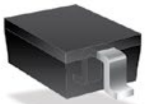
Lightning Surge Protection for Power over Ethernet (PoE) Applications

Using TCS™ High-Speed Protectors (HSPs)

APPLICATION NOTE

PT61020EL

TCS-DL004-250-WH



CDSOD323-T05C

SMLJ58A

MOV-07D820K

MF-RM055/240

INTRODUCTION

As an extension of the "Lightning Protection for Gigabit Ethernet (GbE) Applications Note [1]", we will now review a very robust lightning protection circuit for Power over Ethernet (PoE) applications. The protection circuit is capable of withstanding severe lightning surges such as 4 kV 10/700 µs voltage surges per ITU-T K.44. The TCS™ High-Speed Protector (HSP) solution is expanded to include AC power-cross protection.

CIRCUIT TO BE EVALUATED

The TCS™ HSP circuit that will be evaluated is shown here in figure 1. A comparison between a conventional TVS diode based solution and the superior TCS™ HSP solution can be found in the "Lightning Protection for Gigabit Ethernet (GbE) Application Note [1]".

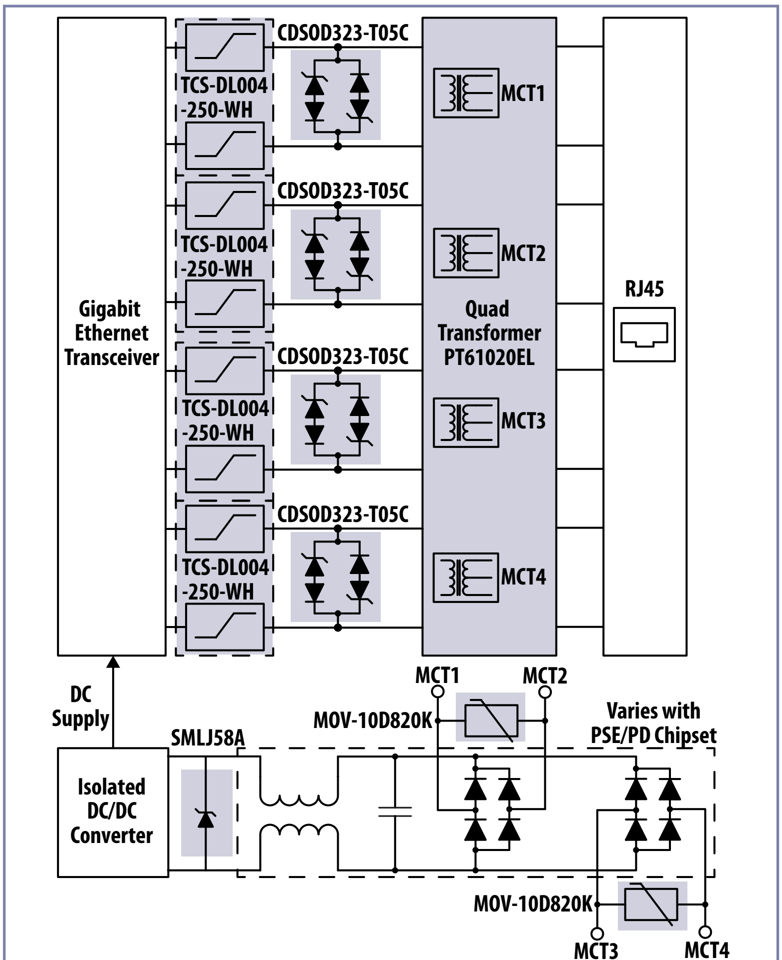


Figure 1. | *TCS™ HSP and Bidirectional TVS Diode Protection Circuit*

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CHARACTERIZATION OF DEVICES

Before we evaluate the performance of this PoE protection solution, it would be beneficial to characterize each component of the solution and understand how it performs under surge conditions.

ETHERNET TRANSFORMERS

Ethernet transformers may be designed and used as Lighting Isolation Transformers (LITs), which mitigate limited duration overvoltage and overcurrent.

Figure 2 below illustrates such an effect of two Bourns® PoE transformers (SM51589L and PT61020L). Each Ethernet transformer was surged with a 100 A, 8/20 µs combination wave (per Telcordia® GR-1089-CORE Issue 6), the worst case maximum secondary surge current was measured with the secondary winding shorted. Notice the reduced secondary peak current, and also the shorter surge current duration.

