APPLICATION NOTE 6965

HOW TO SELECT A TVS DIODE FOR MAXIM'S IO-LINK DEVICES

Abstract: While IO-Link® transceivers are increasingly designed for robustness, external protection is also typically required to protect the devices and system from transient events such as voltage or current surges. This application note presents guidelines for selecting a TVS diode to be used with Maxim's IO-Link transceivers in master and sensor reference designs.

Introduction

Industrial environments have harsh operating conditions for integrated circuits (ICs). While IO-Link® transceivers are designed to be increasingly robust, external protection is also typically required to protect the devices and system from externally generated destructive conditions, such as voltage surges caused by events such as lighting strikes or electrostatic discharge (ESD) events from arcing caused by energy discharges.

The IO-Link standard (IEC 61131-9) is increasingly used in industrial systems for communication with smart sensors and actuators. This standard includes requirements for systems to pass certain levels of EMC immunity tests, including Electrostatic Discharge (IEC 61000-4-2) and Electrical Fast Transient/Burst (IEC 61000-4-4). While Surge (IEC 61000-4-5) testing is not required by the IO-Link standard, it is commonly requested by users. This application note reviews the characteristics of transient voltage suppression (TVS) diodes—one of the most prevalent protection devices used in industrial systems—and presents guidelines for selecting a TVS diode to be used with Maxim's IO-Link transceivers.

Protecting a System from Electrical Transients

When a high-voltage transient event such as ESD or surge pulse reaches the devices on a PCB, some form of system protection must be present to avoid damage from the overvoltage spikes that exceed the absolute maximum (abs max) ratings of the sensitive ICs. Depending upon the system, protection may be required for both the voltage supply and/or the interface lines, as is the case with IO-Link. Therefore, any protection device on the circuit must idle under normal conditions, allowing data to pass through the line without errors, but must work when a transient event occurs. A common device for this type of use is a TVS diode, which is produced by a range of vendors and offered in many configurations for different voltage, power, and form factor.

TVS Diode Terminology

The characteristic curve in **Figure 1** shows the key parameters for a TVS diode.

Reverse Standoff Voltage (V_{RM})
Also known as maximum working peak voltage, this is the normal operating threshold voltage of the device. The TVS diode will appear as a high impedance to the protected circuit when the applied voltage across the diode is less than this threshold.

Reverse Breakdown Voltage (V_{BR})
Also known as breakdown voltage, this is the voltage threshold at which the TVS diode begins to conduct a specified amount of current. Voltage V_{BR} should not exceed the abs max rating for the IC it is protecting.

Clamping Voltage (V_{CL})
The overvoltage transient is clipped to the level defined by V_{CL}, which is the maximum voltage level seen across the protected circuit. Voltage V_{CL} is always defined for a given peak pulse current (I_{PP}).

Peak Pulse Current (I_{PP})
This is the maximum surge current the TVS diode can withstand without damage. The peak pulse current is defined based on the surge-current transient waveform, which in most industrial applications is rated at 8/20µs with 8µs representing rise time (t_1) to peak value and 20µs representing pulse duration until the current falls to 50% of peak value (t_2), as shown in **Figure 2**.

