AC Arc Fault Detection With Edge AI for Circuit Breakers Reference Design

Description

This reference design features an analog front end that enables AC arc fault detection. An AI model runs on an embedded microcontroller. Multiple sensing channels evaluate AI arc fault detection through current filters, voltage sensing, and log detection for high frequency arc energy. A PCB Rogowski current sensor feeds the signal chain. The board pairs with compatible LaunchPad™ like MSPM0G5187-LP.

Resources

TIDA-010971	Design Folder
TLV387, TLV9054	Product Folder
MSPM0G5187, LOG300	Product Folder
UCC28881, TPS709	Product Folder

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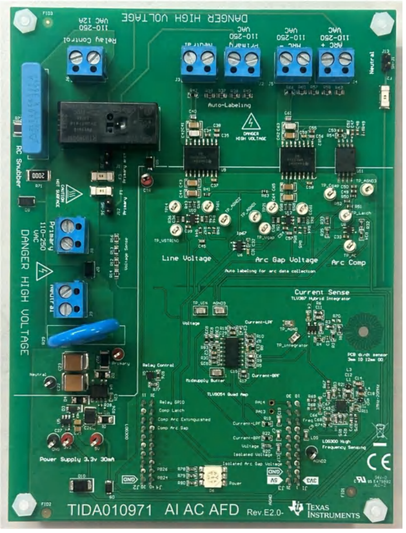
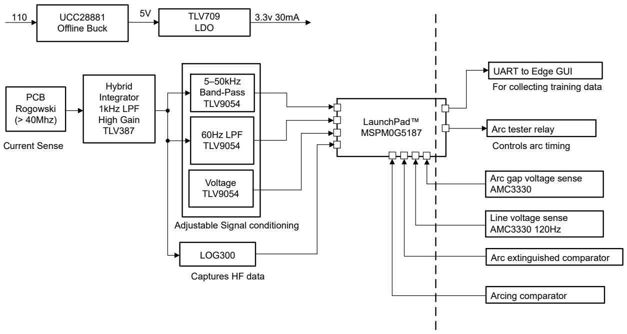
Features

- Built in PCB Rogowski
- LaunchPad™ Development Kit connection for MSPM0G5187 with AI accelerator
- Hybrid integrator with > 10MHz Bandwidth
- LOG300 with 40MHz bandwidth
- Auto labeling circuitry for easy data collection

Applications

- AFCI circuit breaker





1 System Description

1.1 Terminology

AFCI	Arc Fault Circuit Interrupter
AFD	Arc Fault Detection
Arc generator	Arcs created by contacting a graphite rod to a copper rod attached to a linear stage
Carbonizer	Arc generator which uses a high-voltage transformer and a wire sample

1.2 Key System Specifications

Table 1-1 shows the key system specifications:

Table 1-1. Key System Specifications

ITEM	DESCRIPTION
Power Draw	About 7mA to 17mA
Power Supply	Efficiency 17% at 10mA
Input Voltage	110 to 250VAC
Rogowski Bandwidth	50Hz to 40MHz
Rogowski size	12mm diameter × 2 layer PCB thickness
Rogowski Sensitivity	About 0.4mV/A at 6kHz
Hybrid Integrator Bandwidth	2kHz to 40MHz
Gain Amplifier Bandpass	6kHz to50kHz

CAUTION

Do not leave the design powered when unattended.

WARNING

High voltage! *Accessible high voltages are present on the board*. Electric shock is possible. The board operates at voltages and currents that can cause shock, fire, or injury if not properly handled. Use the equipment with necessary caution and appropriate safeguards to avoid injuring yourself or damaging property. For safety, use of isolated test equipment with overvoltage and overcurrent protection is highly recommended.

TI considers the user's responsibility to confirm that the voltages and isolation requirements are identified and understood before energizing the board or simulation. *When energized, do not touch the design or components connected to the design*.

WARNING

Hot surface! Contact can cause burns. Do not touch!

Some components can reach high temperatures > 55°C when the board is powered on. Do not touch the board at any point during operation or immediately after operating, as high temperatures can be present.

WARNING

TI intends this reference design to be operated in a ***lab environment only and does not consider the design as a finished product*** for general consumer use. The design is intended to be run at ambient room temperature and is not tested for operation under other ambient temperatures.

TI intends this reference design to be used only by ***qualified engineers and technicians*** familiar with risks associated with handling high-voltage electrical and mechanical components, systems, and subsystems.

There are ***accessible high voltages present on the board*** . The board operates at voltages and currents that can cause shock, fire, or injury if not properly handled or applied. Use the equipment with necessary caution and appropriate safeguards to avoid injuring yourself or damaging property.

2 System Overview

2.1 Block Diagram

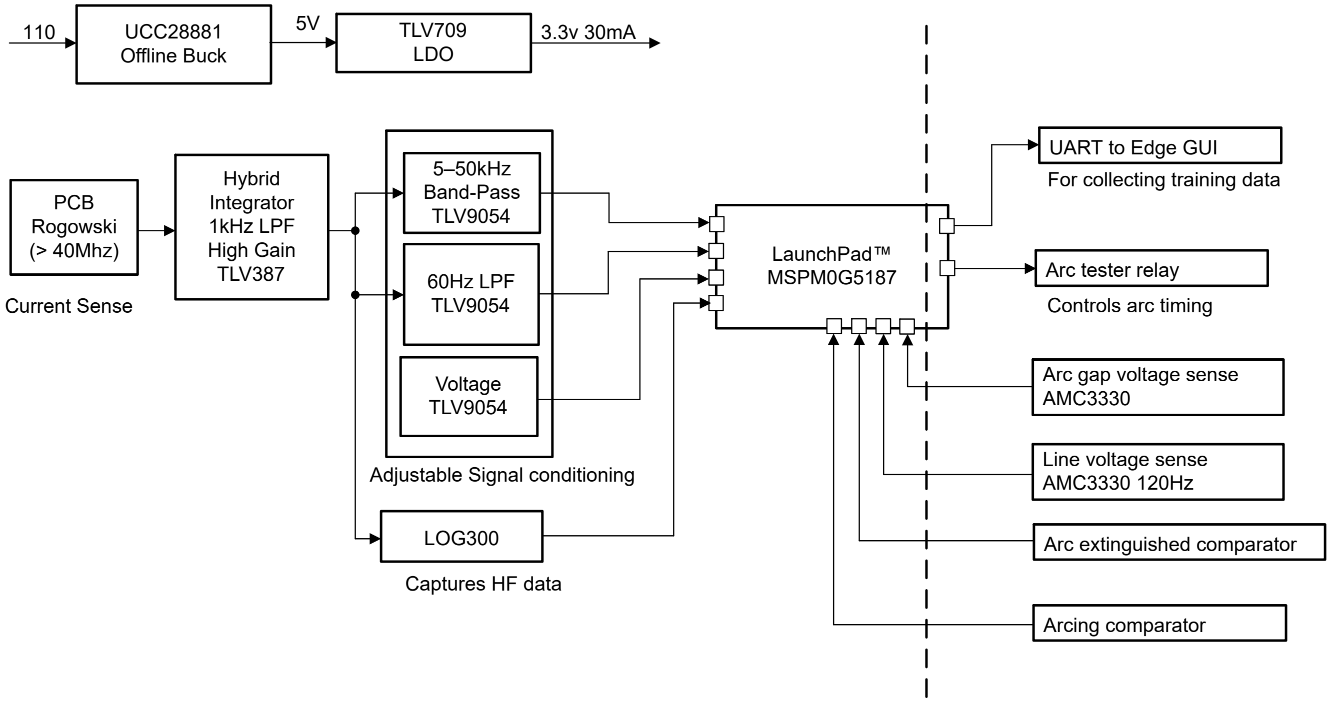


Figure 2-1. System Block Diagram

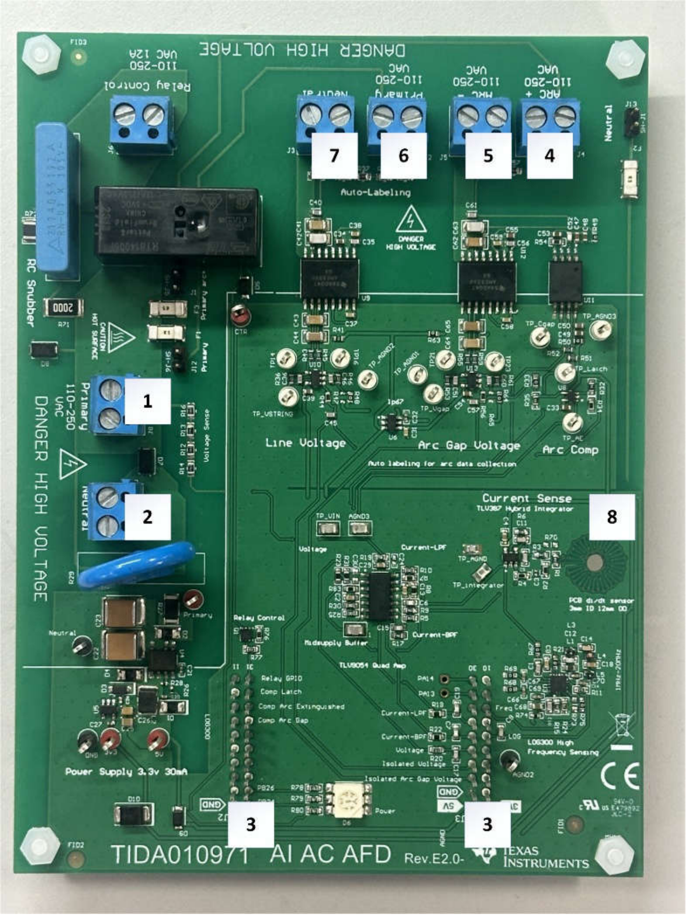


Figure 2-2. Board Image With Connection Labels

1. Input Voltage Primary: 110-250VAC
2. Input Voltage Neutral: 0V
3. LaunchPad connection: (MSPM0G5187-LP)
    a. PA16 A014 bandpass current
    b. PB16 A019 voltage
    c. PB22 A024 LOG300
    d. PB14 A021 isolated voltage
    e. PB15 A020 isolated arc gap
    f. PA15 A015 low pass current
    g. PB4 Red LED
    h. PB5 Green LED
    i. PA11 Relay GPIO
    j. PA10 Relay Latch
    k. PA31 Comparator Arc extinguished
    l. 3.3V
    m. 5V
    n. GND
4. Arc+: 120VAC (optional J1 jumper to primary)
5. Arc–:120VAC
6. Isolated Primary 110-250VAC (optional: J12 jumper to primary)
7. Isolated Neutral 0V (optional: J13 jumper to neutral)
8. Relay Control: Output: 110-250VAC, 12A maximum
9. PCB Rogowski: 12AWG, inner diameter: 3mm

2.2 Design Considerations

2.2.1 Sensor Selection

Circuit breakers must protect circuit branch wiring. Current sensors provide the primary method for this protection. Measuring input branch current offers the easiest approach to accomplish this protection.

