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Understanding Insertion and Return Losses with Bourns® TBU® High-Speed Protectors (HSPs) in High-Speed Applications

APPLICATION NOTE

Introduction

Protecting high-speed applications from transients and faults presents a component selection challenge. While Gas Discharge Tubes (GDTs) offer low capacitance for overvoltage protection, introducing an overcurrent protection component in series can degrade signal integrity due to increased insertion and return losses.

This paper outlines why the overcurrent or short circuit protection in high-speed designs requires additional current limiting. It presents the advantages that Bourns® TBU® High-Speed Protectors (HSPs) can provide with their low impedance and non-inductive resistance that deliver the minimal insertion and return losses that meet high-speed application protection specifications. For the purposes of this paper, the analysis of using TBU® HSPs will be limited to applications that operate at frequencies below 3 GHz.

TBU® High-Speed Protector (HSP) Functionality

Offering rapid current blocking when the current exceeds design limits, a TBU® HSP acts as a resettable fuse. Unlike traditional fuses, which operate in hundreds of milliseconds, the TBU® HSP transitions from low to high impedance in less than 1 microsecond (µs) in most cases. While extensive documentation exists on TBU® HSP's operational behavior, this paper focuses on its relevance for high-speed applications.

Bourns® TBU® High-Speed Protectors (HSPs) for Surge Protection

Depending upon the model and its withstand voltage, a TBU® HSP typically exhibits an impedance between a few ohms and approximately 20 ohms.

Table 1. Bourns® TBU® High-Speed Protector (HSP) models and respective specifications

Models	Withstand Voltage	Trigger Current (mA)	Impedance (Ω)
TBU-025-050-WH-Q*	250	50	15
TBU-025-500-WH	250	500	3
TBU-050-100-WH	500	100	11
TBU-065-100-WH-Q*	650	100	13
TBU-065-200-WH	650	200	10
TBU-065-300-WH	650	300	9
TBU-085-500-WH	850	500	12

*Q suffix denotes for AEC-Q Qualified

Before providing specific measurement analyses, the definitions of the insertion loss and return loss are provided on the following pages.

What is Insertion Loss?

Insertion loss is the loss of signal power that results from inserting a device or component into a transmission line or optical fiber. It's essentially a measure of how much a signal is weakened when it passes through something. Imagine water flowing through a pipe. If you insert a narrow section or a filter into the pipe, it will restrict the flow of water, reducing the amount that comes out the other end. Insertion loss is similar – it's the reduction in signal strength caused by inserting a component into the signal's path.

Key Points On Insertion Loss:

- **Measured in decibels (dB):** Insertion loss is typically expressed in decibels, which is a logarithmic unit that makes it easier to represent large changes in power.
- **Causes:**
  - **Resistance:** The inherent resistance of the component or the transmission line itself.
  - **Impedance mismatch:** When the impedance of the inserted component doesn't match the impedance of the transmission line, some of the signal is reflected back, resulting in a loss.
  - **Dielectric losses:** Energy can be lost in the insulating materials (dielectrics) of cables and components.
  - **Connectors and splices:** Any connection point in the transmission line can introduce some loss.

Why Is Insertion Loss Important?

Excessive insertion loss can degrade signal quality, leading to:

- **Reduced signal strength:** The signal may become too weak to be properly received or interpreted.
- **Increased bit errors:** In digital communication, a weak signal can lead to errors in data transmission.
- **Decreased range:** In wireless communication, insertion loss can reduce the effective range of the signal.

Rule of Thumb for Insertion Loss of TBU® HSPs:

- **Low Insertion Loss (Good):** Especially at high frequencies, so it doesn't significantly weaken the signal it is protecting.
- **High Insertion Loss (Bad):** It weakens the signal that it protects.

What is Return Loss?

Return loss is a measure of how much of a signal is reflected back from a discontinuity in a transmission line or optical fiber. It's essentially the opposite of insertion loss.

