Protecting PoE PSE against Lightning & Power Fault in Internal & OSP Type Environments

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ATIS-PEG-2015

PoE = Power Over Ethernet, PSE = Powered Sourcing Equipment

Topics to be Covered

- Do you feel like you are under water with PoE?

- Presentation will cover:-
- Ethernet interface protection.
  - Ethernet has been extensively covered in various presentations but it still seems to be black magic.
- PSE (Power Source Equipment) interface.
  - Little information on the correct protection techniques for protecting the Powering side of PoE.
  - Where are the possible "Gotchas" to watch out for.
- Standards and how they interpret PoE.
  - Telcordia GR-1089-CORE, Issue 6.
  - ITU-T K.21 (2011) and new version that is soon to be released.

Standards

- Telecom standards have issues for PoE.
  - Ethernet systems are short distance (300ft) and typically FLOATING. Tests in some standards are based on communication systems that are long distance (2000ft or more) that can be EARTH referenced.
    - Electrical stresses will be different between the two topologies!
  - Some standards also consider Ethernet as 2-wire or 4-wire systems when testing.
    - PoE has 8 wires in the jack!

As a result of this….
it causes confusion, forces strange tests that result in compromised designs.

GR-1089-CORE (Issue 6)

- Application chart shows Ethernet but not PoE.
  - Assume Ethernet & PoE can be deployed in the same space.

  - Port type 1 (CO OSP cable ports).
  - Port type 2 (CO intra-building cable ports).
  - Port type 3 (Customer location OSP cable ports).
  - Port type 3a/5a (intra-cell site).
  - Port type 3b/5b (Short reach OSP cable ports).
  - Port type 4 (customer location).
  - Port type 4a (customer location ONT).
  - Port type 5 (OSP Site OSP cable ports).

Table B-3 Application Chart for Equipment Ports (Sheet 2 of 2)

Section	Description	Equipment Port Type											
		1	2	3/5	3a/5a	3b/5b	4	4a	6	7	8	8a	8b
4.5	General Testing Information and Guidelines	X	X	X	X	X	X	X	X	X	X	X	X
4.5.9	Equipment Interfacing With Agreed or Non-Field Replaceable Integrated Primary Protectors			X									
4.6.1.1	Short Circuit Test (Telecommunications Type 1, 3, and 5 Ports)	X		X									
4.6.1.2	Ethernet Interface Considerations (Telecommunications Type 1, 2, 3, 3a/5a, 3b/5b, 4, 4a, or 5 Ports)	X	X	X	X	X	X	X					

- GR-1089-CORE is highlighting that Ethernet can be deployed into any location in the telecommunication network.

GR-1089-CORE OSP Testing

- GR-1089-CORE tests the interface as a 4-wire system.
  - Note 6 from table 4-2 First-Level Lightning Surge.

6. For 10/100 BaseT, test the data pairs to A5/A6, then test unused pairs to A5/A6 if they have components connected to the jack. For GigE, choose 2 pairs and test those 2 pairs to A5/A6, then test the other 2 pairs to A5/A6. For PoE, test the data pairs to A5/A6. In all cases, pairs of the port under test that are not being surged shall be left open circuited at the test generator. Other types of interfaces that have more than 2 pairs should be tested in a similar manner.

  - Note 6 is referenced for 10/1000 ONT interfaces.

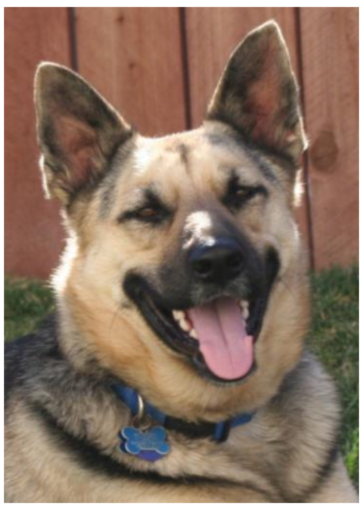
									the testing.
18	4a	Customer Side ONT Interfaces	±1000	100	10/1000	N/A	5	A5, A6 (per Table 4-1)	See Note [6]
									See Section 4.6.2.1.5

    - Assume this test arrangement is also for port type 1,3,5 where the generators limit the interface to 4-wire testing.

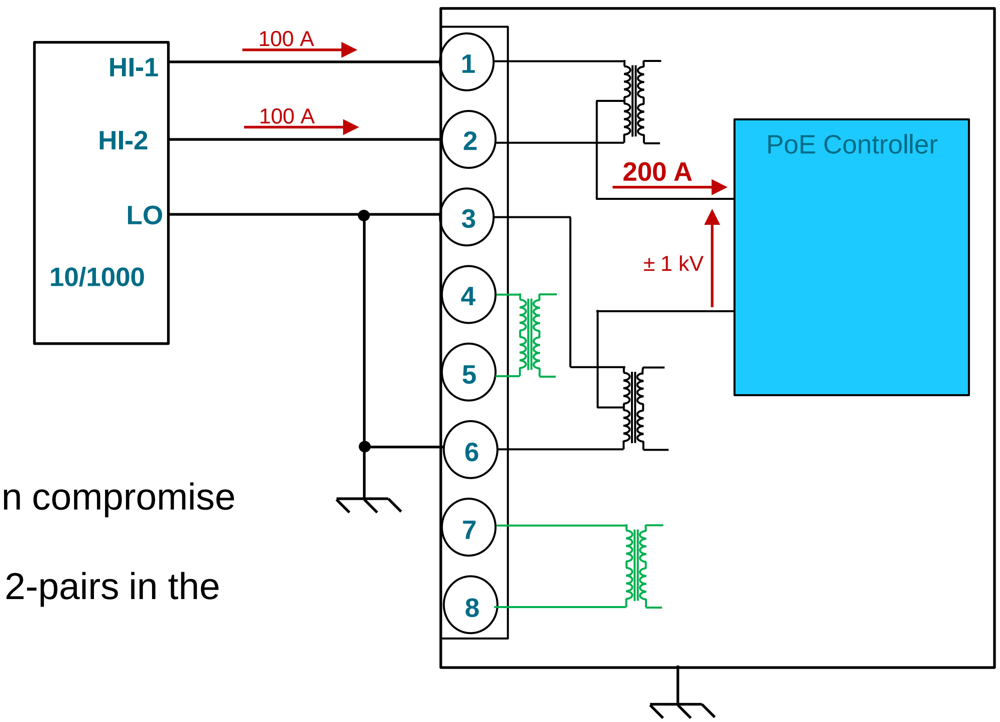
GR-1089-CORE OSP 1/3/5 Port Interface

- Test #2, 1 kV 10/1000 4-wire interface.
  - 1kV, 100 A 10/1000 is an extreme surge for 300ft and could see 200 A as a PoE metallic test!

When this “issue” was raised, was told “this would be the same for Span Powering”



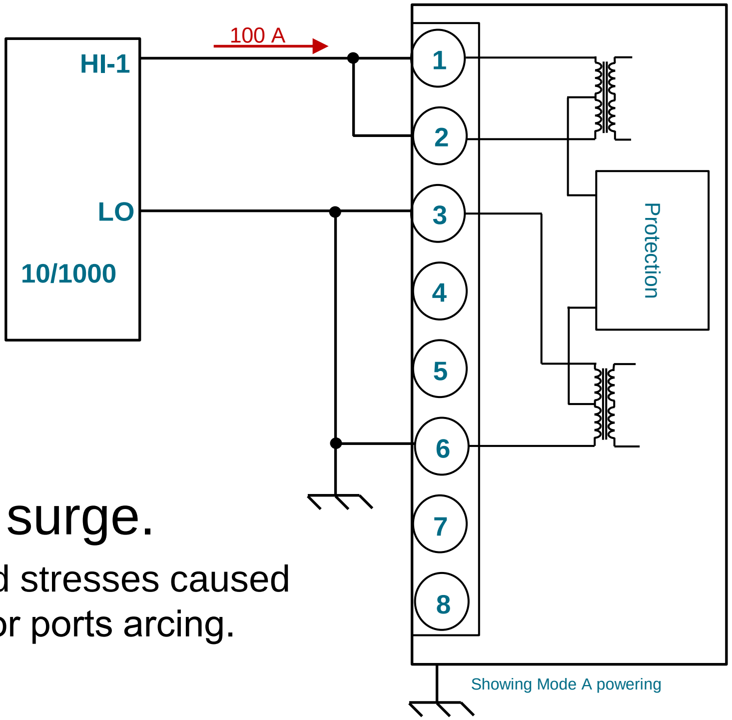
Laughable! But it does start to explain things.



1 kV, 200 A 10/1000 could cause a potential design compromise but…...
GR-1089-CORE does not highlight between what 2-pairs in the Ethernet 4-pair interface to test between.

GR-1089-CORE Metallic Surges

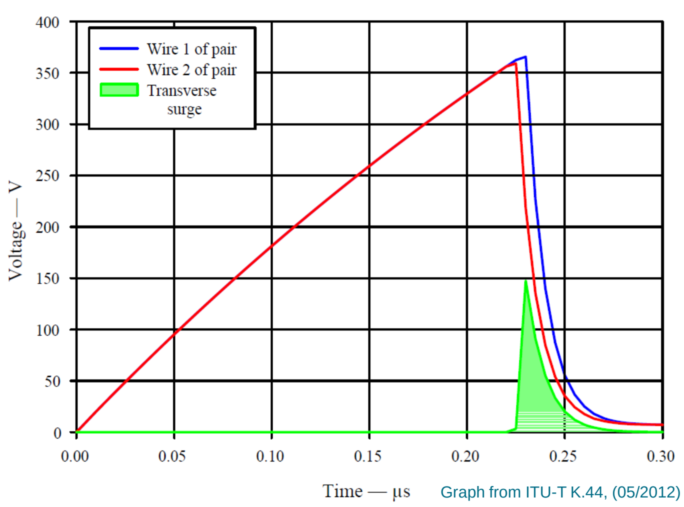
- The Powering interface still needs to be tested.
  - OSP of Metallic ±1 kV, 100 A 10/1000 is still an “excessive” surge.
    - Is this level of transverse surge for 300 ft cable up a lightening rod……?
  - 30 A to 50 A would probably be a better OSP spec.
    - The result of field realistic tests…..



