Design Guide: TIDA-010244

Three-Phase Shunt-Based Energy Metrology Reference Design

TEXAS INSTRUMENTS

Description

This reference design 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.

Resources

TIDA-010244	Design Folder
MSPM0-SDK	Tool Folder
MSPM0G3507, AMC131M03	Product Folder
LMK1C1104, ISOUSB111	Product Folder
TMAG5273, MSP423E401Y	Product Folder
RES60A, CDC6C, CC2340R5	Product Folder

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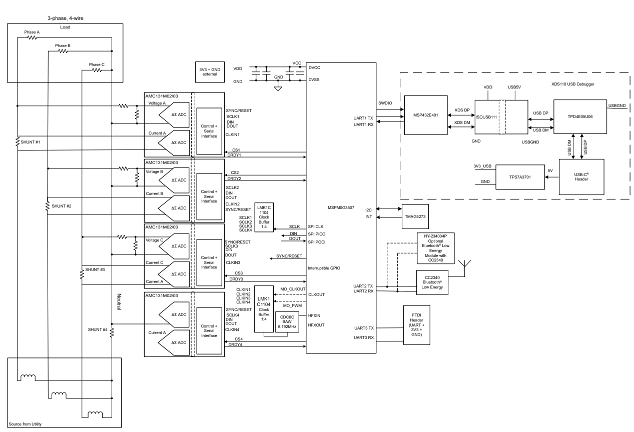
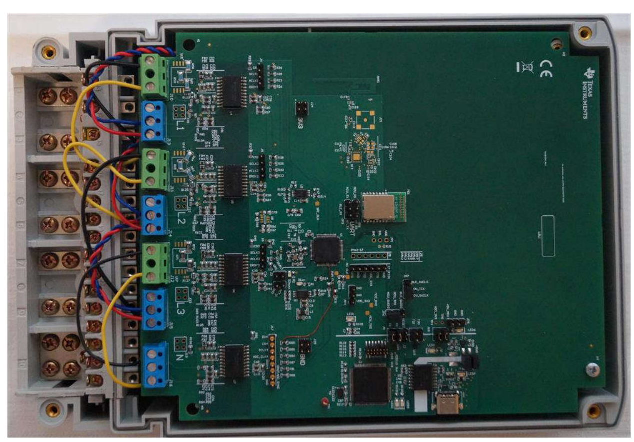
Features

- 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 System Description

TIDA-010244 is a Class 0.2S, high-accuracy, 3-phase shunt electricity meter reference design, using four 4-channel standalone isolated AMC131M03 ADCs and a cost-effective MSPM0G3507 microcontroller (MCU). The reference design can also be used for energy metering in popular products such as EV chargers and AC wallboxes. Each of the three isolated ADCs (one per phase) senses the Mains voltage and current on the respective Phase A, B, or C, while the non-isolated ADC is used for current monitoring of the Neutral line over a shunt.

The TIDA-010244 firmware specifically supports calculation of various metrology parameters for 3-phase energy measurement and a Neutral line. These parameters can be viewed from the calibration GUI or through the ACT and REACT pulsed outputs, connected to a reference test system:

- Total and per-phase active (kWh), reactive (kvarh), and apparent energy (kVAh) with pulse-generation outputs
- Total and per-phase active (kW), reactive (kvar), and apparent power (kVA)
- Per-phase voltage and current root mean square (RMS)
- Power factor
- Line frequency

1.1 Key System Specifications

FEATURES	DESCRIPTION
Number of phases	3 (each phase current is measured through a shunt), voltage through a resistor divider
Accuracy class	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–270V
AMC131M03 CLKIN frequency	8,192,000Hz
AMC131M03 Delta-sigma modulation clock frequency	4,096,000Hz (= CLKIN / 2)
SPI Clock	19,968,000Hz
Oversampling ratio (OSR)	1024
Digital filter output sample rate	4,000 samples per second
Phase compensation implementation	Software
Phase compensation resolution	0.0176° at 50Hz or 0.0210° at 60Hz
Selected 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 GUI through 5kV$_{RMS}$ isolated USB Type-C® or Bluetooth® low energy connection
Utilized LEDs	2 LEDs: ACTive energy and REACTive energy
Board power supply	5V with an LDO to 3.3V or directly 3V3 to DVCC rail and GND

1.2 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 Electricity Meter

Utility providers and customers are driving the need for more features from electricity meters. As the accuracy requirements and amount of processing expected from electricity meters rapidly increase, it becomes more and more difficult to solve these issues with a single metrology system-on-chip (SoC).

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, it is necessary for the current sensors to 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.

1.4 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.

2 System Overview

2.1 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 150µΩ to 200µΩ 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:

1. 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.
    a. TI BAW oscillator CDC6C provides a high-precision clock signal with 8.192MHz to both LMK1C1104 and MSPM0G3507 devices (default option).
    b. 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.
    c. 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).
2. The 4 outputs of LMK1C1104 are fed to the four CLKIN1 through CLKIN4 input pins (one per ADC device).
3. Each of the four AMC131M03 or AMC131M02 devices divides the CLKIN input by 2 and uses that value as the delta-sigma modulation clock.
4. 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.
5. 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.
6. Four separate $\overline{\text{CS}}$ lines are used, these are automatically generated and controlled by the SPI peripheral of the MSPM0+ MCU.
7. When new ADC samples are ready, each AMC131M03 asserts the $\overline{\text{DRDY}}$ output pin ($\overline{\text{DRDY1}}$ through $\overline{\text{DRDY4}}$), which alerts the MCU that new data samples are available.
8. After detecting the $\overline{\text{DRDY}}$ 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 $\overline{\text{DRDY}}$ signals simultaneously but because the ADCs share the same SPI bus, the ADCs are being read out sequentially by the MCU.
9. 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.
10. 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 POR as well as Brownout reset (BOR) supply monitor with four configurable threshold voltages.

This reference design can be powered either by applying 5V through the USB Type-C connector or the marked headers or 3.3V at the designated header pins. See Section 3.3.2 for more details on the proper jumper connections for powering the board.

The USB Type-C interface can be used to program and debug the MSPM0G3507. This interface is isolated and can be used to provide 5V from the USB power to the system. If the 5V option is chosen, the isolation of the USB Type-C interface is not in effect.

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.

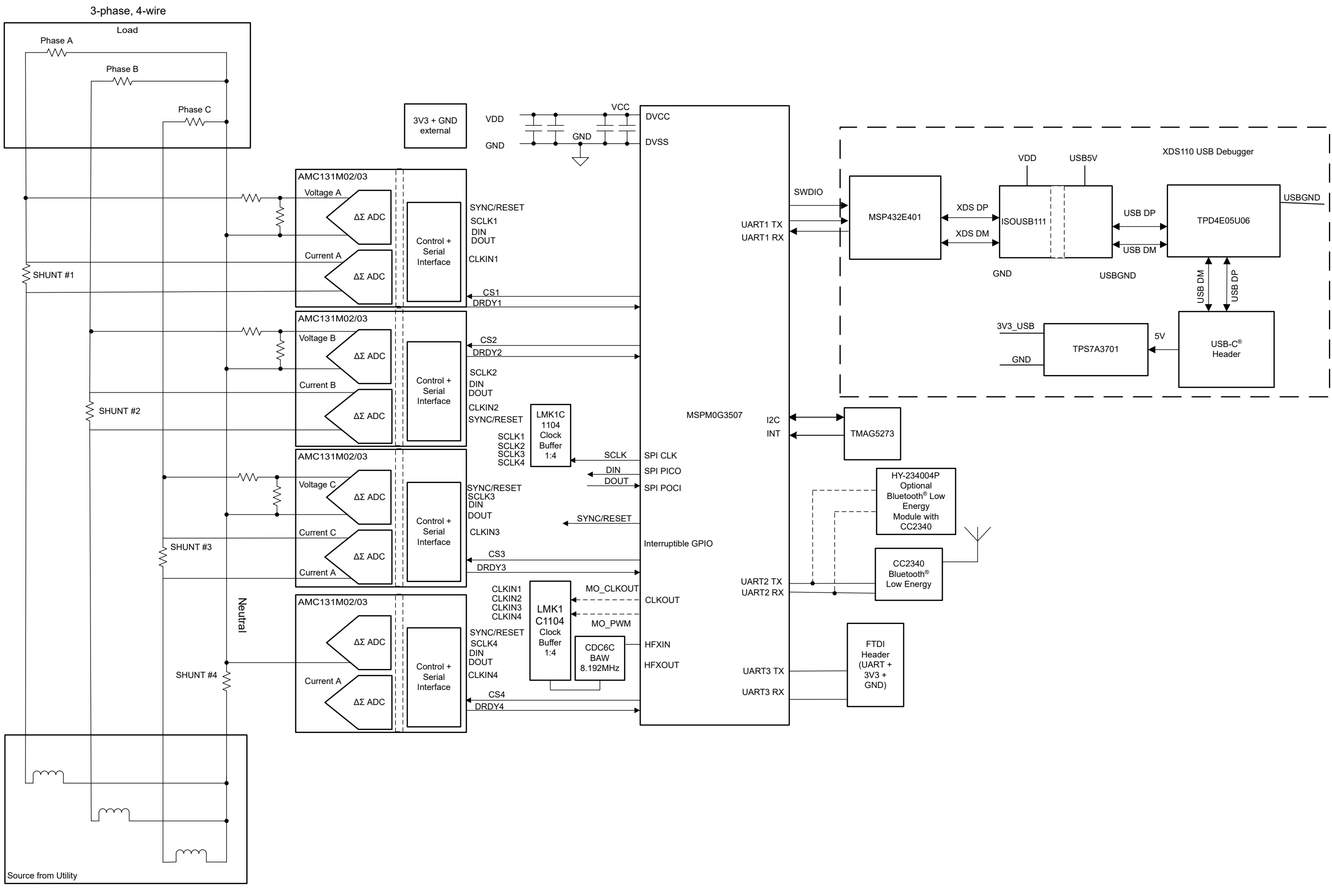


Figure 2-1. MSPM0G3507 and AMC131M03-Based Three-Phase Energy Measurement Block Diagram

2.2 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.

