TI Designs
Industrial Current-Output Pressure Sensor Transmitter, IEC61000-4 Tested Reference Design

Description

The highly-integrated PGA300 is the basis of this pressure sensor transmitter system. This design minimizes component count and board size without losing accuracy and performance. The design also includes typical protection circuitry for the industry-standard IEC61000-4 suite of EMC and EMI tests.

Resources

TIDA-00788	Design Folder
PGA300	Product Folder
PGA300EVM-034	Tools Folder

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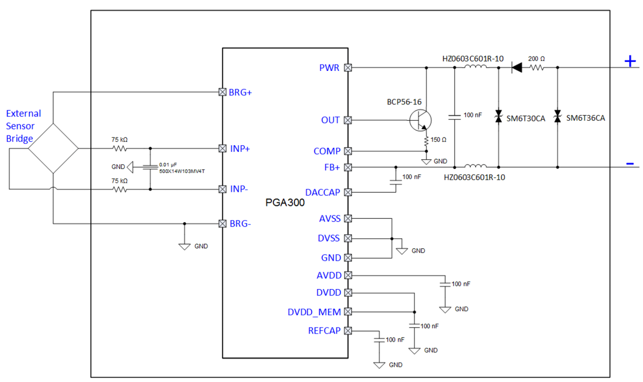
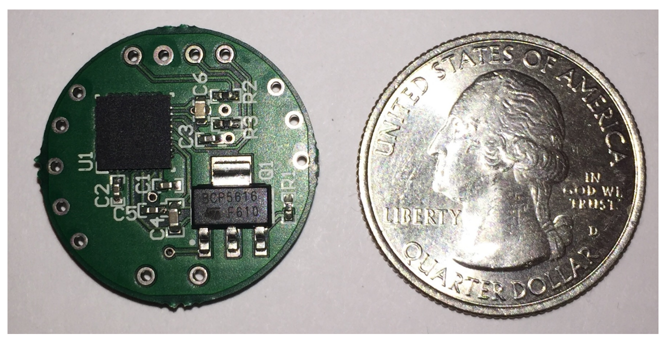
Features

- 4- to 20-mA Current Output
- IEC61000-4 EMC and EMI Tested

Applications

- Industrial Pressure Sensor Transmitters
- Strain Gauges
- Flow Meters
- Liquid Level Meters





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1 System Overview

1.1 System Description

This reference design describes a system for demonstrating a typical application of the PGA300 device, a highly-integrated, resistive-bridge sensor conditioner used in a pressure transmitter system. This design exhibits the minimal component number and board size required to create a high-performance pressure sensor system. TI intends this design to provide a benchmark to comply with IEC61000-4 EMI and EMC standards.

1.2 Key System Level Specifications

Table 1. Key System Level Specifications

PARAMETER	SPECIFICATION	DETAILS
Supply range	3.3 to 30 V	Internal regulators on PGA300 allow for a wide supply range
Bridge voltage	2.5 V	Configurable to 1.25 or 2 V
ADC resolution	16 bit	
Output mode	4- to 20-mA current loop	
Output resolution	14 bit	
Digital communication	One-wire interface	
Protection	IEC61000-4 EMC and EMI	

1.3 Block Diagram

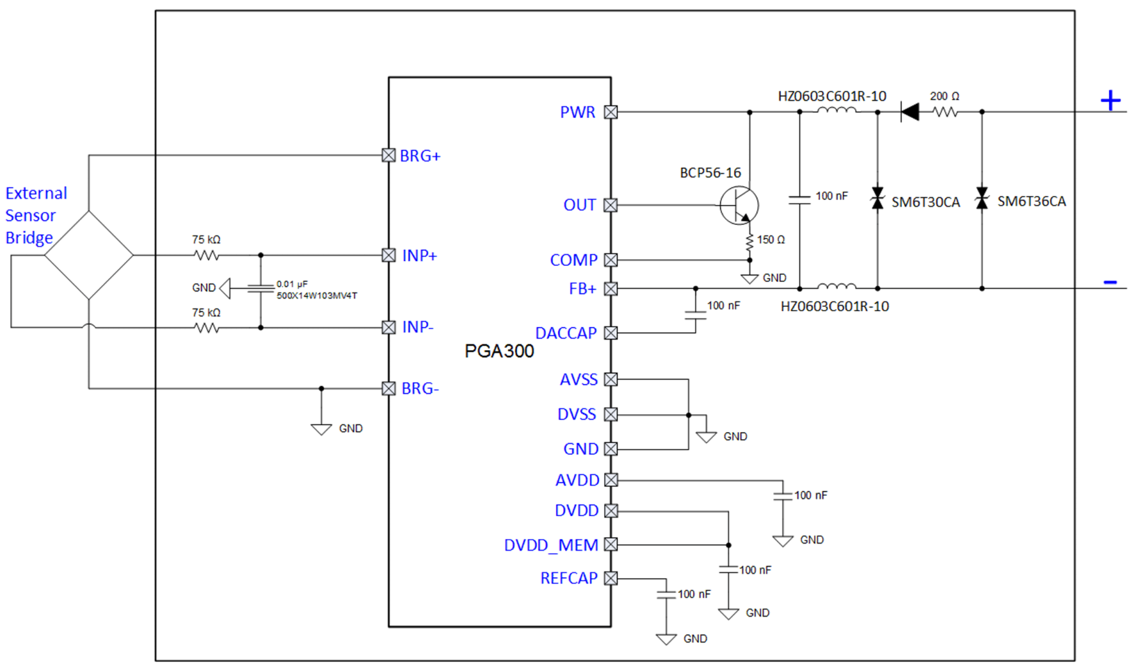

Figure 1. Block Diagram of Design Interfacing With an External Controller and Resistive Bridge Input

1.4 Highlighted Products

1.4.1 PGA300

The PGA300 is an interface device for piezo-resistive and strain gauge pressure sense elements. The device is a full system-on-chip (SoC) solution that incorporates programmable analog front end (AFE), analog-to-digital converter (ADC), and digital signal processing that enables direct connection to the sense element.

Further, the PGA300 device includes integrated voltage regulators and an oscillator to minimize the number of external components. The device achieves high accuracy by employing third-order temperature and nonlinearity compensation. External communication is achieved by using a one-wire serial interface (OWI) through the power-supply pin in order to simplify the system calibration process. An integrated Digital-to-analog converter (DAC) supports absolute voltage, ratiometric voltage, and 4- to 20-mA current-loop outputs.