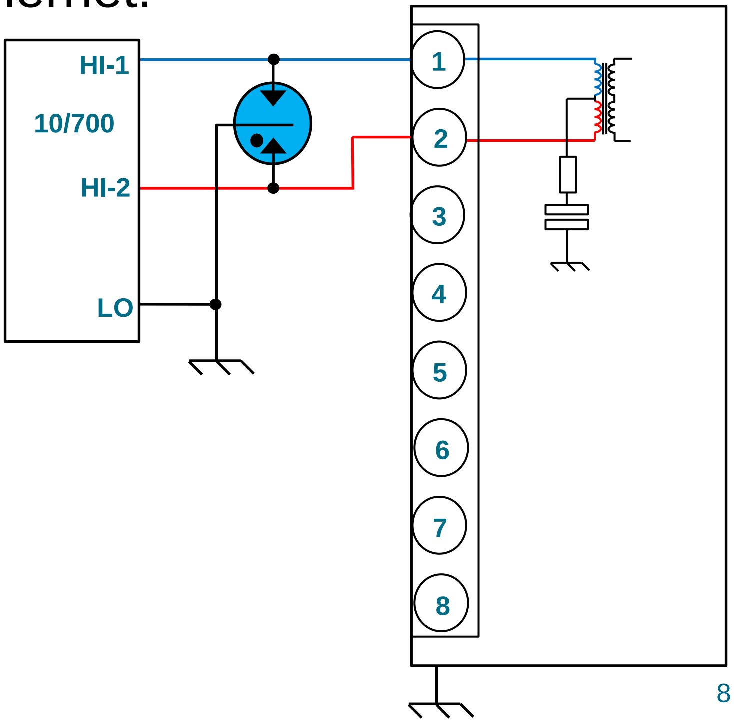
  - ±800 V, 100 A 1.2/50-8/20 Intra-building surge.
    - Looks like it addresses longitudinal to transverse field stresses caused by protection components such as GDT’s operating or ports arcing.

GR-1089-CORE Gas Tube Interaction Test

- OSP Primary Protector test.
  - Port types 1,3,5,3b/5b is where GDT's could be used.
    - To address GDT oscillation issues seen during AC faults but this is not a major threat for PoE.
    - Not going to get away from some deployments that require GDT primary protection, but there should not be any GDT's to ground in the other port types!
  - Tests metallic protection solution for Ethernet:-



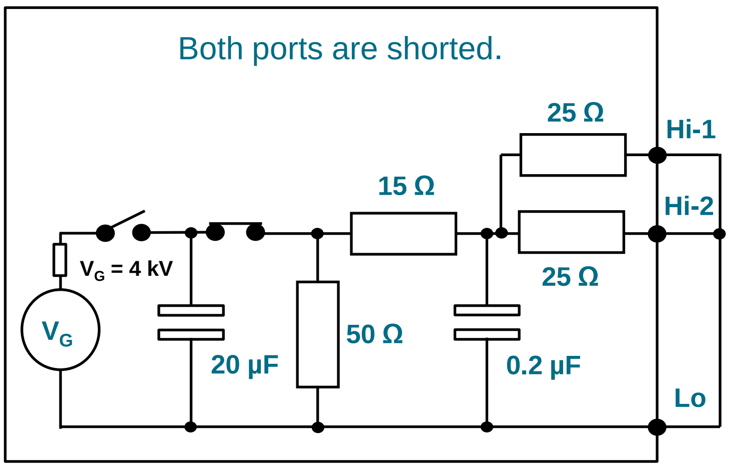
Graph from ITU-T K.44, (05/2012)

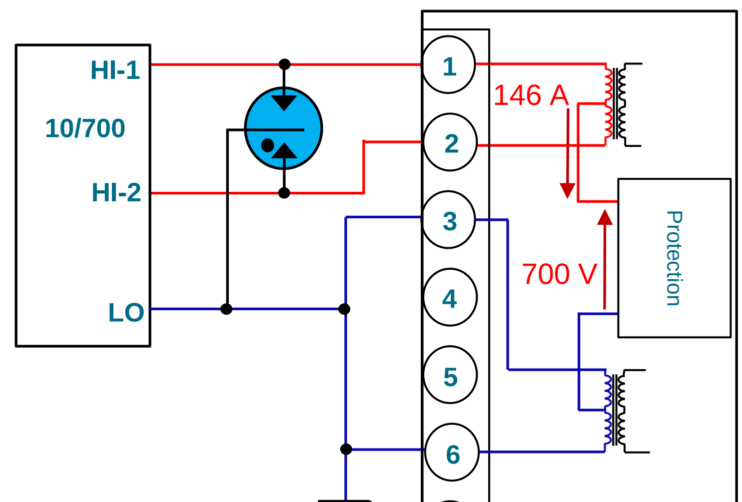


- A metallic surge would serve just as well!

GR-1089-CORE Gas Tube Interaction Test Cont.

- OSP Primary Protector test.
  - Also tests metallic protection solution for PoE.
    - ±4 kV 10/700 through 25 Ω resistors = 146 A.



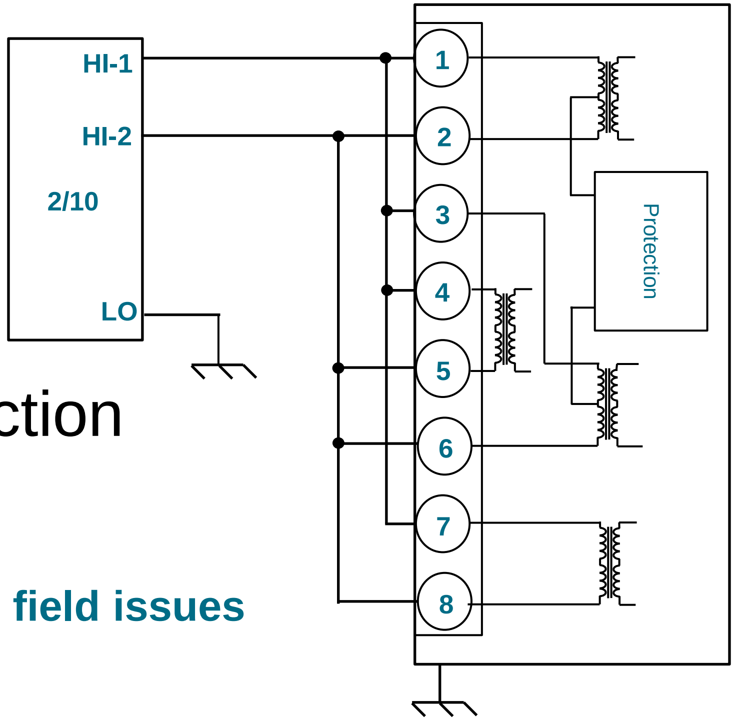


    - Approx ±700 V across terminals with 350 V GDT’s.
  - PoE Options are:
    - Force coordination with primary.
    - Support surge current with over-voltage protection.
    - Use the get-out free jail card (not recommended).

GR-1089-CORE Longitudinal Testing

- Port type 1,3,5 only has a longitudinal test of ± 2.5 kV 2/10.
- Port type 3b/5b (short reach OSP) is only tested to ± 1 kV 10/360.
  - Generator was selected due to having 8x outputs.
- Port types 3a/5a (intra-cell site) is only tested to ±1.5 kV.
- Port types 4/4a is only tested to ±1.5 kV.

Intra-building should be tested to ±2.4 kV to match IEEE-802.

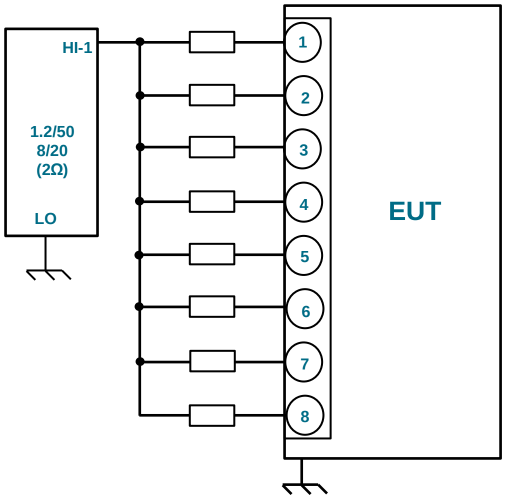


Voltage limits are due to Primary protection expected to be used on the interface!

No wonder there is chaos as customers try to mitigate field issues by adding GDT/primary protection.

Longitudinal OSP Testing

- OSP interfaces should be tested to at least ±6 kV of ISOLATION when no GDT or Primary is used.
  - Isolation should = No surge current (except through Bob Smith components).
    - Ground Potential Rise's (GPR's) are major cause of field failures.
    - 1.2/50-8/20 combination generator should be used to share the surge between the conductors.
    - 10 Ω or 20 Ω per conductor to the generator as done in intra-building testing.



ITU-T K.21 (11/2011) Recommendations

- Current ITU-T also has its problems.
  - K.21 Enhanced has a ±6 kV 10/700 metallic surge if you don't have an agreed primary protector.

3.1.2 agreed primary protection: An agreed primary protector is the type of SPD that will be used to protect the equipment. An agreed primary protector may be a specific SPD or a range of SPDs which comply with a particular Recommendation, standard or specification. The agreed primary protector is often specified by the network operator, but it may be the result of discussions between the network operator and the equipment manufacturer. The agreed primary protector can be nothing if it has been agreed that no external protection elements need to be used for the equipment.

  - How can PoE get this level of metallic surge with an ISOLATED interface?

Next Edition ITU-T K.21 (Customer Premise)

- ITU-T is addressing PoE in its next Edition!
    - Soon to be released so these specifications can change.
  - New tests for external Ethernet Ports!
    - Unshielded twisted Pair Ethernet.

      Is shielded cable interfaces not affected at all in OSP deployments?

    - Transverse ±600 V (basic) or ±1500 V 1.2/50-8/20 with 12 Ω generator.

      GR-1089-CORE intra-building is ±800 V, 8 Ω for PoE test.

    - Longitudinal ±2.5 kV (basic) or ±6 kV 1.2/50-8/20 generator.

      ITU-T K.21 uses 10 Ω for Ethernet.

      GR-1089-CORE intra-building uses 10 Ω for 10/100 Ethernet (2-pairs) and 20 Ω for Gbit Ethernet (4-pairs).

  - New PoE test!
    - Transverse ±800 V (basic) or ±1500 V 1.2/50-8/20 with 12 Ω generator.

      Why is PoE basic metallic test higher than Ethernet?

Next Edition ITU-T K.21 Cont.

- Internal building tests.
  - Unshielded twisted pair Ethernet longitudinal port to earth.
    - ±2.5 kV (basic) or ±5 kV 1.2/50-8/20 generator.
      - » This is up from ±1 kV (basic) or ±1.5 kV in issue 11/2011.

        Internal Basic is the same specification as basic external ports?

        No transverse Ethernet test has been added?
  - Shielded twisted pair Ethernet longitudinal port to earth.
    - ±1 kV (basic) or ±1.5 kV with 1.2/50-8/20 generator.

    How is the cable type going to be policed?

    No transverse Ethernet test has been added?

  - PoE transverse surge test.
    - ±600 V (basic) or ±1000 V with 12 Ω generator.