2.2.1 Voltage Measurement Analog Front End

The nominal voltage from the Mains in many regions of the world varies from 100V–240V 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 J11 for Phase C, similar circuitry is used for each of the Phases A and B.

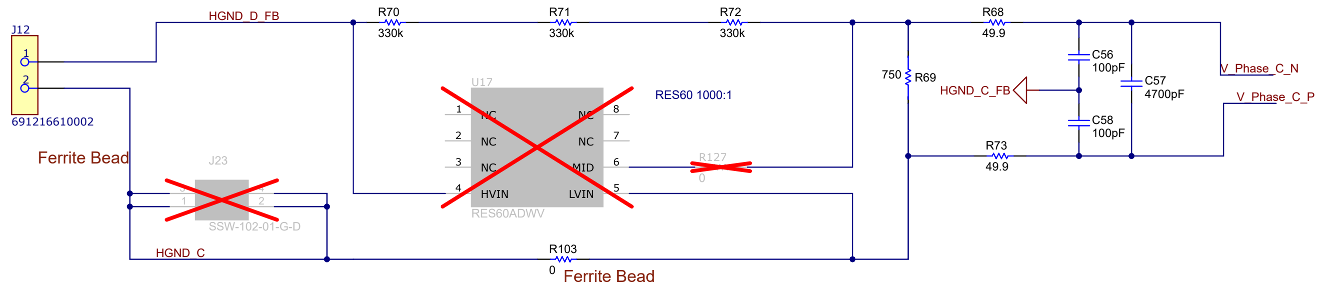


Figure 2-2. Analog Front End for Voltage Inputs

The analog front end for voltage inputs has a voltage divider network (R70, R71, R72, and R69), and an RC low-pass filter (R68, R73, C56, C57) and C58, as shown in Figure 2-2.

Optionally, a high-precision resistor divider RES60A (U17) is added. This resistor divider lowers the voltage with the ratio 1000:1 and is an alternative to the discrete voltage divider with R70, R71, R72, and R69. To use the RES60A instead of the series resistor chain divider network, change the following components:

- Remove R69, R70, R71, and R72
- Place R127 (0Ω)
- Place RES60A

Follow similar steps for Phase A and B.

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

$$V_{ADC\_Swing,\,Voltage} = \pm V_{RMS} \times \sqrt{2}\left(\frac{R_{69}}{R_{70} + R_{71} + R_{72} + R_{69}}\right) \tag{1}$$

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 ±128.47mV (90.8mV$_{RMS}$). 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 ±246.23mV (174.11mV$_{RMS}$). The ±128.47mV and the ±246.23mV voltage ranges are both well within the –1.3V to + 2.7V 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* data sheet), that can be sensed by the ADC.

2.2.2 Analog Front End for Current Measurement

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

The positive and negative leads from the SHUNT sensor are connected to pins 3 and 2 of header J15 (for Phase C). Identical voltage divider circuitry is used for Phases A and B, with terminal blocks J13 and J14 being the connectors for the SHUNT terminals.

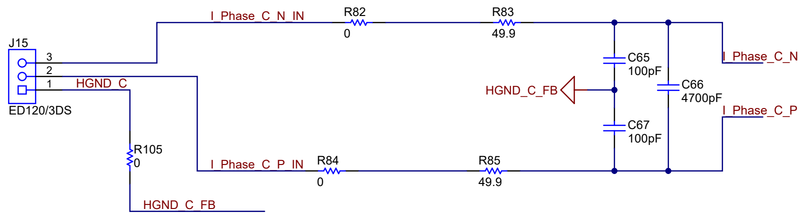


Figure 2-3. Analog Front End for Current Inputs

The analog front end for current consists of footprints for electromagnetic interference filter beads (R82, R84, and R105), and an RC low-pass filter (R83, R85, C65, C66) and C67 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, CT turns ratio, and burden resistor value.

$$V_{ADC_{Swing},Current,Shunt} = \pm\sqrt{2}\left(R_{shunt}\right)I_{RMS,max} \tag{2}$$

Assuming a shunt value of 150µΩ, the input signal to the current ADC has a voltage swing of ±21,21mV when the maximum current rating of the meter, for example 100A, is applied. This relatively low voltage, when using GAIN = 32 is well within the required *Full Scale Range* of ±37.5mV, 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* data sheet.

2.2.3 XDS110 Emulator

This reference design comes with an onboard XDS110 emulator. This emulator is implemented in the MSP432E401Y device which includes a UART-to-USB translator and is also responsible for programming both the MSPM0 and the CC2340 Bluetooth low energy devices. 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 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 or the Bluetooth low energy module or chip please take a look into the dedicated chapters Jumper Settings and Bluetooth Data Transmission.

2.2.4 Bluetooth® Data Transmission

This design enables a Bluetooth Low Energy connection, which can be established through the HY-234004P Bluetooth Low Energy module or the CC2340 device. Therefore, a bidirectional communication between two Bluetooth devices and a connection to a computer through a UART connection is possible.

2.2.5 Bluetooth® Connection Between Two Modules

The following steps are recommended to test the communication between two Bluetooth devices:

1. Set jumpers JP6 and JP7 to enable the Bluetooth connection (position 1-2 for both).
2. Connect a PC with the SmartRF Studio 8 application through a cable with the USB Type-C connector.
3. Start the SmartRF Studio 8 application.
4. Click on CC2340R5, which appears in the XDS110 connection window.
5. In the RX and TX tabs click *Start Test* at the receiver first and then start the transmitter by also clicking on *Start Test*.

2.2.6 Bluetooth® to UART Connection

To run a test for sending data from a command line tool to a TI application use the following steps:

1. Set the jumper JP6 and JP7 for the Bluetooth connection.
2. Connect HY_RX at JP8 and HY_TX at JP9 with jumper wires to RX and TX at J9 respectively, using the pins on XDS110 side of J9.
3. Download the *Bluetooth low energy to UART example* available on GitHub.
4. Download the *SimpleLink Low Power F3 SDK (7.40.00.64)*.
5. Copy the `data_stream_UART_over_BLE` example from GitHub to `<root source folder>\simplelink_lowpower_f3_sdk_7_40_00_64\examples\rtos\LP_EM_CC2340R5\ble5stack`.
6. Build and compile the project in Code Composer Studio™ (CCS).
7. Connect the USB Type-C cable and flash the code to the board.
8. Run the code and open a command line terminal through PuTTy or TerraTerm.
9. Download the SimpleLink Connect mobile application for iPhone® or Android® smartphone and connect to *DataStream UART*.
10. Write in the application or in the terminal and text and appears in the opposite device.

2.2.7 Magnetic Tamper Detection With TMAG5273 Linear 3D Hall-Effect Sensor

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, it is possible to select the magnetic tampering threshold of each axis to anything within the magnetic sensing range of the 3D linear Hall-effect sensor. 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, sometimes it is not possible for one magnetic sensor to sense tampering across the entire meter surface, 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 2-4 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.

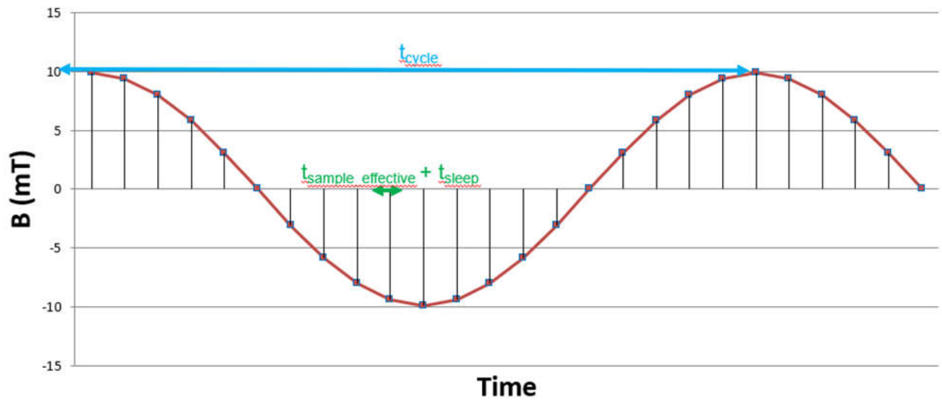


Figure 2-4. Detection AC Magnets

2.3 Highlighted Products

2.3.1 MSPM0G3507

The MSPM0G device family integrates an Arm 32-bit Cortex-M0+ CPU with memory protection unit, clock frequency up to 80MHz and two SPIs, one of those supporting up to 32Mbits/s. Other relevant peripherals for running energy calculations are the Real Time Clock (RTC) with calendar function, CRC-16 or CRC-32 hardware module, four UARTs, two I2Cs with 1Mbit/s and up to 60 GPIOs.

The MSPM0+ MCU in this design retrieves voltage and current samples from the four ADC devices and calculates the metrology parameters. In addition, the device also keeps track of time with the RTC module, and uses one of the UART interfaces to communicate to a PC GUI using the isolated USB interface of the board. The CRC16 hardware module of the MSPM0+ MCU is used to accelerate the CRC calculations needed to verify the integrity of the ADC sampling data packets sent by the ADCs.

