Protecting Ethernet Solutions Against Lightning Disturbances

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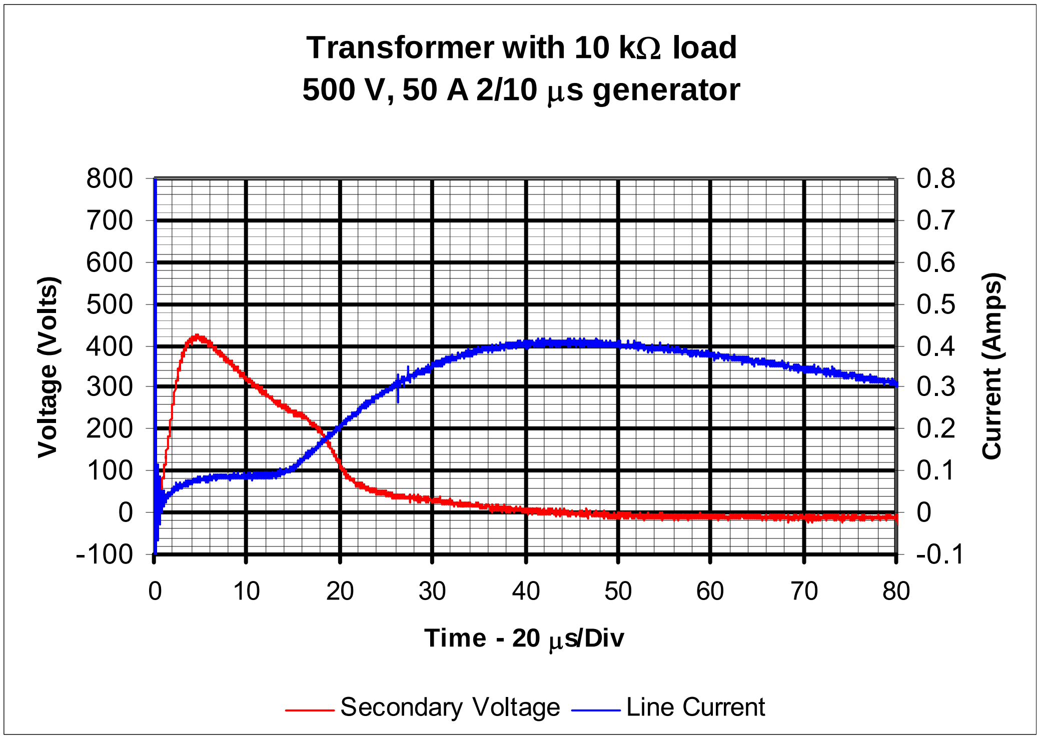
Ethernet Protection Solutions

Ethernet ports utilize transformers to provide isolation between the drive circuitry and communications line due to the long line lengths (up to 100 meters) involved. Traditional Ethernet applications were designed for use within the building for LAN (Local Area Network) and therefore most applications relied on the robustness of the transformer to provide the protection. Transformers provide a high level of inherent protection, but do have a weakness in insulation flashover and excessive heating due to current flow in the primary coil that needs to be considered.

A common curve associated with transformers is the Flux density (B) & Magnetizing force (H) to provide a B/H curve. This curve highlights where the transformer saturates (a minimum of 8 mA DC for Ethernet transformers) and this occurs when an increase in primary coil current does not provide an increase in flux density. The permeability (μ) of the inductor's core material and the amount of windings dictates the value of the inductance. When the core saturates, the permeability of the material reduces which also reduces the inductance.



Graph 1 – Telecom transformer under impulse

This phenomenon can be seen when transformers are surged as shown in Graph 1. The inductance of the line-side (primary) of a transformer will limit the rise-time of the primary current as shown by the blue line. The resistance of the transformer in this test is specified as 70 Ω which would highlight a peak current of 6 A (500/10+70). However, the impedance is more like 5 kΩ before the core saturates under a 2/10 μs impulse due to the reflection of the secondary

impedance $\left(Z_P = \frac{Z_S}{n^2}\right)$ where Z_S is the secondary impedance and n is the turns ratio.

The transformer transfers energy to the secondary until saturation (0 to 5 µs time interval on Graph 1). As the transformer saturates (5 to14 µs time interval on Graph 1), the primary current increases while the secondary voltage reduces to zero. The peak voltage seen on the secondary is dependent on the terminating resistance used and with a 10 kΩ; terminating resistance provided a 420 V peak. With a 10 kΩ load, the impulse waveform is 4/18 µs where a higher resistance will provide a higher peak voltage for a shorter duration. It is therefore important to know the energy transfer characteristics under impulse.

Telecom Intra-building Specifications

Repeated failures of LAN equipment in lightning rich locations highlighted a concern and spawned the requirement for network equipment to be included into the telecommunication port protection requirements. Therefore, network equipment ports in central office (CO) or remote access units that do not interface to outside plant or serve off-premise equipment protection solutions are required to meet Telcordia GR-1089-CORE intra-building lightning surge tests (Electromagnetic Compatibility and Electrical Safety – Generic Criteria for Network Telecommunications Equipment, issue 4, section 4.6.9, page 4-30). US customer premise equipment (CPE) that does not interface to an outside line, does not have any protection requirements to meet. However, Design Engineers see a need to provide protection to reduce field failure returns and look to the latest intra-building to provide a circuit protection guide. Service providers can also specify their own impulse and AC power contact requirements for providing enhanced robustness of their equipment that also needs to be considered.