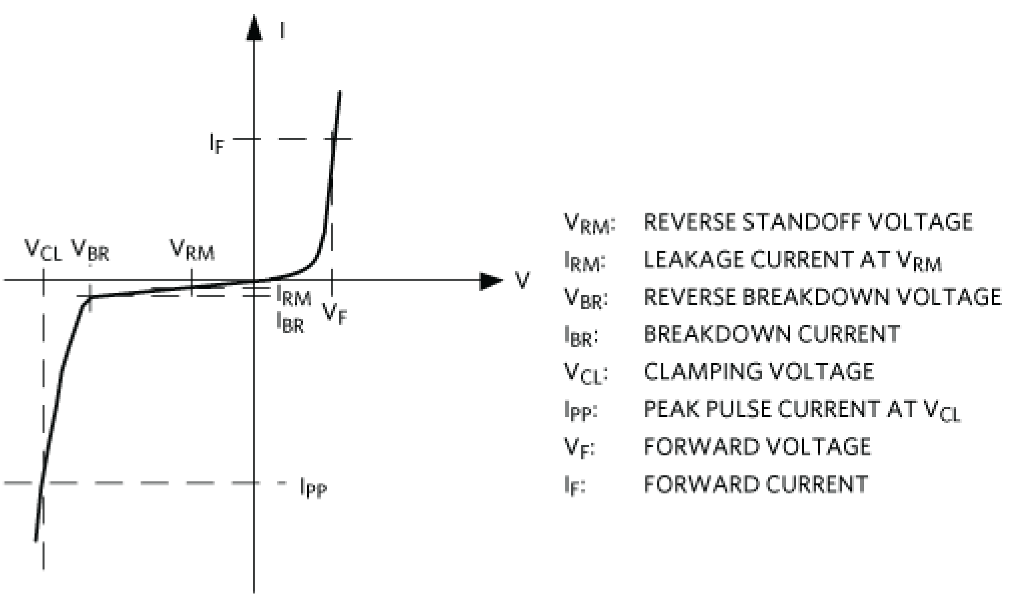

Figure 1. Unidirectional TVS diode IV characteristic curve.

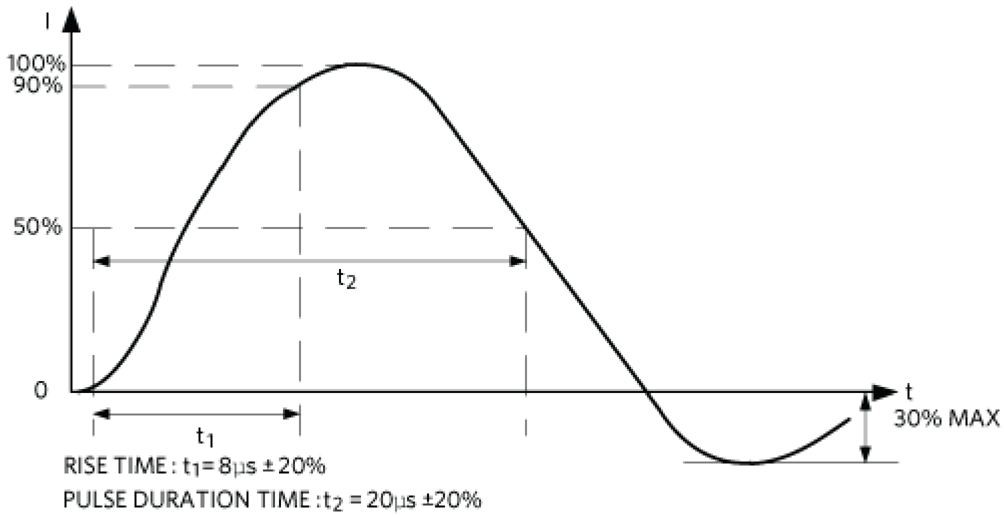

Figure 2. Definition of a surge current waveform, I_{PP}.

Guidelines for Selecting a TVS Diode

TVS diode vendors include generic selection guidelines in their data sheets, but the most important items to consider are the electrical characteristics of the circuit to be protected and the test methodology/standard that the circuit will need to meet. The standard most frequently referenced is IEC 61000-4-5. The test criteria are clearly specified, including voltage levels, current levels, and how the transient is applied to a device or system. For an IO-Link sensor this is typically ±1kV/500Ω, and for an IO-Link master it is ±1kV with a 42Ω + 0.5µF coupling network.

To select a TVS diode, follow these steps:

1. Select a diode with a standoff voltage that is higher than the normal operating voltage. Ensure that the TVS diode maximum clamping voltage is less than the abs max rating of all the devices on the line to be protected. It is important to consider operation during both the transient event (a higher conduction current will result in a higher clamping voltage, for example) and during normal operation when a transient event is not present.
2. Verify that the specified peak current exceeds the expected peak current. Ensure that the diode is specified to handle the required power during a transient event. Diodes that are too small, or are not designed for a given current, may fail and cause the circuit to be destroyed during a surge or EFT event.
3. Calculate the maximum clamping voltage (V_{CL}) of the selected diode. TVS diode data sheets typically list the V_{CL} for a given IPP in the part selection table. For other peak pulse currents, however, this V_{CL} may not be valid. To accommodate other IPP values, the TVS diode manufacturer gives a formula in the data sheet to calculate the V_{CL}. Use this formula to calculate the V_{CL} for a given I_{PP}.
4. Confirm that the calculated V_{CL} is less than the specified abs max rating for the pin.

