

# **How to Design Isolated CAN Systems With Correct Bus Protection**

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## **ABSTRACT**

One common reason for transceiver damage is due to insufficient bus protection. External ESD protection is either not designed in at all, or the protection device is chosen in a way that does not pair well with the transceiver. It is imperative for the protection device to be chosen to interface well with the transceiver. This paper explains the key parameters for both the protection device and the transceiver in order to design an isolated CAN system with correct bus protection.

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## 1 Introduction

Protection from electrostatic discharge (ESD) is often an afterthought in system design even though only one ESD strike can permanently damage a device. ESD protection is a critical component in a system design. If a system does not have the correct ESD protection, the high voltage of an ESD strike through an interface connection (for example, the CAN bus) can cause a large current spike to flow directly into the transceiver device causing damage to the transceiver. This application report provides details to design isolated CAN systems with correct bus protection. The device selected to protect the transceiver from electrical overstress failures is a transient-voltage suppression (TVS) diode. TVS diodes are connected to each signal line between the interface connector (the CANH and CANL pins in this case) and ground before the transceiver device as shown in Figure 1. If an ESD strike occurs, the TVS diode breaks down and creates a low impedance path. The low impedance path diverts the current flow to ground to limit the peak voltage which protects the isolated CAN transceiver. The addition of a TVS diode can be done for a reasonable cost and with minimal additional board space.

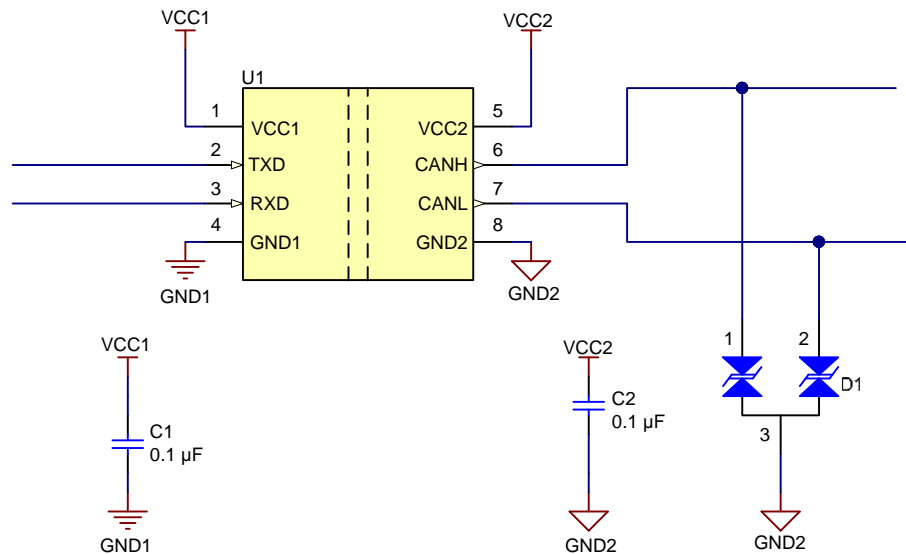


Figure 1. Isolated CAN transceiver With TVS Diode

## 2 Bidirectional TVS Diode Selection

A bidirectional TVS diode can protect the CAN transceiver bus pins for short overvoltage events. TVS diodes offer the most effective protection against ESD, burst EFT, and surge transients because of short response times of a few picoseconds and power ratings up to several kilowatts.

### 2.1 Clamping Voltage

The TVS diode should be selected so that the absolute maximum voltage ( $V_{ABS}$ ) at the bus pins is not violated. For example, the ISO1050 device has absolute maximum voltage range from  $-27\text{ V}$  to  $40\text{ V}$  for the CANH and CANL pins as specified in the ISO1050 datasheet.

Texas Instruments also offers another isolated CAN transceiver; ISO1042. The ISO1042 device has an extended absolute maximum voltage range from  $-70\text{ V}$  to  $70\text{ V}$  on the CANH and CANL bus pins in addition to other benefits such as support of CAN FD datarates and higher CMTI maximizing the flexibility for the system designer. The absolute maximum voltage range can be found in the ISO1042 datasheet. Table 1 shows a comparison of the absolute maximum voltage rating for the CANH and CANL pins of the ISO1050 and ISO1042 devices.

