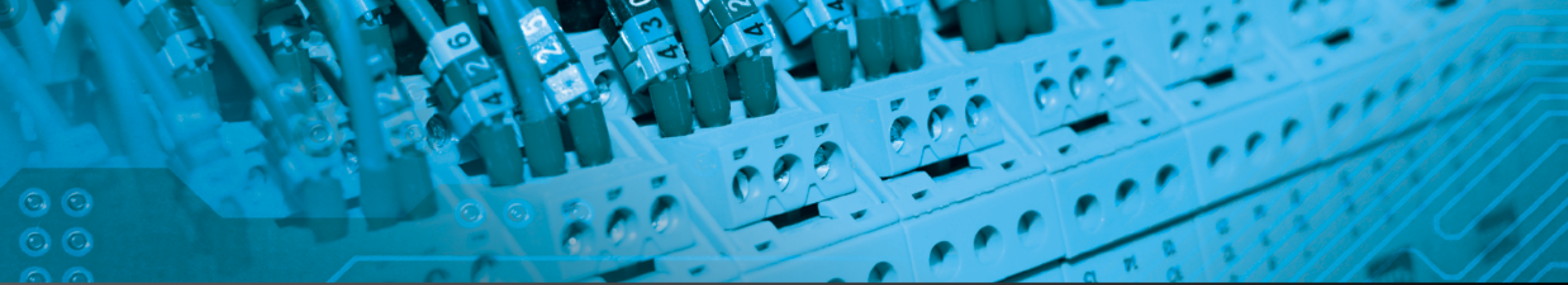

Application Note

Handling Transient Threats in RS-485 Systems

TBU-CA085-300-WH

P40-G240-WH


2031-23T-SM-RPLF

MOV-10D201K

CDSOT23-SM712


TISP4015L1BJ

Today's process control architectures and closed-loop systems are developed with numerous serial drops using point-to-point, multi-drop, or multipoint systems. The distances between serial drops can range from several meters to over a thousand meters. Data transfer protocols such as TIA/EIA-485, TIA/EIA-232, TIA/EIA-422, field buses, CAN, Profibus, Interbus, and LVDS, enable communication with various remote devices such as sensors, actuators, or monitors connected throughout the system. The RS-485 differential interface is useful in long distance communications where immunity to commonmode noise is prevalent, typically found in the process control factory setting. Process control systems must be designed with robust protection needed during installation (handling) and commissioning (miswiring), with high expectation of surviving significant transients (system transients/lightning). This application note describes circuit protection solutions that can be implemented to meet a variety of transient standards for RS-485 serial device ports. Bourns® circuit protection evaluation boards have been introduced to assist the system designer in developing solutions utilizing the Bourns® TBU® High-Speed Protector (HSP), Metal Oxide Varistor (MOV), Gas Discharge Tube (GDT), and Transient Voltage Suppression (TVS) diode products.

Introduction to RS-485

As a standard for industrial communications, RS-485 features fast data rates that achieve 35 Mbps for short distances and 100 kbps over longer distances. It is not unusual to encounter miswiring and short circuit faults, especially when covering longer distances. Transients and surges also can be generated by induced energy on the data lines due to environmental conditions or switching of heavy inductive loads. Any of these issues can degrade the serial port's data transfer performance. RS-485 commonly is deployed in building automation, security system controls, and other industrial communication applications. One common application of RS-485 that illustrates its sensitivity is an elevator control system. With cables in motion, and large motors and inductors in proximity, rugged communication systems are required.

RS-485 systems are inherently more robust than many other networks because the signal is delivered differentially between two wires, relative to a third reference voltage. The reference voltage is often, but not always, the local earth potential. This provides substantial immunity to common mode noise such as ground noise and induced noise from nearby motors, solenoids and transformers. The interface uses voltages that are high by communication system standards, also making it more robust than networks using other protocols. For instance, Ethernet signals are about 2 V and the popular USB standard communicates at a maximum of 5 V, though much internal communication in a computer is even lower. RS-485, on the other hand, allows for common mode voltages from -7 V to +12 V. The voltage drop between distant nodes can be accommodated without adding expensive equipment along the path.

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RS-485 Port Interface Requirements

Displayed in table 1 are the interface specifications for RS-485 ports. Key electrical parameters of -7 V to +12 V operating voltage with 32 Mbps data transfer at distances of 1200 meters are included. A fully compliant RS-485 port must meet IEC 61000-4-2 (ESD), IEC 61000-4-4 (EFT) and IEC 61000-4-5 (Surge) standards.