The main features of MSPM0G3507 are the extended temperature range: –40°C up to 105°C; the wide supply voltage range: 1.62V to 3.6V; and the integrated 64KB of flash memory with built-in error correction code (ECC) and 32KB of ECC protected SRAM with hardware parity.

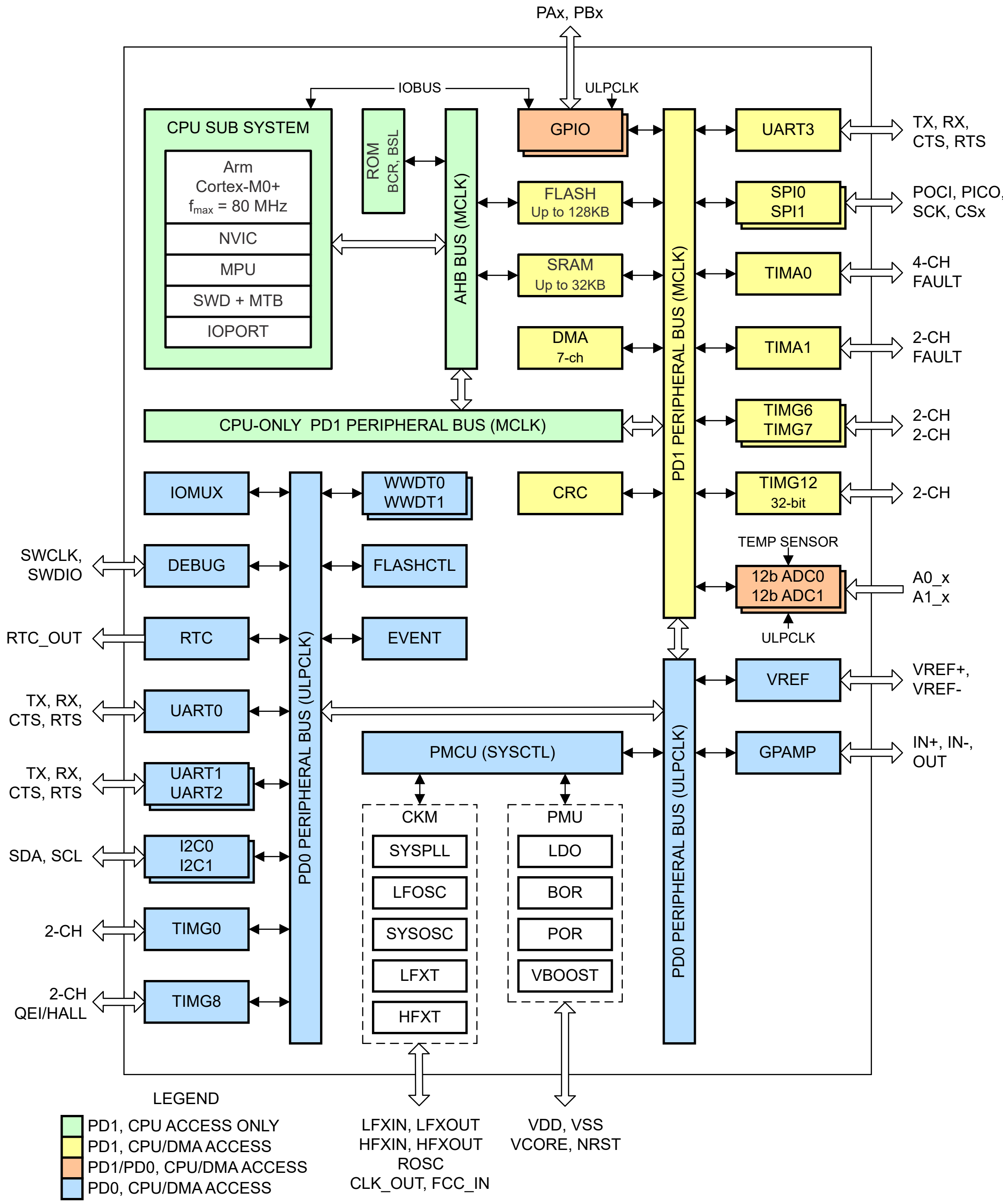


Figure 2-5. MSPM0G3507 Functional Block Diagram

2.3.2 AMC131M03

The AMC131M03 is a precision, three-channel, data- and power-isolated, simultaneous-sampling, 24-bit, delta-sigma (ΔΣ) analog-to-digital converter (ADC).

The AMC131M03 offers wide dynamic range, low power, and energy-measurement-specific features, making the device designed for energy metering and power metrology applications. The ADC inputs can be directly interfaced to a resistor-divider network or a shunt current sensor because of the device high-input impedance.

The AMC131M03 features a fully integrated isolated DC/DC converter that allows single-supply operation from the low side of the device. The reinforced capacitive isolation barrier is certified according to VDE V 0884-11 and UL1577. This isolation barrier separates parts of the system that operate on different common-mode voltage levels and protects lower-voltage parts from damage, making the AMC131M03 an excellent choice for polyphase energy metering applications using shunt current sensors.

The three isolated, simultaneous-sampling ΔΣ ADC channels feature differential inputs and a single-supply operation (3.3V or 5V) with an integrated DC/DC converter in the temperature range: –40°C to +125°C. The device was optimized for low EMI and meets CISPR-11 and CISPR-25 standards and has the safety-related certifications: – 7070V_{PEAK} reinforced isolation per DIN EN IEC 60747-17 (VDE 0884-17): 2021-10 as well as 5000V_{RMS} isolation for 1 minute per UL1577.

The programmable data rate is a maximum 64ksps and the programmable gain up to 128, a low-drift internal voltage reference and an internal temperature sensor are included. Data and registers are being accessed through a 4-wire SPI with cyclic redundancy check (CRC).

If the 3rd input channel is not required (for example, for a temperature measurement with the 1%, 100kΩ linear thermistor TMP63), the very similar AMC131M02 2-channel device can be a used as a cost-effective alternative.

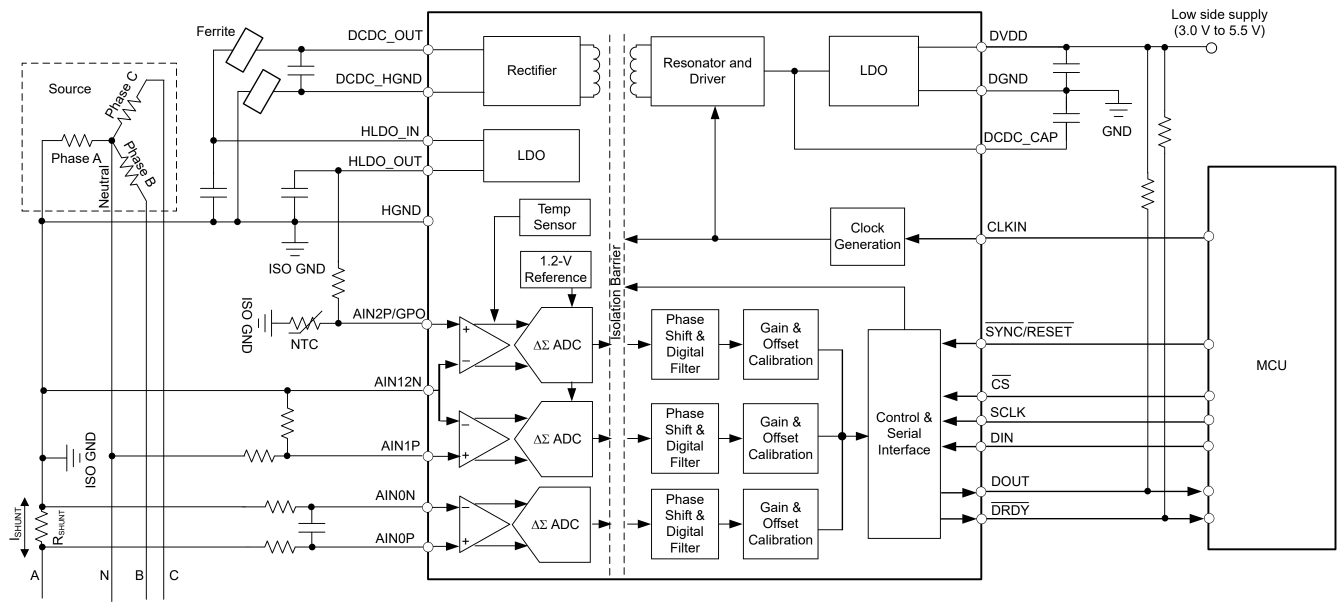


Figure 2-6. AMC131M03 Functional Block Diagram

2.3.3 CDC6C

Texas Instruments' Bulk-Acoustic Wave (BAW) is a micro-resonator technology that enables the integration of a high-precision BAW resonator directly into packages with low-jitter clock circuitry. BAW is fully designed and manufactured at TI factories like other silicon-based fabrication processes. The CDC6C device is a low-jitter, low-power, fixed-frequency oscillator which incorporates the BAW as the resonator source. The device is factory-programmed per specific frequency and function pin. With a frequency control logic and output frequency divider, the CDC6Cx is capable of producing any frequency within the specified range providing a single device family for all frequency needs. The high-performance clocking, mechanical stability, lower power consumption and small package options for this device are designed for reference clock and core clocks in Industrial, Telecom, Data and Enterprise Network, and Personal Electronics end equipment.

