Design Guide: TIDA-010986
Signal Conditioning for Rogowski Coil Reference Design

Description

This reference design is a signal conditioning reference design for Rogowski coils, targeting enhanced accuracy for current measurement in e-meters, circuit breakers, protection relays, and EV chargers enabling Rogowski coil measurements to meet ANSI C12.1 and IEC compliance standards. This op-amp-based active integrator design covers a wide dynamic current range with bandwidth, stability, and adjustable gain (1V/V to 525V/V). The design is optimized for three-phase systems and interfaces with TI's *ADS131M08 Metrology Evaluation Module*. The design aims to achieve current transformer-like accuracy at a cost similar to shunt-based designs and also meet class 0.2 and better accuracy levels compared to a current transformer (CT) without a magnetic core.

Resources

TIDA-010986	Design Folder
INA818, INA828, INA188	Product Folder
TLV9001, LM27762, ADS131M08	Product Folder
TIDA-00601	Design Folder

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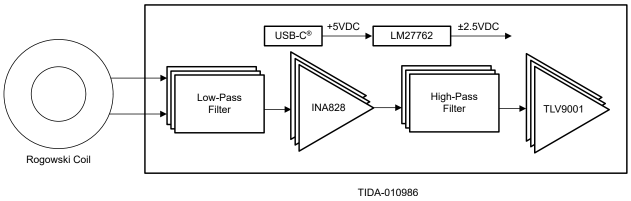
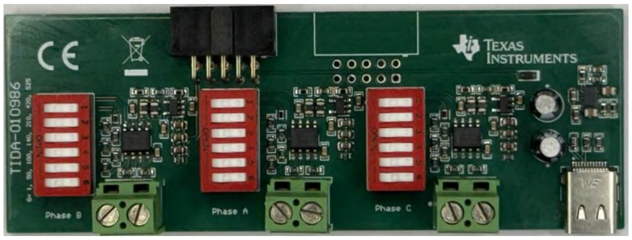
Features

- Current measurement using Rogowski (di/dt) coil-based current sensor
  - Amplification and integration are accomplished using hardware components (op amps)
  - CT-like performance at class 0.2 or better accuracy according to ANSI C12.1
- Wide current range
  - 0.1A to > 1000A (tested up to 100A), adjustable through gain settings
- High performance
  - Theoretical settling time: 30ms
  - Low BOM cost and small PCB footprint
  - Designed to interface directly with ADS131M08 through plug-in form factor

Applications

- Electricity meter
- AC charging (pile) station
- DC fast charging station
- AFCI circuit breaker
- Industrial circuit breaker (MCCB, ACB, VCB)





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1 System Description

E-meters, circuit breakers, protection relays, and EV chargers are essential components of modern grid infrastructure, supporting protection, control, and monitoring across power generation, transmission, and distribution systems. These applications rely on accurate voltage and current sensing through sensor elements to provide reliable performance, safety, and efficiency.

1.1 Key System Specifications

PARAMETER	SPECIFICATION
Current sensor type	PCB and off-the-shelf (OTS) Rogowski coil
Rogowski coil output specifications	PCB Rogowski: 16μV/A to 100μV/A
Number of input currents (phases)	Three phases
Measurements frequency	50Hz, 60Hz
Integrator type	Active
Integrator output	Bipolar
AC current measurement range	0.1A → 1000A (tested at 100A)
Accuracy class	< 0.2%
Phase angle error	< 1º
Integrator time constant	Approximately 30ms
External DC power supply input	USBC, 5VDC

1.2 Electricity Meters

Electronic energy meters (e-meters) are used to accurately measure and monitor electrical energy consumption in residential, commercial, and industrial settings. These meters capture voltage, current, and frequency. E-meters often include metrology engines that use measured values to compute RMS voltage, RMS current, active power, reactive power, power factor (PF), Total Harmonic Distortion (TDH), phase shifts, frequency, and energy usage in real time.

Modern e-meters often integrate Rogowski coils, shunt resistors, and current transformers (CTs) as current sensors. Rogowski coils are advantageous due to the linear output, wide dynamic range, compact form factor, saturation immunity, high bandwidth, and temperature drift resistant. These sensors, combined with high-resolution ADCs and precision analog front ends, enable e-meters to deliver class 0.2 or better measurement accuracy.

To support time-of-use billing, load forecasting, and grid diagnostics, e-meters must maintain high accuracy across a wide dynamic range—from low standby currents to peak loads. Accurate current sensing is critical for both billing accuracy and compliance with regulatory standards like ANSI C12.1 and IEC 62053. Fast response time and stability over temperature and aging are also crucial, especially in smart grid systems where e-meters communicate usage data to utility providers for real-time monitoring and load management.

1.3 Circuit Breakers

Circuit breakers protect electrical systems by detecting overloads and short circuits, then disconnecting power to prevent damage or fire. Fast and accurate current sensing is critical to trip the breaker at the right time.

Rogowski coils are designed for circuit breakers because these coils can detect very high currents during faults without saturating. The fast response and wide measurement range make them an excellent choice for triggering trip units quickly and reliably. Using Rogowski coils helps improve breaker performance, especially in modern electronic trip systems that require precise, real-time current data.

1.4 EV Chargers

EV chargers need to measure current accurately for safety, billing, and control. During charging, current levels can vary widely—from low levels during slow charging to very high currents during fast charging.

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Rogowski coils are an excellent choice for EV chargers because these coils can measure a wide range of currents with high accuracy and do not saturate like traditional current transformers. The coils can also handle fast-changing signals well, making them an excellent choice for the high-frequency switching used in power electronics. Using Rogowski coils helps EV chargers meet safety standards and deliver reliable, efficient charging.

1.5 Protection and Relay

Protection relays provide protection to grid equipment during fault conditions by monitoring multiple voltages and currents. If the relays detect a stressed condition, a trip signal is sent to the circuit breaker to isolate the faulty section from the power system. Protection relays accurately measure current inputs using current transformers (CT), Rogowski coils, or shunts and voltage inputs using potential transformers (PT) or potential dividers. Additionally, protection relays do precise measurement. These relays have auxiliary power (AC or DC).

1.6 Rogowski Coil-Based Current Sensor

1.6.1 Principle

A Rogowski coil is an air cored (non-magnetic) toroidal windings placed round the conductor. An alternating magnetic field produced by the current in the primary conductor (IP) induces a voltage (V_S) in the coil. Due to the non-magnetic core, the output of the coil does not saturate for a large primary current.

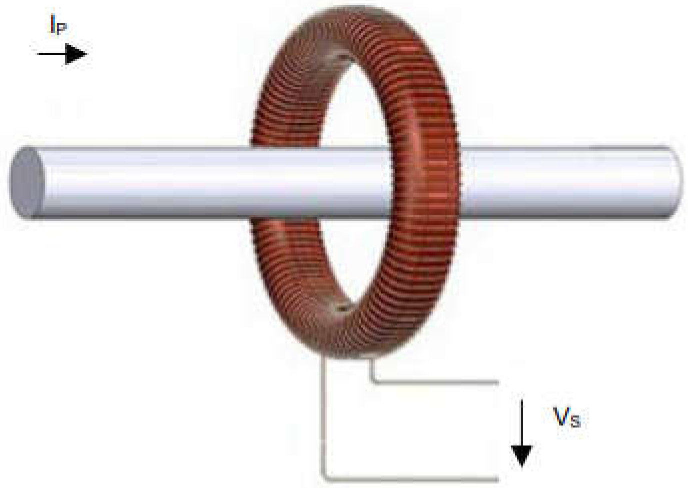

Figure 1-1. Rogowski Coil-Based Current Sensor

The output voltage of a Rogowski coil is proportional to the rate of change of the current in the primary conductor, and the voltage is not affected by the DC current. Rogowski coils with a wide current range can be used for both measurement and protection applications. The coils provide galvanic isolation from the primary circuit. Because Rogowski coils convert input current to an output voltage, no burden resistor is needed. This, in turn, reduces power consumption. Unlike current transformers, Rogowski coils are electrically safe when open.

1.6.2 Rogowski Coil Types

The following list describes three Rogowski coil types:

- Rigid Rogowski coils are wound on a toroidal shape core made of epoxy, plastic, or other nonmagnetic materials.
- Flexible Rogowski coils are wound over flexible material such as silicone or a rubber tube.
- PCB Rogowski coils are tightly wound, uniform traces on a two-layer stackable PCB.

1.6.3 Integration Methods

The voltage (V_S) induced at the output of a Rogowski coil is proportional to the time rate of change of current flowing in the primary conductor (IP). The output voltage has a 90° phase shift and lags input for a sinusoidal

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input current. Because the output of the Rogowski coil is proportional to the derivative of the instantaneous primary current, an integrator is required to retrieve the original current signal. The output voltage is linear, which can be used without integration in applications requiring only current measurement. For applications requiring measurement of power, the phase difference between current and voltage is important and requires phase shifting of the Rogowski current sensor output. This is done using an integrator. A Rogowski integrator can be implemented in two ways:

- Digital (software) integration: Integration in the frequency domain results in –20dB/decade attenuation and a constant –90 degree phase shift. Phase angle correction accuracy improves significantly when done digitally, due to precise phase and magnitude response control. Accurate digital integration requires high-performance microcontrollers (MCUs) and analog-to-digital converters (ADCs) with digital filter implementation. Delayed processing occurs during start-up, attributed to the complexity of digital filter implementation. Digital filters are executed by MCUs and ADCs in the system.
- Hardware integration: A hardware integrator can also be used for correcting the Rogowski current sensor phase shift. This can be achieved using a passive integrator (resistors, capacitors) or an active integrator (combination of active (op amp) and passive elements). This TI Design implements a stable op amp-based active integrator that can be used over the useful temperature range.

A well-designed hardware integrator introduces a 90° phase shift; however, practical limitations can result in phase errors and inaccuracies. Carefully choosing components minimizes the phase error variations.

