Safeguard Your RS-485 Communication Networks from Harmful EMC Events

By James Scanlon and Koenraad Rutgers

Idea In Brief

In real industrial and instrumentation (I&I) applications, RS-485 interface links must work in harsh electromagnetic environments. Large transient voltages caused by lightning strikes, electrostatic discharge, and other electromagnetic phenomenon can damage communications ports. To ensure that these data ports can survive in their final installation environments, they must meet certain electromagnetic compatibility (EMC) regulations.

These requirements include three main transient immunity standards: electrostatic discharge, electrical fast transients, and surge.

Many EMC problems are not simple or obvious, so they must be considered at the start of the product design. Leaving these considerations to the end of the design cycle can lead to overruns in engineering budget and schedule.

This article describes each of these main transient types and presents and demonstrates three different EMC compliant solutions for three different cost/protection levels on RS-485 communication ports.

Analog Devices, Inc., and Bourns, Inc., have partnered to extend their offering of system oriented solutions by co-developing the industry's first EMC compliant RS-485 interface design tool that provides up to Level 4 protection levels for IEC 61000-4-2 ESD, IEC 61000-4-4 EFT, and IEC 61000-4-5 surge. It gives designers the design options depending on the level of protection required and available budgets. These design tools allow designers to reduce risk of project slippage due to EMC problems by considering them at the start of the design cycle.

RS-485 Standard

I&I applications require data transmission between multiple systems, often over very long distances. The RS-485 electrical standard is one of the most widely used physical layer specifications in I&I applications, such as industrial automation, process control, motor control, and motion control; remote terminals; building automation, such as heating, ventilation, and air conditioning (HVAC); security systems; renewable energy.

Some of the key features of the RS-485 that make it ideal for use in I&I communications applications are:

- Long distance links—up to 4000 feet
- Bidirectional communications possible over a single pair of twisted cables
- Differential transmission increases common-mode noise immunity and decreases noise emissions
- Multiple drivers and receivers can be connected on the same bus
- Wide common-mode range (–7 V to +12 V) allows for differences in ground potential between the driver and receiver
- TIA/EIA-485-A allows for data rates of up to 10's of Mbps

TIA/EIA-485-A describes the physical layer of the RS-485 interface and is normally used with a higher-level protocol, such as Profibus, Interbus, Modbus, or BACnet. This allows for robust data transmission over relatively long distances.

In real applications, however, lightning strikes, power induction and direct contact, power source fluctuations, inductive switching, and electrostatic discharge can damage RS-485 transceivers by generating large transient voltages. Designers must ensure that equipment does not only work under ideal conditions but that it will also work in the "real world." To ensure that these designs can survive in electrically harsh environments, various government agencies and regulatory bodies have imposed EMC regulations. Compliance with these regulations gives the end user assurance that designs will operate as desired in these harsh environments.

Electromagnetic Compatibility

An electromagnetic environment is composed of both radiated and conducted energy, so EMC has two aspects: emission and susceptibility. Thus, EMC has the ability of an electronic system to function satisfactorily in its intended electromagnetic environment without introducing intolerable electromagnetic disturbances to that environment. This article deals with increasing the protection level for EMC susceptibility of RS-485 ports against the three main EMC transients.

The International Electrotechnical Commission (IEC) is the world's leading organization that prepares and publishes international standards for all electrical, electronic, and related technologies. Since 1996, all electronic equipment sold to or within the European Community must meet EMC levels as defined in specifications IEC 61000-4-x.

The IEC 61000 specifications define the set of EMC immunity requirements that apply to electrical and electronic equipment intended for use in residential, commercial, and light industrial environments. This set of specifications includes three types of high voltage transients that electronic designers need to be concerned about for the data communication lines:

- IEC 61000-4-2 electrostatic discharge (ESD)
- IEC 61000-4-4 electrical fast transients (EFT)
- IEC 61000-4-5 surge immunity

Each of these specifications defines a test method to assess the immunity of electronic and electrical equipment against the defined phenomenon. The following sections summarize each of these tests.

