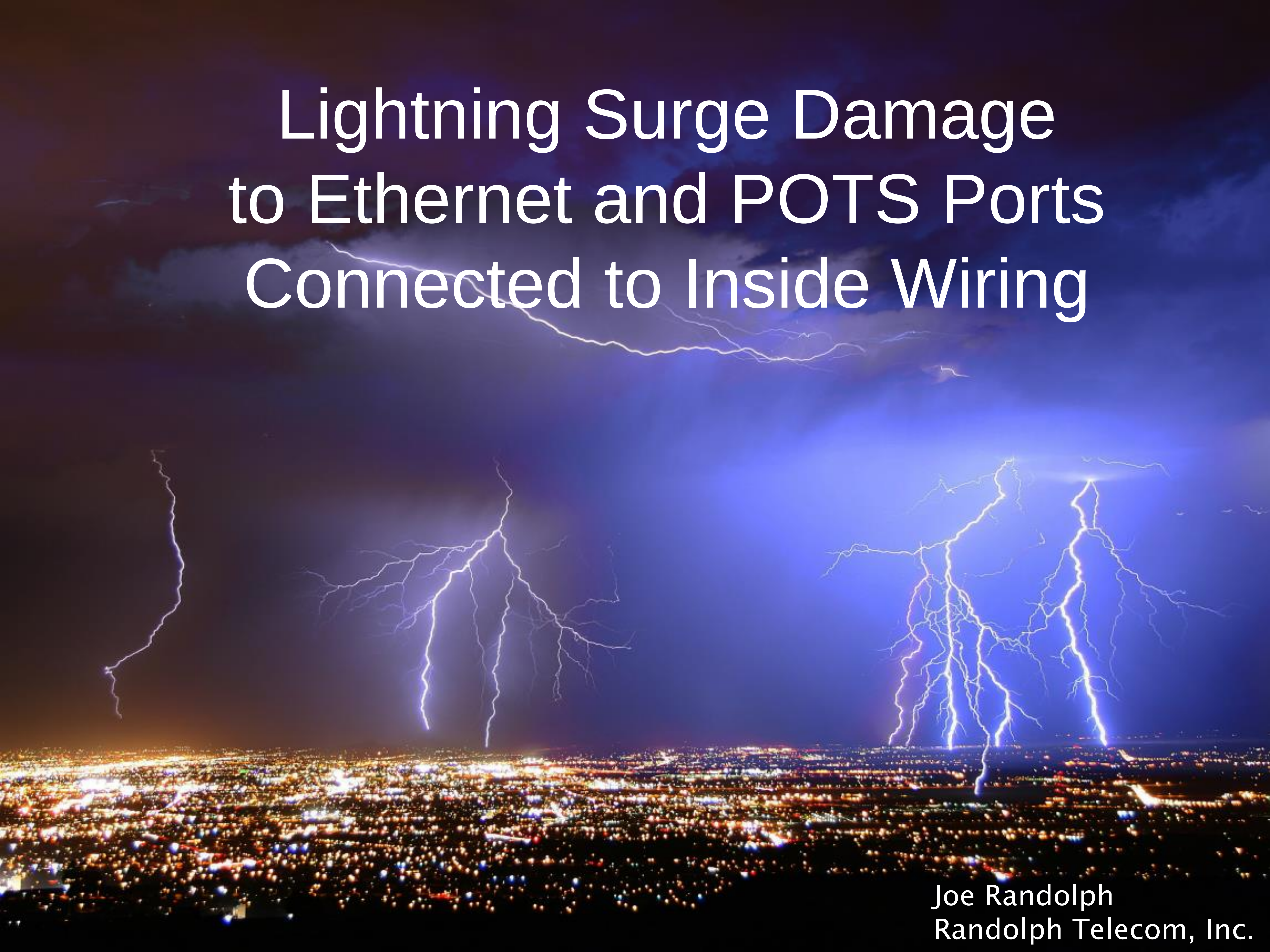


# Lightning Surge Damage to Ethernet and POTS Ports Connected to Inside Wiring

Joe Randolph
Randolph Telecom, Inc.

# Mystery to Solve

How are lightning surges getting onto inside wiring for Ethernet and POTS ports?

# Other Contributors From PEG

- Jim Wiese
- Mick Maytum
- Al Martin

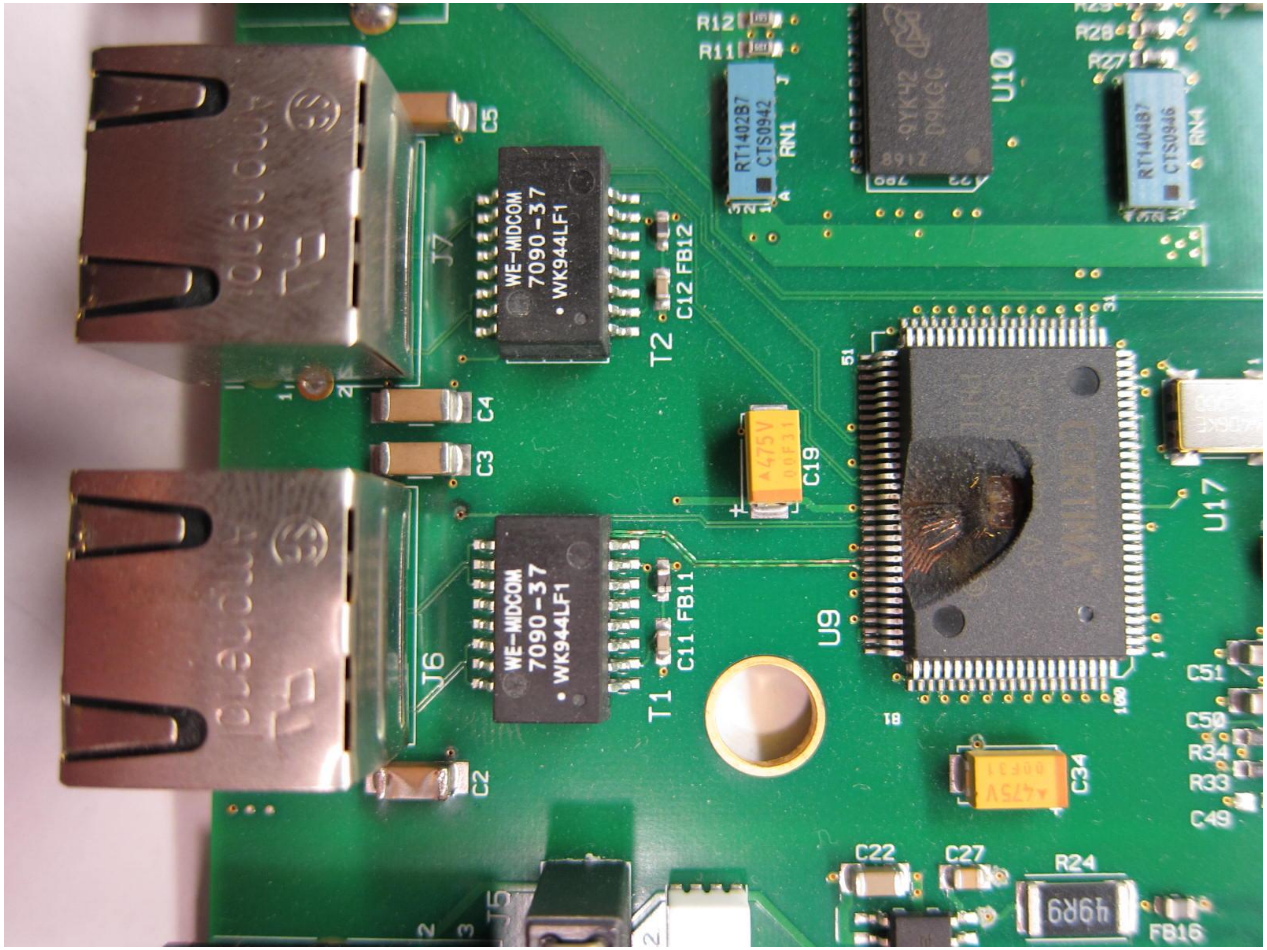
Note:

