AN6498

Application note

Enhancing ST RS-485 transceivers ESD robustness with external TVS diodes

Introduction

Electrostatic Discharge (ESD) events pose a significant risk to the reliability and functionality of electronic devices, particularly in harsh environments such as industrial factory automation lines using RS-485 communication interfaces.

ESD can cause immediate device failure or latent damage, which reduces product lifetime and increases warranty costs.

This application note provides an analysis of methods to improve the ESD robustness of STMicroelectronics RS-485 transceivers such as the ST4Exxxx products family by using external Transient Voltage Suppressor (TVS) diodes on the RE-485 device bus I/O.

Additionally, the use of isolation resistors between the TVS diodes and the devices I/O is investigated to limit the peak transient currents during ESD events.

This application note describes the measurement methodology, test results and practical recommendations for implementing effective ESD protection in RS-485 applications.

1 Background on ESD and RS-485 interfaces

1.1 RS-485 communication interface

RS-485 is a differential serial communication standard defined by TIA/EIA-485. It is widely used for robust, long-distance, and multi-drop networks in industrial, building automation and robotic applications. RS-485 only specifies the electrical layer, including voltage levels, driver and receiver characteristics, and bus topology. It does not define the protocol, which is typically Modbus, Profibus, etc.

RS-485 uses a balanced differential pair of lines, usually called A and B. Data is encoded as the voltage difference between these two lines: a logic “1” or “0” is represented by one line being higher than the other, rather than by an absolute level to ground.

This differential signaling provides high immunity to common-mode noise and allows reliable communication over long cables (up to 1200 m) and in electrically noisy environments.

RS-485 commonly uses a half-duplex, full-duplex or multi-drop bus. Multiple transceivers share the same twisted pair, and one node at a time drives the bus while others listen. Termination resistors, typically 120 Ω, is placed at the ends of the cable to ensure signal integrity.

Figure 1. Typical half-duplex RS485 network

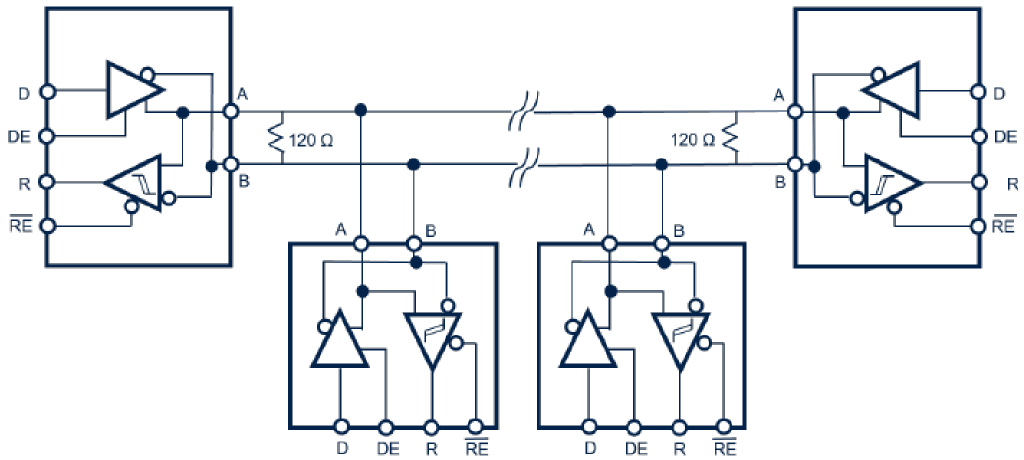


Figure 1 shows a typical configuration of a half-duplex RS-485 network.

When the Driver Enable (DE) pin is high, the driver is enabled. Then the driver outputs (A and B) generate a differential voltage $V_{OD} = V_A - V_B$ which follows the logic state of its input D. V_{OD} is positive when D is high and negative when D is low.

When DE is logic low, A and B are set to high impedance, the driver is disabled, and the D signal does not affect the outputs. Table 1 summarizes the ST4E1240 driver truth table.