1.6.4 Rogowski Coil Selection

Rogowski coils are the best substitution for current transformers and shunt resistors because of EMI rejection, parasitic capacitance elimination, saturation immunity, low drift over temperature, small form factor, and low price. While a rigid coil has better accuracy, flexible coils are convenient for measuring current in large or non-round shaped conductors such as bus bars. PCB coils are preferred because PCB coils are customizable and have a thin form factor. However, for some applications, a signal conditional circuit is needed.

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2 System Overview

The output signal from the coil is very small, shifted 90 degrees, and distorted around the zero crossing. A new differential PCB coil design is proven to be immune to EMI, cancels the effect of parasitic capacitance, and higher CMMR. To accommodate for the changes in the PCB coil design, a new signal conditioning circuit must be redesigned.

2.1 Block Diagram

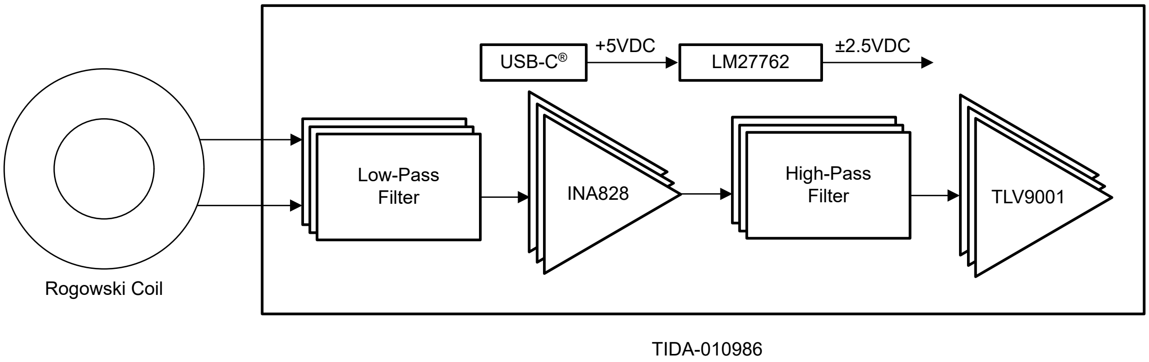

Figure 2-1. TIDA-010986 Block Diagram

The TIDA-010986 consists of 6 main sections:

- Differential gain amplifier
- High-pass filter
- Low-pass filter
- Active integrator
- USB-C® power input
- Bipolar power supply
- Two different output options

2.1.1 Differential Gain Amplifier

Since the signal from the coil is very small, a gain amplification stage is needed to improve the input signal for the ADC. The INA828 device is selected for the gain stage because of the low output noise, high CMMR, and high bandwidth at high-gain settings to be flexible for multiple applications, not just for metering applications. This amplifier uses a single resistor for setting the gain, which allows the end uses to cut down on cost instead of using two resistors for gain setting in a traditional gain op-amp circuit.

2.1.2 High-Pass Filter

The signal from the coil is distorted, with a potential DC offset present. Integrators are sensitive to DC offsets, so any DC offset can cause excessive integration, resulting in huge output offsets. Adding a high-pass filter AC-couples the input to the integrator, removing any DC offsets and improving accuracy at higher amplitudes.

2.1.3 Low-Pass Filter

Rogowski coils are di/dt sensors measuring the rate of change of current rather than the current. As a result, Rogowski coils are highly sensitive to rapid transients and switching noise, especially near the zero-crossing point of the current waveform. At zero crossing, the current (i) is momentarily at zero leading to sharp voltage spikes and high-frequency ringing at the output of the coil. Zero crossing spikes and ringing can distort the signal and introduce non-linearity in the signal chain.

To address the *zero* crossing issues and non-linearity, a low-pass filter is implemented at the input of the differential amplifier. The purpose of the low-pass filter is to attenuate high-frequency components, including the unwanted spikes and ringing, thereby improving signal integrity and making the system behave more linearly.

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2.1.4 Active Integrator

Rogowski coil output, especially PCB Rogowski is very low (about 50μV/A), this becomes an issue at lower currents, for example 100mA, where the signal needs to be amplified by (100V/V – 500V/V) depending on the sensitivity of the coil. The active integrator circuitry acts as an attenuator while shifting the current waveforms by 90 degrees. Attenuating the low input signal decreases the accuracy because the signal becomes very low where the ADC sees the signal as noise. The gain of the integrator must be set to unity gain to cancel the integration attenuation at the frequency of interest (50Hz–60Hz).

To achieve 90 degrees phase shift and gain of one, passive components must be calculated correctly and the type of components must be the right type for math operation for a discreet approach.

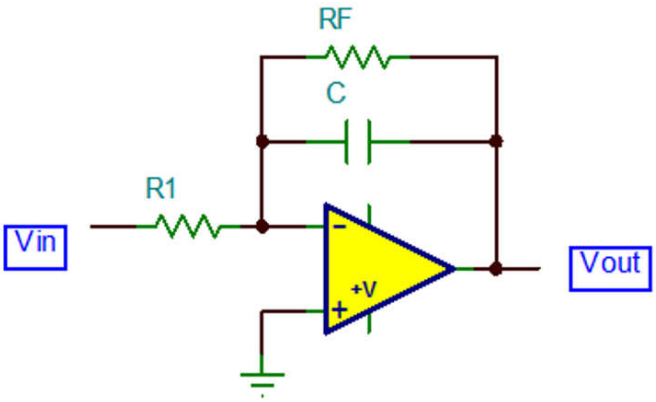

Figure 2-2. Schematics of an Integrator Circuit

2.2 Design Considerations

2.2.1 Components Selection

Gain of the system can be controlled at two stages, the gain stage and the integrator stage. Gain selection is highly influenced by the application. Some applications require stepping down high amplitudes of current to a measurable value for protection purposes where the currents are greater than 1kA. For protection applications, where the precise measurements are crucial, the current is stepped down to the mV ranges where the gain amplifier amplifies the signal, then the integrator (*set to attenuate*) attenuates all the noise in the system for precision measurements. This design has multiple gain settings ranging from 1V/V to 525V/V depending on the type and sensitivity of Rogowski coil where the gain of the integrator has been set to *unity gain*. These gain settings are selected at 100A of maximum current according to class 100 of *ANSI C12.1 2024* standards and to accommodate to different sensitivities.

2.2.1.1 RC Component Selection

This design targets low phase error, low noise, fast settling, and precision measurements. To target low phase error < 3 degrees, an RC time constant of < 30ms is selected. A 100kΩ resistor and 0.3μF capacitor are selected to get 30ms of settling time for the integrator. Select an integrator capacitor with low (< ±5%) tolerance and lower temperature drift. *C0G/NP0* capacitors have good frequency response and temperature stability. The resistors used in the design have a ±0.1% tolerance and are *thin film* material to improve accuracy, repeatability, and does not introduce additional noise to the system.

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2.2.1.2 RG Selection for Gain Setting

Gain selection of the gain amplifier is only controlled by using a single resistor (RG). Resistor RG connects to pin 1 and pin 8 of the INA828 device. This resistor must be as close as possible to the pins of the amplifier to reduce the line capacitance between pin 1 and pin 8. The gain of the amplifier must be set correctly according to:

$$\mathrm{S} \times \mathrm{I}_{\mathrm{max}} \times \mathrm{Gs} = \mathrm{L} \tag{1}$$

where

S = sensitivity of the coil (measured in μV)

I_{max} = the maximum current that is flowing through the conductor

L = limit of the analog input pins of the ADC

Gs = gain of the system

where

$$\mathrm{Gs} = \mathrm{Gain}_{\mathrm{amp}} \times \mathrm{Gain}_{\mathrm{int}} \tag{2}$$

$$\mathrm{Gain}_{\mathrm{amp}} = 1 + \frac{50\mathrm{k}}{\mathrm{RG}} \tag{3}$$

$$\mathrm{Gain}_{\mathrm{int}} = \left(\frac{\mathrm{RF}}{\mathrm{RI}}\right) \times \left(\frac{1}{\sqrt{1 + (2\pi \times \mathrm{F} \times \mathrm{RF} \times \mathrm{C})^2}}\right) \tag{4}$$

Note

To set the gain to the correct value, sensitivity and maximum current *must be known*.

2.3 Highlighted Products

2.3.1 INA828

A 3A instrumentation amplifier is used for voltage monitoring of each phase in the Rogowski coil design. Selecting the right instrumentation amplifier is critical for this front-end.

Key specifications for selecting an instrumentation amplifier include:

- High common-mode rejection ratio helps in reducing the amount of common-mode noise observed on both inputs of the instrumentation amplifier.
- Low-voltage noise density improves accuracy at low-input currents of higher sensitivity Rogowski coil.
- Low gain error offset and gain error drift helps in minimizing calibration as well as degradation in performance over temperature.
- Wide voltage gain range unlocks compatibility with a wide-range of different Rogowski coil outputs.

The INA818 instrumentation amplifier is used in this design for the integrator and gain stage. Alternatively, when looking for a lower noise floor, consider using the INA828 or the INA188 for improved drift over temperature for a small increase in voltage noise.

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2.3.2 TLV9001

An op amp plays a crucial role in providing accurate integration and signal conditioning in current-sensing applications. Choosing the right op amp is essential to achieving precision, stability, and repeatable results over a wide operating range.

Key specifications for selecting an op amp for the integrator stage include:

- Low offset voltage and drift, which reduce the need for frequent calibration and help maintain long-term accuracy across temperature variations.
- Low input bias current, which minimizes loading on the Rogowski coil and helps preserve signal fidelity.
- Low-voltage noise density, improving measurement accuracy and repeatability, especially at low input current levels.

The rail-to-rail input/output and low power consumption of the TLV9001 also make the device a good fit for compact, low-power designs where integration performance cannot be compromised.

2.3.3 LM27762

The LM27762 delivers very low-noise positive and negative outputs that are adjustable between ±1.5V and ±5V. The input-voltage range is from 2.7V to 5.5V, and output current goes up to ±250mA. With an operating current of only 390μA and 0.5μA typical shutdown current, the LM27762 provides best-in-class performance for the power amplifier and DAC bias and other high-current, low-noise negative voltage needs. The device provides a small deign size with few external components.