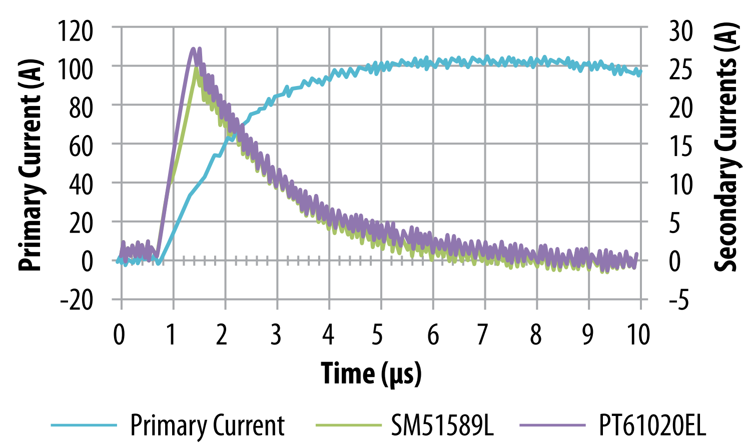

Figure 2. | *Primary and Secondary Currents of Ethernet Transformers with Secondary Winding Shorted*

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ETHERNET TRANSFORMERS *(Continued)*

Figure 3 below further illustrates the surge mitigating capabilities of the Bourns® Model PT61020EL transformer. This PoE transformer was surged with a 100 A, 8/20 µs combination wave (per Telcordia GR-1089-CORE Issue 6), a 1.5 kV, 10/700 µs voltage surge (per ITU-T K.44) and a 4 kV, 10/700 µs voltage surge (per ITU-T K.44). The worst-case, maximum secondary surge currents were measured with the secondary winding shorted. Notice the reduced secondary peak currents and also the shorter surge current durations.

In the TCS™ HSP solution proposed in figure 1, the PT61020EL transformer isolates longitudinal surges and mitigates transverse surges, reducing the requirements on the secondary-side solution that are needed to protect the Ethernet transceiver.

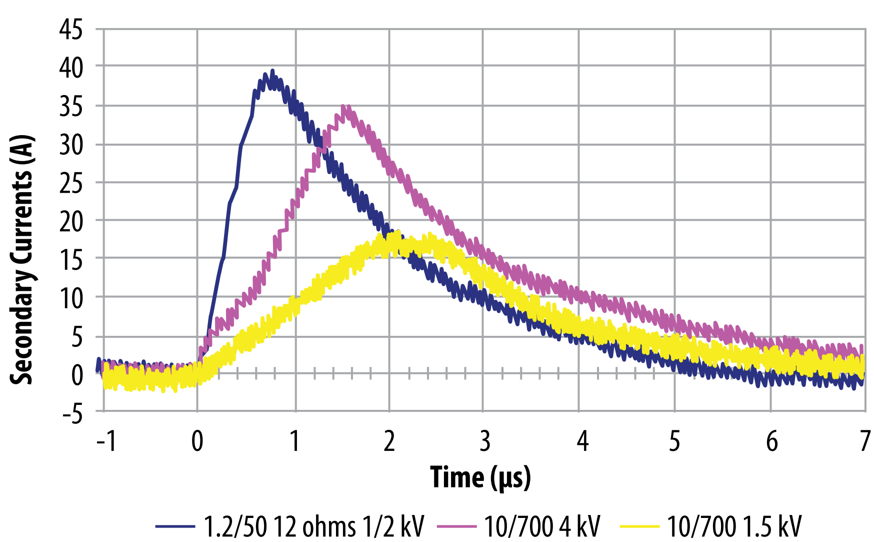

Figure 3. | *Secondary Surge Currents of PT61020EL Transformer with Secondary Winding Shorted*

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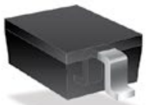

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TCS™ High-Speed Protectors

The new family of TCS™ HSP devices is comprised of low resistance, fast response current limiters that provide excellent protection for low-voltage communication circuits. See Reference [1] for additional information.

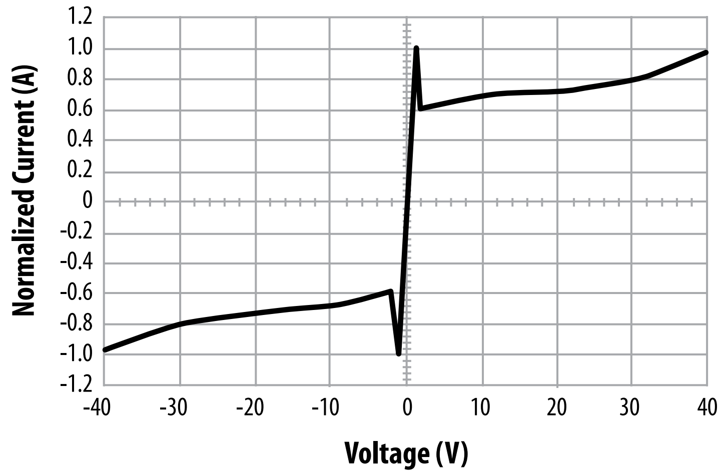

Figure 4. | *TCS™ HSP V-I Characteristic*

Figure 4 above illustrates the TCS™ HSP V-I curve. Notice that the TCS™ HSP has a foldback characteristic; the current folds back after the device is triggered and then slowly increases as the voltage across the device rises. This is analogous to how the clamp voltage of a TVS diode increases as the current through the device increases. Similarly, the TCS™ HSP is limited by its peak impulse voltage withstand V_{imp}, which would be the duality of a TVS diode peak pulse current I_{PP}.