Key Points On Return Loss:

- **Decibels (dB):** Like insertion loss, return loss is measured in decibels. However, a higher dB value for return loss is better.
- **Signal Reflection:** When a signal travels through a transmission line and encounters a change in impedance (like a connector, a component, or the end of the line), some of the signal's energy is reflected back towards the source.
- **Return Loss Measurement:** Return loss quantifies the amount of this reflected power compared to the incident power (the original signal power).

Relationship to Impedance Matching:

Return loss is directly related to impedance matching. When the impedance of the source, transmission line, and load are perfectly matched, there is no reflection, and the return loss is theoretically infinite. In practice, achieving a perfect match is impossible, but minimizing reflections (maximizing return loss) is a key goal in many applications.

Why Is Return Loss Important?

- **Signal Quality:** Reflected signals can interfere with the original signal, causing distortion and errors, especially in digital communication.
- **Power Efficiency:** Reflected power is wasted power. In transmitting systems, you want as much power as possible to reach the destination.
- **Component Protection:** In some cases, excessive reflected power can damage components, particularly in high-power systems.

Rule of Thumb for Return Loss of TBU® HSPs:

- **High Return Loss (Good):** Most of the signal is transmitted forward, and very little is reflected back. This indicates a good impedance match.
- **Low Return Loss (Bad):** A significant portion of the signal is reflected back, indicating a poor impedance match.

Employing Bourns® TBU® HSPs in High-Speed Designs

In summary, both are important metrics for evaluating the performance of transmission lines and components, especially in high-frequency applications.:

- **Insertion Loss:** How much signal is lost going through a component.
- **Return Loss:** How much signal is reflected back from a component or discontinuity.

Because a TBU® HSP has an inherent impedance, some insertion loss is expected. Designers might initially compensate for this loss by increasing power. However, with most components, losses increase with frequency, often due to inherent inductance. A TBU® HSP, however, exhibits very low parasitic inductance, resulting in minimal loss at high frequencies, even up to 3 GHz.

Another important consideration are S-parameters, which are used to describe the electrical behavior of linear electrical networks when subjected to various stimuli by small signals. They are particularly useful for high-frequency applications.

For a two-port network (a network with two input/output ports), there are four main S-parameters:

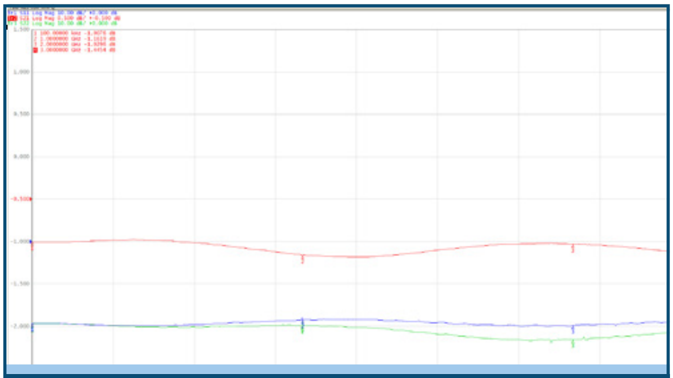
- **S11:** Input reflection coefficient. It represents the ratio of the signal reflected back from port 1 to the incident signal at port 1. It's directly related to return loss at the input.
- **S21:** Forward transmission coefficient. It represents the ratio of the signal transmitted from port 1 to port 2 to the incident signal at port 1. It's directly related to insertion loss.
- **S12:** Reverse transmission coefficient. It represents the ratio of the signal transmitted from port 2 to port 1 to the incident signal at port 2. This parameter was not included in the graph because its behavior is identical to S21.
- **S22:** Output reflection coefficient. It represents the ratio of the signal reflected back from port 2 to the incident signal at port 2. It's directly related to return loss at the output.