All four of us also serve on the IEEE PSES Telecom Advisory Committee

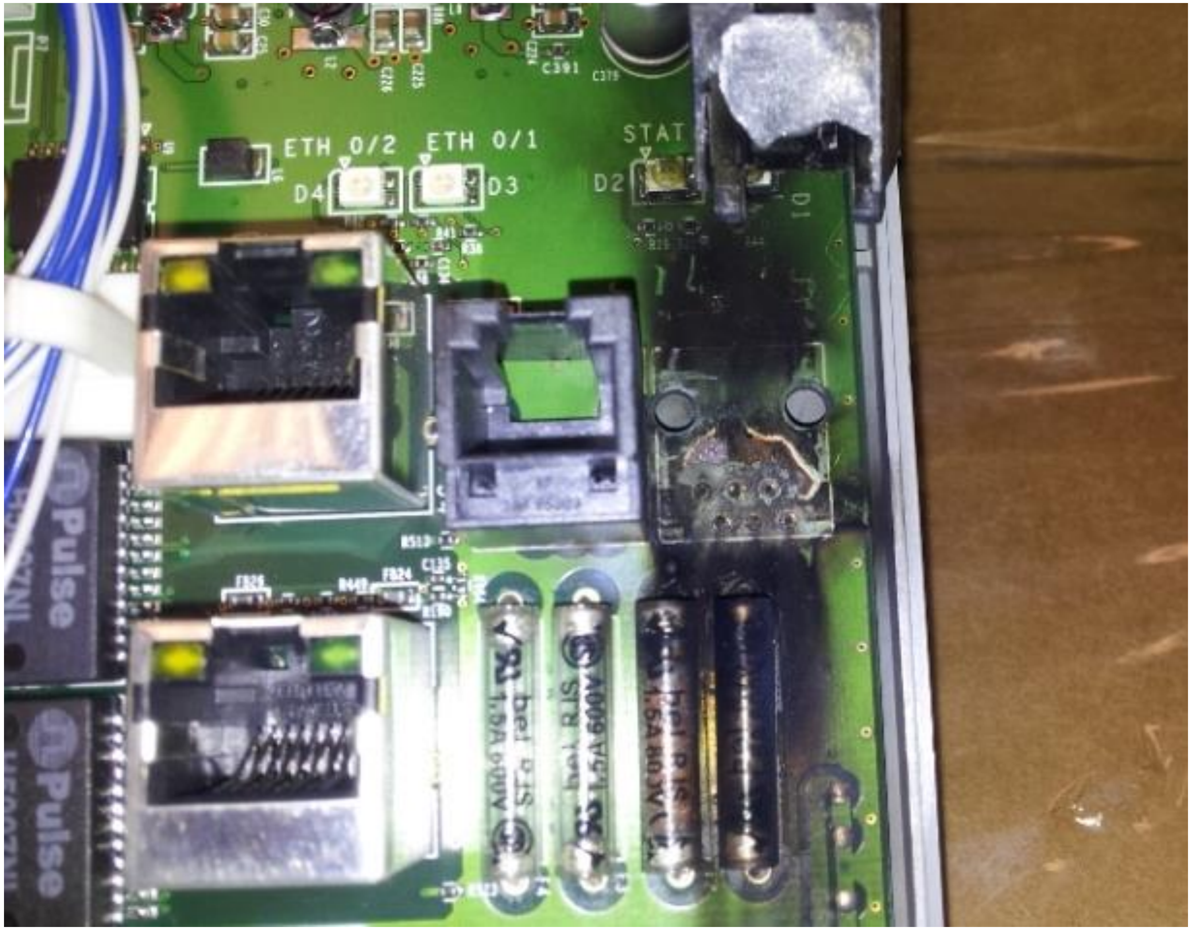
# This Presentation

- Document and analyze known mechanisms
- Document and analyze new theories
- Test the new theories
- Draw some conclusions
- Offer interim design guidelines

# Visual Damage to Ethernet Port



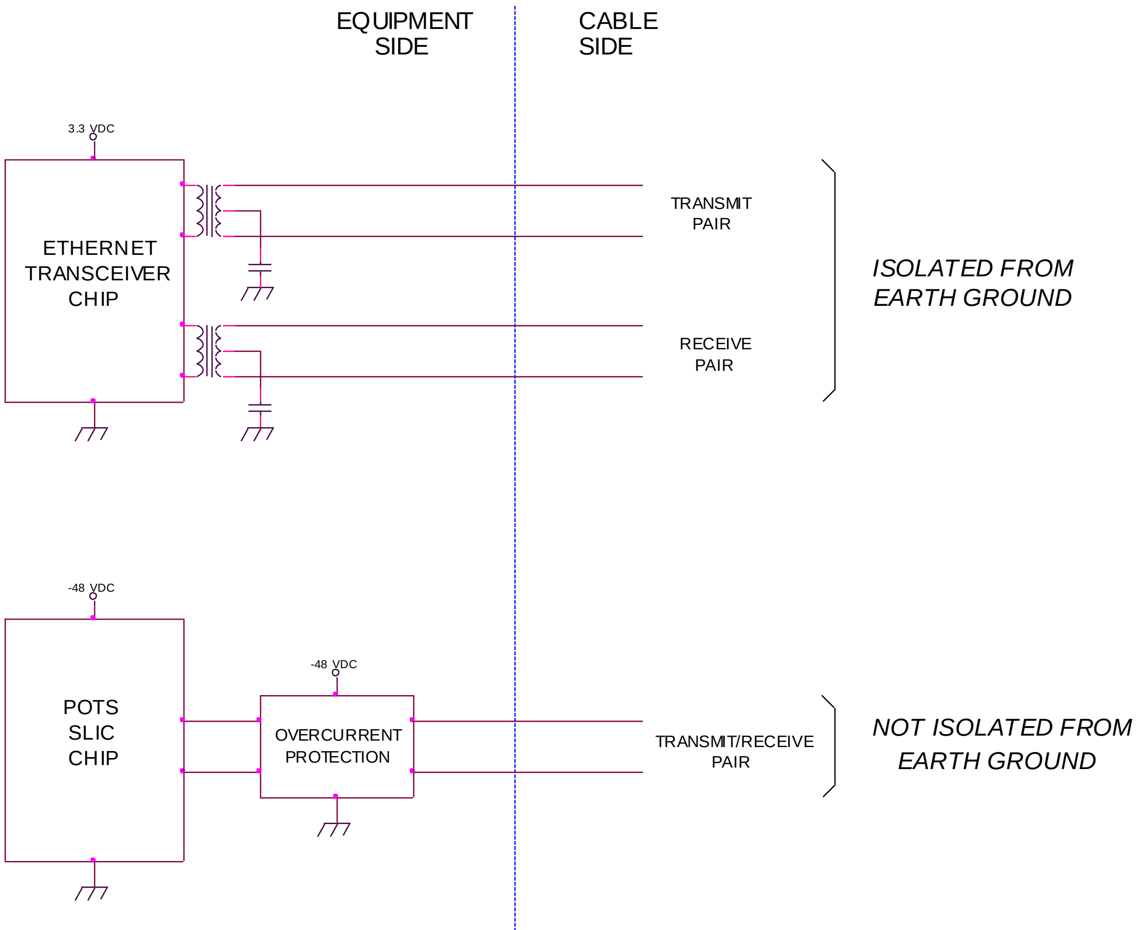
# Visual Damage to POTS port



# Who's Looking at This Problem?

- PEG (of course!)
- IEEE PSES Telecom Advisory Committee
- ITU (K.44, K21, K.22 standards)
- Telcordia (GR-1089 NEBS standard)
- ATIS (draft Ethernet protection standard)
- USA vendor:  Adtran
- Japanese vendor:  NTT