ITU-T also specifies intra-building specifications for equipment ports that do not leave the building premise. GR-1089-CORE and ITU-T tests are different and covered in more detail.

Telcordia GR-1089-CORE Intra-building Specifications for USA

A 4-wire system is tested using a waveform of 2/10 µs and an open circuit voltage of ±800 V with a short-circuit current of 100 A. Each lead is connected to the impulse generator with the other three leads grounded and surged once. This tests the metallic withstand capability of the interface. The second test uses a waveform of 2/10 µs and an open circuit voltage of ±1500 V with a short-circuit current of 100 A where the 4 wires are all connected to the generator and surged simultaneously for a single test. This will test the isolation barrier of the transformer and the 75 Ω impedance matching resistor and capacitor circuit. The impulse generator may need to have additional current dividing resistors for each of the wires if a single generator output is used.

Notes: *Intra-building requirements highlight that the equipment must operate as intended after the impulse tests.*

If the communication lines shield is terminated to ground at both ends, the impulse test does not need to be done.

GR-1089-CORE intra-building specification has an AC power contact test (section 4.6.17, second level intra-building AC power fault tests for network equipment to be located on customer premise, page 4-57). The test is conducted with 120 V rms, 25 A for 900 seconds where the equipment can fail safely. An external wire simulator such as a MDQ 1-6/10 A or MDL 2.0 fuse is used to ensure the equipment port does not consume excessive currents that can damage the interconnect leads. The external wire simulator must not operate during the test to ensure conformance.

ITU-T Internal Port Impulse Recommendations

The ITU-T recommendations include internal port testing where telecommunication lines do not leave the building or interface to outside plant equipment. A summary of the impulse test is highlighted in Table 1. ITU-T internal port testing is done with 8/20 µs (open circuit voltage waveform is 1.2/50 µs) impulse conditions. ITU-T does not include AC power contact recommendations like GR-1089-CORE. Single port applications are tested with an additional external resistance of 10 Ω. The additional external 10 Ω series resistor changes the short circuit current to a 3.3/30 µs as the fictive resistance of the generator is now 12 Ω. This provides a harsher requirement than the original 8/20 µs test since the decay time of the waveform has increased. Multiple port applications with unshielded lines are tested with the other ports powered, terminated or left open.

Port	Test	Lightning Test	Basic test levels			Enhanced test levels			No of tests	Primary protection
			K.20	K.45	K.21	K.20	K.45	K.21		
Single	7.1	8/20 µs unshielded cable longitudinal	500 V R=2+10 Ω	NA	1 kV R=2+10 Ω	1 kV R=2+10 Ω	NA	1.5 kV R=2+10 Ω	5 at each polarity	No
Multiple	7.2	8/20 µs shielded cable longitudinal	500 V R=2 Ω	NA	1 kV R=2 Ω	1 kV R=2 Ω	NA	1.5 kV R=2 Ω		No

Note: 2 Ω is the fictive resistance of the generator. The 10 Ω is the additional external resistance required for the test.

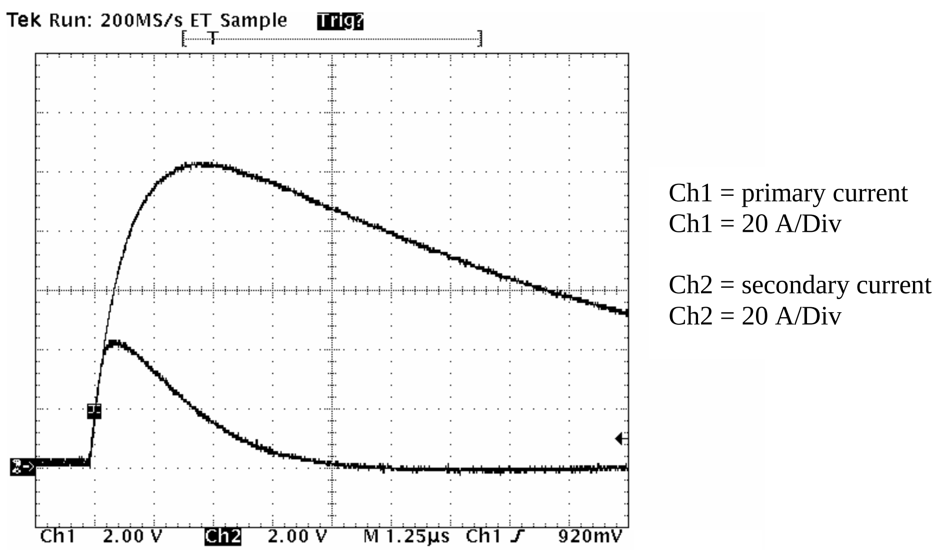
Table 1 – ITU-T Internal or Intra-building Impulse

ITU-T internal or intra-building impulse table was sourced from Compliance Engineering article "The 2003 ITU-T Telecommunications Equipment Resistibility Recommendations".

Ports with shielded cabling are tested in the multiple port configuration where the individual lines and shield are connected together directly to 8/20 µs without any additional series resistance. The equipment is tested with a twenty-meter length of shielded cable where the cable resistance is expected to ensure current sharing between the ports. Internal port tests do not apply to K.45 (remote access equipment) where only the external ports are tested.