Simplified Example

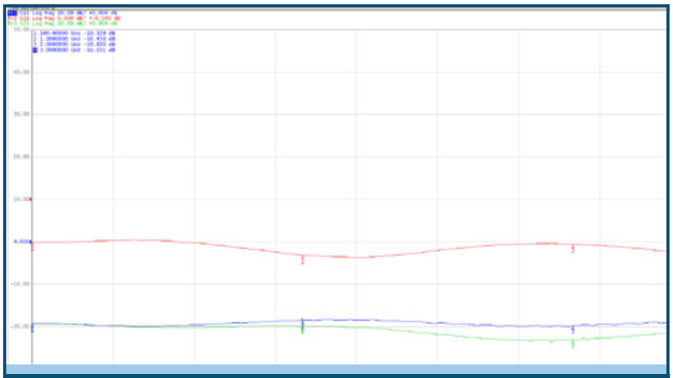
Imagine a signal entering a device through port 1 and exiting through port 2:

- **S21 (Insertion Loss):** This parameter quantifies the signal power transmitted from port 1 to port 2. It's expressed in decibels (dB). The more negative the S21 value (further away from 0 dB in the negative direction), the greater the insertion loss. So, -3 dB of S21 means that there is loss greater than -1 dB of S21. Ideally, 0 dB means no loss in transmission.
- **S11 (Input Return Loss):** This parameter measures the signal power reflected back at port 1. It's also expressed in dB. The more negative the S11 value (further away from 0 dB in the negative direction), the less reflection and the better the impedance matches the input. For example, -20 dB of S11 indicates less reflection and a better match than -10 dB of S11. Preferably, designers would want S11 to be as negative as possible.
- **S22 (Output Return Loss):** This parameter measures the signal power reflected back at port 2. Like S11, it's expressed in dB. The more negative the S22 value (further away from 0 dB in the negative direction), the less reflection and the better the impedance matches the output. The same logic as S11 applies, the closer to negative is better.

The following graphs illustrate the performance characteristics of each TBU® HSP listed in Table 1.



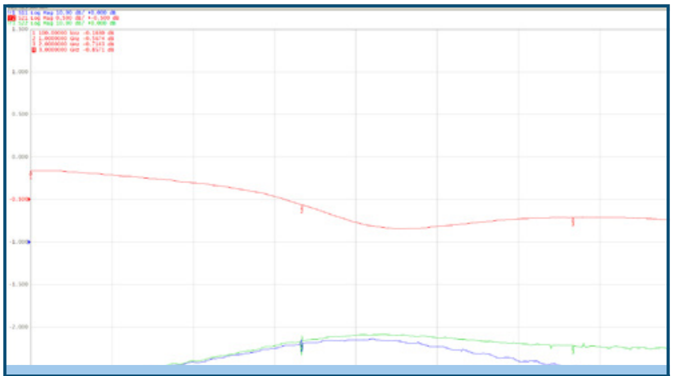
TBU-025-050-WH-Q (S21)



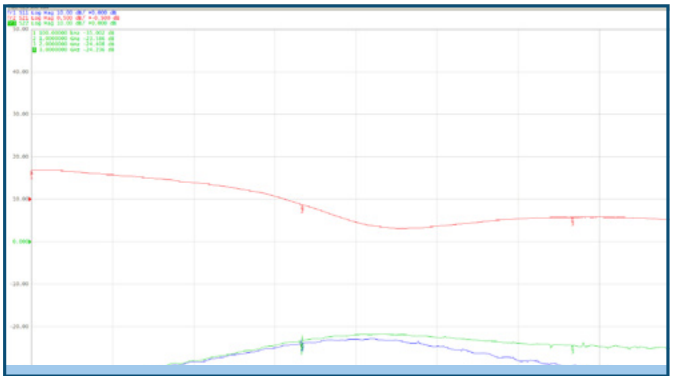
TBU-025-050-WH-Q (S11/S22)

