*Application Note*

# *Electricity Metering Reference Designs Selection Guide*

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**ABSTRACT**

The worldwide demand for electricity meters (E-meters) is growing fast, with smart meters becoming the predominant type across the world. Being smart means that these meters can communicate over wired or wireless links, which can be either one-way (just reporting the billing data) or two-way communication. Key advantages of smart meters are the capability of firmware upgrades in the field or enabling dynamic load management for residential users with renewable power installations. Other high-volume applications for electricity metering are protection relays, circuit breakers, AC- or DC charging stations, and in-house appliances for the EU market, which need to monitor power consumption.

Texas Instruments offers a complete portfolio of reference designs and evaluation modules (EVMs) to address all these high-volume applications. This document briefly describes the key selection criteria for choosing the proper reference design to start with when developing a product, which integrates an energy metrology sub-system.

To enable faster time-to-market TI has released multiple reference designs for E-meters, utilizing a two-chip approach with a dedicated high-precision Analog Front End (AFE) and off-the-shelve cost-optimized low-power Microcontroller (MCU). The wireless communication sub-system is implemented by using TI's Wireless MCUs CC13xx for Sub-1GHz and CC26xx/27xx/2340 devices for 2.4GHz protocols, as shown in:

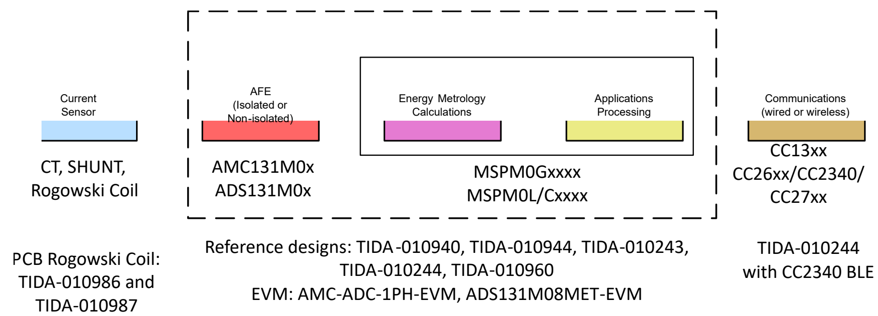


**Figure 1-1. TI Reference Designs and EVMs for Energy Metering Block Diagram**

Such system partitioning as in Figure 1-1 allows the end user to optimize both the AFE and the MCU selection, depending on criteria like measurement accuracy, system cost or feature set supported. Multiple device combinations are possible, depending upon the number of lines (or phases) to be measured, the type of current sensors (CT, Shunt or Rogowski coil) used, or mandatory security and encryption features.

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## Trademarks

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# 1 TI Reference Designs and EVMs with Energy Metrology Overview

## 1.1 Reference Designs for CT and Rogowski

For CTs and Rogowski current sensors, these Reference designs are available:

- ADS131M08MET-EVM ADS131M08 metrology evaluation module
- TIDA-010243 Three-phase current transformer e-meter reference design with standalone ADC
- TIDA-010986 Signal conditioning reference design
- TIDA-010987 Rogowski coil current sensor reference design.

TIDA-010986 offers two main functions: pre-amplifying the Rogowski coils' dI/dt output signal and then integrating the signal by using a second operational amplifier stage. This integration stage per hardware can be bypassed when an alternative software integration step inside the Energy Metrology library is preferred by the user.

To further ease the development process and shorten the time-to-market for customers, TI has developed six different-sized PCB Rogowski coils, provided as break-out PCB variants within the TIDA-010987 Rogowski coil current sensor reference design.

**Figure 1-1. 3-phase E-meter Rogowski Coil Design with TIDA-010987, ADS131M08MET-EVM, and TIDA-010986**

ADS131M08MET-EVM uses the ADS131M08 and the MSPM0G1506SRHB to realize class 0.1 three-phase energy measurements based on IEC-62053, EN 50470 and ANSI C12 test methods.

