Lightning Protection

IEEE/MCPQG Meeting

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BETWEEN OFF AND ON

Overview

- **Purposes of Lightning Protection**
- **Lightning Statistics**
- **Physics of Lightning**
- **Modes of Equipment Damage**
- **How does Lightning “Get-In”**
- **Systems affected by Lightning**
- **Lightning Protection**
  - Grounding and Bonding
  - Shielding
  - Circuit Isolation
  - Surge Protection (lightly covered)
  - Building Envelope Lightning Protection System (not included)

Purposes of Lightning Protection

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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

Lightning Statistics

- **30 to 1200 Lightning Flashes per Second around the World (Cloud-to-Cloud, Intracloud, & Cloud-to-Ground).**
- **Up to 9 Million Flashes per Day Worldwide.**
- **Cloud (Cloud-to-Cloud & Intracloud) Discharges account for more Flashes than Cloud-to-Ground Flashes (Intracloud most common).**
- **Cloud-to-Ground Flash Densities (Flashes / Square km per Year:**
  - Greater Nashville: 5 to 6
  - Tampa, FL: 14+ (Highest in U.S.)
  - Along West Coast: 0+ to 0.1 (Lowest in U.S.)

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Lightning Statistics

- **Insurance Payouts in U.S.: ~ $1 Billion/yr.**
- **Cost of U.S. Lightning Damage: More than $1 Billion/yr.**
- **NFPA Reports ~ 30,000 Lightning Caused House Fires each Year with Cost of $175 Million.**
- **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

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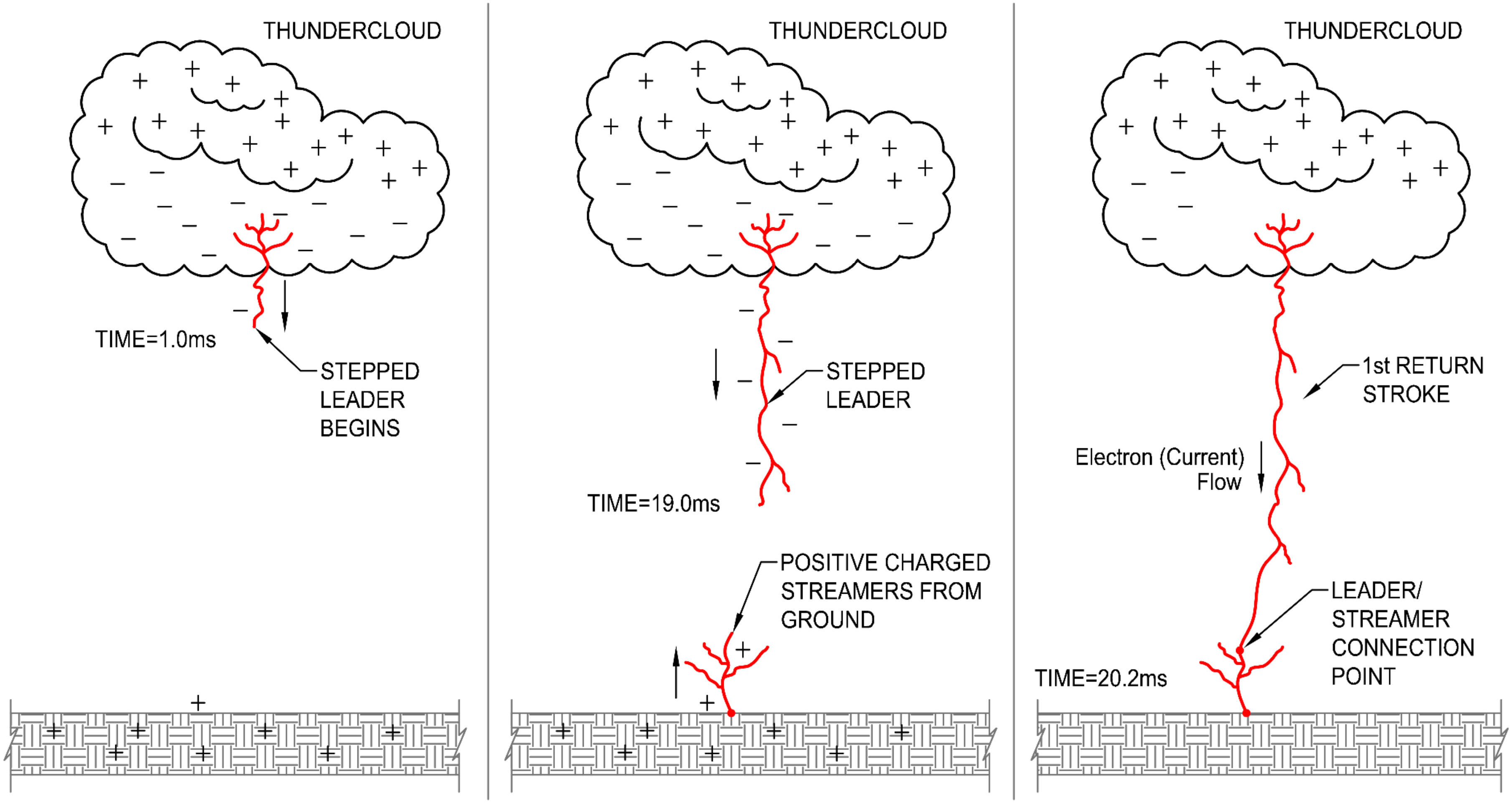
Physics of Lightning

- **Leader Potential of 1,000,000 to 10,000,000 Volts with Respect to Earth.**
- **Typical 1st Return Stroke nearly 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. 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. Equates to 56kHz to 1.1MHz with 227kHz being typical.**

Lightning Stroke



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Lightning Stroke


The shape Represents a Downward Leader

Leader/Streamer Connection

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Modes of Lightning Damage

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Modes of Lightning Damage

- **Direct Lightning Strike**
- **Resistive Coupling (Conduction)**
- **Inductive Coupling (Electromagnetic)**
- **Capacitive Coupling (Electrostatic)**

Direct Lightning Strike

BEFORE STRIKE

AFTER STRIKE

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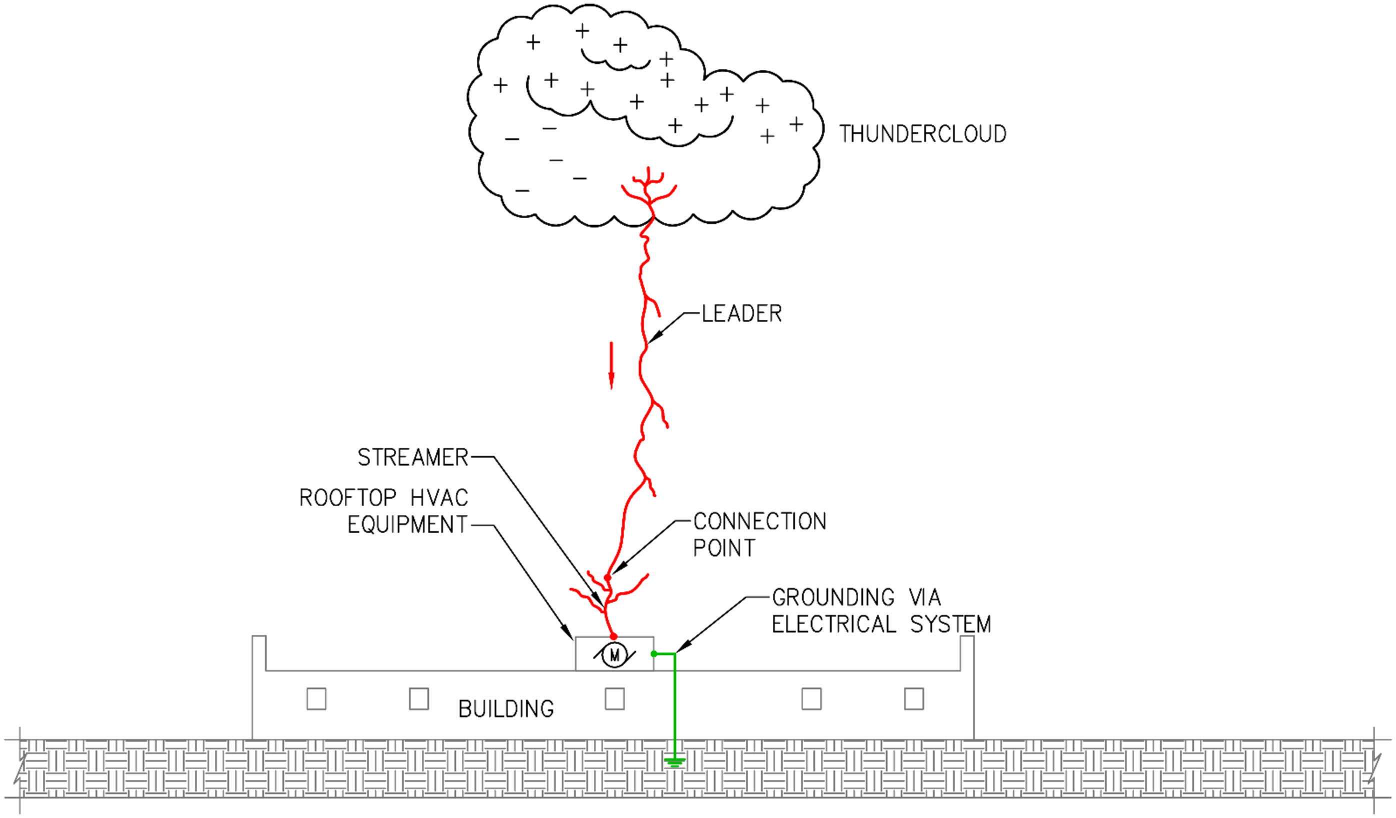
Direct Lightning Strike



- **Direct strike can cause extensive damage to equipment that is struck and to equipment within building**

Direct Lightning Strike

Rooftop HVAC Unit

Typical Compressor Terminals

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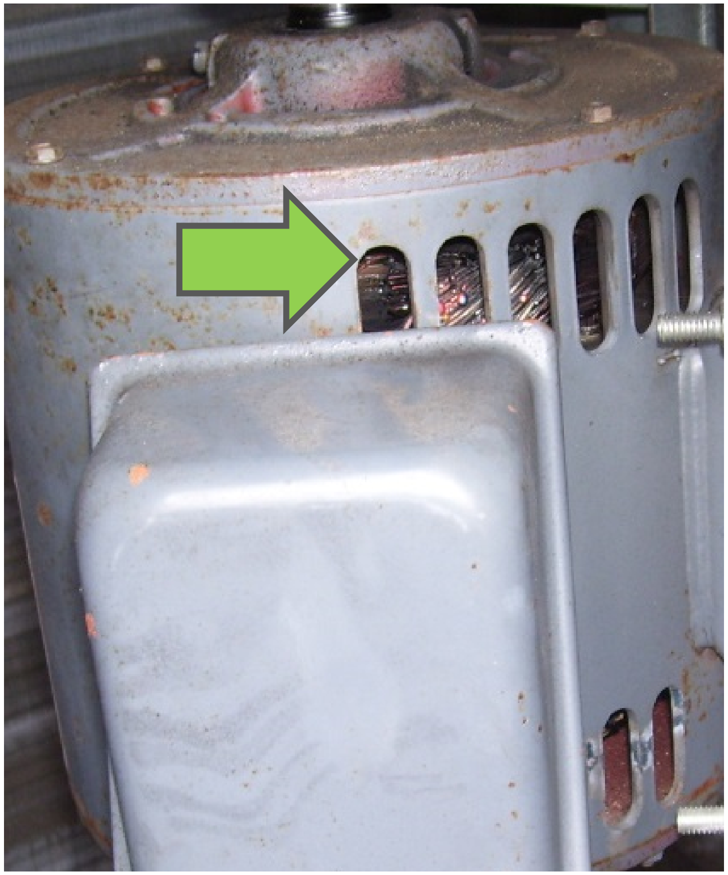
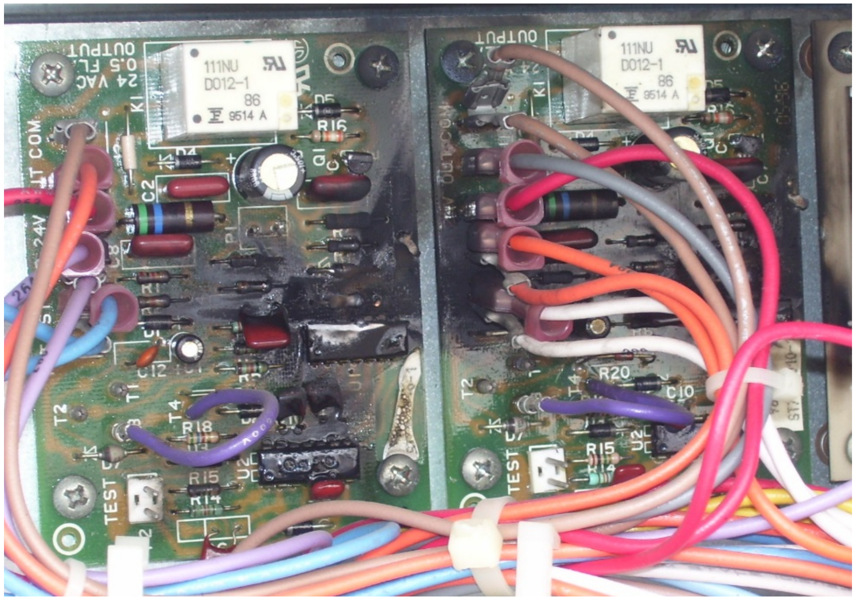
Direct Lightning Strike

Rooftop HVAC Unit, Continued



Fan Motor



Circuit Board

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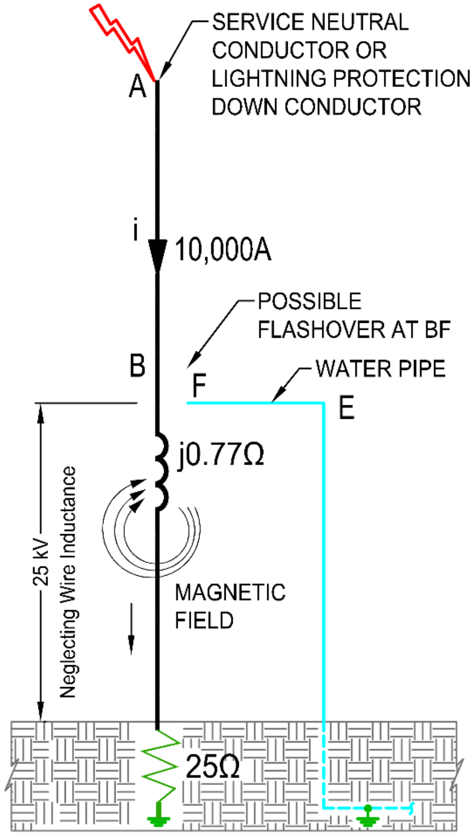
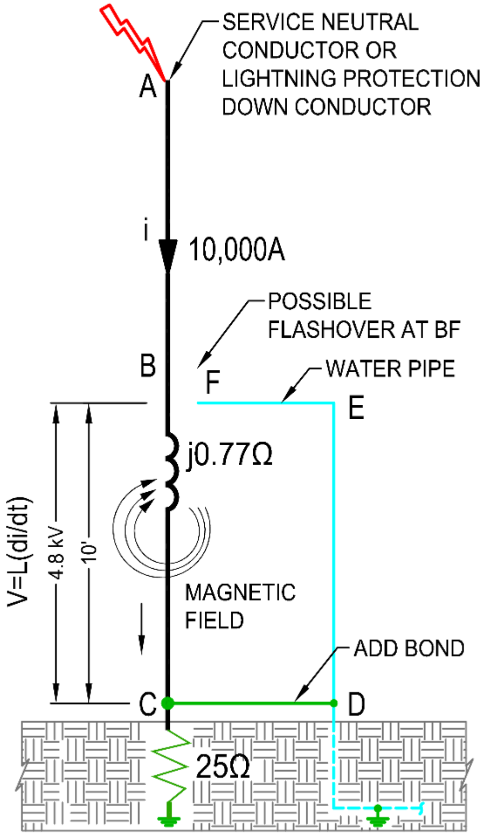
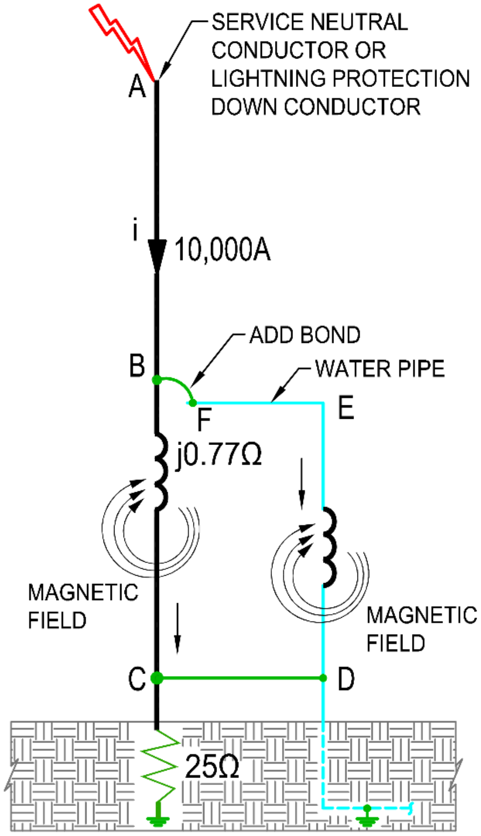
Resistive & Inductive Coupling



RESISTIVE & INDUCTIVE COUPLING



RESISTIVE COUPLING CONTROLLED



BOTH RESISTIVE & INDUCTIVE COUPLING CONTROLLED

- **Based on Typical 1st Return Stroke 5.5µs Rise Time.**
- **NFPA 780 Bonding Distance Calculation is based on Inductive Coupling.**

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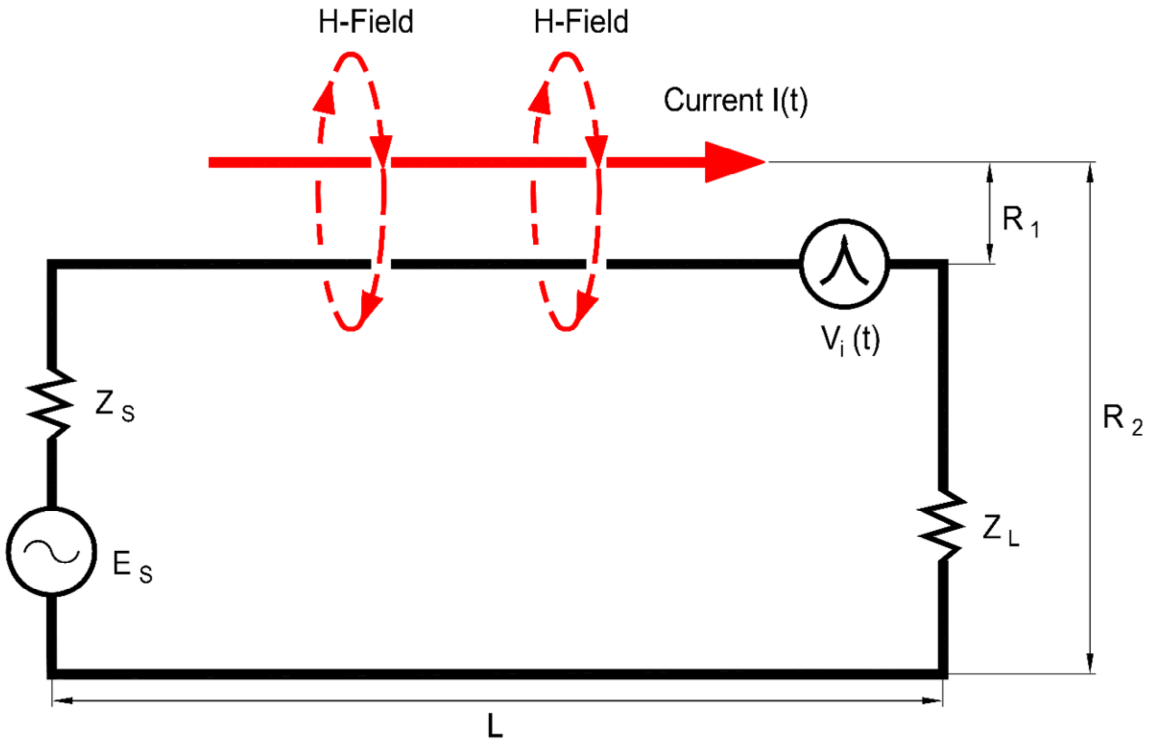
Inductive Coupling



- **Induced Voltage $V_i(t) = \mu L f I(t)[\ln(R_1/R_2)]$, where μ is permeability of the medium and dimensions (L, R_1, and R_2) are in meters.**
- **In free space, $\mu = 4\pi \times 10^{-7}$**

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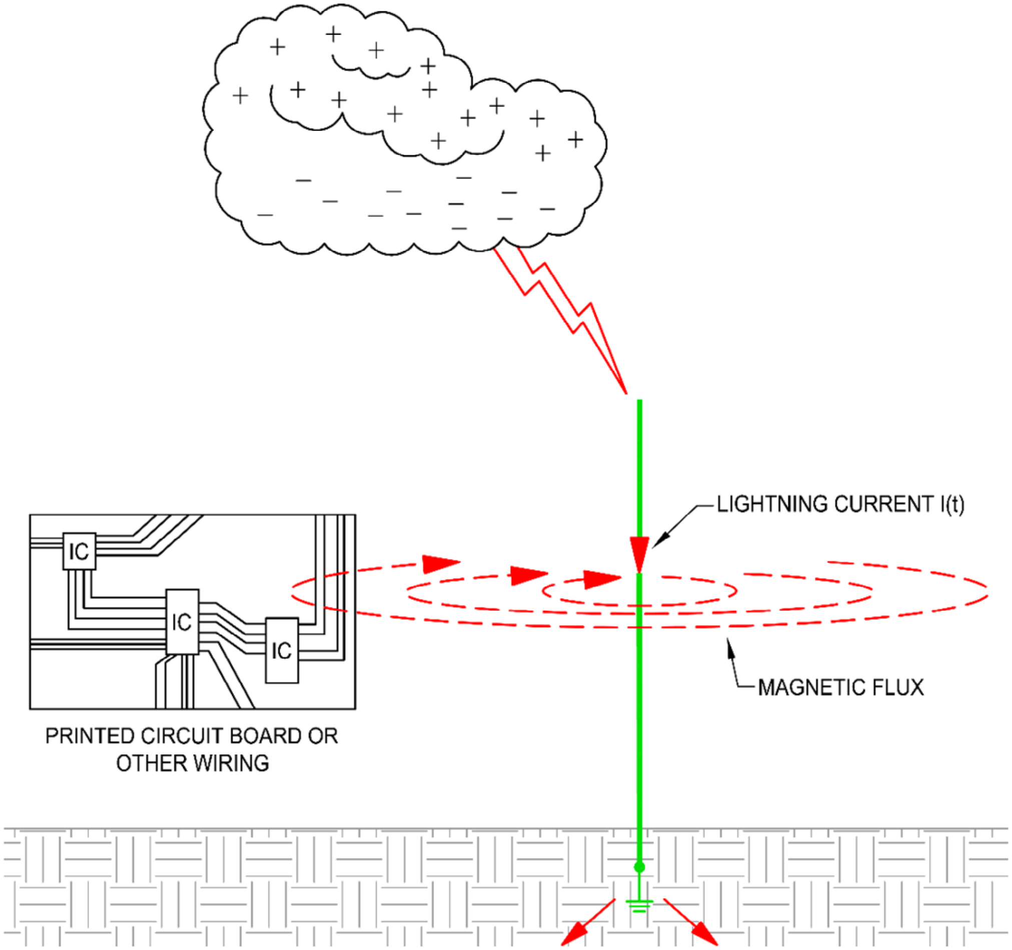
Inductive Coupling



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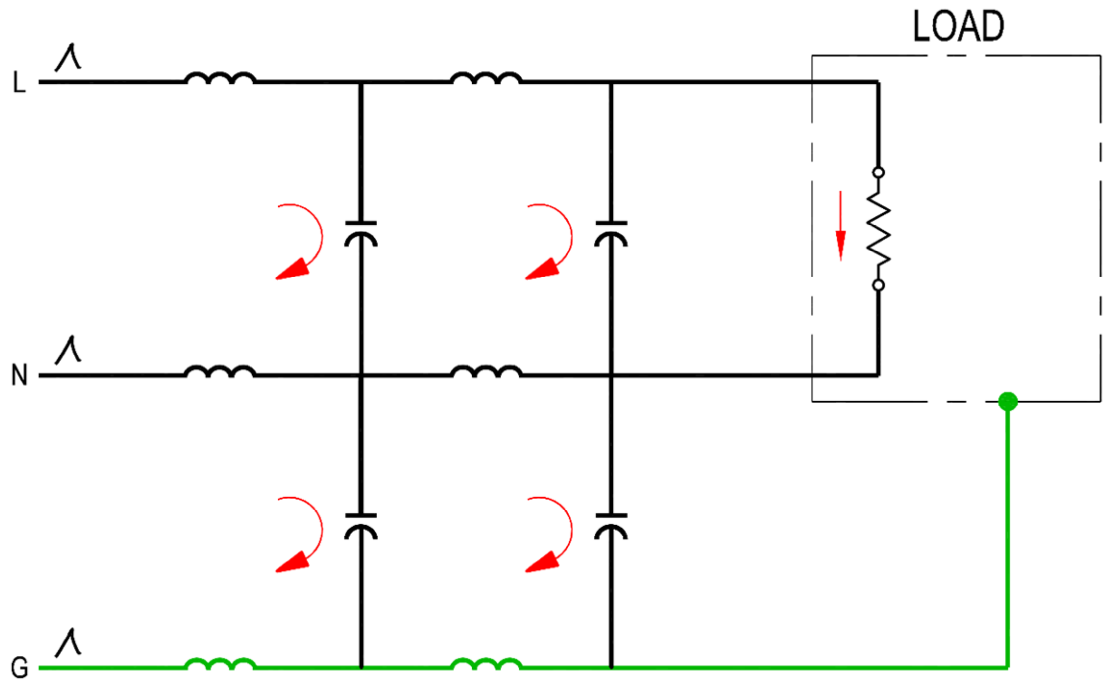
Inductive & Capacitive Coupling



- **Voltage Transients travelling along conductors will couple/induce voltages into adjacent conductors via mutual capacitance and inductance. Zc=1/(2πfC).**
- **Thus, good reason to include all modes of SPD protection.**

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How Does Lightning “Get-In”

How Does Lightning "Get In"

- **Surges Capacitively and Magnetically Coupled through Utility Transformer**
- **Service Neutral Conductor**
- **Surges Induced into Service Entrance Conductors**
- **Shield of Telephone or CATV Service Entrance Cables**
- **Shield of Satellite or TV Antenna Cables**
- **Shield of Radio Antenna Cables**
- **Surges Induced into External Power Circuits**

How Does Lightning "Get In"

- **Surges Induced into External Low-Voltage Circuits (Telephone, CATV, Satellite, CCTV, Security, Fire Alarm, Monitoring, Generator Annunciation & Controls, etc.)**
- **Lightning Protection Down Conductors**
- **Building Steel**
- **Rooftop Equipment**
- **Ground Differential between Electrical Services, Buildings, and/or Sections within same Building**

Systems affected by Lightning

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Systems affected by Lightning:

- **Power**
- **Telephone**
- **CATV and Satellite TV**
- **Radio and TV Communications**
- **Computer Network (Hardwired and Wireless)**
- **Fire Alarm**
- **CCTV**
- **Security (Intrusion and Access Control)**
- **Intercom or Public Address**
- **Annunciators (e.g. outdoor generator)**
- **Monitoring Systems (DCIM, etc.)**
- **Building Automation System**
- **Gate Operators**
- **Etc.**

Lightning Protection

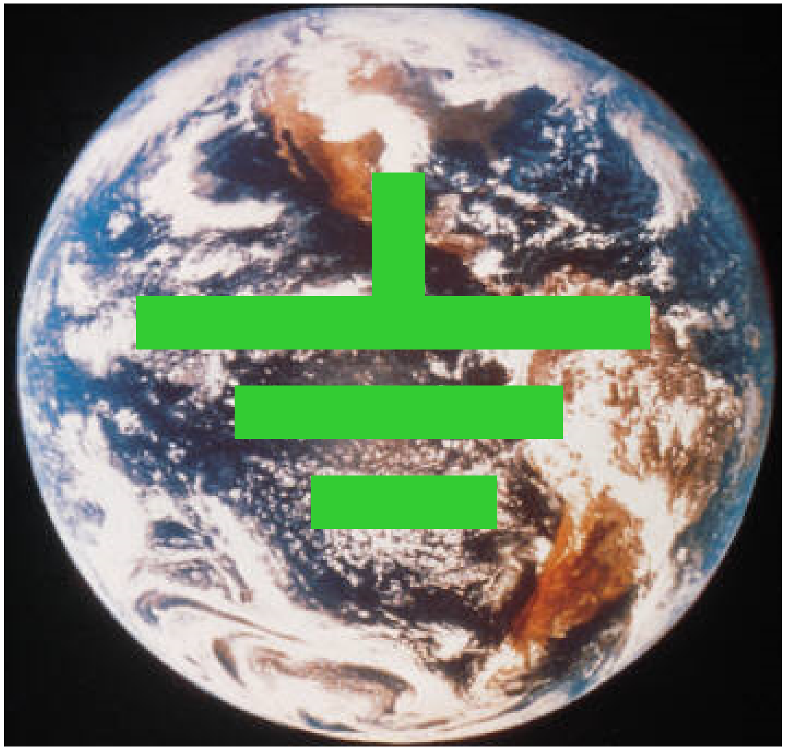
Lightning Protection

- **Grounding and Bonding (1st and Best Defense)**
- **Shielding**
- **Circuit Isolation**
- **Surge Protection**
- **Building Envelope Lightning Protection System**

Grounding and Bonding

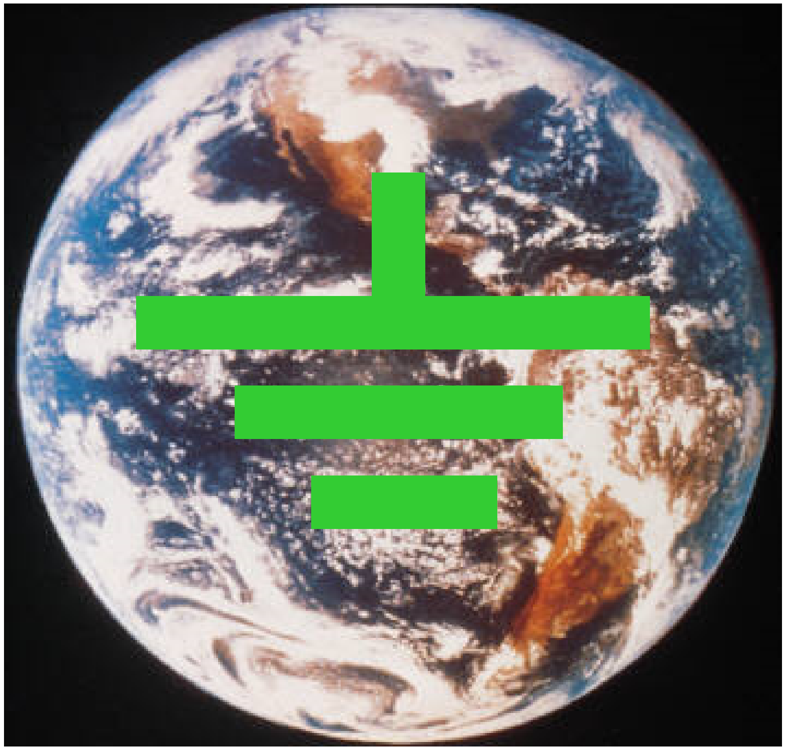
- **Earth Connection**
  - Earth Resistivity
  - Grounding Electrode System
- **Low Impedance Path to Ground (Earth)**
- **Equipotential Ground Reference**

Earth Resistivity



- Earth is composed of (1) rock derivatives (sand, clay, etc.), (2) soluble salts, acids, etc., and (3) water (about 20% normally).
- The first component is very highly resistive so does not contribute to the current flow.
- The 2nd component combined with the 3rd component (water) becomes an electrolyte, which has moderate resistivity.
- It is the combination of the 2nd & 3rd components that carry the electric current. Absence of either one makes the earth highly resistive.

