Design Guide: TIDA-060027
Protecting RS-485 Transceivers from Sustained High-Voltage Electrical Over-Stress Reference Design

Description

This reference design proposes an implementation of combining Positive Temperature Coefficient (PTC) fuses and Silicon Diode Alternating Current (SIDAC) devices to keep the transceivers alive under sustained exposure to high voltage. It highlights the capability of this particular protection device combination for RS-485 transceivers.

Resources

TIDA-060027	Design Folder
THVD1500	Product Folder

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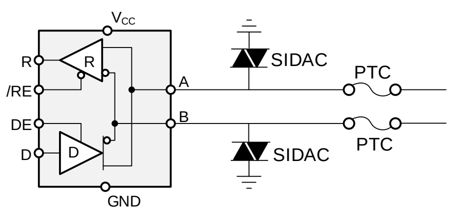
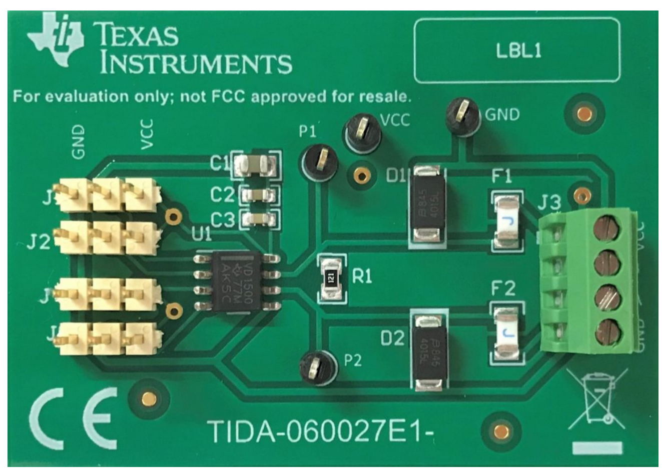
Features

- 15 V low-voltage SIDAC
- 120-240 V PTC fuse
- Extra pads for alternative device testing
- Headers for easy connections

Applications

- Air conditioner outdoor unit
- Building automation





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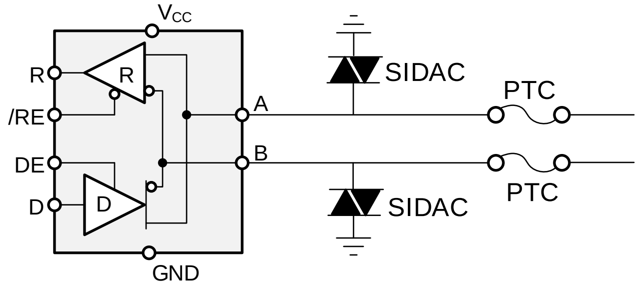
1 System Description

This reference design demonstrates the capability of Silicon Diode Alternating Current (SIDAC) diode and Positive Temperature Coefficient (PTC) fuse working in combination to protect an RS-485 transceiver from sustained high-voltage exposure through the bus lines. This application could be implemented in several forms of industrial, automotive, or HVAC systems where the threat of high-voltage exposure exists. For example, mis-wirings could happen during system installation in the field by technicians in HVAC and building automation. Some building automation sensors application requires RS-485 interface that could tolerate an AC short test. Similarly, the large fault voltage tolerance can be useful in DMX512-controlled lighting installations (similar to stage or venue lighting) where replacing damaged interface circuits can be difficult and costly. Implementing a PTC fuse and SIDAC is relatively straightforward. The PTC fuse operates in series with the transceiver's bus pin and the SIDAC operates from the bus line to ground. The expected operation of the combination is for the SIDAC to clamp under the high-voltage condition causing it to draw a large amount of current. This in turn causes the PTC fuse to trip and enter a high-impedance state thus heavily limiting current. Meanwhile, the transceiver never sees either the high voltage or high current due to the two protection devices working together. When removing the high voltage, the SIDAC exits the breakdown state and the PTC fuse returns to a low-resistance state effectively returning the bus line to normal conditions.