When the Receiver Enable (/RE) pin is low, the receiver is enabled. When the receiver differential input voltage $V_{ID} = V_A - V_B$ is higher than the positive input threshold V_{TH+}, the receiver output R turns high. When V_{ID} is below the negative threshold V_{TH-}, the output R turns low. Lastly, when V_{ID} is in between both threshold voltages, the output R is indeterminate.

If /RE is high, R is high impedance, and the V_{ID} polarity and voltage do not affect it. Typically, the /RE pin has an internal pull-up resistor, thus when left open, the receiver output is disabled by default. Table 2 summarizes the ST4E1240 receiver truth table.

Table 1. **ST4E1240 driver truth table**

INPUT D	ENABLE DE	OUTPUT Y	OUTPUT Z	Function
H	H	H	L	Actively drive bus high
L	H	L	H	Actively drive bus low
X	L	Z	Z	Driver disabled
X	Open	Z	Z	Driver disabled by default
Open	H	H	L	Actively drive bus high by default

Table 2. **ST4E1240 receiver truth table**

Differential input $V_{ID} = V_A - V_B$	ENABLE $\overline{RE}$	OUTPUT R	Function
$V_{TH+} < V_{ID}$	L	H	Receive valid bus high
$V_{TH-} < V_{ID} < V_{TH+}$	L	I	Indeterminate bus state
$V_{ID} < V_{TH-}$	L	L	Receive valid bus low
X	H	Z	Receiver disabled
X	Open	Z	Receiver disabled by default
Open-circuit bus	L	H	Fail-safe high output
Short-circuit bus	L	H	Fail-safe high output
Idle (terminated) bus	L	H	Fail-safe high output

However, the RS-485 transceivers are exposed to a harsh electrical environment, including ESD, which can couple onto the bus lines (A and B).

While modern RS-485 devices such as the ST4E1240 include internal ESD protection structures (±12 kV IEC-61000-4-2), these may not be sufficient to meet more stringent requirements that need protection up to ±30 kV IEC-61000-4-2. Therefore, external protection components, such as TVS diodes, are often required to improve ESD immunity in these applications.

1.2 Electrostatic Discharge (ESD)

Electrostatic Discharge (ESD) is a sudden flow of electricity between two electrically charged objects caused by contact, electrical short, or dielectric breakdown. Common ESD sources include human body discharge, machinery, and environmental factors.

ESD is defined by several standards such as ISO, JEDEC JS-001 and IEC61000-4-2, and different models as shown in Figure 2.

The Human Body Model (HBM) standard simulates a charged person discharging to ground through the circuit under test.

The Machine Model (MM) simulates a charged manufacturing machine discharging through the device to ground.

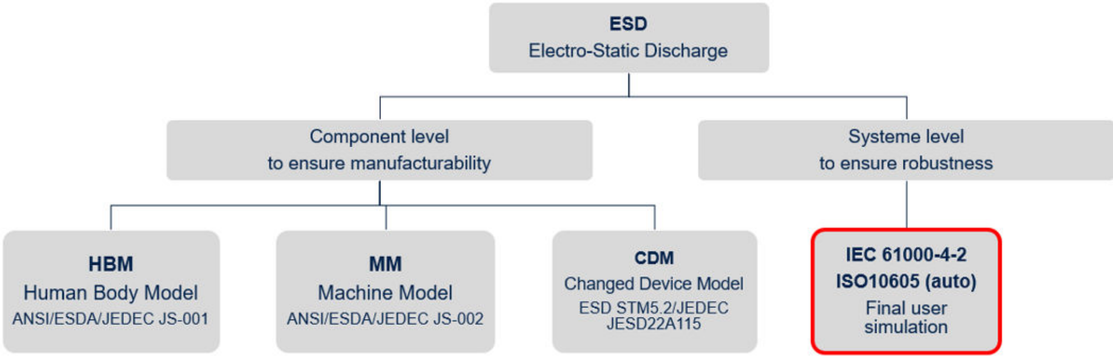
The Changed Device Model (CDM) simulates an IC becoming charged and discharging to a grounded metal surface.

The HBM, CDM and MM models are used for testing in the manufacturing environment, where assembly, final testing, and board-level soldering are performed in controlled ESD environments that limit the level of ESD stress to which the device is exposed.

