

Grounding and Bonding Beyond Code Minimums Can Avoid Down Time

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Copper Development Association Inc.



2018 BICSI Fall Conference & Exhibition



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Agenda

- 1. National Electrical Code® minimums and going beyond the Code**
- 2. Considerations for sensitive equipment**
- 3. Many case histories we can learn from, good and bad**



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What is Poor Power Quality

- Poor power quality...

is evidenced by characteristics of the incoming power to a device that deviate from the customary “pure” 60 Hz sine wave, and that can affect reliable and safe operation of the sensitive equipment

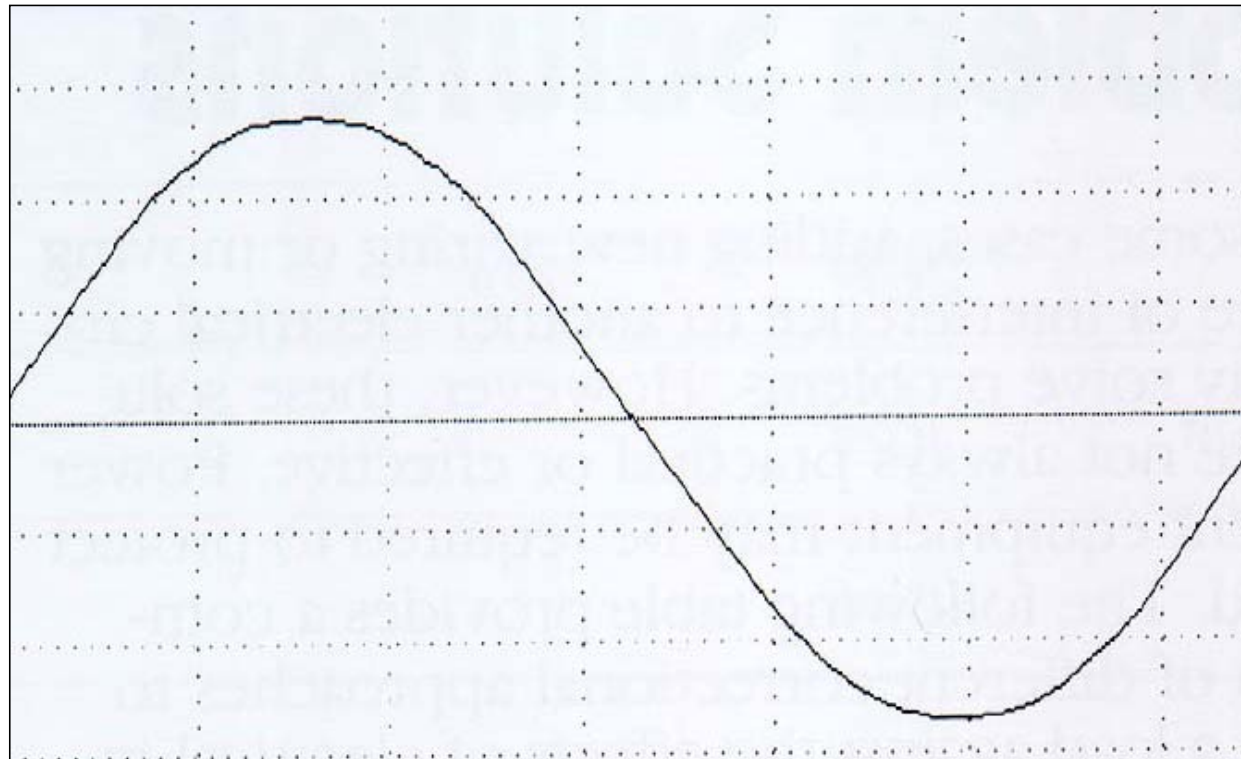


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What The Equipment Wants

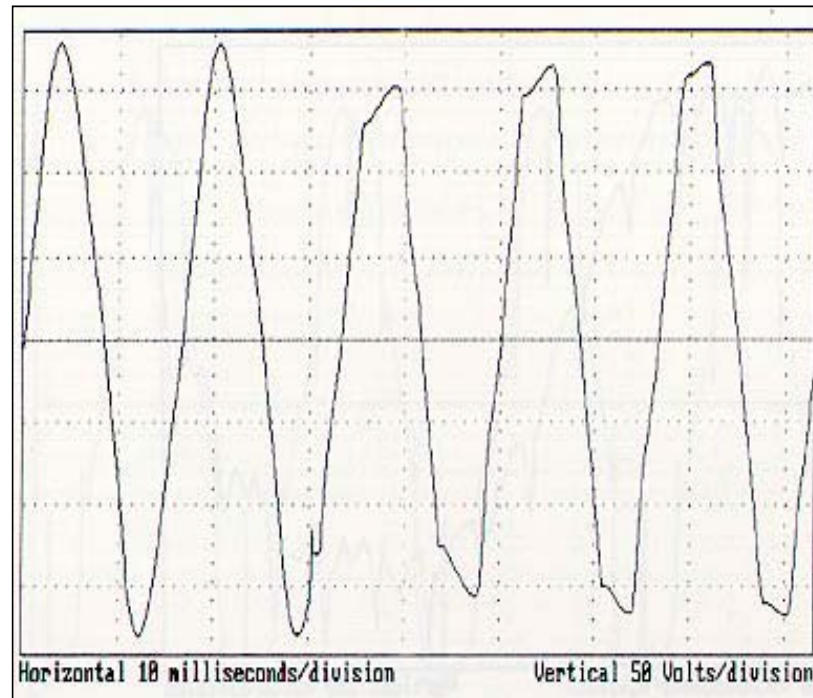


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What The Equipment Sometimes Gets



We Are Going to Discuss

Elements of building infrastructure that can alleviate or cure power quality problems before they affect operations:

Grounding

Bonding

Circuiting

Lightning

You should be able to conduct a preliminary walk-around audit after this presentation.



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Equipment More Sensitive

- **Micro circuits are getting faster (radio frequency range)**
- **Microprocessors more ubiquitous**
- **Circuits are getting smaller**
- **Operating voltages are lower**



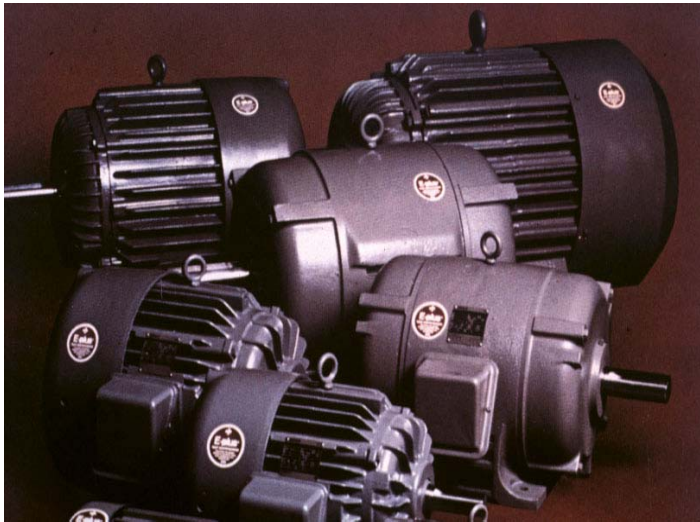
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Old vs. New

What used to be acceptable service characteristics are no longer sufficient



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The Real Cost

The real cost of poor power quality is in lost productivity (downtime).

- **Estimated at \$15-30 billion per year plus in US**
- **Average cost of a data center outage \$740,357 in 2016**
- **Exceeds \$1 million/yr. at some buildings**

• E Source and Penton

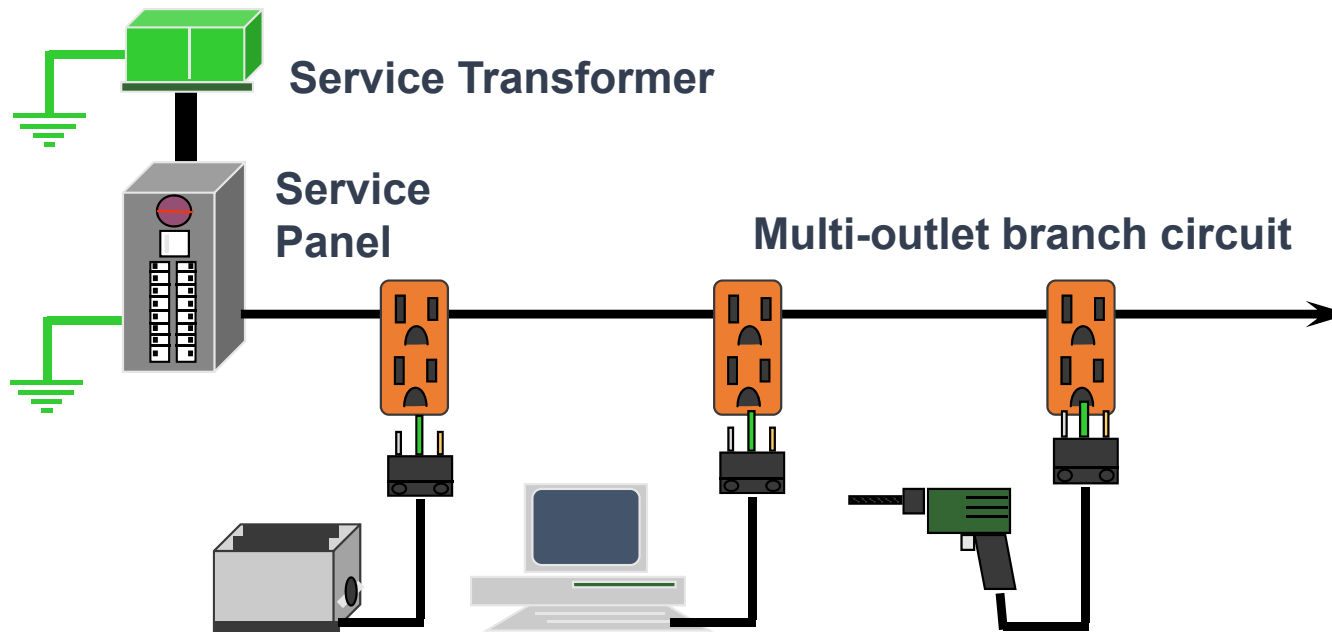


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Is The Computer a Problem? or is it the way it's wired?



All Types of Loads on Same Panel

PANELBOARD/PANNEAU/TABLERO

DATE: _____

| CIR | LOAD / CHARGE / CARGA | CIR | LOAD / CHARGE / CARGA |
|-----|-------------------------|-----|-------------------------------------|
| 1 | Elevator main | 2 | Lobby A.H.U |
| 3 | disconnect | 4 | |
| 5 | Hyd. motor | 6 | |
| 7 | Lobby A/C | 8 | Surge |
| 9 | condenser unit | 10 | Protection |
| 11 | out back | 12 | unit |
| 13 | Parking lot | 14 | Hot water |
| 15 | Light poles | 16 | Heater |
| 17 | Parking lot | 18 | Spare |
| 19 | Light poles | 20 | South Stair way LTS |
| 21 | out side front GFI | 22 | Spare |
| 23 | N+S GFI | 24 | North Stair way LTS + Emergency LTS |
| 25 | GFI under | 26 | Elevator Cab LTS |
| 27 | PHOTO cell | 28 | Fresh Air make up Fan |
| 29 | Entry Lobby GFI | 30 | Time clock |
| 31 | Fire Alarm Booster Pnl. | 32 | Elevator PIT GFI |
| 33 | Fire Alarm Pnl. | 34 | Elevator PIT LTS |
| 35 | | | |



Problems Are Mainly Internal

Most power quality problems are related to grounding and neutral size issues

Over 80% are internally caused

source: EPRI



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Erratic Operation or Downtime

Power Quality issues can lead to erratic operation of sensitive electronic equipment (data errors, lockup, false images in medical diagnostics, premature failures, downtime, nuisance tripping, etc.)



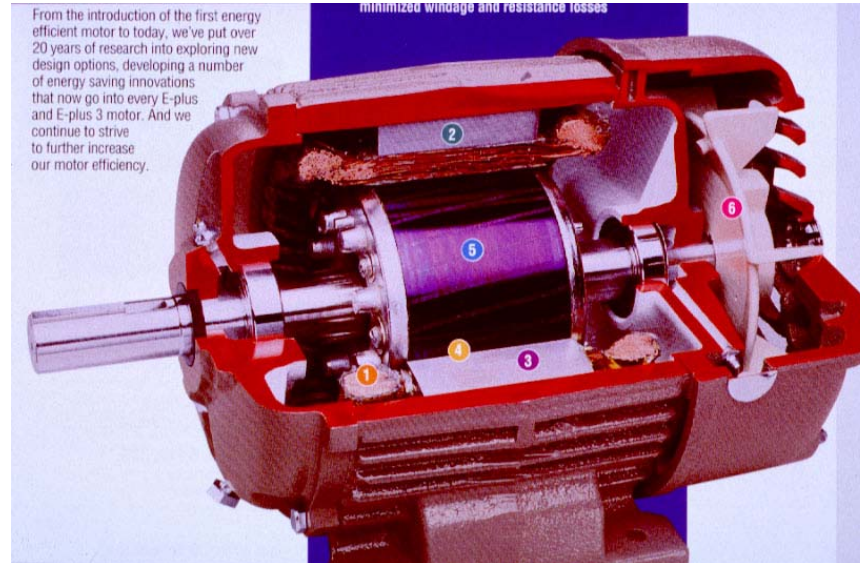
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Motor Failures

Premature burnout of motor windings



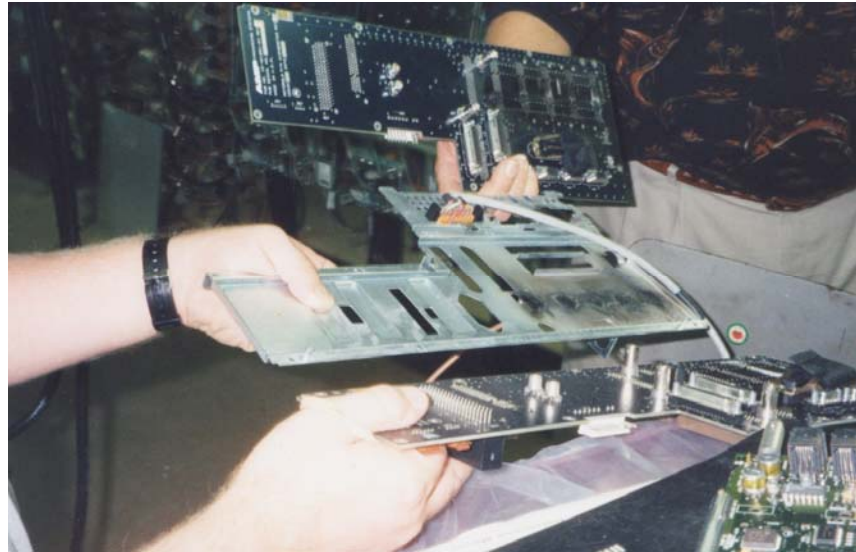
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Effects of Poor Power Quality

Failure of electronic components



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Two Types of “Grounding”

- **System Grounding**
- **Equipment grounding (bonding)**



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“Grounding”

Oddly enough, “ground” is not defined in the NEC. Grounded (Grounding). Connected (connecting) to ground or to a conductive body that extends the ground connection.

The ground path can carry current in the event of a fault.



System or Exterior Grounding

Needed for:

- **Establishing a voltage reference**
- **Discharge high transient voltages (esp. lightning)**
- **Static Discharge**
- **Personnel Safety**



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“Bonding”

The intentional connection of normally non-current carrying parts of equipment together

The two terms are frequently used interchangeably



National Electrical Code® Limitations

Sec. 90.1: The purpose of the NEC is the PRACTICAL safeguarding of persons and property from the hazards resulting from the use of electricity.

Compliance with the Code results in an installation that is essentially safe, but may not work efficiently or adequately.



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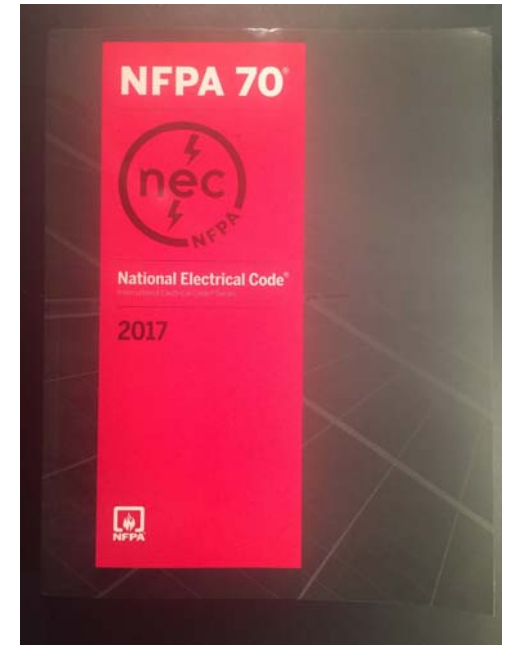
NEC Is Bare Minimum Needed for Safety

Good starting point, BUT..

NEC is Not a PQ Code

NEC is Not a lightning Code

NEC is Not a good grounding Code



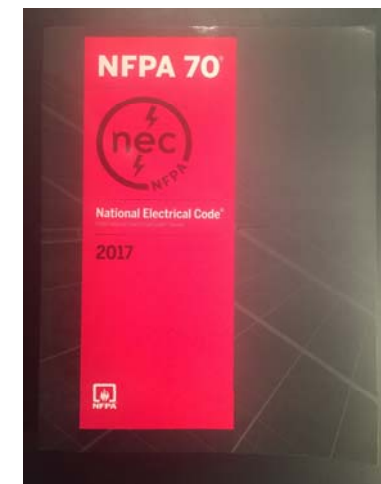
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Grounding Below Moisture Level?

- **250.53 (A)(1)** If practicable, rod, pipe, and plate electrodes shall be embedded below permanent moisture level.



NEC Does NOT Require 25 Ohms

Alludes to 25-ohm standard BUT DOES NOT REQUIRE SUCH.

250.53 (A)(2): A single rod, pipe or plate shall be supplemented by an additional electrode..



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NEC “Alludes” to 25 Ohms

BUT

exception:

Exception: If a single rod, pipe, or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required.

There are no testing parameters.

Thus, if two rods are installed, you’re done!

A second rod is cheaper than measuring!



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NEC Allows 6 Ft. Spacing

- **250.53 (A)(3) Supplemental Electrode.** If multiple rod, pipe, or plate electrodes are installed to meet the requirements of this section, they shall not be less than 1.8 m (6 ft) apart.

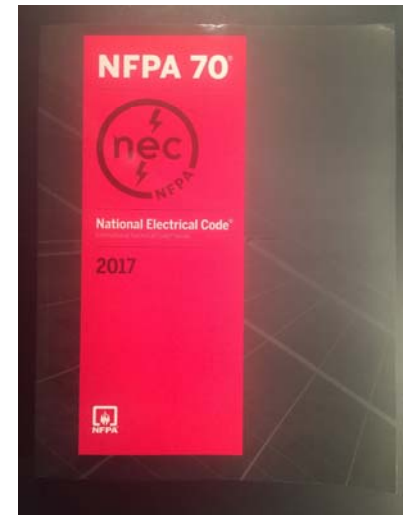


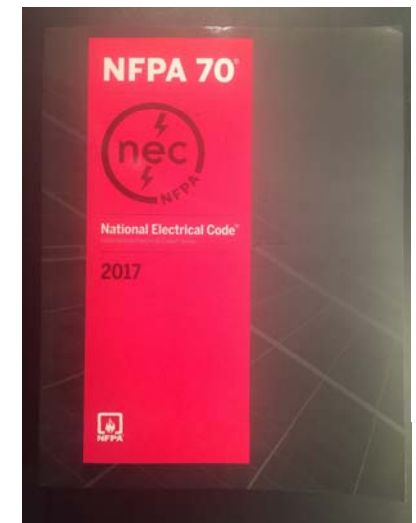
Plate Electrodes Are Fully Recognized

- **250.52 (7) Plate electrodes...**shall expose not less than 2 ft² of surface to exterior soil.
- NEGRP showed plate electrodes are virtually useless.



NEC Allows 30 Inch Depth

- **250.53 (F) Ground Ring.** The ground ring shall be buried at a depth below the earth's surface of not less than 750 mm (30 in.).



Ring Grounds Allowed as Small as #2 AWG

- **250.52 (A)(4) Ground Ring.** ..encircling the building ...in direct contact with the earth consisting at least 20 ft. of bare copper conductor not smaller than #2 AWG.

4/0 to 500 kcmil commonly found



Better Standard: IEEE Emerald Book

- **ANSI/IEEE 1100**
Recommended practices are needed
for power quality.

800-678-IEEE



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System Grounding

Desired Grounding Resistance:

- 5 ohms or less desired for power quality
- Many mfgs. specify under 2 ohms
- IEEE recommends 1-5 ohms (Green Book)



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Ground Rod Spacing



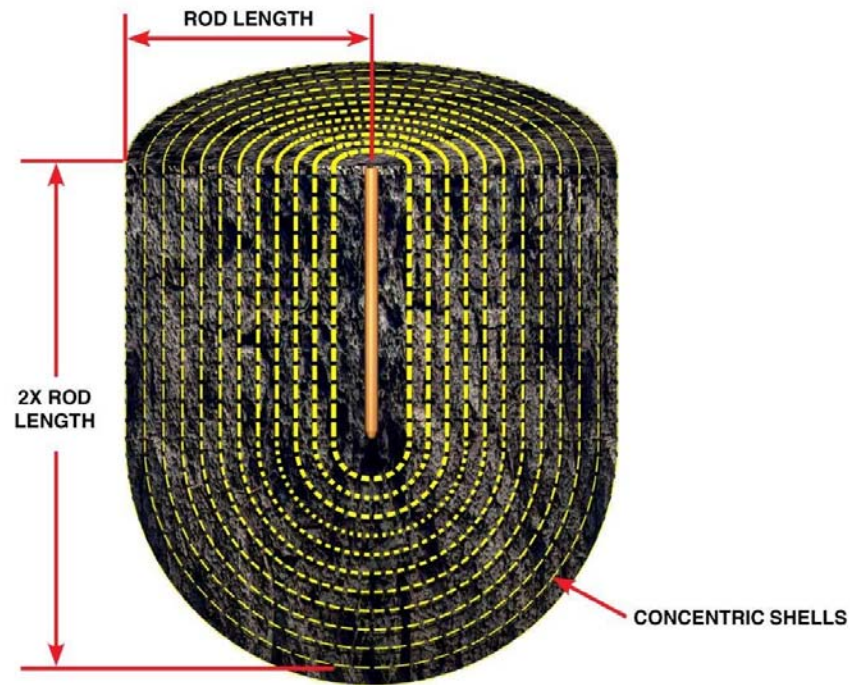
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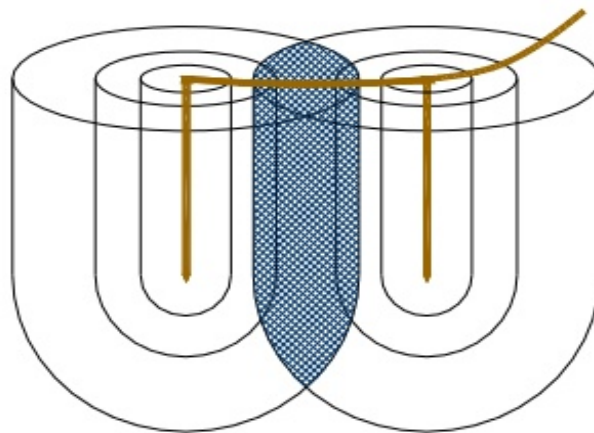
Concentric Shells of Earth Surround Rod

Varies with
rod length &
soil conditions



Overlapping Spheres of Influence

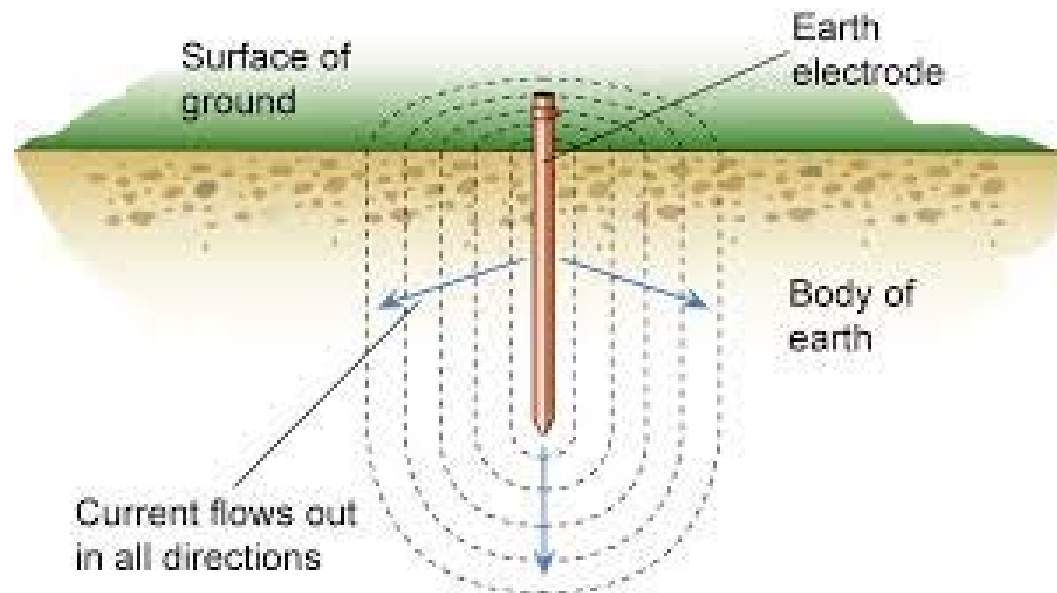
Lowering Ground Resistance



Concentric Shell
Overlap Decreases
Efficiency of
Ground Rod
Resistance



Current=Voltage/Resistance



Poor Example of Ground Rod Spacing



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We Will Discuss Spacing and Testing
In More Detail Later