# Surge Susceptibility: Ethernet vs. POTS



# Key Difference

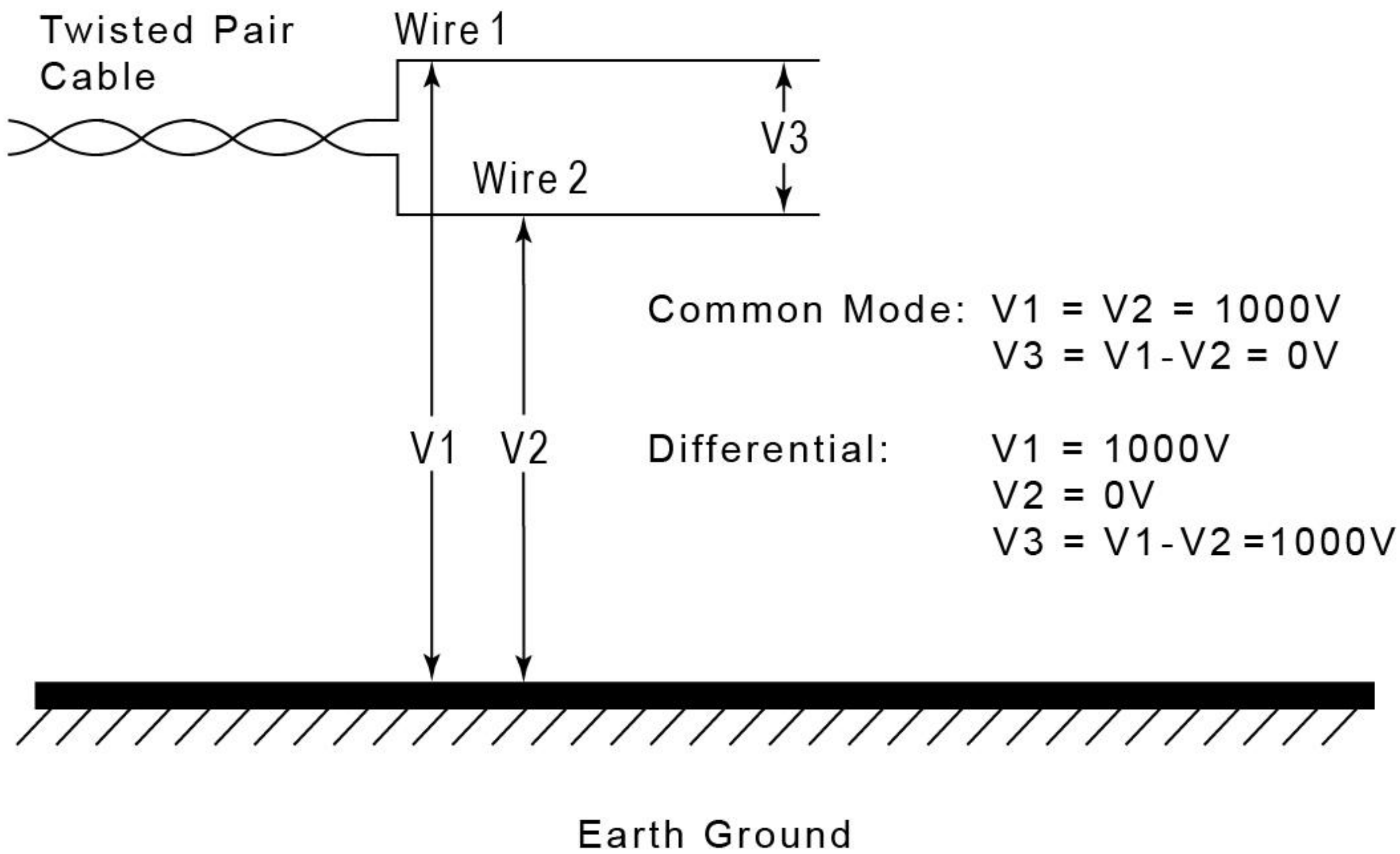
For common mode surges:

- Ethernet ports fail when subjected to *over-voltage*
- POTS ports fail when subjected to *over-current*

# Observed Failures

- Ethernet ports show evidence of surges exceeding 2 kV
- POTS ports show evidence of surges exceeding 100 amps (for a 2/10 uS surge)

# Common-Mode vs. Differential Surges



# Common-Mode vs. Differential

- Present discussion will focus on common mode surges
- Differential surges will be discussed later

# Conventional Wisdom

"Cables routed entirely within a building are inherently protected from lightning."

➔ *Protection engineers have always known that this is not quite true, but high energy coupling was believed to be statistically rare.*