Electrostatic Discharge

ESD is the sudden transfer of electrostatic charge between bodies at different potentials caused by near contact or induced by an electric field. It has the characteristics of high current in a short time period. The primary purpose of the IEC 61000-4-2 test is to determine the immunity of systems to external ESD events outside the system during operation. IEC 61000-4-2 describes testing using two coupling methods. These are known as contact discharge and air-gap discharge. Contact discharge implies a direct contact between the discharge gun and the unit under test. During air discharge testing, the charged electrode of the discharge gun is

moved toward the unit under test until a discharge occurs as an arc across the air gap. The discharge gun does not make direct contact with the unit under test. A number of factors affect the results and repeatability of the air discharge test, including humidity, temperature, barometric pressure, distance, and rate of approach to the unit under test. This method is a better representation of an actual ESD event but is not as repeatable. Therefore, contact discharge is the preferred test method.

During testing, the data port is subjected to at least 10 positive and 10 negative single discharges with a one second interval between each pulse. Selection of the test voltage is dependent on the system end environment. The highest specified test is Level 4, which defines a contact discharge voltage of ±8 kV and an air discharge voltage of ±15 kV.

Figure 1 shows the 8 kV contact discharge current waveform as described in the specification. Some of the key waveform parameters are rise times of less than 1 ns and pulse widths of approximately 60 ns. This equates to a pulse with a total energy in the range of 10's of mJ.

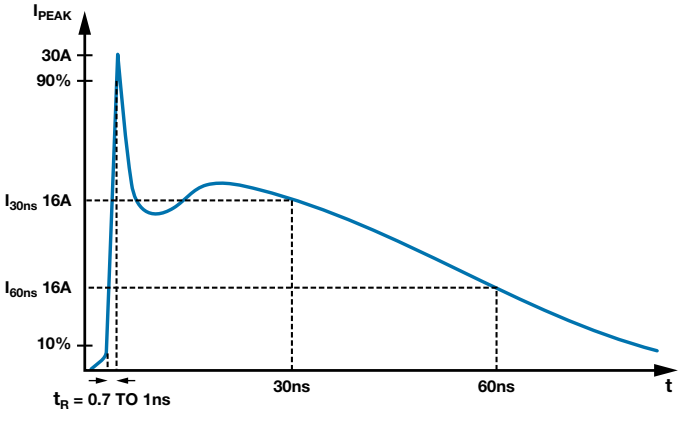

Figure 1. IEC 61000-4-2 ESD waveform (8 kV).

Electrical Fast Transients

Electrical fast transient testing involves coupling a number of extremely fast transient impulses onto the signal lines to represent transient disturbances associated with external switching circuits that are capacitively coupled onto the communication ports, which may include relay and switch contact bounce or transients originating from the switching of inductive or capacitive loads—all of which are very common in industrial environments. The EFT test defined in IEC 61000-4-4 attempts to simulate the interference resulting from these types of events.

Figure 2 shows the EFT 50 Ω load waveform. The EFT waveform is described in terms of a voltage across 50 Ω impedance from a generator with 50 Ω output impedance. The output waveform consists of a 15 ms burst of 2.5 kHz to 5 kHz high voltage transients repeated at 300 ms intervals. Each individual pulse has a rise time of 5 ns and pulse duration of 50 ns, measured between the 50% point on the rising and falling edges of the waveform. The total energy in a single EFT pulse is similar to that in an ESD pulse. The total energy in a single pulse is typically 4 mJ. Voltages applied to the data ports can be as high as 2 kV.