Table 1: RS-485 Interface Specifications

Differential	yes
Max. number of drivers	32
Max. number of receivers	32
Modes of operation	half duplex
Network topology	multipoint
Max. distance	1200 m
Max. speed at 12 m	32 Mbps
Max. speed at 1200 m	100 kbps
Receiver input sensitivity	+/- 200 mV
Receiver input range	-7 V to +12 V
Max. driver output voltage	-7 V to +12 V
Max. driver output voltage with load	+/- 1.5 V

Every serial port design follows the nominal recommended voltage range for the bus pins. RS-485 defines how much protection the device has beyond the –7 V to +12 V. If the environment demands that the bus survives up to ±24 V, then external protection must be added or adapted to meet compliance standards. Bourns offers various circuit protection technologies for overcurrent and overvoltage protection. The selection of a device or combination of devices depends on the requirements of the application and the specifications of other devices such as the serial bus driver.

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Protection for RS-485 Ports

A general protection scheme for an RS-485 network includes a TVS diode array such as the Bourns® Model CDSOT23-SM712 device on each node. This single-stage bidirectional device provides asymmetrical overvoltage protection for the RS-485 transceiver across the entire -7 V to +12 V common mode voltage range. For RS-485 systems with limited exposure, this TVS diode array may be all that is needed for reliable operation.

Effective Circuit Protection in Action

The single-stage TVS diode solution will provide effective clamping of the transient signal up to the peak impulse current, I_{PP}, of the TVS diode. I_{PP} is the maximum current the TVS diode can be subjected to without failure. As the TVS diode is exposed to higher transient voltages, concern for exceeding this device's current limitation rises as well. Current limiting must be used to keep I_{PP} within its rated limit. A TVS diode with series resistance R_x, shown in figure 1, is effective for low level transients. As the transient voltage increases, the power rating (and physical size) of the TVS diode and series resistance also must increase to limit the TVS diode's current below the device's I_{PP} (peak pulse current rating). The transient energy will be a function of the transient pulse width, duration, and slew rate (dv/dt). Most TVS diode data sheets will provide the P_{PP} rating for either 8/20 µs or 10/1000 µs surges. In addition, TVS diode data sheets may provide a log-log graph describing the diode performance when exposed to longer or shorter transient pulses.

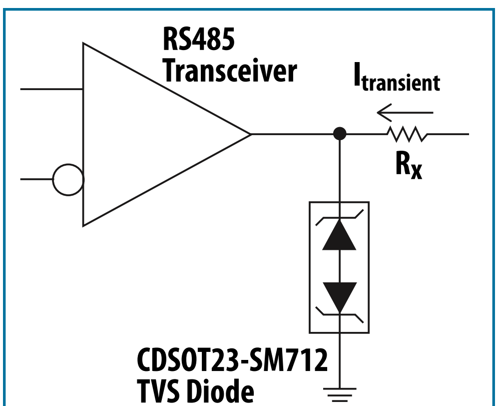

Figure 1: TVS Diode Plus Resistor

As the transient energy increases, the limitation of the single-stage solution becomes apparent. For example, if the series resistance R_x is increased to limit the maximum current to the TVS diode, then the voltage drop during normal operation of the communications loop will affect signal transition levels. The communication loop distance is shortened as a result of the increased resistance. The required size and power dissipation of the R_x resistor increases as the magnitude of the transient voltage and current increases and a practical solution is no longer achievable. As we will discuss, the three-stage transient protection scheme offers the capability to handle large transients with minimal impact on the length of the communication link, occupying a small area on the printed circuit board (PCB).

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Effective Circuit Protection in Action *(Continued)*

The three-stage protection scheme, figure 2, provides an optimal approach when protecting the RS-485 transceiver in applications located in more exposed transient environments with large signal levels and fast rising, long duration surges. This solution uses TVS diodes for secondary protection, Bourns® TBU® HSP devices for coordination, and either MOVs or GDTs for primary protection. The response characteristics of these circuit protection components are coordinated to provide a robust level of protection for the RS-485 interface that far exceeds the transient handling capability of a single-stage component solution.