2.3.4 RES60A-Q1

The RES60A-Q1 is a matched resistive divider, implemented in thin-film SiCr with Texas Instruments' modern, high-performance, analog wafer process. A high-quality SiO2 insulative layer encapsulates the resistors and enables usage at extremely high voltages, up to 1400VDC for sustained operation or 4000VDC for HiPOT testing (60s). The device has a nominal input resistance of RHV = 12.5MΩ, and is available in several nominal ratios to meet a wide array of system needs. The RES60A-Q1 series features high ratio matching precision, with the measured ratio of each divider within ±0.1% (maximum) of the nominal. This precision is maintained over the specified temperature range and aging, with a cumulative drift of only ±0.2% (maximum). Therefore, the lifetime tolerance of an uncalibrated RES60A-Q1 remains within a ±0.3% (maximum) envelope. The RES60A-Q1 is automotive qualified under AEC-Q200 temperature grade 1, with a specified temperature range from –40°C to +125°C. The device is offered in an 8-pin SOIC package, with nominal body size 7.5mm × 5.85mm, and features creepage and clearance distances of at least 8.5mm between the high-voltage and low-voltage pins.

2.3.5 TPS3702

The TPS3702 is an integrated overvoltage and undervoltage window voltage detector in a small SOT-6 package. This highly accurate voltage detector is an excellent choice for systems that operate on low-voltage supply rails and have narrow margin supply tolerances. Low threshold hysteresis options of 0.55% and 1.0% prevent false reset signals when the monitored voltage supply is in the normal range of operation. Internal glitch immunity and noise filters further eliminate false resets resulting from erroneous signals. The TPS3702 does not require any external resistors for setting overvoltage and undervoltage reset thresholds, which further increases overall accuracy and reduces design size and cost. The SET pin is used to select between the two available threshold voltages designed into each device. A separate SENSE input pin and VDD pin allow for the redundancy sought by safety-critical and high-reliability systems. This device also features independent reset outputs for the overvoltage (OV) and undervoltage (UV) pins; as a result of the open-drain configuration, UV and OV can be tied together. This device has a low typical quiescent current specification of 7μA and is qualified for use over the industrial temperature range of –40°C to 125°C.

2.3.6 TPD4E05U06

The TPDxE05U06 is a family of unidirectional Transient Voltage Suppressor (TVS) based Electrostatic Discharge (ESD) protection diodes with ultra-low capacitance. Each device can dissipate ESD strikes above the maximum level specified by the IEC 61000-4-2 international standard. The TPDxE05U06 ultra-low loading capacitance makes the device and excellent choice for protecting any high-speed signal pins. Typical applications for TPDxE05U06 include high-speed signal lines in HDMI 1.4b, HDMI 2.0, USB 3.0, MHL, LVDS, DisplayPort, PCI-Express®, eSata, and V-by-One®® HS.

2.3.7 ISOUSB111

ISOUSB111 is a galvanically-isolated USB 2.0 compliant repeater supporting low-speed (1.5Mbps) and full-speed (12Mbps) signaling rates. The device supports automatic connect and speed detection, reflection of pullups and pulldowns, and link power management allowing drop-in USB hub, host, peripheral and cable isolation. The device also supports automatic role reversal - if after disconnect, a new connection is detected on the upstream facing port, then the upstream and downstream port definitions are reversed. This feature enables the device to support USB On-The-Go (OTG) and USB Type-C Dual Role Port (DRP) implementations. This device uses a silicon dioxide (SiO2) insulation barrier able to withstand voltage of up to 5000V_{RMS} and a working voltage of 1500V_{RMS}. Used in conjunction with isolated power supplies, the device protects against high voltage, and prevents noise currents from the bus from entering the local ground. The ISOUSB111 device is available for reinforced isolation. The ISOUSB111 also supports a wide ambient temperature range of –40°C to +125°C. The device is available in the standard SOIC-16 (16-DW) package and a smaller SSOP-16 (16-DWX) package.

2.3.8 LMK1C1104

The LMK1C110x is a modular, high-performance, low skew, general-purpose clock buffer family from Texas Instruments. The entire family is designed with a modular approach in mind. Three different fan-out variations, 1:2, 1:3, 1:4, are available. All of the devices within this family are pin-compatible to each other and backwards compatible to the CDCLVC110x family for easy handling. All family members share the same high performing characteristics such as low additive jitter, low skew, and a wide operating temperature range. The LMK1C110x supports a synchronous output enable control (1G) which switches the outputs into a low state when 1G is low. These devices have a fail-safe input that prevents oscillation at the outputs in the absence of an input signal and allows for input signals before VDD is supplied. The LMK1C110x family operates in a 1.8V, 2.5V and 3.3V environment and are characterized for operation from –40°C to 125°C.

2.3.9 MSP432E401Y

The SimpleLink MSP432E401Y Arm Cortex-M4F microcontrollers provide top performance and advanced integration. The product family is positioned for cost-effective applications requiring significant control processing and connectivity capabilities. The MSP432E401Y microcontrollers integrate a large variety of rich communication features to enable a new class of highly connected designs with the ability to allow critical real-time control between performance and power. The microcontrollers feature integrated communication peripherals along with other high-performance analog and digital functions to offer a strong foundation for many different target uses, spanning from human-machine interface (HMI) to networked system management controllers. In addition, the MSP432E401Y microcontrollers offer the advantages of widely available development tools, system-on-chip (SoC) infrastructure, and a large user community for Arm-based microcontrollers. Additionally, these microcontrollers use the Arm Thumb®-compatible Thumb-2 instruction set to reduce memory requirements and, thereby, cost. When using the SimpleLink MSP432™ SDK, the MSP432E401Y microcontroller is code compatible with all members of the extensive SimpleLink family, providing flexibility to fit precise needs. The MSP432E401Y device is part of the SimpleLink microcontroller (MCU) platform, which consists of Wi-Fi®, Bluetooth® low energy, Sub-1GHz, Ethernet, ZigBee®, Thread, and host MCUs, which all share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set.

2.3.10 TPS709

The TPS7A37 family of linear low-dropout (LDO) voltage regulators uses an NMOS pass element in a capacitor voltage-follower configuration. This topology is relatively insensitive to output capacitor value and ESR, allowing a wide variety of load configurations. Load transient response is excellent, even with a small 1µF ceramic output capacitor. The NMOS topology also allows very low dropout. The TPS7A37 family uses an advanced BiCMOS process to yield high precision while delivering very low dropout voltages and low ground pin current. Current consumption, when not enabled, is under 20nA and excellent for portable applications. These devices are protected by thermal shutdown and foldback current limit.

2.3.11 TMAG5273

The TMAG5273 is a low-power linear 3D Hall-effect sensor designed for a wide range of industrial and personal electronics applications. This device integrates three independent Hall-effect sensors in the X, Y, and Z axes. A precision analog signal chain along with an integrated 12-bit ADC digitizes the measured analog magnetic field values. The I2C interface, while supporting multiple operating VCC ranges, provides seamless data communication with low-voltage microcontrollers. The device has an integrated temperature sensor available for multiple system functions, such as thermal budget check or temperature compensation calculation for a given magnetic field. The TMAG5273 can be configured through the I2C interface to enable any combination of magnetic axes and temperature measurements. Additionally, the device can be configured to various power options (including wake-up and sleep mode) allowing designers to optimize system power consumption based on the system-level needs. Multiple sensor conversion schemes and I2C read frames help optimize throughput and accuracy. A dedicated INT pin can act as a system interrupt during low-power wake-up and sleep mode, and can also be used by a microcontroller to trigger a new sensor conversion. The ultra-low-power consumption is defined by 2.3mA active mode current, 1µA wake-up current, and just 5nA sleep mode current.

The TMAG5273 operates from 1.7V to 3.6V supply voltage in the –40°C to +125°C temperature range at a maximum 1MHz I2C clock speed.

The TMAG5273 is a linear 3D Hall-effect sensor that is designed for electricity meters. The TMAG5273 is offered in four different factory-programmed I2C addresses. The device also supports additional I2C addresses through the modification of a user-configurable I2C address register. Figure 2-7 shows how the TMAG5273 defines the X, Y, and Z directions.

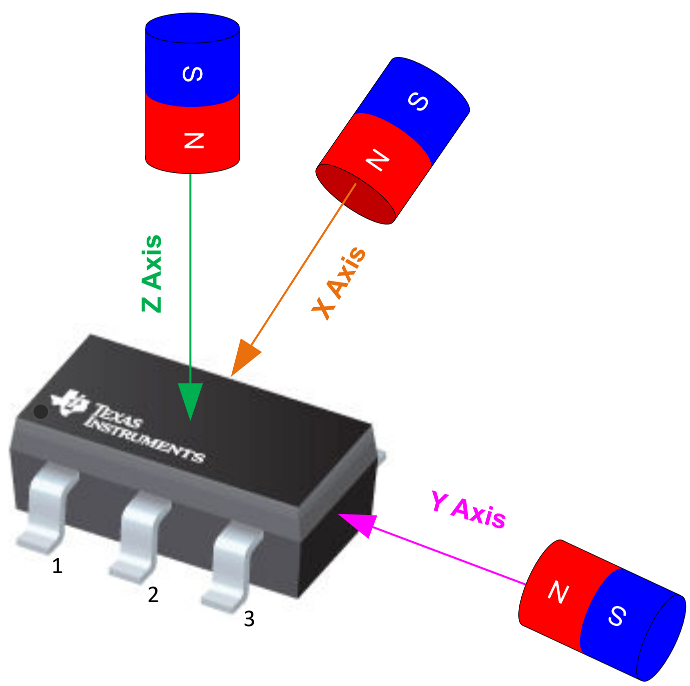


Figure 2-7. Field Direction Definition

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

The MSPM0G3507 device provides the minimum resources for running the Metrology library and has the required peripherals to interface to the standalone ADCs and the PC GUI:

- HF Clocking subsystem using external BAW or XTAL
- SPI with DMA (data transfer between stand-alone ADCs and MSPM0 MCU)
- UART with DMA (data transfer between external PC GUI and MSPM0 MCU for calibration and metrology values read out
- GPIOs (Inputs with Interrupts or Outputs for LEDs and ADCs control)
- I2C for TMAG5273 interface
- Optional RTC (Calendar mode based off 32.768kHz from internal LFOSC)

All the peripherals or MCU modules are configured through the `TIDA-010244.syscfg` file in the SDK middleware, utilizing the graphical SYSCONFIG tool. This tool enables intuitive and easy changes over a GUI, replacing the traditional low-level MCU register access.

