TI Designs: TIDA-01438
Surge, EFT, and ESD Protection Reference Design for PLC Analog Inputs

Description

This reference design shows the superior protection capabilities of new 33-V protection devices (such as TVS3300) for factory automation and control. The Canadian Standards Association (CSA) Group has performed surge testing according to IEC 61000-4-5 on this reference design. The design has the required accuracy to measure the behavior of protection devices before and after EMI stress with respect to leakage and clamping voltage.

Resources

TIDA-01438	Design Folder
TIDA-00550	Tools Folder
TVS3300	Product Folder

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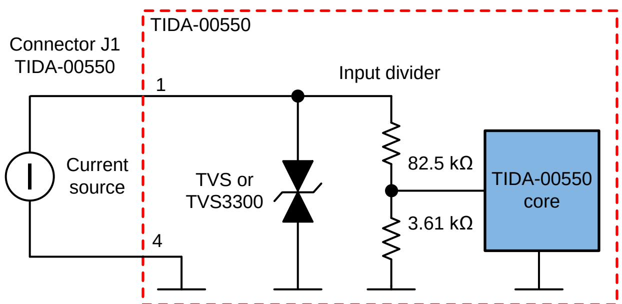
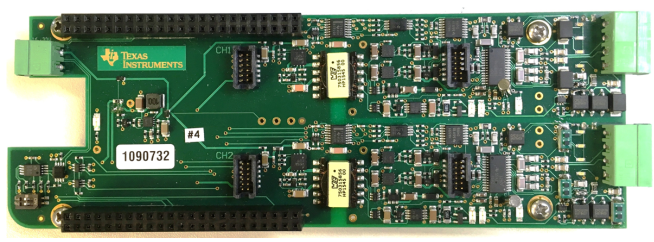
Features

- I-V Curve Measurement of TVS Diodes From 0 mA up to 10 mA With a Maximum Voltage of 50 V
- Differential Current Measurement (TVS Leakage) Accuracy of 35 pA
- Uncalibrated Measurement Repeatability:
  - < 0.002% (25°C)
  - < 0.05% (–35°C to +85°C)
- Simultaneous 50- and 60-Hz Rejection
- IEC61000-4-5 Class II (±1 kV at 42 Ω)

Applications

- Protection of Input Modules for PLCs
- Protection for Analog Outputs
- Protection of Current Loop Power





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1 System Description

This surge and ESD test module reference design is based on the TIDA-00550 reference design. This reference design shows the benefits a design can have by using the TVS3300 protection devices from Texas Instruments. In this design, the TVS3300 devices replaces the classical transient voltage suppression (TVS) diodes. This reference design has a high-voltage input that has been modified from the original setting in the TIDA-00550 reference design. The high-voltage input can now measure up to 50 V when no clamping device is present. Therefore, the configuration can be used to characterize clamping devices with respect to their clamping voltage and leakage. This reference design analyzes the clamping voltage and leakage over temperature before and after exposure to surges. The design also checks possible degradation after surge leading to larger leakage or changed clamping voltage.

The standard TVS diodes in the TIDA-00550 reference design have a high degree of temperature dependency. In particular, the clamping voltage varies significantly when the temperature changes. The TVS diode must not conduct any current at any temperature within the measurement range to preserve accuracy. Therefore, with traditional TVS diodes, it is necessary to select a larger clamping voltage than the largest measurement value. Analog inputs must also withstand a wrong wiring whereby the power supply is applied to the input (24 V). When the TVS diode is located at the connector, it is mandatory to select a TVS diode with a large enough standoff voltage (zero current). This voltage must be greater than the largest occurring power supply overvoltage, typically 33 V.