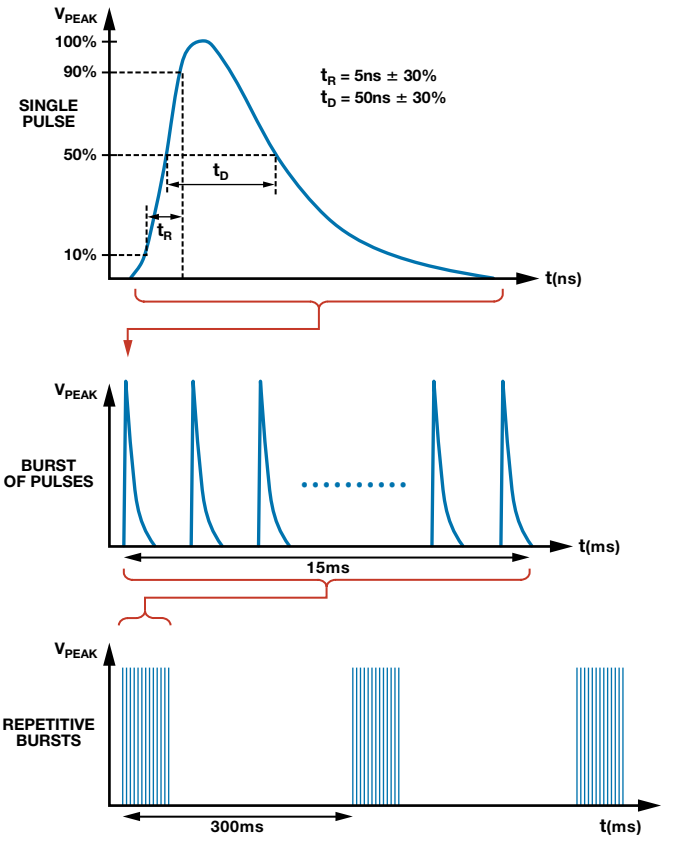

Figure 2. IEC 61000-4-4 EFT 50 Ω load waveforms.

These fast burst transients are coupled onto the communication lines using a capacitive clamp. The EFT is capacitively coupled onto the communication lines by the clamp rather than direct contact. This also reduces the loading caused by the low output impedance of the EFT generator. The coupling capacitance between the clamp and cable depends on cable diameter, shielding, and insulation on the cable.

Surge Transients

Surge transients are caused by overvoltage from switching or lightning transients. Switching transients can result from power system switching, load changes in power distribution systems, or various system faults such as short circuits. Lightning transients can be a result of high currents and voltages injected into the circuit from nearby lightning strikes. IEC 61000-4-5 defines waveforms, test methods, and test levels for evaluating immunity against these destructive surges.

The waveforms are specified as the outputs of a waveform generator in terms of open circuit voltage and short circuit current. Two waveforms are described. The 10/700 µs combination waveform is used to test ports intended for connection to symmetrical communication lines: for example, telephone exchange lines. The 1.2/50 µs combination waveform generator is used in all other cases, in particular short distance signal connections. For RS-485 ports, the 1.2/50 µs waveform is predominantly used and will be discussed in this section. The waveform generator has an effective output impedance of 2 Ω; hence, the surge transient has high currents associated with it.

Figure 3 shows the 1.2/50 µs, surge transient waveform. ESD and EFT have similar rise times, pulse widths, and energy levels; however, the surge pulse has a rise time of 1.25 µs and the pulse width is 50 µs. Additionally, the surge pulse energy can reach up to almost 90 J, which is three to four orders of magnitude larger than the energy in an ESD or EFT pulse. Therefore, the surge transient is considered the most severe of the EMC transients. Due to the similarities between ESD and EFT, the design of the circuit protection can be similar, but due to its high energy, surge must be dealt with differently. This is one of the main issues in developing protection that improves the immunity of data ports to all three transients while remaining cost effective.

Resistors couple the surge transient onto the communication line. Figure 4 shows the coupling network for a half-duplex RS-485 device. The total parallel sum of the resistance is 40 Ω. For the half-duplex device, each resistor is 80 Ω.

During the surge test, five positive and five negative pulses are applied to the data ports with a maximum time interval of one minute between each pulse. The standard states that the device should be set up in normal operating conditions for the duration of the test.

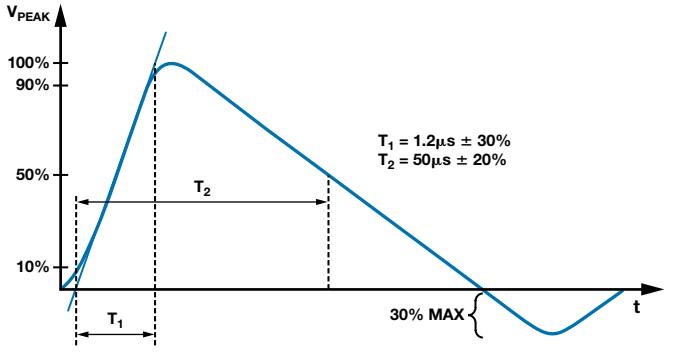

Figure 3. IEC 61000-4-5 surge 1.2/50 µs waveform.

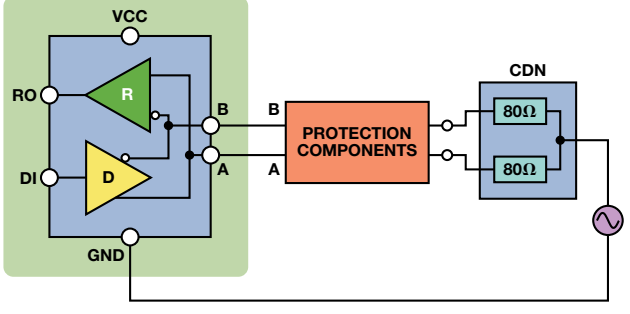

Figure 4. Coupling/decoupling network for a half-duplex RS-485 device.

