RS-485 Networks

RS-485 Transient Protection in Industrial DC-Supply Buses

Abstract

The bus cables of industrial RS-485 networks share the same conduits with industrial DC supply buses, where cable miswiring and insulation brakes (due to sharp cable bends) are the main causes for shorts between data and supply conductors. To survive these fault conditions, overvoltage protected transceivers are needed, because they have bus terminals that possess high DC and AC standoff voltages that exceed the maximum possible DC supply voltage.

However, protecting bus data lines against even higher overvoltage transients, such as those caused by lightning strikes, requires Transient Voltage Suppressors (TVS) with specific switching characteristics.

This paper discusses the combination of an overvoltage protected transceiver and a TVS that protect RS-485 data lines against ESD, EFT, and Surge transients especially in industrial DC buses, which have a nominal 24V that can experience voltage excursions of up to 36V.

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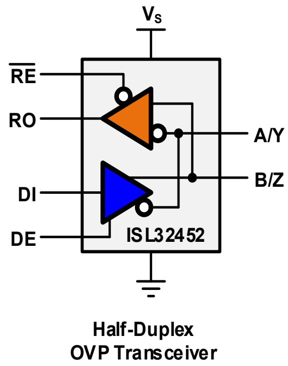
Related Literature

- AN1976: Important Transient Immunity Tests for RS-485 Networks
- AN1977: Transient Voltage Suppressors: Operation and Features
- AN1978: Surge Protection for Intersil’s Standard RS-485 Transceivers
- AN1979: Surge Protection simplified with Intersil’s Overvoltage Protected (OVP) Transceivers

1. The Overvoltage Protected (OVP) RS-485 Transceiver

A transceiver like the one in Figure 1 can withstand AC and DC overvoltages of up to ±60V. One bus line can hang at +60V while the other bus line sits at -60V, resulting in an impressive differential of 120V. Transient events according to EIA-485 can even reach up to ±80V.



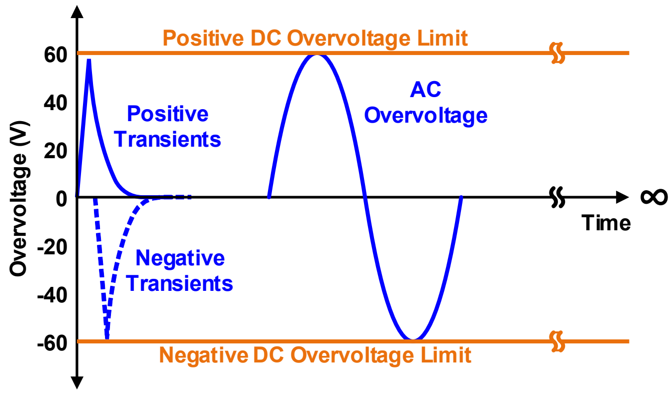


Figure 1. Overvoltage Protected RS-485 Transceiver Symbol and Voltage Range

Withstanding such high voltages is easy for a disabled transceiver, because it relies on the high breakdown voltages of its output transistors. However, overvoltages often occur during the most inconvenient times, such as during actual data transmissions. In this case, one of the bus drivers is enabled, trying to pump sufficient current down the line for the remote located receivers to detect correctly. A superseding overvoltage not allowing this to happen is understandable, as it is going to drive a much stronger current back into the driver.

1.1 Double Fold-Back Current Limiting

To prevent serious damage to the driver, a current limiting scheme that enables the driver to transmit data whenever possible yet limits its current during a fault event is necessary. Fault-protected transceivers (usually providing a common-mode range much wider than specified in the RS-485 standard) have driver stages with double fold-back current limiting.

Figure 2 shows the current limiting function of the fault-protected transceiver in Figure 1, which operates over the wide common-mode range of ±20V.

Here, a first fold-back current level of about 63mA ensures that the driver never folds back when driving loads within the entire 40V (±20V) common-mode range. Then, a much lower second fold-back current level (~13mA) minimizes power dissipation during an overvoltage fault event. This current limiting scheme ensures that the driver output current never exceeds the RS-485 specification, even at the common-mode and overvoltage range extremes.