IO-Link Protection

IO-Link devices (sensor transceiver or master transceiver) have 4 pins (L+, C/Q, L-, and DI/DO) that need to be protected. When testing for surge protection, for example, these pins need to survive surge pulses between any 2 pins, with both negative and positive polarity surges. It is important to understand the impact that the abs max ratings for these pins has on TVS diode selection. The following examples demonstrate that the higher abs max values of Maxim IO-Link transceivers enable the use of significantly smaller TVS products, thus saving board space and cost.

How 65V abs max Helps with Protection (vs. 40V)

Let's consider a test case and see how the abs max ratings can affect the final footprint of the circuit. **Figure 3** shows the current flow and voltages across the protection scheme when a transient surge pulse is applied to the C/Q pin (referenced to L-) on the MAX14827A. Using the standard 42Ω impedance between the surge pulse (±1kV) and the device, the maximum current flow is ±24A.

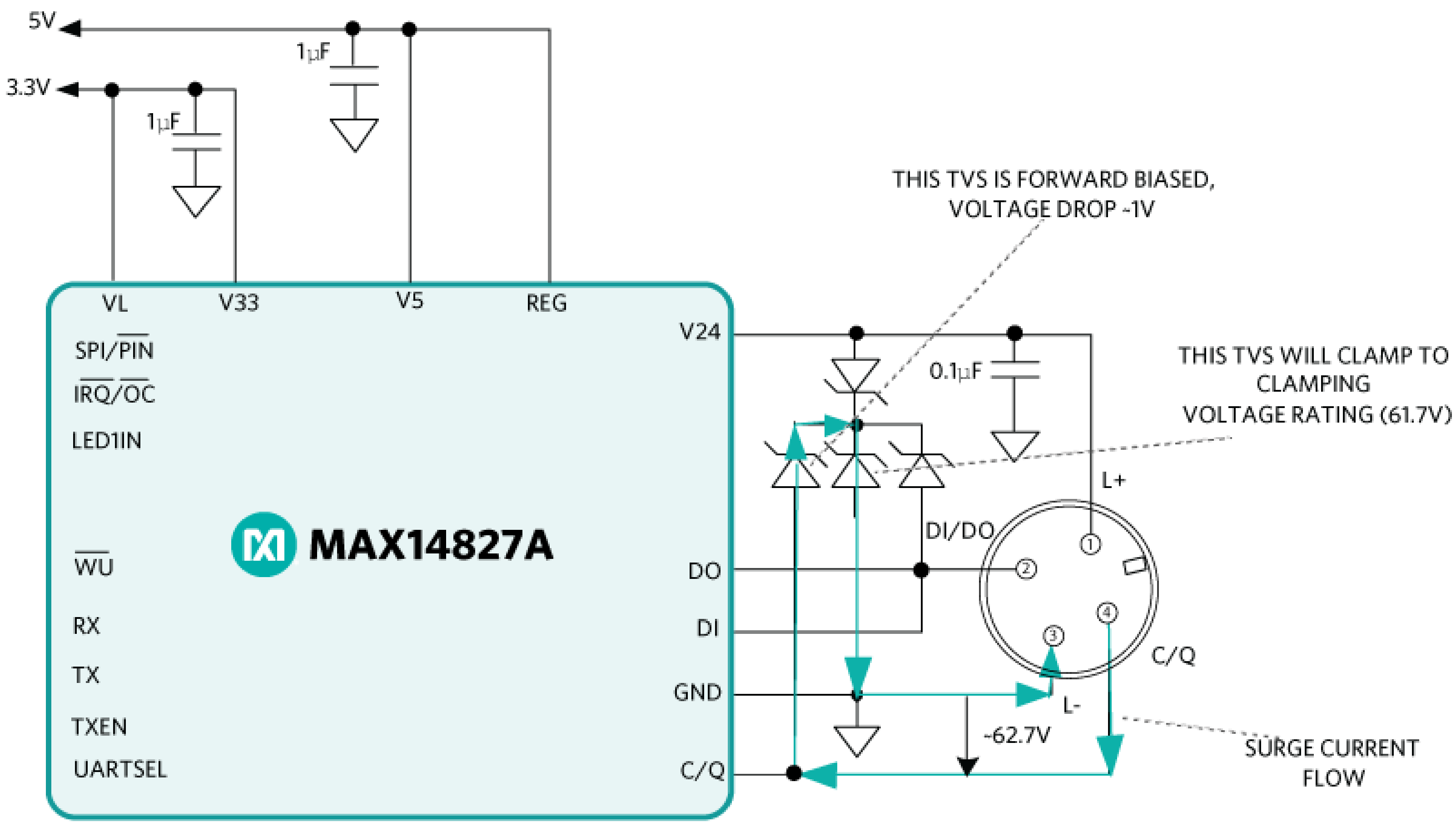

Figure 3. C/Q to L- surge.

SMAJ TVS Diode (2.9mm x 5.25mm)

Following the TVS diode selection steps, we get the following:

1. Standoff voltage must be greater than normal operating voltage, so assuming L+ = 24V and allowing for a 20% tolerance over normal operating conditions, the maximum normal operating voltage is 24V x 1.2 = 28.8V. To ensure a reasonable safeguard, select a TVS diode with V_{RM} = 33V, such as the STMicroelectronics®

SMAJ33A.

2. Peak current for the SMAJ33A is 33A > 24A, so the SMAJ33A can handle the required current (per the TVS diode data sheet for the I_{PP} rating for an 8/20µs impulse waveform).
