

# Direct Current (DC) Electricity Meter Reference Design



## Description

The Direct Current (DC) electricity meter reference design enables end users to evaluate a design combining isolated data converters (ISO-ADC) with an ultra-low-power 32-bit MCU based on the enhanced Arm® Cortex®-M0+ core. This design delivers revenue-grade accuracy appropriate for billing applications.

## Resources

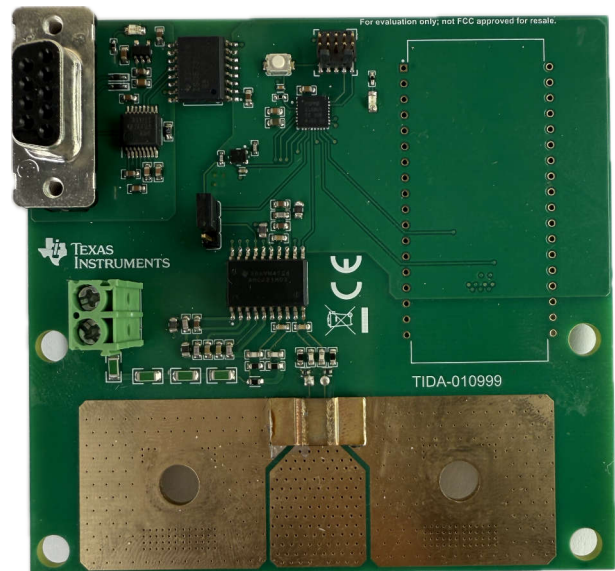
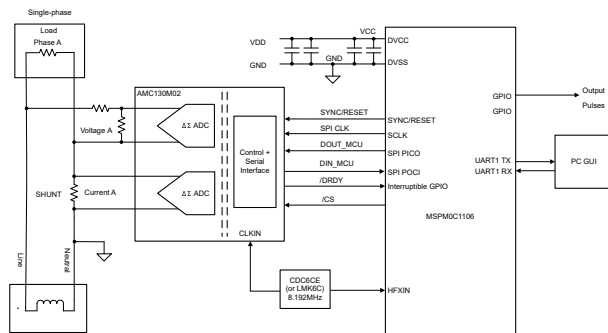
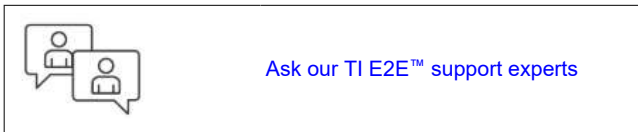
<a href="#">TIDA-010999</a>	Design Folder
<a href="#">AMC131M02</a>	Product Folder
<a href="#">MSPM0G1506</a>	Product Folder
<a href="#">MSPM0L2228</a>	Product Folder
<a href="#">ISO6731</a>	Product Folder
<a href="#">TRS3232</a>	Product Folder

## Features

- Revenue grade DC metering tested against ANSI C12.32-2021:
  - Class B
- Wide current range:
  - 0.1A to 1000A
- Onboard LCD screen:
  - Live updates of energy consumption
- Attachable bus-bar extension for high-current applications

## Applications

- [Electricity meter](#)
- [DC fast charging power module](#)
- [DC fast charging station](#)
- [ESS – Battery management system \(BMS\)](#)