2 System Overview

2.1 Block Diagram

Figure 1. TIDA-060027 Block Diagram



2.2 Design Considerations

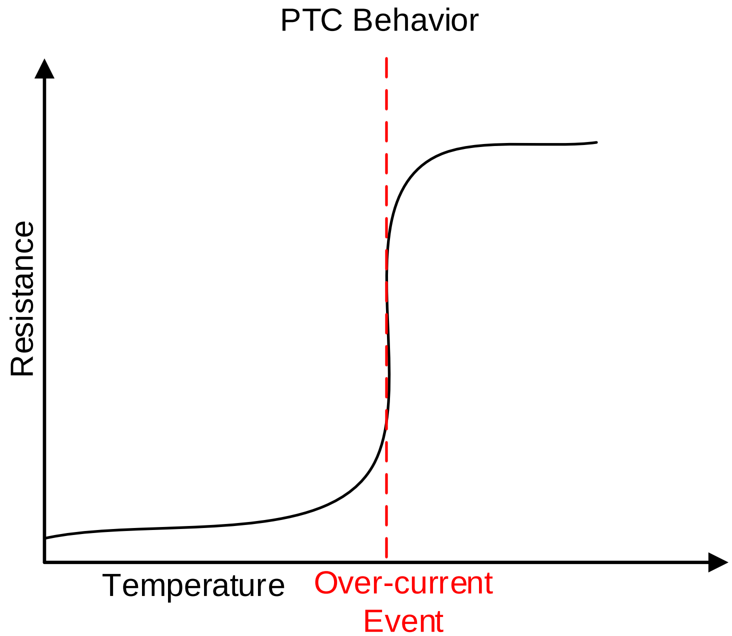
The primary considerations for this design revolve around the proper selection of the PTC and SIDAC devices. Both devices must work together to protect the RS-485 transceiver when the bus lines are exposed to sustained over-voltage.

This system includes the THVD1500 general purpose RS-485 transceiver with ±18 V bus fault voltage. It is protected against a moderate amount of ESD, surge, and fast transient events, but like many other RS-485 transceivers it wouldn't be able to survive sustained exposure to significantly high voltage. This device therefore makes for a perfect example to show how the PTC/SIDAC combo can protect a common RS-485 transceiver from high voltage through the bus lines and preserve functionality after a serious fault event.

In this design guide, the goal is to protect the transceiver from over 70 V DC or 120 V AC voltages. For lower fault voltages, TI has released several high-voltage fault RS-485 transceivers, such as SN65HVD1780 or THVD24xx, which can survive overvoltage faults such as direct shorts to power supplies and mis-wiring faults without requiring additional external protection components.

2.2.1 PTC Resettable Fuses

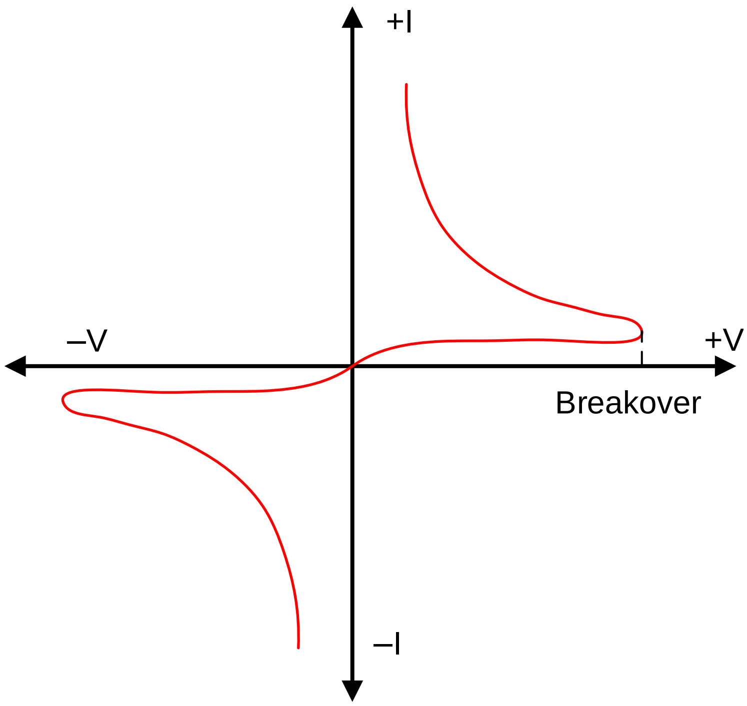
Figure 2. Diagram of Typical PTC Fuse Behavior



