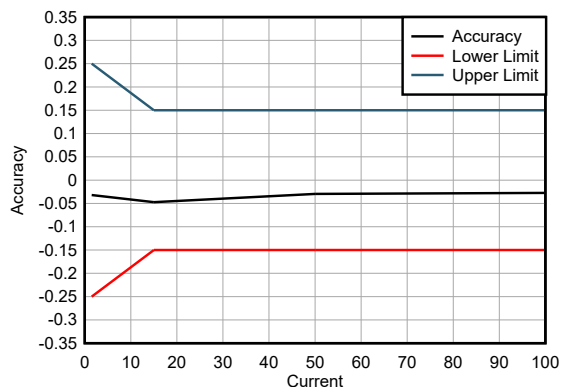


Figure 4-12. Reactive Energy % Error Versus Current, 300 $\mu\Omega$ Shunt (PF = 0.8c, 306.87°)

4.2.2 Radiated Emissions Performance

The plots in [Figure 4-13](#) and [Figure 4-14](#) are captured in a 3m CISPR chamber with a JB3 antenna in accordance to the EN50022 standard. Both plots show a quasi-peak capture of Radiated Emissions (RE) from the AMC-ADC-3PH-EVM when the antenna is either in the Horizontal or in the Vertical position and are labeled with *Spectrum Overview H* and *Spectrum Overview V*, respectively. Within each capture the board is positioned up vertically (top of device facing antenna), connected to the line with a 1m cable, but without a load. The antenna is positioned at board level. Multiple board rotations (0, 90, 180, 270) are also captured within each plot. Across the antenna and board orientation conditions, only the highest emission peaks are shown on the plots.

The radiated emissions of the EVM come from two main sources: the Digital SPI signals and the internal DC-DC transformer of each AMC device. The digital CLKIN signal is running at 8.192MHz and the harmonics are visible across the Emission spectrum. The SPI communication also radiates, causing wider and smaller peaks in the lower half of the frequency range due to the irregular period. Another set of emission peaks comes from the internal DC-DC transformer of the AMC devices which operate in the approximate 32MHz range. These emissions are amplified by the connection to the grid, which creates an antenna for the DC-DC fundamental to radiate through. The next section, [Section 4.2.2.1](#), goes over some of the EMI reduction techniques that can be used to reduce the Radiated Emissions seen during testing.

During the testing, the board is powered with a flyback converter design. The flyback converter is on a separate board that connects to the EVM through the J12, J13, J14, J15, and J16 connectors. The flyback board takes the Phases and Neutral signals as inputs and outputs a 14V signal to J15.