## 1 System Description

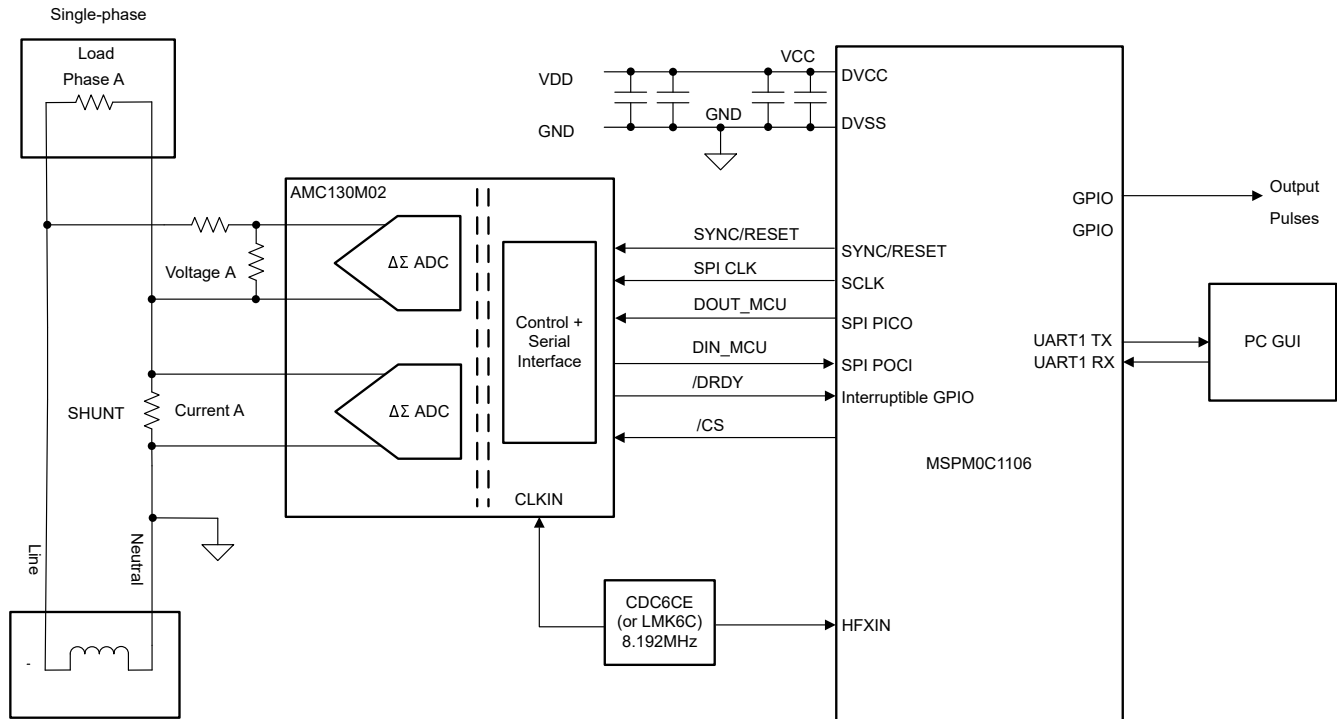
As direct current (DC) becomes increasingly integrated into modern grid infrastructure, the demand for accurate and reliable DC-specific metering continues to grow. Applications such as DC fast charging, renewable energy installations (solar PV), energy storage, and data centers require precise measurement of high voltages and currents to enable safe operation, performance optimization, and fair energy billing.

The TIDA-010999 reference design addresses this need by leveraging the latest data conversion and processing technologies to electronically measure high DC voltages and currents with high accuracy in a compact form factor. This design targets revenue-grade metering applications, enabling end users to evaluate a DC metering reference design appropriate for billing and monitoring across a wide range of emerging DC power infrastructures.

## 2 System Overview

A low-ohmic, high-precision inline resistor, commonly referred to as a shunt resistor, serves as the current-sensing element. The voltage drop across the shunt is measured and fed into an isolated analog-to-digital converter (ADC) for data acquisition. The digitized current data is then processed by the system microcontroller (MCU) for measurement. A simple resistor divider network scales the measured voltage to a level compatible with the ADC input range.

### 2.1 Block Diagram



### 2.2 Design Considerations

Using a shunt resistor for high-current applications presents several challenges, with temperature rise and drift being the most critical. Under typical operating conditions, shunt resistors generally cannot operate continuously beyond approximately two-thirds of rated current, assuming proper heat dissipation occurs. The effectiveness of heat dissipation depends heavily on the mechanical and thermal design. In many applications, physical size constraints prevent the use of heat sinks or forced air cooling, limiting the ability to remove heat from the shunt and conduction pads. Alternative cooling methods, such as increasing the copper area, thickness, or copper weight of the PCB trace or primary conductor, often increase the overall weight, size, and cost of the PCB.

Because shunt resistors connect directly in series with the line and do not provide galvanic isolation, an additional isolation barrier becomes required to protect sensitive electronics from line surges and fault conditions. This necessitates the use of isolated amplifiers or isolated ADCs.

