Diode

Selection Method and Usage of TVS Diodes

Transient voltage suppressor (TVS) diodes are a voltage clamp type of surge protection elements. They are designed to absorb a large amount of energy in a short time with a low operation resistance and high current rating characteristics. To support a wide range of applications, products of various types are listed in ROHM's lineup. This application note explains points for selecting the TVS diodes and introduces application examples.

Points for selecting TVS diodes

A list of selection points is shown below. Points 1 to 3 explain how to select the TVS diodes in a way that prevents various characteristics from being deteriorated when the TVS diodes are added to the existing wiring in order to protect devices. Points 4 to 6 describe how to confirm that the TVS diodes themselves will not be damaged by overvoltage pulses, such as electrostatic breakdown and surges. Point 7 describes how to select a product with a higher protective performance. The details of these methods are explained in the following pages.

- Confirm that the TVS diodes will not affect the wiring to be protected.

1. Selection with consideration of the voltage on the wiring
2. Selection with consideration of the signal frequency on the wiring
3. Selection based on the signal polarities

- Confirm the breakdown ratings of the TVS diodes.

4. Selection of the TVS diodes that can withstand ESD as required
5. Selection of the TVS diodes that can withstand overcurrent as required
6. Selection of the TVS diodes that can withstand overpower as required

- Confirm the protective performance of the TVS diodes.

7. Selection of products with a low clamping voltage

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The TVS diodes are added to the existing wiring in order to protect devices. The wiring includes power lines to supply the power, signal lines to transmit analog and digital signals, communication lines to link devices using controllers, and control lines to transmit commands for turning devices ON and OFF and setting conditions. This application note explains how to select the TVS diodes in a way that prevents various characteristics of the existing wiring from being deteriorated due to additions of the TVS diodes.

1. Selection with consideration of the voltage on the wiring

Figure 1 shows schematic diagrams of the TVS diode operations. The left diagram shows the operation under normal conditions. In this example, the connector is located on the left end and the IC, which is a device to be protected, is located on the right end. They are connected via the wiring and a TVS diode is placed between them. The wiring carries the designed DC voltage and analog or digital signals depending on the applications. The TVS diode is not operated normally because no breakdown has occurred in the TVS diode.

The right diagram shows the operation when a surge is applied. If the surge voltage exceeds the breakdown voltage of the TVS diode, the surge current flows through the TVS diode and a large part of the current flows to the ground. Then, the TVS diode clamps the voltage and protects the target device.

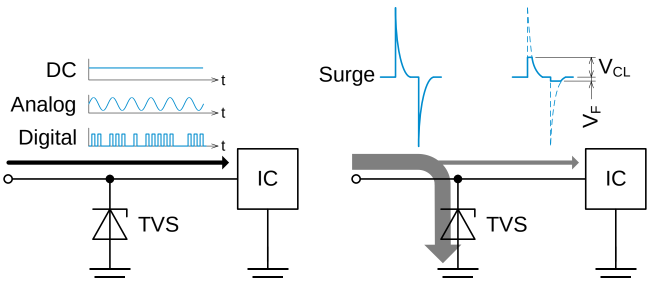


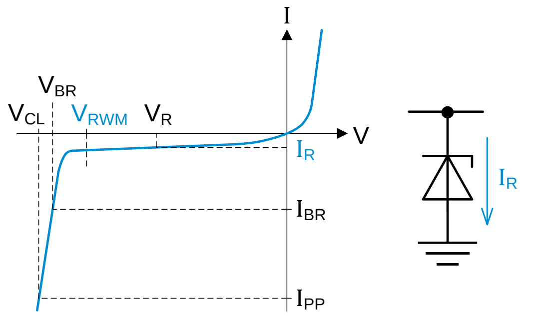
Figure 1. Schematic diagrams of TVS diode operations
Operations under normal conditions and when an overvoltage surge is applied

To prevent breakdown of the TVS diode under normal conditions, it is necessary to select a product according to the voltage and signals transmitted on the wiring.

Figure 2 shows the I-V characteristics of the TVS diode. Standoff voltage V_{RWM} is important among these characteristics. This parameter is the maximum voltage immediately before the TVS diode enters the breakdown state. The TVS diode does not operate below this voltage. Therefore, select a TVS diode with V_{RWM} higher than the voltage processed with the wiring.

It should be noted that reverse current I_R always flows to the ground because of reverse voltage V_R. This current is regarded as a leakage current in terms of the application circuit and may cause malfunction in some circuits. Select a product with an I_R value that the circuit can tolerate. Be sure to check the operation with the actual equipment.

In addition, since I_R is increased as the signal waveform approaches V_{RWM}, the distortion rate could be exacerbated for analog signals. Be sure to check the operation with the actual equipment.



I_R: Reverse current (leakage current)
V_{RWM}: Standoff voltage
V_{BR}: Breakdown voltage
V_{CL}: Clamping voltage

Figure 2. I-V characteristics of TVS diode
Characters in blue indicate important characteristics.

2. Selection with consideration of the signal frequency on the wiring

Since the TVS diode is connected to the wiring even under normal conditions, capacitance between terminals C_t is always added in addition to reverse current I_R described in the previous section (Figure 3).

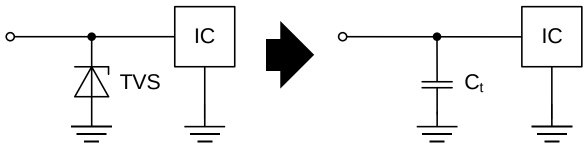


Figure 3. Capacitance between terminals C_t of the TVS diode is added to the wiring under normal conditions

The wiring is not affected by the capacitance if it is a power line with a DC voltage only. However, signal, communication, and control lines may be affected depending on the frequency and communication speed. Therefore, it is necessary to select a capacitance value suitable for the application. If the capacitance value is too large on the signal lines, the distortion rate is exacerbated and waveforms are delayed for analog signals. Digital signals are delayed and their waveforms are blunted. For the communication lines, the eye patterns (bit error rate) could be degraded. For the control lines, malfunction could occur due to delayed or blunted waveforms.