The combination of ADS131M08MET-EVM (horizontal PCB) and TIDA-010986 (vertical PCB with twisted wires to the PCB coils) with a TI proprietary differential Rogowski coil PCB from TIDA-010987 enables a complete cost-optimized E-meter design with Rogowski coils, shown in Figure 1-1.

## 1.2 Reference Designs for SHUNTs

To support shunt current sensors, these reference designs have been developed:

- AMC-ADC-1PH-EVM Single-phase energy meter using standalone isolated multichannel analog to-digital converter
- TIDA-010244 Three-phase shunt-based energy metrology reference design
- TIDA-010944 Single-phase and split-phase shunt energy metrology reference design
- TIDA-010940 Single-phase shunt e-meter reference design
- TIDA-010960 One-phase shunt power meter reference design with isolated ADC

TIDA-010960 offers a reduced current range and slightly lower accuracy, but at lower system design cost to address white goods and appliances or measure server power consumption.

AMC-ADC-1PH-EVM is the orderable version of TIDA-010960 and available on TI.com.

## 1.3 Reference Designs and EVMs Overview

Table 1-1 classifies all TI reference designs and EVMs for Energy Metrology according to their measurement accuracy, sensor type, number of lines and applications:

**Table 1-1. TI Energy Metering Reference Designs Classification**

| # of Phases | Sensor Type | | | Application |
|---|---|---|---|---|
| | SHUNT Accuracy | CT Accuracy | ROGOWSKI Accuracy | |
| 1 (+Neutral monitoring option) | TIDA-010940<br>0.5%<br>TIDA-010944<br>0.2%<br>TIDA-010244<br>0.2%<br>TIDA-010960<br>0.5%<br>AMC-ADC-1PH-EVM<br>0.5% | ADS131M08MET-EVM<br>0.1%<br>TIDA-010944<br>0.2%<br>TIDA-010243<br>0.1% | ADS131M08MET-EVM<br>+<br>TIDA-010986<br>+<br>TIDA-010987<br>0.1% | E-meter, power meter, circuit breaker, protection relay, Appliance<br>Appliance, server power, circuit breaker, protection relay, server power |
| 2 | TIDA-010944<br>0.2% | ADS131M08MET-EVM<br>0.1%<br>TIDA-010243<br>0.1% | ADS131M08MET-EVM<br>+<br>TIDA-010986<br>+<br>TIDA-010987<br>0.1% | E-meter, power meter, AC- and DC-charging stations, circuit breaker, protection relay, server power |
| 3 (+Neutral monitoring option) | TIDA-010244<br>0.2%<br>(BLE integration) | TIDA-010243<br>0.1%<br>ADS131M08MET-EVM<br>0.1% | ADS131M08MET-EVM<br>+<br>TIDA-010986<br>+<br>TIDA-010987<br>0.1% | E-meter, power meter, circuit breaker, protection relay, AC- and DC-charging stations,<br>Appliance, server power |

## 1.4 System Design Components

### *1.4.1 Microcontrollers*

The cost-optimized, low-power MSPM0+ MCU family, which offers a scalable portfolio with large variety of options, based on memory size, integrated analog and digital peripheral modules, is able to meet the computing requirements for energy metrology calculations of up to 8ksps with 3 lines plus neutral monitoring. Multiple devices from this MCU family offer sufficient resources with either 24MHz (MSPM0C), 32MHz (MSPM0L), or 80MHz (MSPM0G) clock frequency and pin-to-pin variants, which allow trading system cost versus performance.

### *1.4.2 Analog-to-Digital converters (ADC) or Analog Front End (AFE)*

The key device families for the signal acquisition are the *isolated* or *non-isolated* AFE devices, which acquire the voltages and currents per each line or phase.

For *shunt-based* current sensing, the AMC131M02 and AMC131M03 *isolated* 24-bit, 32-kSPS, delta-sigma Analog-to-Digital converters (ADC) are widely used due to precision, channel architecture, and robustness. The AMC131M02 is a:

- 2-channel,
- 24-bit,
- 32-kSPS,
- simultaneous-sampling,

isolated delta-sigma ADC designed specifically for current and voltage measurement in systems that require reinforced isolation. The AMC131M03 extends the device family by providing a 3-channel variant with the same 24-bit resolution, isolation rating, and sampling performance.