Table 1. CANH and CANL Absolute Maximum Voltage Ratings

Device	ISO1050	ISO1042
Absolute maximum voltage at CANH and CANL (negative)	$-27\text{ V}$	$-70\text{ V}$
Absolute maximum voltage at CANH and CANL (positive)	$40\text{ V}$	$70\text{ V}$

The maximum clamping voltage ( $V_{CLAMP}$ ) at the peak pulse current ( $I_{PP}$ ) is the most important parameter to consider when selecting a TVS diode. The maximum clamping voltage at the peak pulse current must be less than the absolute maximum rating of the device. This value prevents the bus pins of the transceiver from voltages greater than the absolute maximum specified for the transceiver which will damage the device.

$$|V_{CLAMP}| < |V_{ABS}| \tag{1}$$

An example diode to consider is the [CPDT-12V](#). The maximum clamping voltage is 25 V at a peak pulse current of 1 A. The specifications of this diode result in 2 V of margin for a negative voltage strike and 13 V of margin for a positive voltage for the ISO1050 device. The margin of this diode would be greater for the ISO1042 device.

The [ESDCAN05](#) would be a poor choice of TVS diode for the ISO1050 for the following reason. According to the ESDCAN05 datasheet, the maximum clamping voltage is 61 V at peak pulse current of 5 A. This surpasses the absolute maximum rating of the ISO1050. However, this could be a good candidate for the ISO1042 with an absolute maximum rating of +/-70 V. Note that the ESDCAN05 lists multiple maximum clamping voltages for different peak pulse current values. This is common for TVS diodes. A system designer needs to consider what maximum peak pulse current the bus could experience and determine the appropriate clamping voltage for that system accordingly. If one were to study an IV curve (such as the one listed in [Figure 2](#)) for a TVS diode they would find a continuous set of clamping voltages mapping to applied current. The maximum clamping voltage at peak pulse current is a datasheet guarantee.

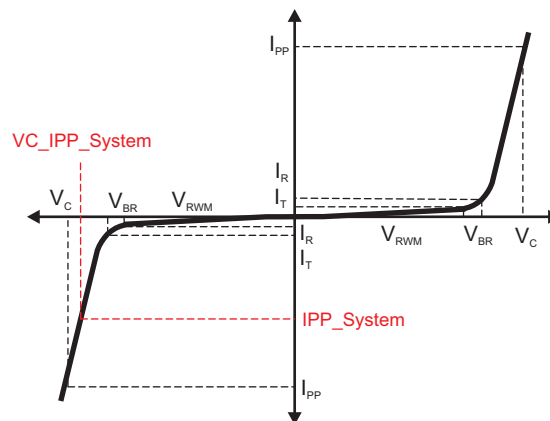


Figure 2. Typical TVS Diode IV Curve

Below is a table comparing the worst case difference between the maximum clamping voltages at the highest peak pulse current listed in the TVS diode datasheet to the absolute maximum rating of the bus pins of the transceiver.

Table 2.  $V_{CLAMP}$  Worst-Case Differences

TVS Diode	ISO1050 (Absolute Maximum -27 V to +40 V)	ISO1042 (Absolute Maximum -70 V to +70 V)
CPDT-12V Minimum Margin ( $V_{clamp} = 25$ V)	2 V	45 V
ESDCAN05 Minimum Margin ( $V_{clamp} = 61$ V)	-34 V	9 V
NUP3105LT3G Minimum Margin ( $V_{clamp} = 66$ V)	-39 V	4 V

From this table it is clear to see the CPDT-12V may be a suitable protection diode for the ISO1050 and all three of the TVS diodes in the table may be suitable for the ISO1042.

## 2.2 Breakdown Voltage

The TVS must also be chosen so it does not interfere with normal operation. The key parameter here is breakdown voltage ( $V_{BR}$ ). The breakdown voltage should be outside of the recommended operating conditions ( $V_{CM}$ ), but before the absolute maximum specifications are violated.

For example, the recommended operating conditions for the ISO1050 bus pins are +/-12 V as can be seen in section 6 of the [ISO1050 datasheet](#).

