Design Guide: TIDA-010987

Rogowski Coil Current Sensor Reference Design

Description

This reference design enables end users to evaluate PCB Rogowski coils of different sizes and sensitivities for a wide range of current-sensing applications. The design supports low and high current measurements up to 500A, high precision at 0.2%, and wide bandwidth sensing exceeding 1MHz. The design consolidates these capabilities into a single platform compatible with multiple current-sensing applications.

Resources

TIDA-010987	Design Folder
ADS131M08MET-EVM	Design Folder
TIDA-010971, TIDA-010986	Design Folders
INA333, TLV9002, TLV2387	Product Folders
LOG300, TL081H, LM2664	Product Folders

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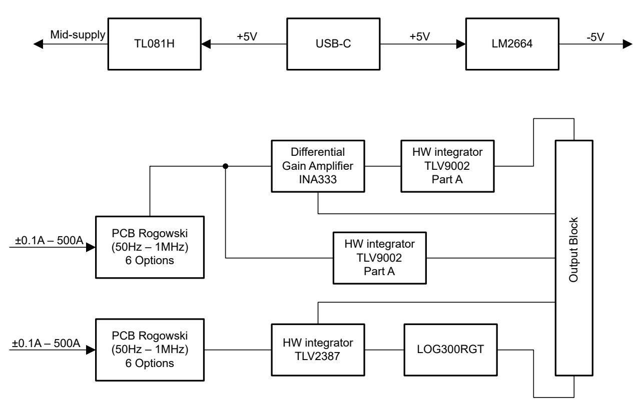
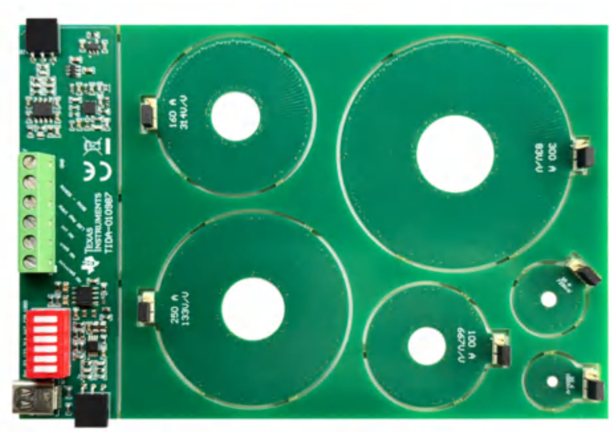
Features

- Signal conditioning with multiple component sequence for multiple application evaluation
- Wide current range:
  – 0.1A–500A adjusted through gain settings
- Different coil sizes:
  – Six different size breakable coils included on the board
- Easy to use, plug-in form factor, and no solder needed

Applications

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





1 System Description

The TIDA-010987 reference design enables the use of PCB Rogowski coils for a wide range of current-sensing applications. Current sensors are a critical part of modern power systems and electronic devices, providing accurate monitoring and protection in areas such as e-metering, power quality analysis, and circuit protection. These sensors provide safe and efficient operation by detecting overloads, tracking power consumption, and providing feedback for control systems.

Rogowski coils are appropriate for these applications because of the wide bandwidth, linear response over a broad current range, and inherent safety. The coils do not saturate like magnetic-core sensors (CTs). The coils are commonly used in e-metering for accurate billing and circuit breakers for fast detection of high-frequency fault currents. The coils also serve power converters in solar and wind systems and industrial equipment where precise current waveform measurement is required.

The TIDA-010987 design incorporates multiple component configurations to provide effective signal conditioning for different use cases. For example, the design employs a precision amplifier followed by a hardware integrator to achieve both high-accuracy performance and support for low-frequency applications. The effective layout allows coils of different sizes to be placed on a single PCB, alongside the required signal-conditioning circuits, providing a compact and unified reference design.

The reference design becomes especially useful for engineers and system designers who need to evaluate Rogowski coil technology across many current-sensing applications. By offering flexibility in coil geometries and signal-conditioning stages, the design enables quick comparisons of performance metrics such as sensitivity, bandwidth, and noise behavior under real-world conditions. The design serves not only as a demonstration platform but also as a development tool for integrating Rogowski coils into next-generation current-sensing methods.

2 System Overview

The TIDA-010987 reference design provides a multipurpose PCB Rogowski coil platform for accurate current measurement across a wide range of applications. The system integrates multiple coil sizes, precision amplifiers, differential signal conditioning, and hardware integrators into a single compact board, enabling flexible and scalable use cases.

The TIDA-010987 reference design offers several key benefits for current measurement applications:

- Compact PCB form factor consolidates multiple coil sizes and signal conditioning circuits into a single reference design.
- Cost-effective alternative to bulky current transformers and shunt resistors.
- Immune to saturation and magnetic tampering, providing higher robustness in industrial and power electronics environments.
- Designed for multiple current-sensing use cases on a single board, reducing design time and improving evaluation flexibility.

2.1 Block Diagram

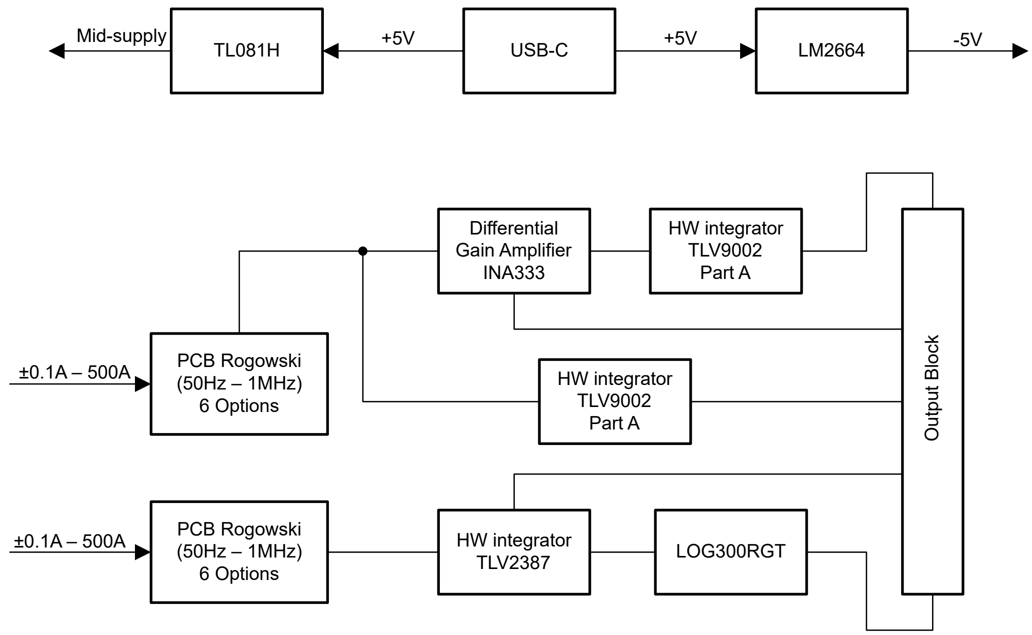


Figure 2-1. TIDA-010987 Block Diagram

2.1.1 PCB Rogowski Coils

The TIDA-010987 reference design integrates six different PCB Rogowski coil sizes, each carefully laid out as a differential winding on a printed circuit board. The design leverages automated Python® based scripting to minimize human error and provide precise symmetry, which is essential for coil accuracy and noise rejection. The approach not only enhances repeatability in manufacturing but also provides consistent coil performance across prototypes and production units.

