Semiconductor Protection Devices

General and Specific

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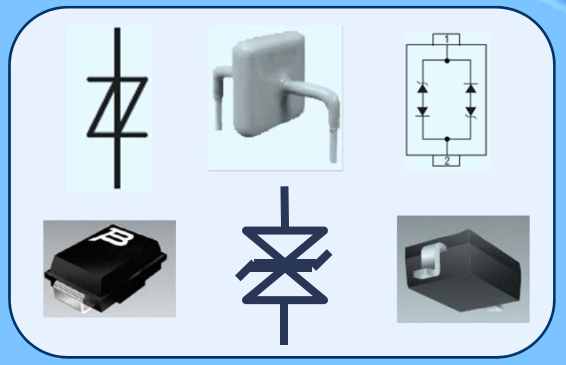
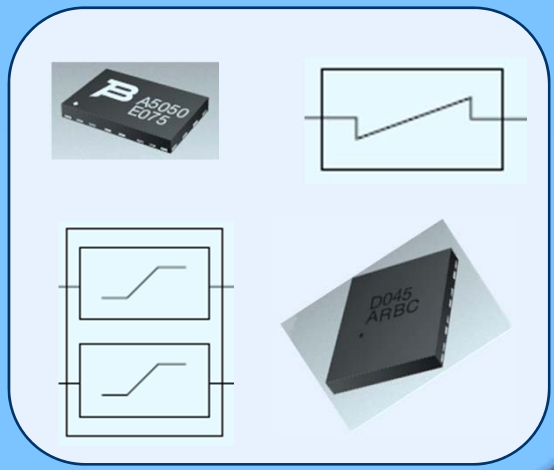
BOURNS®

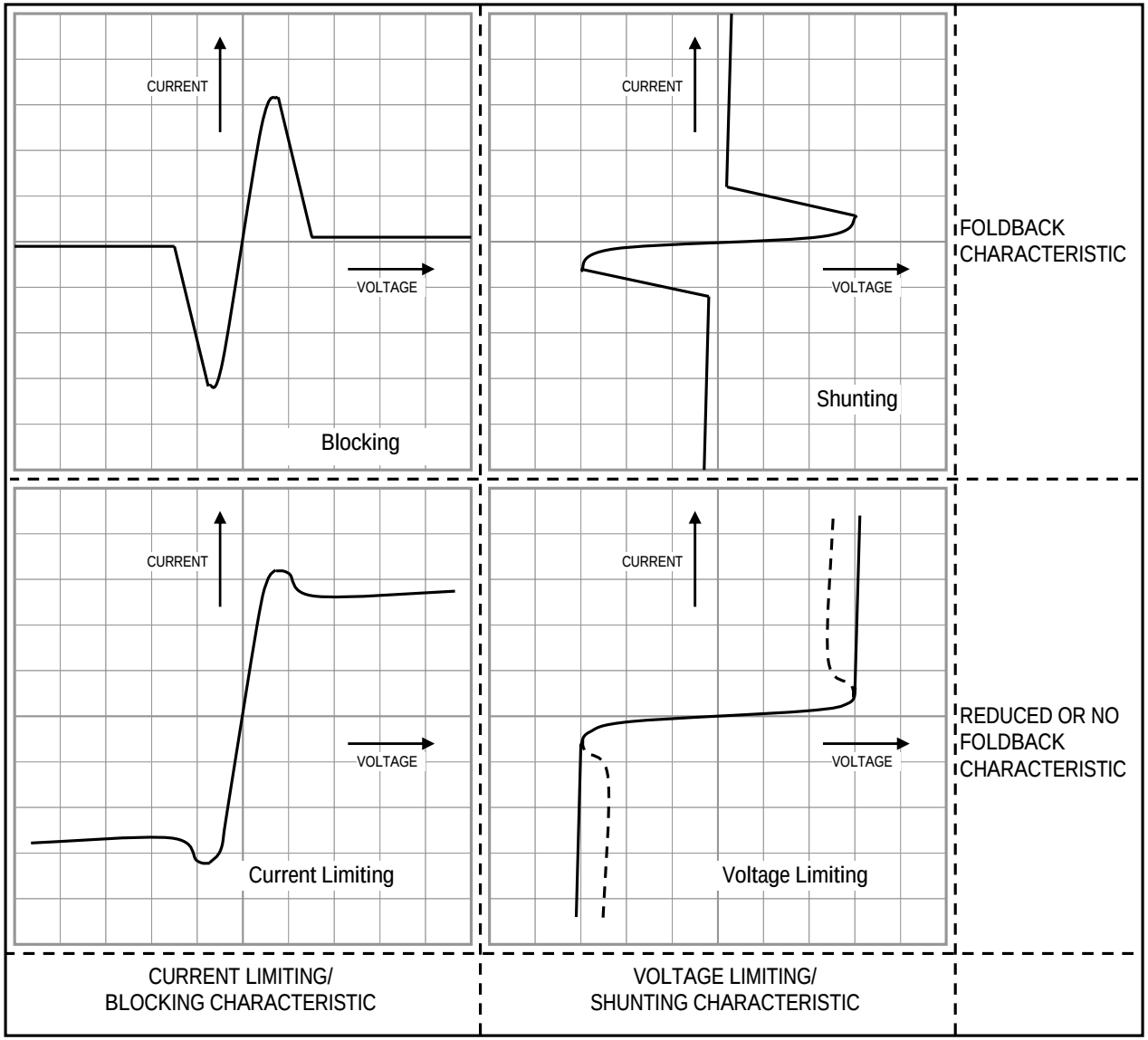
Two General Types of Semiconductor Protection Devices

- Shunting (shorting)
  - Limits Voltage (Crowbar or Clamp)
  - Parallel Connection
  - High resistance when voltage is below trigger point
  - Low (dynamic) resistance when triggered
- Limiting (ECL)
  - Limits or Blocks Current
  - Series Connection
  - Low resistance below trigger point
  - High resistance when triggered



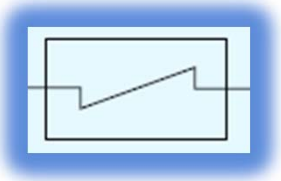


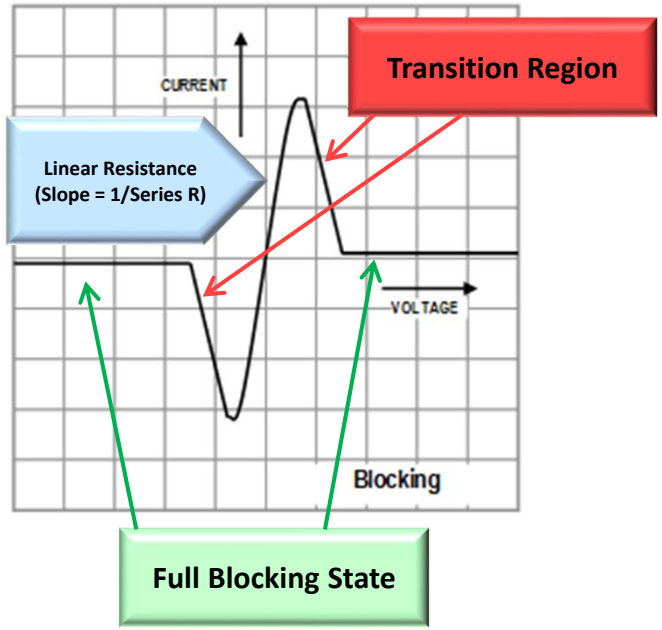
General Characteristics of the Device Types



Blocking Devices

General Characteristics



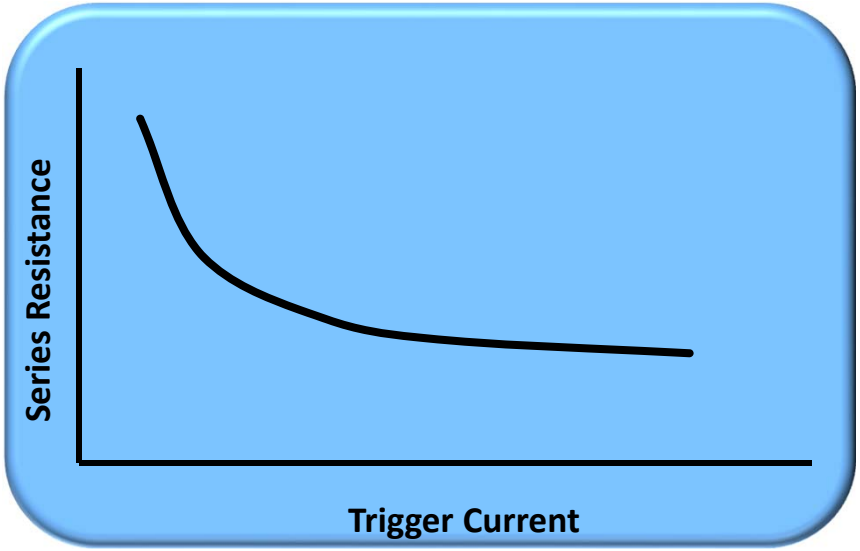


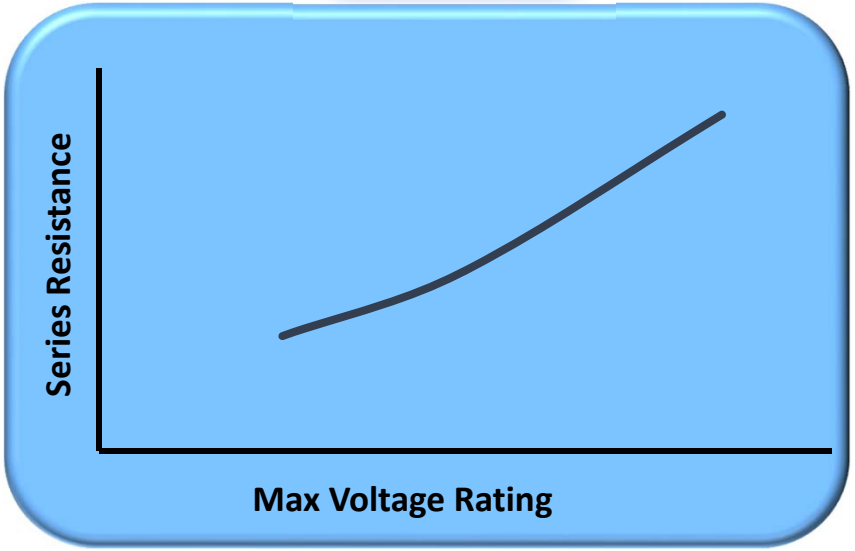
Bidirectional Device

- Linear Resistance Region
  - Very linear response when not triggered
  - Behaves like a resistor
- Transition Region
  - In general, the device should not be continuously operated in this region
    - Power dissipation is the primary concern
- Full Blocking State
  - Low quiescent current
  - Provides voltage isolation up to rated voltage

Blocking Devices

General Characteristics

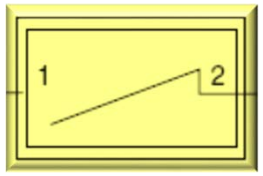




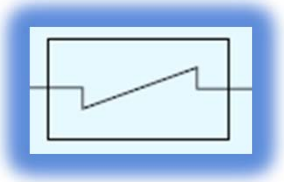
- Series Resistance
  - Lower for higher trigger current level devices with same voltage rating
  - Higher for higher voltage rating devices with same trigger current
- Trigger Current
  - Ranges from 50 mA to more than 500 mA
  - Devices can be paralleled for higher current capability (and lower resistance)
- Max Voltage
  - Ranges from 20V to 850V

Blocking Devices

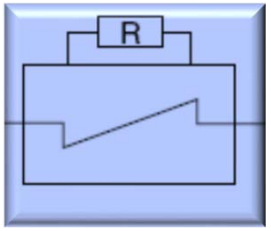
What's Available? Configurations



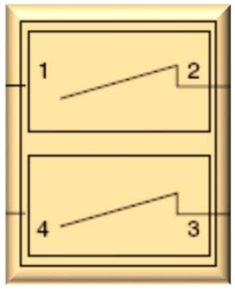
Single
Unidirectional



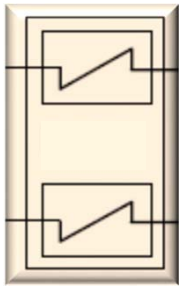
Single
Bidirectional



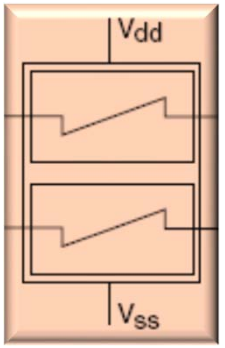
Programmable
Single
Bidirectional



Dual
Unidirectional



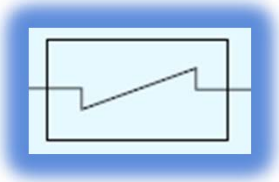
Dual
Bidirectional



Dual Bidirectional
w/Voltage Control

Blocking Devices

What's Available?