Arc fault detection uses voltage, current, light or combinations of these sensor types. The arc signature determines sensor choice for arc detection. The arc signature represents data features characteristic of arcing. Filtering frequencies of interest magnifies these features. Common DSP techniques such as fast Fourier transform (FFT) also enhance signal characteristics.

Final applications create additional requirements. Circuit breakers commonly interrupt 10,000A. Arc fault interrupters stop arcs from 5A to 500A. Arcing signals produce frequencies up to 10MHz and beyond. Cost, size, manufacturability, linearity, and temperature stability affect sensor selection.

Analysis of arcing current data shows arcing as time varying pink noise. This creates a wide frequency spectrum. Figure 2-3 shows this as a vertical line on the FFT that rolls off with frequency. Detection occurs at MHz level frequencies. Magnitude varies randomly with time and across frequency.

AC arcs create a period where voltage builds while current remains zero. The arc gap voltage must reach sufficient magnitude to ionize air in the gap. This current discontinuity creates greater magnitude of arcing characteristics when measuring current versus voltage. Circuit breaker standard UL1699 sets a current threshold for arcing. These factors make current sensors advantageous for arc detection in branch circuit protection.

Voltage offers advantages in other applications. Voltage has a narrower defined dynamic range. This leads to simpler filtering and DSP requirements. Light sensors do not work for this application. Arc detection must occur anywhere along the entire circuit.

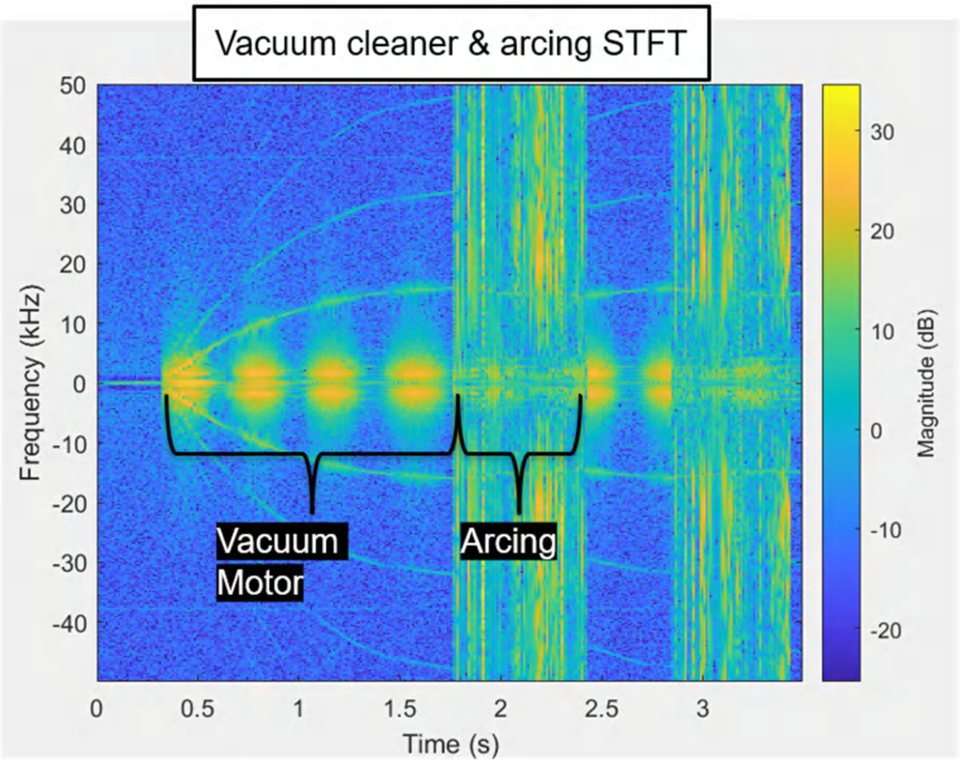


Figure 2-3. Arcing Frequency Spectrum Over Time With Vacuum Load

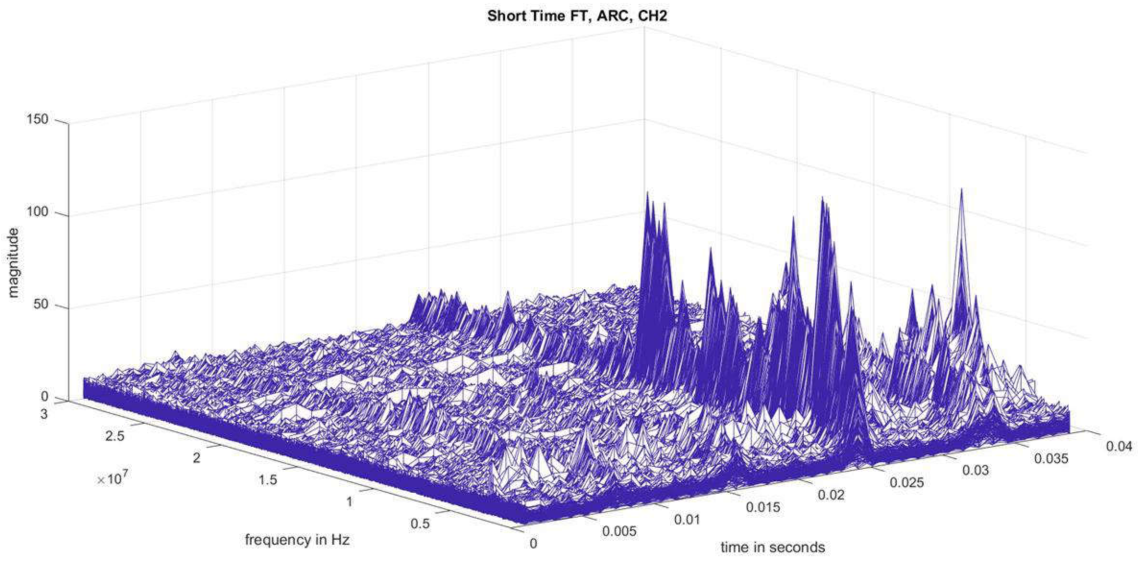


Figure 2-4. Arcing Frequency Spectrum in MHz Over 40ms Period With Vacuum Load

Current sensors considered include current transformers, Rogowski coils, and shunts.

Table 2-1. Current Sensor Comparison

CURRENT SENSOR	ADVANTAGES	DISADVANTAGES
Shunt	Compact, low cost, high bandwidth	Temperature variation, non-isolated, must survive 10,000A
CT	Isolation, good sensitivity, saturation limits induced voltage	Bulky, high cost for high bandwidth
Rogowski	High bandwidth, high sensitivity to arcing frequencies, small size if built into PCB, low cost	Requires integrator, low sensitivity to low frequencies

2.3 Highlighted Products

2.3.1 TLV387

The TLV387 precision amplifier offers state-of-the-art performance. Zero-drift technology provides unparalleled long-term stability for TLV387 offset voltage and offset drift. The TLV387 achieves 5.7MHz bandwidth with 570μA quiescent current. The amplifier delivers $8.5nV/\sqrt{Hz}$ broadband noise and $177nV_{PP}$ 1/f noise. These specifications enable extremely high precision in 16-bit to 24-bit analog to digital converters (ADCs). The specifications prevent linearity degradation. The TLV387 features flat bias current over temperature. High input impedance applications need little to no calibration over temperature.

2.3.2 TLV9054

TLV9054 functions as a quad operational amplifier. The device operates from 1.8V to 6.0V low-voltage supplies. Inputs and outputs operate rail to rail at very high slew rates. This device serves cost-constrained applications requiring low-voltage operation, high slew rate, and low quiescent current.

The TLV905x family drives 150pF capacitive loads. The resistive open-loop output impedance enables easier stabilization with higher capacitive loads. TLV905xS devices include shutdown mode. This mode switches amplifiers into standby with typical current consumption below 1μA.

The TLV905x family provides easy operation. The devices maintain unity-gain stability. RFI and EMI filters are included. Phase reversal does not occur in overdrive conditions.

2.3.3 MSPM0G5187-LP

MSPM0G5187 microcontrollers (MCUs) belong to the MSP highly integrated, ultra-low-power 32-bit MCU family. The enhanced Arm® Cortex® ®-M0+ 32-bit core platform forms the base for these MCUs. The platform operates at frequencies up to 80MHz. These MCUs blend cost optimization and design flexibility. Applications require 32KB to 128KB flash memory. Small packages measure down to 4mm × 4mm. High pin count packages offer up to 64 pins.

These devices include an Edge AI NPU accelerator, cybersecurity enablers, and high performance integrated analog. The devices deliver excellent low-power performance across the operating temperature range. Up to 128KB embedded flash program memory includes built-in error correction code (ECC). Up to 32KB SRAM includes ECC and parity protection.

Flash memory organizes into two main banks to support field firmware updates. Address swap support operates between the two main banks. TI's Edge AI NPU functions as an integrated accelerator module. The module enhances fast, secure AI at the edge with sensing, processing, and control applications within the MSPM0 platform.

Flexible cybersecurity enablers support secure boot, secure in-field firmware updates, IP protection (execute-only memory), and key storage. Hardware acceleration operates for various AES symmetric cipher modes. The cybersecurity architecture awaits Arm PSA Level 1 certification.

High-performance analog modules include one sampling 12-bit 1.6Msps ADC supporting up to 26 external channels. On-chip voltage reference operates at 1.4V or 2.5V. One high-speed comparator includes built-in 8-bit reference DAC.

2.3.4 LOG300

The LOG300 functions as an integrated analog front end (AFE) consisting of low-noise amplifier (LNA) and Log Detector block. This device supports input frequency range from 50Hz to 40MHz and typical dynamic range of 98dB. The LOG300 serves applications requiring wide dynamic range voltage and signal measurement. The Log Detector block supports both single-ended and differential inputs. The integrated LNA low input noise enables measurement of signals as low as $7\mu V_P$. Users adjust transient output response by tuning the capacitor connected at the Log_Out pin. The integrated frequency detect feature enables users to extract input signal frequency and zero-crossing information.

2.3.5 UCC28881

The UCC28881 integrates the controller and a 14Ω, 700V power MOSFET into one monolithic device. The device also integrates a high-voltage current source. This enables start-up and operation directly from rectified mains voltage. UCC28881 belongs to the same family as UCC28880, with higher current handling capability.

The device low quiescent current enables excellent efficiency. The UCC28881 builds the most common converter topologies such as buck, buck-boost, and flyback. These topologies use a minimum number of external components.