The ISO1042 offers an impressive +/-30 V common mode range. The table below details the common mode for each device.

**Table 3. Common Mode Range of Isolated CAN Devices**

Device	ISO1050	ISO1042
$V_{CM}$ CANH / CANL	+/-12 V	+/-30 V

$$|V_{BR}| > |V_{CM}| \tag{2}$$

The breakdown voltage should be chosen such that it is greater than the recommended operating conditions of the transceiver. This will ensure it does not interfere with the operational range of the transceiver.

The breakdown voltage of the TVS diodes is compared to the recommended operating conditions of the isolated CAN transceivers in the following table.

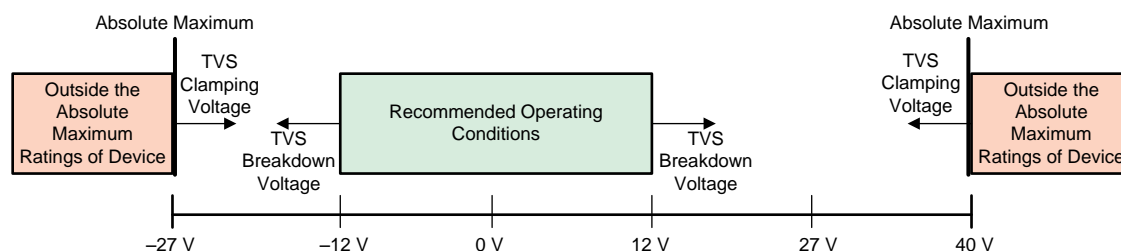
**Table 4.  $V_{BR}$  Worst-Case Differences**

TVS Diode	ISO1050 ( $V_{CM} = +/-12$ V)	ISO1042 ( $V_{CM} = +/-30$ V)
CPDT-12V ( $V_{BR} = 13$ V)	1	-17
ESDCAN05 ( $V_{BR} = 39$ V)	27	9
NUP3105LT3G ( $V_{BR} = 35.6$ V)	23.6	5.6

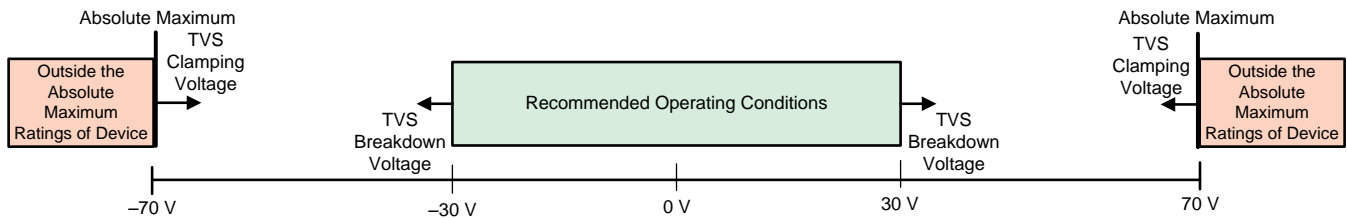
Once again the CPDT-12V is found to be a suitable match for the ISO1050. The CPDT-12V does come within the recommended operating conditions of the ISO1042. This is not an issue from an overvoltage perspective; this will just limit the common mode of the system. With this TVS diode in place, the new common mode will now be +/- 13 V because, beyond the voltage, the CPDT-12V will conduct.

The ESDCAN05 and NUP3105LT3G will not interfere with the common mode range of the ISO1050. However, they have already been disqualified as a suitable match for the ISO1050 because the clamping voltage is greater than the absolute maximum voltage ratings for the ISO1050. ESDCAN05 and NUP3105LT3G do have margin to the ISO1042 recommended operating conditions specification, so these TVS diodes are a good match as they will allow the system to fully utilize the extended common mode of the ISO1042.

Putting these two requirements together,  $|V_{CLAMP}| < |V_{ABS MAX}|$  and  $|V_{BR}| > |V_{CM}|$ , we get the following picture of how these parameters relate to each other.



