GbE Protection

Board Level

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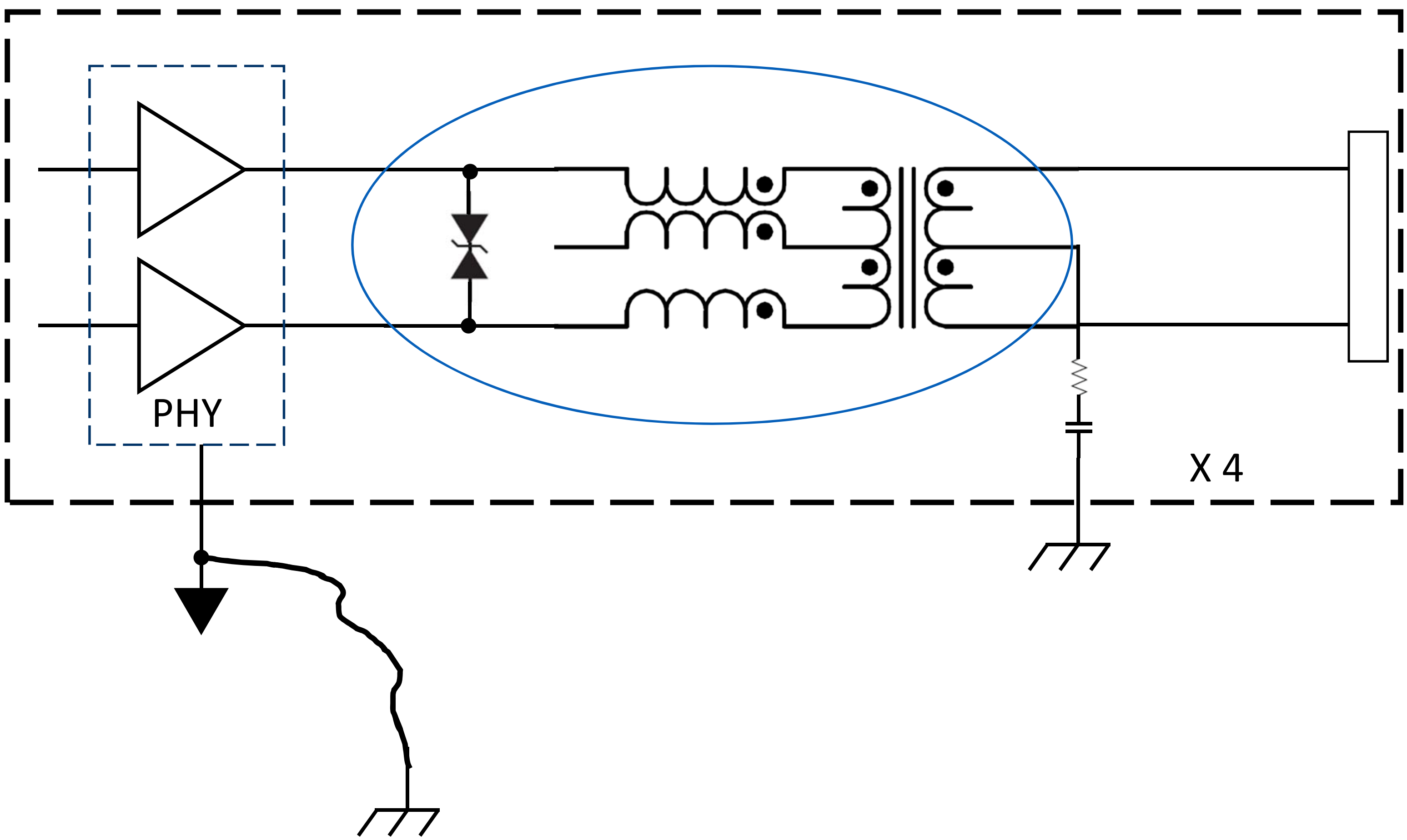
What is Covered in this Presentation?

- ***Transformers***
  - ***Longitudinal Surge Performance***
  - ***Differential Surge Performance***
- ***TVS Diodes***
- ***Ethernet Application Examples***
  - ***GR-1089 Port Type 4 (Intra Building)***
    - ***TVS Diode Design***
    - ***TVS Diode with ECL Design***

Basic Ethernet Surge Protection



Ethernet Transformers

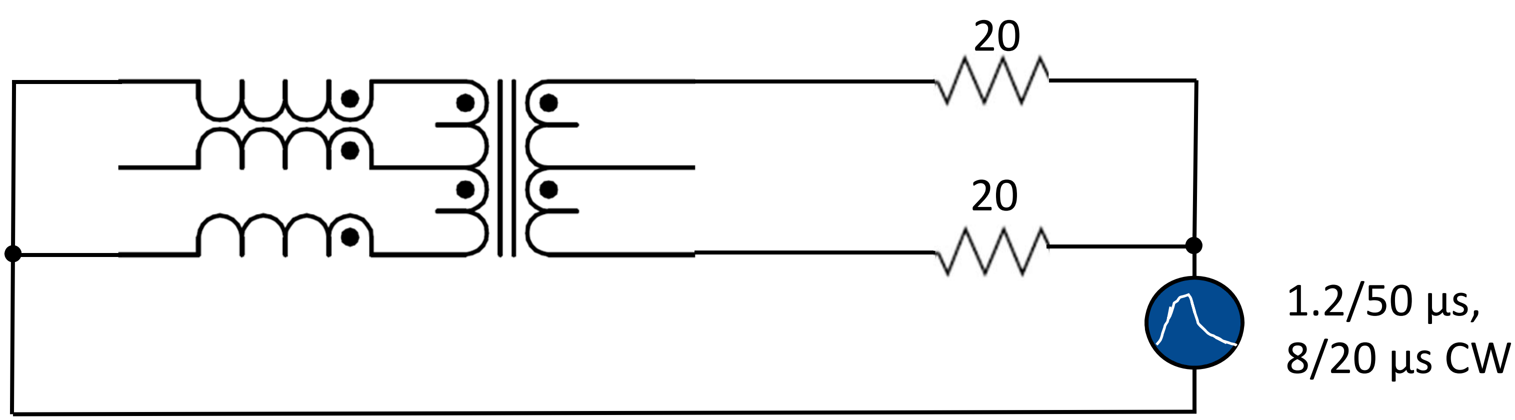
Longitudinal and Metallic Protection

Transformers – Longitudinal Protection

- *Transformers typically are rated at a minimum of 1500 V_{rms} for a 60 second duration*
- *Others are rated higher or are rated for surge, but they are usually custom devices.*
- *Without protection on the line side of the transformer the design is 100% dependent on the isolation properties of the transformer.*
- *IEEE802.3 specifies isolation requirements for Ethernet ports. Adding line side protection that is connected to ground may violate these requirements.*

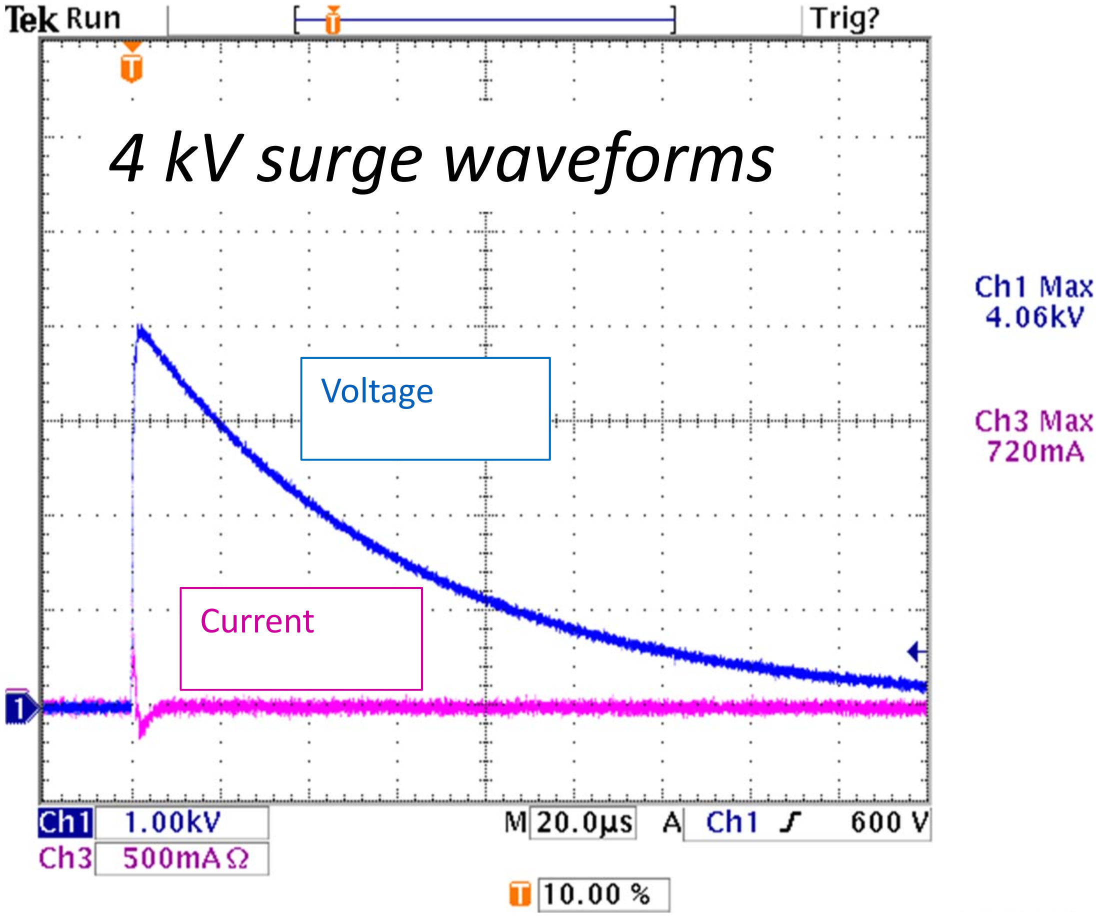
Transformers – Longitudinal Protection

- *I subjected a (1000BASE-T capable) transformer to a series of increasing voltage CW longitudinal surges (1 kV increments) to see how it would fair. The transformer is rated at 1500 Vrms (60 s)*
- *The Test circuit is shown below:*



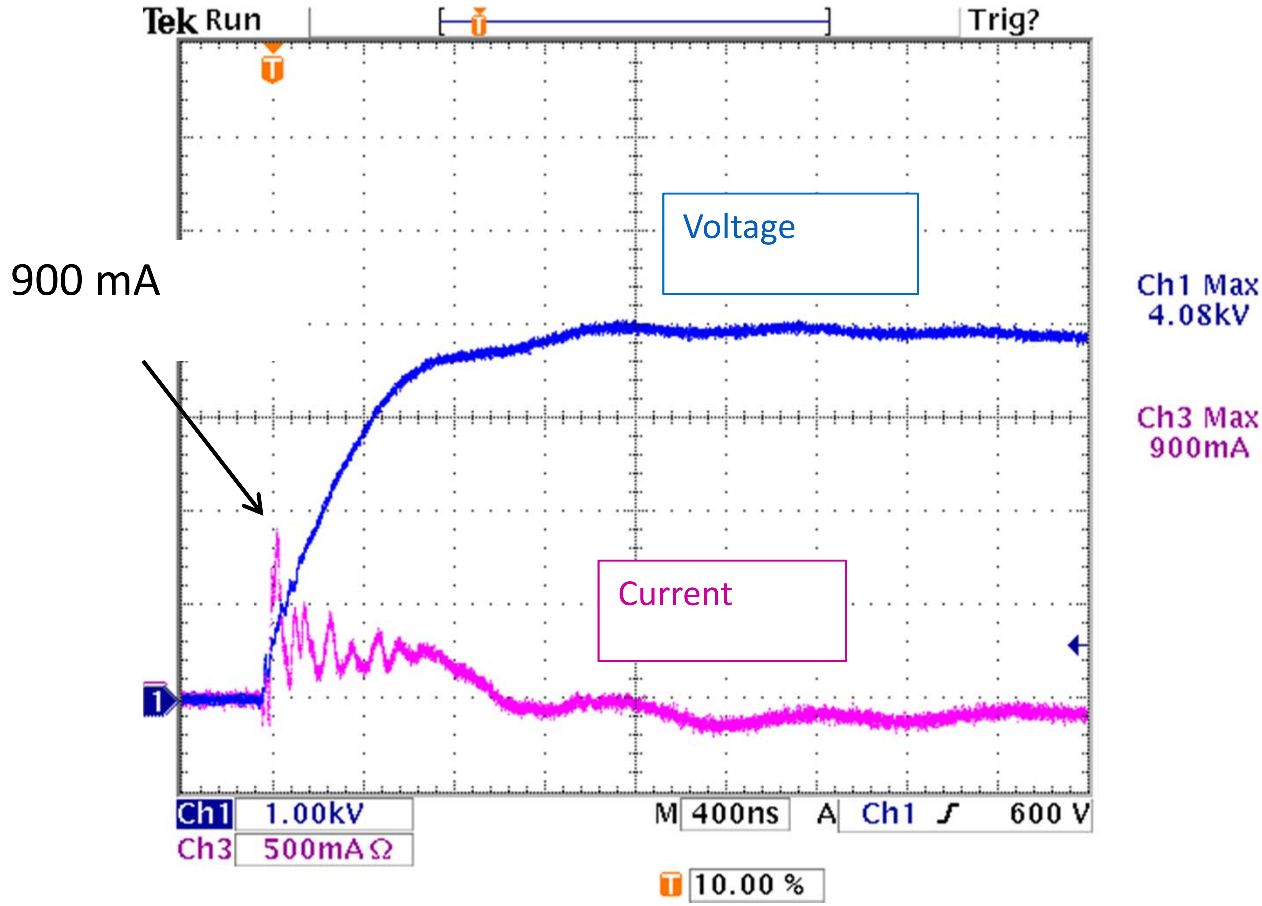
Transformers – Longitudinal Protection

- *Two channels of the same transformer were tested*
- *The first channel survived 4 kV, but failed a 5kV surge*