The IEC-61000-4-2 is a standard which replicates a charged person discharging into a system in an uncontrolled environment. This standard ensures that the system remains operational in an end user environment where no ESD stress precautions are taken.

This application note considers the ESD test method related to the IEC-61000-4-2 standard.

Figure 2. **ESD standards**



1.2.1 IEC-61000-4-2

While device-level models are usually sufficient for the controlled ESD environment of the factory floor, they are inadequate for system-level testing, where the levels of ESD strikes from both voltages and currents can be much greater.

The International Electrotechnical Commission (IEC) model simulates end-user ESD events in real-world conditions.

The IEC-61000-4-2 standard defines the testing and immunity requirements for ESD, specifying test levels up to ±30 kV for air discharge and ±30 kV for contact discharge in harsh environments such as industrial applications (see Figure 3 and Table 3).

The fast rise time and high peak ESD current, shown in Figure 4 and Table 3, can damage semiconductor junctions, degrade device performance, or cause immediate failure.

Figure 3 presents the model used in the application discharge standard IEC 61000-4-2.

Figure 3. **IEC-61000-4-2 ESD equivalent schematic model**

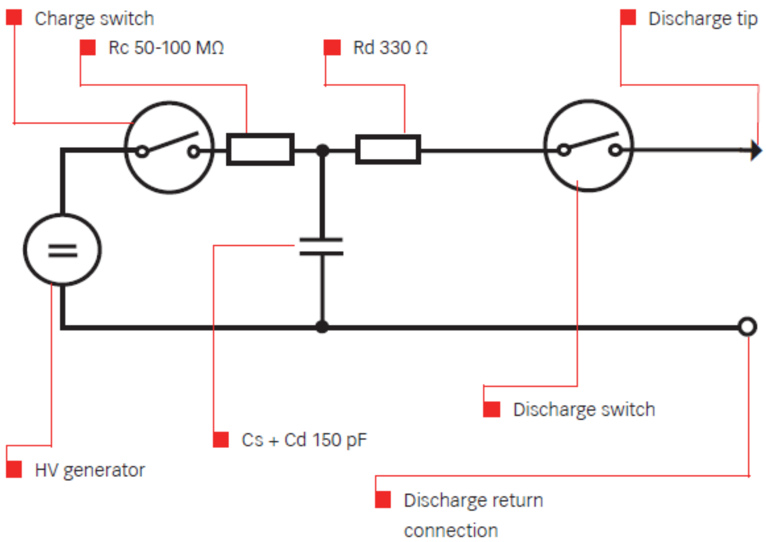


Figure 4. **IEC-61000-4-2 ESD current profile**

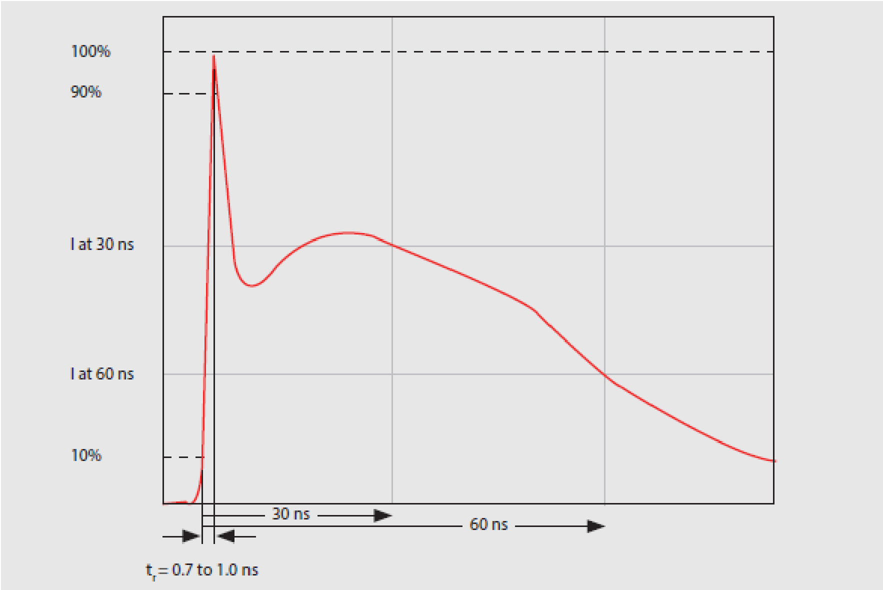


Table 3. **IEC-61000-4-2 discharge voltage**

Level	Indicated voltage (kV)	First peak current of discharge ± 10%	Rise time tr with discharge switch	Current (± 30%) at 30 ns	Current (± 30%) at 60 ns
1	2	7.5 A	7 ns to 1 ns	4 A	2 A
2	4	15 A	7 ns to 1 ns	8 A	4 A
3	6	22 A	7 ns to 1 ns	12 A	6 A
4	8	30 A	7 ns to 1 ns	16 A	8 A
X	up to 30	up to 70 A	7 ns to 1 ns		

1.3 Selection criteria for TVS diodes in RS-485 applications

A Transient Voltage Suppressor (TVS) diode is a protection component specifically designed to clamp fast, high-voltage transients such as Electrostatic Discharge (ESD), surge, or Electrical Fast Transient (EFT) to a safe level for electronic circuits. During normal operation, the TVS diode remains in a high-impedance state and has negligible impact on the signal line. When a transient voltage exceeds its breakdown voltage (V_{BR}), the TVS diode switches rapidly into a low-impedance state, limiting the voltage to its clamping level and diverting the surge current to ground. After the event, it returns to its non-conductive state. Thanks to this very fast response and high surge capability, TVS diodes are ideally suited to protect sensitive interfaces, such as RS-485 bus lines, from IEC-61000-4-2 ESD events.

To protect a device efficiently, the TVS breakdown voltage (V_{BR}) must be below the triggering voltage of the protected device. Thus, the TVS diode will trigger before the protected device.

The ST RS-485 product family, such as the ST4E1240, has a wide common-mode voltage range, from -7 V to +12 V on the bus A and B. Ideally, the TVS V_{BR} must be higher than 12 V to allow the RS-485 device to operate within its full common-mode range.

