Design Considerations That Help Avoid Electrical Disasters

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Copper Development Association Inc.

Agenda

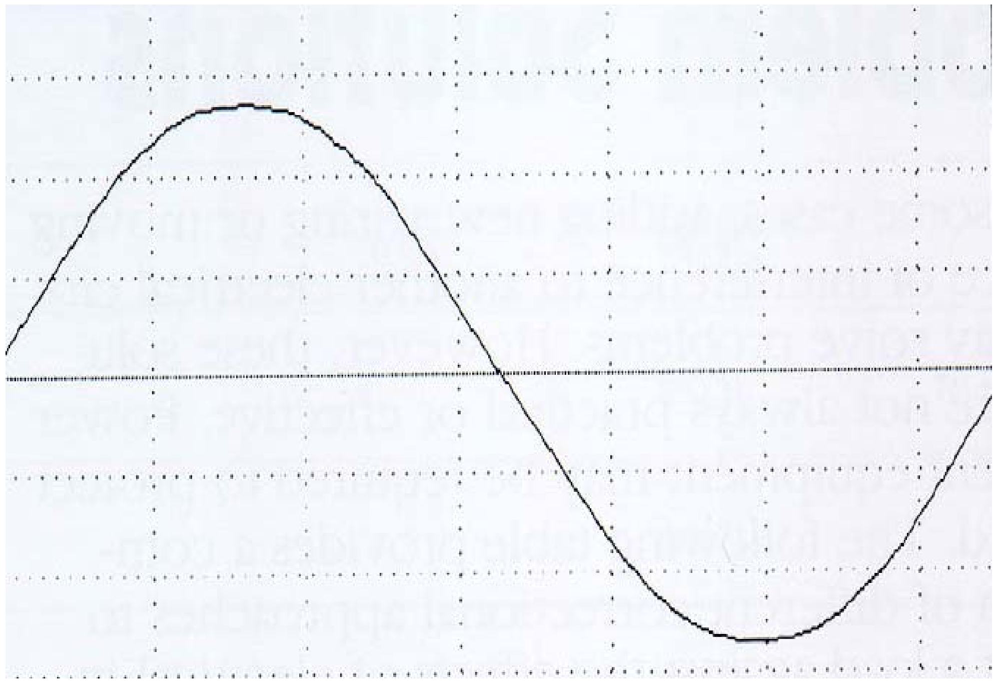
1. National Electrical Code minimum requirements
2. Considerations for sensitive equipment
3. Many case histories we can learn from

What is Poor Power Quality

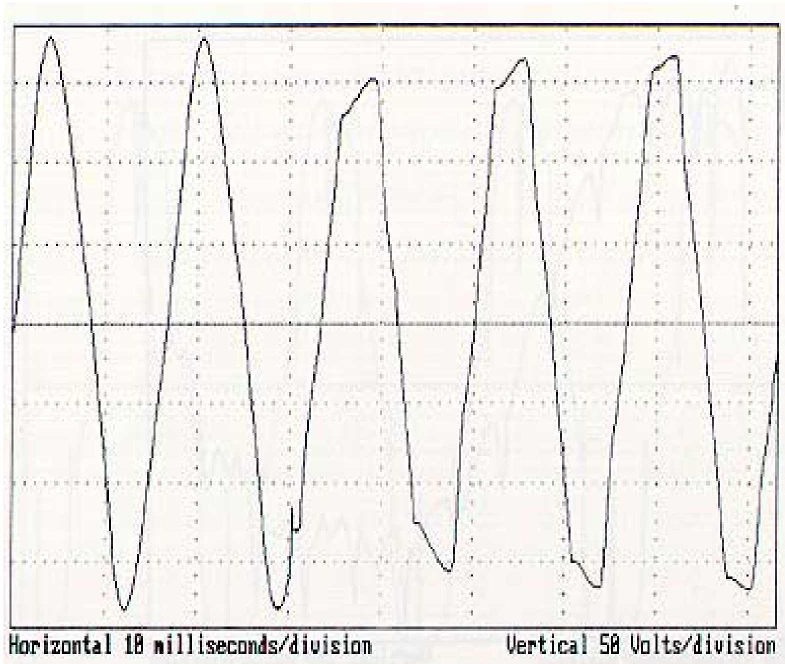
- Poor power quality...

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

What the Equipment Wants



What the Equipment Sometimes Gets



Overview of This Presentation

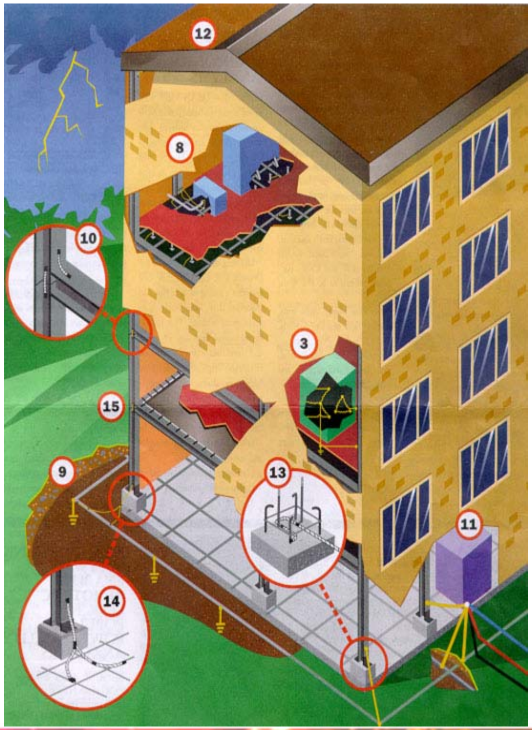
Elements of building infrastructure that can alleviate or cure power quality problems before they affect operations:

Grounding

Bonding

Circuiting

Lightning

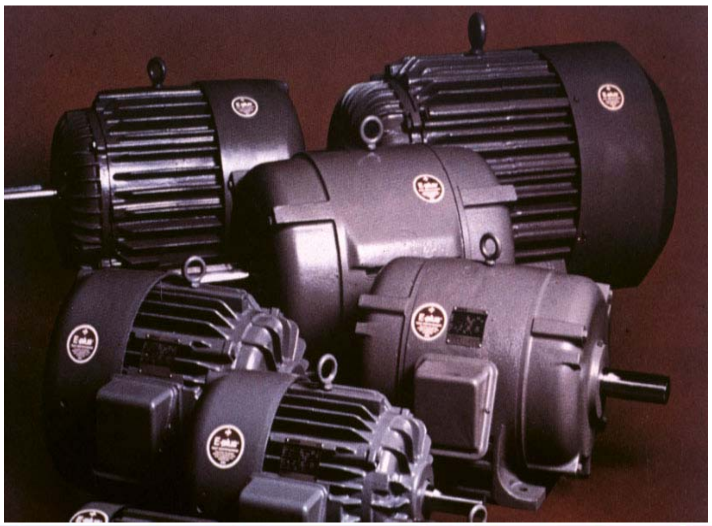


Equipment More Sensitive

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

Old vs. New

What used to be acceptable service characteristics are no longer sufficient



The Real Cost

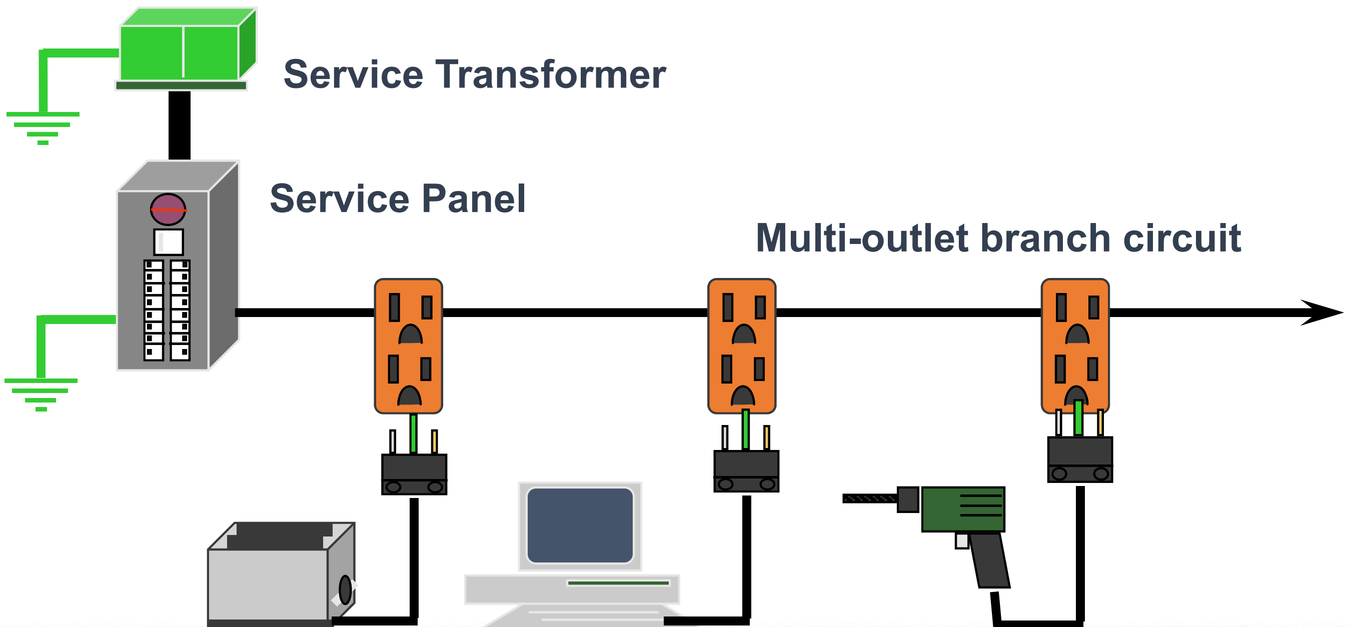
The real cost of poor power quality is in lost productivity (downtime).

- **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**

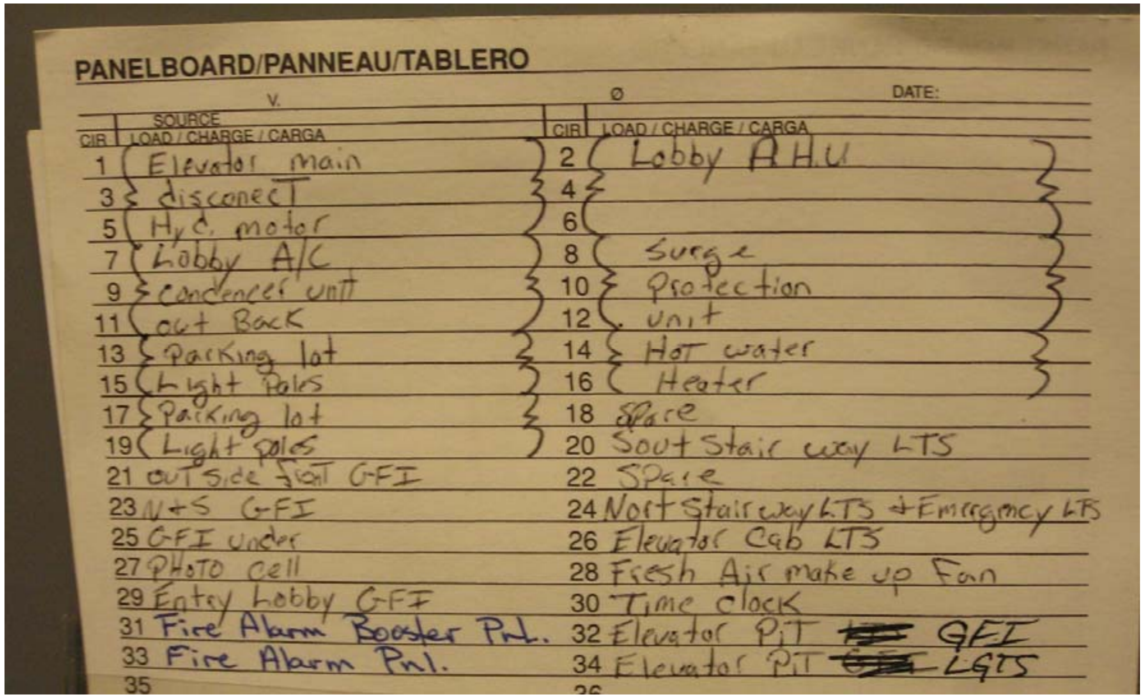
- E Source and Penton

Is The Computer a Problem?

or is it the way it's wired?



Fire Alarm, Elevator and Parking Lot Lights



PANELBOARD/PANNEAU/TABLERO

V. Ø DATE:

SOURCE

CIR	LOAD / CHARGE / CARGA	CIR	LOAD / CHARGE / CARGA
1	Elevator main	2	Lobby A.H.U
3	disconecT	4	
5	Hyd. motor	6	
7	Lobby A/C	8	Surge
9	condencer 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	Sout Stair way LTS
21	out side front GFI	22	Spare
23	N+S GFI	24	Nort Stairway 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 LGTS
35		36	

Problems Are Mainly Internal

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

Over 80% are internally caused

source: EPRI

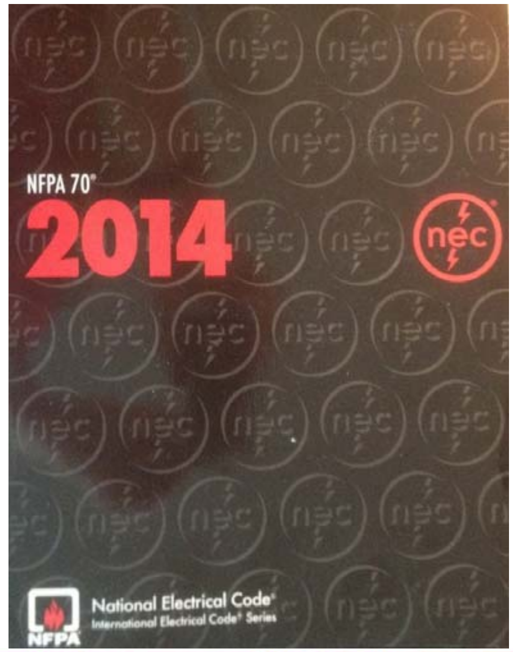
NEC Is Bare Minimum Needed for Safety

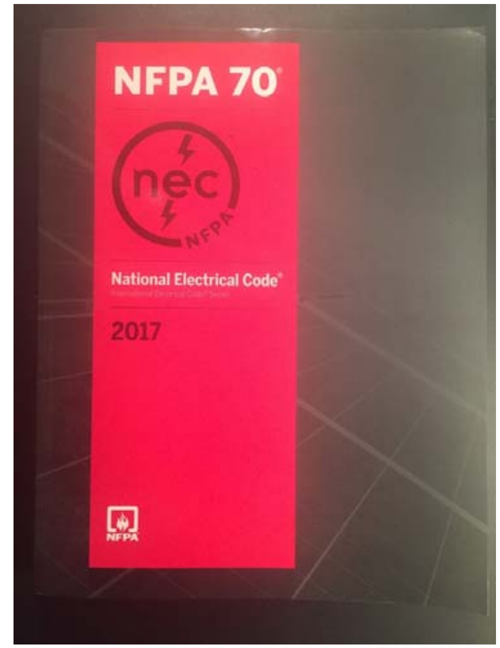
Good starting point, BUT..