3 System Design Theory

3.1 Schematics to Layout

3.1.1 Rogowski Input Connectors

Figure 3-1 and Figure 3-2 show the connector where the differential Rogowski coil interfaces with the signal conditioning circuit. A 2-pin terminal (J1) receives the differential output of the coil through inputs INPUT_1_P and INPUT_1_N. To provide signal integrity and avoid undefined behavior when the coil is disconnected. Pulldown resistors at 47.5kΩ (R9 and R10) are placed from each input to ground as suggested in the *INA828 50μV Offset, 7nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier* data sheet. These resistors prevent the inputs from floating, which can otherwise lead to noise pickup or erratic behavior in the integrator stage.

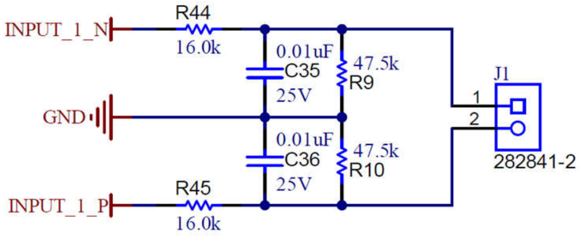

Figure 3-1. Terminal Block Input Connection Schematic

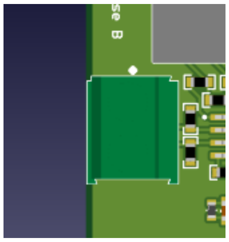

Figure 3-2. Terminal Block Input Connection

3.1.2 Gain Setting Resistor Chain

Figure 3-3 and Figure 3-4 show the resistor chain which sets the gain of the gain amplifier stage. The flexible design of the chain accommodates a wide range of gain values dependent on application requirements and coil sensitivity. A DIP switch (SW1) selects one resistor at a time from a set of precision resistors (R15–R20), each corresponding to a specific gain value that correspond to a range of sensitivities.

Each position on the switch routes pin 1 and pin 8 of the gain amplifier to a different value resistor, providing a discrete set of gain options labeled on the PCB silkscreen: G = 1, 50, 100, 140, 210, 420, and 525. These values are carefully chosen to cover a wide range of Rogowski coil outputs and to provide compatibility with both low- and high-current measurements.

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The resistor chain approach simplifies testing and calibration, allowing engineers to quickly evaluate different gain settings without modifying the PCB layout or reworking components.

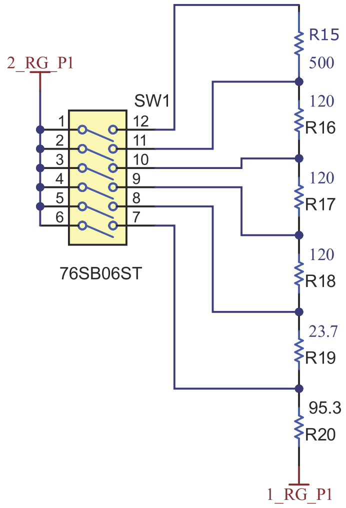

Figure 3-3. Discrete Potentiometer Resistor Chain Schematic

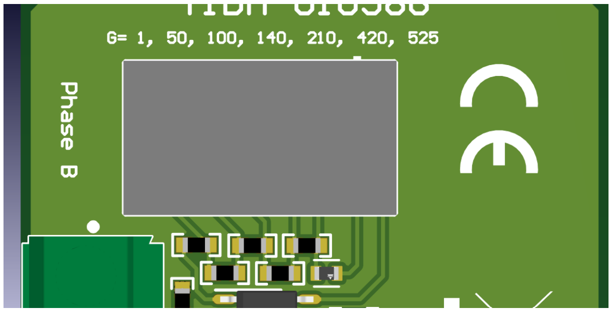

Figure 3-4. Discrete Potentiometer Resistor Chain

3.1.3 Gain Amplifier and High-Pass Filter Stage

This stage utilizes the INA828, a precision instrumentation amplifier, to amplify the differential signal from the Rogowski coil. The amplifier is configured for a bipolar output, with the gain set by an external resistor (connected to RG pins) explained in Section 3.1.2 and calculated in Section 2.2.1.2. This configuration allows for flexible adjustment based on the sensitivity of the coil and the desired output range. The amplifier provides excellent common-mode rejection and high input impedance, making the amplifier an excellent choice for handling the low-level differential signals generated by the Rogowski coil.

Following the amplifier, a high-pass filter is implemented using capacitors C13 and C21 (44μF total) and resistor R33 (50.5kΩ). This filter blocks DC components and low-frequency drift, allowing only the AC signal (representing the proportional waveform) to pass through. This is particularly important to reject baseline shifts that can accumulate due to integration over time, coil disconnection, or long-duration operation.

This stage makes sure that the signal is properly amplified and cleaned before feeding into the integrator, enabling accurate current waveform reconstruction and measurement.

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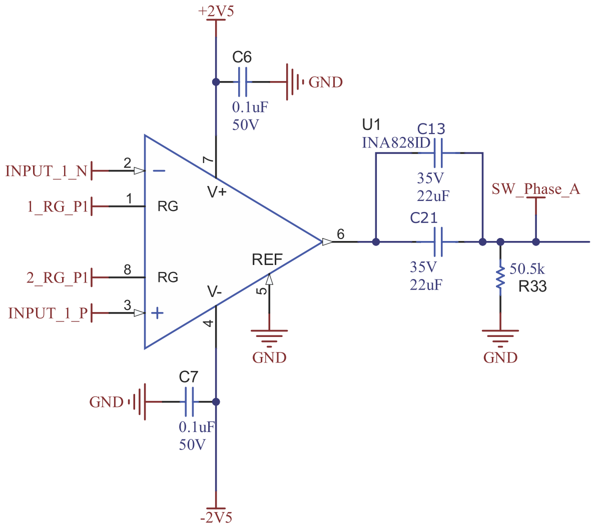

Figure 3-5. Gain Amplifier and High-Pass Filter Schematic

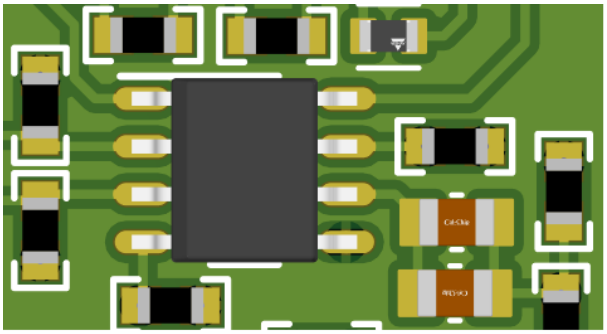

Figure 3-6. Gain Amplifier and High-Pass Filter

3.1.4 Active Integrator Stage

The circuit shown in Figure 3-7 and Figure 3-8 is an active integrator using the TLV9001IDBVR op amp, optimized for precision signal conditioning of the Rogowski coil output. This stage integrates the bipolar proportional output voltage from the differential gain amplifier to reconstruct the corresponding current waveform.

The adjacent layout view in Figure 3-8 shows the compact PCB implementation of this integrator stage. Proper placement of passive components and the TLV9001 provides signal integrity and minimizes noise. Feedback components are routed with short traces to reduce parasitic effects.

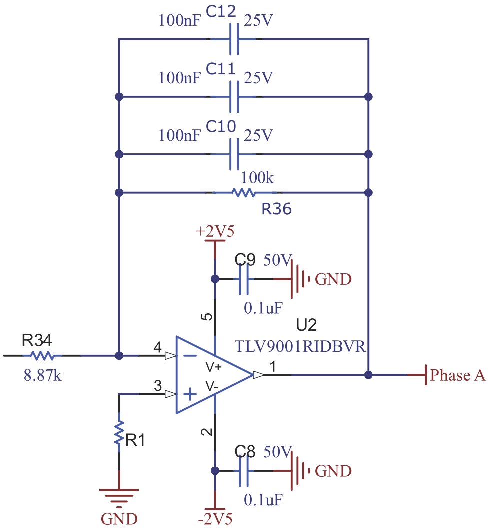

Figure 3-7. Active Integrator Circuit Schematic

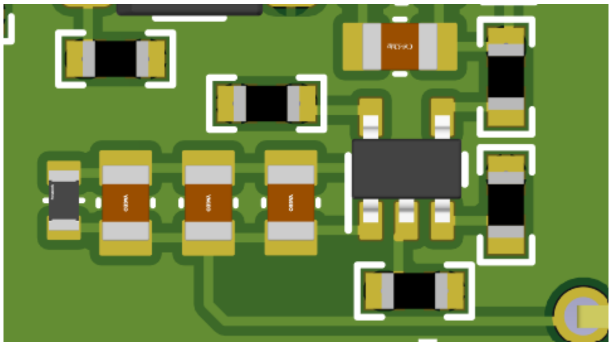

Figure 3-8. Active Integrator Circuit

3.1.5 Output Stage

The output stage provides two types of signals for evaluation and flexibility in testing:

- **Hardware-Integrated Signal Output:** This path provides the output after analog integration using the TLV9001 op amp. This method represents the fully conditioned current signal from the Rogowski coil (CT-like signal), ready for direct measurement and digitization.

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- **Amplified Signal without Hardware Integration:** This path bypasses the integrator stage, allowing the user to test software-based integration methods. The method provides the raw amplified Rogowski coil signal, which is especially useful when evaluating digital integration performance in the *ADS131M08 Metrology Evaluation Module*.

The output connectors are designed to directly interface with the *ADS131M08 Metrology Evaluation Module*, eliminating the need for manual jumper wires or rework. This streamlined approach improves test efficiency, reduces errors from miswiring, and makes sure of a reliable connection between the signal conditioning board and the metrology platform.

The corresponding PCB layout shows the two different output connectors. The top one being the hardware integrated signal and the bottom one being the amplified signal pre-integration.