The UCC28881 incorporates a soft-start feature for controlled start-up of the power stage. This minimizes stress on power-stage components.

2.3.6 TPS709

The TPS709 series linear regulators feature ultra-low quiescent current for power sensitive applications. A precision band-gap and error amplifier delivers 2% accuracy over temperature. Only 1µA quiescent current makes these devices excellent for battery-powered, always on systems requiring minimal idle-state power dissipation. These devices have thermal-shutdown, current-limit, and reverse-current protections for added safety. Shutdown mode activates by pulling the EN pin low. The shutdown current in this mode drops to 150nA, typical.

3 System Design Theory

3.1 Current Sensor

PCB Rogowski is selected due to linearity over wide bandwidth and low cost. TI devices solve the design challenges of integration and low sensitivity of the coil.

The coil functions as a differential coil with matching return loops. Distance from the conductor determines Rogowski sensitivity by controlling magnetic field density and loop area. External magnetic fields couple into the signal when loop path mismatch occurs in this differential signal with high gain.

The coil design uses a novel layout to match loop paths while offsetting inner vias. This allows greater loop density. Four interleaved Rogowski coils accomplish this design. Two coils, an outer and inner coil, wind in opposite directions and connect in series. These connect differentially with the other pair wound identically.

This topology provides inductive and capacitive noise rejection while increasing coil density. Traditional winding schemes do not offset vias. This invention uses contributions from TIDA01063 and PCB Rogowski research into winding topologies(1).

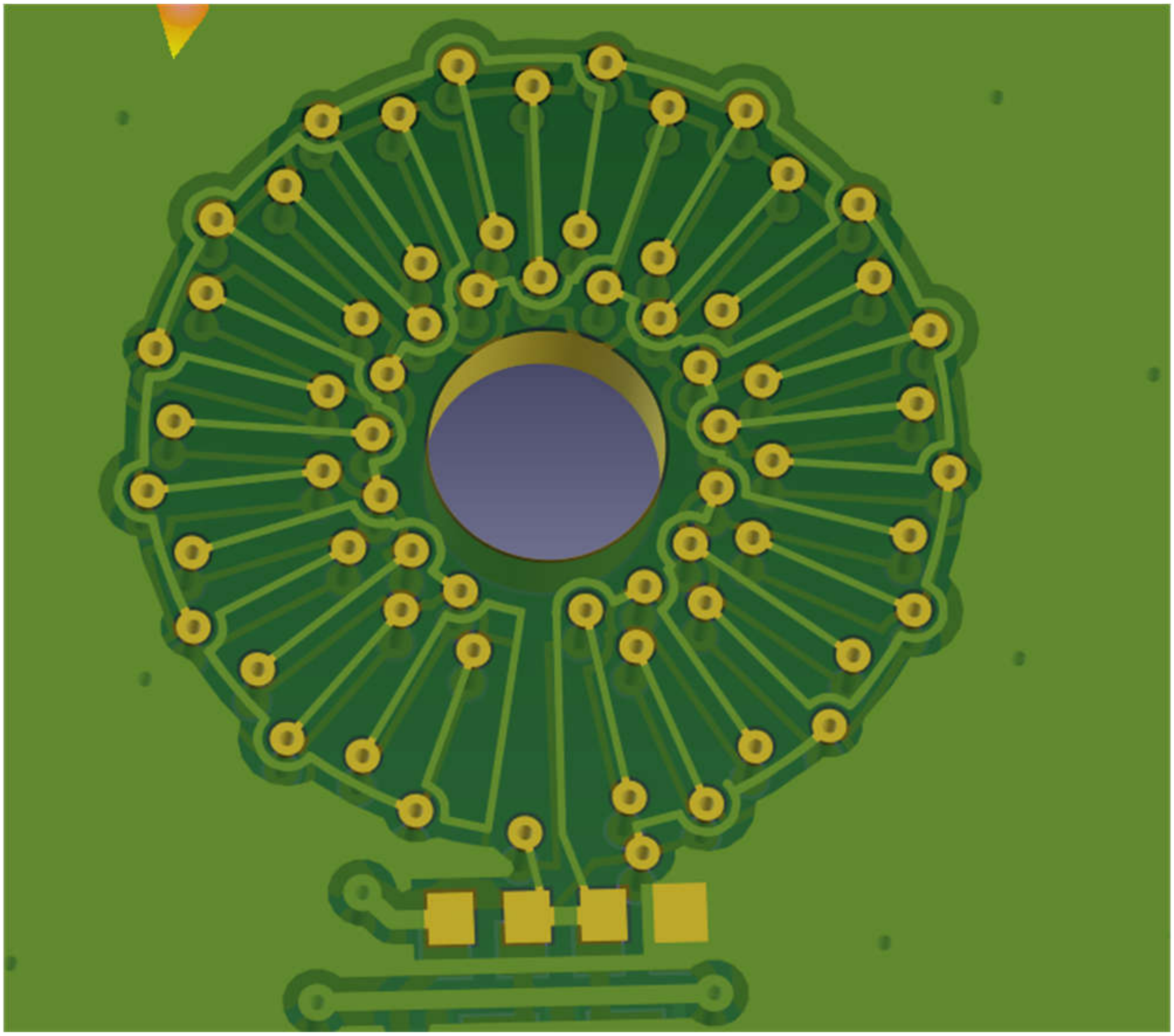


Figure 3-1. PCB Rogowski Winding Layout

Figure 3-2 shows a model of the equivalent circuit.

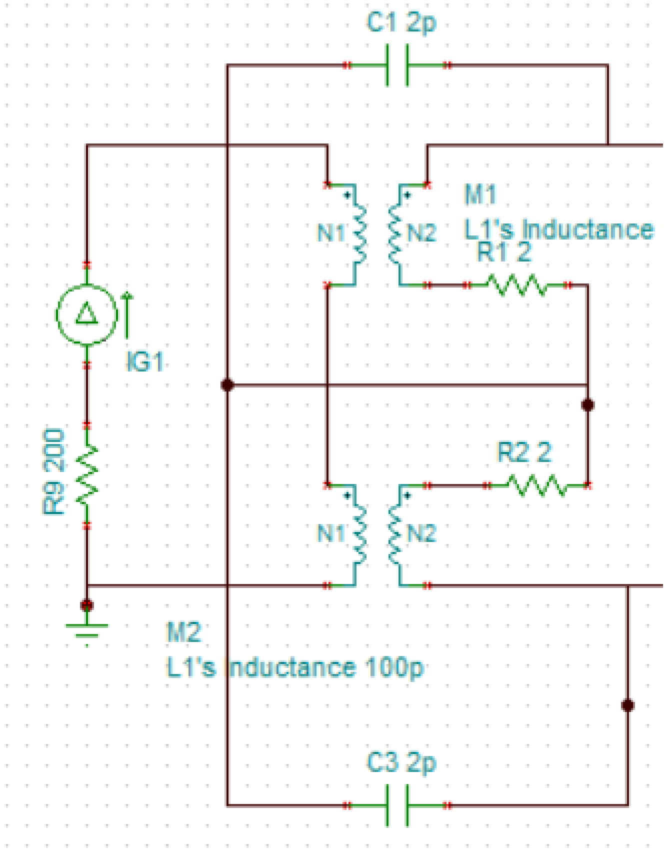


Figure 3-2. TINA Simulation Schematic of Rogowski Coil

The Rogowski coil output equals the derivative of the current. For a periodic signal the derivative can be calculated using Equation 1.

$$\sin(wt) = w \times \cos(wt) \tag{1}$$

This matches the simulated transfer function up to the self-resonance point of the PCB coil. For this small coil the theoretical self-resonance point exceeds 40MHz. See TIDA-010987 and TIDA-01063 for more details about PCB Rogowski design.