Overvoltage Protection Solutions for Ethernet Applications

The key component to consider is the Ethernet transformer. Transformers provide a high level of inherent protection, but do have a weakness in insulation flashover and excessive heating due to current flow in the primary coil. The insulation voltage value of Ethernet transformers is normally 1500 V rms that will be adequate for normal intra-building applications. This removes the need for longitudinal line-side protection, but the voltage rating of the capacitor and wattage rating of the resistor used in the terminating network needs to be rated accordingly. Capacitors rated for 2000 V are normally used. For applications requiring 2000 V or more insulation, longitudinal protection may also be required to protect the 1500 V rms rating of the transformers.



Graph 2 - PT61021 transformer during 1500 V, 100 A 2/10

If the Ethernet transformer can support the impulse tests without failure, protection will only be needed on the secondary side of the transformer to protect the Ethernet IC from the energy transfer before the transformer saturates. Bourns® PT6102x Ethernet transformer series is able to support the single 100 A 2/10 µs intra-building impulse requirements without damage. A typical Ethernet transformer can withstand 200-300 A 2/10 µs before failure occurs, but this needs to be verified by testing. Graph 2 shows the primary current of 100 A (20A/Div) when tested with a 1500 V 2/10 µs impulse. The current transfer to the secondary is 40 A peak with a wave shape of 0.5/2 µs. The secondary protection solution needs to ensure it can support this energy without letting through too much voltage and overstressing the IC.

If the impulse withstand requirement exceeds the transformer protection properties (industrial applications for example), a gas discharge tube (GDT) can be used on the primary side of the transformer directly after the RJ45 socket. The Bourns® RJ45 connector PT44201D device includes the Ethernet transformers, terminating resistors, 2 kV, 1 nF capacitor and yellow/green LEDs to limit board space and component count. The 2035-09-SM GDT can be used for metallic protection while the 2036-09-SM can also be used to protect the isolation barrier for longitudinal protection. A crowbar primary protector such as a GDT will generate a higher secondary energy impulse. This is due to the fast dV/dT switching times from its high voltage off state to a short circuit condition. Therefore, key consideration to the secondary overvoltage protection is required.

This is covered in more detail on page 7, protecting the secondary-side of the transformer.

Protecting the Secondary-Side of the Transformer

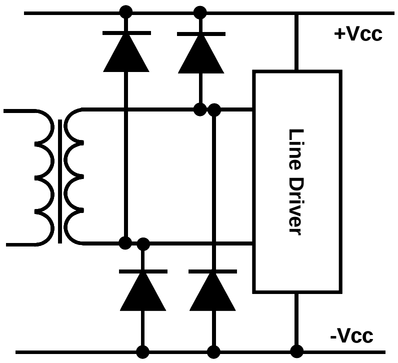


Figure 1 – bridge diode

A bridge diode network as shown in Figure 1 clamps any positive or negative transients to the power supply lines. Therefore, the line driver outputs are limited to an overstress of the forward voltage of the diode under impulse. Diode manufacturers do not specify the forward voltage under the common telecom impulses that makes product selection difficult. Diodes that offer low V_F voltages under fast transients are important to limit the stresses on the Ethernet driver. A "rule of thumb" is to use as high an I_F rating as possible and select ultra-fast diodes to ensure stresses are kept to a minimum. The energy as shown in Figure 1 is also transferred to the power supply. If high efficiency (low quiescent current) line driver components are used, this can have the effect of increasing the supply voltages as the load regulation capacitors absorb the energy. The DC/DC converters used to generate the power supply cannot sink current and therefore will stop regulating if the voltage gets too high. This can make the supply lines become unregulated for a short period of time that can damage the ICs.

The bridge diode network can be constructed by using discrete diodes or an integrated bridge rectifier where Bourns offers a CDSOT23-SR724 device that has two bridge networks in a single SOT23-6 package to protect single TX/RX data ports. The maximum forward current under an 8/20 µs impulse is 12 A. The forward voltage is 2 V with a 1 A 8/20 µs impulse and with a capacitance of just 3 pF, this device is ideal for 1000Base Ethernet applications.

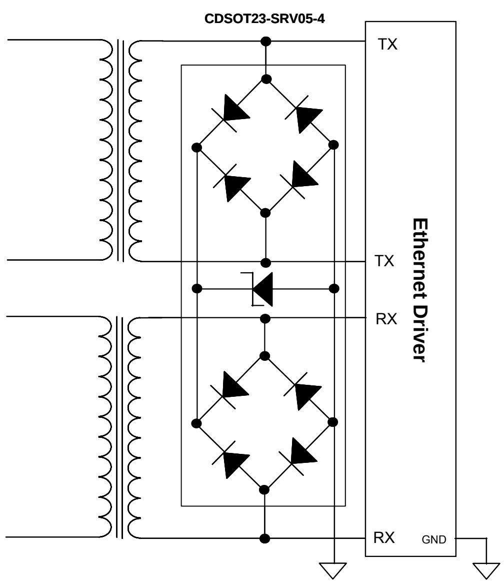


Figure 2 – Bridge diode protection network

TVS (transient voltage suppressor) diodes are also considered in secondary protection. It is important to determine the energy transfer across the windings so that a TVS diode can be suitably selected for the application. A TVS diode reference voltage will increase with an increase in current through it. If in doubt, a higher wattage option is better than an underrated version as this will limit the overvoltage stress on the driver.