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Orange County, FL 911

**Headquarters
Apopka, FL**



Source: Power & System Innovations,
Inc., Orlando



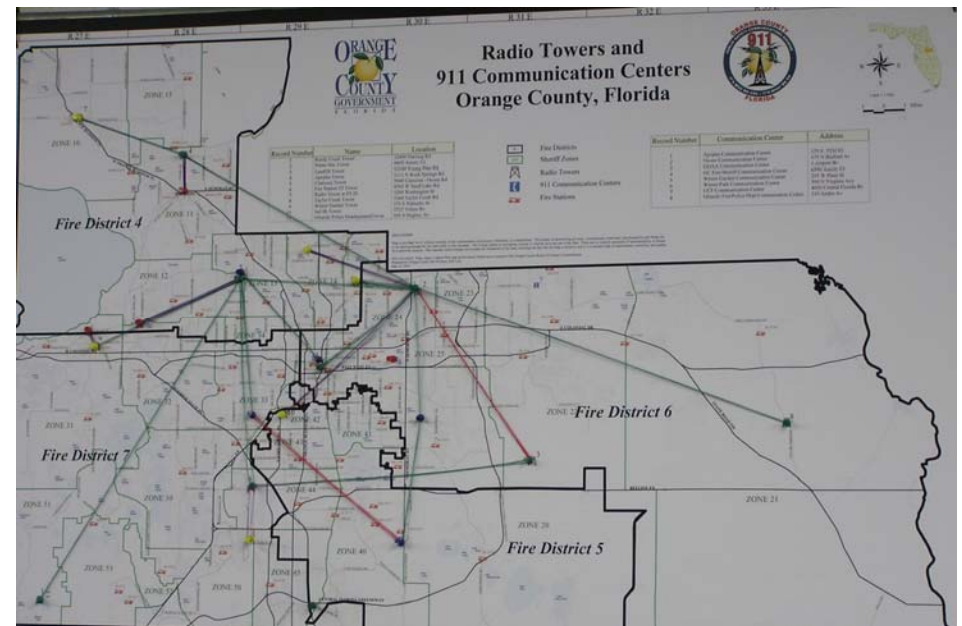
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Case History

13 transmitter sites
Surrounds Orlando, FL
including Disney World



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Headquarters Tower

280 foot tower
3 sets of 5 guys each



Equipment Damages

\$100 K/yr damage at
Apopka alone
Not including downtime

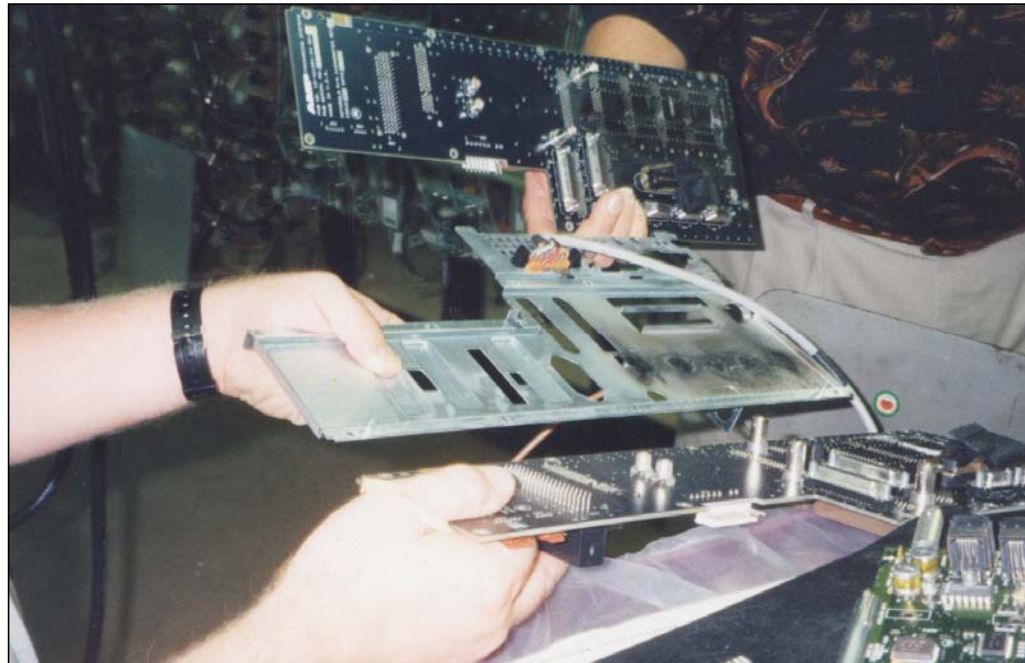


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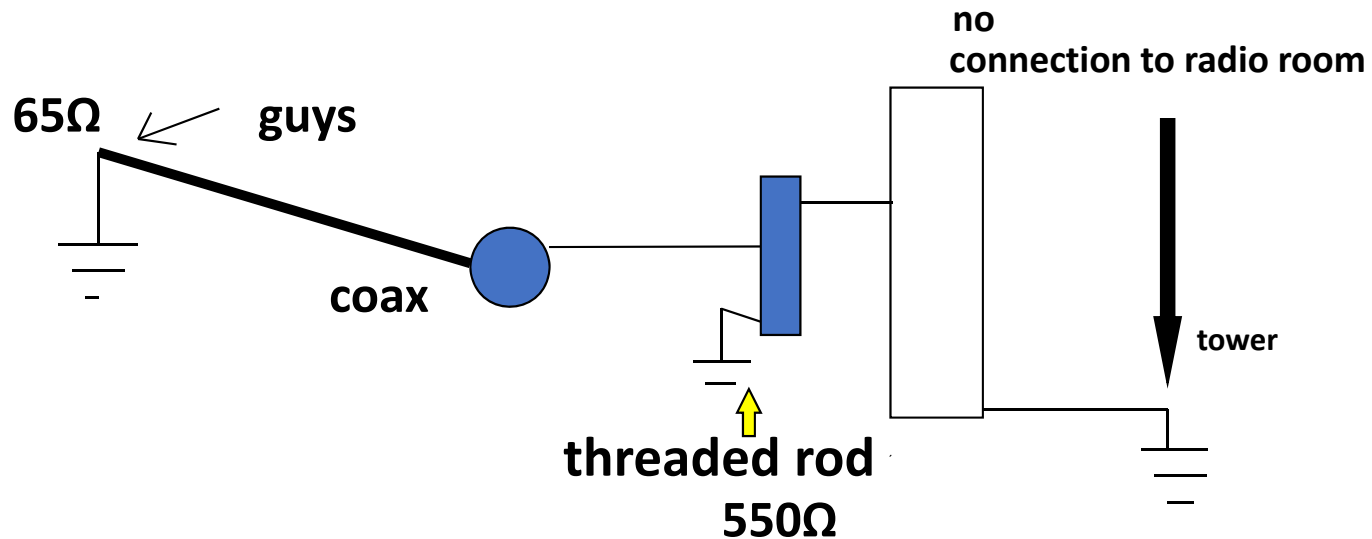


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Internal Arcing



3 Independent Grounds



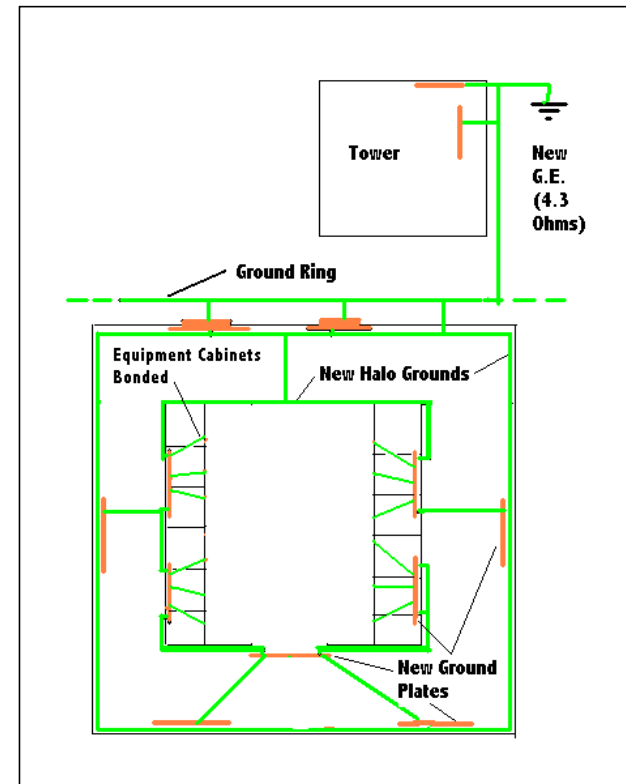
3 ground connections meant 3 potentials

Important step was connecting all the separate grounds into ONE system

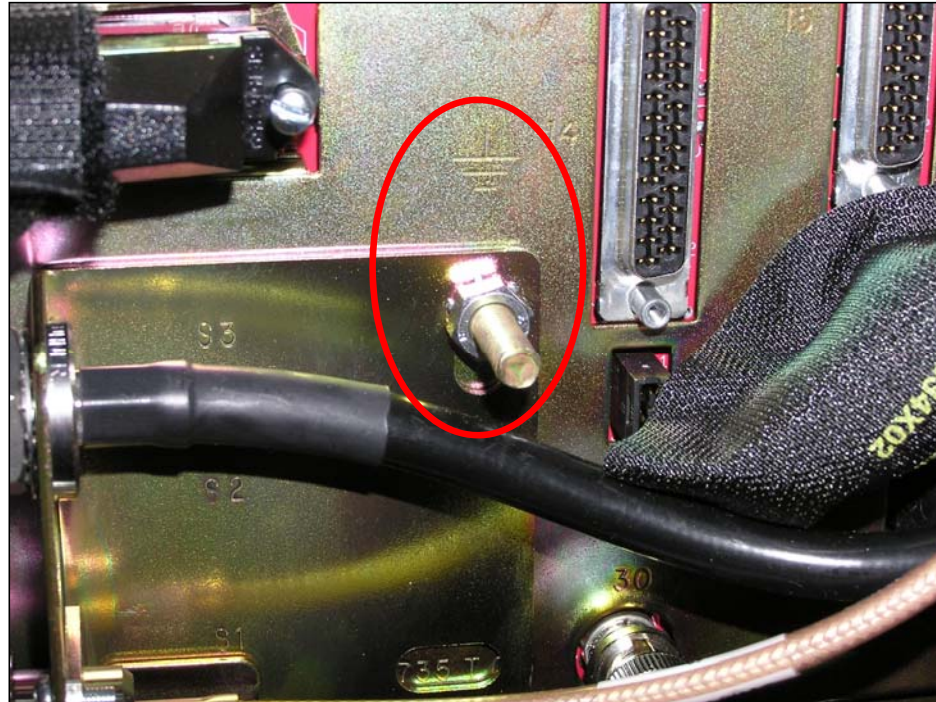


Refitted Site

Everything bonded together



Ungrounded Equipment Cabinets



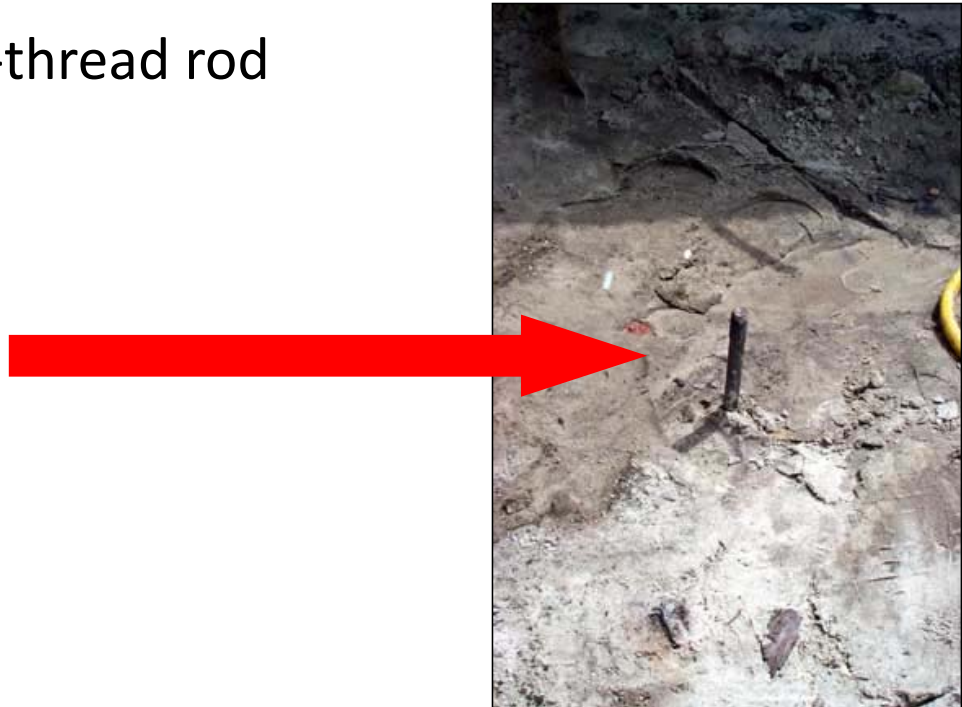
Outside Bulkhead

Only ONE Cu strip
connected to electrode



Facility Ground at Apopka

Main electrode was all-thread rod



Original Ground Resistance

Measured 550 ohms



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Apopka Tower Grounding

Among the retrofits:
Deep (60 ft) electrode
supplements tower grounding



Outside Bulkhead

strip bonded together and to ring with 4/0



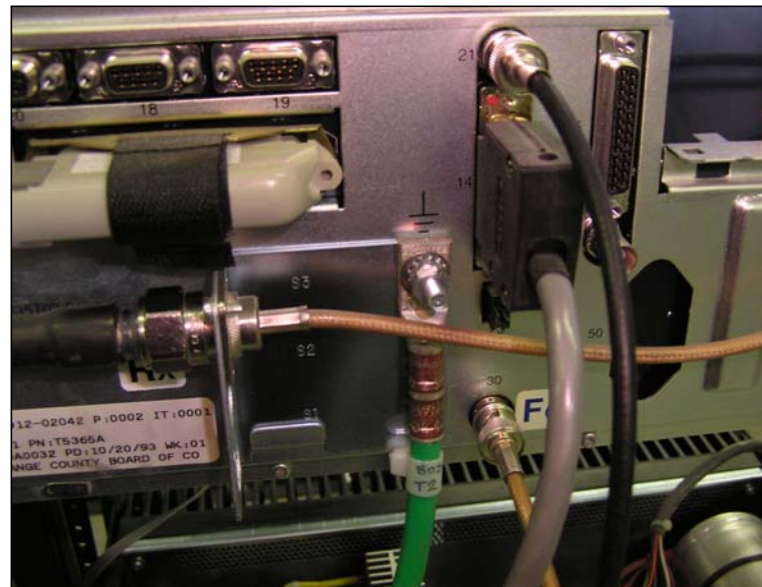
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A Lightning Event is a Vibration Event

Note double nuts and lockwasher



Halo Rings

All equipment bonds brought to buses
Buses tied to halo rings



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Reedy Creek

**Remote repeater
near Disney World**



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Reedy Creek

More real estate to work with



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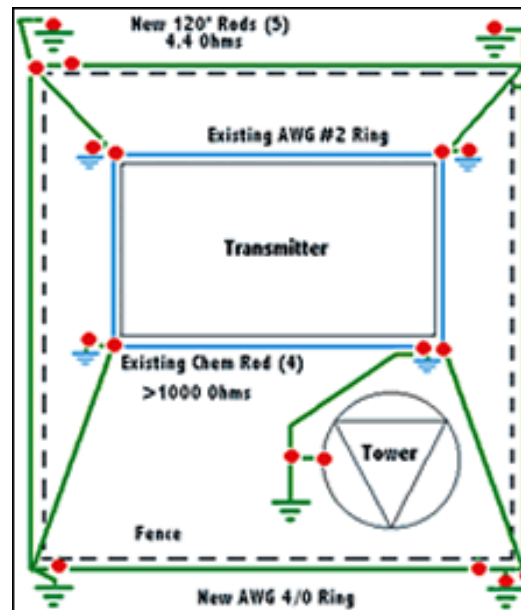
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Reedy Creek

Grounding layout: double rings plus deep electrodes

Ring is 4/0 AWG

Electrodes 120 ft. deep



New Grounding Resistance 3.5Ω

**< 5 ohms
independently**



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Sweeping Turns

Note wide, large diameter turns



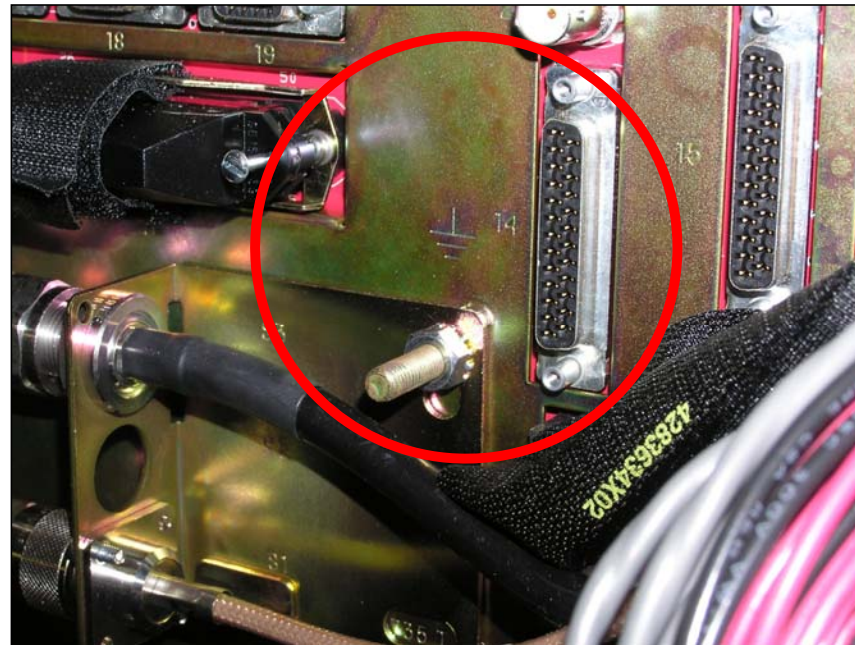
Replaced Connections

How many wires can you fit in a split-bolt?

This is an example of
“daisy chaining”



Ungrounded Equipment at Apopka



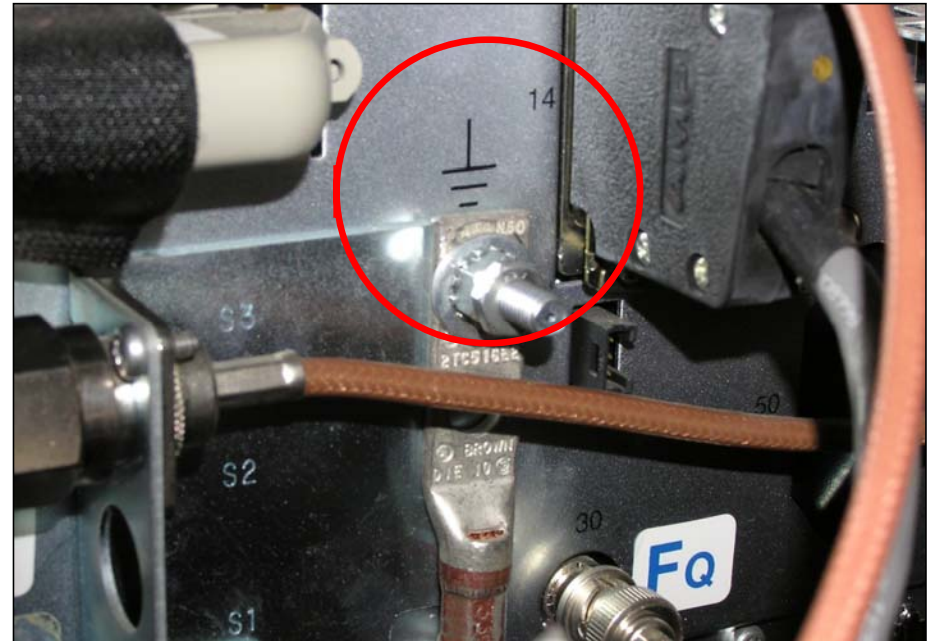
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Lightning Means Vibration

Lock washer, double nuts



Since Retrofit

- Thousands of events recorded
 - One strike witnessed

 - **NO Downtime! No equipment damage.**
<\$500,000 cured \$1 million damages
- 6-mos. to 1 year paybacks common**



Major Lessons

**3 different contractors
meant 3 separate grounds**

- electrical
- radio room
- tower

**No one party had overall
responsibility**



Angel Fire Ski Resort



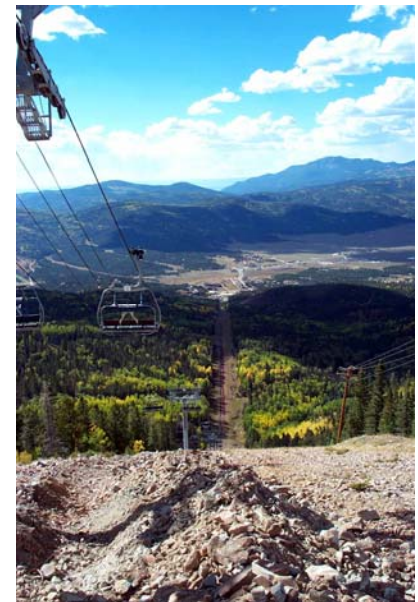
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Angel Fire Ski Resort

- 2001 Spring Break, lightning caused shutdown
- People stranded on lift
- Loss over \$2 M revenue



Base Station

Base control house
Similar at top
Computer controlled



Only Ground Between Towers



Grounding for communications cable



Terminus of messenger wire (only grounding between towers)



System Was Not Integrated



- Ground *system*
- Rod at each tower
- 2 miles of 2/0, each tower connected
- Rings at top and bottom stations
- No outages since!