From a DC metering perspective, additional design considerations must also be addressed. Long-term stability and calibration drift become more critical in DC applications because errors accumulate directly over time with no zero-crossing behavior to naturally average offsets. Thermal gradients across the shunt can introduce offset and gain errors, degrading accuracy at both low and high current levels. Furthermore, parasitic resistance in PCB traces and interconnects can significantly impact measurement accuracy, requiring careful routing and controlled impedance design. Finally, DC metering applications must be designed to handle continuous full-scale current without excessive self-heating, while maintaining accuracy across a wide temperature and current range.

## 2.3 Highlighted Products

In this reference design, isolated analog-to-digital converters are combined with an Arm® Cortex®-M0+ core microcontroller for signal processing and control. A secondary microcontroller is included to drive the onboard LCD display and manage the user interface. A bulk acoustic wave (BAW) resonator serves as the clock source for the ADCs to provide a stable and low-jitter timing reference.

As a best design practice, the user interface remains electrically isolated from the measurement and processing electronics by using digital isolation.

### 2.3.1 AMC131M03

The AMC131M03 is a precision, three-channel, data and power-isolated, simultaneous-sampling, 24-bit, delta-sigma ( $\Delta\Sigma$ ) analog-to-digital converter (ADC). The AMC131M03 offers wide dynamic range, low power, and energy-measurement-specific features 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 0884-17 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.

### 2.3.2 MSPM0G1506

MSPM0G150x microcontrollers (MCUs) are part of the MSP highly integrated, ultra-low-power 32-bit MCU family based on the enhanced Arm® Cortex®-M0+ 32-bit core platform operating at up to 80MHz frequency. These cost-optimized MCUs offer high-performance analog peripheral integration, support extended temperature ranges from  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ , and operate with supply voltages ranging from 1.62V to 3.6V.

### 2.3.3 MSPM0L2228

The MSPM0L2228 is an Arm® Cortex®-M0+ 32-bit MCU operating at up to 32MHz, designed for ultra-low-power and cost-efficient designs. The device provides up to 256KB of embedded flash memory with ECC and dual-bank support for field firmware updates, along with up to 32KB of SRAM featuring ECC and parity protection. The device includes a VBAT backup island with real-time clock, low-frequency clocking, tamper detection, independent watchdog, and backup memory to support battery-backed operation when the main supply is lost. An optional ultra-low-power segmented LCD controller (on select devices) supports low-cost display applications. The comprehensive ultra-low-power architecture maximizes performance while minimizing energy consumption across the operating temperature range.

### 2.3.4 ISO6731DWR

The ISO6731 device provides high-performance, triple-channel digital isolation for cost-sensitive applications requiring up to  $5000V_{\text{RMS}}$  isolation ratings per UL 1577. This device also receives certification by VDE, TUV, CSA, and CQC. The ISO6731 device provides high electromagnetic immunity and low emissions at low power consumption, while isolating CMOS or LVCMOS digital I/Os. Each isolation channel contains a logic input and output buffer separated by TI's double capacitive silicon dioxide ( $\text{SiO}_2$ ) insulation barrier. This device includes enable pins that can put the respective outputs in high impedance for multi-controller driving applications. The ISO6731 device contains two forward and one reverse-direction channels. In the event of input power or signal loss, the default output becomes high for the device without suffix F and low for the device with suffix F. Used in conjunction with isolated power supplies, this device helps prevent noise currents on data buses, such as UART, SPI, RS-485, RS-232, and CAN from damaging sensitive circuitry. Through chip design and layout techniques, the electromagnetic compatibility of the ISO6731 device receives significant enhancement to ease application-level ESD, EFT, surge, and emissions compliance. The ISO6731 device comes available in a 16-pin SOIC wide body (DW) package and provides a pin-to-pin upgrade to the older generations.

### **2.3.5 TRS3232EIDBR**

The TRS3232E device consists of two-line drivers, two-line receivers, and a dual charge-pump circuit with  $\pm 15\text{kV}$  IEC ESD protection pin to pin (serial-port connection pins, including GND). The device meets the requirements of TIA/EIA-232-F and provides the electrical interface between an asynchronous communication controller and the serial-port connector. The charge pump and four small external capacitors allow operation from a single 3V to 5.5V supply. The devices operate at data signaling rates up to 250kbps and a maximum of  $30\text{V}/\mu\text{s}$  driver output slew rate.