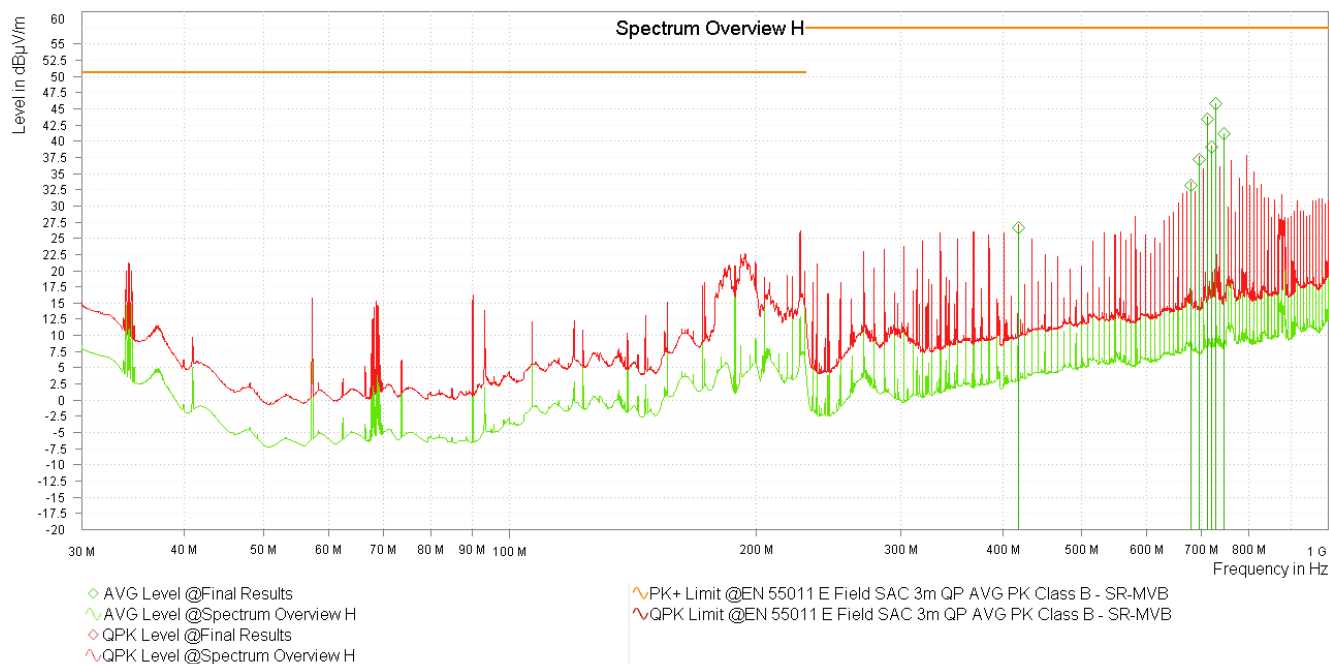


Figure 4-13. Spectrum Overview H

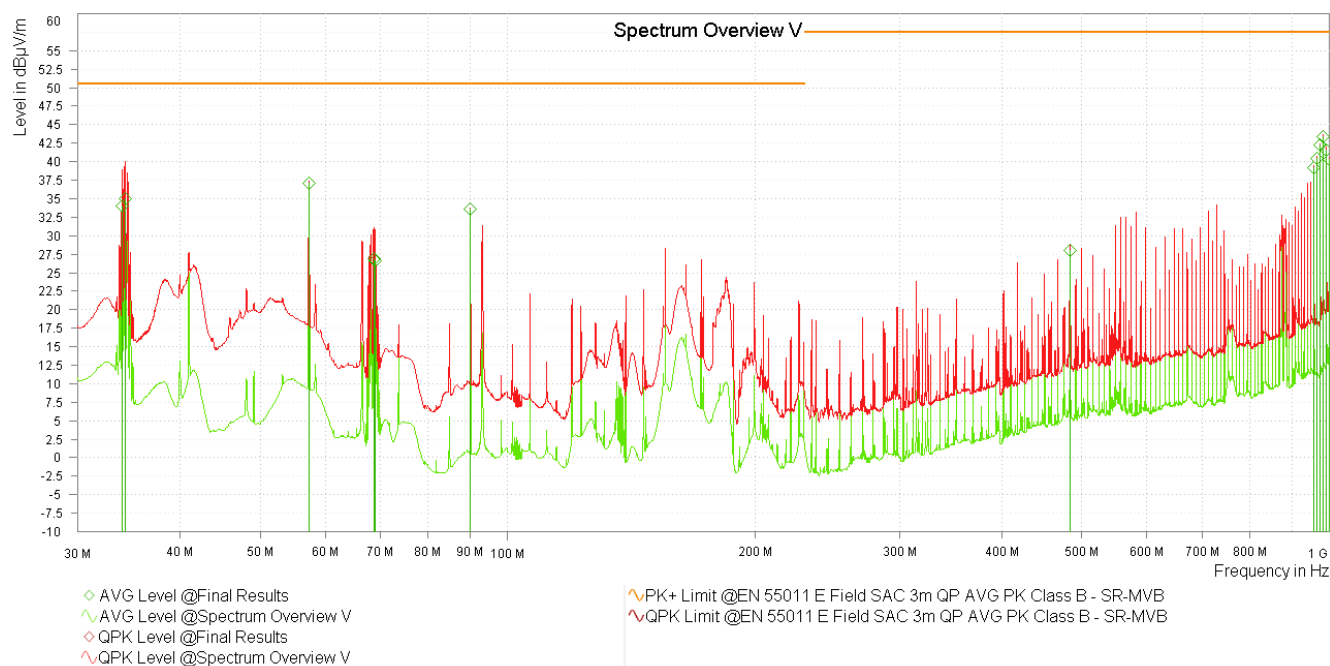


Figure 4-14. Spectrum Overview V

4.2.2.1 EMI Mitigation Recommendations

As mentioned in the previous section, the main sources of radiated emissions on this design is from the Digital SPI signals as well as the integrated DC-DC of the AMC devices. Long traces, large copper planes, and in the case of metering the line cables acts as antennas for high-frequency signals to radiate through. To reduce the radiated signals from these antennas you can change the antenna characteristics such as size to alter the resonant frequency of the antenna and change what frequencies radiate well. You can also reduce the amount of noise on the antenna by blocking the noise and providing lower impedance paths for the high-frequency components to return through. Below are some of the EMI considerations that are tested and implemented on this design.

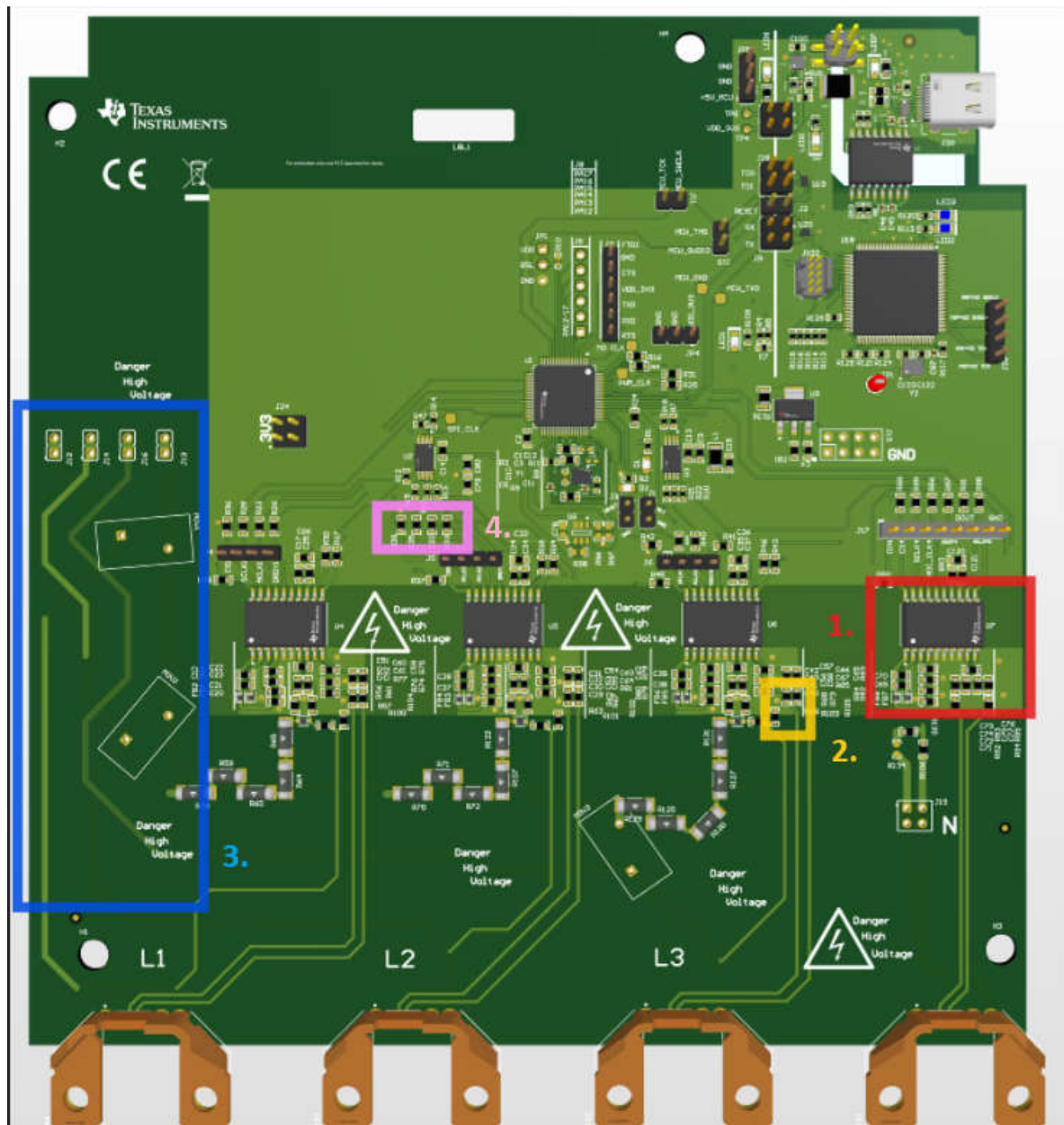


Figure 4-15. EMI Reduction Considerations Implemented on EVM

1. Stitching Capacitance
 - a. Adding stitching capacitance near switching components can help filter out the high-frequency noise from the rest of the system by providing a close, low impedance path for the energy to return.
 - b. To reduce the amount of switching noise to the line cables from the internal DC-DC of the AMC device, a stitching capacitor is added between the HGND and DGND of each device. This capacitance can be discrete or built through the PCB by overlapping copper layers.
 - i. If implementing with discrete capacitors, low ESR caps must be selected that are rated for the system voltage. Adding a capacitor with a capacitance between 100pF and 5nF improves performance.