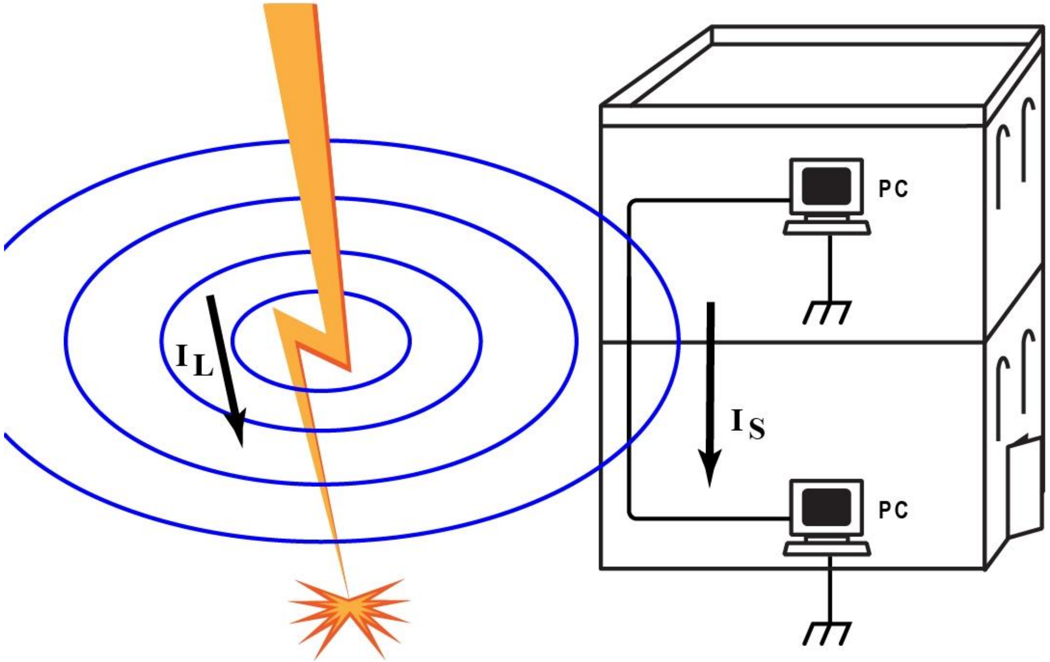
# Known Coupling Mechanisms

1) Far-field coupling from the actual lightning channel

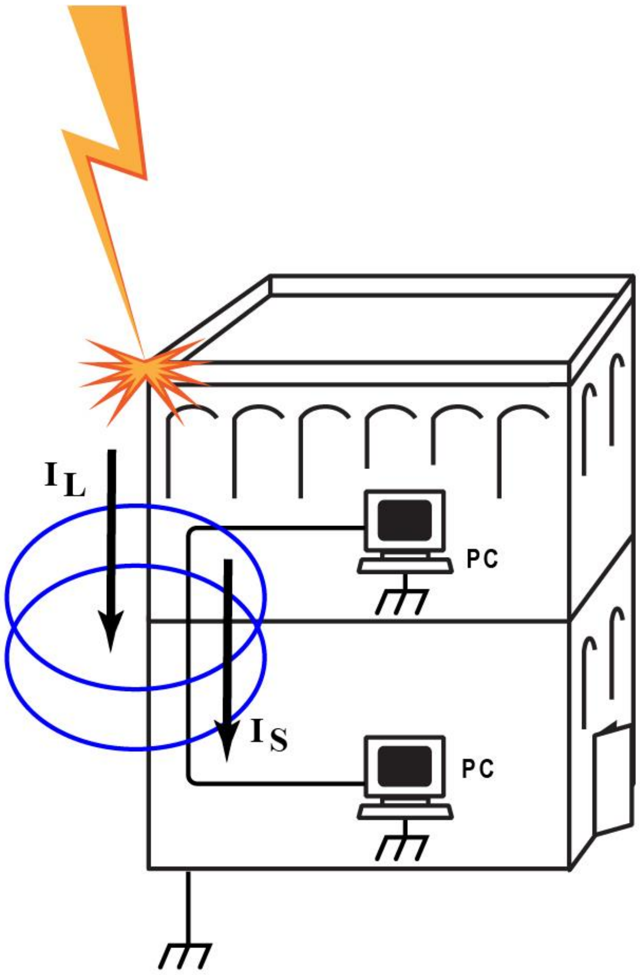
2) Down-conductor coupling from direct strike to building

3) Ground potential rise (GPR)

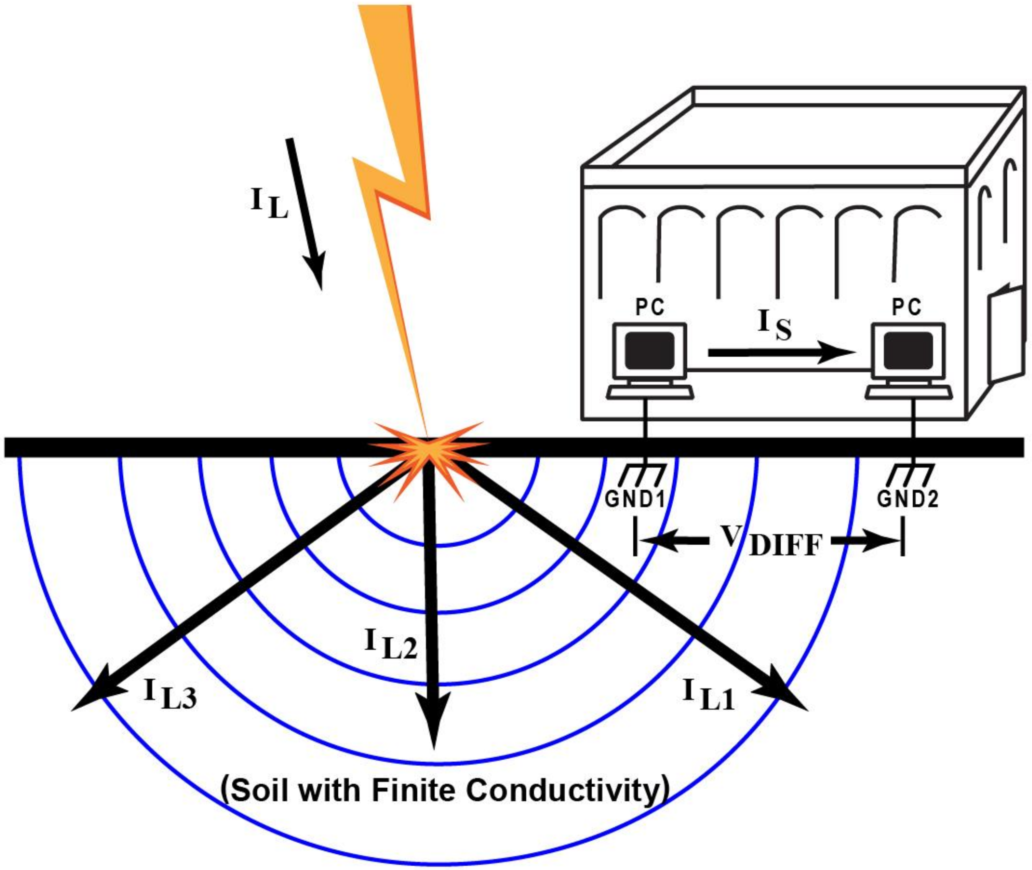
# Mechanism 1:  Far-Field Coupling



# Mechanism 2:  Down-Conductor Coupling



# Mechanism 3:  Ground Potential Rise (GPR)



# Limitations of Conventional Mechanisms

Mechanism 1: Develops only a few hundred volts

Mechanism 2: Requires direct strike to building

Mechanism 3: Requires direct strike to ground within 100 meters
Also requires two different ground references

➔ *Conventional mechanisms seem insufficient to explain the high incidence of surge damage*

# Other Possible Coupling Mechanisms?

If we could identify the surge coupling mechanisms, we could do a better job of defining what we need to protect against:

- Open-circuit voltage ?
- Short-circuit current ?
- Waveform ?
- Common mode vs. differential ?

# New Theories

*Note: All three theories assume coupling of surges that originate on the AC mains*