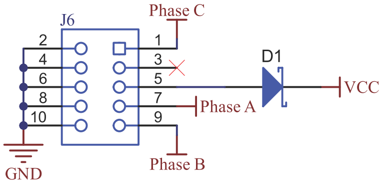

Figure 3-9. Output Connectors Schematic

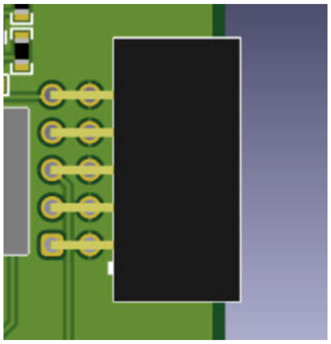

Figure 3-10. Output Connectors

3.1.6 Power Supply

The power supply stage is responsible for providing the required bipolar supply rails for the analog signal chain. This stage uses a USB-C input to accept a standard 5V supply, which is then stepped down and converted to ±2.5V using the LM27762 charge pump inverter.

This setup provides:

- Both +2.5V and –2.5V rails, required for the INA828 and the TLV9001 op amps
- A compact, efficient, and low-noise power design, eliminating the need for external bipolar supplies

The PCB layout shows a clean implementation of the USB-C connector and power circuitry, including proper bypassing and output filtering to provide stable operation. The symmetric layout around the LM27762 minimizes ripple and provides low output impedance, which is essential for analog precision applications.

This self-contained power design allows for easy integration and portability of the entire system using just a USB-C cable, making this power design an excellent choice for development and field testing.

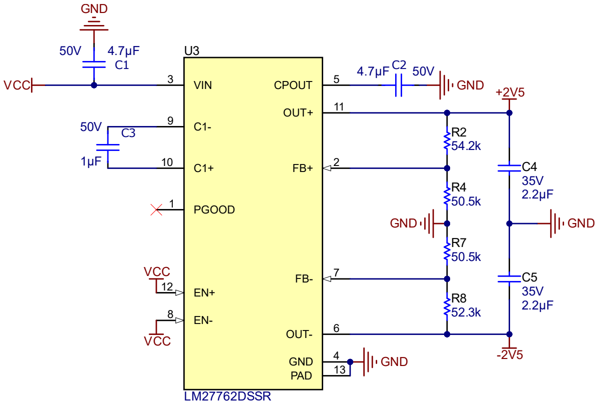

Figure 3-11. Power Supply Schematic

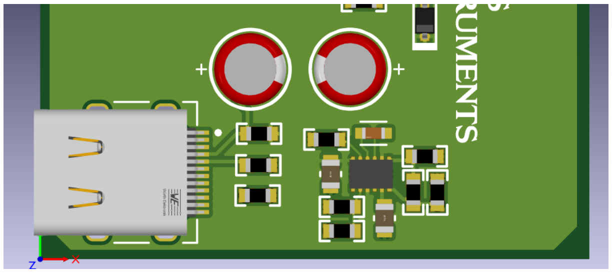

Figure 3-12. Power USB-C® Connectors

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4 Hardware, Testing Requirements, and Test Results

4.1 Hardware Requirements

To accurately evaluate the performance of the Rogowski coil and the associated signal conditioning circuit, the following hardware is required:

1. **Oscilloscope**:
   Used to observe the output waveform from the signal conditioning circuit. A high-bandwidth scope provides accurate capture of fast transients and spike behavior at zero crossings of the Rogowski coil.
2. **USB-C Power Supply** (5VDC):
   Provides stable power to the signal conditioning board. Make sure the power source is clean and isolated to avoid injecting switching noise into the system.
3. **Current Source or Function Generator with Current Injection Capability**:
   A programmable AC or pulsed current source is needed to drive a known current waveform through the Rogowski coil.
4. **Precision Current Measurement Tool** (for example, current clamp meter, calibrated current probe):
   Required for accurate reference measurements of the actual current flowing through the conductor. This allows for comparison against the output of the Rogowski coil to validate amplitude, phase accuracy, linearity, and accuracy.
5. **Load** (resistive or actual):
   Used to create realistic operating conditions and allow the current source to drive current through a known impedance.

4.2 Test Setup

4.2.1 Full System Block Diagram

Figure 4-1 shows the full system setup that is needed to mimic a revenue grade meter targeting *Class 0.1 according to ANSI C12.1*. The test setup consists of five main parts:

- A programmable current and voltage source (PTS3.3C test system)
- Rogowski coil (PCB Rogowski)
- Signal conditioning board (TIDA-010986)
- *ADS131M08 Metrology Evaluation Module*
- GUI for meter performance monitoring and calibration

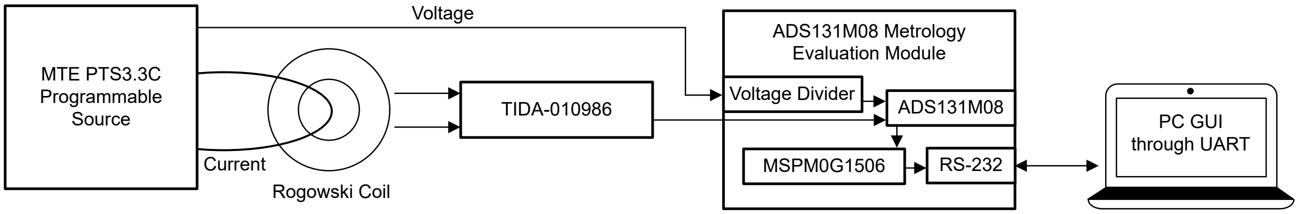

Figure 4-1. Full System Block Diagram

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4.2.2 Test System

Figure 4-2 shows the MTE test equipment. *PTS3.3C* with an accuracy class of 0.05% is used for measurement, which provides minimum uncertainty during measurement.

Figure 4-2. MTE Test Equipment

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4.2.3 Rogowski Coil

Figure 4-3 shows PCB Rogowski Coil which is used for this test as the main current sensor.

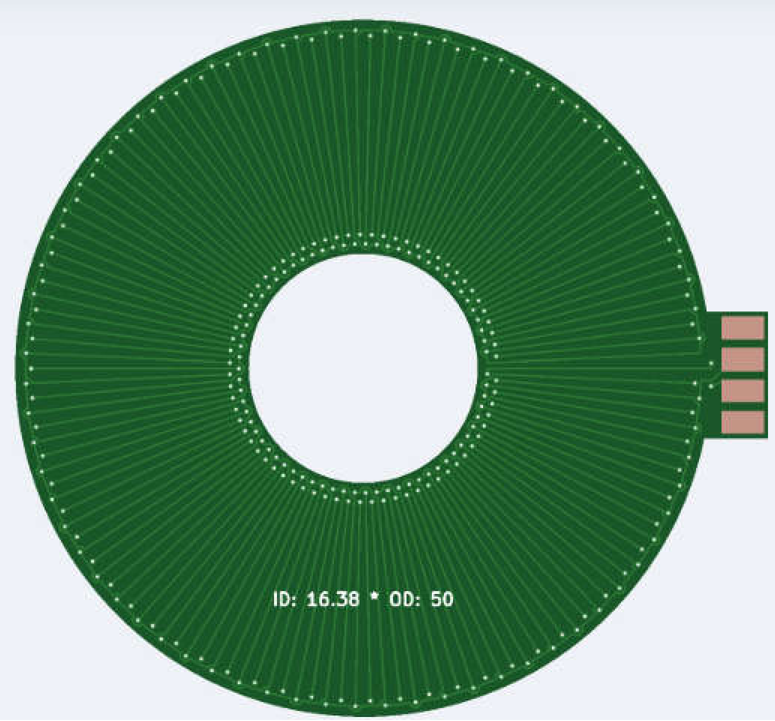

Figure 4-3. PCB Rogowski Coil

4.2.4 TIDA-010986

Figure 4-4 shows the analog signal conditioning circuit board that is used for conditioning the signal when using a Rogowski coil.

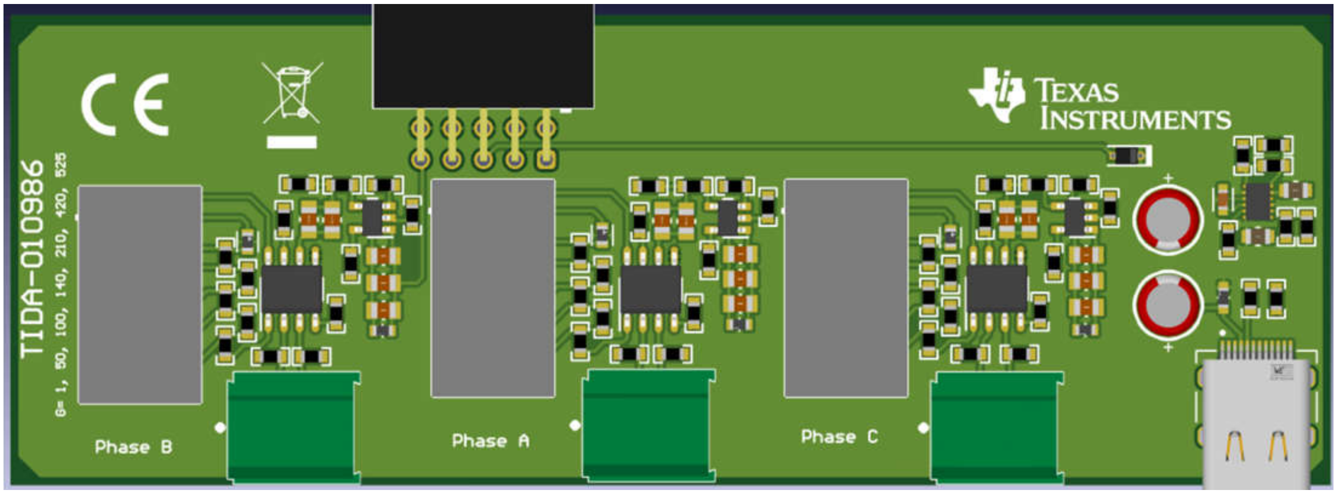

Figure 4-4. TIDA-010986 Analog Signal Conditioning PCB

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4.2.5 ADS131M08 Metrology Evaluation Module

Figure 4-5 shows the EVM that is equipped with the ADC and the MCU that are required for energy calculation and consumption measurements.