NEC is Not a PQ Code

NEC is Not a lightning Code

NEC is Not a good grounding Code





Erratic Operation or Downtime

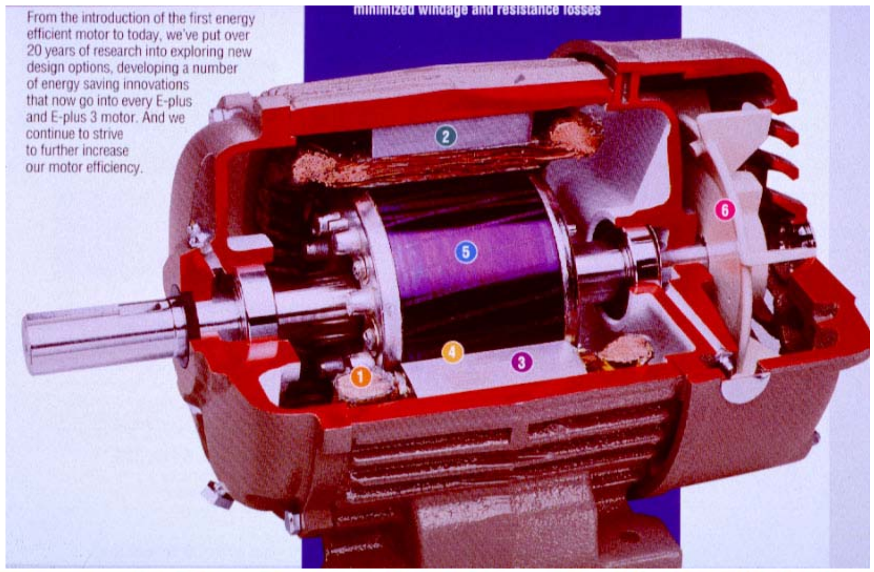
Power Quality issues can lead to erratic operation of sensitive electronic equipment (data errors, lockup, false images in medical diagnostics, downtime, etc.)

Cable Failures

Overheating of phase conductors or neutrals, nuisance tripping

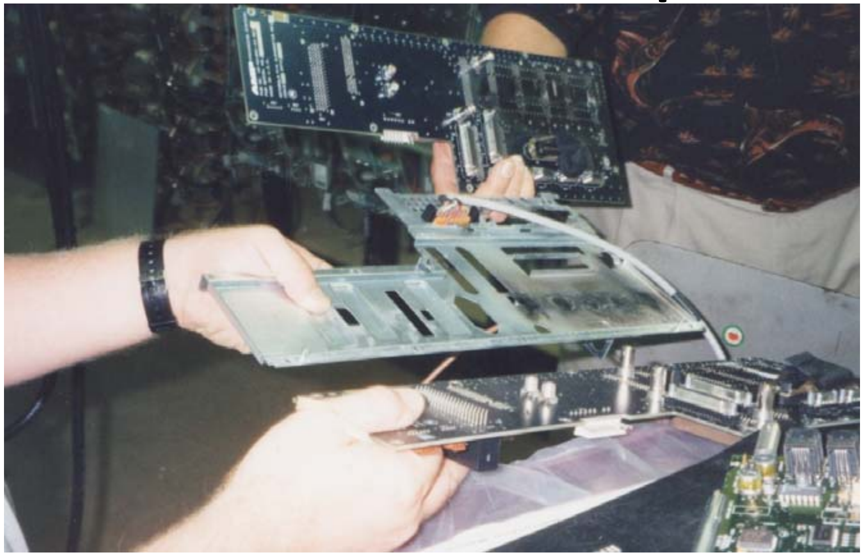
Motor Failures

Premature burnout of motor windings



Effects of Poor Power Quality

Failure of electronic components



Two Types of “Grounding”

- **System Grounding**

- **Equipment grounding (bonding)**

"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.

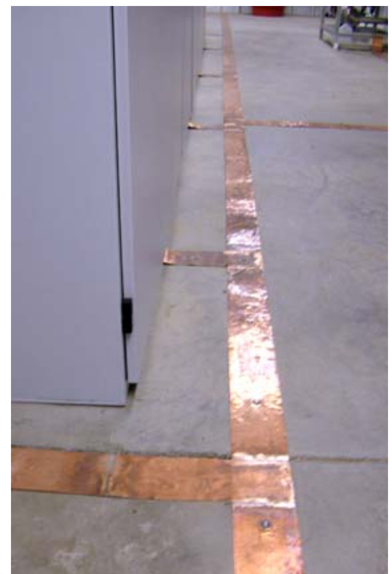
The ground path can carry current in the event of a fault.

System or Exterior Grounding

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

“Bonding”

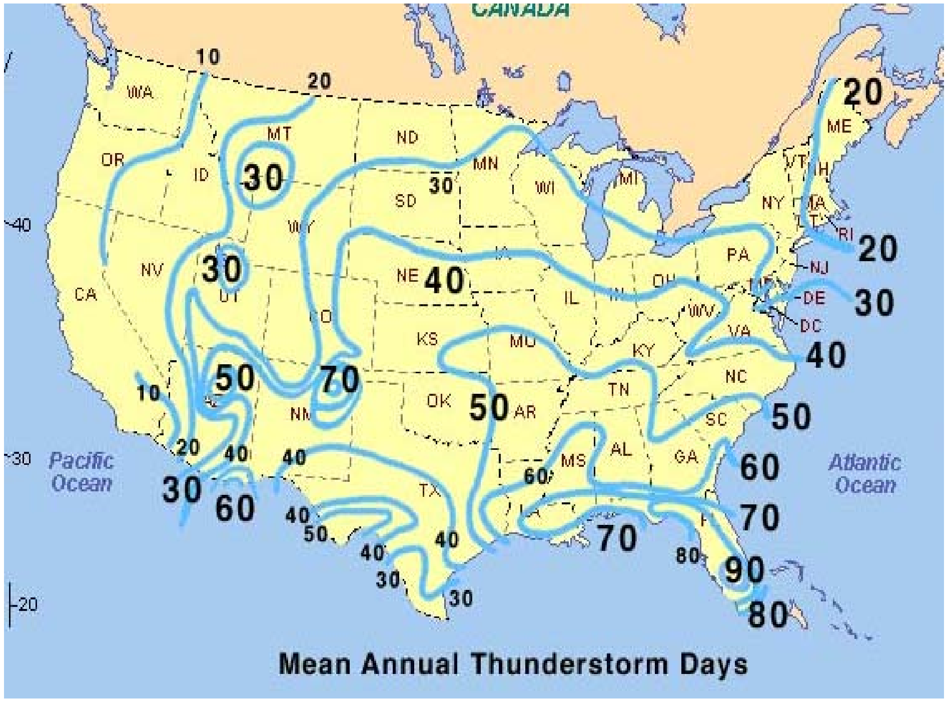
The intentional connection of normally non-current carrying parts of equipment together



The two terms are frequently used interchangeably

Exterior Grounding

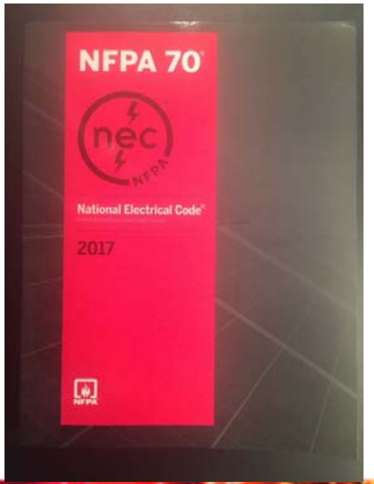
Isokeraunic Map



NEC is NOT Sufficient

- **250.53 (A)(1)** If <u>practicable</u>, rod,

pipe, and plate electrodes shall be embedded below permanent moisture level.