Figure 5. **STM4T14AY/CAY TLP profile**

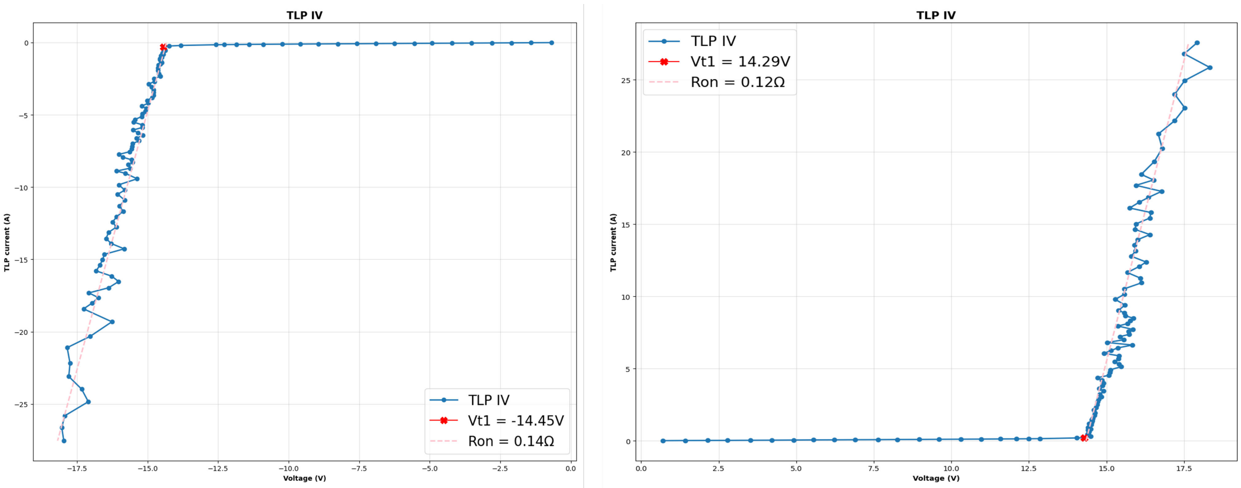
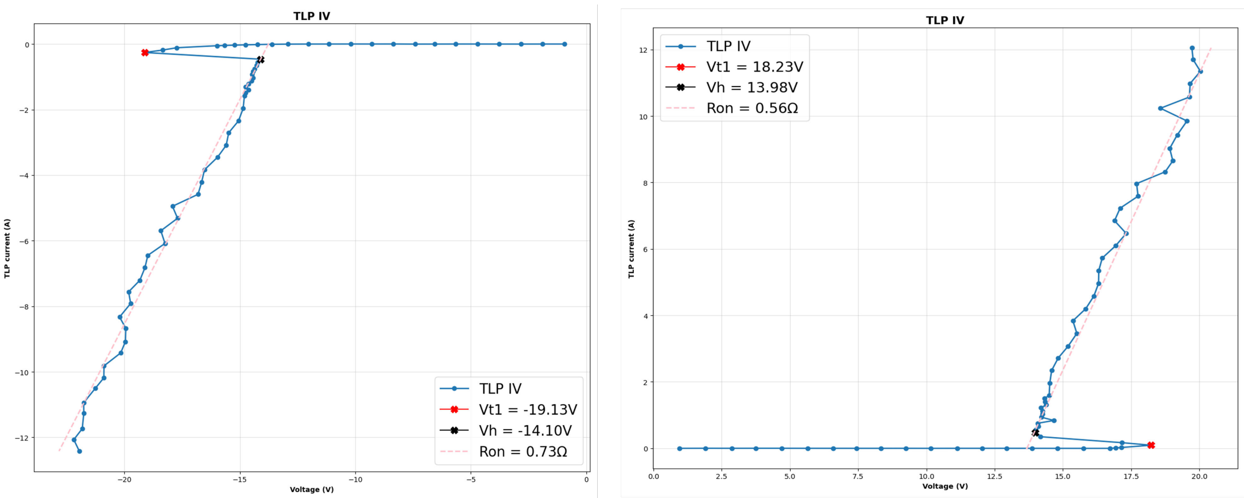


Figure 6. **ST4E1240 TLP profile**



Following the Transmission Line Pulse (TLP) characteristic of the SM4T14AY TVS diode shown in Figure 5, the triggering voltage V_{t1} (also referred to as breakdown voltage V_{BR}) is -14.5 V for the negative TLP and +14.5 V for the positive TLP.

Since this triggering voltage is lower than the ST4E1240 internal protection triggering voltage (V_{t1} = 18.2 V) shown in Figure 5, the external TVS diode activated first absorbs most of the ESD stress, thereby enhancing the overall robustness of the RS-485 interface.

Therefore, a TVS diode with 12 V < V_{BR} < 18 V, such as the SM4T14AY, is an appropriate choice to protect RS-485 devices, including those with internal protections that have a triggering voltage V_{t1} greater than 14.5 V.

