

## Circuit Configuration Options for TVS Diodes

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### APPLICATION NOTE

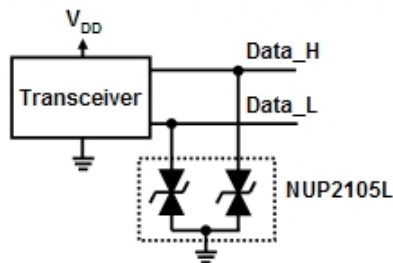
#### INTRODUCTION

Transient Voltage Suppression (TVS) protection is important because EMI and ESD can disturb the operation of the system, produce permanent damage or cause latent damage that will eventually cause a failure. Avalanche TVS diodes and diode arrays are available in a number of different circuit configurations to protect electronic circuits from surge voltages. This document will analyze the attributes and trade-offs of different circuit configurations created with avalanche TVS and diode array protection devices.

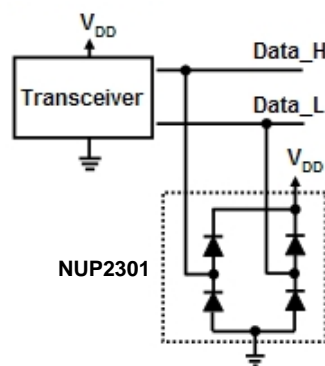
#### TVS Diode Protection Options

Figure 1 shows a schematic representation of avalanche TVS diodes and diode arrays that provide surge protection. Both types of diode devices can be used for surge suppression; however, each option offers unique protection features. Tables 1 and 2 provide a summary of the features of avalanche TVS diode and diode array protection circuits.

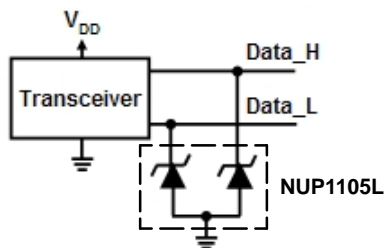
#### Bidirectional Avalanche TVS Diodes



#### Diode Array



#### Unidirectional Avalanche TVS Diodes



#### Diode Array with Avalanche Diode

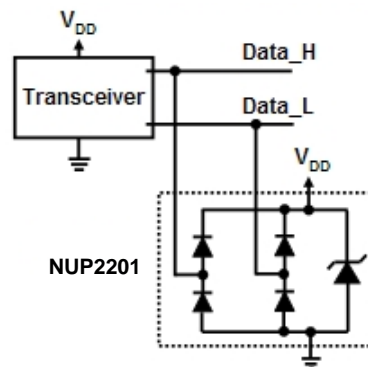


Figure 1. Schematic Representation of TVS Diode Protection Options

**Avalanche TVS Diodes**

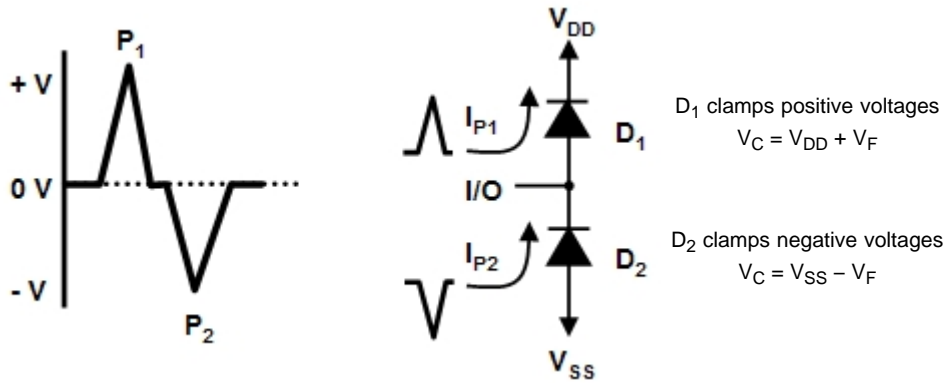
Avalanche diodes are a good TVS device for applications that require power line surge immunity and ESD protection. These devices provide protection by clamping a surge voltage to a safe level. They function as a variable impedance to directly absorb the surge energy and maintain a constant clamping voltage. The avalanche TVS diode's current and voltage characteristics are similar to a Zener diode; however, there are significant differences between these devices. A TVS diode has a junction that is optimized to absorb the high peak energy of a transient event, while a standard Zener diode is designed to clamp a steady state voltage.

**Diode Arrays**

Diode arrays typically have a moderate power rating and low capacitance. These features make this a popular TVS

device for data line ESD protection. In addition, the low clamping voltage of diode arrays is an advantage for protecting low voltage ICs. The effective minimum operating voltage of a diode array is limited only by the forward voltage drop of a diode. Diode arrays can also be used as line terminators to remove overshoot or ringing on high speed data lines. Diode data line termination circuits are often called Thevenin networks.