Exothermic Welding



Lower Base Station

Soaking bentonite with water

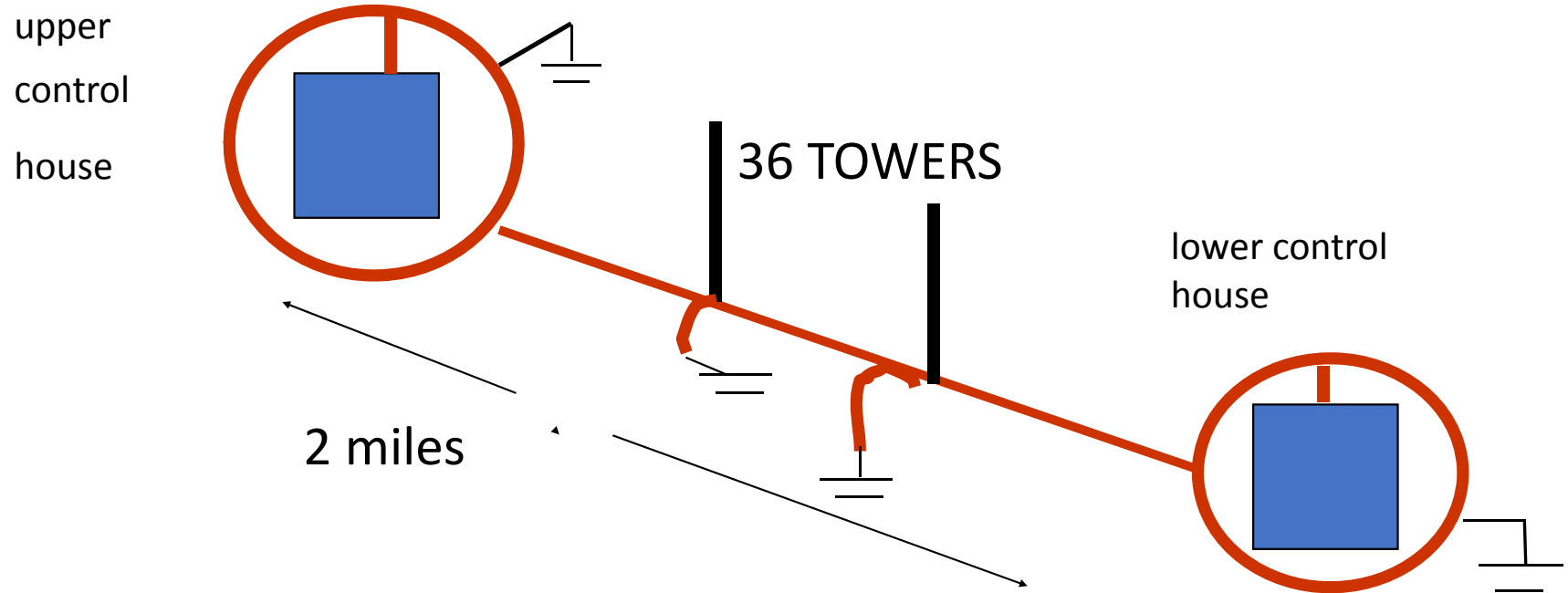


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Angel Fire Result



KKIT - FM



Connection to Electrode



Connection to Water Service



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Multi Building Campus Examples



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Verestar

Largest satellite facility in North America



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Verestar Control Room

6 buildings

Over 100 acres



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Dishes Are Remote

42 satellite dishes

3.5 m to 30 m



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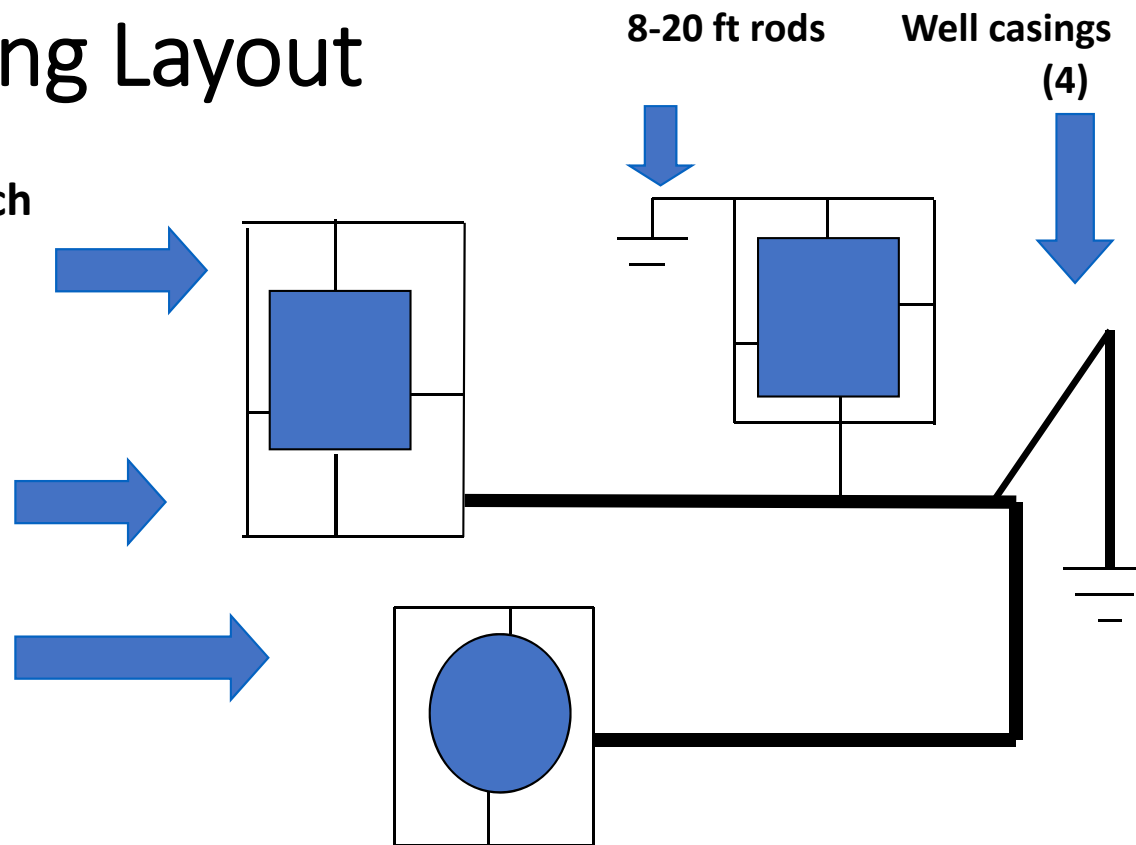
Basic Grounding Layout

4/0 ring ground around each building (6)

750 kcmil spine

4/0 around each dish
(typ of 42)

2 Ohm standard



M.I.T. Case Study

Current Interior Design Standards:

Separate computer feeders, panels, and branch circuits

4 outlets per 20 amp. Branch circuit



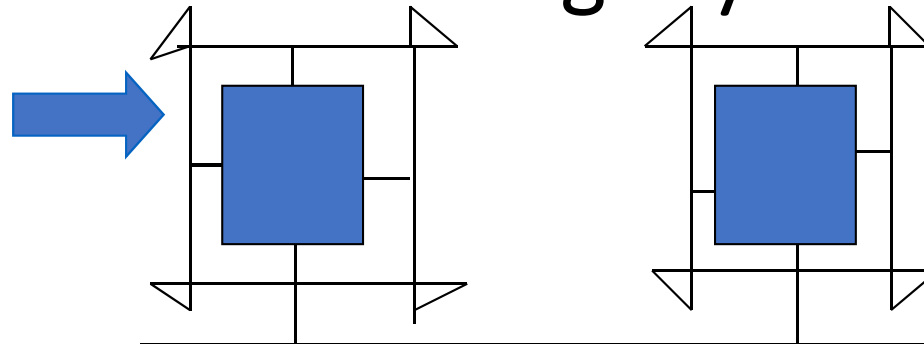
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M.I.T. Basic Grounding Layout

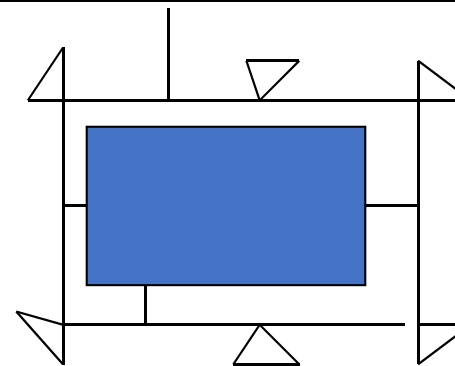
- 500 kcmil ring ground around each building



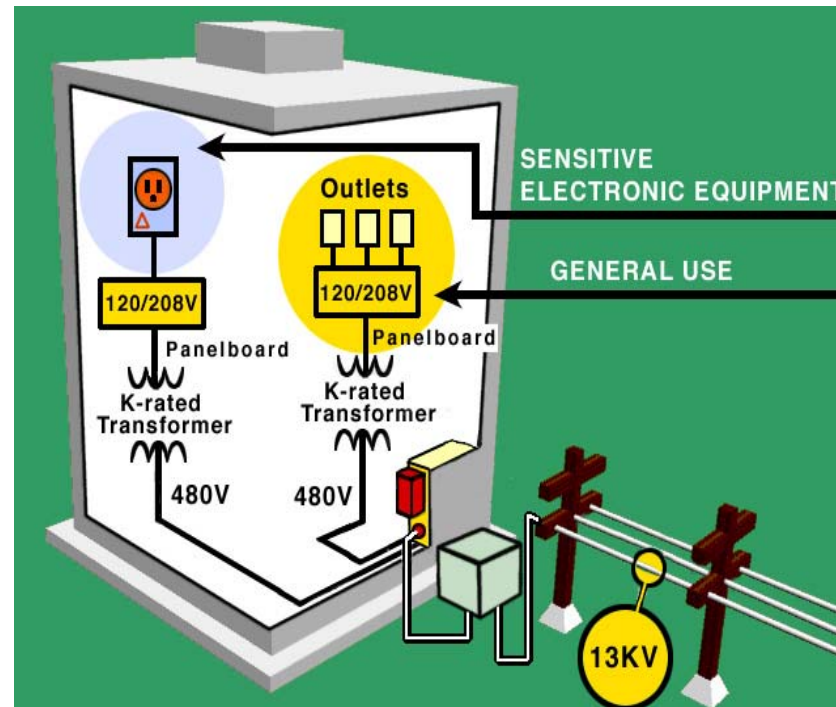
- 1000 kcmil spine



- Triangulated
- 20 ft rods at all corners



Separate Systems



M.I.T. Design Standards

Current Design Standards:

- **10 ohms or less grounding resistance (economic reasons)**
- **Double (and sometimes triple) neutrals**
- **K-rated transformers**
- **Always a separate grounding conductor**
- **Always copper**



“Clean” Grounds vs. Isolated Grounds



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The Earth Cannot Be Used as a Conductor

Earth is never a satisfactory conductor

NEC, Art. 100:

Effective Ground-Fault Current Path. An **intentionally constructed, low-impedance electrically conductive** path designed and intended to carry current under ground-fault conditions from the point of a ground fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent protective device or ground-fault detectors.



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Case Study: “Clean Grounds”

McAfee Tool and Die



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This is a High-Tech Environment



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Every CNC Machine is Computer-driven

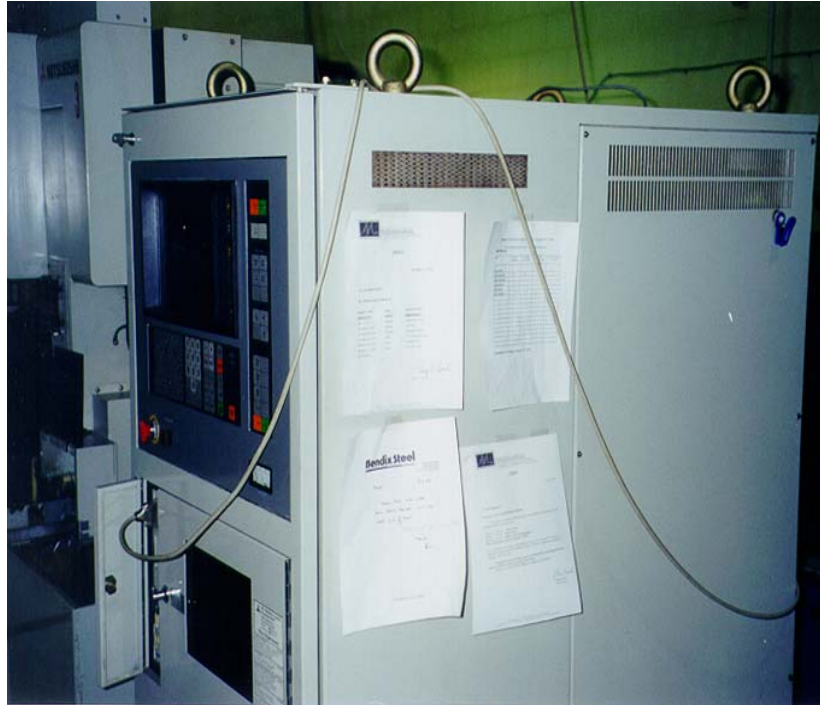


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Comm Cable is Unintentional Antenna

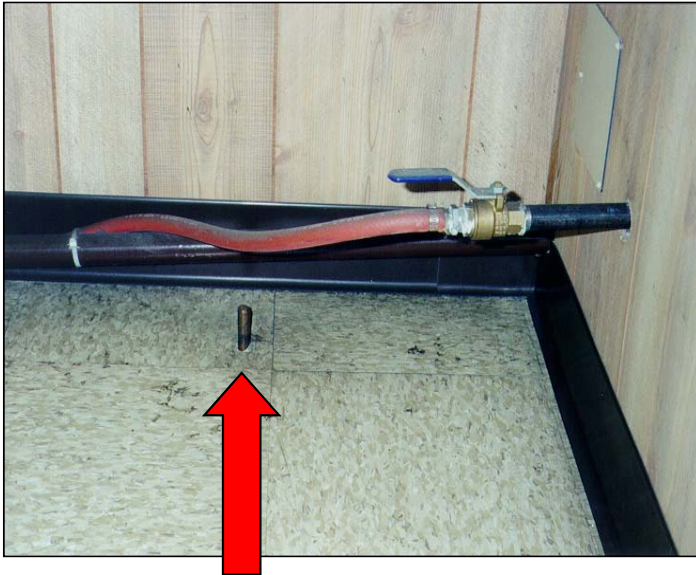


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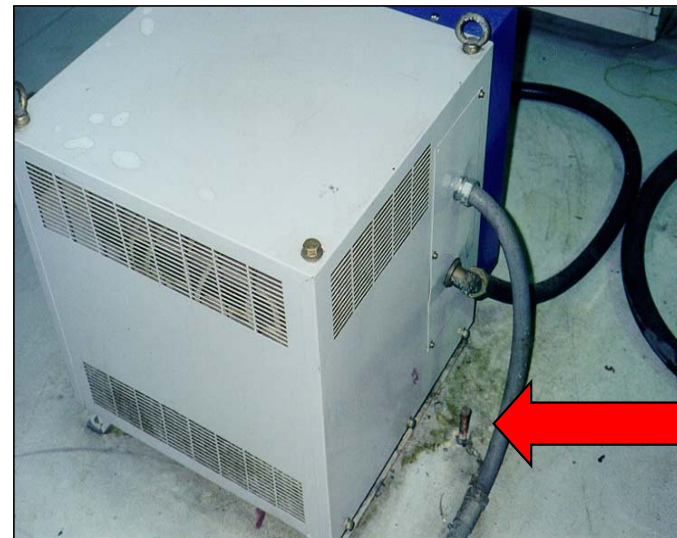


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So-called “Clean Grounds”

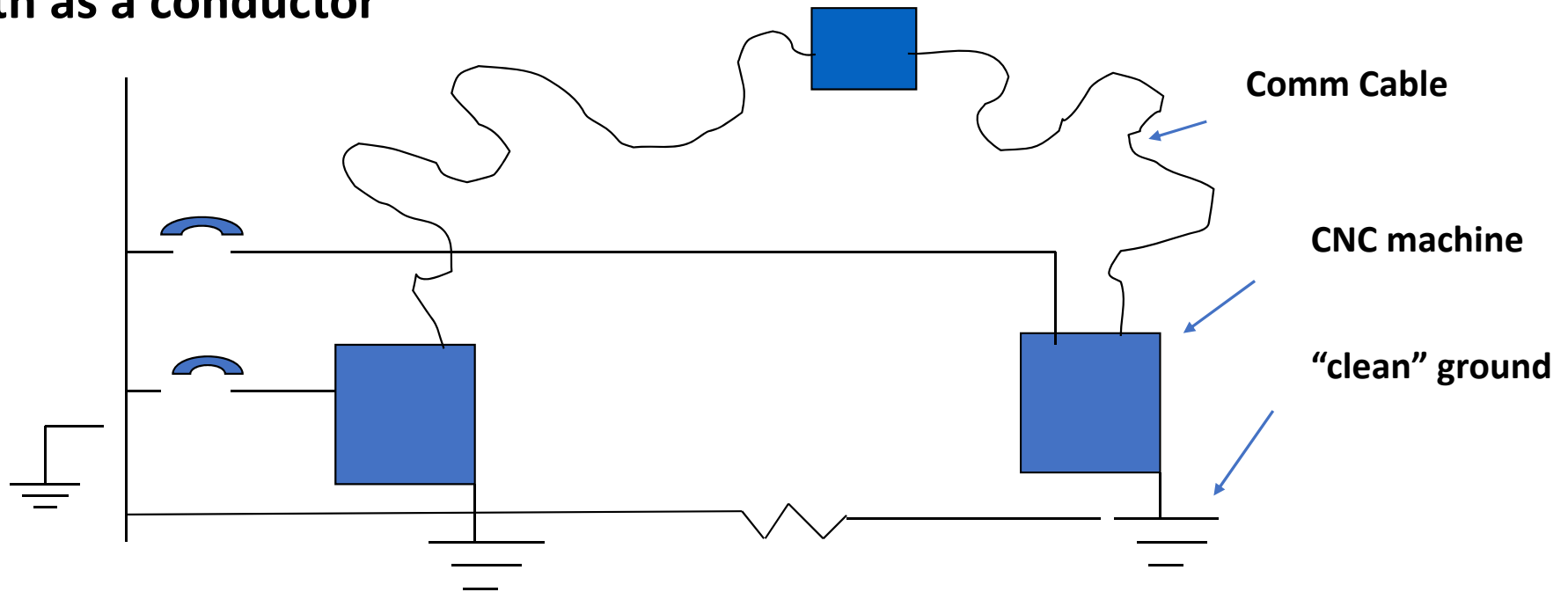


**“Supplemental”
electrodes abandoned**



McAfee Layout

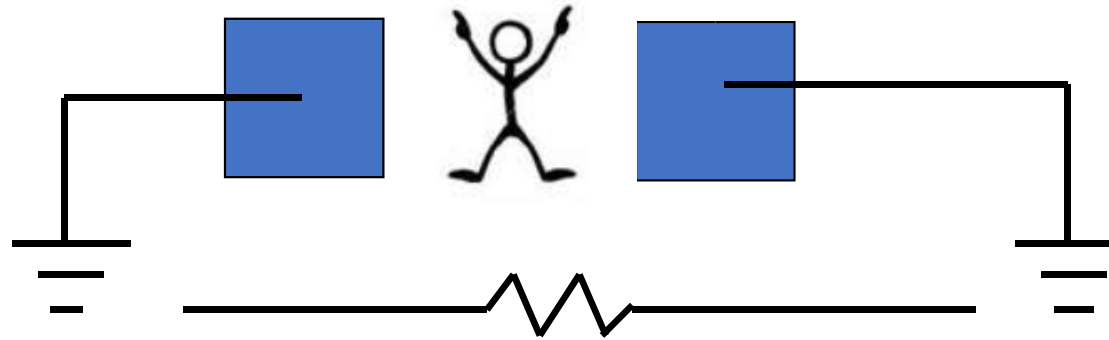
Earth as a conductor



Earth is Not Permitted as a Current Path

**No separate grounds allowed
only one grounding system**

- **250.54** ...the earth shall not be used as an effective ground-fault current path...



McAfee Results

- All “clean” grounds were removed
- Connection to earth was supplemented with 3-20 ft ground rods in a triangle pattern. +/- 5 Ω
- Comm cable re-routed
- After 7 years of outages and service calls, all problems disappeared



What Is an IG?

So if “supplemental” grounds are a no-no, what is an isolated (“insulated”) ground?



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Insulated Grounding



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Insulated Grounding (IG)

Good idea to install in new circuits

Gives flexibility to use or not



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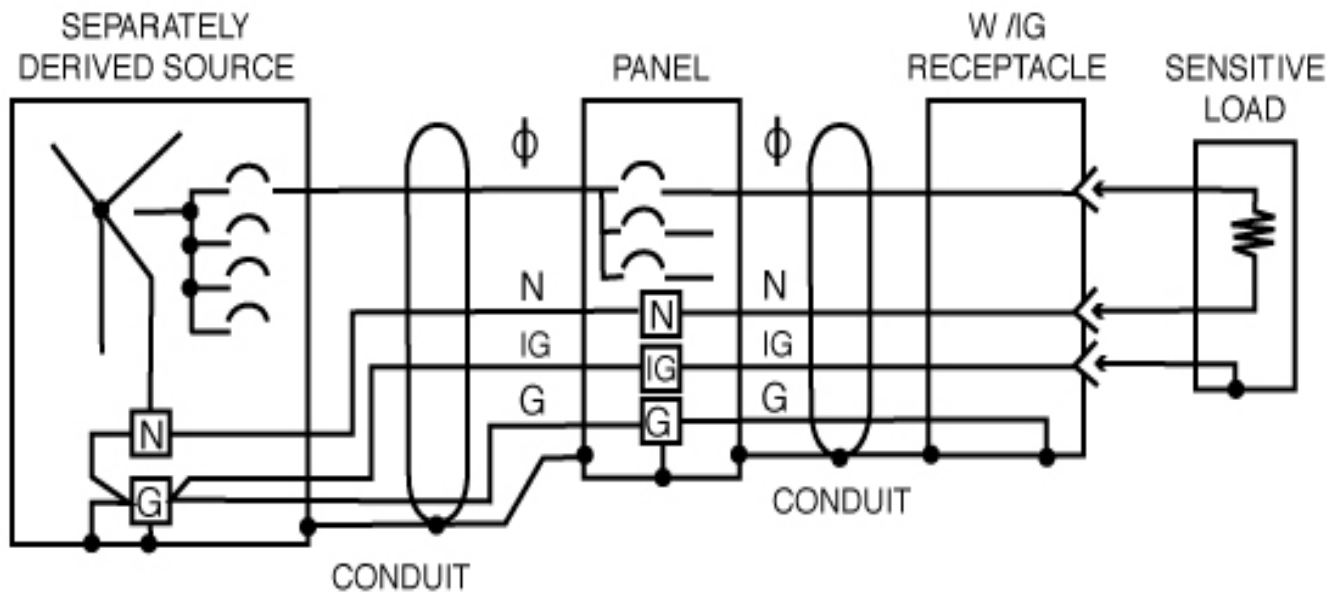


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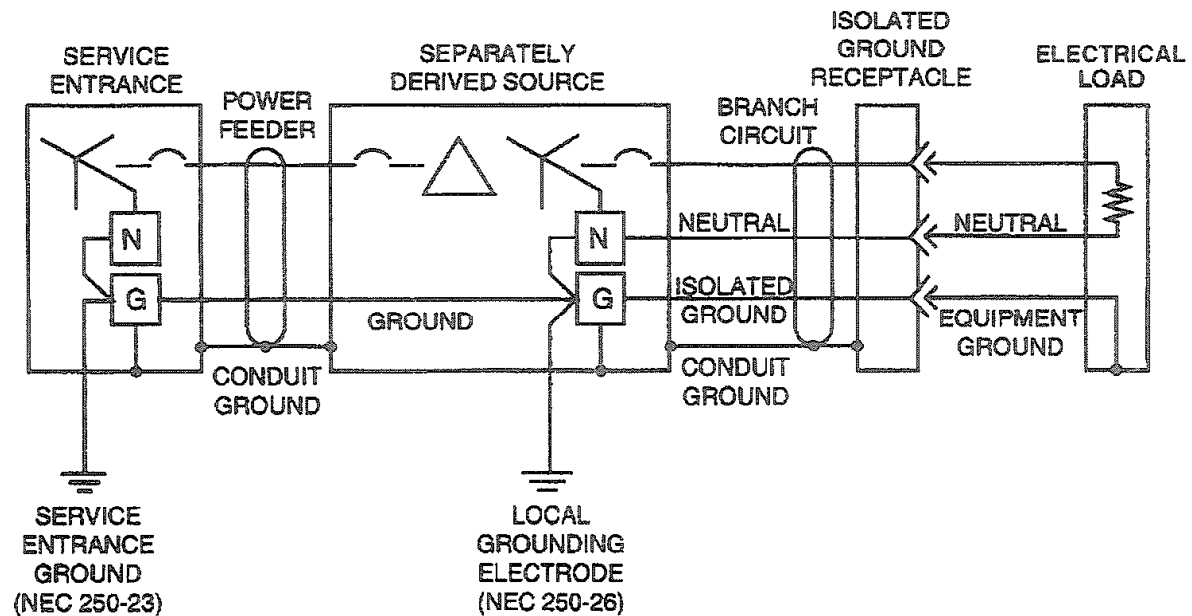
This is NOT IG



Isolated (Insulated) Grounding

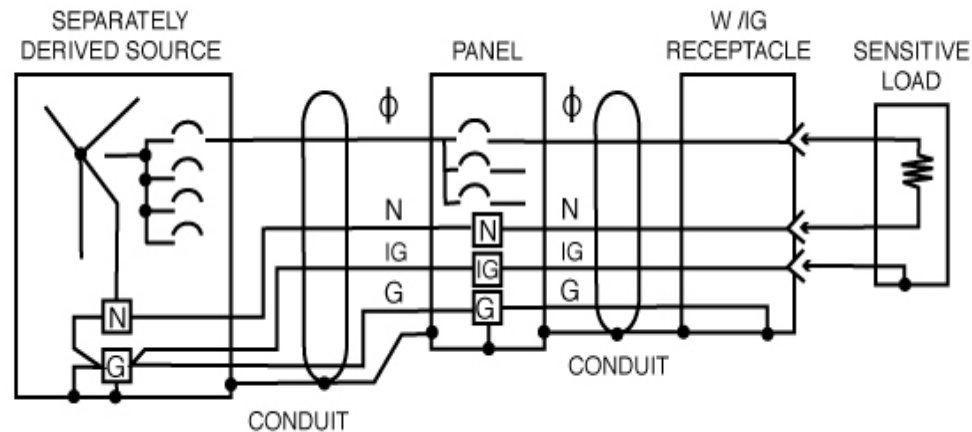


IG Circuit with Transformer

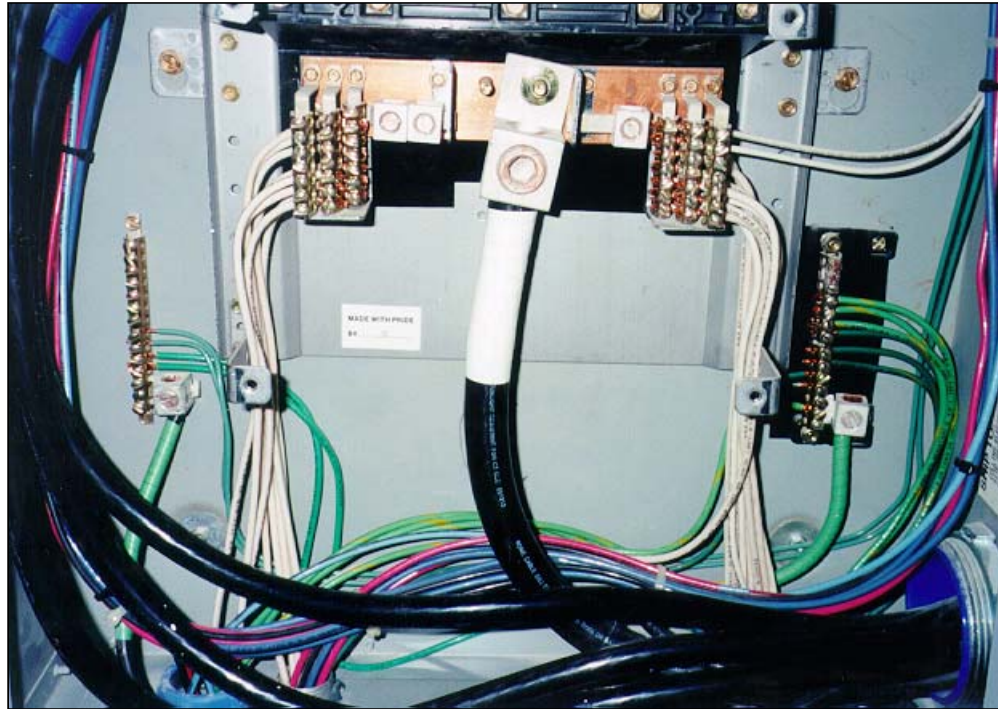


Isolated Grounding

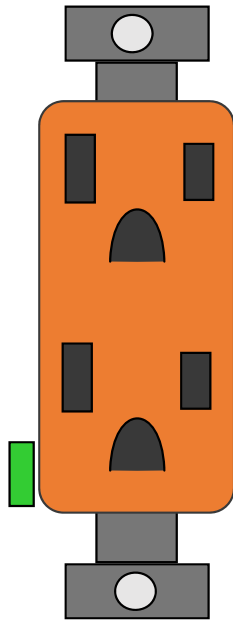
**Good idea to use an IG circuit for all critical loads.
Carry the IG ground all the way back to the service point.**



IG Not Connected to Cabinet



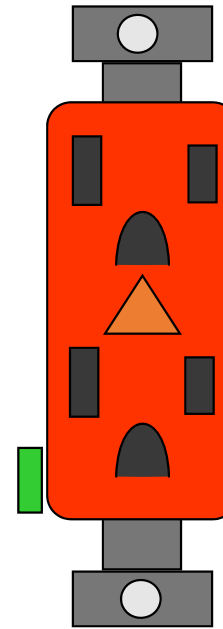
IG or SG?