Transformers – Longitudinal Protection

Zooming In (4kV)



- *The peak current from primary to secondary was 900 mA to charge the inter-winding capacitance*

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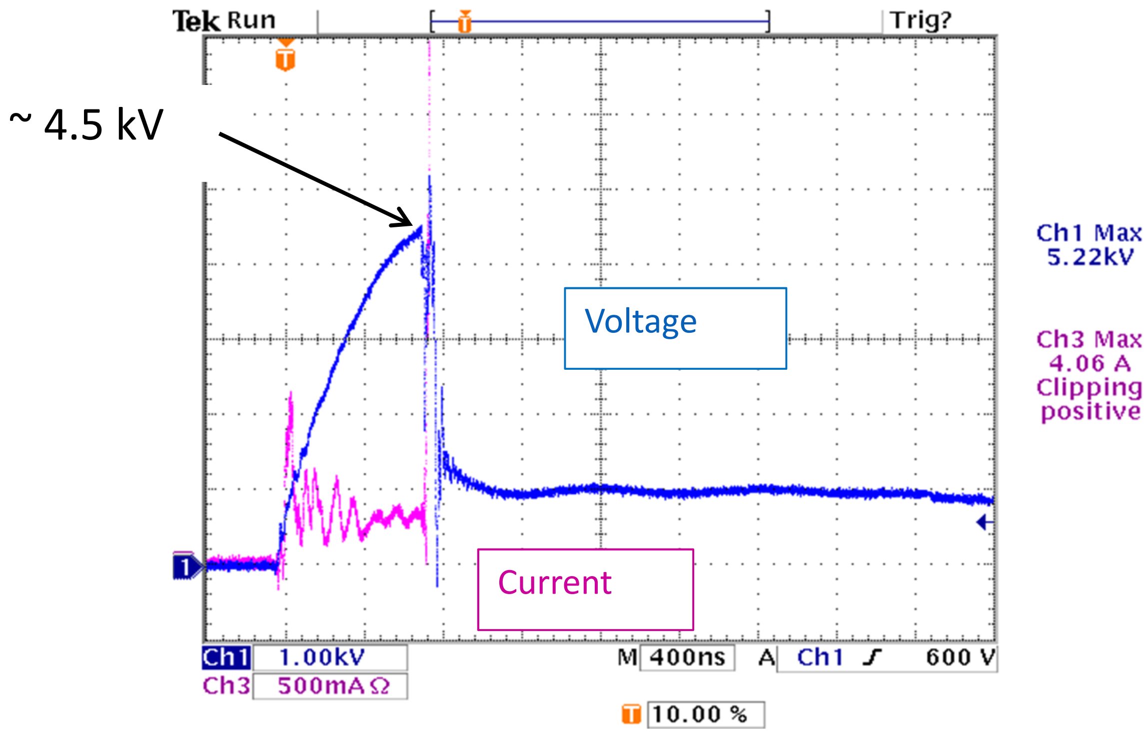
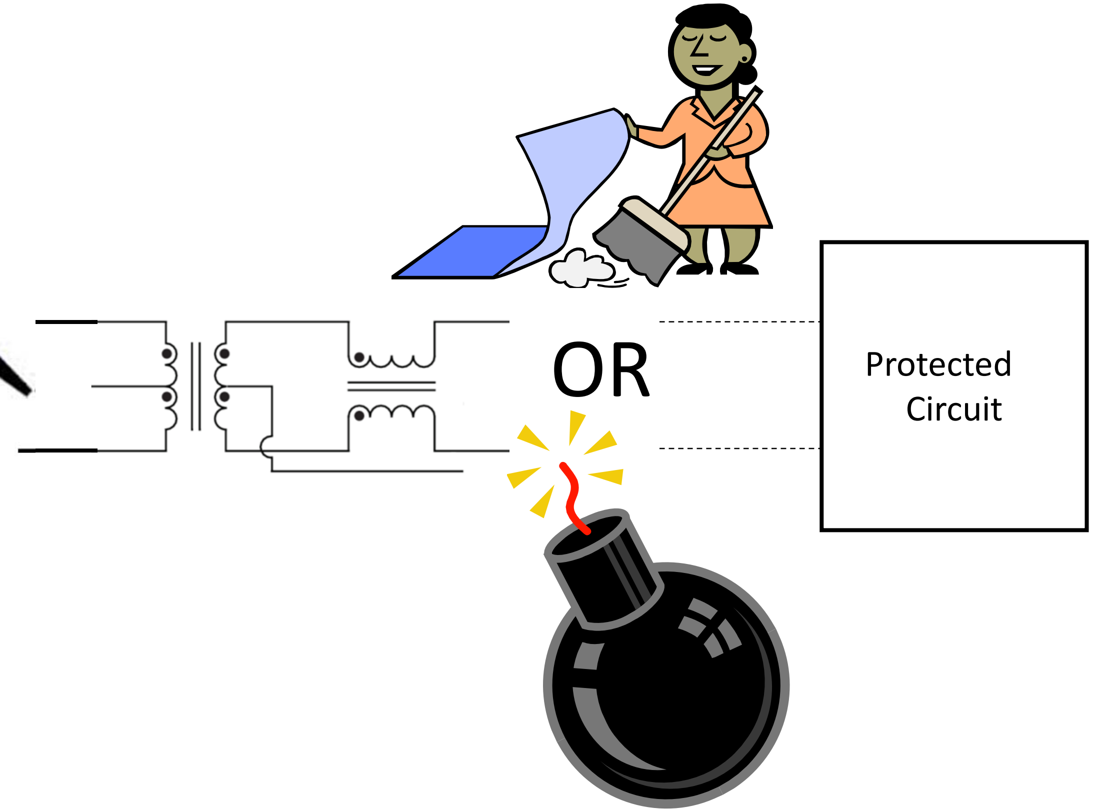
Transformers – Longitudinal Protection

5 kV Surge Test Waveforms



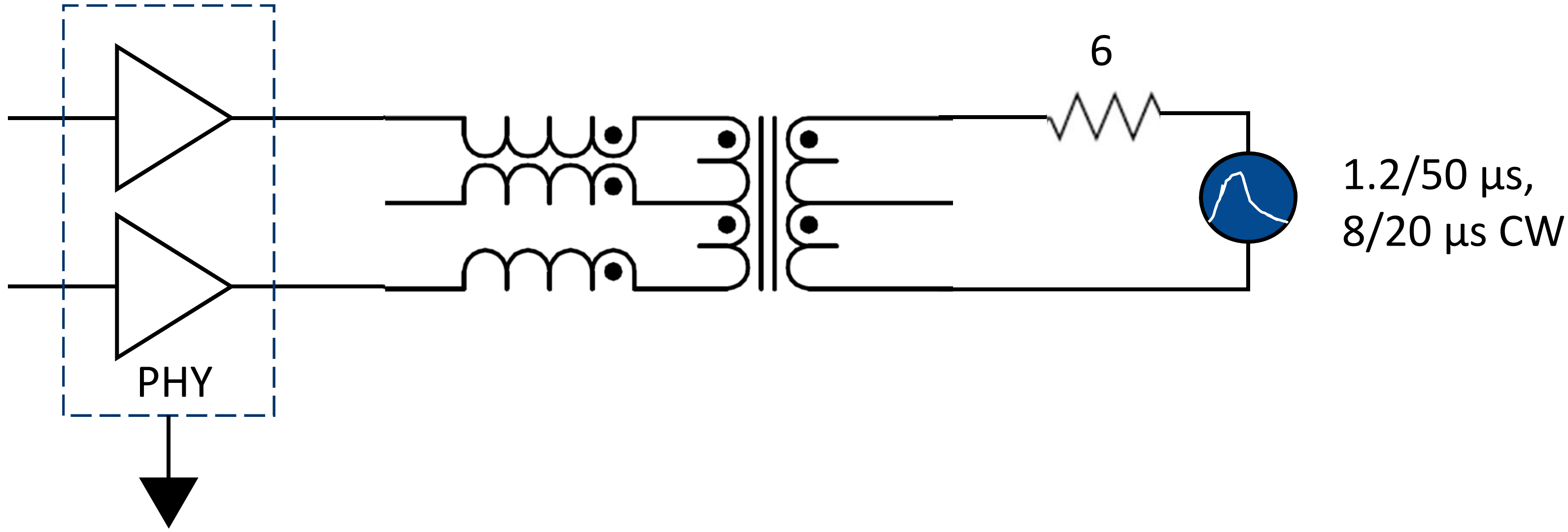
- *The transformer broke down at about 4.5 kV*
- *The second channel that was tested survived out to 6.6kV which is the limit of my test capability*
- *The results are not consistent*

Transformer Summary - Longitudinal Surge



- *We can assume that the surge voltage capability of the transformer will exceed its RMS voltage rating*

Transformers - Metallic Protection

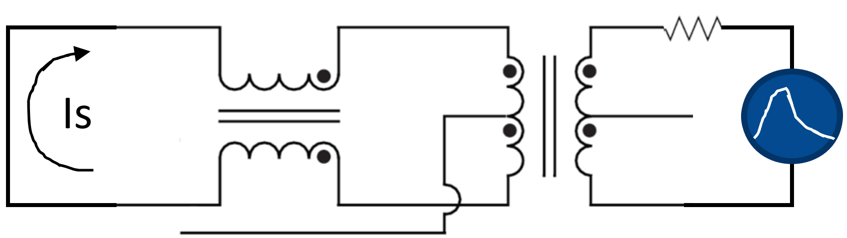


- *Under normal operating conditions we don't want our transformer to saturate.*
- *Under metallic surge conditions the saturation properties of the transformer significantly reduce the energy that couples to the chip side.*
- *We will explore this in the next slides.*

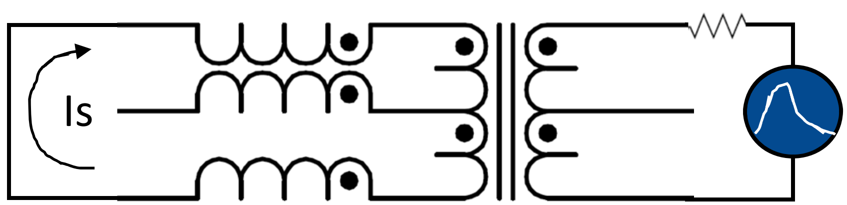
Transformer Surge Characteristics

Metallic Mode Test Circuits

Transformer A



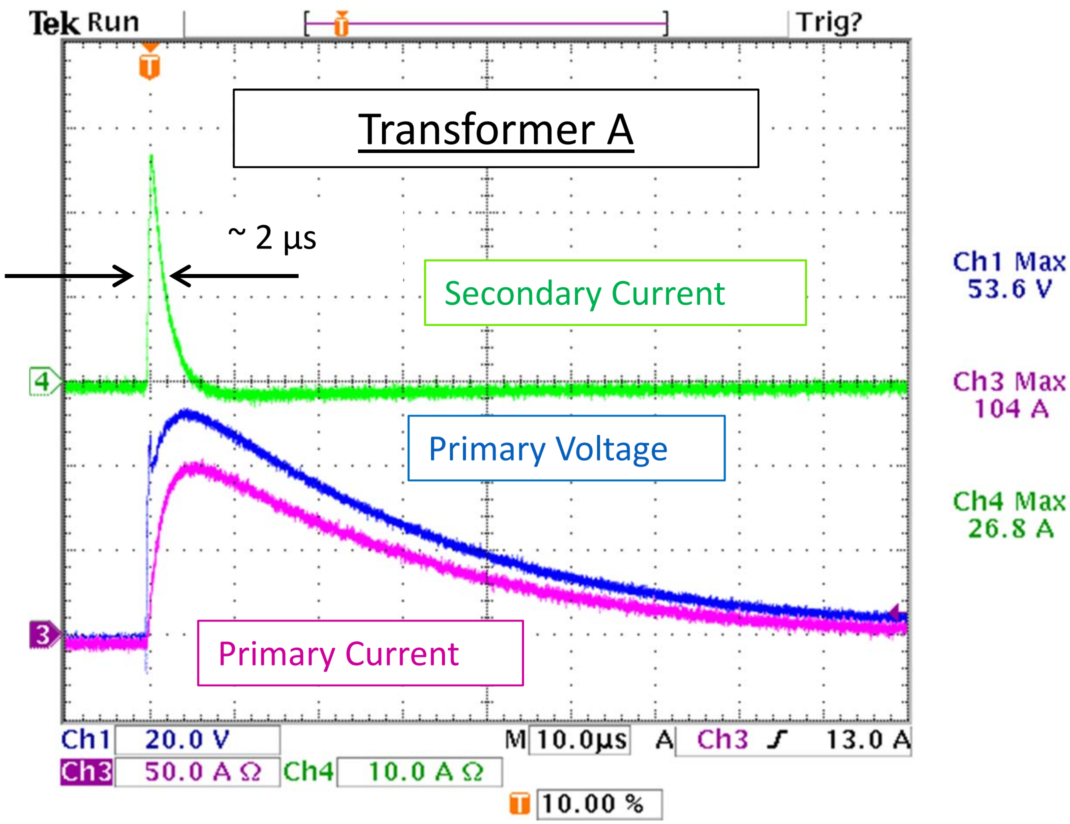
Transformer B



- For our tests:
  - The transformer Secondary was shorted
  - A metallic (differential) surge was applied to the Transformer Primary
- Both Transformers tested support 10/100/1000 Mbps operation
- Transformer A and B are from two different manufacturers with nominally the same specs