Category	Max Voltage (V)	Trigger Current (mA)	Series Resistance (Ω)	Response time (ns)	Package
Low Voltage	20 - 40	150-240*	3.6 - 6.5	60 - 200	SOT23, DFN
High Voltage	250 - 850	50 – 500*	2.6 - 22	1000	DFN
Application Specific	250 - 850	50 – 500*	50, 80	1000	DFN

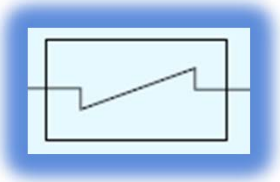
* Several fixed values are available within this range. A programmable device is also available for the high voltage devices.

Notes:

1. Unidirectional and Bidirectional devices are available
2. Response time is from the trigger point to the full blocking state. The device limits current during this transition.

Blocking Devices

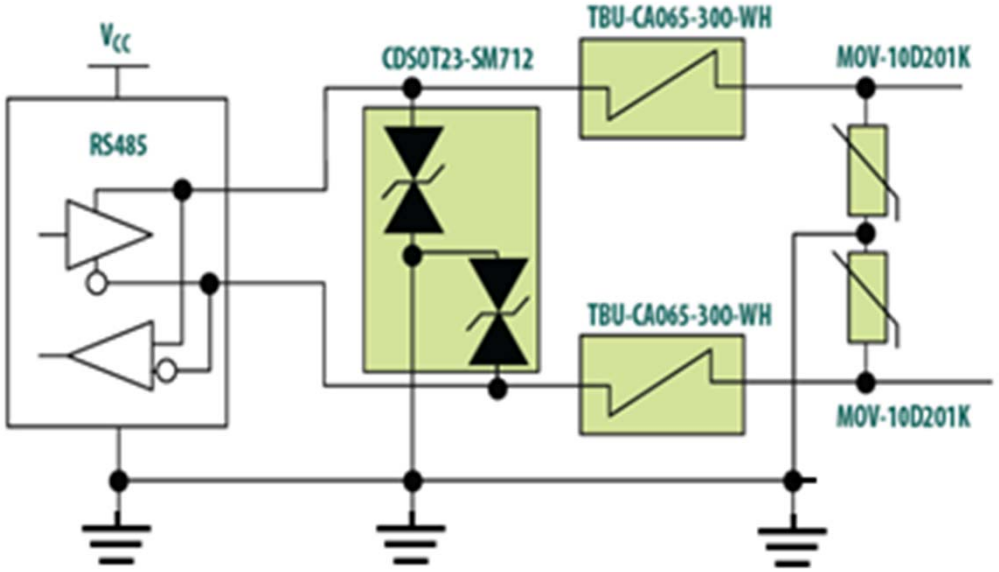
Applications



- Voice Lines
  - SLIC Protection
- Low and High Speed data communication Lines
  - Ethernet
  - XDSL
  - RS-485
  - 4-20ma Current loop
- Protection modules and dongles
- Process control equipment
- Test equipment

Application Example: RS-485 Advanced Circuit Protection

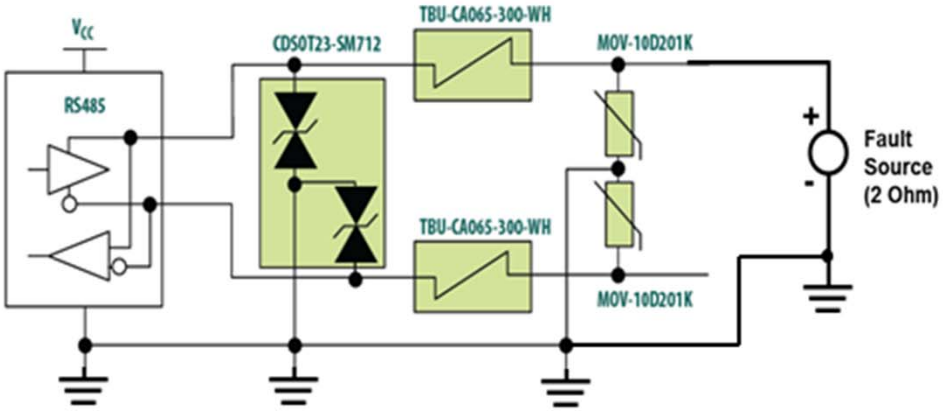
Ultimate Protection Using a Blocking Device



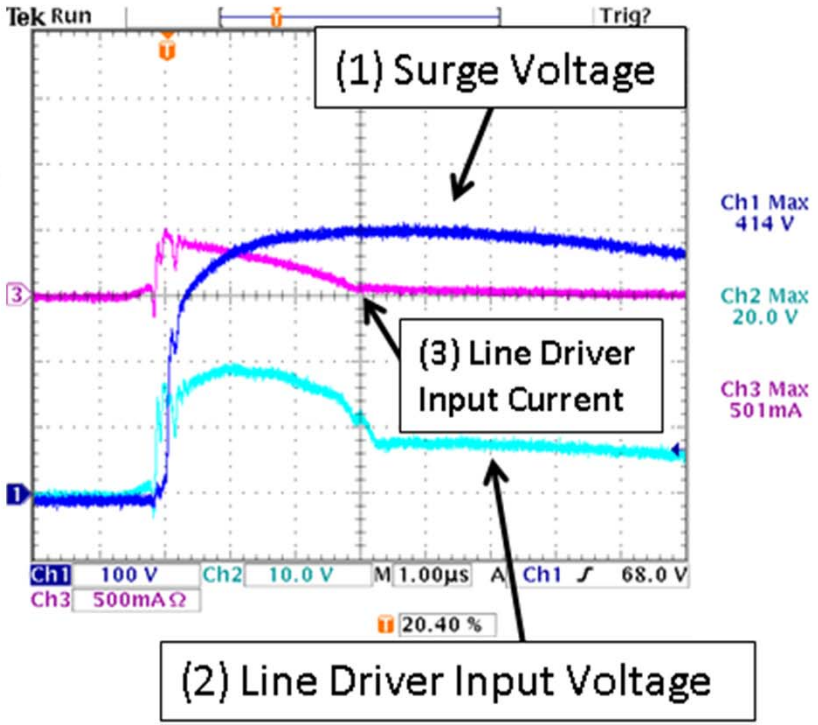
Test Performed	Standard	Level	Notes	Pass/Fail
Surge	IEC 61000-4-5	1, X	Level X=5 kV; 1.2/50 µs, 8/20 µs	Pass
Power Cross	N/A	N/A	125 Vrms, continuous protection	Pass
ESD				
- Air Discharge	IEC 61000-4-2	1,2,4,X	Level X= 16 kV	Pass
- Contact Discharge	IEC 61000-4-2	1,2,3,4	Up to 8 kV	Pass
EFT (Modified, Direct Connect)	IEC 61000-4-4	4	2 kV, 100kHz	Pass

RS-485 Advanced Circuit Protection

5 KV Positive Surge per IEC61000-4-5



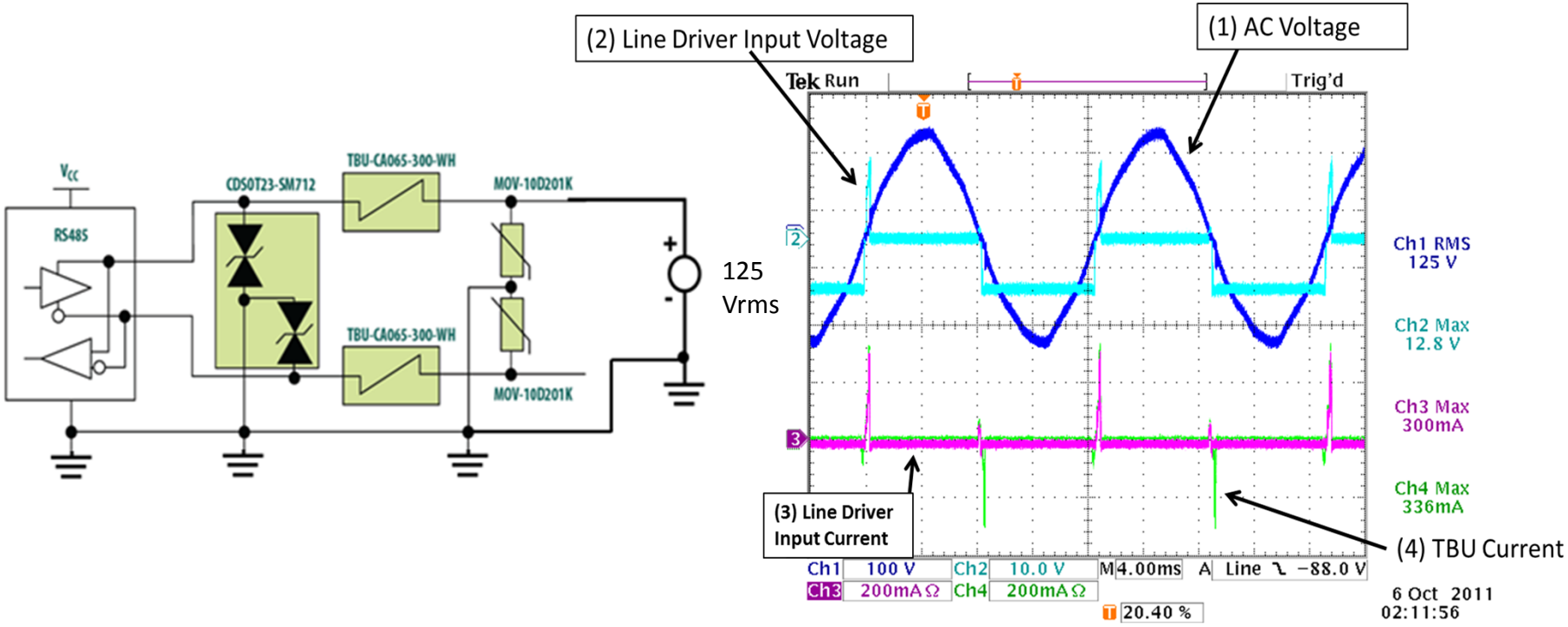
Note: This design is very robust and can handle the extremely high surge current without using an external 40 Ohm resistor in series with each line of the differential pair for the surge test, as allowed by the IEC specification.



The peak current into the transceiver is held to ~500 mA and is reduced to the very low quiescent level (<1 mA) of the Blocking Device in about 3 µs.

RS-485 Advanced Circuit Protection

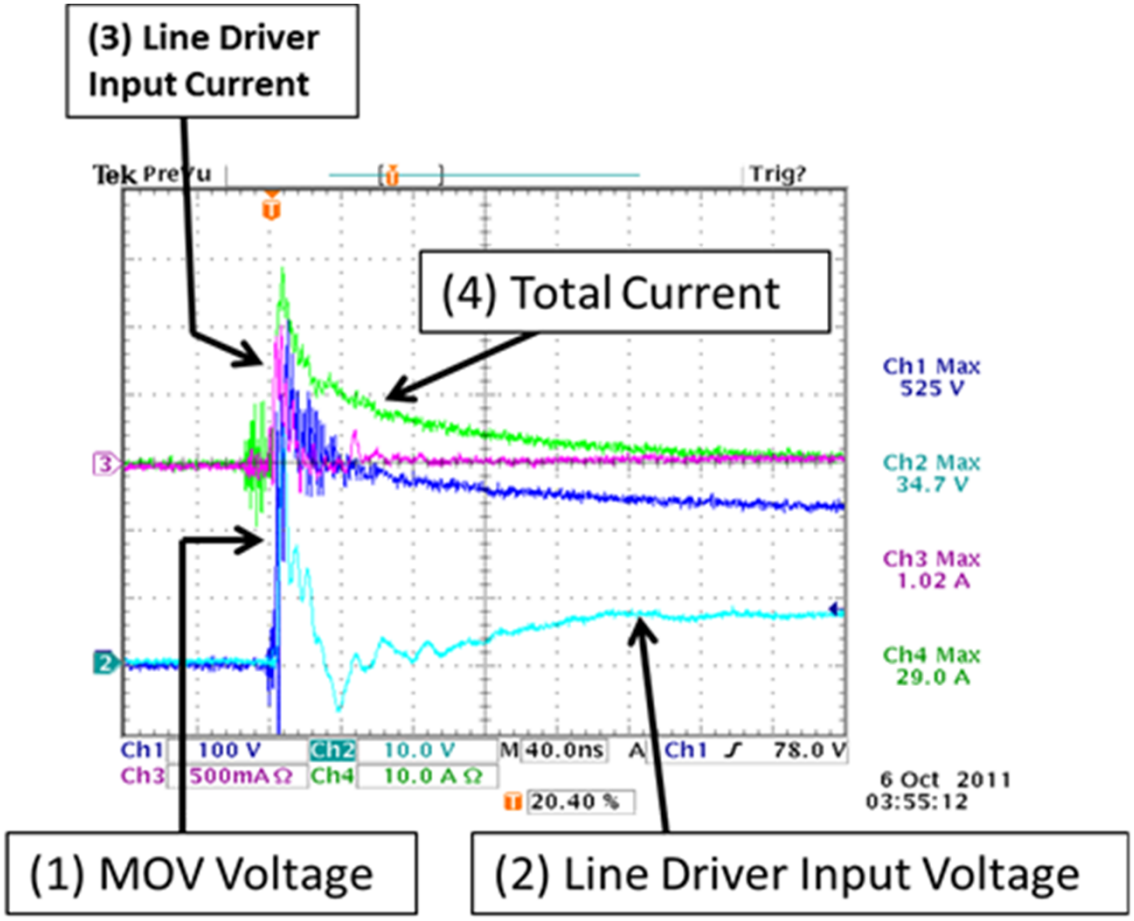
125 Vrms 60 Hz AC Power Cross



The current into the protected device is limited to short duration current pulses with a peak value of ~300 mA as it transitions between normal operation and the blocking state.