Receptacles

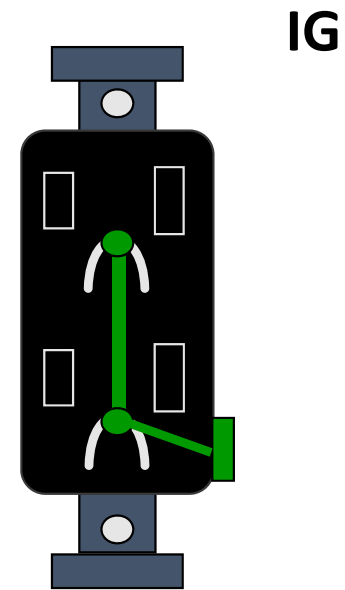
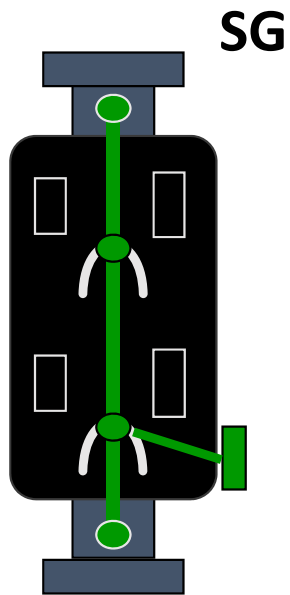
**Either receptacle
may be any
color under the
most recent
NEC editions.**

IG



Receptacles

Do you see the difference?



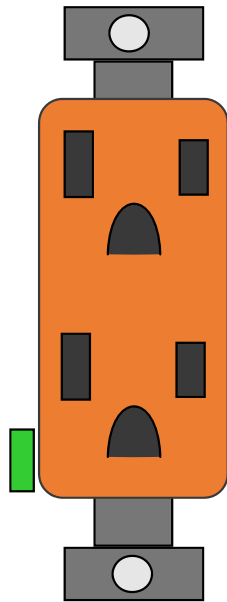
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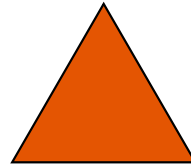
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Receptacles

IG or SG?

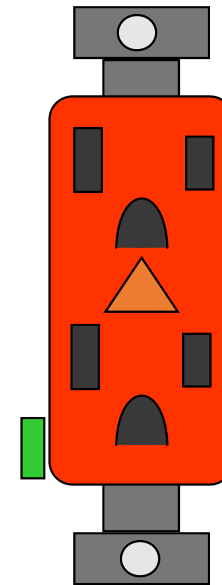


An orange color delta



is required to be embossed on the face

IG

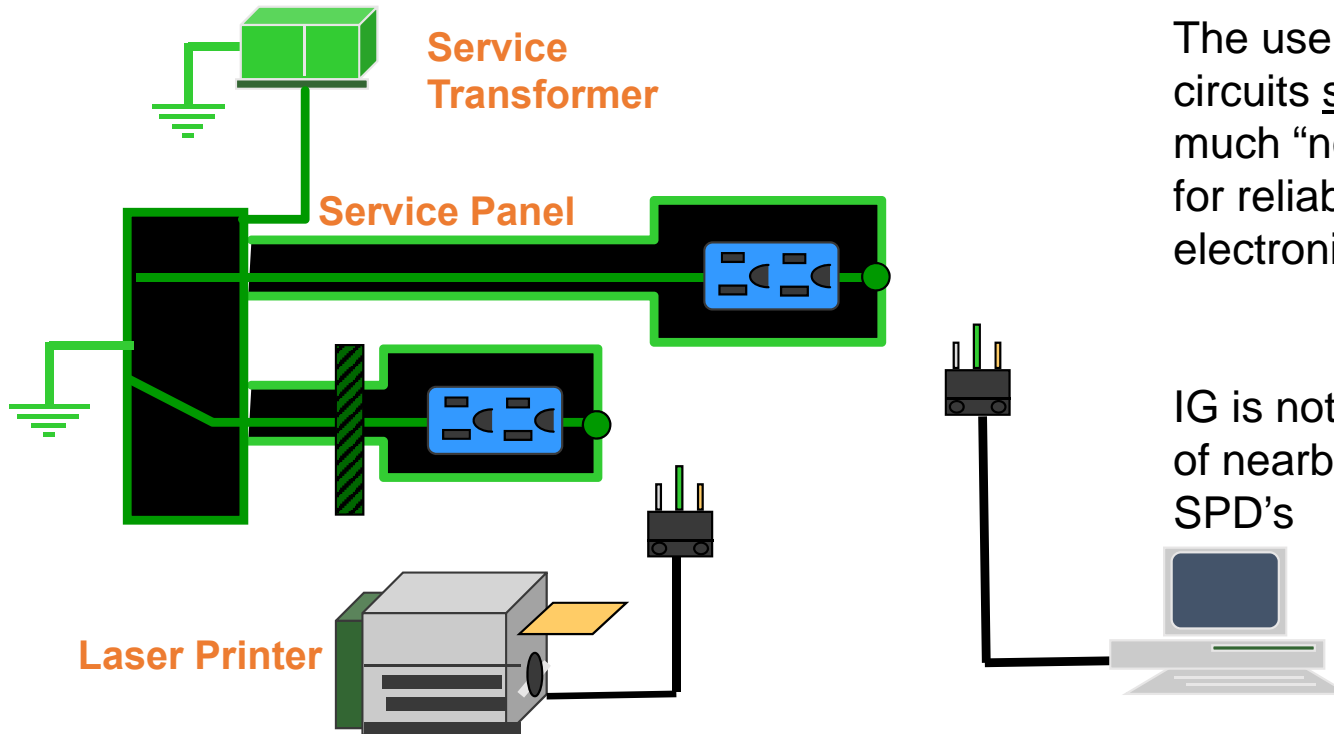


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Why Use IG?



The use of solidly grounded branch circuits sometimes results in too much “noise” on the branch circuit for reliable operation of the electronic loads.

IG is not subject to induced energy of nearby lightning, thus smaller SPD's



Let's Take a Break



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When You Are Involved

- When your equipment is involved, you should be the expert when you walk on site.
- You are responsible to be sure all is right if not, you fix it.
- If you don't have the expertise to "fix", get an expert involved. The key dazzle with brilliance not baffle with BS.
- Learn how to recognize issues that will impact the proper installation of your equipment and its sustainability.
- Inform your customer of the conditions that can impact your installed equipment.
- Some will "ignore" and hope issues go away. Put it in writing, inform and then it is their responsibility. Their choice.



When You Are Not 100% Sure

- Develop a relationship with a someone that has the expertise to assist your efforts.
- Do not guess, hope or assume you are right.
- Learn from them, develop your own expertise.
- Avoid those that are just out to sell something.



Grounding & Bonding

- Grounding (Earthing) is the foundation of the electrical system.
- Bonding is the “rebar” that holds the foundation together.
- The electrical system is not safe or sustainable unless the grounding & bonding are completed to the highest possible standard.
- Anything built upon a flawed foundation will never be proper or sustainable regardless of the effort with which it is built.



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What's Next

- Understand what makes up soil resistivity.
- Know the variables in grounding conditions.
- Understand the different types of grounds.
- Understanding ground testing.
- Ground Augmentation—What works & or will not.



What's Next

- Ground Loops – Learn how to avoid them.
- Why grounding & bonding are critical for SPD.
- SPD – What you need to know about SPD.
- SPD – Your role in making sure they work.



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But First

- Lets look at some examples of very poor workmanship and talk about the down side of these examples.
- Who do you blame for these?
- Who is responsible?
- Do you want your equipment connected to these grounds or ground bonds?



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- Two Wires under the same lug.
- Improper lug for the wire size.
- Screwed, not bolted.
- Connected to painted steel.
- No conductive grease.
- Steel not continuous or contiguous.



Phone System

The lightning arrestors for this phone system are not bonded to a path to ground. This is a life safety issue as well as a formula for equipment damage.



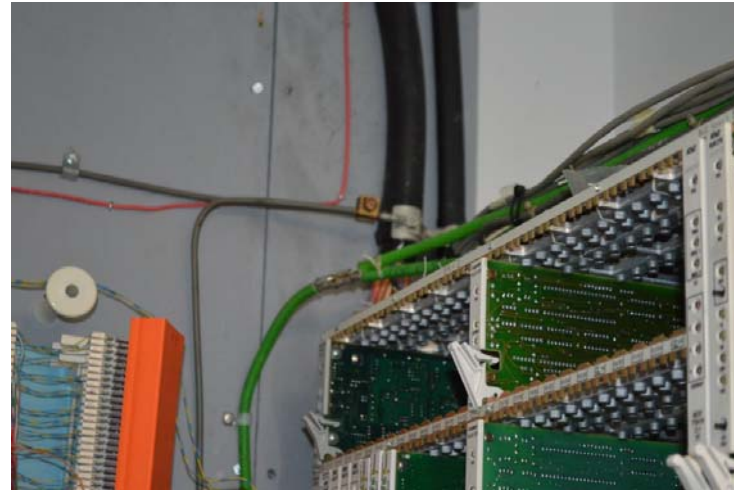
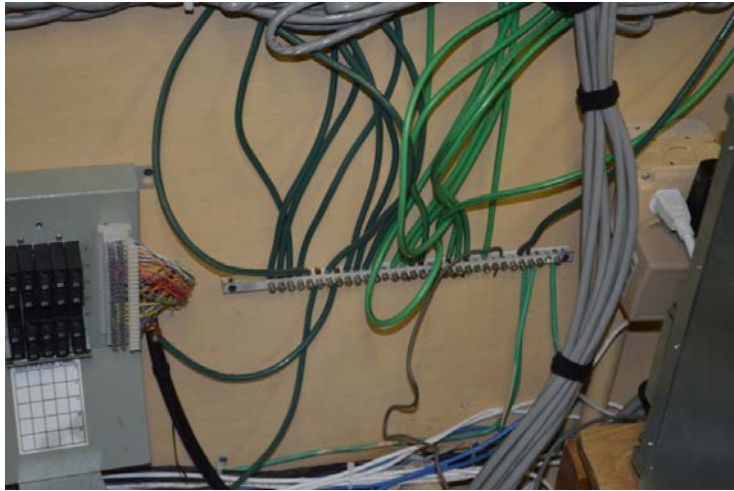


This is one of many electrical systems in a HUGE resort's in central FL.
MS1's Bond is shown to the left, MS2's Bond is shown above...(missing).
THIS PASSED INSPECTION



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This phone system is so unreliable the company that is the owner's telecom contractor kept a box full of replacement cards as they failed all the time. Annual cost? Over \$100,000.00 and they thought that is normal. After the FIX, no damage in years. State of Florida agency site!





The above photo's are from a State of Florida site (500,000 Square Foot Building) Computer Room – where all the file servers and main blade server banks are. Call it computers city..... The computer person said he wanted to make sure the critical equipment was grounded properly so he had additional ground rods, ground bonding bars added.



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Tape Holding the Ground Bonding?



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This Was At a 9-1-1 Center



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Very Expensive Copper Theft!



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Nice Bonding Job..... to What?



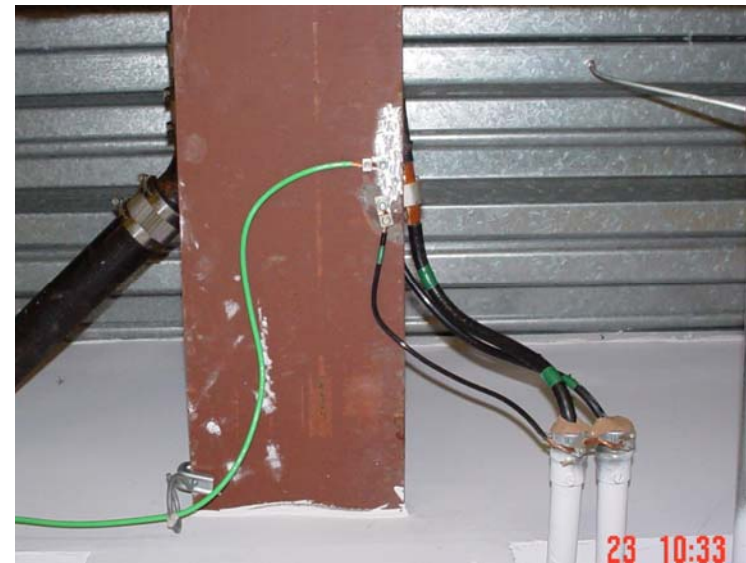
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Bonding to Building Steel

The code allows it, but in a lightning prone environment this is trouble!



What is Wrong Here?



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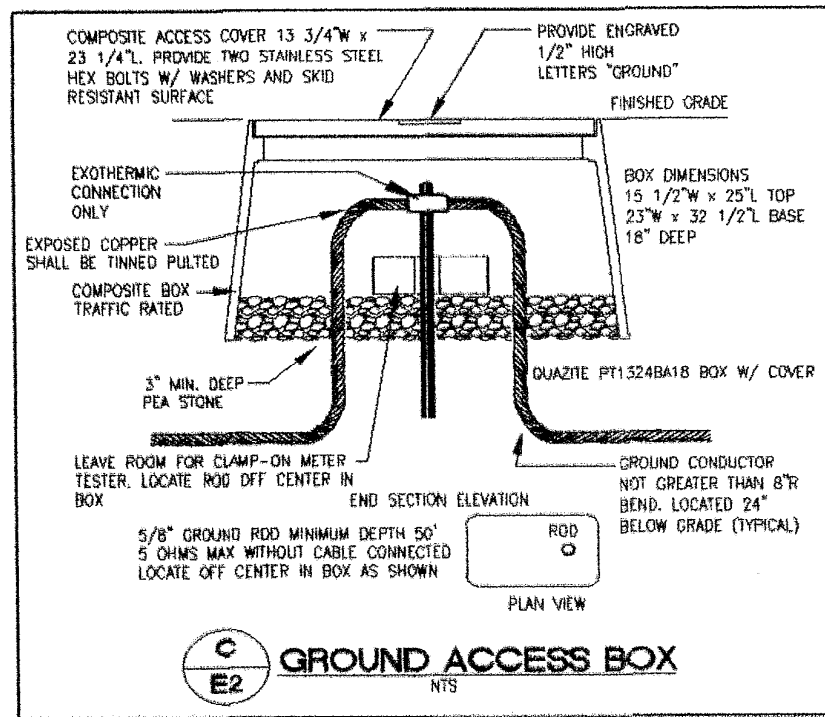


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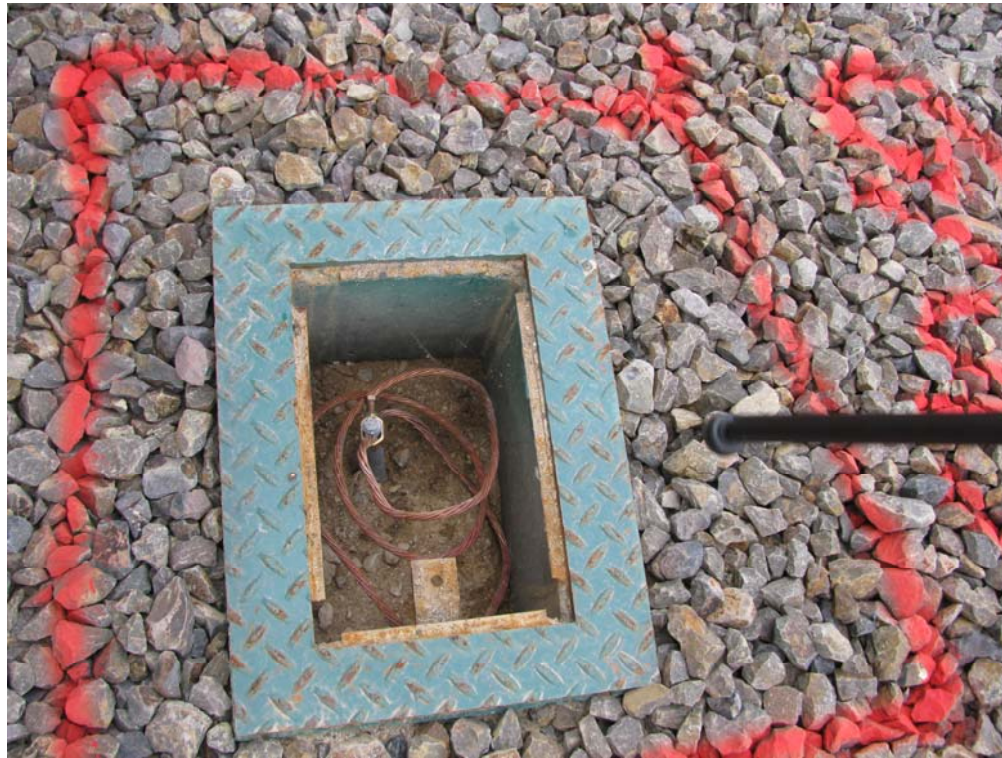
What Should be Done Here?



Ground Ring Test Well



Ground Rod Inspection Box



Ufer Ground Has Limitations

What happens when a Ufer ground is hit by lightning?



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KPTH & KMEG-TV

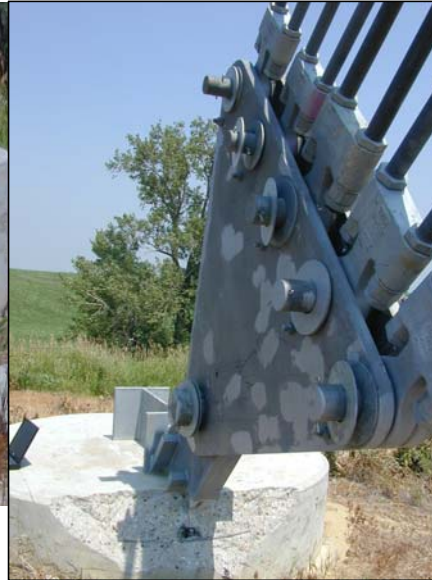


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What Can Happen to a Ufer Ground?



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Path In But Not a Good One Out!



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The Reason for the Damage

Burn scar on shattered concrete is evidence that lightning found a vertical reinforcing rod (center), which likely acted as an efficient Ufer ground, offering lower resistance than that of the installed grounding/lightning protection system.



Testing Ground Systems Performance

- NEC 250 Grounding Performance Requirements.
None!
- NFPA 780 Grounding Performance Requirements.
None!
- UL96A Grounding Performance Requirements.
None!
- IEEE Grounding Recommendations.
5-Ohms or less.



5 – Ohm Grounding

- Should be the requirement for the ground rod system of every electrical system.
- Ufer grounding & bonding is in addition to the 5-Ohm ground rod system.
- The maximum resistance of a lightning protection system ground rod should be 5-Ohms.
- All this added together, properly bonded will assure the odds of damage to the facility is VERY slim.
- Add to this a properly designed and installed surge protection system and the probability of any damage comes close to “0”.



Soil Resistivity

To determine the resistivity of the soil, the Wenner four-point measurement method, it corresponds to IEEE Std. 81.

The Wenner 4-point measurement test employs 4 test probes, spaced apart from each other at equal distances (the distance is critical).

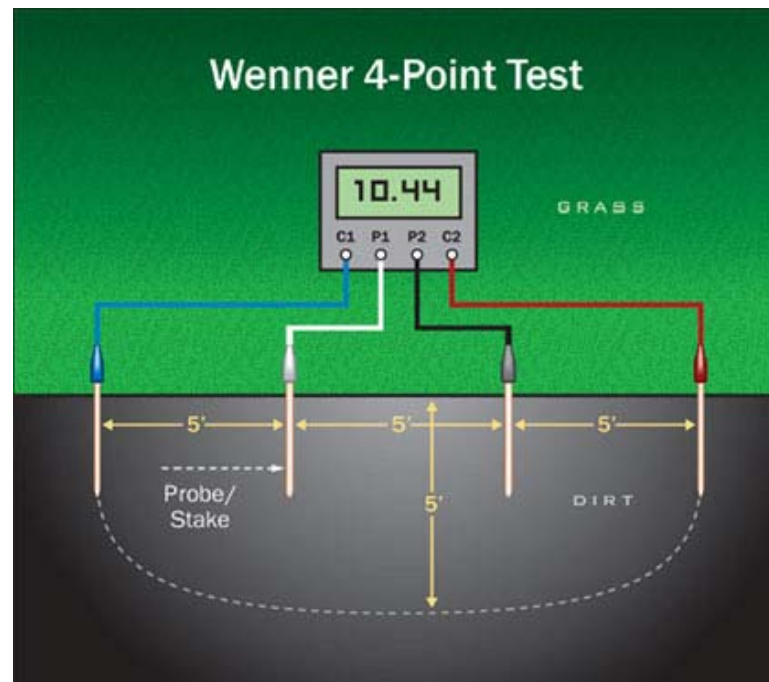


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Note the Distance Between Probes!

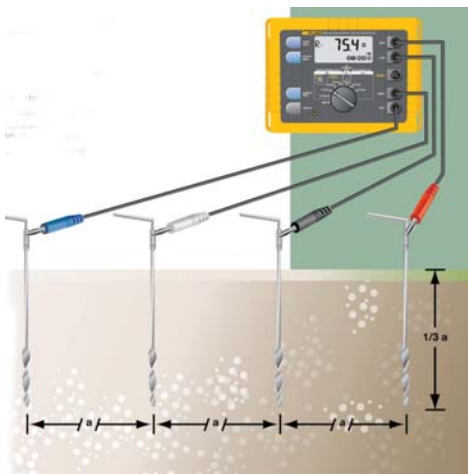


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Long Form Wenner Formula



- Four Point Soil Resistivity Test layout.
- ρ_E = measured apparent soil resistivity (Ωm)
- a = electrode spacing (m)
- b = depth of the electrodes (m)
- R_W = Wenner resistance measured as " V/I " in Figure (Ω) if b is small compared to a , as is the case of probes penetrating the ground only for a short distance.

$$\rho_E = \frac{4 \cdot \pi \cdot a \cdot R_W}{1 + \frac{2 \cdot a}{\sqrt{a^2 + 4 \cdot b^2}} - \frac{a}{\sqrt{a^2 + b^2}}}$$



Simplified Wenner Method

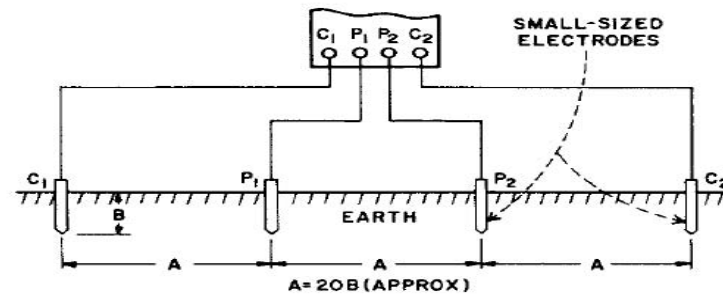


Fig. 1: Four-terminal method of measuring earth resistivity

Dr. Frank Wenner of the U.S. Bureau of Standards (now NIST) developed the theory behind this test in 1915 (see reference pg. 76). He showed that, if the electrode depth (B) is kept small compared to the distance between the electrodes (A)¹, the following formula applies:

$$\rho = 2\pi AR$$

where ρ is the average soil resistivity to depth A in ohm-cm, π is the constant 3.1416, A is the distance between the electrodes in cm, and R is the Megger earth tester reading in ohms.



The Factors That Impact Soil Resistivity

- Electrolytes which consist of moisture, minerals and dissolved salts.
- Regardless of electrolyte content dry soil has high resistivity (Florida “Sugar Sand”)
- The highest resistance “normal” soil conditions are: Gravel, Sand & Stones with little or no clay and/or loam.