Secondary Current Compared to Primary Current

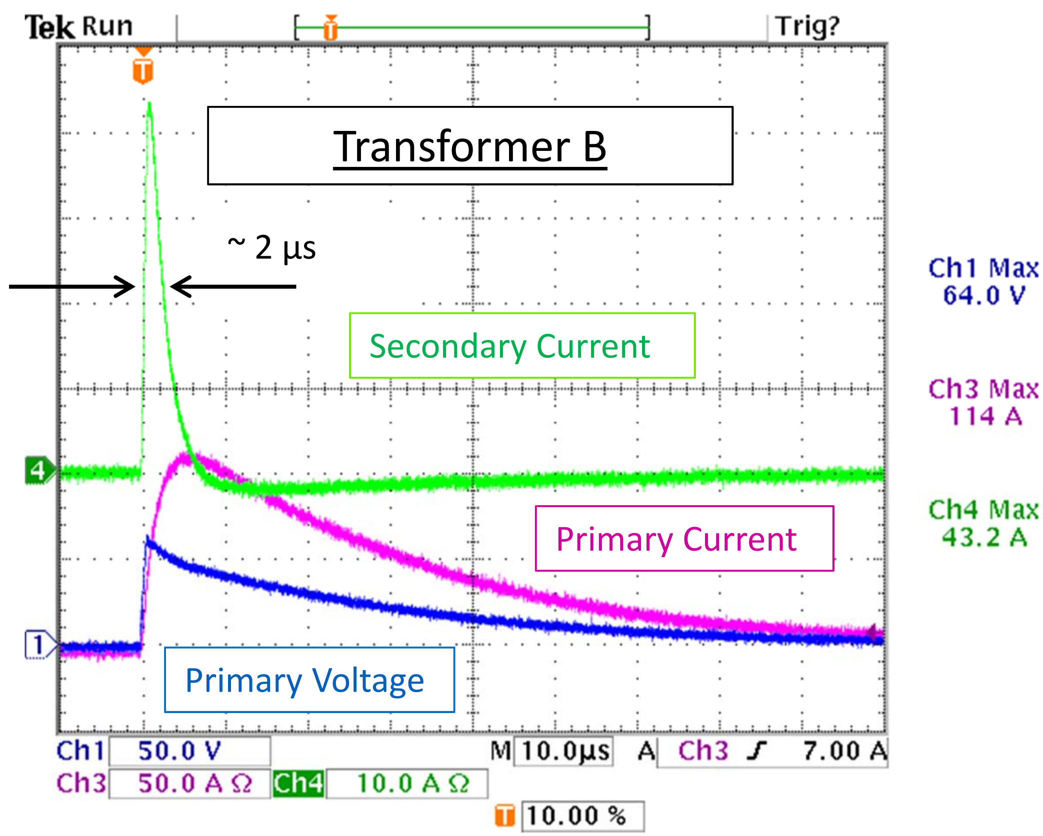
Combination Wave 1.2/50 µs Voltage, 8/20 µs Current



- The current pulse width is narrowed to ~2 µs
- The peak current is reduced by about 75%

Secondary Current Compared to Primary Current

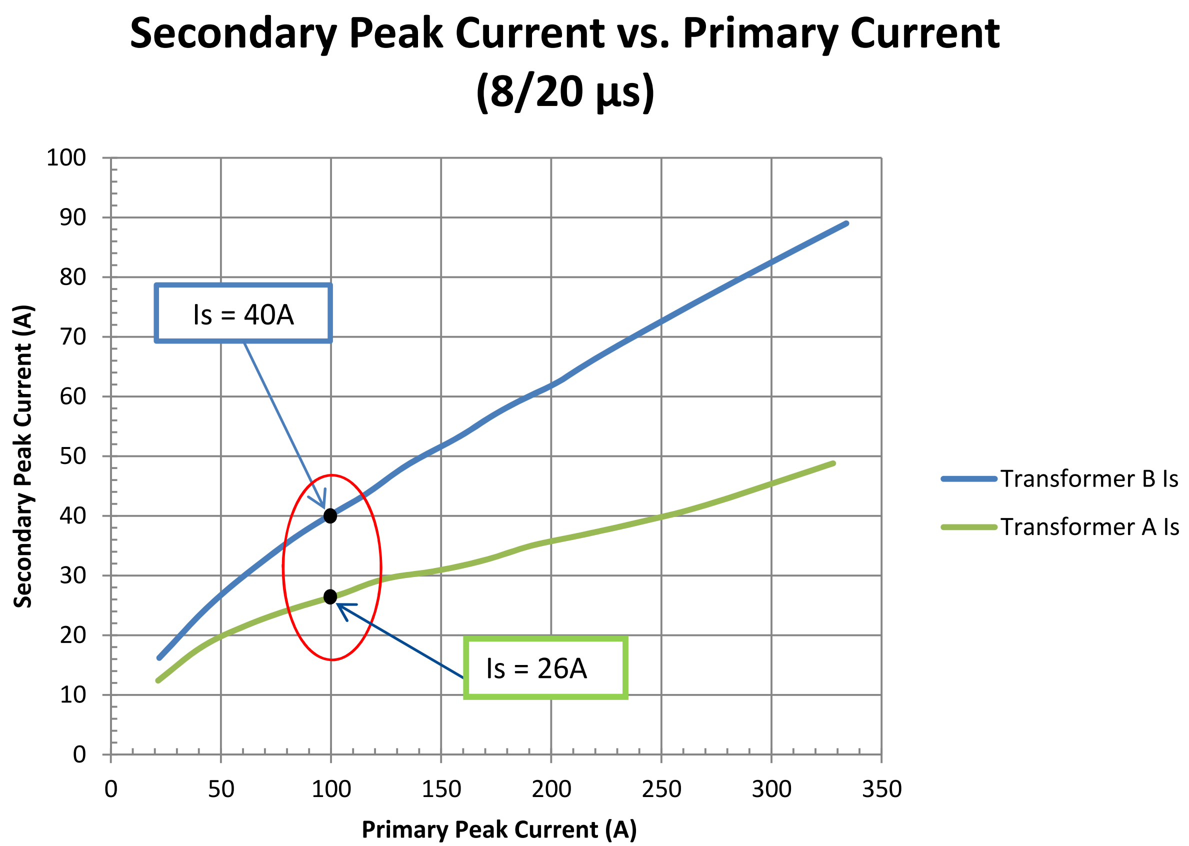
Combination Wave 1.2/50 µs Voltage, 8/20 µs Current



- The current pulse width is narrowed to ~2 µs
- The peak current is reduced by over 60%

Transformer Differential Surge Test Results

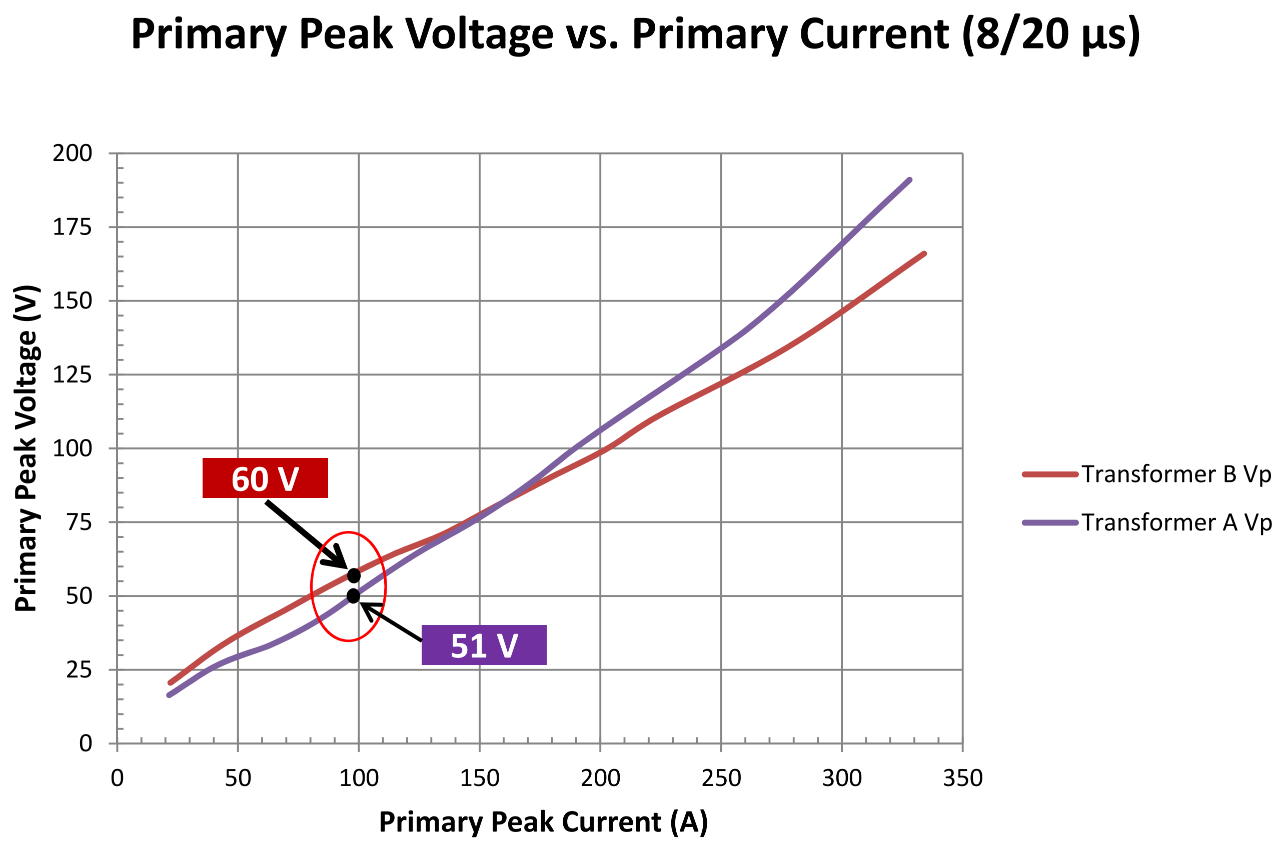
Combination Wave 1.2/50 µs Voltage, 8/20 µs Current



- Significant difference between the two transformers
- Both designs failed with a peak primary current between 400 and 500 A

Transformer Differential Surge Test Results

Combination Wave 1.2/50 µs Voltage, 8/20 µs Current



- 50 – 60 volts across primary with Ip = 100 A

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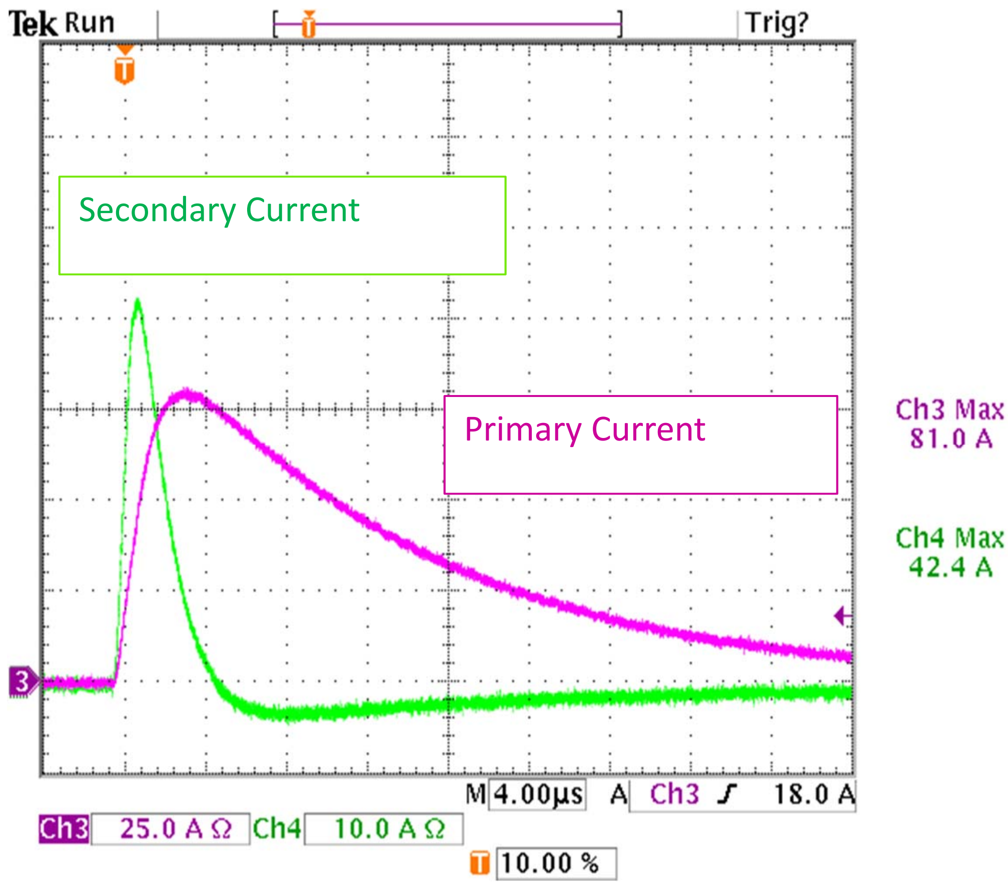
Transformer B Differential Surge Test Results