The additional channel allows for simultaneous measurement of line voltage and two shunt currents or three currents, offering more flexibility for poly-phase systems or systems requiring a dedicated channel for neutral-line monitoring and achieve Class 0.2 accuracy.

Alternatively, for *CTs and Rogowski coils* current sensors, which both offer isolation due to the way of operation, the *non-isolated* 24-bit,32-kSPS, ADS131M08 (8-channel) and ADS131M06 (6-channel) device options delivers the feature set and performance required to achieve Class 0.1 accuracy, while measuring multiple currents, voltages or a combination thereof.

The *non-isolated* 24-bit ADC variants ADS131M02 (2-channel), ADS131M03 (3-channel) and ADS131M04 (4-channel) offer an increased sampling rate of 64-kSPS, while keeping all other advanced features, such as current-detect mode for extremely low power tamper detection.

For Rogowski coil signal amplification and signal integration multiple operation amplifiers have been tested and compared: INA828, INA333 or INA823, verifying that the higher accuracy, lower noise amplifiers also deliver higher accuracy in an Energy Metrology application.

For fastest time-to-market, TI recommends to start with ADS131M08MET-EVM or AMC-ADC-1PH-EVM, both can be purchased on TI.com, as all TI reference designs, listed in Section 1.2, are not orderable.

# 2 Energy Metrology Library Software for E-meters

While all these EVMs and reference designs differ in the number of phases and types of current sensors supported, these all share the same Energy Metrology library, which is integrated into the latest MSPM0-SDK software tool.

Note that a customized firmware example for each reference design or EVM has been developed and tested with the results documented in the associated TI Reference Design Guide or EVM User's Guide document on TI.com.

The energy metrology software library for MSPM0+ MCU devices contains full open-source software implementation of data sample collection for voltages and currents per line, power calculations and energy accumulations.

## 2.1 User Configuration and HW Resources

The TI Energy Metrology library takes inputs from user through the "template.h" file where user specifies key configuration parameters. Additional configuration options are found in the "metrology_defines.h" file, which is inside the /modules/metrology folder for each TI Reference Design or TI EVM code example. The detailed analysis of the MCU load for various CPU frequencies and data sampling rates is shown in:

**Table 2-1. MSPM0+ CPU Load with Energy Metrology Library (SDK 2.08 or Later)**

| Sampling rate per phase | CPU Utilization (SDK 2.04 or later) | | | |
|---|---|---|---|---|
| | MSPM0L Device 32MHz | | MSPM0G Device 80MHz | |
| | Single-Phase | Poly-Phase (010243) | Single-Phase | Poly-Phase (010243) |
| 2ksps | 11.81% | 25.40% | 4.73% | 10.17% |
| 4ksps | 23.12% | 49.33% | 9.25% | 19.73% |
| 8ksps | 45.73% | 97.15% | 18.29% | 38.86% |

In addition, several peripheral hardware modules are needed to support the Energy Library:

- HF Clocking subsystem using external XTAL (generates the MCU clock and the clock for the AFE device)
- SPI over DMA (data transfer between stand-alone ADCs and MSPM0+ MCU)
- UART over DMA (data transfer between external PC GUI and MSPM0 MCU for one-time calibration and continuous metrology values read out by the GUI)
- GPIOs (inputs with interrupts or outputs for LEDs and AFE control lines)
- RTC (calendar mode based off 32.768kHz from either internal LF OSC or external XTAL)

Knowing the mandatory peripheral modules and the CPU load numbers in Table 2-1 enable system designers to select the appropriate MCU device, considering which additional application requirements must be implemented on the MCU.

Note that a small MSPM0+ can be used as a dedicated energy metrology device, reporting the calculated values to another main or host MCU with more FLASH and RAM resources.