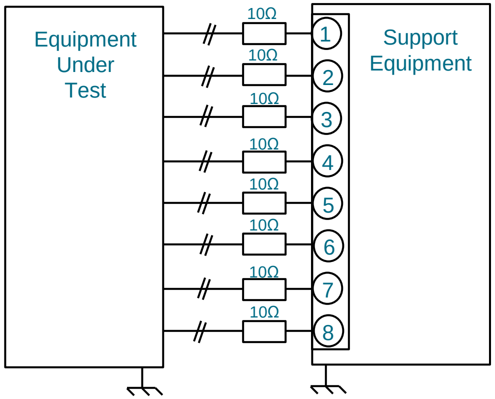
      GR-1089-CORE intra-building is ±800 V, 8 Ω for PoE test.

    WHY TEST transverse PoE and not transverse Ethernet?

ITU-T K.21/K.45 Recommendations

- Ethernet ports do not require traffic during testing.
  - Section A6.7 Ethernet Ports

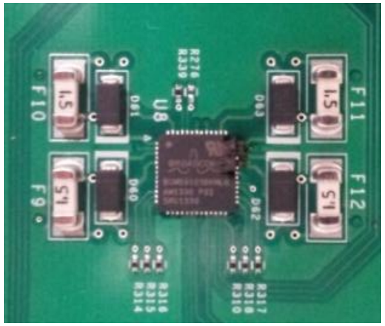
All tests on the Ethernet port except for the insulation resistance test are done in the powered condition but not operational. Ethernet port testing may be done in an unpowered condition when the EUT is a PoE powered device (PD), and the PoE power sourcing equipment (PSE), cannot sense the connected PD EUT. The coupling/decoupling network connected between the PSE and PD maximizes the surge level applied to the PD but may stop the correct operation of PSE load sensing, causing the PD to be unpowered. When the untested Ethernet port is coupled to earth the Ethernet circuit will also be non-operational. The insulation resistance test is performed with the equipment unpowered. Subsequently the equipment must be tested in an operational state to verify it still meets its specification.



  - Why not power through a 48V power supply rather than PSE when testing PD's?
  - Recommends using a 10 Ω decoupling network.
    - Tested PSE with IP phones as support equipment + 10 Ω but saw failures.
      - 300 ft of cable + 10 Ω also saw failures at 6 kV with GDT.
    - Suitable coupling/decoupling networks should be defined.

Field vs Laboratory Failures

- Some field issues seen on the PSE switches.
    - GR-1089-CORE is not a requirement for most customers.
  - Customers were only taking a few ports of a 24/48 port switch outside the building.
  - A typical signature was that all the ports stopped working except for one. Found to be the port that saw an electrical over-stress.
  - The damaged port could always be traced to being taken outside the building.
  - Very little physical damage seen on field returns.
    - IC controller damage (bond wires failing) was most prevalent.
    - Also found a few where schottky diodes in the PoE circuit shorted.
    - No PoE interface fuse damage.



- Surge tested the PoE interfaces and was able to replicate the failure signature on the PoE controller IC.

Is there an OSP Requirement?

- Application notes and protection devices address severe lighting surges to PoE.
  - Points to industry needing a solution.

INTRODUCTION

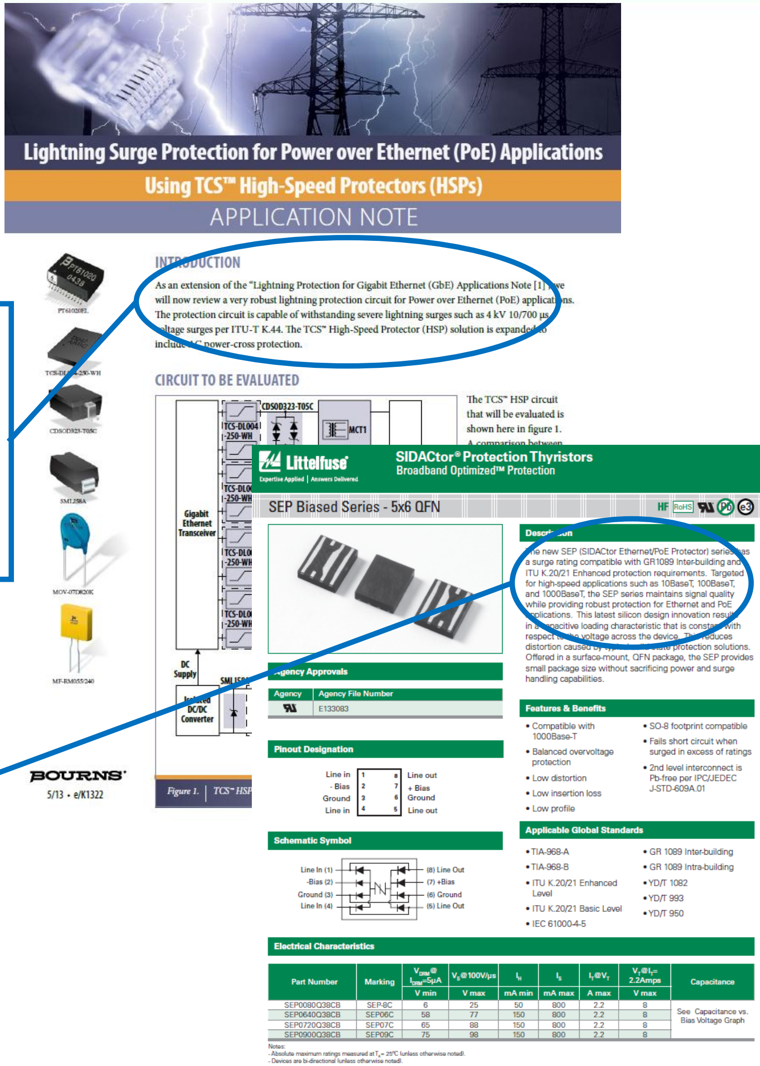
As an extension of the "Lightning Protection for Gigabit Ethernet (GbE) Applications Note [1]", we will now review a very robust lightning protection circuit for Power over Ethernet (PoE) applications. The protection circuit is capable of withstanding severe lightning surges such as 4 kV 10/700 µs voltage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

http://www.bourns.com/data/global/pdfs/Bourns_Lightning_Surge_Prot_PoE_TCS_AppNote.pdf

Description

The new SEP (SIDACtor Ethernet/PoE Protector) series has a surge rating compatible with GR1089 Inter-building and ITU K.20/21 Enhanced protection requirements. Targeted for high-speed applications such as 10BaseT, 100BaseT, and 1000BaseT, the SEP series maintains signal quality

http://www.littelfuse.com/~/media/electronics/datasheets/sidactors/littelfuse_sidactor_sep_biased_5x6qfn_datasheet.pdf.pdf



Switch Analysis

- Reviewed various suppliers PSE.
  - Competition switches selected were the direct competition products.
  - Summary: Good in passing Hi-POT, but not very good with surge.
    - 1 switch passed metallic Ethernet test and only 2 switches passed longitudinal surge.

Tests #	Unit #1	Unit #2	Unit #3	Unit #4	Unit #5	Unit #6	Unit #7	Unit #8	Unit #9	Unit #10
2121 V DC Hi-pot	Fail	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass
2250 V DC Hi-pot	Fail	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass
Metallic ETH 800 V 1.2/50	200V	0V	Pass	400V	0V	400V	200V	200V	400V	0V
Longitudinal 1500 V 1.2/50	400V	200V	1200V	800V	Pass	Pass	600V	800V	200V	400V
Metallic PoE 800 V 1.2/50	Not tested[1]	0V	0V	0V	200V	400V	200V	200V	Not tested[1]	Not tested[1]

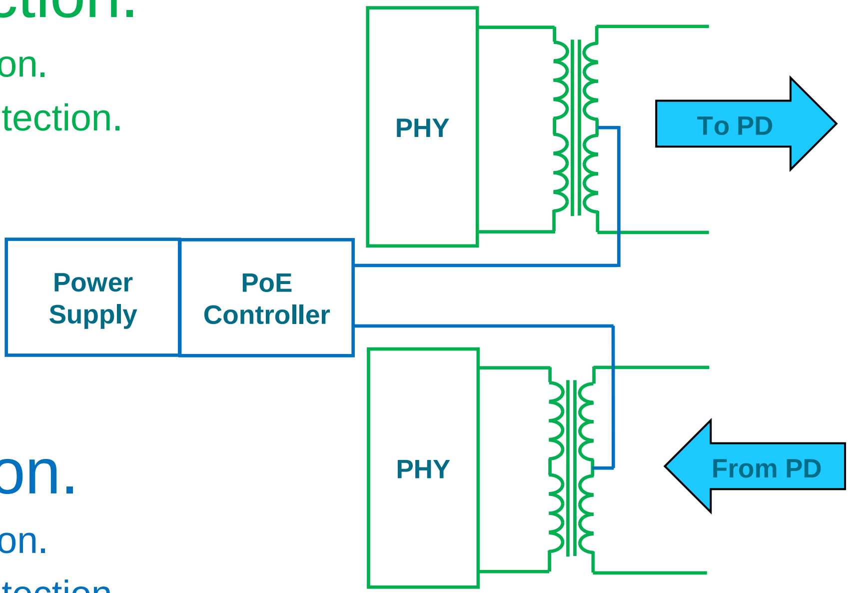
Step-stressed in 200 V increments using 1.2/50-8/20 combination generator as per GR-1089-CORE, issue 6. Voltage highlighted shows last pass surge voltage.
[1] Ports not tested due to all PoE ports failing at the same time during the longitudinal test.

- The industry has a ***BIG*** problem in this market sector. Only 1 switch passed ±800 V metallic intra-building!

Building Blocks of PoE

- PoE can be separated into two design blocks:-

  a) Ethernet protection.
     I. Metallic protection.
     II. Longitudinal protection.

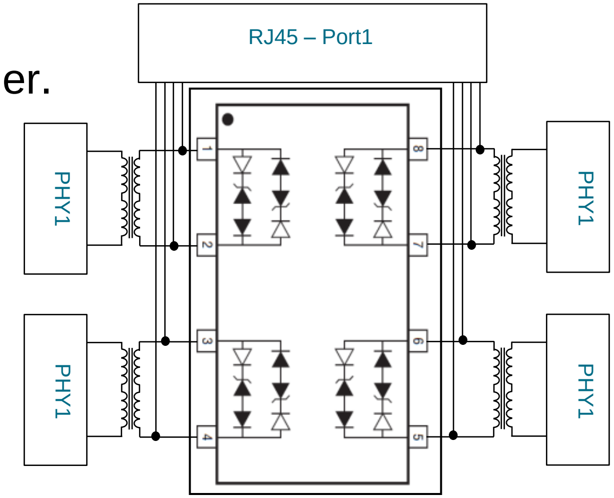


  b) Power protection.
     I. Metallic protection.
     II. Longitudinal protection.