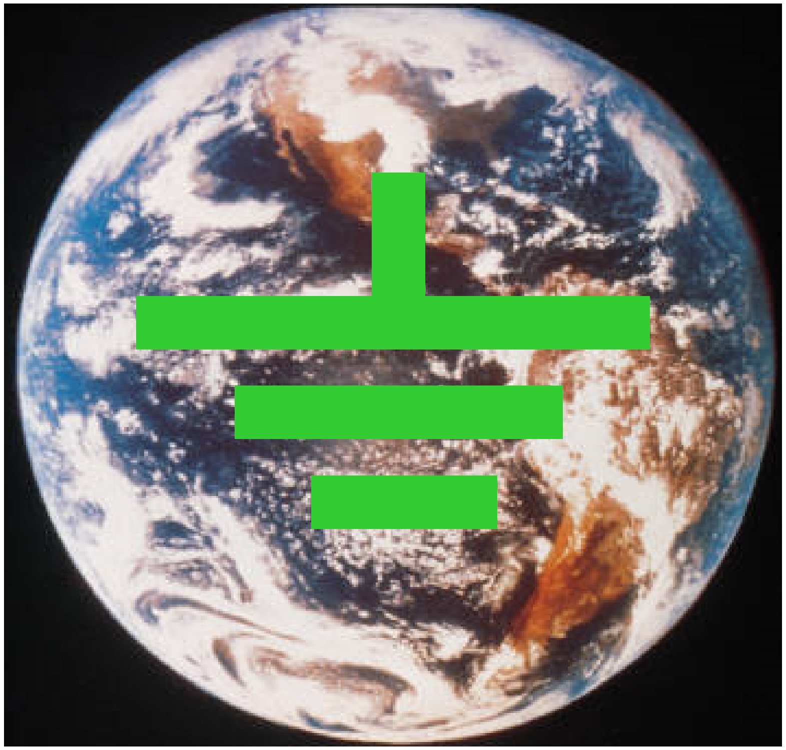
Earth Resistivity



- Soil Resistivity is the measurement of the resistance of a homogenous cubic unit of soil.
- For example, 15,000 ohm-cm soil includes 1 cubic centimeter of homogenous soil that measures 15,000 ohms between any two sides.
- Earth is a relatively Poor Conductor.
- The Resistivity of moist topsoil is about 6 Billion Times higher than Copper.
- The relative low Conductivity is overcome by being so massive; Diameter equal to its Length.

Earth Resistivity

Comparison of Resistivities (Ohm-cm)



- **Salt Marsh: 250 - 1,000 (Soil is Corrosive below 2,000).**
- **Moist Top Soil: 5,000 – 20,000**
- **Concrete: 3,000**
- **GEM: 20**
- **Copper: 1.72 x 10^{-6}**

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Grounding Electrode System

NEC Required Grounding Electrodes, Where Present

- **Rod or Pipe Electrode (Min. 8 ft)**
- **Metal Underground Water Pipe 10’ or more in Earth**
- **Concrete Encased Electrode (Rod , Conductor, or Rebar)**
- **Plate Electrode**
- **Ground Ring Encircling Building**
- **Building Steel Member 10’ or more in Earth**
- **Building Steel Column Hold-Down Bolts connected to Concrete-Encased Electrode**

Grounding Electrode System

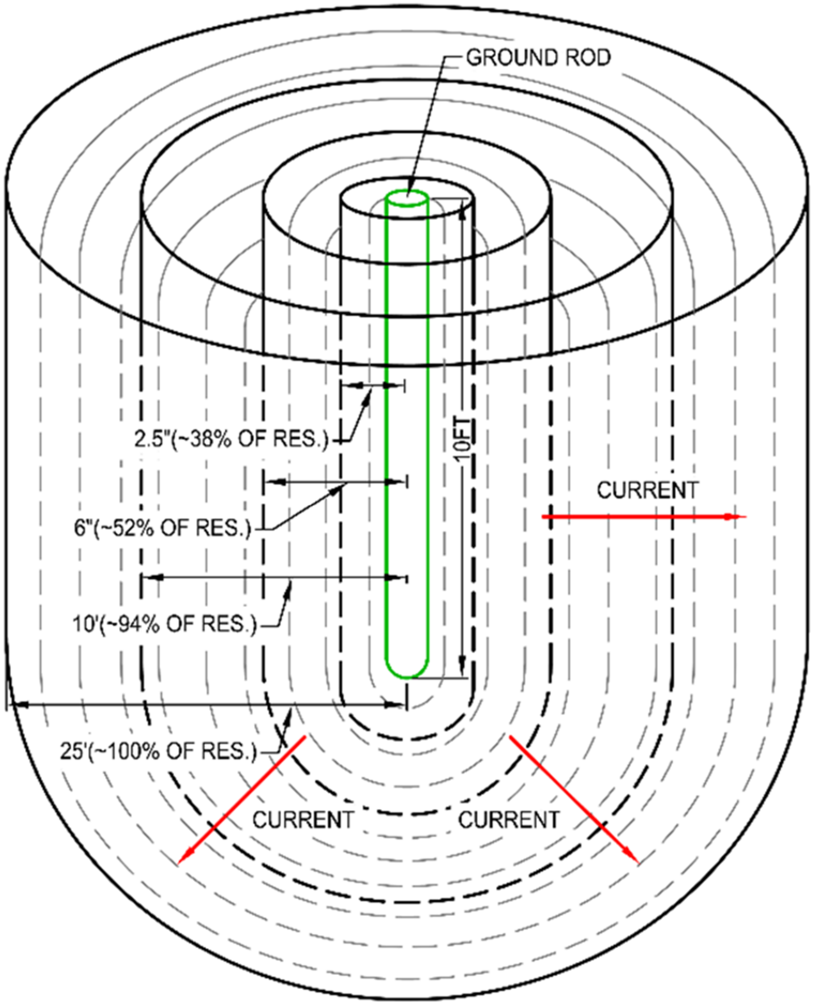
NEC Required Supplemental Grounding Electrodes

- **Metal Underground Water Pipe must be Supplemented by a Rod or other acceptable Electrode**
- **Where Single Rod, Pipe, or Plate Electrode is the only Grounding Electrode, must have an Earth Resistance of 25 Ohms or less or be Supplemented by another Rod, Plate, or other acceptable Electrode**

Grounding Electrode Resistance

“Interfacing Hemisphere”

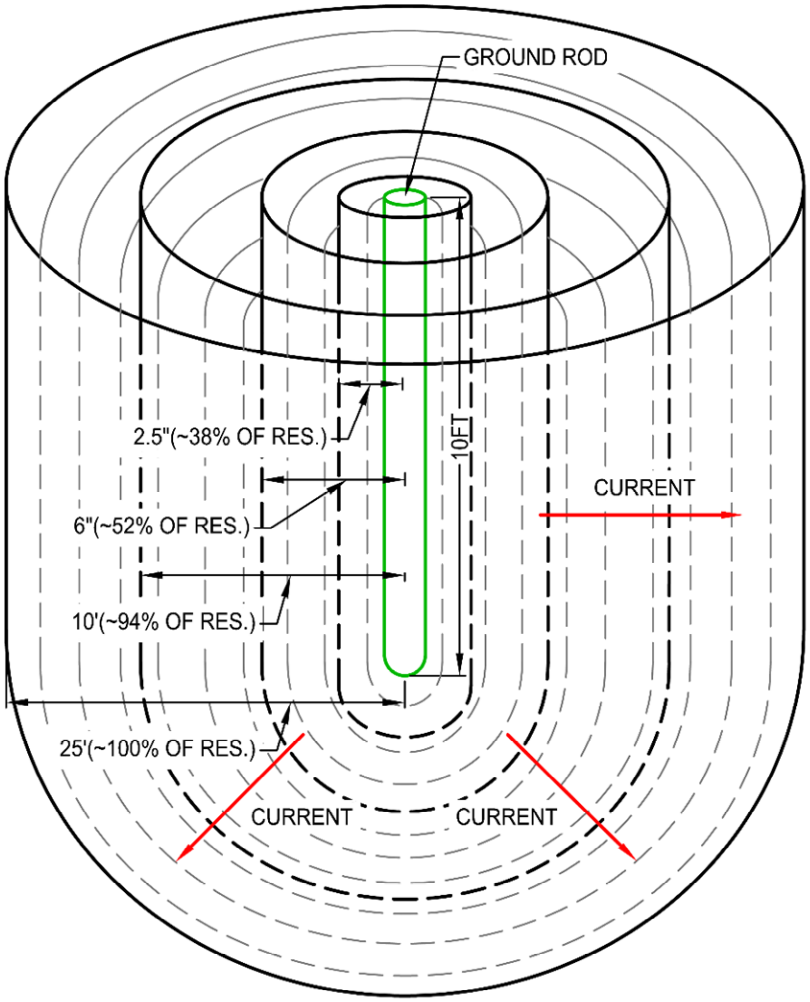
- **The Interfacing Hemisphere makes up approximately 100% of the rod’s earth connection (i.e. resistance).**
- **Virtual Cylindrical Shells of Earth Extend Outward from Rod.**
- **Shells nearest the rod have the smallest cross sectional area and thus the highest resistance and highest voltage gradients.**
- **Therefore, the first few inches away from the rod are the most important for reducing the earth resistance.**



Grounding Electrode Resistance

“Interfacing Hemisphere”

- **Successive shells have progressively larger areas and thus progressively lower resistances. As the radius from the rod increases, the incremental resistance per unit of radius deceases effectively to zero.**
- **Total Electrode Earth Resistance is the sum of the series resistances of the virtual shells of earth.**
- **The Rod’s Effective Interfacing Hemisphere (IH) radius is approximately 1.0 times the rod length. Therefore, it is best to space rods at least 2 times their length.**
- **Closer Spacing Reduces the Full Benefit, analogous to filling overlapping buckets**



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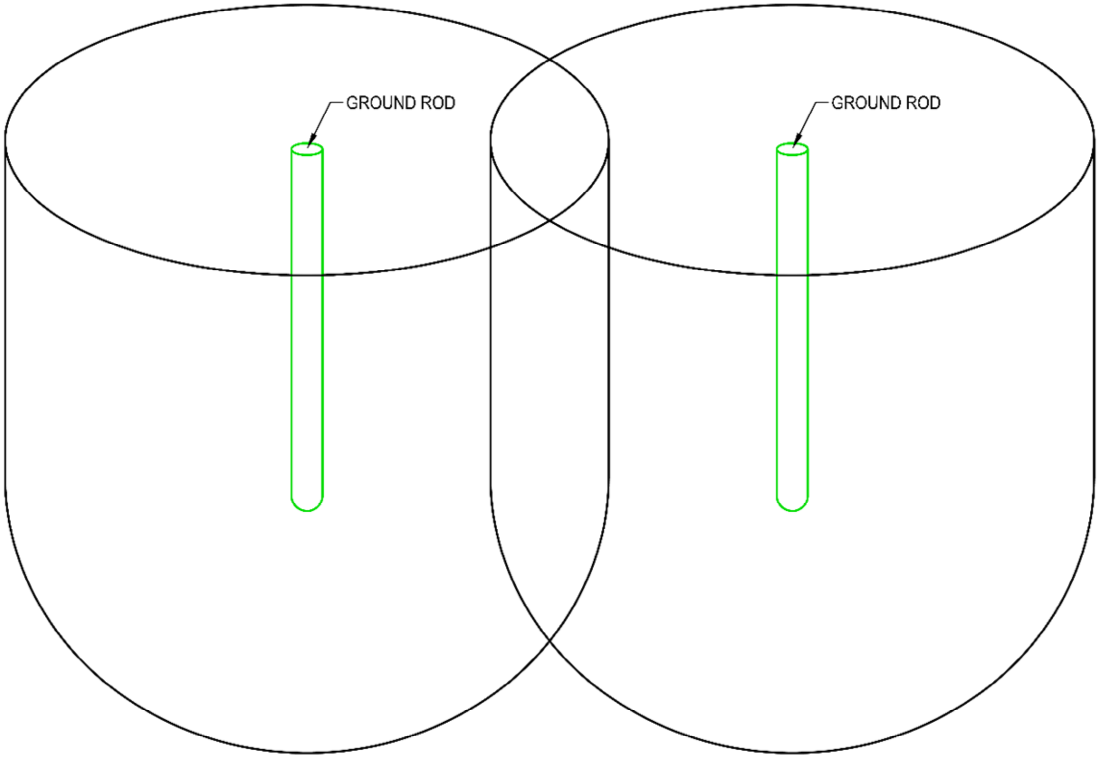
Grounding Electrode Resistance

“Interfacing Hemisphere”



- **Rods are too close causing overlapping of Interfacing Hemispheres**
- **Reduces the Full Benefit, analogous to filling overlapping buckets**

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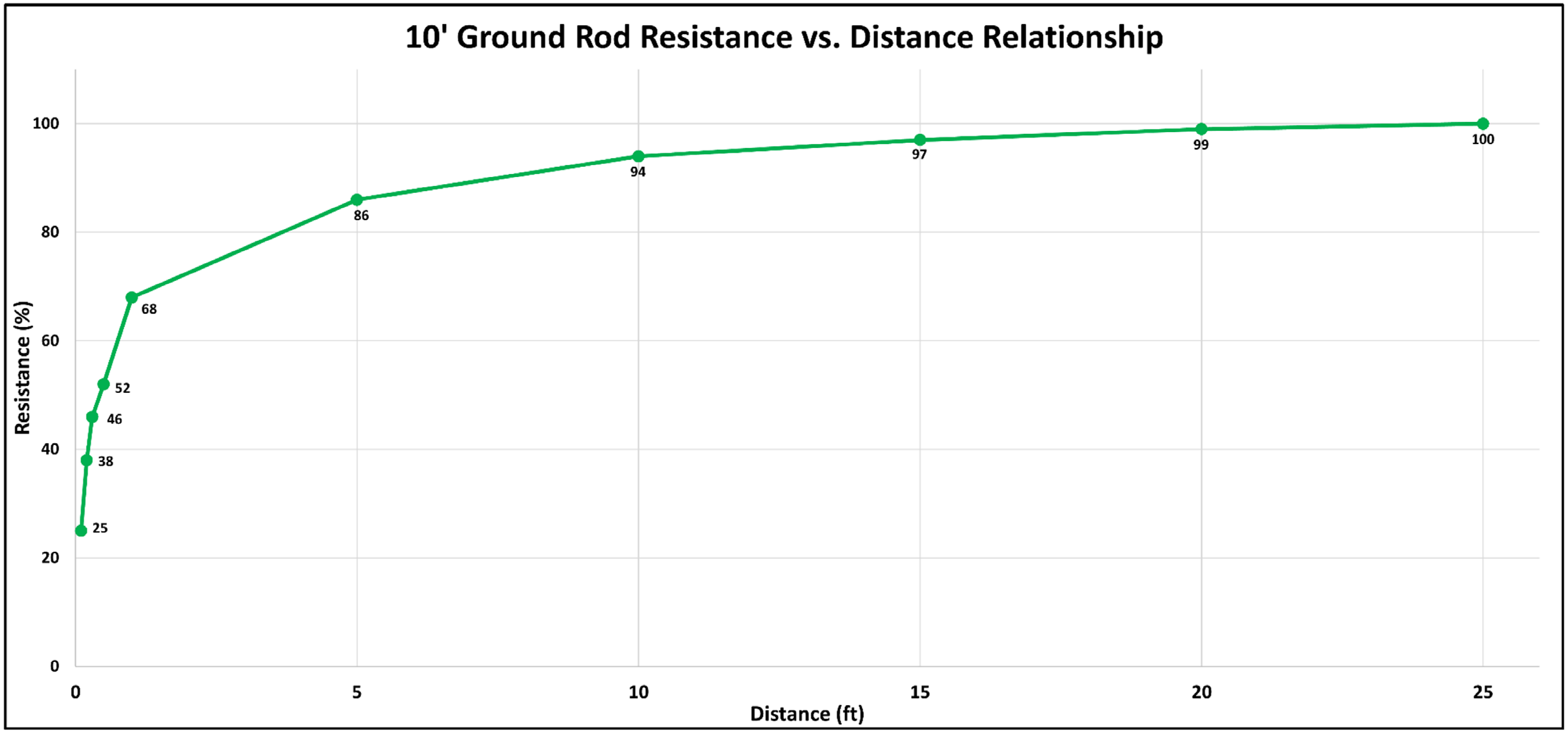
Grounding Electrode Resistance

“Interfacing Hemisphere”



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Grounding Electrode Resistance

Calculating Resistance to Ground

- **Formulas Developed by H.W. Dwight for various Electrode Configurations, as listed in IEEE Green Book and other publications.**
- **One Ground Rod:**
  - $R = (\rho/2\pi L)[\ln(3L/a)-1]$, where ρ is soil resistivity in ohm-cm, L is rod length in cm, and a is rod diameter in cm.
  - For 5/8”x10’ Rod: $R = \rho/339.3$
  - Rod diameter has small effect on resistance (3% less for ¾” vs. 5/8”)
  - May want to use ¾” diameter rod for hard soil or rocky area.
  - 10’ Rod Resistance is 17% Less than 8’ Rod

Grounding Electrode Resistance

Calculating Resistance to Ground

- **Buried Horizontal Conductor Simplified Formula by Ralph Lee (Dupont Engineer):**
  - R = ρ/19L, where ρ is soil resistivity in ohm-cm, L is conductor length in feet. Conductor buried 3 feet deep and greater than 3 feet from a foundation wall. If conductor is 3 feet or less from foundation wall, reduce 19 to 12.
- **Metal Underground Water Pipe Resistance: Typically 1 to 3 Ohms**

Grounding Electrode Resistance

Calculating Resistance to Ground

- **Net Resistance of Rods and Buried Conductors Simplified Calculation by Ralph Lee (Dupont Engineer):**
  - $R = R_L - ½ [R_L - (R_L \times R_H)/(R_L+R_H)]$, Where
    - R is net resistance of system
    - R_L is the lower of the two resistances (one or more rods or wire)
    - R_H is the higher of the two resistances (one or more rods or wire)
    - See later slide for parallel resistance of rods
  - This simplified calculation assumes the net resistance to be midway between the lower of the two and the two in parallel.

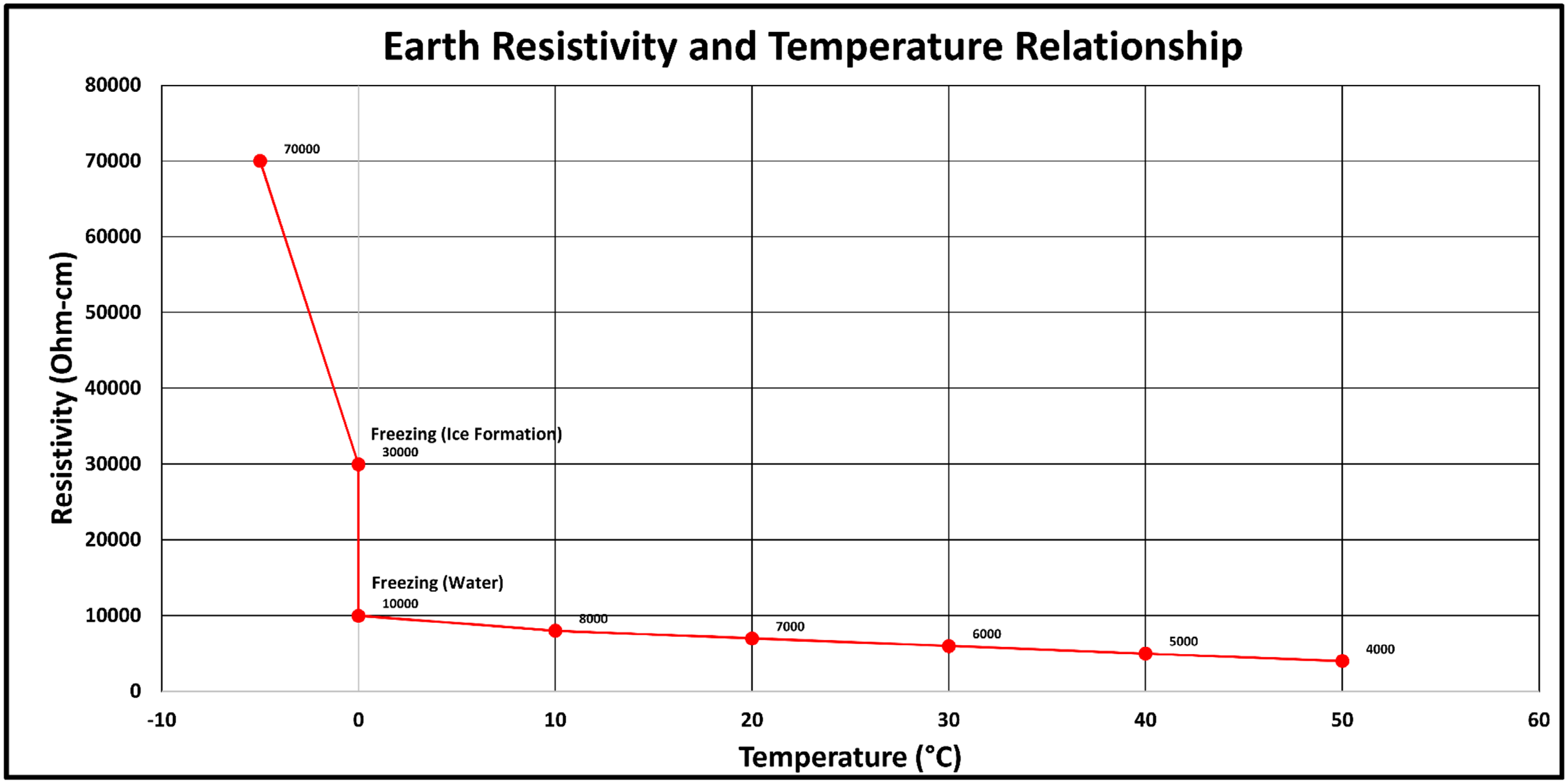
Grounding Electrode Resistance

Calculating Resistance to Ground

- **Soil Resistivity:**
  - Refer to Resistivity Map for average resistivity for the geographic area.
  - Average Resistivity for Middle TN is 250 Ohm-Meter (or 25,000 Ohm-cm) per Resistivity Map.
  - It is best to measure the Earth Resistivity in the area of the ground field.
- **Moisture and Temperature can significantly affect Soil Resistivity:**
  - Lower moisture content results in higher resistivity.
  - Lower temperature results in higher resistivity.
  - From 40°C (104°F) and lower, the rise in resistivity is gradual to just before ice formation and increases 3 times after ice formation.

Grounding Electrode Resistance

Calculating Resistance to Ground



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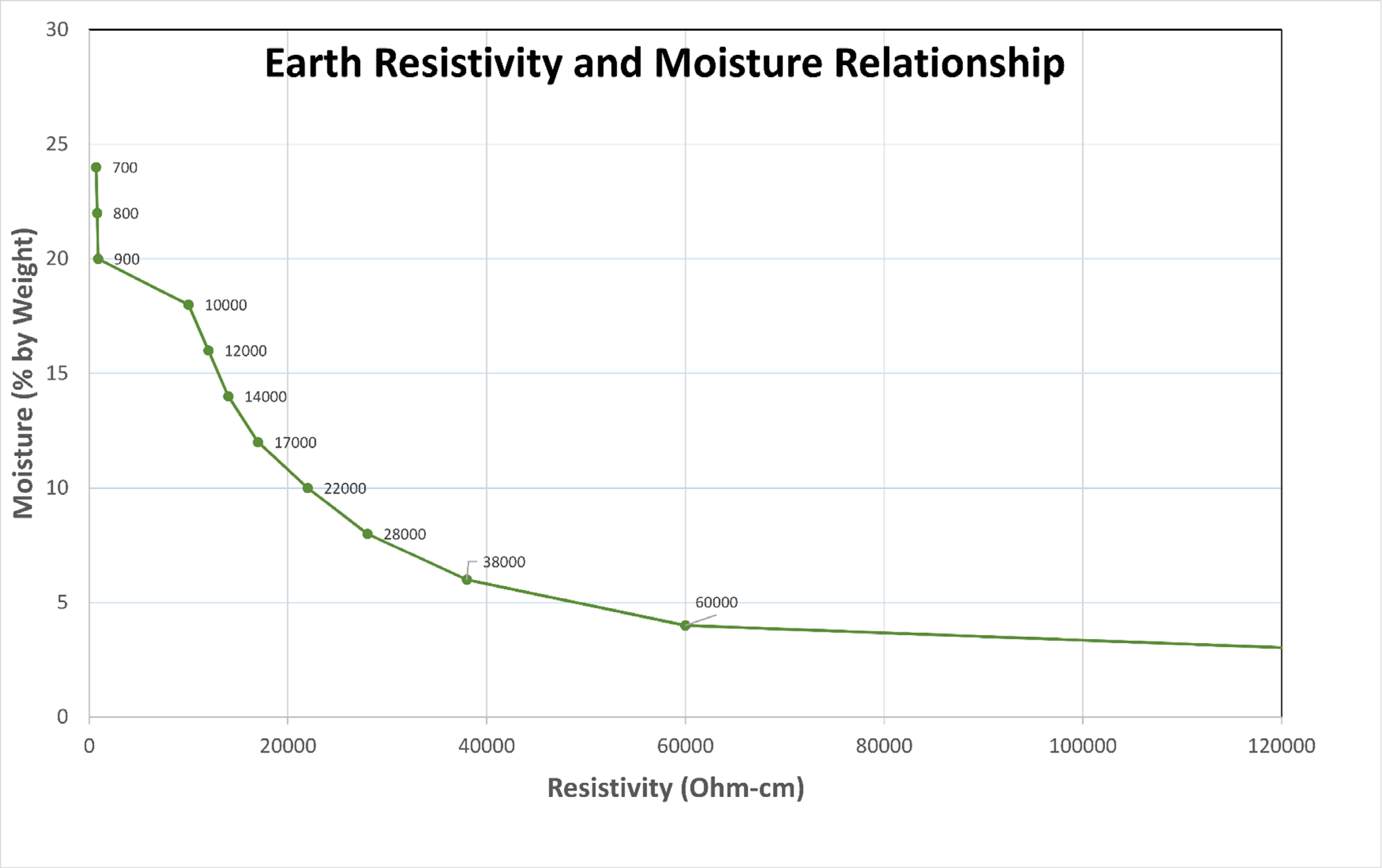
Grounding Electrode Resistance

Calculating Resistance to Ground



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Grounding Electrode Resistance

- **Earth Resistance of Multiple Rods is not Single Rod Resistance divided by number of parallel rods.**
- **$R_N = (R_1/n) \times F$, where**
  - R_N is net resistance of all 2 to 24 parallel rods
  - R_1 is resistance of one rod
  - n is number of rods in a line, triangle, circle, or square, at least one rod length apart
  - F is multiplying factor below:

No. of Rods	F	No. of Rods	F
2	1.16	12	1.80
3	1.29	16	1.92
4	1.36	20	2.00
8	1.68	24	2.16

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Grounding Electrode Resistance

- **Earth Resistance General 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 higher fault currents.

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Grounding Electrode Resistance

- **Benefits of Low Ground Resistance:**
  - Lower touch and step potentials due to fault currents.
  - Lower touch and step potentials due to lightning currents.
  - To minimize impedance in order to quickly dissipate a lightning stroke. Low ground resistance "swamps-out" inductance of buried electrode system.
  - Lower Ground Differentials between Services or Separate Buildings
  - Shielding action more effective for shielded cables

Grounding Electrode Resistance

- Per NEC, a Single Rod, Pipe, or Plate Electrode with earth resistance greater than 25 ohms must be augmented by an another approved electrode.
- For 8’ rod to achieve 25 ohms, Earth Resistivity must be 60 ohm-meters or less.
- Few areas in U.S. have average soil resistivity less than 60 ohm-meters (Middle TN is 250 ohm-meters).

Achieving Low Ground Resistance

- **Use Copper-Bonded Ground Rods for Longevity.**
  - Studies have shown expected 40 to 50 year life with copper-bonded rods with 10 and 13 mil of cladding respectively.
  - Studies have shown expected 10 year life with galvanized rods.
- **Consider 10 foot Rods for higher likelihood of connecting to at least 8 feet of good soil.**
  - Certain section of soil may have lower resistivity.
  - NFPA Lightning Protection Standard requires 8’ rods but driven to 10’.
- **Use Thermal-Weld or Compression for below grade connections**

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Achieving Low Ground Resistance

- **Ufer Grounds (Encased Electrodes):**
  - Concrete Resistivity is 30 Ohm-Meters.
  - GEM Resistivity is 0.20 Ohm-Meters (made by Erico & possibly others)
  - Middle TN Average Soil Resistivity is 250 Ohm-Meters.
  - Concrete and GEM retain moisture and thus can maintain a more constant resistivity.

