“Lightning Protection”

Puckett Engineering PLLC
Engineering Excellence through Vision & Innovation

MCPQG/IEEE, May 3, 2011

"Lightning Protection"

Joint meeting of the Music City Power Quality Group and the IEEE Central TN Section

May 3, 2011

Presented by,

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Overview

- Purposes of Lightning Protection
- Lightning Statistics
- Physics of Lightning
- How does Lightning Damage Equipment
- Lightning Protection
  - Grounding and Bonding
  - Isolation
  - Surge Protection
  - Building Envelope
- Personal Safety from Lightning

Purposes of Lightning Protection

- Protect People
- Protect Equipment
- Protect Power Lines
- Protect Structures (Buildings)
- Protect Storage of Explosive Materials
- Protect Towers and Tanks
- Protect Watercraft
- Protect Livestock

Lightning Statistics

- 30 to 100 Lightning Flashes per Second around the World (Cloud & Cloud-to-Ground)
- Up to 9 Million Flashes per Day worldwide
- Cloud Discharges account for more Flashes than Cloud-to-Ground Flashes (Intracloud most common)

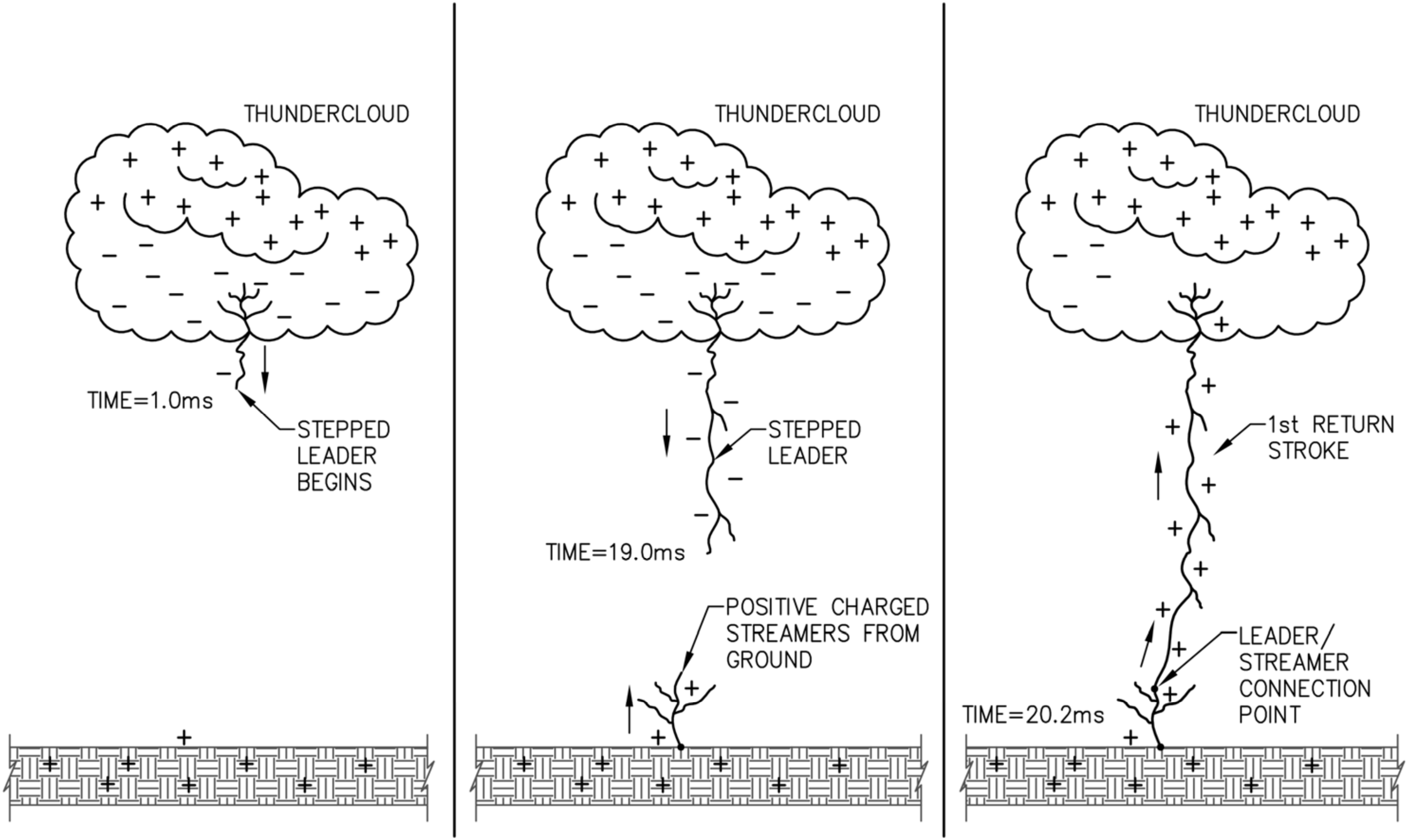
Lightning Statistics, cont.

- Insurance payouts in U.S. 1/3 to 1 Billion/yr.
- Cost of U.S. Lightning Damage ~ 1 Billion/yr.
- NFPA reports ~ 30,000 Lightning Caused House Fires each year with cost of $175 Mil.
- About 30% of all Church Fires are Lightning Related
- Lightning is Primary Cause of Fires on Farms and for more than 80% of Livestock Losses
- In 1999, Lightning Ignited more than 2000 Forest Fires in Florida alone.

Physics of Lightning

- Typical 1st Return Stroke near 30,000 Amps but can be as high as 300kA.
- Subsequent strokes 10,000 to 15,000 Amps.
- 1st Return Stroke Rise Times of 1.8μs to 18μs with 5.5μs being typical for. Equates to 14kHz to 139kHz with 45kHz being typical.
- Subsequent Return Stroke Rise Times of 0.22μs to 4.5μs with 1.1μs being typical for 1st Return Stroke. Equates to 56kHz to 1.1MHz with 227kHz being typical.
- Leader Potential of 1,000,000 to 10,000,000 Volts with respect to earth.

Lightning Stroke



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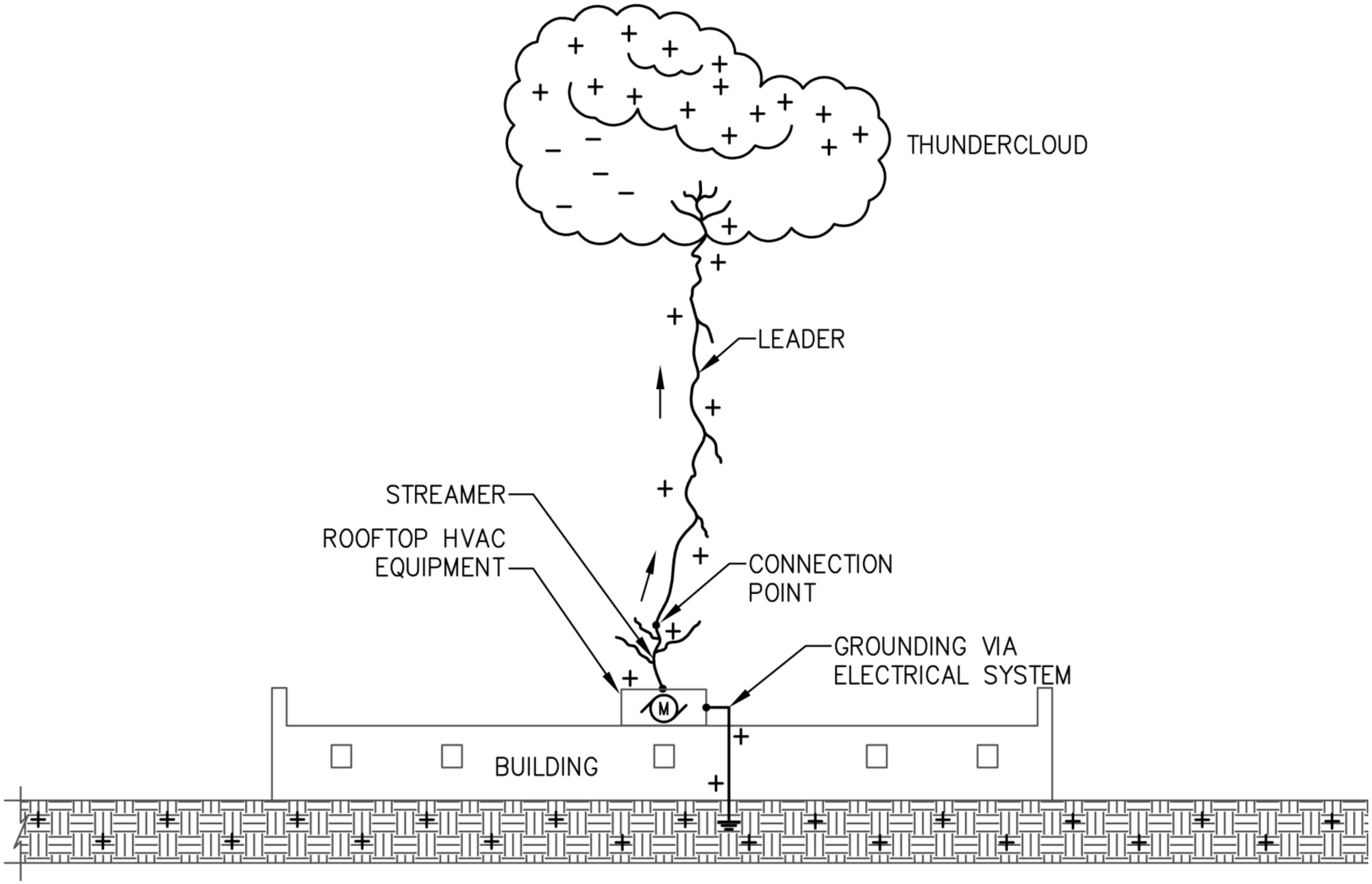
Lightning Stroke

How does Lightning Damage Equipment

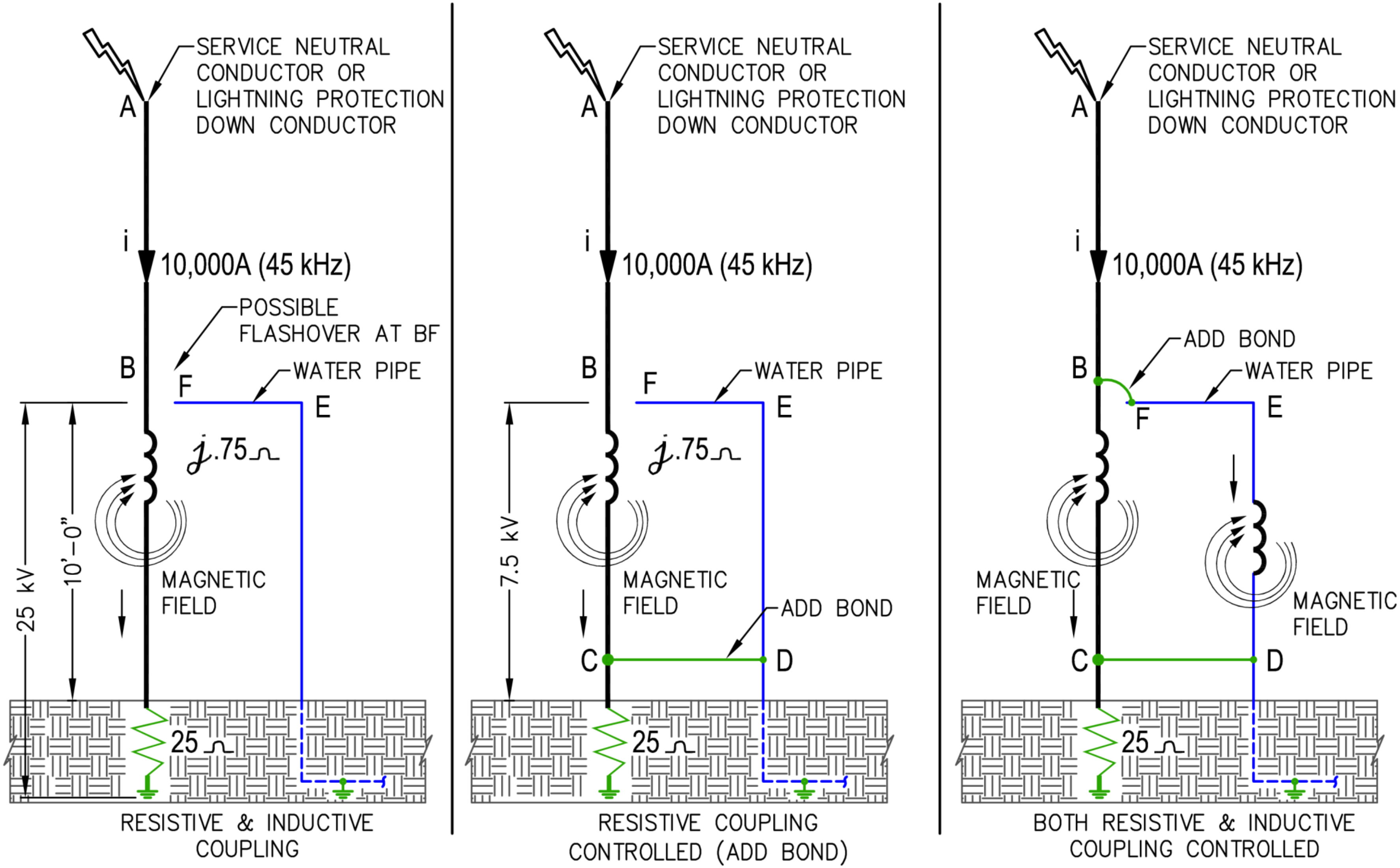
- Direct Lightning Strikes.
- Resistive Coupling.
- Inductive Coupling.
- Capacitive Coupling.

Direct Lightning Strikes



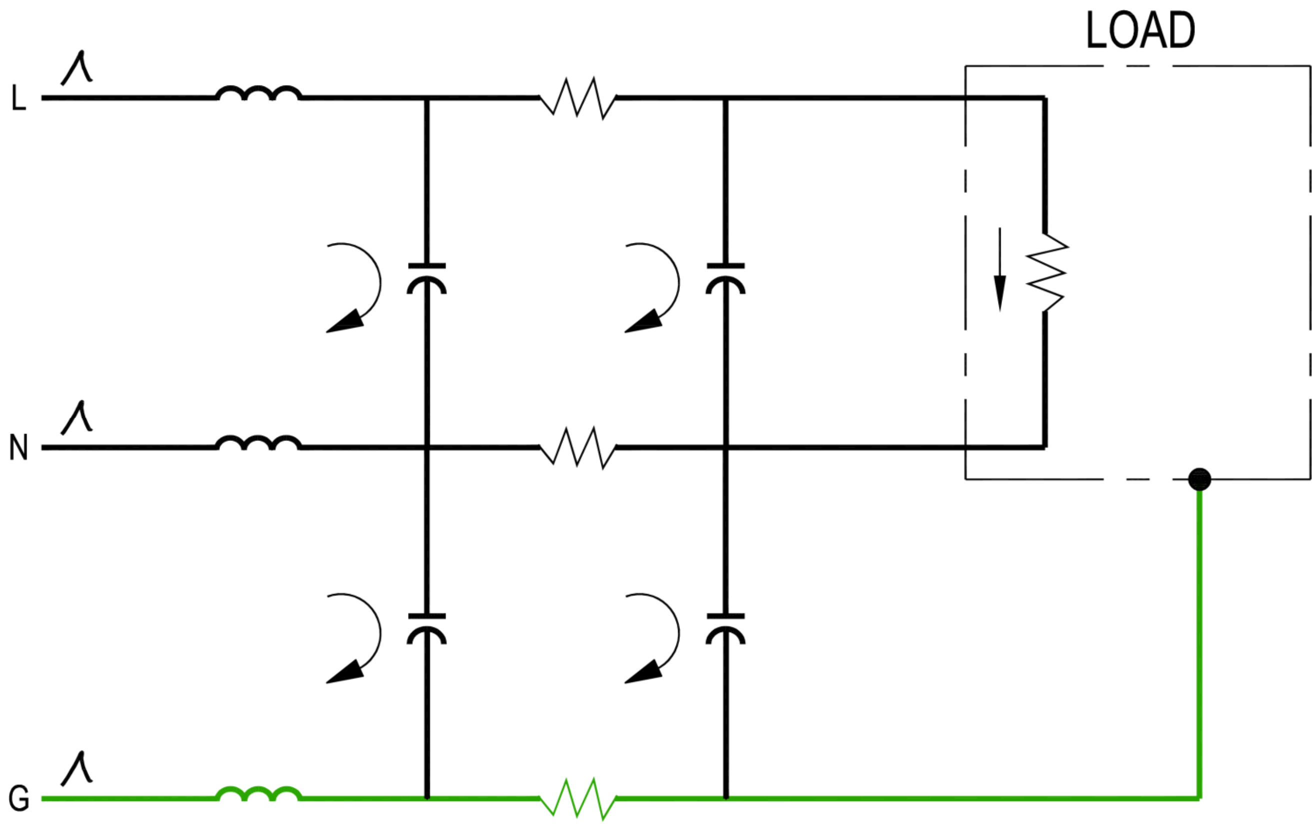
- Strike will cause extensive damage and can also cause damage to equipment inside the building

Resistive & Inductive Coupling



- Inductive coupling can also induce voltages into nearby equipment.