Bourns RS-485 Advanced Circuit Protection

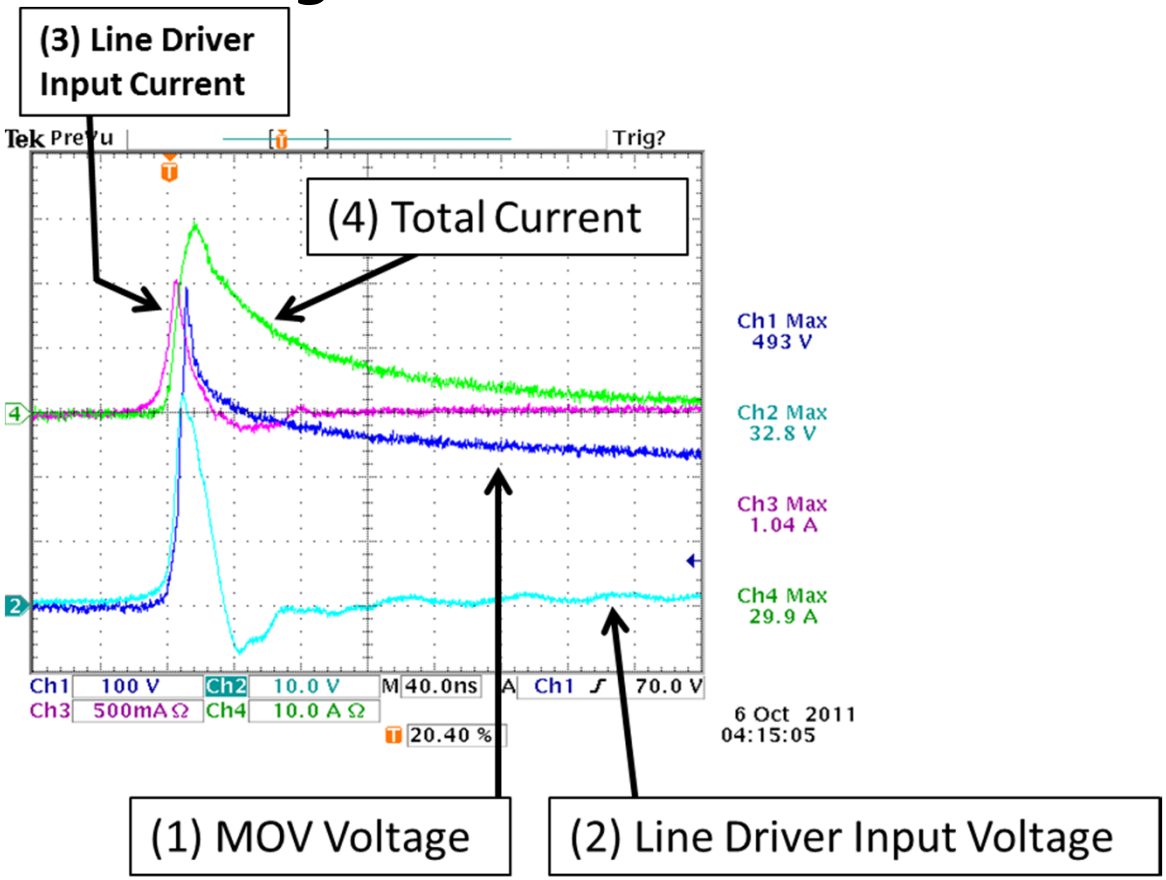
8 kV Contact Discharge ESD Protection



The current into the protected device is limited to just over 1 A, a fraction of the 29 A peak current from the ESD event.

Bourns RS-485 Advanced Circuit Protection

16 kV Air Discharge ESD Protection

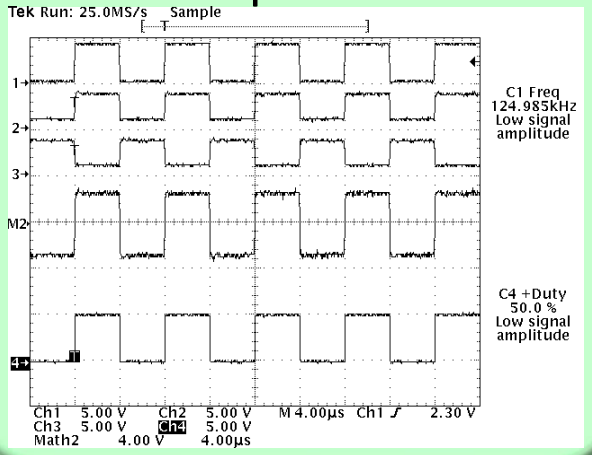


The current into the protected device is limited to just over 1 A, a fraction of the 30 A peak current from the ESD event.

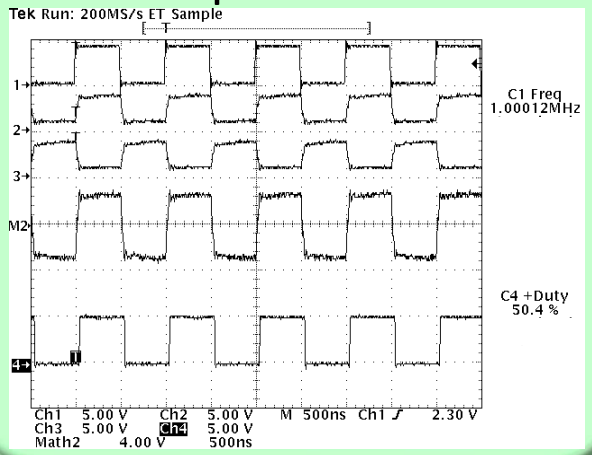
Application Example: RS-485

Signal Quality

- 250 Kbps



- 2 Mbps



CH1 = Txin

CH2 = A,

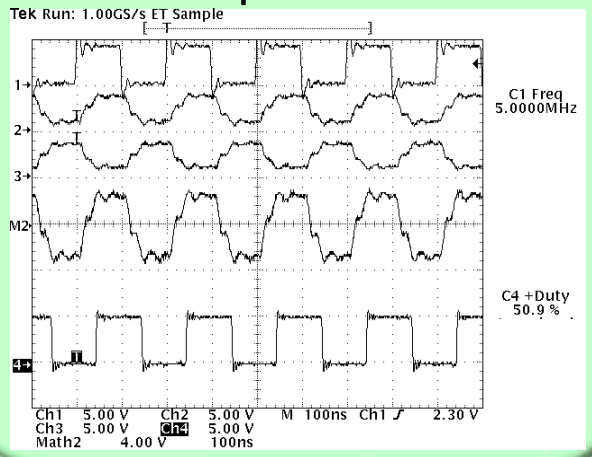
CH3 = B

M = A – B,

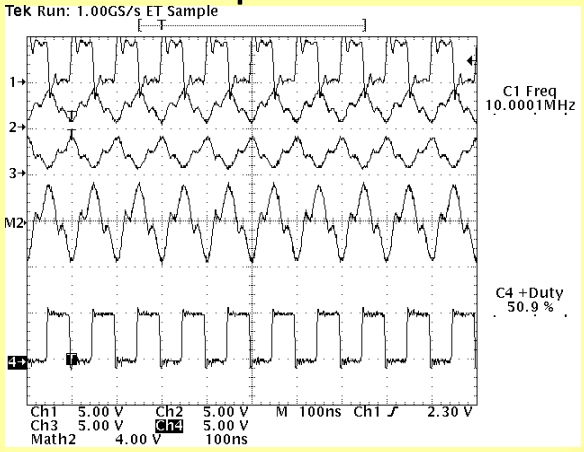
Ch4 = RXout

Test: Two boards connected together with 1 foot of twisted pair and 120 ohm termination at each end.

- 10 Mbps



- 20 Mbps



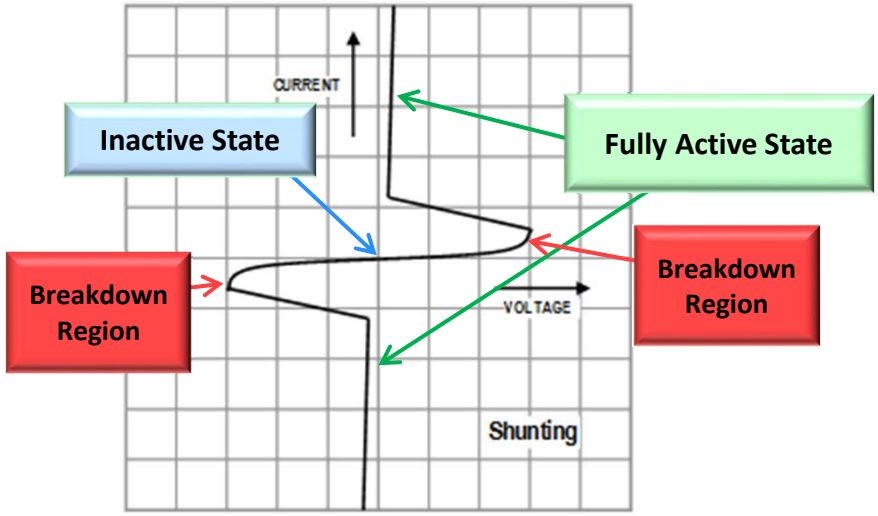
RS-485 Advanced Circuit Protection

Test Results Summary

- *The blocking device used in conjunction with the TVS diode and the MOV provides a high level of protection:*
  - *5 kV Surge Protection (IEC 61000-4-5)*
  - *125 Vrms Power Cross Protection*
  - *8 kV contact and 15 kV Air Discharge ESD Protection (IEC 61000-4-2)*
  - *Level 4 (2kV) Electrical Fast Transient (EFT) Protection (IEC 61000-4-4)*
- *Signal quality was excellent up to a 2 Mbps data rate and acceptable out to 10 Mbps*
  - *Performance at 20 Mbps could be improved by replacing the MOV with a GDT to reduce the capacitive load on the line*

Shunting Devices

General Characteristics: Crowbar

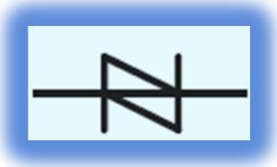


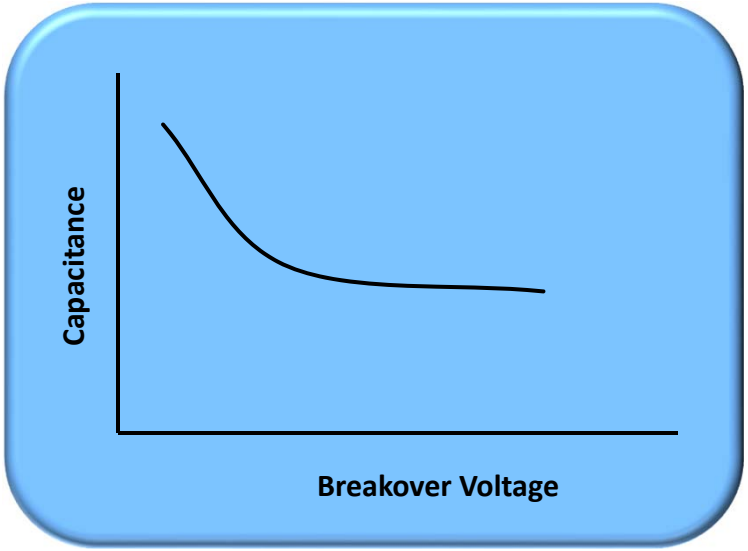
Bidirectional Device

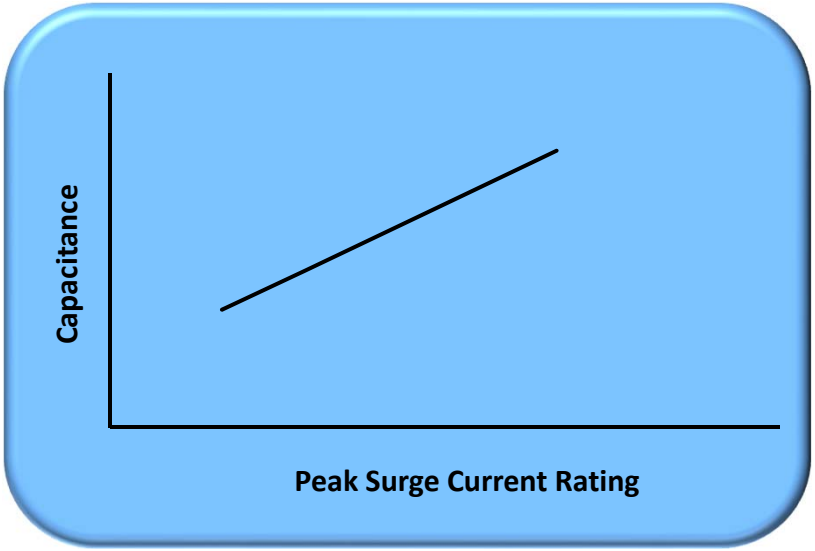
- **Inactive State**
  - *Looks like a high impedance load*
    - *Primarily a capacitive load*
- **Breakdown Region**
  - *Voltage clamping action before switching to the low voltage state*
- **Fully Active (Low Voltage) State**
  - *When the breakover current level is reached the device will switch to the low voltage state*
  - *A minimum current (hold current) is required to remain in this state*