NEC “Alludes” to 25 Ohms

Water Pipe and 2 ground rods, even if result exceeds 25 ohms.

- **250.53 (A)(2)** A single rod, pipe,

or plate electrode shall be supplemented…

NEC "Alludes" to 25 Ohms

BUT

exception:

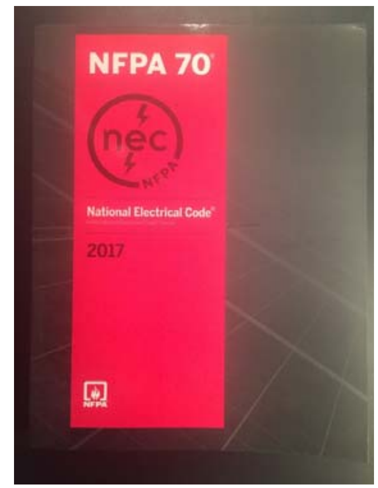
Exception: If a single rod, pipe, or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required.

There are no testing parameters

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

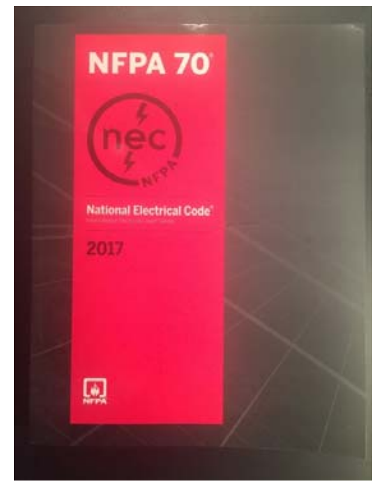
NEC Allows 6 Ft. Spacing

- **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.



NEC Allows 30 Inch Depth

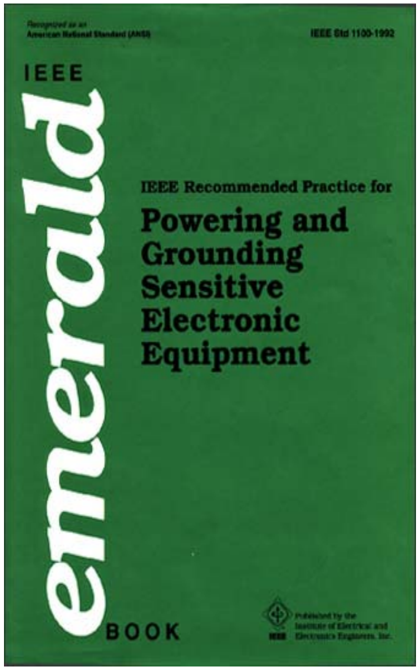
- **250.53 (F) Ground Ring.** The ground ring shall be buried at a depth below the earth's surface of not less than 750 mm (30 in.).



Better Standard: IEEE Emerald Book

- **ANSI/IEEE 1100**

Recommended practices are needed for power quality.



800-678-IEEE

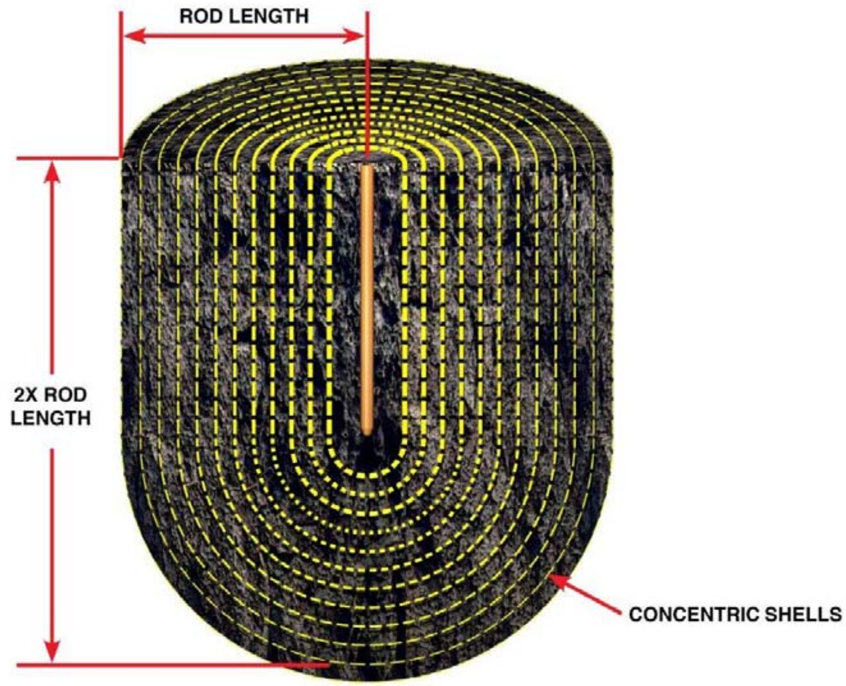
System Grounding

Desired Grounding Resistance:

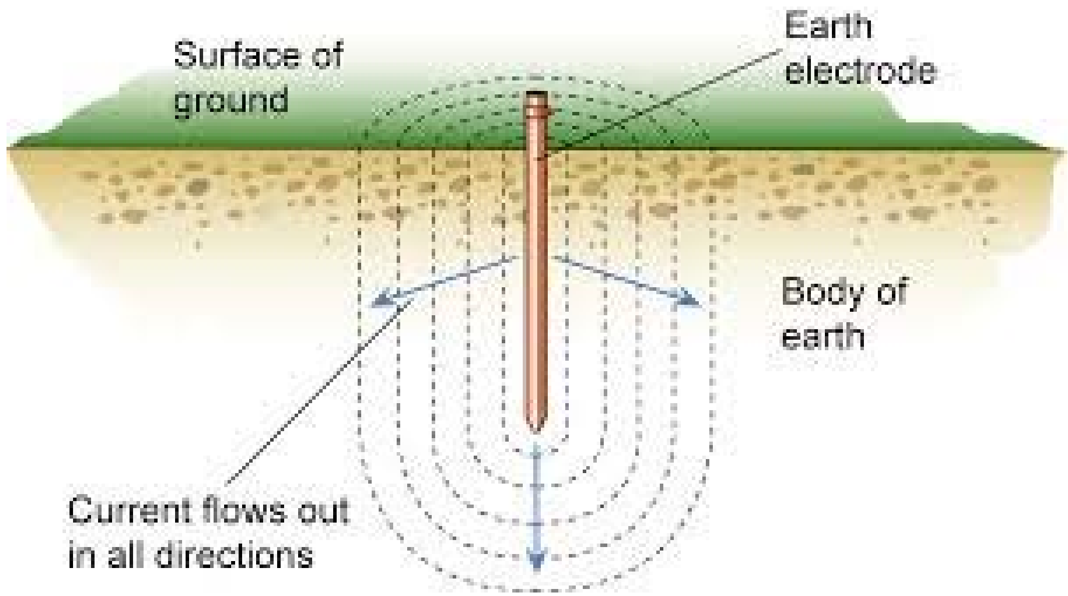
- **5 ohms or less desired for power quality**
- **Many mfgrs. specify <u>under 2 ohms</u>**
- **IEEE recommends 1-5 ohms (Green Book)**