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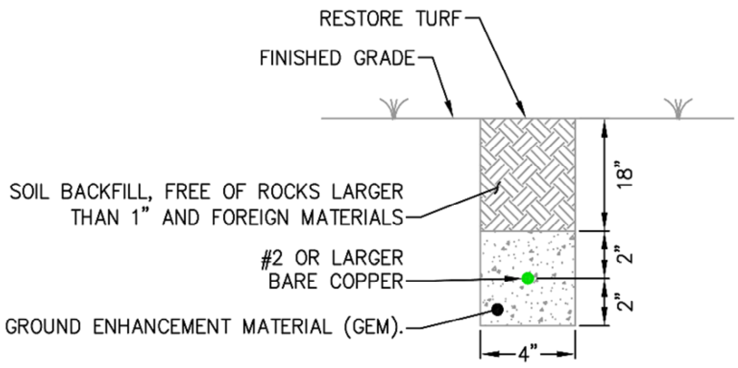
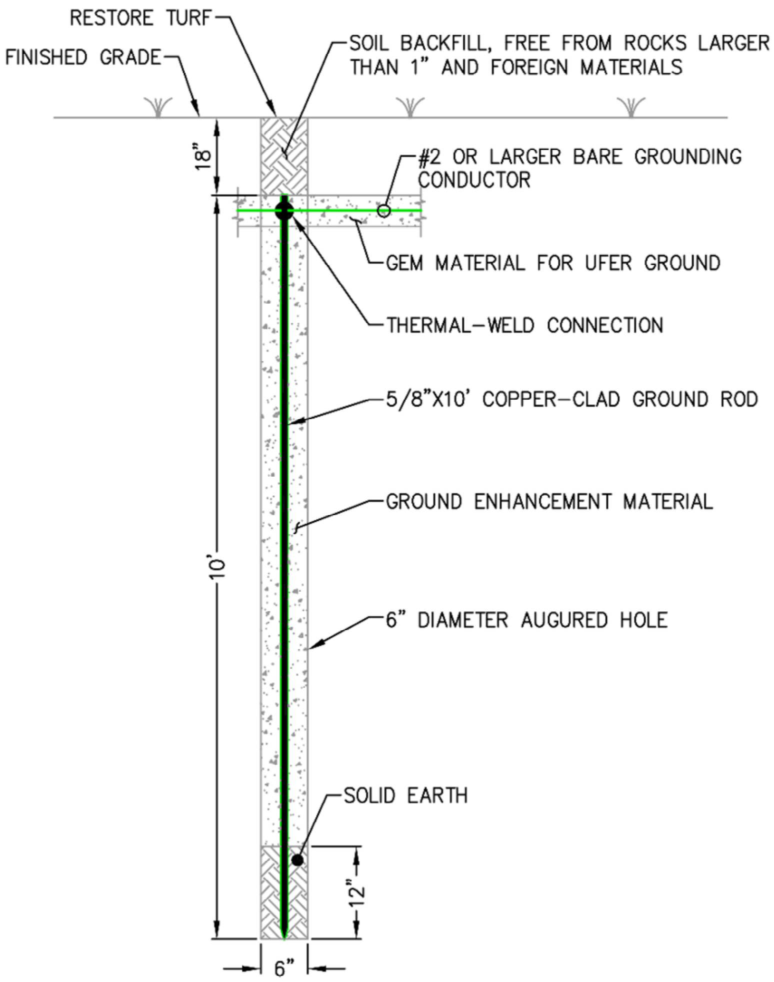
Achieving Low Ground Resistance

- **Types of Ufer Grounds:**
  - Encased Ground Rods
    - Well Driller Augers are about 6” Diameter
  - Encased Buried Conductors
  - Encased Rebar or Conductor in Foundation
  - Encased Rebar in Building Column Footings

Example Encased Electrodes





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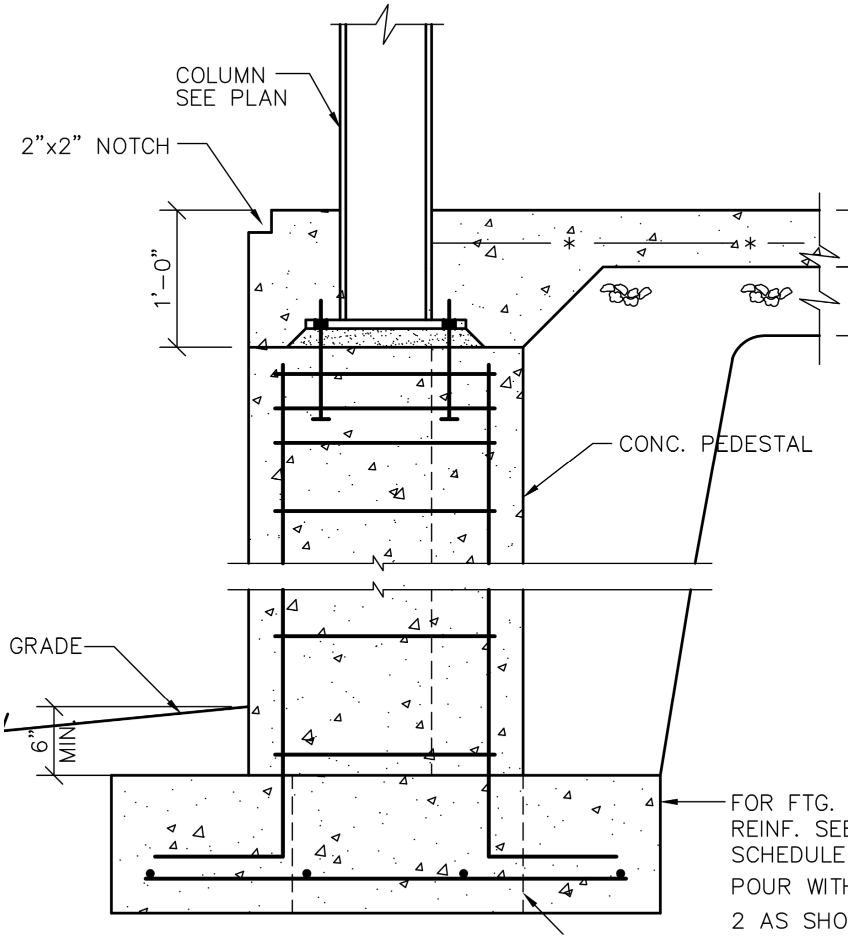
Example Encased Electrodes

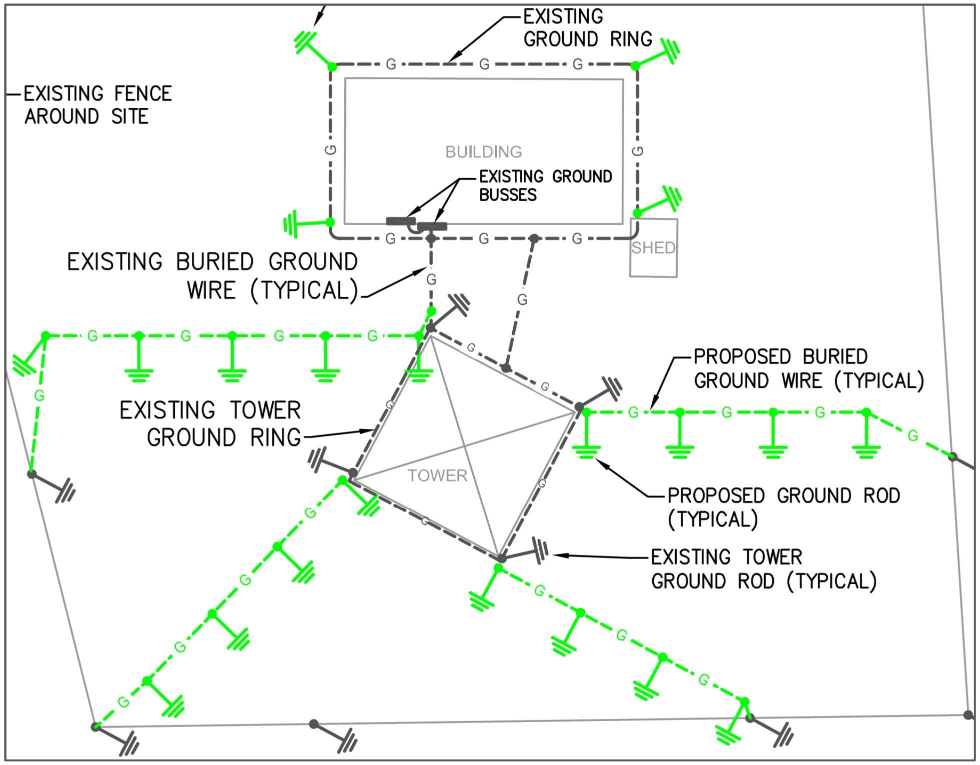
<u>Consider:</u>

- **Weld anchor bolt to rebar using rebar.**
- **Weld anchor bolt & nut to column base.**
- **Size rebar for fault current (see Green Book)**



Achieving Low Ground Resistance

- **Consider a Ground Ring encircling the building.**
- **Can help to maintain equipotential about the building.**
- **Fields from currents splitting around the building will have a cancelling effect within the building.**
- **Be aware of potential issues if connecting interconnected equipment to Ring.**
- **Required by NFPA 780 for Buildings Taller than 60’**



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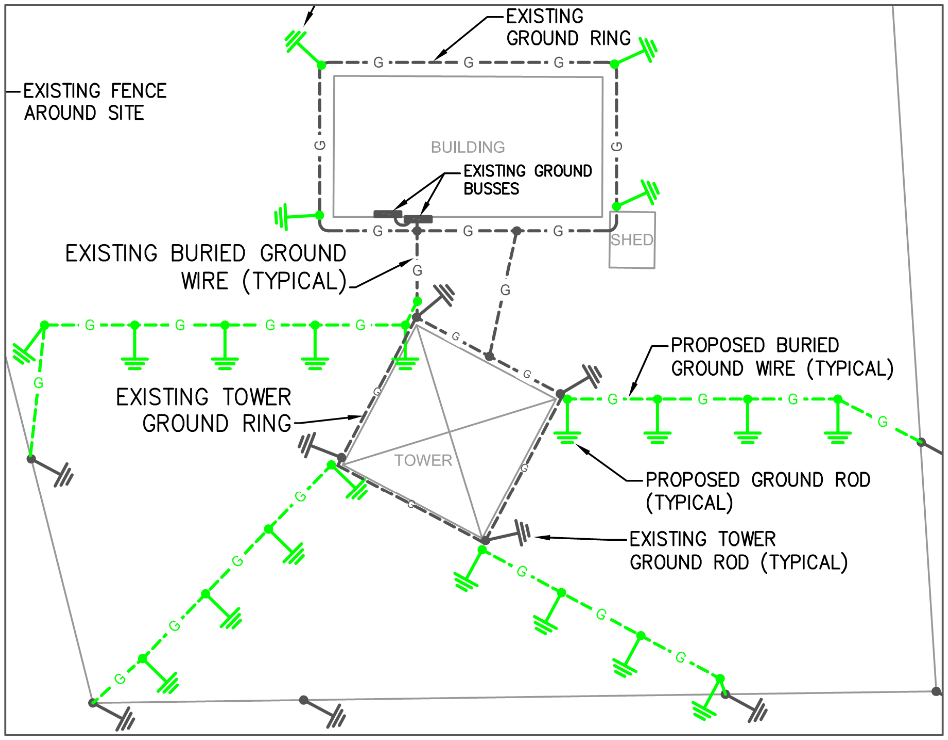
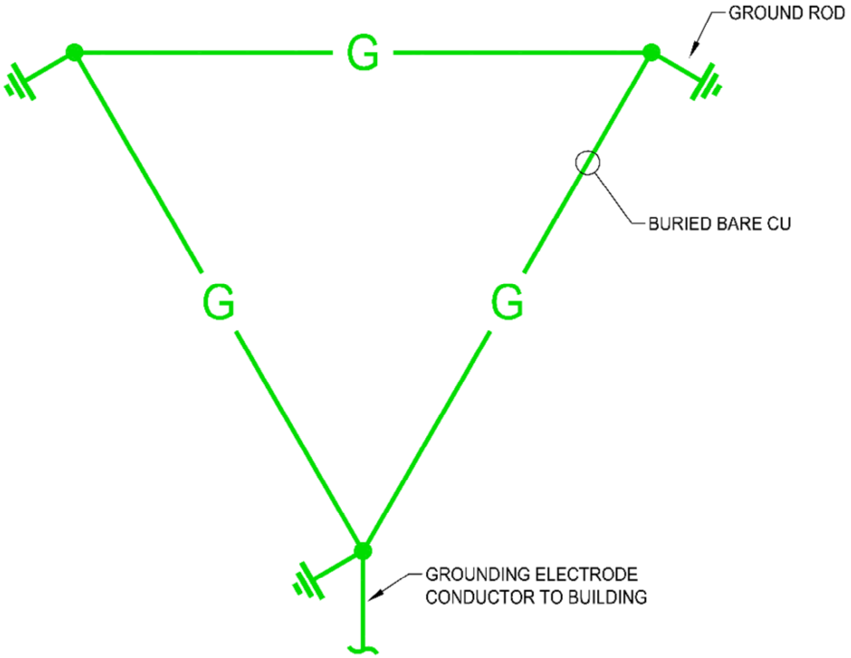
Achieving Low Resistance and Good Dynamic Response

- **Use multiple Ground Radials to reduce Surge Impedance.**
- **Each Radial being 15’ to 75’ in Length and directed away from the building.**
- **Initial value of surge impedance due to lightning current can be 10 times or more the DC ground resistance.**
- **Also applies to building grounding, not just towers like this example. Basic example would be the traditional triad ground.**



Achieving Low Resistance and Good Dynamic Response

- **"Grounding Triad" using 5/8"x10' Ground Rods.**
- **Rods Spaced 20'.**
- **Buried Bare Copper Between Rods, 18" Below Grade.**
- **Achieves approximately 17.5 Ohms in 25,000 ohm-cm soil.**



Low Impedance Path to Ground

Grounding Electrode Conductors

- **Minimize Lengths and sharp bends.**
- **Avoid Bends Less than 90 Degrees.**
- **Use Bending Radius ≥ 8 inches.**
- **Minimizing length is generally more important than bends.**
- **Use Compatible Materials and Protection to Avoid Corrosion**

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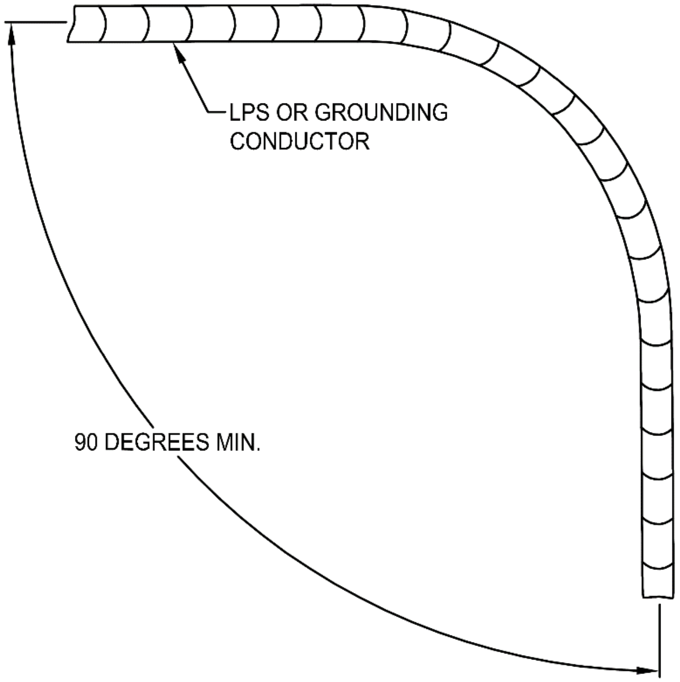
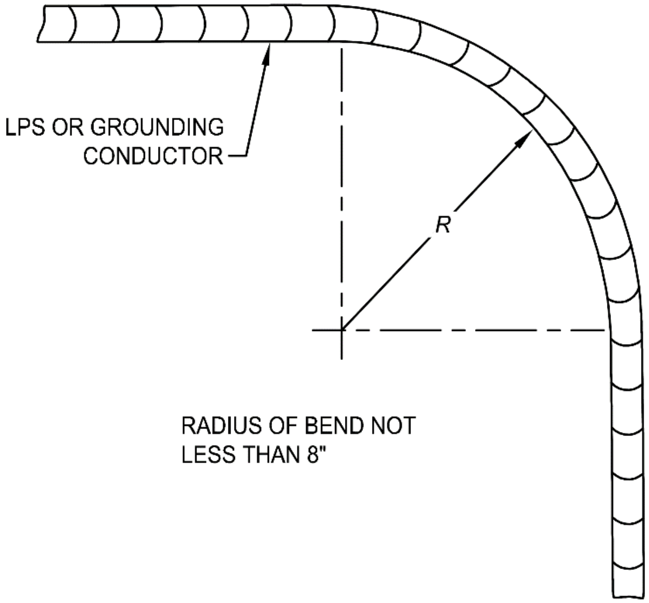
Low Impedance Path to Ground

Grounding Electrode Conductors

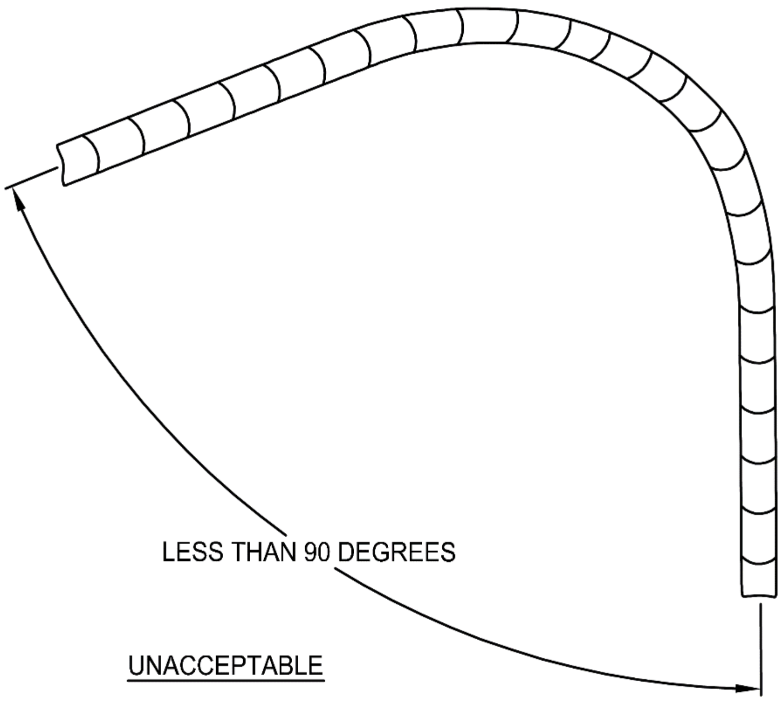




- **Acceptable Conductor Bends**

Low Impedance Path to Ground

Grounding Electrode Conductors



- **Unacceptable Conductor Bends**

Low Impedance Path to Ground

Grounding Electrode Conductors

- **Conductor Z Predominantly Inductive Reactance at HF**
  - $Z \sim X = 2\pi fL$
  - Voltage Drop = $L(di/dt)$ or $(I)(2\pi fL)$
  - Inductance for Wire: L(in μH) = $(0.00508)(l)[2.303\mathrm{Log}(4l/d) - .75]$ where l=Length and d=Diameter (both in inches).
  - L(#2 CU) = 0.2654 μH/ft, L(#4/0 CU) = 0.2293 μH/ft
  - For Typical 1st Return Stroke of 30kA with 5.5μs Rise Time, VD = $L(di/dt)$ = 1448V/ft (1251V/ft for #4/0)
  - For Typical Subsequent Stroke of 12.5kA with 1.1μs Rise Time, VD = $L(di/dt)$ = 3016V/ft (2606V/ft for #4/0)

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BETWEEN OFF AND ON

Low Impedance Path to Ground

Grounding Electrode Conductors

- **Consider Copper Straps for Lower Inductance.**

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Low Impedance Path to Ground

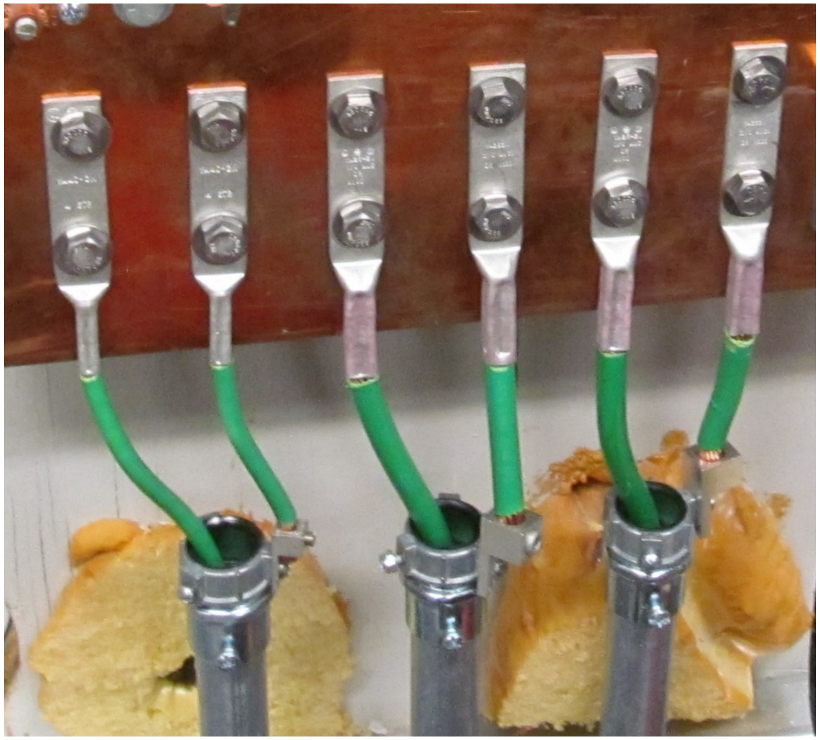
Grounding Electrode Conductors

- **Copper Straps**
  - Inductance for Strap: L(in µH) = (0.00508)(l)[2.303Log(2l/(w+t)) + 0.5 + 0.2235(w+t)/l] where l=Length, w=Width, t=Thickness (all in inches)
  - L (3” Strap) = 0.1915 µH/ft (28% less than #2 & 16% less than 4/0)
  - L (6” Strap) = 0.1553 µH/ft (32% less than 4/0)
  - 3” Strap Cross Sectional Area is close to #4 Wire
  - 6” Strap Cross Sectional Area is close to #1 Wire
  - For Typical 1st Return Stroke of 30kA with 5.5µs Rise Time, 3” Strap VD = 1045V/ft (847V/ft for 6” Strap)
  - For Typical Subsequent Stroke of 12.5kA with 1.1µs Rise Time, 3” Strap VD = 2176V/ft (1765V/ft for 6” Strap)

Low Impedance Path to Ground

Grounding Electrode Conductors

Burndy Type CH
Conduit/Wire Clamp



- **Bond Grounding Electrode Conduits at each end.**

Bonding

- Minimize Lengths and sharp bends.
- Avoid Bends Less than 90 Degrees.
- Use Minimum Bending Radius of 8 inches.
- Minimizing length is generally more important than bends.
- Use Compatible Materials and Protection to Avoid Corrosion.

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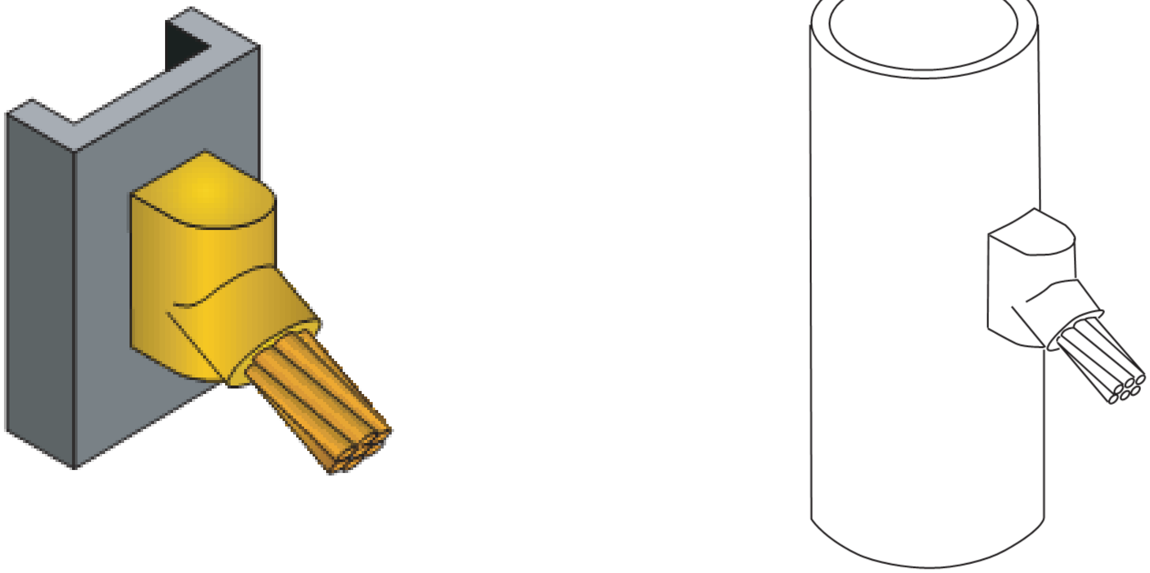
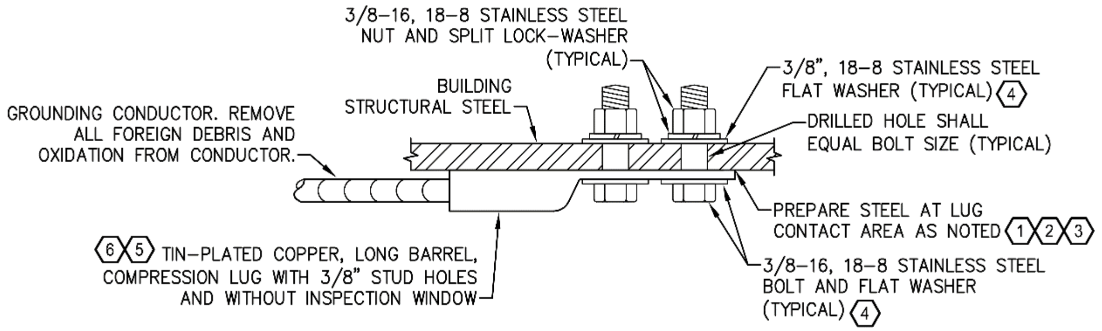
Bonding



- **Consider Thermal-Welded connections where applicable (building steel, fence posts, etc.)**

Bonding



KEYED NOTES: ⟨#⟩

1. REMOVE PRIMER/PAINT WHERE LUG CONTACTS THE STEEL. NOTE: IT IS UNKNOWN WHETHER THE PRIMER/PAINT CONTAINS LEAD. THE INSTALLER SHOULD TAKE NECESSARY PRECAUTIONS TO PREVENT ANY ADVERSE EXPOSURE.

2. APPLY NO–OX–ID "A–SPECIAL" ANTIOXIDANT COMPOUND TO LUG BEFORE ATTACHING TO BARE STEEL.

3. AFTER ATTACHING LUG TO STEEL, APPLY PRIMER/PAINT TO REMAINING EXPOSED BARE STEEL.

4. FLAT WASHERS SHALL INCLUDE STANDARD OUTSIDE DIAMETER OF 7/8".

5. COMPRESSION LUG SHALL INCLUDE STANDARD TONGUE WIDTH. LUG TONGUE DIMENSIONS SHALL BE COORDINATED WITH FLAT WASHER'S DIAMETER SO WASHER FITS FLAT BETWEEN STUD HOLE AND BARREL.

6. THE LUG STUD HOLE SIZE SHALL MATCH THE BOLT SIZE AS SPECIFIED. LARGER STUD HOLES ARE ACCEPTABLE WHERE SAME SIZE BOLT IS PROVIDED. SMALLER STUD HOLES AND THUS SMALLER BOLTS MUST BE APPROVED BY ENGINEER.

(#) STEEL GROUND CONNECTION
2-HOLE COMPRESSION LUG, #2 TO #3/0 AWG
NOT TO SCALE

- **Other applications include drill & tap, 1-Hole Lugs, & terminations for enclosures and ground busses**

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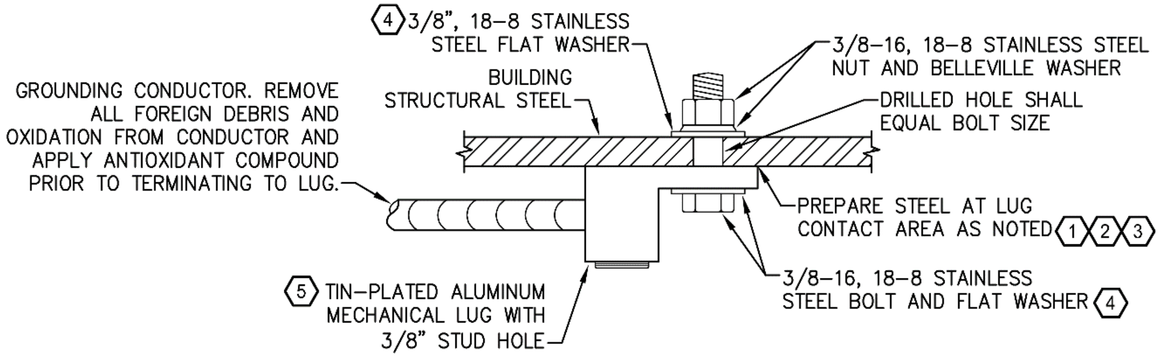
BETWEEN OFF AND ON

Bonding



KEYED NOTES: #

1. REMOVE PRIMER/PAINT WHERE LUG CONTACTS THE STEEL. NOTE: IT IS UNKNOWN WHETHER THE PRIMER/PAINT CONTAINS LEAD. THE INSTALLER SHOULD TAKE NECESSARY PRECAUTIONS TO PREVENT ANY ADVERSE EXPOSURE.
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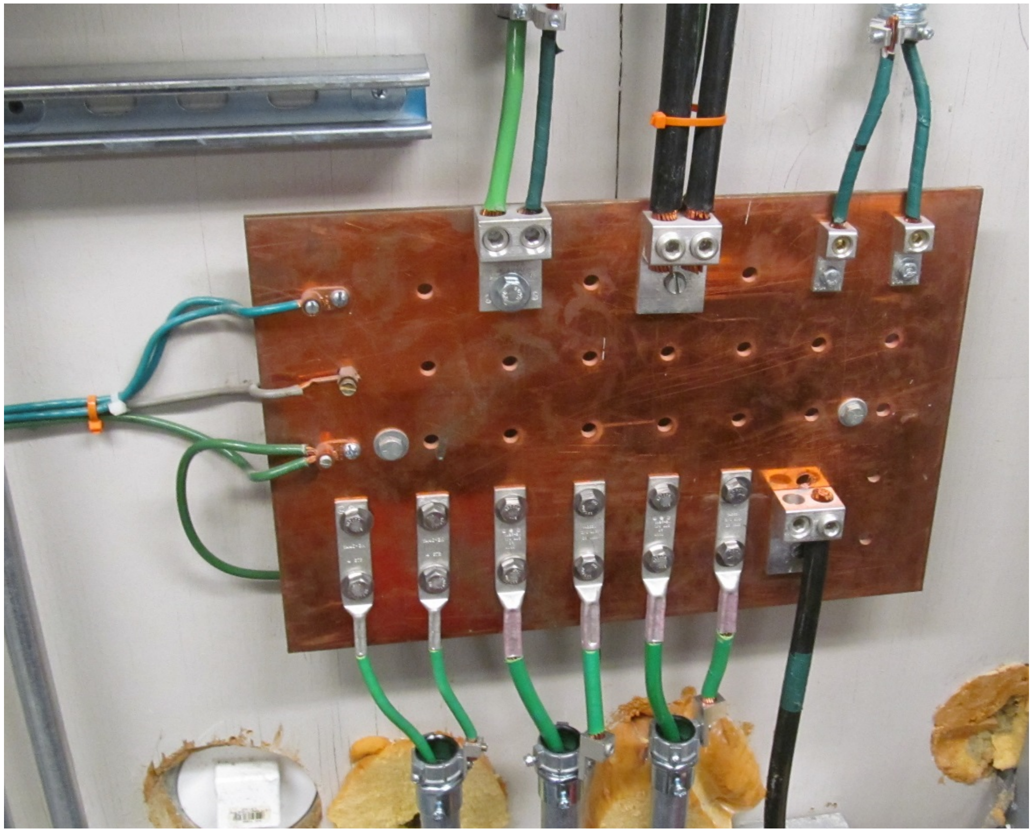
\# STEEL GROUND CONNECTION
MECHANICAL LUG, #2 TO #3/0 AWG
NOT TO SCALE

- **Other applications include drill & tap, 1-Hole Lugs, & terminations for enclosures and ground busses**

Bonding



- **Bond all Electrical Services to Same Bus/Bar (Power, Telephone, CATV).**

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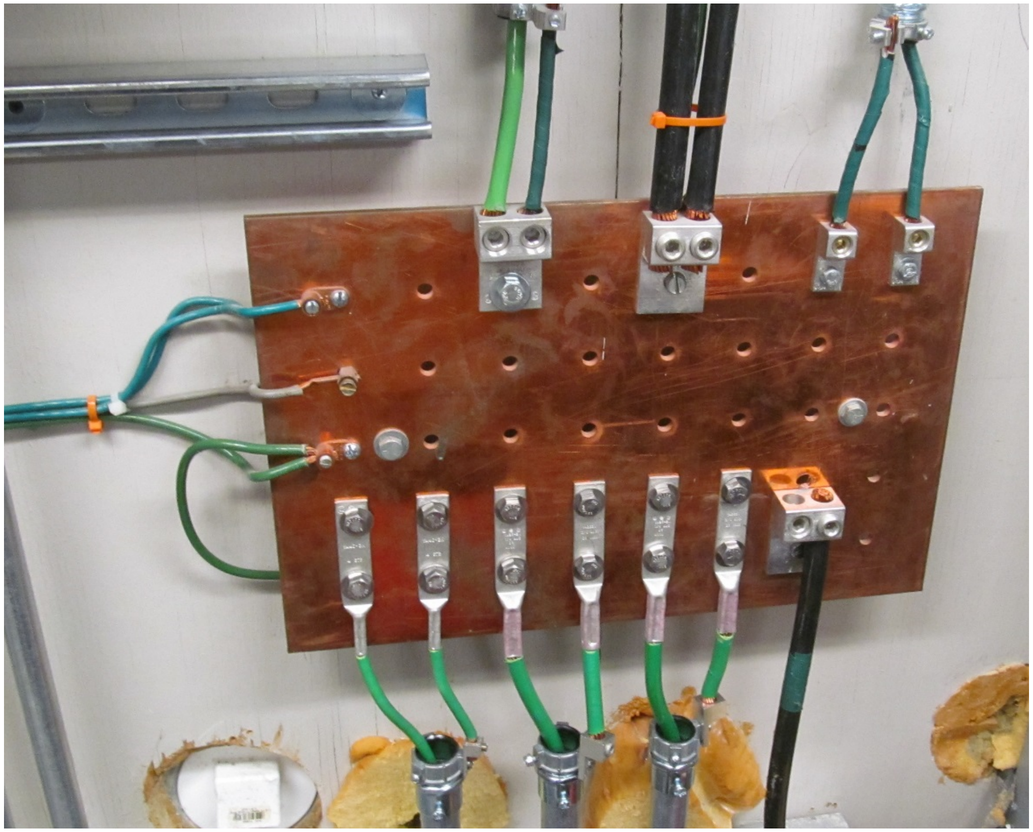
Bonding



- **Bond all Grounding Electrodes together.**

Bonding

- **Bond all External Cables to Building Grounding System where they Enter the Building.**

Bonding

- **Bond across Water Pipe Backflow Preventers and Valves.**

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BETWEEN OFF AND ON

Bonding

- **For Metal Frame Buildings, take advantage of the Structure as a “Grounding Grid”.**
  - The large surface areas and numerous parallel paths provide for a low impedance grounding grid.
  - In Bar Joist Construction, joists are welded to beams and roof deck metal pans are tack welded to joists and tack welded pan-to-pan.
  - Beam-to-Beam and Beam-to-Column connections are usually bolted and in some cases may also include tack welds.
  - Building steel bolted connections for fault and lightning current paths are accepted by NEC and NFPA 780 and other standards.
  - In critical/sensitive applications, consider bonding across a certain number of bolted connections.