TVS diodes are a popular choice to provide voltage clamp protection, but an increase in die size (maximum I_F rating indicates die size) increases the junction capacitance by the same ratio. Capacitance in Ethernet applications can be a hindrance in performance, so to overcome this problem for high-speed communication ports, TVS diodes are used within bridge diode networks as shown in Figure 2. The trade-off with this arrangement is an increase of extra components, but the lower capacitance bridge diode is now in series with the much higher capacitance of the TVS diode. Figure 2 shows an example where the line driver differential voltage is protected to ground. The transmission line will be protected to the TVS diode voltage, V_{BR} plus the V_F of the diode. The differential line transmitter/receiver just needs to be protected; the ground of the bridge can be left floating. This will provide two bridge diodes to in series to reduce the line capacitance further, but the trade-off is the increase of the protection voltage by the additional V_F value.

The Bourns® CDSOT23-SRV05-4 device offers two bridge diodes with a 5 V TVS diode in a single SOT-23 package. The peak impulse current capability is 43 A under an 8/20 μs impulse. The TVS diode is rated for 500 W (with 8/20 μs) where the zener diode voltage will be around 11 V under this extreme impulse. The CDSOT23-SRV05-4 device provides a higher withstand impulse capability than the standard bridge configuration discussed earlier.

Protecting the Primary-Side of the Transformer

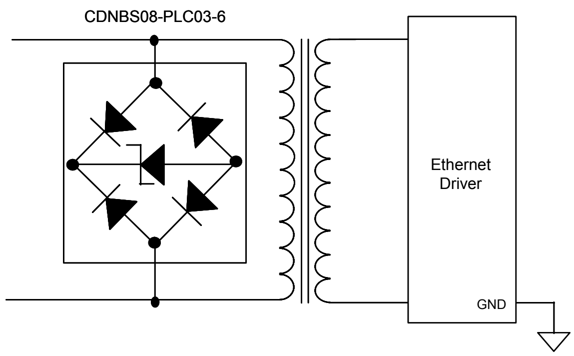


Figure 3 – Primary-side protection using PLC03 series

Circuit Protection Engineers try to limit the energy at the entry point to the equipment (RJ45 socket) to ensure less stresses are applied to the circuit. A popular option is to use the CDNBS08-PLC03-3.3 (for 3.3 V systems) or CDNBS08-PLC03-6 (6 V for 5 V systems) that is an integrated TVS diode and bridge diode network. The CDNBS08-PLC03 series can be used on either the primary or the secondary side of the Ethernet transformer. Placing protection on the primary-side of the transformer usually makes this the vulnerable component when specifying the port against immunity to electrical disturbance. The Ethernet transformer may actually provide a higher level of protection than the protector used to protect it may. Using a primary-side protection solution can allow the fault current to be redirected through the chassis Earth, rather than through the card backplane. Figure 3 shows the CDNB08-PLC03-6 being used to protect the port against metallic voltages and relies on the transformer isolation for longitudinal protection.

To meet the GR-1089-CORE intra-building AC power contact test of 120 V, 25 A, an overcurrent protector such as the B0500T single blow fuse should be considered with the CDNBS08-PLC03 series to ensure the equipment fails safely. The interconnect between the package pins of the overvoltage protector to the die cannot be guaranteed to provide the clearance time and the isolation distance to stop the device from arcing to cause a safe failure during the AC test. The ITU-T intra-building specification does not have any AC tests and therefore does not need a series fuse to protect the overvoltage protector.

The CDNBS08-PLC03 series has a single bridge diode network with a TVS diode to protect a single wire pair. They can support 100 A 2/10 μs (95 A 8/20 μs) where the line impulse rating halves under longitudinal impulses due to the test providing 2x the line current through the TVS diode. The CDNBS08-PLC03 series is specified to meet GR-1089-CORE, issue 4 intra-building and ITU-T, 2003 intra-building impulse requirements within the data sheet.

***Note:** The CDNBS08-PLC03 family has a LINE-GND capacitance of 20 pF and a LINE-LINE capacitance of 8 pF that can make them unsuitable for 1000Base Ethernet applications.*

Extending Impulse Withstand Capability

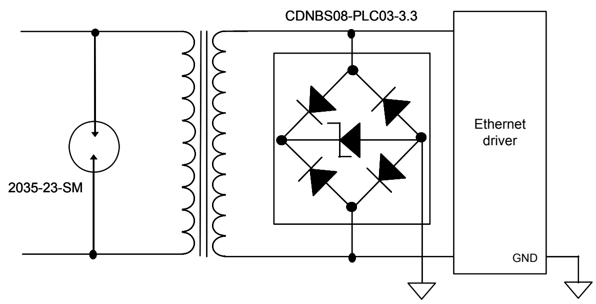
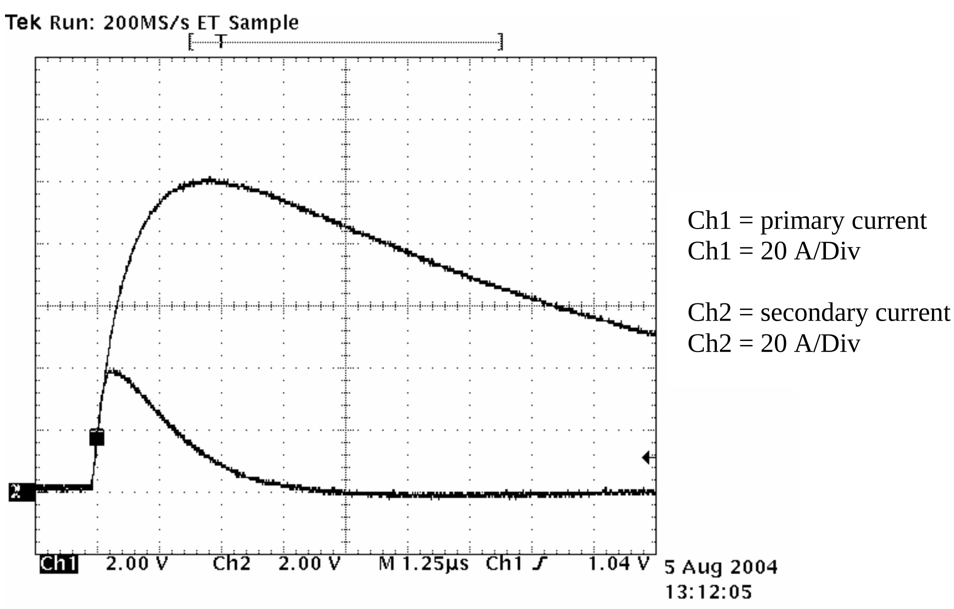