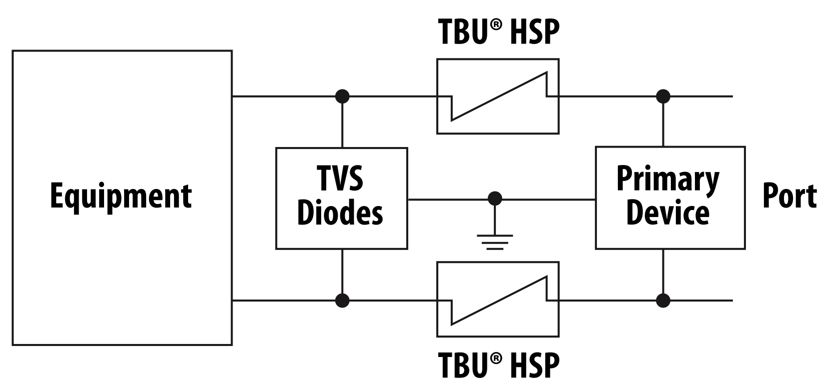

Figure 2: Three-Stage Coordinated Protection

Implementing the Three-Stage Protection Solution

Figure 2 shows the topology for three-stage coordinated protection. Components are chosen to provide coordinated protection beginning where the transient enters the protected port. An MOV or GDT primary device protects the Bourns® TBU® HSP from exposure to excessive transient voltage, clamping or crowbarring to a level less than impulse. When the transient current exceeds the Bourns® TBU® HSP trigger current limit, the sub-microsecond response of the Bourns® TBU® HSP limits the current let-through to the sensitive transceiver. The TVS diodes at the RS-485 transceiver provide a tight voltage clamp to keep the RS-485 signals within the absolute maximum voltage ratings of the transceiver.

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Understanding the Operation of the Bourns® TBU® High-Speed Protector

The TBU-CA Series of Bourns® TBU® HSP products are low capacitance, single, bidirectional, high-speed (sub-microsecond) circuit protection components constructed with MOSFET semiconductor technology. They are designed to protect against faults caused by short circuits, AC power cross, induction, and lightning surges up to rated limits, and then reset once the fault clears. The Bourns® TBU® HSP offers a significant performance increase in terms of response time compared to solutions previously available. The Bourns® TBU® HSP offers simplified place and route manufacturing due to the small size of the Bourns® TBU-CA package, which measures a mere 6.5 mm by 4 mm. The Bourns® TBU® HSP is available in a surface mount DFN package meeting industry standard requirements such as RoHS* and Pb-free solder reflow profiles.

The three-stage topology handles large transient surges through sub-microsecond coordination of the TBU® HSP with the primary and secondary elements. During normal circuit operation, the Bourns® TBU® HSP presents a finite series resistance to the communication loop. As the transient current increases to the TBU® HSP trigger current level, the TBU® HSP switches to a very high resistance or protected state, effectively disconnecting the transient from the sensitive RS-485 transceiver. The Bourns® TBU® HSP enters this protected state in less than 1 microsecond, providing a flat response over operating temperature, independent of frequency of the incident transient signal. The linear, high-speed response of the TBU® HSP helps to minimize transient testing requirements and time spent preparing for regulatory compliance.

In any transient environment, power cross and high surge current are significant challenges for circuit designers especially when working in a finite PCB area. As discussed previously, the TVS diode and resistor single-stage solution is effective in handling small to medium transients but impractical for power cross and large surge currents. The Bourns® TBU® HSP offers a significantly smaller footprint that will handle power cross up to 265 V_{rms} and surge currents above 20 kA when used in combination with the right primary protector. To demonstrate the response of the three-stage protection scheme, measurements were made using the schematic in figure 3. The 100 Ω load resistor featured in the schematic is not necessary in an actual application. It is used in this instance to mimic the load of the application circuit.

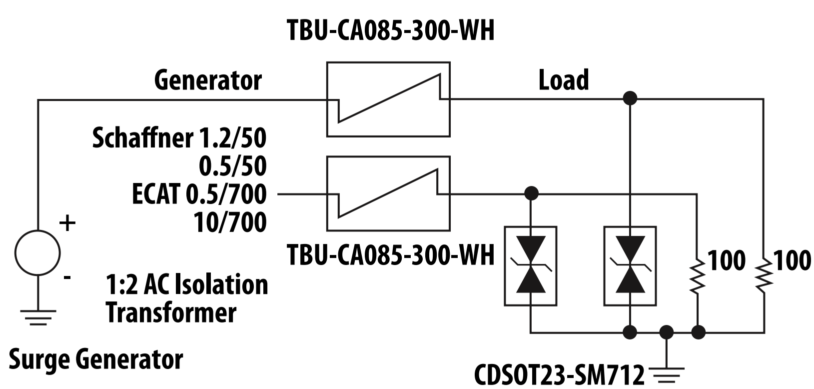

Figure 3: Bourns® TBU® HSP Transient Testing Circuit

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Selecting the Primary and Secondary Protector in a Three-Stage Topology

The purpose of the primary protector is to prevent voltage excursions greater than $V_{impulse}$ from reaching the Bourns® TBU® HSP. Thus the clamping or crowbar voltage of the primary protector must be less than $V_{impulse}$ at the surge current, I_{surge}, where $I_{surge} = V_{generator}/R_{generator}$. I_{surge} is based on the transient environment with threat levels defined per IEC 61000-4-5.