- ii. If implementing through the PCB, the overlapping layers must be placed below the devices to also provide some shielding. Add > 30pF capacitors in the design to improve performance. This design uses a stitching capacitor built through the PCB layers (see the following app note for more details on PCB stitching capacitors: [Digital Isolator Design Guide](#)).

2. Ferrites

- a. Ferrites can be added to block a range of high-frequency signals. Select a ferrite that has a high resistance near the target frequency. For this case, MHF1608BAC352ATD25 ferrite bead are best for the 32MHz frequency.
- i. The sensing input lines of the AMC devices have additional ferrite locations. This blocks the DC-DC noise from reaching the line cable antennas. The [Section 2.1.2.1](#) and [Section 2.1.2.2](#) sections show the ferrite placeholders.

3. PCB Layout

- a. The layout of the design is critical to mitigating EMI sources. A poor layout can cause high emissions and bypass other EMI reduction techniques.
- b. Long traces and large copper planes radiate high-frequency signals. Minimize the trace length and plane size to prevent lower frequency components from radiating.
- c. Have a low impedance return path for high-frequency signals to minimize loop area and inductance and prevent near-field emissions from becoming far-field.
 - i. A ground return path must be near or under the Digital SPI signals.
- d. High frequency sources can couple to nearby traces and components if the traces and components are too close.
 - i. In this design we routed the line connections for the flyback converter to one side of the board leaving space between the traces and nearest AMC device.

4. Series Resistance on Digital Lines

- a. Adding series resistance on the Digital SPI line by the AMC device can help prevent the DC-DC noise from radiating through the SPI traces. The added resistance can also attenuate the high-frequency components of the SPI signals.

5 Hardware Design Files

5.1 Schematics

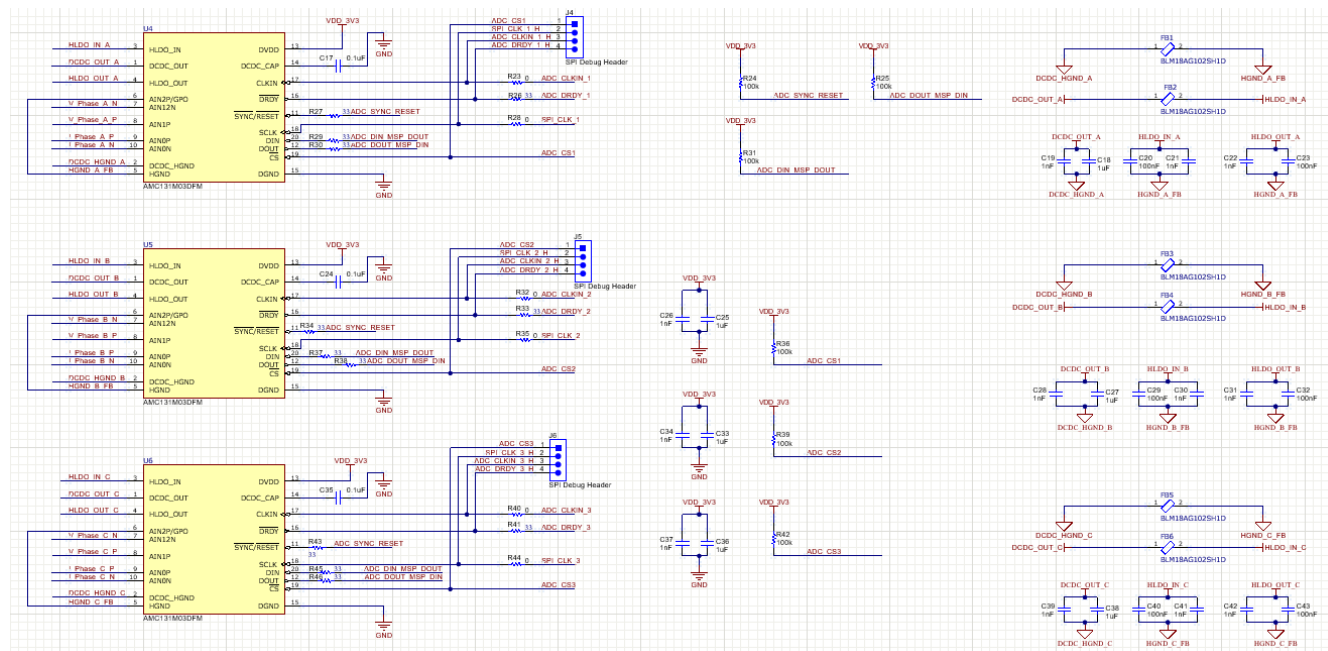


Figure 5-1. AMC-ADC-3PH-EVM Schematic (ADCs)