The TLP current-voltage (I-V) curve of the ST4E1240 (Figure 6) shows a snapback-type protection behavior. The internal ESD structure remains inactive up to a trigger voltage $V_{t1} \approx 18.2\ V$. When this voltage is reached, the clamp turns on abruptly and the characteristic snaps back to a lower holding voltage $V_h \approx 14\ V$, where it can conduct several amperes with a low dynamic resistance $R_{on} \approx 0.56$.

In Table 4, TLP characterization was performed on several ST RS-485 transceivers to select a suitable TVS diode for ESD protection enhancement.

Table 4. ST TVS device selection following the ST RS-485 reference

RS-485 reference	Vt1- (V)	Vh- (V)	Vt1+ (V)	Vh+ (V)	TVS reference
ST4E1240	-19	-14	18	13	**SM4T14AY** (V_{BR} = ±14 V)
ST1480ABDR	-19	-13	19	11	**SM4T14AY** (V_{BR} = ±14 V)
STR485LVQT	-11.11	-2.1	17	7	**SM4T10AY** (V_{BR} = ±10 V)
STR485EBDR	-51	-25	51	23	**SM4T14AY** (V_{BR} = ±14 V)
ST4E1650	-22	-20	20	15	**SM4T14AY** (V_{BR} = ±14 V)
ST4E1650F	-19	-14	17	15	**SM4T14AY** (V_{BR} = ±14 V)

All the ST transceivers listed in Table 4, except for STR485LVQT, have a triggering voltage higher than 14 V. Therefore, they are compatible with the SM4T14AY TVS diode.