The secondary voltage protector is chosen to clamp or crowbar at a voltage less than the absolute maximum voltage rating of the RS-485 transceiver. Since the TBU® HSP has a very fast response of less than 1 µs, only a minimal amount of current is let-through to the secondary device, worst-case leaving a small amount of energy to be handled by the transceiver internal steering diodes.

Capacitance is another key consideration when selecting the primary and secondary protectors. If the maximal allowable capacitance of the interface is exceeded, then the bandwidth of the nodes is limited. The capacitance on this signal is a lumped effect from the cabling, connector, and circuit protection components. Estimating the capacitance from the cabling and connector will indicate the maximum capacitance budget remaining for the circuit protection components. While our example application circuit utilizes a TBU® HSP with a 300 mA current trip level, this level can be higher or lower depending on the cable type and distance of the communication link.

Transient Test Data

The following oscillograms are helpful in understanding the performance of the Bourns® TBU® HSP-based three-stage protection solution for AC power cross and a variety of transient surges. Using the schematic from figure 3, the following waveforms demonstrate the negligible signal energy seen at the secondary TVS diode clamp, i.e. I_{TBU} is a fraction of $I_{transient}$.

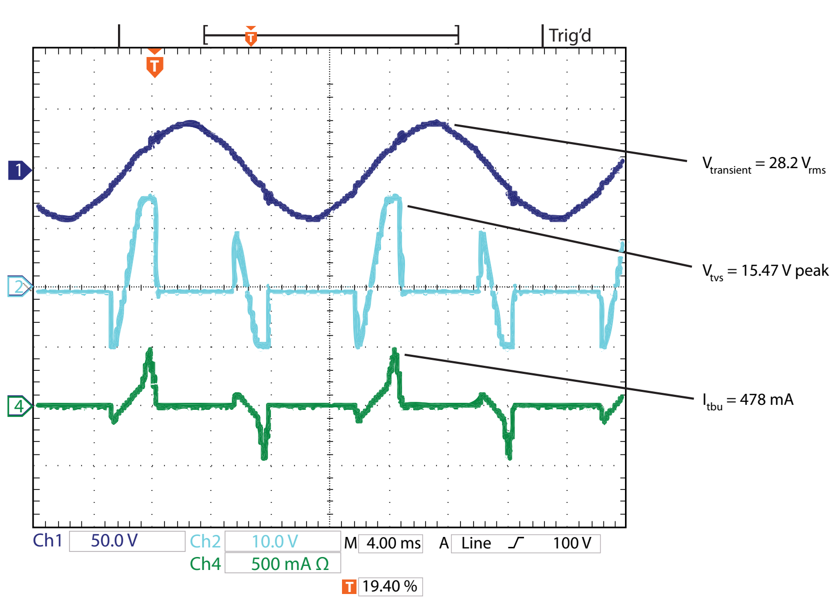

Figure 4: 28 V_{rms} Power Cross

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Transient and Protection Level Test Data *(Continued)*