Each coil is clearly labeled with the maximum measurable current rating and the associated gain requirement for the conditioning circuitry. The labeling allows end users to easily identify and select the most appropriate coil for the application, whether measuring low-level currents for residential metering or handling higher current ranges for industrial protection systems. The labeling and standardized form factor eliminate guesswork, making the design highly practical for engineers who need to evaluate Rogowski coils in real-world conditions.

A key benefit of the implementation is the user-friendly, plug-in architecture. Unlike traditional Rogowski coil setups that can require soldering or external connectors (jumper cables), the TIDA-010987 provides a punch-out and plug-in form factor. Engineers can quickly swap between coil sizes without reworking the board or reconfiguring the setup, dramatically reducing evaluation and prototyping time. The modularity makes the design particularly useful for R&D labs, academic settings, and product teams comparing multiple coil geometries for a given current-sensing challenge.

2.1.2 Integrator Stage

The voltage (VS) 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 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. Phase shifting is accomplished 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 accomplished digitally, due to precise phase and magnitude response control. Accurate digital integration

requires high-performance microcontrollers (MCUs) and analog-to-digital converters (ADC) 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. Phase correction can be achieved using a passive integrator (resistors, capacitors) or an active integrator (combination of active (op amp) and passive elements). The reference 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.

Rogowski coil output, especially PCB Rogowski coil output, is very low (10µV/A–100µV/A). The low output becomes an issue at lower currents, for example 100mA, where the signal needs to be amplified by (100V/V–500V/V) depending on the coil sensitivity. 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 signal hits the noise floor of the ADC. 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 component type must be the right type for math operation. For a discrete approach, thin film resistors and C0G and NP0 capacitors are recommended for high precision applications.

2.1.3 Input Stage

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 coil output. 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 low-pass filter purpose is to attenuate high-frequency components, including the unwanted spikes and ringing, thereby improving signal integrity and making the system behave more linearly.

2.1.4 Differential Amplifier Stage

Since the signal from the coil is very small, a gain amplification stage is needed to improve the input signal for the ADC. The INA333 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. The amplifier uses a single resistor for setting the gain, which allows the end users to cut down on cost instead of using two resistors for gain setting in a traditional gain op-amp circuit.

2.1.5 High-Bandwidth, Low-Noise Amplifier Stage

2.1.5.1 Hybrid Integrator

The stage uses a combination of active integration and passive integration. The passive filter is before the active filter and reduces high frequency spikes and ringing that can saturate the amp. The active integrator has a gain of 2,676 and corner frequency at 1048Hz. The configuration leads to a gain crossover frequency at 2.8MHz. The passive filter resistor value for the chosen gain is 210Ω, to continue the integration the capacitor is selected for a corner frequency at 2.8MHz.

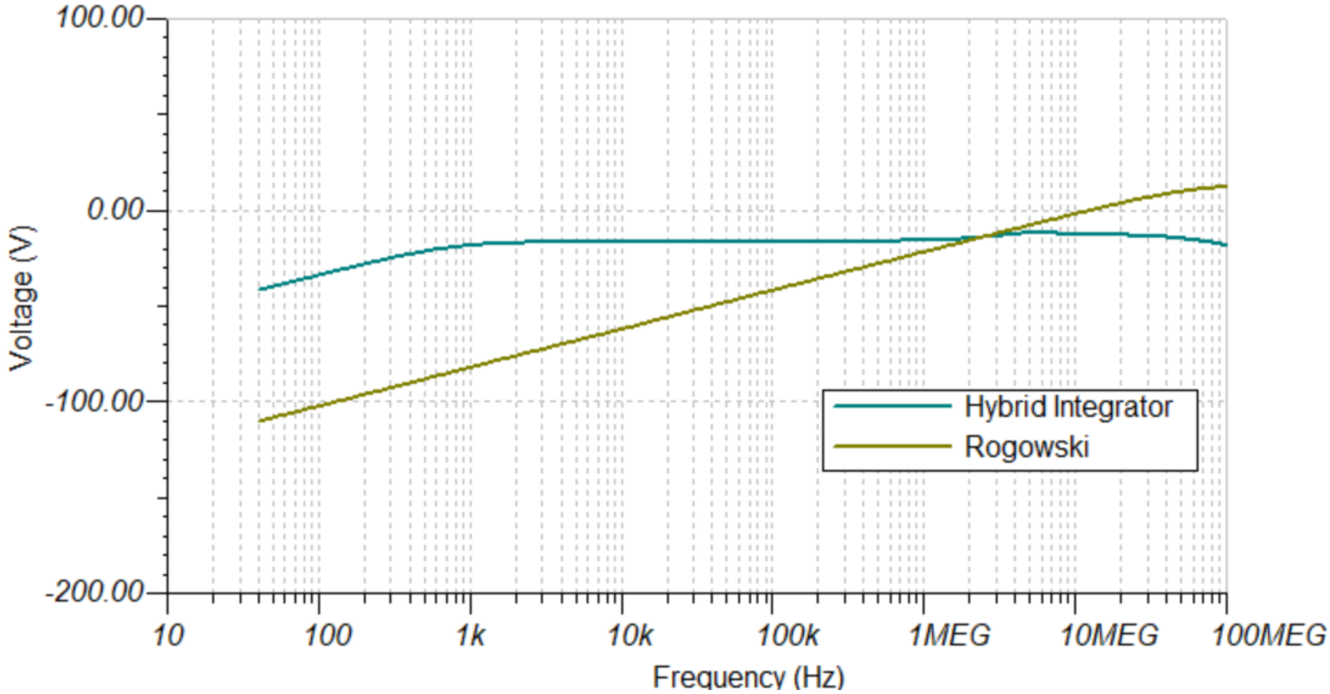


Figure 2-2. TINA Simulation of Hybrid Integrator and PCB Rogowski

2.1.5.2 Band Pass Filter

For some applications such as arc fault detection, filtering a specific band of frequency is useful for isolating the signals of interest. The design features a 5kHz to 50kHz band pass filter that can be adjusted by changing the RC pairs constructing the high-pass and low-pass parts of the filter. The 5kHz frequency is chosen because 60Hz loads commonly have harmonics below 5kHz. For example, typical AC brushed motors operate at revolutions per minute (RPM) around 1kHz to 4kHz.