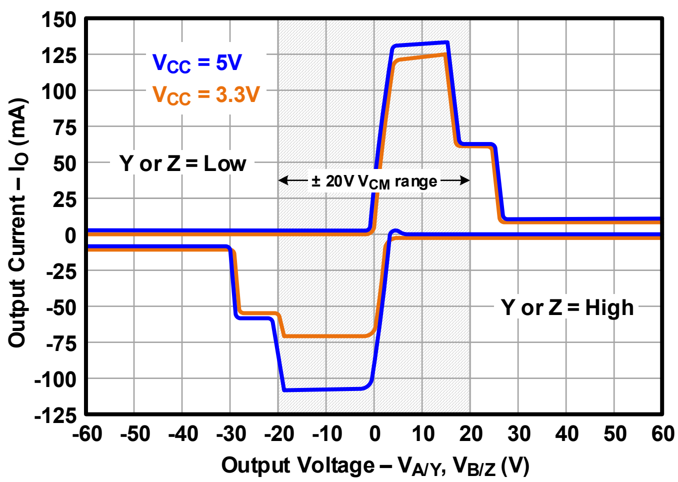


Figure 2. Double Fold-Back Current Limiting

If a major short-circuit condition occurs, the transceiver also provides a thermal shutdown function that disables the driver whenever the die temperature becomes excessive. This reduces power dissipation to zero and allows the die to cool. The driver automatically re-enables after the die temperature drops by about 15°C. If the fault condition persists, the thermal shutdown/re-enable cycle repeats until the fault is cleared. The receiver remains operational during thermal shutdown, and fault-protection is active regardless of whether the driver is enabled, disabled, or the IC is powered down.

1.2 Transceiver Internal ESD Protection

The transceiver internal ESD protection is accomplished with Silicon-Controlled Rectifiers (SCRs). These devices have a snapback rather than a Zener characteristic. They start conducting when an external voltage exceeds their trigger voltage threshold. Because of the high breakdown voltage of the driver output transistors, this trigger threshold is located at about ±70V to prevent erroneous triggering during normal operation. Figure 3 depicts the symmetrical snapback characteristic of the transceiver in blue.

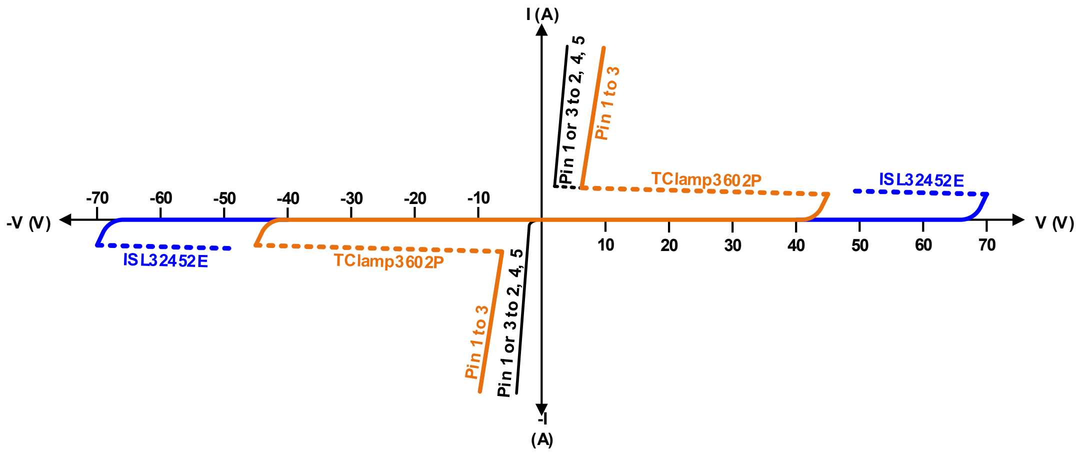


Figure 3. Snapback Characteristics of Transceiver ESD Cells and external TVS Diode

Setting the trigger thresholds far outside the operation limits has the enormous benefit of allowing the use of a wide range of TVS devices, which have high clamping voltages that remain below these trigger thresholds.