Capacitive Coupling



- Transients travelling along circuit conductors will induce voltages into adjacent conductors through mutual capacitance and inductance.
- Similar for cables near objects carrying lightning current.

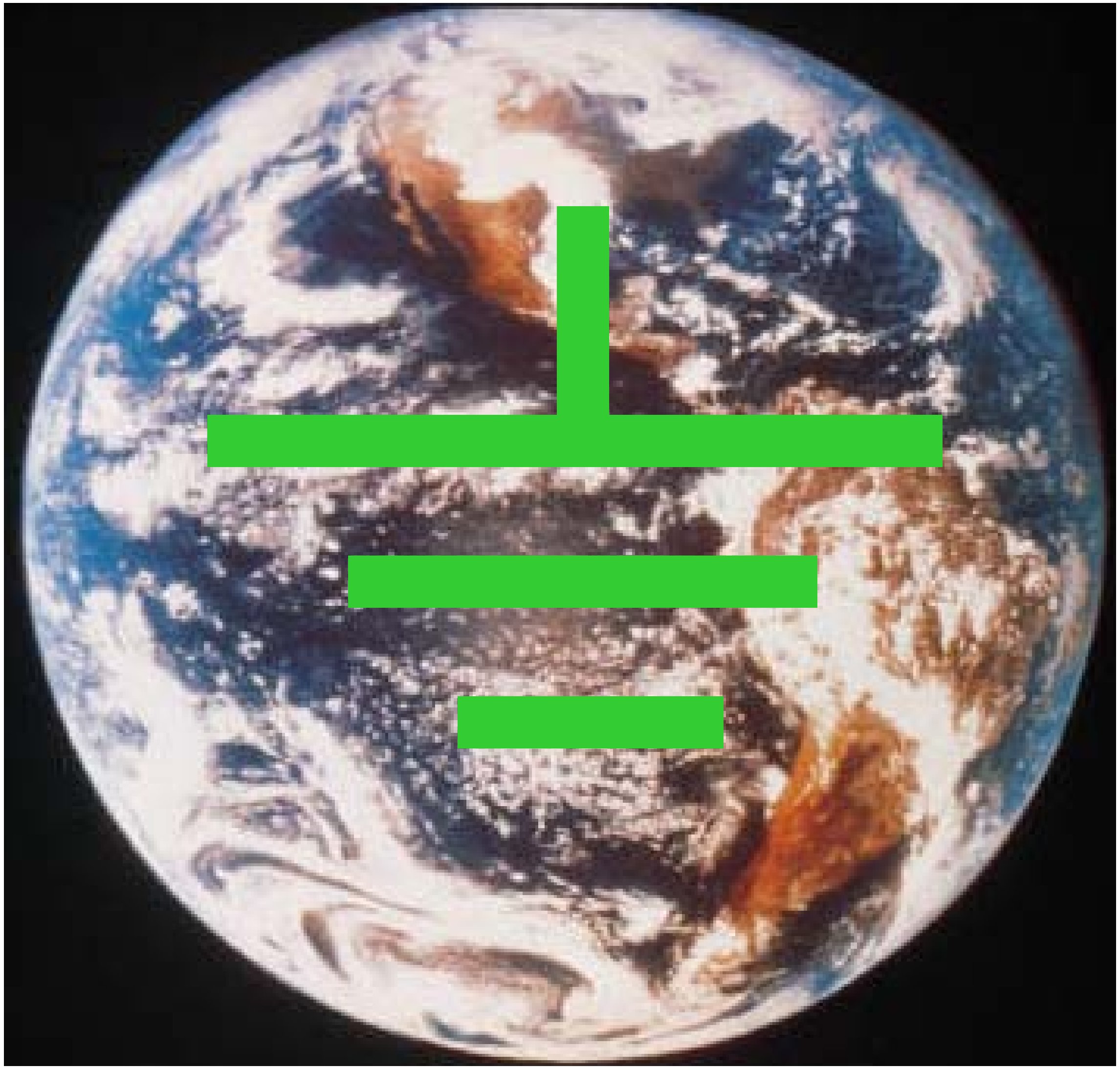
Lightning Protection

- Grounding and Bonding
- Isolation
- Surge Protection
- Building Envelope

Grounding and Bonding

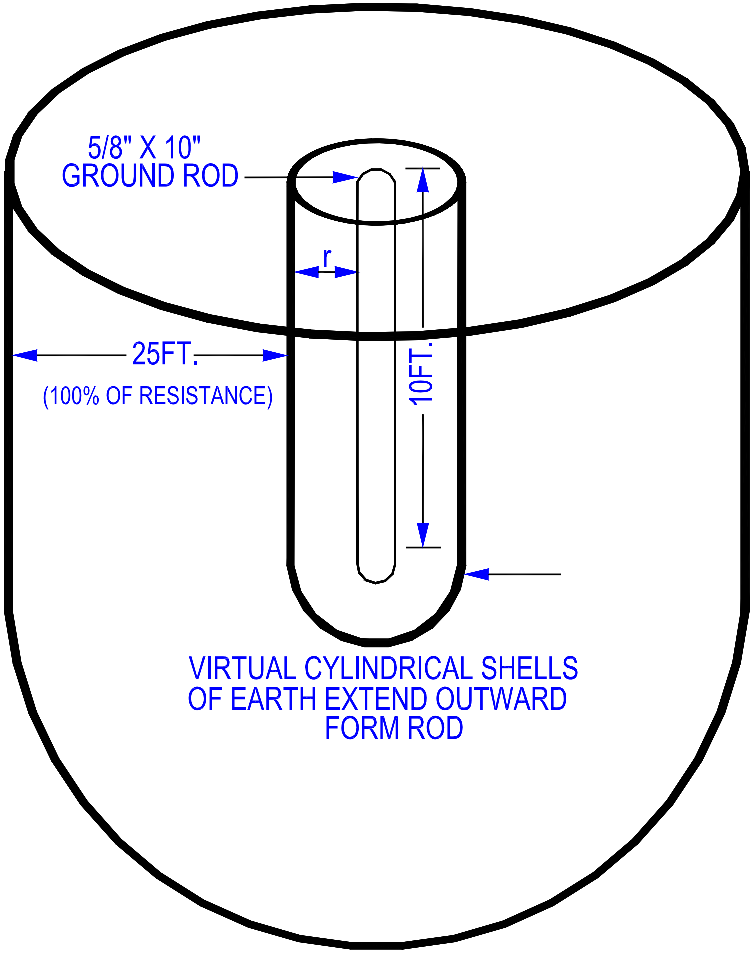
- Relatively Low Earth Resistance
- Equipotential Ground Plane

Earth Grounding



Ground Field Considerations

The Ground Rod's Earth Connection: "Interfacing Hemisphere"



Ground Field Considerations

- Interfacing Hemisphere
  - The rod's interfacing hemisphere (IH) has a radius of approximately 1.0 times the rod's length. Therefore, it is best to space rods at least twice their length.
  - The interfacing hemisphere makes up approximately 94% of the rod's earth connection (i.e. resistance)
  - 25% of the rod's earth resistance is within the first 1.2 inches of the rod's IH. Therefore, the first few inches away from the rod are the most important for reducing the earth resistance.

Ground Field Considerations

- Rod, Pipe, and Plate Electrodes with ground resistance greater than 25 ohms must be augmented by one of the following:
  - » Building steel structure where it is effectively grounded
  - » Concrete encased electrode in foundation or footing
  - » Ground ring encircling the building
  - » Rod or pipe electrode
  - » Plate electrode
  - » Other local underground systems or structures, such as piping systems and underground tanks
- Earth resistivity must be 60 ohm-meters or less for one 8' rod to achieve 25 ohms (Average soil resistivity in Middle TN is 250 ohm-meters according to Soil Resistivity Map)
- Few areas in U.S. have average soil resistivity less than 60 ohm-meters

Ground Field Considerations

- Ufer Grounds (Encased Electrodes)
  - » Average Soil Resistivity for Middle TN = 250 Ohm-Meters Vs 0.12 Ohm-Meters for Erico's "GEM"
  - » Concrete Resistivity is 30 ohm-meters.
  - » Moisture Retention.
- Can use Erico's Calculator for Calculating Earth Resistance with and without GEM or do it manually using the Dwight formulas in the IEEE Green book or other reference. Can calculator download from their website.

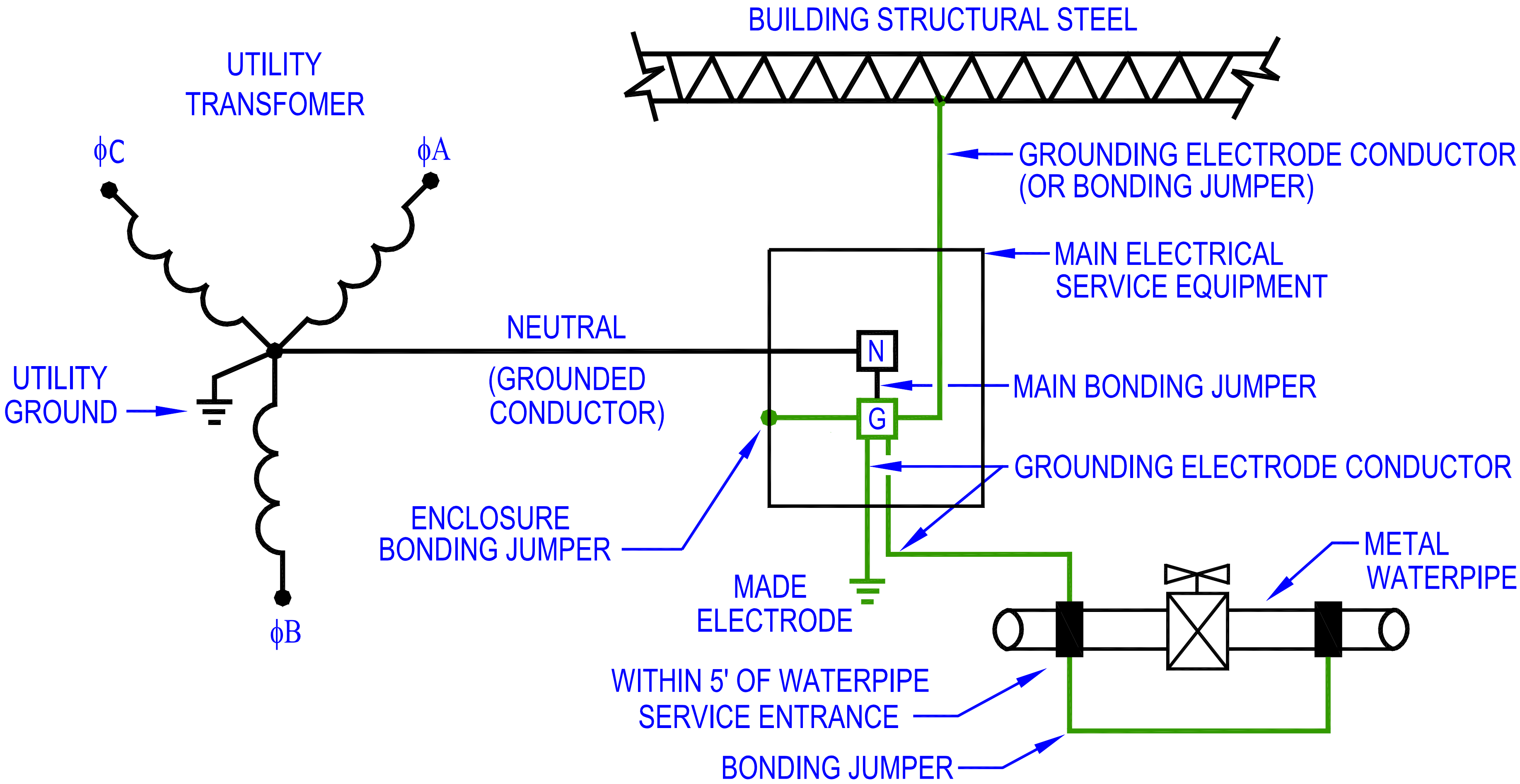
Ground Field Considerations

- Earth Resistance Guidelines:
  - Residence – 25 Ohms
  - Small Commercial – 20 Ohms
  - Industrial, Large Commercial – 10 Ohms Max.
  - Substations – 5 Ohms Maximum
  - With regards to the power system, in general, the larger the electrical system the lower the earth resistance should be due to the higher fault currents.
  - Another reason for lower resistance is for lightning protection. To give lightning the best path possible to earth.