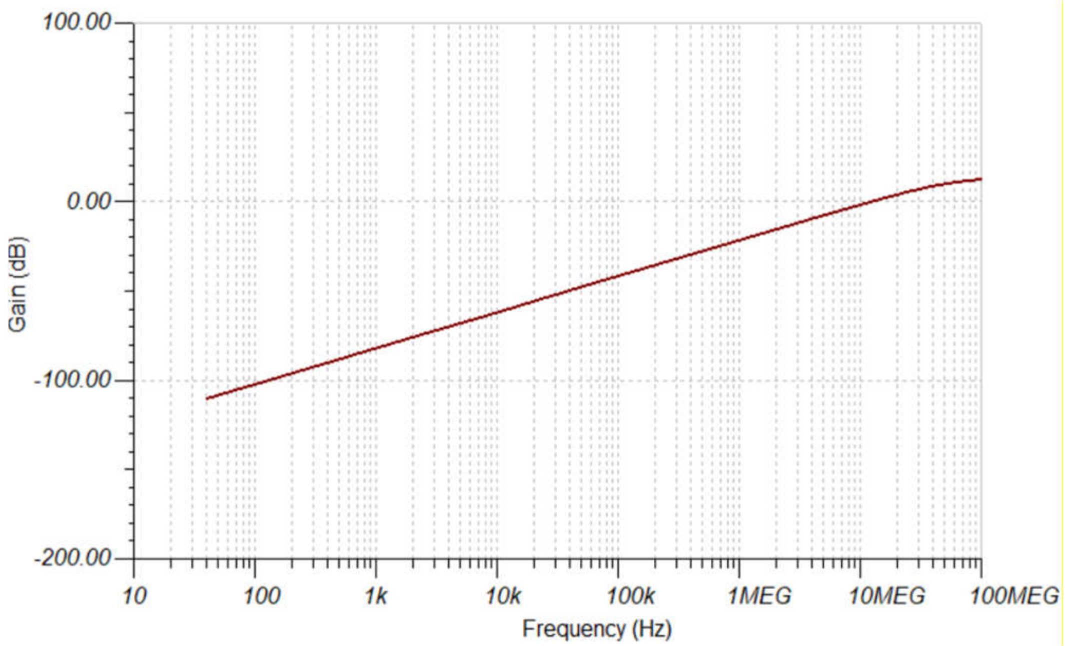


Figure 3-3. Simulated Bode Plot of PCB Rogowski

3.2 Hybrid Integrator

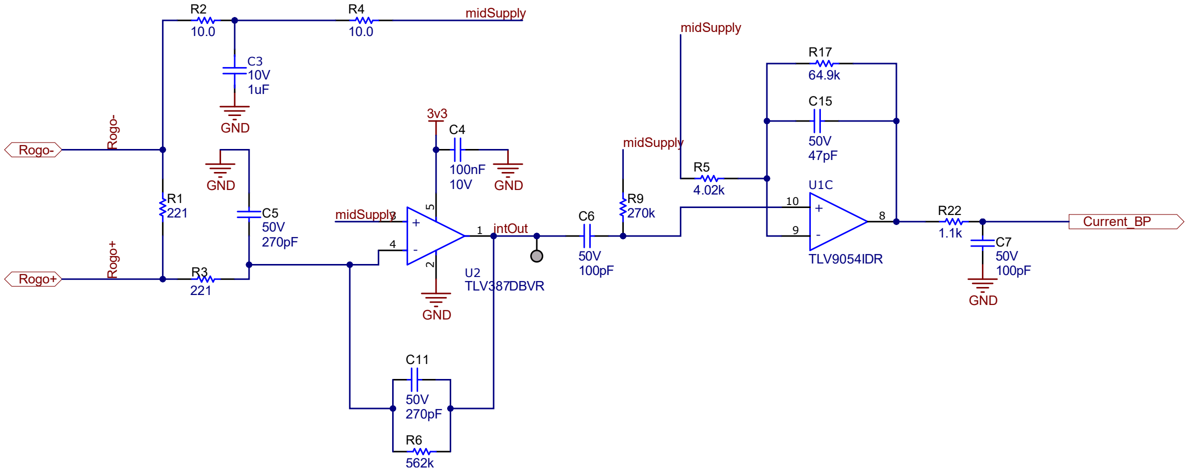


Figure 3-4. Hybrid Integrator Schematic

An integrator provides flat linear response across the full PCB Rogowski bandwidth and amplifies the signal at low frequencies. An integrator has infinite gain at DC. This causes errors to accumulate over time requiring integrator reset. This design avoids that problem by using feedback resistor R6 on the amplifier. R6 and R3 then set the DC gain.

Amplifier noise drives integrator amplifier selection. Rogowski sensitivity calculates at 4μV/A at 60Hz using equations in TIDA-01063. Noise around 8nV provides about 2% accuracy. The Rogowski acts as a high-pass filter. Higher frequencies have larger signals. 1mA at 60kHz with 4nV noise gives 2% accuracy. Similarly, 1μA at 60MHz provides 2% accuracy. TLV387 meets this low noise requirement.

The corner frequency of the integrator is selected above 60hz at 1kHz to attenuate the load signal and provide a sharper cutoff for the band-pass filter.

At 1kHz, the open loop gain reaches 75dB. The DC gain is set at 68.6dB (R6 and R3), or 2543v/v. This represents the upper limit of gain that the amplifier supports with some margin. The phase margin for this circuit simulates to 45.61°. At 2543v/v with 4μV/A sensitivity the integrator output voltage/A at 60Hz equals 10mV/A at 60Hz.

The active low-pass filter has bandwidth limitations. However, a passive RC filter extends the bandwidth. The passive filter must have a cutoff frequency at the crossover frequency of the designed active low-pass filter(2). With 68.6dB gain the crossover frequency occurs at 2MHz. R3 and C5 are chosen with a cutoff frequency at 2MHz extending the integrator bandwidth.

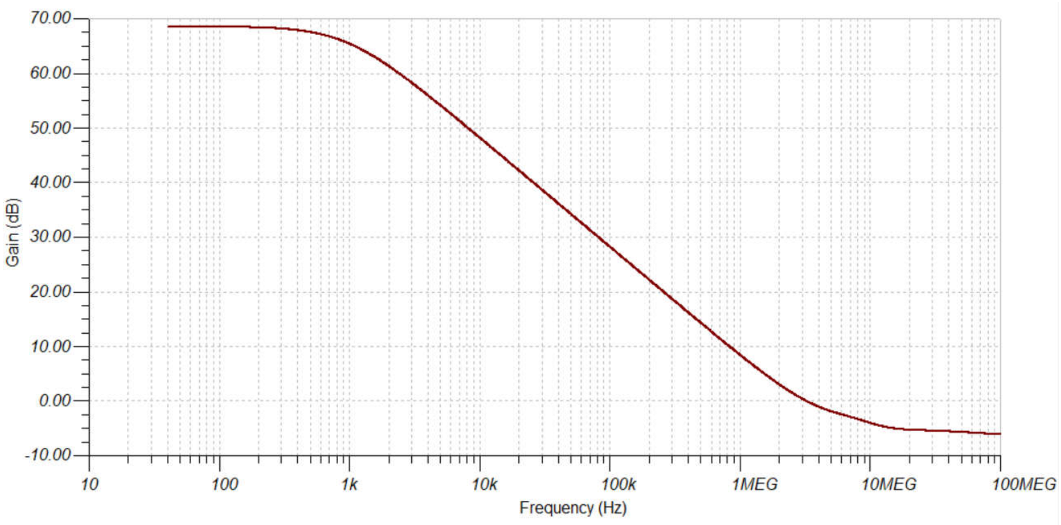
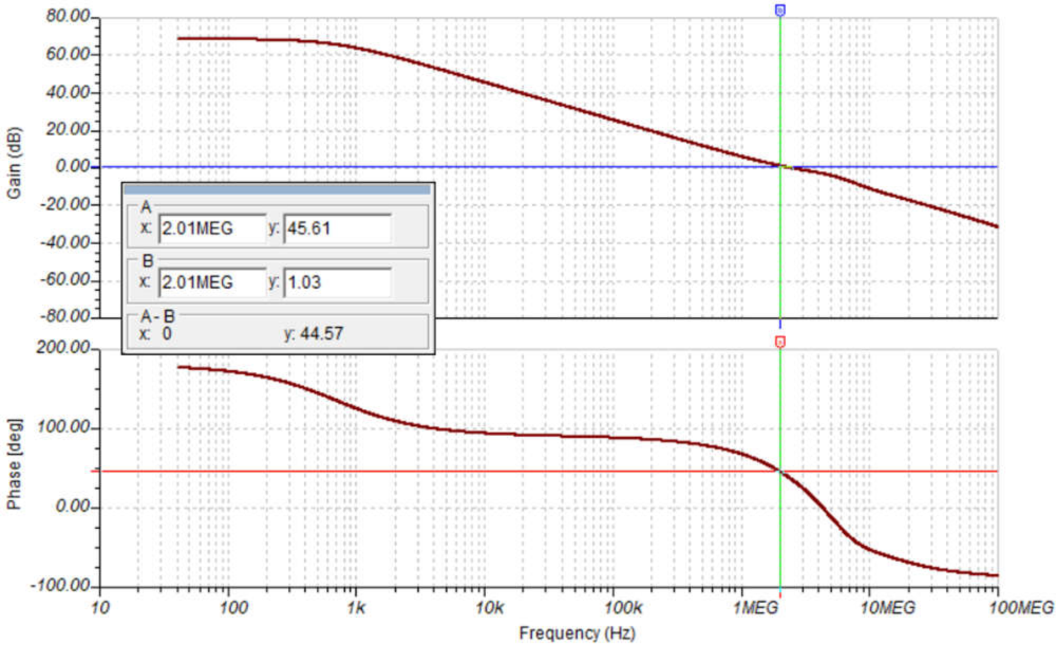


Figure 3-5. Integrator Without Low-Pass Filter



A
x: 2.01MEG y: 45.61

B
x: 2.01MEG y: 1.03

A - B
x: 0 y: 44.57

Figure 3-6. Final Hybrid Integrator Magnitude and Phase After Low-Pass Filter is Added

At this gain the input offset voltage also amplifies. At 0V to 3.3V range the maximum offset voltage with no margin for the signal equals 1.29mV. For TLV387 the maximum input offset voltage reaches 10μV. This leads to ±25mV DC offset that cancels with a high-pass filter in the band-pass stage. Considering the offset, the adjusted range over temp of the amplifier equals 3.3V – 0.25V = 3.05V. The maximum current that can be sensed without clipping with this hybrid integrator calculates as:

$$(\text{adjustedrange}) / (\text{gain} \times \text{sensitivity}) = 3.25\text{V} / (2543 \times 4\mu\text{V/A}) = 320\text{A} \qquad (2)$$

For this design TLV387 is chosen for low noise and low input offset. These characteristics enable significant amplification of the small signal from the PCB Rogowski. A single amplifier makes the hybrid integrator topology work for high bandwidth applications. The passive RC low-pass filter extends the amplifier bandwidth. For designs not needing higher bandwidth, a two-stage integrator + amplifier works with OPAx323 or TLV905x. This negates the input offset voltage causing clipping, but limits the integrator bandwidth by the second stage amplifier.

Table 3-1. Amplifier Comparison

AMPLIFIER	TLVx387	OPAx323	TLV905x
Number of channels	1, 2, 4	1, 2, 4	1, 2, 4
Noise	9nV/√Hz	5.5nV/√Hz	20nV/√Hz
Bandwidth	5.7MHz	20MHz	5.5MHz
Quiescent current	570µA	1.6mA	330µA
Maximum input offset voltage (–40°C to 120°C)	10µV	1.35mV	2mV
Input offset voltage typical	1µV	150µV	330µV

3.3 Band-Pass Filter

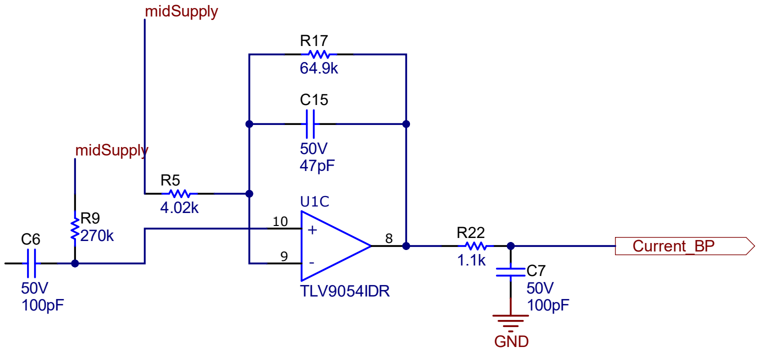


Figure 3-7. Band-Pass Filter Schematic

The band-pass filter functions as a non-inverting second order band-pass filter. R9 and C6 set the high-pass frequency. R5 and R17 set the gain. R17 and C15 set the low-pass frequency. Most energy from loads occurs in the 50Hz to 5kHz range. Filtering this out increases the range of arcing signal. This signal detects more easily in the 5kHz and higher frequency bands. The upper 50kHz frequency range is selected based on digital signal processing limitations. This reduces aliasing and enables oversampling. The AI arc fault algorithm typically uses FFT as feature extraction. On the Arm M0+ core the maximum number of samples in 2^n steps processes in a 50Hz to 60Hz AC half cycle at 1024. This corresponds to greater than 100kHz.

If planning to filter higher frequencies or creating a higher order band-pass filter, consider OPA4323.