Diodes arrays steer the surge current into the power supply rails, as shown in Figure 2. A positive surge pulse will be clamped to a voltage that is equal to a forward diode voltage drop above the supply voltage ( $V_{DD}$ ). Typically the  $V_{SS}$  pin is grounded; thus, a negative pulse will be clamped to a voltage level one diode drop below ground. The energy of the positive and negative surge pulses is dissipated through the PCB's power planes.



( $V_{SS}$  is typically connected to Ground)

**Figure 2. Diode arrays clamp the surge voltage to a diode drop above or below the power rails.**

Diode arrays are constructed by combing switching, avalanche and Schottky diodes. Most diode arrays are built with switching diodes in a stacked configuration; however, a number of products are available that include an avalanche diode to increase the surge rating. The switching diodes provide a low capacitance load for data lines, while the avalanche diode offers energy dissipation ability for the power line. An avalanche diode is selected that has a

breakdown voltage slightly higher than the nominal power supply voltage. The relatively large capacitance load of the avalanche diode is on the power lines and has only a minor effect on the frequency response of the data lines. Another popular option for diode arrays is to use low turn-on voltage Schottky diodes to create an effective TVS device for low voltage applications.

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**Table 1. Avalanche TVS Diode Surge Protection Circuits**

	Bidirectional	Unidirectional	Low Capacitance Bidirectional	Low Capacitance Unidirectional
<b>Schematic</b>				
<b>Clamping Voltage (V<sub>c</sub>)</b> Positive Surge Negative Surge	$V_{F\_Z1} + V_{BR\_Z2}$ $-(V_{BR\_Z1} + V_{F\_Z2})$	$V_{BR\_Z1}$ $-V_{F\_Z1}$	$V_{F\_D1} + V_{BR\_Z1}$ $-(V_{F\_D2} + V_{BR\_Z2})$	$V_{F\_D1} + V_{BR\_Z1}$ $-V_{F\_D2}$
<b>Attributes</b>	<ul style="list-style-type: none"> <li>Solves common mode offset issues</li> <li>Direct replacement for varistors</li> </ul>	<ul style="list-style-type: none"> <li>Low negative clamping voltage</li> </ul>	<ul style="list-style-type: none"> <li>D<sub>1</sub> and D<sub>2</sub> lower the capacitance</li> <li>Z<sub>1</sub> and Z<sub>2</sub> increase power rating</li> </ul>	<ul style="list-style-type: none"> <li>D<sub>1</sub> lowers capacitance</li> <li>Z<sub>1</sub> increases power rating</li> <li>Use with short cables</li> </ul>
<b>Trade-Offs</b>	<ul style="list-style-type: none"> <li>High capacitance compared to a diode array</li> </ul>	<ul style="list-style-type: none"> <li>High capacitance compared to a diode array</li> </ul>	<ul style="list-style-type: none"> <li>Requires four diodes</li> </ul>	<ul style="list-style-type: none"> <li>Requires three diodes</li> </ul>
<b>Applications</b>	<ul style="list-style-type: none"> <li>Differential data lines</li> <li>Use with long cables</li> <li>DC power lines</li> <li>High frequency applications</li> </ul>	<ul style="list-style-type: none"> <li>Single-ended data lines</li> <li>Use with short cables</li> <li>DC power lines</li> <li>Digital logic ICs</li> </ul>	<ul style="list-style-type: none"> <li>High-speed differential data lines</li> </ul>	<ul style="list-style-type: none"> <li>High-speed single ended data lines</li> </ul>
<b>ON Products</b>	<ul style="list-style-type: none"> <li>NUP2105L</li> <li>NUP4102</li> </ul>	<ul style="list-style-type: none"> <li>NUP1105L</li> <li>NZQA5V6</li> </ul>	<ul style="list-style-type: none"> <li>SL05</li> <li>SL15</li> </ul>	