2.1.5.3 Logarithmic Amplifier

LOG300 is a wide bandwidth AFE (40MHz) that provides a logarithmic output capable of detecting 98dB of dynamic range with a tunable filtered input. With the configured gain, the device can be used to measure current signal from µA to A. The amplifier is also useful for arc detection by providing a way to detect high-frequency arcing signals without requiring a high-speed ADC and Digital Signal Processor (DSP) to process the signal.

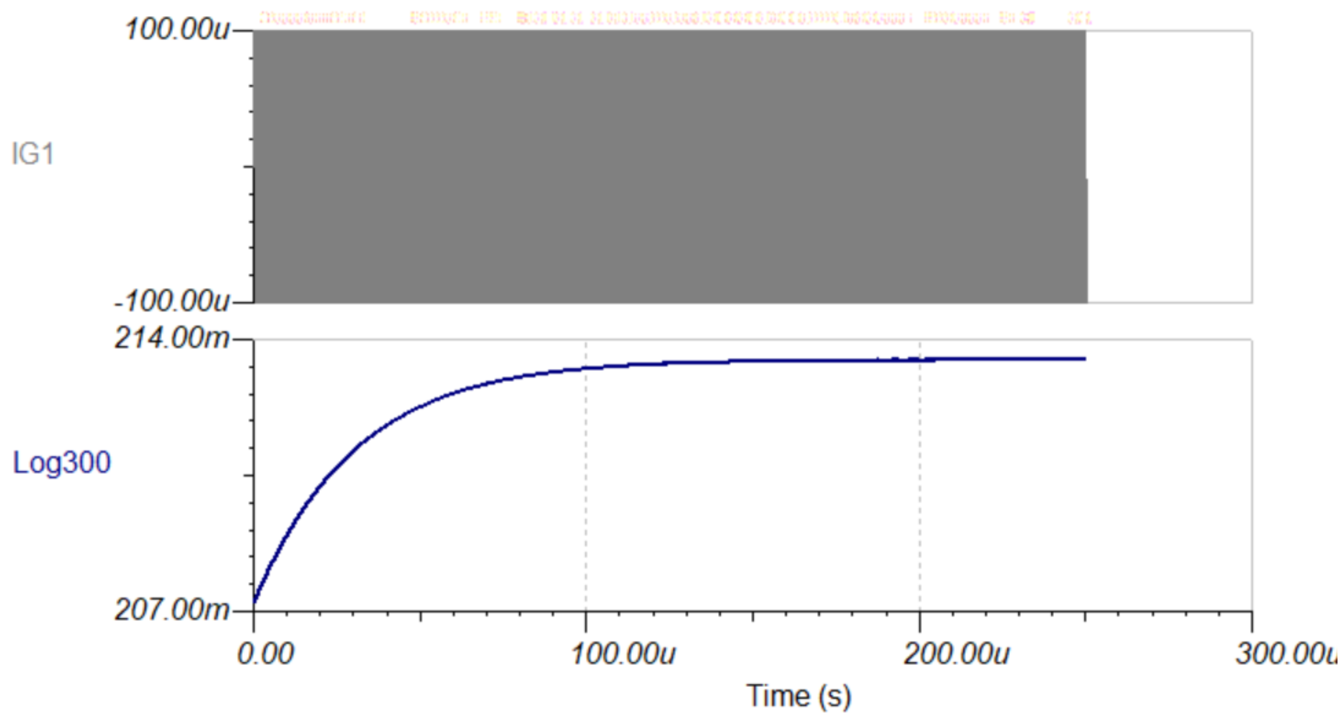


Figure 2-3. LOG300 and PCB Rogowski TINA Simulation With 100A, 1MHz Sine Input

2.2 Design Considerations

2.2.1 Component Selection

System gain can be controlled at three different stages, the gain stage at the differential amplifier (INA333), the integrator stage after the amplifier stage, and the standalone integrator. 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. The integrator (set to attenuate) attenuates all the noise in the system for precision measurements.

The design has multiple gain settings ranging from 1V/V to 1000V/V depending on the type and sensitivity of Rogowski coil where the integrator gain is set to unity gain for multiple component configurations.

2.2.2 RC Component Selection

The design targets multiple features at different component configurations such as low phase error, low noise, fast settling, precision measurements, and high frequency. To target low phase error, an RC time constant of less than 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 (less than ±5%) tolerance and lower temperature drift. C0G and 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 do not introduce additional noise to the system.

For the standalone integrator, a 470kΩ resistor and 100nF capacitor are selected to achieve faster settling time (10ms) with unity gain and a better frequency response.

2.2.3 Gain Setting

The gain amplifier uses only a single resistor (RG) to control gain selection. Resistor RG connects to pin 1 and pin 8 of the INA333 device. Place this resistor as close as possible to the amplifier pins to reduce line capacitance between pin 1 and pin 8. Set the amplifier gain correctly according to Equation 1.

$$S \times I_{max} \times Gs = L \tag{1}$$

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

$$Gs = Gain_{amp} \times Gain_{int} \tag{2}$$

where

- $Gain_{amp} = 1 + (100k\Omega / RG)$
- $Gain_{int} = (RF/RI) \times 1/\sqrt{1 + 2\pi \times F \times RF \times C}$

Equation 3 shows the transfer function where the gain of the standalone integrator is set.

$$\frac{\sqrt{\left(1 + 2 \times \left(\frac{RF}{RI}\right)\right)^2 + (4 \times \pi \times RF \times F \times C)^2}}{\sqrt{\left(1 + (2 \times \pi \times RF \times F \times C)^2\right) \times \left(1 + (2 \times \pi \times RI \times F \times C)^2\right)}} \tag{3}$$

2.3 Highlighted Products

2.3.1 INA333

The INA333 device is a low-power, precision instrumentation amplifier offering excellent accuracy. The versatile three-operational amplifier design, small size, and low power make the device an excellent choice for a wide range of portable applications. A single external resistor sets any gain from 1 to 1000. The INA333 is designed to use an industry standard gain equation: G = 1 + (100kΩ / RG). The INA333 device provides very low offset voltage (25µV, G ≥ 100), excellent offset voltage drift (0.1µV/°C, G ≥ 100), and high common-mode rejection (100dB at G ≥ 10). The device operates with power supplies as low as 1.8V (±0.9V) and quiescent current is only 50µA, making the device appropriate for battery-operated systems. Using autocalibration techniques to provide excellent precision over the extended industrial temperature range, the INA333 device also offers exceptionally low noise density ($50nV/\sqrt{Hz}$) that extends down to DC.