Let’s look at each block in turn.

Metallic Ethernet protection

- Still seeing line-side protection solutions for metallic GR-1089-CORE Intra-building.
  - Protector was between RJ-45 socket and transformer.
  - Protector was 30 A 8/20 rated.
    – Intra-building surge is 100 A 8/20.



- Ethernet transformers make excellent 1st level protectors.
  – Saturate early to limit secondary current.
  – Act like a fuse with too much current.
    - Some manufacturers have figured this out and providing expensive (golden pig) solutions for PHY-side protection, but there is still a lot of snake oil out there!

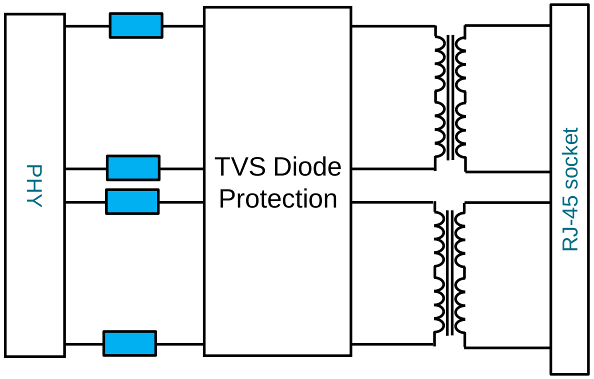
Metallic Ethernet Solution

- Is clamping at the lowest voltage ideal?
  - Found that 2.8 V, 3.3 V options provide small gains if any and under-sized, but often command higher prices.
    - Difficult to do comparable data sheet comparisons between them.
    - The 5 V options are older product and often cheaper.
- 8/20 TVS diode surge current rating of 30 A.
  - Choosing a lower current option increases risk of failure.
    - Ports random failed with TVS diodes shorting with 10-15 A ratings.
    - One Manufacturer rates their TVS diode at 20 A, but their silicon design technique makes for a very robust solution.
    - Some standardization on dynamic electrical specifications would be nice.
- Steering diode Arrays seem to work well.

Metallic Ethernet Solution

- Requiring over-current protection is down to the PHY.
  - Some PHY's can still be protected with just a 5V TVS diode but now a minority.
  - Add over-current protection as a precaution.

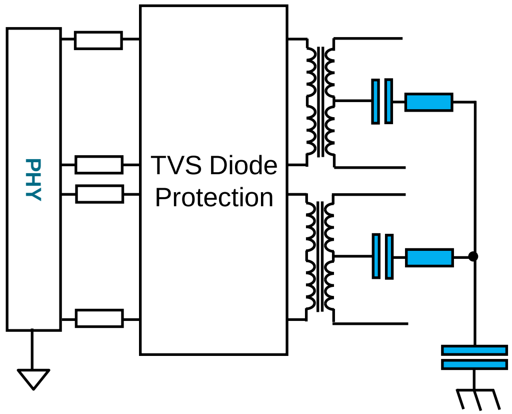
– There are a range of options, but two seem to work well.
  - ECL (Electronic current limiter).
    – Very good protection but expensive.
    – Watch out for over-voltage stress if TVS diodes are not used.



  - Low value Resistor.
    – **NO** (if selected correctly) reduction in performance.
    – Allows 0Ω resistors to also be used.
    – Resistor (if selected correctly) has **NO** impact on line reach.
    – 1/16 Watt resistors are cheap as dirt.

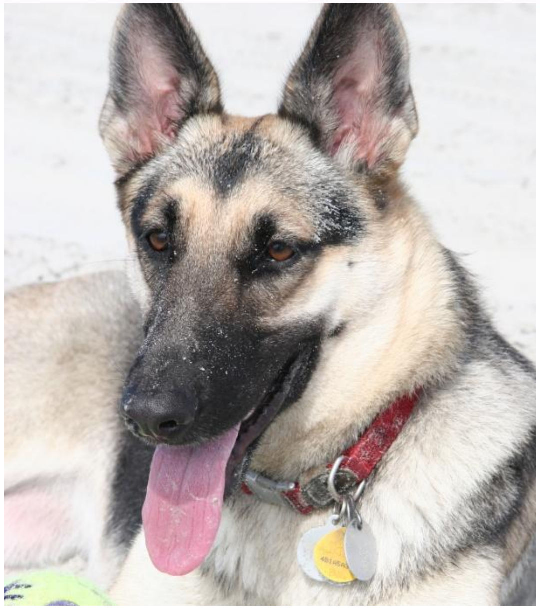
Longitudinal Ethernet Protection

- The Bob Smith Circuit is B.S!
  - High voltage rated capacitors are required.
    - Meeting 6 kV surge withstand compounds the problem.
  - Found not to impact **EMC** for Ethernet.
    - This is what B.S was suppose to address!



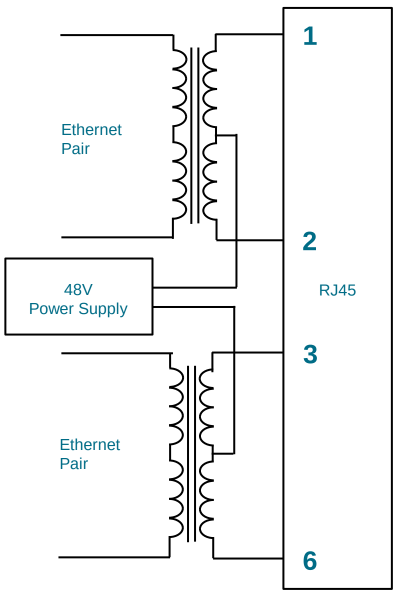
  - Limited testing has not found EMC issues for PoE.
    - The savings on B.S can be used for metallic protection.
- Standard transformers usually achieve 4 kV surge withstand.
  - Watch out for multi-port components pin spacing for port-port.
- RJ-45 sockets with shields can cause isolation problems.
  - Check spacing when assembled onto the board.

Ethernet Testing on a PoE Switch

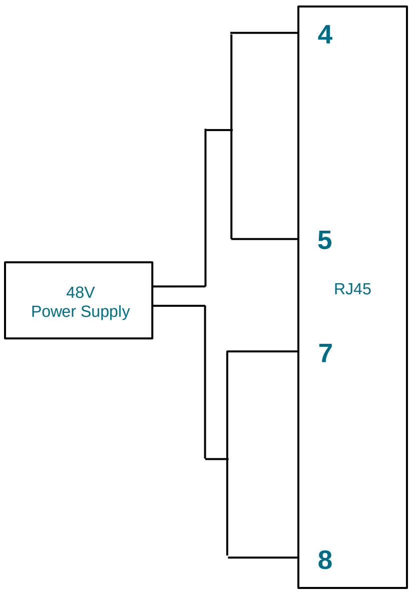


- Ethernet Port Test Results
  - Metallic (transverse/differential)
    - Reference design failed at ±400 V 1.2/50-8/20 (6 Ω external).
    - Revised design **PASSED** ± 3000 V 1.2/50-8/20 (6 Ω external).
    - Revised design **PASSED** ± 4000 V, 100 A 10/700.
    - Revised design **PASSED** ± 1000 V 200 A 2/10.
    - Now exceeding GR-1089-CORE OSP type impulse surges.
  - Longitudinal withstand (standard transformer)
    - Original reference design failed at ±800 V 1.2/50-8/20 (20 Ω external).
    - Design **PASSED** ± 3000 V 1.2/50-8/20 (20 Ω external).
    - Design **PASSED** ± 4000 V 10/700.
    - Design **PASSED** ± 4.5 kV DC @ 60s Hi-POT.
    - Transformers actually designed for 6 kV surge would further boost performance.

Powering Side of PoE



10/100 Mode A
(center-tap shown)

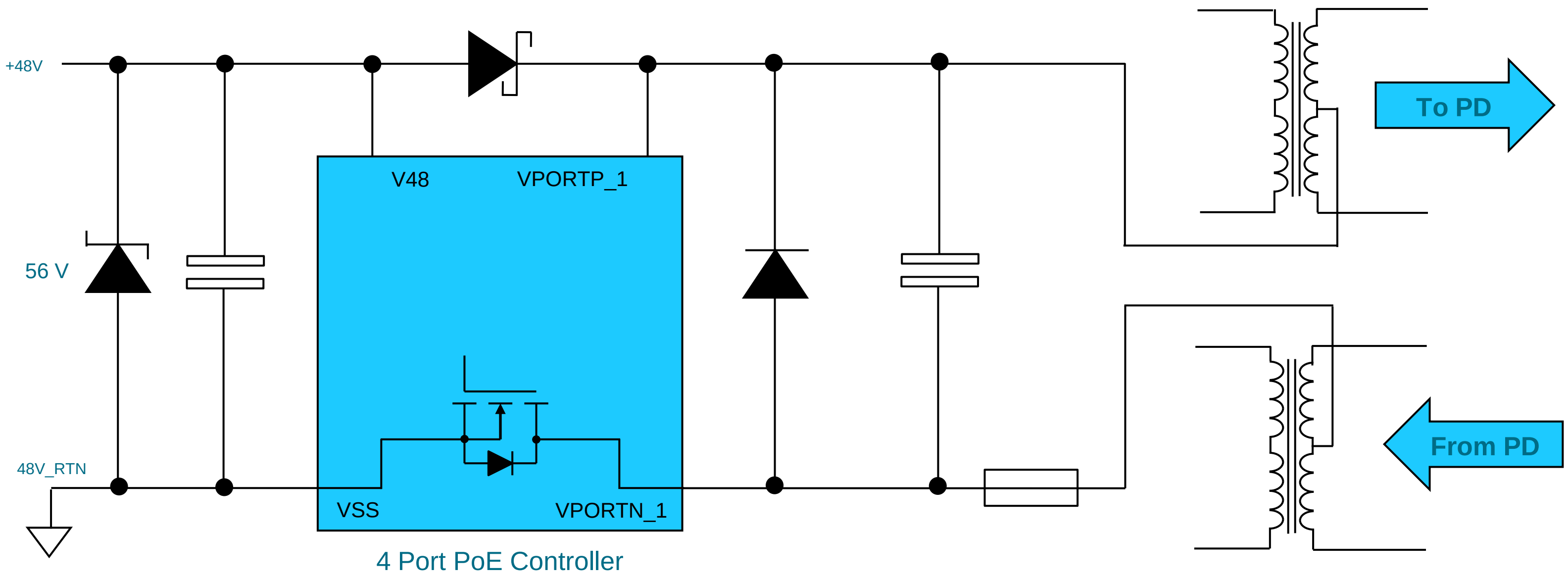


10/100 Mode B
(principle shown)

Note: Gbit Ethernet will also be a transformer center-tap deployment.