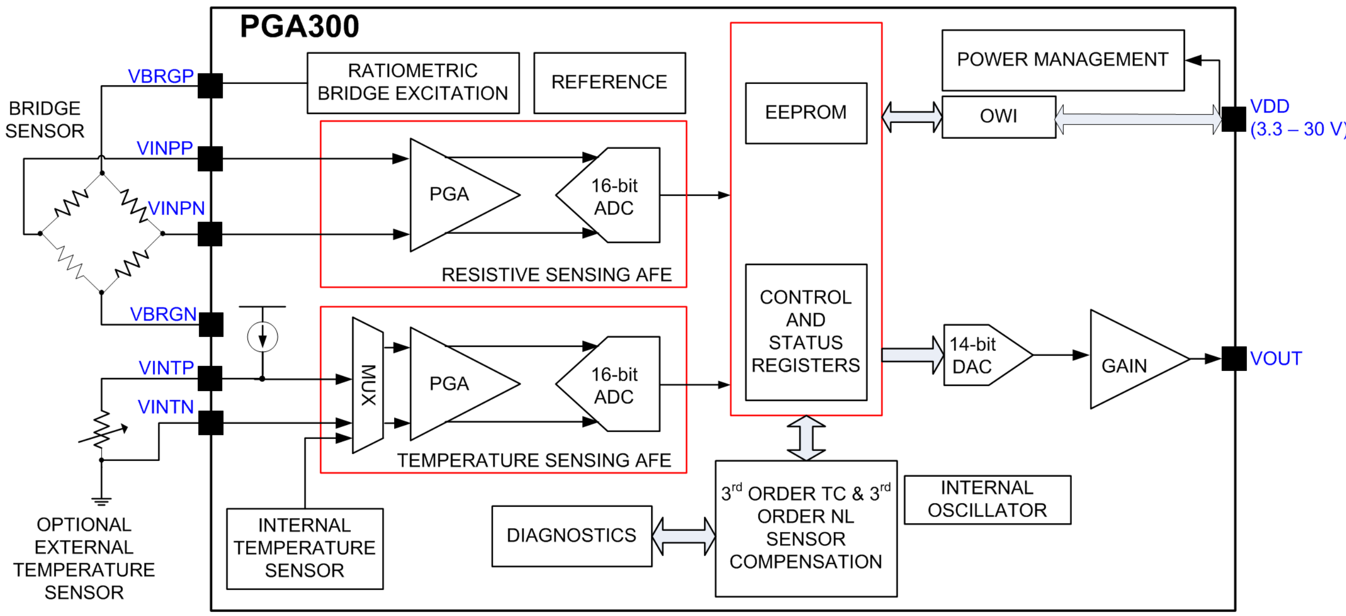

Figure 2. PGA300 Internal Block Diagram

1.5 Design Considerations

This design supports the following features:

- A 3.3- to 30-V power supply operating range
- A 4- to 20-mA current-loop output
- OWI communication
- Easy interfacing with typical industrial resistive bridge sense elements
- Immunity to IEC61000-4 ESD and EMI standards

1.5.1 OWI

This design takes advantage of the One-Wire Interface (OWI) of the PGA300. This proprietary protocol lets the device use the supply voltage (VDD) for digital communication and calibration.

By using OWI and communicating over VDD, TI has eliminated the requirement for any additional pins and terminals to interface with the outside environment. This feature reduces the potential for harsh conditions affecting the performance of the sensor.

For more information about OWI, see the *PGAxxxEVM-034 User's Guide* (SLDU011).

1.5.2 4- to 20-mA Current Mode

This design uses an industry-standard 4- to 20-mA output mode, a linear representation of the change on the sensor bridge through a change in system supply current. This method is very useful for transferring signals large distances. For this design, this is accomplished by driving an external BJT with the PGA300's DAC output. Through the use of DAC output stage feedback and the PGA300's compensation algorithm, a very linear and accurate 4- to 20-mA system can be created. For more details on the requirements and components necessary for using this mode, see Section 3.2.

2 Getting Started Hardware

The design itself does not include a resistive bridge sensor to measure, but provides points for tying to the bridge excitation and pressure input pins, BRG+, BRG-, IN+ and IN-.

This design can be connected to the PGA300EVM-034 for OWI communication with the PGA300GUI by performing the following:

- Lift all jumpers but J12 and J19. J19 should be in the *OWI* position (between pins two and three).
- Connect the positive supply of this design to TP20 and the negative supply pin to TP39.
- On the PGA300GUI's OWI *Configuration* page, set the *Rloop Configuration* to 200 Ω and the *Additional Voltage Configuration* to 0.7 V
- Press the *Activate OWI* button. The box on the top right of the GUI should turn green and say *OWI Activated*.

Communication and calibration to the board is now capable. See the PGAxxxEVM-034 User's Guide (SLDU11) and the PGA300 GUI User's Guide (SLDU022) for additional details and guidelines.

3 Testing and Results

3.1 IEC61000-4 Immunity

TI performed the following five tests, detailed in the IEC61000-4 standard, on this design:

- IEC61000-4-2: electrostatic discharge (ESD)
- IEC61000-4-3: radiated immunity
- IEC61000-4-4: electrically-fast transient (EFT)
- IEC61000-4-5: surge immunity
- IEC61000-4-6: conducted immunity

The classes listed in Table 2 describe the pass or fail criteria for the design when these disturbances are applied to the board.

Table 2. IEC61000-4 Pass or Fail Criteria

Grade	Description
Class A	Normal performance within an error band specified by the manufacturer
Class B	Temporary loss of function or degradation of performance which ceases after the disturbance is removed. The equipment under test recovers its normal performance without operator interference
Class C	Temporary loss of function or degradation of performance, correction of performance requires operator intervention
Class D	Loss of function or degradation of performance which is not recoverable, permanent damage to hardware or software, or loss of data

TI's goal for this design is to meet Class A for all tests. In this case, the device is to not exceed ±0.1% FSR (±16 µA) during the applied disturbance.

A Class B result typically has a specific frequency range or voltage level that causes the device to operate outside the desired range but does not exhibit any damage or performance degradation from the disturbance. In other cases, the nature of the test itself and the measurement methods causes a design to have a Class B result. More details on the specific requirements of each of these tests can be purchased through a license with the IEC and at *IEC 61000-4-x Tests for TI' s Protection Devices Application Report*, (SLVA711).

3.1.1 IEC61000-4-2 Electrostatic Discharge

ESD simulates the discharge of energy from an operator of the equipment onto any exposed terminals. This test can be performed through contact discharge (direct contact to the pin or terminal), air discharge (typically at a higher amplitude compared to contact for similar rating), and through metal planes horizontal and vertical to the device under test.

This design was tested at 15-kV air discharge. The full test applies ten sequential pulses at both positive and negative polarity. Figure 3 shows a IEC61000-4-2 ESD pulse.