PTC fuses are made of a material that is sensitive to temperature. When a PTC fuse rated trip current is experienced, the temperature is raised to a point that causes the material to dramatically increase in resistance and therefore significantly limits current flow. When the cause of the over current event is removed, or the power supply is shut down, the fuse is allowed to cool. The fuse then resets into the low resistance state and allows current to flow through it again. You must choose a PTC with the correct parameters and ratings for the intended application, such as rated trip current, hold current, time-to-trip, and on resistance. The trip current is the current that guarantees tripping the PTC fuse. The hold current is less than the trip current and should be a value that accommodates the current load of the device(s) that it is protecting. The time-to-trip is often given in terms of seconds at a particular number of amps drawn. This is the time it takes for the PTC fuse to go from a low-resistance state to a high-resistance state. This value becomes faster as the current further exceeds the rated trip current and the relationship normally displays as a graph in the data sheet for these devices. The PTC fuses chosen for this reference design have low-trip current ratings so that reactions to faults happen as quickly as possible without interfering with normal operation during non-fault conditions.

2.2.2 SIDAC Devices

Figure 3. Diagram of Typical SIDAC Behavior



Silicon Diode Alternating Current (SIDAC) devices are a type of “crowbar” device that could be thought of as a voltage activated DIAC without a gate. A particular SIDAC will “break over” at a certain voltage that it is rated for and will conduct under the break over condition. After the breaking over, the SIDAC will have a voltage across it that is directly related to the amount of current passing through it. In this “snapback” region, a low voltage is held with high current. When the high voltage is removed, the SIDAC returns to its non-broken over status. Figure 3 helps visualize the behavior of a SIDAC by showing the relation between the voltage across the SIDAC and current flowing through it. As a bidirectional device, it will react to both positive and negative voltages applied, which gives it the capability to react to not only high-voltage DC but also AC voltage as well.

With the working parameters of both the PTC fuse and SIDAC devices, we can put them together to work effectively to prevent damage to THVD1500. First, the SIDAC must allow for normal operation of this RS-485 transceiver and must not break under normal bus voltages. This is why a SIDAC of ±15 V was chosen so that normal communication can happen without interference. 15 V is also still under the absolute maximum bus voltage tolerated by the THVD1500 transceiver so that the SIDAC breaks over before damage occurs to the transceiver. Secondly, the PTC fuse needs to have a low trip current for this type of application, as well as fast time-to-trip. The PTC fuse chosen has a trip current of 160 mA allowing for the normal current flow of RS-485 bus lines but definitely tripping when the SIDAC breaks over at the introduction of ±15V or greater. The TRF250-080U fuse has typical time-to-trip of 2.5 seconds under the condition of 350mA. Though this seems slow, the PTC fuse reacts much quicker under increased current conditions. According to the TRF250-080U data sheet, the time-to-trip reduces to only 20 ms when experiencing a current of 3A, which is about the amount of current flowing on the bus with a 70-V DC short. The TISP4015L1AJR-S SIDAC can draw up to 20 A under a break over condition and can potentially cause the PTC fuse to trip very fast assuming the source of the fault can provide a high level of current. One must also consider the parasitic effects of the SIDAC and PTC fuse when placed on the bus lines. The SIDAC will introduce a certain amount of capacitance and the PTC fuse will introduce certain amount of resistance onto the bus lines. Consider these characteristics since they together form an RC filter and voltage divider on a bus line which may limit the communication data rate as well as reduce signal amplitude.