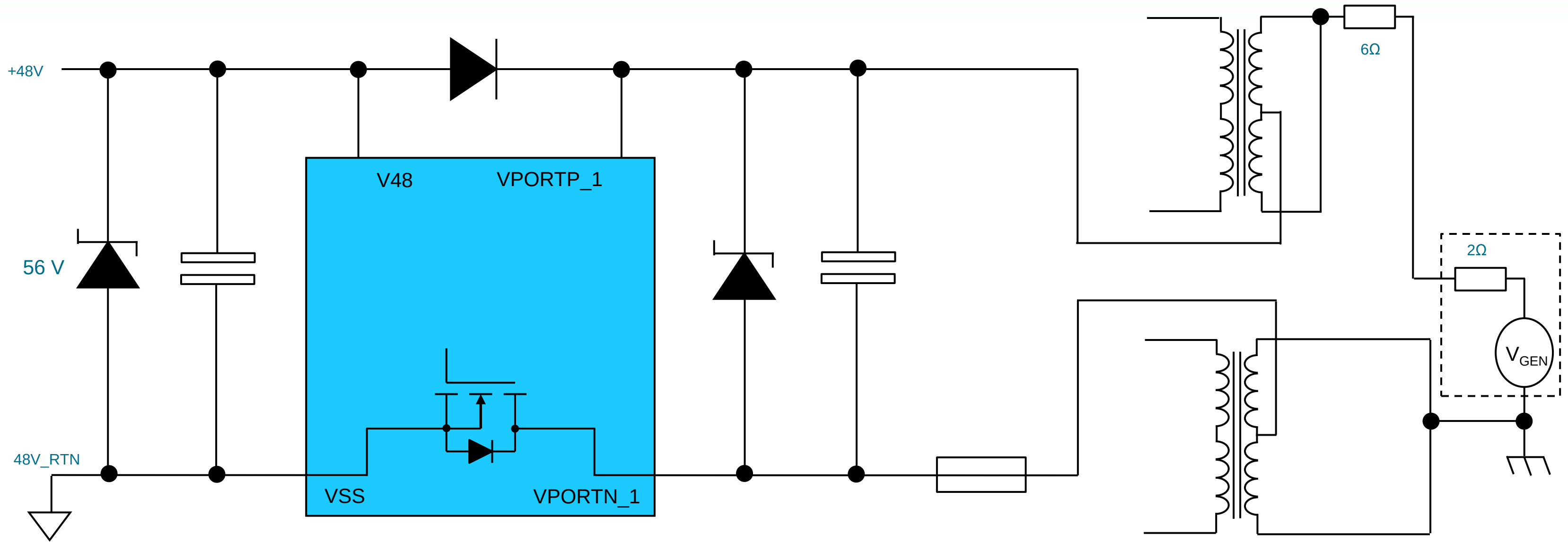
- Mode A powering
  - Provided between pins 1,2 and 3,6 of RJ-45 socket.
    - Center-tap of Ethernet transformer.
    - Most common method used.
- Mode B powering
  - Provided between pins 4,5 and 7,8 of RJ-45 socket.
    - Spare pairs of Ethernet transformer for 10/100BaseT solutions.

PoE Controller Reference Design



- Engineer followed the reference design except for adding in the fuse.
- Field return testing showed just one port working but port had turned dumb (operated just as a DC power supply).
- For the PD to just be powered, the internal FET has to be a short.

Metallic Protection Modifications



- Modifications
  - Replaced the schottky diode with a higher voltage fast recovery diode.
  - Replaced the Diode with a uni-directional TVS diode.

Metallic Protection Results

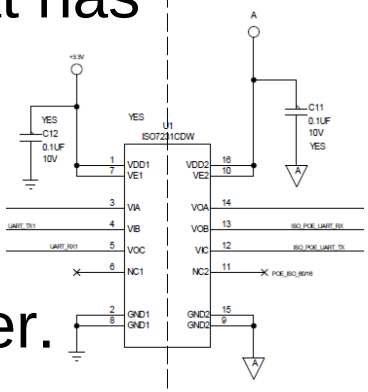
- Results using 1.2/50-8/20 generator with 6 Ω external resistor.
  - Original reference design FAILED at ±200 V.
  - 1.5 A fuse cleared at ±1 kV 8/20.
  - With the fuse shorted, the interface last pass was at ±1.6 kV.
    - Twice as good as GR-1089-CORE Intra-building.
    - The 1.5 A fuse could be changed to make it coordinate a little better.
- Further design modifications saw OSP metallic surges pass the following (without the fuse).
    - ±1 kV, 100 A 10/1000.
    - ± 1 kV, 200 A 2/10.
    - ± 2.5 kV, 500 A 2/10.
    - ± 4 kV, 100 A 10/700.

Longitudinal PoE Protection

- Original reference design failed at ±600 V surge.
  - Interface proved to be weaker on Negative surges.
- Question: How was longitudinal surge currents possible since the 48 V supply should be ISOLATED from Earth?
  - Component(s) breaking down?
  - Went searching in the schematics……

The Enemy of Isolation

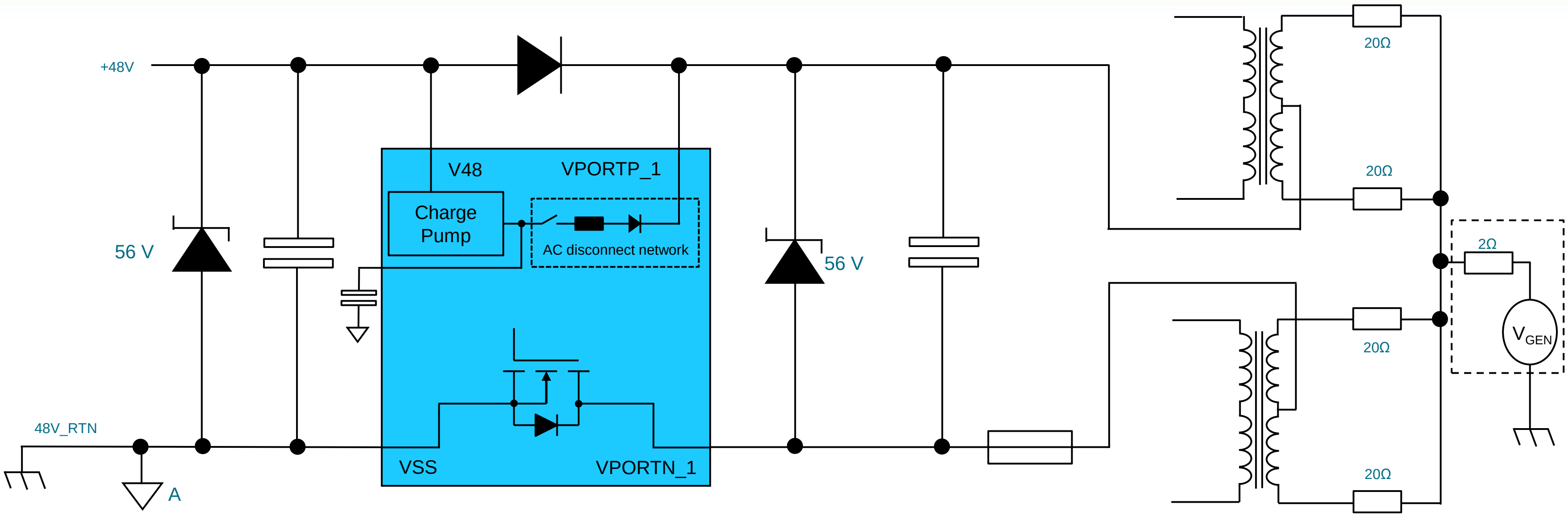
- PoE controllers were isolated.
  - The PoE logic uses a 4 kV opto-isolated IC that has both GNDs referenced.
    - Removed the opto-isolator, but had no impact.
  - No signs of poor spacing through arcing.
  - Power supply was using an isolated transformer.
    - The two digital grounds were kept separate.



So, How WAS the surge current getting back to Earth?

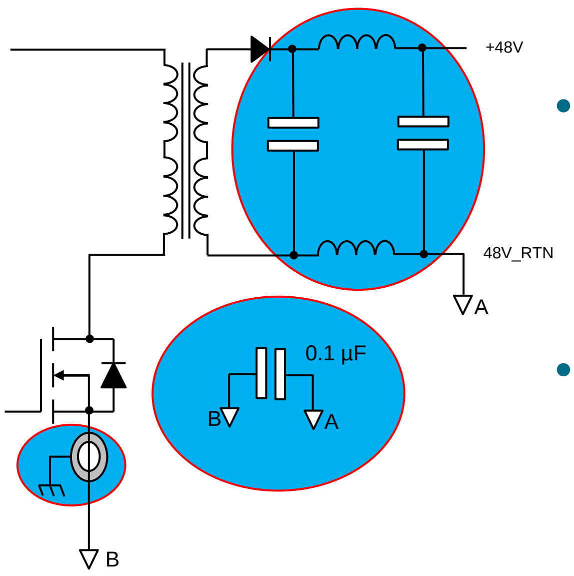
"There are people who think they can defy the laws of Physics but I have only found one who actually can".

Analysing Longitudinal Surge



- With digital GND_A referenced to chassis to complete the circuit:-
  - Positive surge.
    - V_{RRM} of diodes would provide the surge withstand.
    - AC disconnect network surge withstand?
    - **Internal FET switch is rated for 60 V with an absolute max of 72 V.**
  - Negative surge.
    - Diodes would only provide 2x V_F diodes surge withstand.
    - **FET would be 1x V_F of body diode and therefore will conduct first.**

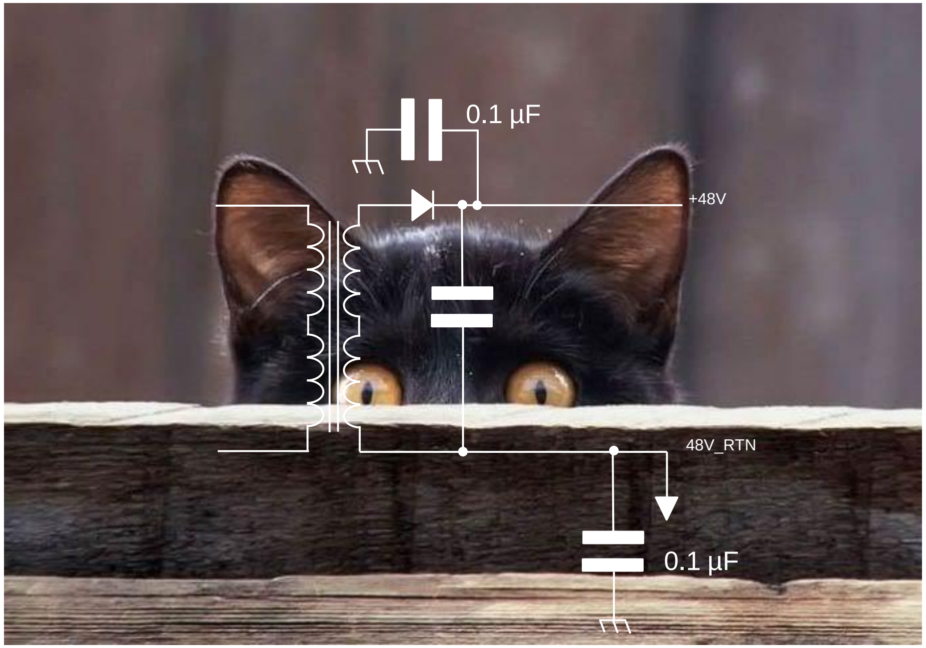
The Enemy of Isolation



- EMC capacitors were being used to help reduce emissions.
  - Indicating a noisy power supply design.
- Capacitors bridging the isolation barrier on the main board.
  - OK for hi-pot but a disaster for impulse surge.
  - Component hidden in the schematics.
- Capacitor connections were camouflaged.
  - Isolated GND was connected to the chassis by the PCB mounting hole.
  - A redesign of the board removed these capacitors.
  - This also caused a change in schematic symbols to also show Earth references.