Figure 4 – GDT for enhanced protection

The maximum impulse withstand of the Ethernet port can be enhanced by adding a GDT (gas discharge tube) on the primary-side of the transformer. GDTs have a very low capacitance of 2 pF or less which makes them ideally suitable for Gbit Ethernet solutions. A GDT is dV/dT sensitive where their data sheets normally specify the impulse spark-over rating at 100 V/µs and 1000 V/µs. The 2035-23-SM, for example, is a 230 V DC rated device and has an impulse spark-over voltage of 600 V under a 1000 V/µs. The increase in spark-over has the consequence of transferring a higher current impulse to the secondary, which needs to be taken into account. Bourns® circuit protection products such as the CDNBS08-PLC03-3.3 or CDSOT23-SRV05-4 can be considered to provide the additional protection required.

Testing with a 1.5 kV 2/10 µs and a GDT as the primary protector

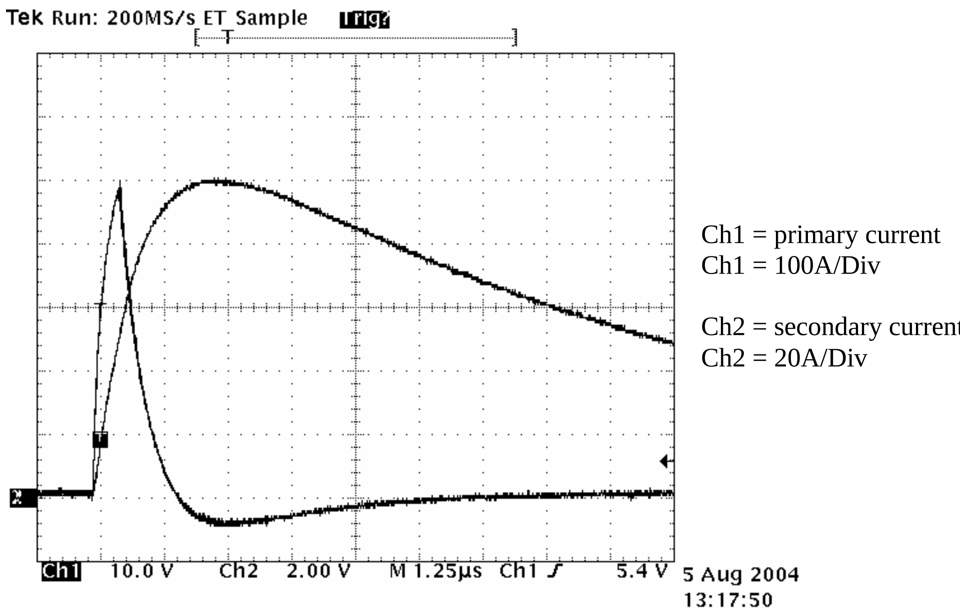
A 2035-09, 90 V GDT was placed across the PT61021 Ethernet transformer and the secondary windings shorted and measured with a current probe. The primary was then tested with a 1500 V 2/10 µs impulse across the GDT terminals. Graph 3 shows that there is very little change in the secondary impulse current under the 1500 V 2/10 µs impulse when compared to Graph 2 on page 4. The 2035-09 GDT across the transformer interface under this test condition is not providing a benefit to the solution if this is the maximum rating the port is expected to see. The solution can therefore concentrate on the secondary protection and not use line-side protection.



Graph 3– PT61021 tested with 1.5 kV, 100 A 2/10 µs and a GDT across primary

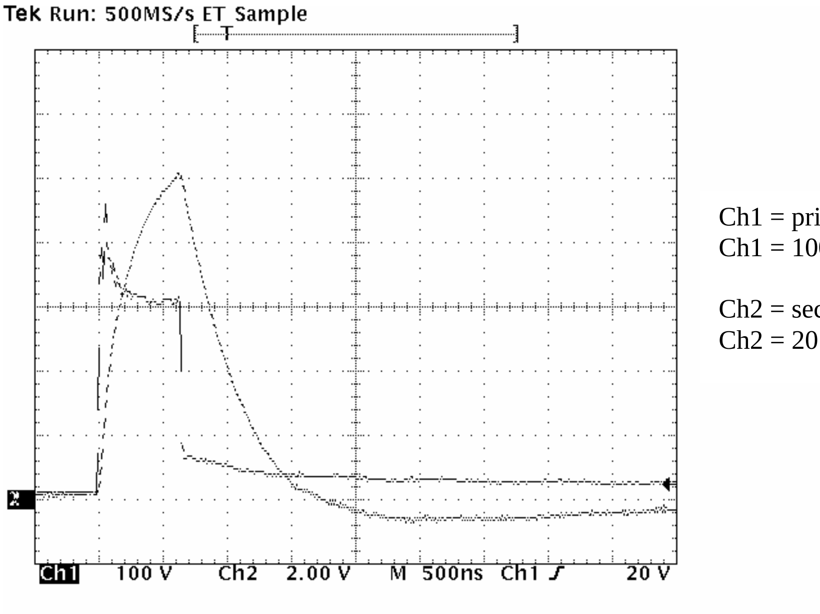
Testing with 5 kV 2/10 µs with a GDT as a primary protector