In some applications, analog inputs can measure voltages of up to 20 or 30 V. These applications need a diode that conducts no current at 30 V at any temperature. Such a diode would have a voltage of 33 V at a current of 1 mA and 36 V (typical) when its clamping is active. Depending on the temperature, the real clamping voltage would then be around 34 to 38 V. The typical internal resistance of 0.5 Ω can lead then to a voltage peak of 12 V over the 38 V at a current of 24 A (8/20-µs pulse, 1 kV, 42-Ω source impedance). With this peak during a surge, the maximum voltage could quickly reach 50 V. The protected circuit must therefore be tolerant of up to 50 V.

The TVS3300 has an ultra-low dynamic resistance of only 40 mΩ and a very precise clamping voltage of 35 to 37 V over the whole temperature range. The resulting voltage peak is 1 V over the breakdown, and the protected circuit sees typically only a voltage of 38 V (max. 40 V) compared to 50 V with a traditional TVS diode. This lower peak voltage reduces stress for the protected components and reduces the dissipated energy in the TVS3300. Now the protection device can have a smaller package and sit closer to the connector. Large transients such as electrostatic discharges (ESD) and electric fast transients (EFT) as well as large currents from surge are kept at connector level and do not travel along PCB traces across the board. This prevents trace-to-trace coupling and the EMI immunity is enhanced.

To test the TVS diodes for potential degradation, the board is characterized before and after surge events. The surge waveforms are 8/20 pulses as per IEC 61000-4-5. Section 3 shows the detailed procedure. The procedure to measure characterization itself has been developed to detect potential small changes between before and after exposure to surge with no calibration required and only one highly precise current source. The procedure also prevents stress of protection devices other than the intended surge stress because these protection devices are not soldered between the two characterizations.

There are two possibilities to measure TVS degradation. In the first method, the test engineer applies a voltage and measures the current. Any additional current beyond the current from the input resistance is additional leakage from the TVS diode. This method requires accurate voltage at the input of this reference design, an accurate input current measurement, and knowledge of the input resistance of the board under test. In the second method, the test engineer applies a known current to create a certain voltage. This voltage can be measured by using the onboard A/D converter. If current is deviated into the TVS diode, then less current is available through the input resistance, which creates less voltage. The voltage difference is proportional to the leakage current. Compared to the first measurement, fewer resources are needed with the second measurement.

The second measurement method is used in this reference design to examine potential degradation from before to after a surge event. The design has an input resistance of 86.1 kΩ and 1 µA of leakage change causes a voltage change of 86 mV. The input divider reduces this voltage to 3.6 mV. The ADS1262 32-bit A/D converter in this reference design has 22 noise free bits at 20 samples per second and can resolve 0.6 µV at its input. This rate is sufficient to detect leakage variations in the nano-Ampere range. The described method can also extract the DC I-V curve up to a current of 10 mA of both the standard TVS and the new TI protection device TVS3300.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER		SPECIFICATION
Number isolated of measurement channels		2
Operating voltage (J2)		16 to 33 V
Power consumption per channel		400 mW
Operating mode		High-voltage measurement
Range (without protection device)		±50 V
Input impedance		86.1 kΩ
Input repeatability without calibration	25°C	±0.001%
	–35°C to +85°C	±0.035%
Surge transient immunity		EN 61000-4-5 class 2 (±1 kV, 24 A)
Operating temperature		–40°C to +85°C
Storage temperature		–40°C to +125°C
Form factor		159 × 55 mm (6.26 × 2.17 in)

2 System Overview

2.1 Block Diagram

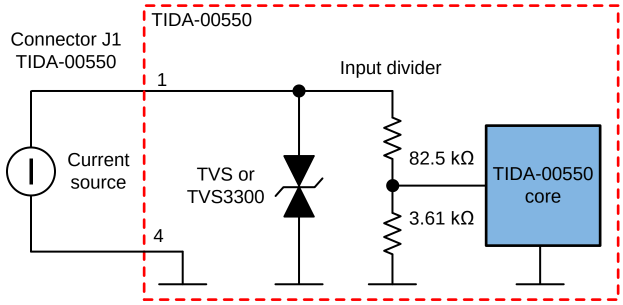

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Figure 1. Block Diagram (One Channel)