3.1.1 Clocking System

This reference design comes with three different options to provide the necessary clock input at the LMK1C1104 to drive the four identical in-phase clock signals CLKIN1 through CLKIN4, making sure all ADCs run and collect data samples synchronized to each other. Both BAW and XTAL configurations were successfully tested, while the PWM option was not tested.

The MSPM0G3507 MCU is configured to have the CPU clock (MCLK) set at 79.87MHz and the M0_CLKOUT clock signal to all AMC131M03 devices is set to 8.192MHz. The external 16.384MHz or 32.768MHz XTAL, which is feeding the PLL module and is being multiplied and divided with specific factors, generates an MCLK frequency (the CPU clock speed) of 79.87MHz. An internal 32.768kHz LFOSC is used as the clock source for the auxiliary RTC clock (RTCCLK) of the device.

3.1.1.1 BAW Oscillator

The default option in TIDA-010244 is the Bulk-Acoustic Wave (BAW) oscillator: TI's BAW CDC6C oscillator is a high-precision clock signal generator with a frequency set to 8.192MHz. This device comes in a 4-pin package, the output clock signal from the CDC6C device is fed in parallel into the HFXOUT of the MSPM0 and the clock input from the LMK1C1104. To use the CDC6C as the main clock provider, populate R8, R9, and C11 and remove R10, R11, R16, R19, C10, and C12. The BAW oscillator is the preferred design because this oscillator has excellent performance: < 1ps RMS jitter for $F_{OUT} \geq 10MHz$.

3.1.1.2 Crystal Oscillator

The external 16.384MHz or 32.768MHz crystal oscillator (XTAL) is divided by 2 or by 4 to create the 8.192MHz output frequency for M0_CLKOUT, which is a dedicated GPIO high-drive pin. To enable this option, populate R10, R11, C10, and C12 next to the XTAL device and remove R8, R9, R19, and C11. Short the C11 pads. The clock settings are implemented in the `TIDA-010244.syscfg` file in the software deliverable, utilizing the graphical *Clock Tree* configuration inside the SYSCONFIG tool. The XTAL option on TIDA-010244 was also tested for measurement accuracy and is comparable to the BAW-based design.

3.1.1.3 PWM

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. The PWM signal can then be selected and generated through the SYSCONFIG tool. The PB10 PWM pin provides the clock signal to the buffer. To connect this signal to the clock buffer input, remove R9 and R16 and populate R19.

3.1.1.4 Clock Buffers

Due to the need to distribute two synchronous clocks to four ADCs, two LMK1C1104 clock buffers are added. The first buffer derives the four synchronous CLKIN1–4 signals with 8.192MHz from the M0_CLKOUT output, while the second buffer takes in the SPI clock from the SPI peripheral and outputs four SCLK1–4 signals to drive each of the ADCs separately.

3.1.2 SPI Bus Configuration

The SPI bus is shared between all four ADCs and the MCU features an SPI controller with four separate Chip Select ($\overline{CS}$) lines, one of each connecting to an ADC. The SPI bus runs at a 19.968MHz or 13,312MHz data rate with DMA support using two channels, one for transmit and one for receive. The PICO and POCI data lines are shared, as these are driven sequentially with only one $\overline{CS}$ line active at a time.

The four $\overline{DRDY}$ lines (one from each ADC) are wired to four GPIO inputs with interrupt enabled on the falling edge.

Three GPIO outputs are needed:

1. One SYNC_RESET line to trigger all ADCs simultaneously, SYNC_RESET is shared by all ADCs
2. ACT output
3. REACT output

The ACT and REACT pulsed outputs are used to report the Active and Reactive energy being calculated by the metrology middleware. The ACT and REACT outputs and are used to measure the TIDA-010244 accuracy using an external test system, which reads these ACT and REACT pulses.

An I2C interface is used to connect the TMAG5273 3D Hall-sensor device, with the MCU being the I2C transmitter. The RTC module supports calendar mode, which is a common requirement for an electricity meter. The M0+ MCU internal 32.768kHz LFOSC is used as the clock source for the auxiliary clock (RTCCLK) of the device.

3.1.3 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 or the onboard Bluetooth low energy chip or Bluetooth low energy module. To program the MSPM0 device, place the following jumpers:

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

   To program the Bluetooth low energy chip or module place the following jumpers:

   - J6: MCU_TMS to BLE_SWDIO
   - J7: MCU_TCK to BLE_SWCLK

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

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 *UART to PC GUI Communication*.

The third optional setting is over Bluetooth low energy. There are several options to test and send data.

a. Send data from PC over UART to Bluetooth low energy chip and to end application.
b. Send data from MSPM0 over UART to Bluetooth low energy and to end application.

For case 1 connect:

- Right side of J9 RX to JP8 (UART) HY_TX
- Right side of J9 TX to JP8 (UART) HY_RX

For case 2 connect:

- JP8 HY_RX to BLE_TX
- JP8 HY_TX to BLE_RX

3.2 Software Requirements

The metrology software used for testing TIDA-010244 is delivered as a middleware example in the latest MSPM0 SDK. 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 TIDA-010244 reference design 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 TIDA-010244 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

3.2.1 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

3.2.2 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 was 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.

3.2.3 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.

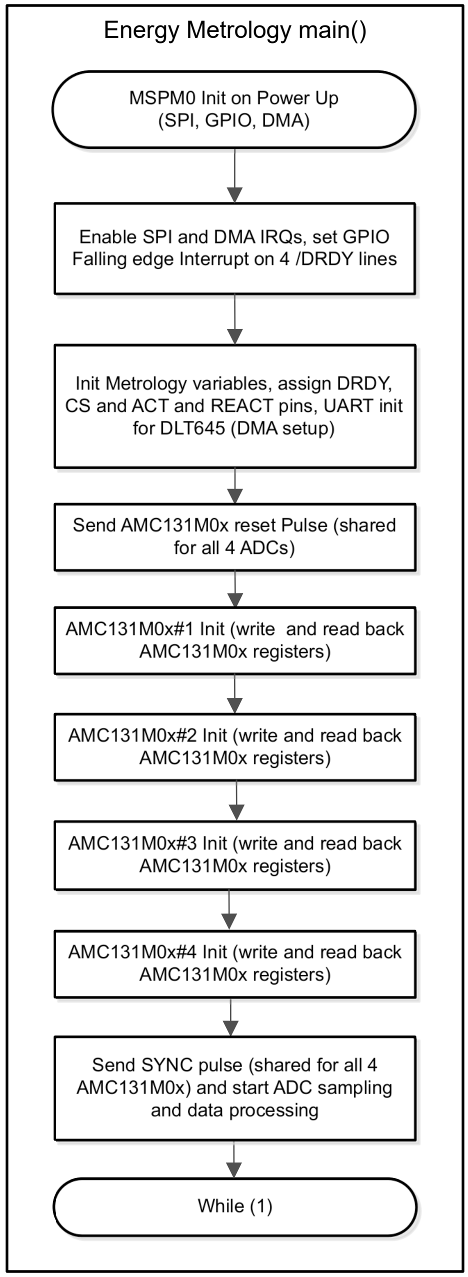


Figure 3-1. Energy Metrology Initialization Sequence in TIDA-010244 Firmware

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 3.

$$f_{\mathrm{S}} = \frac{f_{\mathrm{M}}}{\mathrm{OSR}} = \frac{f_{\mathrm{CLKIN}}}{2 \times \mathrm{OSR}} \tag{3}$$

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)

3.2.4 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.

3.3 Test Setup

Figure 3-2 shows the location of various pieces of the reference design on the top layer of the PCB; the bottom layer of the PCB has only a few components for the XDS110 debugger subsystem.