Simplified Example

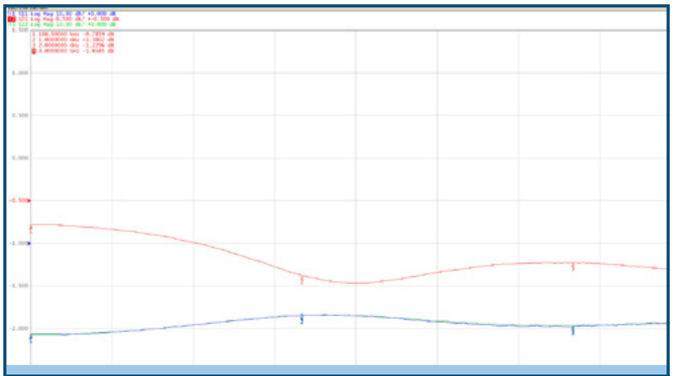
The following graphs illustrate the performance characteristics of each TBU® HSP listed in Table 1.



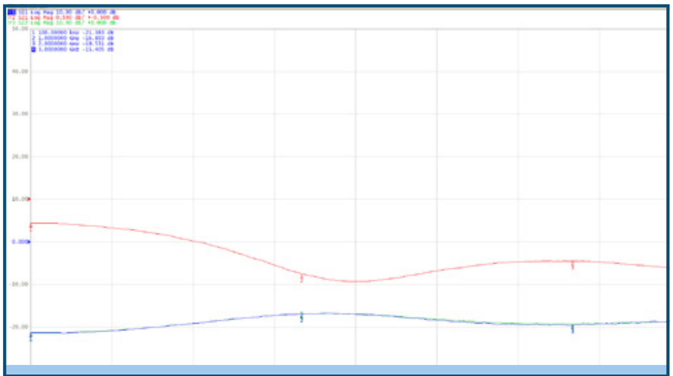
TBU-025-500-WH (S21)



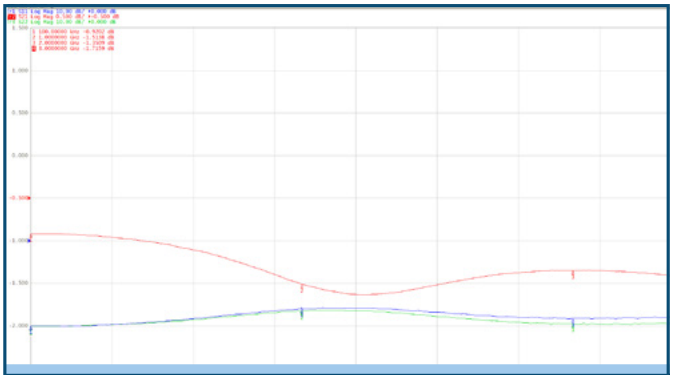
TBU-025-500-WH (S11/S22)



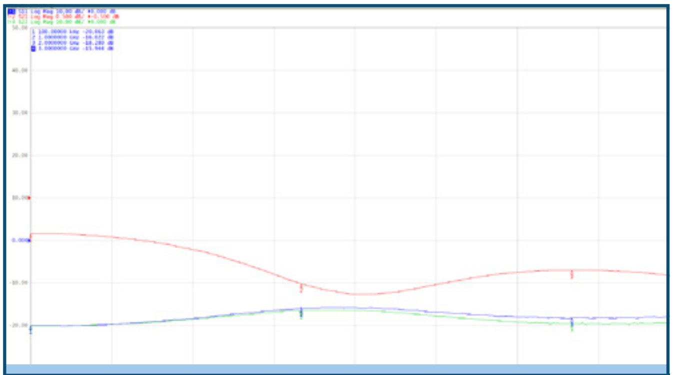
TBU-050-100-WH (S21)



TBU-050-100-WH (S11/S22)