2.2 Highlighted Products

2.2.1 TVS3300

The TVS3300 is a protection device with very low leakage and low leakage variance over its operational temperature range. The component can protect PLC inputs against 1-kV surges from a 42-Ω source impedance. The device clamps the voltage to precisely 36 V + 1 V per 25 A of surge current. The leakage is below 20 nA so that an input current of 20 mA is only distorted by 1 ppm. This result corresponds to 20 bit of A/D converter performance for the current measurement. The TVS3300 is a unidirectional device. If bidirectional protection is needed, the designer can use two of the TVS3300 connected in an anti-serial fashion (see Figure 3). The wiring is shown in the schematics of this reference design.

2.2.2 TIDA-00550

The TIDA-00550 reference design is a universal analog input module with two independent and galvanically isolated measurement channels. The inputs are protected by 33-V TVS diodes, which is ideal for testing the performance of the TVS3300 precision clamp. The characterization details and construction data are available for download from TI.com.

2.3 System Design Theory

2.3.1 Input Circuitry of TIDA-01438

This reference design has one channel populated with TVS3300 protection devices from Texas Instruments and the other channel populated with conventional TVS diodes in SMB (DO-214AA JEDEC) package. With this, it is possible to compare the protection behavior of both protection device types on the same board. The TVS3300 devices sit on adapter boards so that they fit the DO-214AA footprint. Then the device can be used on both channels interchangeably.

This reference design only uses the high input voltage path. The other two input paths are not suited for this type of test. The high-voltage path has the input protection with protection D5 and capacitor C20 as first elements after the connector. For this reference design, opto relay K1 has high impedance (inactive), and K2 is shorted between pins 3 and 4. R18 and R19 form a voltage divider that attenuates the input signal to fit the ADC input voltage range. The original values of R18 and R19 from the TIDA-00550 reference design have been selected to support an input voltage range of ±12.39 V. In this reference design, resistor R19 has a second resistor in parallel (R19b) with a value of 4.53 kΩ. This resistor increases the input voltage range to ±52.4 V. Filter capacitor C21 removes the high frequency content of the input signal completes the discrete part before the 32-bit A/D converter ADS1262.