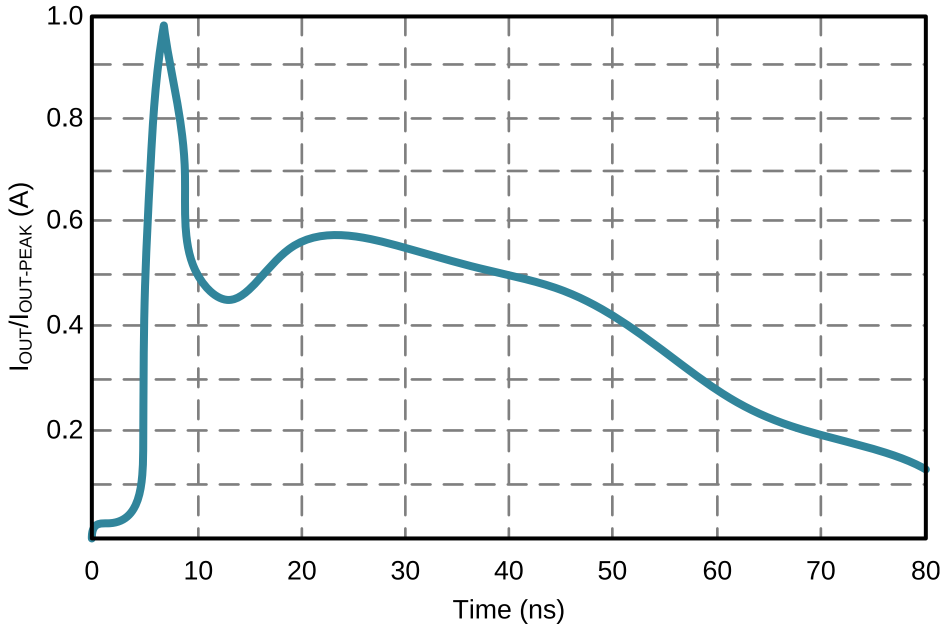

Figure 3. IEC61000-4-2 ESD Pulse

3.1.2 IEC61000-4-3 Radiated Immunity

Radiated immunity simulates the exposure of the design to high-frequency radiated emissions from typical radio and industrial equipment. The frequency band of 80 MHz to 1 GHz was tested at 10-V/m field strength in a horizontal and vertical antennae configuration.

3.1.3 IEC61000-4-4 Electrically-Fast Transient

EFT simulates the switching and loading transients typically found in industrial environments. The test was applied simultaneously to all wires in this design.

The test applied pulses at a rate of 5 kHz for one minute. For this design, TI used an amplitude of 4 kV.

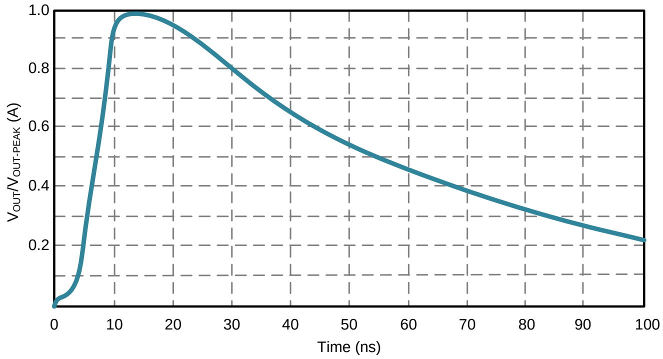

Figure 4. IEC61000-4-4 EFT Pulse

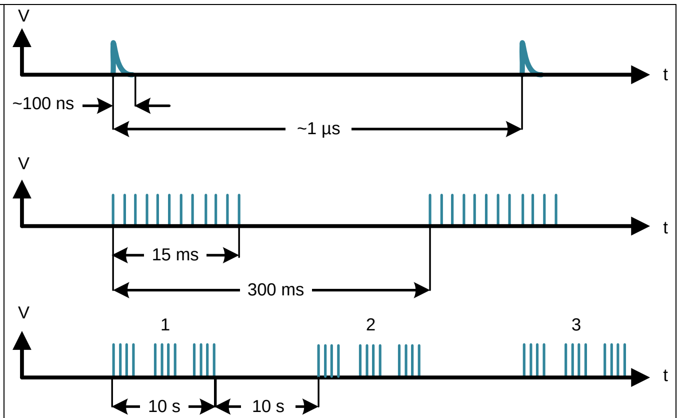

Figure 5. EFT Pulse Burst Timing

3.1.4 IEC61000-4-5 Surge Immunity

Surge simulates very harsh electrical transients generated by events like lightning and electrical mains supply faults. This is the most severe of the transient events, as it delivers the most amount of energy quickly and for a lengthy amount of time.

The test applied five 1kV pulses every 30 seconds.