2.3.2 TLV9002

The TLV9002 is a low-voltage (1.8V to 5.5V) operational amplifier (op amp) with rail-to-rail input and output swing capabilities. The op amps provide a cost-effective method for space-constrained applications such as smoke detectors, wearable electronics, and small appliances where low-voltage operation and high capacitive-load drive are required. The capacitive-load drive of the TLV900x family is 500pF, and the resistive open loop output impedance makes stabilization easier with much higher capacitive loads. The op amps are designed specifically for low-voltage operation (1.8V to 5.5V) with performance specifications similar to the TLV600x devices. The robust design of the TLV9002 simplifies circuit design. The op amps feature unity-gain stability, an integrated RFI and EMI rejection filter, and no-phase reversal in overdrive conditions.

2.3.3 LM2664

The LM2664 CMOS charge-pump voltage converter inverts a positive voltage in the range of 1.8V to 5.5V to the corresponding negative voltage of −1.8V to −5.5V. The device uses two low-cost capacitors to provide up to 40mA of output current. The LM2664 operates at 160kHz oscillator frequency to reduce output resistance and voltage ripple. With an operating current of only 220µA (operating efficiency greater than 91% with most loads) and 1µA typical shutdown current, the LM2664 provides effective performance for battery-powered systems.

2.3.4 TLV2387

The TLV2387 is a precision amplifier that offers state-of-the-art performance. With zero-drift technology, the TLV2387 offset voltage and offset drift provide unparalleled long-term stability. With a mere 570µA of quiescent current, the TLV2387 can achieve 5.7MHz of bandwidth, a broadband noise of 8.5nV/$\sqrt{Hz}$, and a 1/f noise at 177nV_{PP}. The specifications are crucial to achieve extremely-high precision and no degradation of linearity in 16-bit to 24-bit analog-to-digital converters (ADCs). The TLV2387 features flat bias current overtemperature; therefore, little to no calibration is needed in high input impedance applications over temperature.

2.3.5 LOG300

The LOG300 is an integrated analog front end (AFE) consisting of low-noise amplifier (LNA) and a Log Detector block. The device supports an input frequency range from 50Hz to 40MHz and a typical dynamic range of 98dB. The LOG300 is intended for use in applications that require a wide dynamic range of voltage and signal measurement. The Log Detector block of LOG300 supports both single-ended and differential inputs. The low input noise of the integrated LNA allows measurement of signals as low as 7µV_P. The transient output response can be adjusted by tuning the capacitor connected at the Log_Out pin. The integrated frequency detect feature of LOG300 enables users to extract input signal frequency and zero-crossing information.

2.3.6 TL081H

The TL081H device is the next-generation version of the industry-standard TL08x (TL081, TL082, and TL084) devices. The device provides outstanding value for cost-sensitive applications, with features including low offset (1mV, typical), high slew rate (20V/µs), and common-mode input to the positive supply. High ESD (1.5kV, HBM), integrated EMI and RF filters, and operation across the full –40°C to 125°C enable the TL081H device to be used in the most rugged and demanding applications. The device generates a mid-supply reference point to the signal conditioning circuit to allow the use of a single supply operation.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

To accurately evaluate the Rogowski coil performance 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.

3.2 Test Setup

3.2.1 Metering Setup

Figure 3-1 shows the full system setup needed to mimic a revenue-grade meter targeting class 0.2 – class 0.3 according to ANSI C12.1. The test setup consists of four main parts:

1. A programmable current and voltage source (PTS3.3C test system)
2. Signal conditioning board with multiple PCB Rogowski coils (TIDA-010987)
3. ADS131M08 Metrology Evaluation Module
4. GUI for meter performance monitoring and calibration

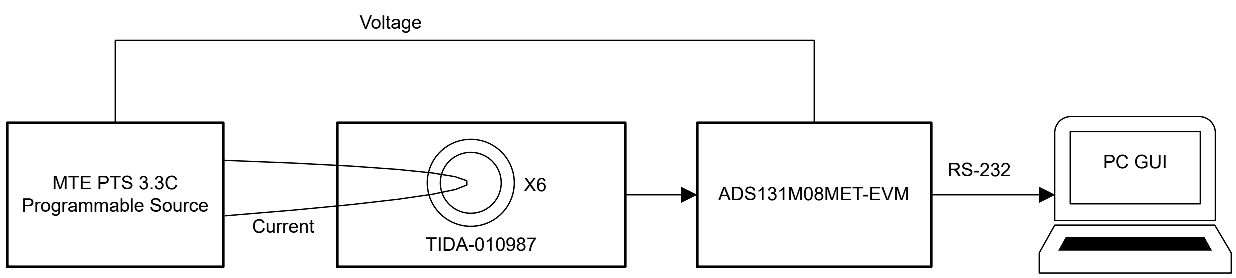


Figure 3-1. Full System Setup

3.2.1.1 Accurate Current Source

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

Figure 3-2. MTE Test Equipment

3.2.1.2 TIDA-010987

Figure 3-3 shows the board with the six different size coils and the analog signal condition circuits in a punch-out and plug-in form factor for ease of use.