In the solution proposed in figure 1, the Ethernet transceiver is well protected by the current limiting characteristic of the TCS™ HSP, regardless of the severity of lightning surge. The TCS™ HSP will limit the current into or out of the transceiver while the TVS diode shunts the remainder of the transformer's secondary current.

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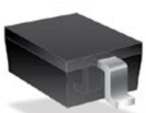

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Clamping Diodes

The Bourns® Model CDSOD323-T05C and CDSOT23-S2004, along with a generic Model BAV99 diode were characterized in the "Lightning Protection for Gigabit Ethernet (GbE) Application Note". Reproduced below in figure 5, the clamping voltage V_{clamp} is plotted against the transformer's secondary surge current I_P through each diode, when a 100 A, 8/20 µs combination wave is applied on the primary winding of the transformer. It is clear that the TVS diode CDSOD323-T05C has the lowest dynamic resistance.

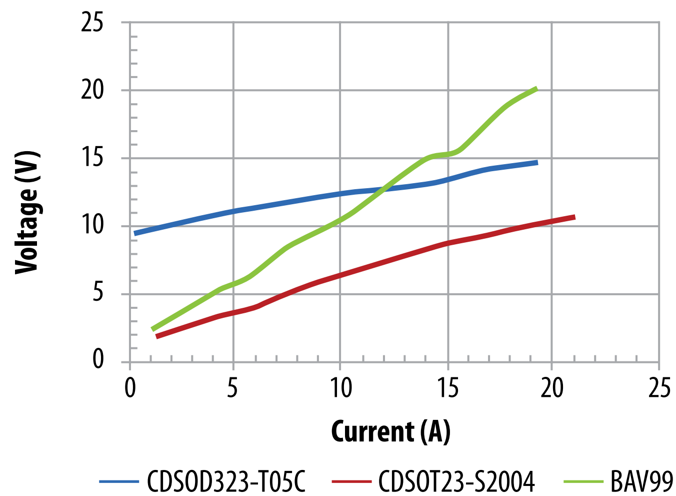

Figure 5. Clamping Voltage vs. Surge Current for the Three Diodes Tested

In the TCS™ HSP solution proposed in figure 1, TVS diodes are used to ensure that the voltage on the lines during surge do not exceed the peak impulse voltage withstand V_{imp} of the TCS™ HSP.

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Metal Oxide Varistors (MOVs) – PoE Power Lines

Bourns® Model MOV-07D820K Metal Oxide Varistor (MOV) was chosen to clamp the voltage on the PoE power lines, so as not to interrupt the operation of PSE/PD during surge events. A shunting type protector is suitable only when power-cycling is expected and acceptable. Shown in figure 6, the MOV-07D820K MOV has a typical V_{clamp} around 150 V during a 4 kV, 10/700 µs voltage surge.

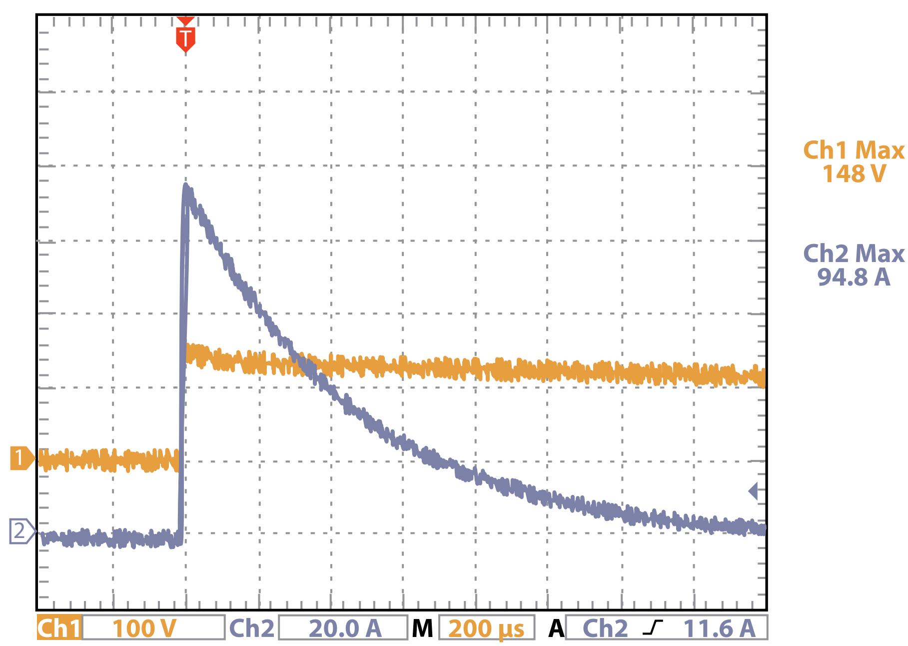

Figure 6. | *Clamping Voltage of MOV-07D820K*

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TVS Diodes – PoE Power Line

Where a lower clamping voltage on the input to the PoE DC/DC converter is desired, MOVs may be stacked in parallel to lower the effective dynamic resistance, hence clamping voltage. Alternatively, TVS diodes offer lower dynamic resistance than MOVs. TVS diodes can also be stacked in parallel to lower the effective dynamic resistance.