**Figure 3. Graphical Representation of Relationship Between Key TVS Diode and Transceiver Specifications for the ISO1050**

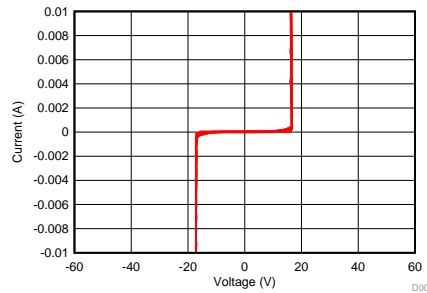


**Figure 4. Graphical Representation of Relationship Between Key TVS Diode and Transceiver Specifications for the ISO1042**

### 3 TVS Diode and Transceiver Curve Traces

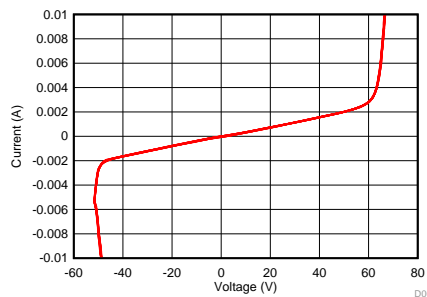
To further illustrate this point, the TVS diodes and isolated CAN transceivers were put on a curve tracer.

Note that these curve traces were done for only one device and at room temperature. These curve traces are provided purely for illustrative purposes. Protection circuitry must be chosen based on datasheet specifications which consider temperature, process variation, and so forth.



**Figure 5. CPDT-12V Curve Trace**

The CPDT-12V curve trace in Figure 5 shows that the TVS diode will draw minimal currents from +/-17 V – which makes sense as the datasheet guarantees the device will not draw more than 1 mA of current up to 13 V and lists 17 V as the typical breakdown. As more energy is injected into the device, TVS diode holds the bus at 17 V and steers the energy to ground.



**Figure 6. ISO1050 Curve Trace**

The ISO1050 curve trace shows there are some internal ESD structures that try to clamp the voltage outside of the absolute maximum rating of the part. These may be sufficient for some ESD strikes, but an external ESD structure will better protect the device and ensure that the absolute maximum ratings are not violated.

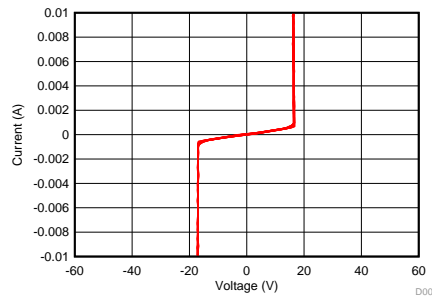


Figure 7. ISO1050 + CPDT-12V Curve Trace (connected as shown in Figure 1)

When the TVS diode is connected as shown in Figure 1, a curve trace CANH or CANL will result in the curve shown in Figure 7. In the middle of the curve, TVS diode has not broken down and curve takes the shape of the ISO1050. At +/-17 V, the curve takes the shape of the CPDT-12V as the diode steers the energy to ground.

All three curves are combined in Figure 8 with some markup.