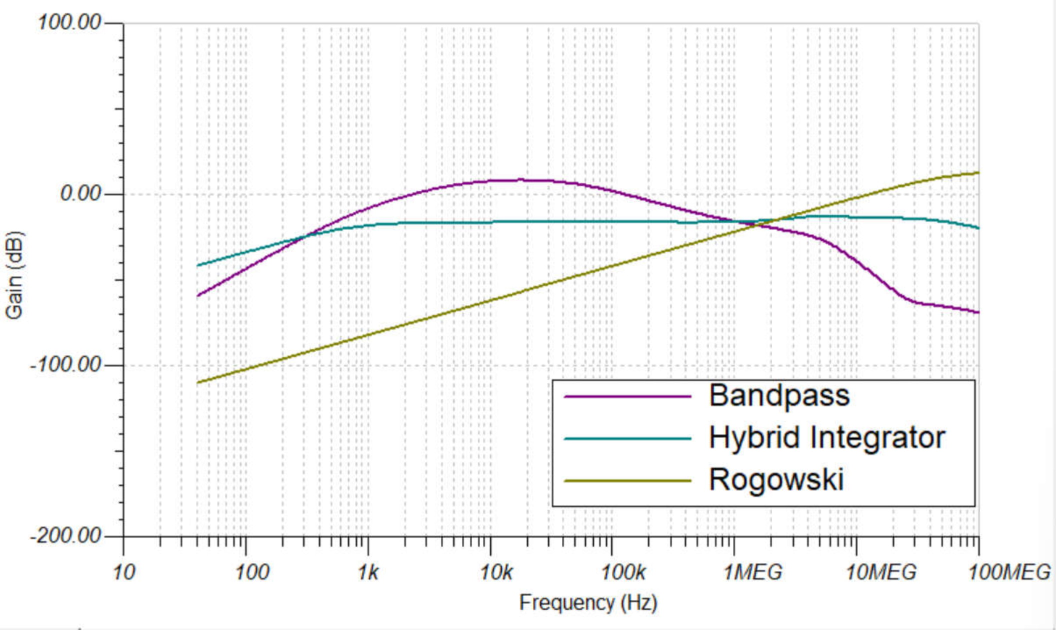


Figure 3-8. TINA Simulation of Rogowski, Integrator, and Band-Pass Combined

3.3.1 Log Amplifier

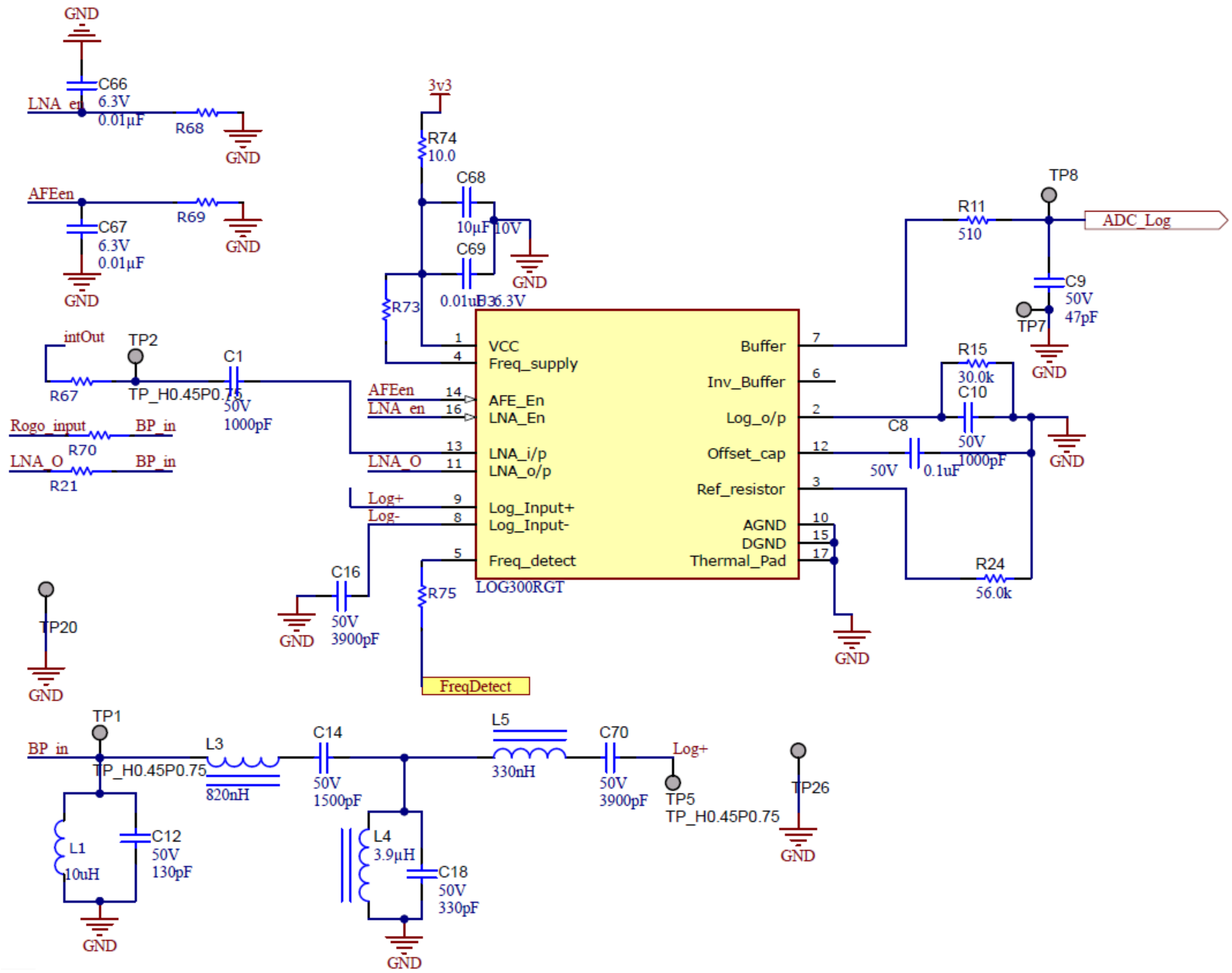


Figure 3-9. LOG300 Schematic

The LOG300 analog front end includes a low-noise amplifier (LNA) and log detector built into the same integrated circuit. The integrator output feeds into the LOG300 to buffer the PCB Rogowski. Jumper R70 connects the PCB Rogowski directly to the LNA. R68 and R69 optionally disable the AFE for power evaluation purposes. The band-pass filter functions as a fourth order 1MHz to 10MHz filter. A 10MHz first order band-pass filter creates with a single LC pair, 330pF for C18 and 681nH for L4. The unused passive components in series must have jumpers and the parallel LC pair must be depopulated. Compared to the fourth order filter more noise from loads appears in the first order filter log detector circuit output.

R15 and C10 adjust the magnitude and settling time of the LOG300 output. A lower value for R15 reduces the sensitivity. Higher C10 smooths the output. More details about the setup and evaluation of the LOG300 appear in the data sheet. The R15 and C10 values chosen form a low-pass filter with a settling time around 0.183ms. This provides enough detail to detect arcing edges compared to typical noise from loads.

3.3.2 Current Low-Pass Filter

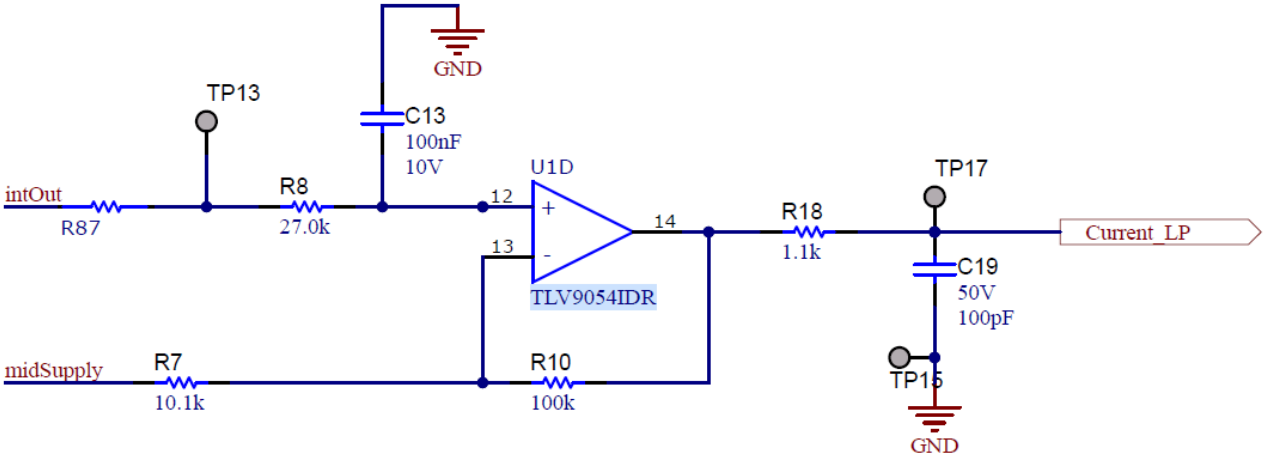


Figure 3-10. Low-Pass Filter Schematic

This filter has a cutoff frequency at 59Hz. R22 and C19 adjust this frequency. R18 and R22 set the gain or attenuation. This filter provides measurement of the line current. This enables the arc fault algorithm to use the current magnitude to adjust arc detection behavior. This filter integrates the 60Hz to 1kHz signal, and when combined with the hybrid integrator forms a low-pass filter starting at 1kHz. The 60Hz filter introduces a delay into the 60Hz signal around 1.54ms. This causes some distortion since high frequencies do not have the same delay.