Ground Field Considerations

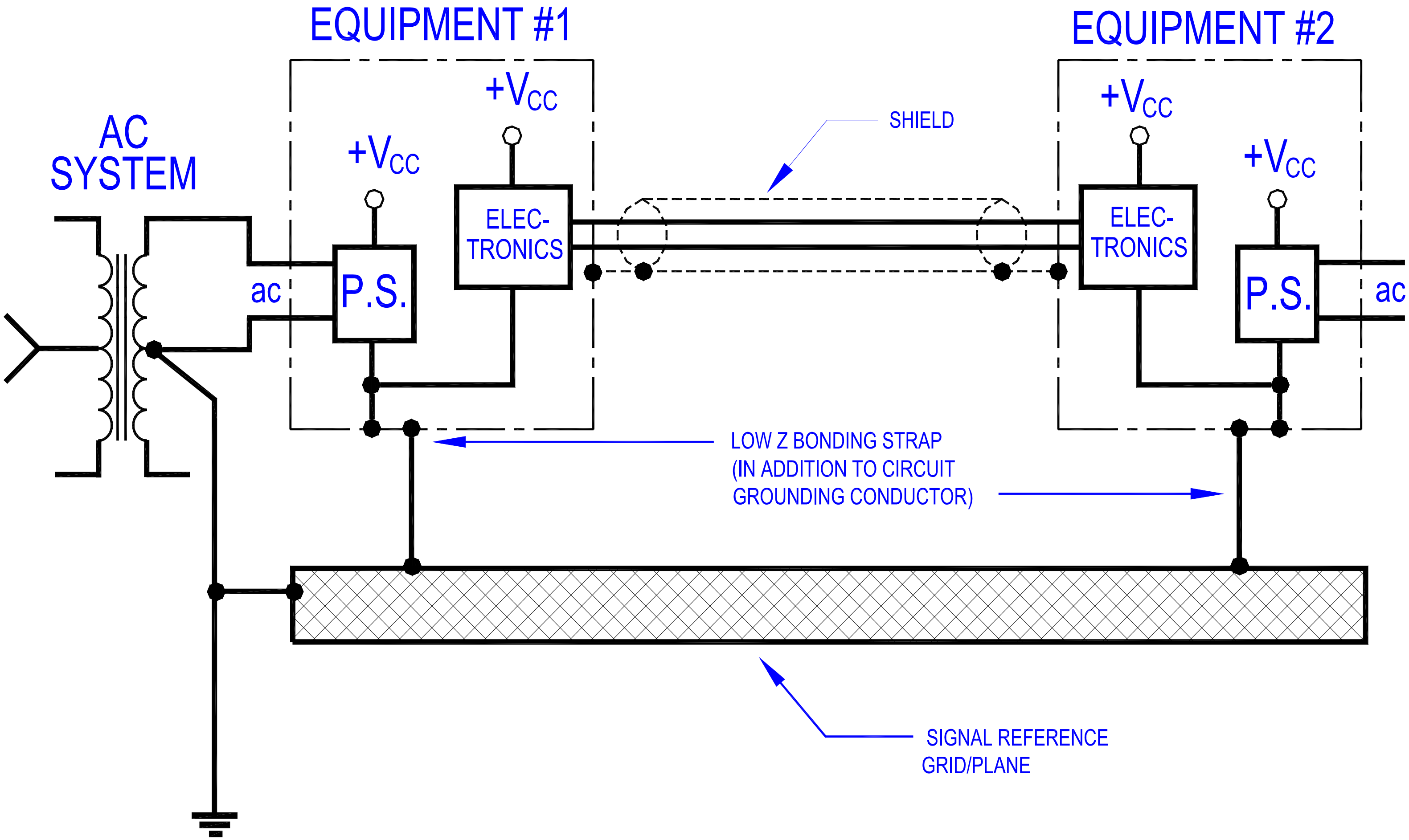
- Grounding Electrode Conductors
  - Minimize Lengths and sharp bends
  - Use minimum bending radius of 8 inches
  - Minimizing length is more important than bends
  - Conductor Z predominantly inductive reactance at HF
    - » $Z \sim X = 2\pi f L$
    - » L (in µH) =.508l[2.303Log(4l/d) -.75] x 0.01
      - – l=Length in inches
      - – d=Diameter in inches
    - » f=Frequency is 45kHz to 227kHz typical (based on 5.5µs and 1.1µs rise times). For IEEE C62.41, 8 x 20µs Waveform, f=32.5 kHz. Lightning can also be in the 1 MHz range or higher.
    - » VD=Z x I = 163 V/FT. (each way) for 3kA, 8 x 20 µs impulse, using 2 AWG conductor.
    - » VD=Z x I = 5002 V/FT. (each way) for 3kA, 1 MHz impulse, using 2 AWG conductor.

Electrical Service Grounding



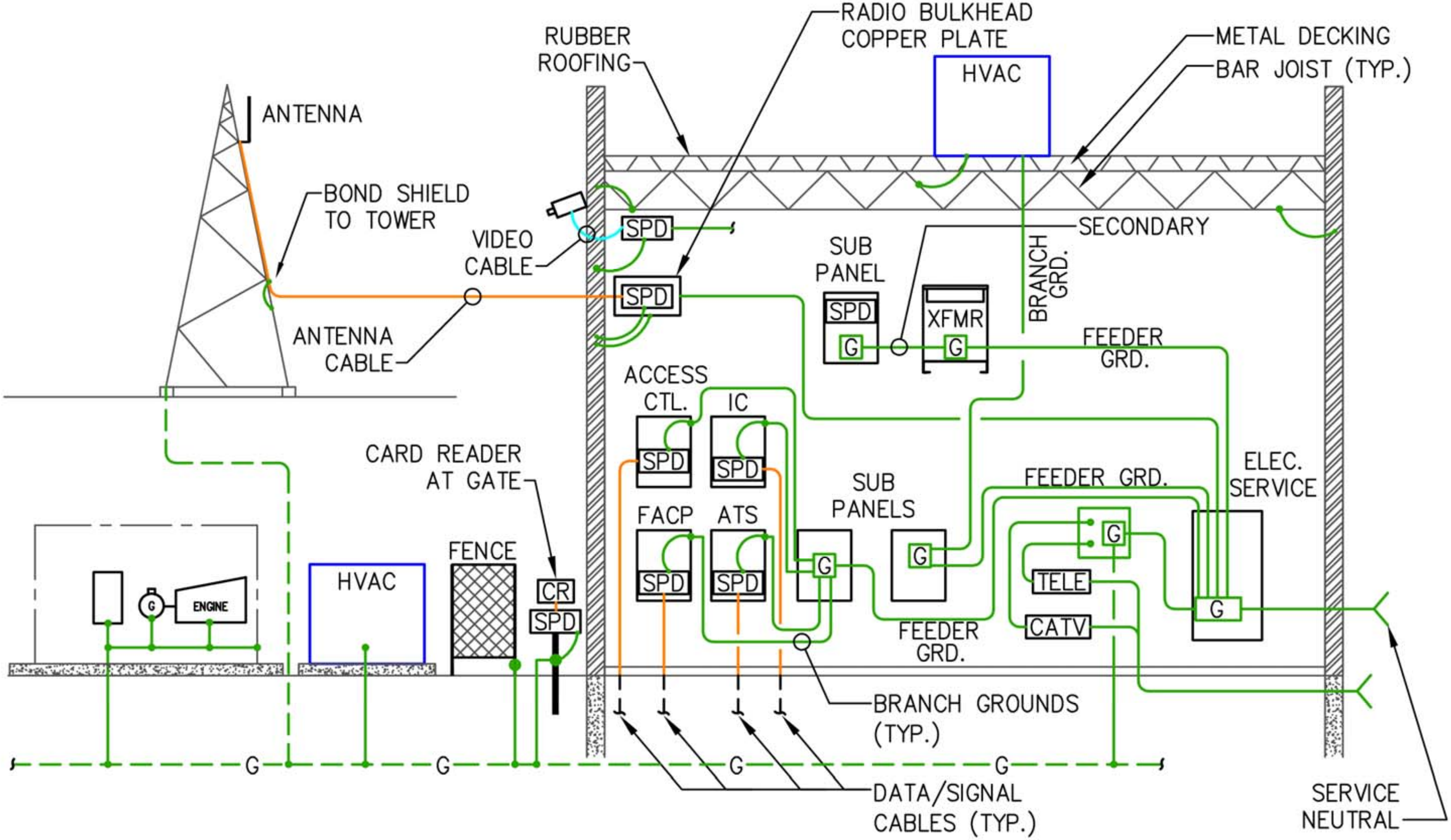
- With few exceptions, it is imperative to bond everything together to create a virtual “Grounding Grid”

Ideal Signal (Grounding) Reference Grid



- SRG provides equipotential plane between equipment, which minimizes or eliminates potential differences between equipment.
- The SRG could include a grid of conductors, solid sheet of copper or sheet metal, and/or a building's steel structure.

Grounding Grid Considerations



- Take a comprehensive approach to grounding/bonding.

Radio Cable Grounding

Radio Cable Bulkhead

Grounding Grid Considerations, cont.

- For steel buildings, take advantage of the building's structure.
  - The massive grid of steel can make for a nice "Grounding Grid" if it is bonded and grounded.
  - Confirm all bolted connections are continuous. If not, add jumpers.
    - » The Lightning Protection standards allow using the steel columns for down conductors but do not require bonding across bolted connections.
  - For bar joist construction, confirm whether the metal deck pan is welded to the joists and if the joists are welded together via cross members.

Grounding Grid Considerations, cont.

- When bonding to steel, remove primer/paint to ensure a good connection (even if the lug is fastened using a tapped hole).
  - Advise installer to take necessary precautions if primer/paint includes lead.
  - Use lock-washers.
  - Reapply primer/paint to exposed bare metal.
  - Apply an antioxidant compound around connection.
  - Where grounding conductors are installed in metal conduit, be sure to bond each end of metal conduit to the same grounding point as the ground wire. Otherwise, the conductor and conduit act like a single turn coil.
  - Use lugs with two bolt holes to minimize twisting lug where wire or lug could be hit.

Grounding Grid Considerations, cont.

- Bonding Jumper across column and beam connection.
- Same for the steel purlins that were screwed to beams.

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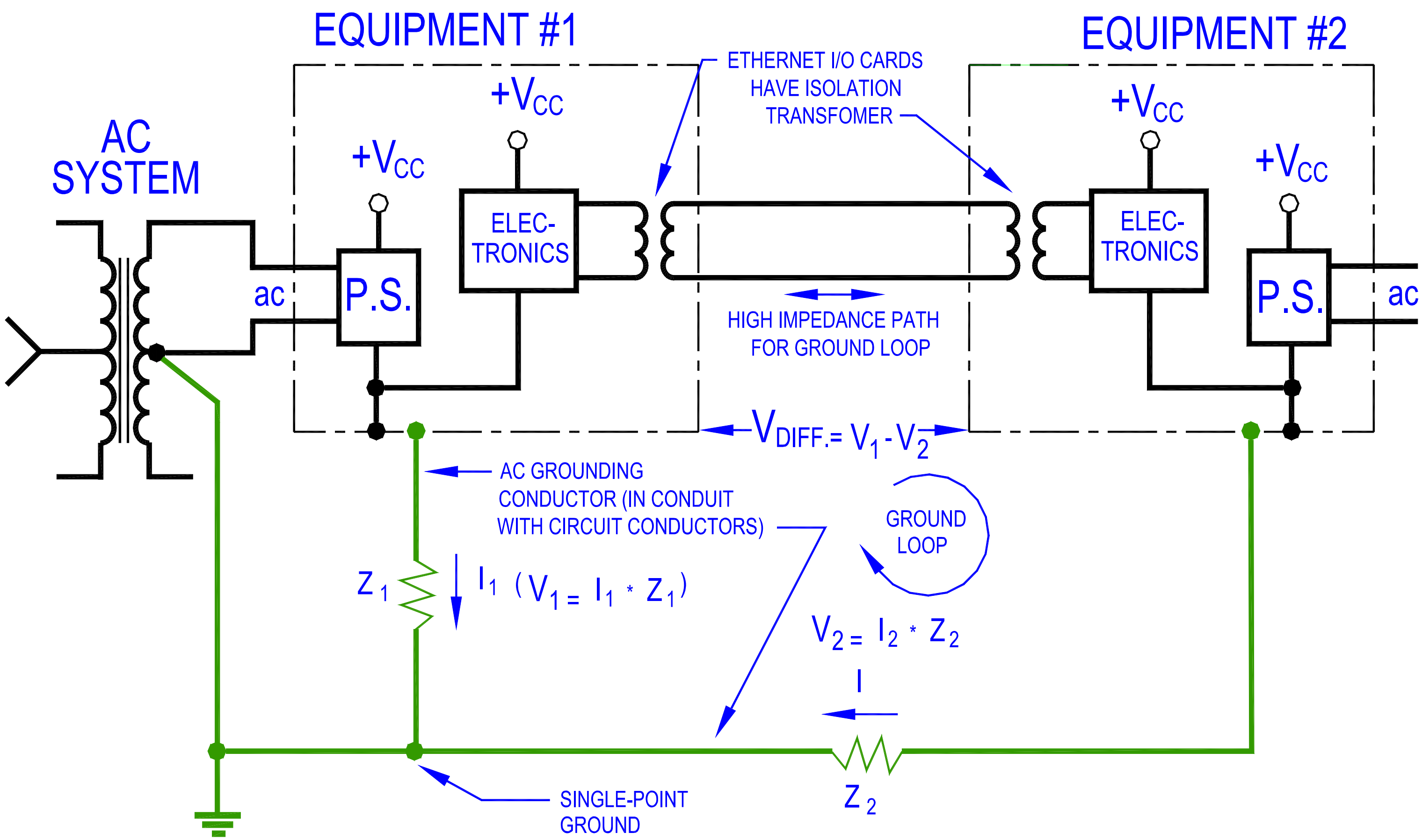
"Isolation"

Minimizing or Eliminating the Adverse Effects of Potential Differences on the Grounding System

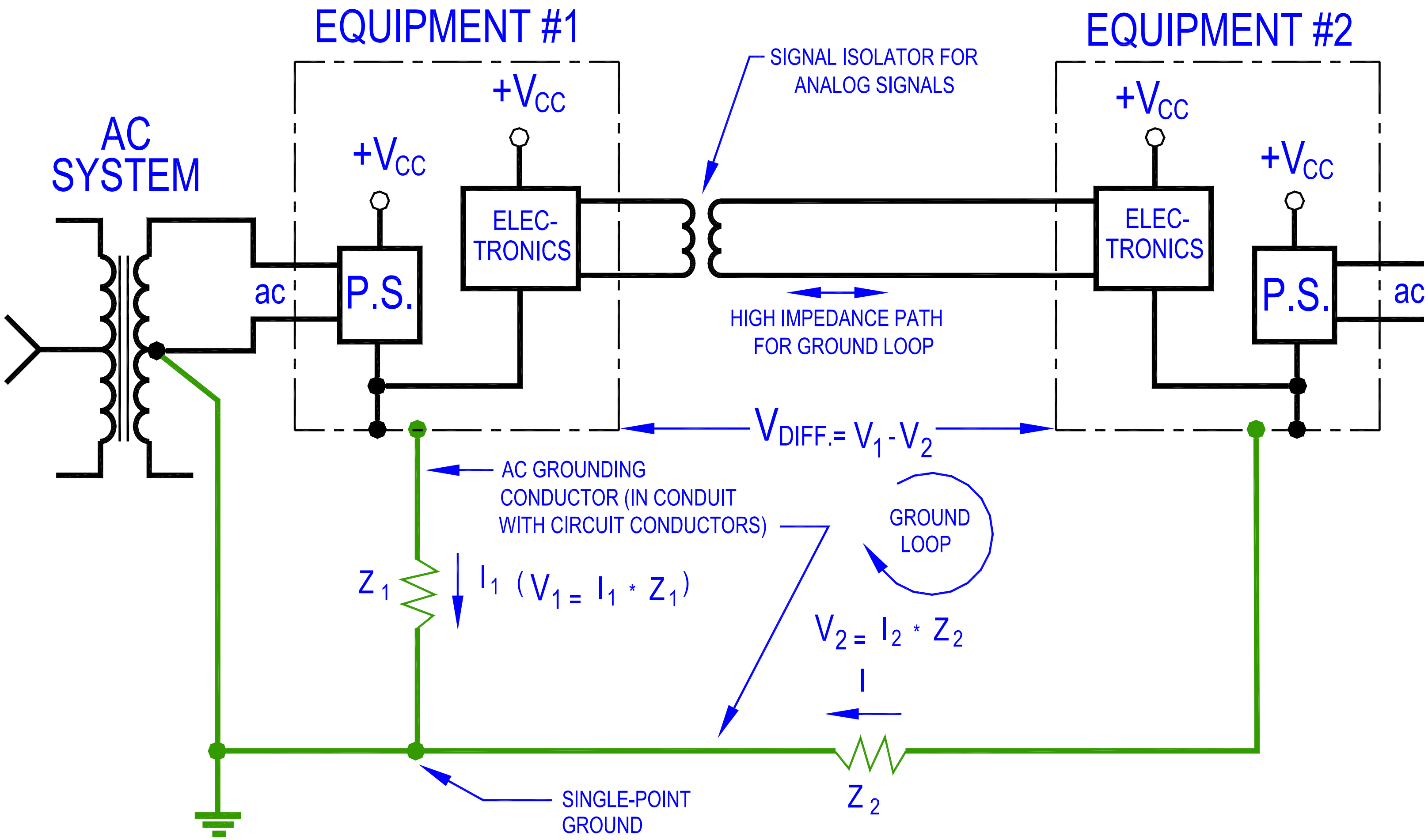
- Equipotential Ground Plane (Grounding Grid) (discussed earlier)
- Ethernet Networks
- Signal Isolators
- Optical Isolators
- Fiber Optic Cables