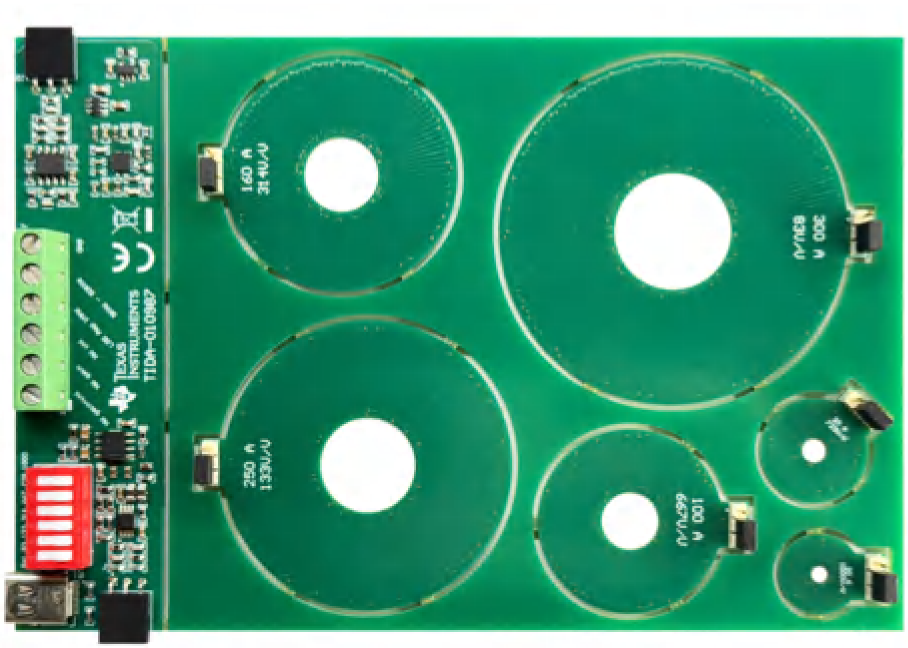


Figure 3-3. Punch-Out Board

3.2.1.3 ADS131M08 Metrology Evaluation Module

Figure 3-4 shows the EVM that is equipped with the ADC and the MCU that are required for energy calculation and consumption measurements.

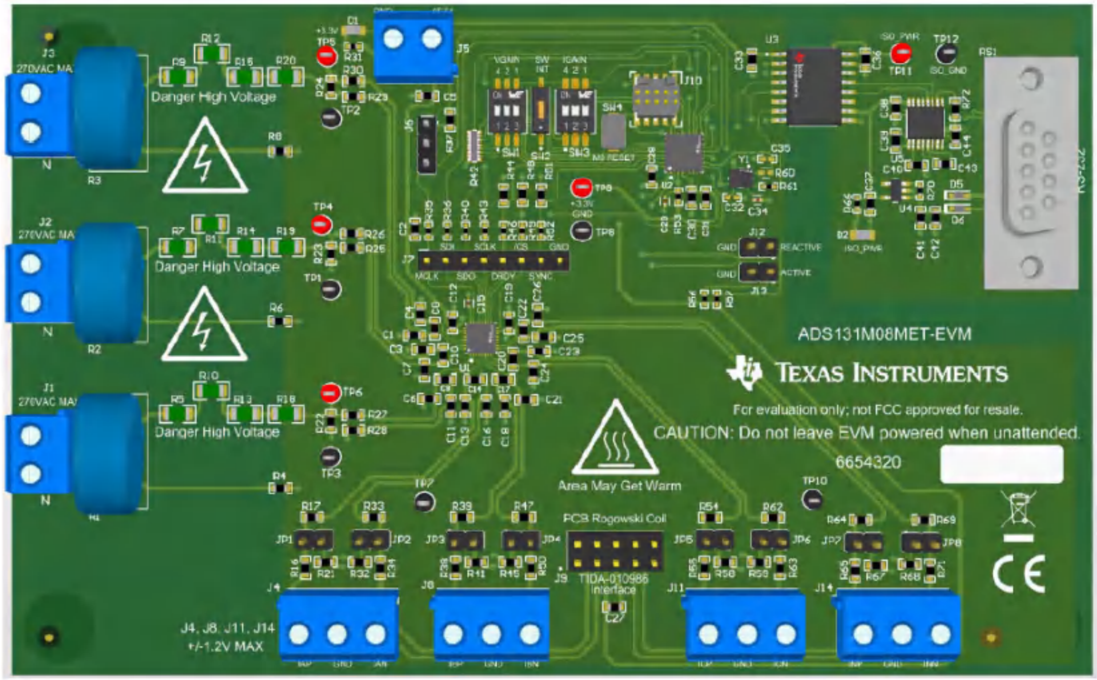


Figure 3-4. EVM With ADC and MCU for Energy Calculation and Consumption Measurements

3.2.1.4 GUI

Figure 3-5 shows the PC GUI that is used to track meter consumption and meter calibration.

Figure 3-5. Track Meter Consumption and Meter Calibration

3.2.2 5kHz to 50kHz Band Pass and Logarithmic Amplifier Test Setup

3.2.2.1 Oscilloscope

The following oscilloscope equipment is suggested for testing and is not included with the reference design:

- Tektronix MDO3050
- 2 × Tektronix TPP0500B 500MHz probe

3.2.2.2 Function Generator

The following function generator is suggested for testing and is not included with the reference design:

- Agilent 33210A 10MHz function, arbitrary waveform generator

3.3 Test Results

This section discusses the various tests performed on the PCB Rogowski coil and the signal conditioning board (TIDA-010987). Tests are conducted in accordance with ANSI C12.1 and applicable IEC standards. The sections also show the test results, highlighting the performance of the system in terms of accuracy, linearity, and noise immunity across different use cases and coils. The goal is to validate the compliance of the design with metering standards and the usefulness for real-world applications.

Table 3-1. Sensitivity Gain Guide

COIL SIZE (OUTER × INNER) mm	SENSITIVITY (μV/A) at 60HZ	GAIN NEEDED	RG
60 × 20	41.77	475	210
50 × 16	34.71	572	175
40 × 12	27.85	713	140
32 × 10	21.79	911	110
16 × 4	11.1	1000 (maximum gain)	100
13 × 3	9.1	1000 (maximum gain)	100

3.3.1 No Load Conditions

3.3.1.1 Objective

This test verifies that the system registers no pulses (current readings) when no current flows through the circuit.

3.3.1.2 Setup

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

3.3.1.3 Requirements

Observe the following requirements for no-load conditions:

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

3.3.1.4 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).

3.3.2 Starting Load Test

3.3.2.1 Objective

This test verifies that the meter operates continuously and reliably under start-up load conditions across minimum rated voltage and measures energy correctly in both directions.

3.3.2.2 Setup

Apply the specified starting load currents for the current class of interest. For this test, a current class 100 and class 0.1 to class 0.2 accuracy are the targets for metering applications.

3.3.2.3 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.

3.3.2.4 Results

Figure 3-6 shows the starting load test results.