Bonding

Metal Building

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Bonding

Metal Building

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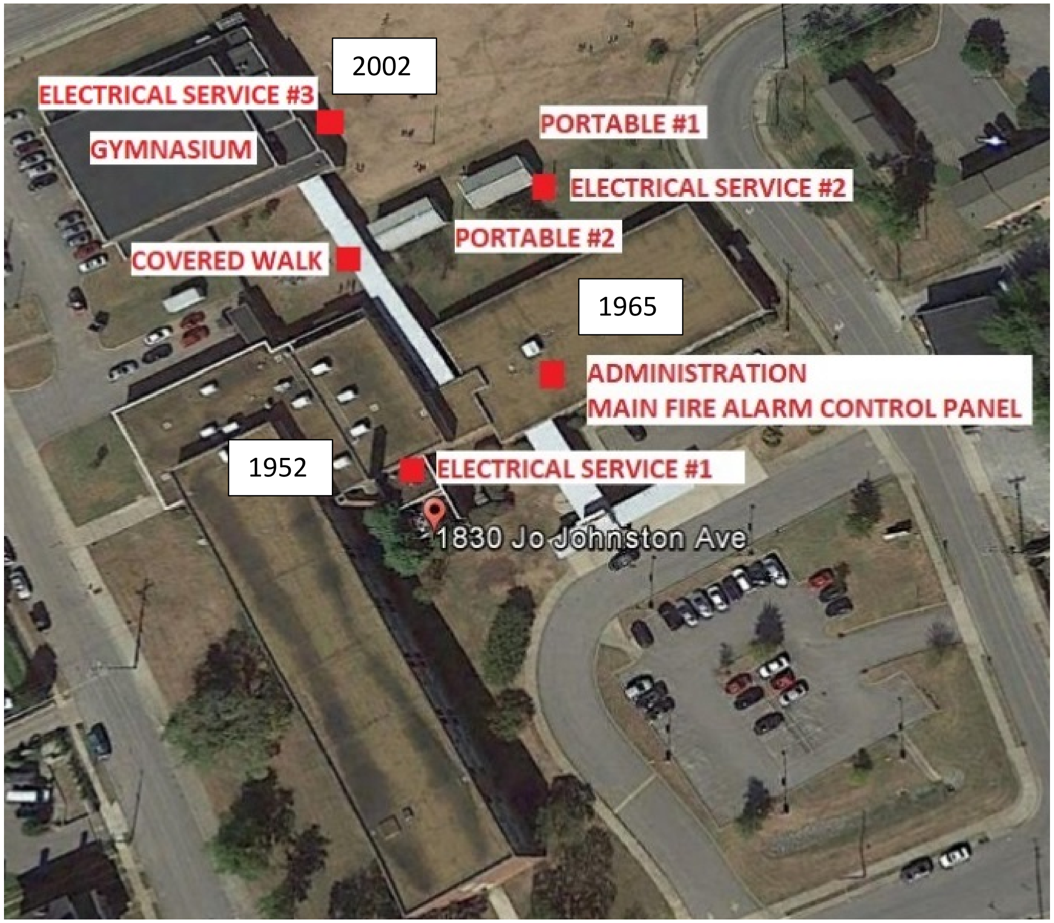
Bonding



- **Bond Isolated Sections of Building Steel & perhaps adjacent buildings.**
- **Building additions are normally not connected structurally.**

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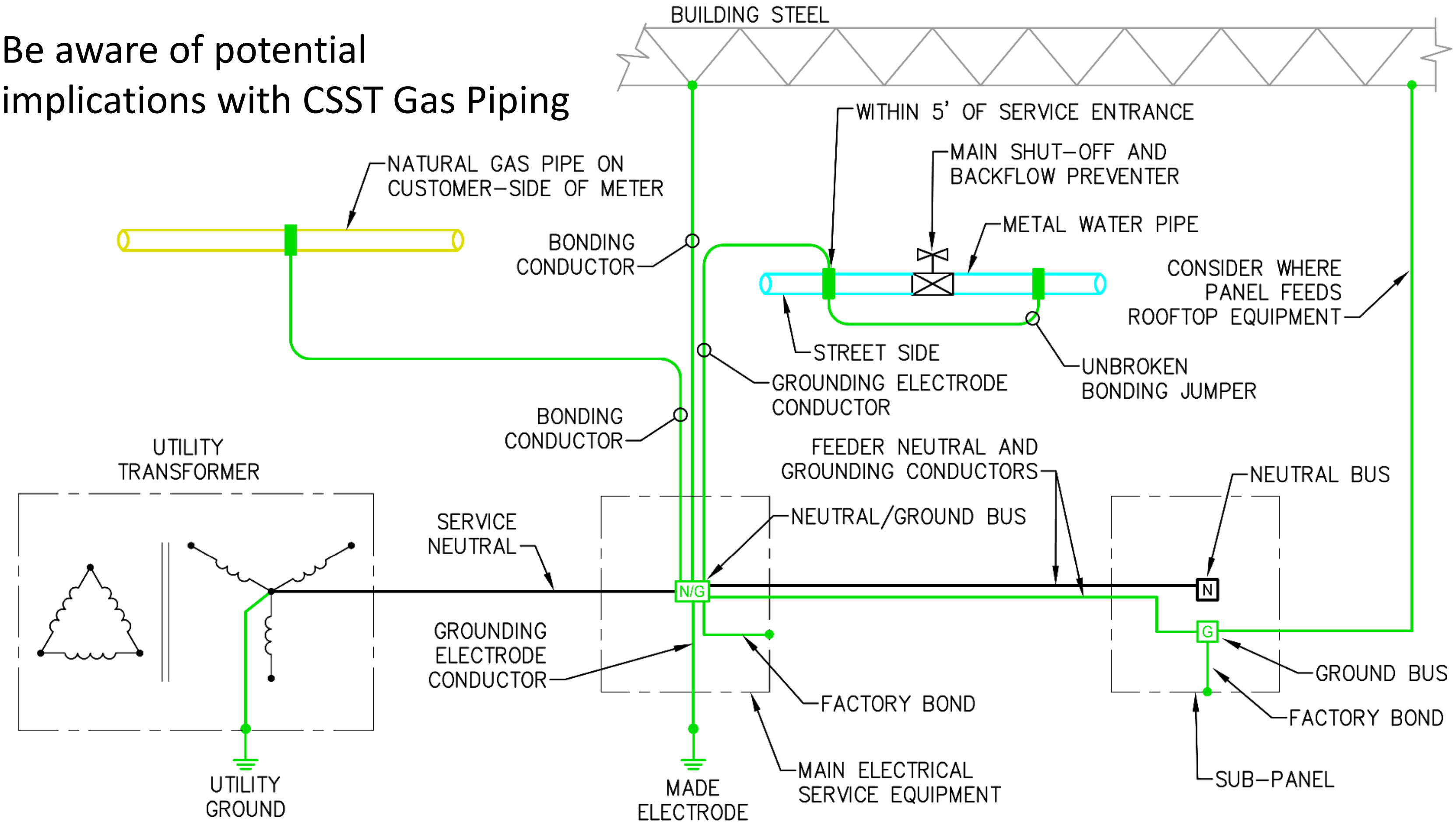
BETWEEN OFF AND ON

Bonding and Grounding Summary

Be aware of potential implications with CSST Gas Piping



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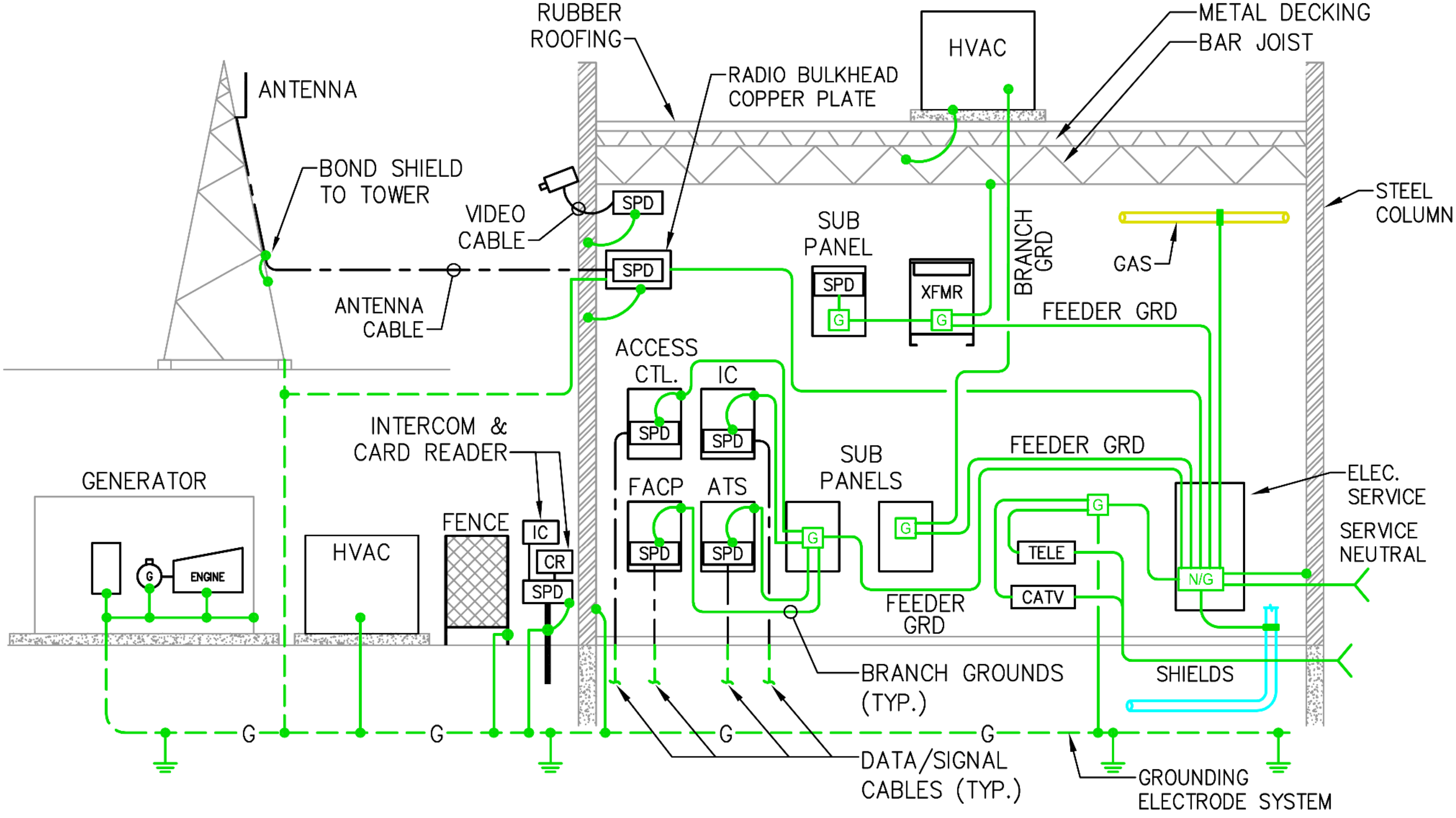
Bonding and Grounding Summary



Shielding

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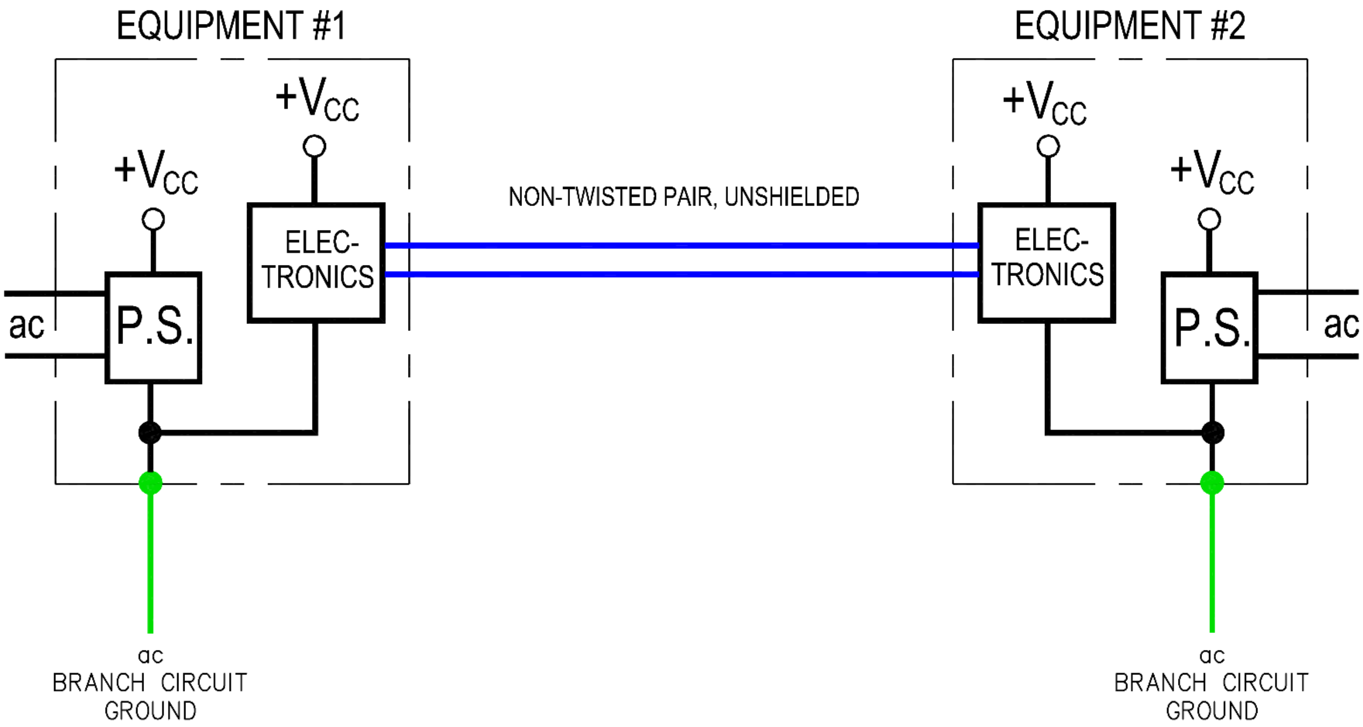
Shielding



- **Cable offers no protection against Electric or Magnetic Fields (E or H-Fields)**

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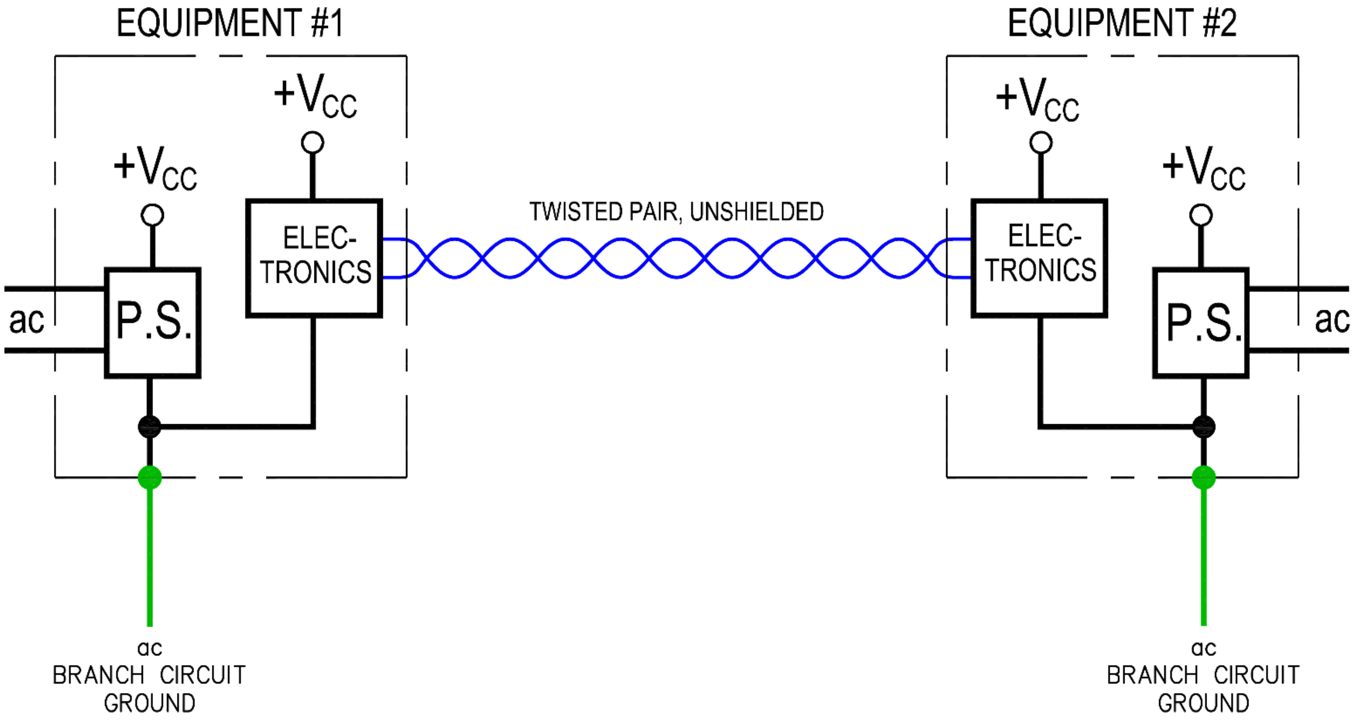
Shielding



- **Twisted Pair provides protection against Common-Mode Induced Voltage from Magnetic Fields.**
- **Ideally, Equal Voltages are Induced on each conductor and they subtract when summed together at the Terminals**

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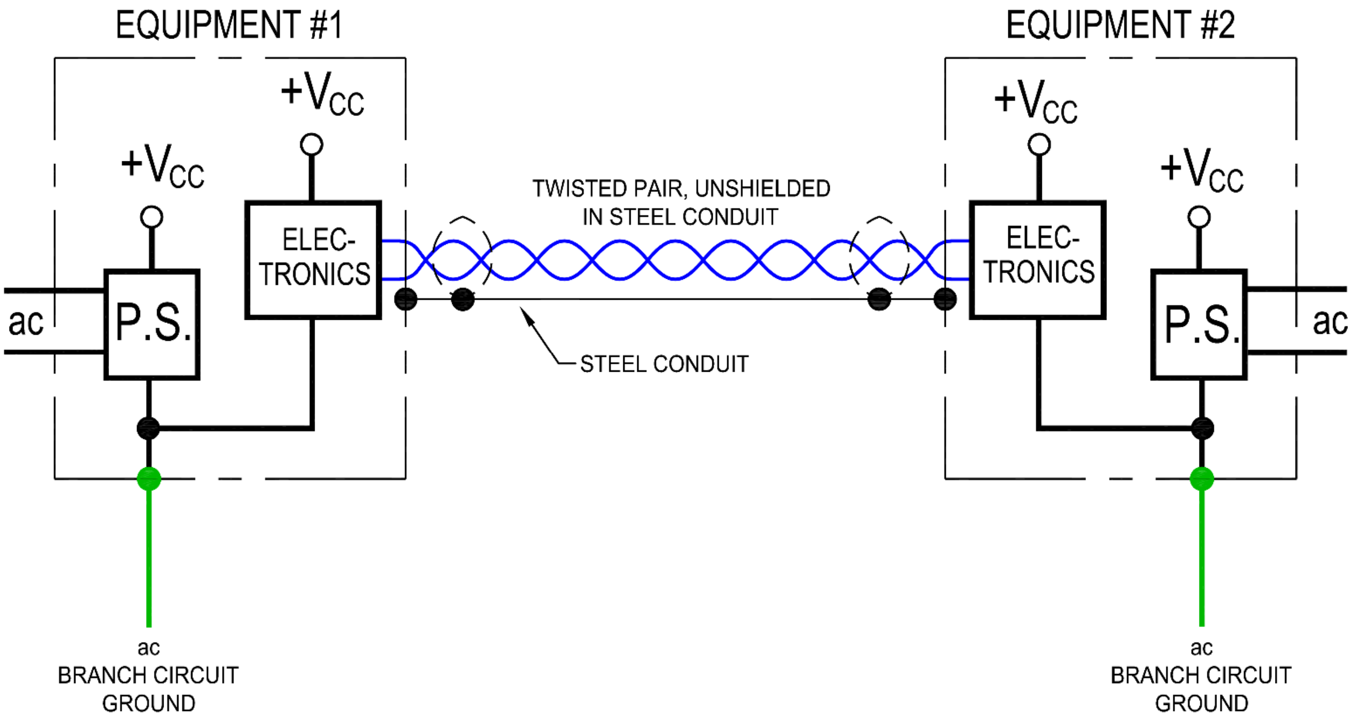
Shielding



- **Twisted Pair provides protection against Common-Mode Induced Voltage from Magnetic Fields.**
- **Continuous & Grounded Steel Conduit provides shielding from E and H-Fields.**

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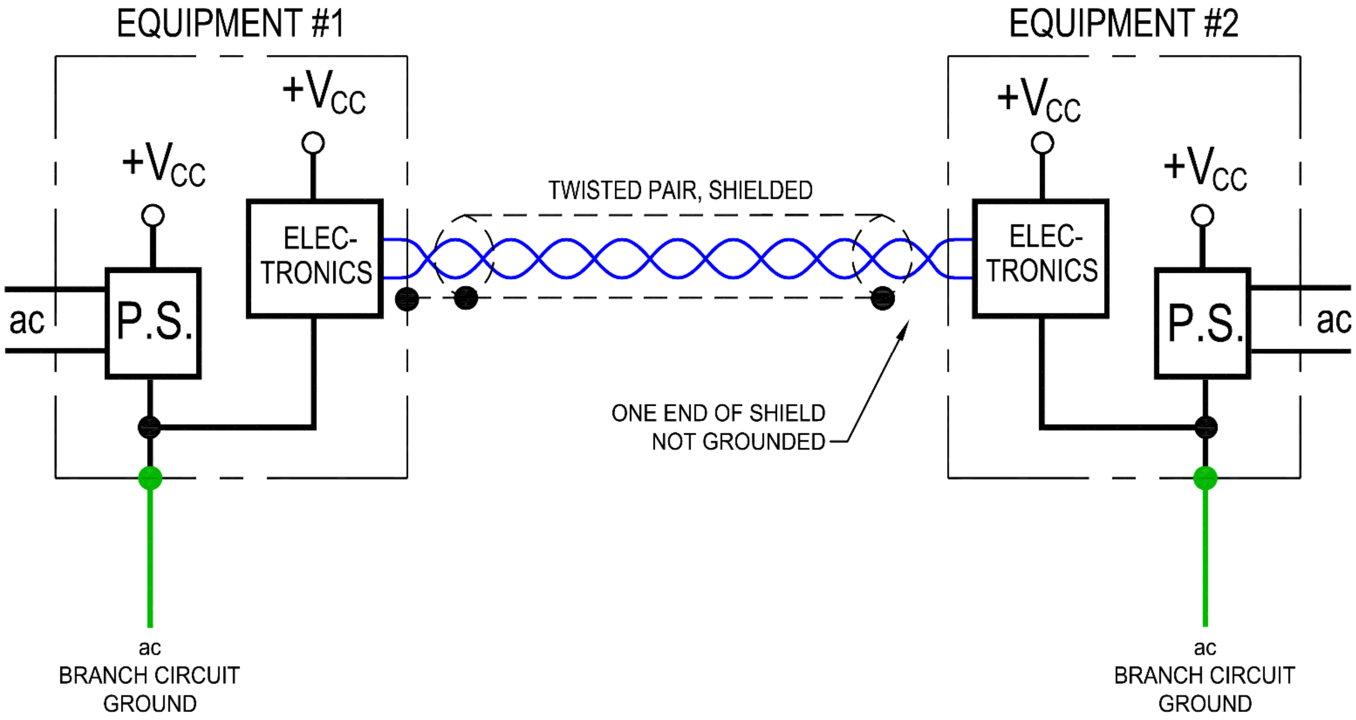
Shielding



- **Twisted Pair provides protection against Common-Mode Induced Voltage from Magnetic Fields.**
- **Shield grounded only at one-end provides E-Field shielding with some limitation.**

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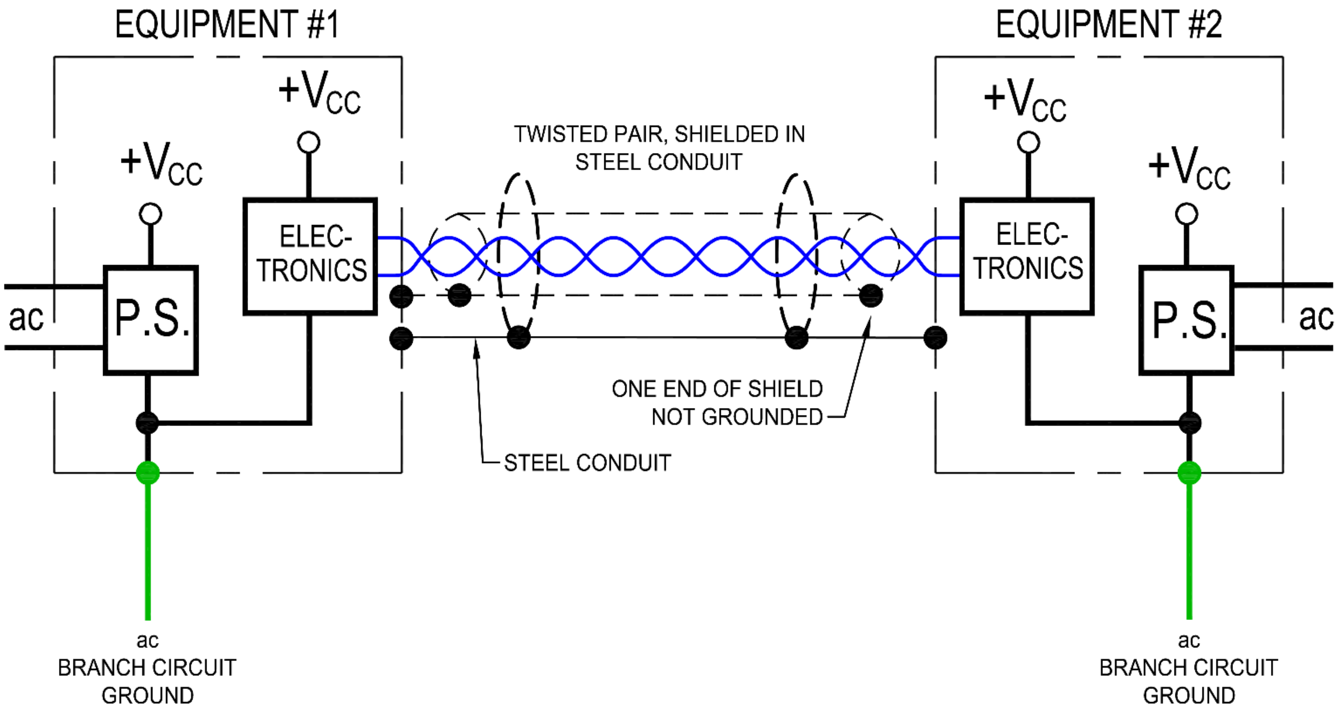
Shielding



- **Twisted Pair provides protection against Common-Mode Induced Voltage from Magnetic Fields.**
- **Good compromise with shield grounded only at one-end.**

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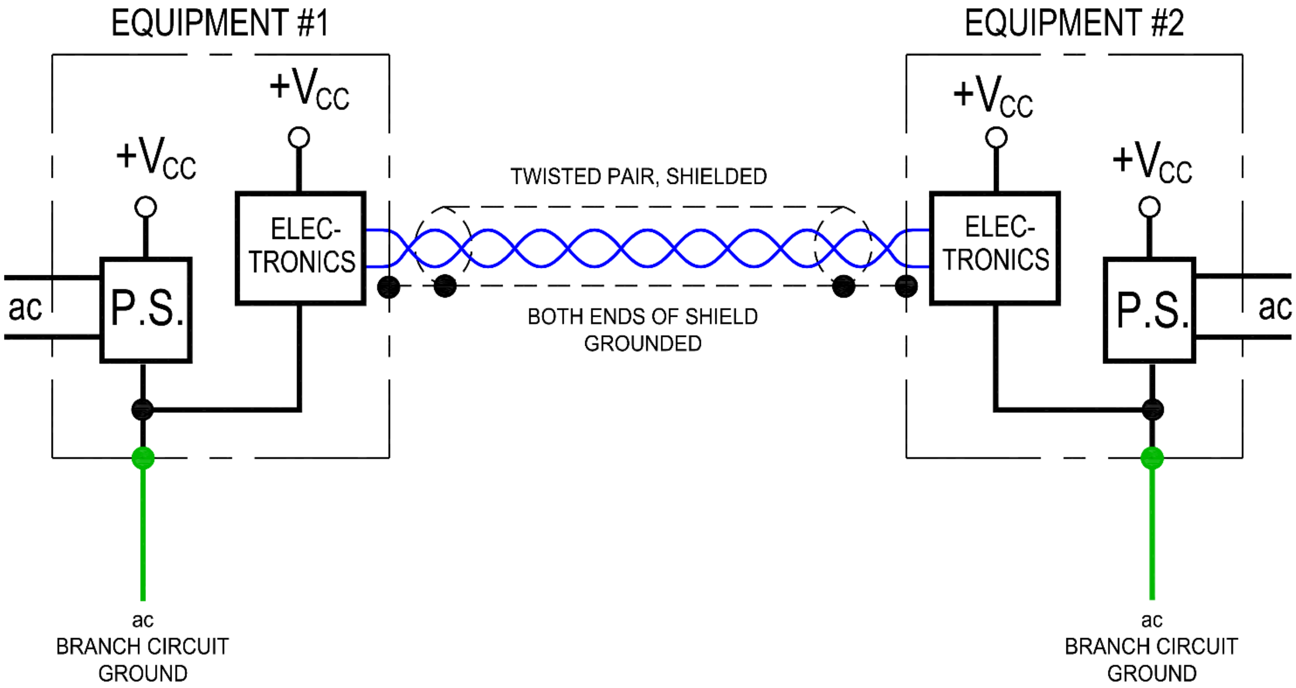
Shielding