Figure 4 shows typical applications and the standards for capacitance between terminals C_t. The capacitance values in this figure are standard values. Be sure to check the operation with the actual equipment.

Applications	Standards for capacitance between terminals C_t
USB3.2 Gen 2x2 (20Gbps) Thunderbolt 2 (20Gbps) Thunderbolt 3 (40Gbps) HDMI 2.0 (14Gbps) HDMI 2.0a/b (18GHz) HDMI 2.1 (48Gbps) Wi-Fi antenna (2.4 GHz) Wi-Fi antenna (5 GHz) Bluetooth antenna (2.4 GHz)	≤ 0.15 pF
USB3.2 Gen 2[NOTE2] (10Gbps) HDMI 1.3 (10.2Gbps) HDMI 1.4 (10.2Gbps) NFC antenna (13.56 MHz)	≤ 0.35 pF
USB 3.2 Gen 1[NOTE1] (5Gbps) HDMI 1.2 (4.95Gbps) DisplayPort 1.0 (2.7Gbps) LVDS (1Gbps) MIPI D-PHY v1.1 (1.5Gbps) MIPI D-PHY v1.2 (2.5Gbps) MIPI D-PHY v2.0 (4.5Gbps) MIPI D-PHY v2.1 (4.5Gbps) MIPI D-PHY v2.5 (4.5Gbps) GPS antenna (1.5 GHz)	≤ 0.5 pF
USB 2.0 (480Mbps) Ethernet 1000BASE (1Gbps)	≤ 1.5 pF
MOST150 (150Mbps) Ethernet 100BASE (100Mbps)	≤ 5 pF
I^2C (3.4Mbps)	≤ 8 pF
USB 1.1 (12Mbps) CAN FD (5Mbps) FlexRay (10Mbps) MOST50 (50Mbps) LIN (20kbps) CXPI (20kbps)	≤ 12 pF
CAN (1Mbps) RS-232C (20kbps) RS-423 (100kbps) RS-422 (10Mbps) RS-485 (10Mbps) Audio microphone (100 kHz) Push button switch	≤ 30 pF
Audio headphones (100 kHz) Audio speaker (100 kHz)	≤ 50 pF
Power line Toggle switch	All

NOTE1: Earlier USB 3.0 and USB 3.1 Gen 1

NOTE2: Earlier USB 3.1 Gen 2

Figure 4. Applications and standards for capacitance between terminals C_t
The capacitance values in this figure are standard values. Be sure to check the operation with the actual equipment.

3. Selection based on the signal polarities

TVS diodes are available as unidirectional and bidirectional products, as shown in Figure 5.

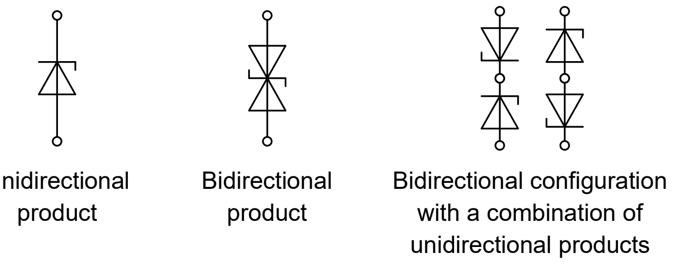


Figure 5. Unidirectional and bidirectional TVS diodes

Figure 6 shows their I-V characteristics. For the unidirectional product, the reverse bias causes no current to flow until it approaches breakdown voltage V_{BR}. However, the forward bias causes the current to start flowing at 0.5 V or less. For the bidirectional products, neither the reverse or forward bias causes the current to flow until it approaches V_{BR}. To prevent any current from flowing through the TVS diode under normal conditions, select a product suitable for the application based on these two characteristics.

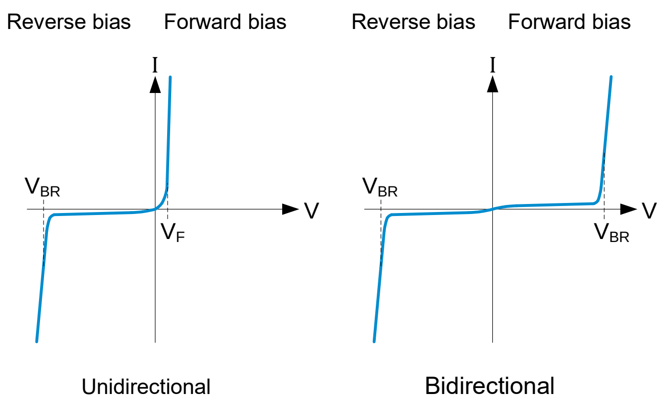


Figure 6. I-V characteristics of TVS diode

Figure 7 shows the waveforms if a unidirectional product is connected to the wiring transmitting digital signals designed with reference to the ground and analog signals designed to provide signals centering around the bias voltage. Since the waveform of each signal has positive polarity with reference to the ground (the reverse bias with reference to the diode anode), no current flows through the TVS diode. Therefore, the unidirectional products can be used. For the same reason, the bidirectional products can be used for the signal wiring with positive polarity (Figure 8).