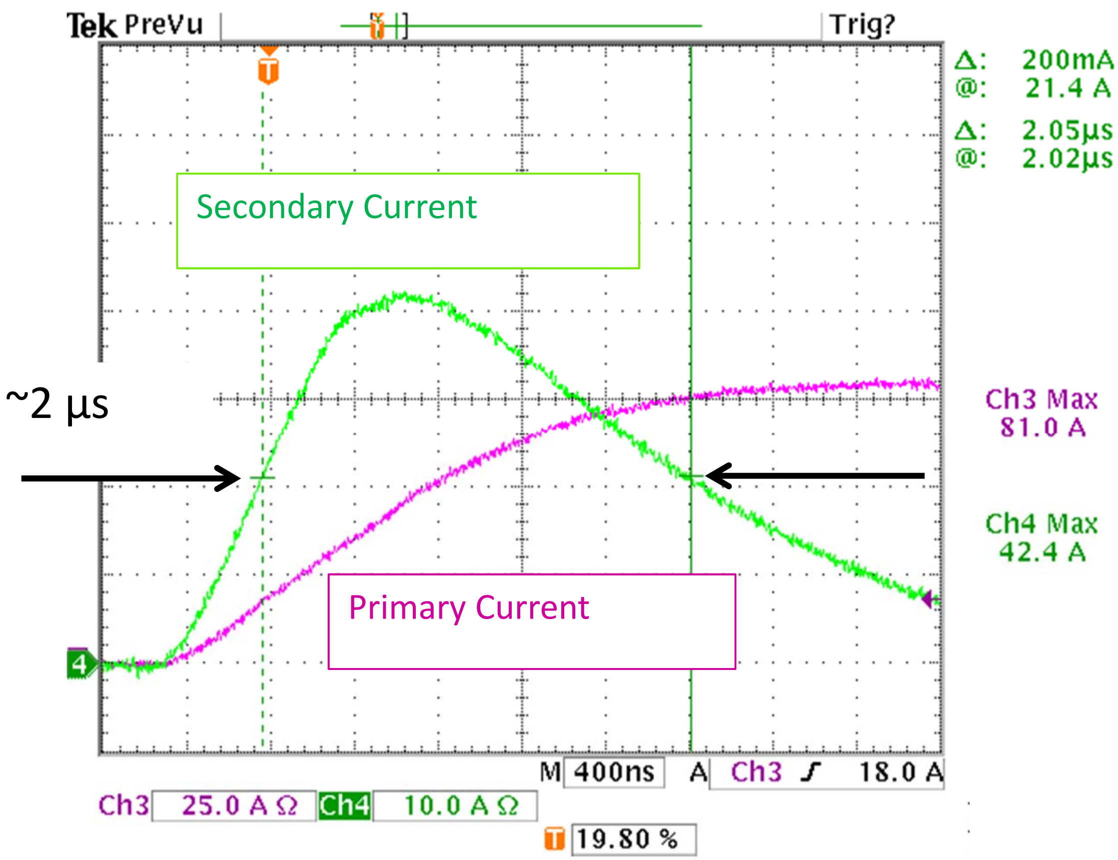
2/10 µs Voltage Surge



- The peak current is reduced by ~ 50%

Transformer B Differential Surge Test Results

2/10 µs Voltage Surge



- The current pulse width is narrowed to ~2 µs

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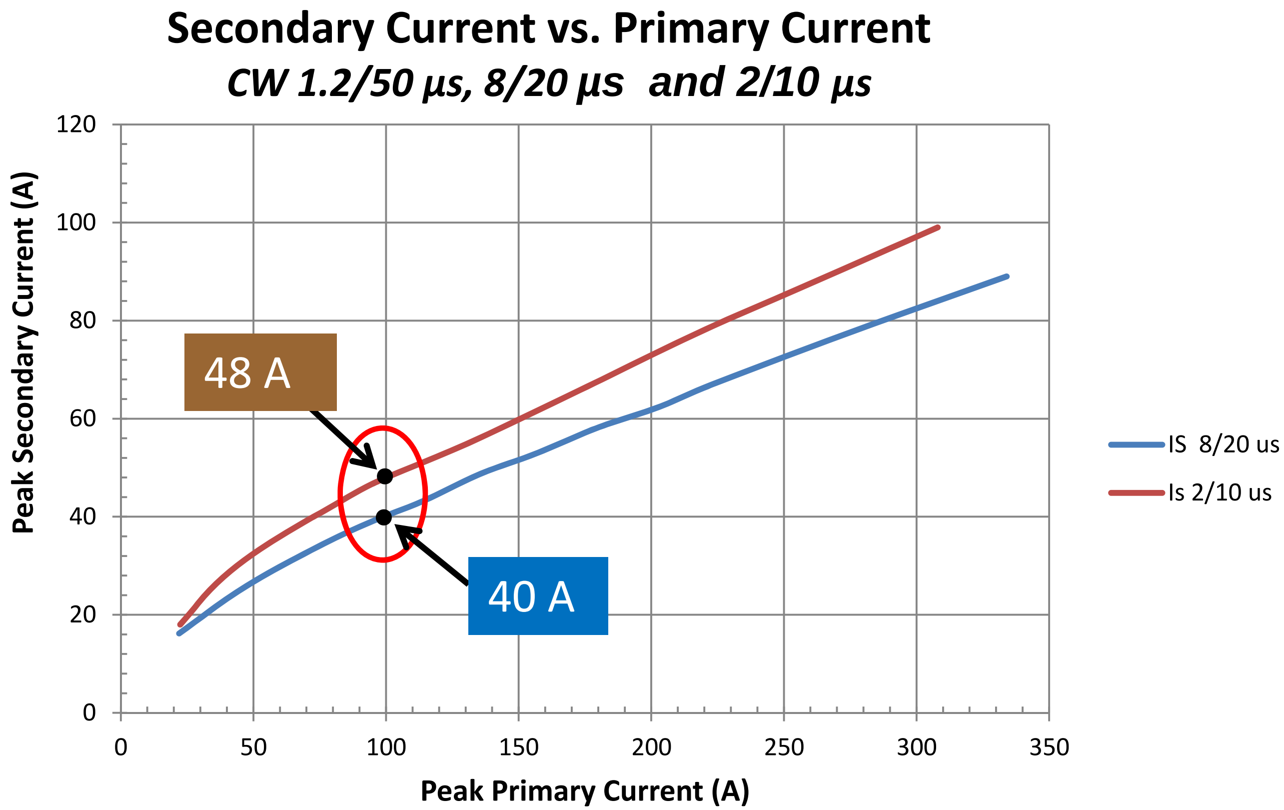
Transformer Differential Surge Test Results

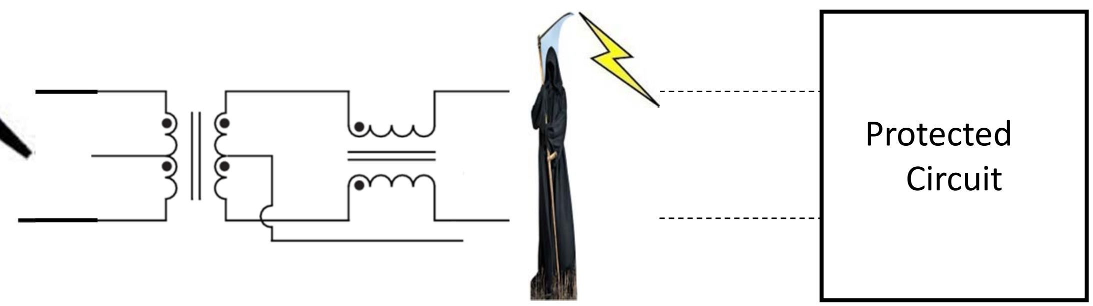
2/10 µs Voltage and CW, Transformer B



- The secondary current is ~ 20% higher for the 2/10 waveform
- Note that it will survive the 2/10, 200A test that is required for port types 3b/5b

Transformer Summary - Differential Surge

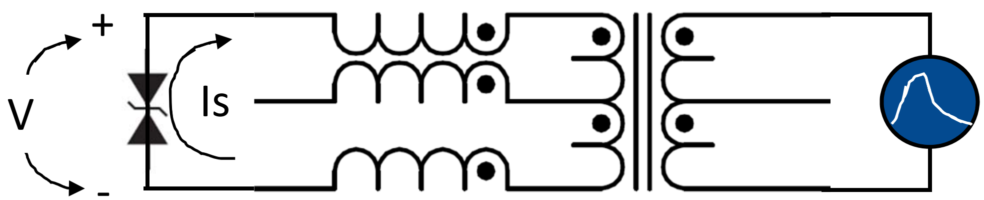
- *The current pulse amplitude at the secondary is much lower than at the primary*
- *The current pulse width is reduced to about 2 µs*



- *Note that it will survive:*
  - *800V/100A, CW surge required for port type 4 in GR1089*
  - *1000V/200A, 2/10 µs voltage surge for port types 3b/5b in GR1089*