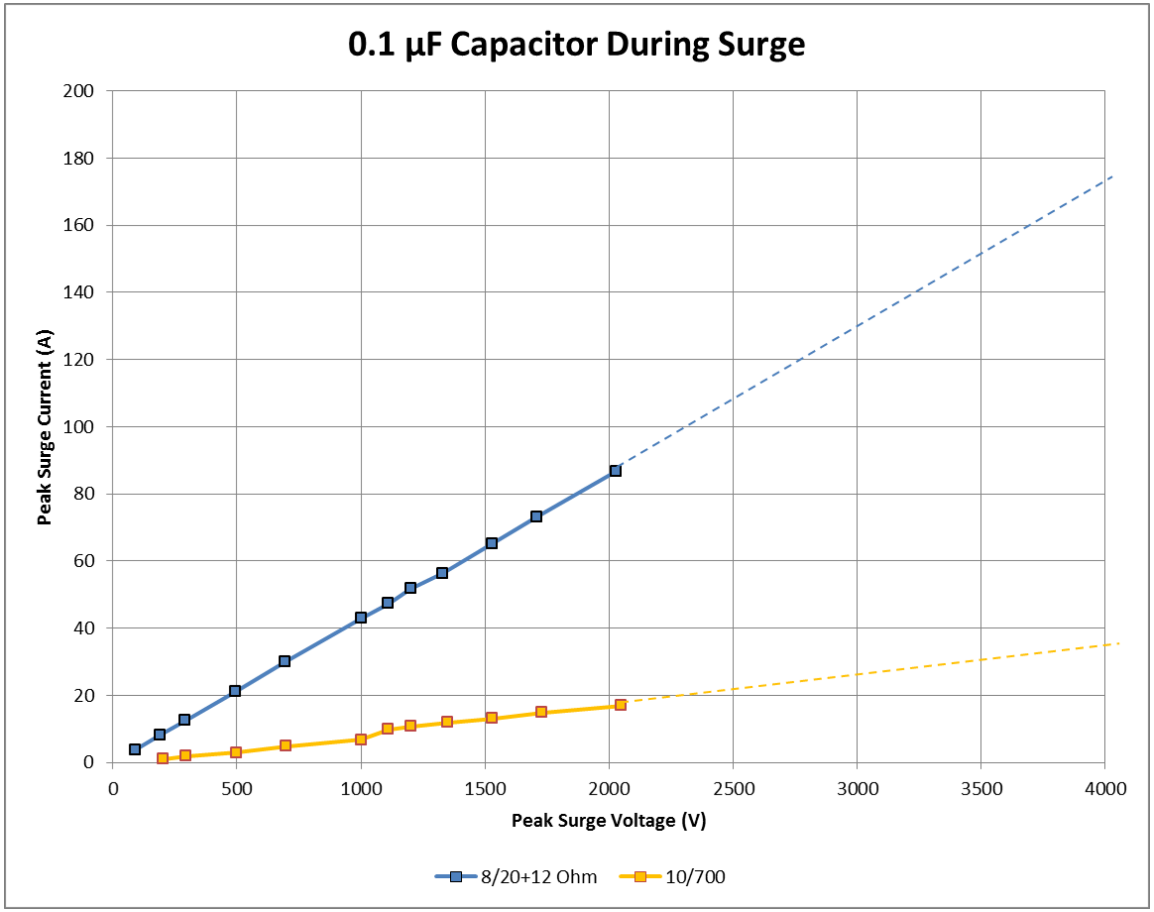
The Enemy of Isolation

- 48 V "Isolated" Power Supply.
  - The PoE board design removed the EMC capacitors, but they were found to also be lurking in the separate AC/DC power supply.
  - A small design modification in the power supply was needed to bring the noise floor back down to meet Class B emissions.



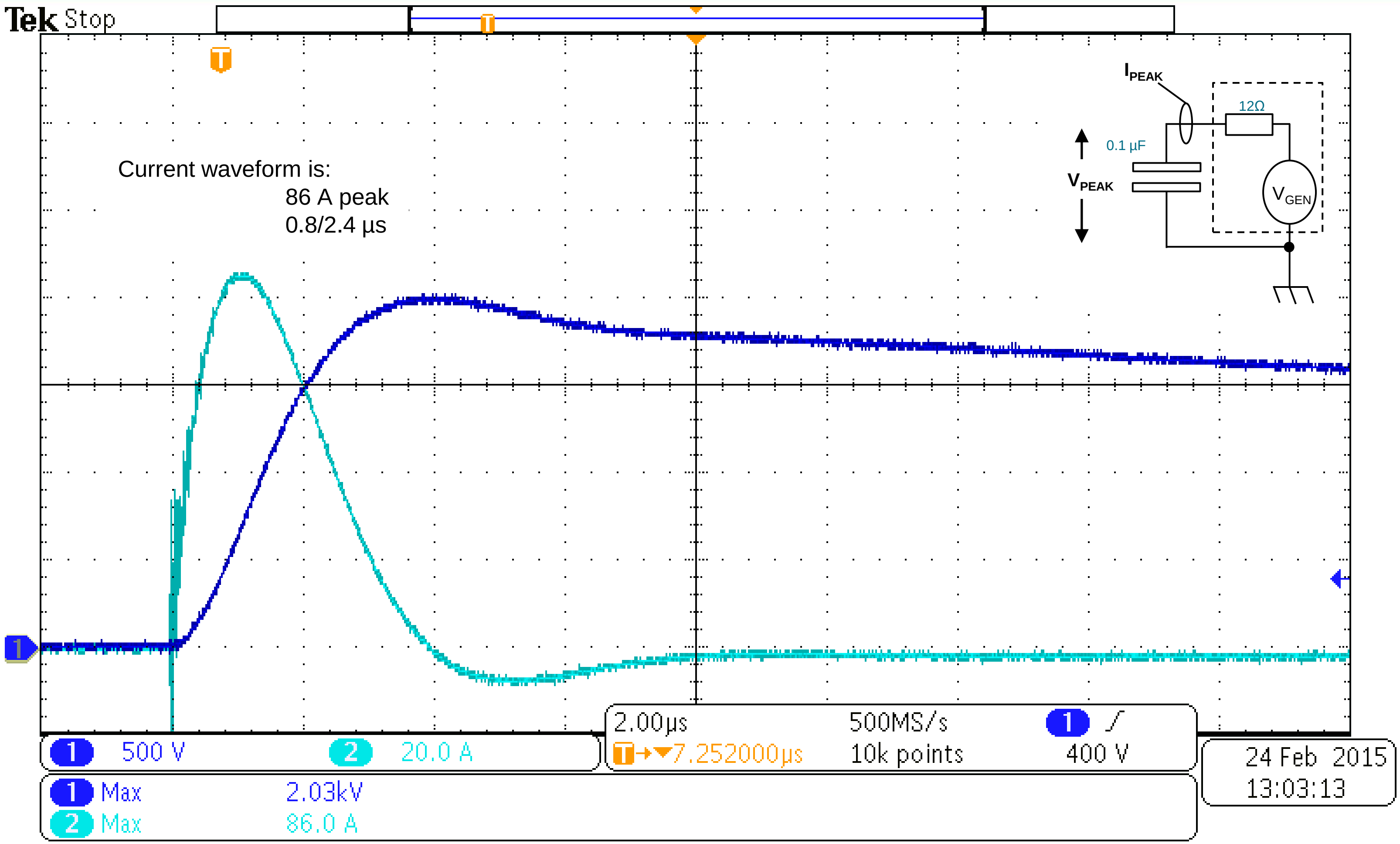
How Bad can one EMC Capacitor Be?

- 0.1 µF capacitor surged tested.