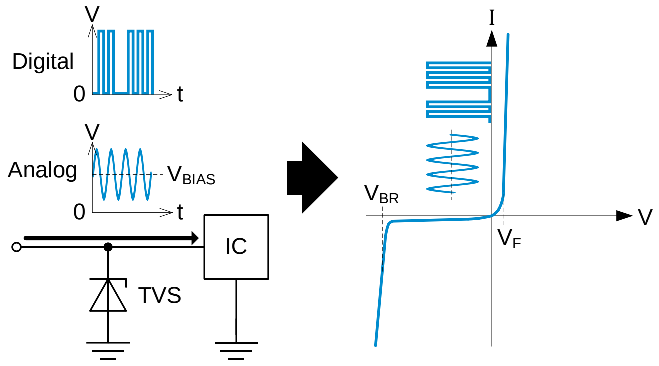


Figure 7. Unidirectional products can be used for the signal wiring with positive polarity

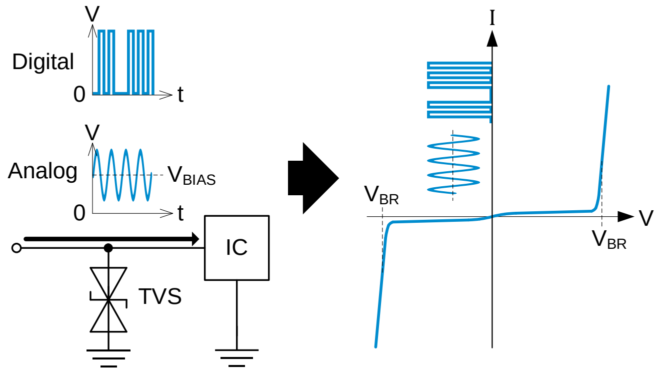


Figure 8. Bidirectional products can also be used for the signal wiring with positive polarity

Next, we explain the situations with wirings for differential digital and analog signals and analog signals with DC cutoff. As shown in Figure 9, since the amplitudes of these signals are centered around the ground, the bidirectional products are used. The bidirectional products can be used because no current flows until the voltage approaches V_{BR}, regardless of whether the signal swings to positive or negative polarity.

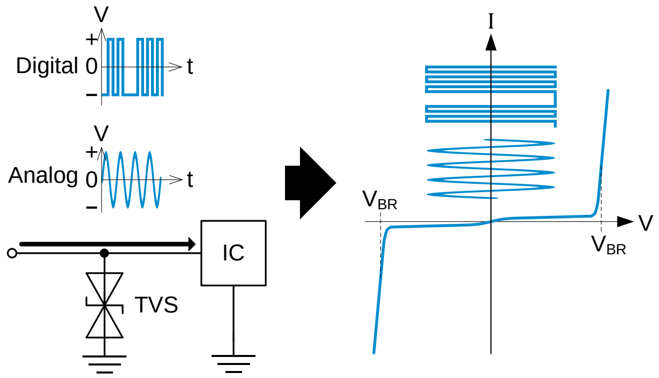


Figure 9. Bidirectional products are used for the signal wiring with both positive and negative polarities

Consider what happens if a unidirectional product is used for bipolar signal wiring. Figure 10 shows the waveforms obtained as a result. Since the amplitude of the waveforms on the negative polarity is clamped by forward voltage V_F of the diode, the information of the transmitted signals is lost. Therefore, the unidirectional products cannot be used for bipolar signal wiring.

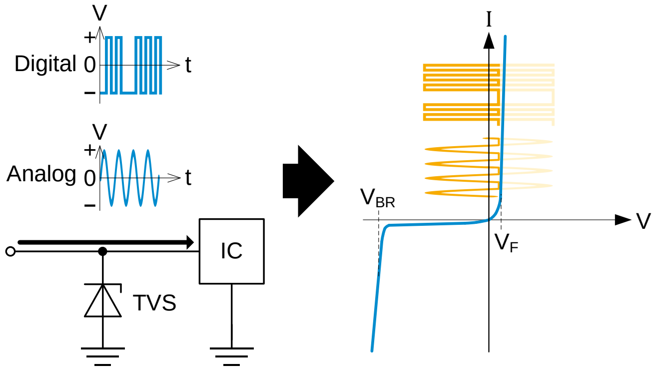


Figure 10. Unidirectional products cannot be used for bipolar signal wiring with positive and negative polarities

Here, we will outline the protective operation against electrostatic discharge (ESD). As shown in Figure 11 for the unidirectional products, when ESD enters, a surge with positive polarity causes the reverse bias. The voltage is clamped when a breakdown occurs and the current flows. A surge with negative polarity causes the forward bias. The voltage is clamped when it exceeds V_F and the current flows. The subsequent stage is protected in this way.

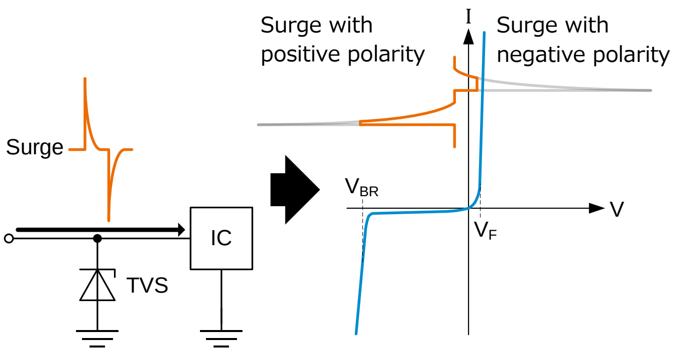


Figure 11. ESD protective operation with unidirectional product

As shown in Figure 12 for the bidirectional products, surges with positive and negative polarities cause the reverse bias. The voltage is clamped when a breakdown occurs and the current flows.

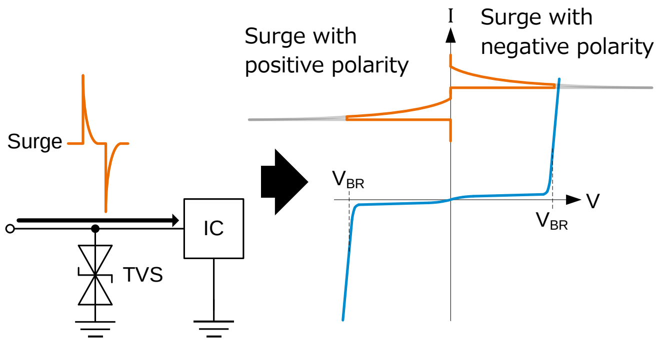


Figure 12. ESD protective operation with bidirectional product

As described above, the unidirectional and bidirectional products perform the ESD protective operation for both positive and negative polarities.