3. Use the formulas in the TVS diode data sheet to calculate V_{CL}.
    1. See the specifications for the SMAJ33A in **Table 1**.
    2. $V_{CL(MAX)} = V_{CL} - R_D \times (I_{PP} - I_{PPAPPLI})$
       = 69.7V - 0.884Ω x (33A - 24A)
       = 61.7V
    3. Confirm V_{CL} < device abs max.
        1. The MAX14827A has abs max = 65V, so this IC will survive a 1kV surge.
        2. Transceivers with abs max < 65V will not survive.

Table 1. STMicroelectronics SMAJ, SMABJ, SMCJ Electrical Characteristics*

	I_{RM} max @ V_{RM}		V_{BR} min @ I_{BR}		V_{CL} max @ I_{PP} (8/20µs)		R_D (8/20µs)
Part	µA	V	V	mA	max V	A	Ω
SMAJ33A	0.2	33	36.7	1	69.7	33	0.884
SMBJ33A	0.2	33	36.7	1	69.7	57	0.512
SMCJ33A	0.2	33	36.7	1	69.7	143	0.204

*T_A = +25°C

SMBJ TVS Diode (3.95mm x 5.6mm)
Using the data sheet for the SMBJ33A and **Table 1**, we follow the same steps:

1. Standoff voltage (33V) > normal operating voltage (24V).
2. Peak current (57A) > 24A, so the SMBJ33A can handle the required current.
3. $V_{CL(MAX)} = V_{CL} - R_D$ x $(I_{PP} - I_{PPAPPLI})$
   = 69.7V - 0.512Ω x (57A - 24A)
   = 52.8V
4. Confirm that V_{CL} < device abs max.
   Note that devices with abs max < ~55V will not survive when this diode is used for protection.

SMCJ TVS Diode (6.25mm x 8.15mm)
Using the data sheet for the SMCJ33A and **Table 1**, we follow the same steps:

1. Standoff voltage (33V) > normal operating voltage (24V).
2. Peak current (143A) > 24A, so the SMCJ33A can handle the required current.
3. $V_{CLMAX} = V_{CL} - R_D$ x $(I_{PP} - I_{PPAPPLI})$ = 69.7V - 0.204Ω x (143A - 24A) = 45.4V
4. Confirm V_{CL} < device abs max.
   Note that devices with abs max < ~47V will not survive when this diode is used for protection.