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Resistivity of Soil Types

Chart is Influenced by Temperature and Moisture

| Resistivity (approx.), n-cm | | | |
|---|--------|---------|---------|
| Soil | Min. | Average | Max. |
| Ashes, cinders, brine waste | 590 | 2,370 | 7,000 |
| Clay, shale, gumbo or loam | 340 | 4,060 | 16,300 |
| Same, with varying proportions of sand & gravel | 1,020 | 15,800 | 135,000 |
| Gravel, sand, stones with little clay or loam | 59,000 | 94,000 | 458,000 |



Soil Dictates Depth Required

The “Depth” Require to Reach:

| <u>SOIL RESISTIVITY</u> | <u>LENGTH FOR A 5-Ohm GROUND</u> | <u>LENGTH FOR A 10-Ohm GROUND</u> |
|-------------------------|----------------------------------|-----------------------------------|
| 50 Ω-M | 33 Feet | 9.8 Feet |
| 70 Ω-M | 52.5 Feet | 20 Feet |
| 100 Ω-M | 85 Feet | 33 Feet |
| 150 Ω-M | 145 Feet | 59 Feet |
| 200 Ω-M | 207 Feet | 85 Feet |
| 300 Ω-M | 344 Feet | 144 Feet |
| 500 Ω-M | 636 Feet | 276 Feet |
| 1000 Ω-M | 1444 Feet | 636 Feet |



Temperature and Resistivity

| <u>Temperature</u> | | <u>Resistivity</u> |
|--------------------|------------|--------------------|
| <u>C</u> | <u>F</u> | <u>Ohm-cm</u> |
| 20 | 68 | 7200 |
| 10 | 50 | 9900 |
| 0 | 32 (water) | 13,800 |
| 0 | 32 (Ice) | 30,000 |
| -5 | 23 (Ice) | 79,000 |
| -15 | 14 (Ice) | 330,000 |

*As temperature varies throughout the seasons therefore soil resistivity will also vary with the moisture content and the temperature. This is one of the reasons deep earth grounding is preferred in areas where the "frost line" is deep. A 10' ground rod in some areas does not provide a ground in all seasons.



Resistivity of Various Waters

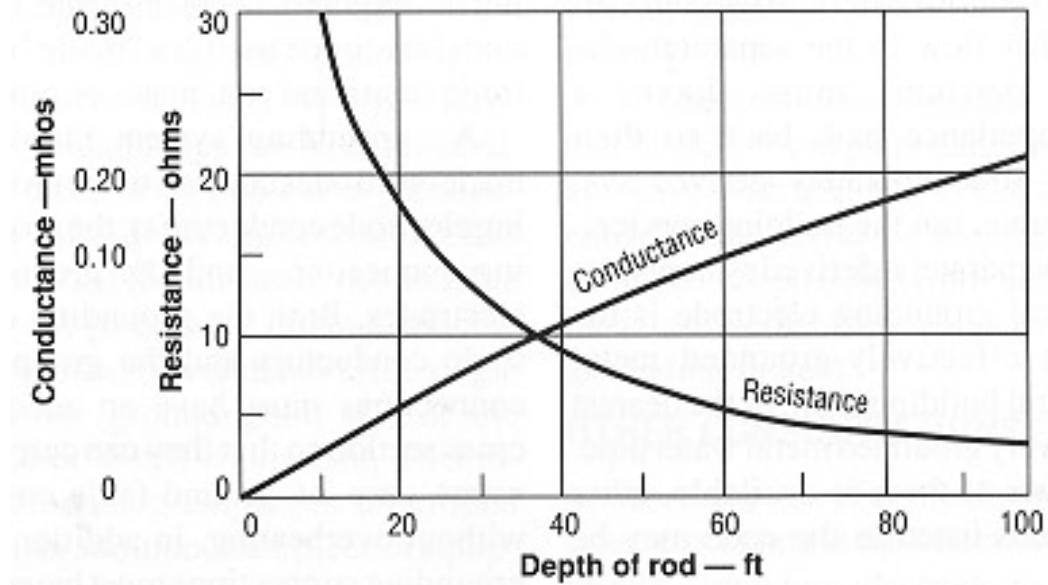
| Classified Water | $\Omega - m$ |
|------------------------------|--------------|
| Pure Water | 200,000 |
| Distilled Water | 50,000 |
| Rain Water | 200 |
| Tap Water | 70 |
| Well Water | 20~70 |
| Mixture of River & Sea Water | 2 |
| Sea Water (Inshore) | 0.3 |
| Sea Water (Ocean 3%) | 0.2~0.25 |
| Sea Water (Ocean 5%) | 0.15 |

Table 9 : Resistivity of Water(Approx.Value)



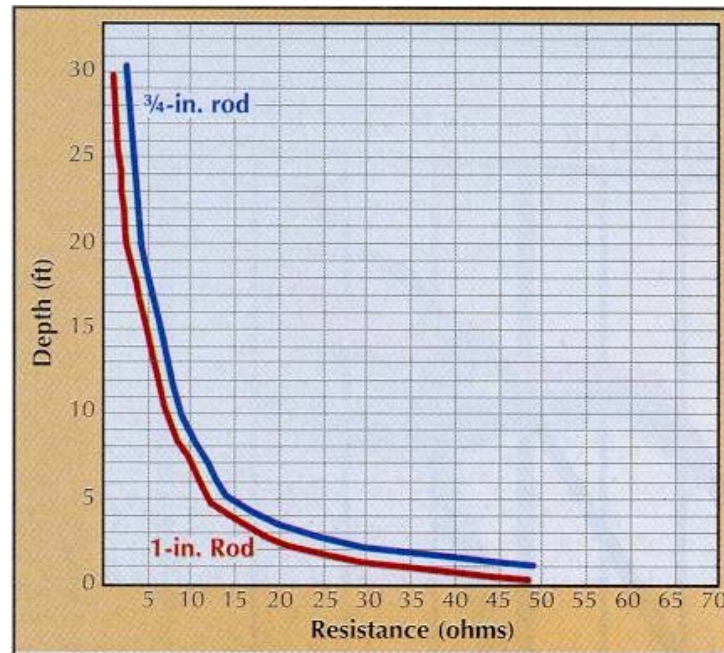
Depth of Rod

- Depth has significant effect



Diameter of Rod

Diameter has little effect



Ground Rod Resistance & Rod Size

- Increasing the diameter of the ground rod does little to reduce the resistance to earth.

Doubling the diameter reduces the resistance by less than 10%.

The only logical reason for a larger rod is the soil conditions (aka: Conditions require a $\frac{3}{4}$ " or larger ground rod so the rod can be installed. It is not unusual to have to "drill rock" or other hard earth structure.



Why These Factors Are Important

- $I = E/R$
- Current is what causes the damage
- The most current will flow when R is minimal (in the ground system)
- So you can have all the voltage you can imagine and if the “R” of the intended path is close to “0” you have “0” damage inside.



Annual Ground Testing

- The technician that completes ground testing must have been trained by the factory or their approved training representative.
- The technician **MUST** be certified to complete the testing.
- It is recommended the technician have a minimum of 5-years experience.
- A detailed written report with photo's must be provided.
- Anything less is **NOT** reliable.



Which Ground Tester(s) Will Meet Your Needs & Testing Requirements?

- Ground testers come in two versions. Stake type testers & clamp-on ground testers.
- Before you decide which style will meet your needs understand the benefits & limitations of each tool.
- Suggested sites Megger.com and AEMC.com



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After Training on Both Types

The Fall-of-Potential Checklist

- Identify and locate any and all conductive elements (wires, pipes, cables, metal fences, tree roots, etc.) or any condition or conductive element in the soil that would impact the test results.
- To insure accuracy of a “stake type” fall of potential test it is necessary to verify the test results. This is done by a completion of two additional tests that are at: 90°, 180° or at 270° from the initial test. This confirms there is no conductive elements.
- Do you have access to enough area or real estate to allow completion of two additional tests? If you cannot do both you don't have a reliable initial test.
- Verify the soil is un-disturbed and virgin soil, no fill has been added.

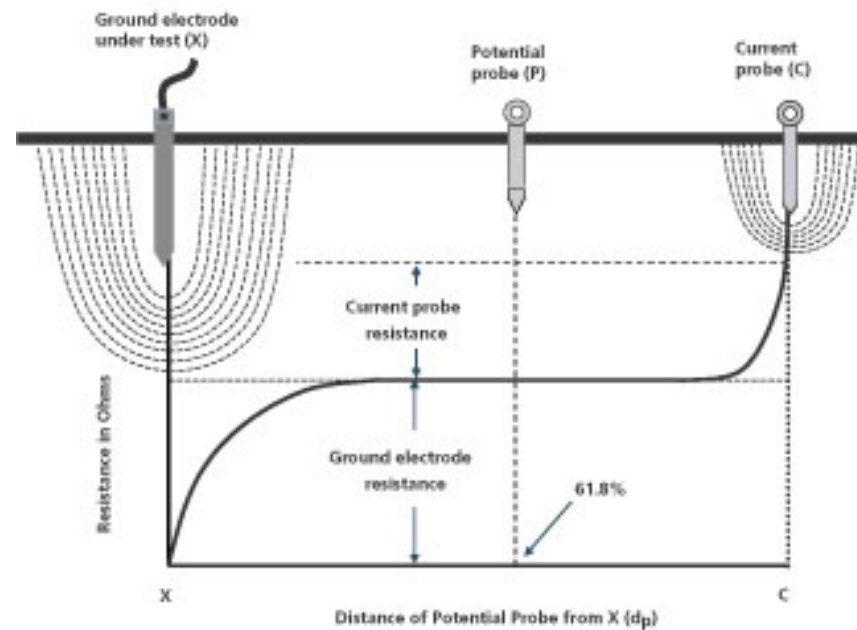


Fall-of-Potential Tester Checklist

- If necessary use ground penetrating radar to be sure the soil in the area can be used for testing.
- Verify the moisture content of the soil does not exceed the worst case lack of seasonal moisture.
- Test and record; the soil temperature, moisture content, PH, salt content.
- Confirm if any ground enhancement material was used when the grounding was installed. If anything other than Bentonite or conductive concrete the testing may (will) not be accurate.



Ground Rod Fall of Potential Testing & Concentric Shells of Earth



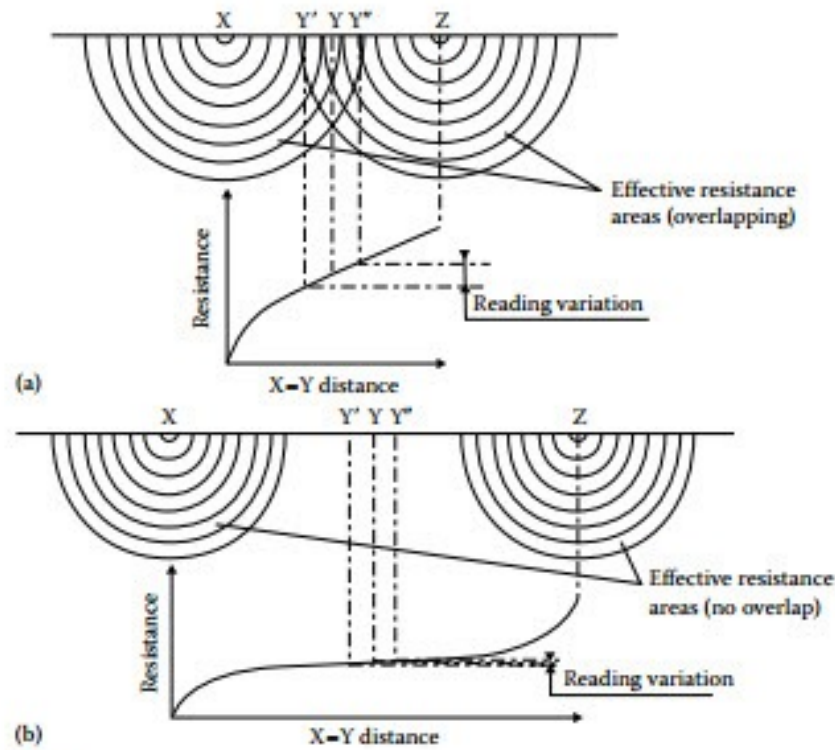


FIGURE 11.17
 Effective resistance areas (cylinders of earth) (a) overlapping and (b) not overlapping.



“Adding a second rod does not provide total resistance of half that of a single rod, unless the two are several rod lengths apart.”

IEEE Green Book

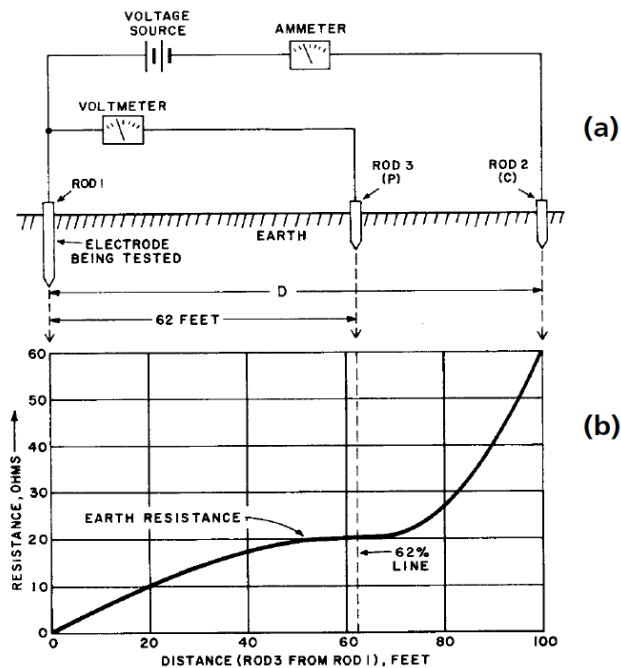


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Fall-of-Potential Ground Testing



1. 10: Principle of an earth resistance test



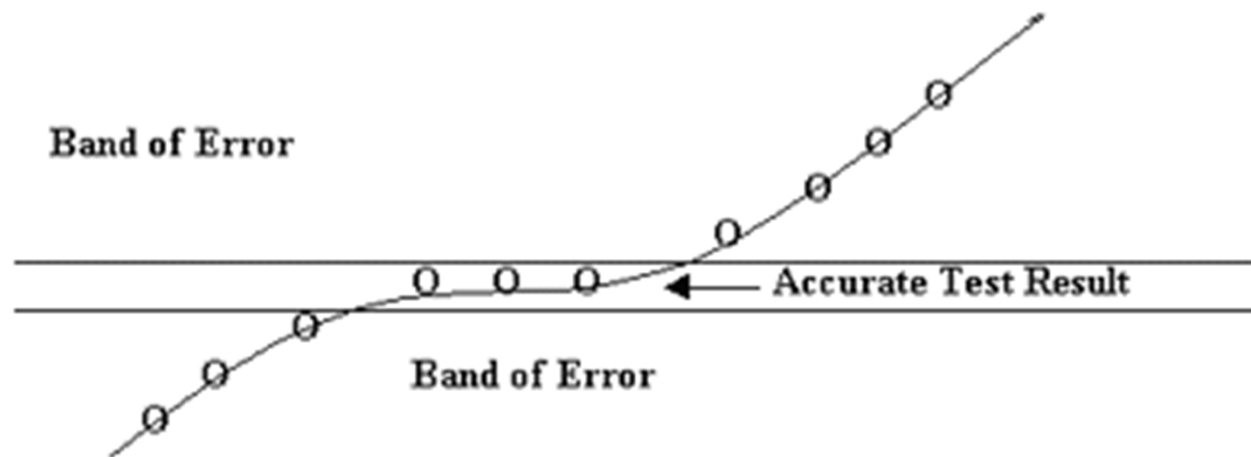
Distance in feet to the Auxiliary Electrodes Using the 62% Method**

| <u>Depth Driven</u> | <u>Distance to "Y"</u> | <u>Distance to "Z"</u> |
|---------------------|------------------------|------------------------|
| 6 | 45 | 72 |
| 8 | 50 | 80 |
| 10 | 55 | 88 |
| 12 | 60 | 96 |
| 18 | 71 | 115 |
| 20 | 74 | 120 |
| 30 | 86 | 140 |

** The above is for "average" conductive soil with a 5% moisture content. The distances will triple if the soil has 10% moisture content and increase 12 times if the soil has 20% moisture content.



Band of Error Fall-of-Potential



Multiple Rod Lengths Coupling

Lowering Ground Resistance

- Add More Rods
- Deep Driven Rods
 - Threaded Couplings
 - Compression Couplings
 - Exothermic Ground Rod Splice



Grounding & Bonding for Lightning

- Lightning strikes most often occur to outside wiring.
- Grounding & bonding the electrical system will assist the flow of lightning into the earth.
- The electrical system is a calibrated spark gap.
- Over voltages will arc to a lower potential.
- If the lower potential is capable of handling the current that will develop you divert what would otherwise be trouble.
- Low resistance & impedance ground paths facilitate that to happen.



Bonding to the Highest Level

- Bonding should be designed and installed to a level that will provide a very **low impedance path** to the facilities electrical system earth ground.
- Bonding must be robust, **use stranded cables** and have a “flow” to the earth ground.
- Bonding **must not have hard bends.**



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Bonding Installation

- Electrical service entrance ground bonds should be to a **common bonding bar** that is both robust and provides a low impedance path to earth ground.
- All bonds should be **exothermic welds or double lugs** and made using conductive grease and robust hardware. (lock washers, double nuts, etc.)
- This bonding bar should be the **common point of all bonds**: Neutral, plumbing, water, gas pipe, lighting protection, Ufer, building steel, all metallic elements of the electrical panels, conduit, etc.
- Allow for the flow of lightning energy imposed on any and all elements of the electrical system.
- Bonding must be “serviced”, verified, checked, etc.



Surge Protective Devices



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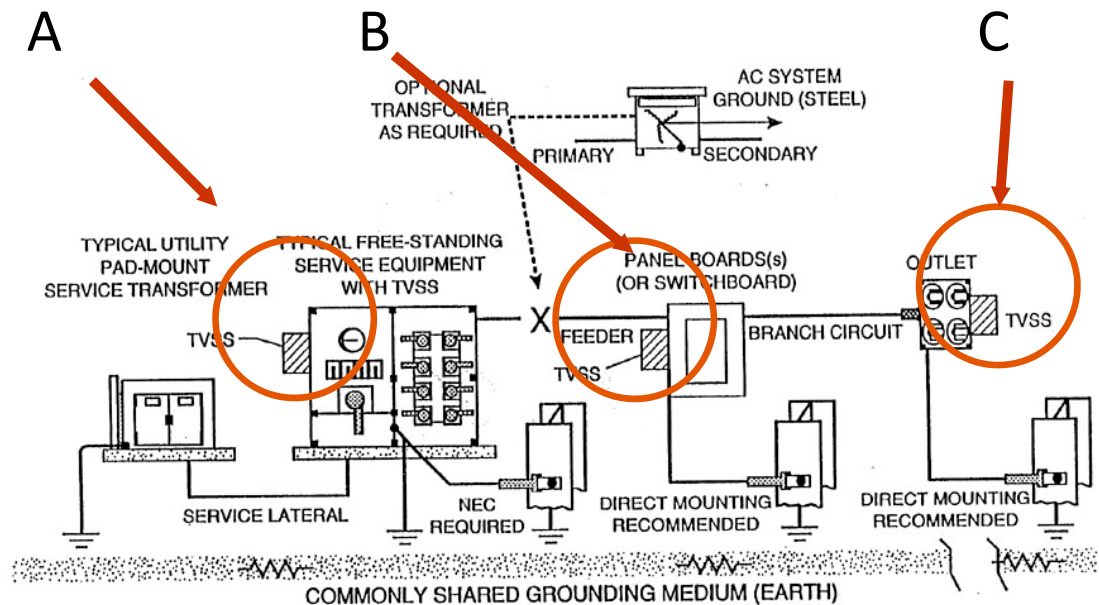


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SPD (TVSS) Placement

Use Surge Suppressors in 3 places

- At the service
- At feeder level
- At branch level



AC Power Surge Protection Devices

- SPD are classified by UL based upon how they are installed
- Type “1” – Hardwired ahead of the main means of disconnect.
- Type “2” – Hardwired after the main means of disconnect.
- Type “3” – Cord connected or direct plug in devices.
- Type “4” – Component Assemblies – One or more components that are listed as part of Type 5.
- Type “5” – Individual components such as MOVs.



What To Use Where (ratings in kA per mode)

- Service Entrance – 100kA to 300kA.
- Primary Distribution – 100kA to 200kA.
- Distribution “outside loads” – 100kA to 200kA.
- Distribution panels – 50kA to 100kA.
- Sub Panels – 40kA to 50kA.
- Outside Loads – 40kA to 50kA series device.
- Critical Loads – 50kA series device.
- Point of use – Cord connected 10-20kA.



At the Service Level

Type 1 devices
150 kA per mode minimum suggested



At the Feeder Level

Type 2 devices

75 kA per mode minimum suggested



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At the Device Level

Type 3 devices
25 kA per mode min.
50 kA if critical load



MOV Based SPD

- SPD is a diversion device, it shunts the lightning energy to ground.
- SPD must have a good ground to divert the energy
- If you don't have a good low-R ground, don't install SPD's. It will make matters worse.



MOV

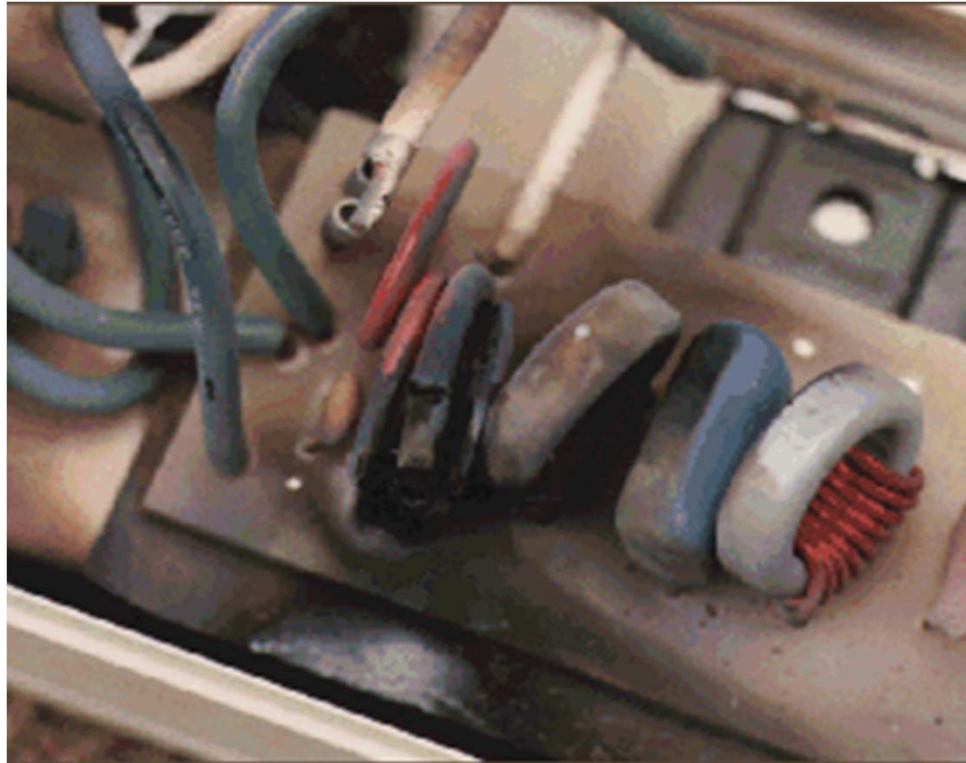


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A Failed MOV



MOVs

- MOVs are bi-directional components.
- MOV's degrade with use.
- SPD references ground conductor.
- A surge can sometimes come from telephone or other connections to ground. Thus, you want low resistance to earth.



SPD Characteristics

Surge Suppressors Should Have:

- All-mode protection: ϕ - ϕ , ϕ -G, ϕ -N, N-G
- Listed to UL 1449, Version 3
- High Joule (W•Sec) rating
- Have filtering, fuses, indication
- Must be well-grounded to work



SPD Inspection & Testing

- Most SPD lights only mean you have power.
- Industry people call SPD lights, “idiot lights”.
- Some SPD lights are diagnostic.
- Ask the company how their lights know there is a change in the status of the SPD.



SPD Testing



Surge Suppressor Location is Critical



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Lightning Protection Systems

- The codes and standards for lightning protection systems allow building steel to be used as the “down conductor”.
- Simply put the steel framework of a building becomes the conductor for lightning.
- What happens to the metal conduit that is in contact with the building steel?



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Rating SPD – What is Important

- NEMA LS-1 1992 Testing.
- Rated kA per mode rather than by phase.
- SPD Noise Filters are rated in dB.
- SPD manufacturer reputation for SPD.
- Expert application support.
- SPD manufacturers field support.
- SPD manufacturers warranty policy.



General Wiring Practice

- Surge Suppressors should be connected to a full size grounding conductor
- By “full size” I mean equal to the phase size



Wire Length is DELAY!



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This SPD Will Not Protect Panel



AC Power SPD & Facility Protection

- Proper “facility” protection is much more than the installation AC power SPD.
- Coordinate with other service providers: CATV, Telecom, etc.
- Be sure they have connected properly to the ground bonding system.
- Be sure they have also protected their services.



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Installation Conditions

- Geographic Considerations.
- Building Construction.
- System Topology.
- Power distribution system configuration.
- Control cabinet or equipment location.
- Interface considerations.
- Customer specific requirements.



WRZN

Multiple things to learn



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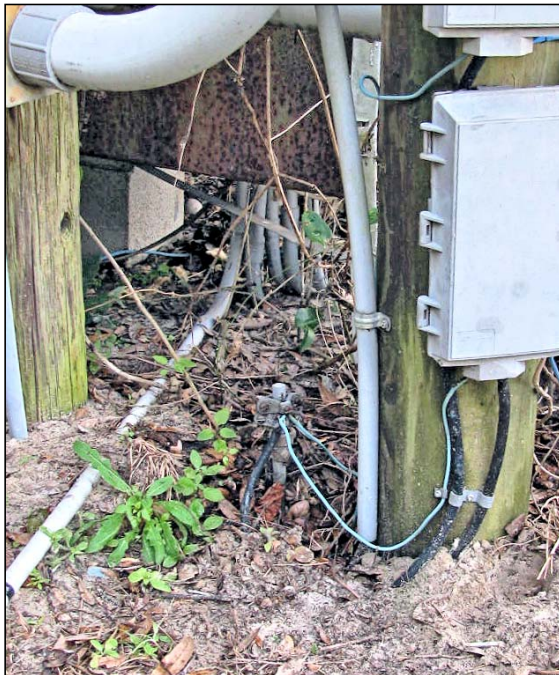
Where to Place Electrode?