TVS diode(s) may be used in parallel with MOV(s) as another method of improving clamping performance, such as when the TVS diode's peak pulse current (IPP) is insufficient to meet the expected surge currents. It is recommended that coordinated impedance be placed between the TVS diode(s) and the MOV(s).

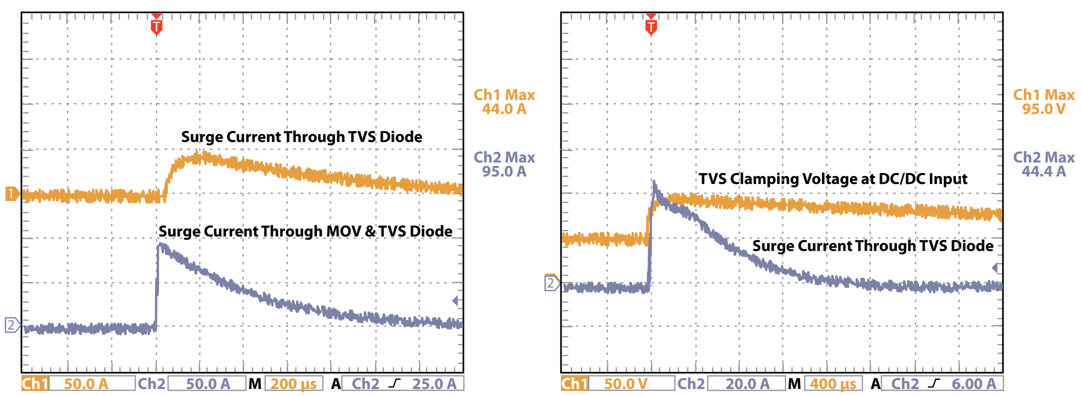

Figure 7. Clamping Voltage of SMLJ58A & MOV-07D820K on PoE Power Lines

In the TCS™ HSP solution proposed in figure 1, the Bourns® Model SMLJ58A TVS diode is used in parallel with the Bourns® Model MOV-07D820K MOV to ensure that the clamping voltage on the PoE power lines is within 100 V as illustrated in figure 7, during a 4 kV, 10/700 µs voltage surge.

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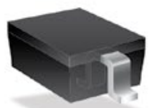

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Multifuse® PPTC Resettable Fuses

Where an AC power fault is expected, resettable fuses are preferred for a low cost Criteria A-compliant solution (per ITU-T K.44). The Bourns® Model MF-RM055/240 PPTC resettable fuse was chosen to allow for Class 3 implementation (per IEEE 802.3afTM), taking into consideration a maximum ambient temperature of 85 ˚C typically required of industrial applications. This would naturally conform to the maximum 400 mA current limit specified as well.

Where a Powered Device (PD) implementation of lower power classification is required, Bourns® Multifuse® PPTC Resettable Fuses offer a lower current trip limit (I_{trip}), making them an ideal solution without impacting the AC power fault protection. Figure 8 illustrates the various models available and corresponding trip currents at 23 ˚C.

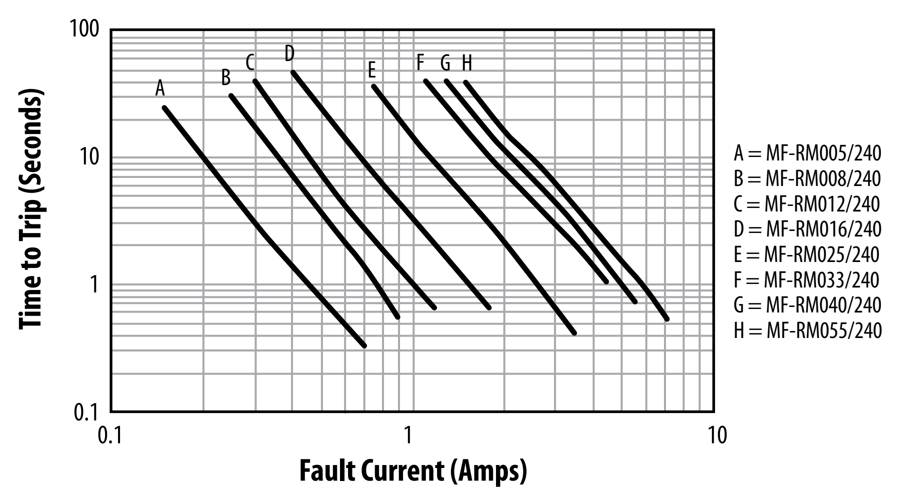

Figure 8. | Multifuse® PPTC Resettable Fuses for PoE Applications

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Summary of Component Evaluation

While the TCS™ HSP protects the Ethernet transceiver by ensuring that surge currents to the Ethernet transceiver will be limited, the proper selection of the PoE transformer and clamping diodes ensures the overall performance and integrity of the complete TCS™ HSP solution.