Advantages of 65V abs max for Protection
The MAX14827A and MAX14828 have a specification of 65V abs max, allowing for flexible protection of the IO-Link pins for surge conditions. While competitor parts require bigger, more expensive TVSs, these high abs max Maxim ICs only require small, low-cost TVSs/varistors as follows:

- Smallest TVS diode/standard surge (±1kV/2A): Semtech® µClamp®3603T; PCB area = 1.7mm^2
- Lowest cost TVS diode/standard surge (±1kV/2A): AVX VC060330A650DP varistor; cost is ~50% of regular TVS diode
- High-level surge (±1kV/24A): SMAJ33 TVS diode (vs. competitor SMCJ33 TVS diode); 5x smaller PCB area

Examples of Protection when Using Maxim ICs in IO-Link Reference Designs

MAX14828 in MAXREFDES164# Sensor Application
The MAXREFDES164# is a temperature sensor using the MAX14828 as the IO-Link transceiver. This design requires a tiny footprint and uses AVX® TransGuard® varistors for protection, specifically the VC060330A650DP, which has a working voltage of 30V and a clamping voltage of 67V, and it supports a peak current of 30A. Due to the high abs max (65V) rating of the MAX14828, the design can use these tiny varistors that are just 1.6mm long x 0.8mm wide (standard 0603 package), helping to enable a tiny footprint, as demonstrated in **Figure 4**. This board has been tested to pass up to ±1.2kV/500Ω between the different pairs of IO-Link pins.

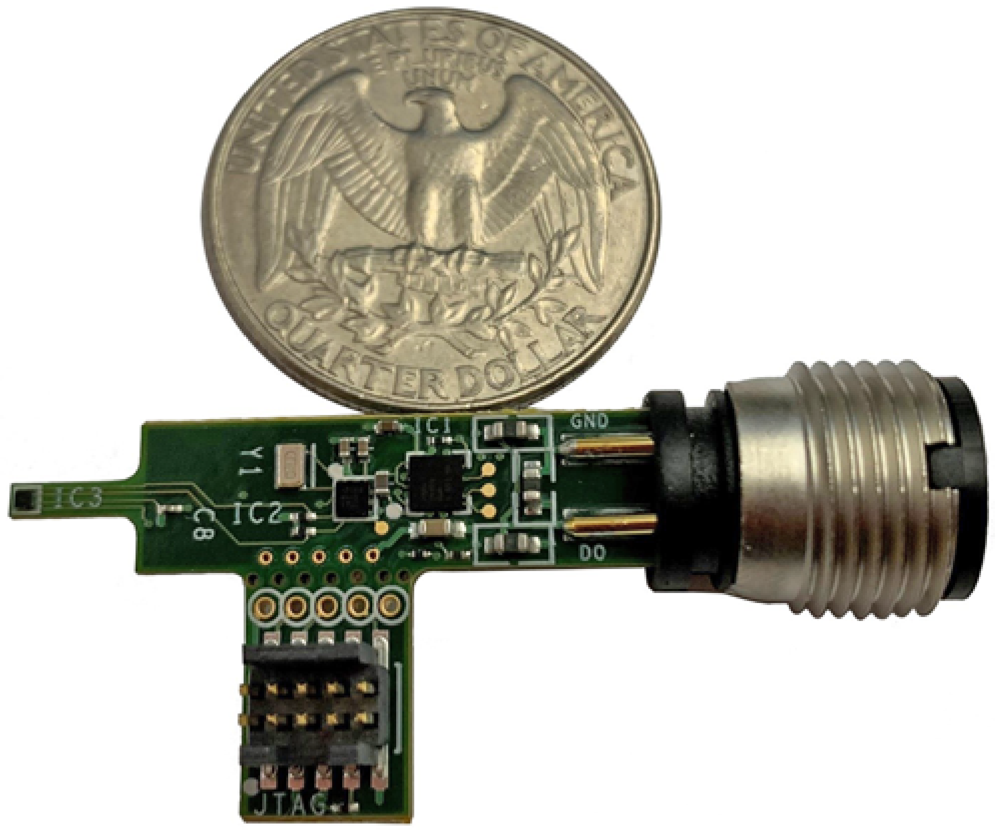

Figure 4. The MAXREFDES164# features the MAX14828.