- **Twisted Pair provides protection against Common-Mode Induced Voltage from Magnetic Fields.**
- **Shield provides protection against both E and H-Fields.**

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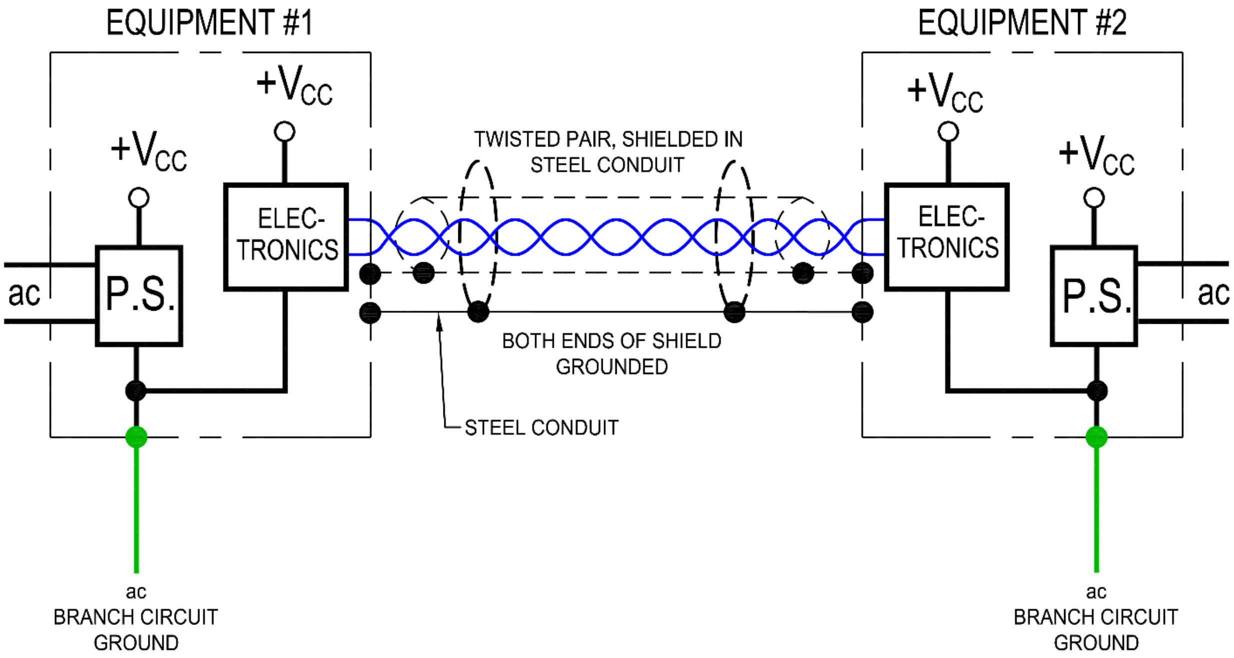
BETWEEN OFF AND ON

Shielding



- **Twisted Pair provides H-Field protection.**
- **Shielded cable plus steel conduit provides double shielding against both E and H-Fields.**
- **Double Shielded cables also available.**

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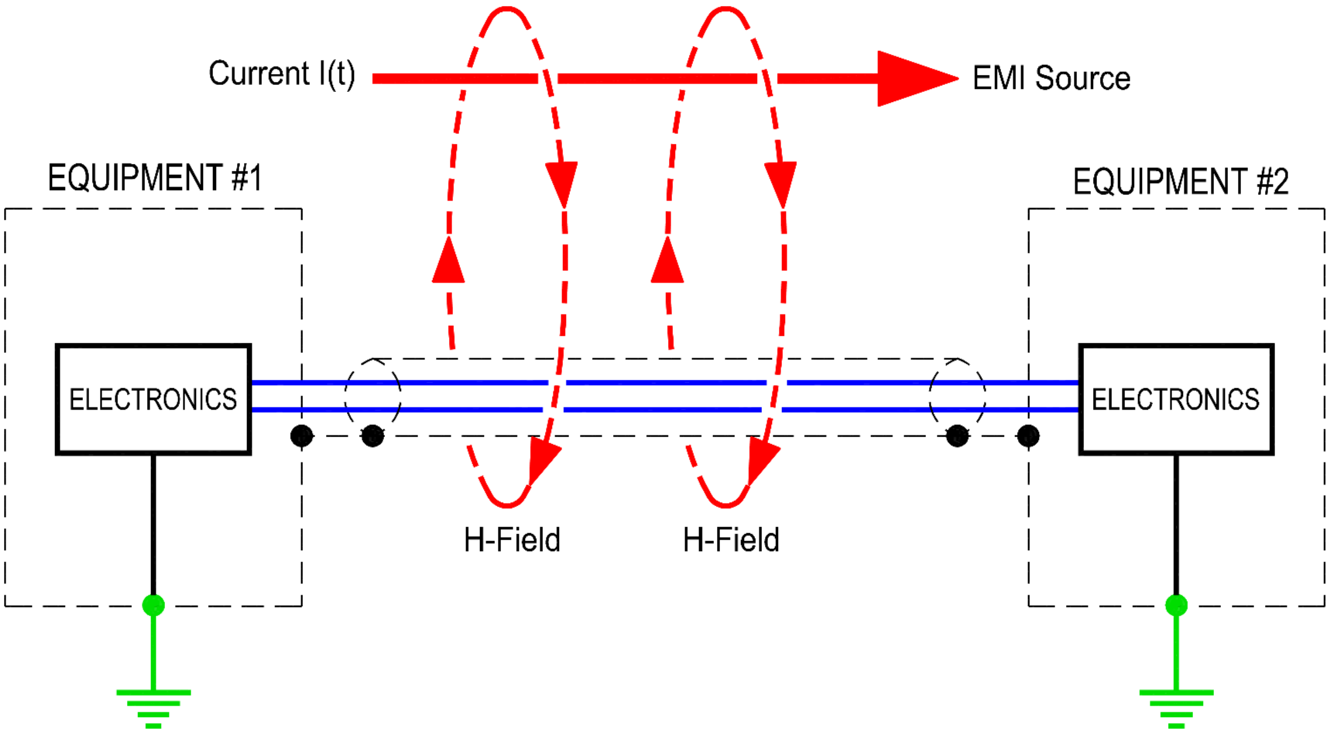
Shielding



- **Cable could also be Twisted Pair.**

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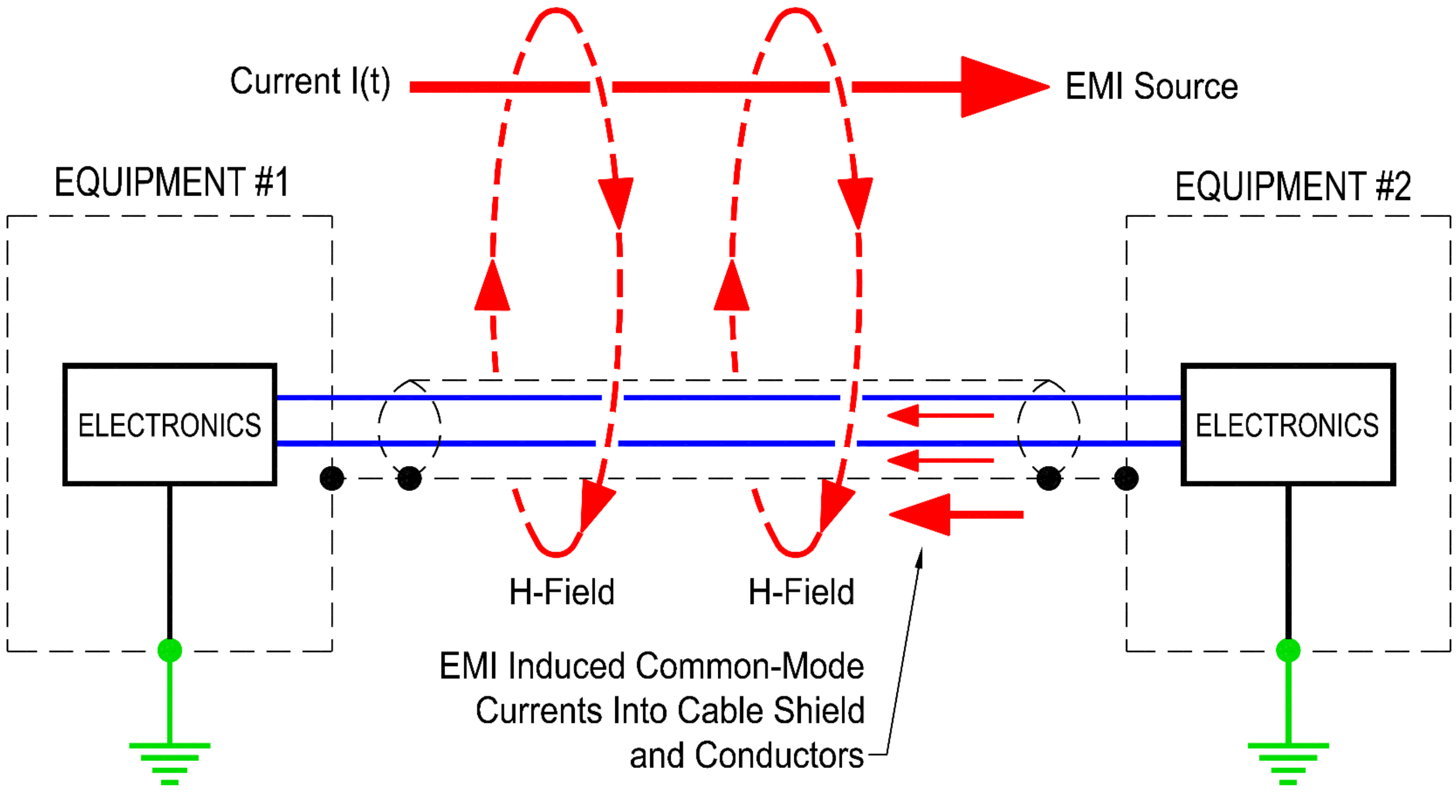
Shielding

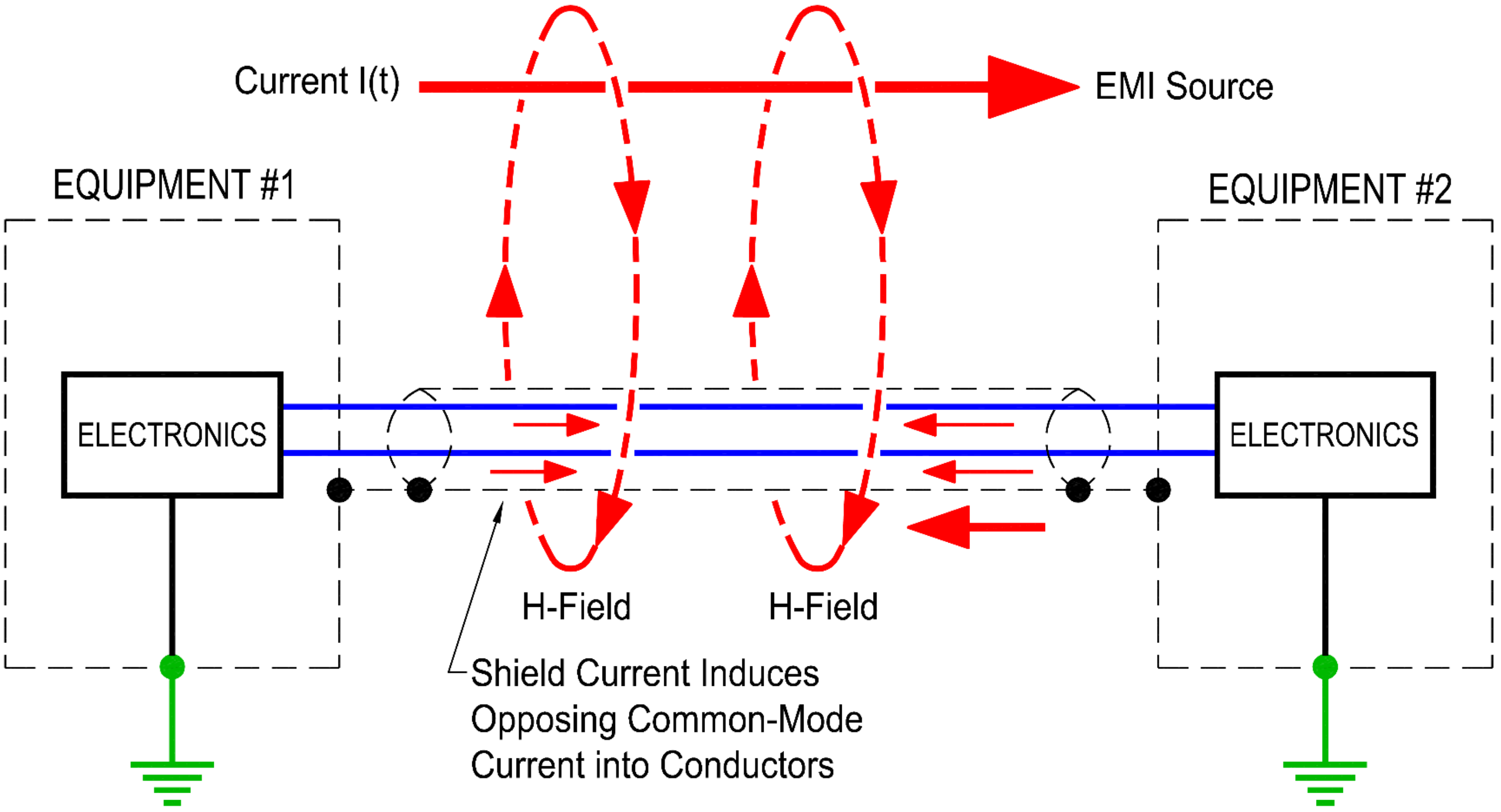


EMI Induced Common-Mode Currents Into Cable Shield and Conductors

Portion of E and H-Fields are also Reflected and Dissipated in Shield as Heat

The induced conductor currents can also include Normal-Mode.

Shielding



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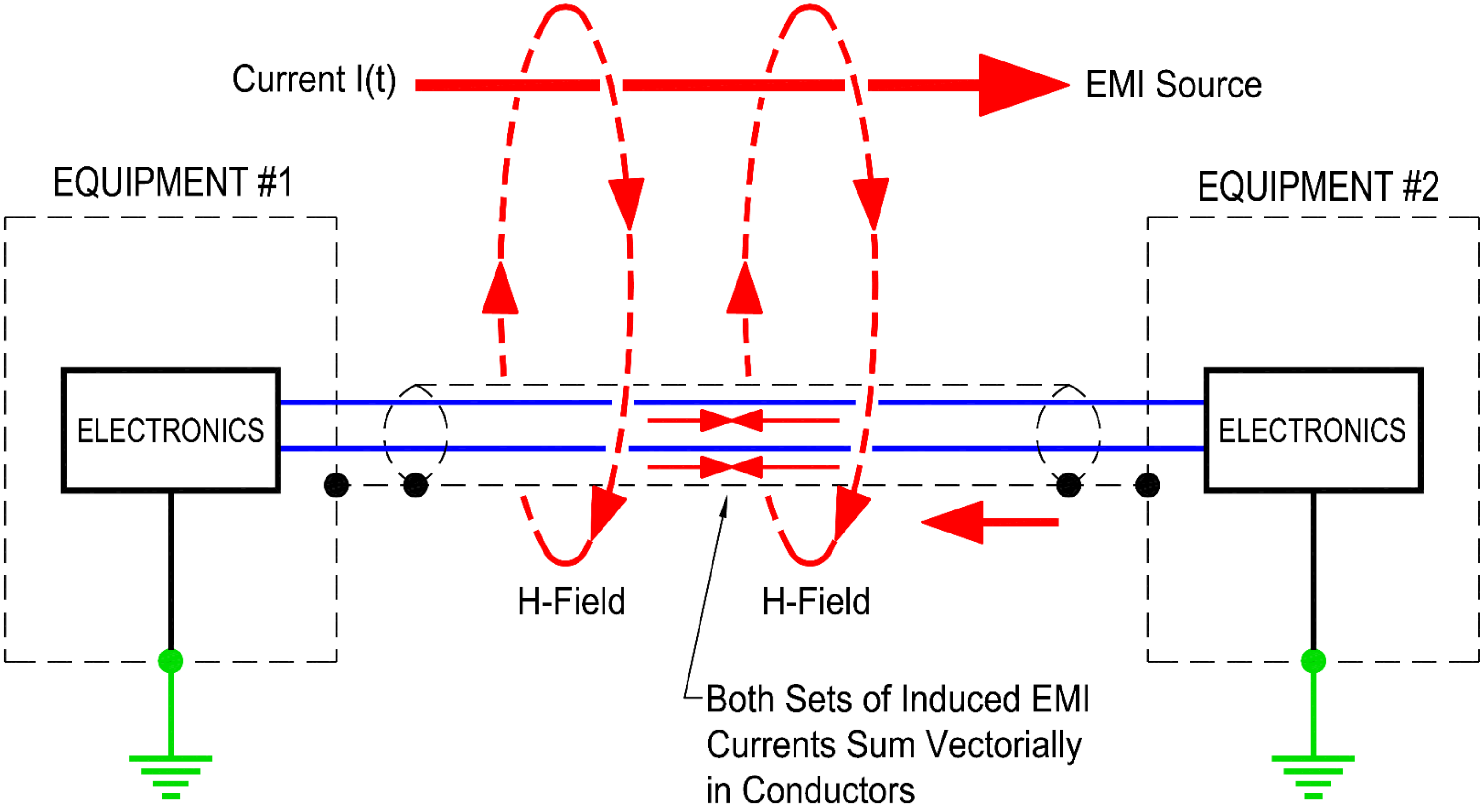
Shielding



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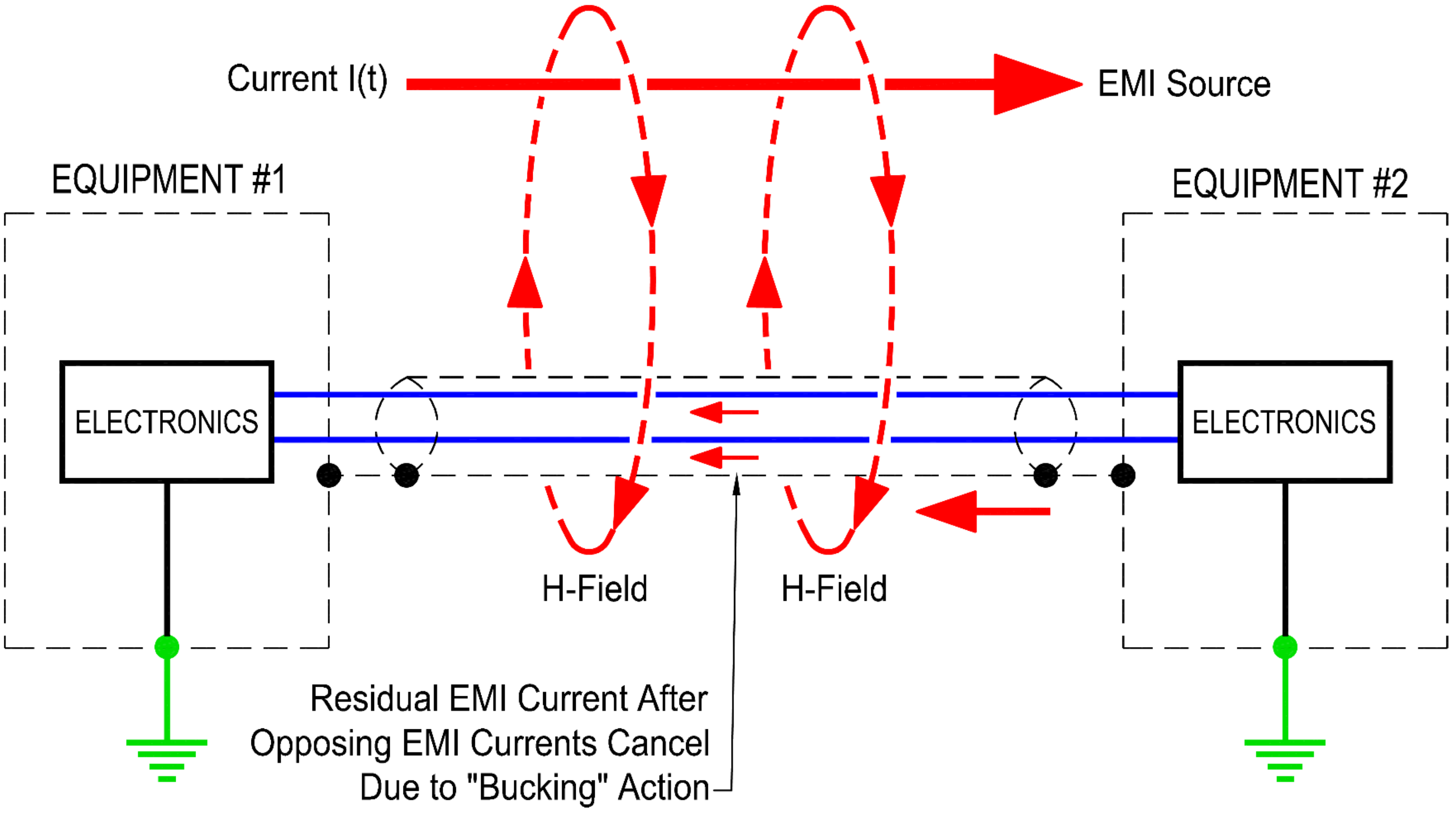
Shielding



- **Another way of looking at the shielding action is the induced shield current H-Field opposes the incident H-Field resulting in a net (residual) current.**

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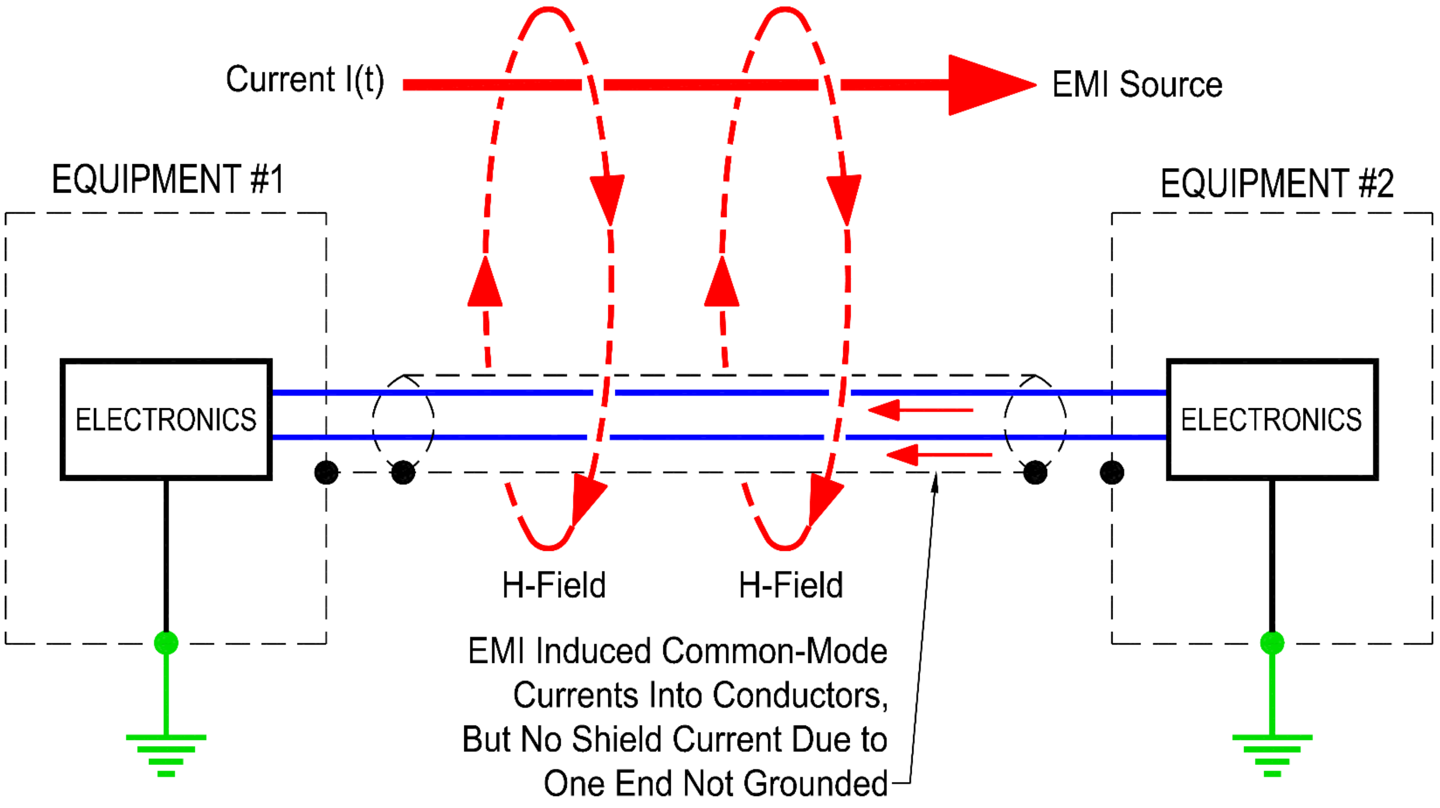
Shielding



- **If stray ground currents or ground differential could cause issue with signal, can only ground shield at one end.**
- **Grounding at one end provides E-Field Protection but not H-Field Protection**

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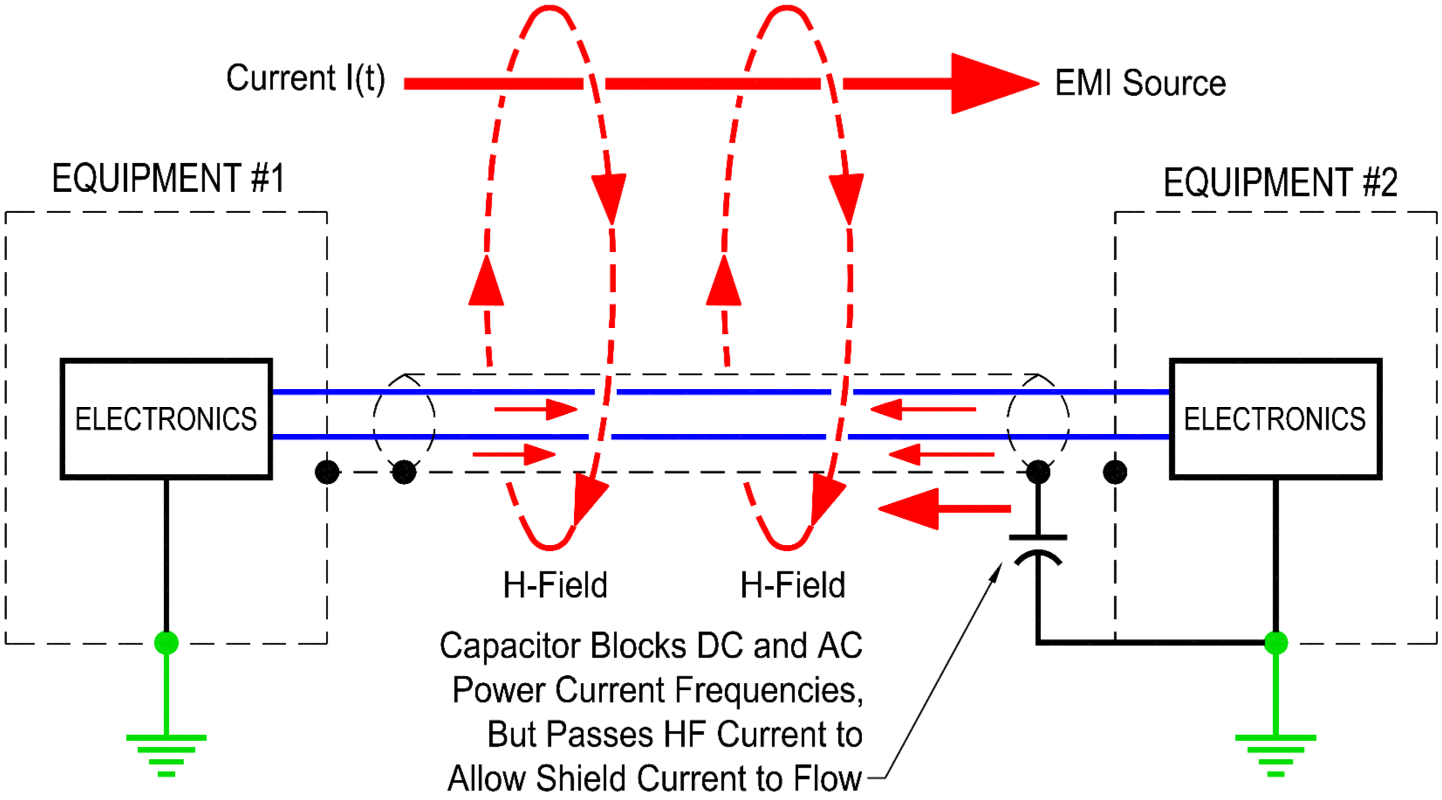
THE CRITICAL DIFFERENCE BETWEEN OFF AND ON

Shielding



Capacitor Blocks DC and AC Power Current Frequencies, But Passes HF Current to Allow Shield Current to Flow

- **This could be applicable for recording studios or other applications where grounding both ends of shield creates ground loops and thus noise.**