Theory 1: Catastrophic breakdown

Theory 2: Capacitive coupling

Theory 3: Interaction with multi-port surge protectors

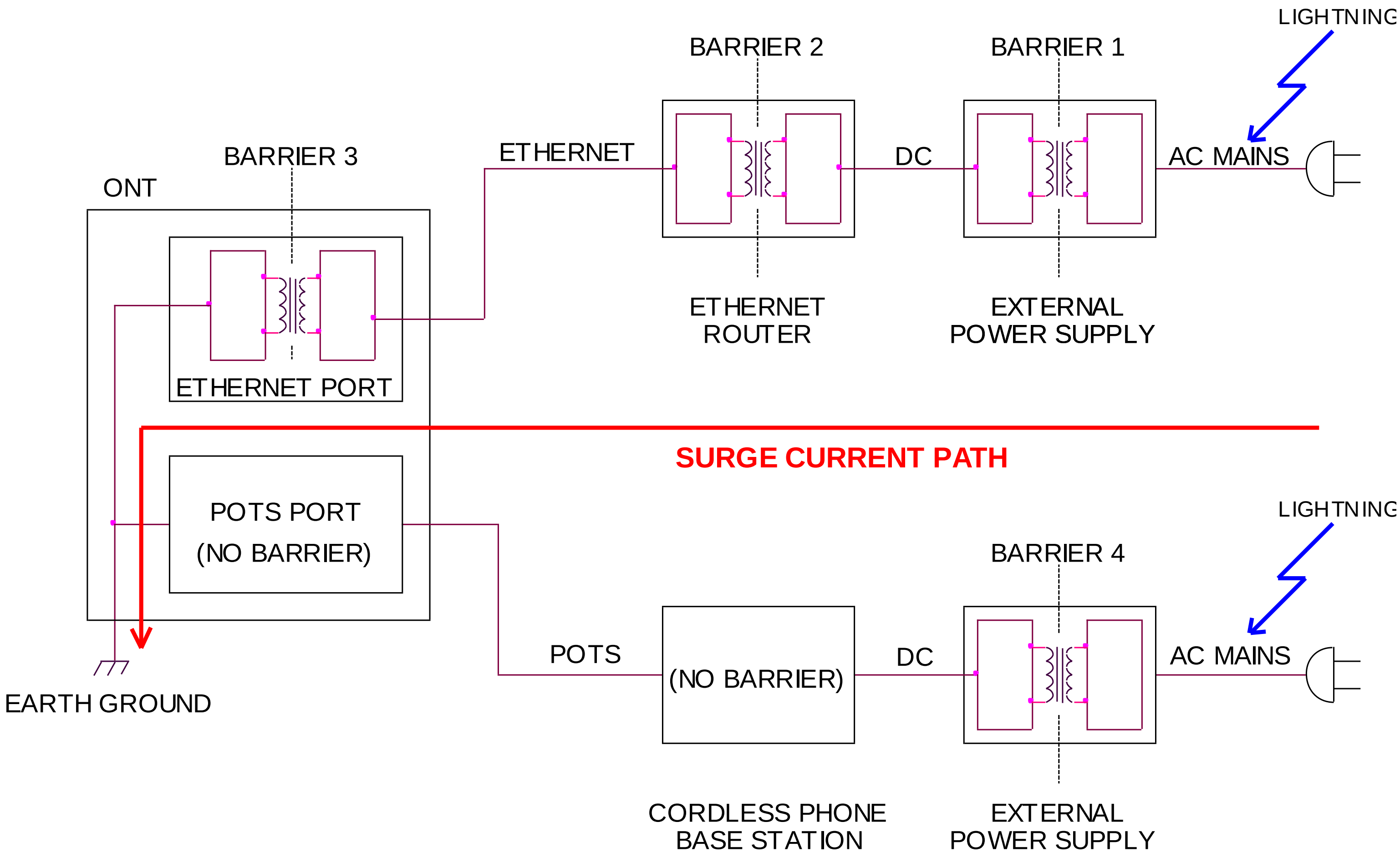
# Surges on the AC Mains

IEEE C.62.41.2

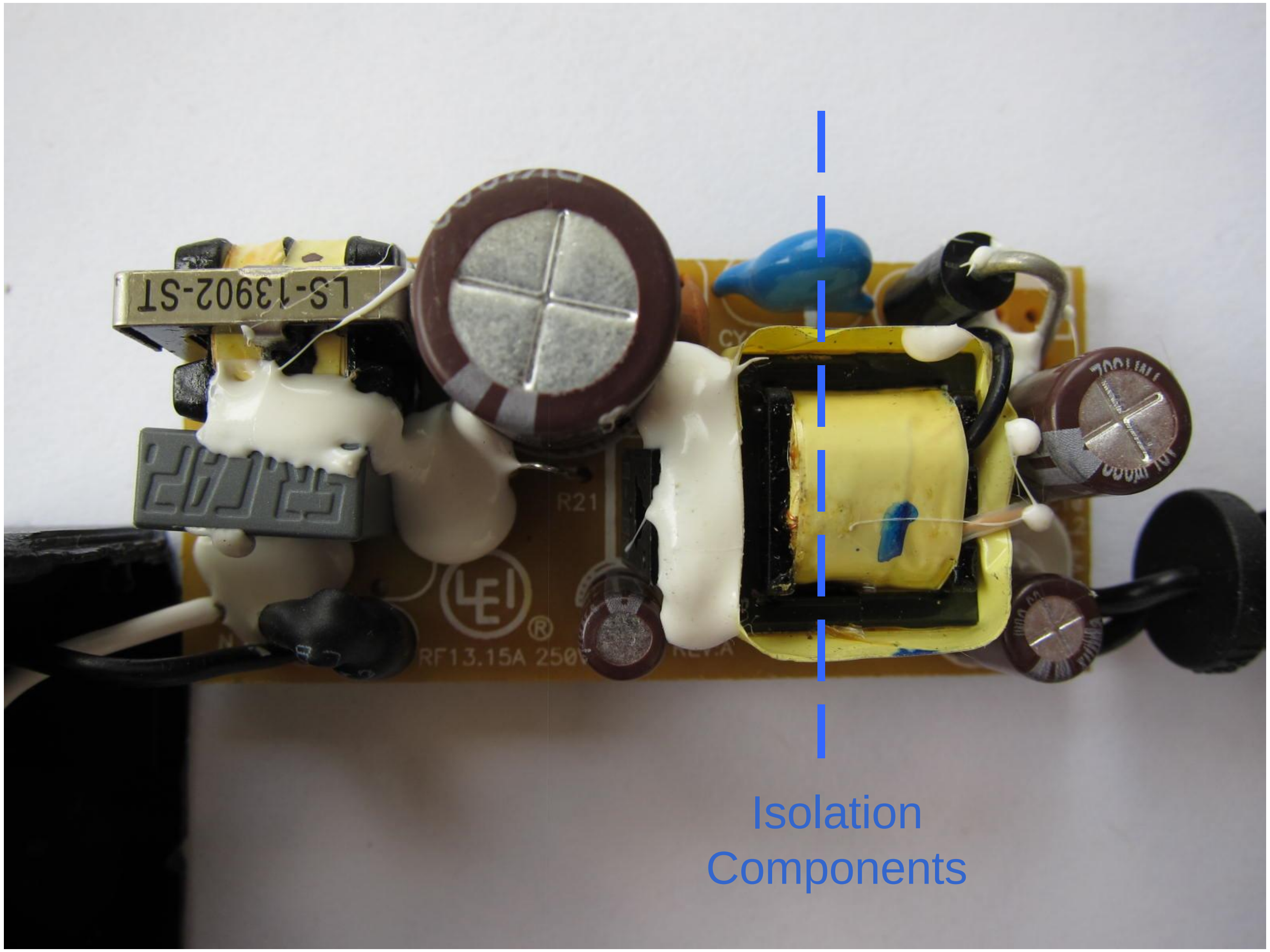
*"Recommended Practice on Characterization of Surges in Low Voltage (1000V and Less) AC Power Circuits"*

➔ Surges in the range of 6 kV to 10 kV are possible, but infrequent, on AC mains outlets inside buildings