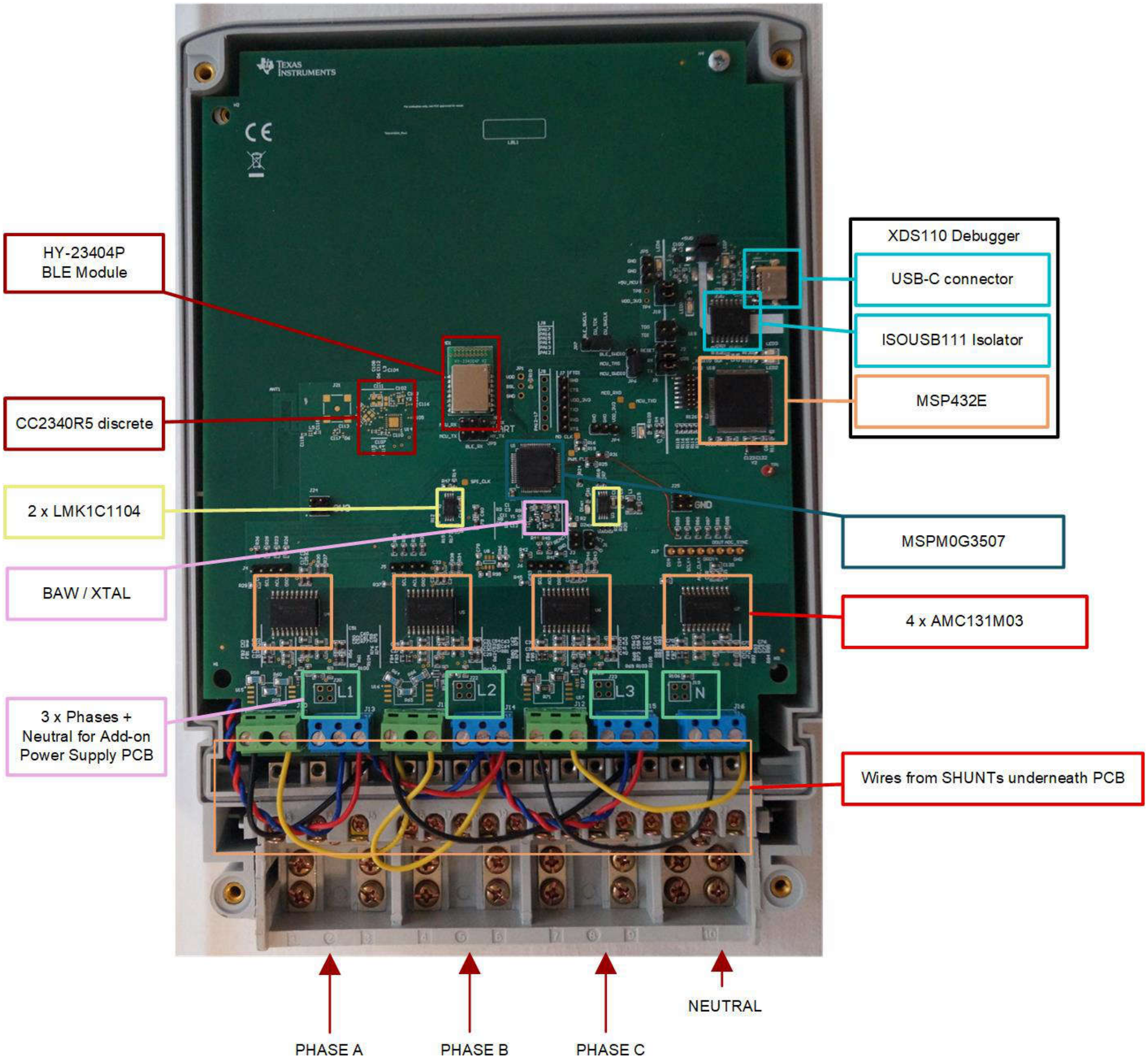


Figure 3-2. Top View of TIDA-010244 Design With Components Highlighted

3.3.1 Connections to the Test Setup

AC voltages and currents can be applied to the board for testing purposes at these points:

- Terminal blocks *J10*, *J11*, and *J12* have two positions: the 2nd one corresponding to the Phase Line A, B, and C, respectively. Tie the 1st position to Neutral.
- Terminal blocks *J13*, *J14*, and *J15* have three positions, where the 2nd and 3rd positions on each block are used to connect to the Phase Line A, B, or C and the shunt is connected to position 1. The 1st position is the other connection to the shunt. Do not allow the differential voltage across the *1* and *3* terminals of this terminal block to exceed ±37.5mV. The *HGND* terminal can be used to connect the Phase voltage and use this voltage to reference the current circuitry.

- Terminal block *J16* is used to obtain differential voltage across the shunt for the Neutral and is a three-position terminal block. The 1st position, which is connected to GND, is the Neutral voltage. Connect the differential wires from the shunt to the most right and most left positions to measure the current flowing through. Select the applied current to the input of the shunts to not exceed the maximum shunt current allowed, for example, 120A. In addition, before performing any test, verify that this terminal block is securely connected to the output leads of the shunt.

3.3.2 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 *Jumper Settings for LED and UART* 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 3-2, 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 3-2. Header Names and Jumper Settings

HEADER OR HEADER OPTION NAME	TYPE	MAIN FUNCTIONALITY	VALID USE CASE	COMMENTS
J10, J11, J12	2-pin terminal blocks	Phases A, B, and C voltages **(WARNING)**	Voltage inputs for line A, B, and C	Each of these terminal blocks connect with one terminal to the Neutral voltage, while the second terminal is wired to either phase A, B, and C, respectively.
J13, J14, J15	3-pin terminal blocks	Connect shunts for line A, B, and C **(WARNING)**	Current inputs after the shunt sensors for line A, B, and C	This terminal block is a three-position terminal block but only the leftmost and rightmost positions are used. The center position, which is connected to GND, is not connected to the CT. Before performing any test, verify that this terminal block is securely connected to both output leads of the CT.
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 *ISO_ACT* pin of J2 instead, which is isolated. If testing the active power pulses is desired, use the *ISO_ACT* 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 *ISO_REACT* 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 *no Mains* 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, $\overline{RST}$ signal, CLKIN signal, and $\overline{DRDY}$ signal of the respective AMC131M03 device.	The $\overline{RST}$ pin resets the AMC131M03, driven by MSPM0G3507 during initialization of all ADCs. The $\overline{DRDY}$ 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 *not* isolated from AC Mains, so do *not* 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, $\overline{RST}$ signal, CLKIN signal, and $\overline{DRDY}$ 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 $\overline{SYNC}$, $\overline{RESET}$ pin • Pin 8: GND

Table 3-2. 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.
J16	3-pin terminal block	Neutral Connection **(WARNING)**	Current input after the shunt for Neutral line (if Neutral current monitoring is desired).	This terminal block is a three-position terminal block but only the leftmost and rightmost positions are used. The center position, which is connected to GND, is not connected to the shunt. Before performing any test, verify that this terminal block is securely connected to both output leads of the shunt.
J19, J20, J22, J23	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	Use this header for external power supply.	
J25	4-pin header block	GND header	Use this header for a ground connection.	
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 = 47kΩ 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		
JP6	3-pin header	External programming connection	Connection (SWDIO) of the debugger to program the MSPM0 or the Bluetooth low energy chip.	
JP7	3-pin header	External programming connector	Connection (SWCLK) of the debugger to program the MSPM0 or the Bluetooth low energy chip.	
JP8, JP9	3-pin header	MCU or Bluetooth low energy UART RX and TX connector	Send data from the MSP to the Bluetooth low energy chip or module over UART.	

3.3.3 Cautions and Warnings

At high currents, the terminal block can get warm. In addition, observe that the phase voltages are fed to the board, so take the proper precautions.

WARNING

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

CAUTION

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

3.4 Test Results

The TIDA-010244 design supports up to 3 Phases + Neutral configuration with shunt sensors and requires connections to four current inputs and three voltage inputs in this configuration.

AC voltages and currents can be applied to the board for testing purposes at these points:

- Terminal blocks *J5*, *J6*, and *J7*, correspond to the line voltage connections for Phases A, B, and C, respectively. These terminal blocks have two positions.
- Terminal blocks *J8*, *J9*, and *J10* correspond to the current inputs from the shunt sensors for Phases A, B, and C, respectively. These are three-position terminal blocks but only the leftmost and rightmost positions are used. The center position, which is connected to GND, is not connected to the shunt sensor. During testing make sure that the applied current to the shunt does not exceed 120A. *In addition, before performing any test, verify that this terminal block is securely connected to both output leads of the shunt.*
- Terminal block *J11* corresponds to the current input from the shunt sensor for the Neutral line. This terminal block is a three-position terminal block but only the leftmost and rightmost positions are used. The center position, which is connected to GND, is not connected to the shunt. During testing make sure that the applied current to the shunt does not exceed 120A. *In addition, before performing any test, verify that this terminal block is securely connected to both output leads of the shunt.*

3.4.1 Electricity Meter Metrology Accuracy Results

To test for metrology accuracy in the electricity meter configuration, a source generator is used to provide the voltages and currents to TIDA-010244. 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 ϕ = 1i), sin ϕ = 0.5i (inductive), and sin ϕ = 0.8c (capacitive) are used, and cumulative reactive energy error is plotted.

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

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

Table 3-3. Active Energy % Error Versus Current, 200µΩ Shunts

CURRENT (A)	AVG ERROR % PF = 1, cos ϕ = 0°	LIMIT (%) [CLASS 0.2] IEC 62053-22 (PF 0.5i/0.8c)	LIMIT (%) [CLASS 0.5] IEC 62053-22 (PF 0.5i/0.8c)	AVG ERROR % PF = 0.5i, cos ϕ = 60°	LIMIT (%) [CLASS 0.2] IEC 62053-22 (PF 0.5i/0.8c)	LIMIT (%) [CLASS 0.5] IEC 62053-22 (PF 0.5i/0.8c)	AVG ERROR % PF = 0.8c, cos ϕ = –36.87°
0,1	0,05	0,4	1	–0,0062	0,5	1	0,0844
0,5	0,022	0,4	1	0,0088	0,5	1	0,052
0,75	0,019	0,4	1	–0,0044	0,5	1	0,0484
1,5	0,014	0,2	0,5	–0,0126	0,3	0,6	0,044
3	0,016	0,2	0,5	–0,016	0,3	0,6	0,0522
7,5	0,008	0,2	0,5	–0,0488	0,3	0,6	0,0546
15	–0,006	0,2	0,5	–0,0556	0,3	0,6	0,0368
30	–0,013	0,2	0,5	0,0116	0,3	0,6	0,0154
60	–0,037	0,2	0,5	–0,0398	0,3	0,6	–0,018
75	–0,082	0,2	0,5	–0,1036	0,3	0,6	–0,058
100	–0,096	0,2	0,5	–0,2234	0,3	0,6	–0,118