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Circuit Isolation

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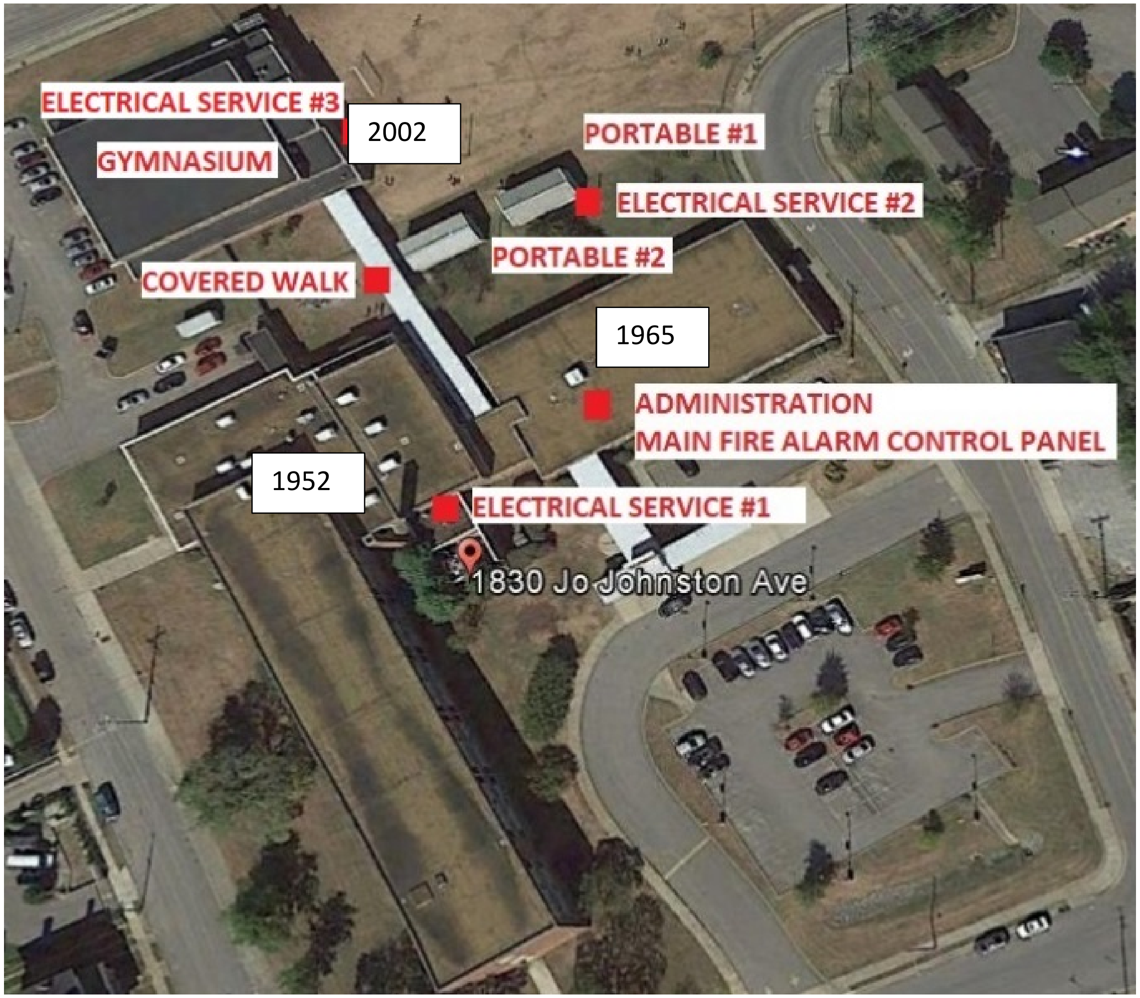
THE CRITICAL DIFFERENCE BETWEEN OFF AND ON

Circuit Isolation

- **Ground Differentials**
- **Ethernet**
- **Signal Isolators**
- **Optical Isolators**
- **Fiber Optics**

Circuit Isolation

Ground Differentials



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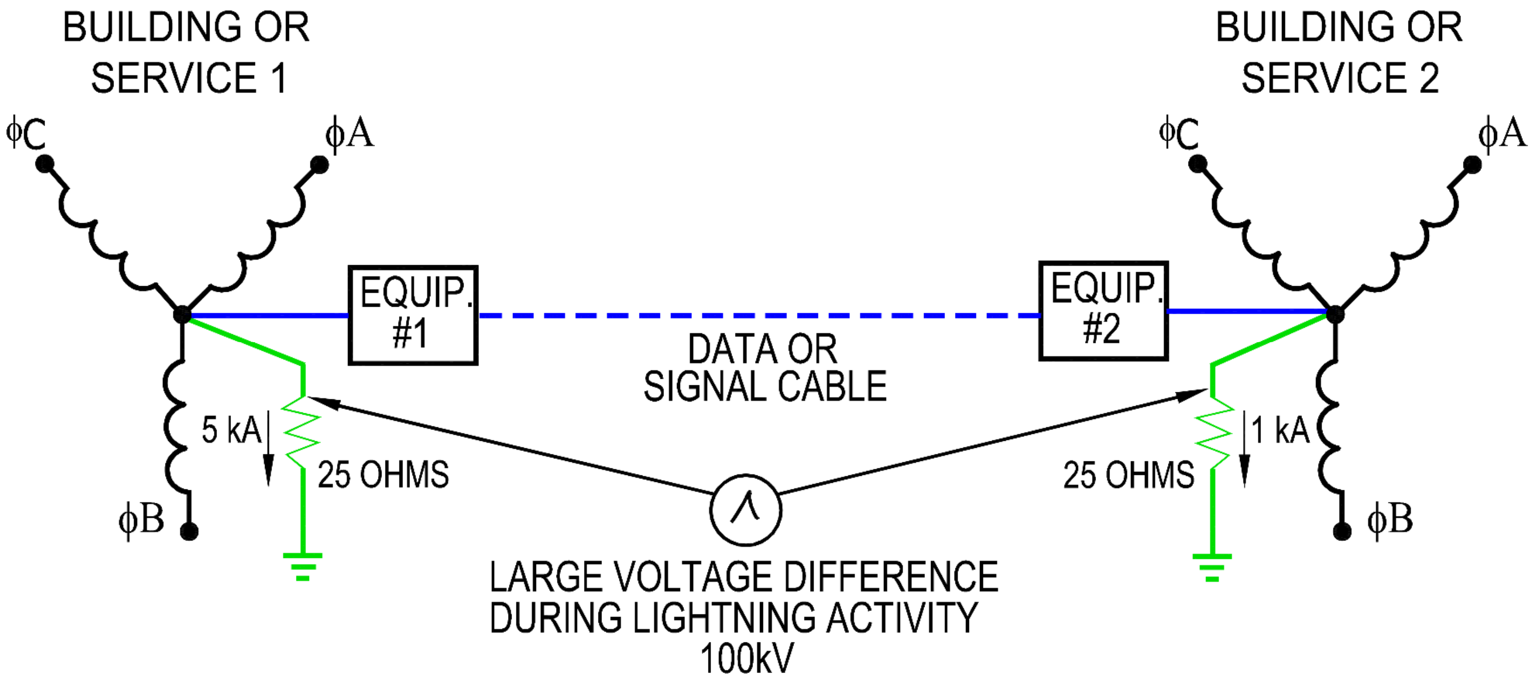
Circuit Isolation

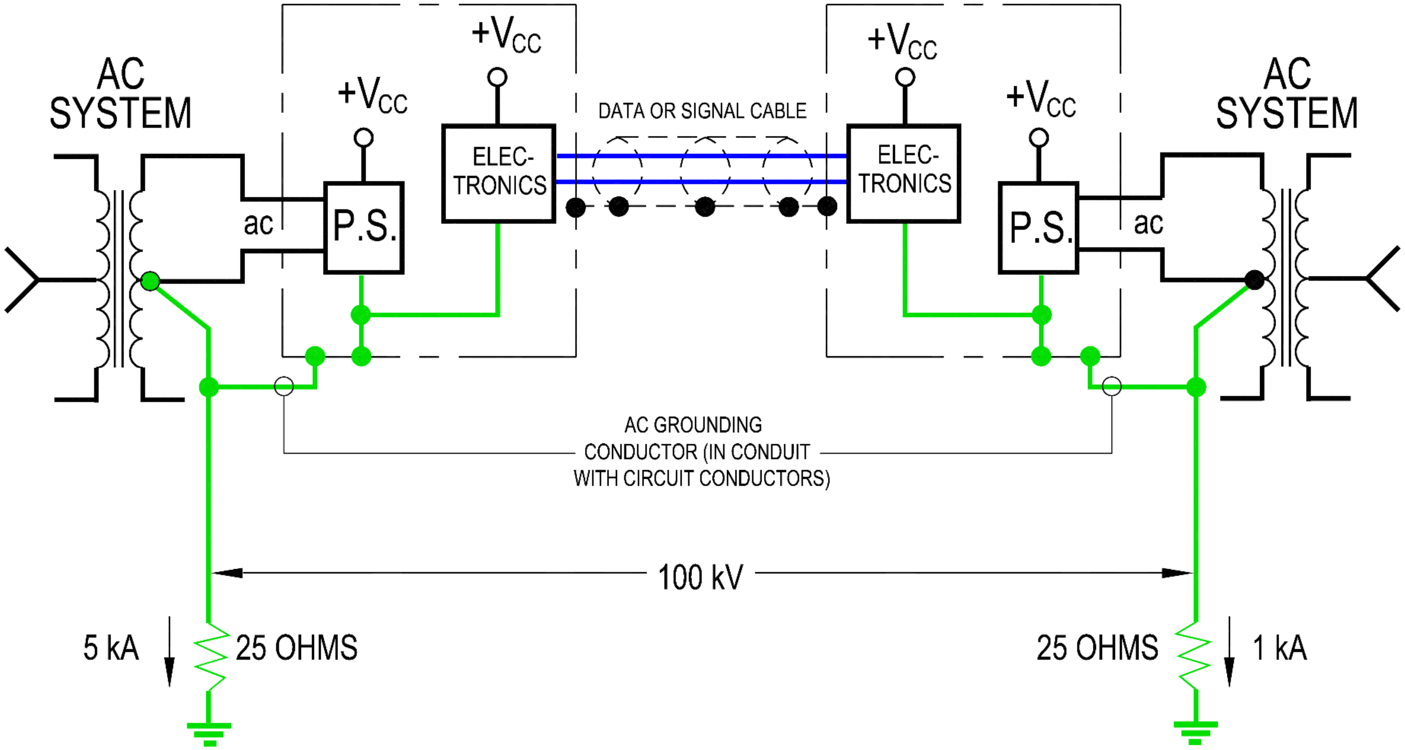
Ground Differentials



- **Ground Differential will be divided among all paths between the two grounding points, which will help**

Circuit Isolation

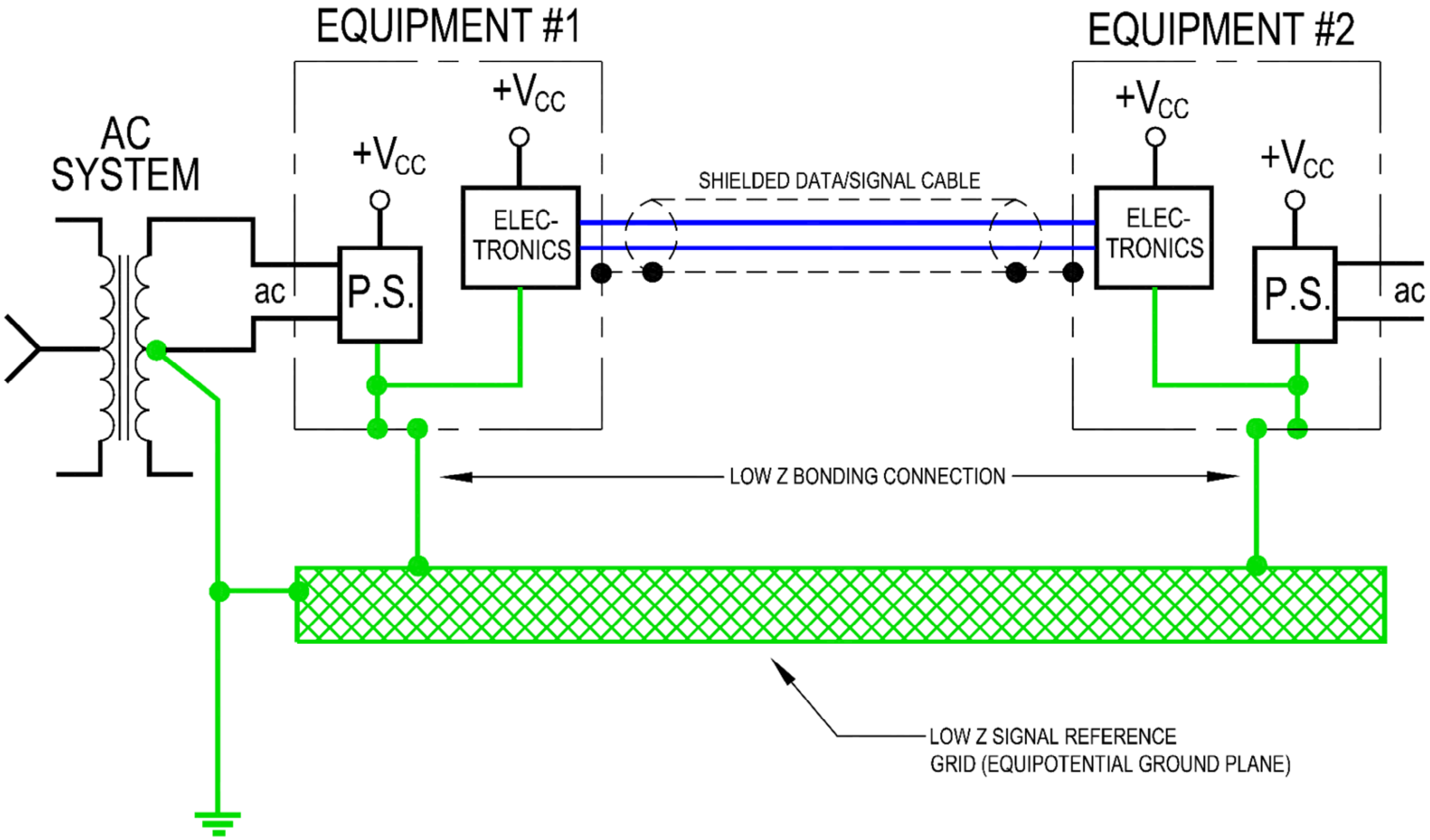
Ground Differentials



- **Typical for data, communications, & signal circuits, such as RS-485, RS-422, Ethernet, Telephone, BAS, Fire Alarm, Security, etc.**

Circuit Isolation

Ground Differentials



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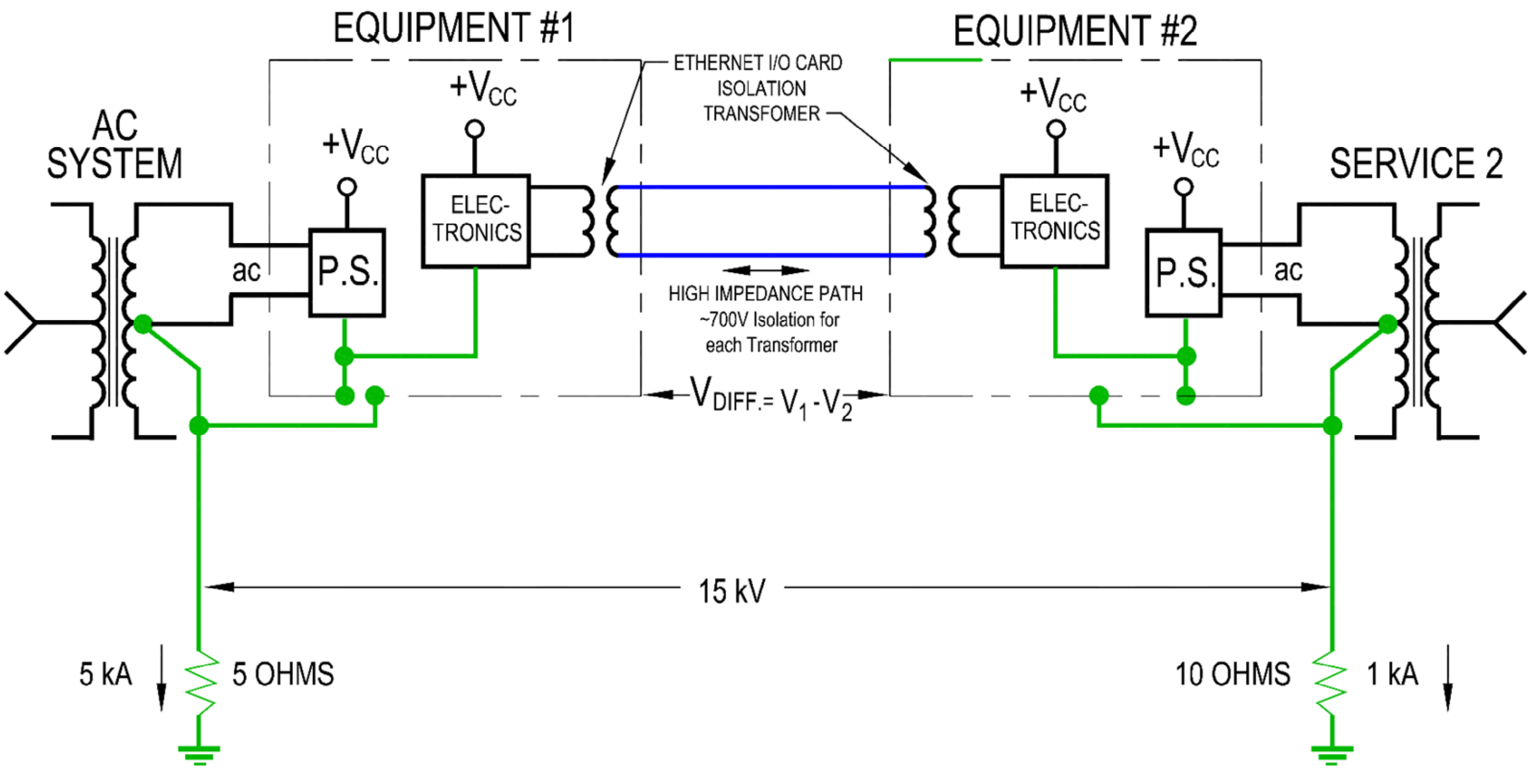
Circuit Isolation

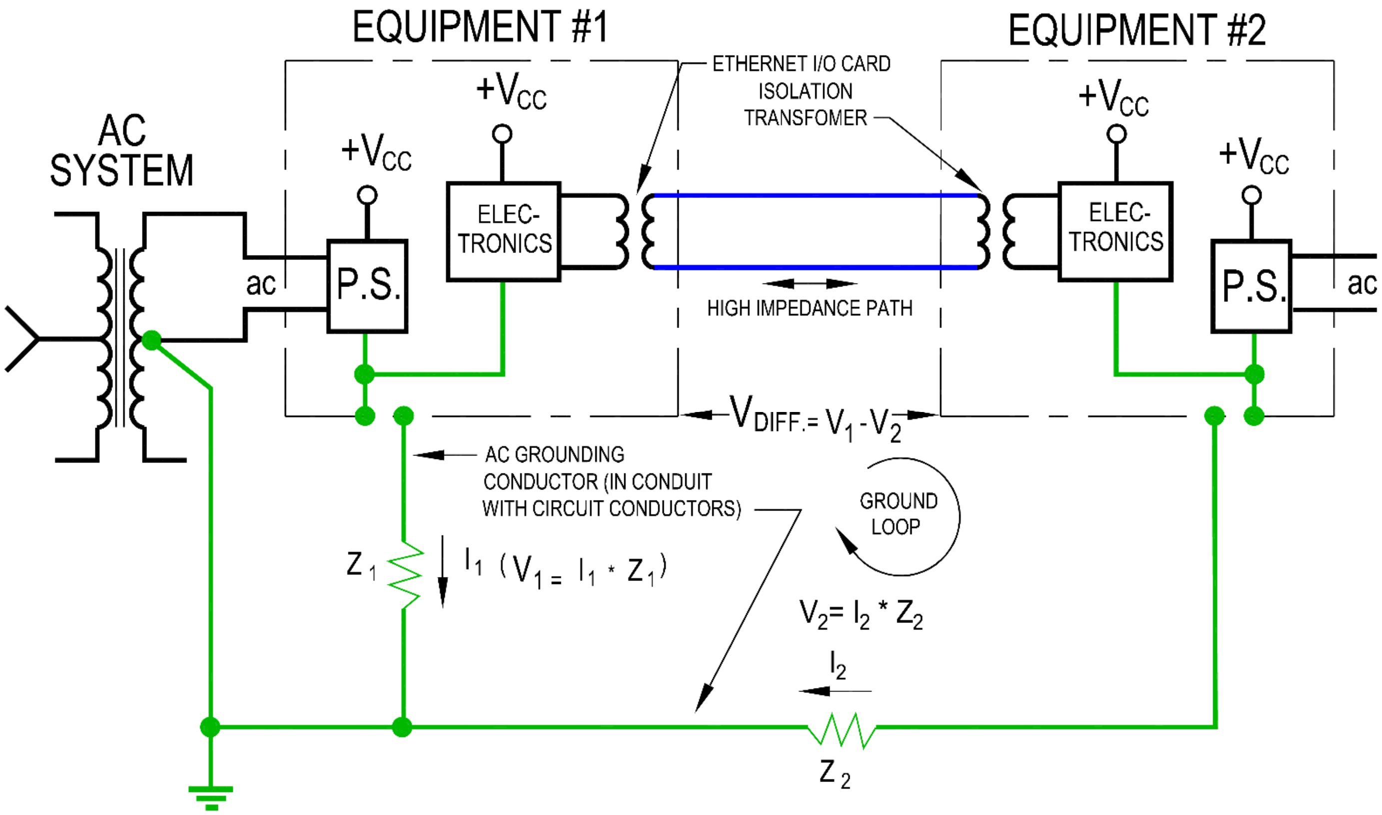
Ethernet



- **Ethernet transformers can provide approx. 700V of isolation each.**
- **One of 4 Data Pairs shown.**
- **Cat. 5/5e includes two active pairs and Cat. 6 uses all four pairs.**

Circuit Isolation

Ethernet



- **Ground Differential can be created via circuit grounding conductors due to EMI Filters, SPD operation, Faults, etc.**

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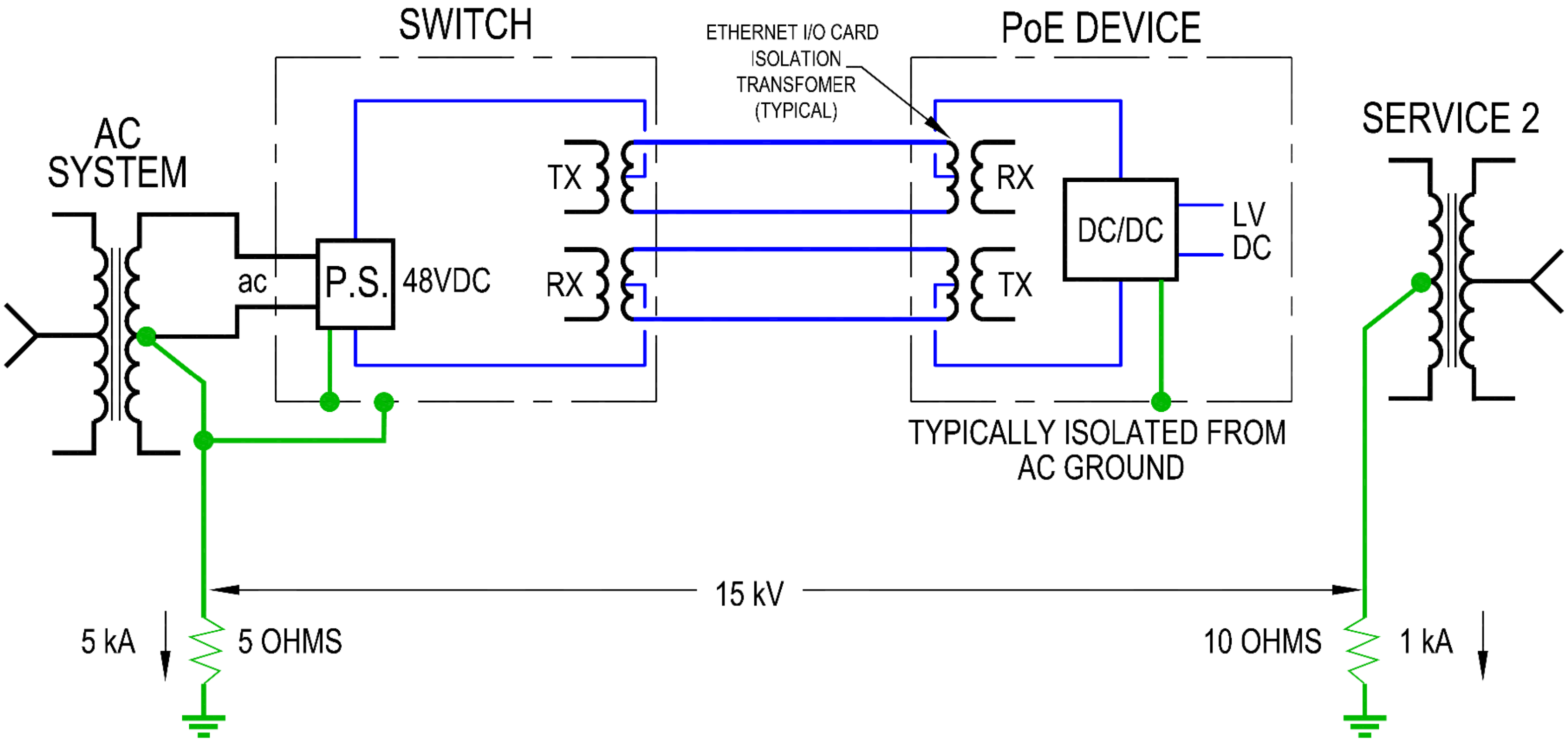
Circuit Isolation

Ethernet with PoE



- **Two of 4 Pairs are used for Powering the PoE Device.**
- **Cat 5/5e Mode B uses two spare pairs without transformers.**

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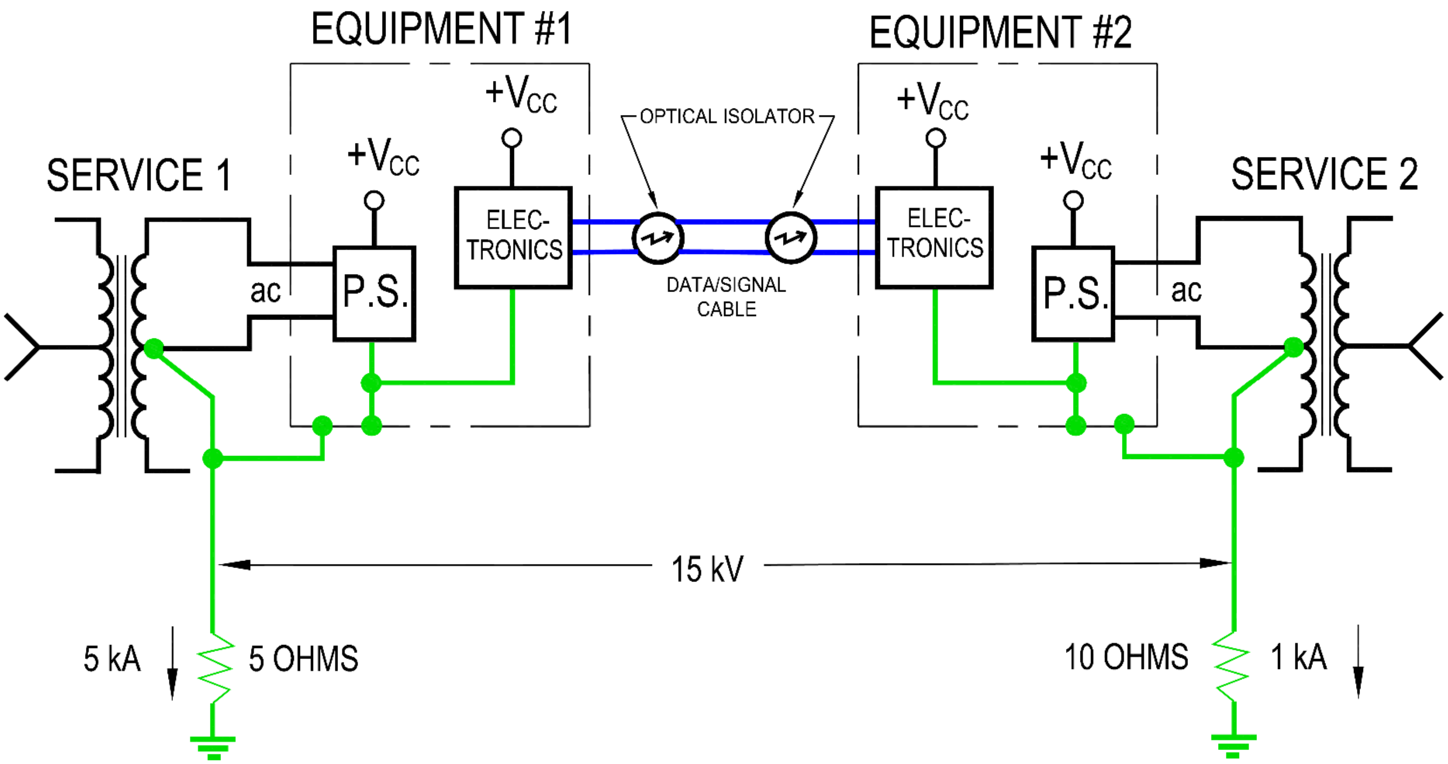
Circuit Isolation

Optical Isolators



- **Optical Isolators can provide 2kV or more of isolation each.**

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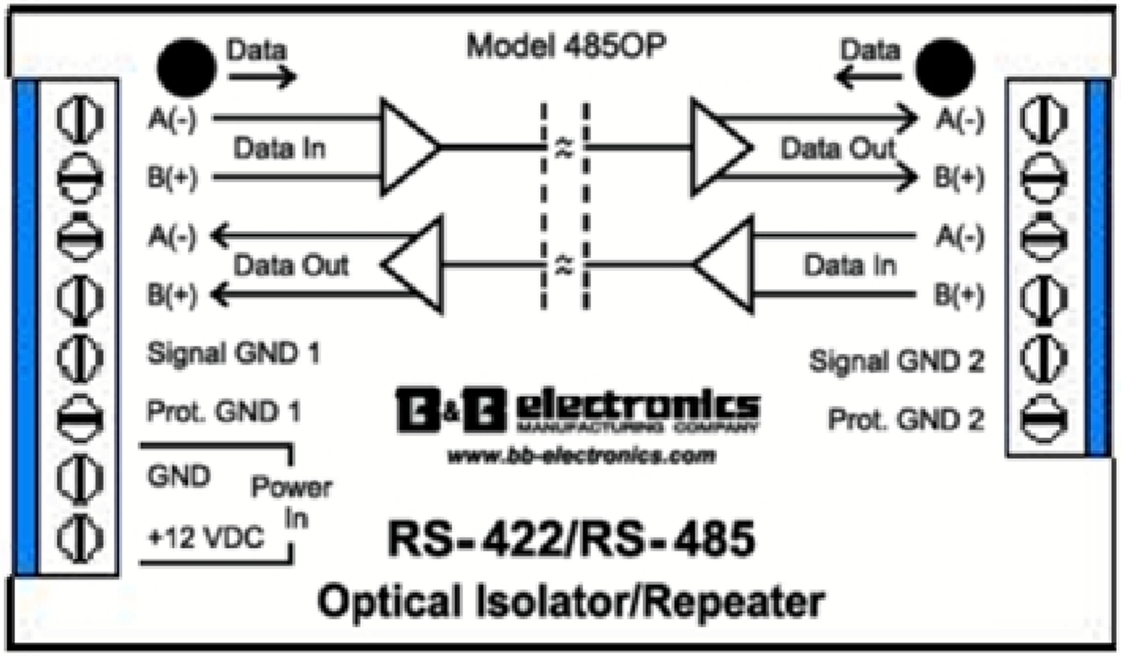
Circuit Isolation