TVS Diodes

How Do They Affect the Metallic Surge Picture



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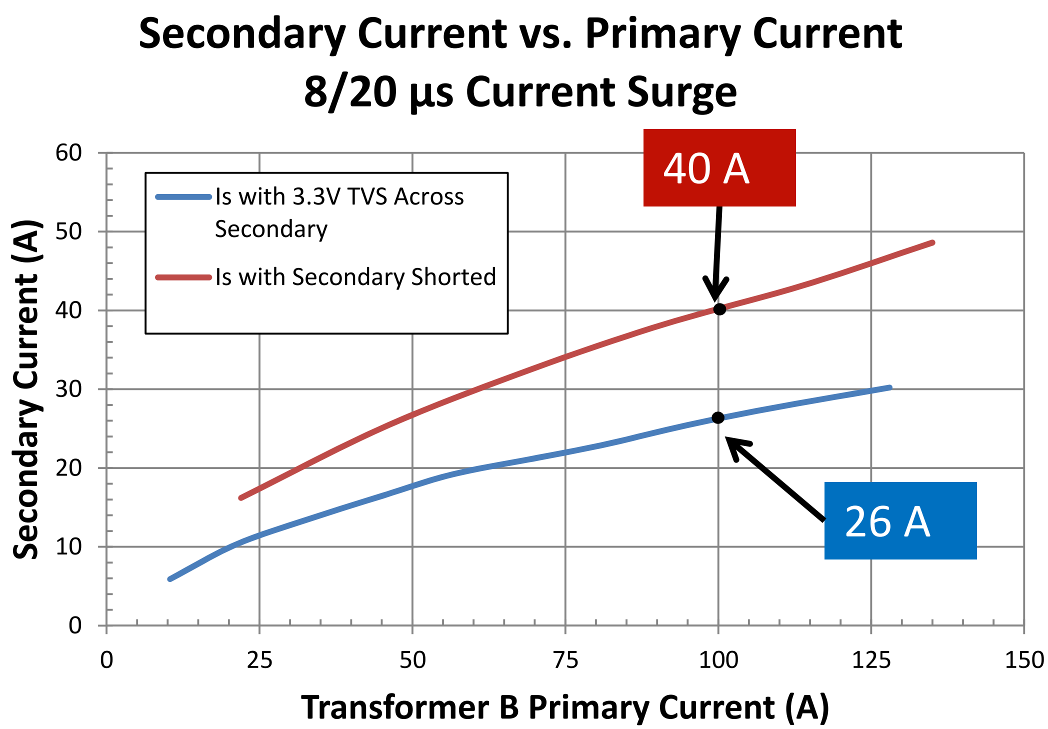
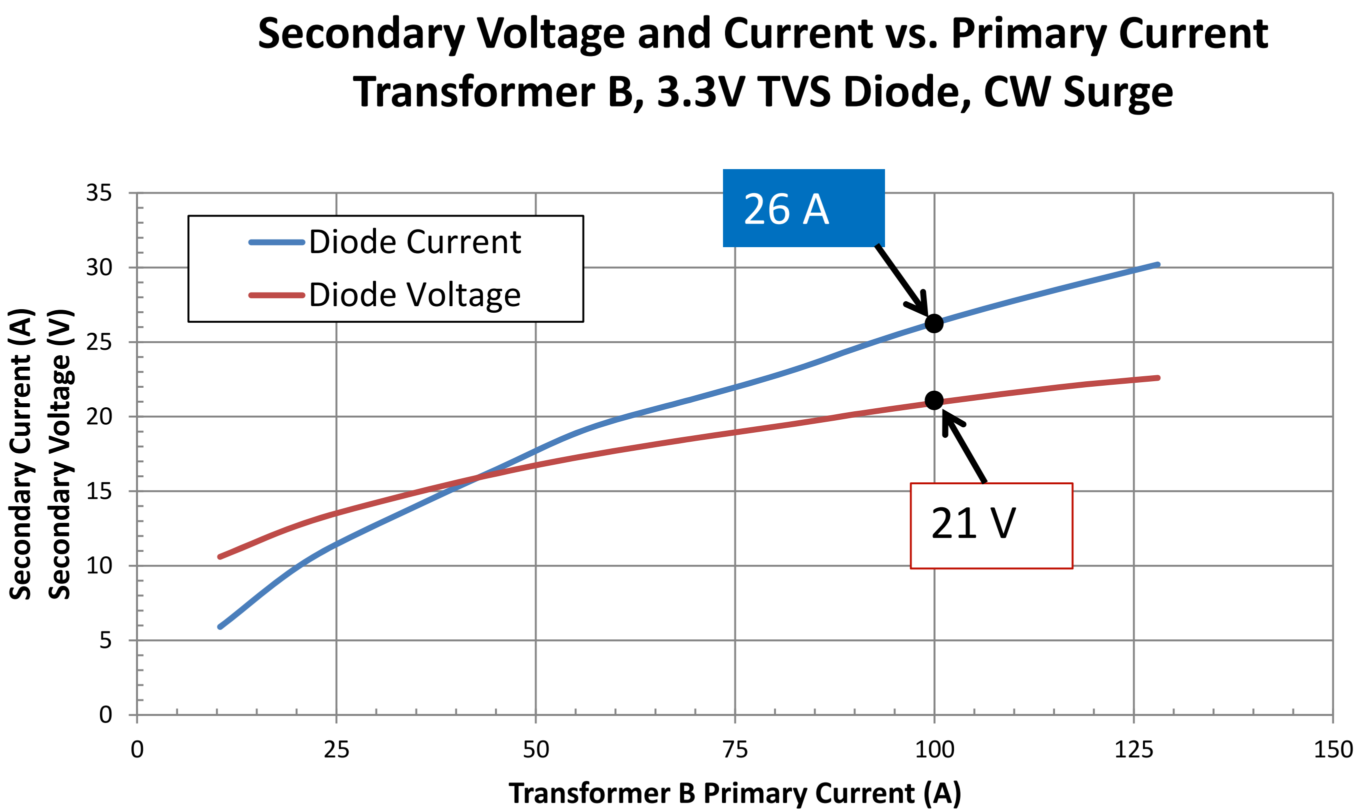
How Does the Diode Affect Secondary Current?



- *The voltage across the diode (transformer secondary)reduces the peak secondary current*
- *Compared to the shorted secondary case, the secondary current with the TVS diode installed is reduced to 26A from 40 A with a primary current of 100 A*

How Does the Diode Affect Secondary Current?



- *The voltage across the diode (transformer secondary) is 21 V when the diode (secondary) current is 26 A*

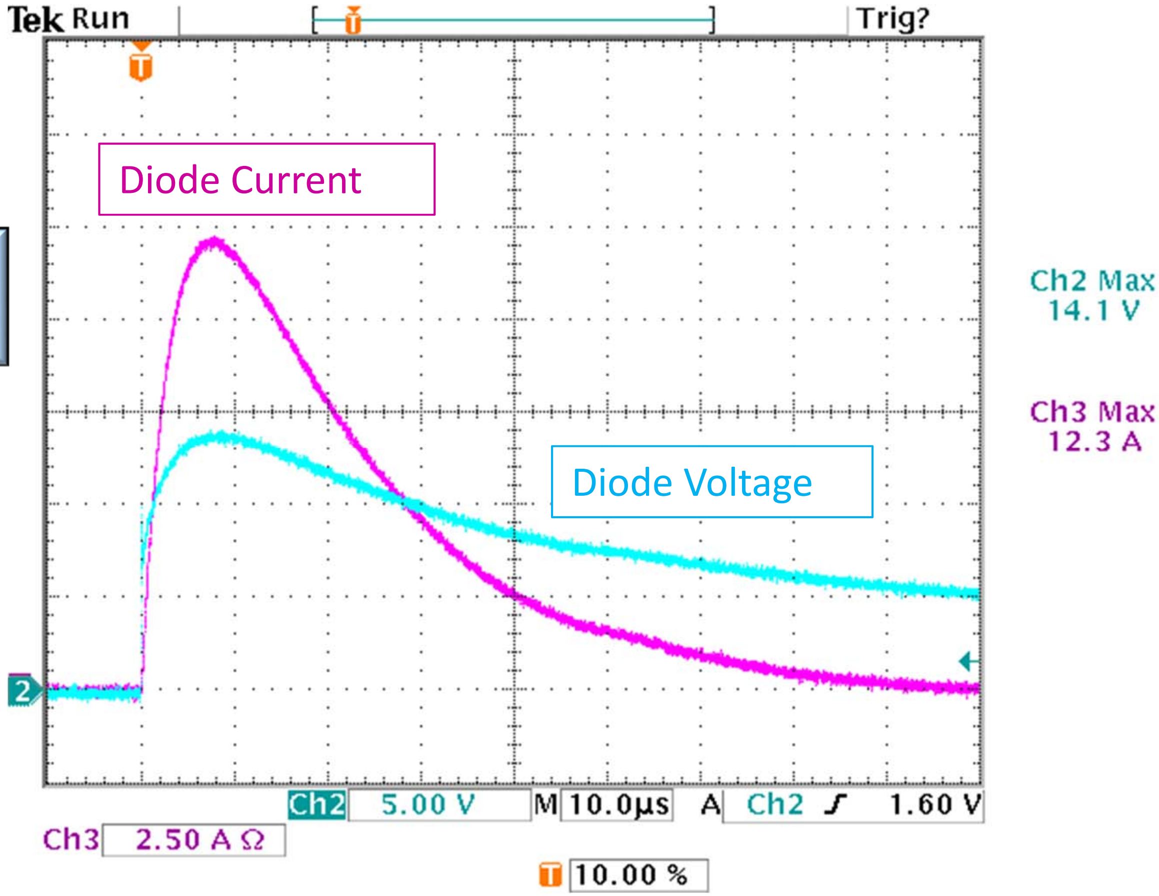
TVS Diode Specifications

- *TVS diodes specify a peak current rating for a specific surge waveform*
- *Most of the diodes used on high speed signal lines are rated against the 8/20 µs Current waveform*
- *That's a good waveform to use since many are used to protect systems that are surge tested against the Combination Waveform*
- *However, we just reviewed how the saturation characteristics of the Ethernet transformer reduces the secondary current pulse width to about 2 µs. How does this affect the diode selection process?*

TVS Diode Specifications

Diode Ratings: V_{WM} = 3.3 V, I_{PP} = 12 A (8/20 µs)

8/20 µs current waveform

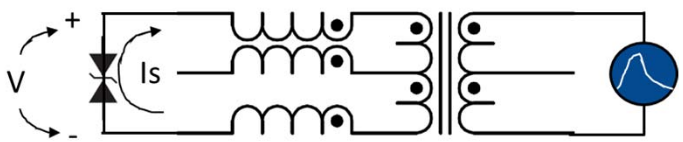


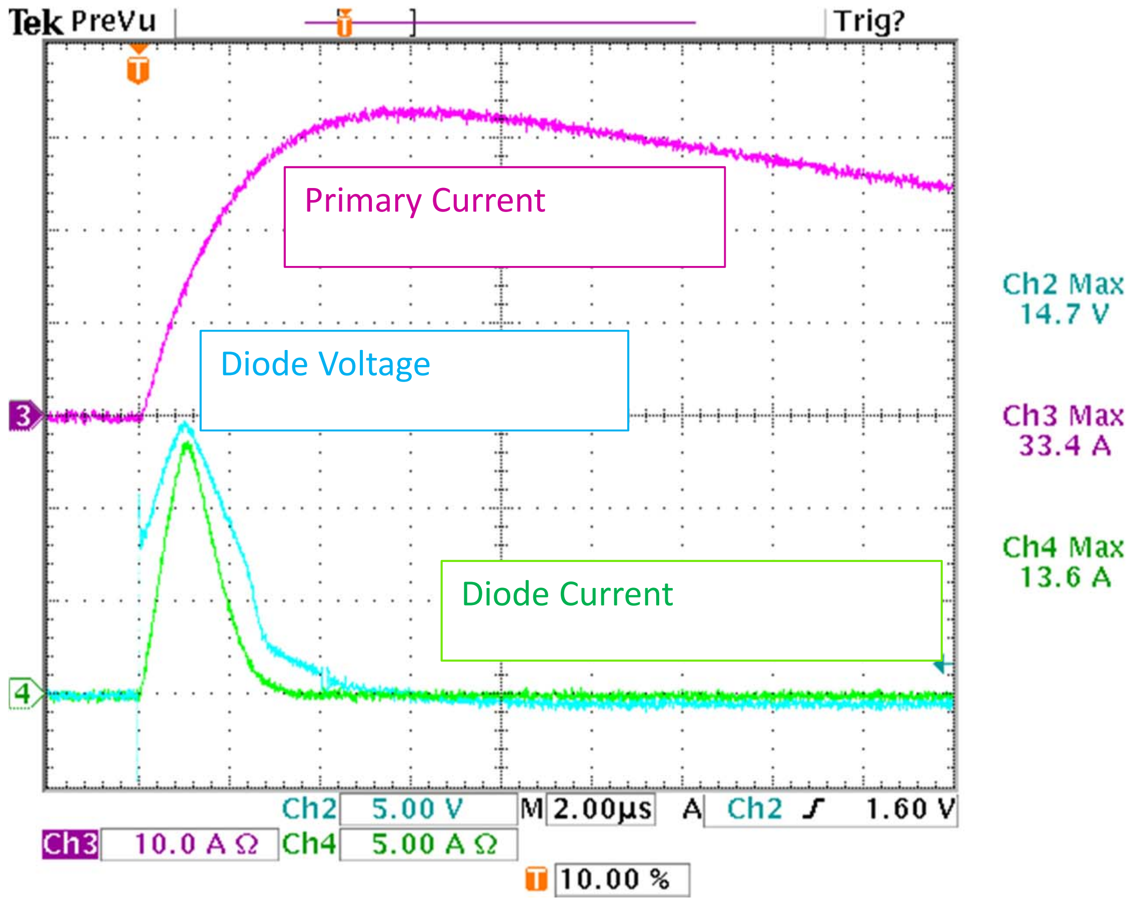
- Note that the diode voltage after turn on is the same shape as the diode current. This is due to the dynamic (effective series) resistance of the device. Also note that the peak voltage at 12A for this 3.3V diode is ~14 V.