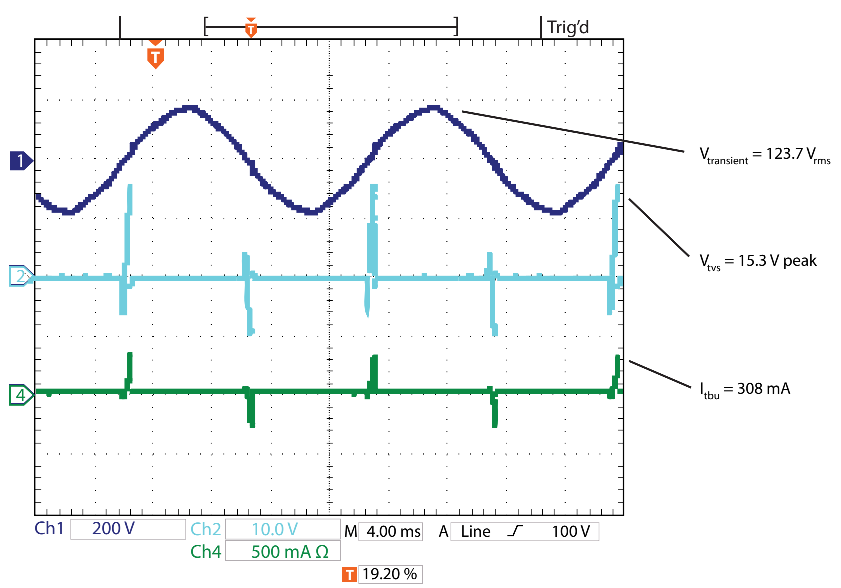

Figure 5: 120 V_{rms} Power Cross

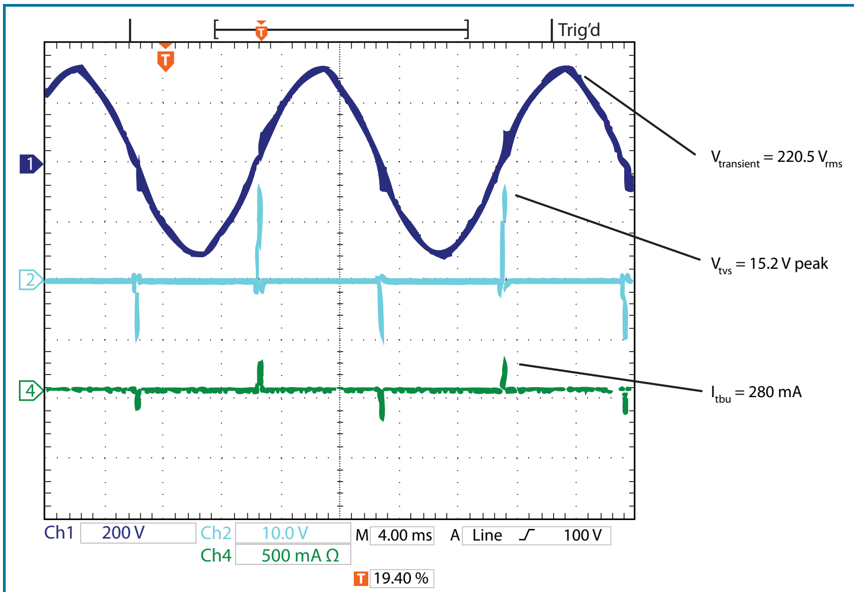

Figure 6: 220 V_{rms} Power Cross

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Transient and Protection Level Test Data *(Continued)*