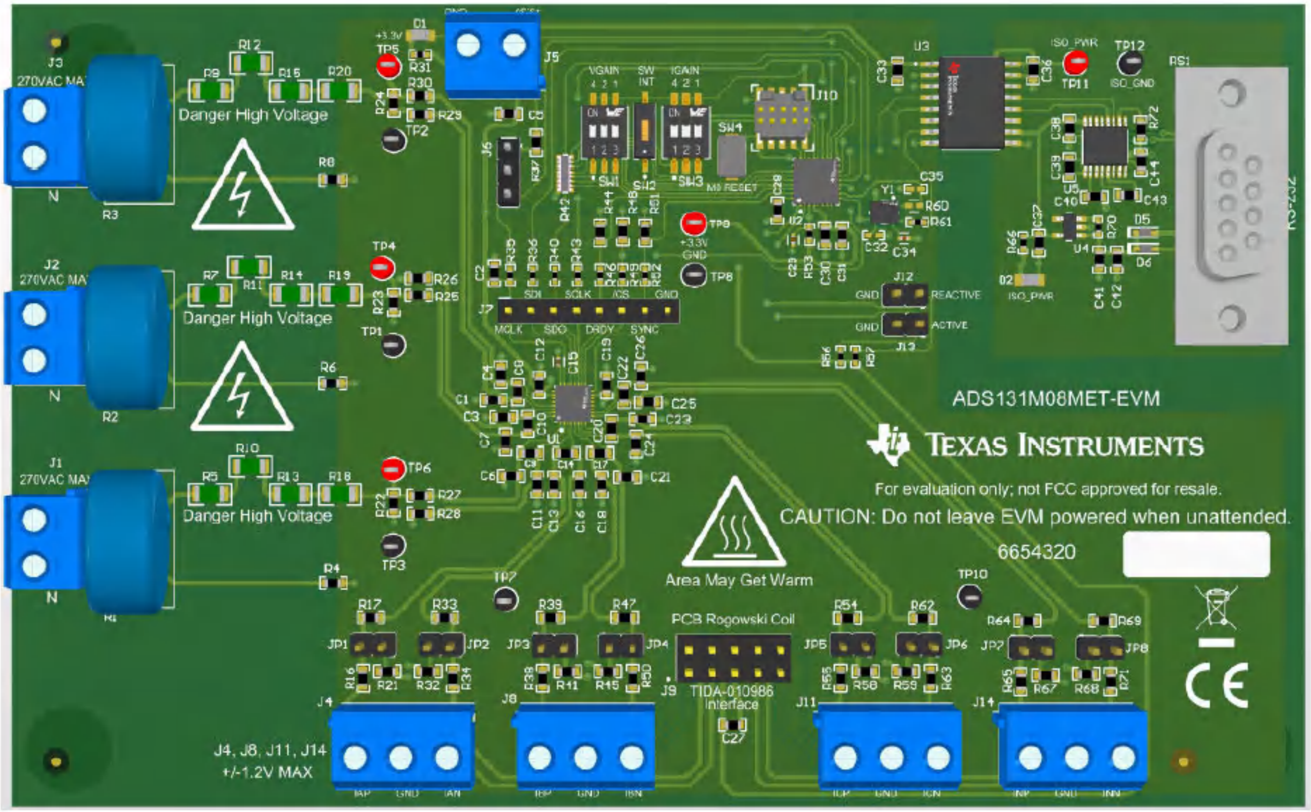

Figure 4-5. ADS131M08 Metrology Evaluation Module

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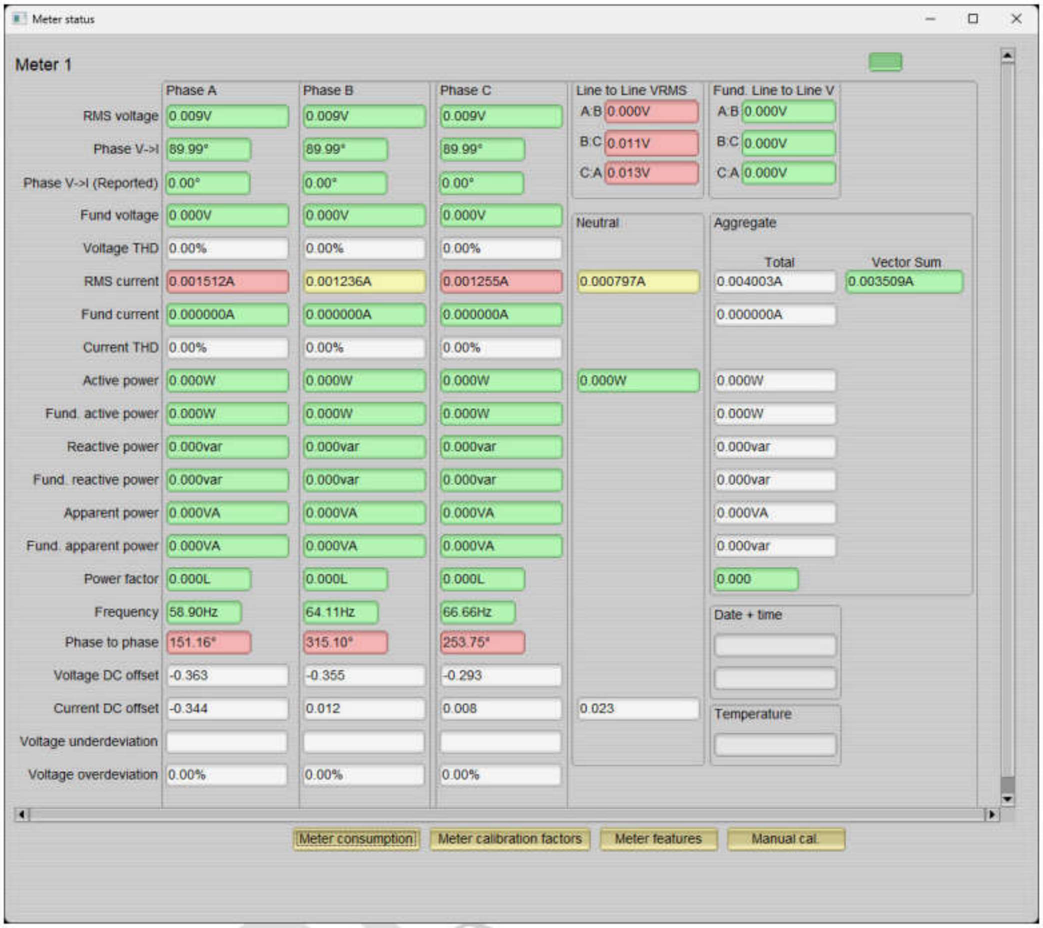
4.2.6 GUI

Figure 4-6 shows the PC GUI that is used to track meter consumption and meter calibration.



	Phase A	Phase B	Phase C	Neutral	Aggregate Total	Aggregate Vector Sum
RMS voltage	0.009V	0.009V	0.009V			
Phase V->I	89.99°	89.99°	89.99°			
Phase V->I (Reported)	0.00°	0.00°	0.00°			
Fund voltage	0.000V	0.000V	0.000V			
Voltage THD	0.00%	0.00%	0.00%			
RMS current	0.001512A	0.001236A	0.001255A	0.000797A	0.004003A	0.003509A
Fund current	0.000000A	0.000000A	0.000000A		0.000000A	
Current THD	0.00%	0.00%	0.00%			
Active power	0.000W	0.000W	0.000W	0.000W	0.000W	
Fund. active power	0.000W	0.000W	0.000W		0.000W	
Reactive power	0.000var	0.000var	0.000var		0.000var	
Fund. reactive power	0.000var	0.000var	0.000var		0.000var	
Apparent power	0.000VA	0.000VA	0.000VA		0.000VA	
Fund. apparent power	0.000VA	0.000VA	0.000VA		0.000var	
Power factor	0.000L	0.000L	0.000L		0.000	
Frequency	58.90Hz	64.11Hz	66.66Hz			
Phase to phase	151.16°	315.10°	253.75°			
Voltage DC offset	-0.363	-0.355	-0.293			
Current DC offset	-0.344	0.012	0.008	0.023		
Voltage underdeviation						
Voltage overdeviation	0.00%	0.00%	0.00%			

	Line to Line VRMS	Fund. Line to Line V
A:B	0.000V	0.000V
B:C	0.011V	0.000V
C:A	0.013V	0.000V

Date + time

Temperature

Figure 4-6. PC GUI

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4.2.6.1 Getting Started

This section provides the different type of connections that are provided on a PCB Rogowski coil, TIDA-010986 tool, and *ADS131M08 Metrology Evaluation Module* and how to interface the boards together for a full meter design.

4.2.6.1.1 PCB Rogowski Coil Setup

Pins D1 and D2 are the outputs of the Rogowski coil, jumper wires must be soldered to pin D1 and pin D2 to interface the Rogowski coil with the TIDA-010986. To get an output from the coil, a jumper (0Ω resistor) must be connected between pin D1 and D2 from the bottom side (the side without any silkscreen). This design also allows stacking, when stacking the coils, sensitivity doubles and less gain if needed thus less noise, more stability, and higher accuracy.