A MOV, a TVS diode, or a combination of both devices clamps the PoE power line voltage during surges to prevent damage to the PoE isolated DC/DC converter. Where AC power fault protection is required, Multifuse® PPTC Resettable Fuses are chosen for the applicable power classification and placed on each powered line.

Where less harsh surges are expected, the TCS™ HSP solution may be varied by choosing less robust PoE transformers and clamping diodes/TVS diodes/MOVs of higher dynamic resistances.

Surge and AC Power Fault Tests

A summary of the tests performed on the TCS™ HSP solution proposed in figure 1 is shown below in table 1. The protection afforded by the TCS™ HSP solution is quite dramatic; it reduced the energy into the PHY to a couple of microjoules (~90 % improvement over conventional solutions), regardless of surge or AC power fault applied within rated limits.

The effectiveness of the TCS™ HSP solution proposed in figure 1 enables designers to consider the variation in robustness of Ethernet transceivers.

Table 1. Clamping Voltage of SMLJ58A & MOV-07D820K on PoE Power Lines

Test Description	Typical Differential Input Voltage at PHY	Typical Current into PHY	Approximate Energy into PHY
1.5 kV, 10/700 µs voltage surge per ITU-T K.44 A.6.1-1 (a and b)	< 6 V	< 300 mA	3 µJ
4 kV, 10/700 µs voltage surge per ITU-T K.44 A.6.1-1 (a and b)	< 6 V	< 300 mA	4 µJ
240 V_{ac}, 60 Hz, 15 min. R = 10, 20, 40, 80, 160 Ω per ITU-T K.44 A.6.1-1 (a and b)	< 6 V	<300 mA (Worst-Case Maximum)	—

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Lightning Surge – 1.5 kV, 10/700 µs Voltage Surge

Figure 9 below illustrates the robustness of the TCS™ HSP solution proposed in figure 1. Despite the 37.5 A primary winding surge current in the Ethernet transformer applied by the 1.5 kV, 10/700 µs voltage surge, causing up to 20 A of secondary winding surge current (as shown in figure 3), the TCS™ HSP immediately limits this to ~250 mA entering the Ethernet transceiver.

In other words, the TCS™ HSP solution would work to prevent surge currents from damaging the Ethernet transceiver under the tested conditions.

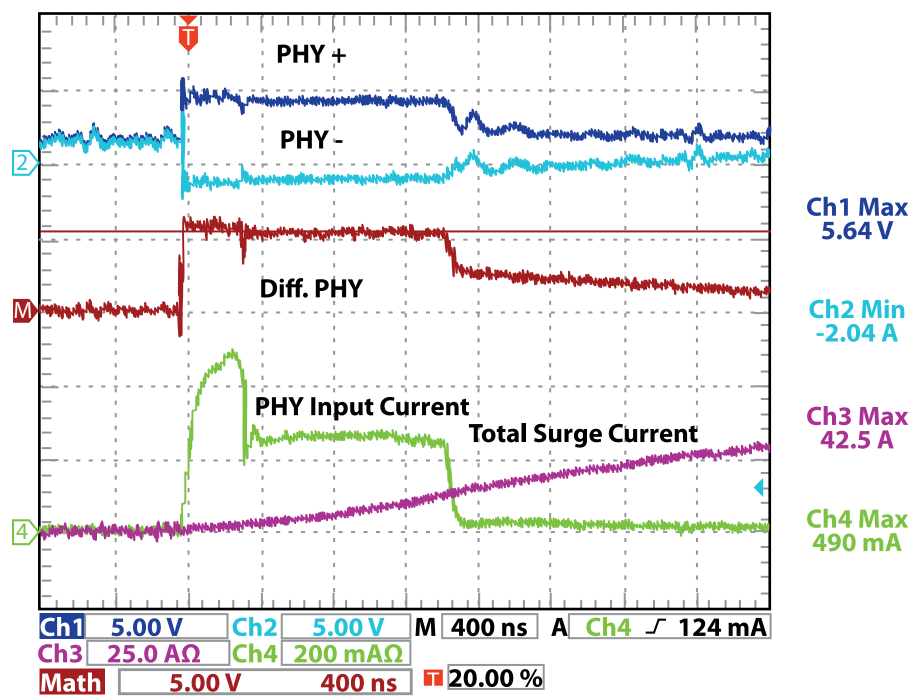

Figure 9. TCS™ Solution - 1.5 kV, 10/700 µs Voltage Surge

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Lightning Surge – 4 kV, 10/700 µs Voltage Surge

Figure 10 below illustrates the robustness of the TCS™ HSP solution proposed in figure 1. Despite the higher 100 A primary winding surge current in the Ethernet transformer applied by the 4 kV, 10/700 µs voltage surge, the TCS™ HSP again immediately limits this to ~250 mA entering the Ethernet transceiver. The TCS™ HSP solution holds the stress on the PHY relatively constant even if higher surge levels are applied.