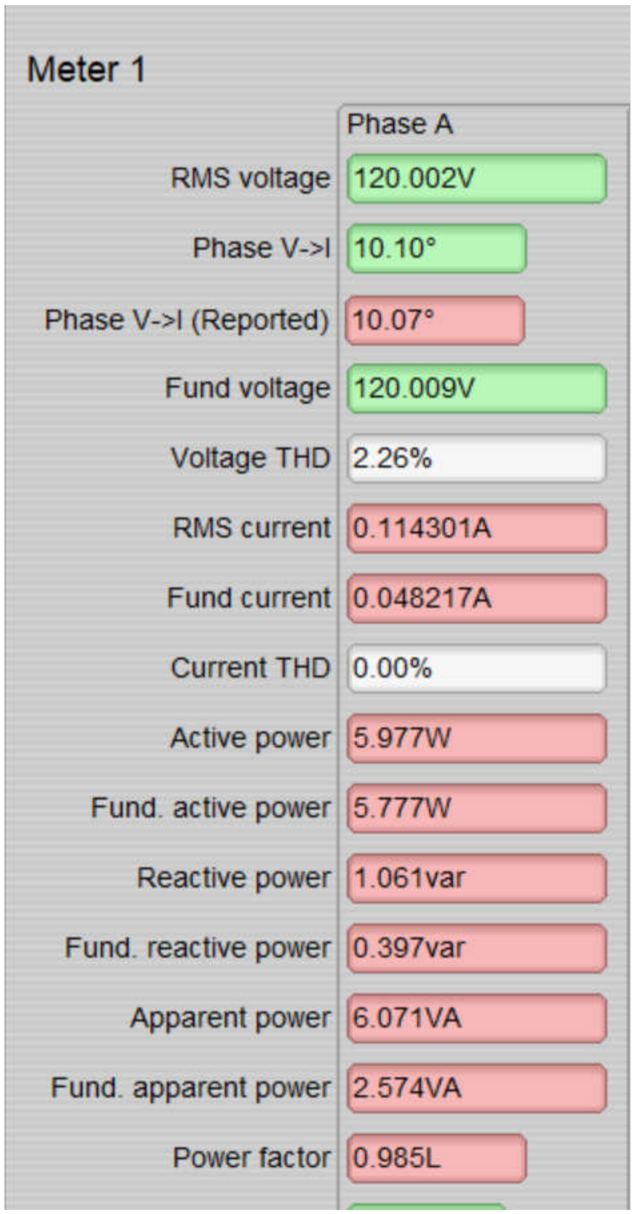


Figure 3-6. Starting Load Test Results

3.3.3 Active Power Measurements

3.3.3.1 Objective

This test verifies that the meter maintains class 0.1 to class 0.2 accuracy with varying load conditions and stays within allowable error limits.

3.3.3.2 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.

3.3.3.3 Requirements

Accuracy must stay within the allowable deviation from reference.

3.3.3.4 Results

Table 3-2 shows the active power measurement results.

Table 3-2. Active Power Measurement Results

CURRENT	(0 DEGREES)											
	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	ERROR 6	AVG ERROR %	DELTA ERROR	DELTA FROM REF	LIMIT (%) [CLASS 0.5]	LIMIT (%) [CLASS 0.2]	LIMIT (%) [CLASS 0.1]
1.0	–0.296	0.174	–0.013	–0.236	0.044	–0.280	–0.1012	0.4700	–0.0955	1.000	0.400	0.200
1.5	0.035	0.113	0.109	0.005	–0.103	–0.122	0.0062	0.2350	0.0118	0.500	0.200	0.100
3.0	0.028	–0.086	–0.151	0.102	0.167	0.029	0.0148	0.3180	0.0205	0.500	0.200	0.100
10.0	–0.040	–0.035	–0.082	–0.032	0.034	–0.090	–0.0408	0.1240	–0.0352	0.500	0.200	0.100
15.0	**–0.028**	**–0.048**	**–0.045**	**0.073**	**0.023**	**–0.009**	–0.0057	**0.1210**	**(REF)**	**0.200**	**0.100**	**0.050**
30.0	0.025	0.017	0.034	0.008	0.000	–0.013	0.0118	0.0470	–0.0175	0.500	0.200	0.100
50.0	0.027	0.017	0.014	0.010	0.033	0.040	0.0235	0.0300	–0.0292	0.500	0.200	0.100
75.0	0.022	0.035	0.031	0.026	0.037	0.014	0.0275	0.0230	–0.0332	0.500	0.200	0.100
90.0	0.041	0.036	0.056	0.054	0.051	0.039	0.0462	0.0200	–0.0518	0.500	0.200	0.100
100.0	0.066	0.061	0.068	0.059	0.072	0.074	0.0667	0.0150	–0.0723	0.500	0.200	0.100

3.3.4 Variation of Power factor

3.3.4.1 Objective

This test verifies that the meter operates continuously, reliably, and accurately under different power factors beyond unity power factor.

3.3.4.2 Setup

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

3.3.4.3 Requirements

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

3.3.4.4 Results

Table 3-3 and Table 3-4 show the variation of power factor results at different conditions.

Table 3-3. Variation of Power Factor Results at 60 Degrees

Current	(60 DEGREES) LEADING										
	Error 1	Error 2	Error 3	Error 4	Error 5	Error 6	AVG Error %	Delta Error	Delta From REF	Limit (%) [Class 0.5]	Limit (%) [Class 0.2]
1.500	**0.035**	**0.113**	**0.109**	**0.005**	**–0.103**	**–0.122**	0.006	0.235	**(REF)**	NA	NA
3.000	–0.180	0.099	0.082	–0.110	0.102	0.055	0.008	0.282	–0.002	**1.000**	**0.500**
15.000	**–0.028**	**–0.048**	**–0.045**	**0.073**	**0.023**	**–0.009**	–0.006	0.121	**(REF)**	NA	NA
15.000	–0.040	–0.181	0.018	0.036	0.080	–0.013	–0.017	0.261	0.011	**0.600**	**0.300**
50.000	**0.027**	**0.017**	**0.014**	**0.010**	**0.033**	**0.040**	0.024	0.030	**(REF)**	NA	NA
50.000	0.055	0.020	0.032	0.073	0.026	0.003	0.035	0.070	–0.011	**0.600**	**0.300**
100.000	**0.066**	**0.061**	**0.068**	**0.059**	**0.072**	**0.074**	0.067	0.015	**(REF)**	NA	NA
100.000	–0.042	–0.036	–0.062	–0.056	–0.051	–0.021	–0.045	0.083	0.111	**0.600**	**0.300**

Table 3-4. Variation of Power Factor Results at 323.13 Degrees

CURRENT	(323.13 DEGREES) LAGGING											
	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	ERROR 6	AVG ERROR%	DELTA ERROR	DELTA FROM REF	LIMIT (%) [CLASS 0.5]	LIMIT (%) [CLASS 0.2]	LIMIT (%) [CLASS 0.1]
1.500	**0.035**	**0.113**	**0.109**	**0.005**	**–0.103**	**–0.122**	0.006	0.235	**(REF)**	NA	NA	NA
3.000	0.086	0.012	–0.120	–0.092	–0.062	0.053	–0.021	0.206	0.027	**1.000**	**0.500**	**0.250**
15.000	**–0.028**	**–0.048**	**–0.045**	**0.073**	**0.023**	**–0.009**	–0.006	0.121	**(REF)**	NA	NA	NA
15.000	0.022	–0.038	–0.115	–0.086	–0.104	–0.001	–0.054	0.137	0.048	**0.600**	**0.300**	**0.150**
50.000	**0.027**	**0.017**	**0.014**	**0.010**	**0.033**	**0.040**	0.024	0.030	**(REF)**	NA	NA	NA
50.000	0.074	0.104	–0.012	0.027	–0.007	0.009	0.033	0.116	–0.009	**0.600**	**0.300**	**0.150**
100.000	**0.066**	**0.061**	**0.068**	**0.059**	**0.072**	**0.074**	0.067	0.015	**(REF)**	NA	NA	NA
100.000	0.093	0.104	0.106	0.100	0.109	0.118	0.105	0.025	–0.038	**0.600**	**0.300**	**0.150**

3.3.5 Variation of Voltage Test

3.3.5.1 Objective

This test verifies that the meter operates continuously, reliably, and accurately across voltage ranges beyond nominal voltage.