For cost-sensitive single-phase E-meters, which are popular in many regions, TIDA-010940 with MSPM0L2228 can provide all blocks and enable a single-MCU design, including LCD support, external serial FLASH Interface and isolated RS-485 port.

## 2.2 SW Architecture of Energy Metrology

The Energy Measurement software is divided into three layers:

1. MSPM0 DriverLib layer consists of all the peripherals defined and is configured using TIs' SYSCONFIG tool.
2. The TI reference design specific folder TIDA-010244, containing the Interrupt handler and the hardware related functions in TIDA-010244.c and TIDA-010244.h (if TIDA-010244 is used as an example).
3. Modules layer with four sub-modules:
   - Hardware Abstraction Layer (HAL) module
   - Analog Front End (AFE) AMC131M03 module (for TIDA-010244)
   - Metrology module
   - Communication module

The HAL module provides Application Programming Interfaces (APIs) to manipulate and configure MCU pins and peripherals while the AFE module provides Application Programming Interfaces (APIs) related to configuration of AMC131M0x or ADS131M0x devices and SPI communication for Register Read/write access or AFE sampling data read out.

The Metrology module provides the APIs to process the sampled data and do all relevant energy metrology mathematical calculations.

The Communication module is used to receive commands from the PC GUI, which is a separate tool included in the MSPM0-SDK under: *C:\ti\mspm0_sdk_2_08_00_03\tools\metrology_gui*.

## 2.3 Getting started with TI Reference Design or EVM for Energy Metrology

The complete test and verification setup is shown here:

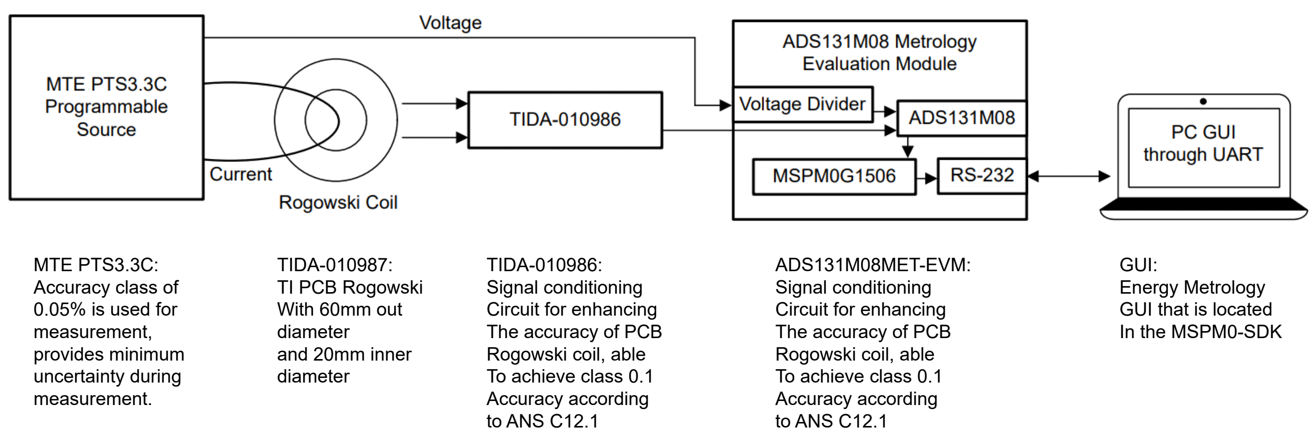


**Figure 2-1. Hardware and Software Setup With External MTE and PC GUI for ADS131M08MET-EVM with TIDA-010986 and TIDA-010987**

Further details on the SW Tools and how to connect the reference design or EVM to the MTE and the PC GUI are listed in the respective Design Guide or User's Guide document.