Concentric Shells of Earth Surround Rod

Varies with
rod length &
soil conditions



Current=Voltage/Resistance



2X Rod Length (average) Dependent on Soil Resistivity

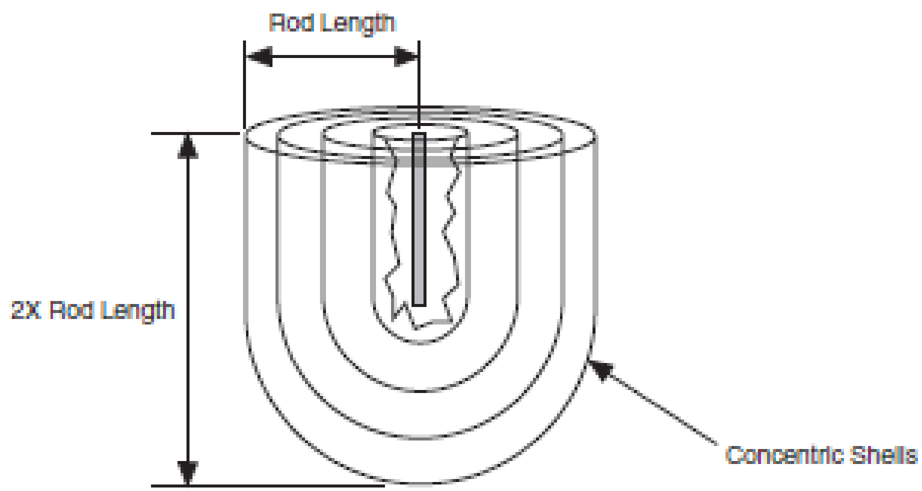
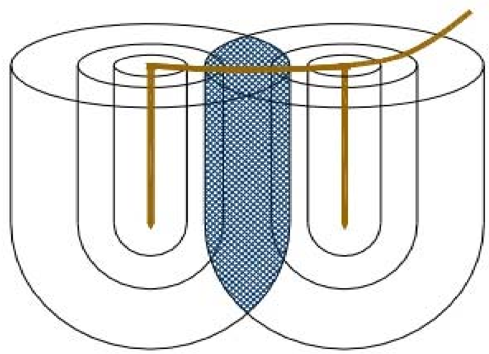


FIGURE 4-5 GROUNDING ELECTRODE SPHERE OF INFLUENCE

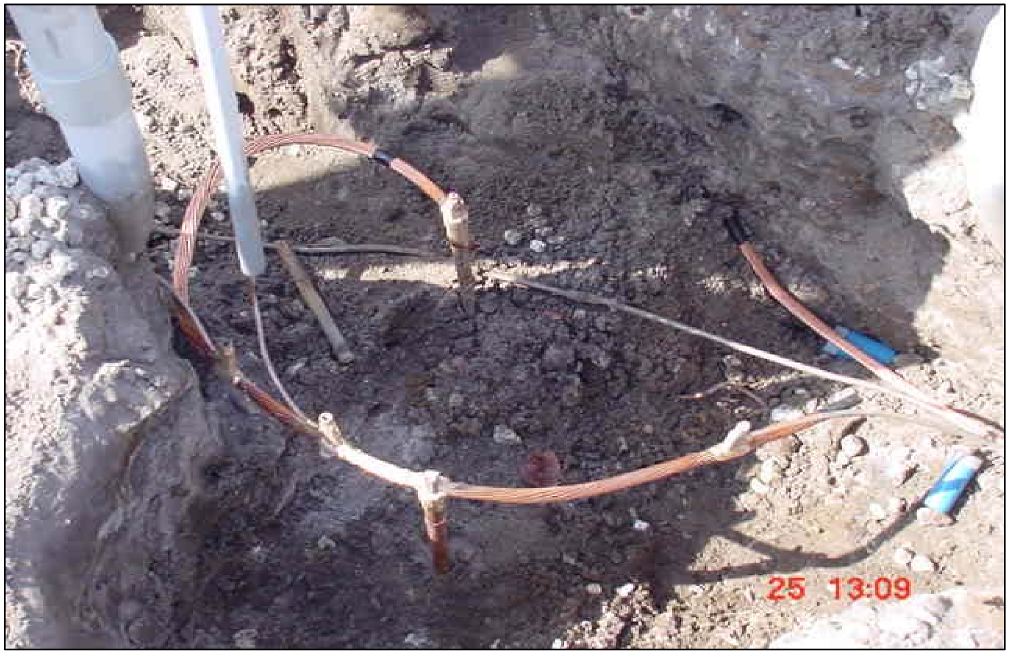
Overlapping Spheres of Influence

Lowering Ground Resistance



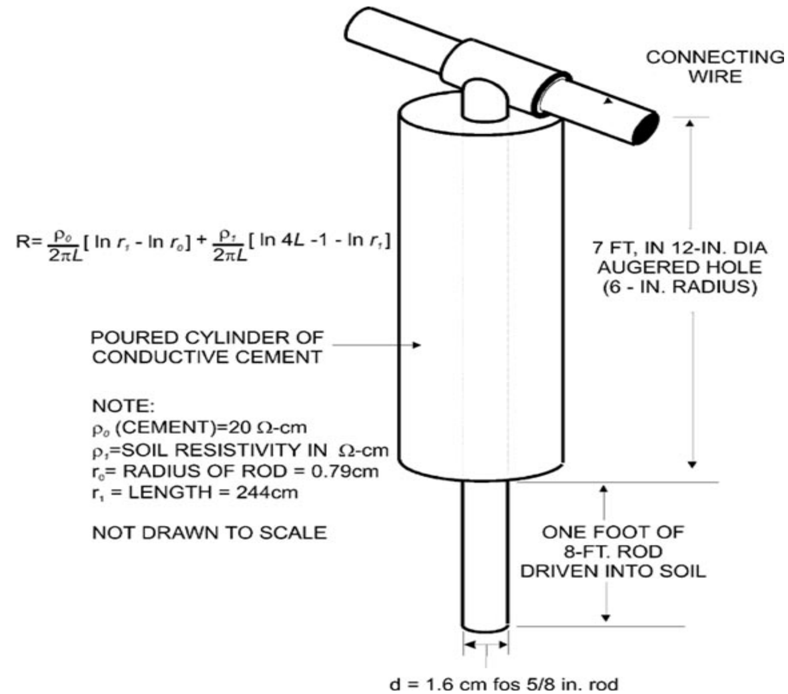
Concentric Shell Overlap Decreases Efficiency of Ground Rod Resistance