MAX22513 with Integrated Surge Protection in MAXREFDES171# Sensor Application

The MAX22513 is an IO-Link transceiver with integrated surge protection rated for ±1kV/500Ω, enabling the smallest form-factor solutions for smart sensors. The MAXREFDES171#, seen in **Figure 5**, is a distance sensor based on the MAX22513.

This board has been tested to pass up to ±1.2kV/500Ω between the different pairs of IO-Link pins without an external varistor or TVS. External TVS diodes may be used in systems that require higher levels of protection.

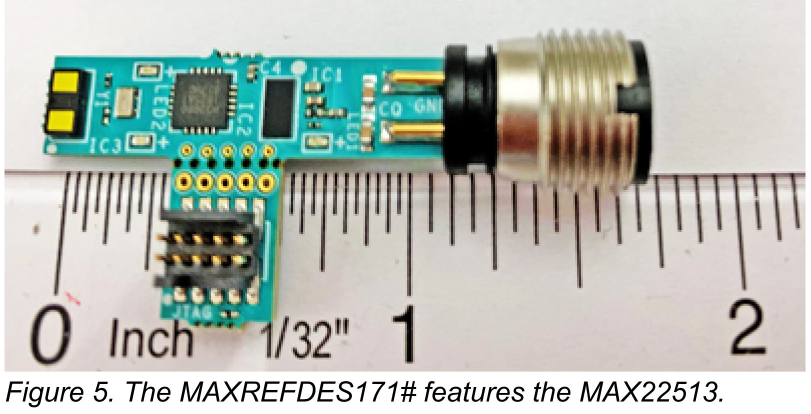

Figure 5. The MAXREFDES171# features the MAX22513.

MAX14819 and MAXREFDES165# IO-Link Master

The MAXREFDES165# is a 4-port IO-Link master based on the MAX14819 IO-Link master transceiver, as seen in **Figure 6**. This design uses the SMM4F33A TVS diode. The maximum clamping voltage for the SMM4FxxA is 56.4V, which is less than the 65V abs max rating of the MAX14819.

This board has been tested to pass up to ±1.2kV/42Ω between the different pairs of IO-Link pins.

Figure 6. The MAXREFDES165# features the MAX14819.

Conclusion

TVS diodes are included on a circuit to protect sensitive devices. During normal operation, the TVS diode must have no significant impact on circuit performance. However, when a high-voltage transient occurs, the TVS diode must activate and limit the voltage across the circuit. Large transient events (such as high voltage and current pulses) typically require large diodes for satisfactory protection. Maxim offers the most robust IO-Link transceivers with high voltage tolerances and abs max ratings of up to 65V to provide greater flexibility when selecting TVS protection diodes. Additionally, devices such as the MAX22513 integrate surge protection and remove the need for external TVS devices in many applications.

References/Other Resources

IEC 61000-4-5 Electromagnetic Compatibility (EMC) – Testing and measurement techniques – Surge immunity test STMicroelectronics data sheets:

- SMAJ, SMBJ, and SMCJ Transil TVS diodes
- SMM4FxxA Transil TVS diode

AVX data sheet:

- TransGuard varistor

Related Parts

MAX14819	Dual IO-Link Master Transceiver with Integrated Framers and L+ Supply Controllers	Free Sample
MAX14827A	Low-Power, Ultra-Small, Dual Driver, IO-Link Device Transceiver	Free Sample
MAX14828	Low-Power, Ultra-Small IO-Link Device Transceiver	Free Sample
MAX22513	Surge Protected Dual Driver IO-Link Device Transceiver with DC-DC	Free Sample

Next Steps

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