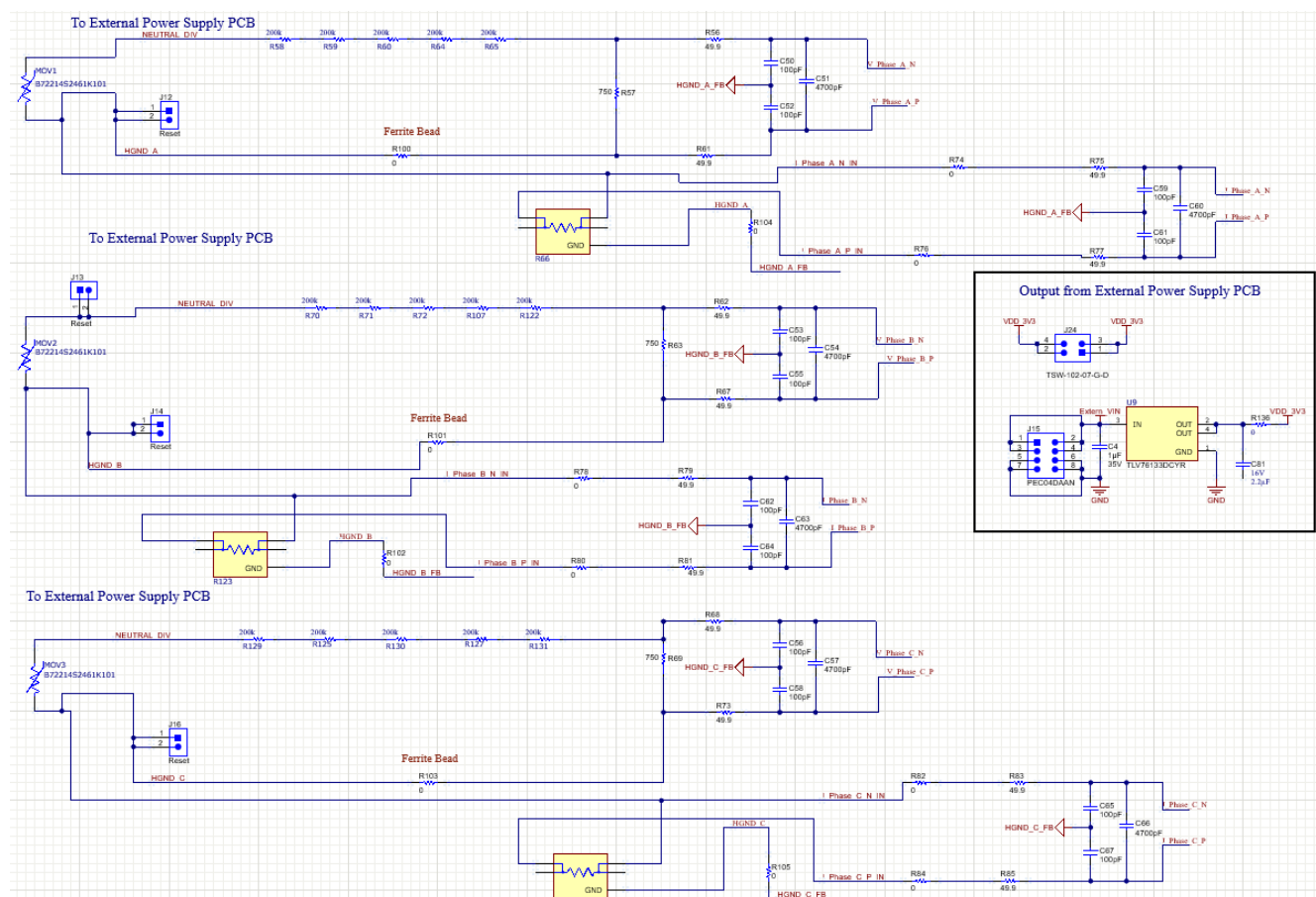


Figure 5-2. AMC-ADC-3PH-EVM Schematic (ADC Phase Input Front End)

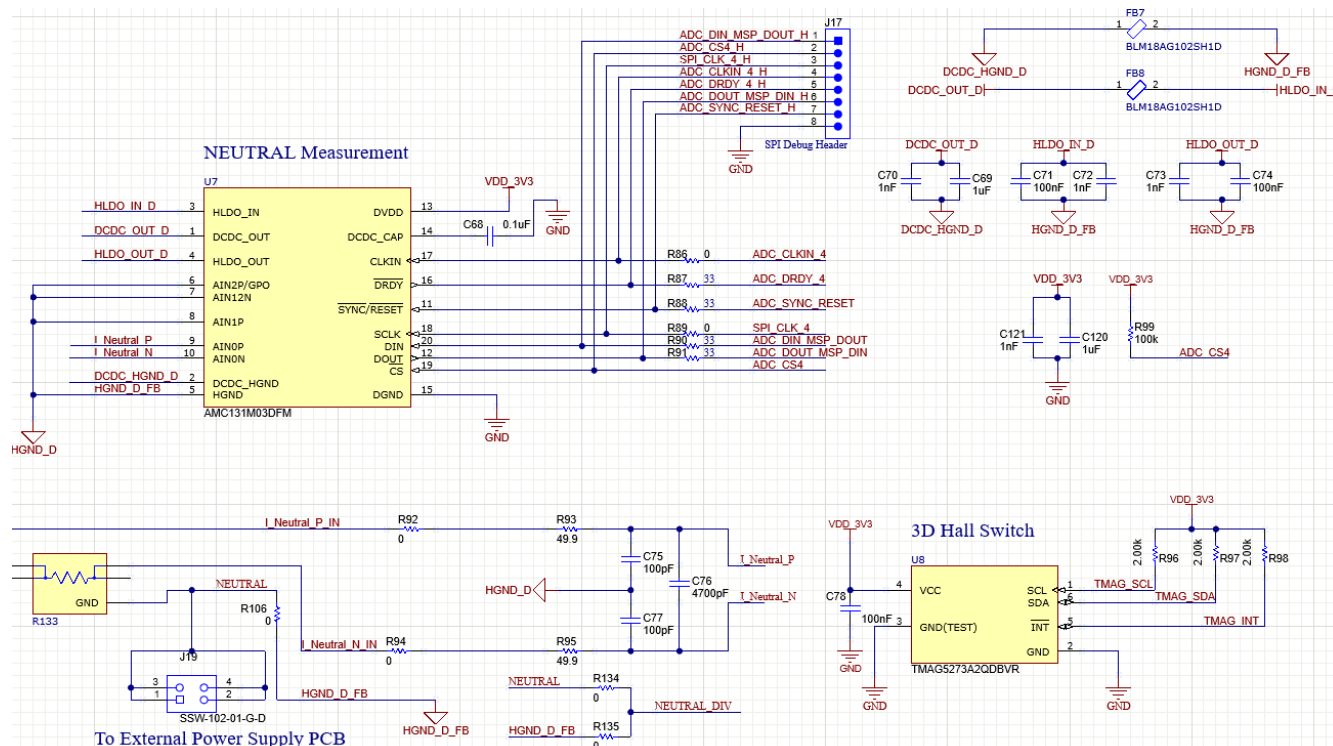


Figure 5-3. AMC-ADC-3PH-EVM Schematic (ADC Neutral Input Front End)