Poor Example of Ground Rod Spacing

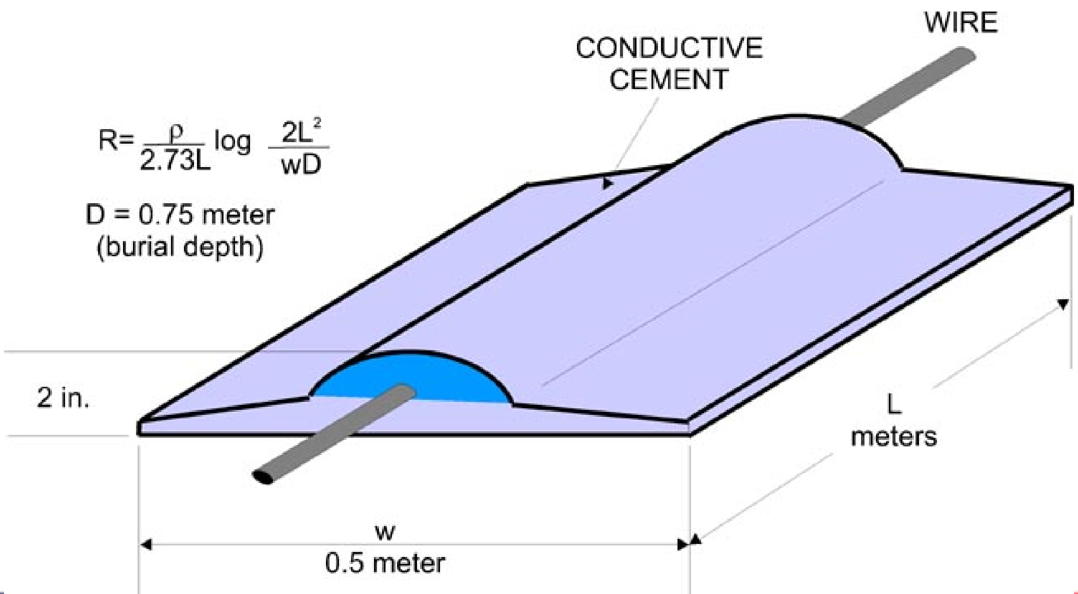


Ground Rod is Embedded in Conductive Concrete

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



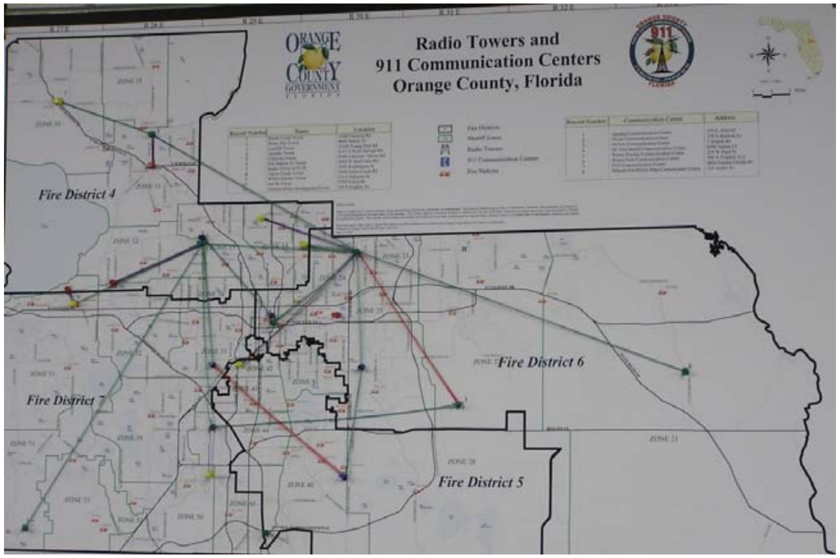
Conductive Cement Effectively Enlarges the Contact with the Earth of the Wire.



Case History

Orange County, FL 911

13 transmitter sites



Orange County, FL 911

Headquarters
Apopka, FL

Source: Power & System Innovations, Inc., Orlando

Headquarters Tower- Apopka, FL

280 foot tower

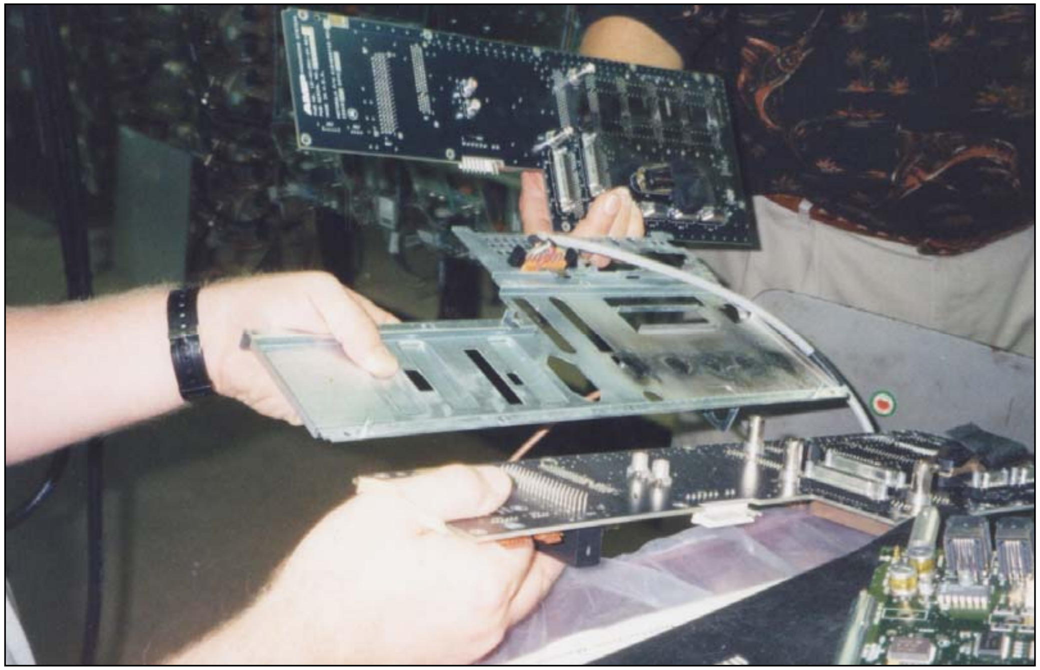
3 sets of 5 guys

Equipment Damages

$100 K/yr. damage at Apopka alone

Not including downtime

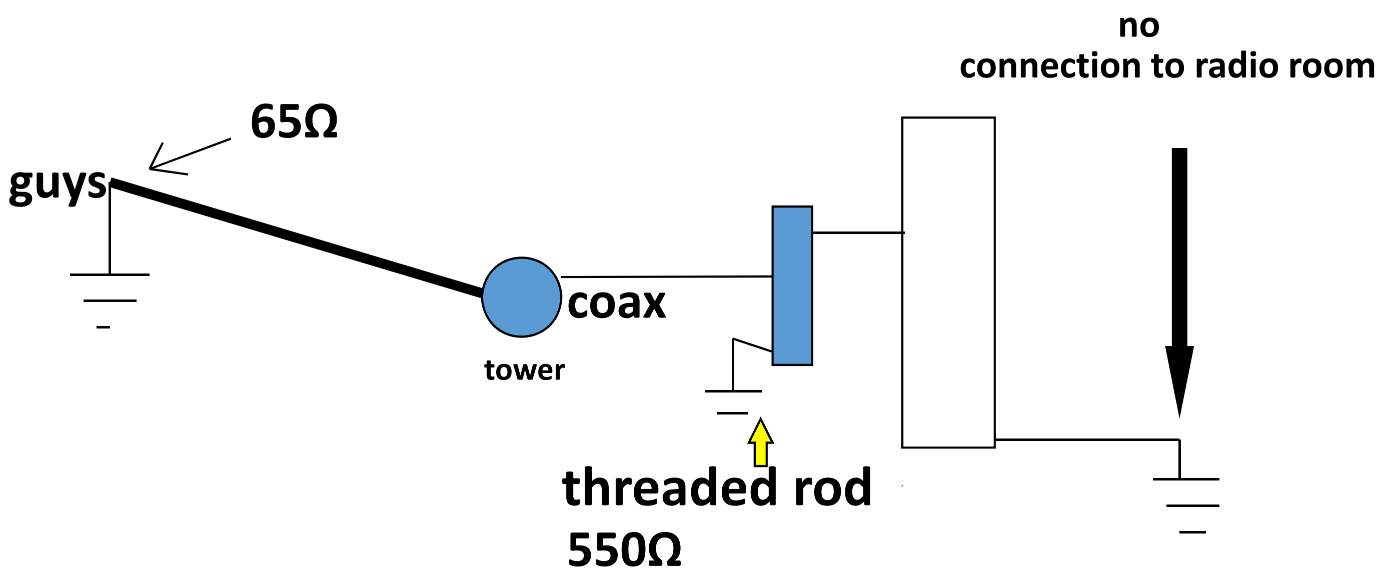
Internal Arcing



Staff Knew They Needed Help

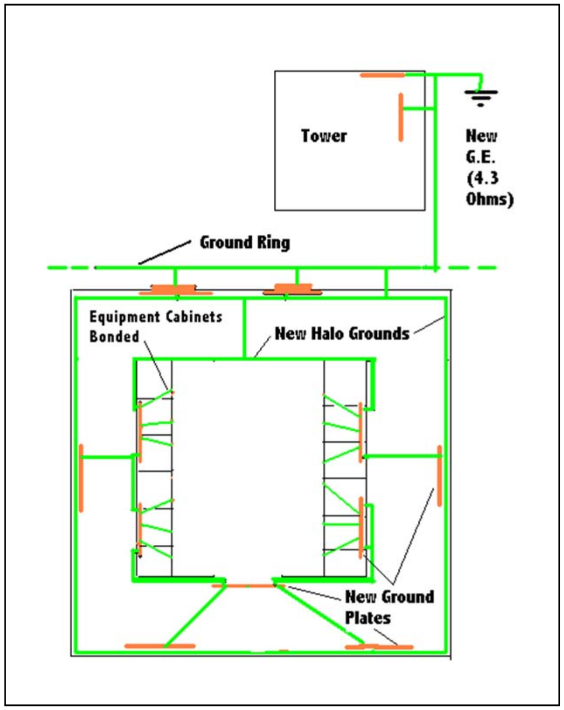
Staff was not expert in power quality, called in knowledgeable professional