TVS Diode Specifications

Diode Ratings: V_{WM} = 3.3 V, I_{PP} = 12 A (8/20 µs)

Driven by Transformer

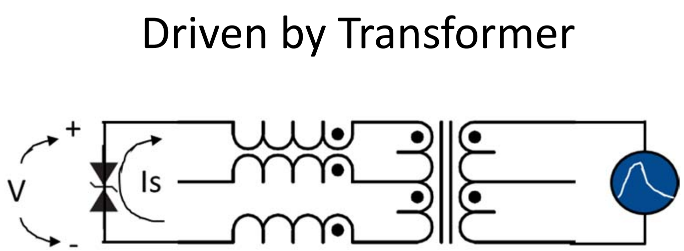


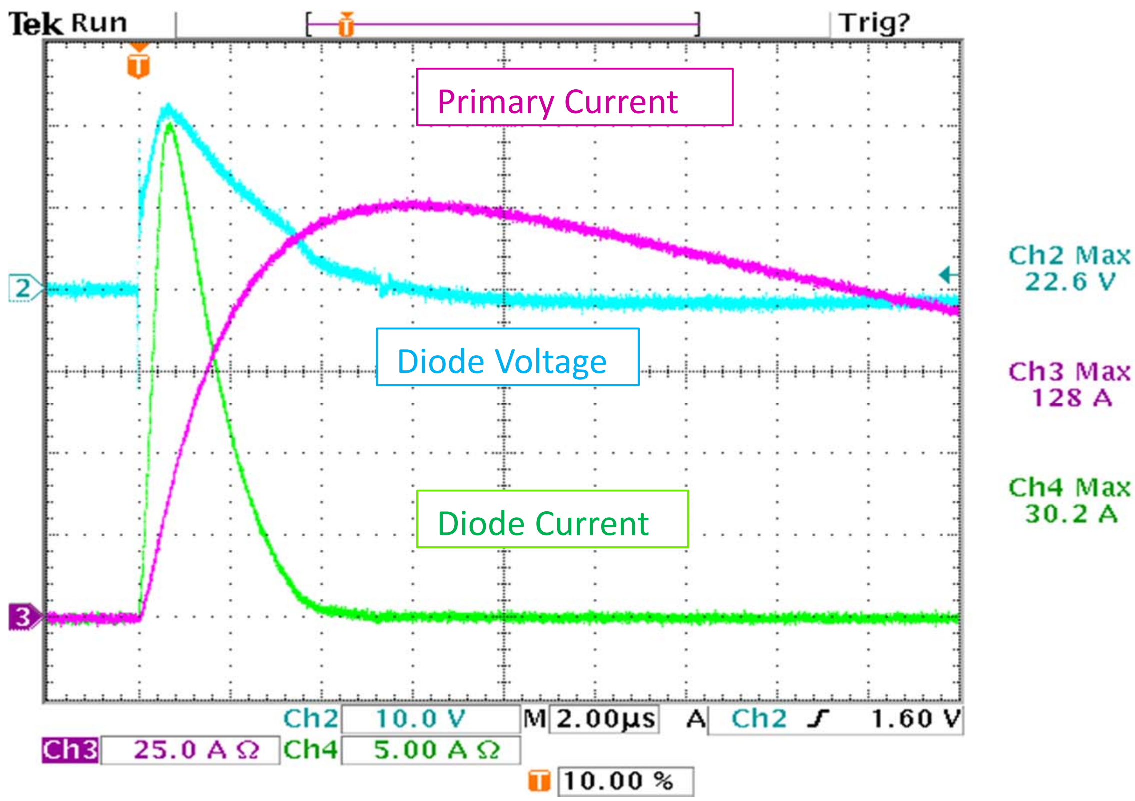


- Again note that the diode voltage (after turn on) is the same shape as the diode current. This is due to the dynamic resistance of the device.

TVS Diode Specifications

Diode Ratings: V_{WM} = 3.3 V, I_{PP} = 12 A (8/20 µs)

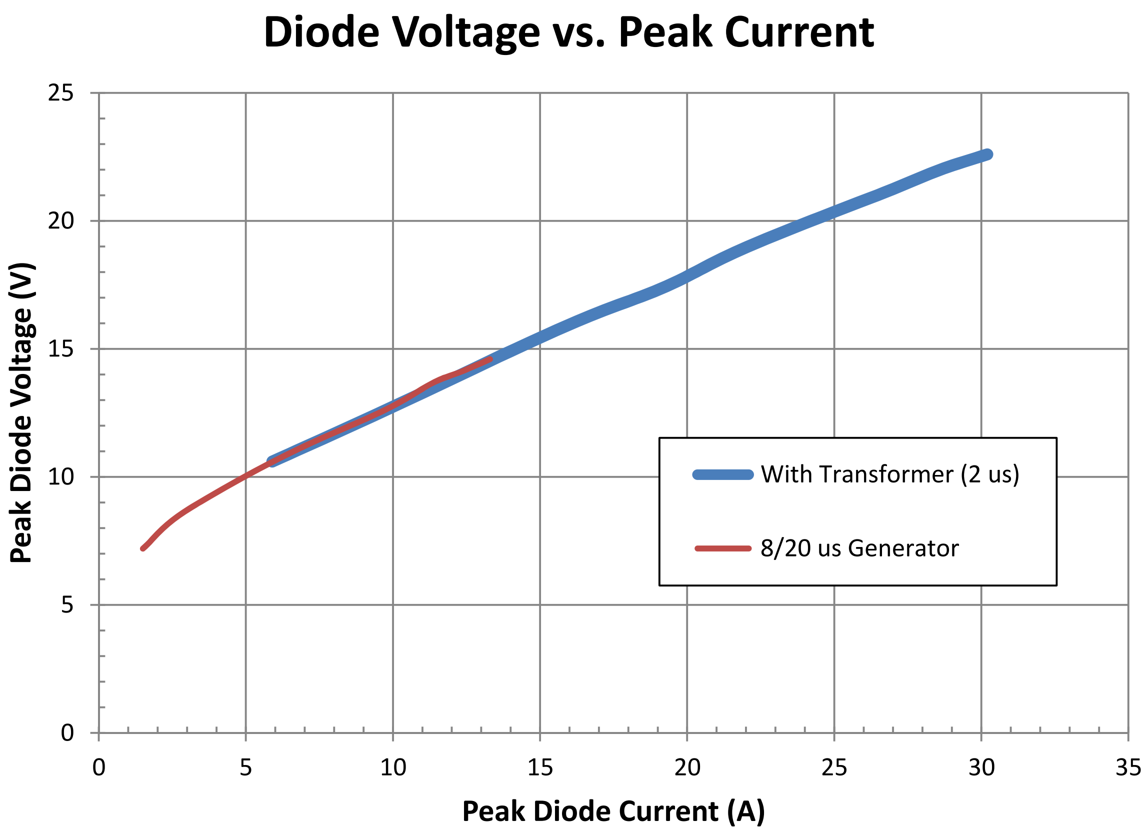




- Even at a peak current of 30 A the diode is still performing well.

TVS Diode Specifications

Diode Ratings: V_{WM} = 3.3 V, I_{PP} = 12 A (8/20 µs)



The slope of the graph is 0.5 Ω. This represents the dynamic resistance of the device.

- The narrower pulse width due to the saturation characteristics of the transformer extends the operating range of the TVS diode
- Note that the peak voltage at a given peak current is the same for both.

Notes on Diode Selection

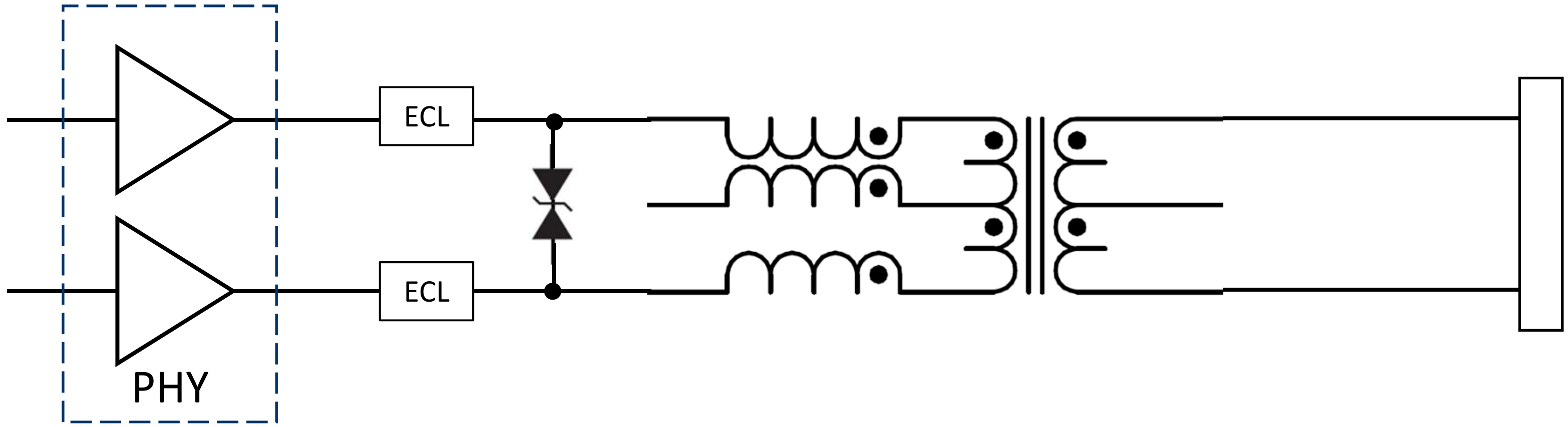
- *The reduced current pulse width on the secondary side of the transformer allows a given diode to handle higher peak surge current levels than its 8/20 µs rating.*

- *However, the clamp voltage vs. current characteristics must be matched with the transformer as well as to the voltage and current levels that the device being protected can tolerate.*

- *This requires careful evaluation of the device that you are trying to protect so that you can determine how much margin your protection design has.*

Additional Design Notes

- *In cases where there is a large variation in the characteristics of the transformer or the TVS diode, electronic current limiters could be used. This will limit the current into the PHY to a very low level with minimal dependence on the transformer secondary current and the TVS diode voltage.*
- *Electronic current limiters could also be used if the PHY is very sensitive to damage*



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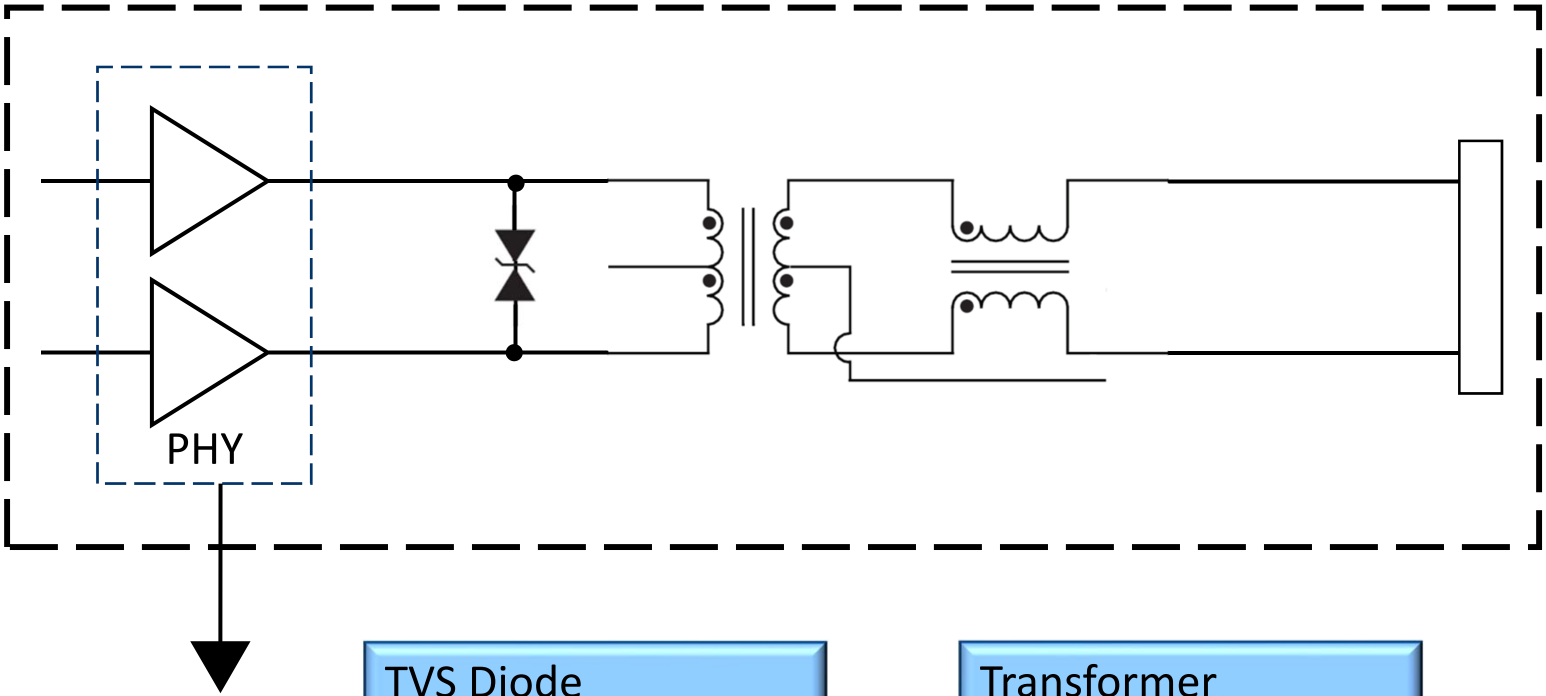
Ethernet Application Example 1