Ethernet Networks



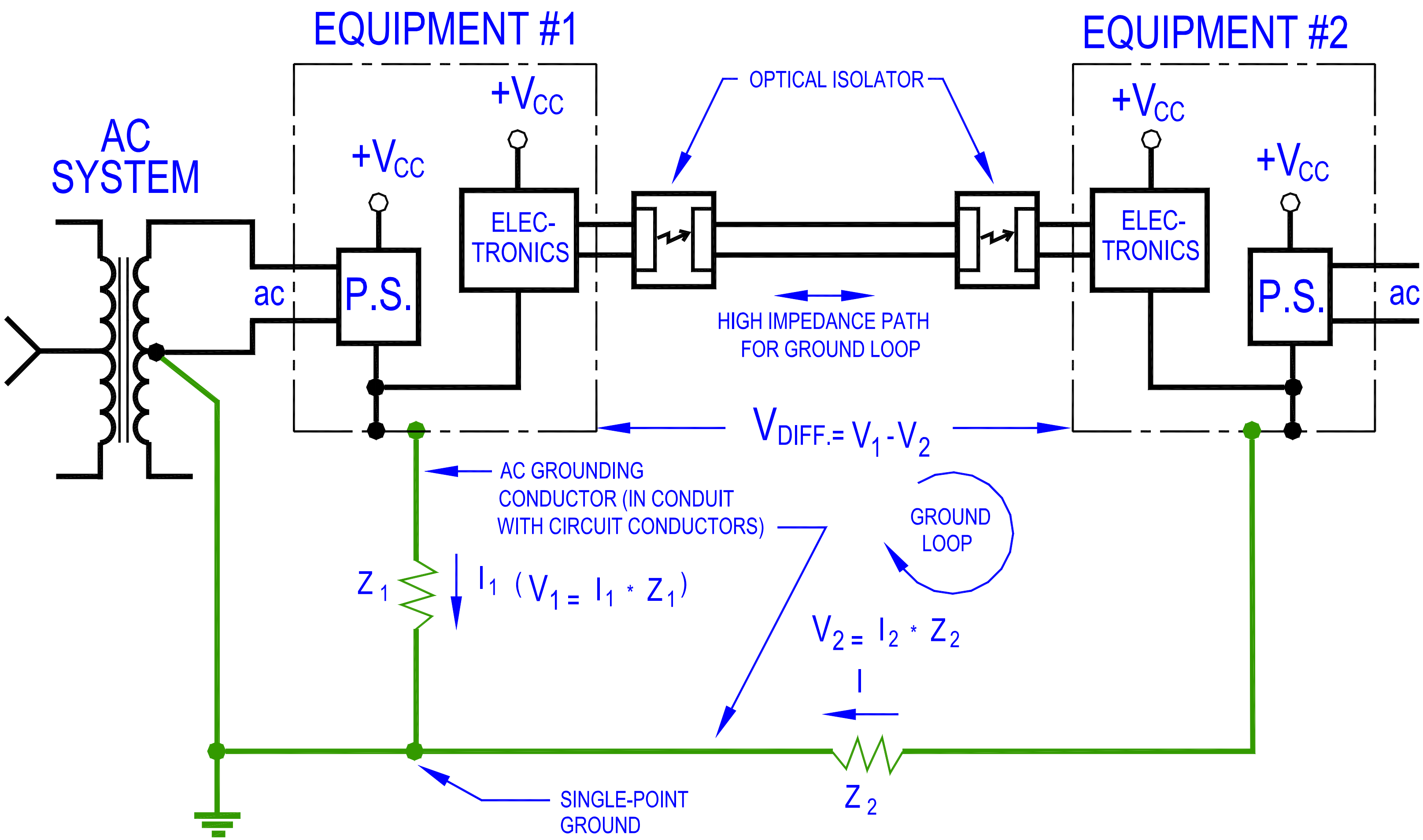
- Ethernet networks are more immune to ground loops due to internal isolation on data ports
- Isolated ground usually not be necessary

Signal Isolator



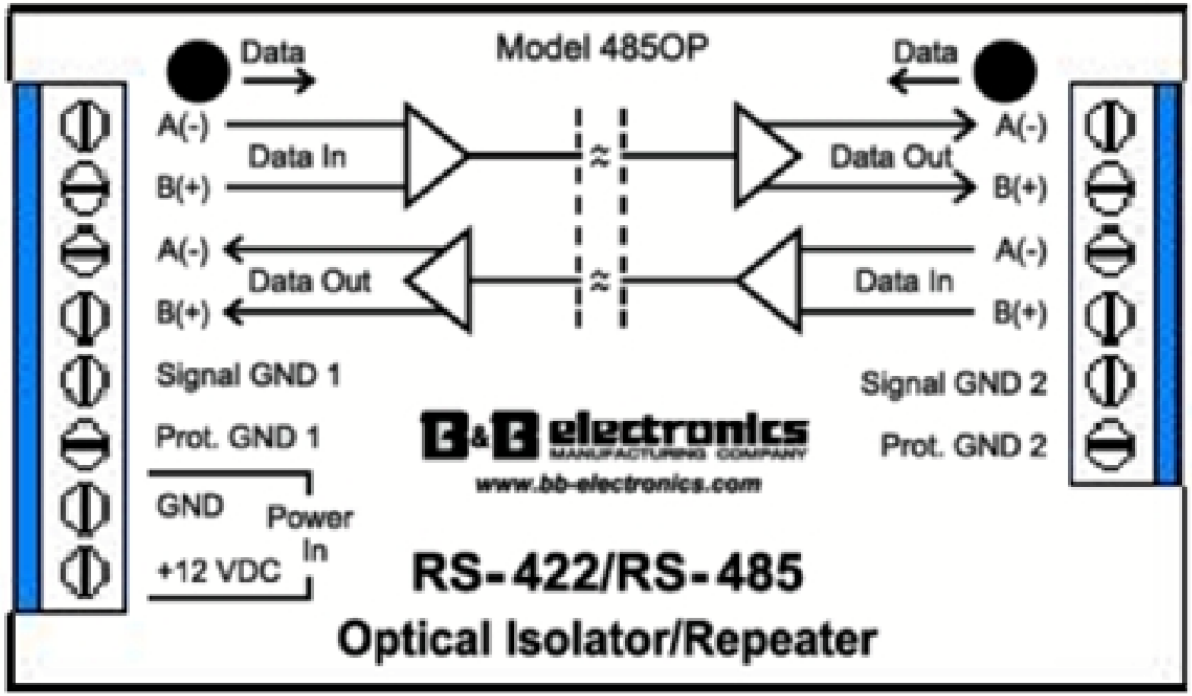
- This is normally used in process controls
- Isolated ground may not be necessary

Optical Isolator



- Optical isolators can provide 2.0kV or more of isolation
- For 100% isolation use fiber optic cable between equipment

Optical Isolator



- ➢ B&B Electronics offers models for various applications
- ➢ For Ethernet, use Fiber Optic Media Converters.

Surge Protection

➢ Locations

- Each Electrical Service Entrance
- Sub-Panels supplied from transformers, and/or supplying critical/sensitive equipment.
- Each Communications Service (Telephone, Cable TV, Satellite, etc.)
- Each power or communications or data circuit that extends beyond the building for outdoor equipment or remote buildings.
- Critical/Sensitive utilization equipment. Consider combination units where the equipment is connected to both power and communications/data.

Surge Protection, cont.

- SPD Conductor Connections
  - SPD let-through voltage is insignificant compared to the effect of conductor lengths
  - Conductor Z predominantly inductive reactance at high frequency
    - » L (in µH) =.508l[2.303Log(4l/d) -.75] x 0.01
      - – l=Length in inches
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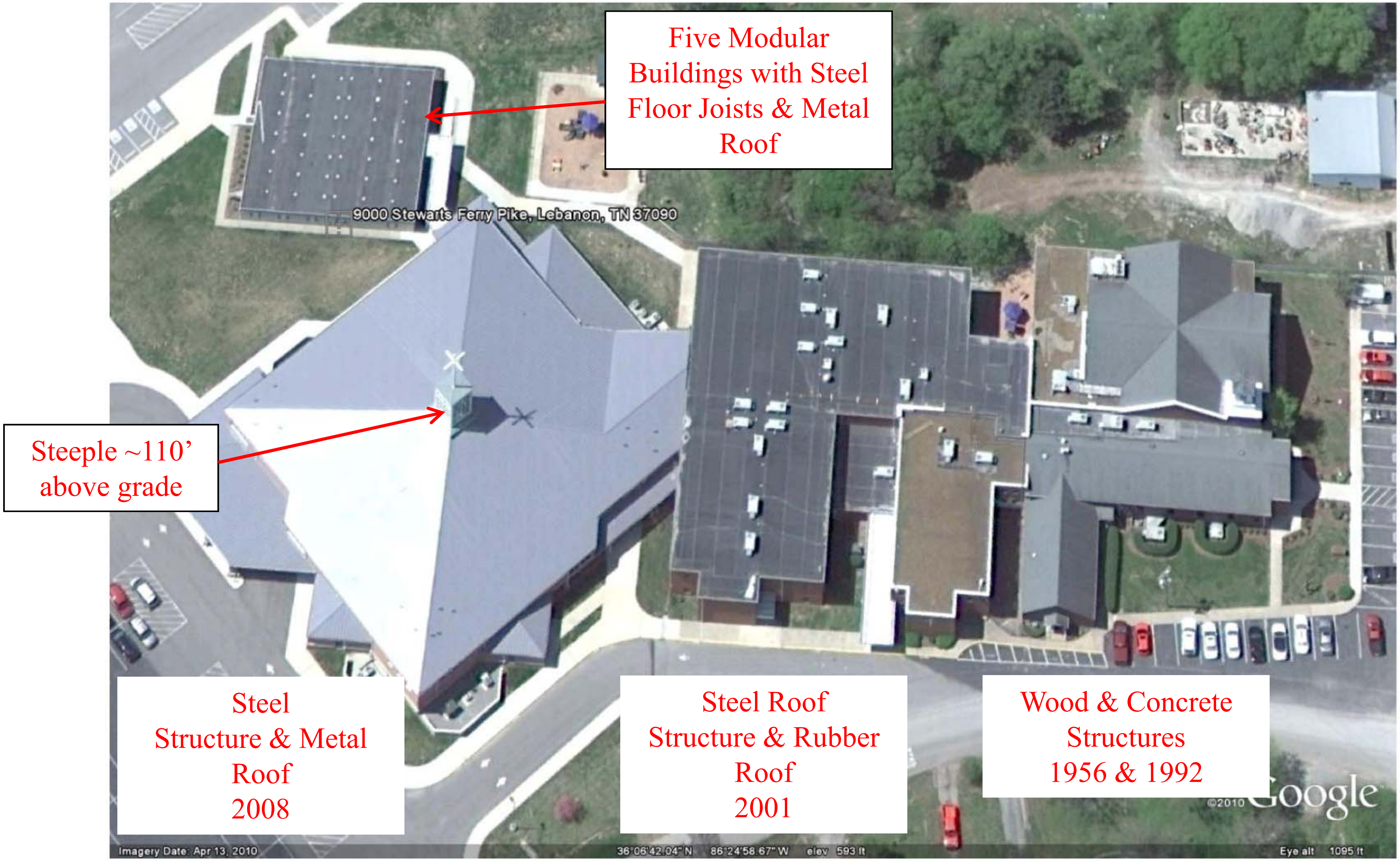
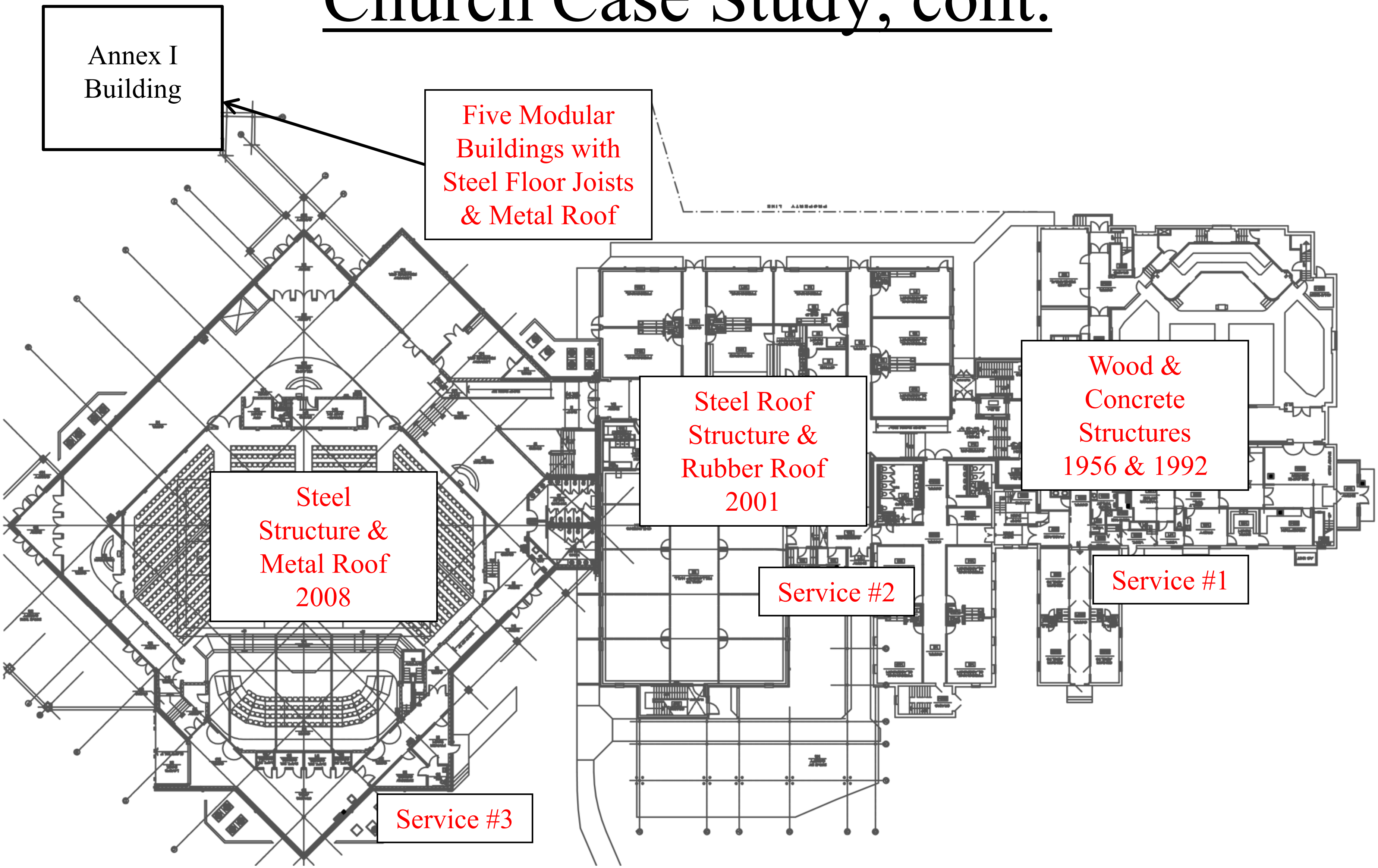
    - » VD=Z x I = 5002 V/FT. (each way) for 3kA, 1 MHz impulse, using 2 AWG conductor.
  - Consider SPD units integrally-mounted in panels. Be aware if it fails destructively, the panel could also fail.