Graph 4 shows the secondary impulse current when a 5 kV, 500 A 2/10 µs impulse is applied to the primary of the transformer. A standard Ethernet transformer would be expected to fail under this type of impulse test. However, with the 2035-09 GDT across the transformer TX terminals, the transformer was not damaged by the impulse. The secondary current impulse under the 5 kV 2/10 µs was 100 A with a wave shape of 0.5/1 µs. The secondary waveform highlights that an overvoltage protector with a rating of at least 100 A 2/10 µs should be considered for the secondary protection. However, a consideration to note is that the Ethernet IC is overvoltage sensitive to its supply voltage value. Therefore, the IC will be subjected to a maximum of 20 V, which the IC needs to withstand. A standard bridge network using good fast recovery diodes as shown in Figure 1, page 5 may be a better option to keep the overvoltage stresses to a minimum under these test conditions.



Graph 4 – PT61021 and GDT under 5 kV, 500 A 2/10 µs impulse

The primary voltage was also monitored during the 5 kV, 2/10 μs impulse to monitor the performance of the GDT. Graph 5 shows the primary-side impulse voltage during the test where the GDT switched into a short circuit within 600 ns. A peak voltage of 460 V was seen with the 90 V DC spark-over rated GDT. From Graph 5, reducing the switching time of the GDT to 300 ns would have limited the peak secondary current to 80 A. As the secondary current was interrupted by the GDT turning on, this points to the transformer not being driven to its saturated condition by the impulse before the GDT operated. The secondary maximum current rise time is not dependent on the 2500 V/μs impulse, but the B/H curve characteristics of the transformer.



Ch1 = primary voltage
Ch1 = 100 V/Div

Ch2 = secondary current
Ch2 = 20 A/Div

Graph 5 – PT61021 transformer tested with 5 kV, 500 A 2/10 μs and a GDT across primary

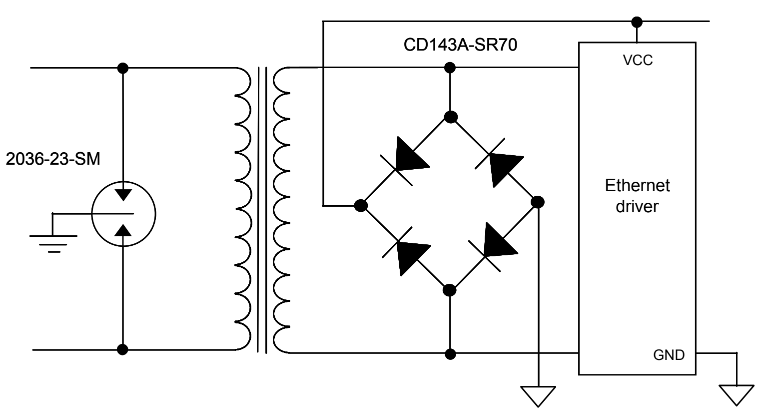


Figure 5 – Transformer isolation protection

The 2036-xx-SM mini GDT series from Bourns is designed to withstand a single impulse of 10 kA 8/20 μs impulse to provide an extremely robust solution. Under lightning impulse conditions, the Ethernet cable is assembled as twisted pairs in the CAT5 bundle. The cables as twisted pairs will share the electrical disturbance and therefore should not add a significant metallic differential to the input of the RJ45. The high voltage threat will therefore be longitudinal which requires the transformer isolation to be protected.

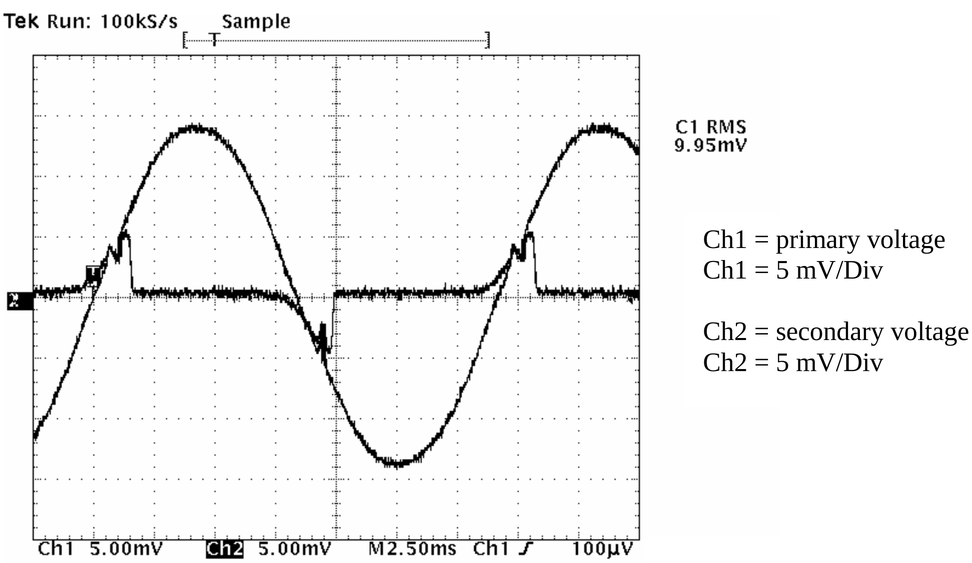
The mini GDT 2036-xx-SM is a common chamber three-connector device that will also protect the isolation barrier of the transformer.