2.3 Highlighted Products

2.3.1 THVD1500

The THVD1500 is used as the general purpose example, half-duplex RS-485 transceiver for the design. This device is rated for ± 16 kV HBM ESD, ± 8 kV IEC 61000-4-2 Contact Discharge, ± 10 kV IEC 61000-4-2 Air Gap Discharge, and ± 2 kV IEC 61000-4-4 Fast Transient Burst. As mentioned previously, these ratings are good for handling momentary over-voltage faults but the transceiver would not be able to stand up to sustained high-voltage without damage.

2.3.2 TISP4015L1AJR-S

The TISP4015L1AJR-S is a low-voltage SIDAC from Bourns. The breakover voltage is at ±15 V and comes in a DO-214 surface mount package. It has 50-mA minimum holding current and low capacitance around 28 pF.

2.3.3 TRF250-080U Resettable Fuse

The TRF250-080U is one of Littelfuse's PolySwitch devices designed for use in telecommunications systems. The TRF250-080U has a relatively quick trip time and is rated for up to 60 V DC or 250 Vrms AC. It is a leaded device but chip versions of this family of devices exist if a surface mount package is desired.

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

3.1.1 Hardware

Two DC power supplies, a signal generator, and an oscilloscope are used for the tests. An Agilent 6624A system DC power supply is used to power the board, while a Chroma 62006P-100-25 is used to provide 70 V to 100 V DC fault voltage. An Agilent 33220A generates 1-kHz, 5-V clock signal. An Agilent MSO6104A monitors the activities on bus.