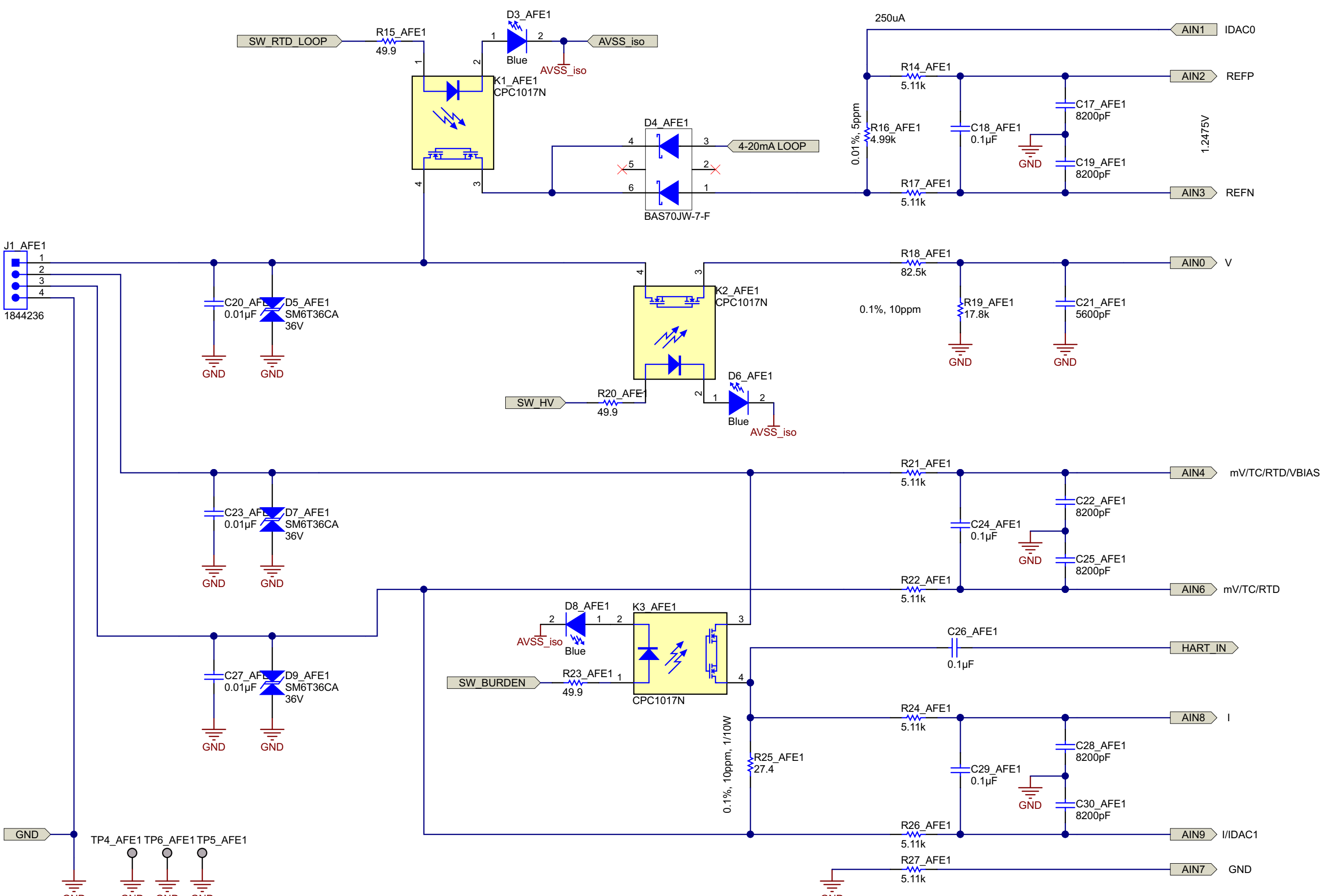

Figure 2. AFE Schematic of Channel With Conventional TVS Diodes

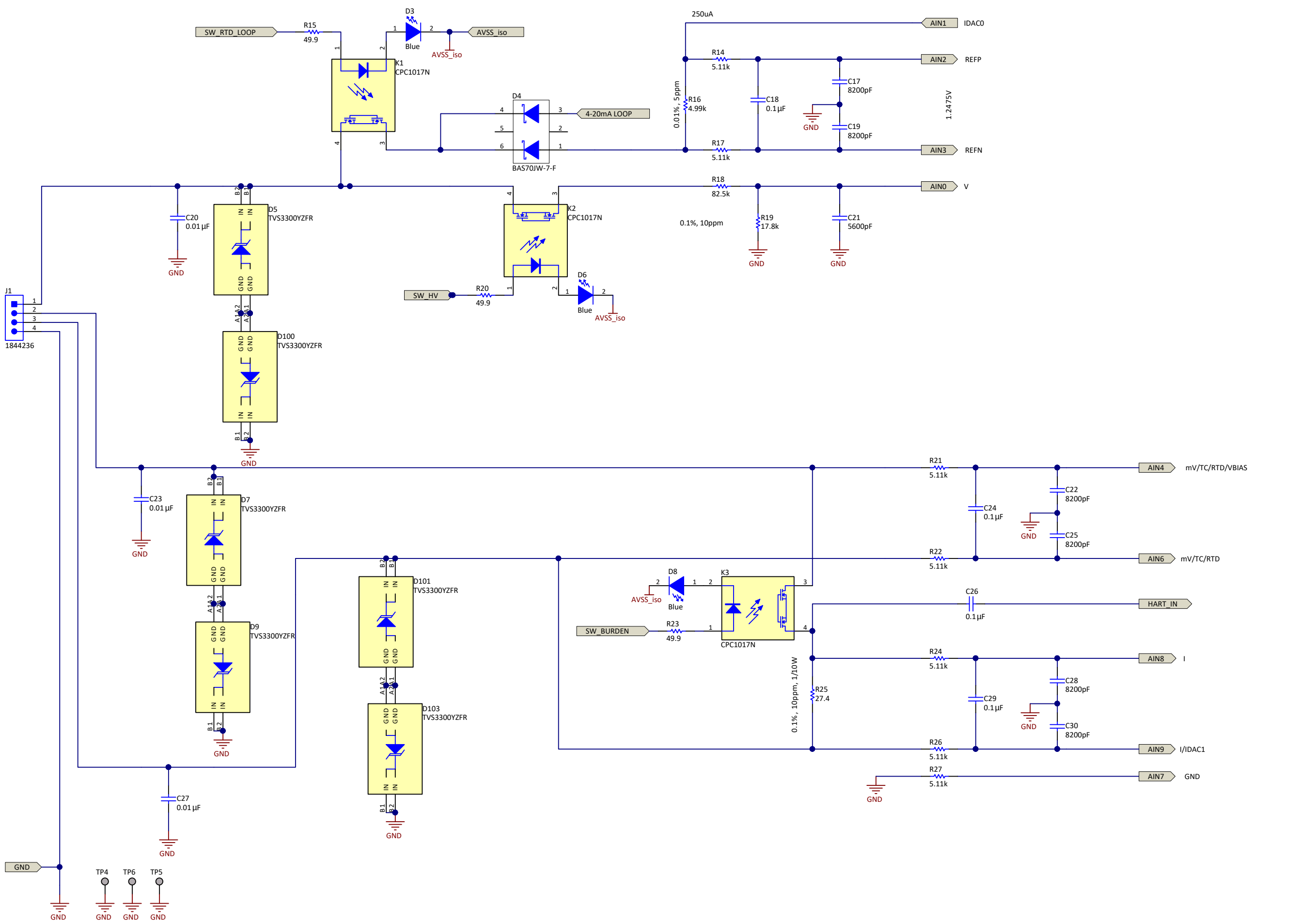

Figure 3. AFE Schematic of Channel With TVS3300

In this reference design, the ADS1262 is operated at a low sampling rate of 2.5 samples per second. For each measurement run, there are 128 samples collected. Both measures together increase the accuracy to a level of 25 usable bits. This level corresponds to the beforehand mentioned 3-µV resolution to measure down to 35 pA of leakage variation.

2.3.2 Protection

Protection against electromagnetic influence in forms of surges, EFT, or ESD is mandatory as per PLC standards. In this reference design, the terminal pins must be protected because they are exposed to the outside world. The protection of analog input stages is a trade-off between leakage and strength of the protection. Stronger TVS protection diodes have more leakage. This leakage causes a temperature dependent distortion (offset) of the measurement signal and causes a reduction of usable bits in the A/D converter. This reference design does not protect the power supply. For more information on power supply protection, see the TIDA-00233 reference design.

To protect the signal lines, the original TIDA-00550 reference design uses TVS diodes to clamp excessive high and low voltages to ground. As a second requirement, analog input terminals need to withstand the PLC supply voltage of 24 V for an infinite duration. This threshold is needed to protect against miswiring during the build of the machine with the PLC. In this case, the current flow must be small; otherwise, the TVS diodes overheat. These requirements define the properties of TVS diodes. The minimum breakdown voltage must be above the maximum specified PLC power supply voltage. The breakdown voltage must be also as low as possible because a larger voltage means more heating in the TVS during a surge event and more stress for the protected circuits.

If the breakdown voltage has a production or temperature variance, then the breakdown voltage must be higher to compensate the potential variation. Therefore, breakdown voltage for 33-V inputs must be in the range of 36 to 40 V. The TVS diode should have a very small differential resistance above the breakdown voltage. This resistance keeps the peak voltage during high-current surges low and reduces stress to the protected components.