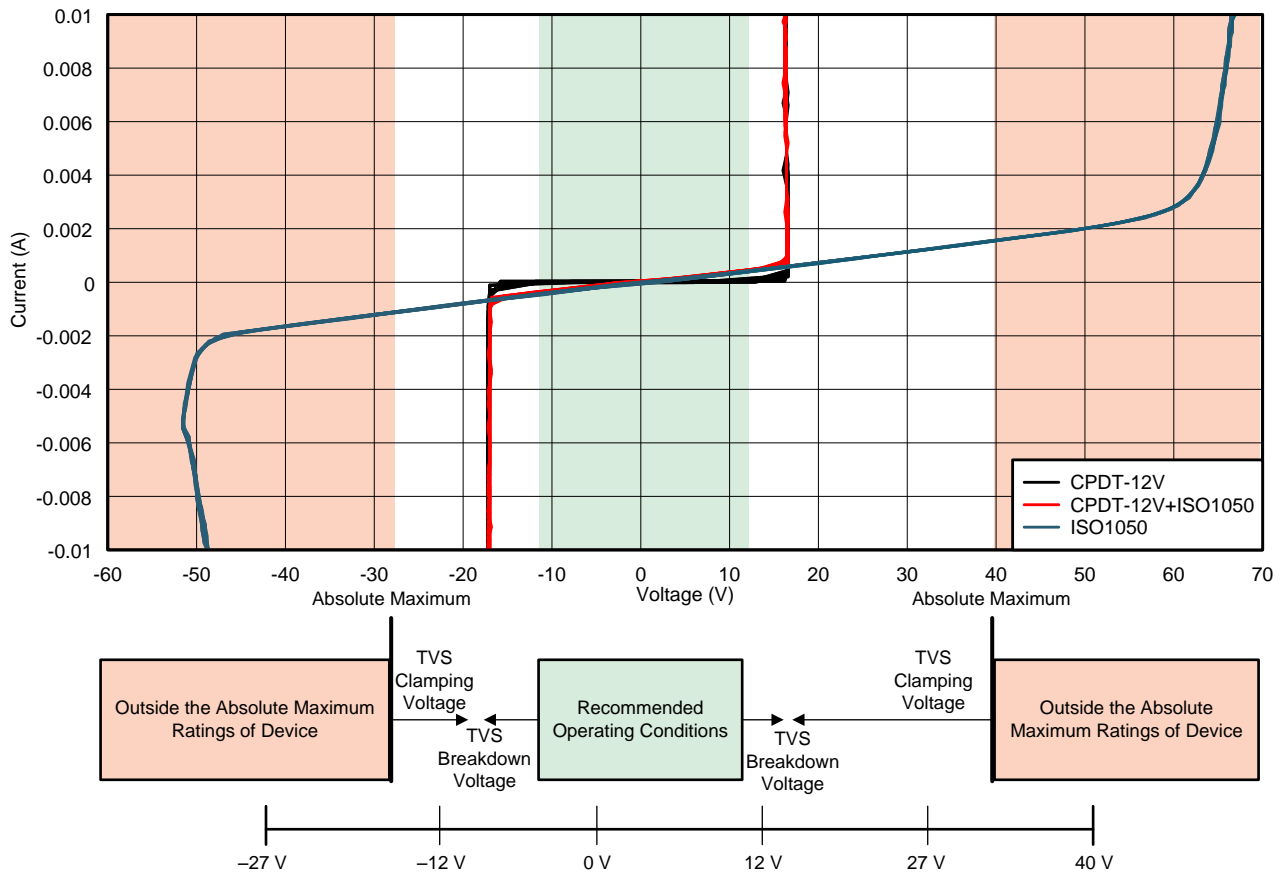
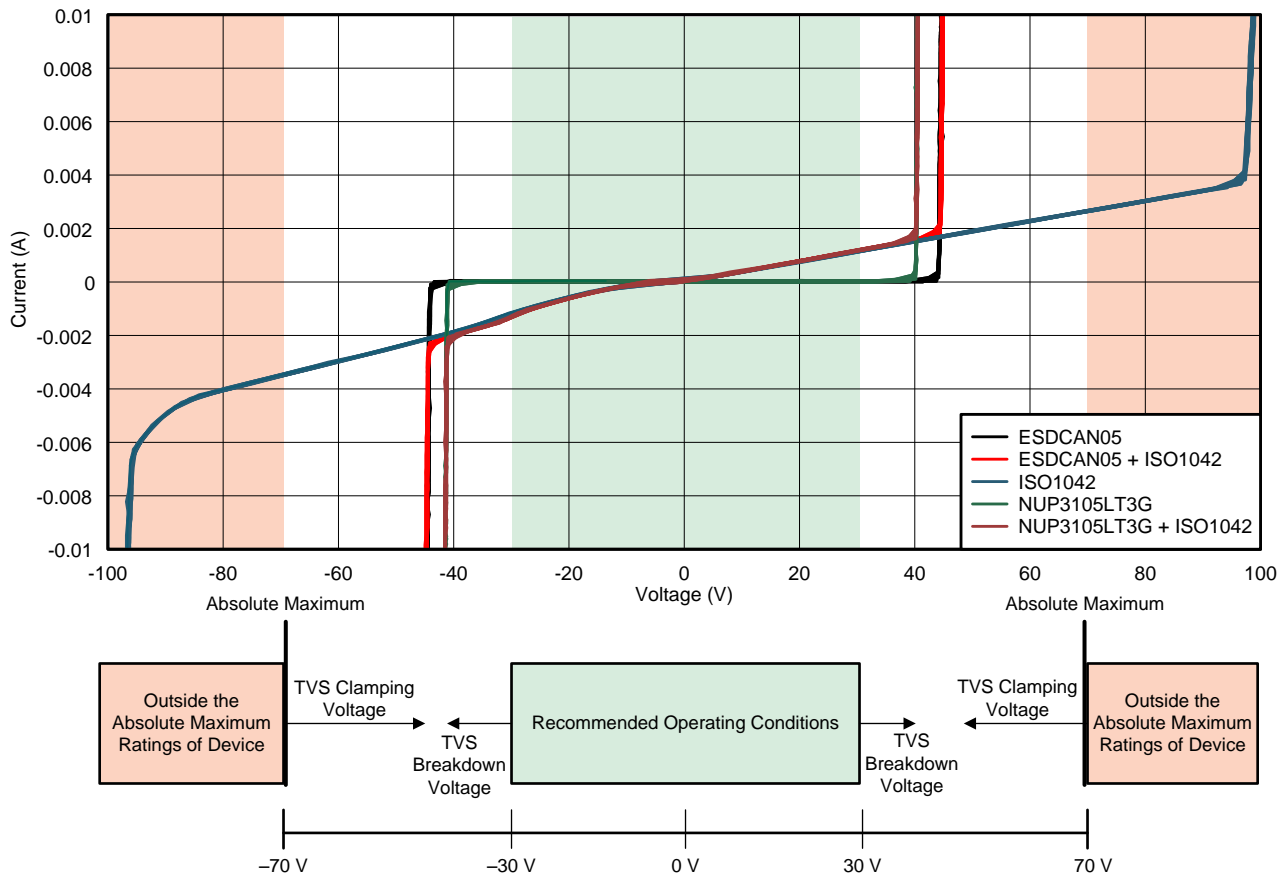