Shunting Devices

General Characteristics: Crowbar





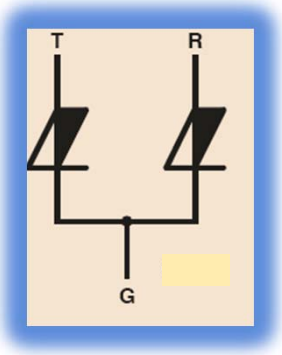


- Capacitance
  - Decreases as breakover voltage is increased
  - Increases as surge current capability is increased
- Maximum Peak Pulse Current Rating
  - Up to ~200 A for the 10/1000 µs waveform
- Breakover Voltage Range
  - 15 V to 600 V

Shunting Devices

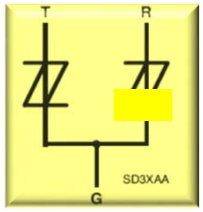
What's Available

Single Unidirectional

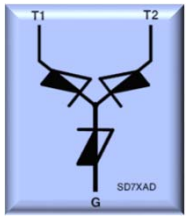


Dual Unidirectional

Single Bidirectional

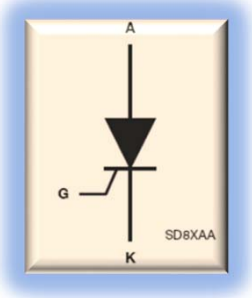


Dual Bidirectional

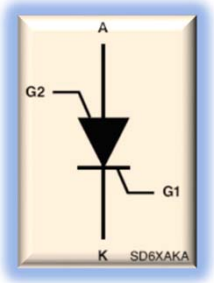


Triple Element

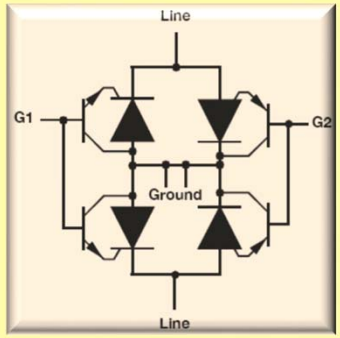
Triple Element



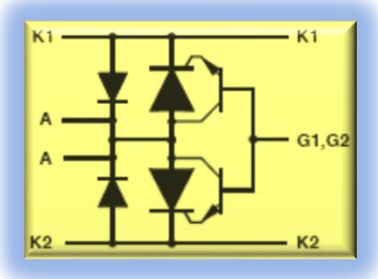
Gated Unidirectional



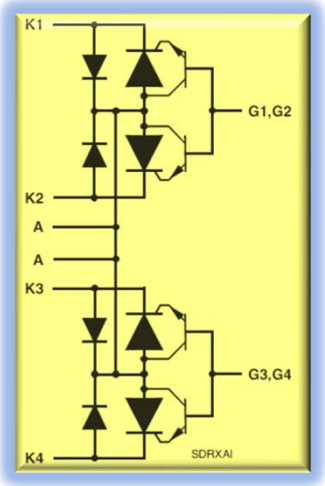
Dual Gate Unidirectional



Dual Complementary Gate



Dual Gated w/Anti Parallel Diodes

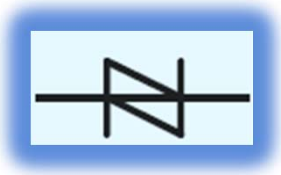


Quad Gated w/Anti Parallel Diodes

Note: This is not an exhaustive survey.

Shunting Devices

What's Available



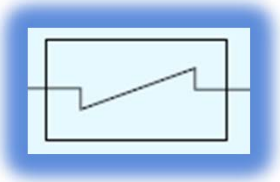
Category	Type	I_{PPM} (A) 10/1000 µs	V_{DRM} (V)	Capacitance (pF)	I_H (mA)	Package(s)
Low Current, Fixed Voltage	Unidirectional, Bidirectional, Single/Dual	18 - 80	8 - 550	3.3 - 150	10 - 150	SOT23-5, SMA, SMB, SOIC (8), DO-15, QFN, TO220
High Current, Fixed Voltage	Unidirectional, Bidirectional, Single/Dual	100 - 200	58 - 550	35 - 300	50 - 225	SMB, TO-92, QFN, TO-220
Programmable*	Single, Dual, Quad	20 -150	90 - 250	32 - 100	20 - 180	SOIC (8), MS-013
Triple element	Delta, "Y" config.	30 - 45	8 - 270	17 - 50	30 - 150	SOIC (8)

* With and without antiparallel diode, single and dual polarity are available

Note: This is not an exhaustive survey.

Shunting Devices

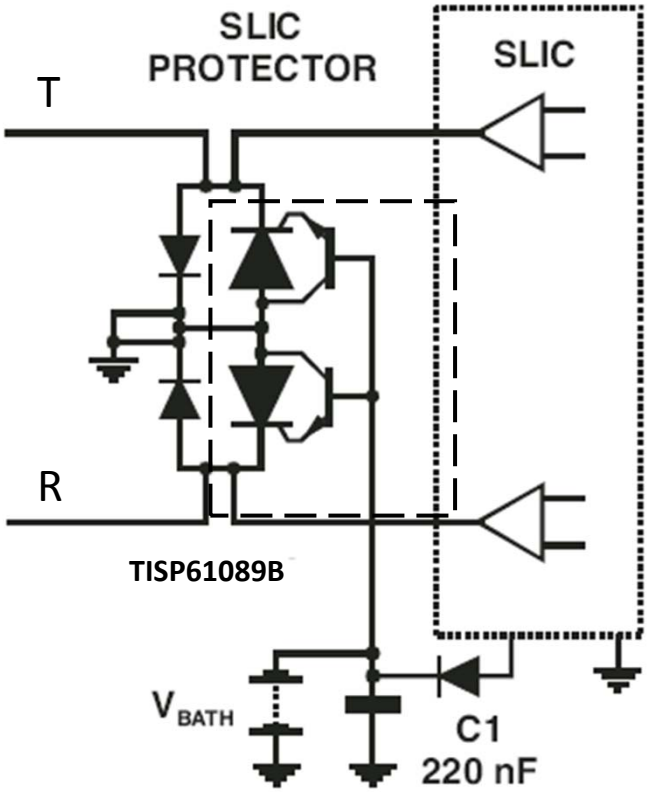
Applications



- Primary and Secondary Protection
- SLIC Protection
- Signal, Data and Control Lines
  - Ethernet
  - ISDN
  - RS-232
  - XDSL
  - RS-485
  - 4-20ma Current loop
- Process control equipment
- Test equipment

Application Example

Programmable Thyristor for SLIC Protection



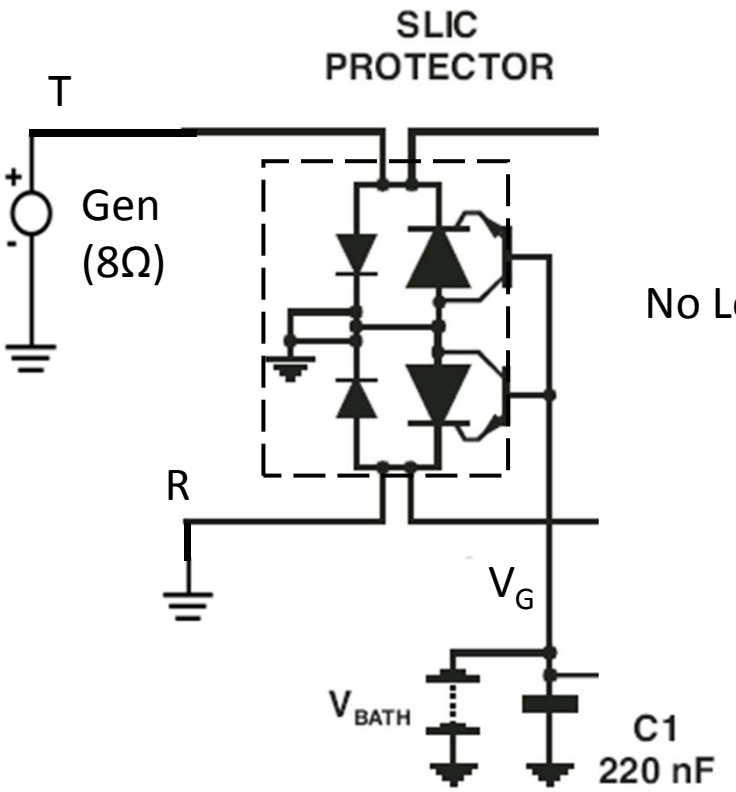
V_{BATH} = - 60 V

GR1089 Intrabuilding Lightning Protection				
Test connection	**Waveshape**	**Open-Circuit Voltage (V)**	**Short-Circuit Current (A)**	**Generator Resistance (Ω)**
Transverse	2/10 µs	800	100	8
Longitudinal	2/10 µs	1500	100	15

- *No series resistor is shown.*
- *If a series resistor is required the peak current into the protector will be lowered.*
- *For example, if an 8 Ohm series resistor were used, the current for the Transverse and Longitudinal tests would be reduced to 50 A and 65 A (2 x 65), respectively*