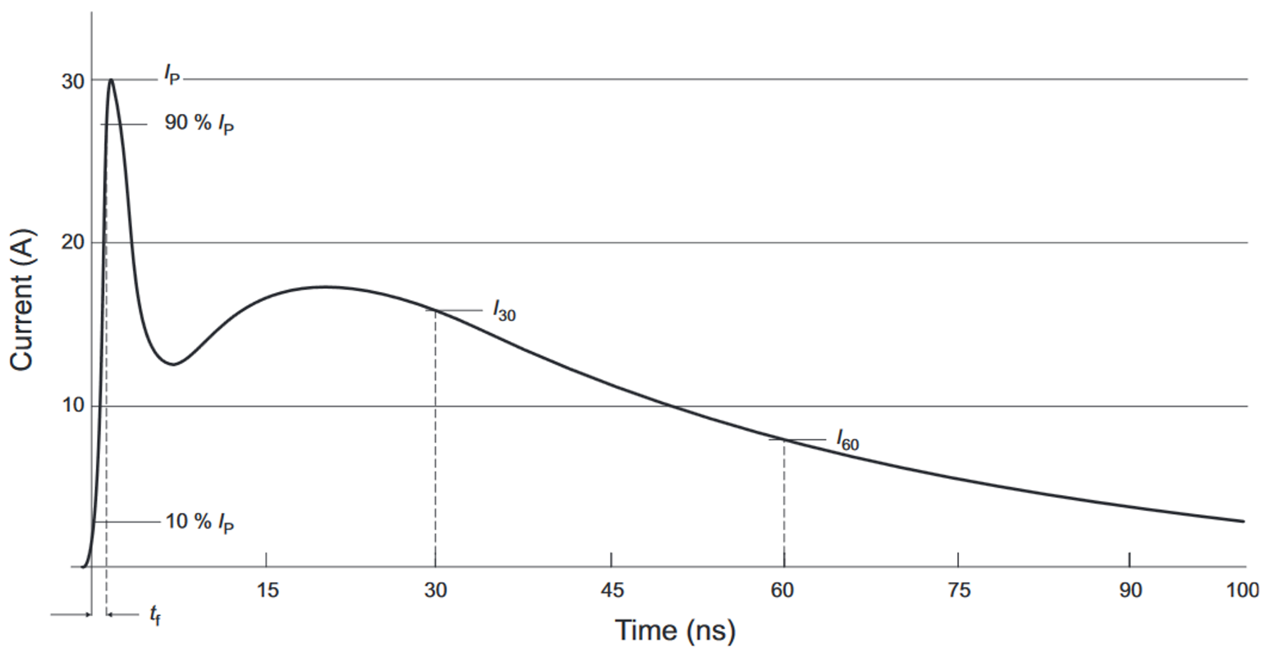

Figure 6. IEC61000-4-5 Surge Pulse

3.1.5 IEC61000-4-6 Conducted Immunity

CI simulates the disturbance of electromagnetic fields that come from typical radio-frequency transmitters, as conducted through the wires interfacing with the environment. This test was performed at a frequency range from 15 kHz to 80 MHz at a field strength of 10 V/m.

3.2 Circuit Design and Component Selection

3.2.1 Input Filter

A low-pass RC filter is at the sensor input pins of the PGA300 device, IN+ and IN-. The filter reduces high-frequency noise and minimizes any Electromagnetic Interference (EMI) effects between the sensor bridge external to this design and the PGA300. TI chose an X2Y capacitor to reduce the components and board space required, as compared to three capacitors serving this purpose.

3.2.2 Current Output Circuit

An external NPN bipolar junction transistor (BJT) is controlled through the output amplifier (OUT) to generate the 4- to 20-mA output.

There were two main factors in deciding to use the BCP56-16:

1. When choosing a BJT, ensure that the rating of V_{ce} is at least twice as large as a maximum input voltage to ensure proper linear operation across the supply operating range. The maximum supply voltage of this design is 30 V. The 80-V rating of the BCP56-16 far exceeds that requirement.
2. This circuit requires a BJT I_c greater than 20 mA to function across the range of the operating current mode. TI also recommends a rating of at least 500 mA to prevent damage in a fault condition. This BJT has a rating of 1 A, which easily meets these conditions.

TI chose the 150-Ω emitter resistor value based on the optimal quiescent point and guidelines found in *PGA900 as a 4- to 20-mA Current Loop Transmitter* (SLDA030). This resistor value ensures correct operation for OWI communication, sets the Q-points, and minimizes the impact of the BJT's small-signal impedances on the stability of the system.

3.2.3 Decoupling Capacitors

The decoupling capacitors for PWR, AVDD, DVDD, DVDD_MEM and REFCAP are standard X7R 0.1-µF decoupling values as specified in the *PGA300 Pressure Sensor Signal Conditioner Datasheet* (SLDS204). TI chose a 100-V rating for the capacitor between PWR and FBP to help handle large amounts of energy from ESD and EFT disturbances. This capacitor also minimizes noise on the PWR line to prevent issues with OWI communication.

3.2.4 IEC61000-4 Protection

In many applications, a single TVS diode rated for 30 V will meet the ESD and EFT protection requirements of the system. For this design, a two-stage bidirectional TVS diode configuration is used to handle the extremely fast and large amounts of energy generated in a typical Surge pulse.

When it pertains to Surge, the main parameter to be concerned with on a TVS diode is the clamping voltage, V_{CL}. In many applications, it is very feasible to find a TVS diode that has a clamping voltage less than the absolute maximum rating of the protected device, while still allowing the device to work across the entire operating supply voltage range. For this design, the PGA300 has an Absolute Maximum of 33 V on PWR and FB+, and we want the device to operate with a supply voltage as close to the maximum operating voltage of 30V as possible. TI found that a diode with a 30 V working voltage will typically have at least a 60 V clamping voltage when handling surge energy levels. To compensate for this, a current limiting resistor and an additional TVS diode was added to the design. With the combination of the voltage clamp from the initial diode and the current limiting from the resistor, the second TVS diode can be chosen to have a breakdown voltage within the operating range of the device. With this in mind, we chose the SM6T model of TVS diode, with the initial diode rated for 36V and the secondary rated for 30V. A final consideration for choosing a TVS diode is to minimize the leakage current rating to prevent inaccuracies during current-mode calibration.

A reverse protection diode was also added to this design to protect both the BJT and the PGA300 from mis-wiring, as well as provide some more protection from large negative-voltage surge and ESD events. This diode will limit the path that these transients have to the device.

Ferrite beads provide a current limit to the device and high-frequency filtering for conducted and radiated immunity. These ferrite beads have 0.45-Ω impedance at DC and 600 Ω at 100 MHz.

NOTE: The reverse voltage protection diode and the current limiting resistor will lead to a voltage drop that needs to be compensated for to maintain the proper voltage levels for OWI communication. The PGA300EVM-034 has an OWI communication circuit with feedback circuitry to compensate for this voltage drop.

3.3 IEC61000-4 Test Results

For each of these tests, the calibration coefficients of the PGA300 were set to a value that equals a 12-mA draw on the supply. Table 3 shows the EEPROM variables for these tests configured using the PGA300 EVM and GUI. The current loop was measured with an Agilent™ 34401A digital multimeter in fast 5.5-digit mode, collecting the samples through GPIB.

The current output must vary less than 0.1% FSR (±16 µA) to achieve Class A performance.

All figure drawings provide red lines to indicate the Class A performance range.

Table 3. EEPROM Configuration Values

Variable	Setting
DAC_RATIOMETRIC	No
DAC_GAIN	No Gain
4-20MA_EN	Yes
DACCAP_EN	No
VBRDG_CTRL	2.5 V
P_GAIN	20
P_INV	No
Normal Pressure Lower	3.9 mA
Normal Pressure Upper	21 mA
Clamp Value – lower	3.75 mA
Clamp Value – upper	22mA

3.3.1 IEC61000-4-2 ESD

ESD was performed at ±15-kV air discharge. TI was unable to detect that the ESD affected the performance of the system. See Table 4 and Figure 7 for the test results.