Pass/Fail Criteria

When transients are applied to the system under test, the results are categorized into four pass/fail criteria. Following is a list of the pass/fail criteria giving examples of how each one might relate to an RS-485 transceiver:

- Normal performance; no bit errors would occur during or after the transient is applied
- Temporary loss of function or temporary degradation of performance not requiring an operator; bit errors might occur during and for a limited time after the transient is applied
- Temporary loss of function or temporary degradation of performance requiring an operator; a latch up event may occur that could be removed after a power on reset with no permanent loss of function or degradation to the device
- Loss of function with permanent damage to equipment; the device fails the test

Criteria A is the most desirable with Criteria D being unacceptable. Permanent damage results in system down time and the expense of repair and replacement. For mission critical systems, Category B and Category C will also be unacceptable, as the system must operate without errors during transient events.

Transient Protection

When designing circuitry to protect against transients, the designer must consider a few main items:

1. The circuitry must prevent or limit damage caused by the transient and allow the system to return to normal operation with minimal impact on performance.
2. The protection scheme should be robust enough to deal with the type of transients and voltage levels the system would be subjected to in the field.
3. The length of time associated with the transient is an important factor. For long transients, heating effects can cause certain protection schemes to fail.
4. Under normal conditions, the protection circuitry should not interfere with system operation.
5. If the protection circuitry fails during overstress, it should fail in such a way as to protect the system.

Figure 5 shows a typical protection scheme, which can be characterized as having primary and secondary protection. Primary protection, which diverts most of the transient energy away from the system, is typically located at the interface between the system and the environment. It is designed to remove the majority of the energy by diverting the transient to ground.

Secondary protection protects various parts of the system from any transient voltages and currents let through by the primary protection. It is optimized to ensure that it protects against these residual transients while allowing normal operation of these sensitive parts of the system. It is essential that both primary and secondary designs are specified to work together in conjunction with the system I/O to minimize the stress on the protected circuit. These designs typically include a coordinating element such as a resistance or a nonlinear overcurrent protection device between the primary and secondary protection devices to ensure that coordination occurs.

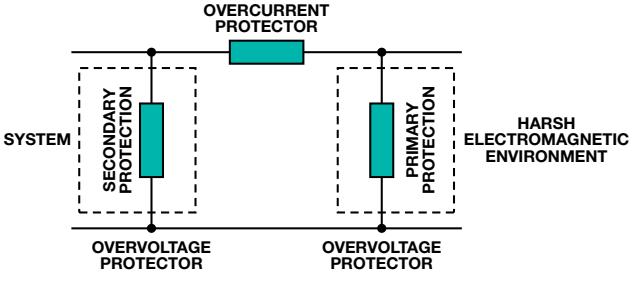

Figure 5. Protection scheme—block diagram.

RS-485 Transient Suppression Networks

By nature, EMC transient events vary in time, so the dynamic performance and the matching of the dynamic characteristics of the protection components with the input/output stage of the protected device lead to successful EMC design. Component data sheets generally only contain dc data, which is of limited value given that the dynamic breakdowns and I/V characteristics can be quite different from the dc values. Careful design, characterization, and an understanding of the dynamic performance of the input/output stage of the protected device and the protection components are required to ensure that the circuit meets EMC standards.

The circuits shown in Figure 6 illustrate three different fully characterized EMC compliant solutions. Each solution was certified by an independent external EMC compliance test house, and each provides different cost/protection levels for the Analog Devices ADM3485E 3.3 V RS-485 transceiver with enhanced ESD protection using a selection of Bourns external circuit protection components. The Bourns external circuit protection components used consist of transient voltage suppressors (CDSOT23-SM712), transient blocking unit (TBU-CA065-200-WH), thyristor surge protectors (TISP4240M3BJR-S), and gas discharge tubes (2038-15-SM-RPLF).

Each solution was characterized to ensure that the dynamic I/V performance of the protection components protects the dynamic I/V characteristics of the ADM3485E RS-485 bus pins such that the interaction between the input/output stage of the ADM3485E and the external protection components function together to protect against the transient events.