The STR485LVQT part has a low triggering voltage (Vt1- = -11 V). During an ESD event, the SM4T10AY TVS diode triggers before the STR485LVQT and protects it.

However, the common-mode voltage range on bus A and B will be limited from -7 V to +10 V. In applications with short to medium cable distances, this common-mode range is sufficient. But for long-distance applications (up to 1200 m), if the common-mode range exceeds +10 V, then precautions are necessary. Use an appropriate TVS diode in these cases.

1.4 Isolation resistor impact on driver output voltage

Isolation resistors placed between the TVS diode and the device I/O pin limit the peak transient current flowing during an ESD event.

Typical resistor values range from 5 Ω to 20 Ω. While higher resistance improves current limiting, it also introduces a voltage drop on the bus output voltage (V_{OD}) and can affect signal integrity.

1.4.1 Test setup

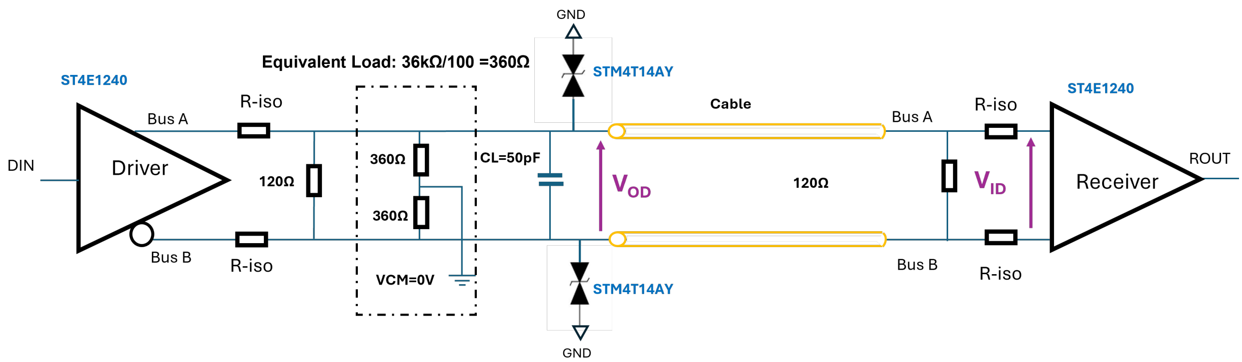
Figure 7 shows the test circuit that simulates a full load condition with 100 nodes connected to the RS-485 bus lines. The equivalent resistor for 100 nodes is:

$$Req = 36 \quad k\Omega/100 = 360 \quad \Omega$$

The ST4E1240 driver and receiver are connected through a 1 m cable terminated by 120 Ω adaptation resistor. The equivalent differential bus load capacitor is 50 pF.

The SM4T14AY TVS diodes are connected on each bus line. A serial isolation resistor (R-iso) is also placed on the bus lines at both the driver and receiver side.

Figure 7. ST4E1240 full load equivalent test circuit



1.4.2 Measurement result

The driver output voltage (V_{OD}) and the receiver input voltage (V_{ID}) are measured with different isolation resistors (R-iso) values on the bus.

Table 5. Bus differential voltage with different R-iso values

R-iso value	V_{CC} = 3.3 V		V_{CC} = 5 V	
	V_{OD}	V_{ID}	V_{OD}	V_{ID}
0 Ω	4.16 V	4.16 V	7 V	7 V
4.7 Ω	3.8 V	3.6 V	6.7 V	6.3 V
10 Ω	3.68 V	3.16 V	6.5 V	5.6 V
20 Ω	3.35 V	2.54 V	5.5 V	4.21 V

Table 5 shows the impact of the serial isolation resistor on the V_{OD} and V_{ID} values.