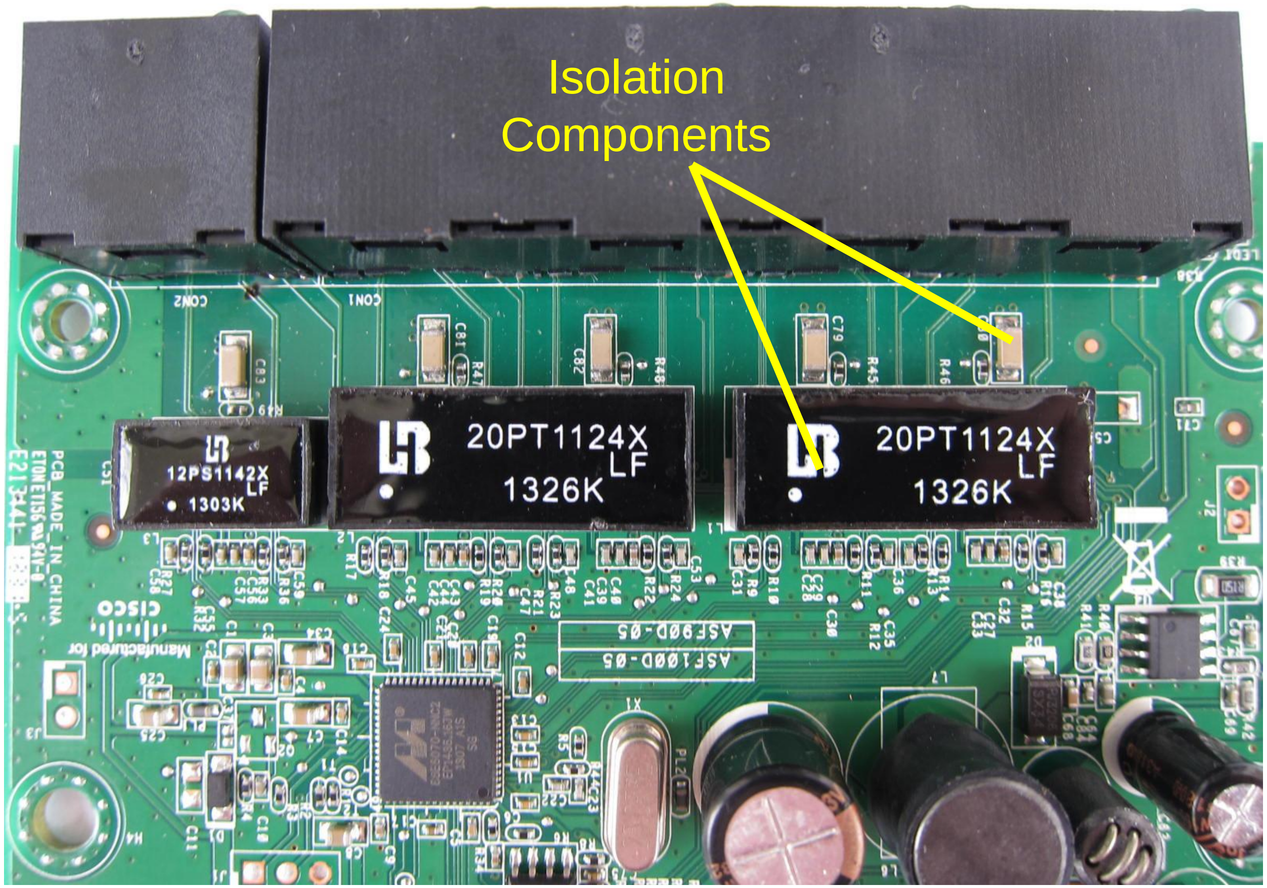
# Theory 1
## Catastrophic Breakdown Through AC Mains



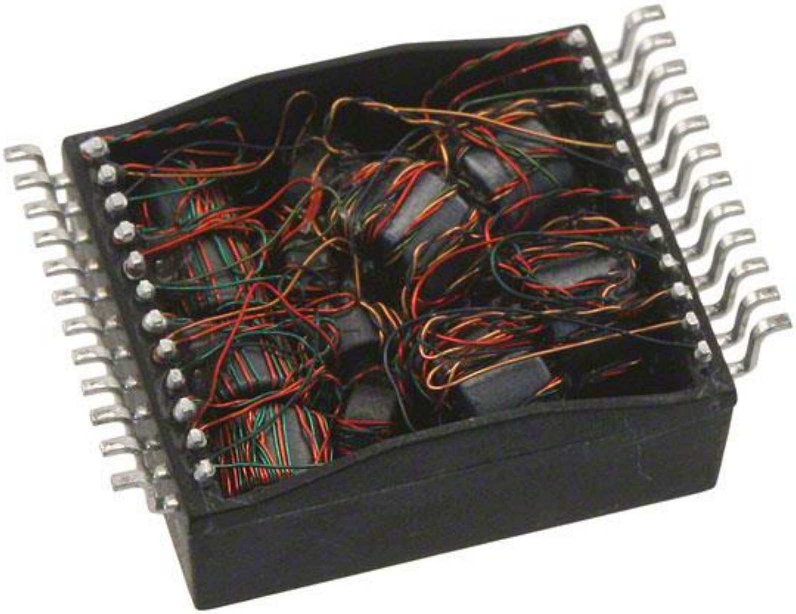
# Typical AC Wall Supply



# Typical Ethernet Port



# Typical Ethernet Transformer



# Measured Failure Thresholds of Ethernet Transformers

| Ethernet Transformer | Breakdown | Notes |
|---|---|---|
| Wurth 7090-37 | 8 kV | |
| Wurth 7090-37 | 7 kV | |
| Falco LV2001 | 10 kV | |
| Pulse H1164 | Over 10 kV | |
| Halo TG110-RP26NY | Over 10 kV | |
| Pulse T1144 | 9 kV | |
| Pulse H1102 | 8 kV | |
| Pulse H2009 | 10 kV | |
| Pulse H5007NL | 5 kV | Second sample was 9 kV |

# Measured Failure Thresholds of Ethernet Devices

| Product Description | Breakdown AC to DC-In | Breakdown DC-In to Ethernet | Total Breakdown | Notes |
|---|---|---|---|---|
| Cisco SF-100D-05 5-port switch | Over 10 kV | 6 kV | Over 16 kV | Enet Layout spacing |
| Zyxel GS-105B 5-port switch | Over 10 kV | 8 kV | Over 18 kV | Enet Jack shield |
| Netgear FS105 switch | 10 kV | 4 kV | 14 kV | Enet Smith cap |
| Linksys SE1500 5-port switch | 8 kV | 4 kV | 12 kV | Enet Smith cap |
| TP-Link TL-SG1008D 8-port gigabit switch | Over 10 kV | 7 kV | Over 17 kV | Enet Layout spacing |
| Trendnet TW100-S4W1CA router | 10 kV | 4 kV | 14 kV | Enet Smith cap |
| Networking Products POE100 POE injector | Over 10 kV | N/A | Over 10 kV | Integrated power supply |
| TP-Link TL-POE150S POE injector | 9 kV | 4 kV | 13 kV | Enet Smith cap |
| Linksys BEFSX41 broadband router | Over 10 kV | 2 kV | Over 12 kV | Enet Jack shield |