### **2.3.6 TPS70933DBVR**

The TPS709 series of linear regulators are ultra-low, quiescent current devices designed for power sensitive applications. A precision band gap and error amplifier provide 2% accuracy over temperature. Quiescent current of only  $1\mu\text{A}$  makes these devices an excellent choice for battery-powered, always-on systems that require very little idle-state power dissipation. These devices have thermal-shutdown, current-limit, and reverse-current protections for added safety. Shutdown mode is enabled by pulling the EN pin low. The shutdown current in this mode goes down to  $150\text{nA}$ , typical. The TPS709 series is available in WSON-6 and SOT-23-5 packages.

### **2.3.7 CDC6C**

Texas Instruments' high-precision Bulk-Acoustic Wave (BAW) micro-resonator technology is integrated directly into a package allowing for low-jitter clock circuitry. BAW is fully designed and manufactured at TI factories like other silicon-based fabrication processes. The CDC6Cx 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 can produce any frequency within the specified range providing a single device family for all frequency needs. The high-performance clocking, mechanical stability, lower power consumption, flexibility, 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.

## 3 Hardware, Software, Testing Requirements, and Test Results

### 3.1 Hardware Requirements

#### 3.1.1 Shunt Resistor Requirements

Selecting the appropriate shunt resistor is one of the most critical and challenging aspects of a high-current DC metering design. The shunt must provide accurate current sensing while dissipating significant power

For high-current applications, such as a maximum current of 200A, a low-resistance, high-power shunt is required. In this design, a 0.2mΩ resistor is selected. [Equation 1](#) shows the expected power dissipation calculation.

$$P = I^2R = (200)^2 \times 0.0002 = 8W \quad (1)$$

In practice, do not operate shunt resistors continuously at the maximum rated power. Without adequate cooling, shunts are limited to approximately two-thirds of the rated power.

To improve thermal performance and current-handling capability, two 5931, 15W shunt resistors are connected in parallel. This configuration reduces the resistance to 100μΩ, distributes heat more evenly, and increases the overall power rating of the sensing element.

Additionally, the selected shunt must have:

- Low temperature coefficient of resistance (TCR) to minimize drift
- High long-term stability
- Low inductance for dynamic current measurements

#### 3.1.2 PCB Layout Requirements

High-current DC metering places significant thermal and electrical stress on the PCB. Most power dissipation occurs in the current-carrying copper traces and connection points.

To support high current levels, the following layout guidelines are required:

- High-current traces must be as wide and short as possible
- Copper thickness must be at least 4 oz
- Make sure PCB thickness is 2mm or greater
- Multiple copper layers – four or more is recommended – can be paralleled using vias to increase current capacity
- Make current paths symmetrical to prevent localized heating

Avoid thermal relief on high-current pads to minimize resistance and temperature rise.

#### 3.1.3 Component Placement Requirements

Key placement guidelines include:

- Sensitive analog components (ADC, amplifiers, references) must be placed away from high-current and high-temperature areas.
- Maintain adequate spacing to prevent thermal coupling

This approach reduces thermal drift and helps maintain long-term measurement accuracy.

### 3.1.4 Thermal Management Requirements

Effective thermal management is essential for high-current DC meters.

Recommended practices include:

- Use of copper pours and heat-spreading planes
- Thermal vias under high-power components
- Optional external heat sinks for shunts
- Forced-air cooling for enclosed systems
- Ventilation openings in the enclosure

Make sure that component junction temperatures remain within specified limits under worst-case operating conditions.

### 3.1.5 Isolation Requirements

For regulatory compliance, electrical isolation and spacing must be considered.

Design requirements include:

- Adequate creepage and clearance distances
- Reinforced insulation between high-voltage and low-voltage domains
- Isolation amplifiers or isolated ADCs
- Proper grounding of exposed conductive parts

### 3.1.6 EMI and EMC Considerations

High-current switching and load variations can introduce electromagnetic interference.