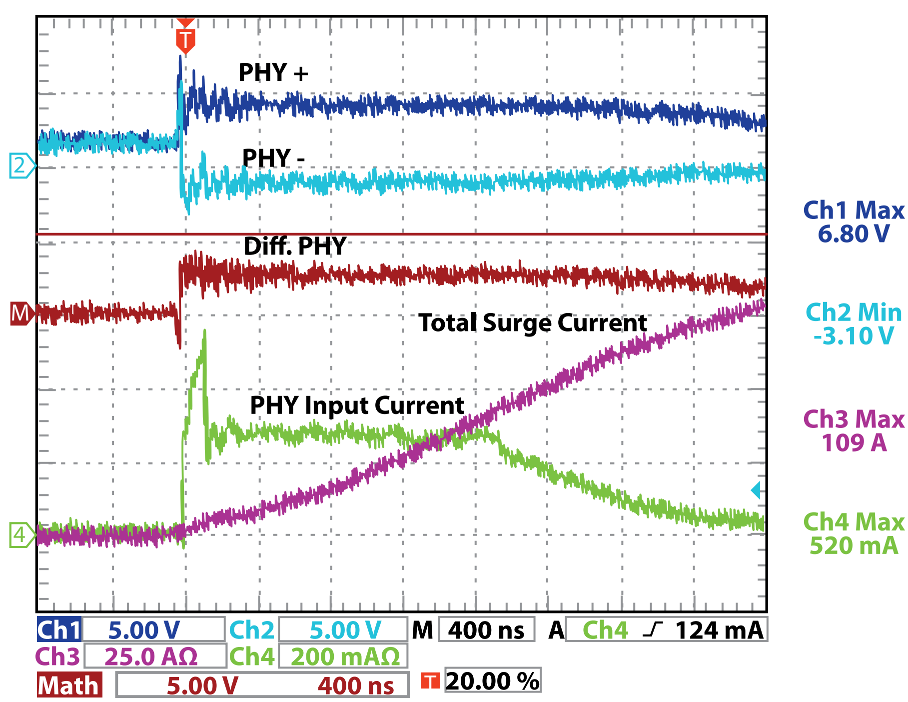

Figure 10. | *TCS™ HSP Solution - 4 kV, 10/700 µs Voltage Surge*

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AC Power Fault – 230 V_{ac} 60 Hz, 15 Min.

Table 2 summarizes the performance of the added Bourns® Multifuse® PPTC MF-RM055/240 under various AC power fault conditions. Larger fault currents trip the Multifuse® PPTC resettable fuses faster, tending to reduce the stress on the primary windings of the Ethernet transformer.

The Ethernet transformer PT61020EL in the TCS™ HSP solution proposed in figure 1 has been chosen to withstand the worst-case scenario occurring between 0.55 A and 1.25 A (I_{hold} and I_{trip} of MF-RM055/240, respectively) where the typical time to trip is expected to exceed 30 seconds or possibly the entire 15 minute test.

Table 2. Summary of AC Power Fault Test Results

Test Description 240 Vac, 60 Hz, 15 Min. per ITU-T K.44 A.6.1-1 (a and b)	Typical Fault Current	Typical Time to Trip	Approximate Transformer Power Dissipation
R = 10 Ω	24 A_{ac}	~ 80 ms	41.47 J
R = 20 Ω	12 A_{ac}	~ 160 ms	20.73 J
R = 40 Ω	6 A_{ac}	~ 800 ms	25.92 J
R = 80 Ω	3 A_{ac}	~ 3 s	24.3 J
R = 160 Ω	1.5 A_{ac}	~ 30 s	60.75 J
R = 300 Ω	0.8 A_{ac}	~ 120 s	69.12 J
R = 600 Ω	0.4 A_{ac}	—	129.6 J
R = 1000 Ω	0.24 A_{ac}	—	46.65 J

For example, when R = 600 Ω, the corresponding fault current of 0.4 A_{ac} is below the maximum operating current of a Class 3 implementation (per IEEE 802.3af). By design, the MF-RM055/240 used in the TCS™ HSP solution proposed in figure 1 will not trip. Hence, the primary windings of the transformer must be rated to handle this level of current, making the PT61020EL transformer a good choice.

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AC Power Fault – 230 V_{ac} 60 Hz, 15 Min. *(Continued)*

Due to the low frequency nature of an AC power fault, an insignificant secondary fault current is induced. As long as the primary windings of the Ethernet transformer can withstand the fault currents prior to the Multifuse® PPTC resettable fuse tripping, the TCS™ HSP solution proposed in figure 1 will offer robust protection against an AC power fault as shown in figures 11 and 12 below.