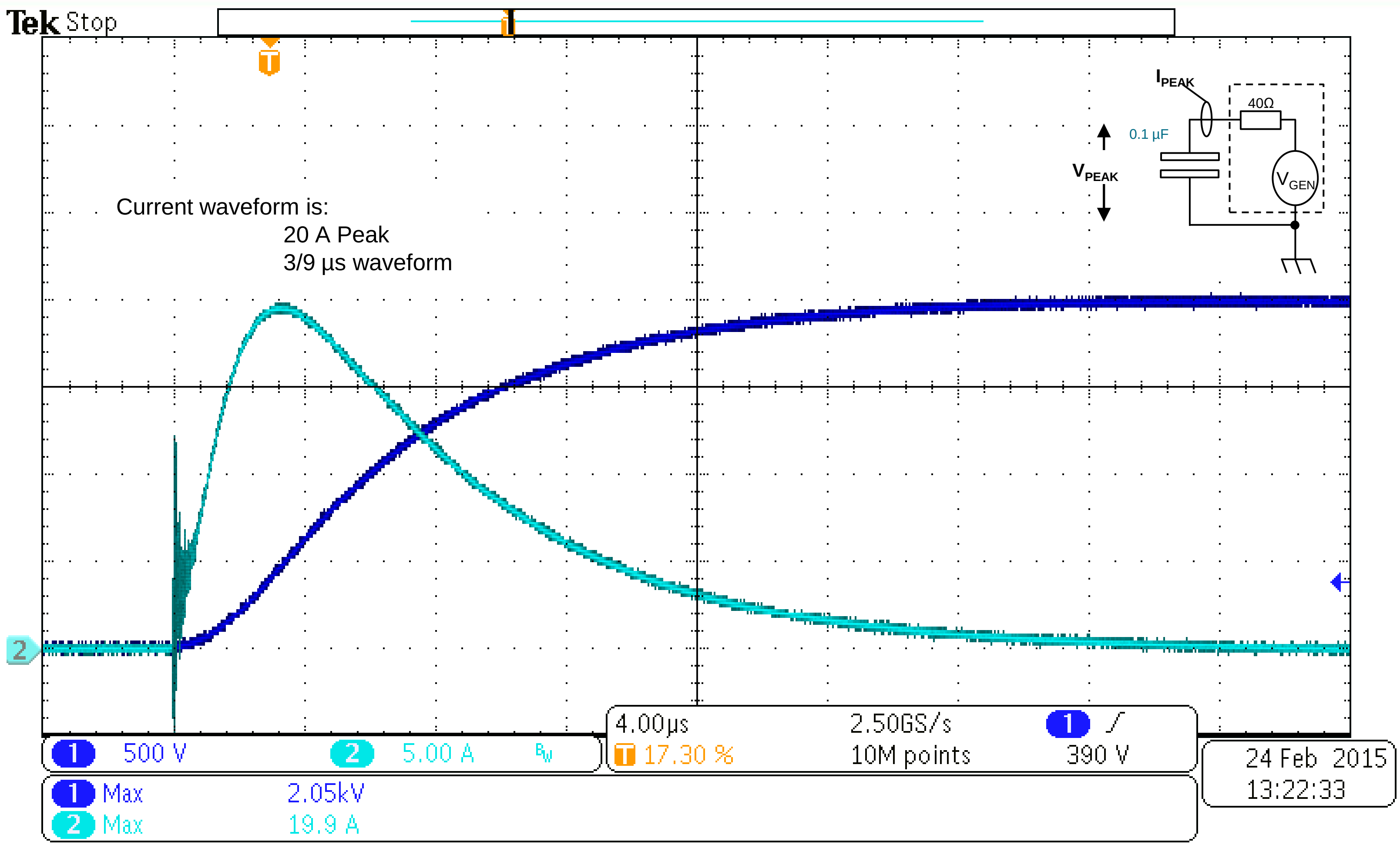


8/20 = 1.2/50-8/20 combination with 12Ω total impedance

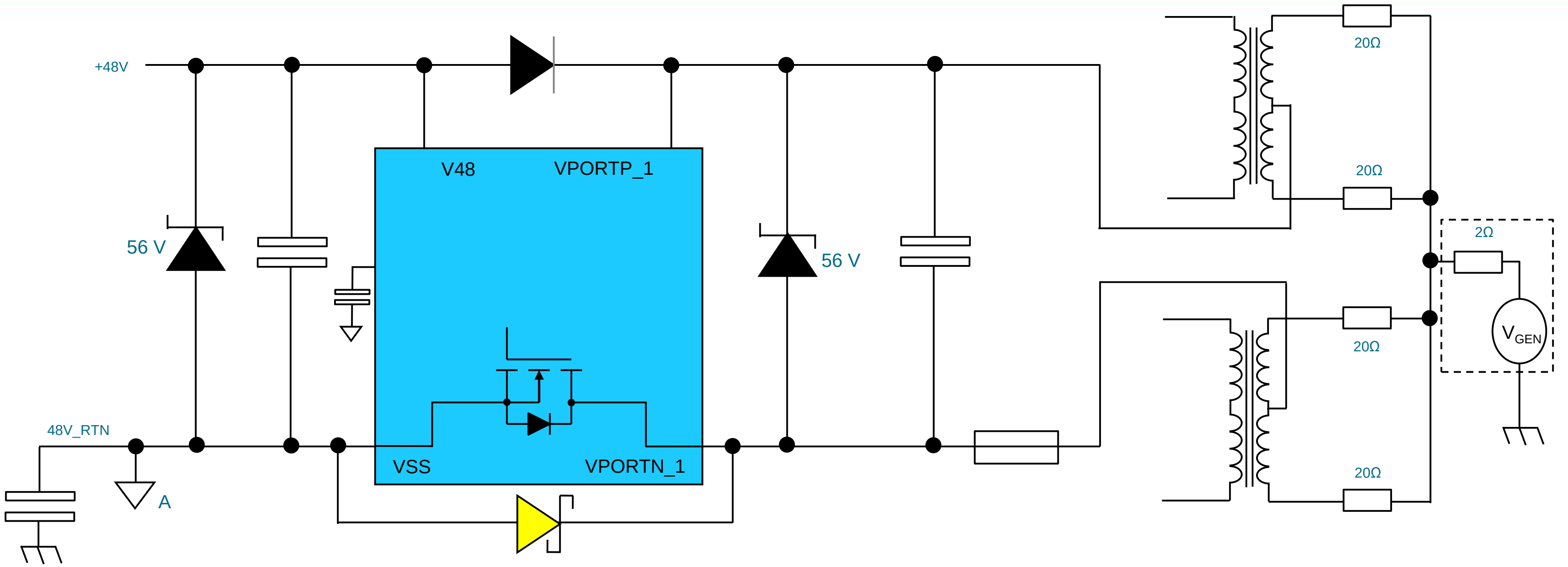
2 kV 1.2/50-8/20 Surge Waveform



2 kV 10/700 Surge Waveform

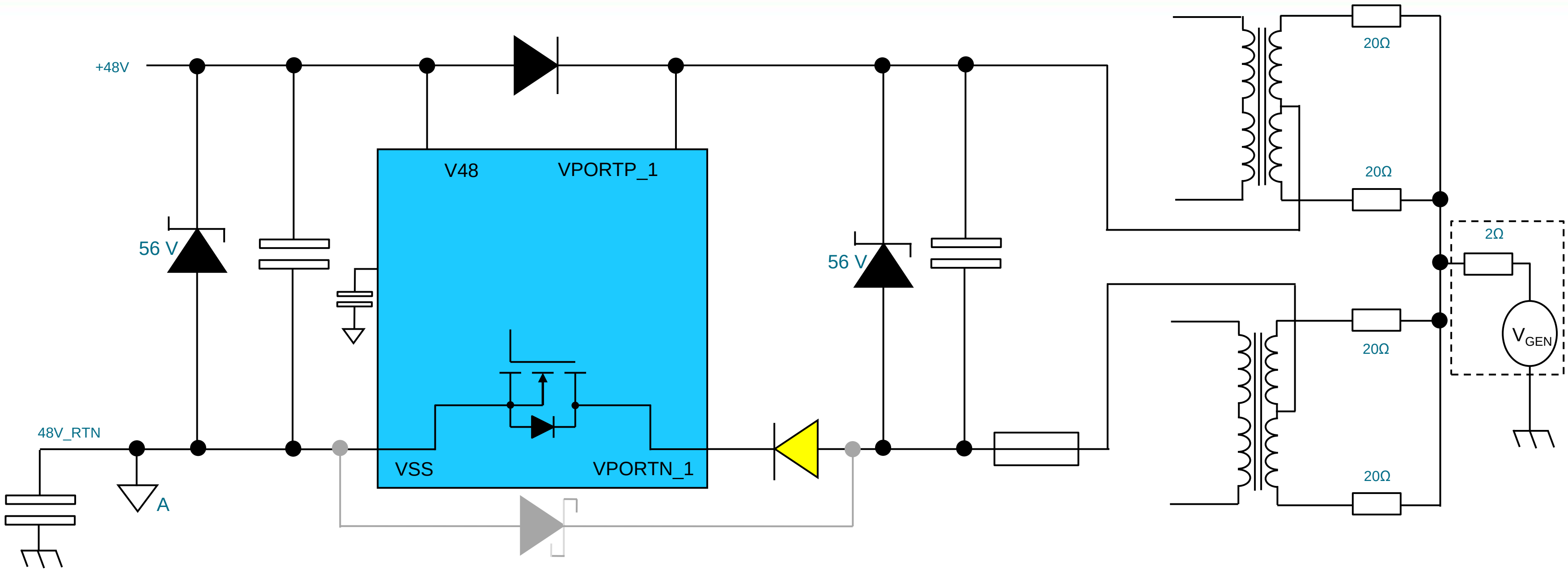


Protecting Against –Ve Surges



- Shunted the FET with a schottky diode and saw improvement in surge withstand.
  - Large diode to get I_F close to intra-building requirements.
  - Problems with leakage current under extended temperatures were seen.
  - Not a fix, but showed to be on the right track.

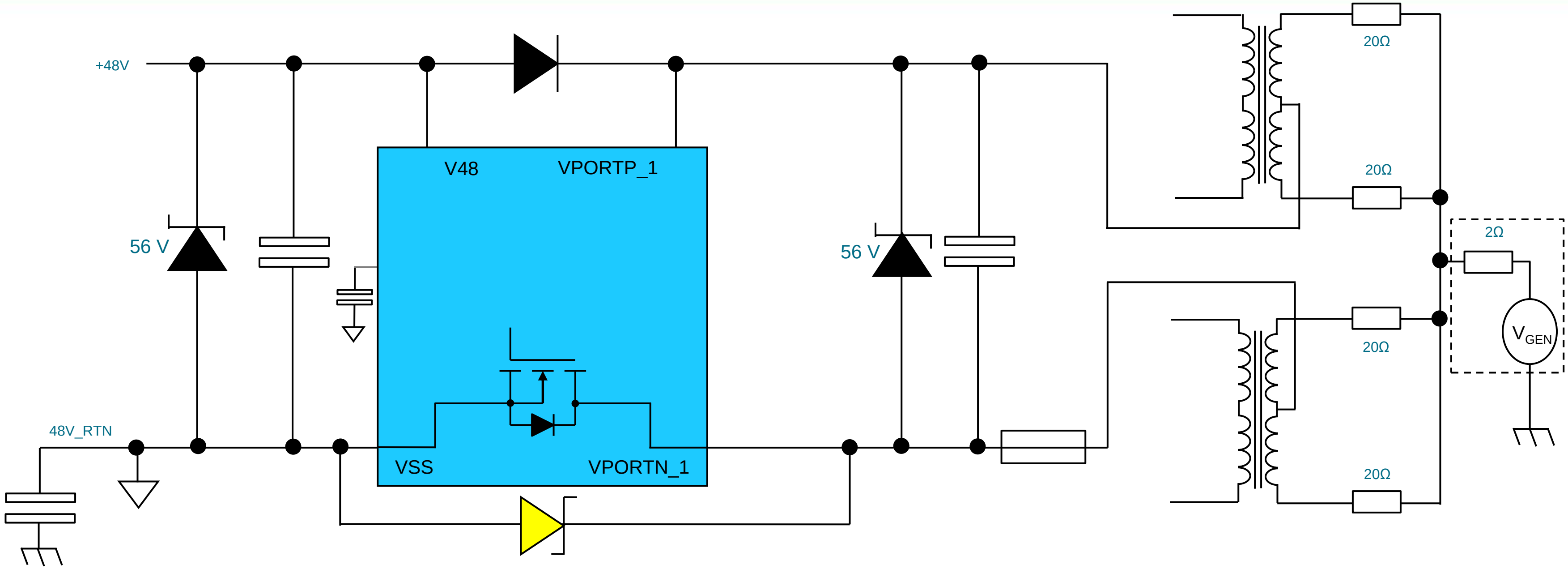
Experiment with –Ve Surges



- Rather than shunting the current around the FET with a schottky diode, blocked the current instead with a diode.
  - Better results with a smaller package and lower cost component.