Design practices include:

- Proper filtering on power inputs
- Shielding of sensitive circuits
- Controlled return paths
- Ferrite beads where needed
- Compliance with applicable EMC standards

These measures reduce noise and improve measurement stability.

## 3.2 Software Requirements

To use the TIDA-010999 design, three pieces of software must be installed on the PCB to evaluate DC metering.

1. This reference design uses a USB-to-RS-232 cable to communicate to GUI. The drivers for the cable must be installed. Download the U209-000-R cable drivers from the [EATON serial adapter cable](#).
2. Download the [MSPM0-SDK](#). The SDK package includes the Energy Metrology GUI.

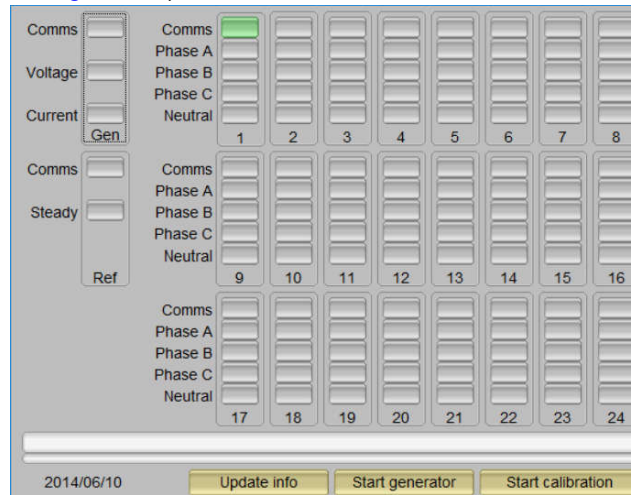
### 3.2.1 TIDA-010999 Metrology

Metrology software is flashed onto the reference design with 1% out-of-the-box accuracy.

### 3.2.2 GUI Operation

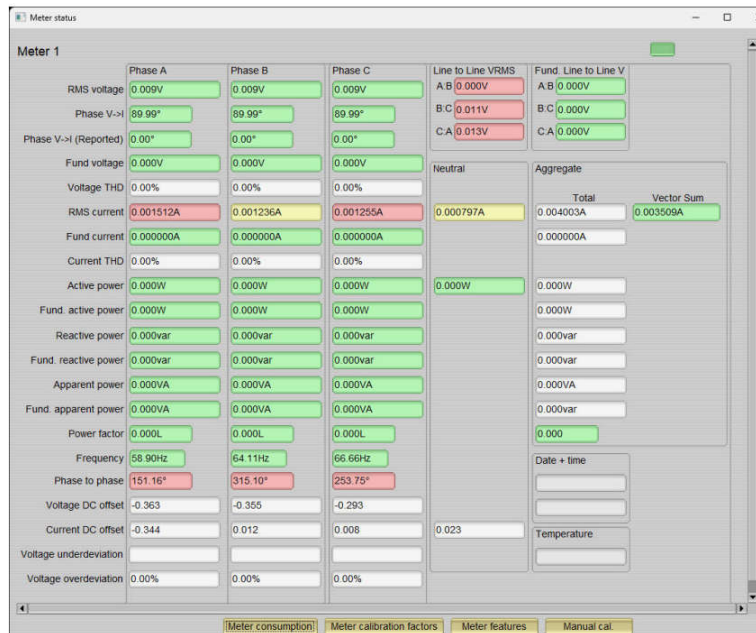
Follow these steps to operate the reference design GUI:

1. Once code is flashed onto the reference design, TIDA-010999 is ready for evaluation.
  - a. Connect the RS-232 cable from the TIDA-010999 to the PC.
  - b. Open device manager to see which COM port connects the TIDA-010999.
  - c. Open calibration-config in a text editor to set up the connection:
    - i. Press *Ctrl + f* and search for COM. Once COM is located, change the COM setting to whatever COM TIDA-010999 is connected to from step b. Make sure the baud rate is 115200.
    - ii. Save settings and close the text editor.
2. Locate the GUI folder in the SDK files and open *Calibrator* in metrology-gui in the sdk file C:\ti\mspm0\_sdk\_2\_10\_00\_01\tools\metrology\_gui
  - Open the green cell (see [Figure 3-1](#))



**Figure 3-1. Green Cell Selection**

- The meter is ready for calibration (see [Figure 3-2](#))



**Figure 3-2. Meter Status GUI**

### 3.2.3 Voltage and Current Measurements

Voltage and current measurements are stored in DC voltage offset and DC current offset in the GUI. Power measurement is calculated and stored in active power.