In the following sections, we explain the points for selecting the TVS diodes that can withstand surge pulses as required for the applications. When the energy of the entering surge pulse exceeds the protective performance of the TVS diode, the TVS diode cannot absorb the energy completely, possibly causing damage to the TVS diode itself and the device to be protected.

4. Selection of the TVS diodes that can withstand ESD as required

To protect the target device, the TVS diode itself must not be damaged. Select a product with a rating value larger than the ESD rating required for the application.

Tests were performed in accordance with IEC 61000-4-2 and the two values of the ESD ratings (V_{ESD}) for the direct contact and air discharges are listed as the rating values on the data sheets. The values at ±30 kV were obtained as the maximum values with the testing equipment (electrostatic discharge generator, as of August 2023).

In the earliest years of development of the TVS diodes, the ESD rating tended to decrease as the capacitance between terminals was decreased, causing a trade-off. In recent years, however, products having a small capacitance between terminals and a high ESD rating simultaneously have been developed. Therefore, this relationship is resolved to some degree. Figure 13 shows the relationship between these two values among the ROHM products. When selecting products on a higher level than the test level required by IEC 61000-4-2, approximately 40 pF or larger capacitance between terminals can be considered as a high rating.

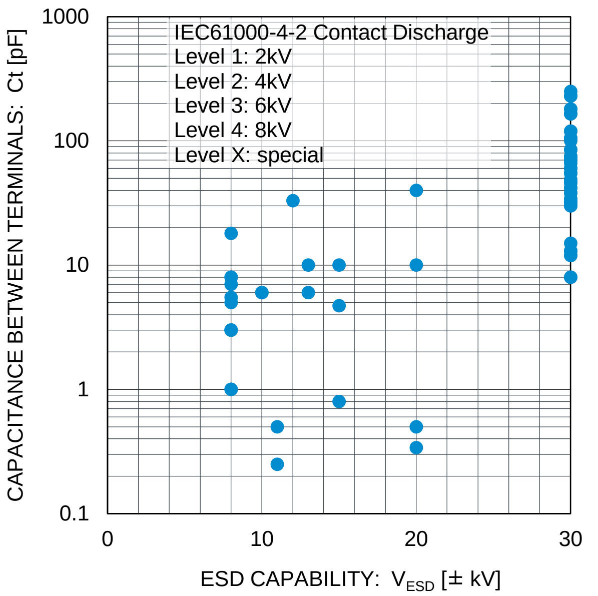


Figure 13. Relationship between capacitance between terminals and ESD rating among ROHM products
IEC 61000-4-2 direct contact discharge test
±30 kV is the maximum value of the testing equipment (electrostatic discharge generator)

5. Selection of the TVS diodes that can withstand overcurrent as required

Select a product with a rating value larger than the peak pulse current required for the application.

The rating values are listed as peak pulse current I_{PP} on the data sheets. The test waveform used is a 10/1000 μs impulse waveform as specified in Telcordia GR-1089-CORE, which is the industry standard test condition, or a 8/20 μs impulse waveform as specified in IEC 61000-4-5.

6. Selection of the TVS diodes that can withstand overpower as required

Select a product with a rating value larger than the peak pulse power required for the application.

The rating values are listed as peak pulse power P_{PP} on the data sheets. The test waveform is the same as the one used for peak pulse current I_{PP} above.

7. Selection of products with a low clamping voltage (V_{CL})

Select a product with V_{CL} as low as possible for V_{RWM} selected in point 1.

The TVS diodes have achieved a faster response compared with other protective elements. However, there is a region where they cannot sufficiently respond immediately after ESD is applied. Therefore, a voltage higher than V_{CL} may be applied to the subsequent stage, causing damage to the device to be protected.

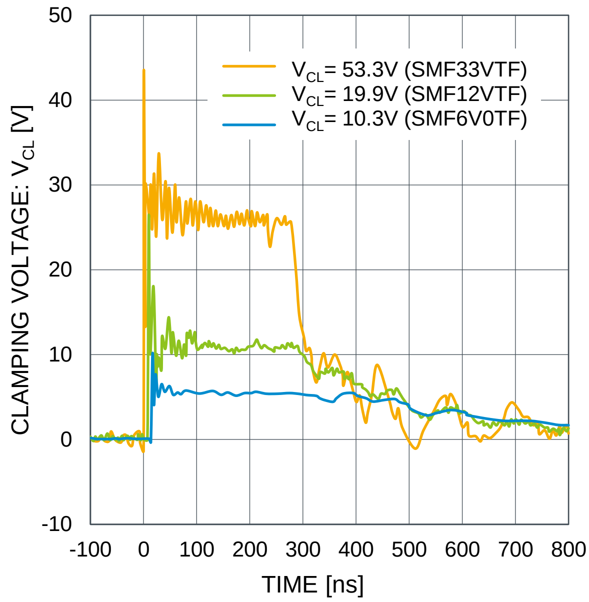


Figure 14. Comparison of peak voltages immediately after ESD application among products with different clamping voltages
IEC 61000-4-2 +8 kV direct contact discharge test

Figure 14 shows a comparison of peak voltages immediately after ESD is applied among products with different V_{CL}. It can be seen that the peak voltage is lower as V_{CL} is lower. In addition, since damage to the subsequent stage can be reduced further if the total area of the clamping waveform is smaller, products with a lower V_{CL} are considered to show a higher protective performance.

Summary

The points for selecting the TVS diodes are summarized as follows.