Church Case Study



- Built in 3 Phases between 1956 and 2008

Church Case Study, cont.



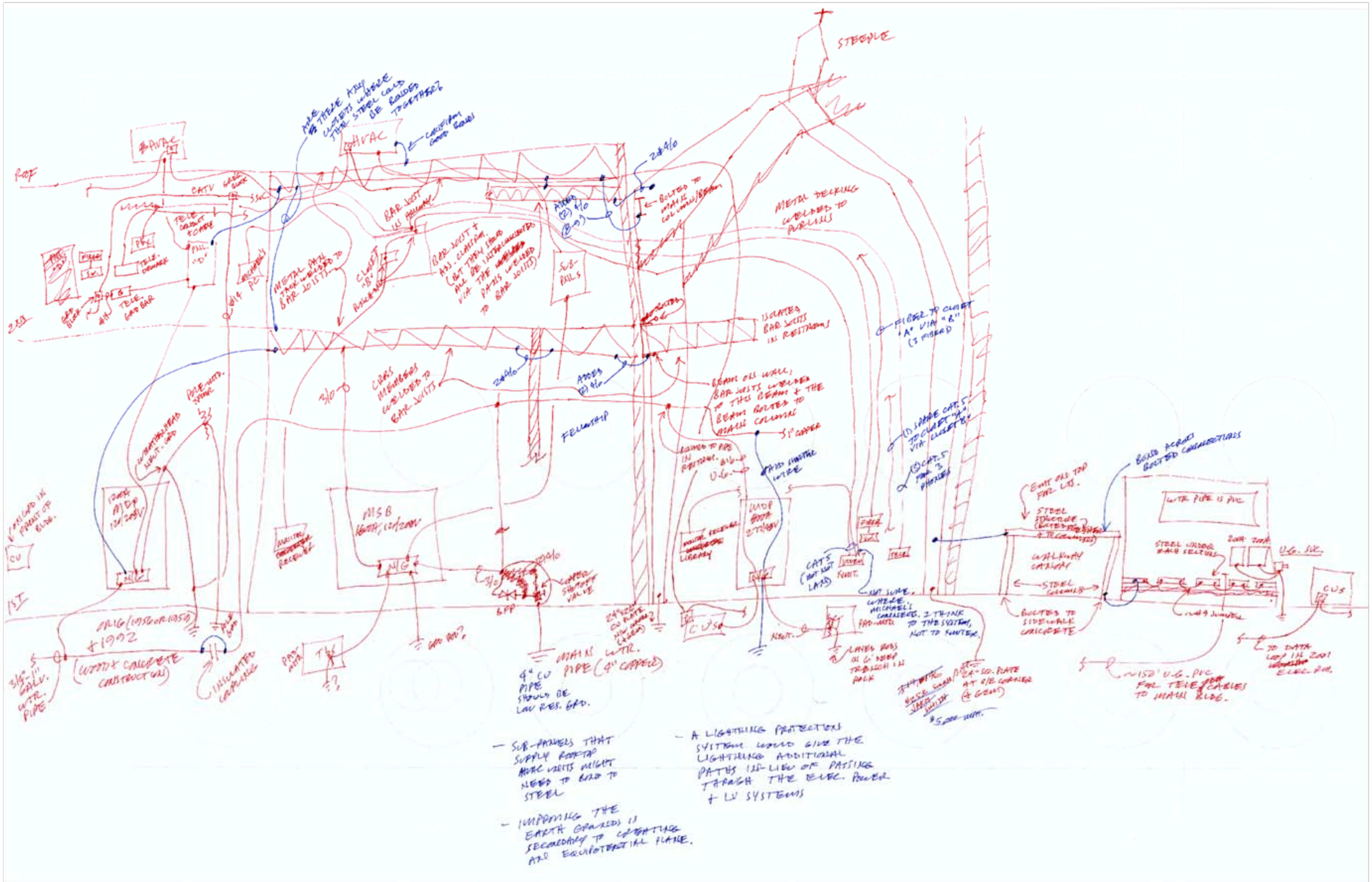
- Built in 3 Phases between 1956 and 2008

Church Case Study, Cont.

Church Case Study, Systems

- 49 HVAC Units with 26 roof-mounted on 2001 section roof.
- HVAC DDC Control System.
  - » This system includes a data cable (RS-485 protocol) that daisy-chains through all HVAC unit controllers.
- LAN that originates in 1992 section with fiber optic cables between 1992 section and 2008 section.
- A/V Control Room in 2008 section for Sanctuary.
- Video Transmitter in 2008 A/V Control Room with video Receiver in 2001 Café and in 2008 Library.
- Intercom at main front entrance for communicating with receptionist in front lobby.
- Access Control System with three card readers.

Church Case Study, Analysis



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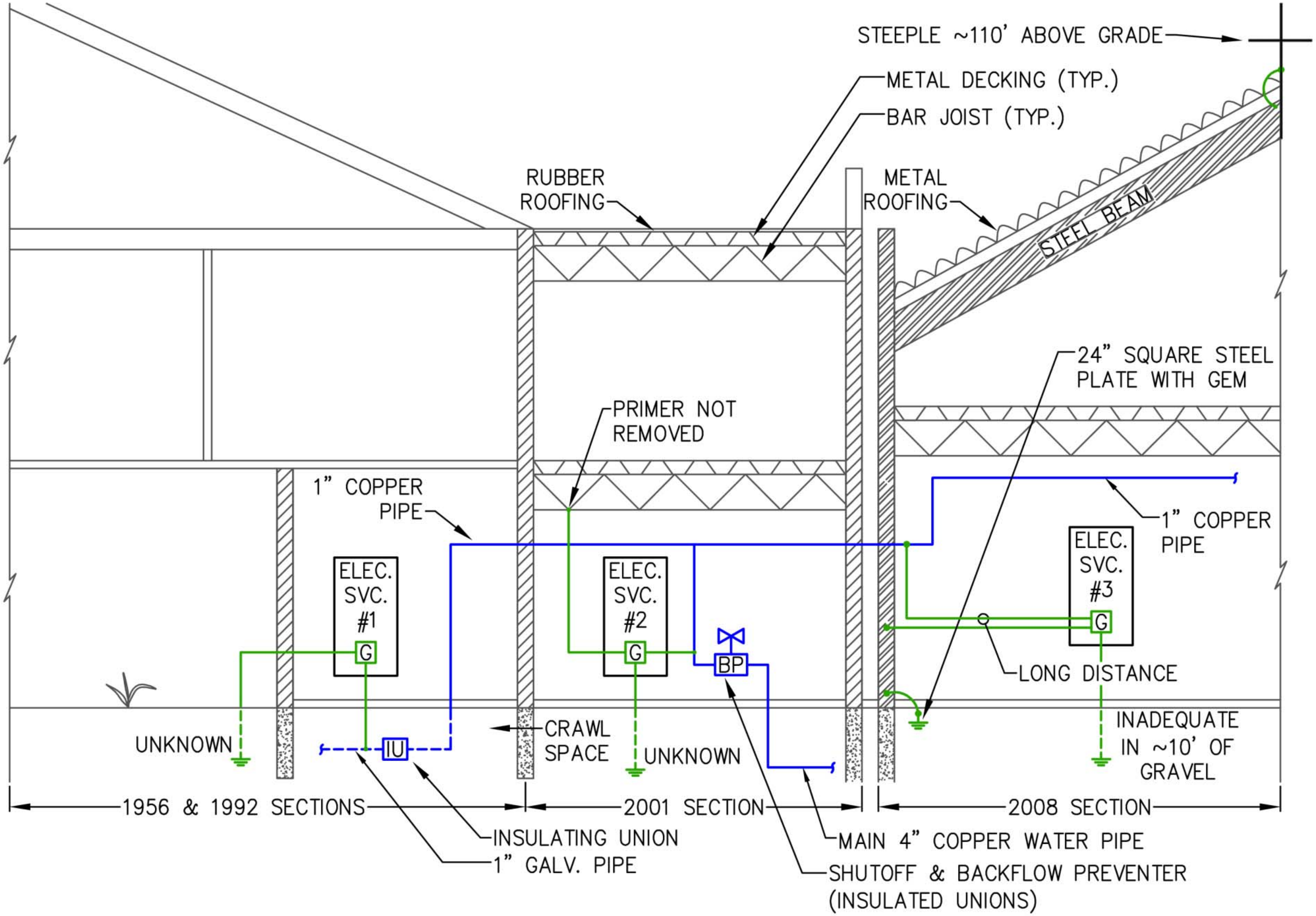
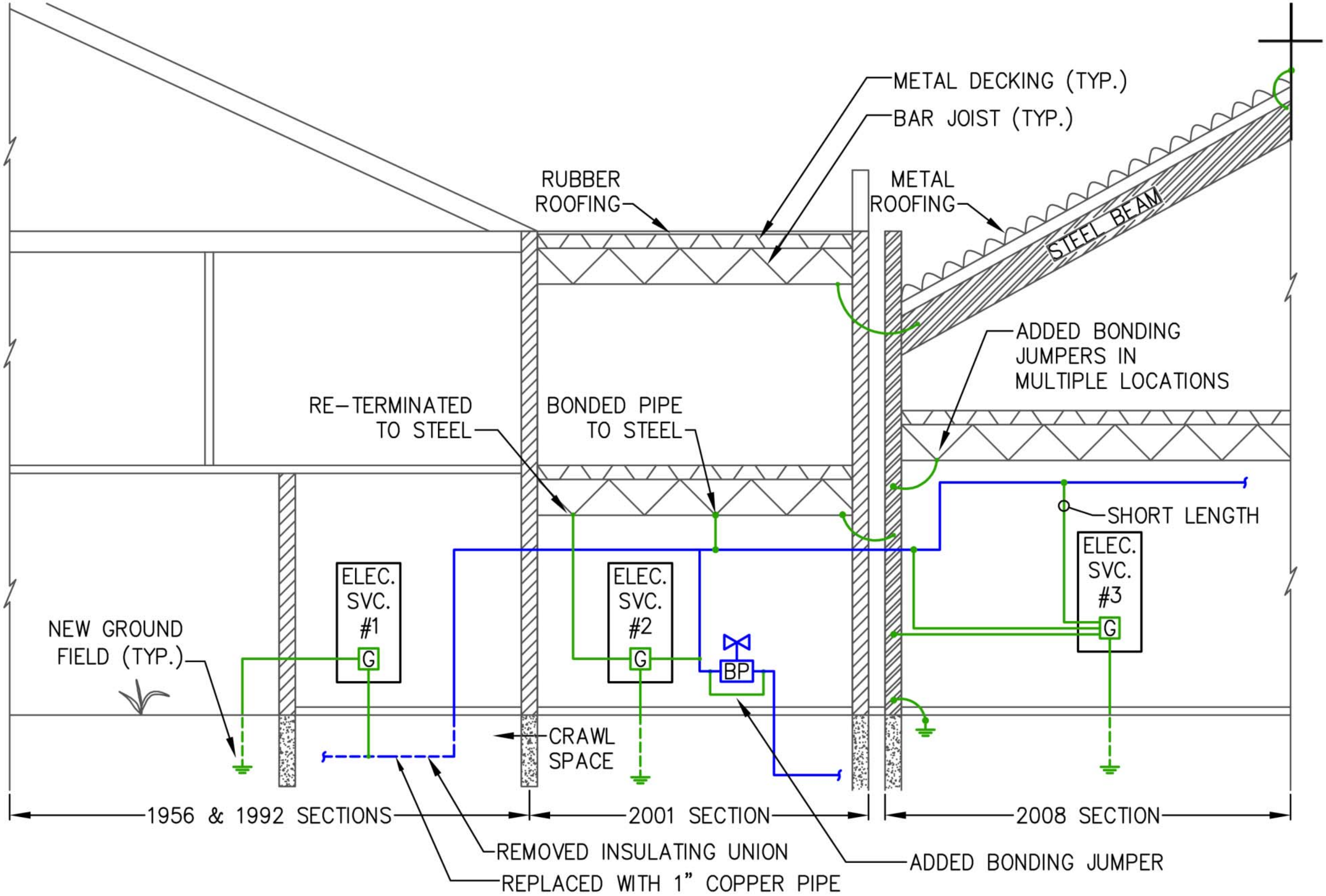
Church Case Study, Lightning Damage

- HVAC DDC Control System.
  - This was the main damage that occurred repeatedly.
  - It occurred occasionally before the 2008 section but escalated after the 2008 section.
  - This system includes a data cable (RS-485 protocol) that daisy-chains through all HVAC unit controllers.
- Video Transmitter in 2008 A/V Control Room and video Receiver in 2001 Café. The café receiver had been damaged 2 to 3 times prior to 2010.
- Intercom and Card reader at main front entrance.