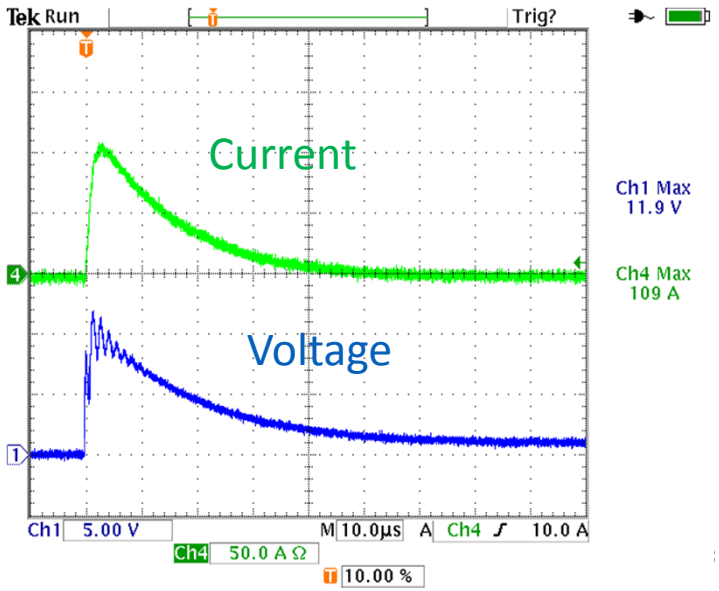
SLIC Protection

800V, 100A 2/10 µs, Transverse Surge

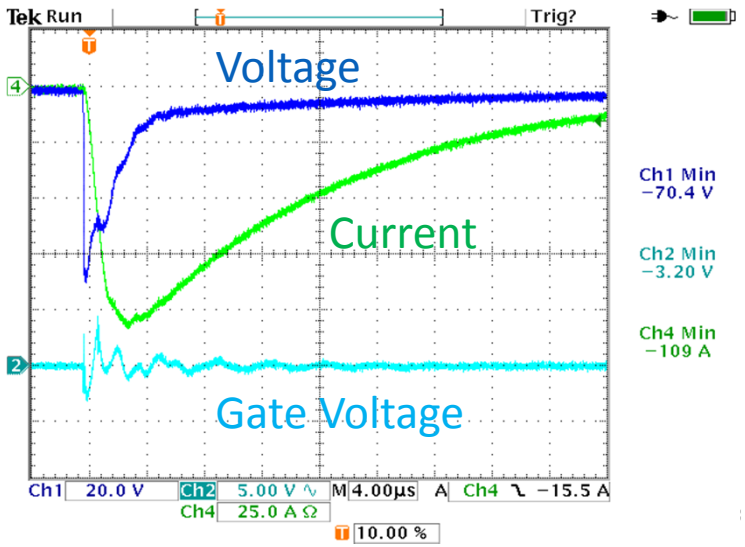


No Load

Positive



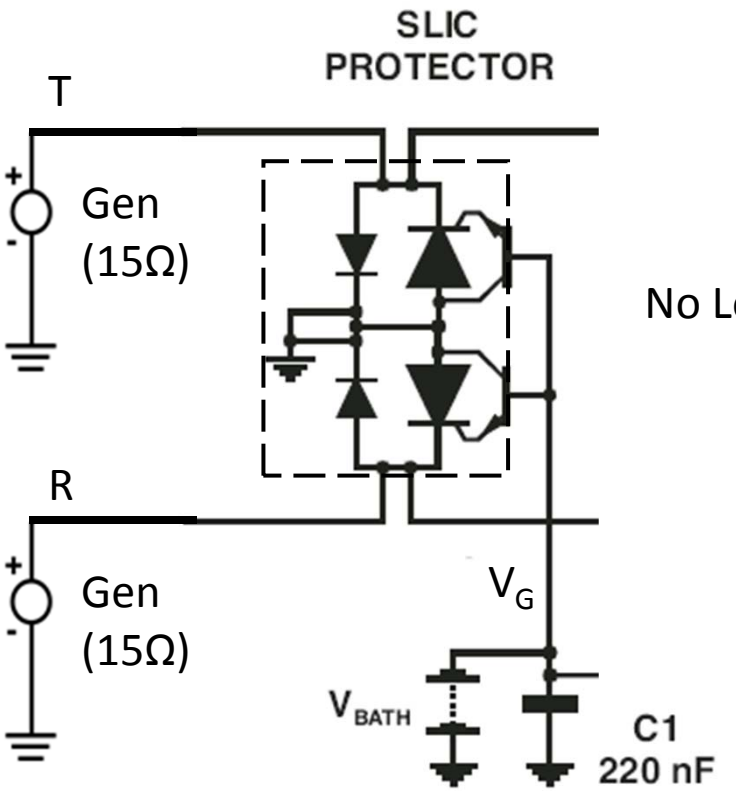
Negative



BOURNS®

SLIC Protection

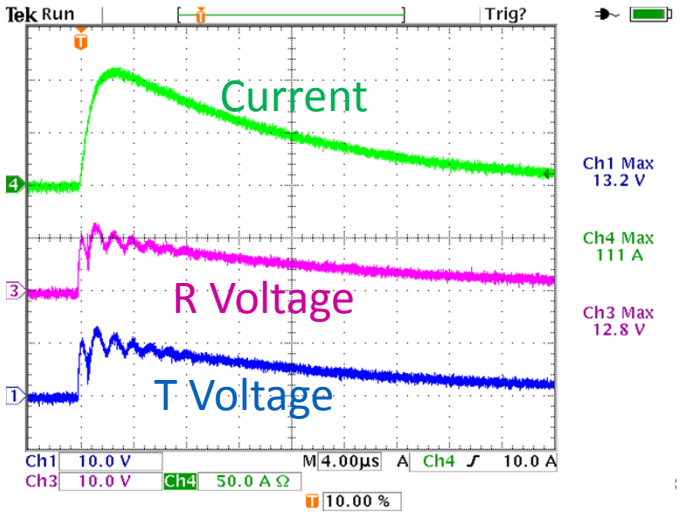
1500V, 2/10 µs, Longitudinal Surge



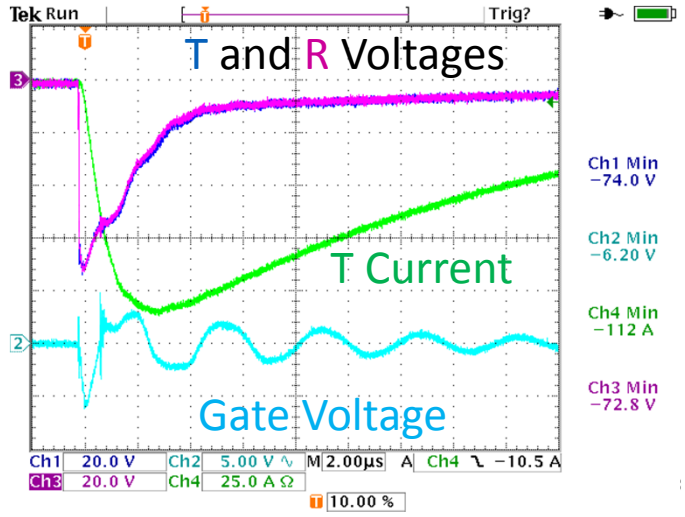
No Load

VG = - 60 V

Positive



Negative



BOURNS®

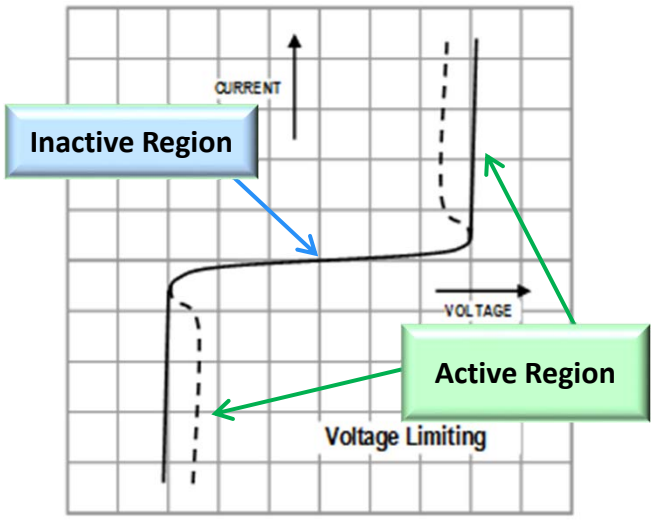
Programmable Thyristor

Test Results Summary

- *The Intrabuilding lightning test per GR1089 was performed with no series resistance*
  - **Transverse (2/10 µs, 800 V, 100A)**
    - *Positive Direction - Clamp voltage was 11.9V for 109 A of surge current*
    - *Negative Direction – Clamp voltage was -70.4 V for -109 A of current (Note that the gate voltage dropped 3.2 V)*
  - **Longitudinal (2/10 µs, 1500 V, 100A)**
    - *Positive Direction - Clamp voltage was 12.8. to 13. 2 V for 111 A of surge current*
    - *Negative Direction – Clamp voltage was -72.8 to 74.0 V for -112 A of current (Note that the gate voltage dropped 6.2 V)*

Voltage Limiting Devices (TVS Diodes)

General Characteristics



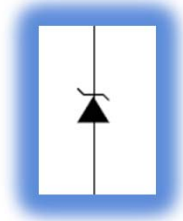
Bidirectional Device

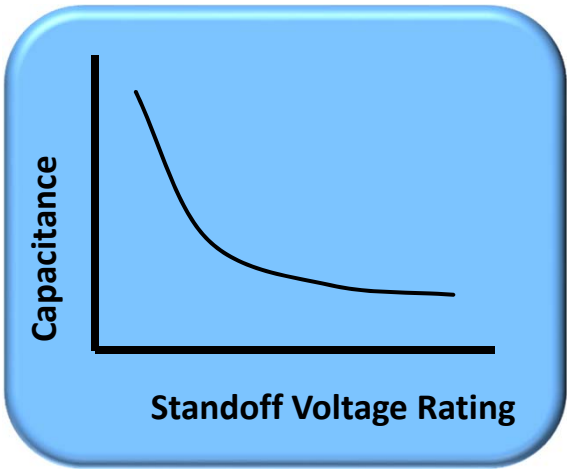
– – – – Device with Foldback

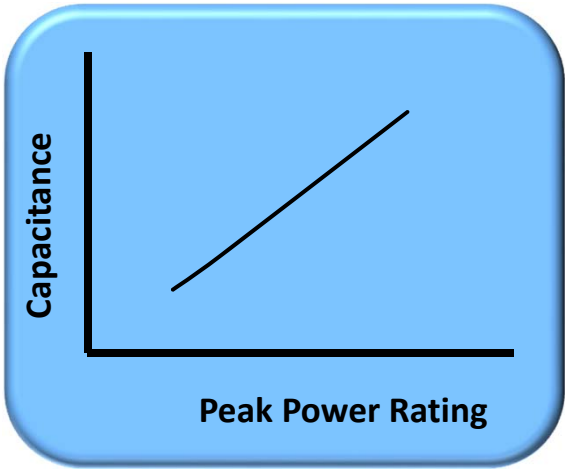
- Inactive Region
  - 0 V to working (standoff) voltage in each direction for a bidirectional device
  - Primarily a capacitive load
- Active Region
  - Clamping/Breakdown
    - Voltage continues to increase as current increases
  - Some devices have significant foldback
    - e.g. punch-through diodes

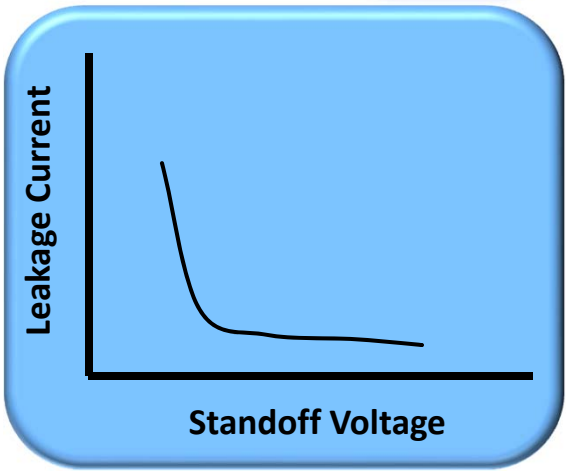
Voltage Limiting Devices (TVS Diodes)

General Characteristics (Unidirectional Devices)





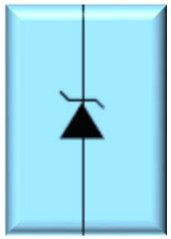




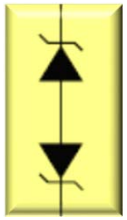
- Capacitance decreases as the standoff voltage capability of the diode is increased
- Capacitances increases as the peak power capability of the diode is increased
- Leakage current increases as the standoff voltage is reduced (especially levels $\leq$ 3.3 V)

Voltage Limiting Devices (TVS Diodes)

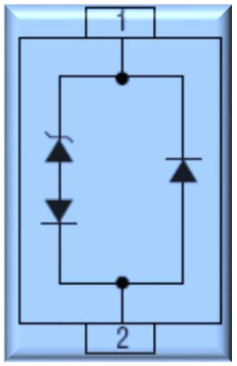
What's Available? Sample of Available Configurations



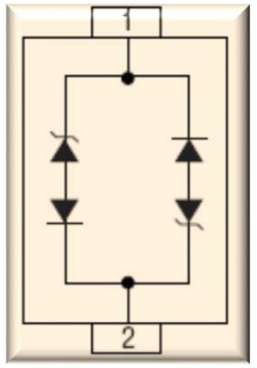
Unidirectional



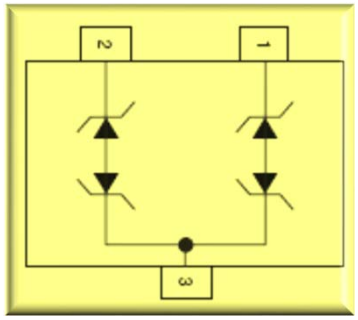
Bidirectional



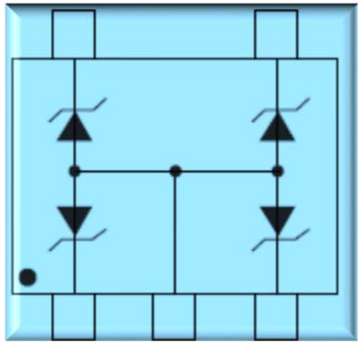
Unidirectional
w/Steering Diodes



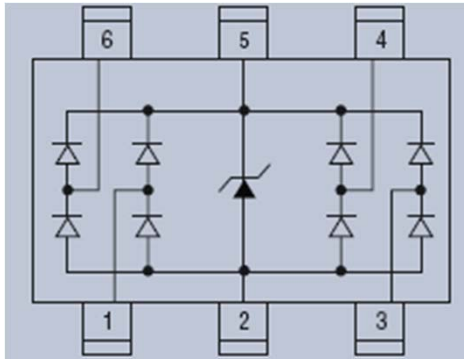
Bidirectional
w/Steering Diodes



Dual
Bidirectional



Quad
Unidirectional

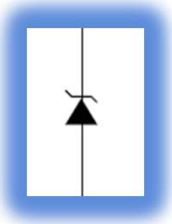


Quad Unidirectional
w/Steering diodes

Note: Devices are available to protect 1, 2, 4 ,5, 6, 8 or more lines

Voltage Limiting Devices (TVS Diodes)

What's Available?