A higher resistor value results in a lower V_{OD} and V_{ID}. With a high value of R-iso in a long-distance communication, such as 1200 m, the V_{ID} can decrease enough to not meet the RS-485 receiver requirements. It is generally recommended to use a serial resistor of up to 10 Ω.

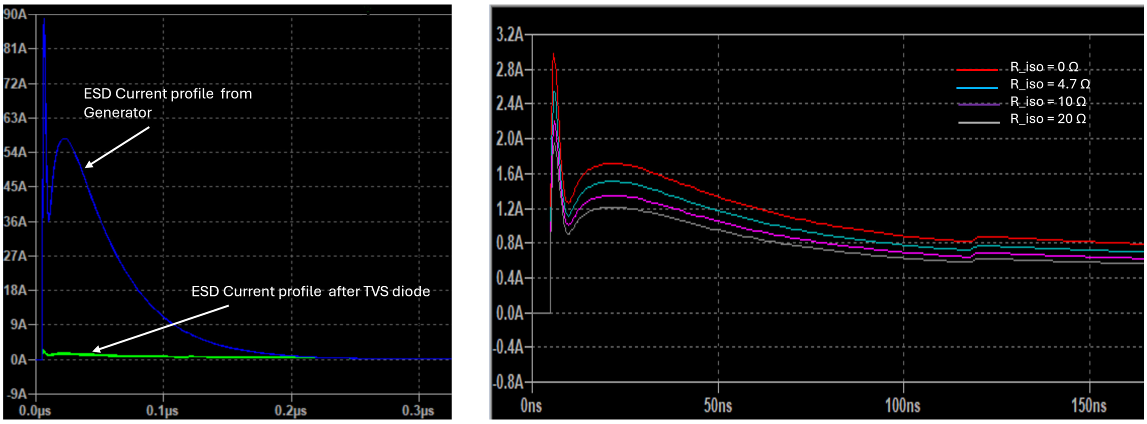
1.5 TVS diode impact on ESD protection

1.5.1 IEC-61000-4-2 ESD current profile

Figure 8, from the ESD current simulation, shows how the TVS diode reduces the peak transient current and limits stress on the device.

A higher isolation resistor value results in a lower peak current.

Figure 8. Simulated ESD current profiles for different isolation resistor (R-iso) values