Table 4. IEC61000-4-2 Results

Orientation	Result	Class
Air discharge: 15 kV	Pass	A

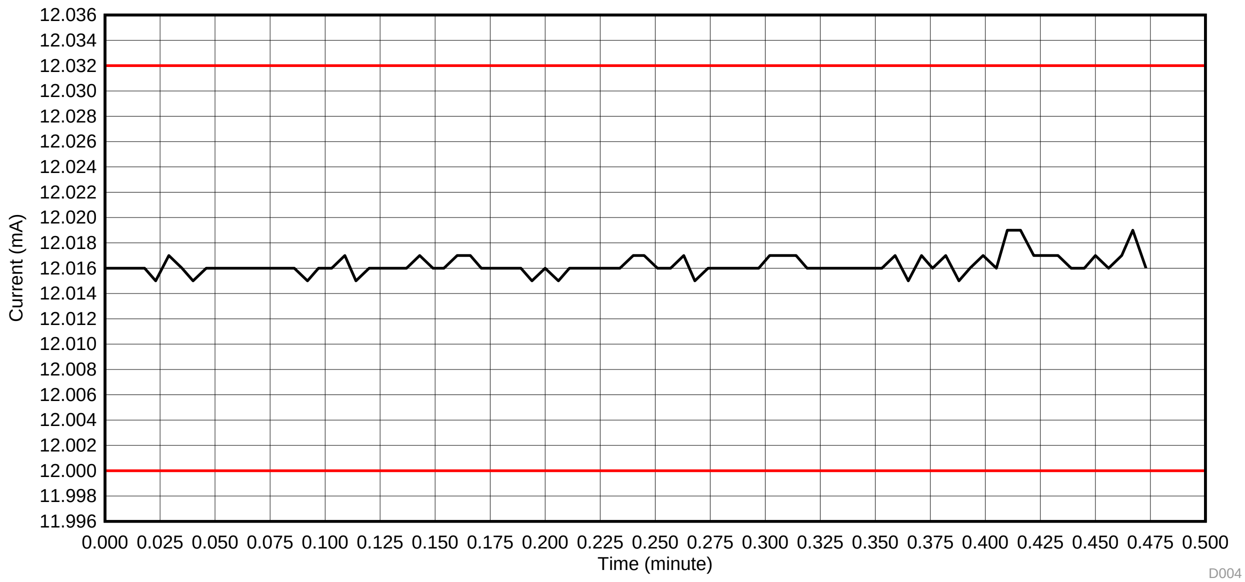

Figure 7. ±15-kV ESD Air Discharge Reading

3.3.2 IEC61000-4-4 EFT

TI found significant disturbances on the current loop. When the EFT effects ended, the output returned to its initial state. Due to the nature of the test at hand for a current loop system, it is very difficult to reduce the significant amount of measured current being placed into the loop.

This system achieved Class B performance. See Table 5 and Figure 8 for the test results.

Table 5. IEC61000-4-4 Results

Orientation	Result	Class
EFT: ±4 kV	Pass	B

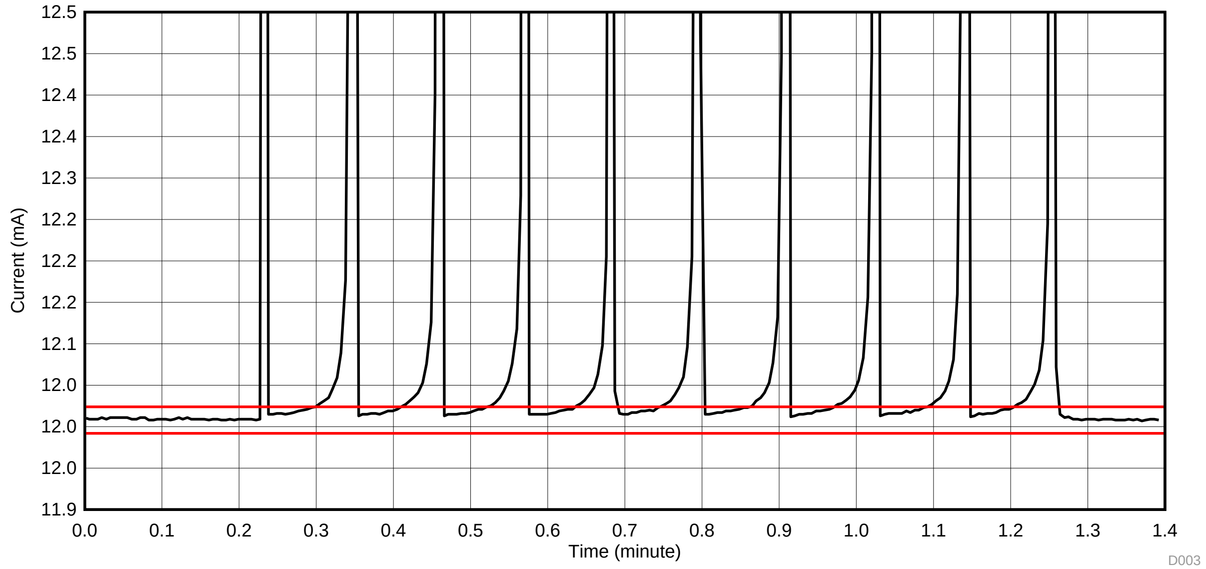

Figure 8. 4-kV EFT Reading

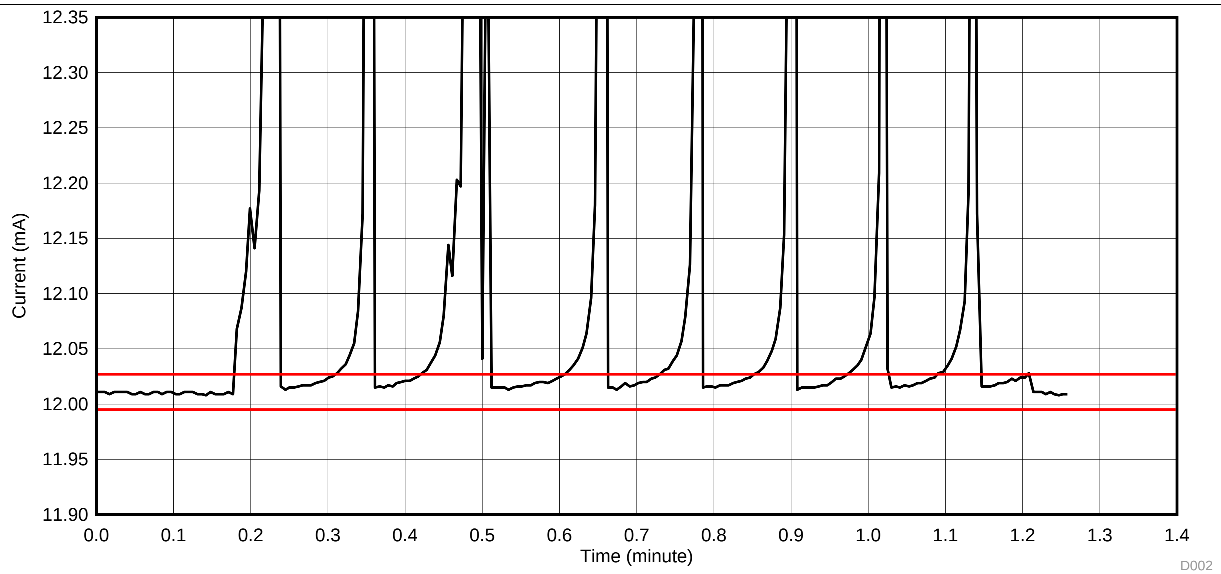

Figure 9. –4-kV EFT Reading

3.3.3 IEC61000-4-3 EMI

The system remained within the requirements for a 10-V/m signal in the frequency range of 80 MHz to 1 GHz for the entire vertical orientation frequency range. A small frequency band in the 90- to 100-MHz range on the horizontal orientation did not meet Class A requirements. See Table 6, Figure 10, and Figure 11 for the test results.