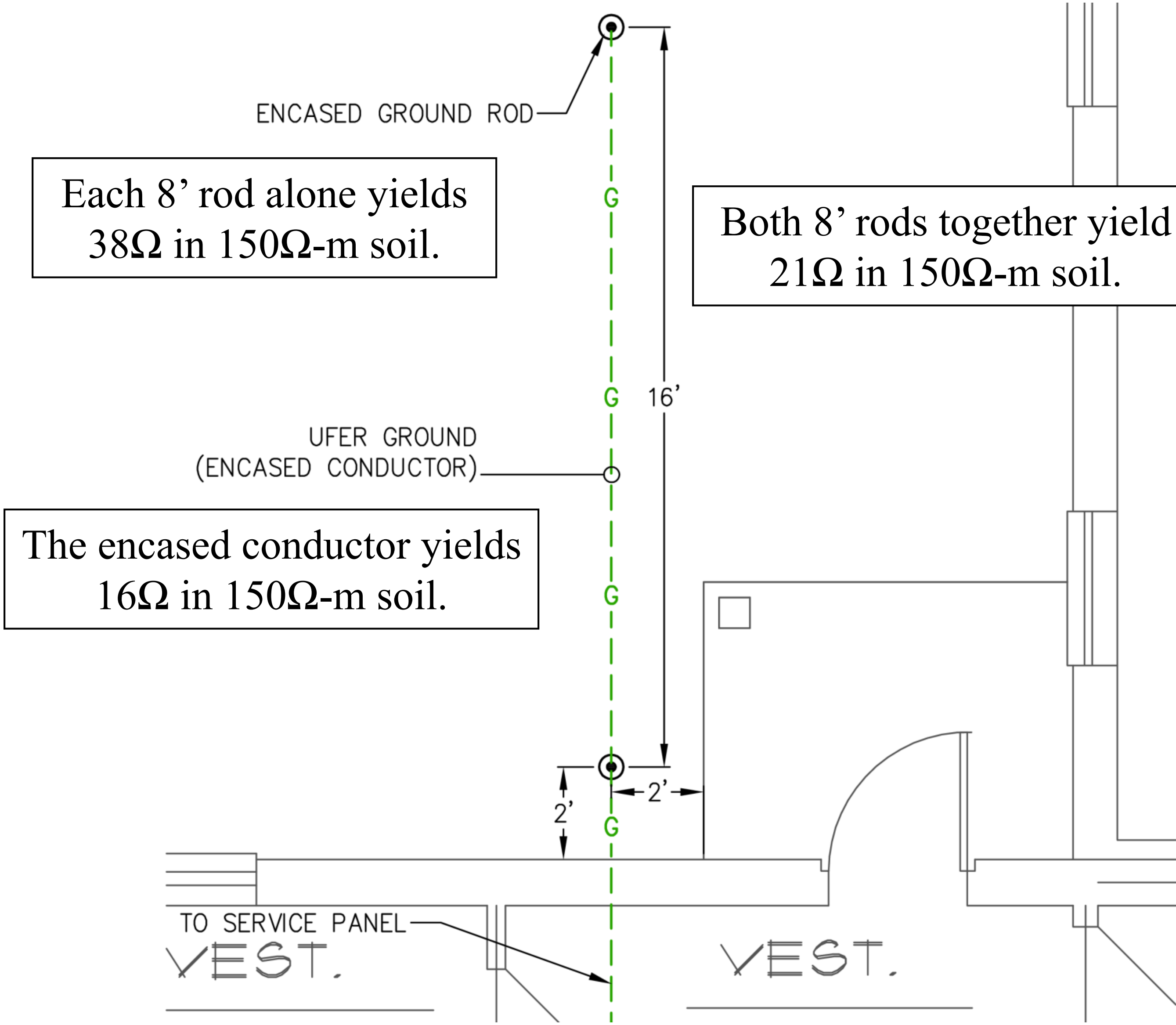
Church Case Study, Grounding Before



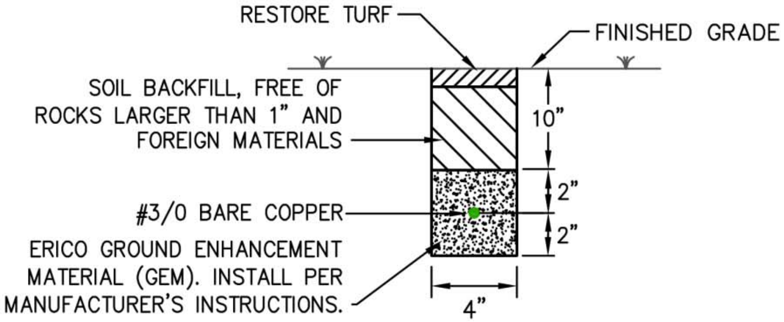
Church Case Study, Grounding After

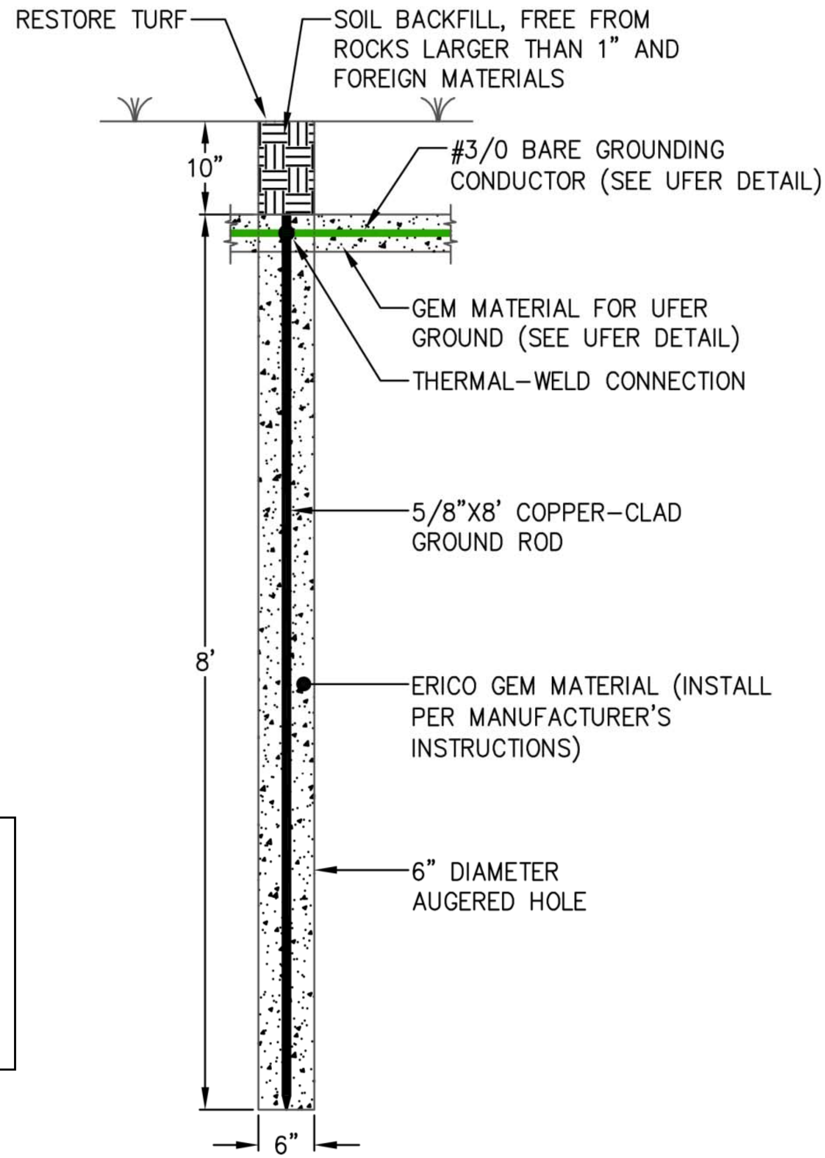


Church Case Study, Typical Ground Field



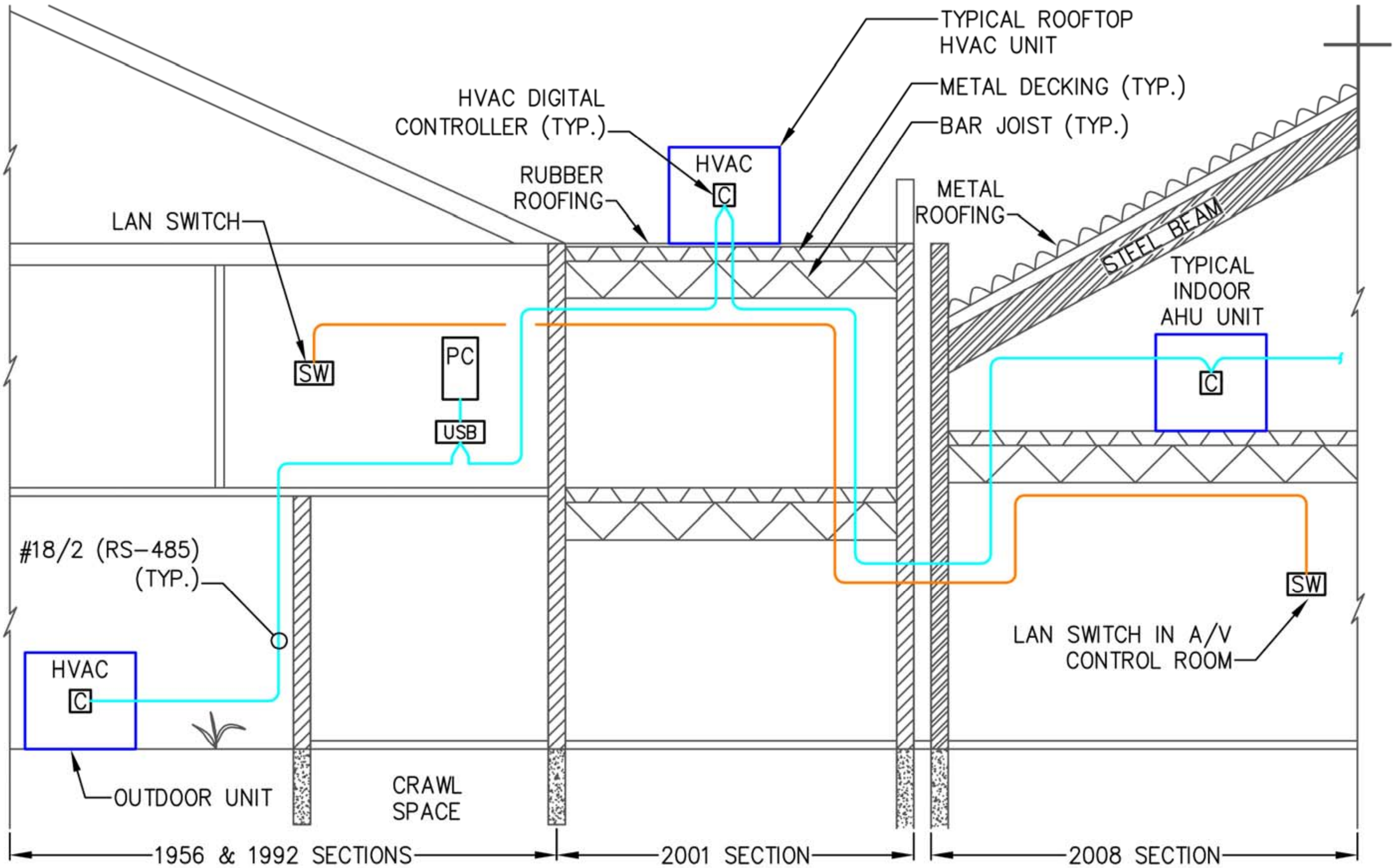
Church Case Study, Ground Field Details



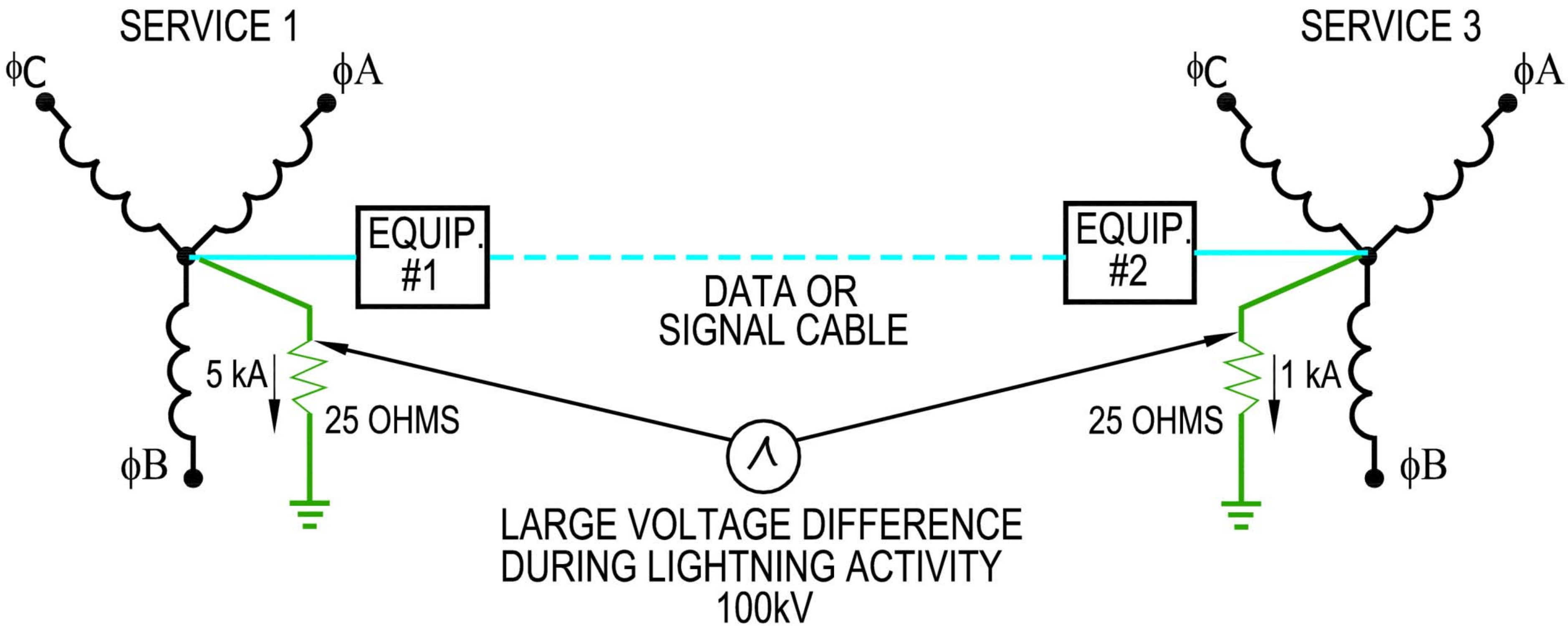


Can download Erico's Ground Resistance calculator from their website or calculate manually per IEEE Green book.