1.3 Transient Voltage Suppressors (TVS) with high DC Standoff

Many TVS devices exist that protect against the three major types of overvoltage transients: ESD, EFT, and Surge. To survive DC potentials of up to 36V, a TVS must have a working voltage of similar value and a reverse breakdown voltage of more than 40V. **Note:** The working voltage is the voltage where the leakage current into the TVS remains below 1mA. This is followed by the reverse breakdown, where the device starts slightly conducting and the current increases to 10mA.

Figure 4 on page 4 depicts a TVS device, where inner structure consists of four current steering diodes and one center snapback diode with a typical reverse breakdown of 45V. The I-V characteristics are shown in Figure 3.

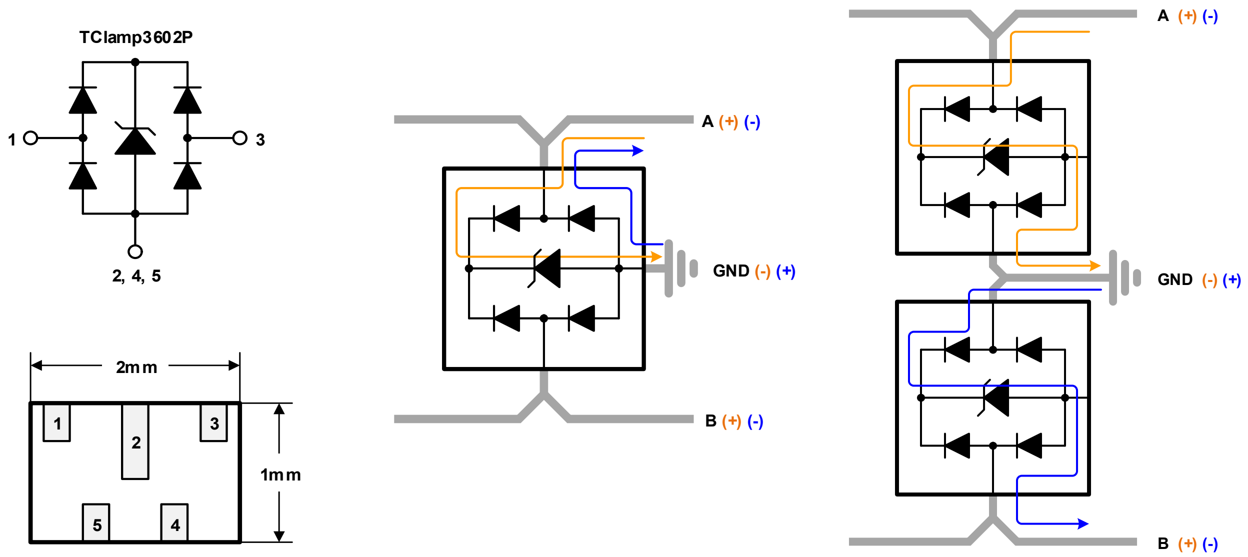


Figure 4. Internal TVS Structure and Wiring Options

Despite its high breakdown voltage accompanied with a 350mW power absorption capability, this TVS has a footprint of only 2mmx1mm. Terminals 1 and 3 connect to the data lines while terminals 2, 4, and 5 present the ground connection.

Two wiring options exist. Using one TVS to protect two data lines leads to an asymmetrical clamping profile. For clarity the current paths for only one conductor are shown. Applying test pulses with positive polarity to the A and B conductors causes the transient currents to flow through a steering diode and the center snapback device. For negative pulses the currents only pass through a single diode. The resulting asymmetrical clamping characteristics is shown in Figure 3 in black lines, denoted as Pin 1 or 3 to 2, 4, 5.

Using two TVS devices, one for each data line, results in the symmetrical clamping characteristic, denoted in Figure 3 as Pin 1 to 3. Here the ground pins 2, 4, and 5 are not connected. Instead one the I/O terminals, 1 or 3, connect to a data line and the other one to ground. Therefore, the flow of transient current for positive and negative pulses remains symmetrical.

As can be seen in Figure 3, the trigger thresholds of the TVS devices are way below the trigger thresholds for the internal SCRs of the transceiver; therefore, preventing interaction between the internal and the external protection schemes.