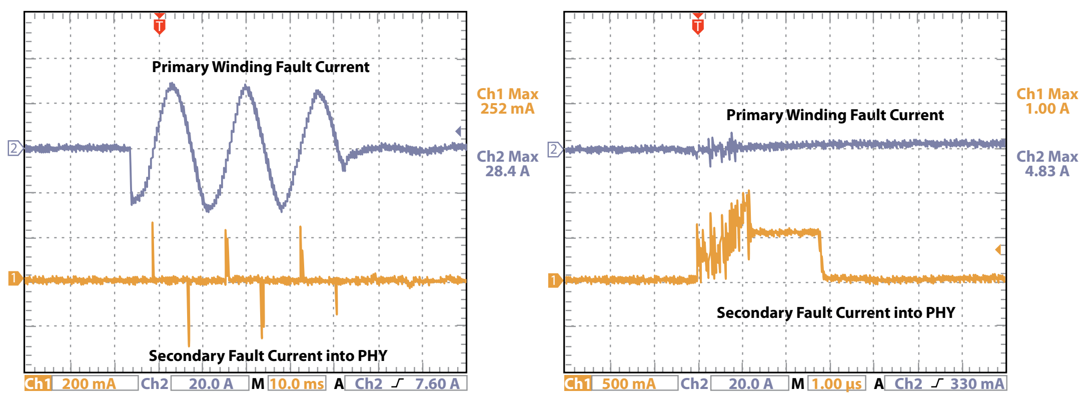

Figure 11. *TCS™ HSP Solution – 240 V_{ac} AC Power Fault, R = 10 Ω*

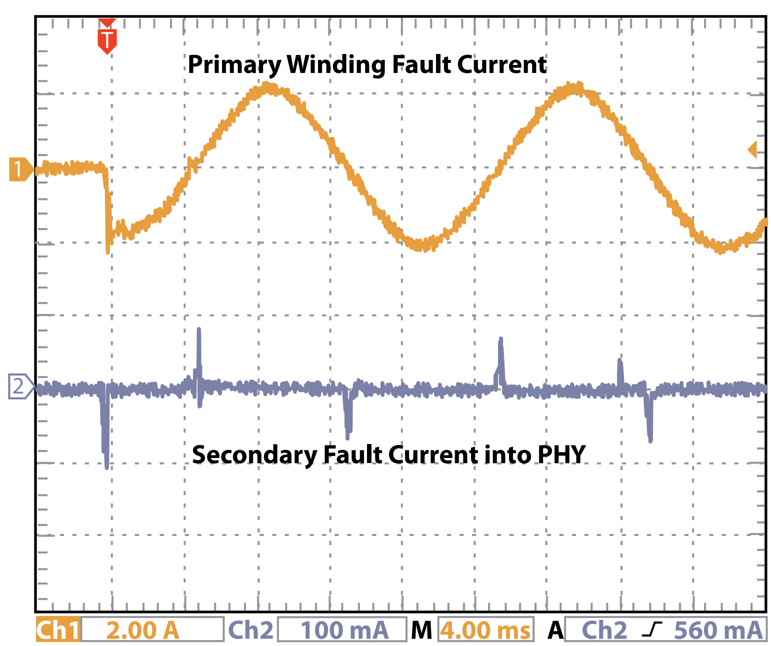

Figure 12. *TCS™ HSP Solution – 240 V_{ac} AC Power Fault, R = 160 Ω*

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820.3-2008 Template and Amplitude Tests

Complete IEEE 802.3 signal template and amplitude tests were conducted on the TCS™ HSP solution proposed in figure 1. Table 3 summarizes some of the test results. It can be seen that the addition of a TCS™ HSP had minimal impact on the quality of the test signal.

Table 3. Summary of 802.3 Test Results

Test	Specification Range	Baseline Measured Value	Bourns® TCS™ HSP Solution w/o Multifuse® PPTC Measured Value	Bourns® TCS™ HSP Solution with Multifuse® PPTC Measured Value
Template Test Point A	Fit the Template	Pass	Pass	Pass
Template Test Point B	Fit the Template	Pass	Pass	Pass
Template Test Point C	Fit the Template	Pass	Pass	Pass
Template Test Point D	Fit the Template	Pass	Pass	Pass
Template Test Point F	Fit the Template	Pass	Pass	Pass
Template Test Point H	Fit the Template	Pass	Pass	Pass
Peak Voltage Point A	670 mV to 820 mV	696.9 mV	690.0 mV (-6.9 mV / -0.09 dB)	678.3 mV (-18.6 mV / -0.24 dB)
Peak Voltage Point B	670 mV to 820 mV	696.9 mV	690.4 mV (-5.6 mV / -0.07 dB)	677.9 mV (-18.1 mV / -0.23 dB)
% Diff A and B	< 1 %	0.14 %	0.07 %	Point B
Peak Voltage % Diff C	< 2 %	0.81 %	0.61 %	Point B
Peak Voltage % Diff D	< 2 %	0.11 %	0.09 %	Point B

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820.3-2008 Template and Amplitude Tests *(Continued)*

The TCS™ HSP solution offers superior protection while not compromising signal integrity in any significant way. Even the addition of Multifuse® PPTC resettable fuses on the line-side of the Ethernet transformer does not impact signal integrity in any significant way. Figures 13 through 15 illustrate this.