Discrete TVS Diodes						
Category	**Type**	**P_{PPM} Range (W)***	**V_R Range (V)**	**Capacitance (pF)**	**Packages**	**Notes:**
Low Power	Unidirectional, Bidirectional	≤ 500	2.5 - 36	1 - 500	0402, 0603, 0805, SOD-323, SOD-523, SOT-23	Steering diodes are used to achieve low capacitance
Medium Power	Unidirectional, Bidirectional	600 - 3,000	5 - 170, 400	20 - 10,000	SMA, SMB, SMC,	Bidirectional devices have lower capacitance than unidirectional devices
High Power	Unidirectional, Bidirectional	5,000-30,000	28 - 300	80 - 30,000	SMC, Axial lead	Bidirectional devices have lower capacitance than unidirectional devices
Very High Power	Unidirectional, Bidirectional	> 30,000	15 - 470	2,000 - 12000	Axial Lead, Surface Mount	1,3,6,10 and 15 kA devices

TVS Diode Arrays						
Category	**Capacitance Range(pF)**	**# of Lines**	**I_{PPM} Range (A)***	**V_R Range (V)**	**Packages**	**Notes:**
Ultra Low Capacitance (≤ 3 pF)	0.25 - 3	2, 4, 6, 7	1-25	2.8 - 5	SOT-143A, SC70-6, DFN-10, SOT23-6, SOT563, DFN-6, DFN-10, SC-89, SC-75	Steering diodes are used to achieve low capacitance
Low Capacitannce (≤ 10 pF)	3.5 - 10	2, 4, 6, 8	2 - 40	2.8 - 12	SOT-143A, SO-8, SOT353, SLP2020P6, DFN-10, SLP3020N10	Steering diodes are used to achieve low capacitance
High Capacitance (> 10 pF)	12 - 500	2, 4, 5, 6, 7, 8	7-100	3 - 36	SOT-23, SO-8, SO-16, SOT-563	Steering diodes are used to achieve low capacitance , Unidirectional devices without steering diodes have higher capacitance

Note: This is not an exhaustive survey.

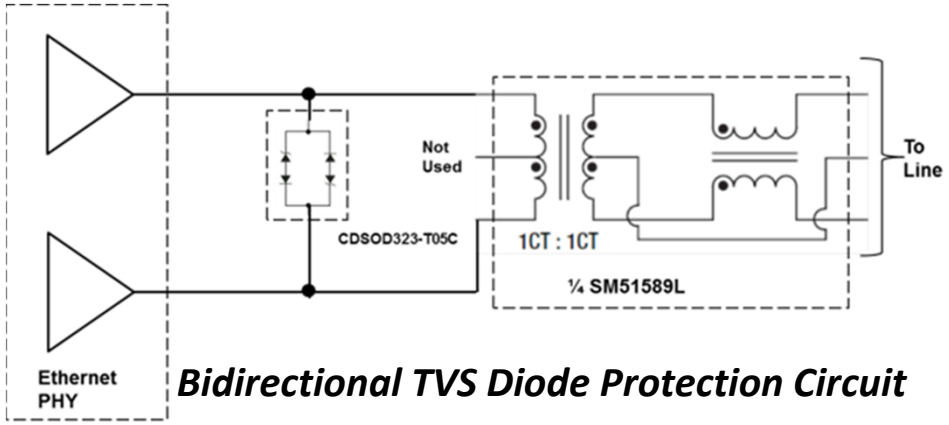
Voltage Limiting Devices (TVS Diodes)

Applications

- Primary and Secondary Protection
- Signal, Data and Control Lines
  - Ethernet
  - USB
  - HDMI
  - XDSL
  - Thunderbolt
- Power Port Protection
  - AC and DC power lines
- Process control equipment
- Test equipment

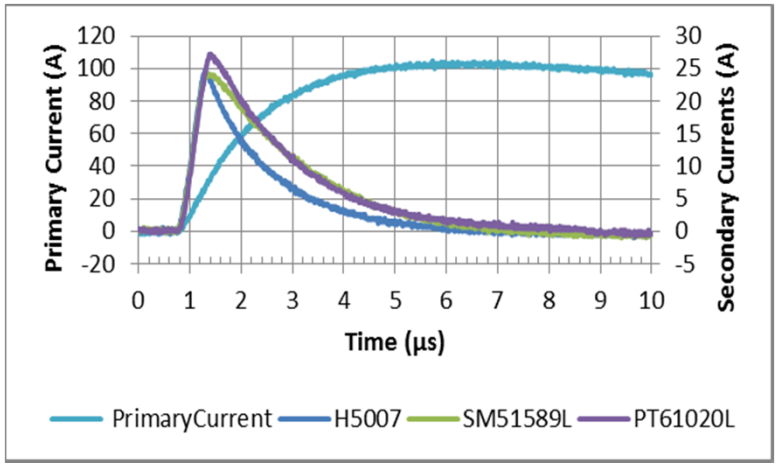
TVS Diode Application Example

Ethernet: GR1089 Port Type 4 Lightning Protection



Bidirectional TVS Diode Protection Circuit

Ethernet Transformers (1.2/50 µs, 8/20 µs Combination Wave)

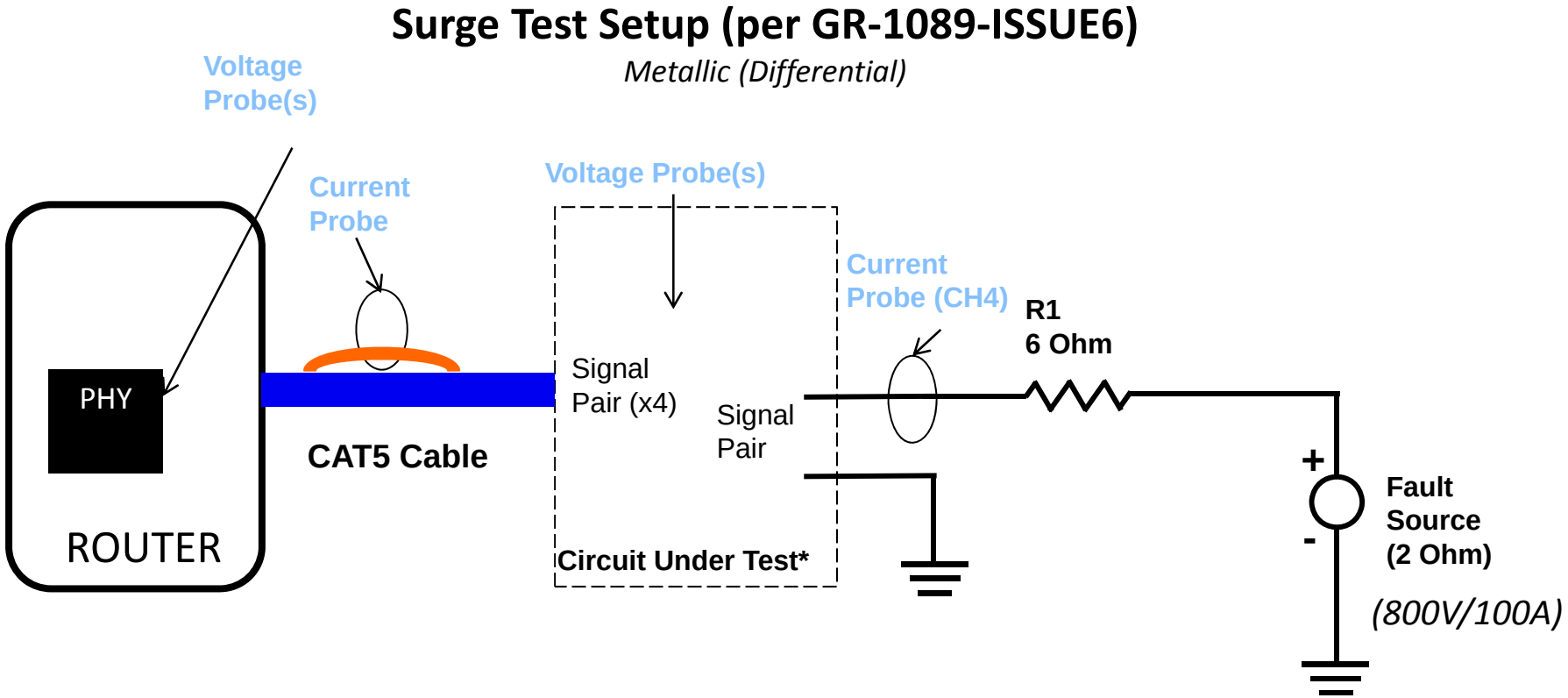


With Secondary Shorted

- *Secondary Current is reduced by about a factor of 4*
- *Duration of Surge current is reduced*

TVS Diode Application Example

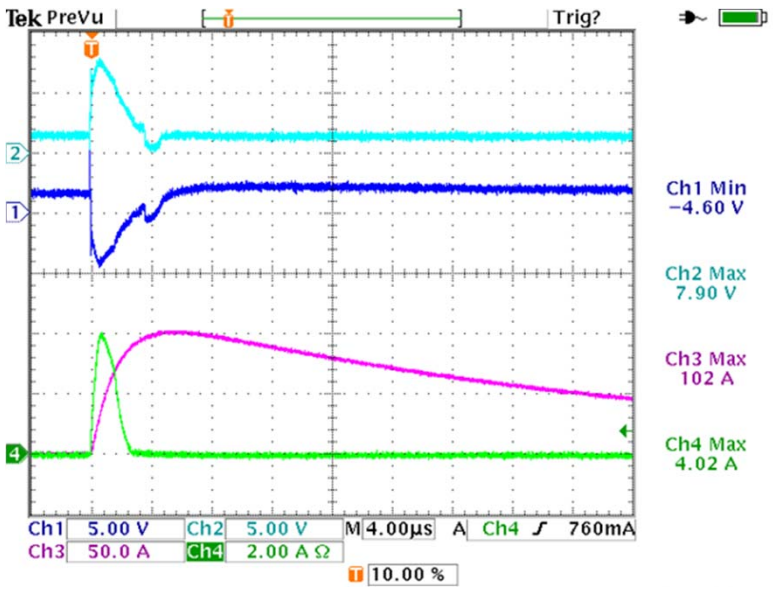
1.2/50 µs, 8/20 µs Combination Wave Test Circuit

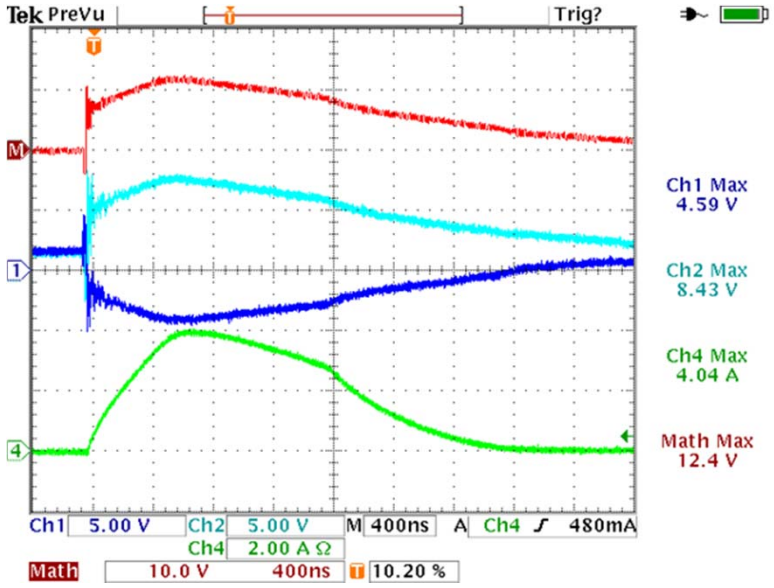


A Gigabit router was used as the load. The on board transformer was replaced with shorts and the evaluation board was connected to the router with a 3 inch long CAT5 cable . Part of the casing was removed from the cable so that a current probe could be attached to the line under test. For this test,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

Application Example: Ethernet

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





CH1 = PHY – VOLTAGE
CH2 = PHY + VOLTAGE
CH3 = Total Surge CURRENT
CH4 = PHY INPUT CURRENT

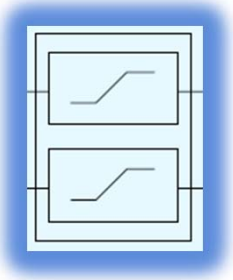
Peak Voltage: 12.4 V
Peak Current: 4 A
Energy: ~ 50 µJ