Figure 8. Combined View of Curve Traces and ISO1050 Datasheet Specifications

The green region in the center marks the recommended operating conditions. In a proper design, the TVS diode is not interfering with this region and so the common mode of the transceiver is the common mode of the system. The TVS breakdown occurs before reaching the red region which designates voltages beyond that of the absolute maximum voltage specifications of the ISO1050 isolated CAN transceiver.

The combined plots and markup are for ESDCAN05, NUP3105LT3G, and ISO1042 is shown below in Figure 9.



**Figure 9. Combined View of Curve Traces and ISO1042 Datasheet Specifications**

#### 4 Other Considerations (ESD, Leakage Current, Junction Capacitance, Package Size, and Operating Temperature)

ESD Capability is the amount of voltage the TVS diode can handle without damage. Note that the ESD rating of the diode is not the same as the ESD rating of the system. The rating gives no indication of whether the downstream circuitry will be protected. If the system is to survive an 8 kV ESD strike, the TVS diode should have a rating of at least 8 kV. Check out [www.ti.com/ESD-ClampingVoltage](http://www.ti.com/ESD-ClampingVoltage) for more information.

Leakage Current is the amount of current the diode conducts at voltages less than the breakdown voltage. An ideal TVS diode would have zero leakage current which means it would have zero effect on the recommended operating range of the bus pins. An actual TVS diode will have leakage currents in the microamp range which will have a negligible effect. Leakage current is typically specified for a smaller range than breakdown voltage of the TVS diode. Make sure the voltage listed is outside of the operating range of the transceiver bus pins to avoid any issues.

Junction capacitance should be considered as this could violate systems specifications if it is too large, and will also limit the maximum data rate of the bus. As a rule of thumb, junction capacitance should be less than 50pF.

Package size and layout will affect the total solution size. Many TVS diodes come in a SOT-23 package that is not only a small form factor, but is relatively easy to add to a layout. Figure 10 shows an example layout of the ISO1042 device in the DWV package. The D1 component is the TVS diode. Pin 1 and 2 connect to CANH and CANL. Pin 3 is connected to GND.