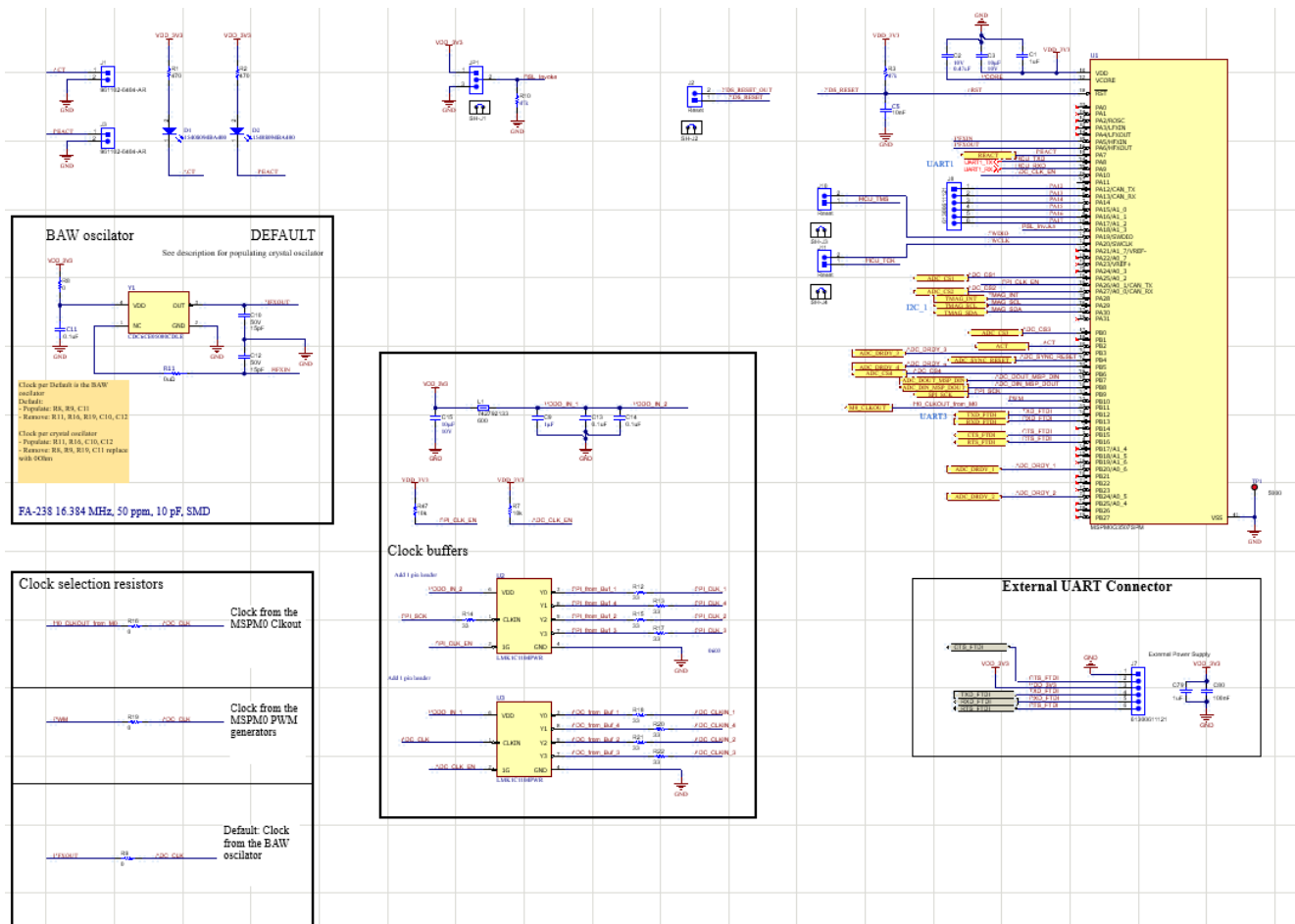


Figure 5-4. AMC-ADC-3PH-EVM Schematic (MCU, Clocking, and UART)

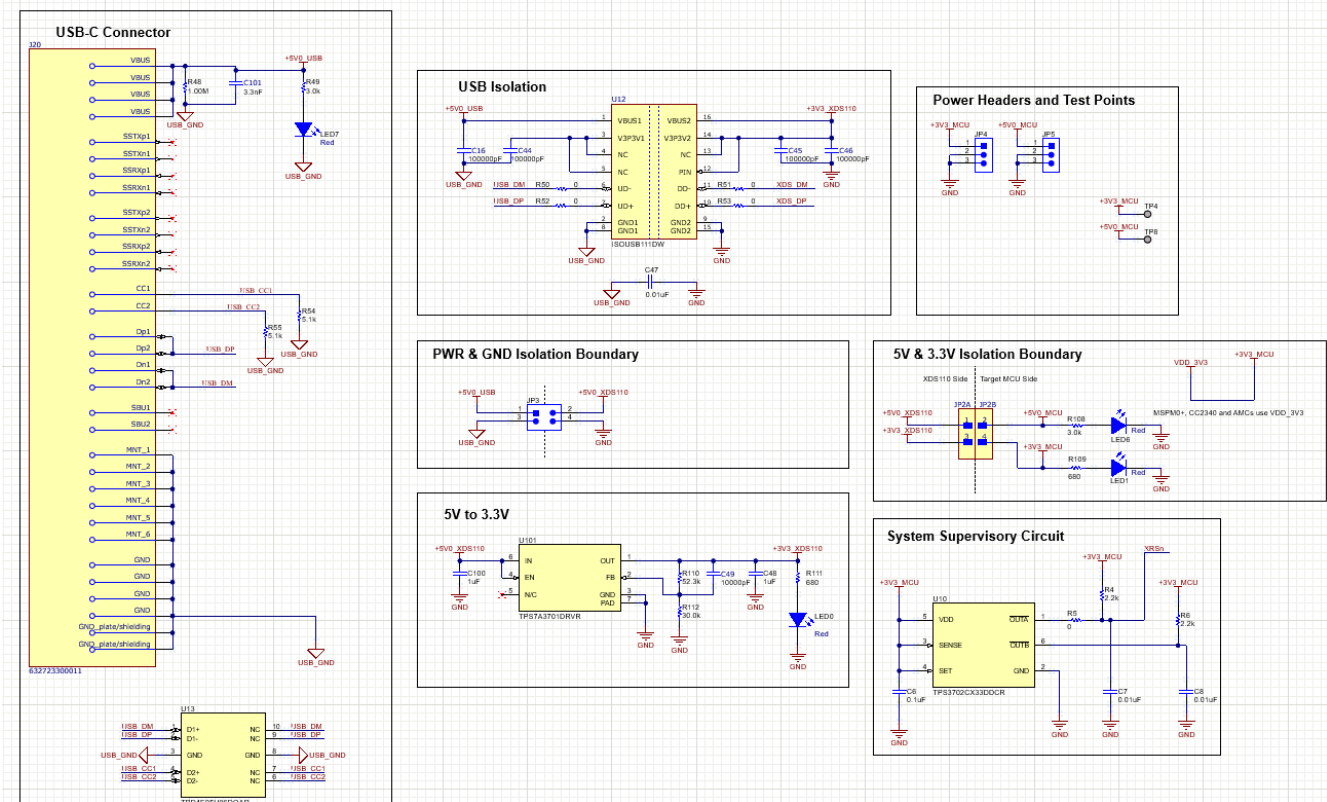


Figure 5-5. AMC-ADC-3PH-EVM Schematic (ISO-USB and Power)