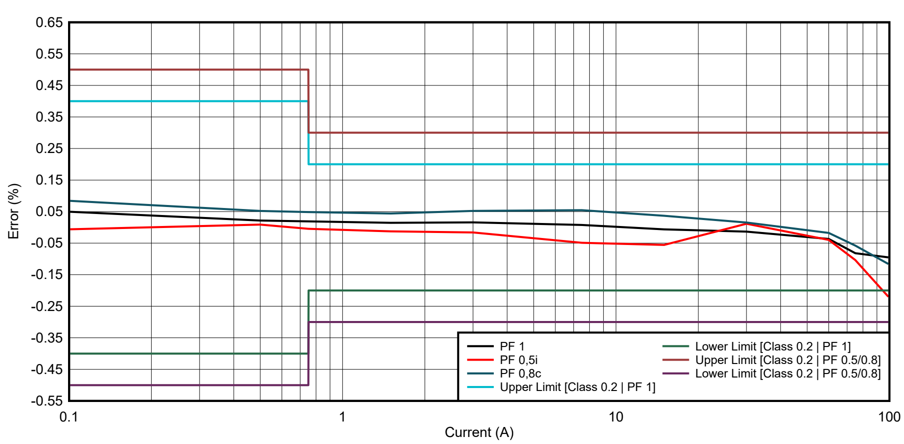


Figure 3-3. Active Energy % Error

Table 3-4. Reactive Energy % Error Versus Current, 200µΩ Shunts

CURRENT	AVG ERROR % sin ϕ = 1i (90°)	LIMIT (%) [CLASS 1]	Limit (%) [CLASS 0.5]	AVG ERROR % sin ϕ = 0.5i (30°)	Limit (%) [CLASS 1]	Limit (%) [CLASS 0.5]	AVG ERROR % sin ϕ = 0.8c (–53.13°)
0,1	–4,6028			–9,0318			6,3002
0,5	–0,8614	3	2	–1,6634			1,3914
0,75	–0,5374	3	2	–1,0236			0,9742
1,5	–0,2142	2	1	–0,4482	3	2	0,543
3	–0,0452	2	1	–0,1348	2	1	0,334
7,5	0,0504	2	1	0,0656	2	1	0,194
15	0,0796	2	1	0,112	2	1	0,1502
30	0,1006	2	1	0,1416	2	1	0,1354
60	0,0904	2	1	0,1272	2	1	0,1026
75	0,0608	2	1	0,1004	2	1	0,0746
100	–0,0642	2	1	0,0532	2	1	–0,0596

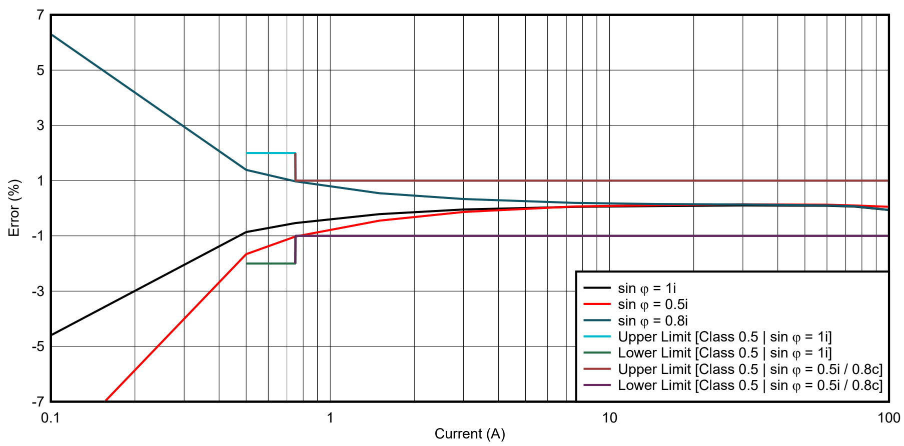


Figure 3-4. Reactive % Energy Error (3 phases)

Table 3-5. Current RMS % Error at 120V, 200µΩ Shunts

CURRENT (A)	PHASE A	PHASE B	PHASE C
	% DIFF	% DIFF	% DIFF
0,025	–3,583	–2,67	–6,677
0,05	–1,306	–1,051	–2,144
0,1	–0,382	–0,35	–0,268
0,25	–0,076	–0,097	–0,095
0,5	–0,021	–0,06	–0,013
1	–0,025	–0,109	–0,014
2	–0,01	–0,066	0,0025
5	–0,04	–0,093	0,0098
10	–0,051	–0,095	–0,021
20	–0,038	–0,075	0,011
30	–0,038	–0,072	0,01
40	–0,01	–0,055	–0,002
50	0,0114	–0,07	0,0006
60	–0,021	–0,071	0,0157
70	–0,015	–0,032	0,0353
80	0,0007	0,008	0,0733
90	0,03	0,063	0,0974
100	0,0462	0,05	0,0648

Here the plot for the current errors of all 3 phases:

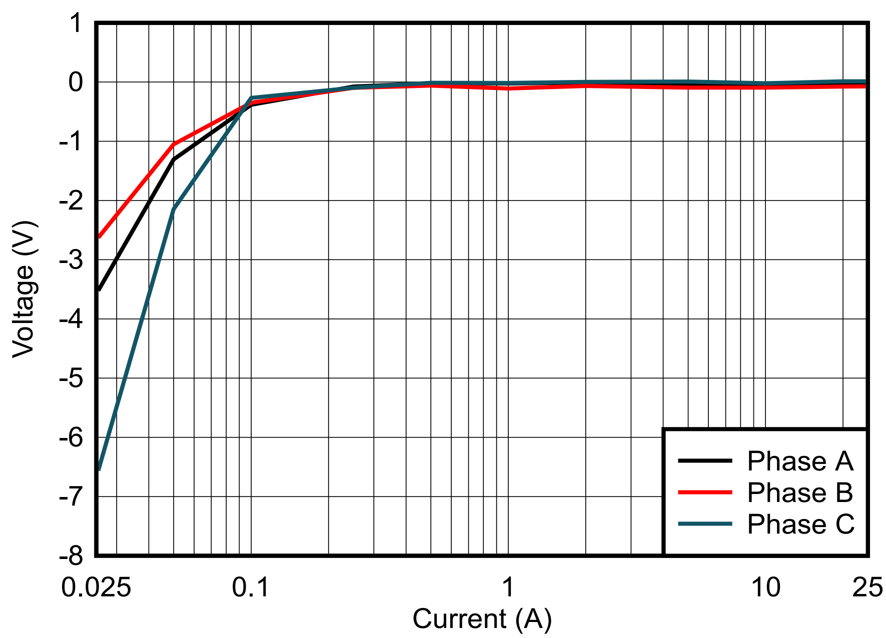


Figure 3-5. Current RMS % Error at 120V, 200µΩ Shunts for Phases A, B and C

Table 3-6. Voltage RMS % Error at 10A, 200µΩ Shunts

VOLTAGE (V)	PHASE A	PHASE B	PHASE C
	% DIFF	% DIFF	% DIFF
9	0,088	0,0856	0,0633
10	0,097	0,05	0,06
30	0,093	0,0463	0,043
50	0,031	0,0238	0,0178
70	0,03	0,0027	0,0084
90	0,022	0,0059	–0,006
100	0,073	–0,013	–0,016
120	–0,013	–0,014	–0,026
140	–0,047	–0,05	–0,021
160	–0,054	–0,066	–0,05
180	–0,046	–0,069	–0,071
200	–0,07	–0,089	–0,063
220	–0,098	–0,107	–0,089
230	–0,097	–0,112	–0,096
240	–0,084	–0,108	–0,1
260	–0,137	–0,126	–0,118
270	–0,13	–0,138	–0,138

Here is the combined plot for all 3 phases:

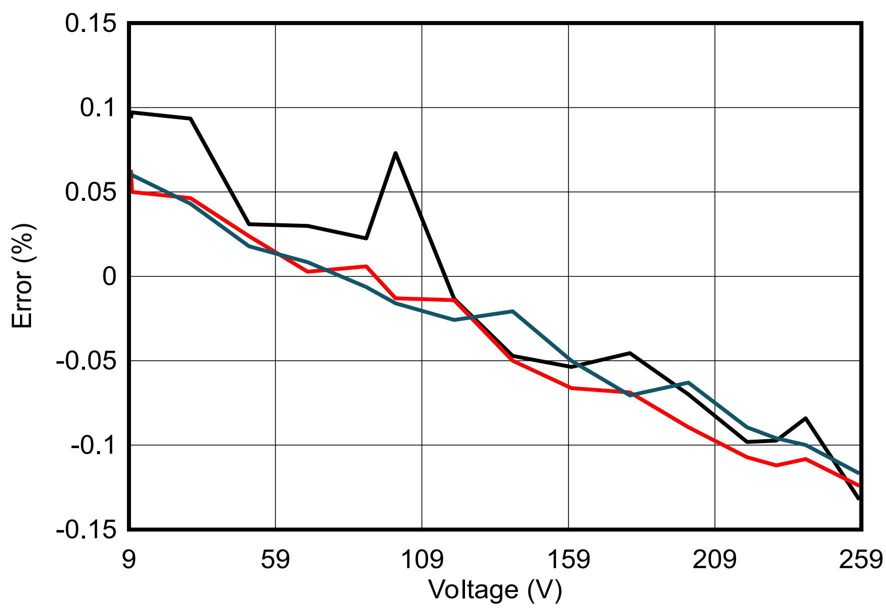


Figure 3-6. Voltage RMS % Error at 10A, 200µΩ Shunts for Phases A, B, and C

3.4.2 Radiated Emissions Performance

The plots in Figure 3-7 and Figure 3-8 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 TIDA-010244 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, but without a load. The antenna is positioned at *0m* and *1m*, with the antenna at board level and 1m above board level in height. Multiple board rotations (0, 90, 180, 270) are also captured within each plot. Across the antenna height and board orientation conditions, only the highest emission peaks are shown on the plots.