GR1089 Port Type 4 Lightning Protection



TVS Diode
V_{WM} = 5V
I_{PP} = 17A (8/20 µs)
Cj = 3 pF

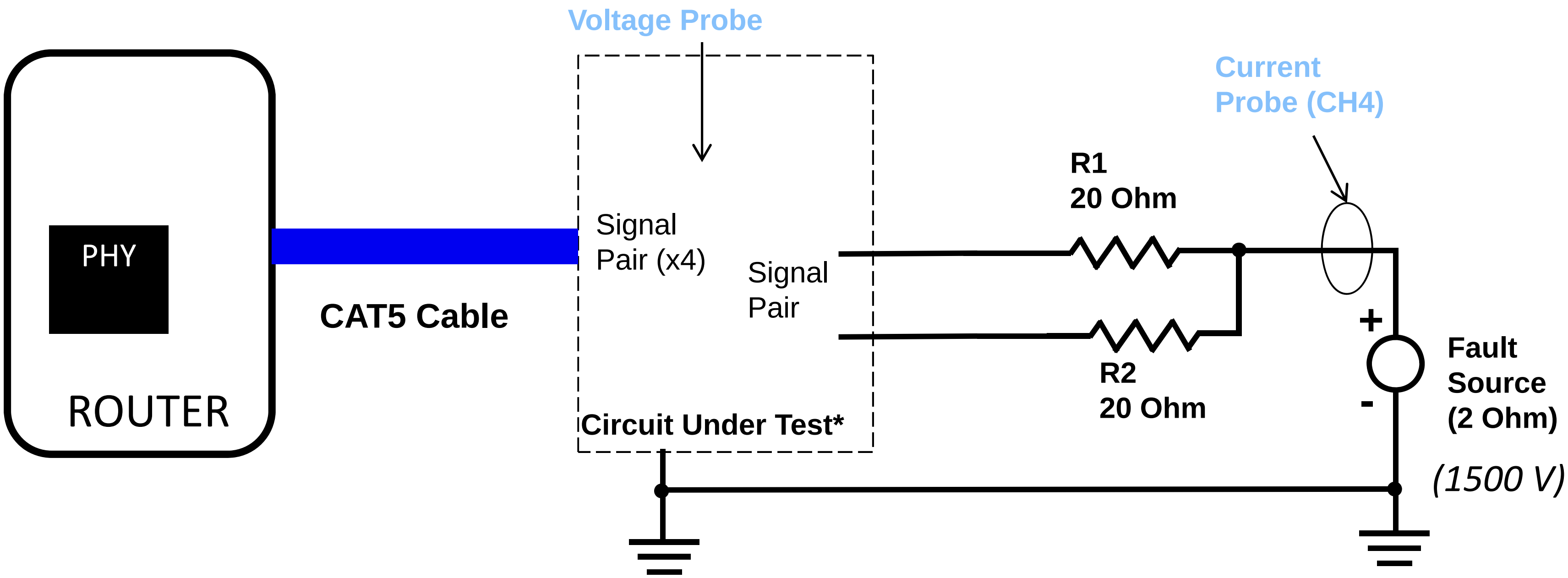
Transformer
GbE (1:1)
1500 V_{RMS} (60 s)

Ethernet Application Example 1

1.2/50 µs, 8/20 µs Combination Wave Test Circuit

Surge Test Setup (per GR-1089-ISSUE6)

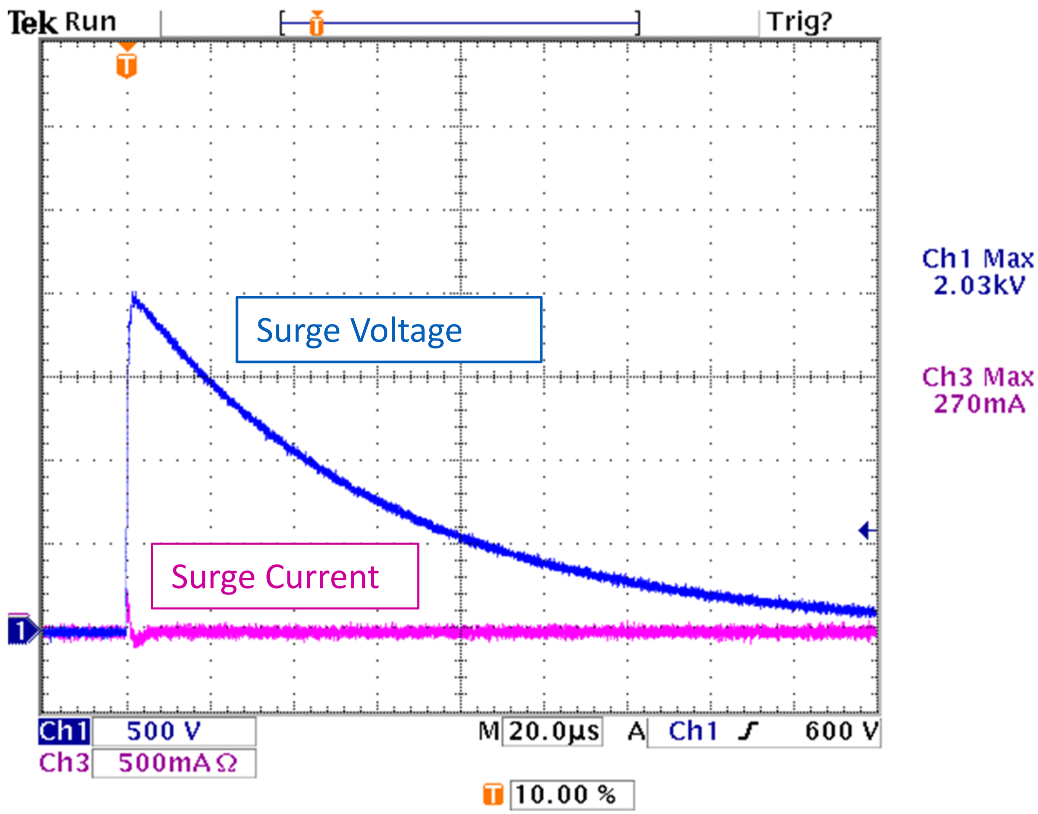
Longitudinal (Common Mode)



A Gigabit router was used as the load. The on board transformer was replaced with shorts and the evaluation board was connected to the router with a 3 inch long CAT5 cable.

Ethernet Application Example 1

Longitudinal 1.2/50 µs, 8/20 µs Combination Wave Test



- This photo shows the waveforms for a 2 kV longitudinal surge (requirement is 1500V)

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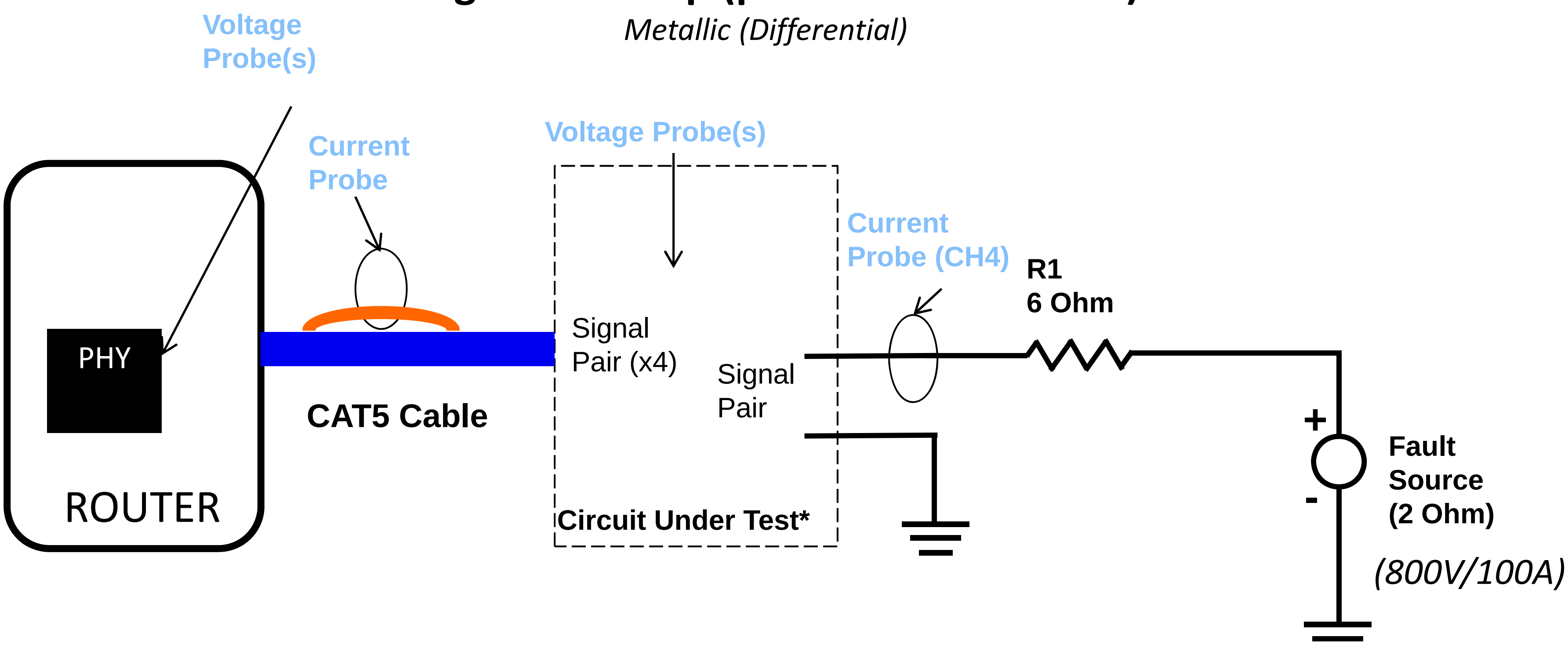
Ethernet Application Example 1

1.2/50 µs, 8/20 µs Combination Wave Test Circuit

Surge Test Setup (per GR-1089-ISSUE6)

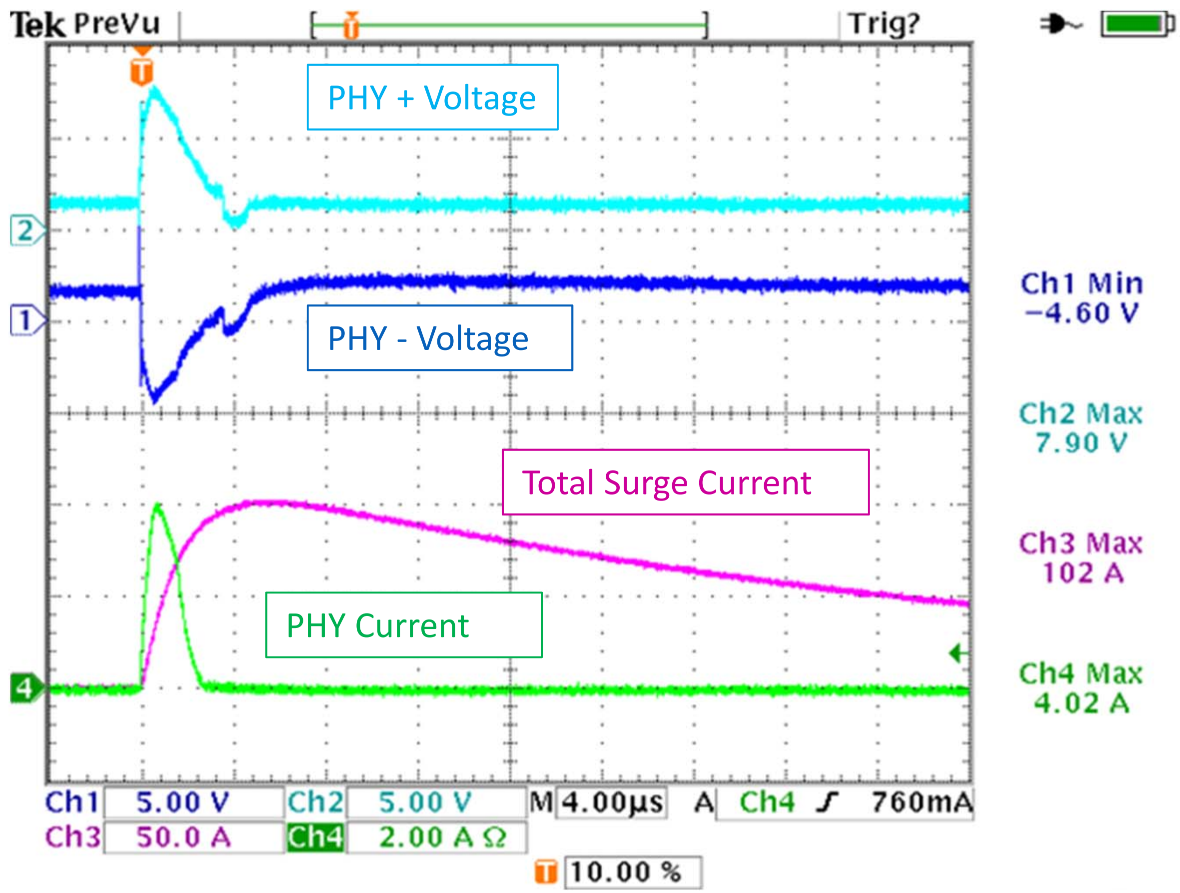
Metallic (Differential)



A Gigabit router was used as the load. The on board transformer was replaced with shorts and the evaluation board was connected to the router with a 3 inch long CAT5 cable . Part of the casing was removed from the cable so that a current probe could be attached to the line under test. For this test, one line (1/2 of a signal pair) is tested at a time with the other seven lines grounded.