3.2 Testing and Results

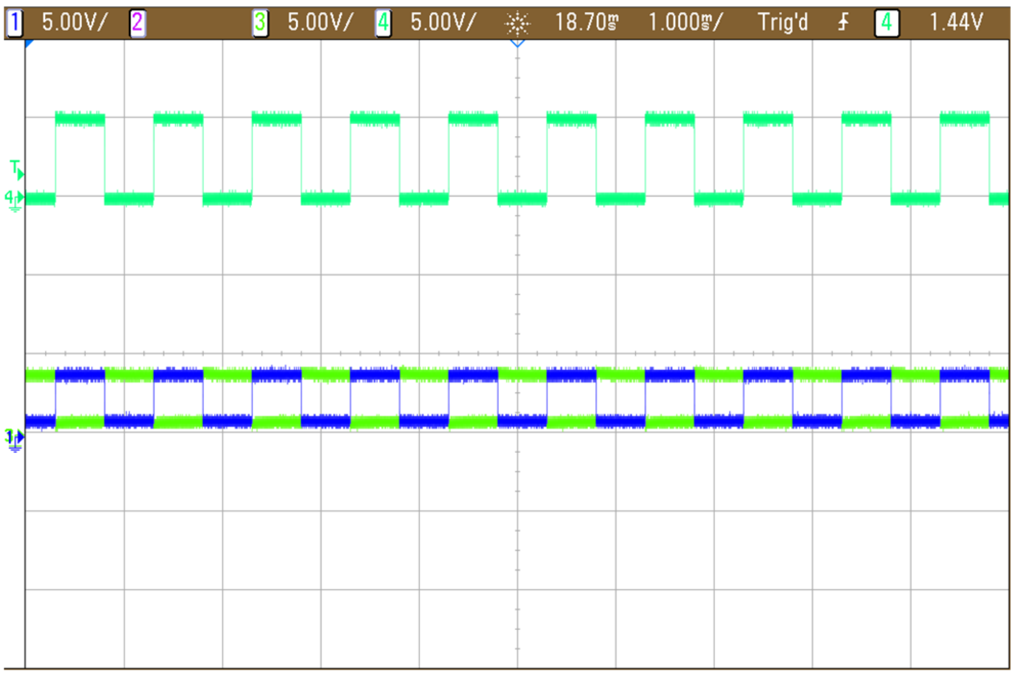
3.2.1 Test Setup

The test is set up with a TIDA-060027 board. A 5-V voltage supply provides power to the board via the VCC and GND connections. High-voltage DC or AC is attached to the bus lines through the terminal block. The waveforms are captured by the oscilloscope through test points P1 and P2 on the board.

3.2.2 Test Results

The test results for the PTC fuse and SIDAC combined with the THVD1500 general purpose RS-485 transceiver shows that the protection devices are effective for up to 100 V DC and 120 V AC. In Figure 4, the top pink waveform shows the input signal (1-kHz clock) fed to THVD1500's D pin, while its DE pin is set to H. The yellow (A pin) and purple (B pin) waveforms are corresponding the bus signal with a 120-Ohm termination resistor load in normal operation.

Figure 4. A and B Bus Lines Transmitting at 1 Kbps With No Fault



From Figure 5 we can view the bus voltages before and during exposure to 70 V DC. The first spike shows as 70 V DC is attached to the bus, the SIDAC reaches to its impulse breakover point and enters the snapback region to hold the bus voltage low as the current keeps increasing. After about 50 ms, the PTC's temperature becomes high enough to make its resistance increase dramatically. Therefore, the current flowing on the bus decreases and the SIDAC moves back to its breakover region. As the PTC's resistance keeps increasing, the SIDAC current keeps decreasing. During the entire process, the maximum voltage at the bus pins of THVD1500 does not exceed 13 V due to the SIDAC and PTC fuse combination, which is below the 18-V absolute maximum voltage.