A/C makes perfect
moisture drip



WRZN

Original 280 Ohms



WRZN

After new grounding
3.4 Ohms



Telephone Service

Lightning does not
travel up!

Ground bar was there
all the time.



Mutual Induction

Neat but induction
will worsen situation



Lightning is Frequently on Telephone System

Telephone and cable TV mixed on common ground bar.

Lightning will be transferred to cable TV, then electric system



General Guidelines

Circuitry

Voltage Drop

Full Size Conductors

General Principals

- Source: Dranetz Field Handbook



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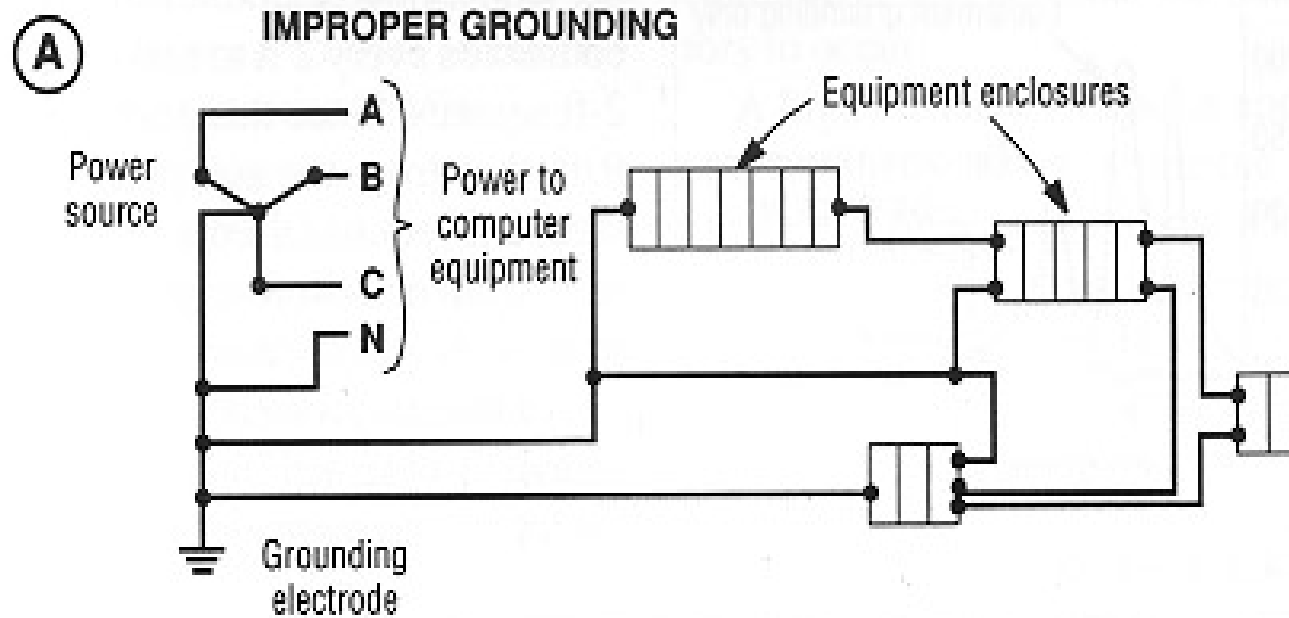
Internal Causes of PQ Problems

- Poor electrical system design and layout
- Lack of or inadequate electrical system maintenance
- Shared mixed load distribution panels
- Too many outlets per circuit
- Mixed load use on circuits
- Inadequate and shared neutrals
- Poor, inadequate and shared grounding
- Intermittent connections
- Standard equipment and wiring (inadequate conductors, IG, etc.)
- etc.

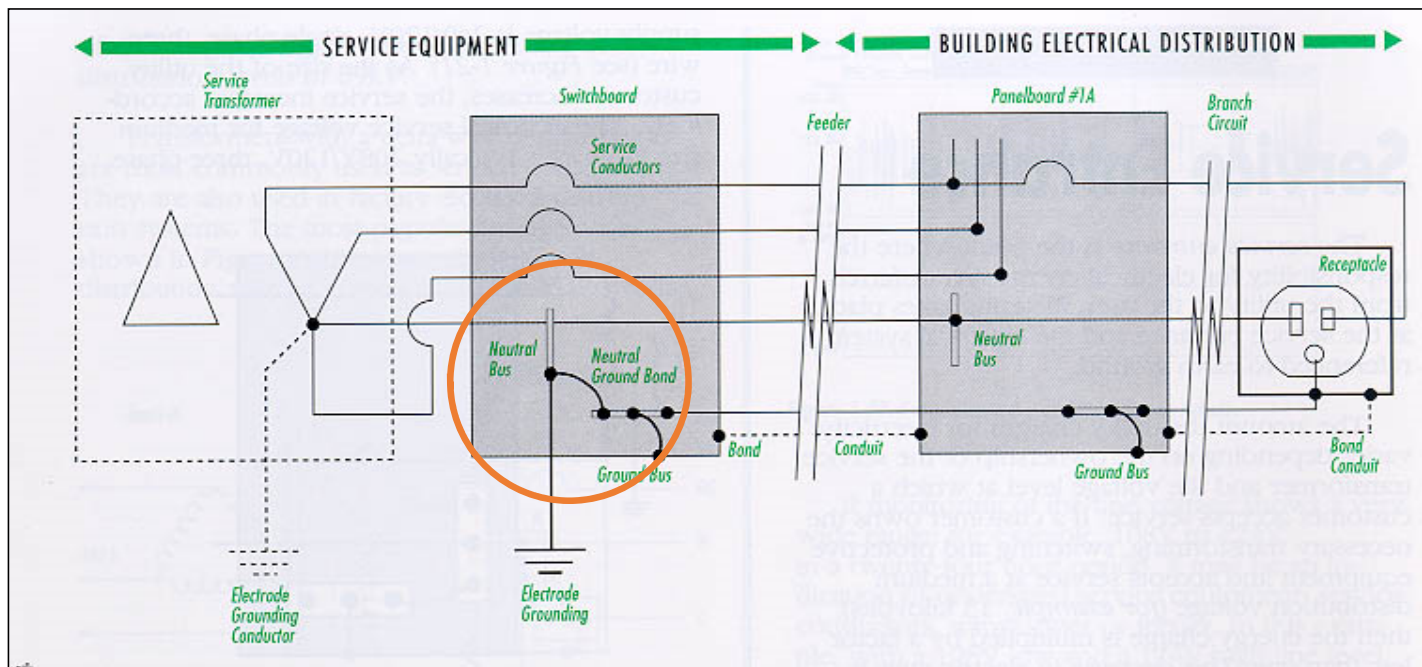


Avoiding Daisy-Chaining Equipment

Each piece is home-runned to an SGB or MGB



Only N-G Bond is at Service (or separately-derived system)

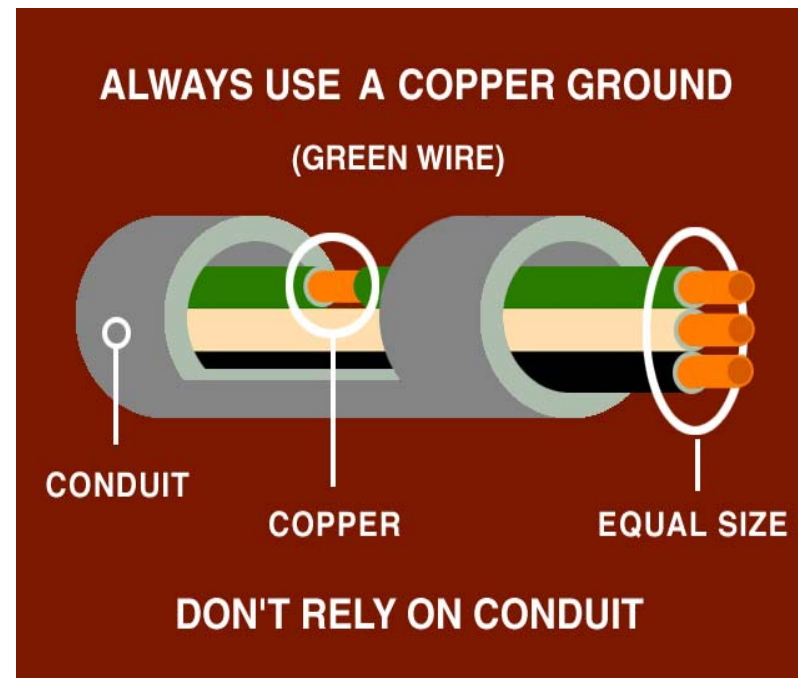


Avoid Conduit as a Ground Path

Can you imagine a
joint every 10 feet?



Full Size Equipment Grounding

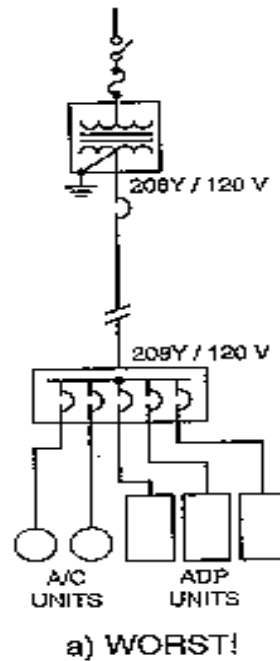


General Wiring Practice

- **Sensitive loads should be separated:**
 - **Separate branch circuits**
 - **Separate panelboards**
 - **Separate feeders**
 - **Separate transformers**



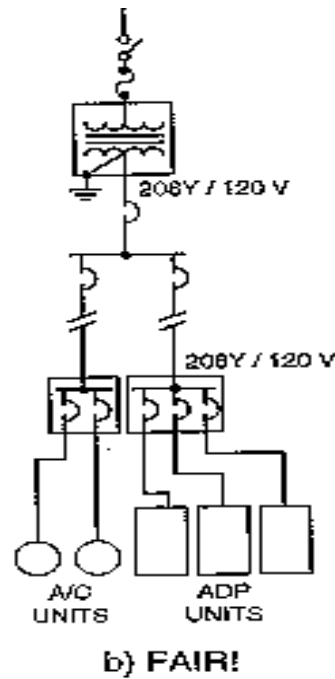
Typical Wiring Method



source: IEEE
Emerald Book



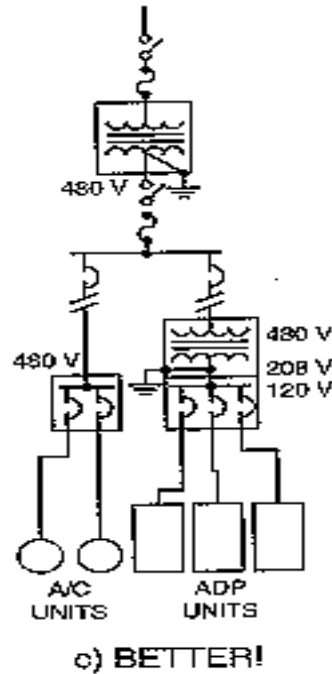
Slightly Better Wiring Method



source: IEEE
Emerald Book



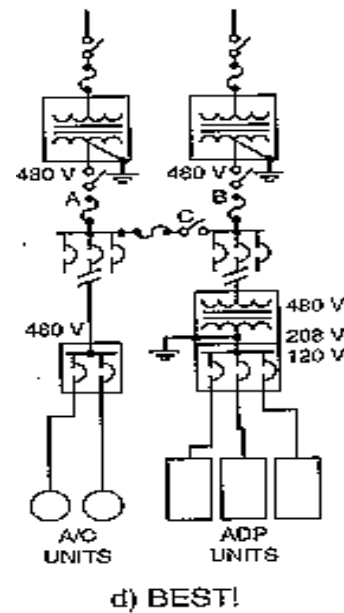
Much Better Wiring Method



source: IEEE
Emerald Book



Optimal Wiring Method



source: IEEE
Emerald Book



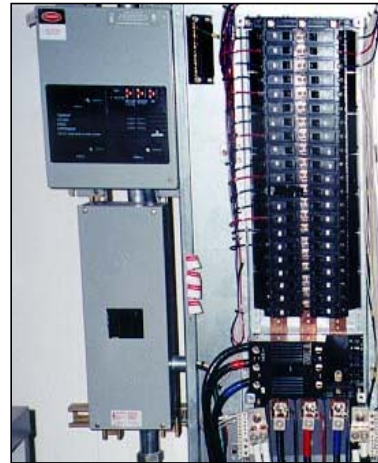
Limit the Number of Outlets Per Circuit

- **3-6 per 20 amp. branch circuit (maximum):**
- **Prevent interaction among loads**
- **Limit voltage drop**



General Wiring Practice

- Use Surge Suppressors, connected to a full size grounding conductor
 - - at the service
 - - at the panelboard
 - - at the load



General Wiring Practice

Surge Suppressors:

**Must be well-grounded
to work**



Caveat

MOV's can degrade with use!



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Data Center Inside



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Lightning Hit Service Drop

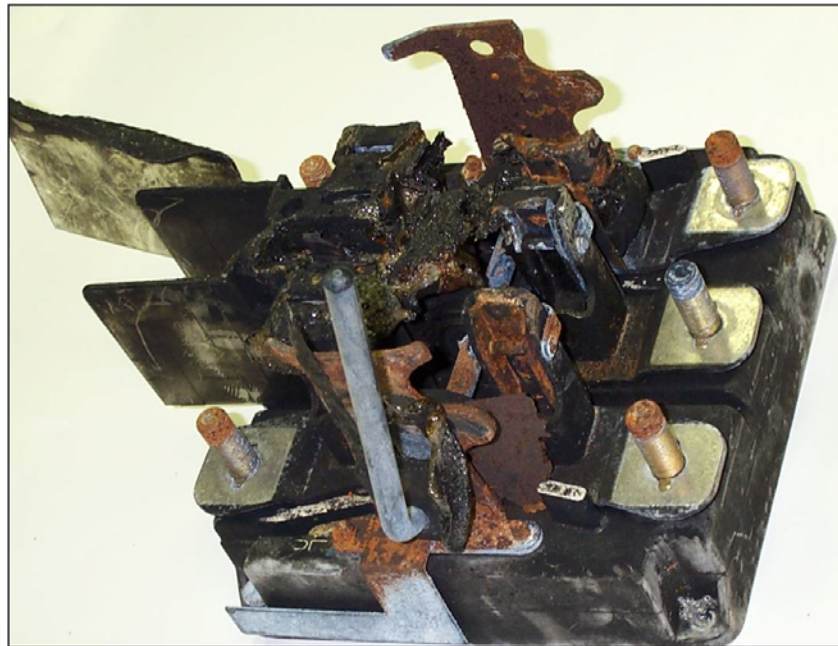


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SunCoast Credit Union's Data Center 480Y/400-Amp Meter Base Disconnect



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7 Levels of SPD's



Lightning vs. The Meter Base

- The meter base took the brunt of the lightning damage.
- The meter base housing was “bonded” to the ground system.
- The impedance of the path to the switchgear higher than the path to the ground rod system.
- Nothing inside the data center was damaged.
- The most robust was a SPD was rated at 120kA per mode.



Lightning vs. The Meter Base

- The lightning energy imposed on the electrical service went to earth ground on the conductor that bonded the meter base and other metal cases of the electrical system to the ground rod system.
- The ground resistance of the service: 4.3 Ohms (Fall-of-Potential) tested.
- The only damage was to the “outside” elements of the electrical service. (Meter base, gutter work, pole, transformer, utility wires, etc.)



SPD's Need Good Ground

Without a good, low impedance ground to discharge to SPD's don't work.



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Suncoast's Data Center

No downtime

No equipment damage

Cost around \$40,000

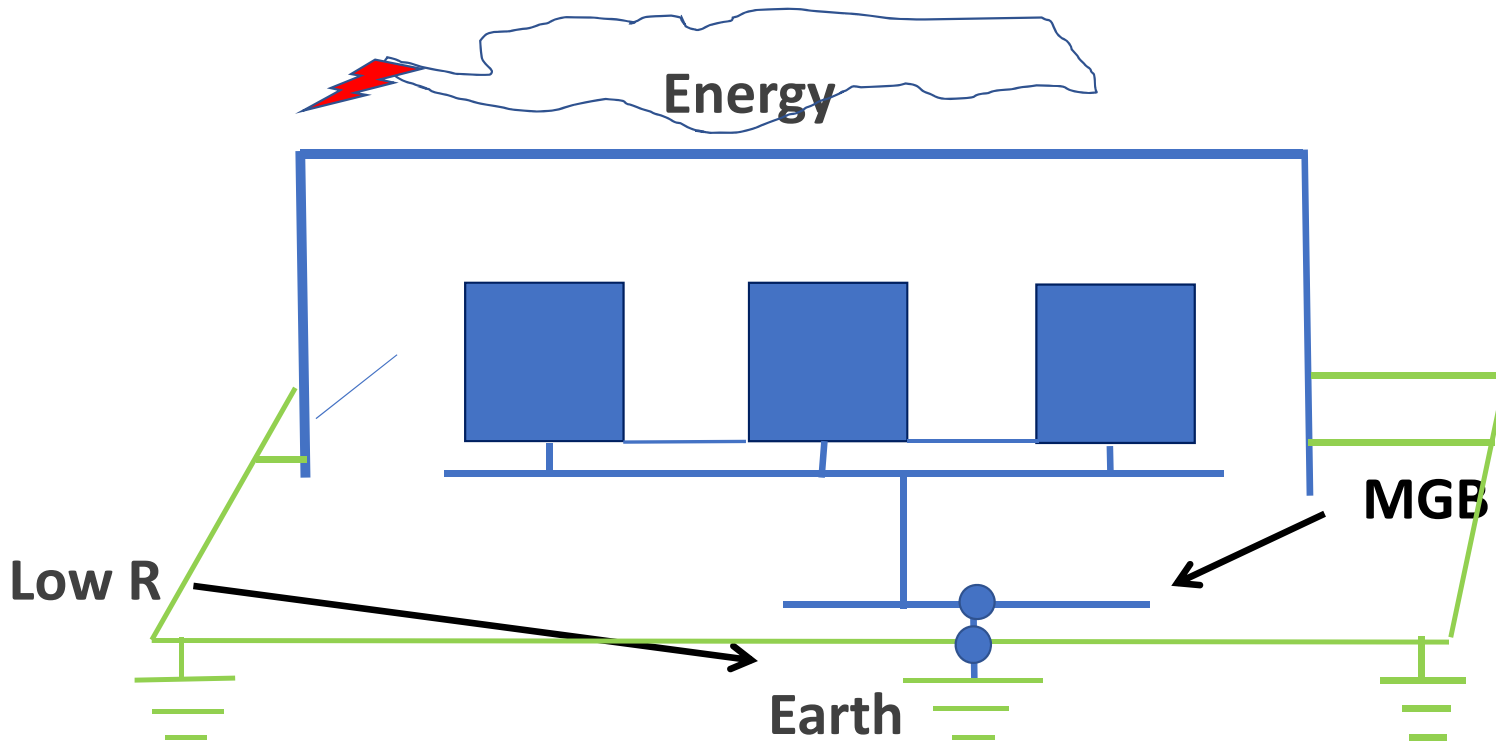


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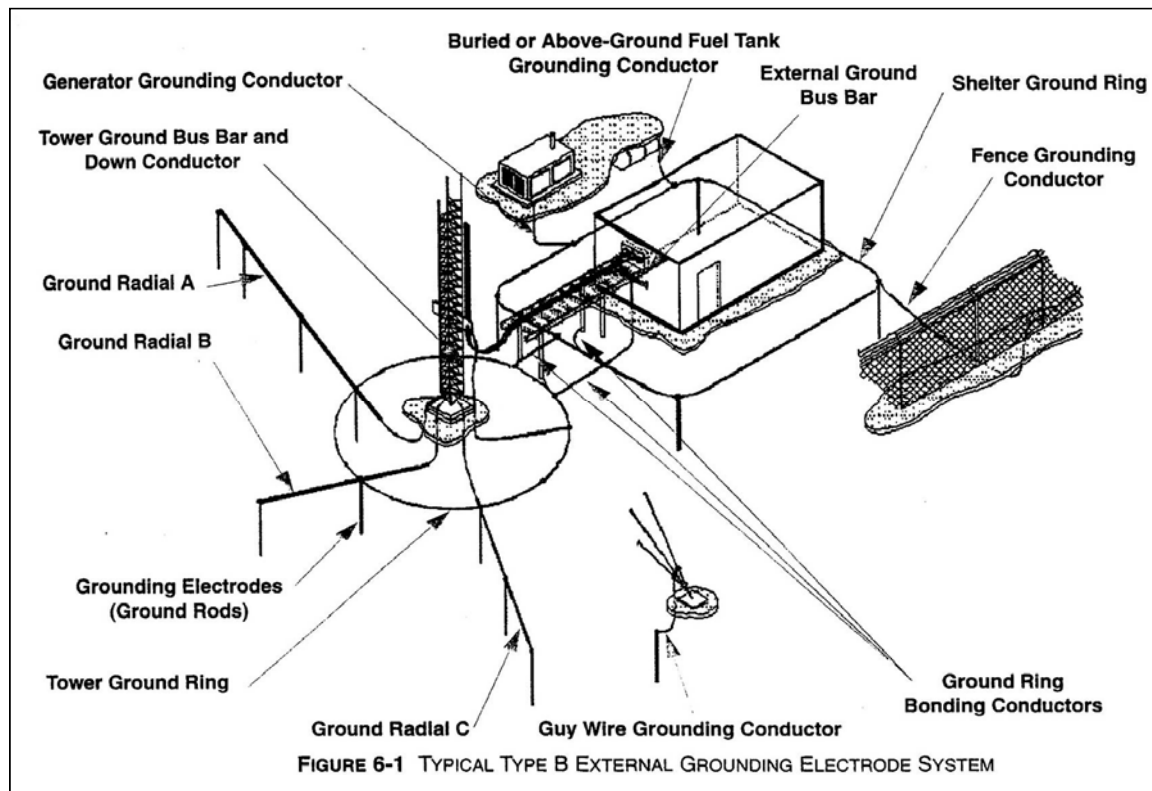


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Think of a “Current Divider”



Desired Grounding



Example of Current Divider

Macomb County, Michigan 9-1-1



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Note Tower in Rear



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Gas and Water Services Bonded



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Labeled So No One Removes



Conductor Welded to Base, Not Tower Leg



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Coax Braid Bonded on Vertical Run



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Then to Strap at Bulkhead



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Inside Radio Room

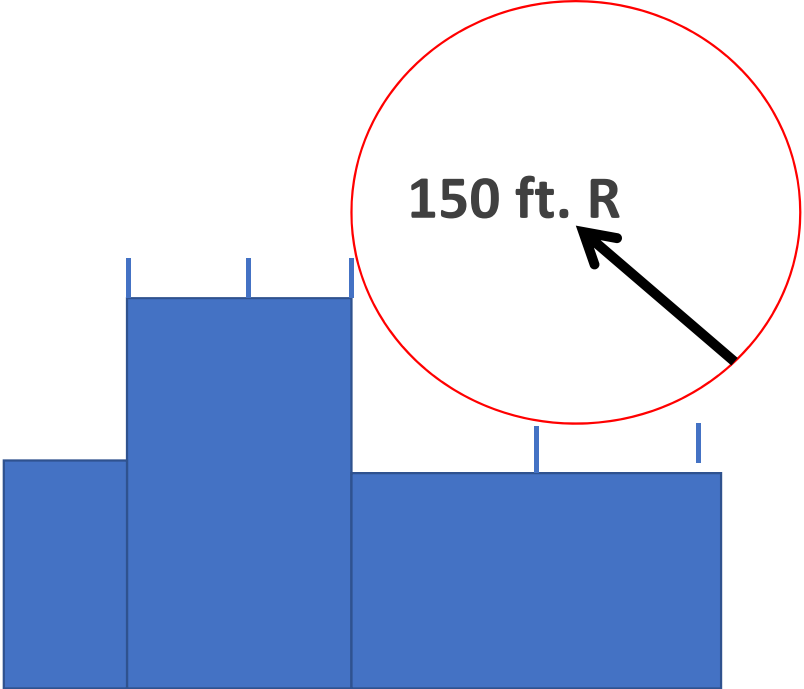


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Rolling Ball



Costs

- **Cost of materials is CHEAP compared to labor, equipment, downtime**
- **Cost for all PQ improvements:**
- **Adds about 1 to 1-1/2% to the overall cost of construction, but....**

- **Never have to revisit infrastructure for foreseeable future**



Larger Data Center

Involta, Cedar Rapids, Iowa - 18,000 sq. ft.

Akron, OH – 26,400 sq. ft.



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500 kcmil Ring Surrounds Building

- Supplemented by vertical electrodes every 100 ft.