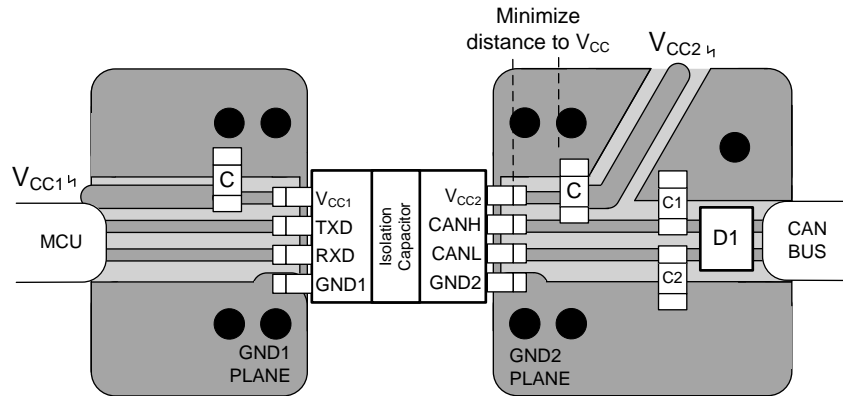


Figure 10. Example Layout of CAN Transceiver Device and TVS Diode

The operating temperature of the selected TVS diode should be greater than or equal to the specified operating temperature of the system.

Table 5 shows the specifications for the example TVS diodes selected in this application report.

Table 5. TVS Diode Specifications

TVS Diode	V <sub>BR</sub>	V <sub>CLAMP</sub>	Package	ESD Contact	Leakage Current	Junction Capacitance	Operating Temperature
CPDT-12V	13 V	25 V	SOT-23	8 kV	2 μA	12 pF	125°C
ESDCAN05	35.6 V	66 V	SOT-23	30 kV	0.1 μA	30 pF	150°C
NUP3105LT3G	39 V	61 V	SOT-23	30 kV	0.1 μA	3.5 pF	175°C

## 5 Same-Side ESD Testing

One form of testing for industrial or automotive CAN would be subject to is same side ESD testing. A system including the components shown in Figure 1 are subjected to high voltage strikes from ESD tester. In this test, an ESD gun would be attached to the CANH or CANL pin and tested for a specific voltage with respect to GND2. The device is then checked for damage.

Table 6 shows the bench test results for a limited number of tests for each isolated CAN transceiver and TVS diode configuration. These tests were done to illustrate the potential benefits of the TVS diode on the system. A very small sample size of tests was completed for each configuration. Process variation and temperature were not considered. *As such, these pass levels should not be considered as guaranteed for all devices but rather should be read as relative performance differences for systems with and without a TVS diode.*

Table 6. ESD Test Results

Devices Being Tested	Typical Pass Level
ISO1050	4 kV
ISO1050 + CPDT-12C	8 kV
ISO1042	8 kV
ISO1042 + ESDCAN05	15 kV
ISO1042 + NUP3105LT3G	15 kV

These conclusions can be made from the results:

- A transceiver can withstand ESD strikes with a higher voltage when paired with an appropriate TVS diode. This is because the TVS diode guides the ESD energy away from the transceiver pins into the local ground. The TVS diode also clamps the ESD energy at a safe value within the absolute maximum voltage rating of the transceiver. Therefore the transceiver does not receive the full energy impact of the ESD event.

- The ISO1042 device can withstand higher voltage same-side ESD strikes than the ISO1050 device when a TVS device is not installed.
- For a system specification of 8 kV same-side ESD, a TVS diode may not be required when using the ISO1042.
- The ISO1042 device can withstand a 15-kV ESD strike with an appropriate bus protection device.

## 6 Conclusion

Using a TVS diode helps protect a device from overvoltage events on a CAN bus. Choosing the right TVS diode based on the clamping voltage and breakdown voltage with respect to the transceiver specifications will ensure that the TVS diode can protect the device when necessary but does not interfere with the operational range. If a correct TVS diode is selected, the system can withstand higher ESD strikes on the bus pins than that of a system with no TVS diode.

## 7 References

See these documents for additional reference:

- Texas Instruments, [ISO1042 Isolated CAN Transceiver With 70-V Bus Fault Protection and Flexible Data Rate data sheet](#)
- Texas Instruments, [ISO1050 Isolated CAN Transceiver data sheet](#)

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