Item	Characteristics to be noted	Point for selection
1. Selection with consideration of the voltage on the wiring	Standoff voltage V_{RWM}	Select a product with V_{RWM} higher than the voltage processed with the wiring.
	Reverse current (leakage current) I_R	Select a product with an I_R value that the circuit can tolerate. Be sure to check the operation with the actual equipment.
2. Selection with consideration of the signal frequency on the wiring	Capacitance between terminals C_t	Select a product with a C_t value that can be tolerated in the application. Be sure to check the operation with the actual equipment.
3. Selection based on the signal polarities	Configuration of TVS diode	- The unidirectional and bidirectional products can be used for the signal wiring if the signal swings only to positive polarity with reference to the ground. - Use the bidirectional products for the signal wiring if the signal swings to positive and negative polarities centering around the ground.
4. Selection of the TVS diodes that can withstand ESD as required	ESD rating V_{ESD}	Select a product with a rating value larger than the ESD rating required for the application.
5. Selection of the TVS diodes that can withstand overcurrent as required	Peak pulse current I_{PP}	Select a product with a rating value larger than I_{PP} required for the application.
6. Selection of the TVS diodes that can withstand overpower as required	Peak pulse power P_{PP}	Select a product with a rating value larger than P_{PP} required for the application.
7. Selection of products with a low clamping voltage	Clamping voltage V_{CL}	Select a product with V_{CL} as low as possible for V_{RWM} selected in point 1.

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Application examples

1. Protection of switching systems

Since switches and buttons are touched by the human body when they are operated, ESD may cause damage to the IC or malfunction. They require protection with the TVS diodes.

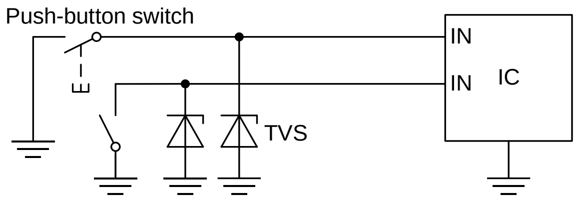

Figure 15. Protection against ESD entering via switches and buttons touched by human body

2. Protection of DC plug/jack system

Hot-plugging (hot swapping) could be used to connect a DC output plug of an AC adapter to electronic equipment. However, the inductance component of long wiring causes a high-voltage surge when the connection is established. Use the TVS diodes to provide protection so that the devices inside the equipment are not damaged by the surge voltage. In addition, they also provide protection against ESD entry caused by the plug and jack being touched by the human body.

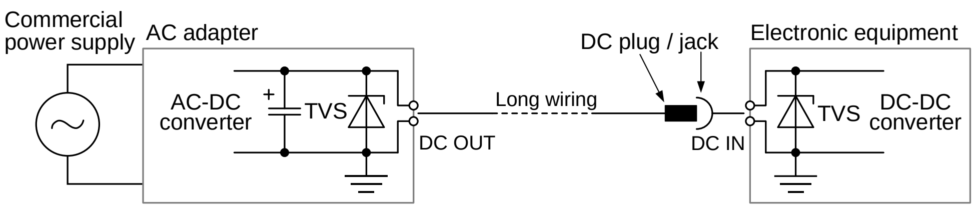

Figure 16. Protection when DC plug of AC adapter is connected to electronic equipment using hot plugging

3. Protection of audio system

When wired headphones or headset are plugged into a jack of a mobile device, ESD may occur and damage the inside of the device if the human body is electrically charged. In addition, the wiring must be protected because the speaker and microphone inside the device are usually placed on the peripheral part of the device, making them susceptible to ESD.

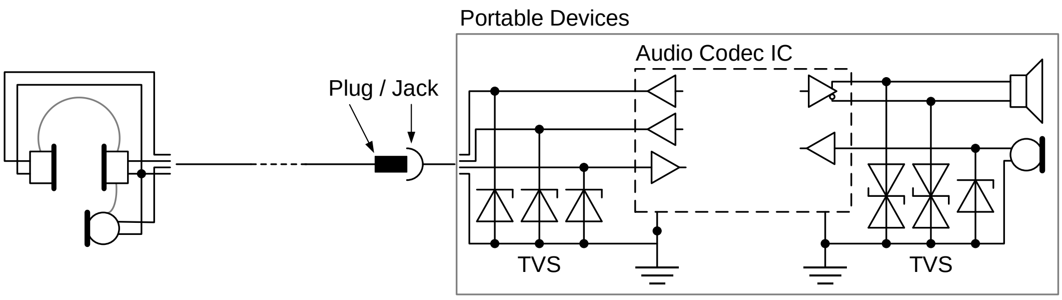

Figure 17. Protection of audio system including speaker and microphone

4. Protection of USB 2.0 interface

USB connectors must be protected from ESD because they are frequently touched by the human body when USB cables and USB devices are plugged in or unplugged.

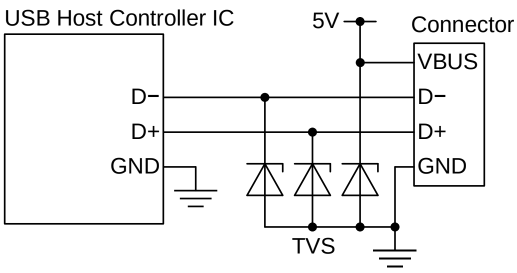

Figure 18. Protection of USB 2.0 interface

5. Protection of USB 3.2 interface

To accommodate fast data transfer rates at 5 Gbps for USB 3.2 Gen 1 (earlier USB 3.0 and USB 3.1 Gen 1) and 10 Gbps for USB 3.2 Gen 2 (earlier USB 3.1 Gen 2), use the TVS diodes with a small capacitance between terminals for the communication lines.