The radiated emissions of the TIDA-010244 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. Ferrites are added between the AMC device inputs and the line connection to block the DC-DC fundamental from propagating to the line and reduce the emissions. TIDA-010244 is battery-powered during the RE tests.

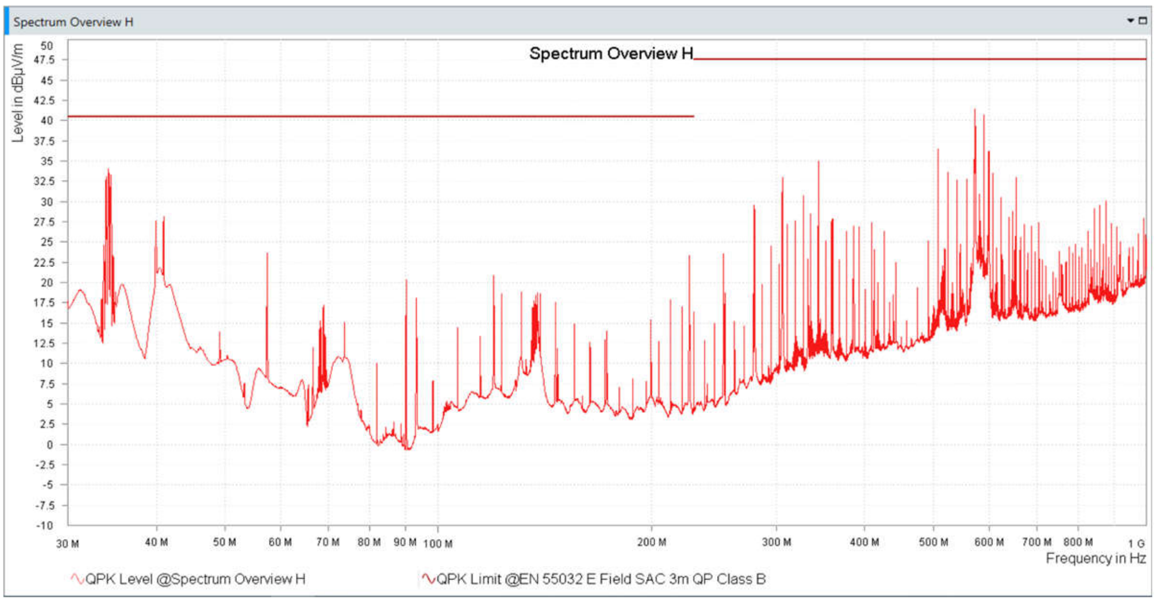


Figure 3-7. Spectrum Overview H

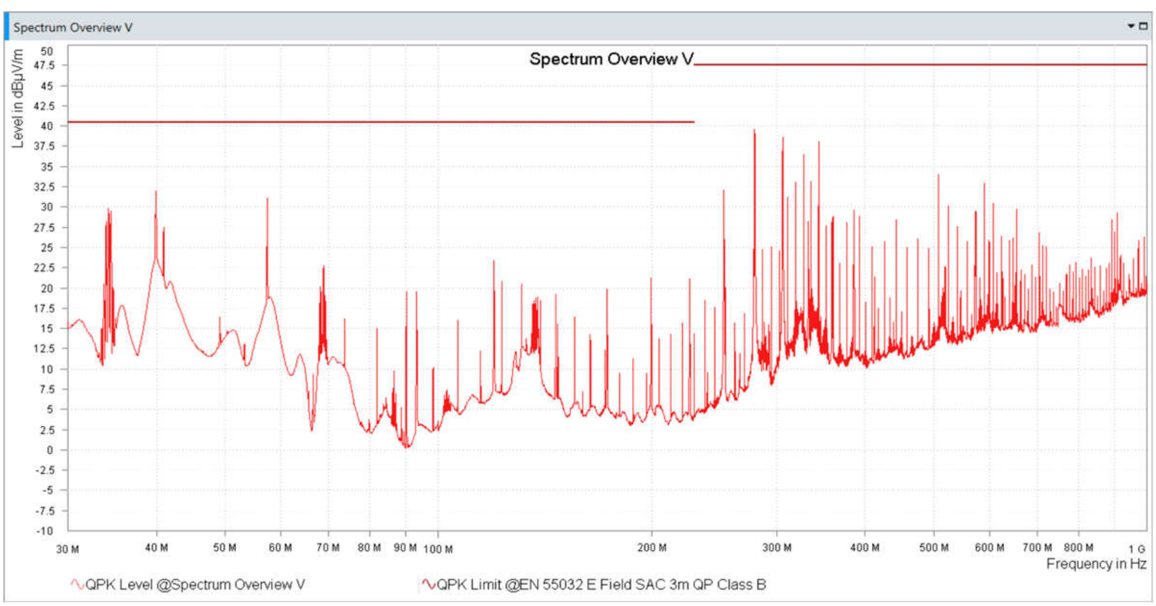


Figure 3-8. Spectrum Overview V

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-010244.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010244.

4.1.3 PCB Layout Recommendations

For this design, follow these general guidelines:

- Place decoupling capacitors close to the associated pins.
- Use ground planes instead of ground traces and minimize the cuts in the ground plane, especially near the AMC131M03. In this design, there is a ground plane on both the top and bottom layer; for this situation, make sure that there is good stitching between the planes through the liberal use of vias.
- Keep the two differential traces to the inputs of an ADC channel symmetrical and as close as possible to each other.
- For the AMC131M03 devices, place the 0.1μF capacitor closer to the AVDD pin than the 1μF capacitor. Do the same thing for the 0.1μF and 1μF capacitors connected to DVDD.
- Minimize the length of the traces used to connect the crystal to the microcontroller. Place guard rings around the leads of the crystal and ground the crystal housing. In addition, there must be clean ground underneath the crystal oscillator (XTAL) or the BAW device, so placing any traces underneath must be avoided. Also, keep high-frequency signals away from the clocking island for the MSPM0G3507.
- Use wide traces for power-supply connections.
- Make sure that the recommended clearance and creepage spacing are met for the AMC131M03 and ISOUSB111 isolation devices in this design.

4.1.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-010244.

4.2 Tools and Software

Tools

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

TIDA-010244 Firmware	Source code of Energy Library for TIDA-010244 in MSPM0 SDK with default install path: C:\ti\mspm0_sdk_2_03_00_07\examples\nortos\LP_MSPM0G3507\energy_metrology\TIDA_010244\TIDA_010 SW

4.3 Documentation Support

1. Texas Instruments, *AMC131M03 3-Channel, 64-kSPS Simultaneous-Sampling 24-Bit Isolated Delta-Sigma ADC With Integrated DC/DC Converter Data Sheet*
2. Texas Instruments, *MSPM0G350x Mixed-Signal Microcontrollers With CAN-FD Interface Data Sheet*
3. Texas Instruments, *CC2340R SimpleLink™ Family of 2.4GHz Wireless MCUs Data Sheet*
4. Texas Instruments, *ISOUSB111 Full/Low Speed Isolated USB Repeater Data Sheet*
5. Texas Instruments, *TMAG5273 Low-Power Linear 3D Hall-Effect Sensor With I2C Interface Data Sheet*
6. Texas Instruments, *TPS7A37 1% High-Accuracy, 1-A, Low-Dropout Regulator With Reverse Current Protection Data Sheet*
7. Texas Instruments, *RES60A-Q1 Automotive, 1400V_{DC}, Precision Resistor Divider Data Sheet*
8. Implementing magnetic tamper detection in electricity meters
9. PTS 3.3 genX – EMH Portable 3-phase Testsystem

4.4 Support Resources

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

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5 About the Author

MILEN STEFANOV (M.Sc.E.E) is a system engineer at TI, working in the Grid Infrastructure field and an expert in RF communication technologies and (smart) metering applications. After graduating, he spent 5 years as a research assistant at the University of Chemnitz (TUC) and 3.5 years in the semiconductor industry in high-speed optical and wired communications as a system engineer. He joined TI in 2003 to become a Wi-Fi ® expert and to support TI's Wi-Fi products at major OEMs. Since 2010, he has focused on metering and Sub-1GHz RF designs for the European Grid Infrastructure market. Mr. Stefanov has published multiple articles on wM-Bus technology in Europe and presented technical papers at the Wireless Congress and Smart Home and Metering summits in Munich.

GAVIN LOERA (B.S BME) is a system engineer at TI, working in the Grid Infrastructure field and focusing on Current Sense technologies and metering applications. After graduating, he spent some time as a Test Technician for Abbott Laboratories, before accepting a position at TI in the Applications Rotation program in 2022. He joined the Grid Infrastructure SEM team, with focus on metering and current sensing. Gavin spent 6 months with the Precision Analog-Digital Converters (PADC) Applications team, where he learned more about precision ADCs, the key analog component for electricity meters.

FELIX DEBUS (M. Sc. E. E.) a field application engineer at TI, working in the sales team covering contract manufacturers in Europe. During his student time he worked at TI on automotive topics for 3 years until he accepted the Field Application Engineer Rotation program after his graduation in 2024. During this program he rotated in the energy infrastructure team to work on electricity meters.

6 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (February 2025) to Revision A (March 2025)	Page
• Updated schematic image	1

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265