Table 6. IEC61000-4-3 Results

Orientation	Result	Class
EMI: 10-V/m horizontal	Pass	B
EMI: 10-V/m vertical	Pass	A

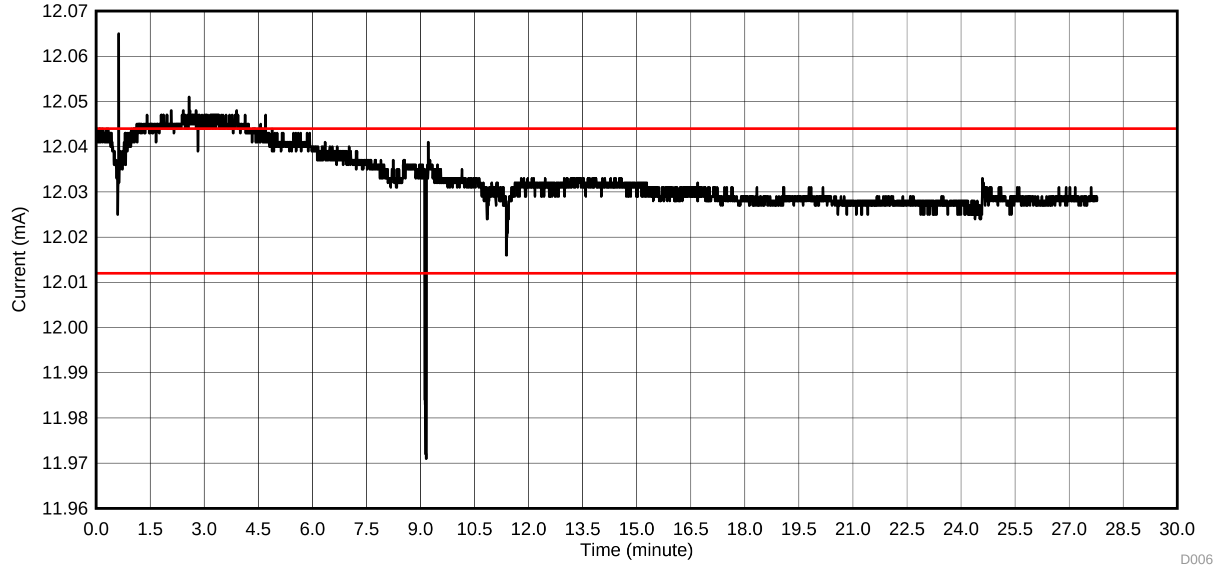

Figure 10. EMI 10-V/m Horizontal Reading

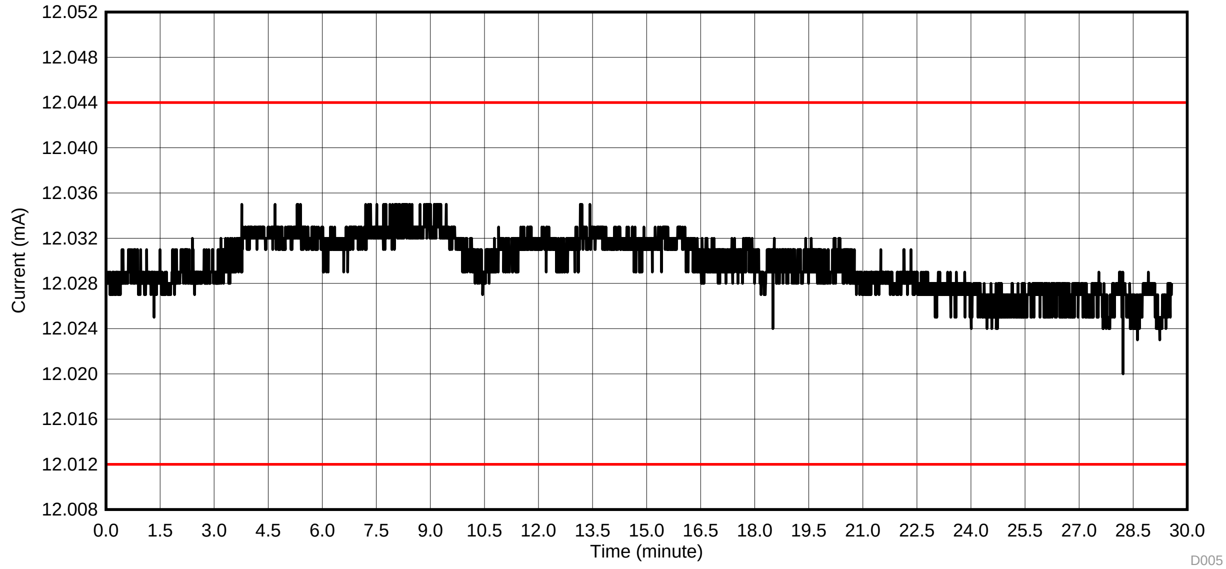

Figure 11. EMI 10-V/m Vertical Reading

3.3.4 IEC61000-4-5 Surge

TI used a 42 Ohm source impendence and applied a common-mode Surge pulse to the device. A total of 5 pulses were applied to the board every 30 seconds for both Positive and Negative 1 kV. See Table 7, Figure 12, and Figure 13 for the test results.