Dual Electric Circuits

Dual utility feeds, 2- 2500 kVa transformers,
4- 750 kVa generators, A&B circuitry



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A and B Circuits

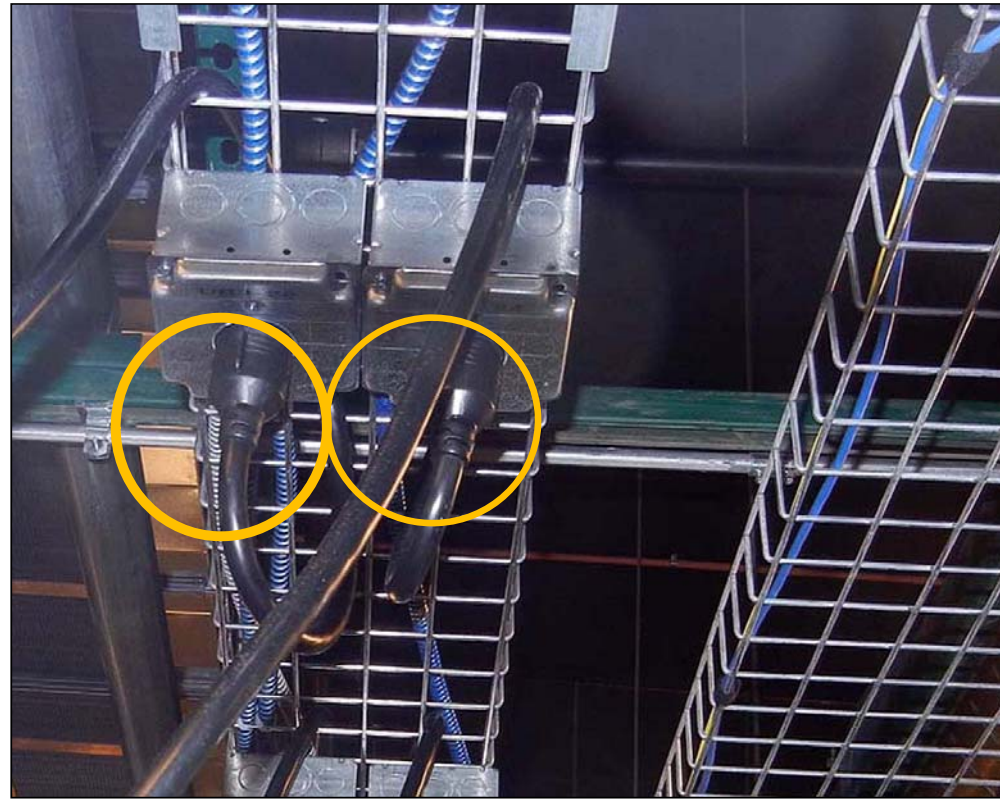


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Dual Feed to Cabinets



Cabinets to Overhead Collector



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From Racks Collectors go to SGB



From SGB to MGB



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Very Large Data Center

800,000 Sq. Ft. in Boston

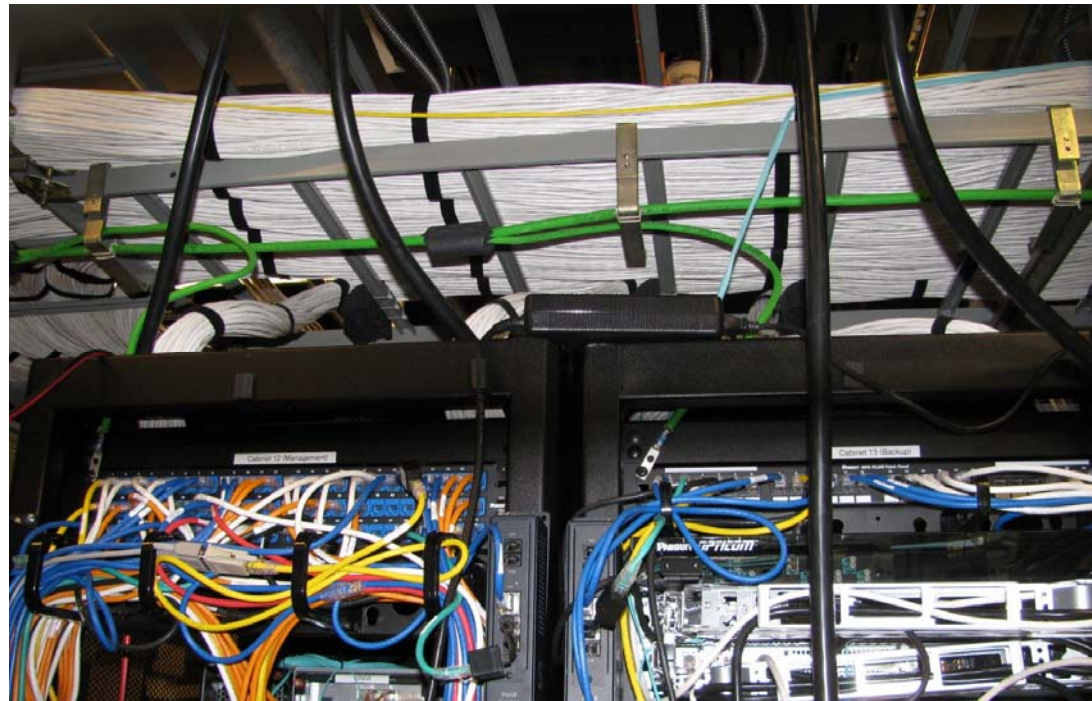


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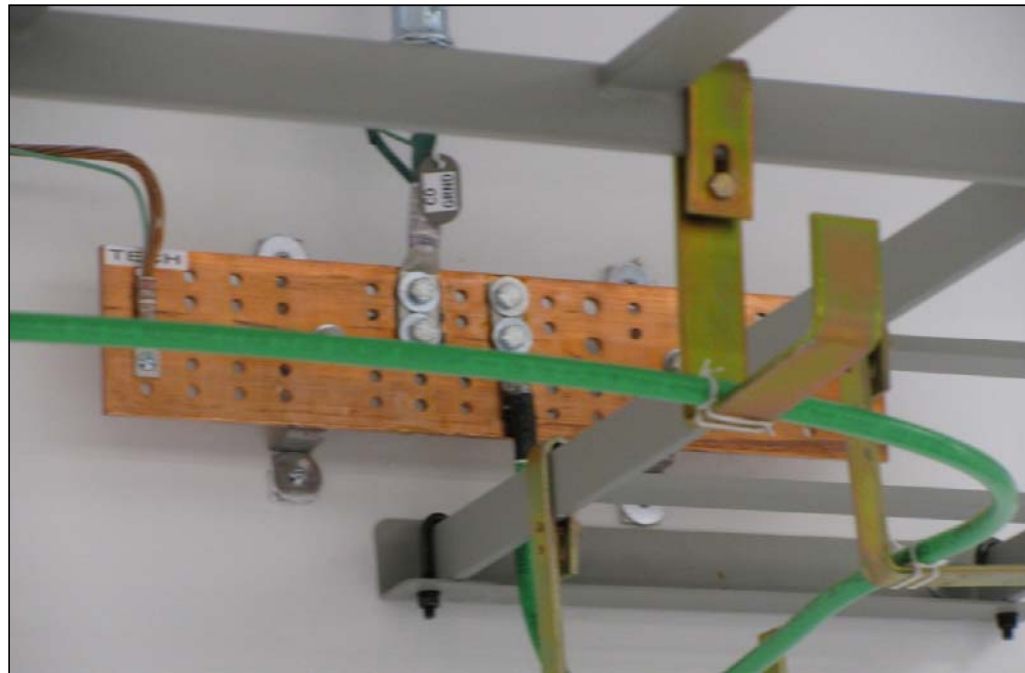


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Each Rack Tied to Overhead Bus



Each Room Has Signal Ground Bus Then to MGB



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Separate Runs to Master Ground Bus



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Master Ground Bus (MGB)

- Note that all conduits are labelled.
- MGB located at lowest point in building.



MGB Connections Labelled

Every connection neatly labelled



Co-Sentry
Data Center



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Imagine a Joint Every 10 Feet?

Never Rely on Conduit as Ground Path

Always use a full-sized separate ground conductor



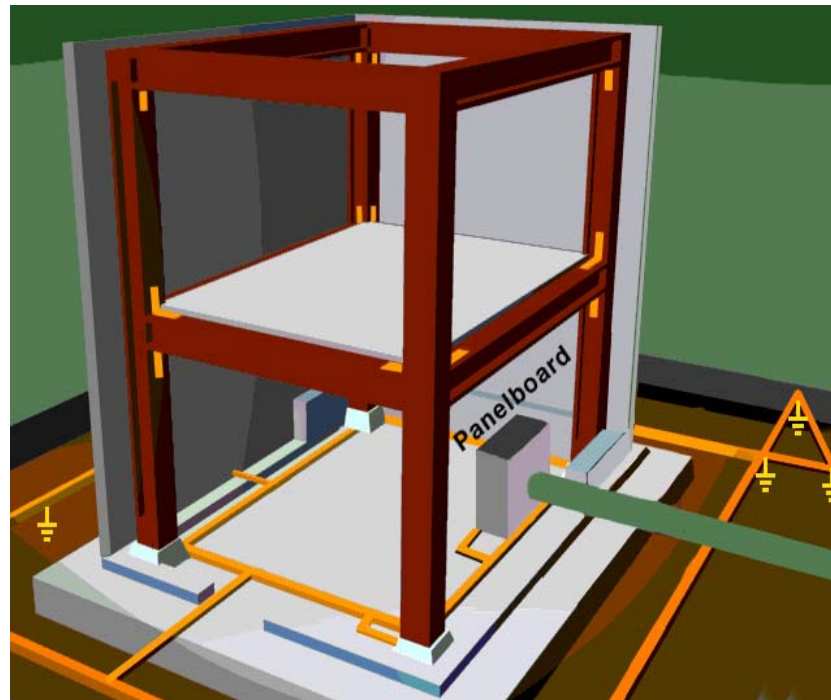
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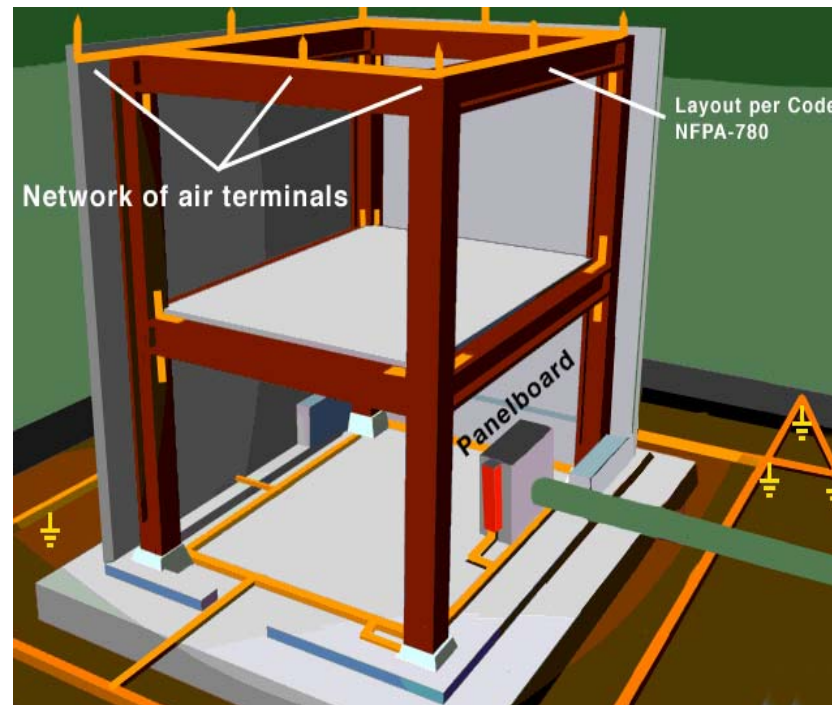
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Start With Ring Ground

Suggested size
4/0 AWG Or better

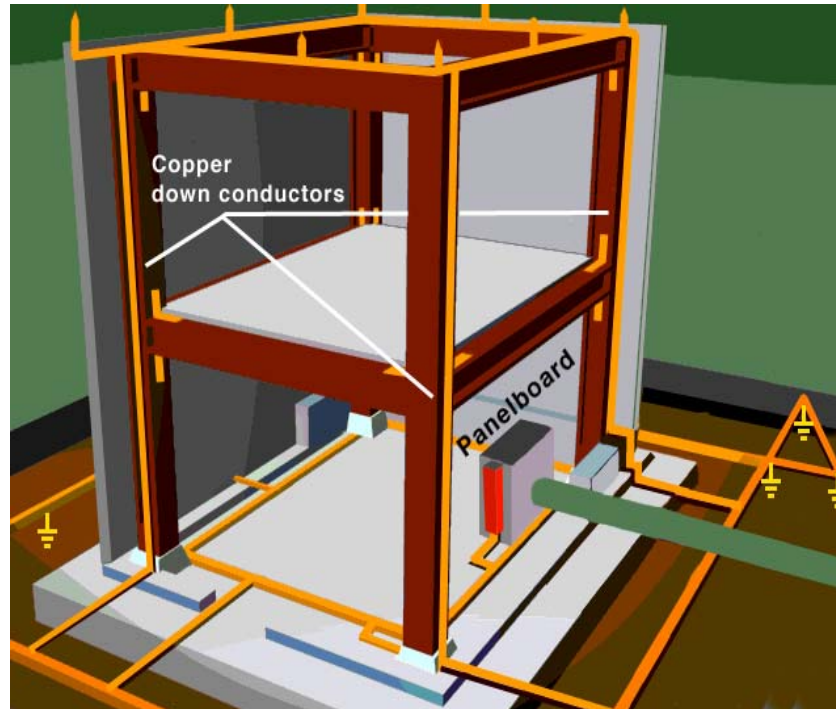


Network of Air Terminals



Heavy Duty Down Conductors

Not steel
framing

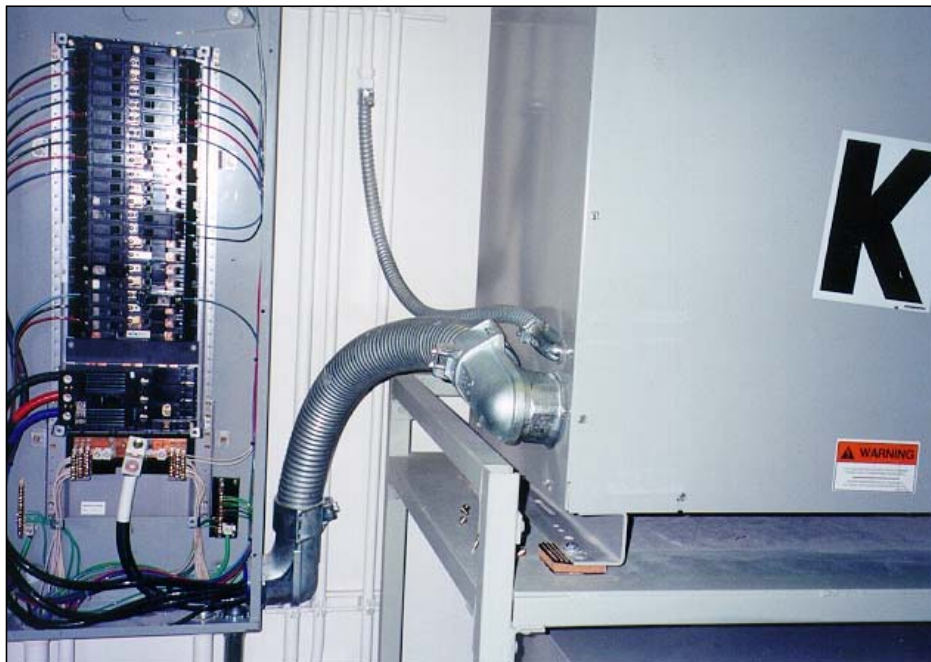


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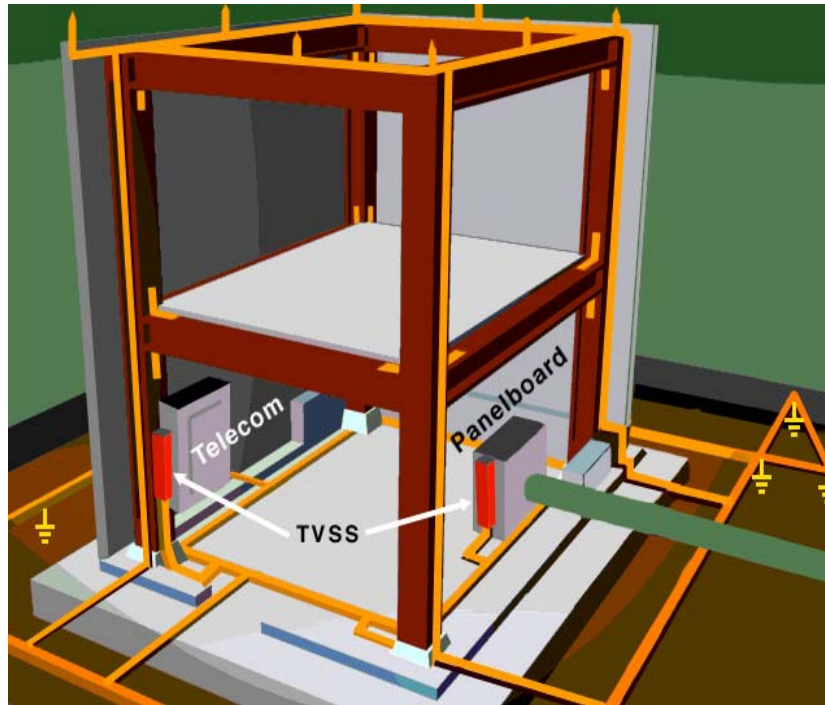
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Do Not Use Building Steel For Down Conductor

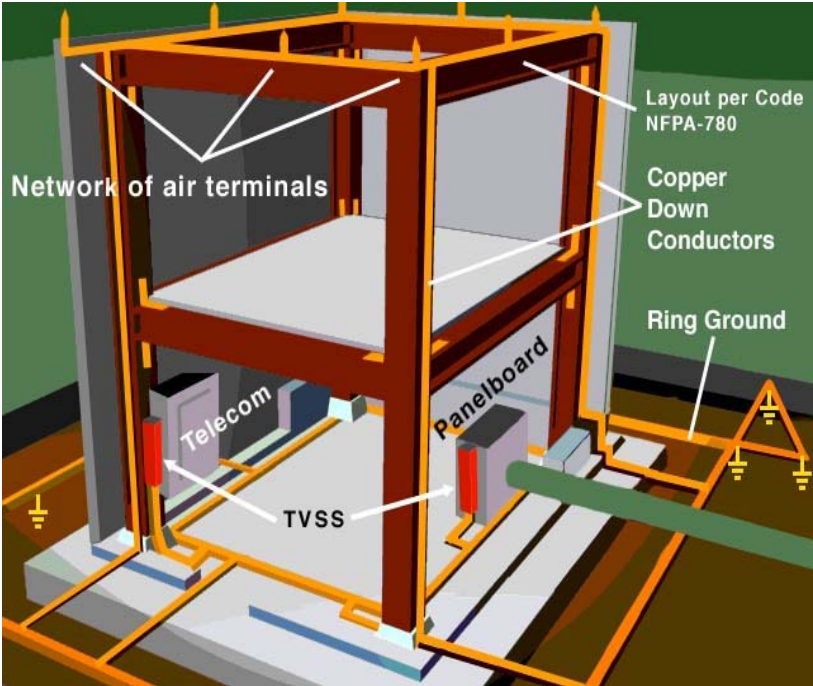


Surge Suppression

Don't omit telephone
or cable TV

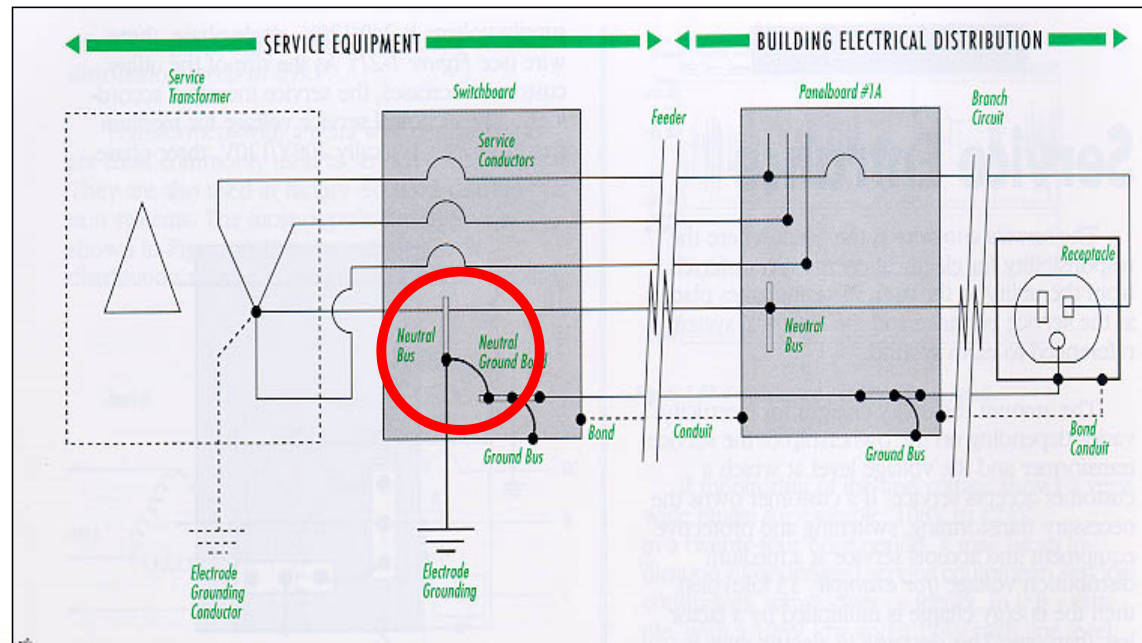


Overall Result



System Grounding

There should be **ONE and ONLY ONE** point connecting the neutral to the exterior grounding electrode system



Isolated Ground Circuits Recommended

We recommend all sensitive equipment should be connected to an isolated ground circuit.

Nothing else on it.



Interior Review

- **Separate circuits, panels for sensitive loads**
- **Limit receptacles to 3-6 per circuit**
- **Limit voltage drop to 3% or less (Code) 2% recommended.**

wire gage, circuit length



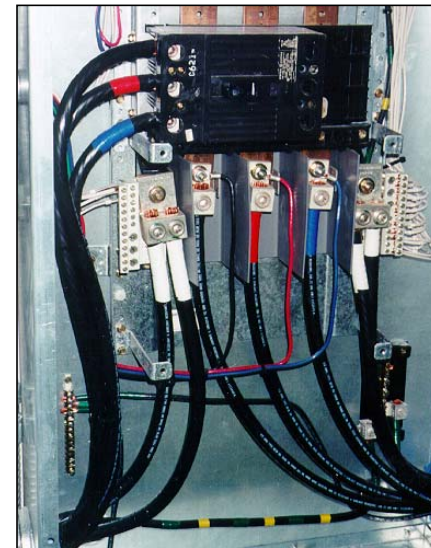
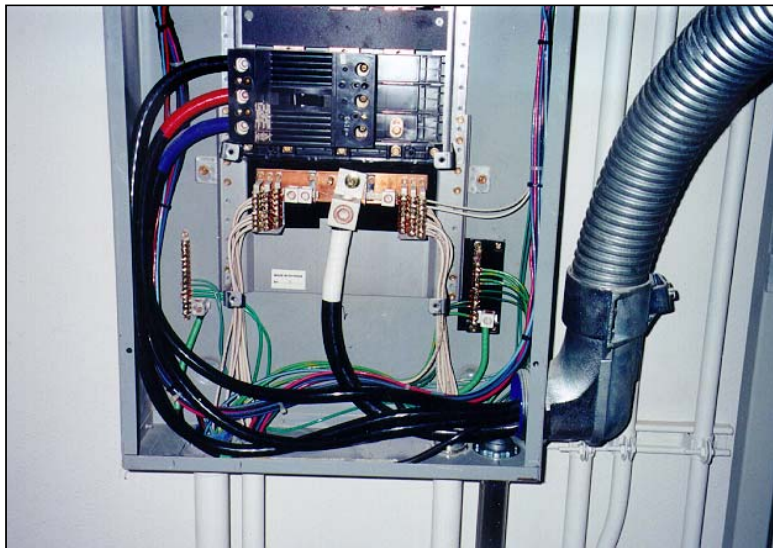
Trap Harmonics

Shielded isolation transformer
helps isolate harmonics



To Handle Harmonics

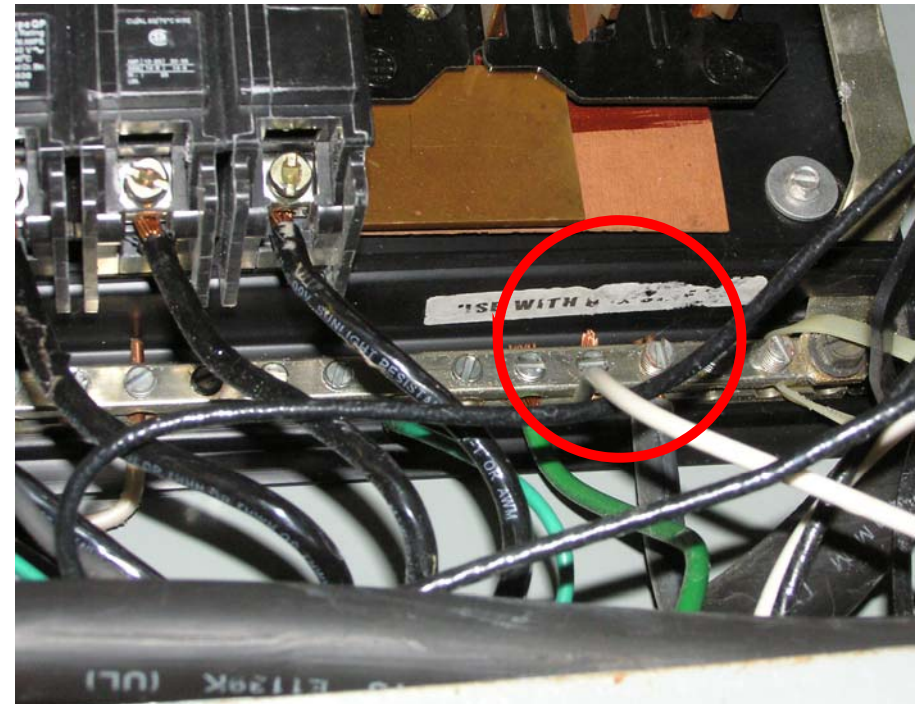
Use a 200% rated neutral or separate neutrals per phase



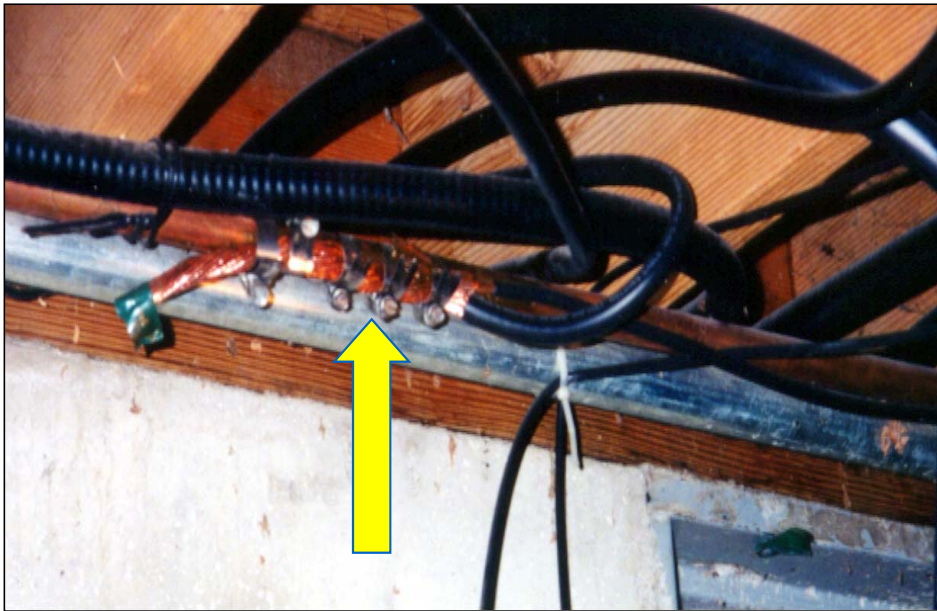
Check For N-G Bonds

Interior:

- Check neutral – ground voltage
 - could mean harmonics
- Check for ground current
 - illegal N-G bonds



Use Only Listed Connectors



- Look for UL Listing on all electrical equipment
- Water tube is not a good conductor



Limit Voltage Drop

- NEC does not mandate voltage drop
- Limit voltage drop to 3% maximum in branch circuits, less if practical
- It's the law in CA, NY, IL, maybe other states



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Environment Considerations



- Rusty or corroded connections
- Unlisted components
- Different metals
- Undersized conductors



Low Resistance is Vital



- Under 5 ohms
- Spacing 2X length
- Below frost line



Choice of rod types

Pick the right rod for the
soil conditions



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Bentonite

- Bentonite is a Ground Improvement Material.
- Bentonite is not a Ground Enhancement Material. (There is a difference.)
- GIM is:
 - Naturally Inert.
 - Compactable & soil compacting.
 - Have low and stable resistivity.
 - Able to maintain low resistance with minimal fluctuations.
 - Does not leach with time.
 - Economically viable.