In this reference design, one of the channels uses the TVS3300 device. This new TVS diode architecture has properties that make it very suitable for protection of analog inputs. The breakdown voltage is precise and to a smaller degree temperature dependent than traditional TVS diodes. Therefore, the TVS3300 breakdown voltage can be closer to the maximum power supply voltage. With just 40 mΩ, the differential resistance is less than that of traditional TVS diodes at ten times the size. This protects the connected circuits much better from surge stress. The leakage is 10 to 100 times lower and the temperature dependance two times lower. This dependance is for higher measurement accuracy. The ultra-small size makes it fit closer to the point where the protection is needed, which is the connector to the outside world. This keeps noise and distortion away from the sensitive parts of the circuits. Figure 4 shows the protection of the original TIDA-00550 reference design. On one of the two channels on the board, D5, D7, and D9 are replaced by TVS3300 devices, as shown in Figure 5.

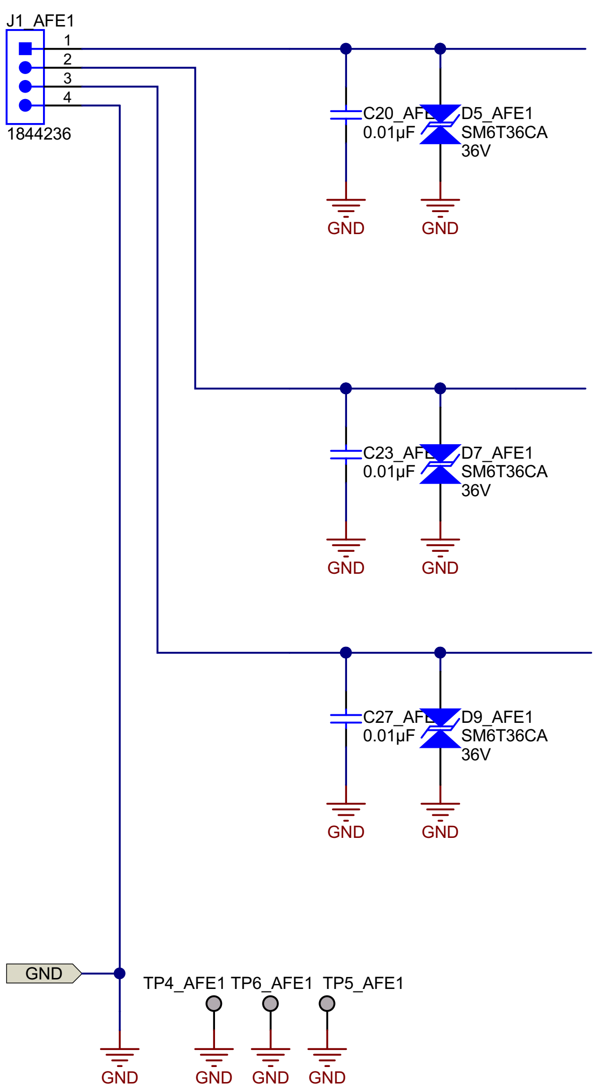

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Figure 4. Input Protection Schematic