Table 7. IEC61000-4-6 Results

Orientation	Result	Class
Common Mode Surge: ±1 kV	Pass	A

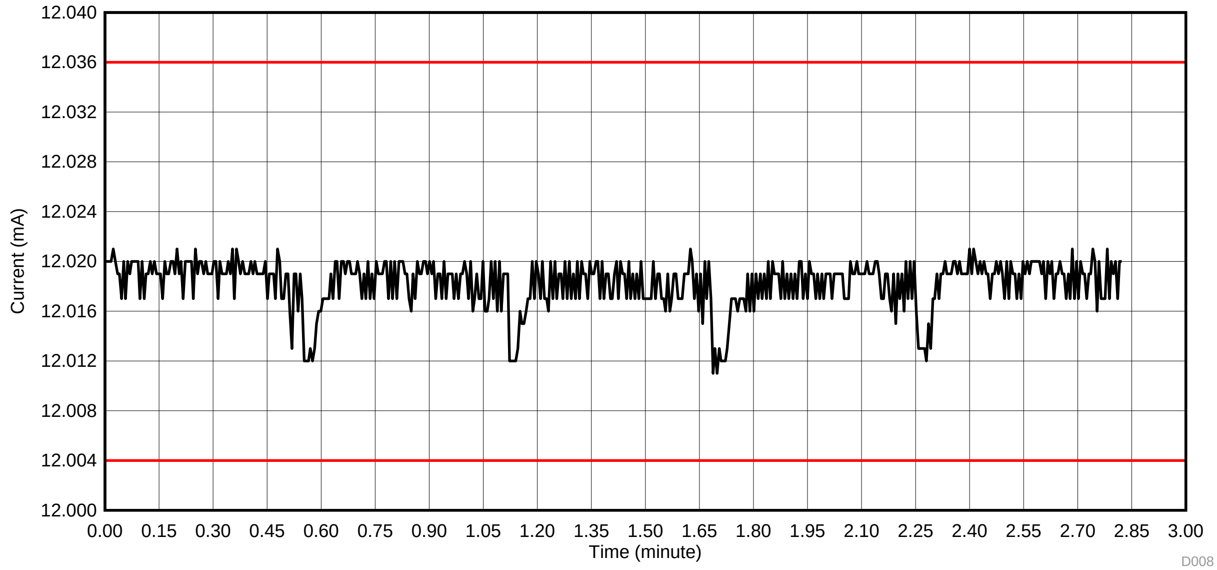

Figure 12. +1 kV Surge Reading

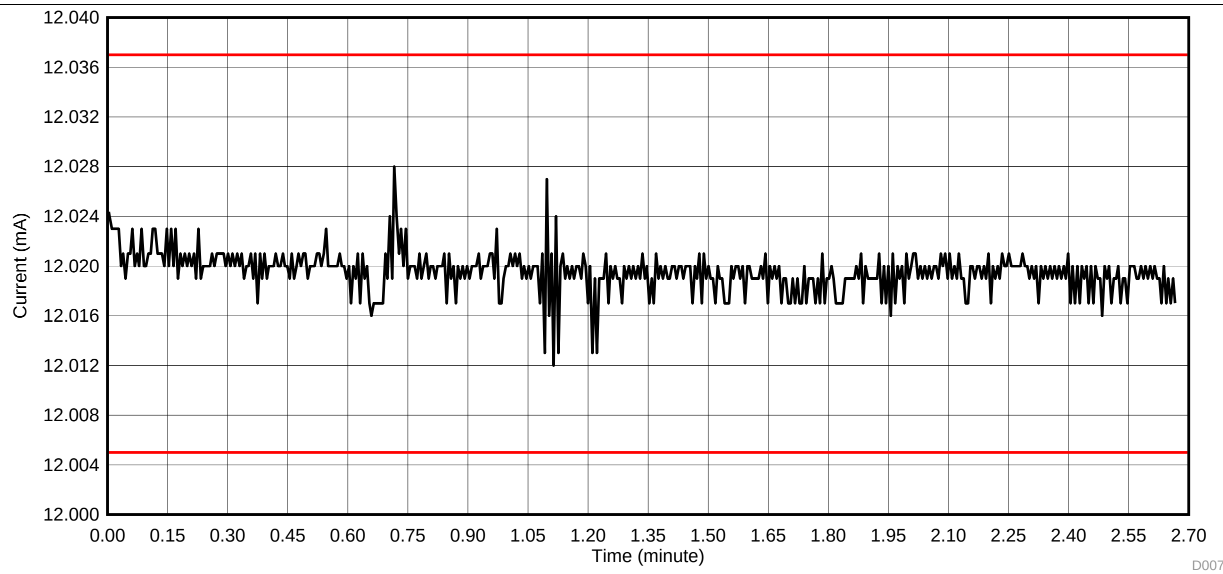

Figure 13. -1 kV Surge Reading

3.3.5 IEC61000-4-6 Conducted Immunity

A small region in the 60 to 80 MHz range did not meet Class A requirements. This range is similar to the radiated immunity results. See Table 8 and Figure 14 for the test results.

Table 8. IEC61000-4-6 Results

Orientation	Result	Class
Conducted immunity: 10 V/m	Pass	B

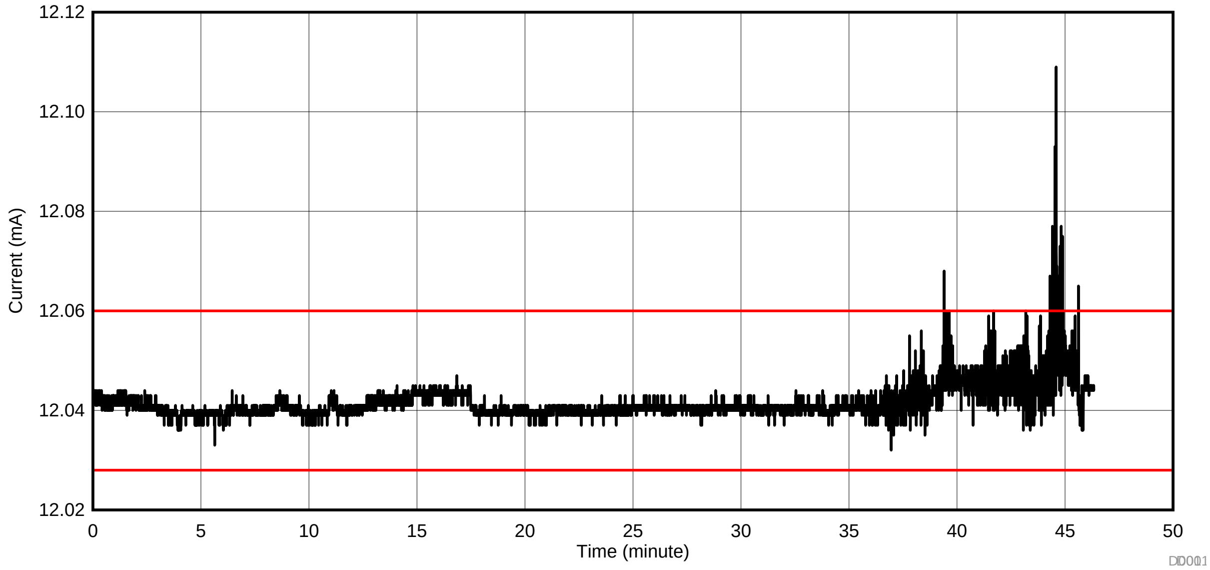

Figure 14. Conducted Immunity 10-V/m Reading

3.3.6 Test Results Summary

Orientation	Result	Class
Air discharge: 15 kV	Pass	A
EFT: ±4 kV	Pass	B
EMI: 10-V/m horizontal	Pass	B
EMI: 10-V/m vertical	Pass	A
Surge: ±1 kV	Pass	A
Conducted immunity: 10 V/m	Pass	B

4 Design Files

4.1 Schematics

To download the schematics for each board, see the design files at TIDA-00788.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00788.