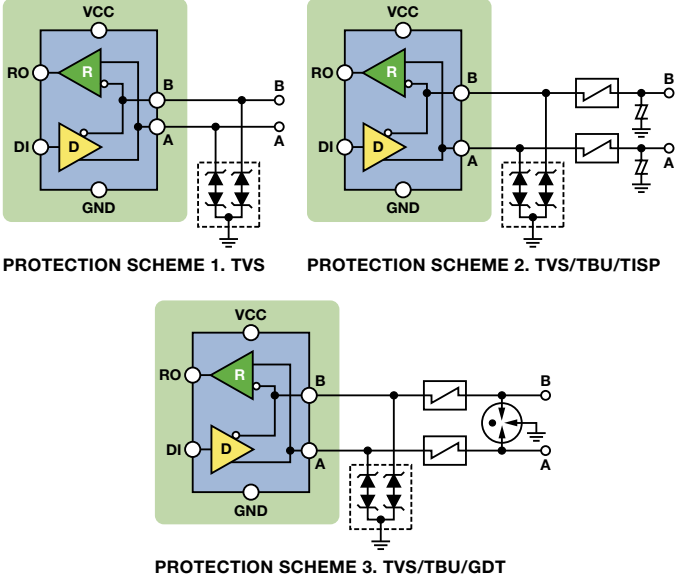

Figure 6. Three EMC compliant ADM3485E circuits (simplified schematic, all connections not shown).

Protection Scheme 1

As described earlier, the EFT and ESD transient have similar energy levels, while the surge waveform has energy levels three to four magnitudes greater. Protecting against ESD and EFT is accomplished in a similar manner, but protecting against high levels or surge requires more complex solutions. The first solution described here protects up to Level 4 ESD and EFT and Level 2 surge. The 1.2/50 μs waveform is used in all surge testing described in this article.

This solution uses the Bourns CDSOT23-SM712 transient voltage suppressor (TVS) array, which consists of two bidirectional TVS diodes optimized to protect RS-485 systems with minimal overstress while allowing the full range of RS-485 signal and common-mode excursions (–7 V to +12 V) on the RS-485 transceiver. Table 1 shows the voltage levels protected against for ESD, EFT, and surge transients.

Table 1. Solution 1 Protection Levels

ESD (-4-2)		EFT (-4-4)		Surge (-4-5)	
Level	Voltage (Contact/Air)	Level	Voltage	Level	Voltage
4	8 kV/15 kV	4	2 kV	2	1 kV

A TVS is a silicon based device. Under normal operating conditions, the TVS has high impedance to ground; ideally, it is an open circuit. The protection is accomplished by clamping the overvoltage from a transient to a voltage limit. This is done by the low impedance avalanche breakdown of a PN junction. When a transient voltage larger than the breakdown voltage of the TVS is generated, the TVS clamps the transient to a predetermined level that is less than the breakdown voltage of the devices that it is protecting. The transients are clamped instantaneously (<1 ns), and the transient current is diverted away from the protected device to ground.

It is important to ensure that the breakdown voltage of the TVS is outside the normal operating range of the pins protected. The unique feature of the CDSOT23-SM712 is that it has asymmetrical breakdown voltages of +13.3 V and –7.5 V to match the transceiver common-mode range of +12 V to –7 V, therefore providing optimum protection while minimizing overvoltage stresses on the ADM3485E RS-485 transceiver.

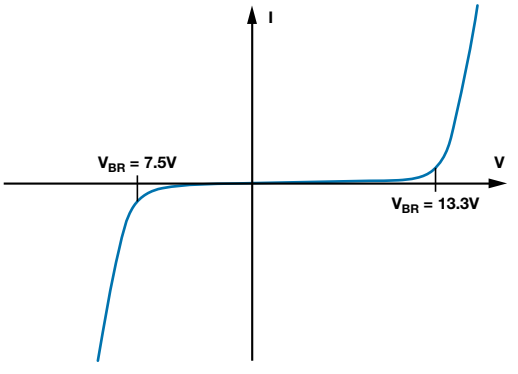

Figure 7. CDSOT23-SM712 I/V characteristic.

Protection Scheme 2

The previous solution protects up to Level 4 ESD and EFT but only to Level 2 surge. To improve the surge protection level, the protection circuitry gets more complex. The following protection scheme will protect up to Level 4 surge.