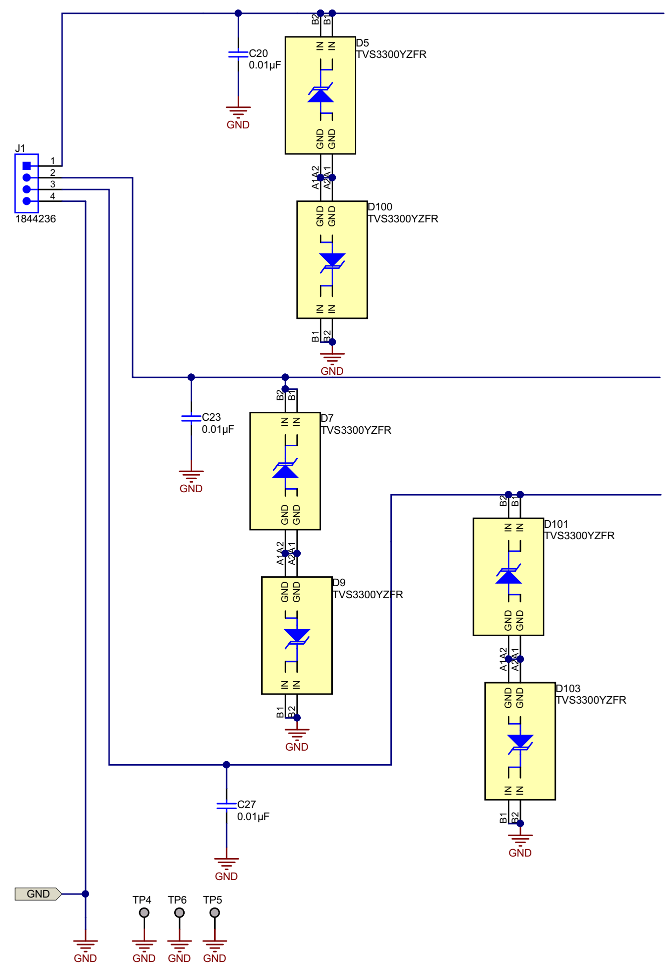

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Figure 5. Input Protection Schematic With TVS3300

3 Testing and Results

This reference design is built to measure the influences of EMI events on the key parameters of surge protecting elements. The details of the measurement procedures are described in the TIDA-00550 design guide[2]. The high performance of the TIDA-00550 reference design is used to check whether protection elements change their parameters after surge events. Table 2 shows four TIDA-00550 design boards that are prepared to use the TVS3300 device on one channel and a standard TVS diode on the other channel.

Table 2. TVS Population of Test Boards

BOARD NUMBER	TVS POPULATION	
	CHANNEL 1	CHANNEL 2
1	TVS3300	SM6T36CA
2	SM6T36CA	TVS3300
3	TVS3300	SM6T36CA
4	TVS3300	SM6T36CA

All boards are modified such that they permanently measure voltages up to 50 V between pin 1 and pin 4 of the input connector J1. All boards are then characterized for input leakage overvoltage and temperature. A current source applies step by step a range of different currents to the input. These currents cause a set of voltages across the input resistance of 86.1 kΩ between pin 1 and pin 4 on J1. Table 3 shows the relationship between current and voltage on the input:

Table 3. I/V Relationship of Test Boards

INPUT CURRENT	VOLTAGE OVER INPUT RESISTANCE
100 nA	8.6 mV
200 nA	17.2 mV
500 nA	43.1 mV
1 µA	86.1 mV
2 µA	172.2 mV
5 µA	430.5 mV
10 µA	861.1 mV
20 µA	1.7 V
50 µA	4.3 V
100 µA	8.6 V
200 µA	17.2 V
500 µA	43.1 V (with no TVS)
1 mA	86.1 V (with no TVS)
2 mA	172.2 V (with no TVS)
5 mA	430.5 V (with no TVS)
10 mA	861.1 V (with no TVS)

Any current through the TVS diode creates a difference between the measured voltage with TVS present and the theoretical voltage with no TVS present. Up to 33 V, this difference comes from TVS leakage. Once the input voltage reaches the TVS breakdown point the difference between measured and theoretical voltage comes from the desired TVS operation (clamping and protection). This method makes it possible to measure the leakage current and clamping behavior in one setup and measurement automation needs no manual intervention.

The surge immunity test according to IEC 61000-4-5 are done on both channels. One channel is tested completely before the other channel is tested. All four boards are exposed to 500-V 1.2/50-µs surges out of a 42-Ω generator impedance. Figure 6 shows a wiring diagram example.