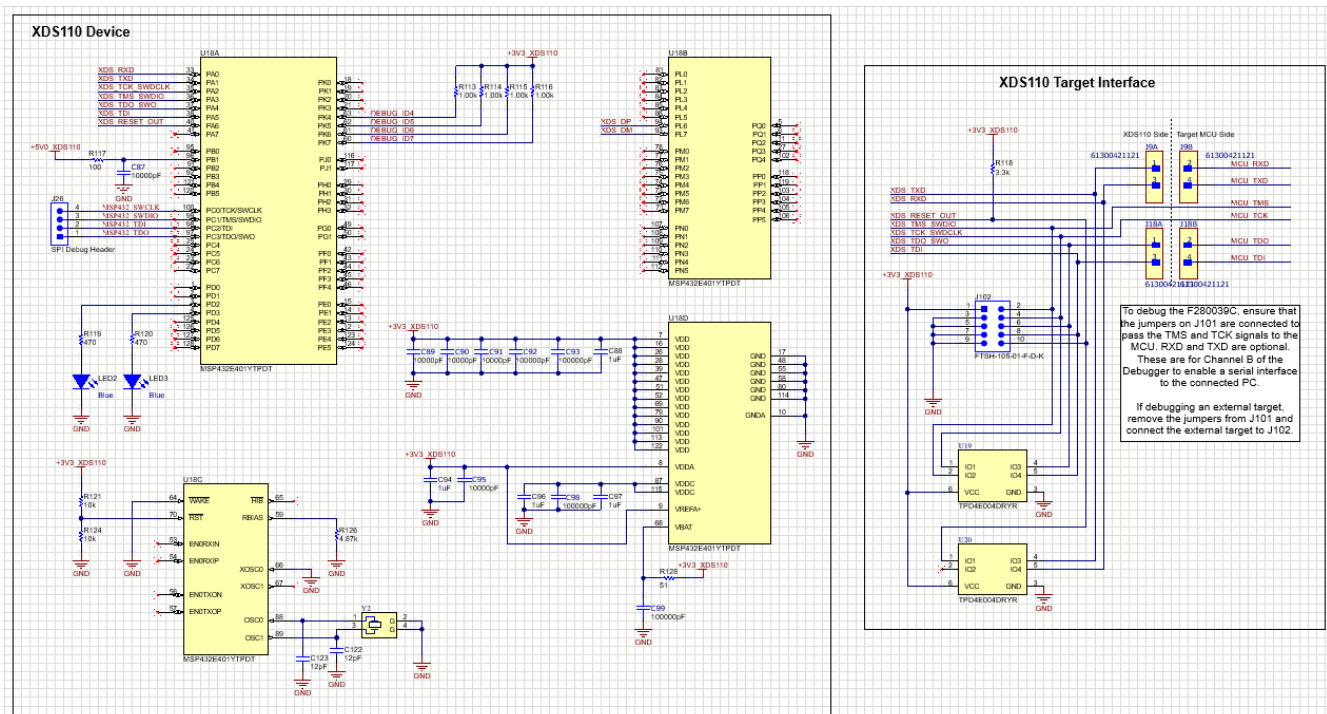


Figure 5-6. AMC-ADC-3PH-EVM Schematic (XDS110)

5.2 PCB Layouts

Figure 5-7 and Figure 5-8 show the top and bottom printed circuit board (PCB) drawings of the AMC-ADC-3PH-EVM respectively.