Application Example: Ethernet

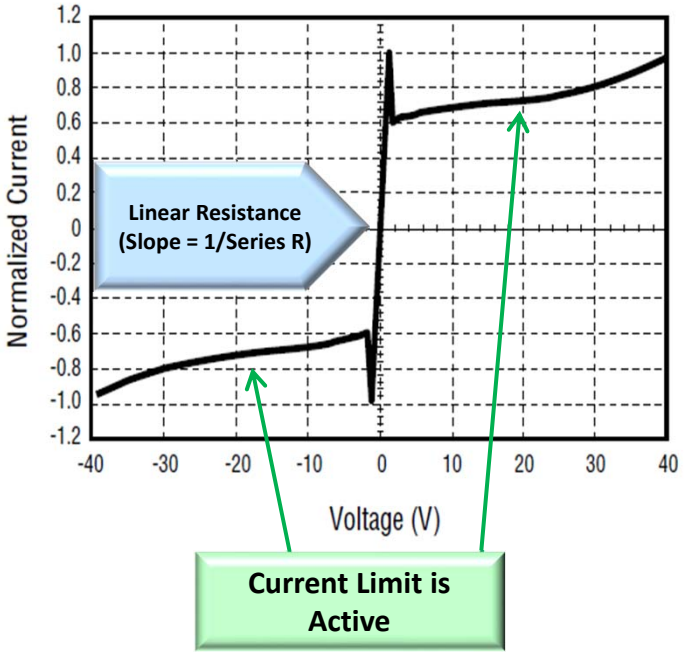
TVS Diode Circuit Test Results Summary

- **GR1089 , Port type 4**
  - *Metallic (1.2/50 µs, 8/20 µs, 800 V, 100A)*
    - *Voltage across the PHY differential input is limited to 12.4 V*
    - *Current into the PHY is limited to just over 4 A*
    - *Energy PHY is subjected to is limited to ~50* µJ

Current Limiting Devices



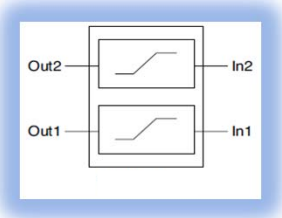
Bidirectional Device

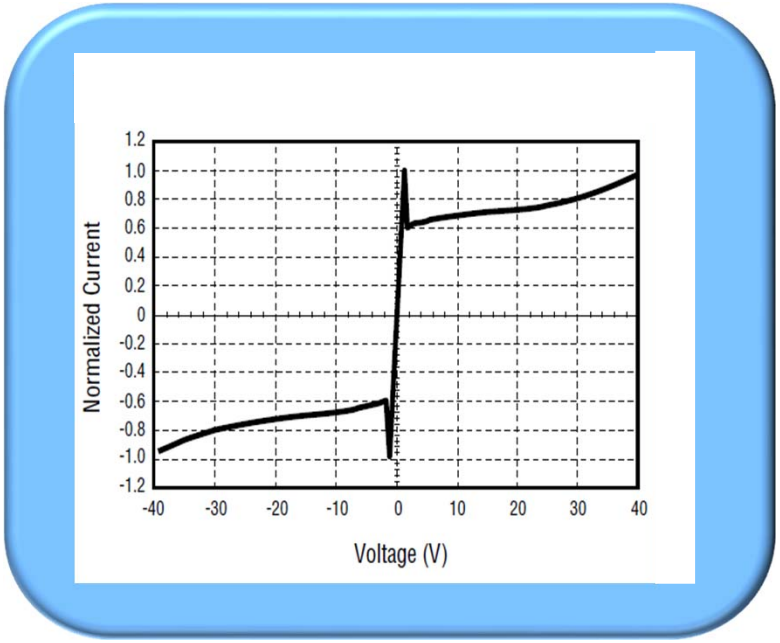


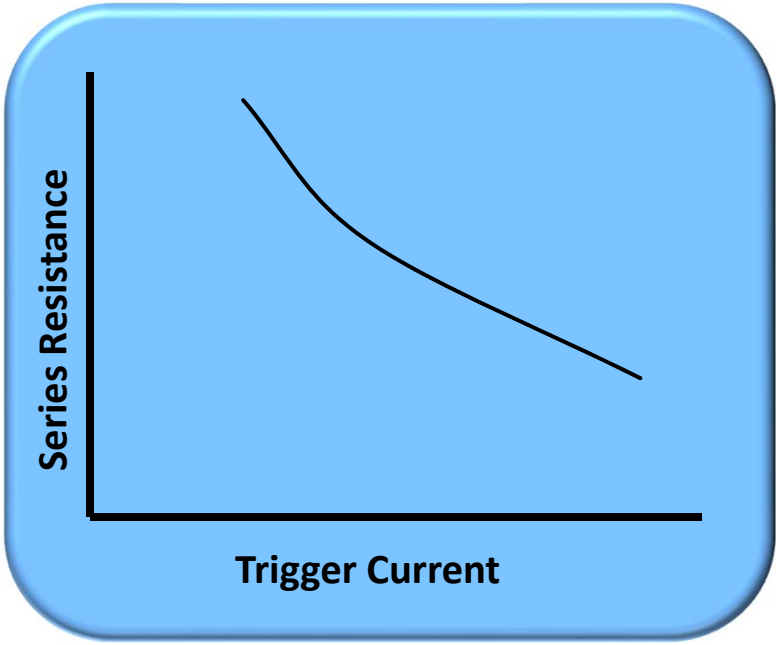
- Linear Resistance Region
  - Very linear response when not triggered
  - Behaves like a high quality resistor
- Current Limiting State
  - Limits to a predetermined level
  - Provides voltage isolation up to rated voltage

Current Limiting Devices

General Characteristics



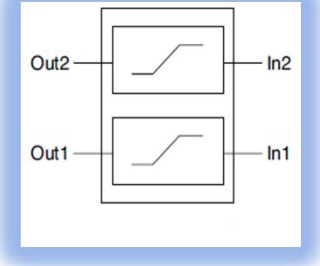




- Devices exhibit 30-40% of foldback from the peak current
- The current level increases as the voltage across the device is increased
- Series resistance decreases as the trigger current value of the device is increased

Current Limiting Devices

What's Available?



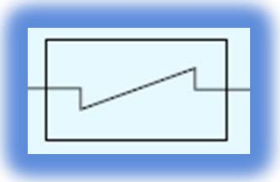
Type	Package Style	Trigger Current (mA)			Series Resistance	Channel to Channel Resistance Match	Max Voltage (V)
		Min.	Nom.	Max			
Dual Channel	*DFN 2.5 x 4 mm*	*250*	*375*	*500*	*2.3 Ω*	*± 0.05 Ω*	*40*
Dual Channel	*DFN 3.5 x 4 mm*	*500*	*750*	*1000*	*1.4 Ω*	*± 0.03 Ω*	*40*
Dual Channel	*DFN 4.5 x 4 mm*	*750*	*1125*	*1500*	*1.0 Ω*	*± 0.02 Ω*	*40*

Notes:

1. All devices are Bidirectional

Current Limiting Devices

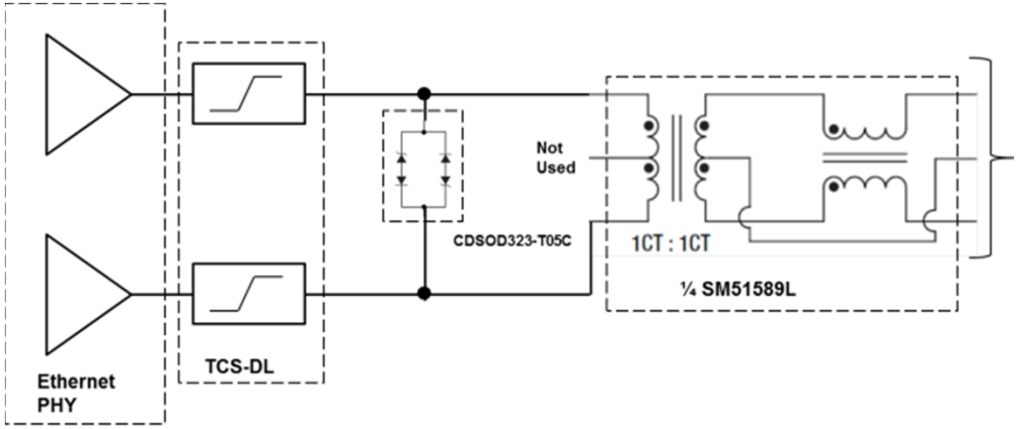
Applications



- Low and High Speed data communication Lines
  - Ethernet
  - xDSL
  - RS-485
  - 4-20ma Current loop, HART Modem
- Protection modules and dongles
- Process control equipment
- Test equipment

Application Example: Ethernet

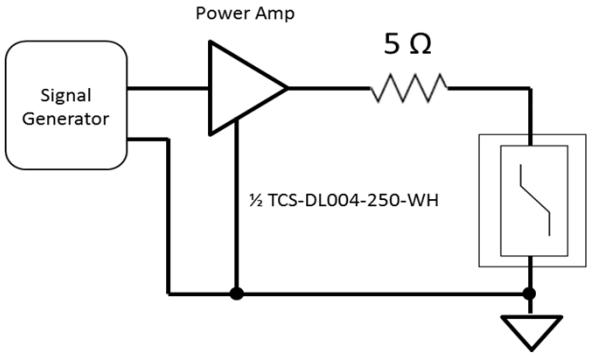
Current Limiter with TVS Diode

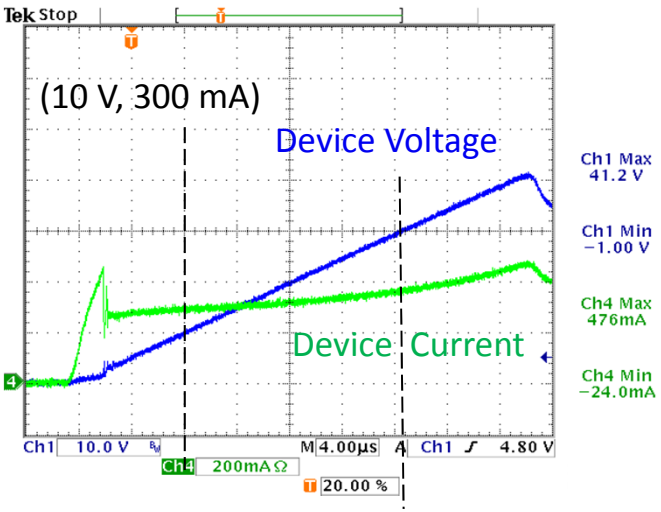


- SM51589L Ethernet Transformer
- CDSOD323-T05C TVS Diode
- TCS-DL004-250-WH Transient Current Suppressor

Current Limiter Current vs. Voltage

Test Circuit





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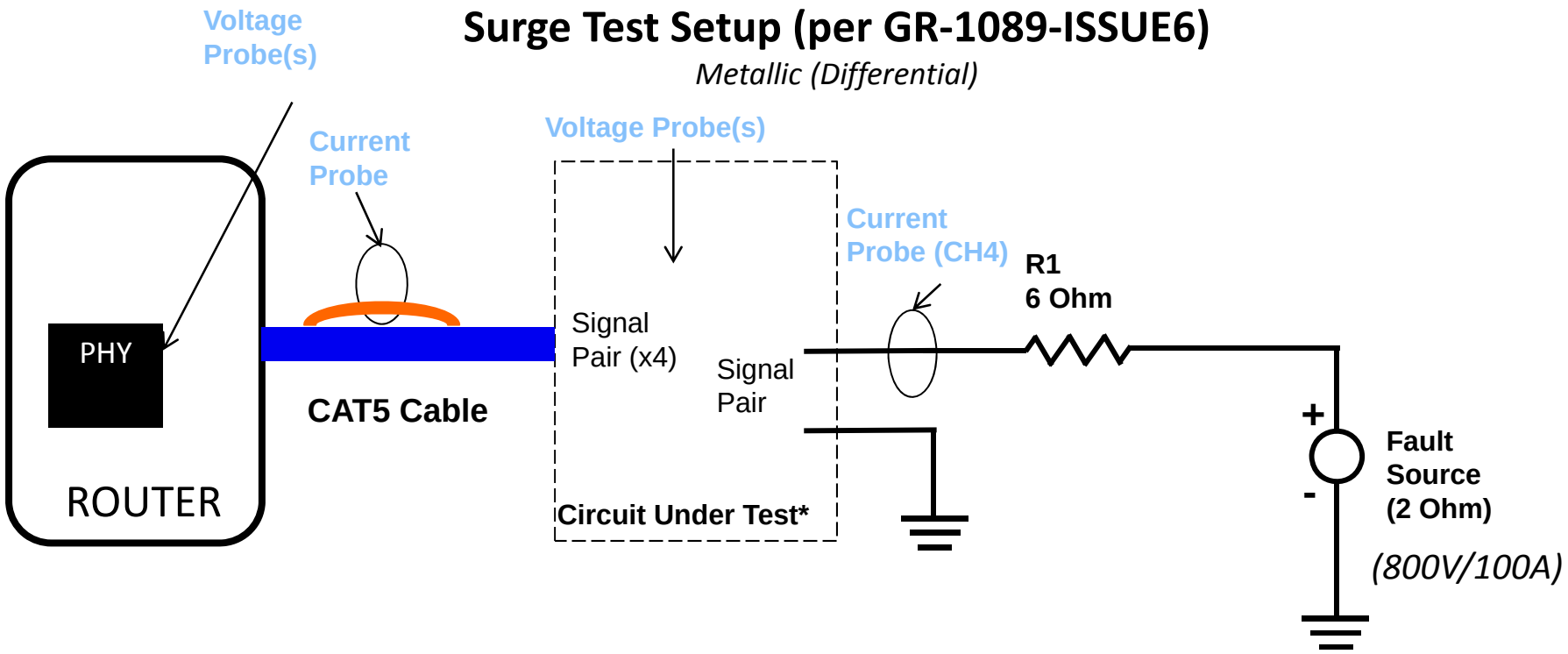
Application Example: Ethernet