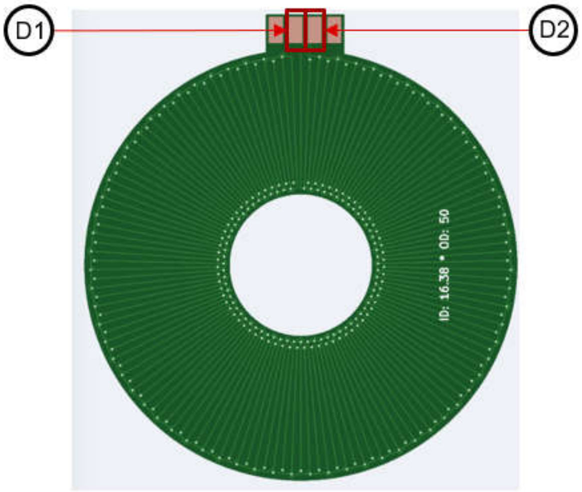

Figure 4-7. PCB Rogowski Coil - A

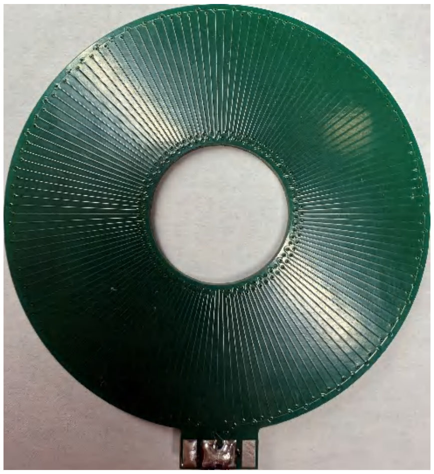

Figure 4-8. PCB Rogowski Coil - B

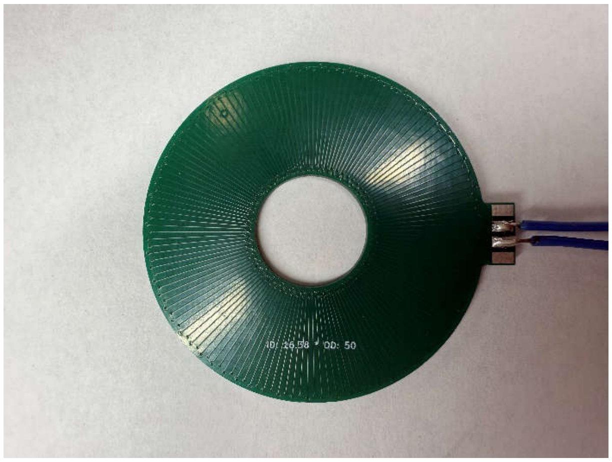

Figure 4-9. PCB Rogowski Coil - C

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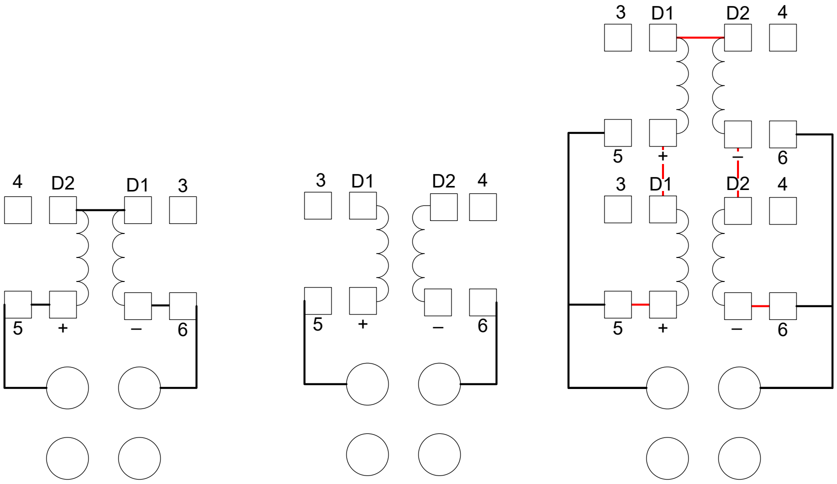

Figure 4-10. Example of Stacking Two Coils

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4.2.6.1.2 TIDA-010986 Connectors

4.2.6.1.2.1 Input Terminal Block

Figure 4-11 shows the terminal block on TIDA-01086 for one of the phases for the jumper wire connections to the Rogowski coil.

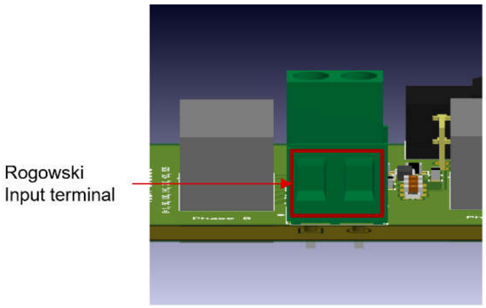

Figure 4-11. Input Terminal Block

4.2.6.1.2.2 Power Connection

Figure 4-12 shows the USB-C connector that is located on the bottom left of the board. The USB-C connector is used for power only.

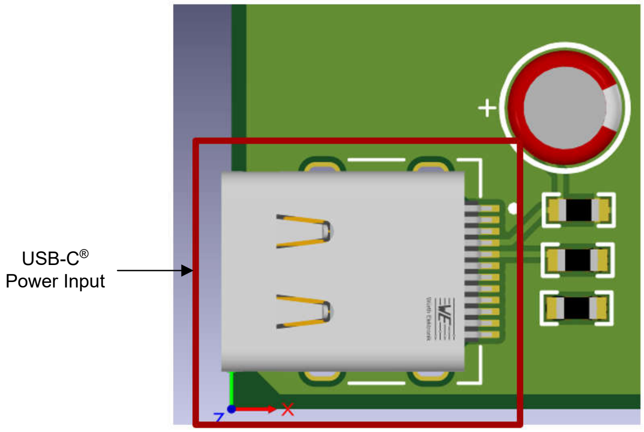

Figure 4-12. USB-C® Connector

4.2.6.1.2.3 Output Connections

Figure 4-13 shows the output connectors that interface with the *ADS131M08 Metrology Evaluation Module*. Figure 4-13 corresponds to the hardware integrated output where pins 1–6 correspond to phase C output, NC, 5VDC input, phase A output, phase B output, and GND, respectively.

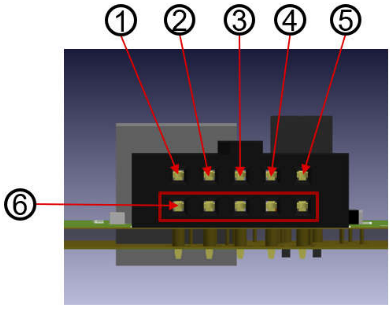

Figure 4-13. Output Connectors Pinout 1–6

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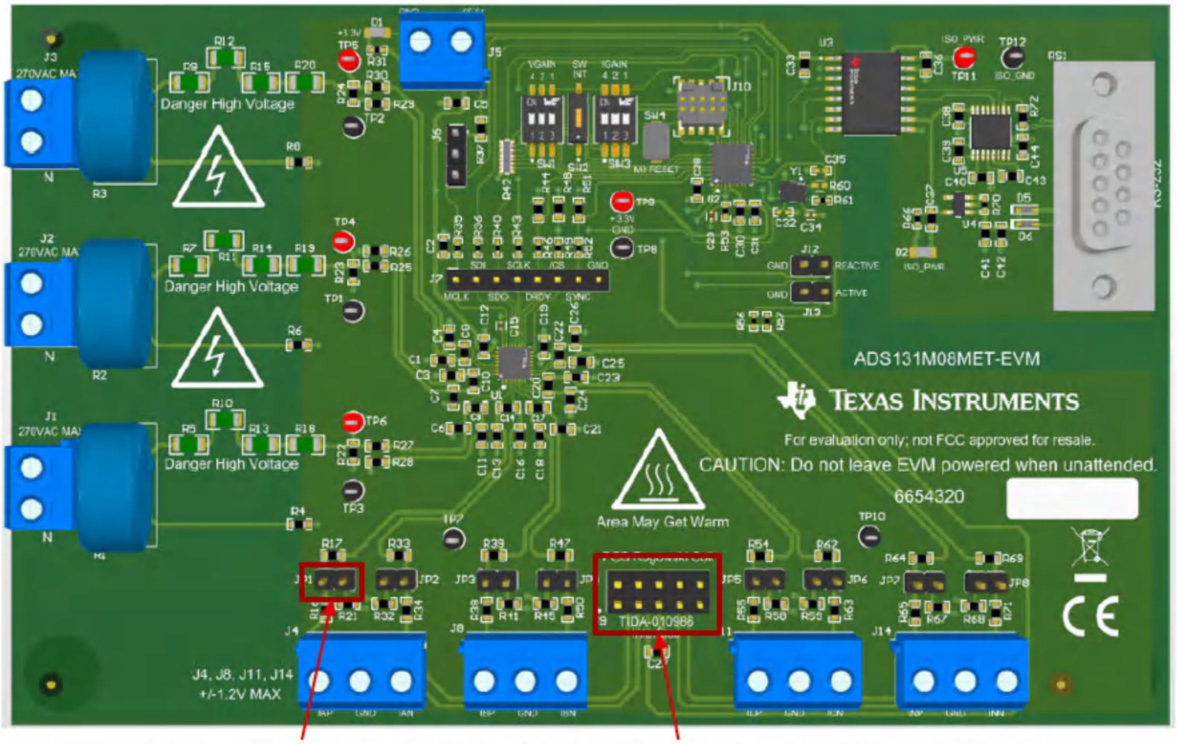
4.2.6.1.3 ADS131M08 Metrology Evaluation Module Connectors

Figure 4-14 shows the header connectors that allow the TIDA-010986 to interface with the *ADS131M08 Metrology Evaluation Module* without any jumper wire connection and make the process easy to use.



Burden resistor jumper

TIDA-010986 interface port

Figure 4-14. Connection Points of the TIDA-010986

Note

To interface all boards together properly, the burden resistor jumpers need to be removed.

Note

If the TIDA-010986 and *ADS131M08 Metrology Evaluation Module* are connected, there is no need to connect the USB-C to TIDA-010986, because the TIDA-010986 receives power from the *ADS131M08 Metrology Evaluation Module*.

4.3 Test Results

4.3.1 Functional Test

Table 4-1 shows the functional checks.