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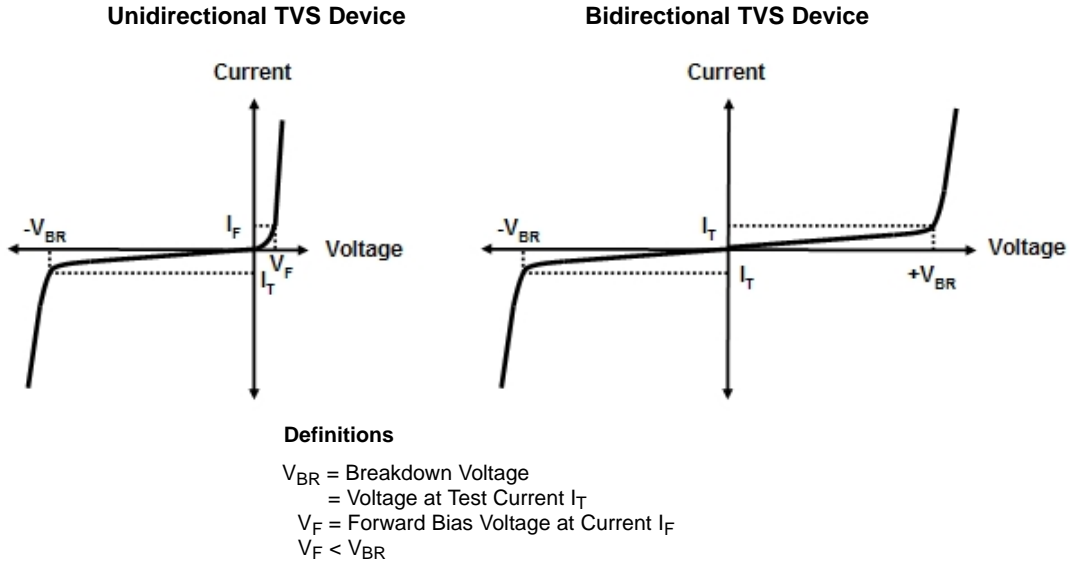
**Table 2. Diode Array Surge Protection Circuits**

	Diode Array		Diode Array Plus TVS		Schottky Diode Array	
<b>Schematic</b>						
<b>Clamping Voltage (V<sub>C</sub>)</b>	I/O <sub>1</sub>	I/O <sub>2</sub>	I/O <sub>1</sub>	I/O <sub>2</sub>	I/O <sub>1</sub>	I/O <sub>2</sub>
	Positive Surge $V_{F\_D1} + V_{DD}$ Negative Surge $-V_{F\_D2}$	$V_{F\_D3} + V_{DD}$ $-V_{F\_D4}$	$V_{F\_D1} + V_{DD} \leq V_C \leq V_{Z1\_BR}$ $-V_{F\_D2}$	$V_{F\_D3} + V_{DD} \leq V_C \leq V_{Z1\_BR}$ $-V_{F\_D4}$	$V_{F\_D1} + V_{DD}$ $-V_{F\_D2}$	$V_{F\_D3} + V_{DD}$ $-V_{F\_D4}$
<b>Attributes</b>	<ul style="list-style-type: none"> <li>• Low capacitance</li> <li>• Good capacitive matching (small <math>\Delta C</math> I/O<sub>1</sub>-to-I/O<sub>2</sub>)</li> <li>• Low clamping voltage</li> </ul>		<ul style="list-style-type: none"> <li>• Low capacitance, with moderate power rating</li> <li>• Z<sub>1</sub> increases power rating</li> <li>• Z<sub>1</sub> has minor effect on I/O line capacitance</li> <li>• Z<sub>1</sub> functions as a decoupling capacitor</li> </ul>		<ul style="list-style-type: none"> <li>• Low clamping voltage</li> <li>• Low V<sub>F</sub> ( <math>\cong 0.3</math> V)</li> <li>• Low V<sub>C</sub> ensures surge event is clamped by external protection circuit</li> </ul>	
<b>Trade-Offs</b>	<ul style="list-style-type: none"> <li>• Poor power rating compared to avalanche TVS diodes</li> <li>• V<sub>F</sub> <math>\cong 0.7</math> V</li> </ul>		<ul style="list-style-type: none"> <li>• Z<sub>1</sub> is large compared to diodes – which increases package size</li> <li>• V<sub>F</sub> <math>\cong 0.7</math> V for D<sub>1</sub> – D<sub>4</sub></li> </ul>		<ul style="list-style-type: none"> <li>• Power rating is poor compared to a switching diode</li> <li>• Relatively poor reverse bias surge rating</li> </ul>	
<b>Applications</b>	<ul style="list-style-type: none"> <li>• Differential data lines</li> <li>• Use with short cables</li> <li>• ESD protection</li> </ul>		<ul style="list-style-type: none"> <li>• Use with single-ended data line</li> <li>• Use with short cables</li> <li>• ESD protection</li> </ul>		<ul style="list-style-type: none"> <li>• Differential data lines</li> <li>• Use with short cables</li> <li>• ESD protection</li> <li>• Low voltage ICs</li> </ul>	
<b>ON Products</b>	<ul style="list-style-type: none"> <li>• NUP1301</li> <li>• NUP4301</li> </ul>		<ul style="list-style-type: none"> <li>• NUP2201</li> <li>• NUP4201</li> </ul>		<ul style="list-style-type: none"> <li>• NUP4302</li> </ul>	

**Uni- Versus Bidirectional Protection**

Avalanche TVS diodes are available in either a uni- or bidirectional configuration. In contrast, diode arrays are typically used only as a unidirectional protection device. Uni- and bidirectional devices both provide protection against positive and negative surges; however, the magnitudes of the breakdown voltages are different, as shown in Figure 3. A unidirectional device has a clamping voltage equal to the