Current Limiter with TVS Diode

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

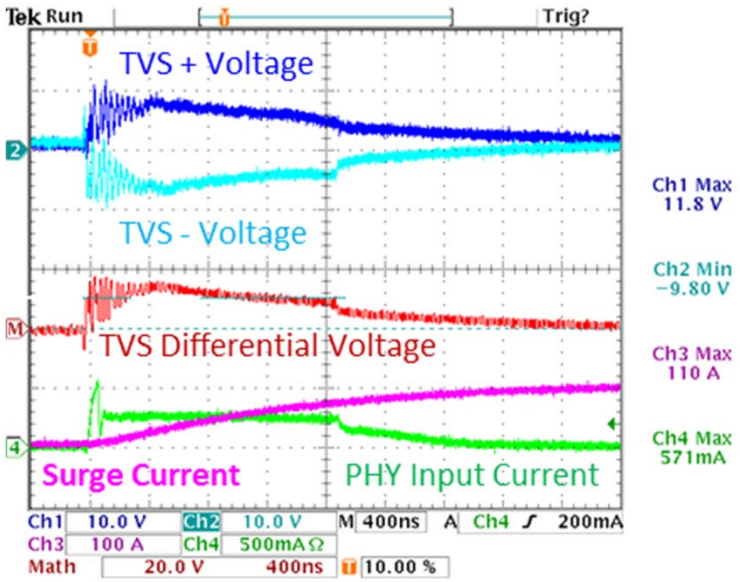


A Gigabit router was used as the load. The on board transformer was replaced with shorts and the evaluation board was connected to the router with a 3 inch long CAT5 cable . Part of the casing was removed from the cable so that a current probe could be attached to the line under test. For this test,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

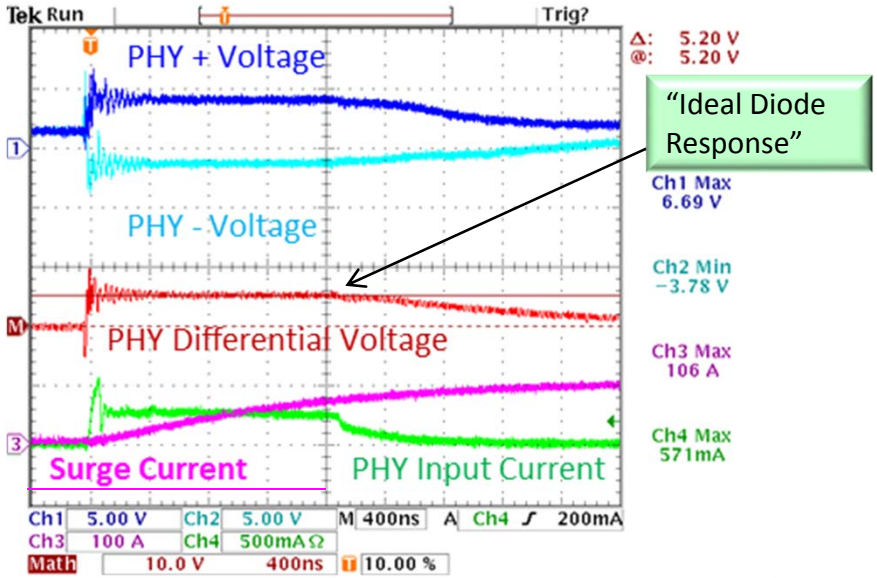
Application Example: Ethernet

Current Limiter with TVS Diode

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



TVS Peak Voltage: ~15 V



PHY sees:

Peak Voltage: 5.2 V
Peak Current: 571 mA
Energy: ~ 3 µJ

Application Example: Ethernet

Current Limiter with TVS Diode

GbE Signal Amplitude and Template Tests per IEEE802.3

Line Pair	Point	TVS diode Only (mV)	% Peak voltage difference Between Points A and B	TCS-DL004-250-WH and TVS diode (mV)	% Peak voltage difference Between Points A and B	Loss due to TCS™ (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:

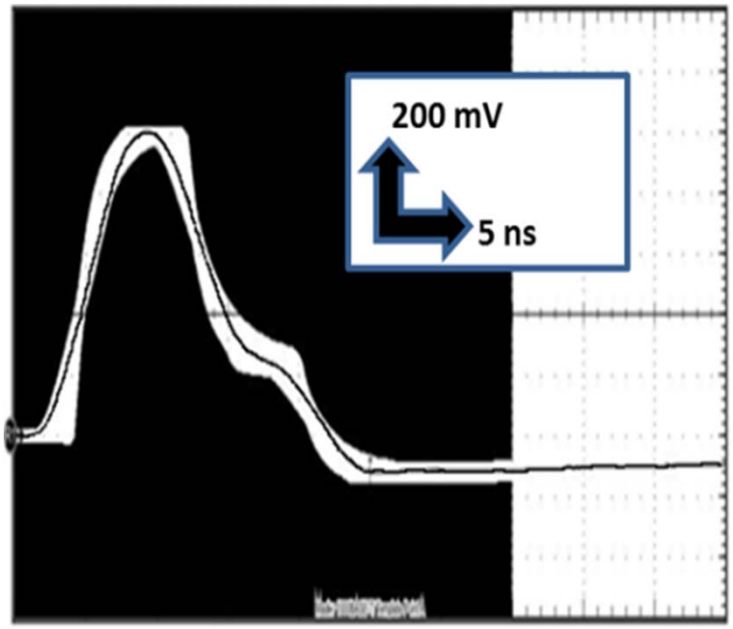
1. The required amplitude range for the signal at points A and B is 670 mV to 820mV.
2. The % peak voltage difference between points A and B must be < 1 %

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

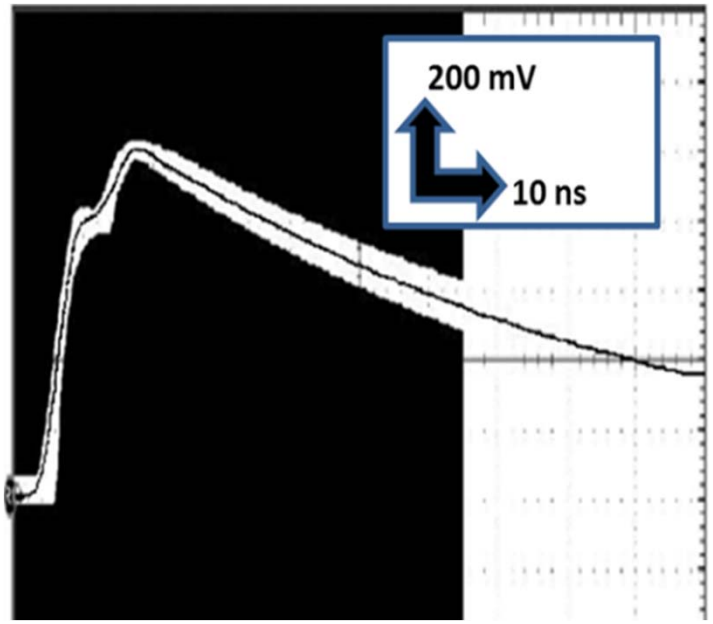
Application Example: Ethernet

Current Limiter with TVS Diode

GbE Signal Amplitude and Template Tests per IEEE802.3



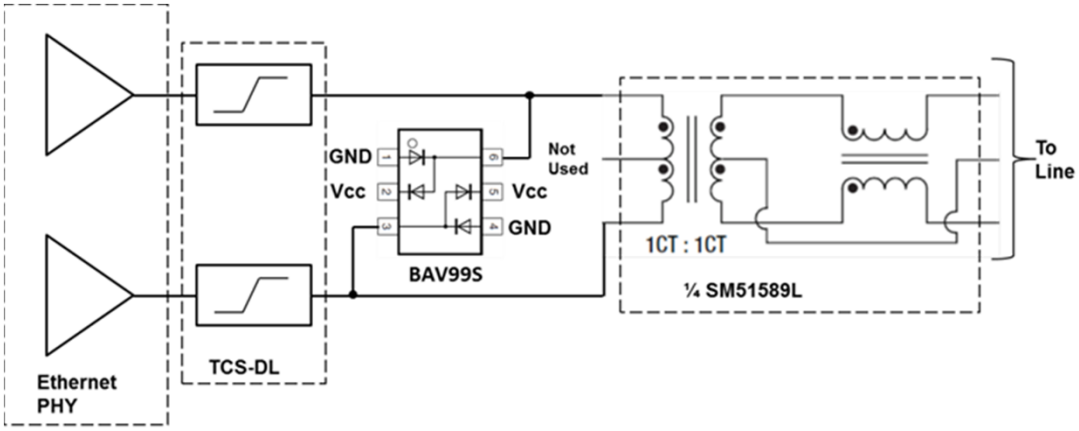
Point A Template Test

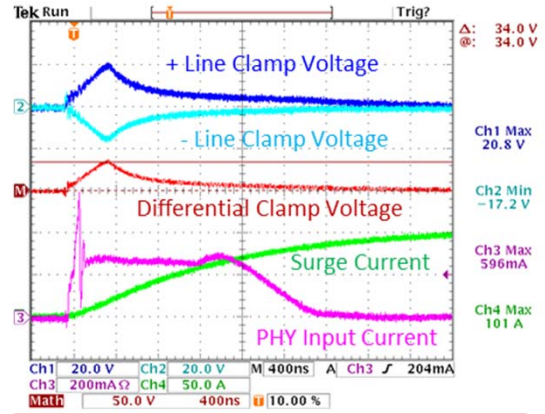


Point F Template Test

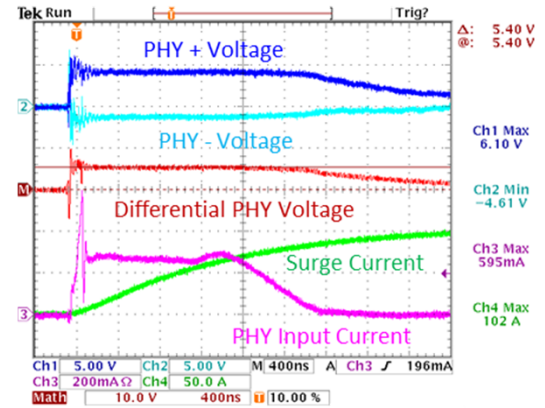
Application Example: Ethernet

Current Limiter with Steering Diodes





Diode Clamp Voltage: ~34 V



- SM51589L Ethernet Transformer
- BAV99S Clamp Diodes to Supply and Ground
- TCS-DL004-250-WH Transient Current Suppressor

PHY sees:

Peak Voltage: 5.4 V
Peak Current: 595 mA
Energy: ~ 3 µJ

Application Example: Ethernet

Summary: Protecting a PHY Using a Current Limiter

Test	Protection Circuit	Diode Clamp Differential Voltage (V)	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*	*12.4 (same)*	*4A peak*	*54*
	TVS Diode with Current Limiter	*~15*	*5.2*	*<300mA**	*3*
	Steering diodes with Current Limiter	*34*	*5.4*	*<300mA**	*3*

* After initial peak

- **The current limiter reduces the current seen by the PHY signal inputs**
  - *After the initial peak, current is reduced by over 90 %.*
- ***The current limiter also isolates the PHY inputs from the voltage across the TVS diode or steering diodes***
  - *Peak PHY input voltage is determined by its ESD protection and the current through the TCS-DL device. In this case the voltage level is reduced by over 50 %.*
- ***The energy the PHY had to absorb was reduced by more than 90 % compared to using a TVS diode alone***
- ***All designs pass IEEE802.3 signal amplitude and template tests***

General Summary

Semiconductor Protection Technology

			Performance				
Type	**Subtype**	**Technology**	**Limiting Speed**	**Precision**	**Impulse Capability**	**Parallel Capacitance**	**Series Resistance**
Shunt	Crowbar	Thyristor	→	→	→	→	NA
Shunt	Clamp	TVS Diodes	Best →	Best →	→	→	NA
Shunt	Clamp	TVS w/steering Diodes	Best →	Best →	→	Best →	NA
Shunt	Clamp	Power TVS Diodes	Best →	Best →	Best →	→	NA
Blocking	Full Block	TBU®	→	→	Best →	NA	→
Blocking	Limiter	TCS™	Best →	→	Best →	NA	→


Thank you!
BOURNS®