3.3.3 Non-isolated Voltage Sensing

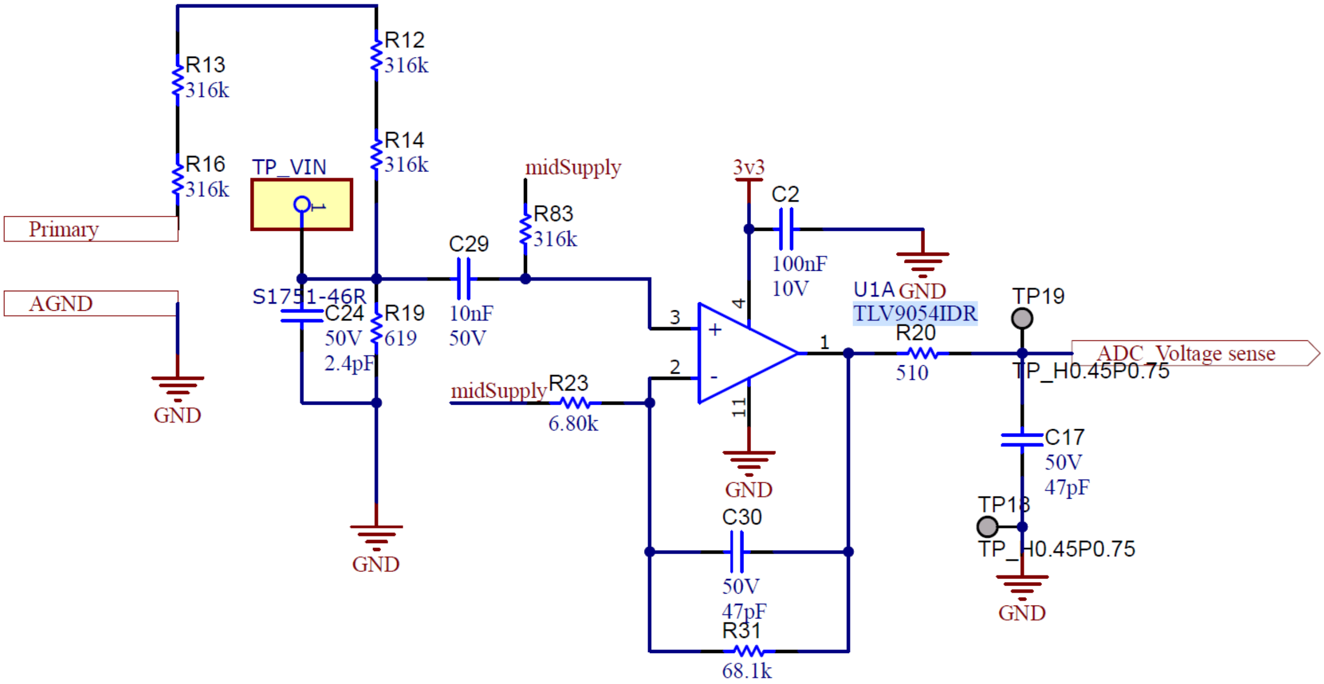


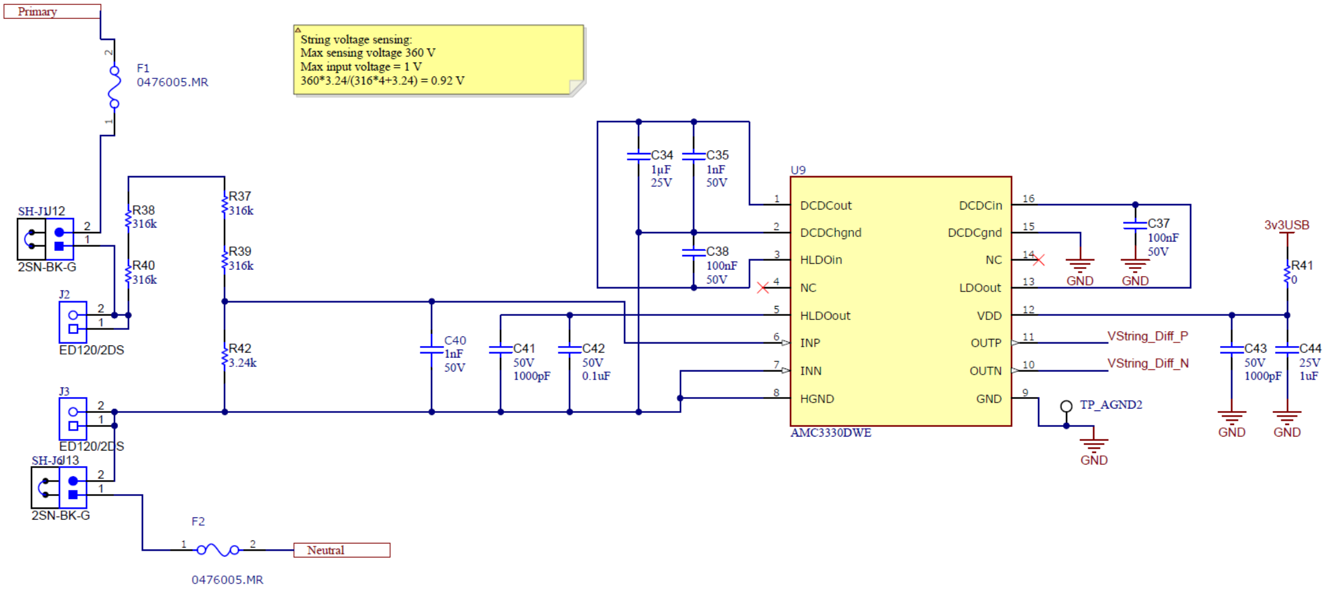
Figure 3-11. Voltage Sensing Schematic

R12, R13, R14, R16, and R19 form a voltage divider to drop the voltage down. C24 and C30 are unpopulated, but can be placed to provide some low-pass filtering. C29 and R83 create a 50Hz high-pass filter and capacitively couple the signal and center on the mid-supply reference. This works with the current low pass output for simple power measurement. For arc detection a higher cutoff frequency works since the grid stabilizes most variations at low frequencies.

3.3.4 Auto Labeling Circuit

The arc-labeling circuit consists of two isolated amplifiers, and an isolated comparator. The arc-labeling circuit gathers and labels arc signatures in a controlled lab environment. The design uses the fact that in a lab environment, the AC line voltage and the arc gap voltage are available, unlike in the field. Figure 4-2 shows the typical arc test setup in the lab. An arc generator generates reproducible arcs at different operating conditions. The relation between the arc gap voltage, measured across the arc generator and line voltage, serves as an indicator for an arc. This information then labels the data sampled by standard arc detection signal chain. The labeled data then trains an embedded AI model. This portion of the board works with a compatible TI LaunchPad development kit and draws power from the 3V3 LaunchPad output. The MSPM0 SDK includes a software example to transfer data from the LaunchPad to the connected computer.

3.3.4.1 Line Voltage Sensing



String voltage sensing:
Max sensing voltage 360 V
Max input voltage = 1 V
360*3.24/(316*4+3.24) = 0.92 V

Figure 3-12. Isolated Line Voltage Sensing Schematic

Figure 3-12 shows the line voltage sensing circuit. The circuit consists of a resistor divider connected to AMC3330, a reinforced isolated amplifier with a fixed gain of 2.0V/V. The differential output of the AMC3330 connects to the circuit described in Section 3.1.7.3. This differential to single-ended conversion introduces a gain of 1.65V/V. The conversion output then connects to an internal ADC of the MCU.

Equation 3 describes the relation of input voltage between J2 and J3 to output voltage of the differential to single-ended conversion:

$$\mathrm{Vout} = \mathrm{Vin} \times 3240\Omega / (4 \times 316000\Omega + 3240\Omega) \cong \mathrm{Vin} \times 0.00256 \tag{3}$$

3.3.4.2 Arc Gap Voltage Sensing

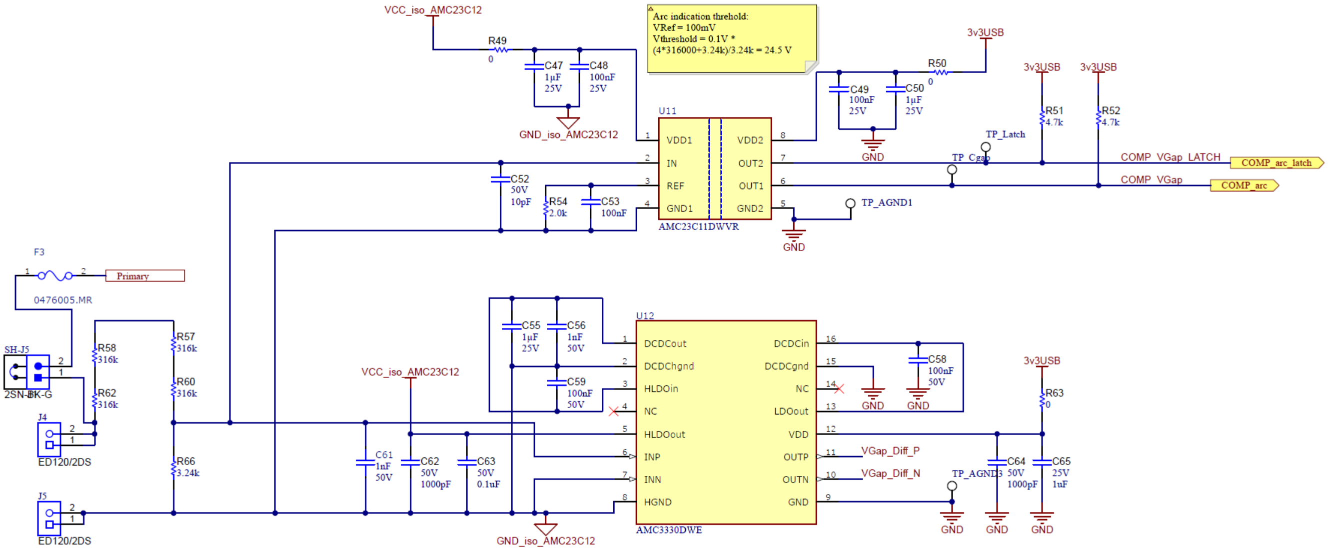


Figure 3-13. Arc Gap Voltage Sensing

To sense the arc gap voltage, the same circuit as for line voltage sensing operates. In addition, an isolated comparator AMC23C11 indicates when the arc gap voltage exceeds a threshold. R54 programs this threshold. A 100µA current source implements in the REF pin of AMC23C11 to generate the threshold voltage. R54 selects at 1000Ω, resulting in a voltage of 200mV at the REF pin. This equals an input voltage of 24.5V. The existing schematic configures for 120VAC. For 240VAC a lower burden resistor R86 about 1.62kΩ and threshold value R54 about 500Ω are needed for equivalent operation.