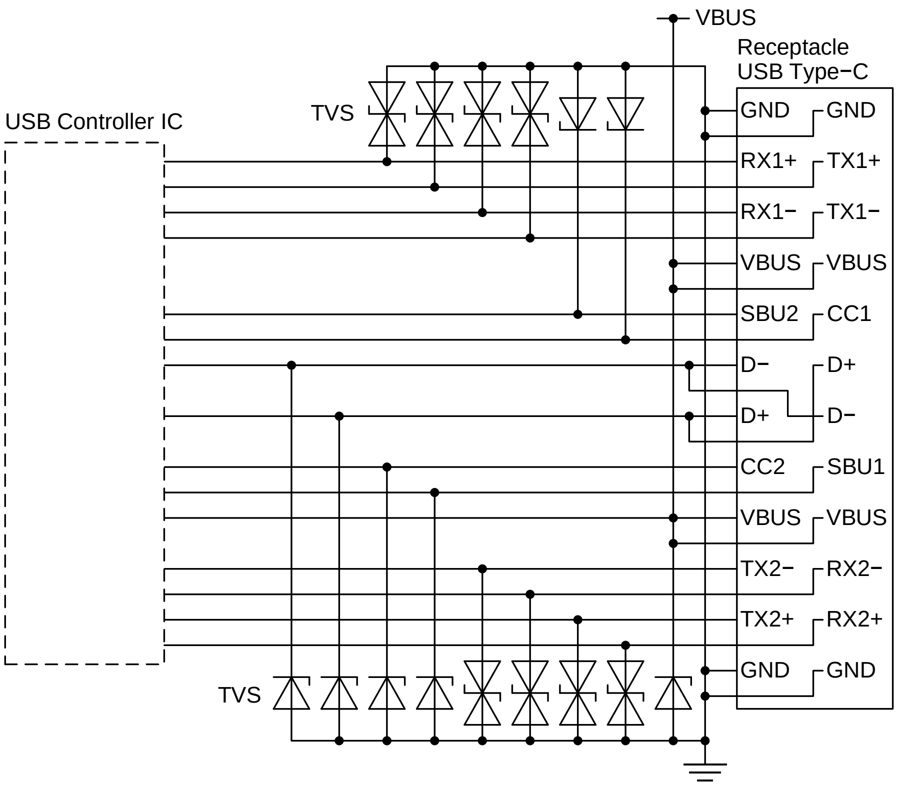

Figure 19. Protection of USB 3.2 interface

6. Protection of HDMI interface

To accommodate a fast transmission rate at 10.2 Gbps for HDMI 1.4, use the TVS diodes with a small capacitance between terminals for the TMDS signal lines.

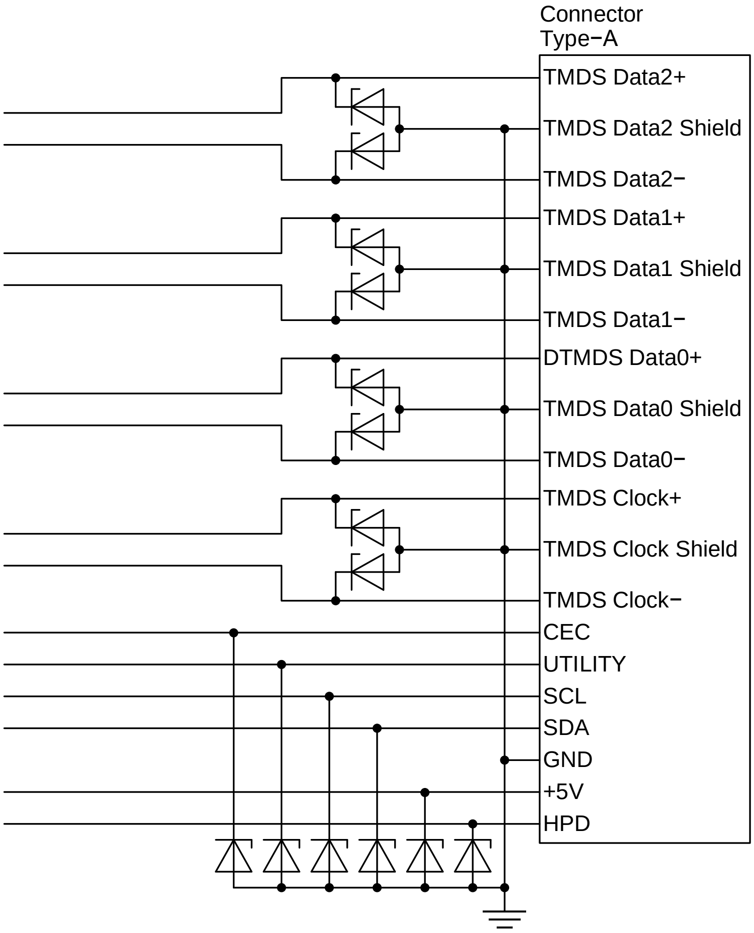

Figure 20. Protection of HDMI interface

7. Protection of LIN/CXPI interface

To accommodate a slow communication speed for LIN/CXPI of 20 kbps at maximum, a TVS diode with a large capacitance between terminals may be considered acceptable. However, since the maximum capacitance is limited to 250 pF as the responder node, care must be taken so that the total capacitance including C1 does not exceed this value.

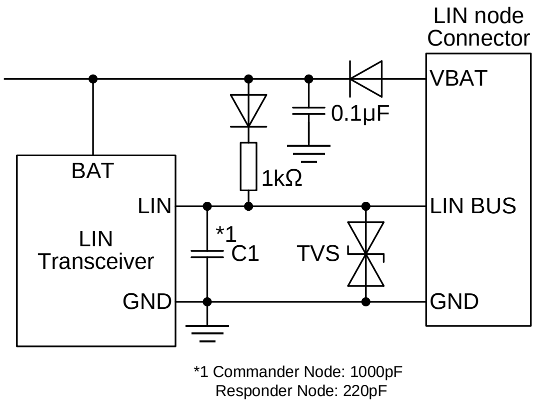

Figure 21. Protection of LIN/CXPI interface

The figure shows an example for LIN. The same applies to CXPI.

8. Protection of CAN/CAN FD interface

The maximum communication speed is 1 Mbps for CAN and 5 Mbps for CAN-FD. Therefore, provide protection by selecting the TVS diodes with a capacitance between terminals that will not affect the signal quality.