Figure 5. A and B Bus Pins Transmitting With Bus Line A Exposed to 70 V DC

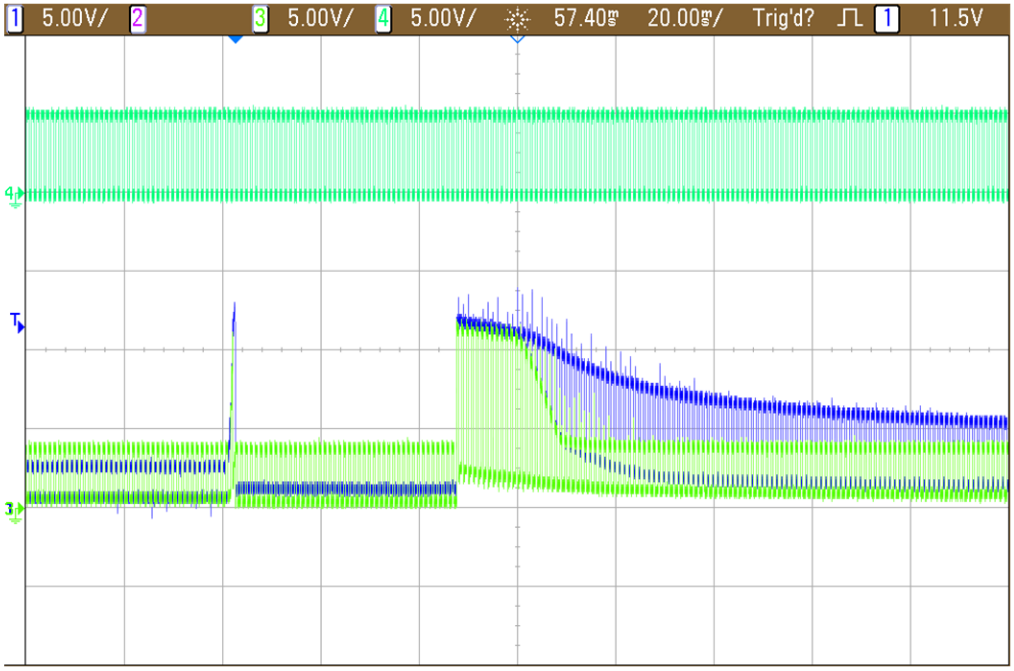
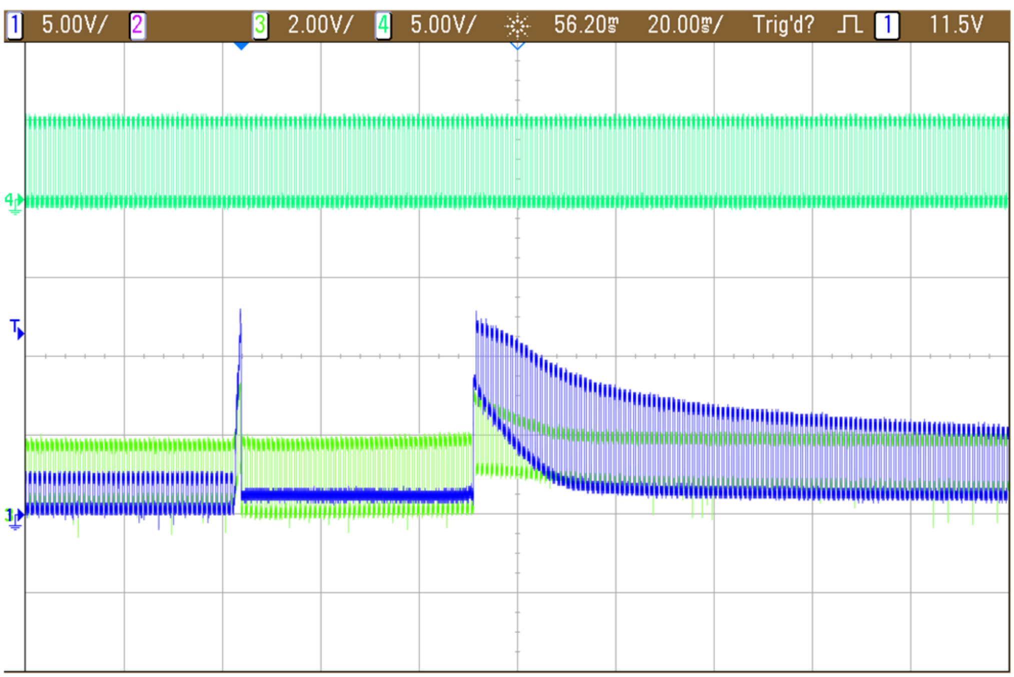


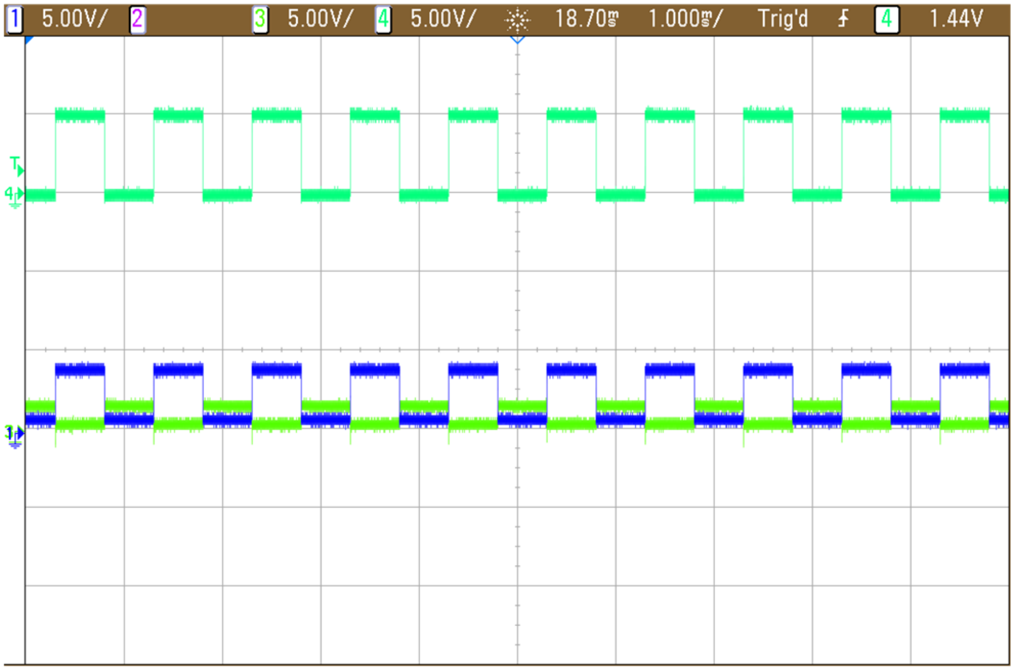
Figure 6 displays a similar test while 70 V DC is applied on both A and B pins. The B pin is biased to the DC ground of 70 V DC.