4.3 Layout Guidelines

To download the layout guidelines for each board, see the design files at TIDA-00788.

4.4 Altium Project

To download the Altium project files for each board, see the design files at TIDA-00788.

4.5 Gerber Files

To download the Gerber files for each board, see the design files at TIDA-00788.

4.6 Assembly Drawings

To download the assembly drawings for each board, see the design files at TIDA-00788.

5 Software Files

To download the software files for this reference design, please see the link at TIDA-00788.

6 References

1. *Low-Cost Loop-Powered 4-mA to 20-mA Transmitter EMC/EMI Tested Reference Design* (TIDU299)
2. *IEC 61000-4-x Tests for TI's Protection Devices Application Report* (SLVA711)
3. IEC Publication 61000-4-2 "Electromagnetic Compatibility (EMC) – Part 4-2: Testing and Measurement Techniques – Electrostatic Discharge Immunity Test," International Electrotechnical Commission, 2008.
4. IEC Publication 61000-4-3 "Electromagnetic Compatibility (EMC) – Part 4-3: Testing and Measurement Techniques – Radiated, Radio-Frequency, Electromagnetic Field Immunity Test," International Electrotechnical Commission, 2006.
5. IEC Publication 61000-4-4 "Electromagnetic Compatibility (EMC) – Part 4-4: Testing and Measurement Techniques – Electrical Fast Transient/Burst Immunity Test," International Electrotechnical Commission, 2012.
6. IEC Publication 61000-4-5 "Electromagnetic Compatibility (EMC) – Part 4-5: Testing and Measurement Techniques – Surge Immunity Test," International Electrotechnical Commission, 2005.
7. IEC Publication 61000-4-6 "Electromagnetic Compatibility (EMC) – Part 4-6: Testing and Measurement Techniques – Immunity to Conducted Disturbances, Induced by Radio-Frequency Fields," International Electrotechnical Commission, 2008.

7 Acknowledgments

Thank you to Dieu Vo and his team at National Technical Systems for providing the equipment, test site, and test expertise for the EMC and EMI testing. Also, thank you to Kevin Duke, Collin Wells, and Juergen Schneider of TI for their recommendations and knowledge of IEC61000 protection that helped create this design.

8 About the Author

MATTHEW SULLIVAN is an applications engineer in the Sensor Signal Conditioners group at TI. He supports all devices and sensor types in the PGA9xx family. Matt received his BSEE from the University of Southern California.

Appendix A Test Setup Images

Figure 15. EFT Test Setup

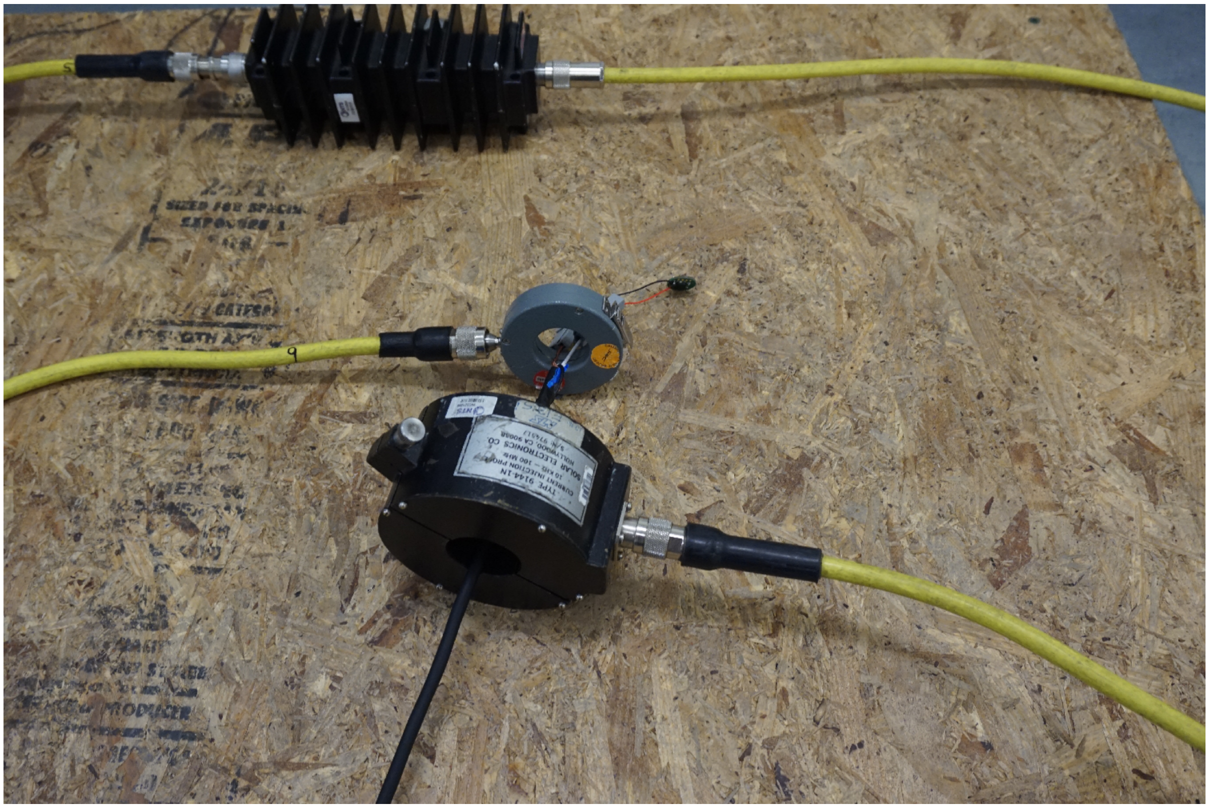

Figure 16. Conducted Immunity

Figure 17. Radiated Immunity

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