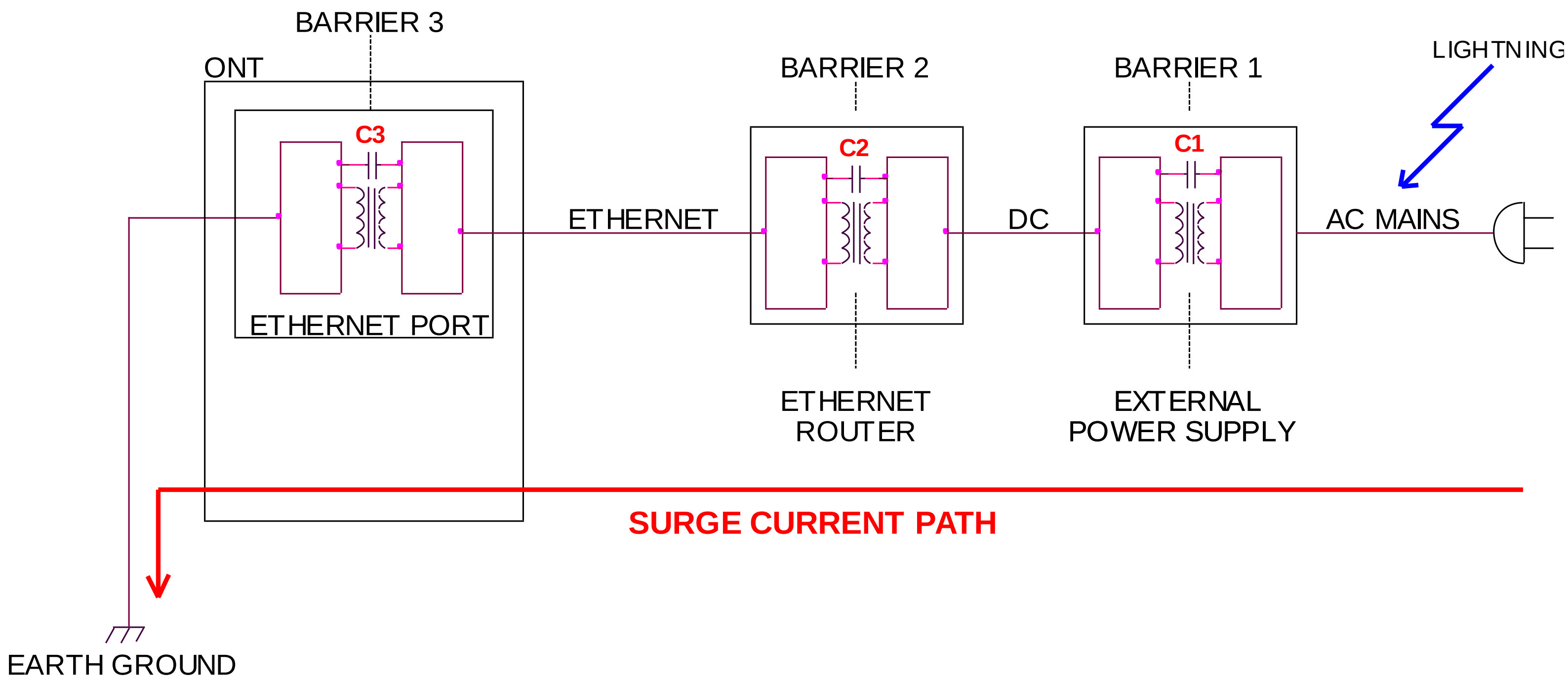
# Measured Failure Thresholds of Cordless Phones

| Product Description | Breakdown, AC to POTS | Notes |
|---|---|---|
| PanasonicKX-TGA542M cordless phone | Over 10 kV | Linear wall supply |
| GE 28512AE1 cordless phone | Over 10 kV | Switching wall supply |
| Vtech CS114 cordless phone | 10 kV | Linear wall supply |

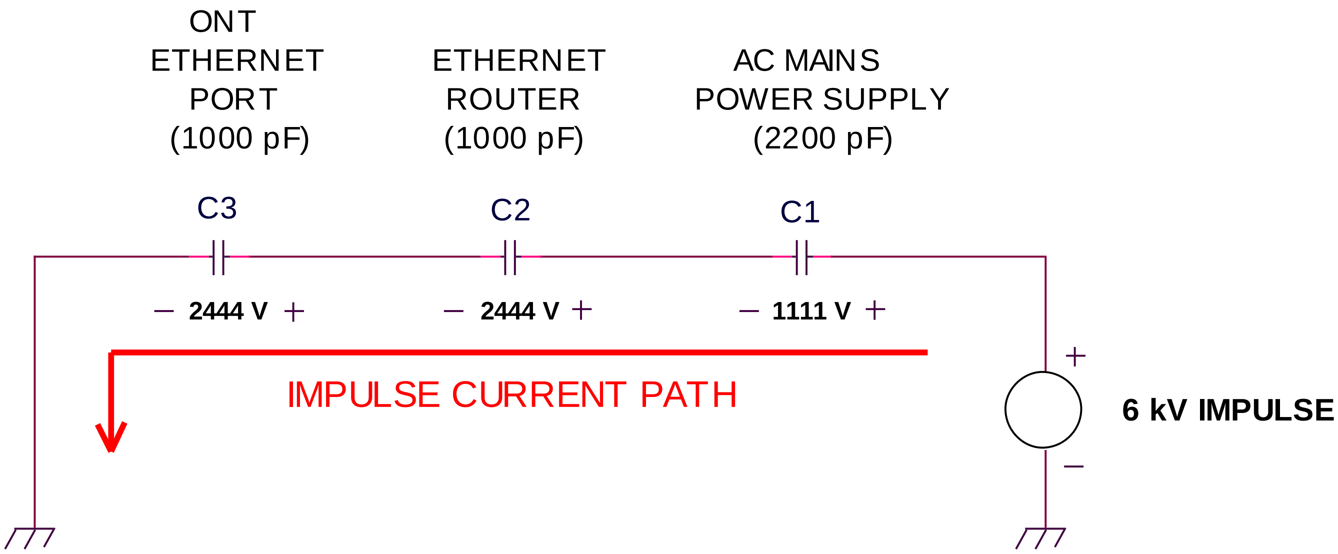
# Observations About Theory 1

- Typical surge tolerance for Theory 1 catastrophic breakdown:
  - 14 kV for path through Ethernet router
  - 10 kV for path through cordless phone
- Specific combinations may be far less
- But, statistically, this does not seem like a promising theory