Table 4-1. Functional Checks

PARAMETER	EXPECTED	OBSERVED
Power supply input	+5 VDC	+5.08 VDC
Power supply positive rail	+2.5 VDC	+2.478 VDC
Power supply negative rail	–2.5 VDC	–2.48 VDC
Gain settings	1, 50, 100, 140, 210, 420, 525	1, 52.07, 105.38, 140.27, 210.2, 421.16, 525.65
Integrator gain	1V/V	0.99V/V
Phase shift	90º	90.72º

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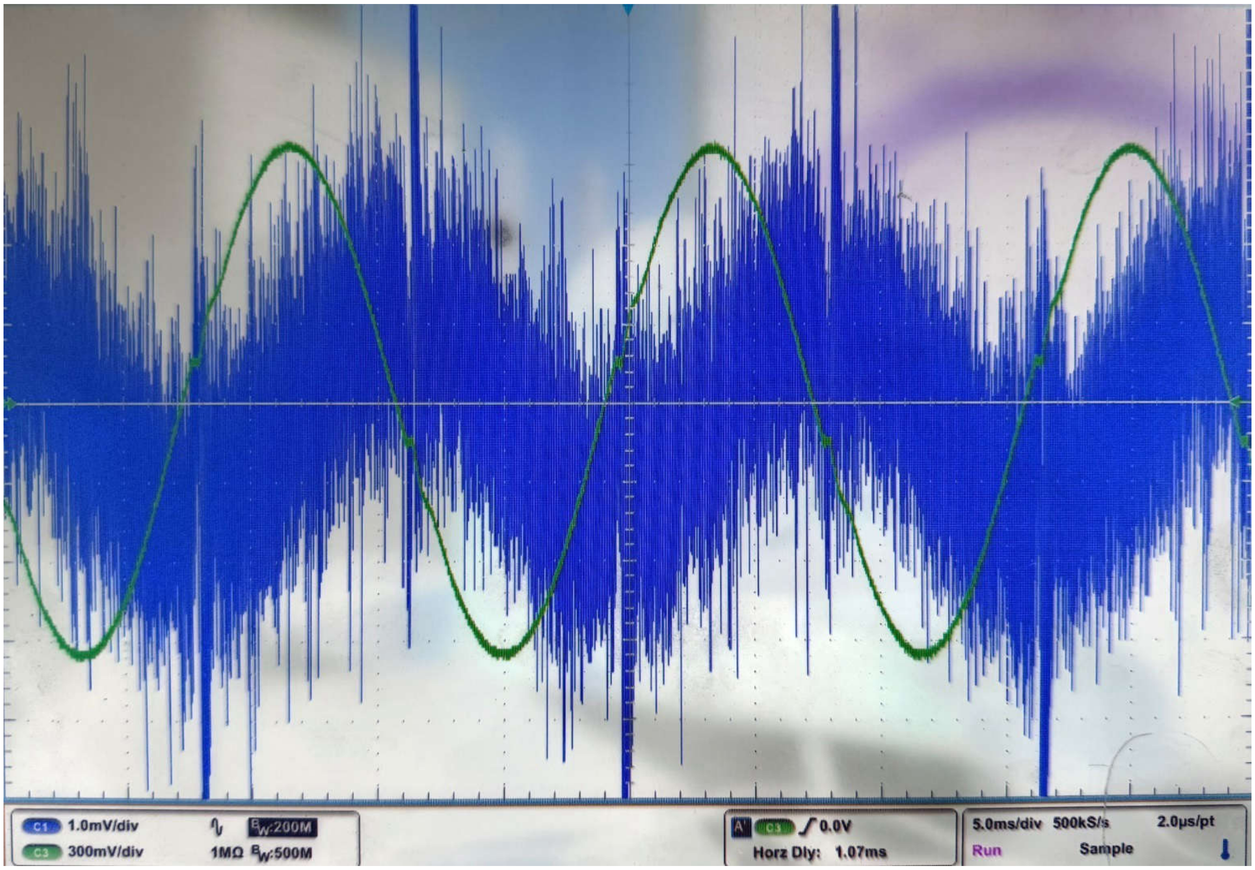

Figure 4-15. Scope Capture of System Operating at 100A

4.3.2 Accuracy Measurements

This section discusses the various tests performed on the PCB Rogowski coil and the signal conditioning board (TIDA-010986). Tests are conducted in accordance with *ANSI C12.1* and applicable IEC standards. The sections also shows the test results, highlighting the performance of the system in terms of accuracy, linearity, and noise immunity across different use cases. The goal is to validate the compliance of the design with metering standards and the usefulness for real-world applications.

Note

Tests are performed using one stacked PCB Rogowski coil shown in Figure 4-3.

4.3.2.1 No Load Conditions

4.3.2.1.1 Objective

The objective of this test is to verify that the system is not registering pulses (current readings) while there is no current present in the circuit.

4.3.2.1.2 Setup

Voltage must be present in the circuit and the current must be disconnected from circuit.

4.3.2.1.3 Requirements

Observe the following requirements for no-load conditions.

- In the first 10 minutes:
  - Must not issue more than one 1 test pulse
  - Must not accumulate energy more than the equivalent of 1 test pulse
- In the next 20 minutes:
  - Must not issue any more test pulses

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  - Must not accumulate any more energy

4.3.2.1.4 Results

Voltage is present in the circuit and all current circuits are disconnected. The system registered one pulse during the duration of the test (20 minutes).

4.3.2.2 Initial Load Operation Test

4.3.2.2.1 Objective

The objective of this test is to verify that the meter operates continuously and reliably under start-up load conditions across the intended minimum rated voltage as well as to make sure that the meter can correctly measure energy in both directions.

4.3.2.2.2 Setup

Apply the specified starting load currents for the current class of interest

- For this test, a current class 100 and class 0.1–class 0.2 accuracy are the targets for metering applications.

Apply the lowest rated voltage.

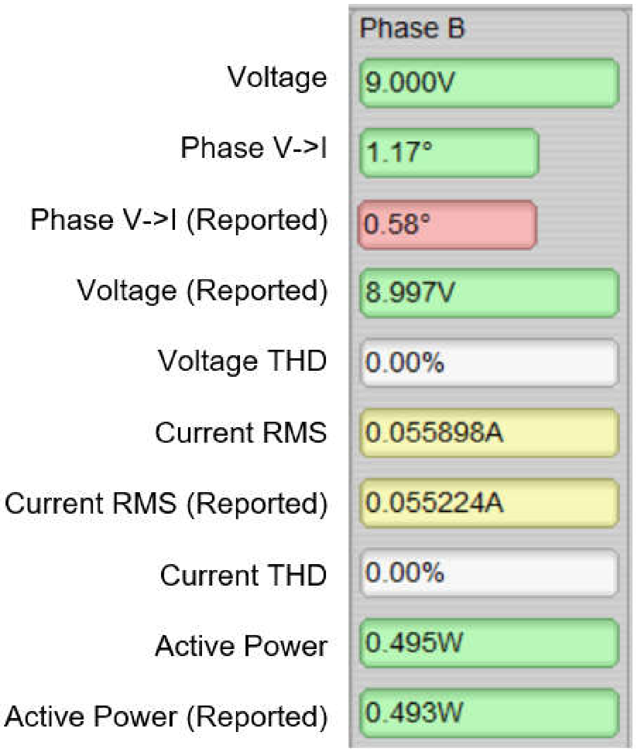
4.3.2.2.3 Requirements

Observe the following requirements for the initial load operation test.

- The meter must stay in continuous operation during the entire test.
- This test must pass in both energy directions.

4.3.2.2.4 Results

At core current class 100, the meter is able to register accurate current readings at the lowest rated voltage and starting load currents



	Phase B
Voltage	9.000V
Phase V->I	1.17°
Phase V->I (Reported)	0.58°
Voltage (Reported)	8.997V
Voltage THD	0.00%
Current RMS	0.055898A
Current RMS (Reported)	0.055224A
Current THD	0.00%
Active Power	0.495W
Active Power (Reported)	0.493W

Figure 4-16. GUI Capture at Starting Load Conditions

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4.3.2.3 Accuracy Test at Different Load Conditions

4.3.2.3.1 Objective

The objective of this test is to make sure that the meter passes class 0.1–class 0.2 accuracy with varying load conditions and does not exceed the allowable error.

4.3.2.3.2 Setup

Observe the following setup for the accuracy test at different load conditions.

- Calibration must be done at nominal current, voltage, power factor, and frequency values.
  - Calibration conditions for this test are 15A, 120V, 1, and 60Hz, respectively.
- Apply the specified load currents for the current class of interest.

4.3.2.3.3 Requirements

Accuracy must stay within the allowable deviation from reference.

4.3.2.3.4 Results

Table 4-2 shows the results of the accuracy test at different load conditions with accuracy at power factor (PF) = 1.

Table 4-2. Accuracy at PF = 1

CONDITION	NUMBER OF PULSES	CURRENT	cos ϕ = 1i (0 DEGREES)							ANSI C12.1 (PF 1)		
			ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	AVG ERROR %	DELTA REF	LIMIT (%) [CLASS 0.5]	LIMIT (%) [CLASS 0.2]	LIMIT (%) [CLASS 0.1]
1	**3**	**1**	0.023	0.190	0.008	–0.184	–0.189	–0.030	–0.027	1.0	0.4	0.2
2	**6**	**1.5**	–0.153	–0.180	–0.109	–0.088	0.028	–0.100	–0.097	0.5	0.2	0.1
3	**6**	**3**	–0.102	–0.066	–0.039	0.008	0.028	–0.034	–0.030	0.5	0.2	0.1
4	**22**	**10**	0.035	0.028	0.028	0.013	0.008	0.022	0.026	0.5	0.2	0.1
5	**29**	**15**	**0.005**	**0.014**	**0.016**	**0.008**	**–0.002**	0.008	**REF**	**0.2**	**0.1**	**0.05**
6	**58**	**30**	–0.004	–0.008	–0.003	–0.001	–0.003	–0.004	0.000	0.5	0.2	0.1
7	**115**	**50**	–0.01	–0.018	–0.01	–0.016	0	–0.011	–0.007	0.5	0.2	0.1
8	**230**	**75**	0	–0.002	–0.006	–0.003	0	–0.002	0.002	0.5	0.2	0.1
9	**298**	**90**	0.000	–0.003	0.001	0.004	0.008	0.002	0.006	0.5	0.2	0.1
10	**384**	**100**	0.006	0.013	0.015	0.013	0.010	0.011	0.015	0.5	0.2	0.1

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4.3.2.4 Variation of Power Factor Test

4.3.2.4.1 Objective

The objective of this test is to verify that the meter continuously, reliably, and accurately operates under different power factors not just unity power factor.