3 Independent Grounds

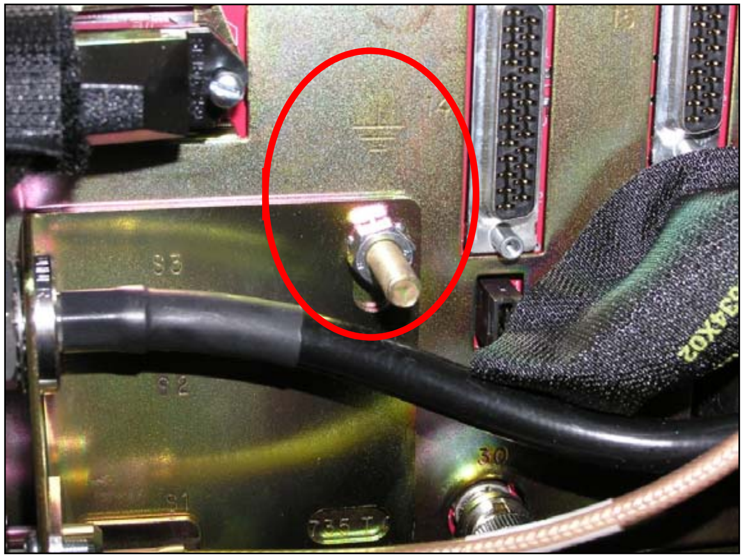


Refitted Site

Everything bonded together



Ungrounded Equipment Cabinets



Equipment Incorrectly Bonded

How Many Conductors Can You Get On One Split-bolt?

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

Apopka Tower Grounding

Retrofits:

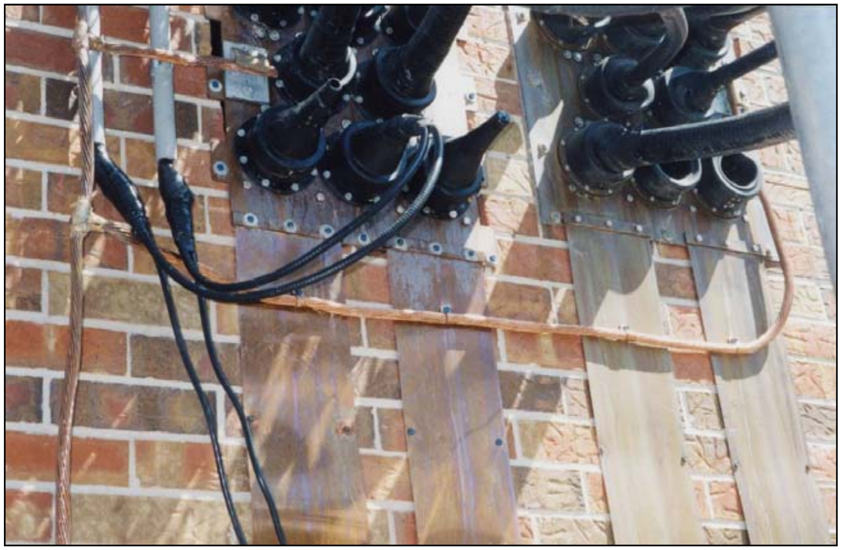
Deep (60 ft.) electrode supplements tower