1.4 Final Circuit Design

The asymmetrical clamping of the single TVS solution drastically limits the common-mode range of the transceiver for negative common-mode voltages. Use this solution only in applications with small common-mode variations. In any other case, protect each line with a single TVS. The added footprint of $2mm^2$ lets you enjoy the full ±20V common-mode range and ensures you RS-485 compliance.

Another benefit of this TVS is its low junction capacitance of 4pF (maximum), which allows you to either protect each single node in long-haul networks, or the protection of high-speed (40Mbps) point-to-point data links without affecting signal integrity.

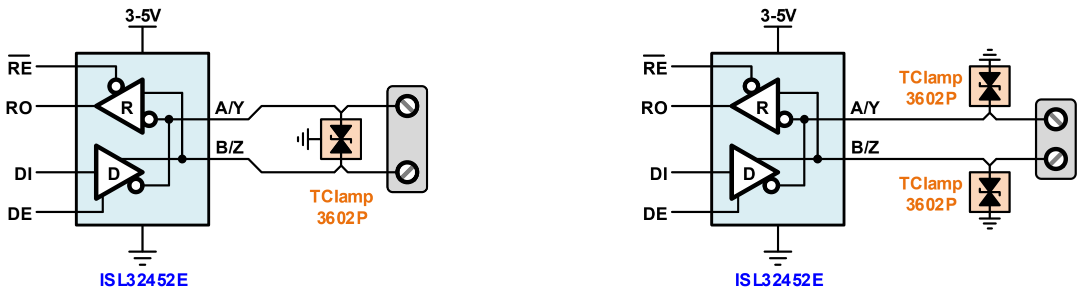


Figure 5. Lightning-protected RS-485 Bus Nodes

There are of course several design hints that let you proactively minimize the effects of overvoltage transients. Recall that the front and half times of ESD and EFT pulses is in the lower nano-second range. These transient times lead to a frequency spectrum ranging from some 30Hz up to 300MHz. Therefore, designing a robust overvoltage protection scheme turns into an RF design with all its requirements for decoupling and low-inductance return paths.

Hence, ensure your reference planes, GND and VCC, are true copper planes such as without holes or cutouts. These ensure low-inductance return paths. **Note:** High-frequency signals follow the path of least inductance, not the one of least impedance.

This in turn requires the use of multi-layer boards. Route signal traces on the top layer, followed by the ground (second layer) and VCC (third layer) planes. Route control signals, such as the enable signals, DE and /RE, on the bottom layer.

Place the TVS device as close as possible to the board connector to prevent transients from penetrating the board. Design the data line traces such, that currents flow easily into the TVS part before they proceed towards the transceiver bus terminals. Typical trace design uses small V-connections as shown in Figure 5.

Use decoupling capacitors close to the supply terminals of the transceiver as well as other IC you might on the board.

Preferably use one capacitor value for decoupling. Construct larger values through paralleling capacitors. The reactance of capacitors is first capacitive and later, with increasing frequency, inductive. Using multiple capacitor values might cause the inductance of one cap-value to form an LC-tank with the capacitance of another cap-value, causing significant EMI.

Use a minimum of two ground vias for TVS devices and decoupling capacitors to minimize via inductance.

2. Conclusion

The combination of overvoltage protected transceivers (fault-protected transceivers) in combination with modern transient voltage suppressors simplifies overvoltage protection design cost, space, and time drastically. The results of the overvoltages tests applied to the two protection schemes in Figure 5 are listed in Table 1:

Table 1. Overvoltage Test Results

Protection Scheme	TVS Device	V_{RWM} (V)	Transceiver	Surge Voltage (kV) (Note 1)	EFT Voltage (kV)	ESD Voltage (kV)		Bus Cap. (pF)
1 TVS	TClamp3602P	36	ISL32452E	±1.75	±2	±30	Contact	2.6
						±30	Air	
2 TVS	TClamp3602P	36	ISL32452E	±3.00	±2	±25	Contact	2.3
						±30	Air	

Note:
1. The surge level reported is the maximum passing voltage. Customer can reference to the surge rating in datasheet for PCB design.

Renesas has an arsenal of OVP transceivers, which in combination with Semtech TVS devices provide a variety of transient protection solutions for a wide range of applications.

3. Revision History

Rev.	Date	Description
1.00	Nov.18.19	Initial release

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