The three Design Guides are linked here:

- ADS131M08 Metrology Evaluation Module
- TIDA-010986
- TIDA-010987

## 2.4 Code example per Reference design or EVM

Extensive firmware documentation has been included into the MSPM0-SDK, enabling easy and fast integration of TI's energy metrology designs into customer products. Each TI Reference Design has a version of the Energy Metrology library; Figure 2-2 shows all four designs, utilizing the same MSPM0G3507 MCU:

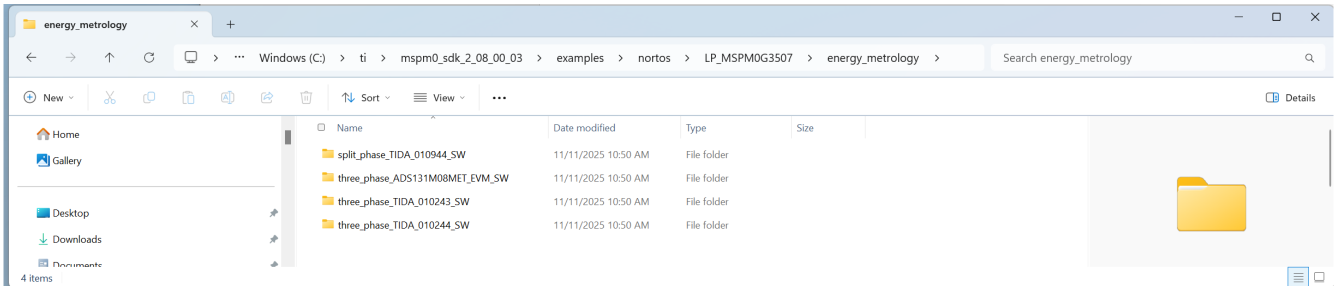


**Figure 2-2. MSPM0+ SDK Folder for Energy Metrology with MSPM0G3507, No RTOS Used**

The required memory resources for FLASH and RAM memory per reference design differ slightly, where the largest configurations are the 3-phase reference designs TIDA-010243 and TIDA-010244 with 36kB FLASH and 12.5KB RAM. These numbers apply for the Energy Metrology Firmware library compiled with CCS12.8.1 and MSPM0-SDK v2.08.00.03 using the default software project settings.

# 3 Summary

Texas Instruments provides a complete portfolio of energy metrology system designs for residential E-meters, AC- and DC- charging stations, electricity sub-meters, circuit breakers, protection relays, home appliances and server power.

All three popular current sensors are supported: Shunt, CT and Rogowski coil; multiple reference designs for single-phase, split-phase (or 2-phase) and 3-phase (with optional neutral monitoring) achieve accuracy of Class 0.1, Class 0.2, or Class 0.5, mainly limited by the accuracy of the current sensor being used.

TI performs ten applicable tests focused on electrical performance as per ANSI C12.1 2024, IEC-62053, or EN 50470 for each design and for some also EMI tests have been conducted and documented. According to ANSI C12.1 these tests are performed:

- – Test No. 3: Load performance
  - Test No. 4: Effect of power factor variation
  - Test No. 7: Equality of current circuits
  - Test No. 14: Effect of sequence reversal

These tests verify compliance, accuracy, and reliability of E-meters sub-system designs with TI devices and TI energy metrology library for all TI Reference designs and EVMs listed in this document.

Each Reference Design is released with fully tested hardware and is paired with an optimized Energy Metrology software example in source code, making them an excellent starting point for developing ANSI or MID compliant E-meters in a very short time-to-market period.

A key differentiation is the newly released TIDA-010987 "Rogowski coil current sensor reference design" with performance optimized signal chain and unique differential PCB coil design, which achieves up to factor 5 improved signal output in the same PCB area compared to legacy PCB coil designs. The TI developed PCB coils can also be stacked above each other to achieve double or multiple signal output strength and eliminate the amplification stage all together.

Finally, the open-source TI energy metrology library for MSPM0+ MCU devices in the MSPM0+ SDK tool is a unique and integration-friendly feature. Customers can build upon the fully documented and extensively tested library, provided by TI, and add own features for harmonics analysis or data logging.

The code-size and MCU load optimized energy metrology library examples for each released TI reference design and TI EVM enable customers to quickly verify the performance of the full TI energy metrology system design and easily integrate into products.

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