Protecting the Transformer against AC

For GR-1089-CORE intra-building requirements, the equipment will also need to ensure the port opens safely under the AC power contact test without the external current limiter indicator (MDQ1-6/10A or MDL 2.0A fuse) operating. The transformer primary wire is normally a thin gauge wire that may operate as a low current fuse. The primary impedance of the Ethernet transformer at 50/60 Hz is usually sufficiently high enough to limit the current so as not to damage the transformer and limit energy transfer to the secondary. If this is not the case, a primary overcurrent protector such as the Bourns® B0500T fuse is required to protect the transformer.

Testing P61021 immunity to AC

The test was conducted with a 120 V rms voltage applied across the primary winding of the Ethernet transformer. There was no indication of damage through fire, fragmentation, etc and the windings were still intact after 15 minutes. The transformer was also electrically tested to ensure there was no damage to the wire insulation of the transformer. Graph 6 shows that the energy produced on the secondary-side of the transformer is the result of the AC test equipment having a fast dV/dT "glitch" in the sine wave. Without this glitch, no current was evident on the secondary.



Graph 6 – P61021 transformer during AC test

Note: *The primary-side AC voltage in Graph 6 was reduced to show the effects of noisy AC and is not a representation of the peak AC withstand voltage. The secondary voltage amplitude did not change with a reduction in the primary AC peak voltage.*

Protecting a GDT under AC

If the equipment also needs to pass AC tests, there are two options to consider when designing with a GDT as the primary-side protector.

1. The GDT can be selected to ensure it does not operate during the AC test. For example, to withstand 120 V rms, the GDT selected should have a DC spark-over of 230 V or greater. A 240 V rms requirement should select a GDT with a minimum DC spark-over of 470 V.

2. The overvoltage protector operates during the AC test to limit the maximum spark-over voltage under impulse. A GDT cannot support high current AC due to an on-state voltage of approximately 10 V and therefore can dissipate power, causing the device to get hot. A discrete GDT would not be able to support the 120 V rms, 25 A for 15 minutes in GR-1089-CORE and therefore a suitable overcurrent protector is required. The surface mount 2035-xxx-SM and 2036-xxx-SM can only be used with the 0.5 A B0500T fuse where extra consideration (more copper for interconnects, multi-layer boards, etc is ideal to allow the heat to be dissipated into the PCB while the GDT supports the current under the fuse's I^2t curve. The trade-off when using the B0500T fuse is that it will also limit the impulse withstand capability of the application. The B0500T will have a typical current withstand of 440 A under 2/10 µs and 310 A under 8/20 µs.

RJ45 Ethernet Socket Integration

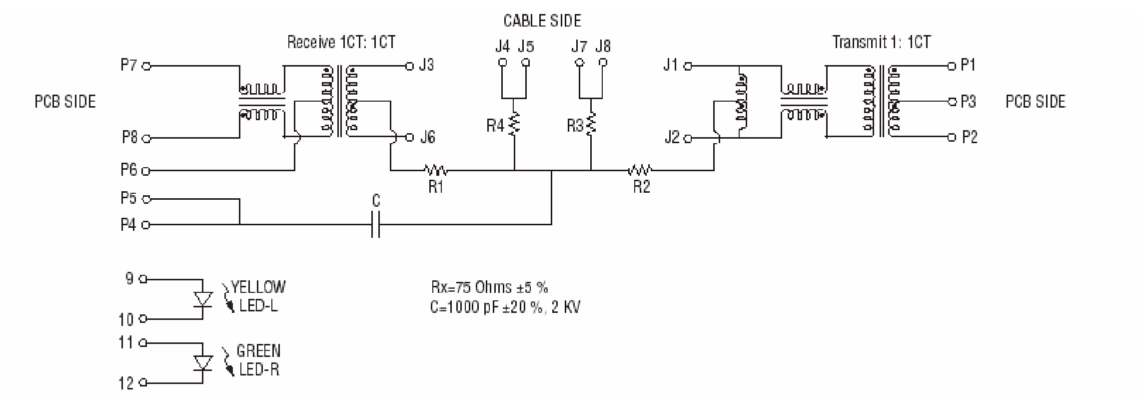


Figure 6 – Integrated RJ45 schematic

Bourns has released a new family of integrated RJ45 plugs that contain the magnetics, terminating resistors, coupling capacitor and LEDs in a single solution. The integrated solutions are to address 10/100Base Ethernet where the family will be expanded and address 1000base Ethernet and Power Over Ethernet (PoE) type solutions in the future. The PT44201D is a single port where the PT44216M4 is an inline quad solution. The family can be customized to offer different LED colors. The PT44201M4 is the same version as the PT44216M4, but without the LEDs.