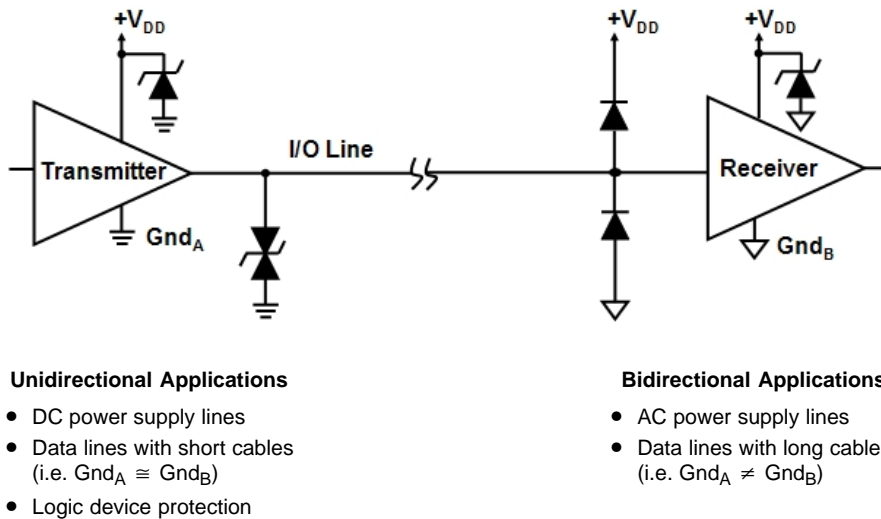
breakdown voltage when reversed biased and a forward diode drop if forward biased. A bidirectional device typically has a symmetrical  $V_{BR}$  for both positive and negative voltages. Diode arrays can be connected to a positive and negative power supply to create a bidirectional device; however, most applications connect the bottom diode to ground which forms a unidirectional device.



**Figure 3. Definition of a Uni- and Bidirectional TVS Circuit**

Although both uni- and bidirectional devices can often be used in the same application, there are many applications where one of the clamping options provides a distinct advantage. In applications such as the protection of a DC power supply or a logic IC, a unidirectional diode device offers a lower clamping voltage (i.e.  $-V_F$ ) for negative surge

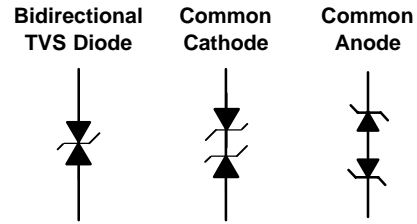
voltages. Bidirectional TVS devices offer several advantages, including solving a common mode offset voltage problem. Often bidirectional TVS diodes are selected simply because they are replacing metal oxide varistors (MOVs) which are inherently bidirectional. Figure 4 provides an overview of typical applications of uni- and bidirectional TVS devices.



**Figure 4. Typical Applications of Uni- and Bidirectional TVS Devices**

**Creating a Bidirectional Diode**

TVS diodes are inherently unidirectional. A bidirectional device can be created by combining two unidirectional diodes, as shown in Figure 5. The electrical characteristics of a common cathode and common anode device are typically equivalent. The clamping voltage ( $V_C$ ) of the composite bidirectional device is equal to the breakdown voltage ( $V_{BR}$ ) of the diode that is reversed biased, plus the diode drop of the second diode that is forward biased.



**Figure 5. A bidirectional TVS diode is created by combining two unidirectional diodes to form a common cathode or common anode device.**

**General TVS Diode Selection Guidelines**

The following guidelines can be used to select a TVS diode.

1. Select a device with a breakdown voltage greater than the maximum specified voltage to ensure that the TVS device does not turn-on during normal operation.
2. A bidirectional TVS device maybe required for a circuit that has a common mode voltage requirement. The common mode specification is required when there is a significant difference in the voltage potential between the ground reference of the transmitting and receiving nodes.
3. Choose a TVS device that is capable of dissipating the energy of the surge pulse.
4. The power rating of most TVS devices decreases with temperature and a derating of the TVS’s energy specification maybe necessary.
5. The capacitance of the TVS devices should be minimized for high speed circuits in order to reduce signal distortion. In addition, the capacitance of two differential signals must be matched in order to maintain pulse width integrity in the amplifier’s output signal.
6. Some systems bundle power and data lines in the same cable and require the unit to survive a short between the power and data lines. This requirement means that the breakdown voltage of the data line protection device must be higher than the maximum value of the supply voltage.

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3. Lepkowski, J., “AND8232 – PCB Design Guidelines that Maximize the Performance of TVS Diodes”, ON Semiconductor, 2005.
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