The CDSOT23-SM712 is specifically designed for RS-485 data ports. The next two circuits build on the CDSOT23-SM712 to provide higher levels of circuit protection. The CDSOT23-SM712 provides secondary protection while the TISP4240M3BJR-S provides the primary protection. Coordination between the primary and secondary protection devices and overcurrent protection are accomplished using the TBU-CA065-200-WH. Table 2 shows the voltage levels protected against for ESD, EFT, and surge transients with this protection circuit.

Table 2. Solution 2 Protection Levels

ESD (-4-2)		EFT (-4-4)		Surge (-4-5)	
Level	Voltage (Contact/Air)	Level	Voltage	Level	Voltage
4	8 kV/15 kV	4	2 kV	4	4 kV

When a transient is applied to the protection circuit, the TVS will break down, protecting the device by providing a low impedance path to ground. With large voltages and currents, the TVS must also be protected by limiting the current through it. This is done using a transient blocking unit (TBU), which is an active high speed overcurrent protection element. The TBU in this solution is the Bourns TBU-CA065-200-WH.

A TBU blocks current rather than shunting it to ground. As a series component, it reacts to current through the device rather than the voltage across the interface. A TBU is a high speed overcurrent protection component with a preset current limit and a high voltage withstand capability. When an overcurrent occurs and the TVS breaks down due to the transient event, the current in the TBU will rise to the current limiting level set by the device. At this point, the TBU disconnects the protected circuitry from the surge in less than 1 µs. During the remainder of the transient, the TBU remains in the protected blocking state, with very low current (<1 mA) passing through to the protected circuit. Under normal operating conditions, the TBU exhibits low impedance, so it has minimal impact on normal circuit operation. In blocking mode, it has very high impedance to block transient energy. After the transient event, the TBU automatically resets to its low impedance state and allows resumption of normal system operation.

Like all overcurrent protection technologies, the TBU has a maximum breakdown voltage, so a primary protection device must clamp the voltage and redirect the transient energy to ground. This is commonly done using technologies such as gas discharge tubes or solid-state thyristors, such as the totally integrated surge protector (TISP). The TISP acts as a primary protection device. When its predefined protection voltage is exceeded, it provides a crowbar low impedance path to ground, hence diverting the majority of the transient energy away from the system and other protection devices.

The nonlinear voltage-current characteristic of the TISP limits overvoltage by diverting the resultant current. As a thyristor, a TISP has a discontinuous voltage-current characteristic caused by the switching action between high and low voltage regions. Figure 8 shows the voltage current characteristic of the device. Before the TISP device switches into a low voltage state, with low impedance to ground to shunt the transient energy, a clamping action is caused by the avalanche breakdown region. In limiting an overvoltage, the protected circuitry will be exposed to a high voltage for the brief time period that the TISP device is in the breakdown region before it switches into a low-voltage protected on-state. The TBU will protect the downstream circuitry from high currents resulting from this high voltage. When the diverted current falls below a critical value, the TISP device automatically resets allowing normal system operation to resume.

As described, all three components work together in conjunction with the system I/O to protect the system from high voltage and current transients.

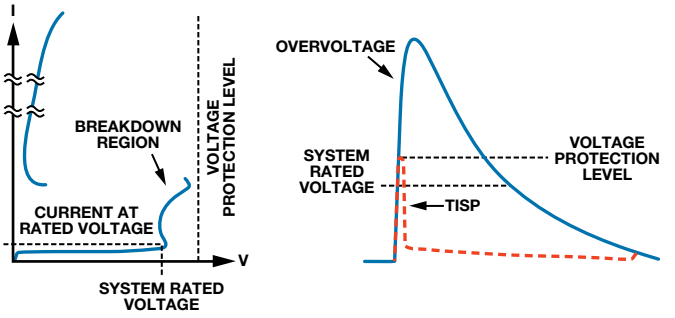

Figure 8. TISP switching characteristic and voltage limiting waveshape.

Protection Scheme 3

Protection levels above Level 4 surge are often required. This protection scheme will protect RS-485 ports up to and including 6 kV surge transients. It operates in a similar fashion to protection scheme 2, but in this circuit, a gas discharge tube (GDT) is used in place of the TISP to protect the TBU, which is, in turn, protecting TVS, the secondary protection device. The GDT will provide protection to higher overvoltage and overcurrent stress than the TISP described in the previous protection scheme. The GDT for this protection scheme is the Bourns 2038-15-SM-RPLF. The TISP is rated at 220 amps versus the GDT rating of 5 kA per conductor. Table 3 shows the protection levels provided by this design.