### 3.3 Test Setup

For this reference design, ANSI C12.32 standards tests are implemented to provide accuracy and reliable DC metering. For the test setup, a current source and a separate voltage source is used to provide separate voltage and current to the meter.

### 3.4 Test Results

#### 3.4.1 Test Number One: Determination of the Initial Intrinsic Error

**Objective:** The objective of this test is to verify that the error of the meter at reference conditions is less than the relevant BMPE given in [Table 3-1](#).

**Error Measurements:** Sweep accuracy measurements from minimum current to maximum current, then leave the meter running at maximum current for 10 minutes, then sweep down to minimum current. Record the error measurement at each test point for current up and current down. The actual error measurement is the mean between each test point at the same current level.

Do not spread each individual test point result about the mean of the two test-point results at each test current by more than  $\pm 34\%$  of the Base Maximum Permissible Error (BMPE).

For example, Class B is targeted at  $\pm 1\%$ :

- $1\% \times 34\% = 0.34\%$
- Up sweep = 0.55%
- Down sweep = 0.45%
- Mean =  $(0.55 + 0.45) / 2 = 0.50\%$
- $0.5\% \pm 0.34\% = 0.16\% - 0.84\%$

Both up sweep and down sweep must be within 0.16% and 0.84% to qualify for Class B accuracy.

**Table 3-1. Determination of the Initial Intrinsic Error Test Results**

CURRENT UP	ERROR 1	AVG Error %	CURRENT DOWN	ERROR 1	AVG ERROR %	MEAN	ACCURACY CLASS
50	0.07925	<b>0.0793</b>	50	0.097661749	<b>0.0977</b>	0.0885	Class E
55	0.12459	<b>0.1246</b>	55	0.063479625	<b>0.0635</b>	0.0940	Class E
60	0.17664	<b>0.1766</b>	60	0.037994094	<b>0.0380</b>	0.1073	Class D
70	0.09946	<b>0.0995</b>	70	-0.10031581	<b>-0.1003</b>	-0.0004	Class C
80	0.08925	<b>0.0893</b>	80	-0.19100382	<b>-0.1910</b>	-0.0509	Class C
100	-0.01020	<b>-0.0102</b>	100	-0.43800876	<b>-0.4380</b>	-0.2241	Class B
150	-0.32369	<b>-0.3237</b>	150	-0.72834159	<b>-0.7283</b>	-0.5260	Class B
170	-0.52407	<b>-0.5241</b>	170	-0.8458809	<b>-0.8459</b>	-0.6850	Class C
185	-0.69228	<b>-0.6923</b>	185	-0.94364049	<b>-0.9436</b>	-0.8180	Class C
200	-0.79506	<b>-0.7951</b>	200	-1.03807256	<b>-1.0381</b>	-0.9166	Class C

**Summary:** The meter passes Class B accuracy at 200A with an onboard shunt.

### 3.4.2 Test Number Two: Starting Current

**Objective:** The purpose of this test is to verify that the meter can generate the appropriate number of pulses within the allowable time frame between one pulse and the next.

The expected time, T, between two pulses is given by [Equation 2](#).

$$\frac{3.6 \times 10^6}{m \times k \times V_{\min} \times I_{st}} \quad (2)$$

where

- m = number of elements = 1
- k = number of pulses = 10000
- $V_{\min}$  = minimum voltage = 90V
- $I_{st}$  = starting current = 0.5, 1, 2

**BMPE:** The time between each test pulse at  $I_{st}$  must be less than 1.5T for each current range.

**Table 3-2. Starting Current Test Results**

CURRENT	TIME OF TP1 (S)	TIME OF TP2 (S)	TIME OF TP3 (S)
<b>0.5</b>	<b>8.90</b>	<b>8.88</b>	<b>9.03</b>
<b>1</b>	4.23	4.21	4.25
<b>2</b>	<b>2.10</b>	<b>2.16</b>	<b>2.03</b>

**Summary:** The meter passes **class E** for this test.

### 3.4.3 Test Number Three: No-Load Conditions

**Objective:** This test is to make sure that the meter does not produce pulses when the current is not flowing through the meter.