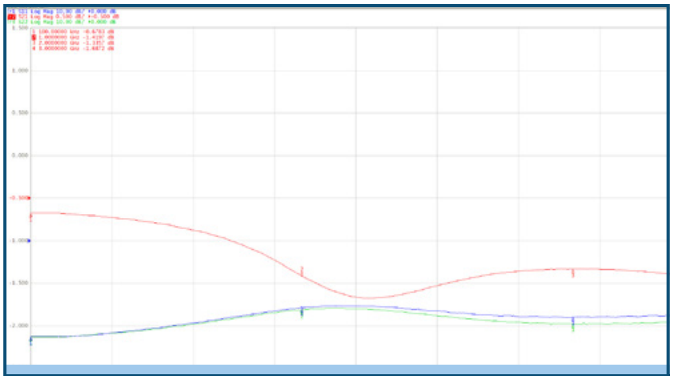
TBU-065-100-WH-Q (S21)



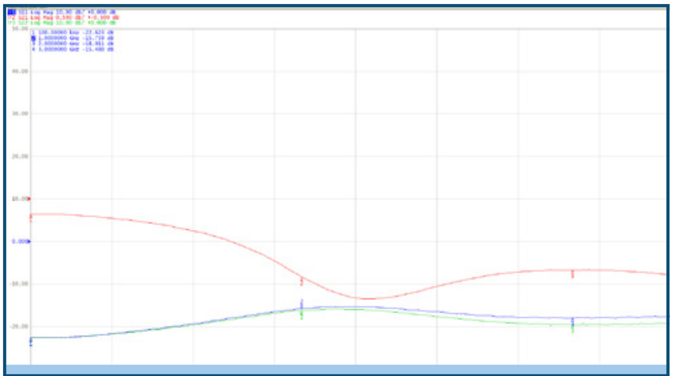
TBU-065-100-WH-Q (S11/S22)

Simplified Example (Continued)

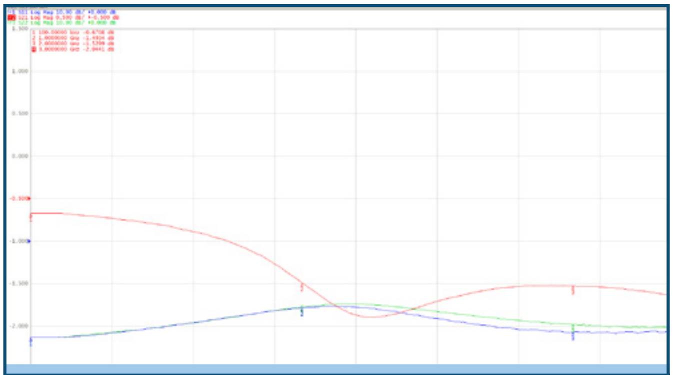
The following graphs illustrate the performance characteristics of each TBU HSP listed in Table 1.



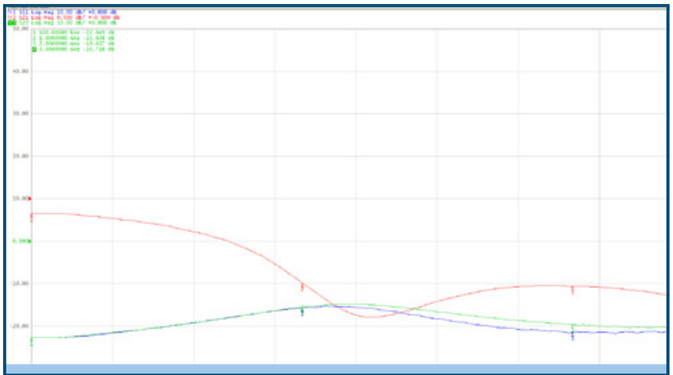
TBU-065-200-WH (S21)