Table 3. Solution 3 Protection Levels

ESD (-4-2)		EFT (-4-4)		Surge (-4-5)	
Level	Voltage (Contact/Air)	Level	Voltage	Level	Voltage
4	8 kV/15 kV	4	2 kV	X	6 kV

Predominately used as a primary protection device, a GDT provides a low impedance path to ground to protect against overvoltage transients. When a transient voltage reaches the GDT spark-over voltage, the GDT will switch from a high impedance off-state to arc mode. In arc mode, the GDT becomes a virtual short, providing a crowbar current path to ground and diverting the transient current away from the protected device.

Figure 9 shows the typical characteristics of a GDT. When the voltage across a GDT increases, the gas in the tube starts to ionize due to the charge developed across it. This is known as the glow region. In this region, the increased current flow will create an avalanche effect that will transition the GDT into a virtual short circuit, allowing current to pass through the device. During the short circuit event, the voltage developed across the device is known as the arc voltage. The transition time between the glow and arc region is highly dependent on the physical characteristics of the device.

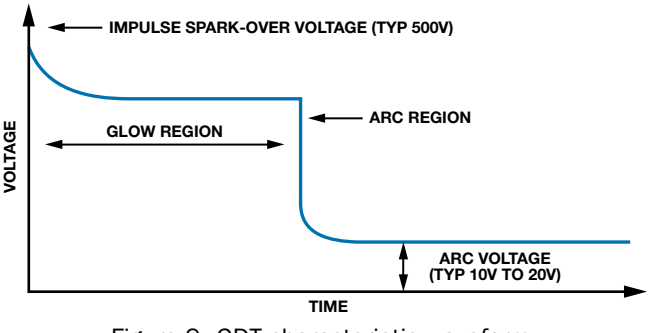

Figure 9. GDT characteristic waveform.

Table 4. Three ADM3485E EMC Compliant Solutions

	ESD (-4-2)		EFT (-4-4)		Surge (-4-5)	
Protection Scheme	Level	Voltage (Contact/Air)	Level	Voltage	Level	Voltage
TVS	4	8 kV/15 kV	4	2 kV	2	1 kV
TVS/TBU/TISP	4	8 kV/15 kV	4	2 kV	4	4 kV
TVS/TBU/GDT	4	8 kV/15 kV	4	2 kV	X	6 kV

Conclusion

This article described the three IEC standards of interest that deal with transient immunity. In real industrial applications, RS-485 communication ports subjected to these transients can be damaged. EMC problems discovered late in a product design cycle may require expensive redesign and can often lead to schedule overruns. EMC problems should, therefore, be considered at the start of the design cycle and not at a later stage where it may be too late to achieve the desired EMC performance.

The key challenge in designing EMC compliant solutions for RS-485 networks is matching the dynamic performance of the external protection components with the dynamic performance of the input/output structure of the RS-485 device

This article demonstrated three different EMC compliant solutions for RS-485 communication ports, giving the designer options depending on the level of protection required. The EVAL-CN0313-SDPZ is the industry's first EMC compliant RS-485 customer design tool, providing up to Level 4 protection levels for ESD, EFT, and surge. The protection levels offered by the different protection schemes are summarized in Table 4. While these design tools do not replace the due diligence or qualification required at the system level, they allow the designer to reduce risk of project slippage due to EMC problems at the start of the design cycle, hence reducing design time and time to market. For more information, please visit: www.analog.com/RS485emc.

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Authors

James Scanlon [james.scanlon@analog.com] is a senior evaluation engineer at Analog Devices, Inc. He received his BE in electronic engineering from the University College Dublin in 2001 and his M.Eng. in VLSI Systems from the University of Limerick in 2008. In 2001, James joined Analog Devices, Limerick, Ireland, as a design evaluation engineer specializing in laser diode drivers. He currently works in the interface and isolation technology group, predominantly dealing with a broad portfolio of transceivers.

Koenraad Rutgers is a senior field applications engineer at Bourns, Inc. He previously managed the European and Asian Telecom Circuit Protection team and now manages new product development for the semiconductor division. His key achievements include the integration of reference design activities with the new product development process and the launch of circuit protection products to multiple international tier-one customers. Koenraad has co-authored two IEEE papers and four patents.