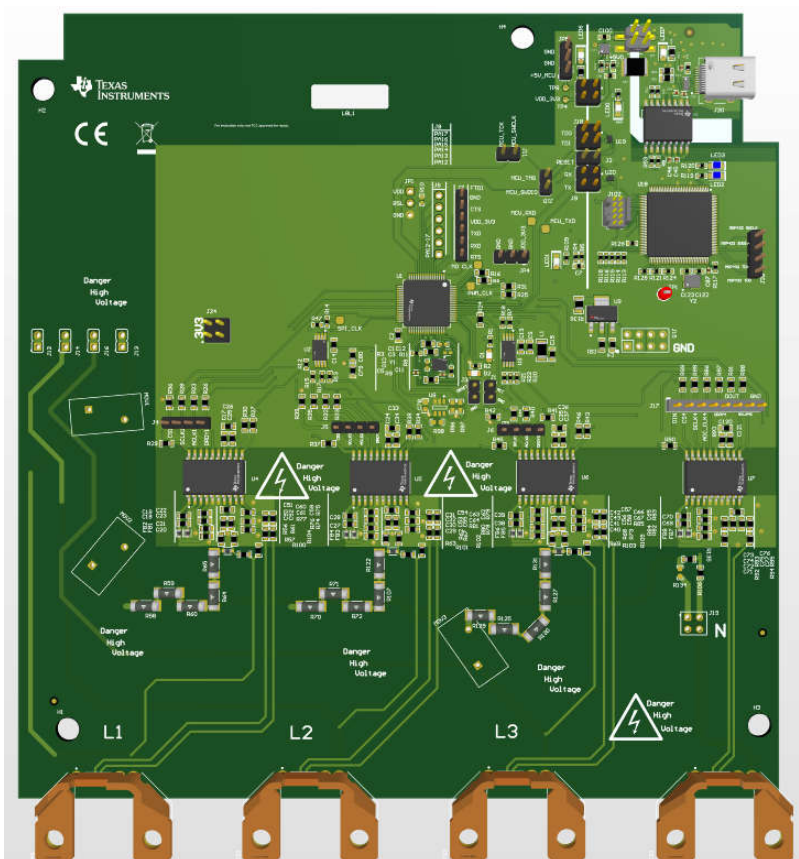


Figure 5-7. AMC-ADC-3PH-EVM Top PCB Drawing

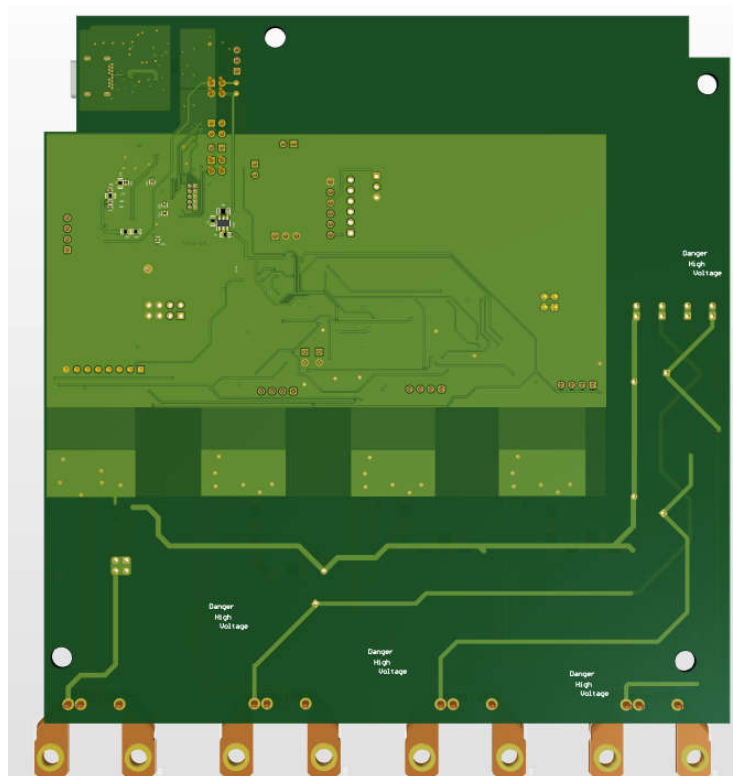


Figure 5-8. AMC-ADC-3PH-EVM Bottom PCB Drawing

5.3 Bill of Materials (BOM)

Table 5-1. Bill of Materials

DESIGNATOR	DESCRIPTION	MANUFACTURER	PART NUMBER
!PCB1	Printed Circuit Board	Any	DC454
C1, C18, C25, C27, C33, C36, C38, C69, C79, C120	CAP, CERM, 1uF, 25V, +/- 10%, X7R, 0603	Kemet	C0603C105K3RACTU
C2	CAP, CERM, 0.47uF, 10V, +/- 10%, X5R, 0603	MuRata	GRM188R61A474KA61D
C3, C15	CAP, CERM, 10 μ F, 10V, +/- 10%, X5R, 0603	MuRata	GRM188R61A106KAALD
C4	CAP, CERM, 1 μ F, 35V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	TDK	CGA3E1X7R1V105K080AE
C5, C49, C87, C89, C90, C91, C95	10000pF $\pm$ 10% 25V Ceramic Capacitor X7R 0402 (1005 Metric)	Wurth Electronics	885012205050
C6	CAP, CERM, 0.1uF, 10V, +/- 10%, X7R, 0402	MuRata	GRM155R71A104KA01D
C7, C8	CAP, CERM, 0.01uF, 25V, +/- 10%, X7R, 0402	MuRata	GRM155R71E103KA01D
C9	CAP, CERM, 1 μ F, 16V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	TDK	CGA3E1X7R1C105K080AC
C11, C16, C44, C45, C46, C92, C93, C98, C99	0.1 μ F $\pm$ 10% 10V Ceramic Capacitor X7R 0402 (1005 Metric)	Wurth Electronics	885012205018
C13, C14, C17, C20, C23, C24, C29, C32, C35, C40, C43, C68, C71, C74	CAP, CERM, 0.1uF, 50V, +/- 10%, X7R, 0603	TDK	C1608X7R1H104K080AA
C19, C21, C22, C26, C28, C30, C31, C34, C37, C39, C41, C42, C70, C72, C73, C121	CAP, CERM, 1000pF, 50V, +/- 10%, X7R, 0603	Kemet	C0603C102K5RACTU
C47	CAP, CERM, 0.01uF, 1500V, +/- 10%, X7R, 1812	AVX	1812SC103KAT1A
C48, C88, C94, C96, C97, C100	CAP, CERM, 1uF, 10V, +/- 20%, X5R, 0402	Wurth Elektronik	885012105012
C50, C52, C53, C55, C56, C58, C59, C61, C62, C64, C65, C67, C75, C77	CAP, CERM, 100pF, 50V, +/- 5%, C0G/NP0, 0603	Wurth Elektronik	885012006057
C51, C54, C57, C60, C63, C66, C76	CAP, CERM, 4700pF, 100V, +/- 5%, C0G/NP0, 0603	Kemet	C0603C472J1GAC7867
C80	CAP, CERM, 0.1uF, 25V, +/- 10%, X7R, 0603	Kemet	C0603X104K3RACTU
C81	CAP, CERM, 2.2uF, 16V, +/- 10%, X7R, 0603	MuRata	GRM188Z71C225KE43
C101	Cap Cer 3300pF 50V X7R 0402	Wurth Electronics	885012205064
C122, C123	CAP, CERM, 12pF, 50V, +/- 5%, C0G/NP0, 0402	MuRata	GRM1555C1H120JA01D
D1, D2	15408094BA400 Ir Emitter, 940Nm, 0805 Rohs Compliant: Yes		
FB1, FB2, FB3, FB4, FB5, FB6, FB7, FB8	Chip Ferrite Bead, 0603, 1000 Ω @ 100MHz, 0.5 Ω , 25%, 450mA	Murata	BLM18AG102SH1D
H1, H2, H3, H4	5mm PCB Hole	Any	5MM HOLE
H5, H6, H7, H8	MACHINE SCREW PAN PHILLIPS M3	APM HEXSEAL	RM3X6MM 2701
J1, J3	Header, 2.54mm, 2x1, TH	3M	961102-6404-AR
J2, J10, J11	Header, 2.54mm, 2x1, TH	3M	961102-6404-AR
J4, J5, J6, J26	Header, 2.54mm, 4x1, Gold, TH	Wurth Elektronik	61300411121
J7	Header, 2.54mm, 6x1, Gold, TH	Wurth Elektronik	61300611121
J9, J18, JP2	THT Vertical Pin Header WR-PHD, Pitch 2.54mm, Dual Row, 4 pins	Wurth Electronics	61300421121
J17	Header, 100mil, 8x1, TH	Mill-Max	800-10-008-10-001000

Table 5-1. Bill of Materials (continued)

DESIGNATOR	DESCRIPTION	MANUFACTURER	PART NUMBER
J20	USB-C (USB TYPE-C) USB 3.2 Gen 2 (USB 3.1 Gen 2, Superspeed + (USB 3.1)) Receptacle Connector 24 Position Surface Mount, Right Angle; Through Hole	Würth	632723300011
J24	Header, 100mil, 2x2, Gold, TH	Samtec	TSW-102-07G-D
J102	Header, 1.27mm, 5x2, Gold, TH	Samtec	FTSH-105-01F-D-K
JP3	Header, 2.54mm, 2x2, Gold, SMT	Samtec	TSM-102-01L-DV
JP4, JP5	Header, 2.54mm, 3x1, Gold, TH	Würth Elektronik	61300311121
L1	Ferrite Bead, 600ohm @ 100MHz, 0.5A, 1206	Würth Elektronik	742792133
LBL1	Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	Brady	THT-14-423-10
LED0, LED1, LED6, LED7	LED, Red, SMD	Würth Elektronik	150080SS75000
LED2, LED3	LED, Blue, SMD	Lite-On	LTST-C170TBKT
R1, R2, R119, R120	RES, 470, 1%, 0.063W, 0402	Yageo America	RC0402FR-07470RL
R3	RES, 47k, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040247K0JNED
R4	RES, 2.2k, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04022K20JNED
R5	RES, 0, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04020000Z0ED
R6	RES, 2.2k, 5%, 0.1W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW06032K20JNEA
R7, R47, R121	RES, 10k, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040210K0JNED
R8, R50, R51, R52, R53	RES, 0, 5%, 0.063W, 0402	Yageo America	RC0402JR-070RL
R9, R23, R28, R32, R35, R40, R44, R86, R89	RES, 0, 5%, 0.1W, AEC-Q200 Grade 0, 0603	Panasonic	ERJ-3GEY0R00V
R12, R13, R14, R15, R17, R18, R20, R21, R22	RES, 33, 5%, 0.063W, 0402	Vishay-Dale	CRCW040233R0JNED
R24, R25, R31, R36, R39, R42, R99	RES, 100k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW0603100KFKEA
R26, R27, R29, R30, R33, R34, R37, R38, R41, R43, R45, R46, R87, R88, R90, R91	RES, 33, 5%, 0.1W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW060333R0JNEA
R48	RES, 1.00M, 1%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04021M00FKED
R49, R108	RES, 3.0k, 5%, 0.1W, 0603	Yageo	RC0603JR-073KL
R54, R55	RES, 5.1k, 5%, 0.1W, 0603	Yageo	RC0603JR-075K1L
R56, R61, R62, R67, R68, R73, R75, R77, R79, R81, R83, R85, R93, R95	RES, 49.9, 1%, 0.1W, 0603, RES, 49.9, 1%, 0.1W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW060349R9FKEA
R57, R63, R69	750 Ohms $\pm 0.5\%$ 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Thin Film	Yageo	RT0603DRD07750RL
R58, R59, R60, R64, R65, R70, R71, R72, R107, R122, R125, R127, R129, R130, R131	Res Thin Film 2309 200K Ohm 0.1% 2/5W $\pm 25\text{ppm}/^\circ\text{C}$ Conformal Melf SMD Blister T/R	Vishay	MMB02070D2003BB200
R66, R123, R132, R133	0.3 mOhms $\pm 5\%$ 3W Current Sense Resistor	Isabellenhuetten	BKW-M-R0003-5.0
R74, R76, R78, R80, R82, R84, R92, R94, R100, R101, R102, R103, R104, R105, R106, R135	RES, 0, 5%, 0.1W, 0603	Yageo	RC0603JR-070RL
R109, R111	RES, 680, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW0402680RJNED