Optical Isolators



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

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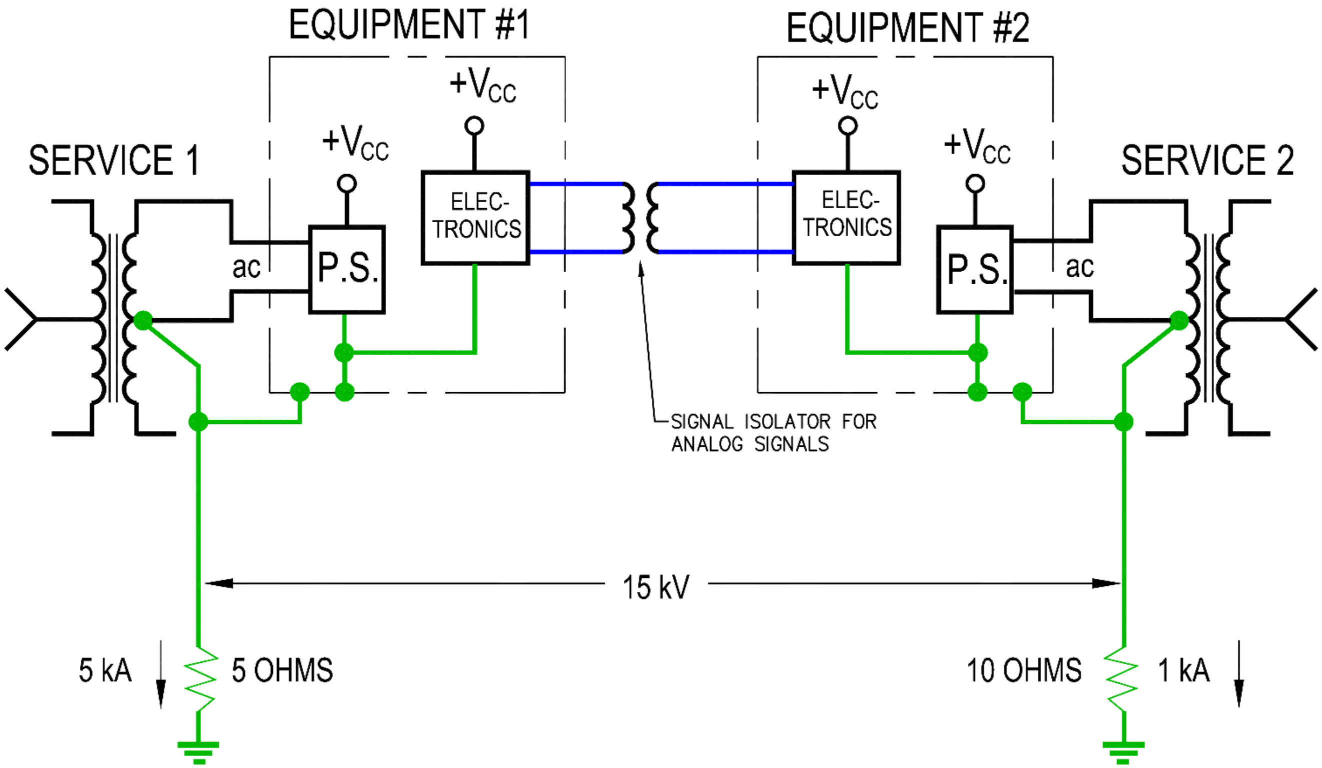
Circuit Isolation

Signal Isolator



- **Typical application would be process controls.**

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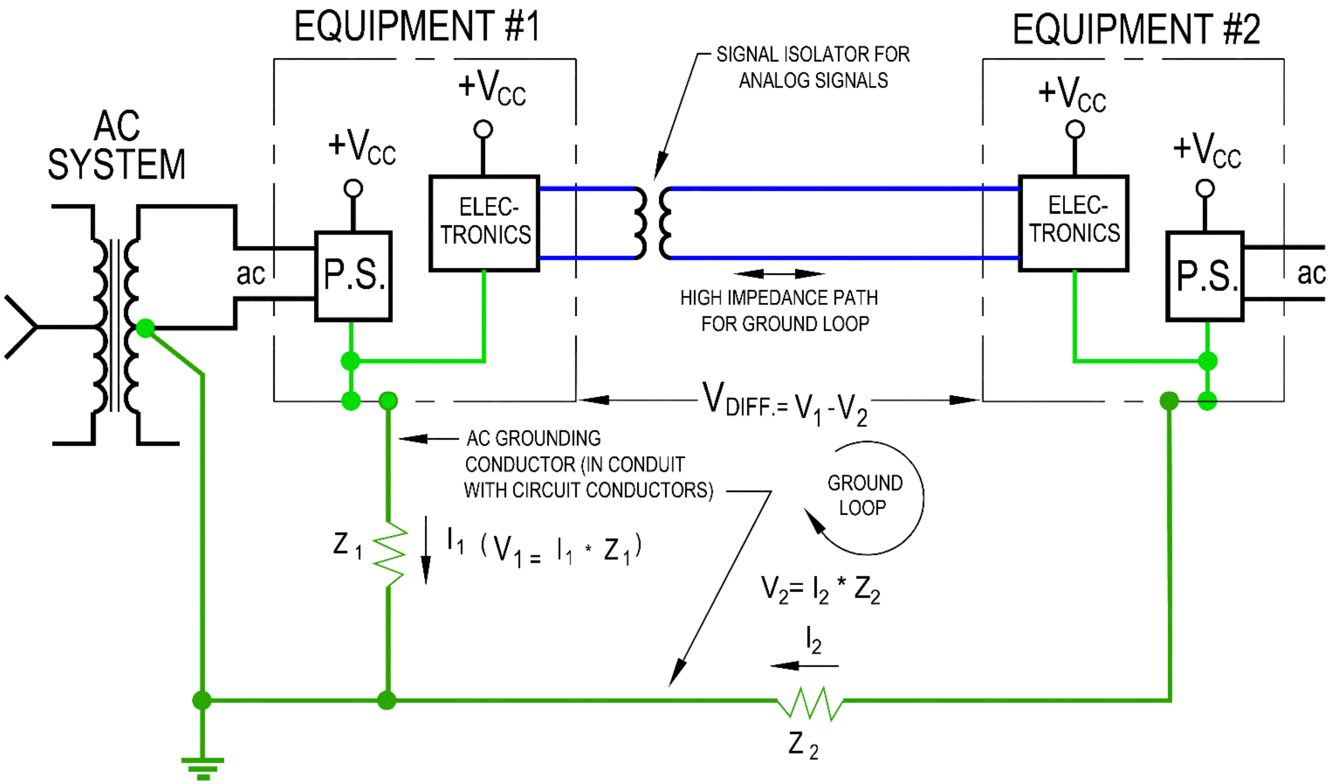
THE CRITICAL DIFFERENCE BETWEEN OFF AND ON

Circuit Isolation

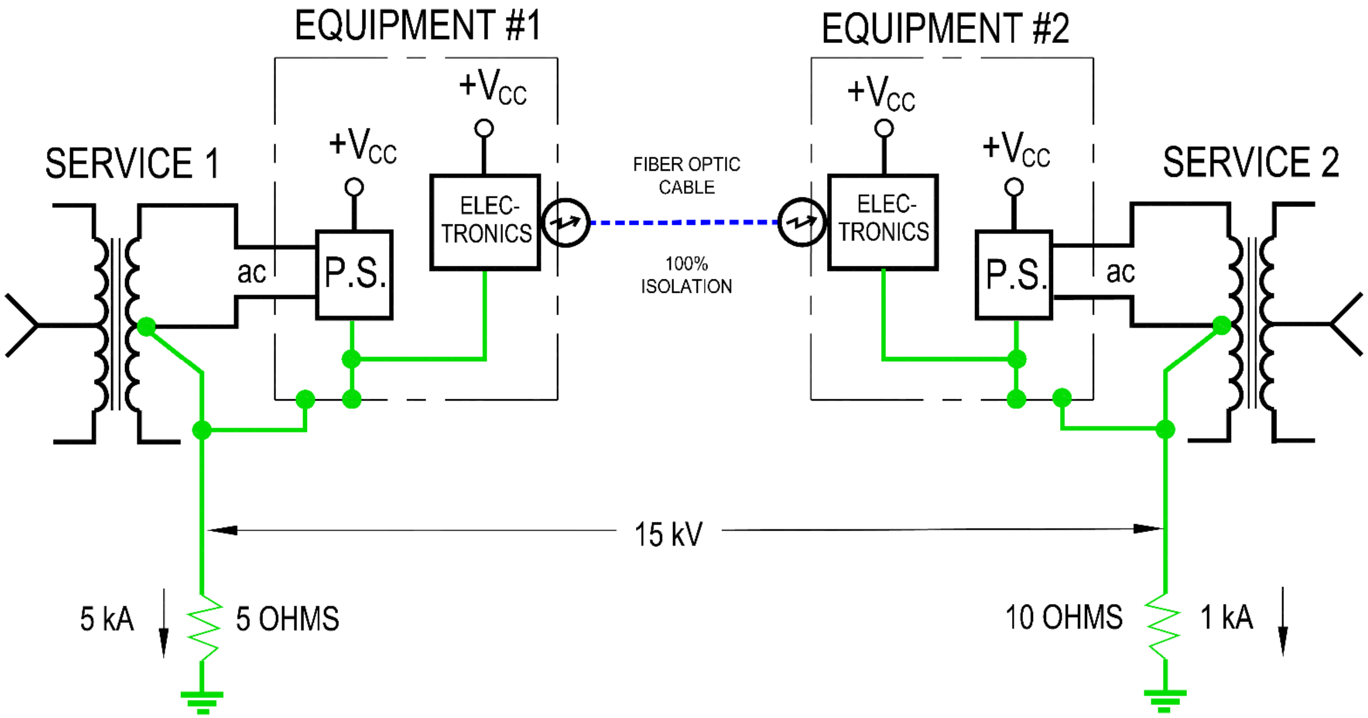
Signal Isolator



- **Typical application would be process controls.**

Circuit Isolation

Fiber Optics



- **Fiber Optics provides 100% isolation.**
- **Wireless also provides 100% isolation but exposed to lightning.**

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THE CRITICAL DIFFERENCE BETWEEN OFF AND ON

Surge Protection

Surge Protection is Beneficial for Protecting Against:

- **Lightning-induced voltages on the utility power lines or electrical service entrance.**
- **Utility switching.**
- **Utility power interruptions, especially repetitive on/off interruptions.**
- **Faults on the utility or the facility electrical system.**
- **Lightning-induced voltages on telephone or cable TV services.**
- **Lightning-induced voltages into facility power circuits.**
- **Lightning-induced voltages on outdoor circuits.**
- **Ground (voltage) differential between two ends of a circuit that extends between buildings or different sections of a building.**
- **Starting and stopping of motor loads.**
- **Switching loads within the facility.**
- **Direct or indirect effects of lightning on outdoor equipment like rooftop mechanical equipment, outdoor lighting, etc.**

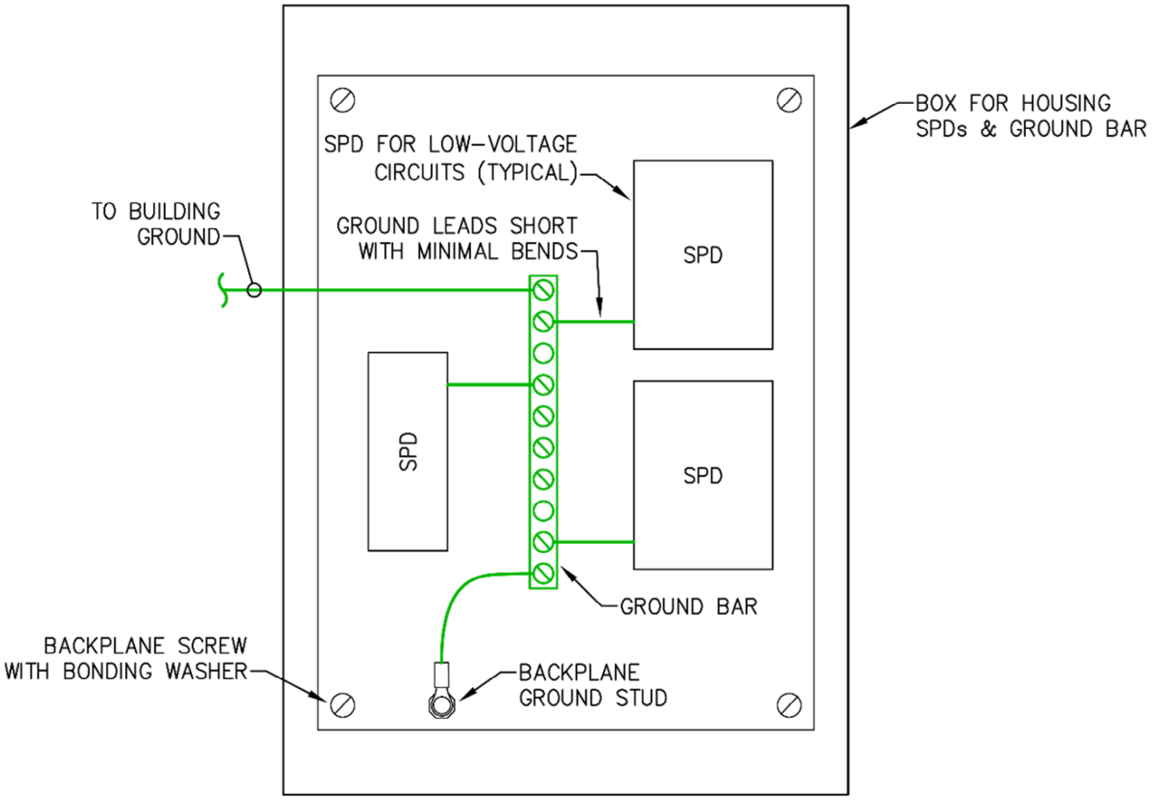
Systems that can be affected by Surges:

- **Power**
- **Telephone**
- **CATV and Satellite TV**
- **Radio and TV Communications**
- **Computer Network (Hardwired and Wireless)**
- **Fire Alarm**
- **CCTV**
- **Security (Intrusion and Access Control)**
- **Intercom or Public Address**
- **Annunciators (e.g. outdoor generator)**
- **Monitoring Systems (DCIM, etc.)**
- **Building Automation System**
- **Gate Operators**

SPD Locations

- **Each Electrical Service**
- **Sub-Panels supplied from transformers, feeders exposed to lightning, and/or supplying critical/sensitive equipment.**
- **Each Communications Service (Telephone, Cable TV, Satellite, etc.)**
- **Each power, communications, controls, or data circuit that extends beyond the building for outdoor equipment or a remote building. Also required by NEC Articles 725, 800, and 820 for certain conditions.**
- **Critical/Sensitive utilization equipment. Consider combination units where the equipment is connected to both power and communications/data.**

Surge Protection for Low-Voltage (<120V) Circuits



- **Consider an "Interface Box" for interface between indoor and outdoor wiring**

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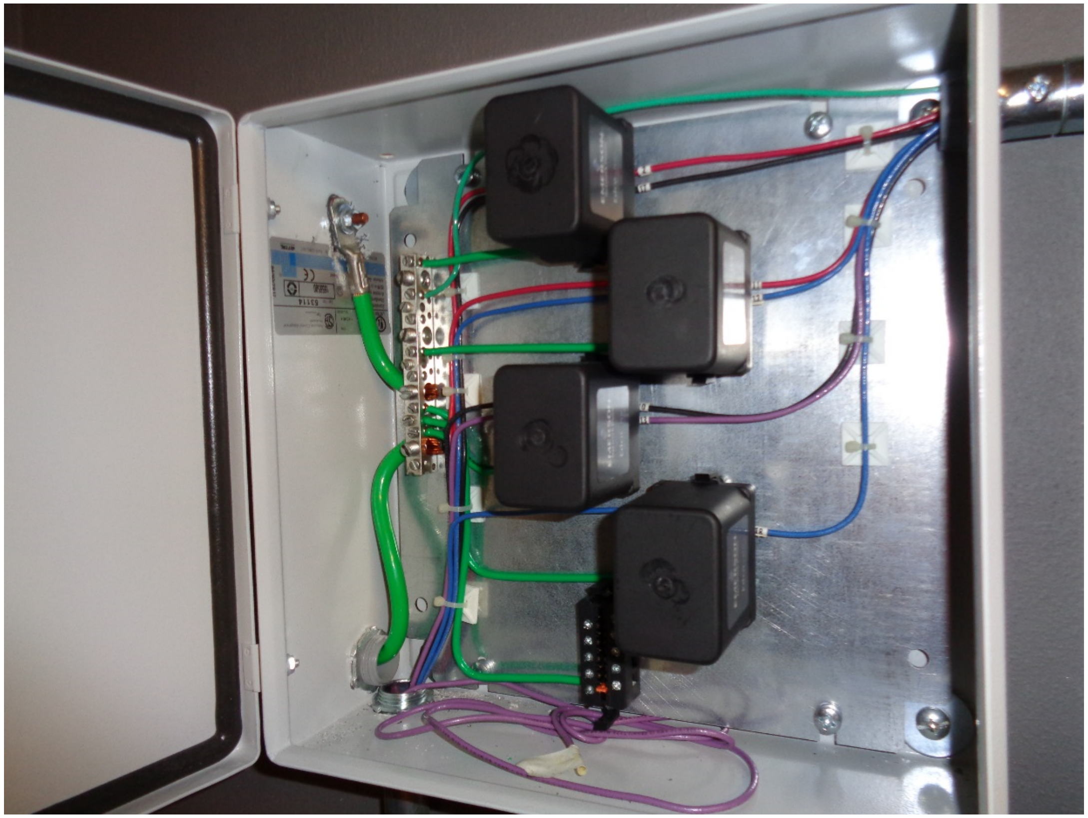
Surge Protection for Low-Voltage (<120V) Circuits



- **Consider an "Interface Box" for interface between indoor and outdoor wiring**

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Case Studies

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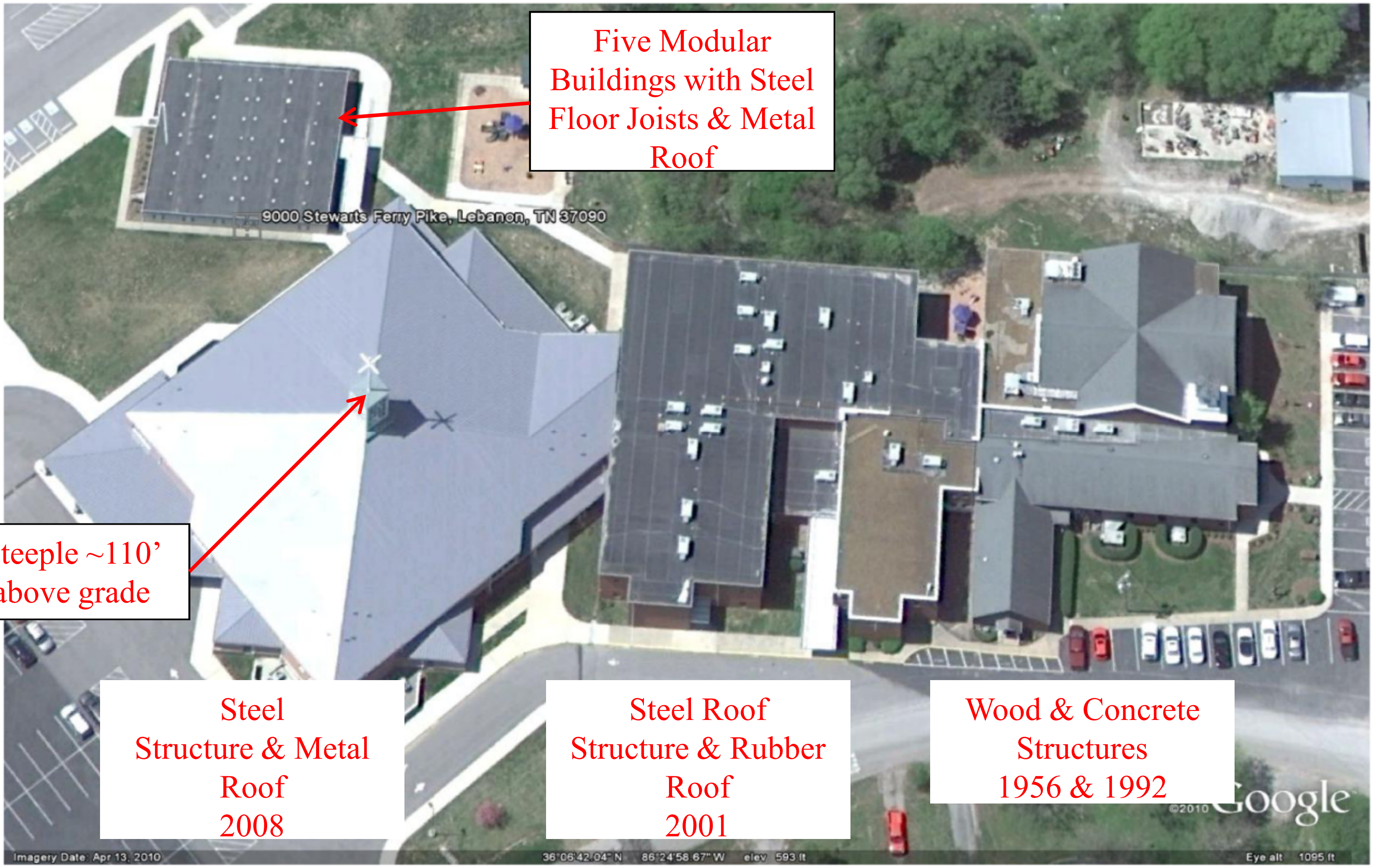
Church Case Study



Five Modular Buildings with Steel Floor Joists & Metal Roof

Steeple ~110' above grade

Steel Structure & Metal Roof
2008

Steel Roof Structure & Rubber Roof
2001

Wood & Concrete Structures
1956 & 1992

- **Built in 3 Phases between 1956 and 2008**

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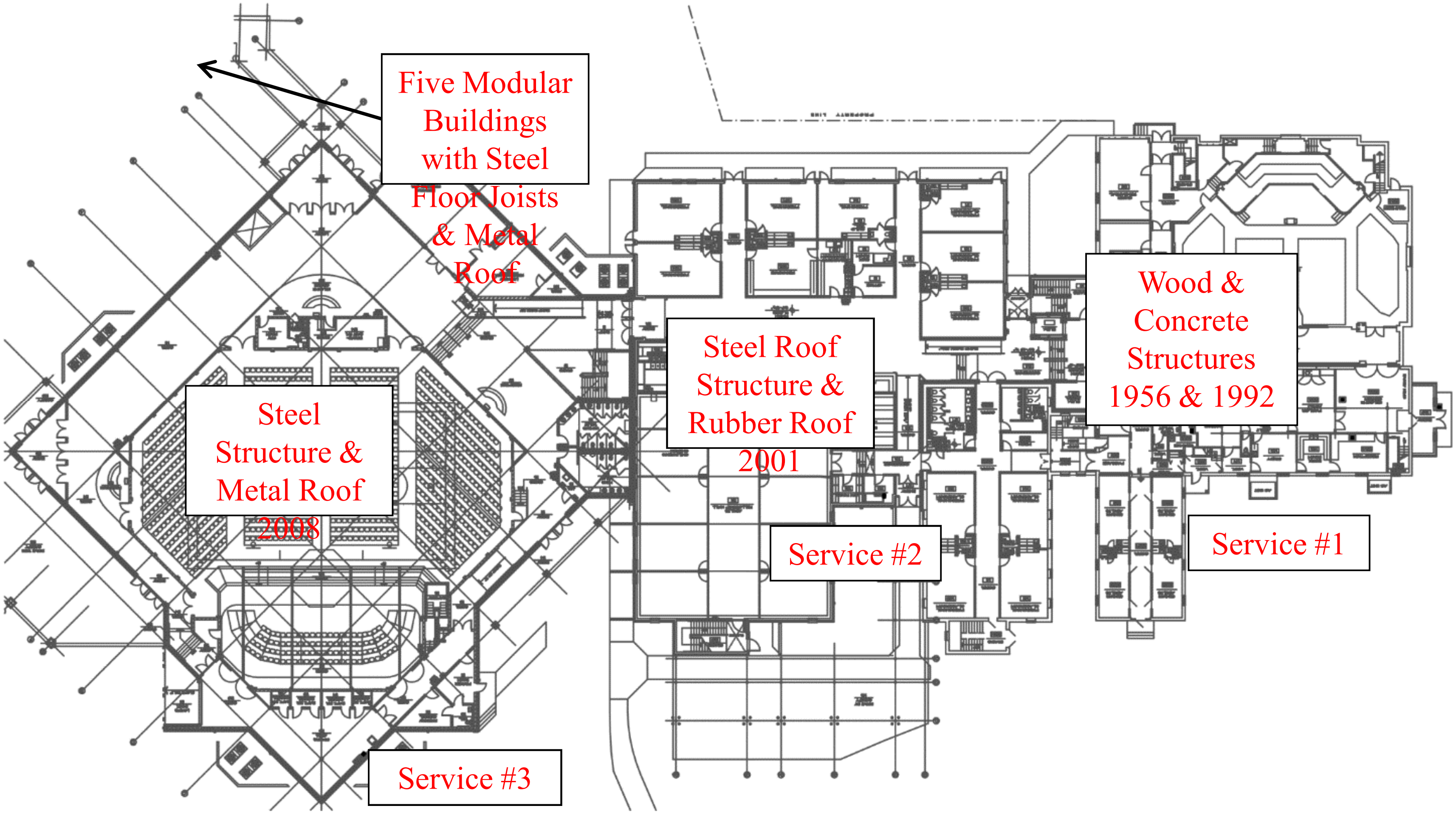

Five Modular Buildings with Steel Floor Joists & Metal Roof

Steel Structure & Metal Roof 2008

Steel Roof Structure & Rubber Roof 2001

Wood & Concrete Structures 1956 & 1992

Service #3

Service #2

Service #1

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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.**

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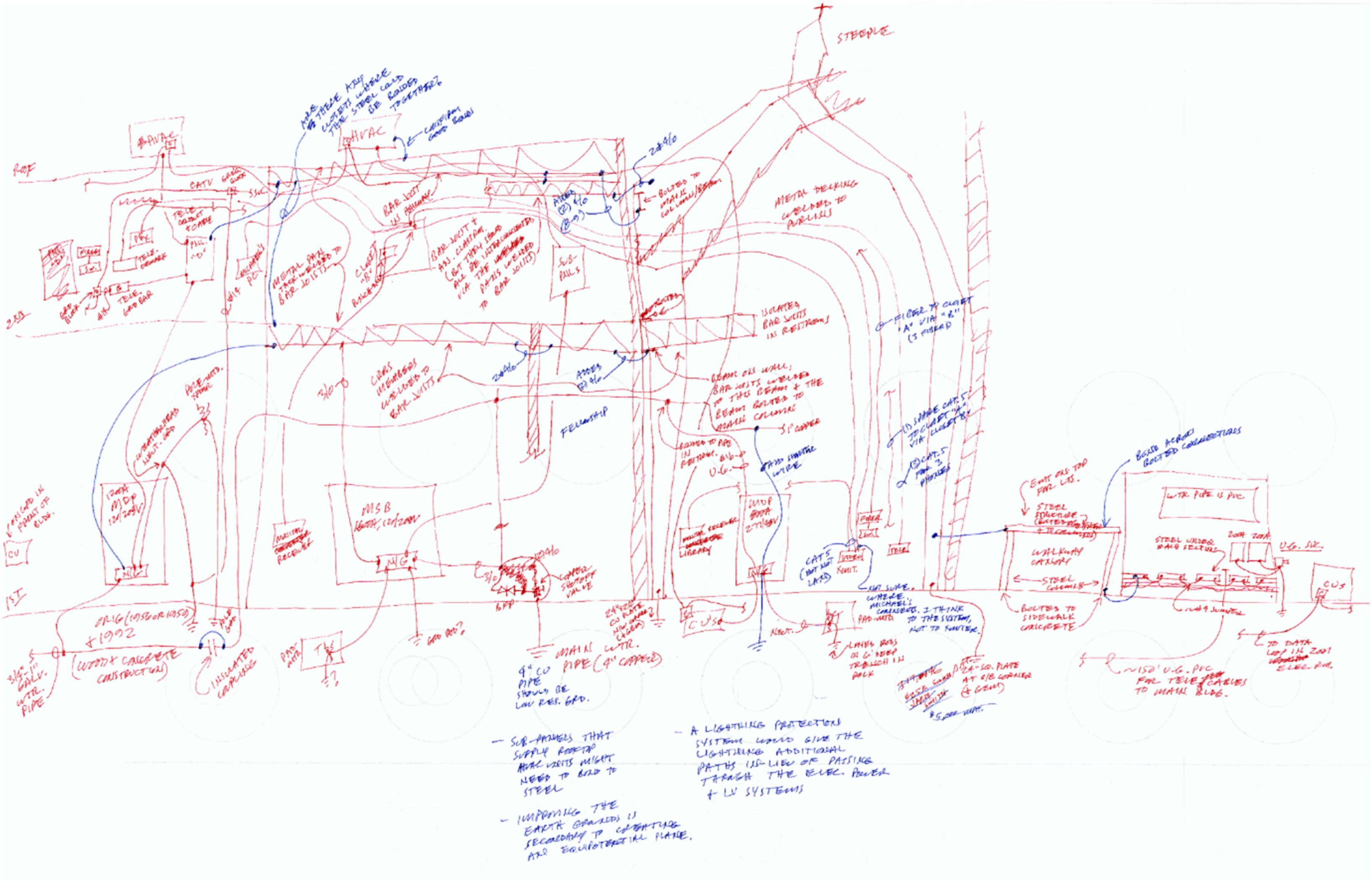
“Field Work”



- SUB-PANELS THAT SUPPLY ROOFTOP HVAC UNITS MIGHT NEED TO BOND TO STEEL

- IMPROVING THE EARTH GROUNDS IS SECONDARY TO CREATING AN EQUIPOTENTIAL PLANE.