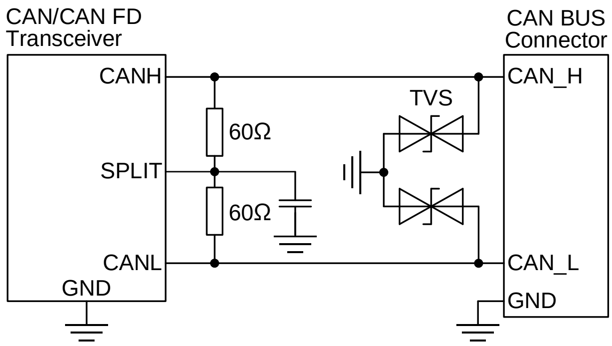

Figure 22. Protection of CAN/CAN FD interface

9. Protection of automotive Ethernet (LAN) interface

Since the automotive Ethernet performs high-speed communications at 100 Mbps to 1 Gbps, use the TVS diodes with a small capacitance between terminals. If the ESD protection with the TVS diodes is insufficient, place an ESD suppressor or varistor that complies with OPEN Alliance standards directly below the automotive connector.

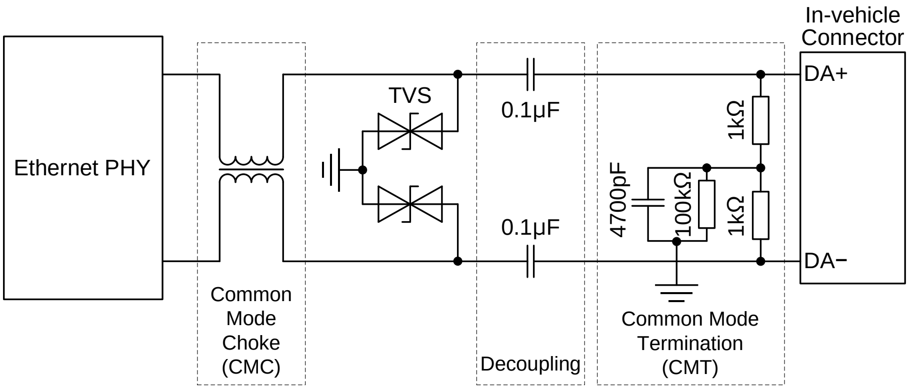

Figure 23. Protection of automotive Ethernet interface

10. Protection of RS-232C/RS-423 interface

If the I/O of a transceiver IC is not equipped with an ESD protection function, it is necessary to provide protection against ESD by placing the TVS diodes directly below the connector.

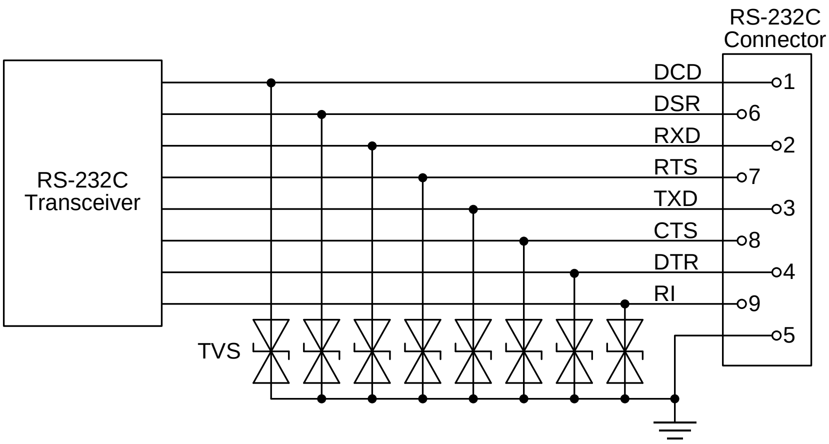

Figure 24. Protection of RS-232C/RS-423 interface

11. Protection of NFC antenna

An NFC antenna is built in directly under the cover of equipment. This environment is vulnerable to the ESD entry. Therefore, the ESD protection must be provided.

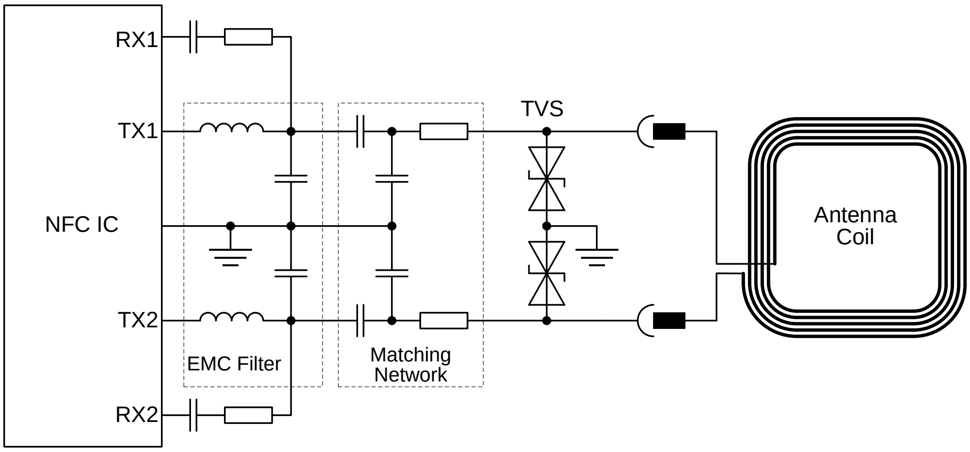

Figure 25. Protection of NFC antenna

12. Protection of wireless power supply antenna

A wireless power supply antenna is built in directly under the cover of equipment. This environment is vulnerable to the ESD entry. Therefore, the ESD protection must be provided.