3.3.5.2 Setup

Apply different voltages depending on the specified voltage range of the meter. The test point conditions include the following:

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

3.3.5.3 Requirements

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

3.3.5.4 Results

Table 3-5 shows the results of the variation of voltage.

Table 3-5. Variation of Voltage Test Results

VOLTAGE	cos ϕ = 1i (0 DEGREES)							ANSI C12.1 2022		
	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	DELTA ERROR	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)	**0.023**	**0.068**	**0.018**	**0.129**	**0.113**	**0.111**	0.070	(REF)	REF	REF
108	0.114	0.177	0.09	0.046	–0.113	**0.290**	0.0628	0.007	±0.1	±0.2
235	–0.076	–0.022	–0.019	–0.053	0.109	**0.185**	–0.0122	0.082	±0.1	±0.2
270	0.046	0.006	–0.073	–0.039	0.012	**0.119**	–0.0096	0.080	±0.1	±0.2
297	0.006	0.029	–0.005	–0.068	–0.062	**0.097**	–0.0200	0.090	±0.1	±0.2
	TEST CURRENT (TA)									
	15	**15**	**15**	**15**	**15**					
120 (REF)	**–0.077**	**–0.073**	**–0.065**	**–0.117**	**–0.077**	**0.052**	–0.0818	(REF)	REF	REF
108	–0.071	–0.1	–0.077	–0.119	–0.086	**0.048**	–0.0906	0.009	±0.1	±0.2
235	–0.019	0.094	0.032	0.09	0.009	**0.113**	0.0412	0.123	±0.1	±0.2
270	0.02	–0.003	–0.05	0.036	0.012	**0.086**	0.0030	0.085	±0.1	±0.2
297	–0.05	–0.081	–0.081	–0.097	–0.057	**0.047**	–0.0732	0.009	±0.1	±0.2

3.3.6 Variation of Frequency

3.3.6.1 Objective

This test verifies that the meter operates continuously, reliably, and accurately across frequency ranges beyond nominal frequency.

3.3.6.2 Setup

Apply different frequencies depending on the specified frequency range of the meter. The test point conditions include the following:

- 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

3.3.6.3 Requirements

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

3.3.6.4 Results

Table 3-6 shows the variation of frequency results.

Table 3-6. Variation of Frequency Results

FREQUENCY	ERROR 1	ERROR 2	ERROR 3	ERROR 4	ERROR 5	DELTA ERROR	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					
50 (REF)	**0.067**	**0.18**	**0.112**	**0.164**	**–0.066**	**0.246**	**0.0914**	**(REF)**	**REF**	**REF**
49	0.193	–0.126	0.059	0.176	0.23	0.356	0.1064	0.015	±0.05	±0.1
51	0.152	0.224	0.187	0.177	–0.195	0.419	0.1090	0.018	±0.05	±0.1
60 (REF)	**–0.048**	**0.140**	**–0.069**	**–0.139**	**–0.080**	**0.279**	**–0.0392**	**(REF)**	**REF**	**REF**
58.8	–0.08	–0.073	0.099	0.042	–0.025	0.179	–0.0074	0.032	±0.05	±0.1
61.2	0.13	–0.107	0.11	–0.296	0.076	0.426	–0.0174	0.022	±0.05	±0.1
	TEST CURRENT (TA)									
	15	**15**	**15**	**15**	**15**					
50 (REF)	**0.008**	**–0.028**	**–0.036**	**–0.006**	**–0.014**	**0.044**	**–0.0152**	**(REF)**	**REF**	**REF**
49	0.007	0.016	0.000	0.000	–0.012	0.028	0.0022	0.017	±0.05	±0.1
51	–0.008	–0.033	0.010	0.008	0.000	0.043	–0.0046	0.011	±0.05	±0.1
60 (REF)	**0.069**	**0.073**	**0.097**	**0.085**	**0.050**	**0.047**	**0.0748**	**(REF)**	**REF**	**REF**
58.8	0.079	0.090	0.095	0.094	0.094	0.016	0.0904	0.016	±0.05	±0.1
61.2	0.097	0.079	0.086	0.013	–0.002	0.099	0.0546	0.020	±0.05	±0.1

3.3.7 Band Pass

3.3.7.1 Objective

This test verifies the frequency response of the AFE.

3.3.7.2 Setup

Attach the function generator to the AFE input in place of the Rogowski coil. Use an oscilloscope at the 5kHz to 50kHz marked output test point referenced from ground to measure the frequency response from 50Hz to 400kHz. Passive probes are AC coupled to allow for scaling and peak-to-peak measurements.

The system measures input and output voltages. A normalization factor applies based on an effective Rogowski coil that scales linearly with frequency. The combined plot in Figure 3-7 shows the measured AFE response.

3.3.7.3 Requirements

The band pass requirements include –3db cutoff frequencies corresponding to 5kHz and 50kHz.

3.3.7.4 Results

Table 3-7 and Figure 3-7 show the TLV387 band pass filter frequency response data and graph.