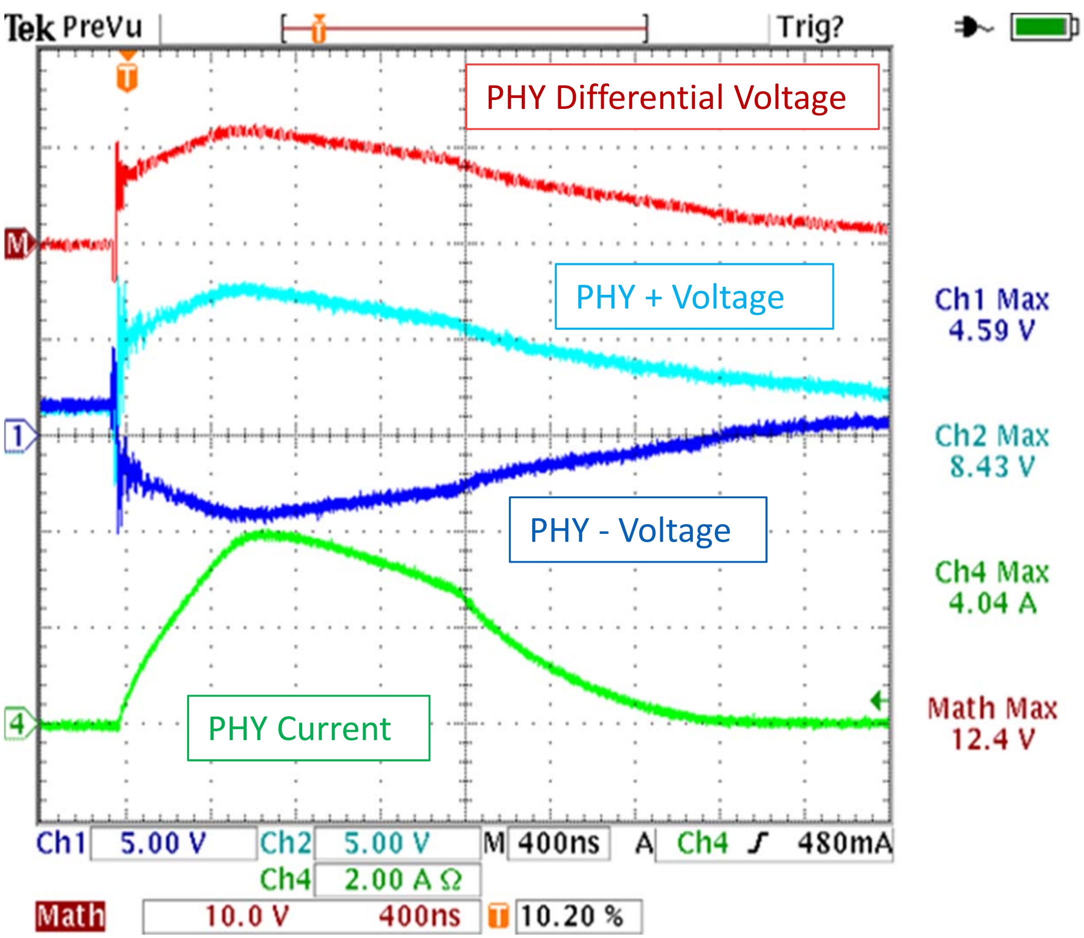
Ethernet Application Example 1

Metallic 1.2/50 µs, 8/20 µs Combination Wave Test



Ethernet Application Example 1

Metallic 1.2/50 µs, 8/20 µs Combination Wave Test



<u>The PHY sees:</u>
Peak Voltage: 12.4 V
Peak Current: 4 A

Not shown: Peak TVS diode current ~14 A

Ethernet Application Example 1

Test Results Summary

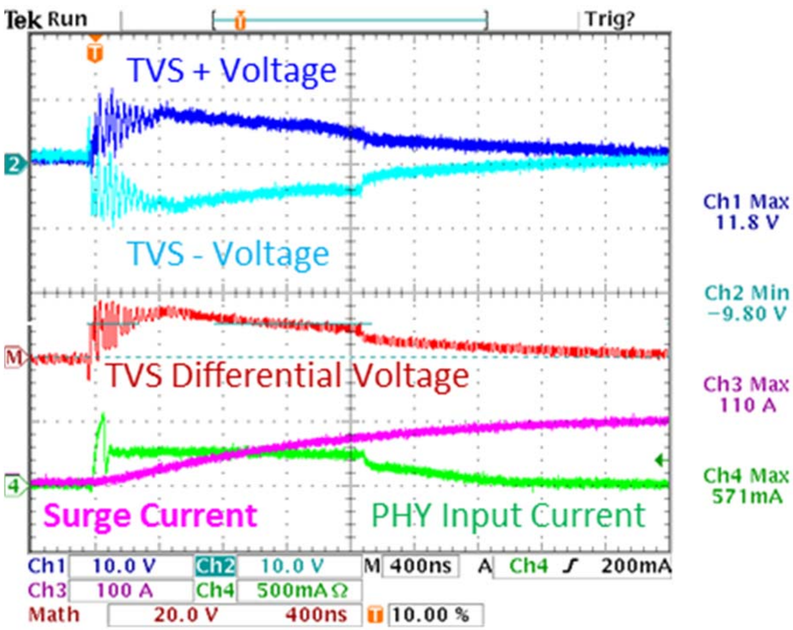
- **GR1089 , Port type 4, Surge Testing**
  - *Longitudinal (1.2/50 µs, 8/20 µs, 1500 V, 100A): Passed*
  - *Metallic (1.2/50 µs, 8/20 µs, 800 V, 100A): Passed*
    - *Voltage across the PHY differential input is limited to 12.4 V*
    - *Current into the PHY is 4 A*
    - *TVS Diode Current is ~14 A*

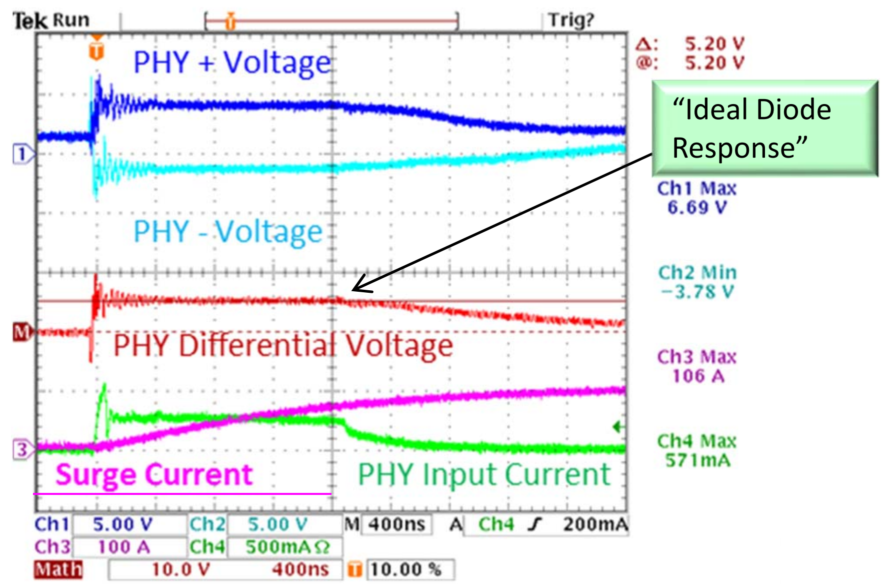
- One of the keys to a successful choice for the TVS diode is get the right current sharing balance between the TVS diode and the ESD structure (or internal protection) of the PHY.

Ethernet Application Example 2

TVS Diode with ECL (375 mA trip point)

1.2/50, 8/20 µs CW Surge Test (800 V/100 A), Metallic





TVS Peak Voltage: ~15 V (scale: 20 V/Div)

PHY sees:

Peak Voltage: 5.2 V
(scale: 10V/Div)
Peak Current: 571 mA
Energy: ~ 3 µJ

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Gigabit Ethernet (GbE) Application Comparison

1.2/50 µs, 8/20 µs Combination Wave Test

Test Results Summary

Test	Protection Circuit	Diode Clamp Differential Voltage (V)	TVS Diode Current (A)	PHY Differential Input Voltage(V)	PHY Input Current	Estimate of Energy Absorbed by PHY (µ J)
Differential Surge Test per GR-1089-CORE-ISSUE 6 (800V/100A)	TVS Diode Only	12.4	14	12.4 (same)	4A peak	54
	TVS Diode with ECL	15	17	5.2V	<300mA*	3

** After initial peak*

Ethernet Application Examples

GbE Signal Amplitude Test per IEEE802.3

Line Pair	Point	Example 1: TVS diode Only (mV)	% Peak voltage difference Between Points A and B	Example 2: TVS diode with ECL (mV)	% Peak voltage difference Between Points A and B	Loss due to Addition of ECL (dB)
1	A	768.7	0.73%	754.1	0.49%	-0.17
	B	763.1		750.4		-0.15
2	A	760.7	0.50%	746.5	0.44%	-0.16
	B	756.9		743.2		-0.16
3	A	772.4	0.06%	759.9	0.13%	-0.14
	B	771.9		760.9		-0.12
4	A	768.7	0.88%	754.5	0.76%	-0.16
	B	762.0		748.8		-0.15

Notes:

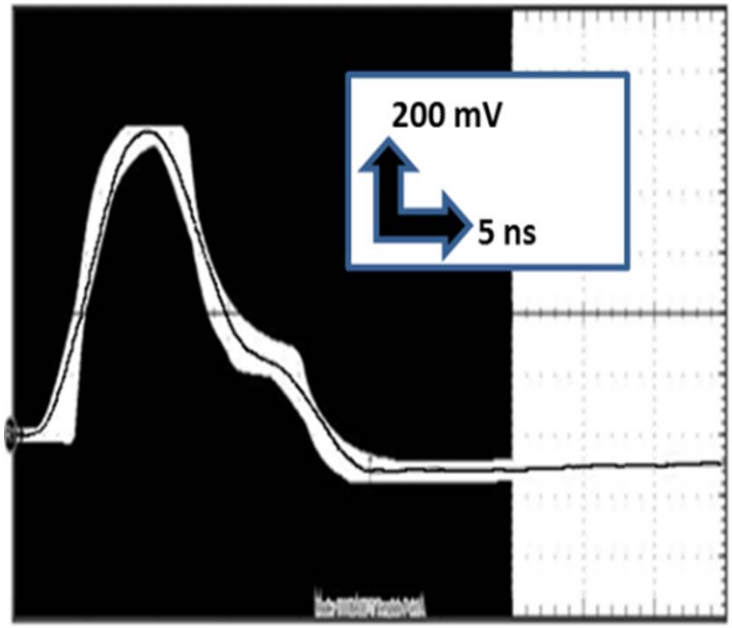
1. The required amplitude range for the signal at points A and B is 670 mV to 820mV.
2. The % peak voltage difference between points A and B must be < 1 %

The loss due to the addition of the ECL results in < 0.2 dB of attenuation. This is equivalent to less than 1 m of CAT5 cable.

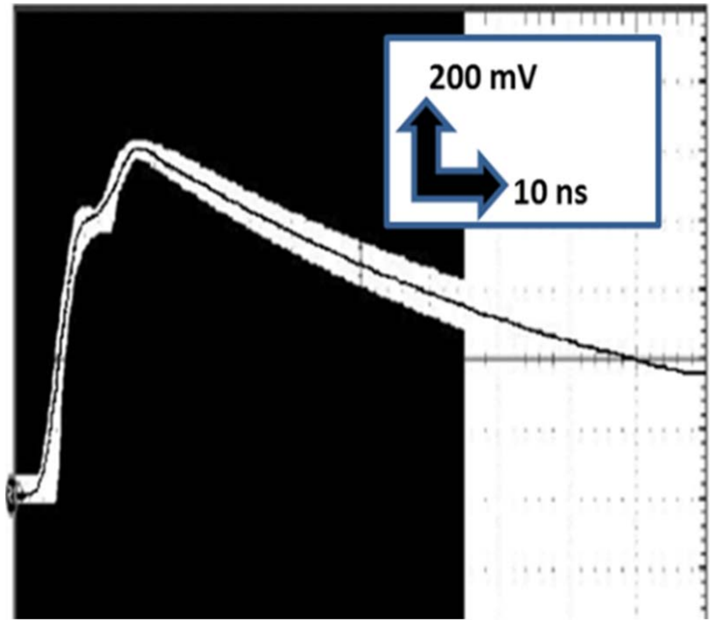
Application Example: Ethernet

GbE Template Tests per IEEE802.3

- ***Both designs pass the template tests. The pictures below show a sample of the test results for the TVS with ECL design.***



Point A Template Test



Point F Template Test

Presentation Summary

- *Transformer Characteristics*
  - *The saturation of the Ethernet transformer by a metallic surge waveform reduces the surge current peak amplitude and pulse width on the PHY side.*
  - *There is significant variation between transformer designs. Therefore, it is important to characterize the one used in a given design.*
  - *If the transformer is rated to withstand the peak longitudinal voltage required by the design then additional protection on the line side can be avoided.*

- *TVS Diode Considerations*
  - *The reduced current pulse width due to the transformer allows the TVS diode to handle higher surge currents than its 8/20 rating.*
  - *However, care must be taken to ensure that the voltage across the device at the maximum current does not cause damage to the device being protected.*

Presentation Summary (Con't)

- *Effective Design*
  - *The transformer, the TVS diode and the PHY must all be characterized to ensure that excessive stress is not put on the PHY.*
  - *Use of an ECL with a TVS diode (or other voltage limiting design) will limit the stress level on the PHY to low level that is almost independent of surge voltage level as well as the TVS diode clamp voltage.*

Thank you!

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