4.3.2.4.2 Setup

Apply different power factors, both leading (capacitive) and lagging (inductive).

4.3.2.4.3 Requirements

Error due to power factor variation must not exceed the limits specified for the current class and accuracy class of interest.

4.3.2.4.4 Results

Table 4-3 shows the results of the variation of power factor testing. Reference data for this test is in Section 4.3.2.3.4.

Table 4-3. Accuracy at PF = 0.5 and 0.8

CURRENT	cos ϕ = 0.5i (60 DEGREES)							ANSI C12.1 (PF 0.5 | 0.8)			cos ϕ = 0.8c (–36.87 DEGREES) (323.13)						
	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	AVG ERROR (%)	DELTA REF	LIMIT (%) [CLASS 0.5]	LIMIT (%) [CLASS 0.2]	LIMIT (%) [CLASS 0.1]	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	AVG ERROR %	DELTA REF
1.5	**–0.153**	**–0.180**	**–0.109**	**–0.088**	**0.028**	–0.100	**(REF)**	NA	NA	NA	**–0.153**	**–0.180**	**–0.109**	**–0.088**	**0.028**	–0.100	**(REF)**
3	0.047	0.184	–0.064	–0.192	–0.168	–0.039	0.062	**1.00**	**0.50**	**0.25**	–0.128	–0.166	–0.175	–0.122	–0.124	–0.143	–0.043
15	**0.005**	**0.014**	**0.016**	**0.008**	**–0.002**	0.008	**(REF)**	NA	NA	NA	**0.005**	**0.014**	**0.016**	**0.008**	**–0.002**	0.008	**(REF)**
15	–0.034	–0.070	–0.071	–0.037	–0.017	–0.046	–0.054	**0.6**	**0.3**	**0.15**	0.044	0.057	0.051	0.045	0.051	0.050	0.041
50	**–0.010**	**–0.018**	**–0.010**	**–0.016**	**0.000**	–0.011	**(REF)**	NA	NA	NA	**–0.010**	**–0.018**	**–0.010**	**–0.016**	**0.000**	–0.011	**(REF)**
50	–0.100	–0.104	–0.098	–0.095	–0.095	–0.098	–0.088	**0.6**	**0.3**	**0.15**	0.068	0.071	0.07	0.081	0.083	0.075	0.085
100	**0.006**	**0.013**	**0.015**	**0.013**	**0.010**	**0.011**	**(REF)**	NA	NA	NA	**0.006**	**0.013**	**0.015**	**0.013**	**0.010**	0.011	**(REF)**
100	–0.11	–0.116	–0.114	–0.111	–0.114	**–0.113**	–0.124	**0.6**	**0.3**	**0.15**	0.095	0.093	0.094	0.098	0.097	0.095	0.084

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4.3.2.5 Variation of Voltage Test

4.3.2.5.1 Objective

The objective of this test is to verify that the meter continuously, reliably, and accurately operates over a range of voltages not just nominal voltage.

4.3.2.5.2 Setup

Apply different voltages depending on the specified voltage range of the meter.

Test points:

- 90% of the lowest rated voltage
- Nominal voltage
- Random midpoint
- Highest rated voltage
- 110% of highest rated voltage

4.3.2.5.3 Requirements

Errors due to voltage variation must not exceed the limits specified for the current class and accuracy class of interest.

4.3.2.5.4 Results

Table 4-4 details the variation of voltage results.

Table 4-4. Variation of Voltage Results

VOLTAGE	cos ϕ = 1i (0 DEGREES)							ANSI C12.1 2022		PULSES
	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	AVG ERROR (%)	DELTA FROM REF	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]	
	TEST CURRENT (TA)									
	1.5	1.5	1.5	1.5	1.5					
120 (REF)	–0.153	–0.180	–0.109	–0.088	0.028	–0.100	(REF)	REF	REF	12
108	–0.157	0.083	0.159	–0.195	–0.038	–0.0296	0.071	±0.1	±0.2	12
235	0.023	–0.04	–0.172	–0.23	–0.117	–0.1072	0.007	±0.1	±0.2	12
270	–0.141	0.162	0.138	–0.129	–0.186	–0.0312	0.069	±0.1	±0.2	29
297	–0.192	0.127	–0.059	–0.135	0.077	–0.0364	0.064	±0.1	±0.2	58
	TEST CURRENT (TA)									
	15	15	15	15	15					
120(REF)	**0.005**	**0.014**	**0.016**	**0.008**	**–0.002**	0.0082	(REF)	REF	REF	58
108	–0.005	–0.006	–0.014	–0.003	0.012	–0.0032	0.011	±0.1	±0.2	58
235	–0.012	–0.001	–0.002	–0.003	–0.002	–0.0040	0.012	±0.1	±0.2	115
270	–0.01	0.002	0.02	0.023	0.017	0.0104	0.002	±0.1	±0.2	230
297	0.028	0.028	0.018	0.026	0.018	0.0236	0.015	±0.1	±0.2	288

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4.3.2.6 Variation of Frequency Test

4.3.2.6.1 Objective

The objective of this test is to verify that the meter continuously, reliably, and accurately operates over a range of frequencies not just nominal frequency.

4.3.2.6.2 Setup

Apply different frequencies depending on the specified frequency range of the meter.

Test points:

- Condition 1: 98% of reference frequency
- Condition 2: 102% of reference frequency
- Condition 3: 98% of reference frequency for higher currents
- Condition 4: 102% of reference frequency for higher currents

4.3.2.6.3 Requirements

Error due to frequency variation must not exceed the limits specified for the current class and accuracy class of interest.

4.3.2.6.4 Results

Table 4-5 details the variation of frequency results.

Table 4-5. Variation of Frequency Results

FREQUENCY	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	AVG ERROR %	DELTA FROM REF	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]	PULSES
	TEST CURRENT (TA)									
	1.5	1.5	1.5	1.5	1.5					
50(REF)	–0.249	–0.277	–0.26	–0.217	–0.226	–0.2458	(REF)	REF	REF	6
49	–0.305	–0.234	–0.253	–0.252	–0.28	–0.2648	0.019	±0.05	±0.1	6
51	–0.209	–0.223	–0.217	–0.193	–0.173	–0.2030	0.043	±0.05	±0.1	6
60(REF)	–0.153	–0.180	–0.109	–0.088	0.028	–0.1004	(REF)	REF	REF	6
58.8	–0.045	–0.043	–0.056	–0.043	–0.06	–0.0494	0.051	±0.05	±0.1	6
61.2	–0.032	–0.029	–0.019	–0.026	0	–0.0212	0.079	±0.05	±0.1	6
	TEST CURRENT (TA)									
	15	15	15	15	15					
50(REF)	–0.205	–0.206	–0.203	–0.198	–0.204	–0.2032	(REF)	REF	REF	58
49	–0.233	–0.241	–0.239	–0.242	–0.235	–0.2380	0.035	±0.05	±0.1	58
51	–0.171	–0.168	–0.172	–0.17	–0.169	–0.1700	0.033	±0.05	±0.1	58
60(REF)	**0.005**	**0.014**	**0.016**	**0.008**	**–0.002**	0.0082	(REF)	REF	REF	58
58.8	–0.013	–0.009	–0.015	–0.009	–0.012	–0.0116	0.020	±0.05	±0.1	58
61.2	0.012	0.009	0.008	0.01	0.011	0.0100	0.002	±0.05	±0.1	58

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4.3.2.7 Phase Sequence Reversal Test

4.3.2.7.1 Objective

The objective of this test is to verify that the meter continuously, reliably, and accurately operates when the phase sequence is reversed.

4.3.2.7.2 Setup

The reference point is recorded when all circuits are connected in *ABC* configurations. Accuracy measurements are then recorded when the phase sequence is reversed (*CBA* configuration).

4.3.2.7.3 Requirements

Error due to phase sequence reversal in current circuits must not exceed the limits specified for the current class and accuracy class of interest.

4.3.2.7.4 Results

Table 4-6 details the phase sequence reversal results.

Table 4-6. Phase Sequence Reversal Results

CIRCUIT	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	AVG ERROR %	DELTA FROM REF	LIMIT (%) [CLASS 0.1]	LIMIT (%) [CLASS 0.2]	PULSES
	TEST CURRENT (TA)									
	1.5	1.5	1.5	1.5	1.5					
ABC	**–0.153**	**–0.180**	**–0.109**	**–0.088**	**0.028**	–0.1004	(REF)	REF	REF	6
CBA	–0.102	–0.087	–0.029	–0.008	0.023	–0.0406	0.060	±0.1	±0.3	6
	TEST CURRENT (TA)									
	15	15	15	15	15					
ABC	**0.005**	**0.014**	**0.016**	**0.008**	**–0.002**	0.0082	(REF)	REF	REF	58
CBA	–0.031	–0.038	–0.035	–0.039	–0.037	–0.0360	0.044	±0.1	±0.3	58

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5 Design and Documentation Support

5.1 Design Files

5.1.1 Schematics

To download the schematics, see the design files at TIDA-010986.

5.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010986.

5.1.3 Layout Prints

To download the layer plots, see the design files at TIDA-010986.

5.2 Tools

PSPICE-FOR-TI	PSpice® for TI design and simulation tool
TINA-TI™ Software	SPICE-based analog simulation program

5.3 Documentation Support

1. Texas Instruments, *INA818 35µV Offset, 8nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier Data Sheet*
2. Texas Instruments, *INA828 50µV Offset, 7nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier Data Sheet*
3. Texas Instruments, *INA188 Precision, Zero-Drift, Rail-to-Rail Out, High-Voltage Instrumentation Amplifier Data Sheet*
4. Texas Instruments, *TLV900x Low-Power, RRIO, 1MHz Operational Amplifier for Cost-Sensitive Systems Data Sheet*
5. Texas Instruments, *LM27762 Low-Noise Positive and Negative Output Integrated Charge Pump Plus LDO Data Sheet*
6. Texas Instruments, *ADS131M08 Metrology Evaluation Module User's Guide*

5.4 Support Resources

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6 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 hands-on experience with both analog hardware design and system-level integration, including EMC testing and calibration for high-accuracy measurement.

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