Backfill

- Bentonite is the recommended backfill
 - Conductive concrete second
- Be wary of anything containing graphite



Augured Hole with Rod & Bentonite

- A hole is augured into the soil.
- The hole is filled with Bentonite.
- A ground rod is installed into the center of the augured hole and the conductor is exothermically welded to the rod.
- Water is added, the Bentonite swells and fills all the voids.

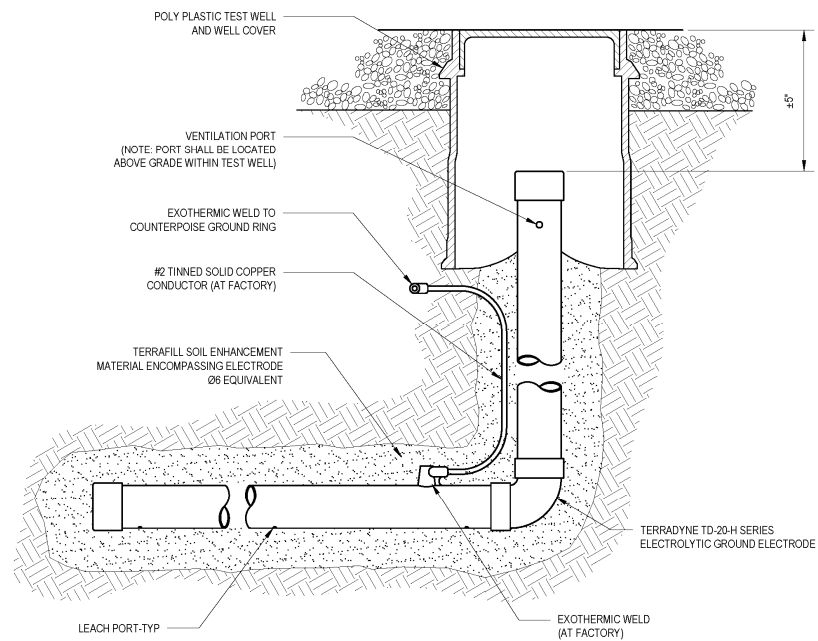


Benefits of Bentonite

- The formation of an electrolyte when Bentonite is ionized by water & this layer around the grounding electrode serves as a pathway for dispersion of lightning charges.
- Increased current dispersion of lightning when compared to installations lacking Bentonite.
- Bentonite is an approved Ground Improvement Material and recommended by CDA



Chemical Ground Rods



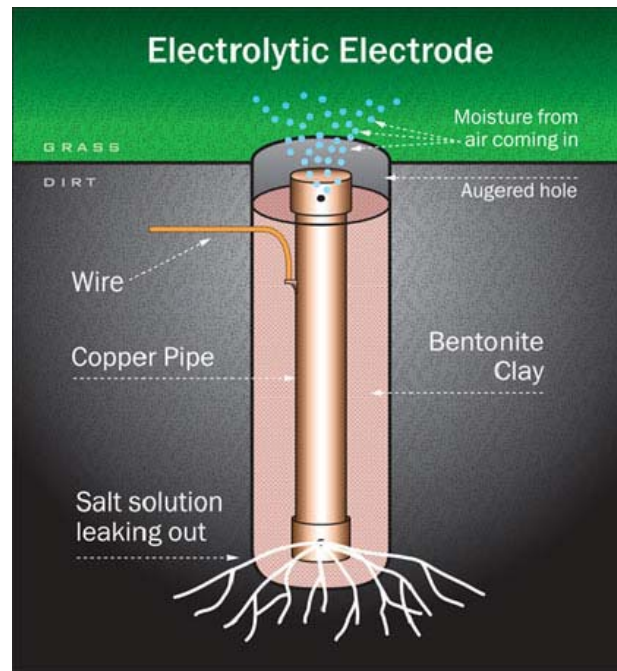
What is a Chemical Ground Rod?

- Simple version: Salt in a Copper pipe with holes drilled into it that is installed in the earth where the moisture will cause the salt to leach into the soil.
- The truth, it is a very viable grounding solution “IF” you understand what it is, what is needed to maintain it (AKA Replace it in time).
- The bottom line is what works in one environment may or may not work in another.
- Use what is most cost effective, sustainable and reasonable in cost for your application.



A Chemical Ground Rod in Action

Copper pipe Full of Salt Will Last How Long?



Chemical Electrodes

Salt-filled pipe after 7 years



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Ground Enhancement Material

- GEM is marketed as the best way to lower the resistance in difficult grounding conditions.
- GEM is a product that is a “waste” or by product of a manufacturing process. In some cases GEM is not subject to a quality control process or procedure that would insure it is not corrosive.
- Depending on “luck” and not knowing if you are installing a highly corrosive product that will be all around a soft metal (copper) is not a wise decision.
- If you wish to ignore the issue with corrosion, just use the “cheap version” of GEM, Rock Salt or fertilizer of some type.
- Carbon “enhanced” or based products are know to be corrosive and not recommended.



Galvanized Rod After 7 Years



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Galvanized Rod

$\frac{3}{4}$ inch to pencil-thin



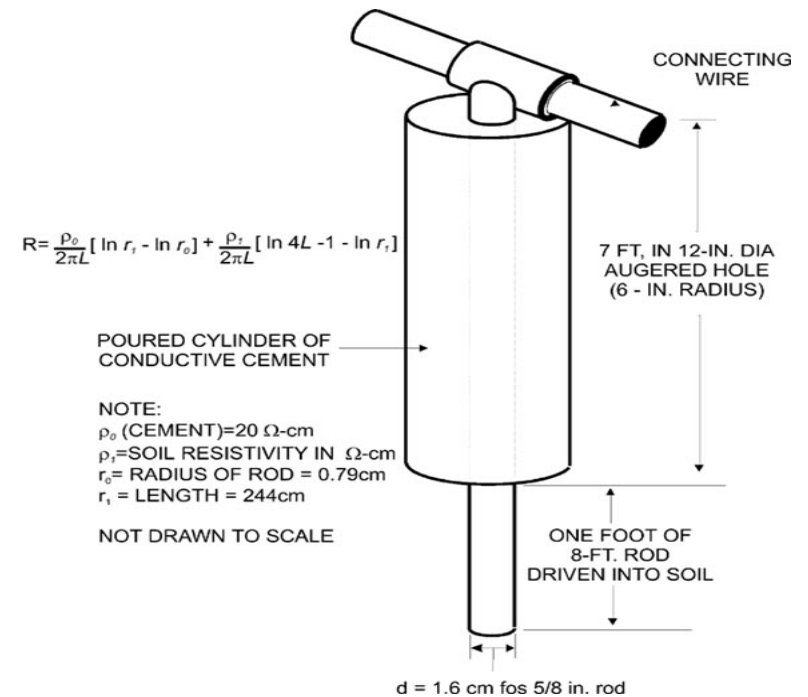
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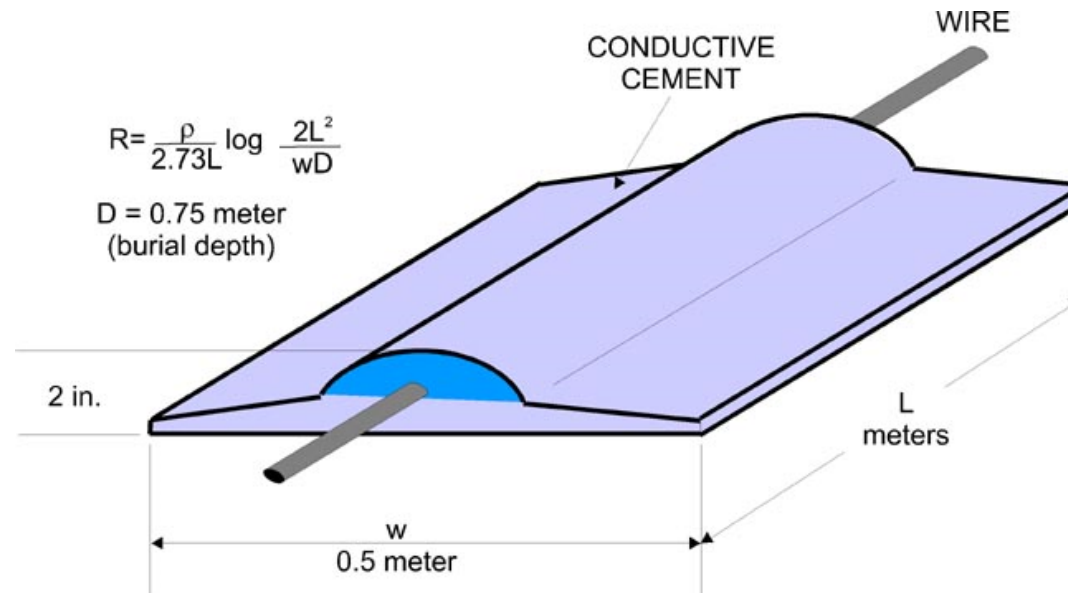
Ground Rod in Conductive Concrete

and takes advantage of the fact 50% of the earth resistance is within 6" of the rod. (credit to gpr-expert.com)

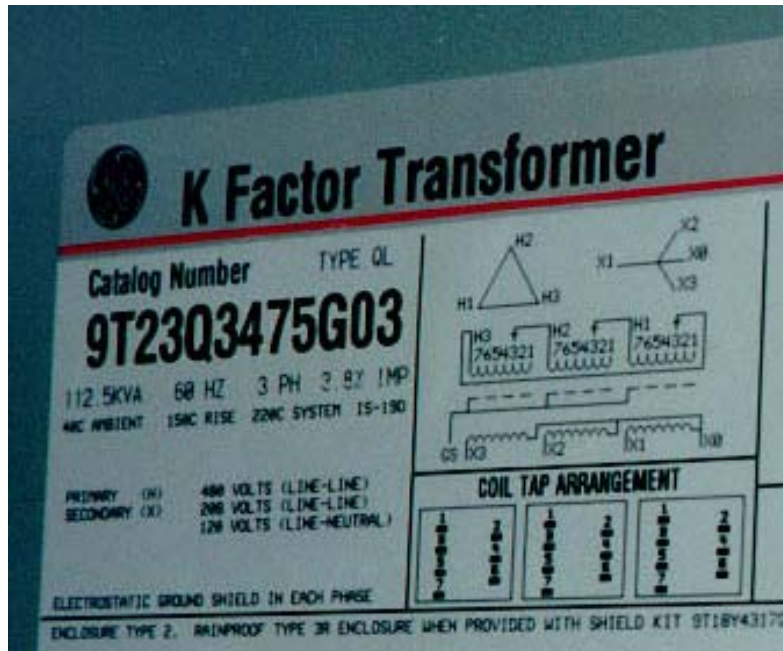


Conductive Cement

Effectively Enlarges the Contact with the Earth of the wire.



Use Harmonic Rated Panels and Transformers



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First Step

Get the wiring and grounding right

This may solve the problem at minimum cost!

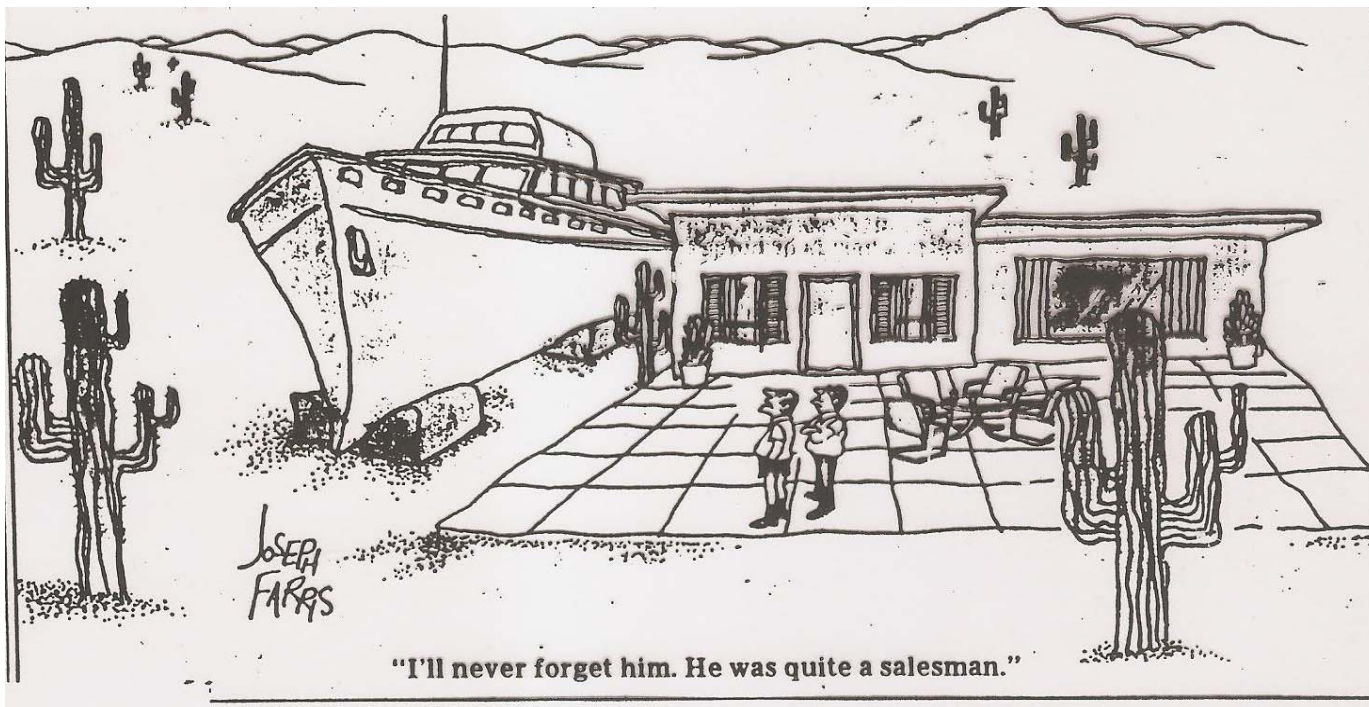


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Buy What I Sell



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Grounding System Must be Checked

Check resistance of grounding electrode system annually (or more often as conditions dictate).



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Is Ufer Actually Connected?

Bonded to rebar?



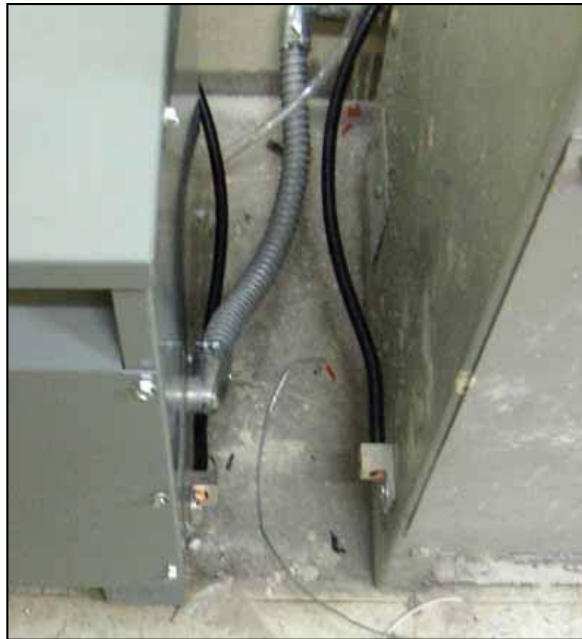
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Building Steel Was Not Grounded

2 transformers were grounded to building steel, but steel was not bonded to ground electrode



Sumter County 911



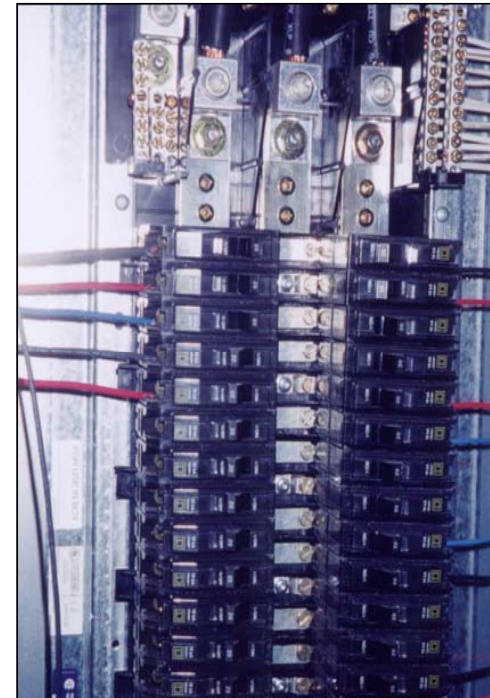
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Use Bolt-in CB's

- Bolt-in circuit breakers do not loose tension. Can be retightened.
- Twist-lock plugs/receptacles



What Happens to Lightning

Telephone grounding
but nothing connected



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Are Connections Proper?

Look for paint or other insulation



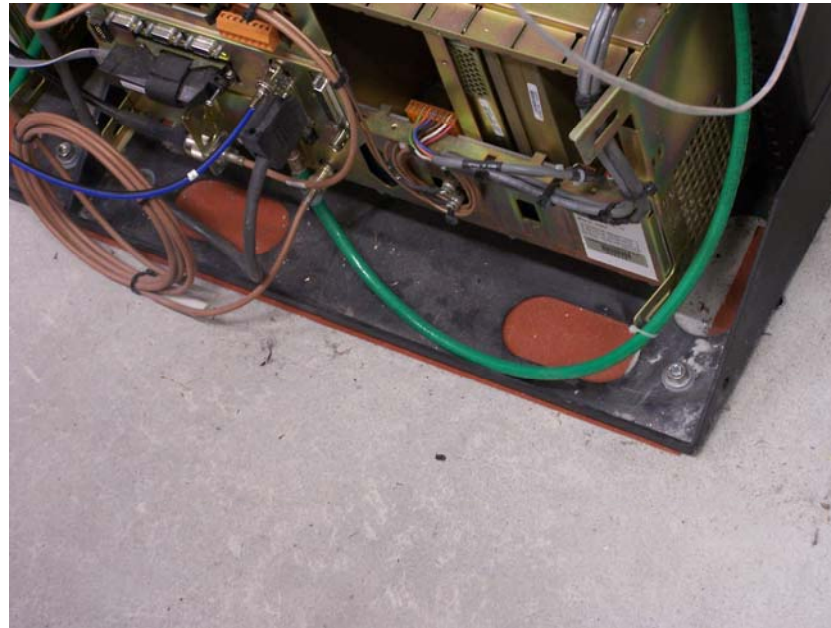
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Isolation From Floor

Non-Conductive Mat Under Racks Recommended



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Do Not Mix Load Types On Panel



PANELBOARD/PANNEAU/TABLERO

V. DATE:

| CIR | SOURCE LOAD / CHARGE / CARGA | CIR | LOAD / CHARGE / CARGA |
|-----|---------------------------------|-----|------------------------------------|
| 1 | Elevator main | 2 | Lobby A.H.U |
| 3 | disconnect | 3 | |
| 5 | Hyd. motor | 5 | |
| 7 | Lobby A/C | 8 | Surge |
| 9 | condenser unit | 10 | Protection |
| 11 | out Rack | 12 | unit |
| 13 | Parking lot | 14 | Hot water |
| 15 | Light poles | 16 | Heater |
| 17 | Parking lot | 18 | spare |
| 19 | Light poles | 20 | South Stair way LTS |
| 21 | outside vent GFI | 22 | SPare |
| 23 | N+S GFI | 24 | North Stairway LTS + Emergency LTS |
| 25 | GFI vent | 26 | Elevator Cab LTS |
| 27 | PHOTO cell | 28 | Fresh Air make up Fan |
| 29 | Entry Lobby GFI | 30 | Time clock |
| 31 | Fire Alarm Booster Pnl. | 32 | Elevator PIT GEI GFI |
| 33 | Fire Alarm Pnl. | 34 | Elevator PIT GEI LGTS |
| 35 | | 36 | |
| 37 | | 38 | |
| 39 | | 40 | |
| 41 | | 42 | |



Separate Circuits

Sensitive loads should be separated:

- **Separate branch circuits**
- **Separate ground conductors**
- **Separate panelboards**
- **Separate feeders**
- **Separate transformers**
- **BUT everything must be bonded together**



With Many Projects There Are 6 Phases

1. Enthusiasm!
2. Disillusionment!
3. Panic!
4. Search for the Guilty!
5. Punishment of the innocent!
6. Praise for the non-participants.

Where to you want to be on the above list at the end of the day?



Take-aways

- 1. Exceed the Code, but don't violate the Code!
(Code minimum is one step above "illegal")**
- 2. You don't get what you expect,
you only get what you inspect.
Contractors do not get final payment until inspection**



Take-aways

3. Have a written plan and procedures.

Insist contractors follow it.

4. Get the grounding and bonding right before anything else.

Most lightning and transient problems can be cured at minimal cost.



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Tips

This stuff isn't taught in school.

“A man's got to know his limitations.”

- Clint Eastwood as Dirty Harry

Call in a professional when there is doubt.



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Free Educational Seminars

- www.copper.org/electricalseminars
- Case Histories
- Recommendations
- Bibliography
- CD-ROMs, DVDs

Copper Applications
A Case Study
ELECTRICAL/GROUNDING SYSTEMS
Copper Grounding System for Mt. Washington Tower
Eliminates saves hundreds of dollars

Thus, while not having a strict basis measurement, terms like "poor power quality" generally mean there is efficient deviation from norms in the power supply to cause equipment misoperation or premature failure. "Good power quality" conversely, means there is a low level of such deviations mis-operations. Because the sensitivity to such variations varies from one piece of equipment to another, what may be considered poor power quality for one price may be perfectly acceptable power quality for another. Poor power quality affects the reliable operation of computers and computer-based equipment, which are now so ubiquitous. Often more important than the physical effect on the equipment is the loss of productivity.

| | Old Practice or Code Minimum | Helpful Procedures or Current Recommended Practice |
|---------------------------------------|--|--|
| Receptacle outlets per 20 amp circuit | 13 maximum | 3 to 6 maximum |
| Neutrals | Shared neutral, or even daisy-chained (on 3-phase systems) One neutral shared among equipment (single phase branch) | Use double-size neutral or larger on 3-phase systems Use separate full-size neutral for each phase, back to panel |
| Phase Conductors | Standard phase conductor size per Code | Use oversized phase conductors to minimize voltage fluctuations |
| Circuits & Panels | Can be shared among many outlets and uses | Use separate branch circuits for sensitive loads, emanating from separate panels, supplied by separate busbars from separate 4-wire feeders, if possible |

POWER QUALITY V 3.0
Video segments and text include segments that discuss:

- Equipment grounding and bonding
- Harmonics
- Transients and lightning
- Power conditioning and surge protection
- Robust wiring for power quality considerations
- Case histories

CDA



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Thank You!

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Questions?



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