Figure 6. A and B Bus Lines Transmitting With Both Buses Exposed to 70 V DC



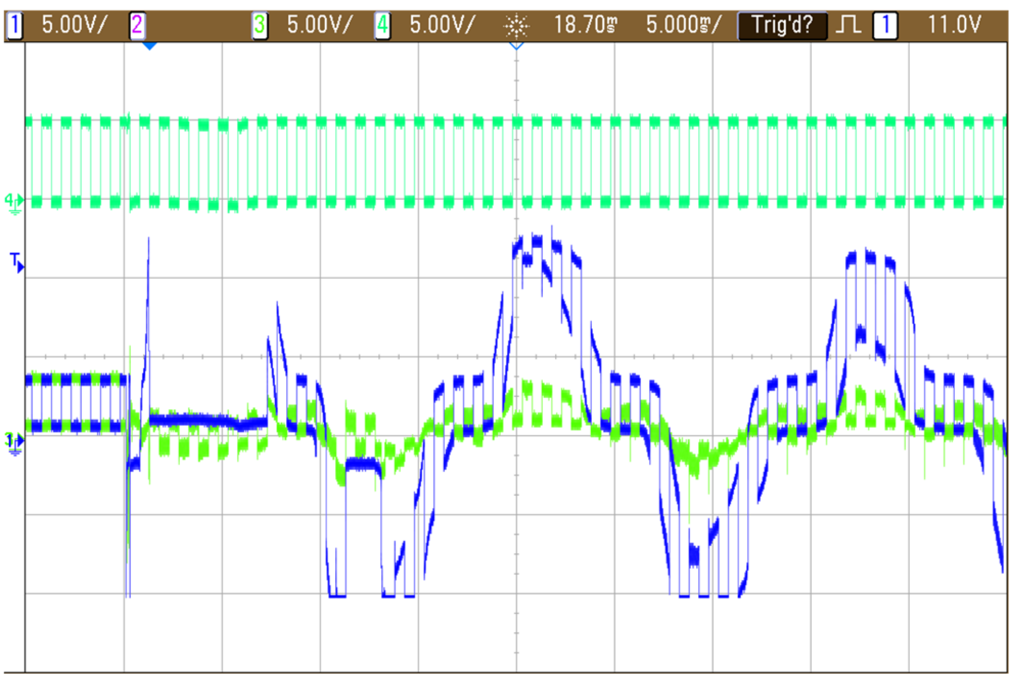
After several seconds, the PTC and SIDAC reach an equilibrium state when the current flowing through the PTC is below 10 mA as shown in Figure 7. THVD1500 drives the A pin similar to normal operation. Since the PTC on B line is below normal temperature, THVD1500 drives the B pin with a 20-Ohm PTC resistance to DC ground, which generates a lower bus voltage than the A side. When 70 V DC is removed from the bus, the bus line goes back to the normal operation similar to Figure 4. The test was also repeated with up to 100 V DC and the results were similar.