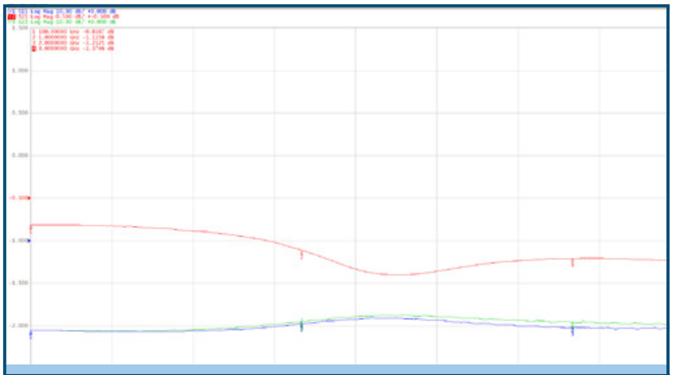
TBU-065-200-WH (S11/S22)



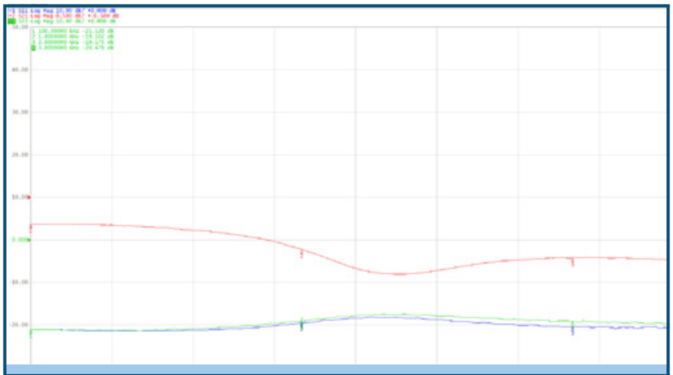
TBU-065-300-WH (S21)



TBU-065-300-WH (S11/S22)



TBU-085-500-WH (S21)



TBU-085-500-WH (S11/S22)

Conclusion

Return Loss: Given the measurements, which show a return loss of at least -15 dB, the Bourns tests conclude that the return loss performance meets many standards. This includes Telcordia GR-974-CORE that only covers up to 250 MHz at -10 dB.

Insertion Loss: The table below presents the insertion loss performance of each model.

Table 2. Insertion Loss Performance of Each Model Bourns TBU® HSP

Models	100 kHz dB	1 GHz dB	2 GHz dB	3 GHz dB	Impedance (Ω)	Signal Variation Max - Min
TBU-025-050-WH-Q*	-1.0076	-1.1619	-1.0296	-1.4454	15.3	0.44
TBU-025-500-WH	-0.1630	-0.5674	-0.7143	-0.8571	3.0	0.69
TBU-050-100-WH	-0.7859	-1.3802	-1.2296	-1.6585	10.9	0.87
TBU-065-100-WH-Q	-0.9202	-1.5138	-1.3509	-1.7159	13.2	0.79
TBU-065-200-WH	-0.6783	-1.4197	-1.3357	-1.6872	9.8	1.01
TBU-065-300-WH	-0.6708	-1.4934	-1.5299	-2.0441	8.8	1.37
TBU-085-500-WH	-0.8187	-1.1158	-1.2125	-1.3746	12.2	0.55

*Q suffix denotes for AEC-Q Qualified

Only two of the eight tested models exhibited more than 1 dB of insertion loss variation across the frequency range up to 3 GHz. The outcome of these tests demonstrates that Bourns® TBU® HSPs are excellent high-speed overcurrent protection solutions that deliver superior high-frequency performance, while exhibiting minimal insertion loss and meeting return loss requirements.

Applications That Typically Operate At Frequencies Up To 3 GHz:

- **Communication:**
  - Cellular phones (UHF: 300 MHz - 3 GHz)
  - Wi-Fi (2.4 GHz band)
  - Bluetooth (2.4 GHz)
  - GPS (~1.5 GHz)
  - Two-way radio (UHF)
- **Broadcasting:**
  - Television broadcasting (UHF)
- **Other:**
  - Radar (up to 3 GHz)
  - Microwave ovens (2.4 GHz)