3.3.4.3 Differential to Single-Ended Conversion

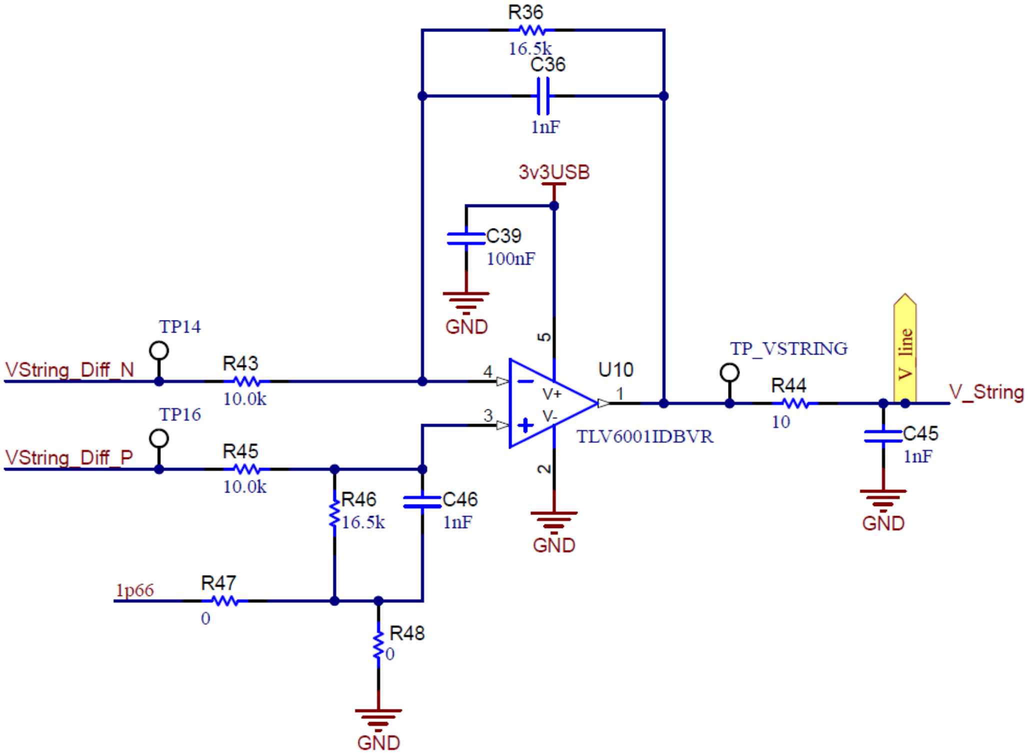


Figure 3-14. Differential to Single-Ended Schematic

AMC3330 used for both voltage sensing paths has a differential signal output. To interface this signal to the single-ended ADC of the LaunchPad MCU a conversion stage is implemented using TLV6001. See also the *Interfacing a Differential-Output (Isolated) Amp to a Single-Ended Input ADC* application brief. R65 remains unpopulated since the circuit operates bidirectionally. The gain of this conversion stage sets by the relation between R55 and R53 and R59 and R61. A gain of 1.65 is used, since the maximum output of AMC3330 reaches 2V and the maximum input of the ADC reaches 3.3V.

3.3.5 Power Supply

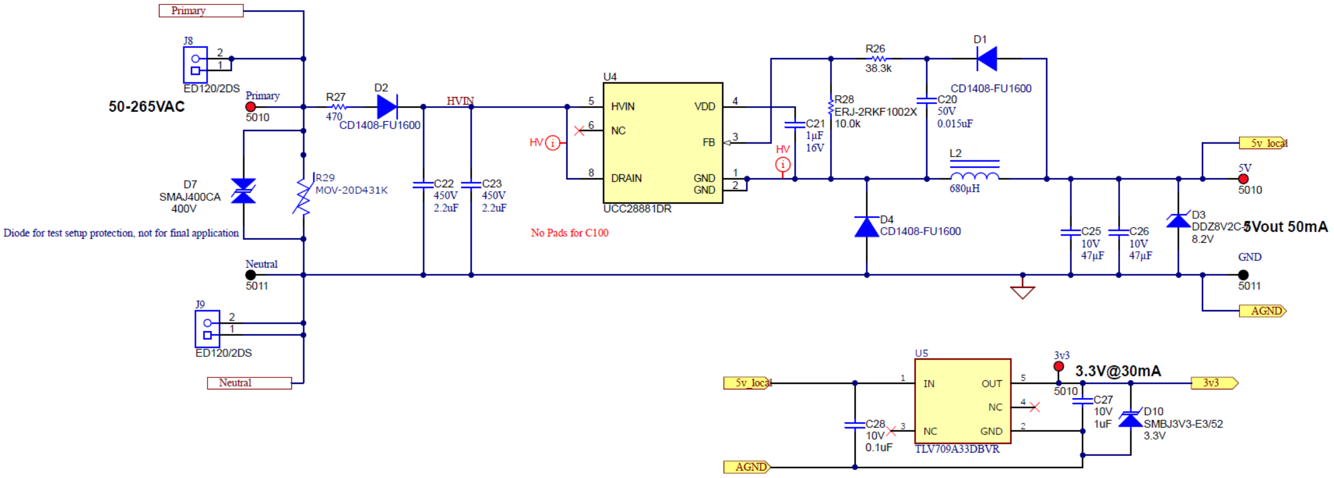


Figure 3-15. Power Supply Schematic

This auxiliary power supply takes a 110V to 250VAC input and provides a stable 3.3V rail. UCC28881 offline switcher steps down the voltage. With no load present, the 5V rail exceeds 5V, limited by D3 at 8.2V. MOV R29 and diode D7 add overvoltage protection. This supply tests the analog portion of the board, but remains optional. The 3V3 rail does not power the auto labeling portion of the board because the LaunchPad connection handles data transfer. If 110V to 250VAC input lacks power the LaunchPad 5V rail routes to provide an input to LDO U5.

4 Hardware, Software, Testing Requirements, and Test Results

4.1 Hardware Requirements

The following hardware components and specifications are required for proper system operation and performance of the reference design:

1. 12 AWG wire maximum for connectors and Rogowski coil
2. High-voltage safety box (see warnings before testing)
3. Arc generator test setup
4. Oscilloscope
5. Signal generator
6. Personal computer for data collection
7. Compatible LaunchPad (MSPM0G5187-LP)
    a. USB Cable for LaunchPad (USB Type-C®)
    b. USB to USB isolator cable
8. AC power supply
9. Power resistor 1500W rated, 12Ω
10. AC loads

4.2 Software

See MSPM0SDK and EDGE AI studio link.

4.3 Test Setup

Before powering the board verify that all connections are properly screwed down and that the LaunchPad connects with the ground and power pins matching the reference design. First verify the analog signal chain before high-voltage testing.

1. Connect the LaunchPad to the interface below the board according to the connections in Section 2.1, Figure 2-2:

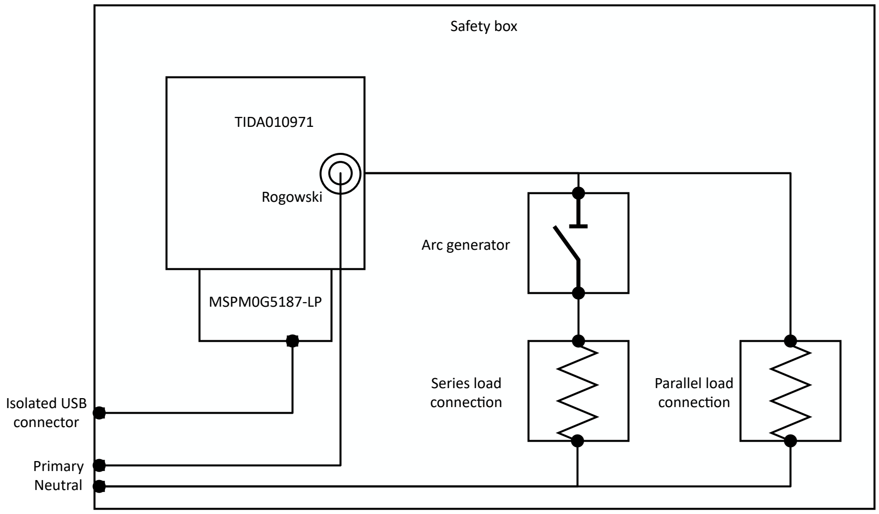


Figure 4-1. Test Setup Diagram

2. Wire a 12AWG insulated wire through the Rogowski and connect to AC power supply and 12Ω power resistor rated for more than 50W to the parallel load connection.
3. Plug in the USB cable to a USB power source and the LaunchPad. On power up, check that the LED D6 glows blue.
4. The test pins are labeled *Current-LPF*, and *LOG*. Test with low voltage first, 12VAC, 1A 60Hz load. Have the low-pass and band-pass filter inputs AC coupled on the oscilloscope.

a. Verify *Current LPF* output is 134mV peak to peak
b. Verify *Integrator* output is 15mV peak to peak
c. Verify *LOG*: output is 900mV – this can fluctuate depending on the environmental noise.

4.3.1 Arc Testing Setup

For arc testing, follow connections from Figure 4-1.

Additional equipment used for arc testing:

- Arc generator as defined in UL1699
- 12AWG wire
- Resistive loads for rated power
- Nema 5-15p plugs

The data collection or arc detection software and user guides are both available on MSPM0 SDK.

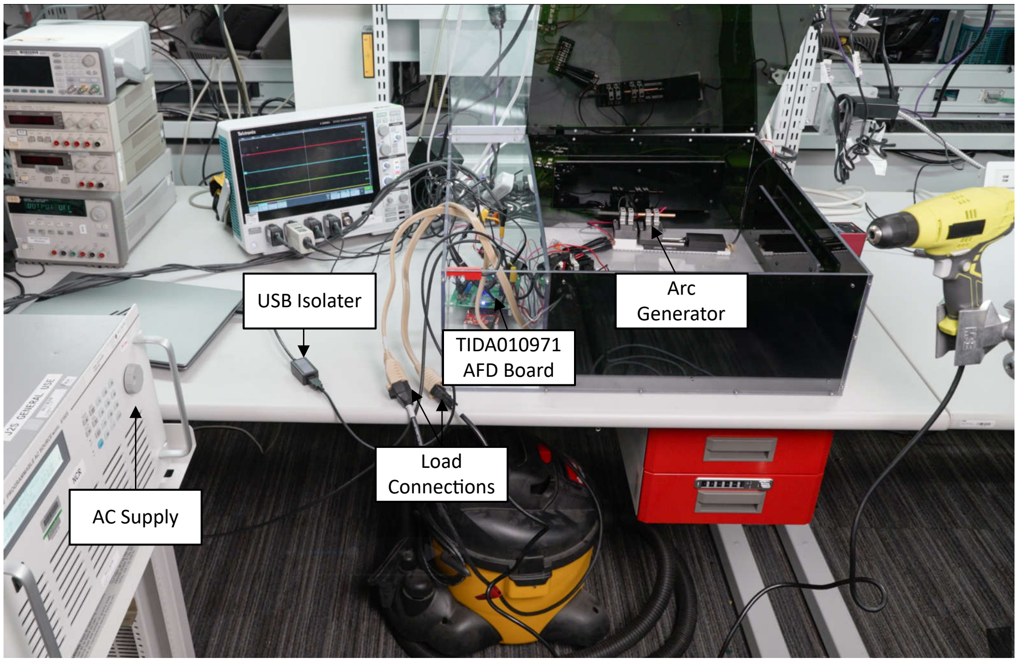


Figure 4-2. Arc Generator Test Setup

4.4 Test Results

Figure 4-3 shows the transfer function of the bandpass filter from section 3.1.3. An AC input from the signal generator is injected into the input of C6 separated from the integrator output trace. The output of the bandpass filter is measured with the high bandwidth passive probe of the oscilloscope at the output of R22.