Figure 7. A and B Bus Lines Transmitting With Both Buses Exposed to 70 V DC After Several Seconds



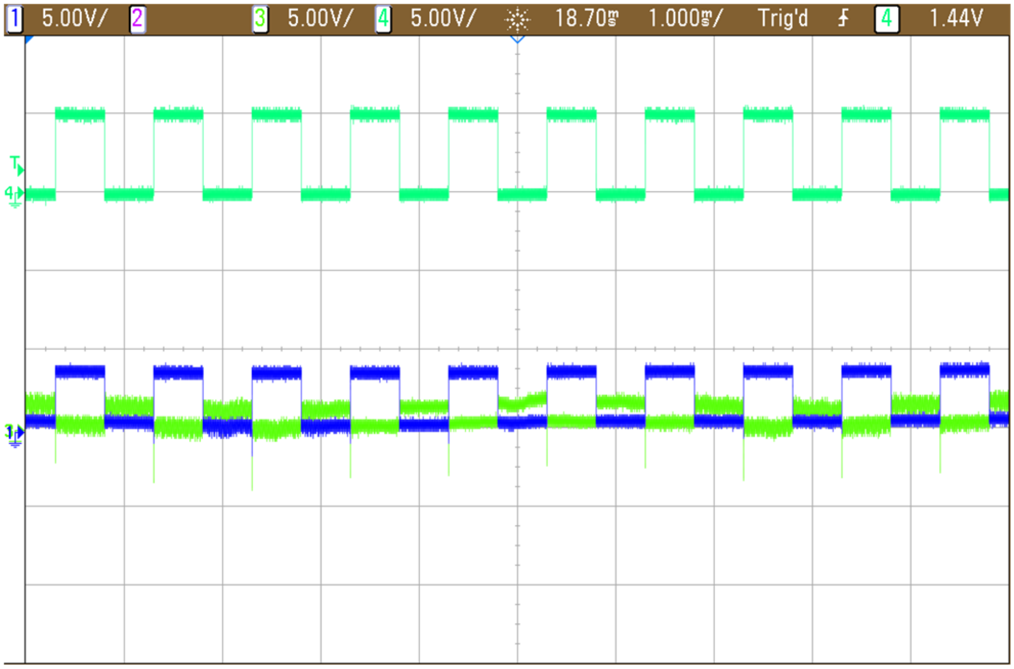
With the same setup, the bus lines are exposed to 120 V AC Figure 8. Similarly, the SIDAC trips first and holds in the snapback state. As the PTC resistance increases, the bus-peak voltage becomes smaller. The image displays the 60-Hz cycling of 120-V AC. The maximum and minimum voltages seen at the bus pins were 13 V and -11 V respectively. These voltages are still well within the absolute maximum voltage of the THVD1500.

Figure 8. A and B Bus Pins Transmitting When Bus Lines Exposed to 120 V AC



Similar to the case of the high-voltage DC fault, the PTC and SIDAC eventually reach an equilibrium state and shown in Figure 9. The transceiver bus lines return to normal voltage levels when removing the fault.

Figure 9. A and B Bus Pins Transmitting When Bus Lines Exposed to 120 V AC After Several Seconds



4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-060027.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-060027.

4.3 PCB Layout Recommendations

Place decoupling capacitors close to the power pins of each device to help filter out noise.

- Use VCC and ground planes to provide low inductance.

NOTE: High-frequency currents follow the path of least impedance and not the path of least resistance.

- Use at least two vias for VCC and ground connections of bypass capacitors and protection devices to minimize effective through inductance.

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-060027.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-060027.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-060027.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-060027.

5 Software Files

To download the software files, see the design files at TIDA-060027.

6 Related Documentation

IEC ESD, EFT, and Surge Protected RS-485 reference design

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