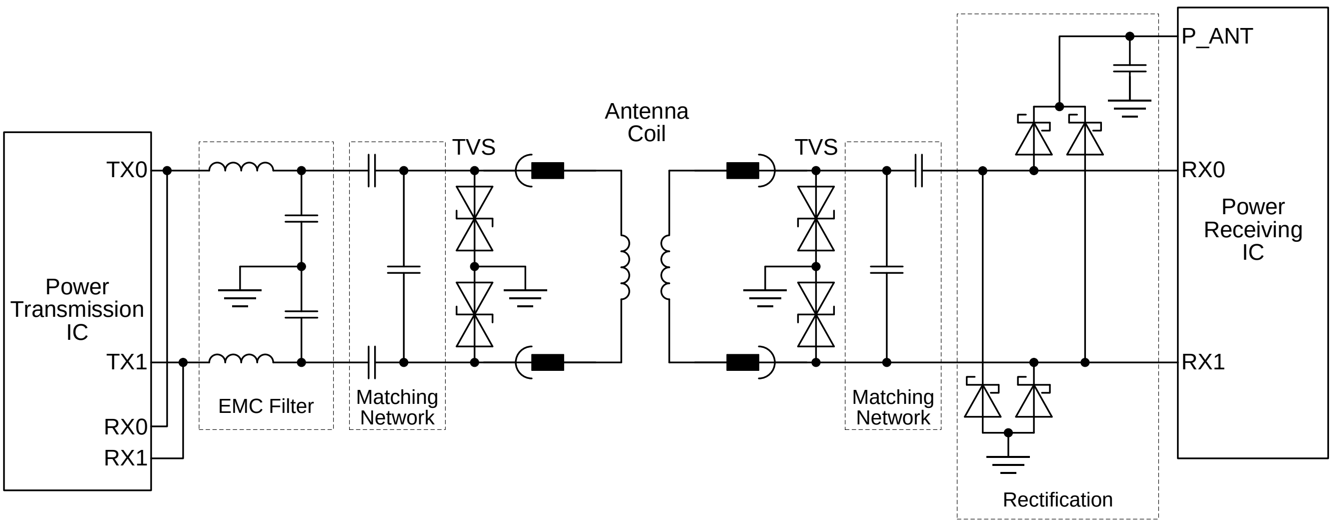

Figure 26. Protection of wireless power supply antenna

13. Snubber circuit for AC-DC converter

This circuit is a pseudo-resonant converter. In this example, an RCD snubber circuit is incorporated to suppress a surge that occurs in the primary side of the transformer at the moment the MOSFET is turned from ON to OFF. A snubber circuit is usually configured with a resistor, capacitor, and fast recovery diode (FRD). However, a TVS diode can be connected in parallel with R and C if a higher protective performance is required. The transient spike noise can be clamped by adding the TVS diode. Check the switching waveform of the MOSFET to determine whether or not to use the TVS diode. If the voltage applied to this part is higher than clamping voltage V_{CL} of one TVS diode, connect several TVS diodes with the same item number in series so that the sum of V_{CL} becomes higher than the voltage applied to this part in order to clamp the transient voltage.

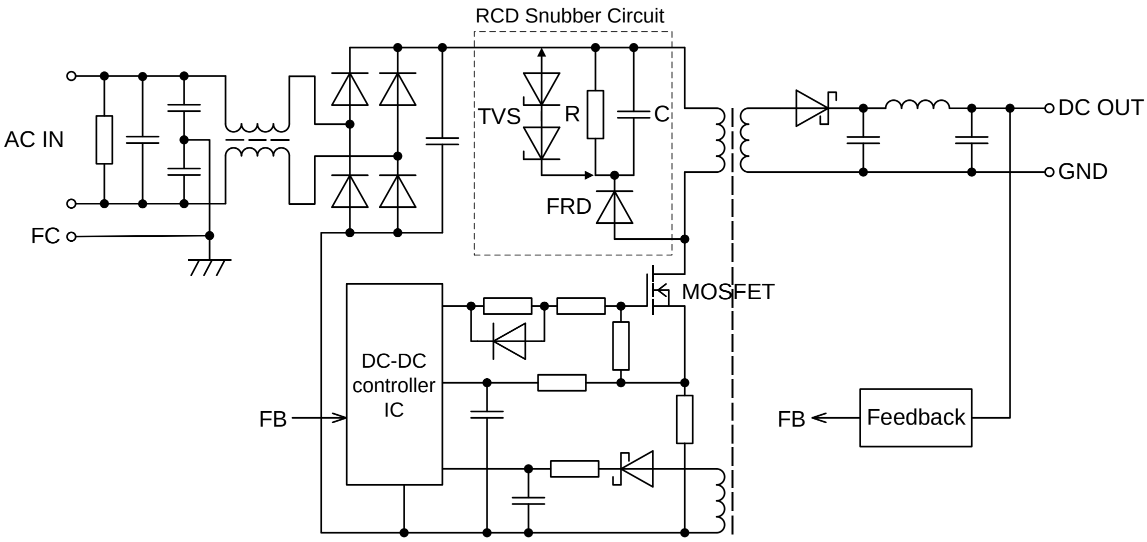

Figure 27. Clamping transient spike noise by adding TVS diodes to snubber circuit for AC-DC converter

14. Overvoltage protection on the secondary side of a power supply circuit

An overshoot of the output voltage may occur in a power supply circuit for some reason. If the IC is not equipped with an overvoltage protection (OVP) function, countermeasures must be taken as needed. Clamp the overvoltage by inserting a TVS diode for the output of a DC-DC or AC-DC converter. TVS diodes are designed to clamp transient voltages that occur for a short time (order of nanoseconds), such as ESD and surge waveforms. Therefore, to clamp a voltage in waveforms longer than about several tens of milliseconds, it is necessary to select a product with a power dissipation of the package larger than the power in the overvoltage part. In addition, when the overvoltage is continuously applied, for example, due to a short circuit between the input and output, the TVS diode could be damaged if the power in the overvoltage part exceeds the power dissipation of the package.

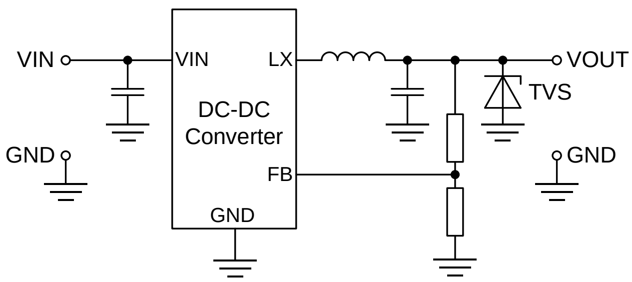

Figure 28. Overvoltage protection for DC-DC converter output

Notice

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