Table 3-7. Band Pass Results

FREQUENCY	INPUT VOLTAGE	OUTPUT AMPLITUDE (V)	NORMALIZATION FACTOR	V/V	dB
100	3.76	0.504	2	0.268085	–11.4345
500	2.8	1.78	10	6.357143	16.06524
1000	0.72	0.82	20	22.77778	27.15023
2000	0.72	1.56	40	86.66667	38.75704
4000	0.72	2.56	80	284.4444	49.07995
6000	0.72	3.16	120	526.6667	54.43072
8000	0.72	3.48	160	773.3333	57.76733
10,000	0.72	3.6	200	1000	60
12000	0.72	3.56	240	1186.667	61.48657
14000	0.72	3.52	280	1368.889	62.72736
16000	0.72	3.4	320	1511.111	63.58593
18000	0.72	3.28	360	1640	64.29688

Table 3-7. Band Pass Results (continued)

FREQUENCY	INPUT VOLTAGE	OUTPUT AMPLITUDE (V)	NORMALIZATION FACTOR	V/V	dB
20000	0.72	3.08	400	1711.111	64.66556
25000	0.72	2.76	500	1916.667	65.65093
30000	0.72	2.36	600	1966.667	65.87462
35000	0.72	2.06	700	2002.778	66.03266
45000	0.72	1.54	900	1925	65.68861
55000	0.72	1.19	1100	1818.056	65.19214
65000	0.72	0.928	1300	1675.556	64.48318
80000	0.72	0.64	1600	1422.222	63.05935
100000	0.72	0.444	2000	1233.333	61.82161
200000	0.72	0.116	4000	644.4444	56.18371
400000	0.72	0.036	8000	400	52.0412

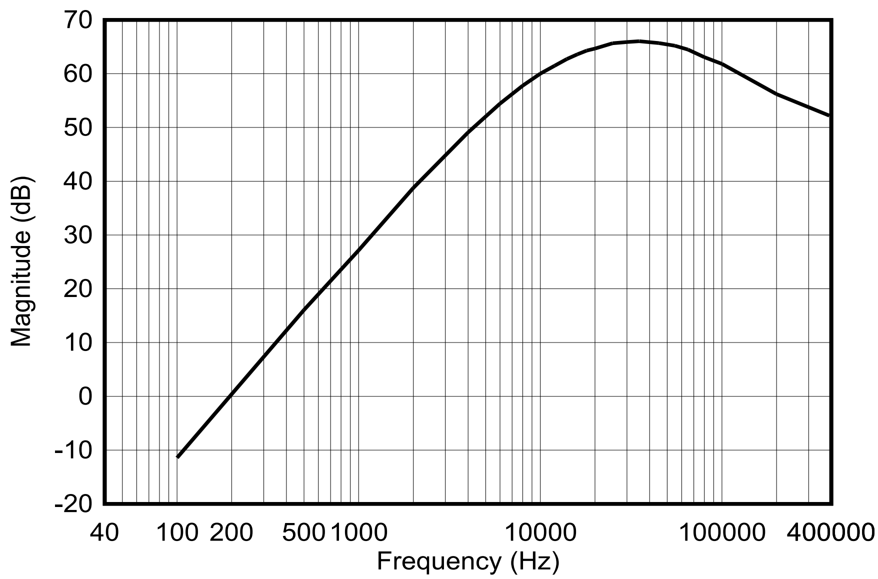


Figure 3-7. TLV387 Band Pass Filter Frequency Response

3.3.8 Logarithmic Amplifier

3.3.8.1 Objective

This test verifies the response and magnitude of the LOG300 AFE.

3.3.8.2 Setup

Attach the function generator to the AFE input in place of the Rogowski coil. Use the oscilloscope at the logarithmic amplifier marked output test point. Measure the magnitude of the logarithmic amplifier output in volts. Peak sensitivity occurs at 1MHz based on the LC pair between the low-noise amplifier output pin and log detector input pin.

3.3.8.3 Requirements

The following list shows the logarithmic amplifier requirements:

- The output scales logarithmically
- Peak sensitivity occurs at 1MHz

3.3.8.4 Results

Figure 3-8 shows the LOG300 output magnitude graph.

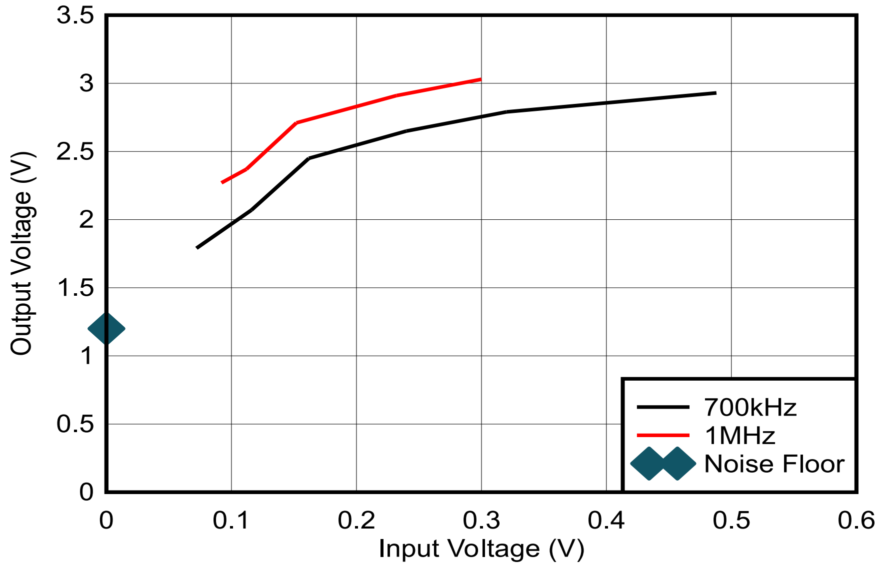


Figure 3-8. LOG300 Output Magnitude

4 Design and Documentation Support

4.1 Design Files

To download the design files, see the design files at TIDA-010987.

4.1.1 Schematics

To download the schematics, see the design files at TIDA-010987.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010987.

4.1.3 PCB Layout Recommendations

4.1.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-010987.

4.2 Tools

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

4.3 Documentation Support

1. Texas Instruments, *INA333 Micro-Power (50μA), Zerø-Drift, Rail-to-Rail Out Instrumentation Amplifier Datasheet*
2. Texas Instruments, *INA818 35μV Offset, 8nV/$\sqrt{Hz}$ Noise, Low-Power, Precision Instrumentation Amplifier Datasheet*
3. Texas Instruments, *INA828 50μV Offset, 7nV/$\sqrt{Hz}$ Noise, Low-Power, Precision Instrumentation Amplifier Datasheet*
4. Texas Instruments, *TLV900x Low-Power, RRIO, 1MHz Operational Amplifier for Cost-Sensitive Systems Datasheet*
5. Texas Instruments, *TLVx387 High Precision, Zero-Drift, Low-Input-Bias-Current Op Amps Datasheet*
6. Texas Instruments, *TL08xx FET-Input Operational Amplifiers Datasheet*
7. Texas Instruments, *LM2664 Switched Capacitor Voltage Converter Datasheet*
8. Texas Instruments, *ADS131M08 Metrology Evaluation Module User's Guide*
9. Texas instruments, *TIDA-010986 Signal Conditioning for Rogowski Coil Reference Design Guide*

4.4 Support Resources

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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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