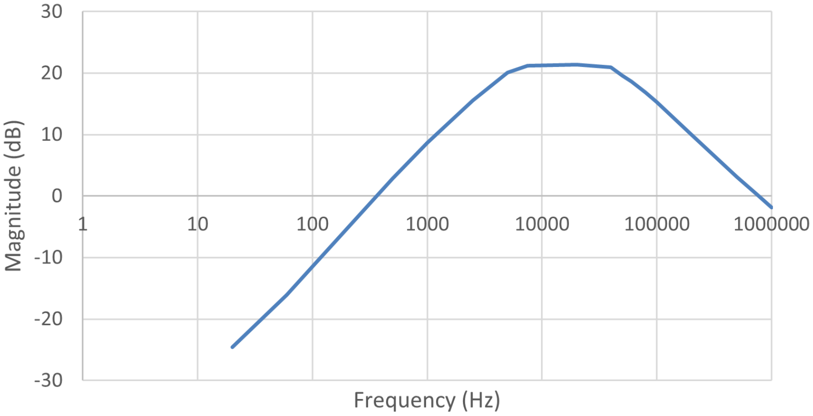


Figure 4-3. Current Band-Pass Filter Magnitude Plot

Figure 4-4 shows the band-pass output noise. This noise is less than the resolution of a 12-bit, 3.3V ADC.

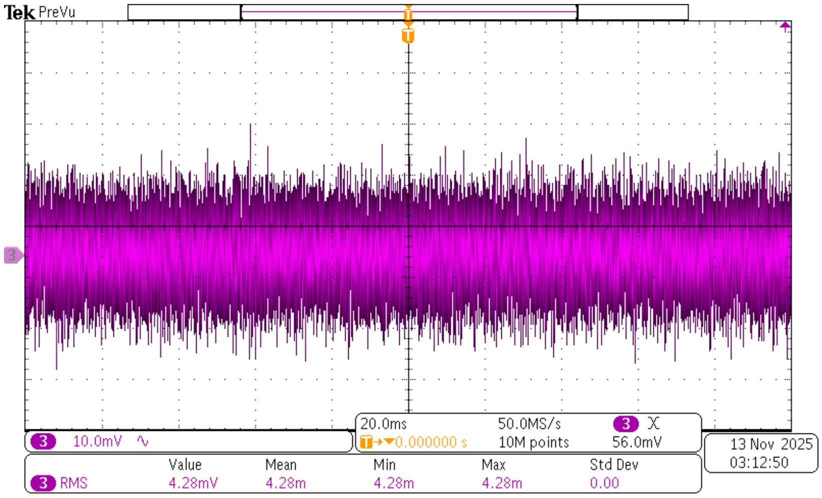


Figure 4-4. Output Noise of Band-Pass Filter

Figure 4-5 shows the output of the low-pass filter with a resistive load of 9.74A. The RMS voltage corresponds to Equation 4.

$$472\text{mV}/9.74\text{A} = 180\text{mV}/\text{A} \tag{4}$$

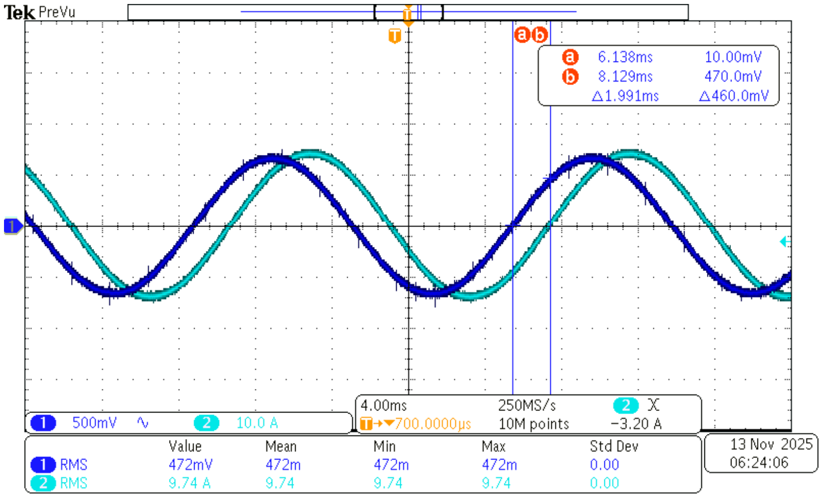


Figure 4-5. Low-Pass Filter Output With Resistive Load

Figure 4-6 and Figure 4-7 show the LOG300 output for normal vs arcing for a two different loads. This demonstrates how the arcing signal reaches up to the 1MHz to 10MHz range but noise from the loads is significantly reduced. For Figure 4-6 and Figure 4-7, the top subplot shows the LOG300 output, the bottom subplot shows the oscilloscope current probe output.

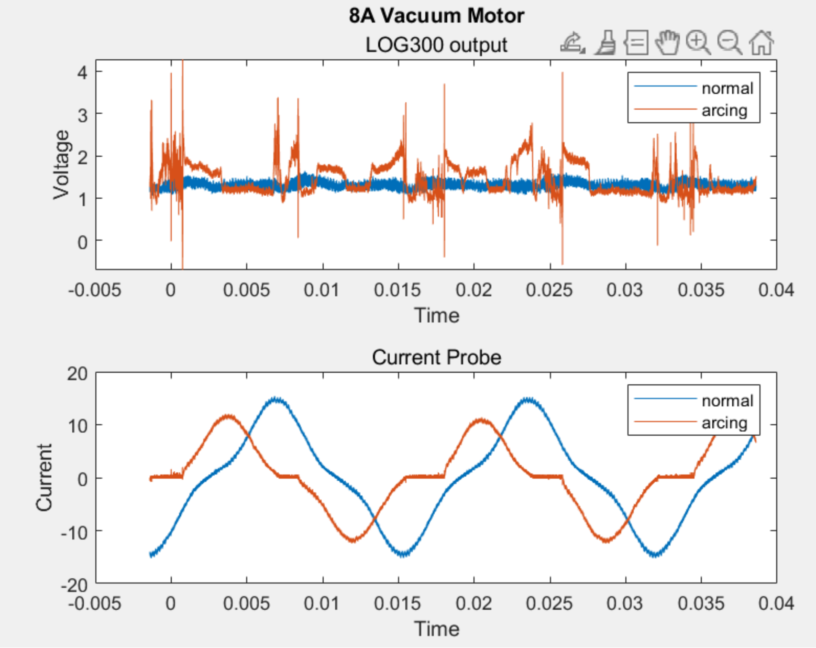


Figure 4-6. Vacuum Motor Load – Top: LOG300 Bottom: Current Probe

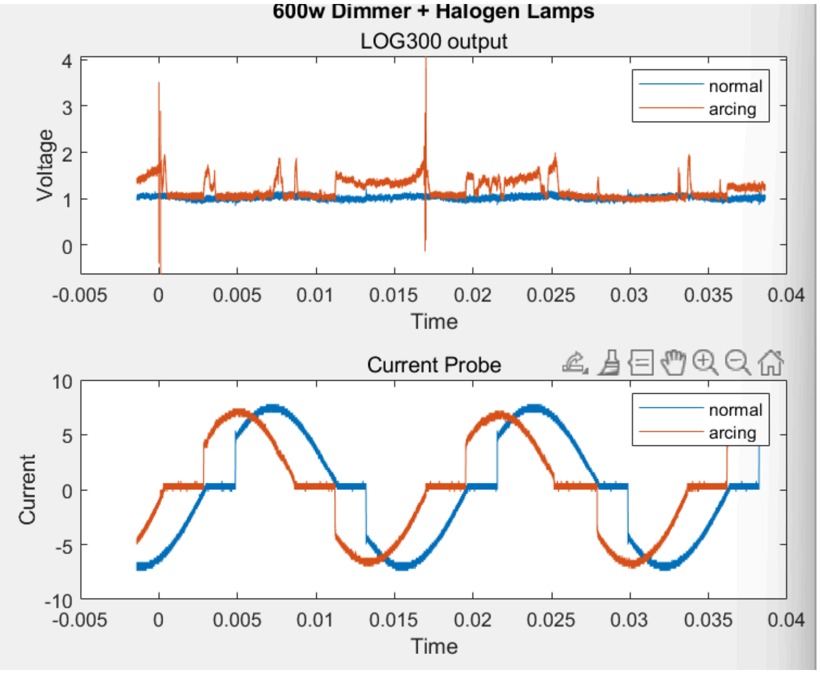


Figure 4-7. 600W Tungsten Lamp With Dimmer Load – Top: LOG300 Bottom: Current Probe

5 Design and Documentation Support

5.1 Design Files

To download the design files, see the design files at TIDA-010971.

5.1.1 Schematics

To download the schematics, see the design files at TIDA-010971.

5.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010971.

5.2 Tools and Software

Tools

LP-MSPM0G5187	MSPM0G5187 LaunchPad™ development kit evaluation module
CCSTUDIO	Code Composer Studio™ integrated development environment (IDE)

Software

MSPM0-SDK	MSPM0 software development kit (SDK)
TI Resource Explorer Software	TI Resource Explorer Software package in TI Resource explorer
EDGE-AI-STUDIO	Software development tools for edge AI

5.3 Documentation Support

1. Fritz, J. N., Neeb, C., and De Doncker, R. W. (January 2015). *A PCB Integrated Differential Rogowski Coil for Non-Intrusive Current Measurement Featuring High Bandwidth and dv/dt Immunity*. ResearchGate. Retrieved from https://www.researchgate.net/publication/302567997
2. Xue, Y., Lu, J., Wang, Z., Tolbert, L.M., Blalock, B. J., Wang, F. (2014) *A compact planar Rogowski coil current sensor for active current balancing of parallel-connected Silicon Carbide MOSFETs*. *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*. IEEE, 2014. Retrieved from https://ieeexplore.ieee.org/document/6954042
3. Texas Instruments, *TLVx387 High Precision, Zero-Drift, Low-Input-Bias-Current Op Amps Data Sheet*
4. Texas Instruments, TLVx387 High Precision, Zero-Drift, Low-Input-Bias-Current Op Amps
5. Texas Instruments, *AMC3330 Precision, ±1V Input, Reinforced Isolated Amplifier With Integrated DC/DC Converter Data Sheet*
6. Texas Instruments, *AMC23C11 Fast Response, Reinforced Isolated Comparator With Adjustable Threshold and Latch Function Data Sheet*
7. Texas Instruments, *MSPM0G5187-LP User's Guide*

5.4 Support Resources

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

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6 About the Author

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