Table 5-1. Bill of Materials (continued)

DESIGNATOR	DESCRIPTION	MANUFACTURER	PART NUMBER
R110	RES, 52.3k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040252K3FKED
R112	RES, 30.0k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040230K0FKED
R113, R114, R115, R116	RES, 1.00k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04021K00FKED
R117	RES, 100, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW0402100RJNED
R118	RES, 3.3k, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04023K30JNED
R126	RES, 4.87k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04024K87FKED
R128	RES, 51, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040251R0JNED
R136	RES, 0, 5%, 0.125W, AEC-Q200 Grade 0, 0805	Vishay-Dale	CRCW08050000Z0EA
SH-J1, SH-J2, SH-J3, SH-J4	Shunt, 100mil, Gold plated, Black	TE Connectivity	881545-2
TP1	Test Point, Miniature, Red, TH	Keystone	5000
U1	Mixed-Signal Microcontrollers With CAN-FD Interface LQFP64	Texas Instruments	MSPM0G3507SPM
U2, U3	1.8V, 2.5V, and 3.3V LVCMOS Clock Buffer Family	Texas Instruments	LMK1C1104PWR
U4, U5, U6, U7	3-Channel, Simultaneously-Sampling, 24-Bit, Reinforced Isolated DeltaSigma ADC With Integrated DC/DC Converter	Texas Instruments	AMC131M03DFM
U9	1A 16V high-PSRR linear voltage regulator 4-SOT-223 -40 to 125	Texas Instruments	TLV76133DCYR
U10	High-Accuracy, Fixed-Threshold OV/UV Monitor, DDC0006A (SOT-23T-6)	Texas Instruments	TPS3702CX33DDCR
U12	Full/Low Speed Isolated USB Repeater, SOIC16-Wide	Texas Instruments	ISOUSB111DW
U13	4-Channel Ultra-Low-Capacitance IEC ESD Protection Diode, DQA0010A (USON-10)	Texas Instruments	TPD4E05U06DQAR
U18	MSP432E401YTPDT, PDT0128A (TQFP-128)	Texas Instruments	MSP432E401YTPDT
U19, U20	4-Channel ESD Protection Array for High-Speed Data Interfaces, DRY0006A (USON-6)	Texas Instruments	TPD4E004DRYR
U101	1% High-Accuracy, 1A, Low-Dropout Regulator with Reverse Current Protection, DRV0006A (WSON-6)	Texas Instruments	TPS7A3701DRVR
Y1	Crystal replacement: Ultra-low Power LVCMOS Oscillator 4-pin, VSON 3.2x 2.5x 0.9mm	Texas Instruments	CDC6CE05000CDLE
Y2	Crystal, 16MHz, 8pF, SMD	NDK	NX3225GA-16.000M-STD-CRG-1

6 Additional Information

6.1 Trademarks

Code Composer Studio™ is a trademark of Texas Instruments.

USB Type-C™ is a trademark of USB Implementers Forum.

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Microsoft® and Windows® are registered trademarks of Microsoft Corporation.

Bluetooth® is a registered trademark of Bluetooth SIG, INC.

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7 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.
MIDDLEWARE for Energy Library	SDK metrology example as Middleware software package implements various metrology parameters for energy measurement typical of electricity meters using high-performance, multichannel analog-to-digital converters (ADCs).

Software

AMC-ADC-3PH-EVM Firmware	Source code of Energy Library for AMC-ADC-3PH-EVM in MSPM0 SDK with default install path: C:\ti\mspm0_sdk_2_03_00_07\examples\nortos\LP_MSPM0G3507\energy_metrology\ TIDA_010244\TIDA_010244_SW
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8 Related Documentation

- Texas Instruments, [AMC131M03 3-Channel, 64-kSPS Simultaneous-Sampling 24-Bit Isolated Delta-Sigma ADC With Integrated DC/DC Converter Datasheet](#)
- Texas Instruments, [MSPM0G350x Mixed-Signal Microcontrollers With CAN-FD Interface Datasheet](#)
- Texas Instruments, [CC2340R SimpleLink™ Family of 2.4GHz Wireless MCUs Datasheet](#)
- Texas Instruments, [ISOUSB111 Full/Low Speed Isolated USB Repeater Datasheet](#)
- Texas Instruments, [TMAG5273 Low-Power Linear 3D Hall-Effect Sensor With I2C Interface Datasheet](#)
- Texas Instruments, [TPS7A37 1% High-Accuracy, 1A, Low-Dropout Regulator With Reverse Current Protection Datasheet](#)
- [Implementing magnetic tamper detection in electricity meters](#)
- [PTS 3.3 genX – EMH Portable 3-phase Testsystem](#)

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.
 - 1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software
 - 1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.
2. *Limited Warranty and Related Remedies/Disclaimers:*
 - 2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.
 - 2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.
 - 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 DEGRADATION 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 instructions, 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/sds/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.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社
東京都新宿区西新宿 6 丁目 2 4 番 1 号
西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/sds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html>

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.

4.3 Safety-Related Warnings and Restrictions:

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