Church Case Study, DDC Controls Before



Church Case Study, Ground Differential



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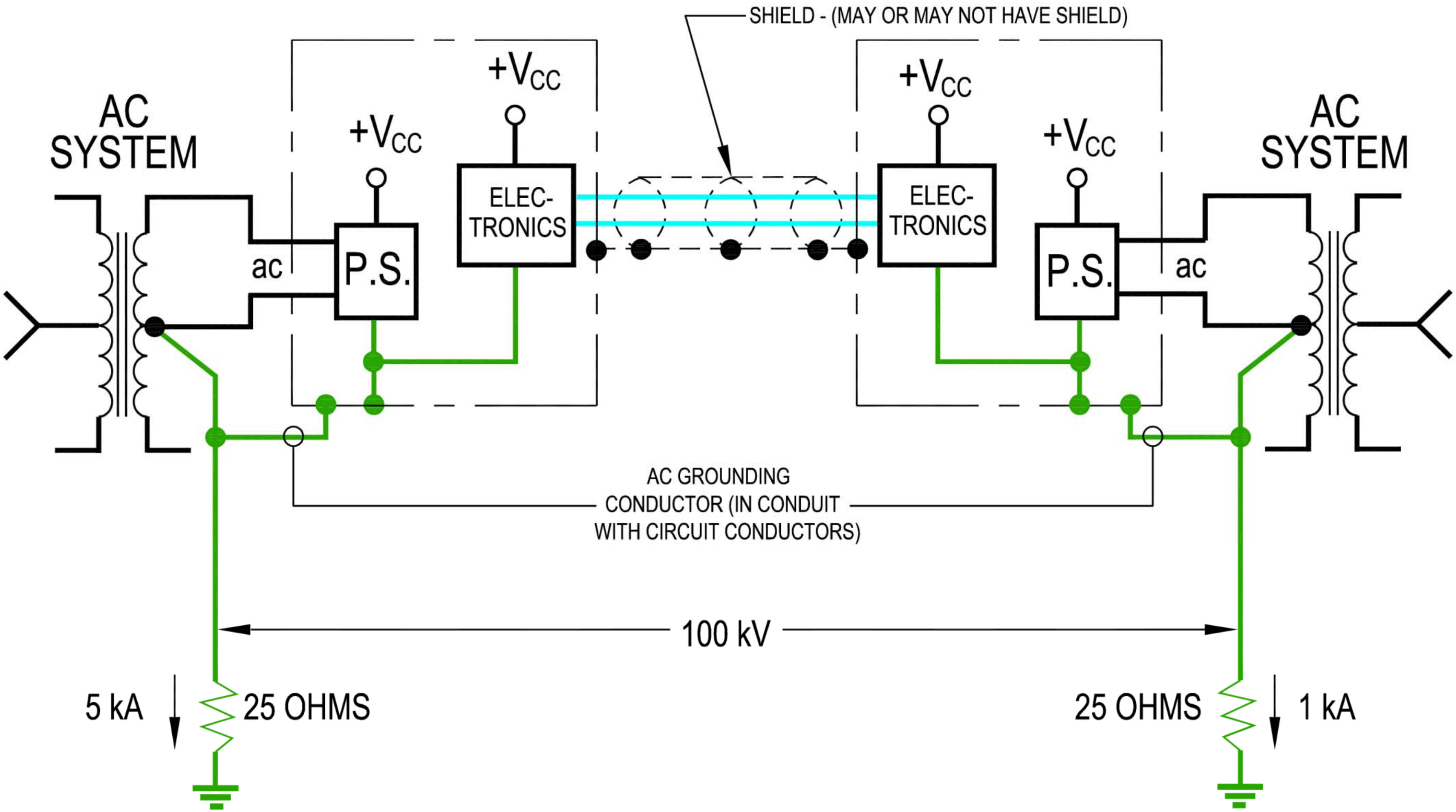
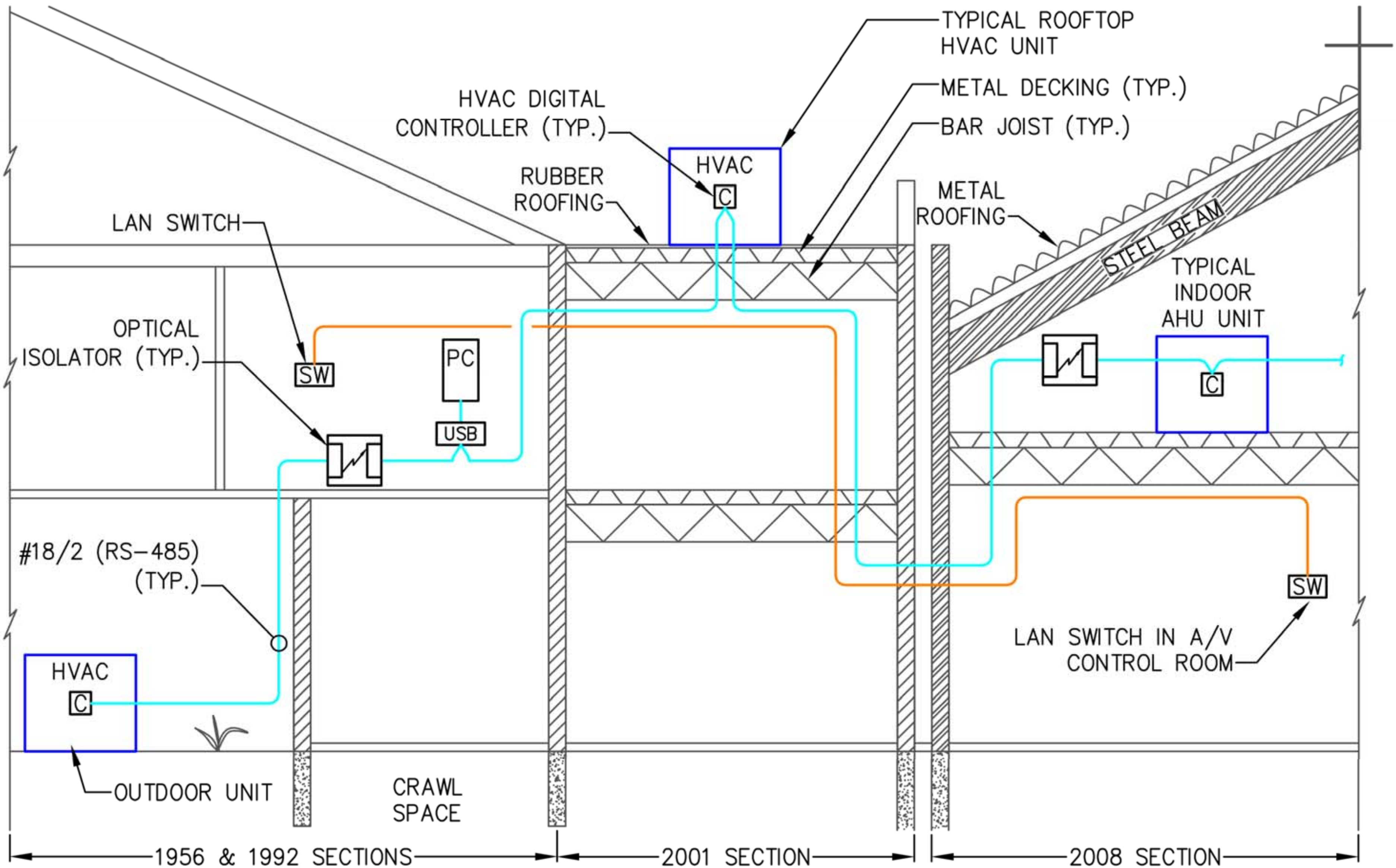
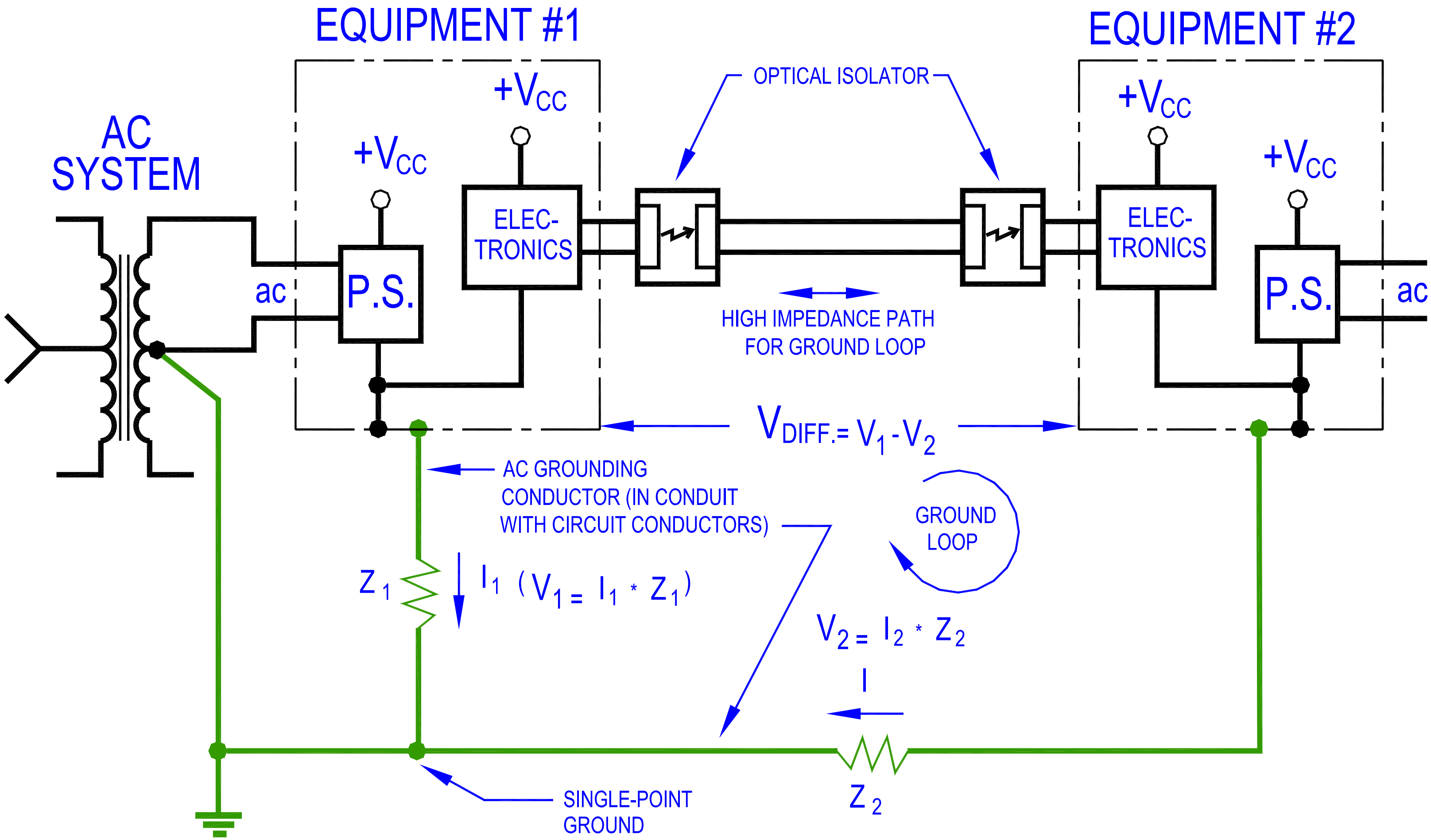


Church Case Study, DDC Controls After



Optical Isolator



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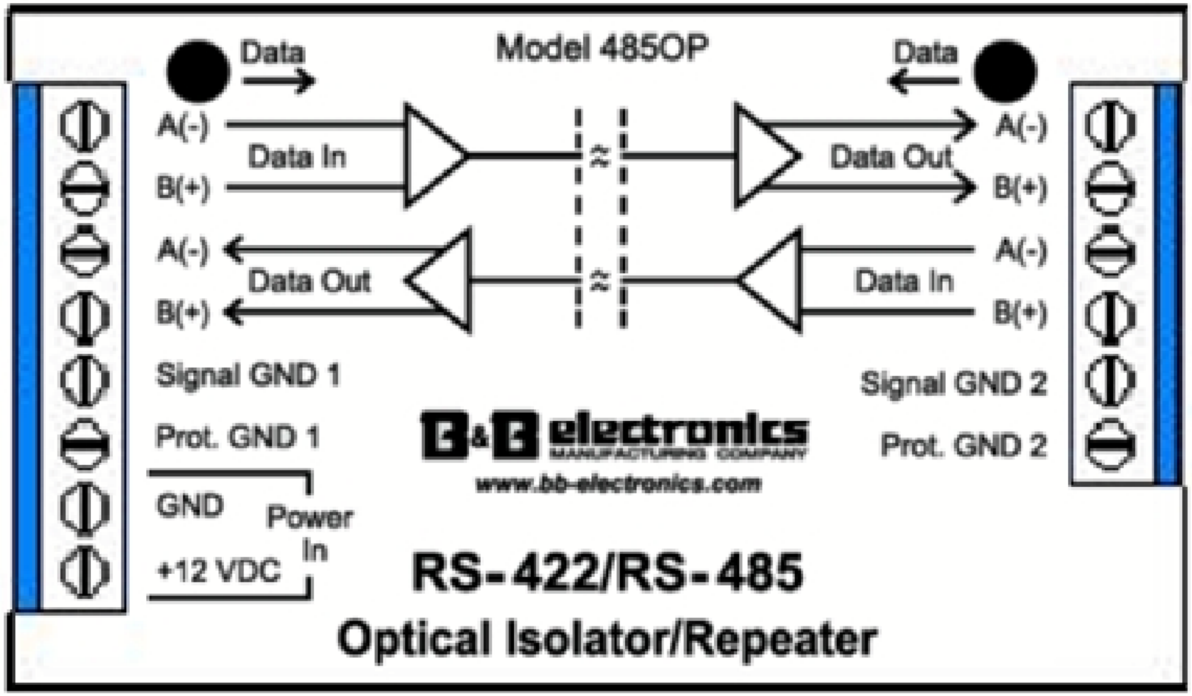
- For 100% isolation use fiber optic cable between equipment

Optical Isolator



- B&B Electronics offers models for various applications
- For Ethernet, use Fiber Optic Media Converters.

Church Case Study, Other Improvements

- SPD for all Electrical Services.
- SPD for all sub-panels that supply rooftop equipment.
- Bonded the same sub-panels to the building steel.
- Monitoring system for SPDs to send alarms via the LAN.
- Improved installation of ac supply SPDs for fire alarm control panels and for low-voltage SPD for fire alarm outdoor circuit to PIV.
- Installed outdoor exposed DDC data cables in steel conduit.
- Intercom and Card reader at main front entrance.

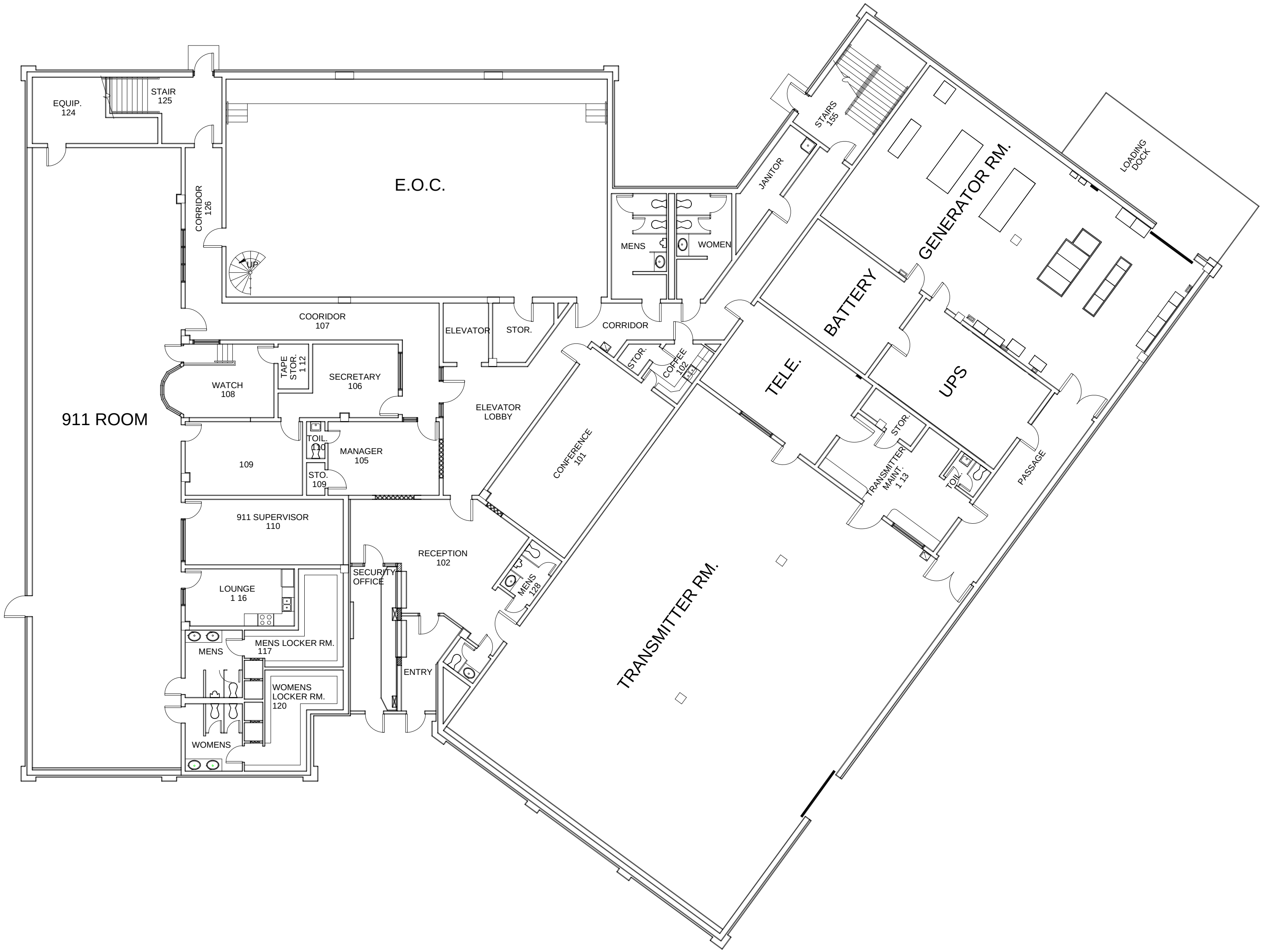
Church Case Study, Lightning Events Since Improvements

- As of December 2010, bonding of steel and water pipes were completed.
- 2/24/11 thunderstorm, no damage.
- 2/28/11 thunderstorm, three DDC controllers failed. Several had to be reset.
- 3/23/11 and 4/4/11, Thunderstorms, no damage.
- Earth Grounding work completed 4/4/11.
- Optical Isolators installed 4/5/11.
- Most other work completed by 4/22/11.
- No problems in recent severe thunderstorms.