# Theory 2
## Capacitive Coupling From AC Mains



# Circuit Model for Theory 2



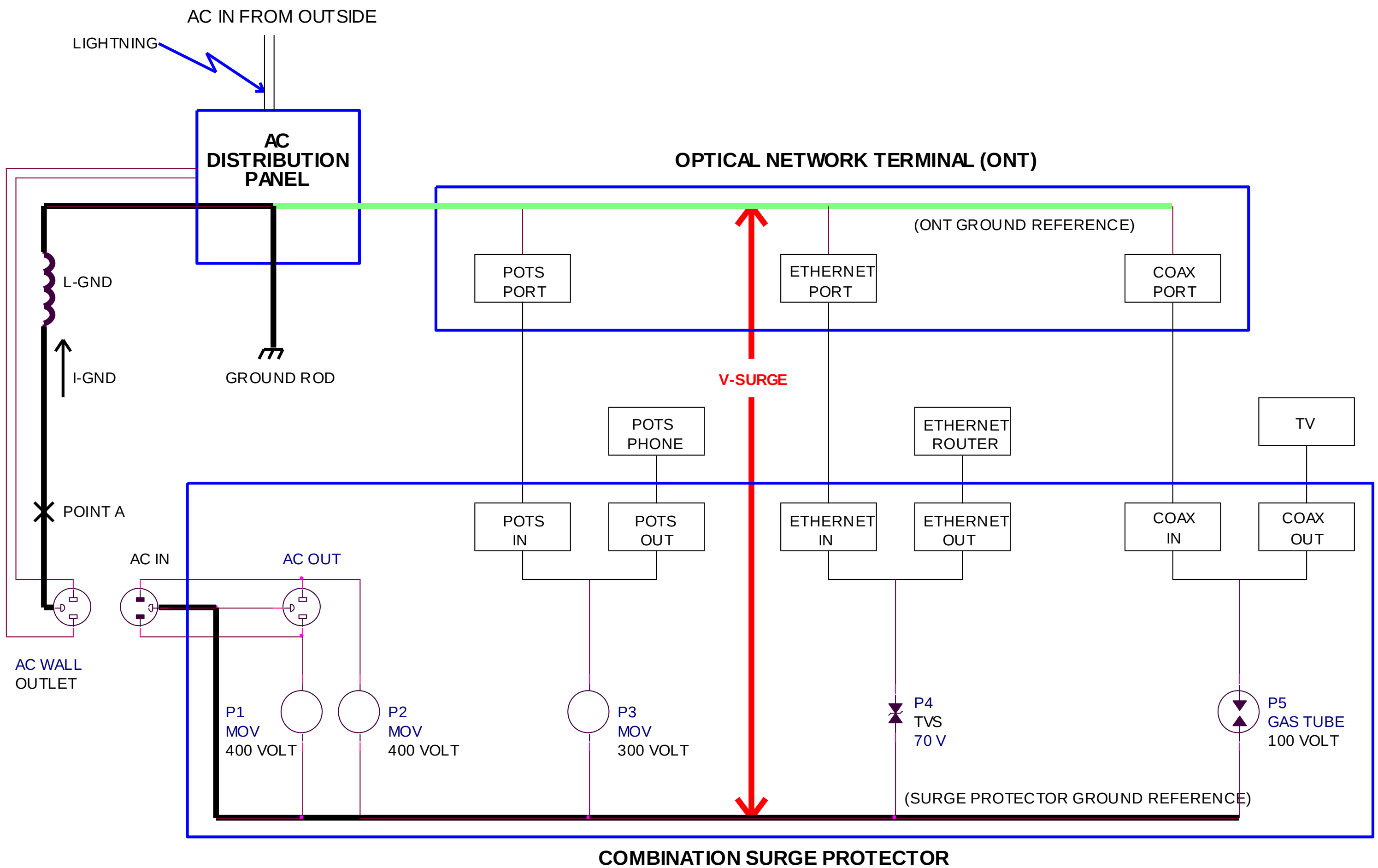
# Observations About Theory 2

- Seems promising for explaining some Ethernet failures, but still requires very high voltages on AC mains (typically at least 8 kV)
- Can not be used to explain POTS damage because impulse *current* is small

# Theory 3

## Interaction With Multi-Port Surge Protectors

# Circuit Model For Theory 3



# Inductive Effect of a Long Ground Wire

- A single, straight wire has an inductance of approximately 2 microhenries per meter
- So, a 50 meter ground wire will be approximately 100 microhenries
- Voltage across an inductor: V = L(di/dt)
- For a 500 amp, 8 uS rise time surge through a 100 microhenry inductance for L-GND:

$$V = (100\times10^{-6})(500/(8\times10^{-6})) = 6.25\ \text{kV}$$

# Observations About Theory 3

- Valid mechanism that can generate observed damage on both Ethernet and POTS ports

- But, only applies when multi-port surge protectors have been installed on equipment connected to these ports

# Summary of Limitations

Theory 1: Requires unusually high surge voltages on AC mains (typically more than 10 kV)

Theory 2: Looks good, but delivers only high *voltage*, not high *current*. Can not explain POTS failures. Also, requires high surge voltages on AC mains (typically more than 8 kV)

Theory 3: Looks good, delivers high voltage and high current, but only if multi-port surge protectors are installed

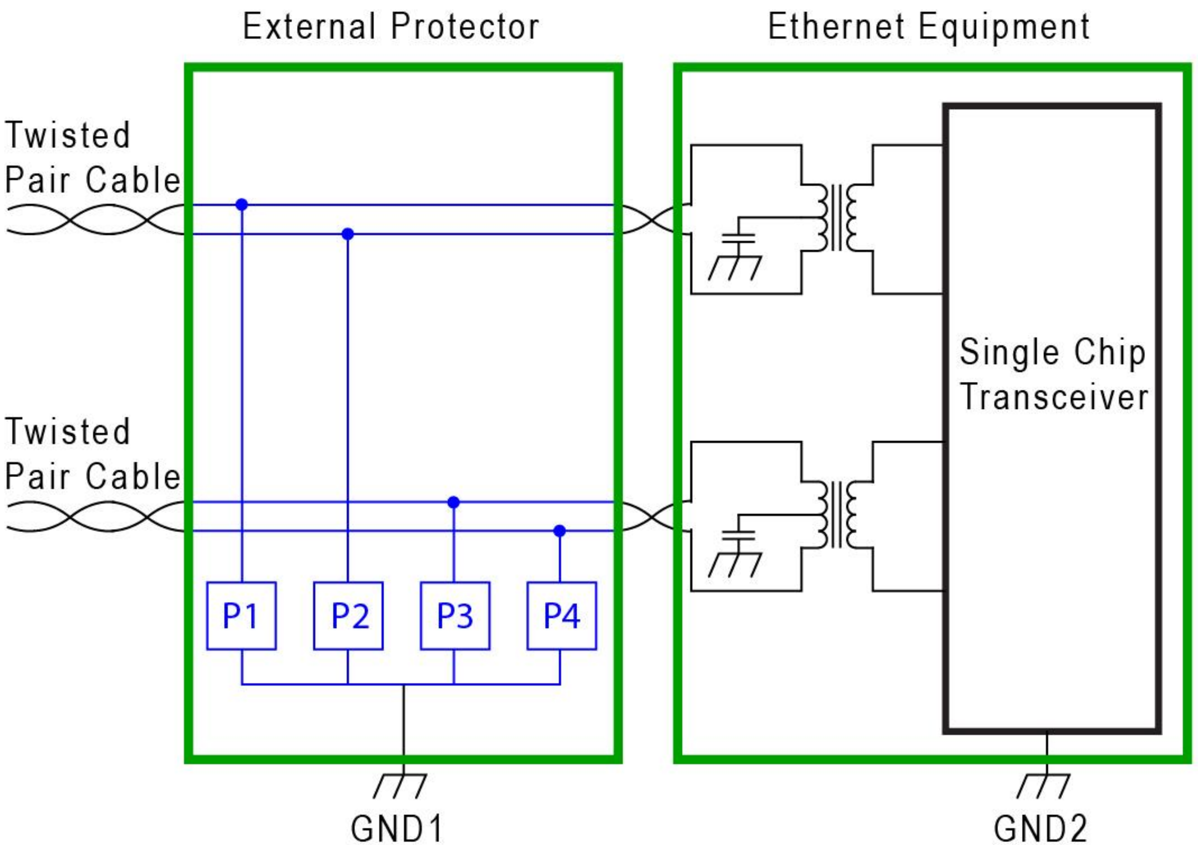
# Common-Mode vs. Differential Surges

- The preceding discussion has focused on common mode surges
- In some cases differential surges should also be considered

# Conventional Theory

- All surges on twisted-pair cables begin as as common-mode surges
- Only an external mechanism (such as a surge protector) can cause a a "common-mode-to-differential conversion"

# Common-Mode-to-Differential Conversion Caused by Asymmetric Triggering of External Protectors



# Common-Mode-to-Differential Conversion (Continued)

- Ethernet ports can be sensitive to this:
  - Designed to pass high frequency differential signals
  - Typically not well protected for differential surges
- POTS ports generally not sensitive to this:
  - Typical POTS protection operates equally well for both common mode and differential surges

# Mitigating Factors for Differential Surge Risk to Ethernet

- External Ethernet protectors are not always present
- Only certain types of external protectors will create a common-mode-to-differential conversion

➔ These factors limit the potential hazard, but a conservative strategy would include differential protection on Ethernet ports

# Interim Guidelines

- Design POTS ports to survive a 500 amp, 2/10 uS common mode surge
- Design Ethernet ports to survive a 6 kV, 2/10 uS common mode surge
- Differential surge tolerance for Ethernet ports may be desirable if external surge protectors will be used

# Guidelines Not Difficult or Expensive

- POTS guideline is similar to commonly used standard for outside POTS lines
- Ethernet guideline requires three elements:
  - Improved insulation on transformer wires
  - Careful attention to capacitors that bridge barrier
  - Careful attention to spacings in board layout
- Ethernet Protection for differential surges requires careful selection of additional components

# Continuing the Investigation

- Examine actual field failures to try and match their characteristics to a particular coupling mechanism
- Evaluate designs presently in the field to compare their failure rates and the failure mechanisms

*These steps will help identify the surge coupling mechanisms, and will help guide development of surge requirements that match the actual field environment*