1.5.2 IEC-61000-4-2 ESD application

Figure 9. ST4E1240 ESD test setup

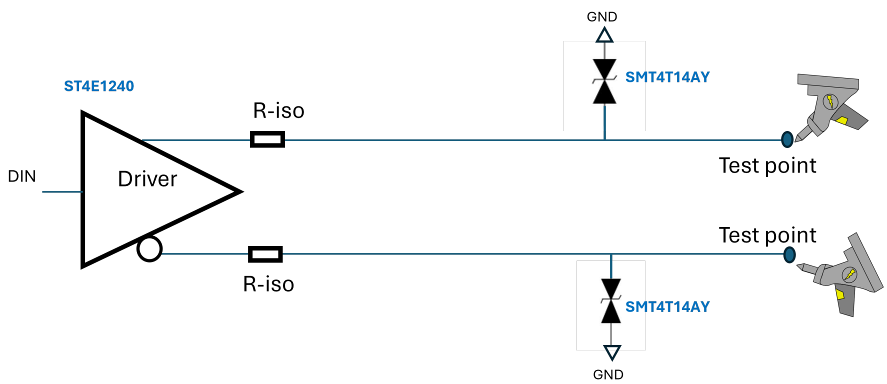


Figure 10. **ESD IEC-61000-4-2 test bench**

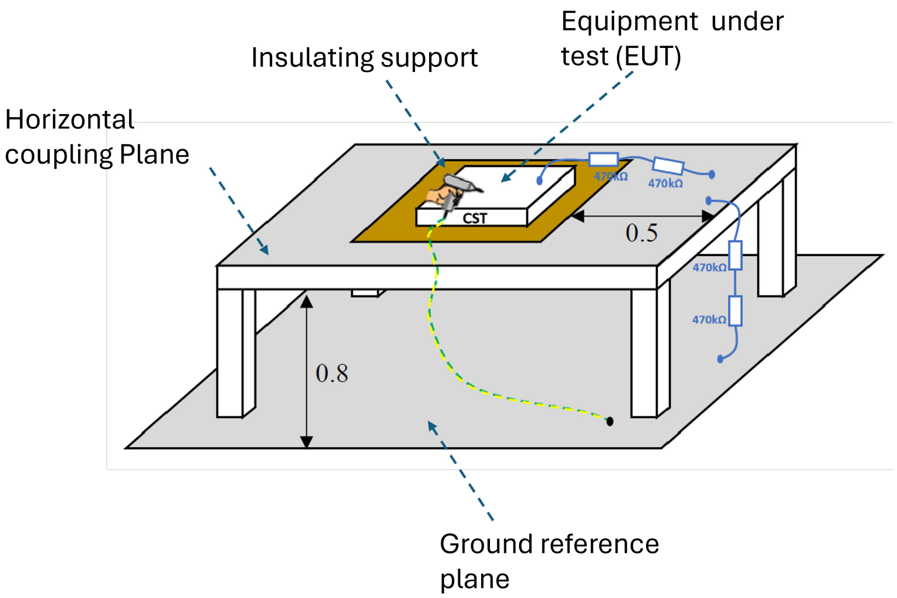


Figure 9 illustrates the ST4E1240 electrostatic discharge (ESD) test setup, showing the driver circuit, isolation resistors, the SMT4T414AY TVS diodes connected to bus A and B, and test point where the ESD gun is applied.

Figure 10 depicts the IEC-61000-4-2 ESD test bench, including the equipment under test (EUT), insulating support, horizontal coupling plane, and ground reference plane.

1.5.3 Test result

Table 6. ST4E1240 ESD-IEC-61000-4-2 test results

Test condition	BUS	IEC-61000-4-2 Level	V_{CC}	Test Status
ST4E1240 Standalone (no TVS, no R-iso)	A, B	±12 kV	5.5 V	PASS
ST4E1240 with TVS and R-iso = 5 Ω	A, B	±24 kV	5.5 V	PASS
ST4E1240 with TVS and R-iso = 10 Ω	A, B	±24 kV	5.5 V	PASS
ST4E1240 with TVS and R-iso = 20 Ω	A, B	±24 kV	5.5 V	PASS

Table 6 shows the ESD stress results for ST4E1240 with and without the SM4T14AY TVS diode.

The ST4E1240 in standalone mode withstands up to ±12 kV. Adding the external SM4T14AY TVS diode allows the ST4E1240 to support up to 24 kV.

Moreover, for R-iso values of 5 Ω or higher, the combination of the ST4E1240 and the SM4T14AY diode provides strong protection against ESD events.

2 Conclusion

This application note demonstrates that integrating external TVS diodes with an isolation resistor, such as SM4T14AY, significantly enhances the ESD robustness of the ST RS-485 transceiver family. The TVS diode's lower triggering voltage (V_{BR} = ± 10 V to V_{BR} = -/+14 V) ensures activation before the RS-485 internal protection triggers (V_{t1} = ± 11 V to ± 51 V). Therefore, RS-485 devices are effectively protected against high transient voltages and safeguarded during ESD events.

A critical finding from the study is the impact of the isolation resistor (R-iso) on both ESD protection effectiveness and signal integrity. Increasing R-iso improves current limiting during ESD events, but it also introduces a voltage drop that reduces the RS-485 driver output voltage (V_{OD}), potentially affecting communication performance.

The test results indicate that using a SM4T14AY with a low-value isolation resistor (for example, 5 Ω) maximizes the RS-485 transceiver V_{OD} while providing sufficient ESD protection to pass stringent ESD IEC-61000-4-2 tests at ± 24 kV.

The optimal design approach balances trade-offs by selecting a low isolation resistor value, which preserves signal integrity and maximizes driver output voltage, while the external TVS diode ensures robust ESD protection.

Revision history

Table 7. **Document revision history**

Date	Revision	Changes
17-Jul-2026	1	Initial release.

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