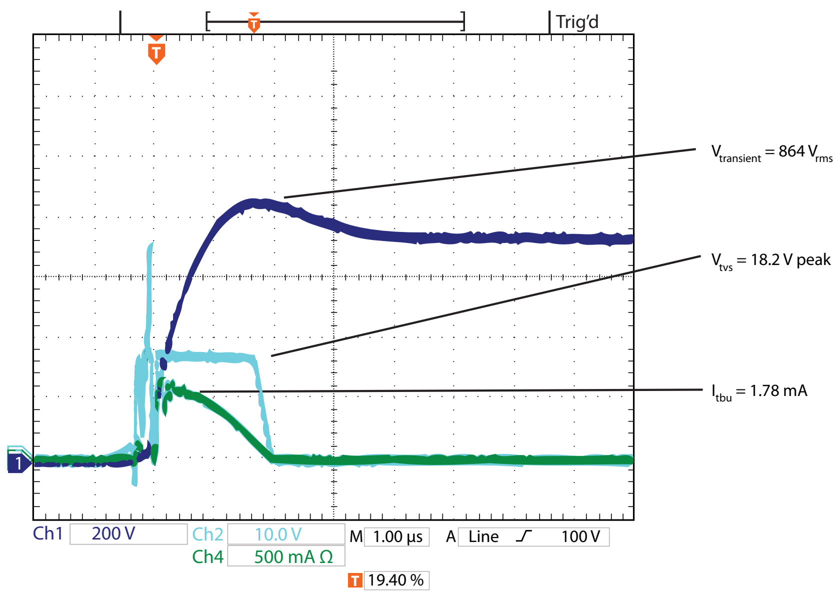

Figure 7: 1.2 µs t_{rise}/50 µs t_{fall} Surge

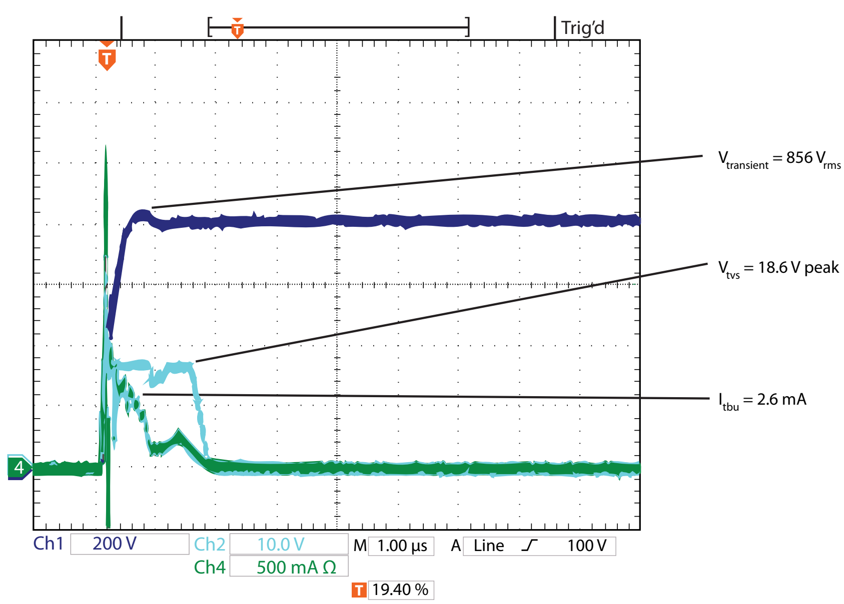

Figure 8: 0.5 µs t_{rise}/700 µs t_{fall} Surge

The above power cross and transient surge examples demonstrate the predictable response of the TBU® HSP in limiting current to the protected load. Further, the three-stage protection topology allows the designer to easily select primary and secondary components to provide a robust transient response with minimal verification testing.

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Handling DC Power Faults using the TBU® HSP

A DC bus, used for relay control and actuators, is typically found in the implementation of industrial communication systems. This leaves the potential for DC power being miswired from installation mishaps resulting in a DC power connection to the RS-485 differential signal lines. This 'hard fault' (vs. transient fault) requires special consideration when designing a TBU® HSP electronic current limiter-based protection circuit. As the TBU® HSP is a semiconductor, the power dissipation with a sustained fault from direct current is significant and a design which ensures the TBU® HSP is in the protected (high-impedance) state is critical to a repeatable and robust solution. The circuit configuration in figure 4 utilizes a P40-G240-WH HSP to handle the ±24 V power fault case:

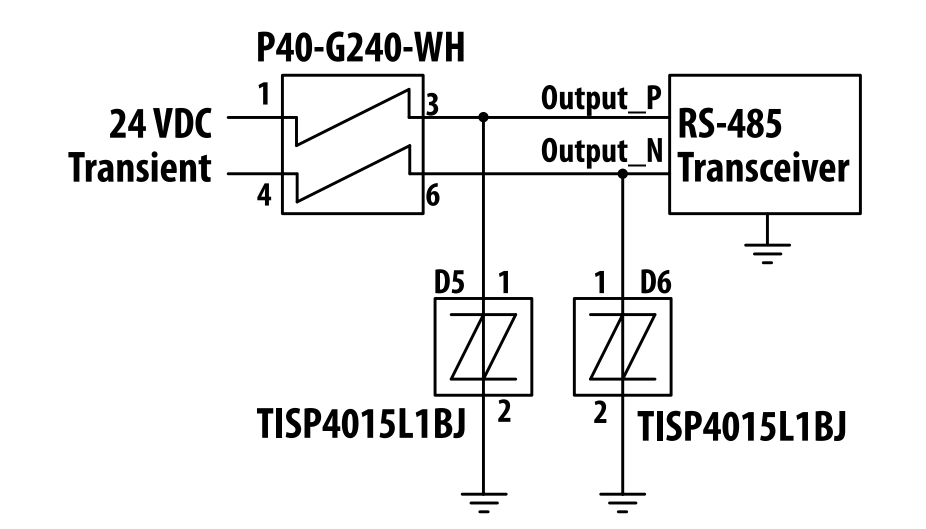

Figure 9: Handling DC power faults with the TBU® HSP

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Handling DC Power Faults using the TBU® HSP *(Continued)*

The TBU® HSP operates in the high-impedance (protected) state when the voltage across the TBU® HSP is greater than V_{reset} (typically 7 volts). During the DC power fault, the thyristor (TISP4015L1BJ) is used to crowbar the power fault to zero volts at the RS-485 transceiver. The 24 V across the TBU® HSP exceeds the P40-G240-WH V_{reset} forcing the TBU® HSP into the protected state. After the power fault is cleared, the TBU® HSP resets and normal RS-485 circuit operation resumes. The P40-G240-WH solution can handle faults less than or equal to 40 V ($V_{impulse}$).