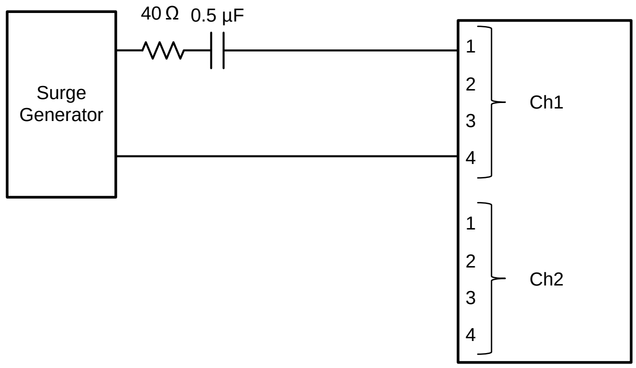

Figure 6. Surge Test Wiring Diagram

The surges create a 12-A current peak in the protection element. Five of these pulses are applied in the positive direction and then five pulses in the negative direction. The time between two pulses is one minute. Two of the boards, board 2 and board 4, receive the next level of 1 kV, which corresponds to a 24-A peak. The number of pulses and the time between is the same as before. The generator, voltage levels, pulse shapes, and generator source impedances are as per the applicable standards. The tests are performed at a facility of the CSA Group, using equipment and methods as per IEC 61131-2 and IEC 61000-4-5.

After the exposure to these surge events, the boards undergo the same characterization as before. This characterization shows how leakage, temperature behavior, and clamp voltages are impacted by the EMI events.

The characterization data shows that the properties leakage and clamp voltage of the protecting elements are stable throughout the surge testing. This behavior is also stable over the full temperature range. This shows that the necessary surge protection can be done with the TVS3300 device with much less board space. The advantage from using the TVS3300 is that the protection can move closer to the connector and therefore prevent EMI from entering the board at a much earlier stage. Coupling and other side effects are minimized and EMI immunity is improved.

The exact waveforms during surge are more precisely extracted on specialized test equipment. Figure 7 shows the clamping behavior of a conventional TVS compared to that of a TVS3300 at a surge with a 24-A peak current. Such a current profile can be the result of a 1-kV surge from a 42-Ω source impedance.

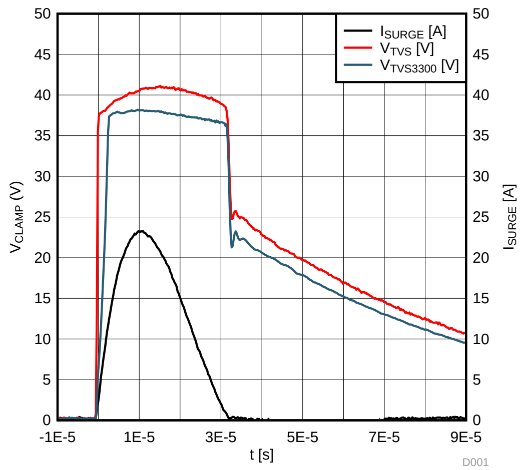

Figure 7. Clamping Voltage Over Surge Current

Figure 7 shows that with the same clamping voltage, the peak voltage of the TVS3300 is significantly lower than that of the conventional TVS diode. The TVS3300 also shows a slope limiting function, which reduces dangerous trace-to-trace energy transfer from large transients.

4 Design Files

This reference design is based on a modified TIDA-00550 reference design and comes with a set of updated design files to enable a quick and flawless conversion into other designs. These design files are located in the TIDA-01438 design folder. The design files consist of schematics, BOM, and an Altium Designer project including Gerber files, assembly drawings, and layout prints.

5 Related Documentation

1. Texas Instruments, *TVS3300 33-V Precision Surge Protection Clamp Data Sheet*
2. Texas Instruments, *TIDA-00550 Dual Channel-to-Channel Isolated Universal Analog Input Module for PLC Reference Design*

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6 About the Authors

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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