Case Study: "Too Much" Grounding

Metro Emergency Communications Center

Case Study: "Too Much" Grounding



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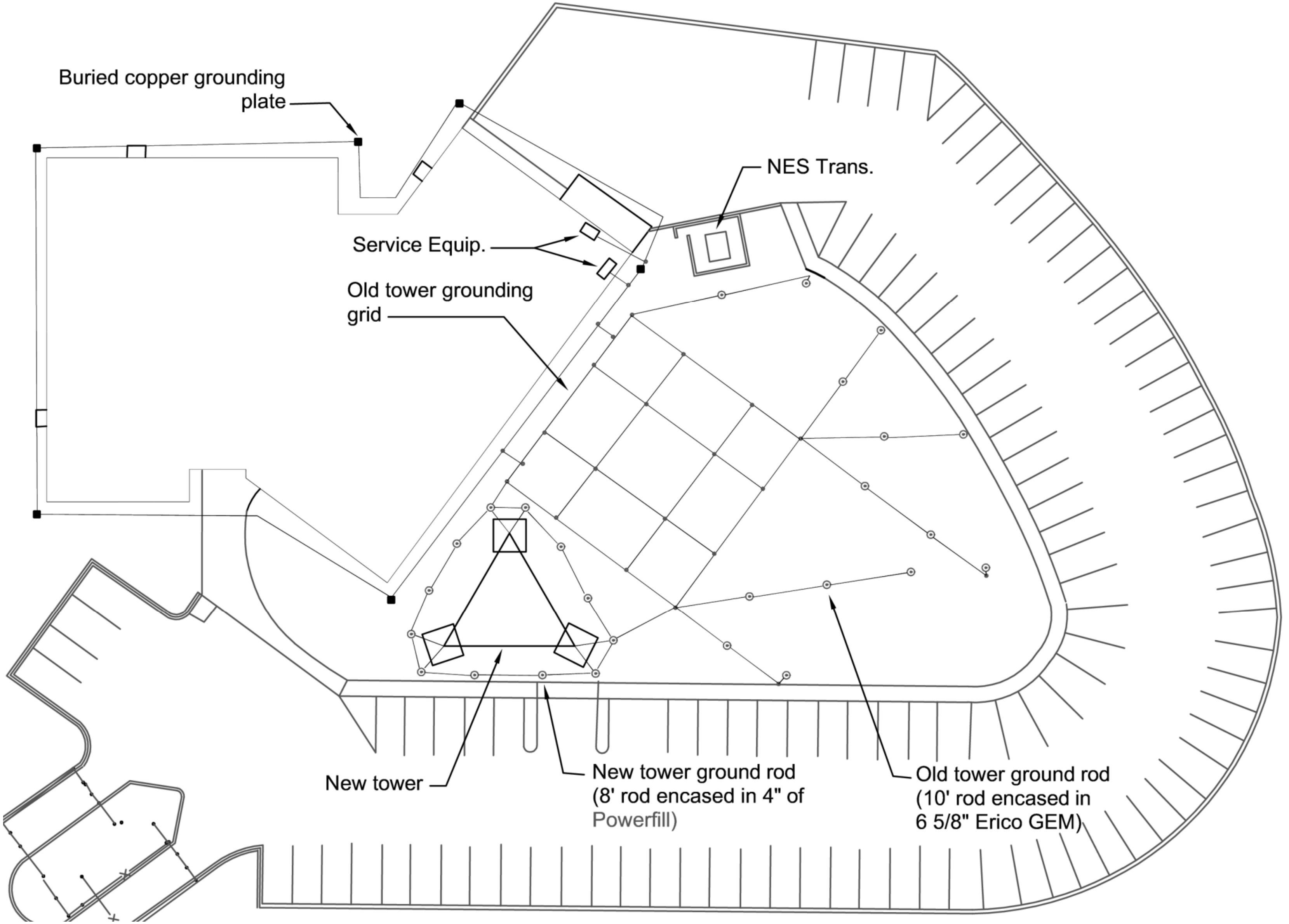
Case Study: "Too Much" Grounding



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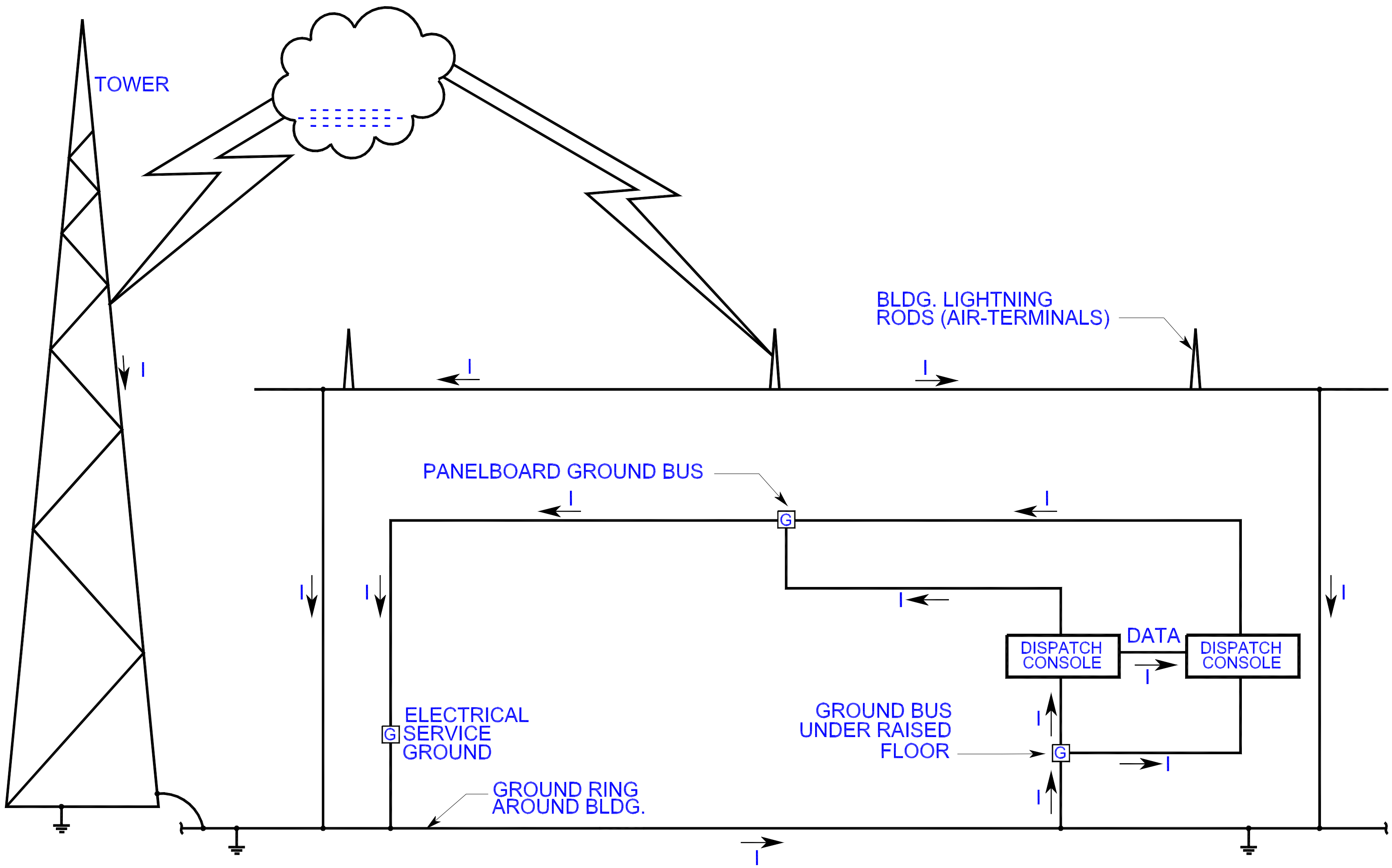
Case Study: "Too Much" Grounding



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Personal Safety from Lightning

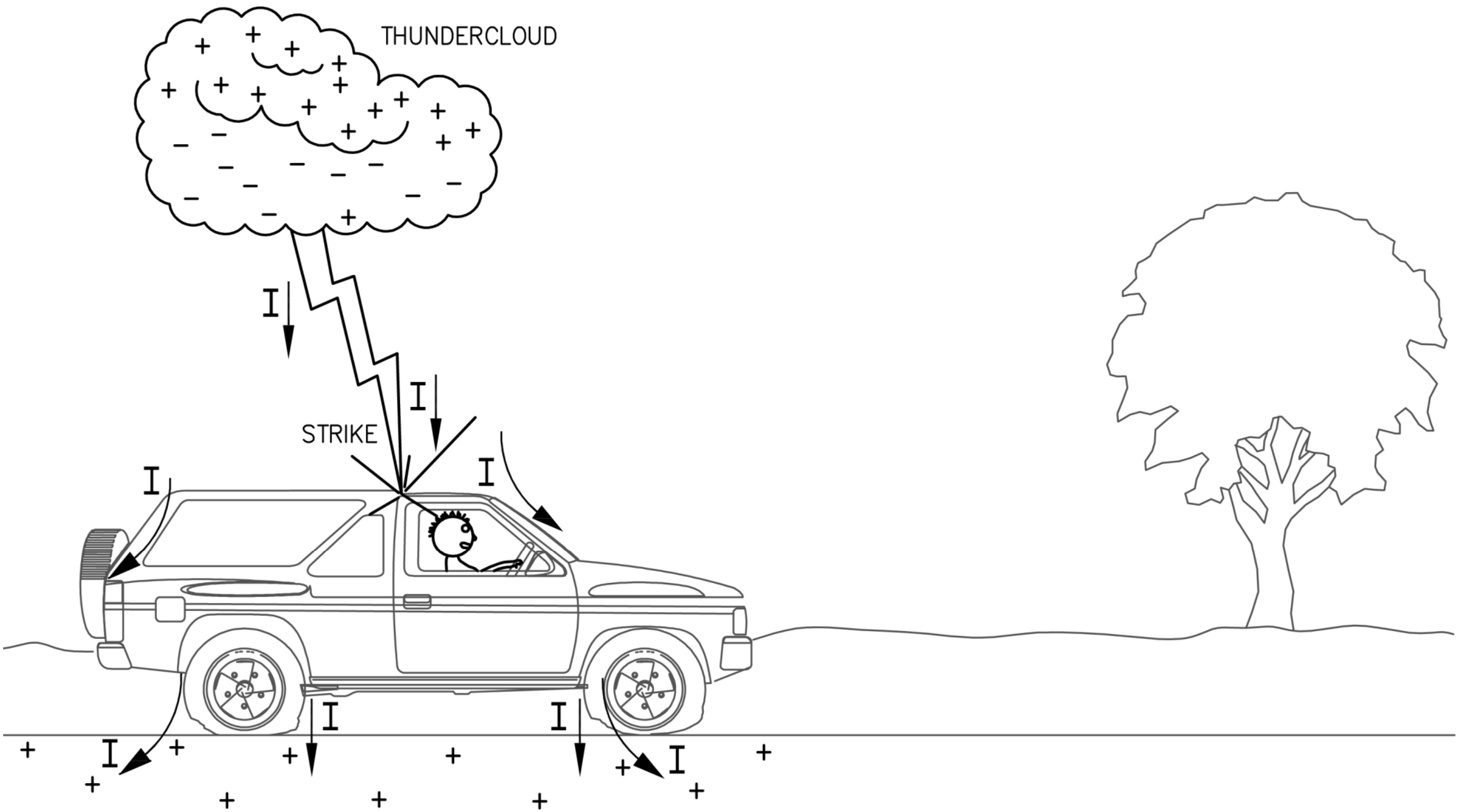
- Safer places include:
  - Buildings that are protected against lightning.
  - Large metal frame buildings.
  - Enclosed automobiles or other vehicles with metal top and bodies.
  - Enclosed metal boats or ships.
  - City streets shielded by nearby buildings. However, be aware of possible voltage gradients should lightning hit a nearby building.

Personal Safety from Lightning, cont.

- If caught in an open area:
  - Crouch as low as possible,
  - Keep feet together,
  - Put hands on knees,
  - To minimize risk of a direct strike, keep as low as possible.
  - To minimize risk of step potential, minimize the area of the body in contact with the ground. Do not lie flat.

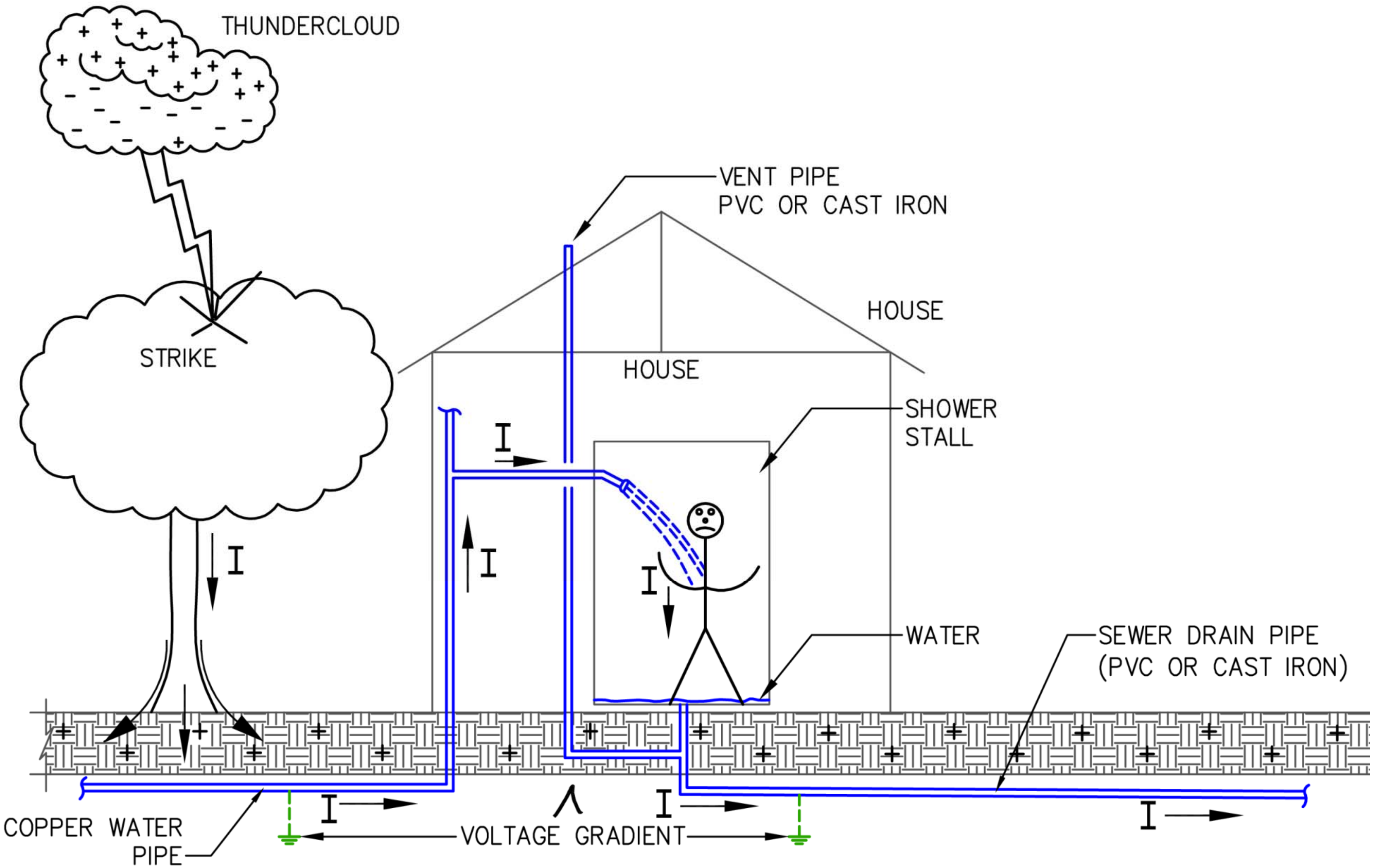
- Refer to NFPA 780 and/or other lightning publications for more safety information.

Personal Safety from Lightning, cont.



Car Protection (Faraday Cage)

Personal Safety from Lightning, cont.



The Shower Jolt!

For Effective Lightning Protection

- Look at THE BIG PICTURE.
- Consider all Systems and Equipment Involved.
- For Personal Safety, Respect Lightning

God Bless America and Our Troops