PoE (Power over Ethernet) Protection

The IEEE 802.3af standard for PoE defines remote powering capabilities for Ethernet that can still use standard Ethernet Cat-5 cable. This new standard helps applications like VoIP (Voice over Internet Protocol) phones and security cameras where they currently require an independent AC wall adaptor to provide power to the remote unit. PoE can also address backup power facilities such as 911 calls when local power is lost, a requirement of current POTS (plain old telephone service) systems.

PoE can be split into power-sourcing equipment (PSE) and powered device (PD). The PSE units nominal voltage is –48 V DC (-56 V maximum) with a maximum of 15 W for each port. The power can be available either from the spare contacts (mid span or end span) in the RJ45 socket or by the use of a center-tap on the TX & RX transformers. The PSE must only select one of these methods on the unit during its design. To check that a PD has been connected to the Ethernet line, the PSE will probe (through a control circuit) the remote equipment with a low voltage bias (2.7-10 V) to see if a 25 kΩ load resistance is present. Standard Ethernet use will have around 150 Ω (2x 75 Ω terminating resistors) for the center-taped transformer or high impedance for the spare contacts. If 25 kΩ is not detected, the PSE will not power the Ethernet cable.

If all the Ethernet ports are required to support up to 15 W, this can require a high power supply to be used in the PSE. Therefore, IEEE 802.3af has defined four classes of current consumption categories where this will inform the PSE how much current is required from 10 mA to 350 mA. The use of multiple lines for transmitting the power helps to reduce the power losses associated with line resistance. There are also discussions to use both options (end span and center-tap) to reduce the losses further. Figure 7 shows the interface relationship between the PSE and PD.

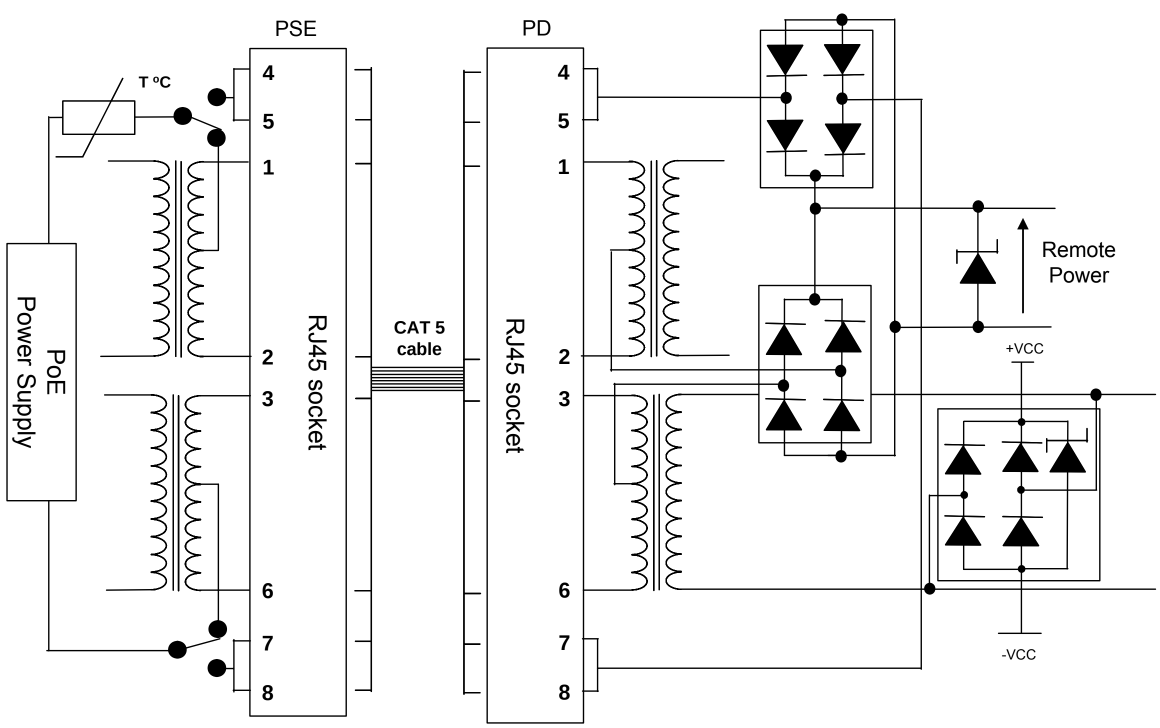


Figure 6 – PoE PSE and PD interface

Bourns has released a family of 10/100Base PoE transformers for PD and PSE applications. The SM51108 and SM5152x series contains the transformer and common mode choke and covers single TX/RX ports, dual port and quad port solutions in discrete packages.

The PSE needs to provide overcurrent protection should the power supply be shorted. A common method is to use a polymer PTC (positive temperature coefficient) thermistor to limit the current should a short occur. A MF-SMDF050 provides a 500 mA holding current specification at 23 ºC to ensure the PTC does not trip at 50 ºC ambient temperatures. Two bridge diode networks on the PD side allow either power transfer to be used. Integrated bridge diode networks such as the Bourns® CDNBS04-B08200 or CD2320-B1200 device can be considered.

The DC/DC converter in the PSE and PD (convert from –48 V down to 5 V or 3.3 V) need to have protection against impulse and AC power line cross. A TVS diode such as the CD214C-T54ALF (unidirectional device) is used to protect the PD DC/DC converter. A suitable rated single blow fuse or PTC thermistor can be used to provide the overcurrent protection if this is not built into the DC/DC converter. Bourns is also considering a family of point of load DC/DC converters to address the PD interface from the Micro Modules group. Please contact your local applications engineer or sales representative for an update.