- The series diode principle was first seen in a 2007 PEG Meeting called “Power over Ethernet (POE), what is it? How to protect it?” By Michael J Maytum.

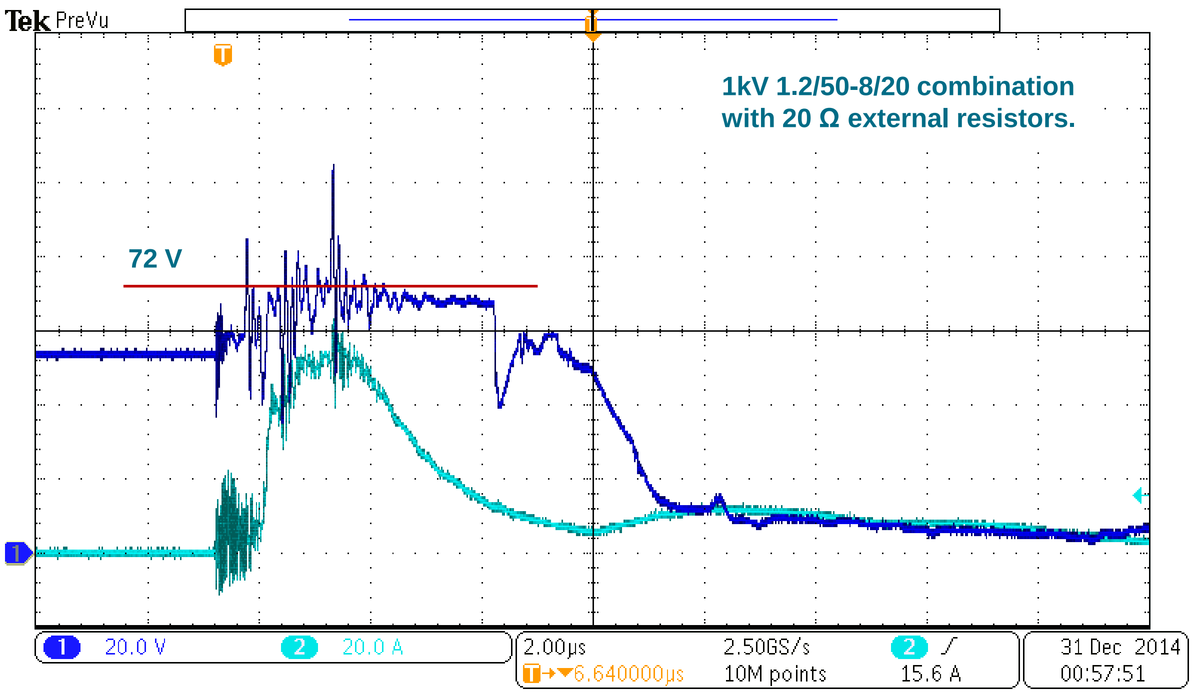
Experiment with +Ve Surges



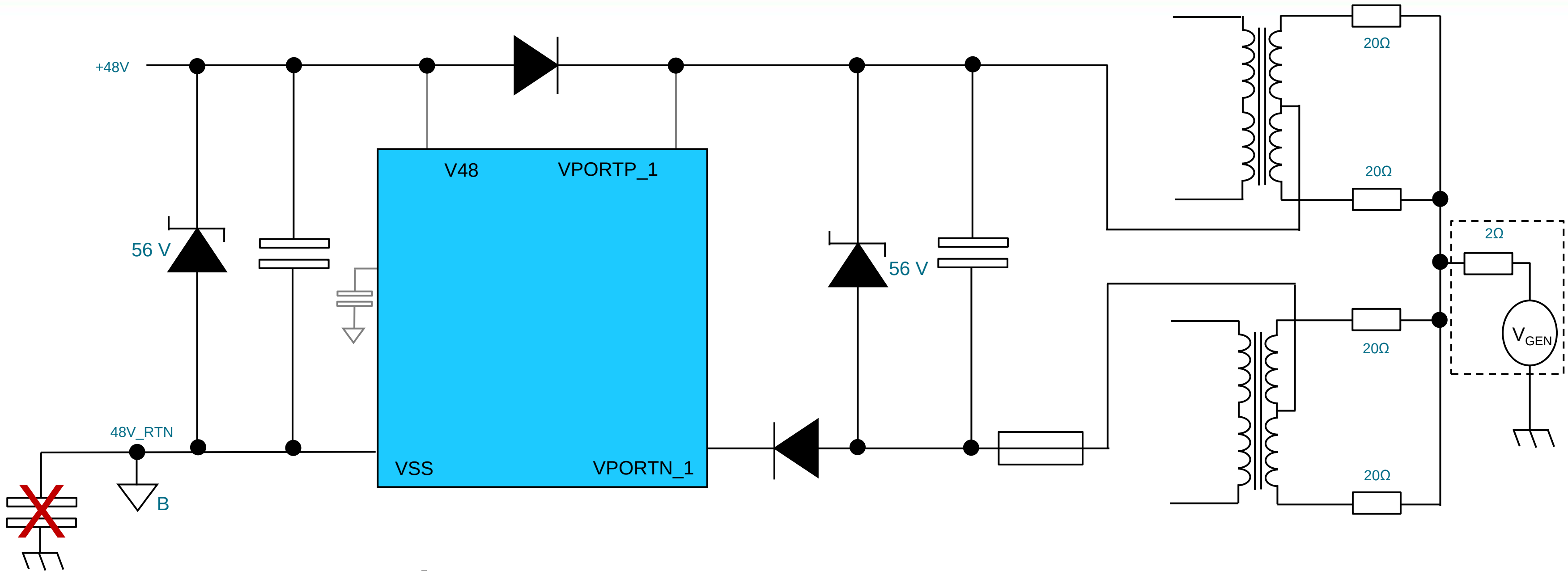
- Shunted the FET with a 56 V uni-directional TVS diode.
  - The switch is turned off when testing and therefore need to limit the voltage below the abs max rating of 72 V.
  - Failed at +1 kV with the FET shorted.

The Failings of the FET Switch

- A 3 kW, 56 V TVS diode was not suitable.
- Also Safe Operating area needs to be considered.
- The 0.1 µF EMC capacitor in the supply has to go!



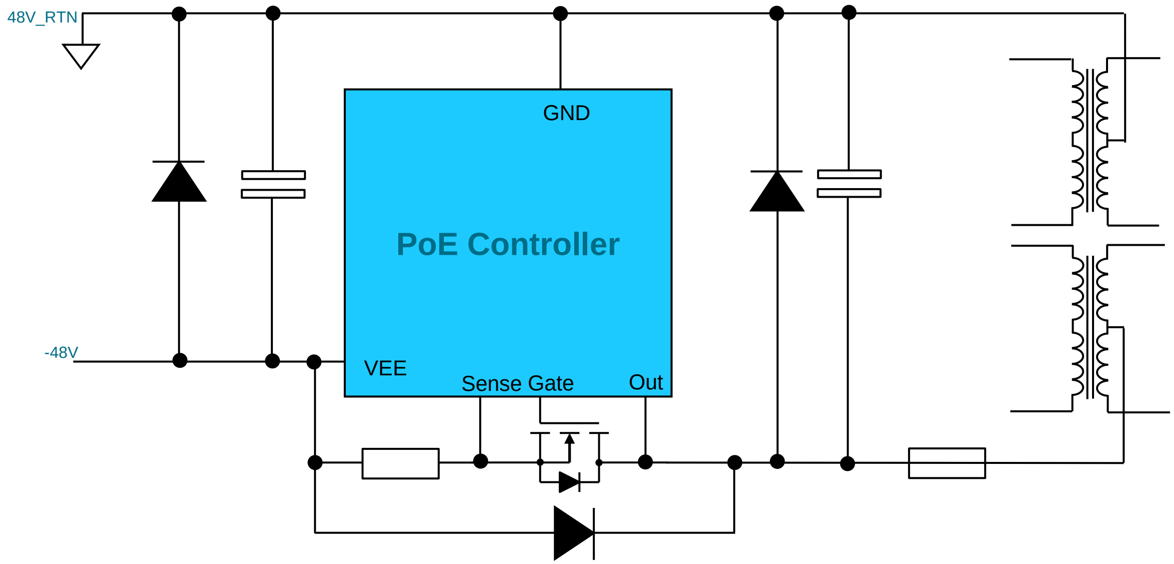
Testing with 0.1 µF Removed



- Test results.
  - Original PoE reference design failed at ±600 V.
  - Revised design passed ±3 kV 1.2/50 longitudinal surge.
    - Passes GR-1089-CORE OSP requirements.
    - The failure point was the power supply and therefore a simple redesign of the power supply would be needed to get the unit to pass 4 kV and above.

PoE Controllers

- Not all PoE Controllers are equal.
  - But there are a lot of similarities that make designing easier.
  - External FET provide better surge protection "tuning".



- Concern is port-port surge withstand on multi-port chipsets. The internal isolation between ports may not be up to scratch and should be investigated further.

PoE Protector and Injector Dongle

- Knowledge from the PSE design was used in the PoE protector module.
  - Can be powered from PoE+ switch or external AC/DC power supply (supplied).
- PoE Protector/Injector goes between the PSE and OSP cable:-
  - **Provides 5 kV DC of ISOLATION** between input and output **jacks**.
  - Passes GR-1089 Port type 1,2,3,5, 3a/5a, 3b/5b, 4, 4a.
    - Includes ±6 kV L-N-E tests on the AC/DC wall-wart.
  - Passes ITU-T K.21 OSP that includes:-
    - Longitudinal surge withstand of ±6 kV 10/700 without a GDT,
    - Metallic Ethernet/PoE surge withstand of ± 4 kV 10/700 without a GDT,
    - ± 4 kV 10/700 Metallic/Longitudinal withstand with a 350 V GDT,
    - 600 Vrms, 1 A, 0.2s first level.
  - **Passes ±6kV 1.2/50-8/20 ISOLATION withstand**.
  - No EARTH connection required.
  - Can use GDT/Primary protection on the front of the module.

Summary

Before you disappear for lunch:-

- **Standards need to address PoE as its own port type.**
- **Need to have tests that are pertinent to PoE OSP deployment.**
- **Write sensible requirements based on field data.**
- **Engineering also needs to use common sense during these "dark times" until the standards get smarter.**
    - **The ultimate goal is to ensure field reliability.**

QUESTIONS

In loving memory of Braveheart who was my best friend, the perfect male to Sharon, mentor to Zoe and guardian to Jasmine