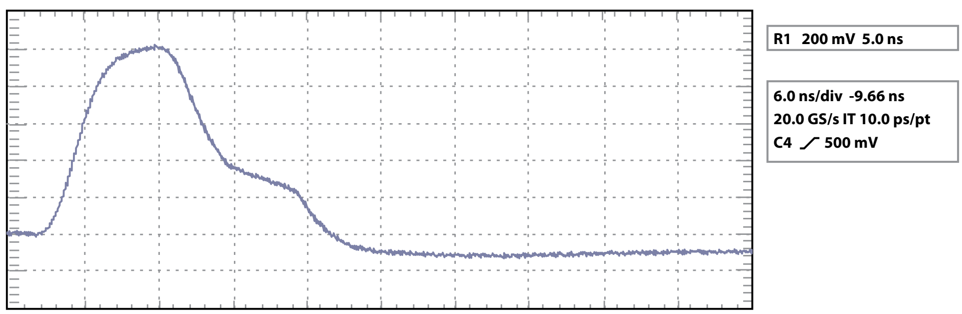

Figure 13. | *Baseline Template Measurement (No Protection Devices)*
IEEE Std 802.3ab, Sec 40.6.1.2.3: 1000Base-T Differential Output Template Point A

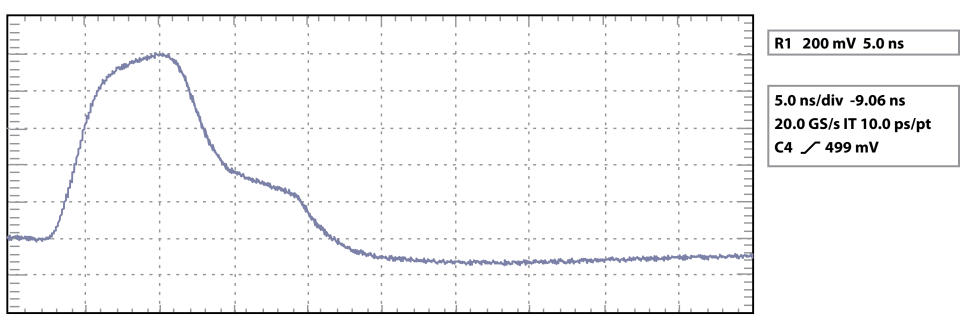

Figure 14. | *Template Measurement (TCS-DL004-250-WH)*
IEEE Std 802.3ab, Sec 40.6.1.2.3: 1000Base-T Differential Output Template Point A

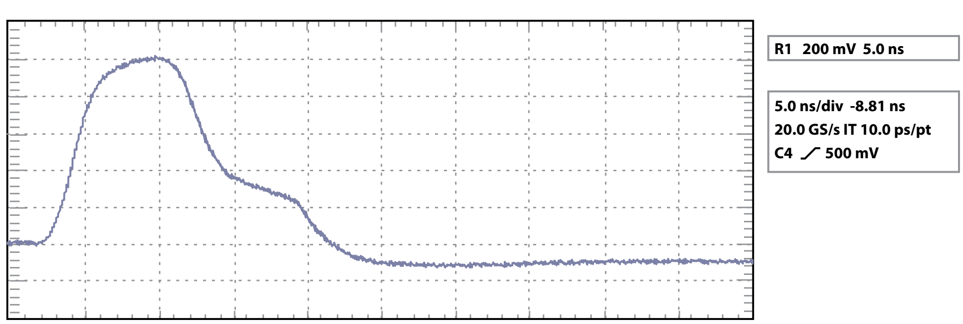

Figure 15. | *Template Measurement (TCS-DL004-250-WH and MF-RM055/240)*
IEEE Std 802.3ab, Sec 40.6.1.2.3: 1000Base-T Differential Output Template Point A

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Summary

Figure 1 shows a very robust lightning protection circuit for PoE applications, capable of severe lightning surges within rated limits, such as 4 kV 10/700 µs voltage surges (per ITU-T K.44). Each component of the solution was reviewed and the surge and AC power fault capability of the solution was shown. In addition, the minimal impact on signal integrity was demonstrated.

The TCS™ High-Speed Protector provides excellent protection and is well-suited for low-voltage, high-speed communication circuits.

REFERENCE

[1] A. Morrish and L. Stencel, (2012 Oct 16). Robust Protection and Excellent Signal Quality for Gigabit Ethernet Applications Using Transient Current Suppressor (TCS™) Technology White Paper [Online]. Available at:
http://www.bourns.com/data/global/pdfs/Bourns_TCS_GBE_White_Paper.pdf

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