By combining the transient solution from figure 3, and the DC power fault solution of figure 4, high-speed transients and AC and DC power cross are able to be handled in the following TBU® HSP-based circuit, figure 5:

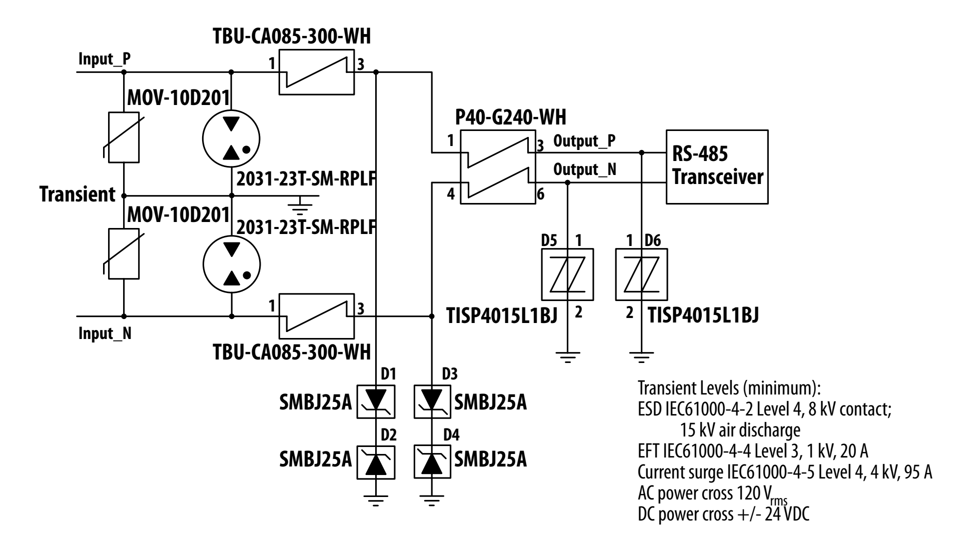

Figure 10: Handling AC & DC Power Fault & High-Speed Transients with the TBU® HSP

In the robust transient solution above, the MOV provides ESD/EFT protection while the GDT handles high surge current, protecting the TBU-CA085 from signals greater than 850 V (TBU-CA085 $V_{impulse}$). At the input to the P40, back-to-back TVS diodes are used to protect the P40-G240-WH, clamping signals to less than 40 V. (P40-G240-WH $V_{impulse}$). The DC fault is handled by the combination of the thyristor (TISP4015L1BJ) and P40-G240-WH HSP.

As the transient environment varies in each application, the TBU® HSP configurations discussed are for the specific conditions outlined within. Please contact Bourns to discuss your specific application requirements.

Bourns Evaluation Boards

Two evaluation board options are available to designers when evaluating the bidirectional Bourns® TBU-CA HSP Series. RS-485 Evaluation Board 1 provides a very high current primary protector solution with a GDT. This solution will support high bandwidth signals with no signal degradation because of the GDT's extremely low 1 pf capacitance loading. RS-485 Evaluation Board 2 will support medium bandwidth signal interfaces above 10 MHz using an MOV primary protector. This level of protection provides a low cost solution for most RS-485 interfaces and transient currents up to 2.5 kA. To offer maximal flexibility these evaluation boards support many protection combinations. It is important to review the transient requirements prior to use to ensure the current surge and power cross levels are capable of the required performance. Please contact a local Bourns representative or Bourns customer service to order evaluation boards.

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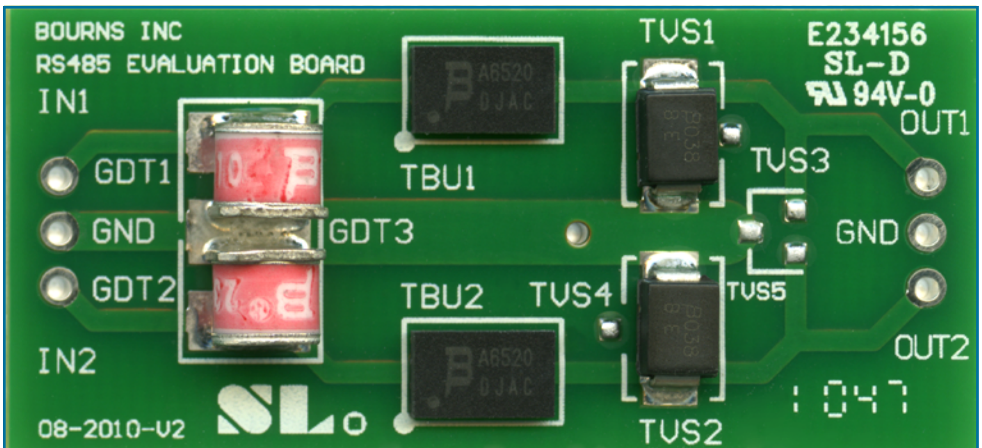

