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

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Mystery to Solve

How are lightning surges getting onto inside wiring for Ethernet and POTS ports?
Other Contributors From PEG

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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

**Ethernet Transceiver Chip**
- **EQUIPMENT SIDE**
  - 3.3 VDC
  - OVERCURRENT PROTECTION
- **CABLE SIDE**
  - TRANSMIT PAIR
  - RECEIVE PAIR

**POTS SLIC Chip**
- **EQUIPMENT SIDE**
  - -48 VDC
- **CABLE SIDE**
  - TRANSMIT/RECEIVE PAIR

**Isolated from Earth Ground**

**Not Isolated from Earth Ground**
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

Twisted Pair Cable

Wire 1

Wire 2

V1  V2

V3

Earth Ground

Common Mode: $V_1 = V_2 = 1000\text{V}$
$V_3 = V_1 - V_2 = 0\text{V}$

Differential: $V_1 = 1000\text{V}$
$V_2 = 0\text{V}$
$V_3 = V_1 - V_2 = 1000\text{V}$
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

[Diagram showing various components and their connections, including AC mains, surge current path, and barriers.]
Typical AC Wall Supply
Typical Ethernet Port

Isolation Components
Typical Ethernet Transformer
# Measured Failure Thresholds of Ethernet Transformers

<table>
<thead>
<tr>
<th>Ethernet Transformer</th>
<th>Breakdown</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wurth 7090-37</td>
<td>8 kV</td>
<td></td>
</tr>
<tr>
<td>Wurth 7090-37</td>
<td>7 kV</td>
<td></td>
</tr>
<tr>
<td>Falco LV2001</td>
<td>10 kV</td>
<td></td>
</tr>
<tr>
<td>Pulse H1164</td>
<td>Over 10 kV</td>
<td></td>
</tr>
<tr>
<td>Halo TG110-RP26NY</td>
<td>Over 10 kV</td>
<td></td>
</tr>
<tr>
<td>Pulse T1144</td>
<td>9 kV</td>
<td></td>
</tr>
<tr>
<td>Pulse H1102</td>
<td>8 kV</td>
<td></td>
</tr>
<tr>
<td>Pulse H2009</td>
<td>10 kV</td>
<td></td>
</tr>
<tr>
<td>Pulse H5007NL</td>
<td>5 kV</td>
<td>Second sample was 9 kV</td>
</tr>
</tbody>
</table>
# Measured Failure Thresholds of Ethernet Devices

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

<table>
<thead>
<tr>
<th>Product Description</th>
<th>Breakdown, AC to POTS</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PanasonicKX-TGA542M cordless phone</td>
<td>Over 10 kV</td>
<td>Linear wall supply</td>
</tr>
<tr>
<td>GE 28512AE1 cordless phone</td>
<td>Over 10 kV</td>
<td>Switching wall supply</td>
</tr>
<tr>
<td>Vtech CS114 cordless phone</td>
<td>10 kV</td>
<td>Linear wall supply</td>
</tr>
</tbody>
</table>
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

ONT
ETHERNET PORT (1000 pF)
ETHERNET ROUTER (1000 pF)
AC MAINS POWER SUPPLY (2200 pF)

C3
2444 V +

C2
2444 V +

C1
1111 V +

IMPULSE CURRENT PATH

6 kV IMPULSE
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: \( V = L \frac{di}{dt} \)
- For a 500 amp, 8 uS rise time surge through a 100 microhenry inductance for L-GND:

\[
V = (100 \times 10^{-6}) \frac{500}{(8 \times 10^{-6})} = 6.25 \text{ kV}
\]
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 common-mode surges

• Only an external mechanism (such as a surge protector) can cause 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.*