Perform this test at  $V_{min}$ .

$$\Delta t \geq \frac{3.6 \times 10^6}{b \times m \times k \times V_{min} \times I_{min}} \text{hours} \tag{3}$$

where

- B = accuracy at the specified class in  $I_{min}$  range = accuracy class of interest (0.2)
- K = test pulses = 10000
- M = number of elements = 1
- $I_{min}$  = minimum current = 0.5
- $V_{min}$  = minimum voltage = 90V

**Requirement:** The meter must not produce more than one test pulse during the time specified from Equation 3.

**Table 3-3. No-Load Conditions Test Results**

CLASS	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E
TIME IN H	0.0800	0.1333	0.2000	0.5000	1.0000
TIMER SETTING	04:48	08:00	12:00	30:00	01:00:00
REGISTERED PULSES	0	0	0	0	0

**Summary:** The meter passes **Class E** for this test. The meter did not accumulate any pulses when there is no current flowing through the meter.

### 3.4.4 Test Number Four: Voltage Variation, Voltage Measurement Port

**Objective:** To verify that the meter operates accurately when the input voltage varies during normal operation.

**Test points:**  $0.9 \times V_{min} - 1.1V$  maximum while current is at  $I_{tr}$ .

**Table 3-4. Voltage Variation, Voltage Measurement Port Test Results**

VOLTAGE	TEST CURRENT = 100A	
	ERROR	CLASS
50	-0.208	Class C
100	-0.351	Class B
150	-0.378	Class B
300	-0.404	Class B
500	-0.434	Class B
8405.5	-0.456	Class B

**Summary:** The meter passed *Class B* for this test. This is the result of temperature drift over current. And the voltage divider is placed close to the pads where the current connects to the board. Better layout and heat compensation is required for better performance.

## 4 Design and Documentation Support

### 4.1 Design Files

#### 4.1.1 Schematics

To download the schematics, see the design files at [TIDA-010999](#).

#### 4.1.2 BOM

To download the bill of materials (BOM), see the design files at [TIDA-010999](#).

#### 4.1.3 PCB Layout Recommendations {Optional Section}

##### 4.1.3.1 Layout Prints {Optional Section}

To download the layer plots, see the design files at [TIDA-010999](#).

## 5 Tools and Software

### Tools

<a href="#">LaunchPad Development Board</a>	Required for flashing code onto the reference design
<a href="#">J-Tag Debugger</a>	Hardware interface tool (based on IEEE 1149.1) that connects a PC to the processor of an embedded system or FPGA to debug code, test hardware, and program flash memory directly.

### Software

<a href="#">EATON Serial Adapter Cable Link</a>	USB-A to RS-232 (DB9) Serial Adapter Cable (M/M), software, firmware, and drivers
<a href="#">MSPM0-SDK</a>	MSPM0 software development kit (SDK)

## 6 Documentation Support

1. Texas Instruments, [LMR436x0-Q1, 36V, 1A / 2A, Automotive Buck Converter With < 2.5μA I<sub>Q</sub> at 150°C T<sub>JMAX</sub> in 4mm<sup>2</sup>HotRod™ QFN Datasheet](#)
2. Texas Instruments, [TPS62850x-Q1 2.7V to 6V, 1A / 2A / 3A Automotive Step-Down Converters in SOT583 Package Datasheet](#)
3. Texas Instruments, [TLIN1021A-Q1 Fault-Protected LIN Transceiver With Inhibit and Wake Datasheet](#)

## 7 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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## 9 About the Author

**DANIEL MAAYA** is a systems engineer at Texas Instruments in Dallas, where he focuses on the development of precision analog front-end designs for power metering and grid infrastructure applications. Daniel brings to this role a multidisciplinary background in electrical and power electronics with deep expertise in signal conditioning, metrology compliance (ANSI/IEC), power converters, and Rogowski coil-based sensing systems. He has direct experience with both analog hardware design and system-level integration, including EMC testing and calibration for high-accuracy measurement.

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