Figure 11: RS-485 Evaluation Board 1: GDT Primary Protector

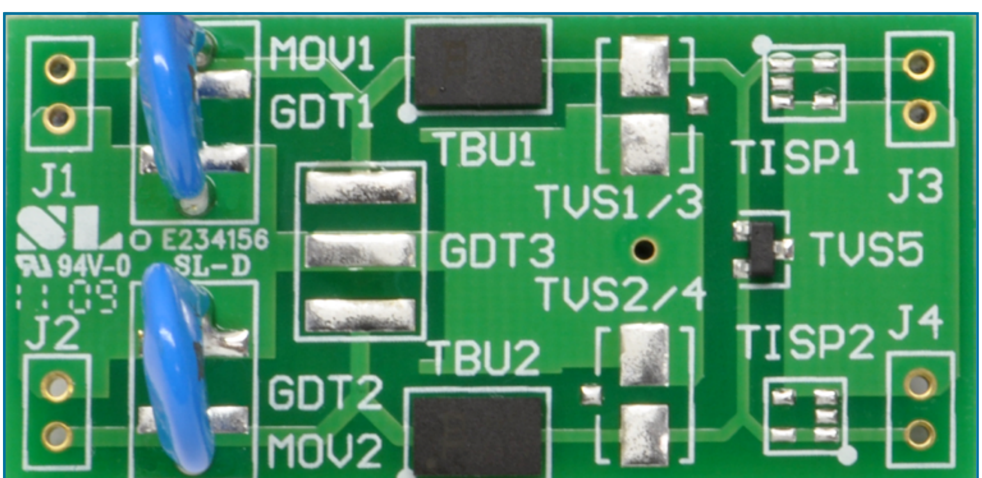

Figure 12: RS-485 Evaluation Board 2: MOV Primary Protector

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Summary

The recommended three-stage protection solution featuring Bourns® TBU® HSP devices offers enhanced performance over competing solutions. Design engineers can take advantage of this three-stage solution to increase the surge and transient protection levels on RS-485 ports and have robust protection against significant transient events such as AC power cross, ESD, EFT, and surge current. Bourns' approach protects the RS-485 transceiver by combining the Bourns® TBU® HSP to limit the let-through voltage and energy, the TVS diode to keep the signal within the maximum limits of the RS-485 transceiver, and a primary GDT or MOV to protect the TBU® HSP by limiting the maximum voltage to which it is exposed. Bourns offers developers evaluation boards to allow easy prototyping. Board configuration options assist in selecting the most suitable part number for this Bourns® TBU® HSP-based three-stage solution. The compact size of the TBU® HSP can reduce the overall board area compared to what was required previously to meet the protection requirements.

The use of Bourns® TBU® HSP devices brings a new level of overvoltage and overcurrent protection to RS-485 drivers.

Why Bourns?

The TBU® High-Speed Protector technology is unique to Bourns, a company that has been a proven leader in the circuit protection industry for several decades. Bourns invests in innovative new products through internal development and strategic acquisition of companies and products lines. Bourns serves diverse markets from computers and peripherals to telecommunications. The company's commitment to excellence in design and customer service and its established track record in circuit protection for over half a century sets Bourns apart from its competition in terms of quality and integrity.

References:

More information on the Bourns® TBU® HSP and other Bourns® circuit protection solutions can be found online:

- **http://www.bourns.com/data/global/pdfs/bourns_tbu_white_paper.pdf**
- **http://www.bourns.com/data/global/pdfs/TBU-CA_MDS.pdf**
- **http://www.bourns.com/ProductFamily.aspx?name=circuitprotection**
- **http://www.bourns.com/data/global/pdfs/Bourns_FU1106_RS-485_Evalboard_DesignNote_1.pdf**
- **http://www.bourns.com/data/global/pdfs/Bourns_FU1106_RS-485_Evalboard_DesignNote_2.pdf**

For further technical support and for complete port solutions, please visit
www.bourns.com

*RoHS Directive 2002/95/EC Jan. 27, 2003 including Annex.

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