- A LIGHTNING PROTECTION SYSTEM WOULD GIVE THE LIGHTNING ADDITIONAL PATHS IN-LIEU OF PASSING THROUGH THE ELEC. POWER + LV SYSTEMS

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.**

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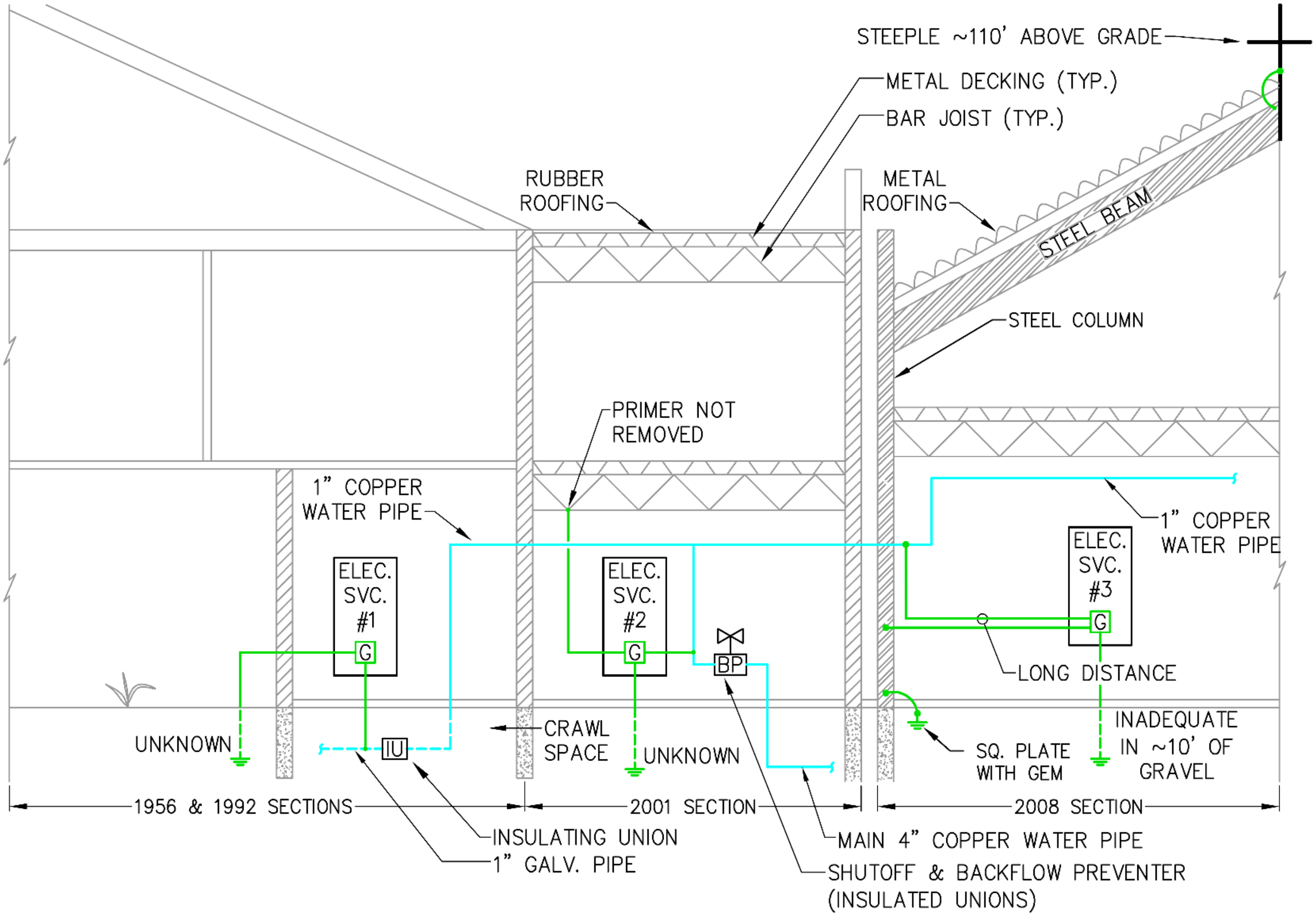
Grounding Before



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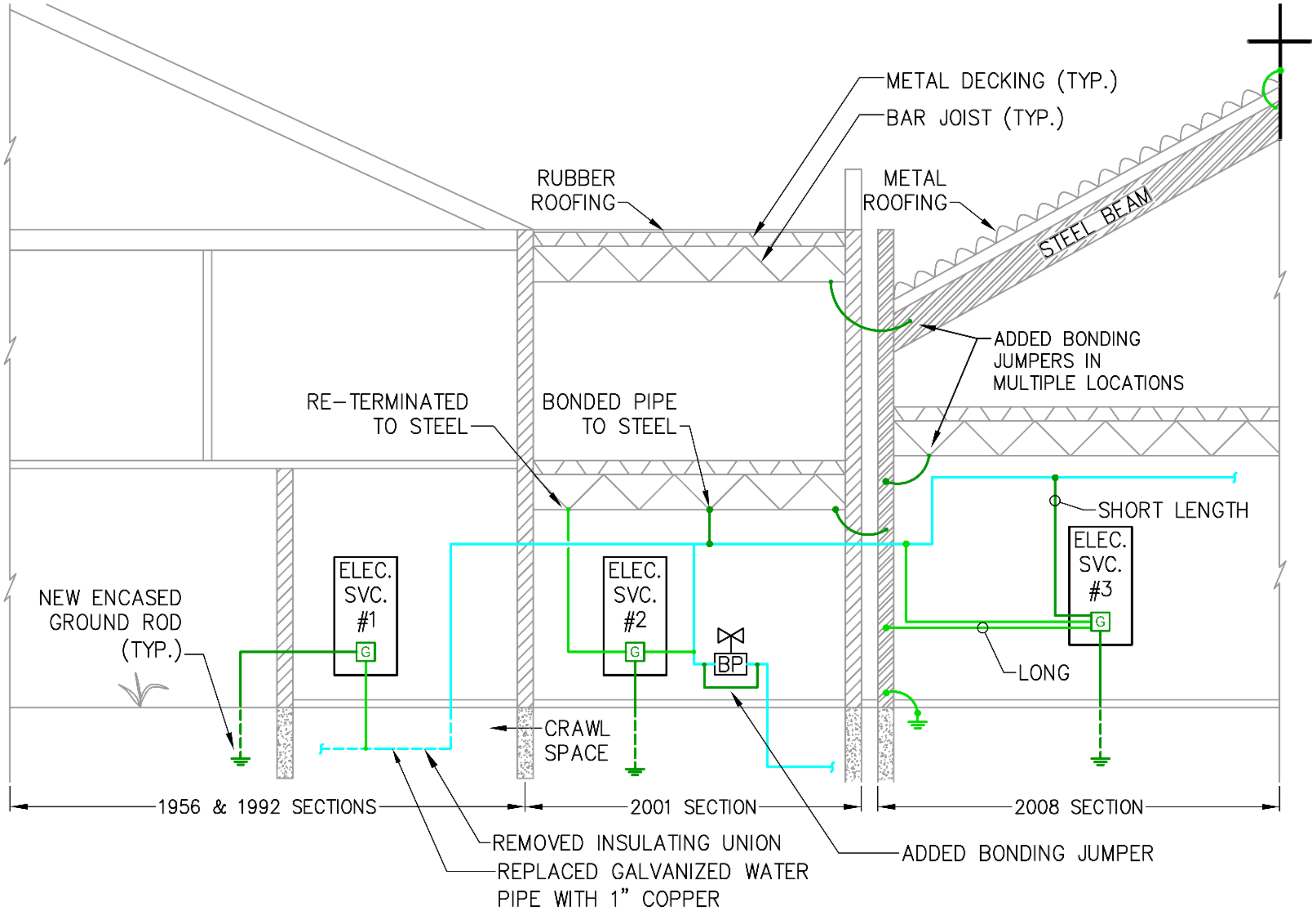
Grounding After



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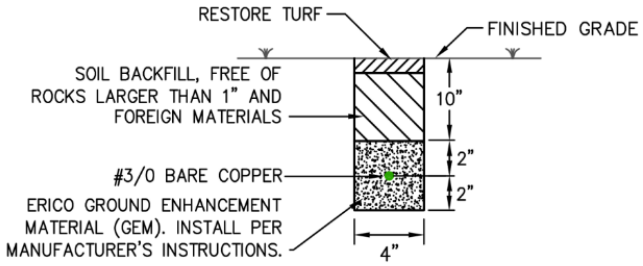
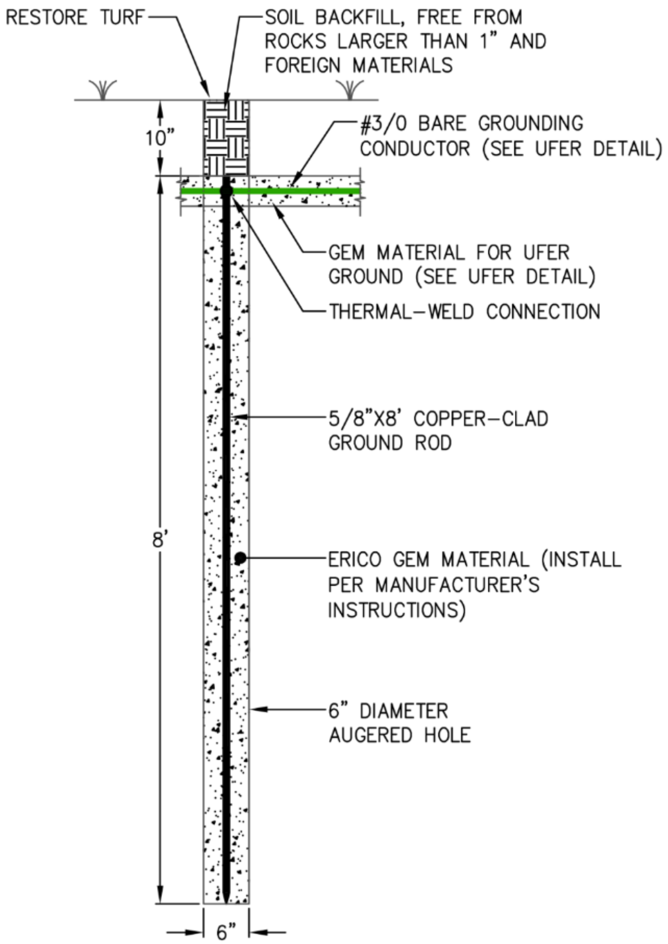
Grounding Electrodes





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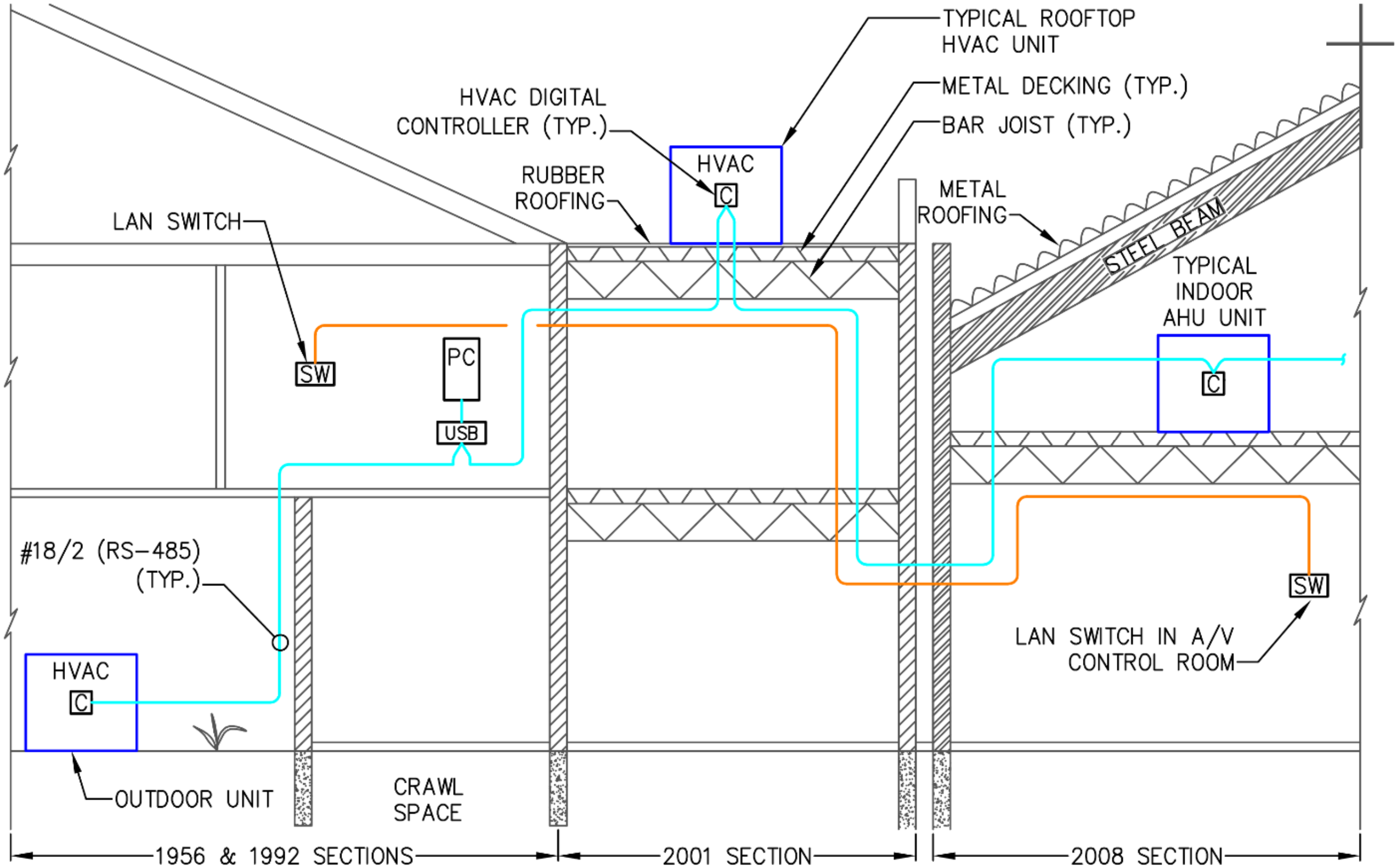
DDC Controls Before



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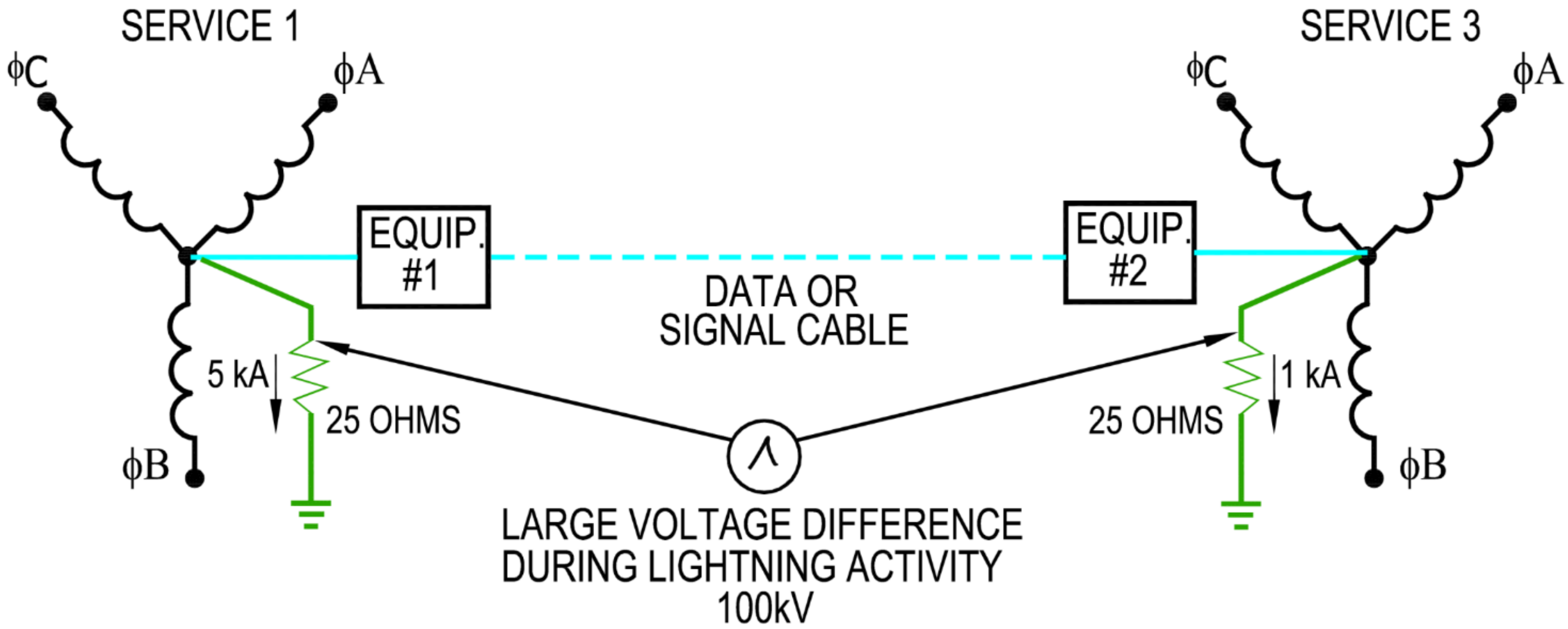
Ground Differential Conditions



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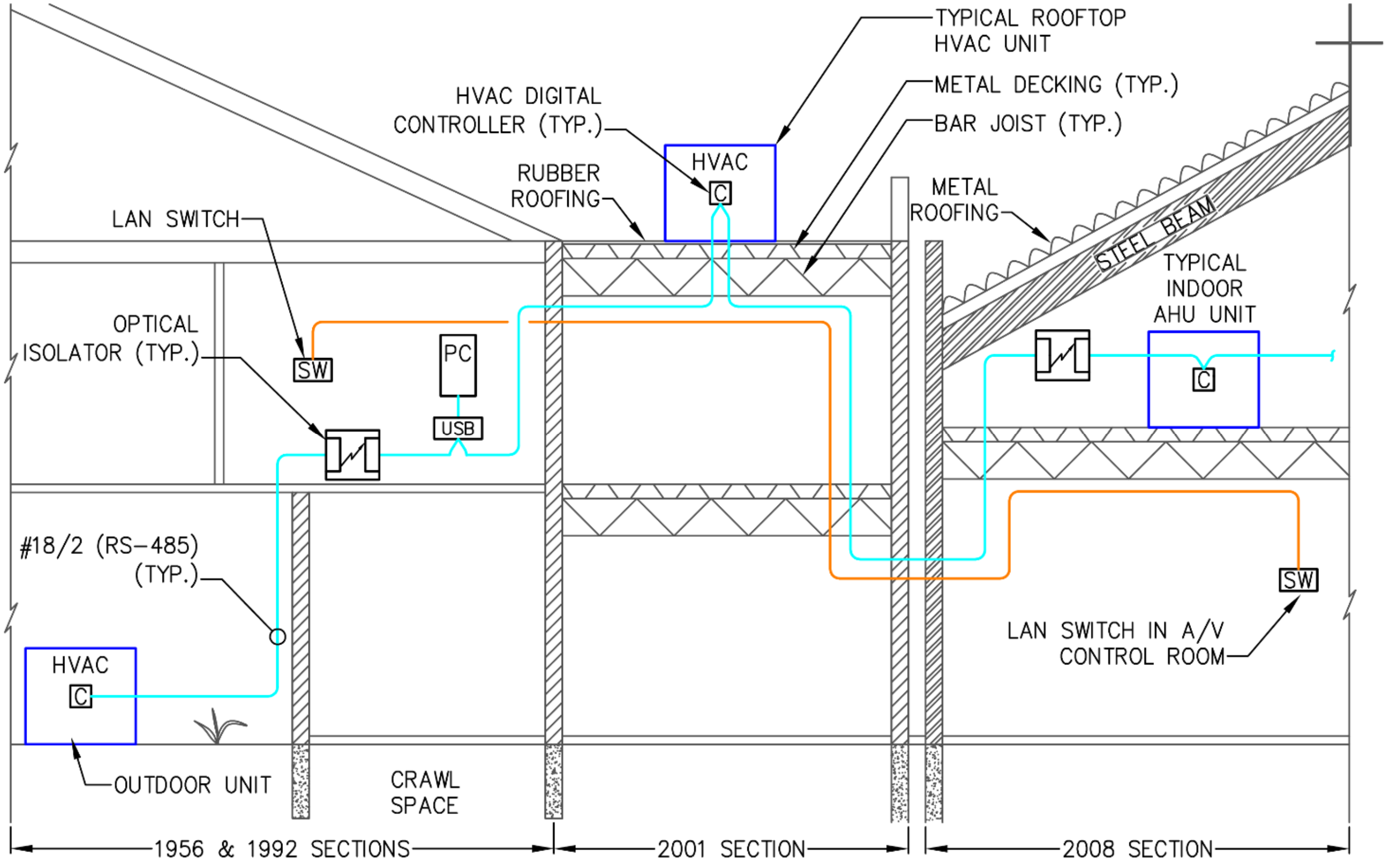
DDC Controls After



Church Case Study

Other Improvements

- **SPD for each Electrical Service.**
- **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.**
- **SPDs for Intercom and Card reader at main entrance.**

Facility with Radio Tower Case Study

Damaged Equipment

- **Radios**
- **Standby Generator Annunciation and Controls**
- **PCs**
- **Printers**
- **Wireless Access Point**
- **VoIP Phone**
- **CCTV DVR**

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Radio Rack

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Antenna Tower and Cables

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Antenna Cables at Entry Panel (Bulkhead)

06/16/2011

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Arcing between Rack and Ceiling Grid

06/16/2011

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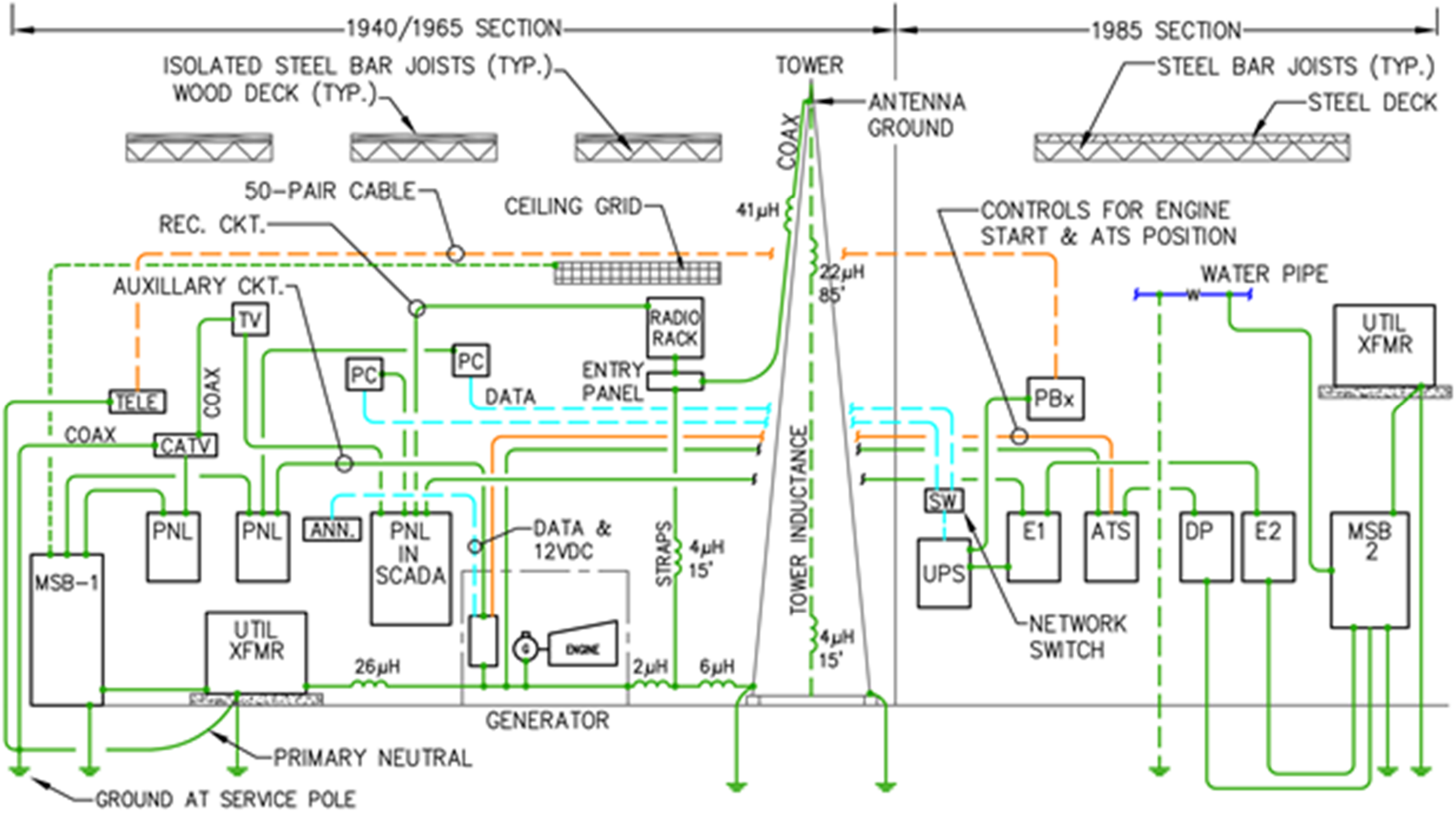
Grounding & Bonding Before



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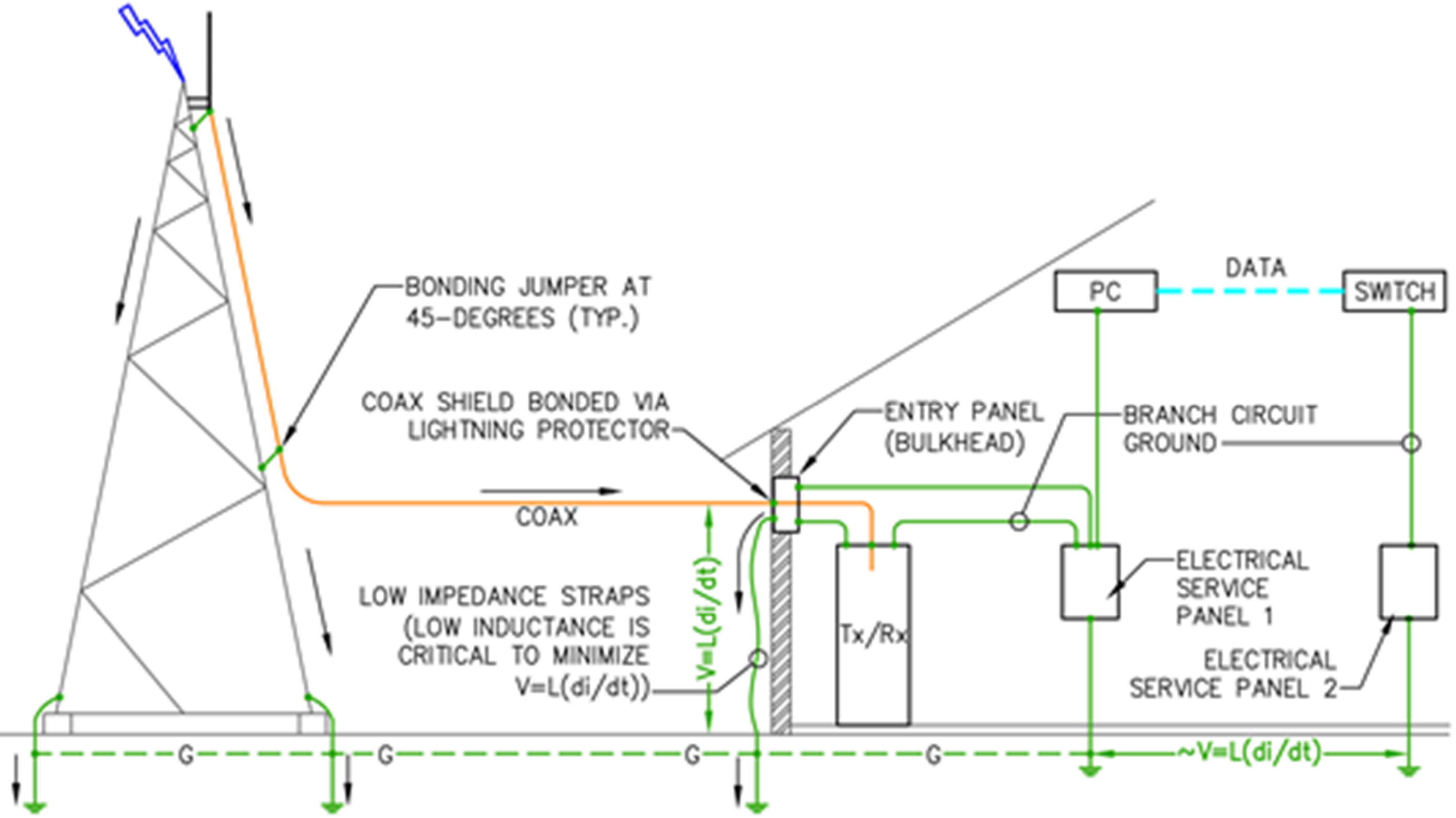
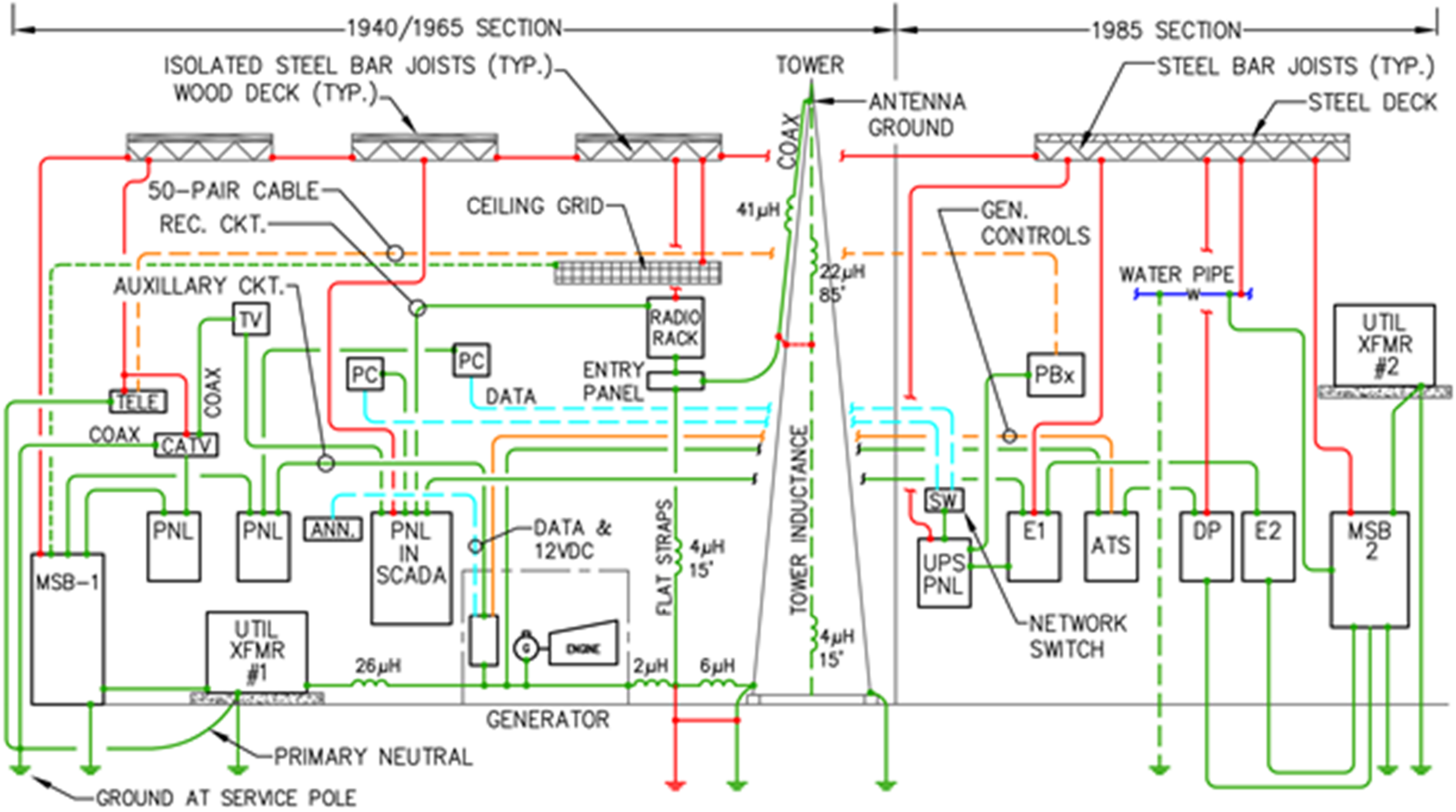
Ground Differential Condition



Facility with Radio Tower Case Study

Grounding & Bonding After



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Recommended References

- Military Handbook 419A, Volumes 1 and 2, "Grounding, Bonding, and Shielding for Electronic Equipment and Facilities"
- "Lightning Protection & Grounding Solutions for Communication Sites" by Ken R. Rand, Polyphaser
- "The Art and Science of Lightning Protection" by Martin A. Uman, PhD, University of Florida
- IEEE 142 (Green Book), IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.
- IEEE 1100 (Emerald Book), IEEE Recommended Practice for Powering and Grounding Electronic Equipment
- NFPA 780, Lightning Protection Standard
- Lightning Protection Institute

For Effective Lightning Protection

- **Look at THE BIG PICTURE.**
- **Consider all Systems and Equipment Involved.**
- **For Personal Safety, <u>Respect Electricity and Lightning!</u>**

God Bless America and Our Troops

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