New Coax Grounding On Tower

for coax grounds then 4/0 to electrode

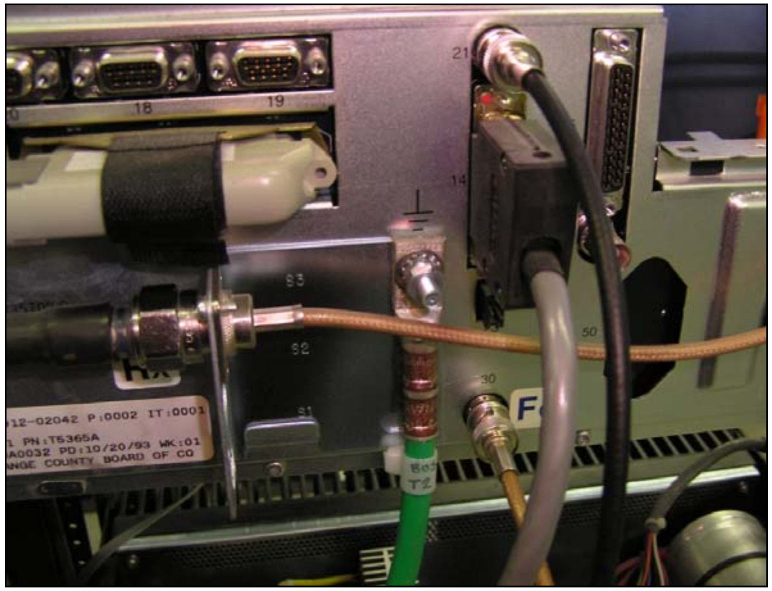
Outside Bulkhead

strip bonded together and to ring with 4/0



Bond Equipment Properly

Note double nuts and lockwasher

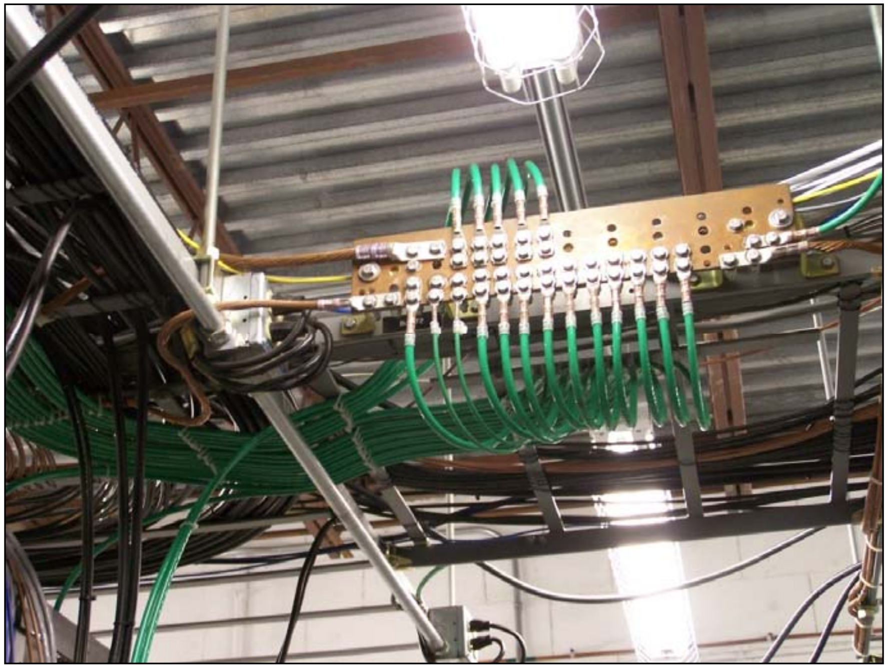


Halo Rings

All equipment bonds brought to buses

Buses tied to halo rings

Sweeping Curves



2017 BICSI Fall CONFERENCE & EXHIBITION
SEPTEMBER 24-28 | LAS VEGAS, NV

Proper Coax Shield Grounding

- Andrews Cuffs

Reedy Creek

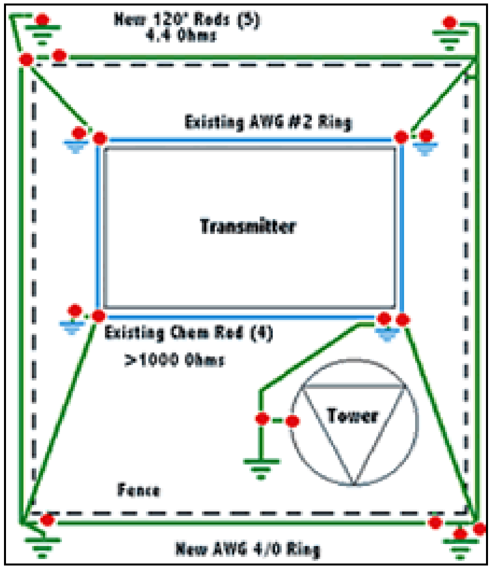
Remote repeater near Disney World

Reedy Creek

More real estate to work with

Reedy Creek

Grounding layout: double rings plus deep electrodes

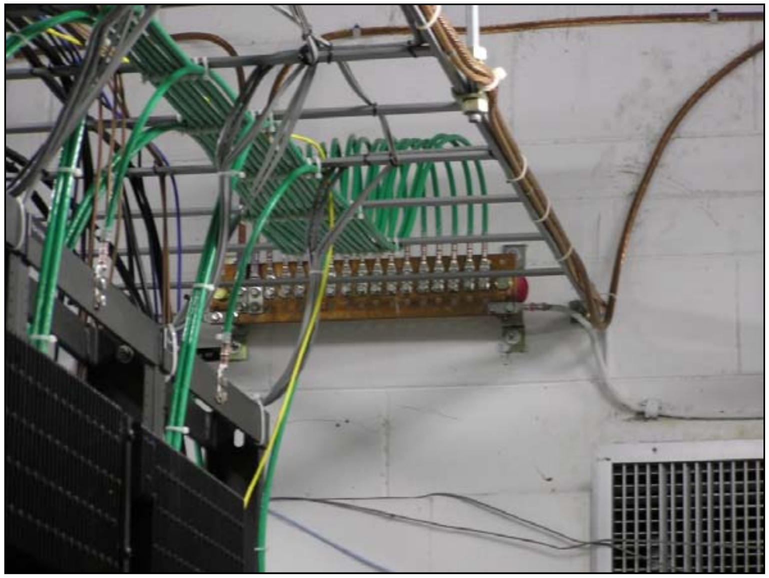


New Resistance 3.5Ω

< 5 ohms independently

Sweeping Turns

Note wide, large diameter turns



2017 BICSI Fall
CONFERENCE & EXHIBITION
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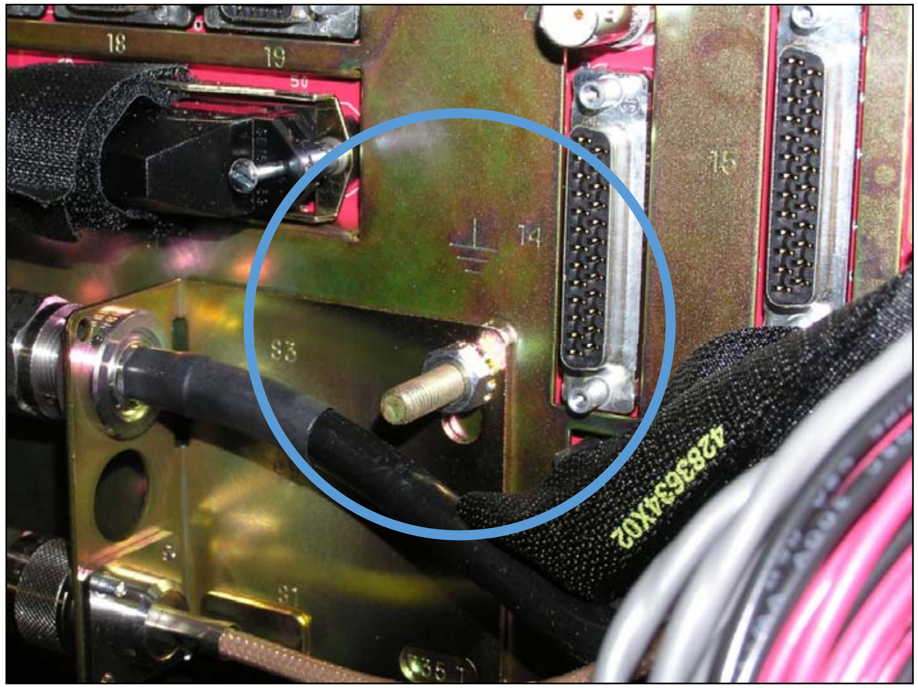
Replaced Connections

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

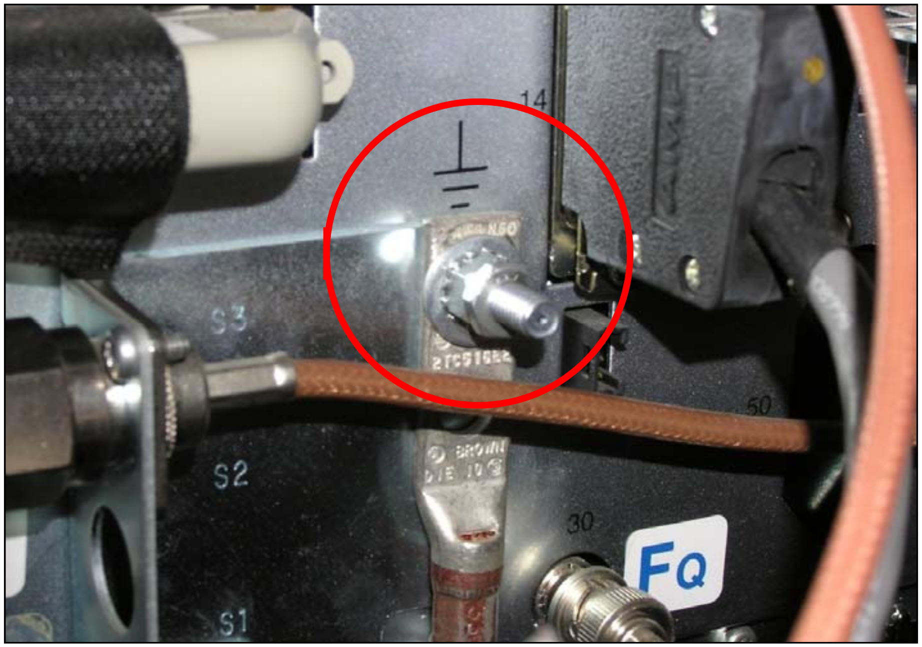
Ungrounded Equipment at Apopka

And this



Lightning Means Vibration

Lock washer, double nuts



SPD's on Three Levels

SPD's on main service entrance

Since Retrofit

- Thousands of events recorded
- One strike witnessed

- NO Downtime! No equipment damage.

Major Lessons

3 different contractors

- **electrical**
- **radio room**
- **tower**

No one party had responsibility

Power Quality is Cost-effective

OC 911:

<$500,000 cured $1 million damages

6-mos. to 1 year paybacks common

Angel Fire Ski Resort

2017 BICSI *Fall*
CONFERENCE & EXHIBITION
SEPTEMBER 24-28 | LAS VEGAS, NV

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

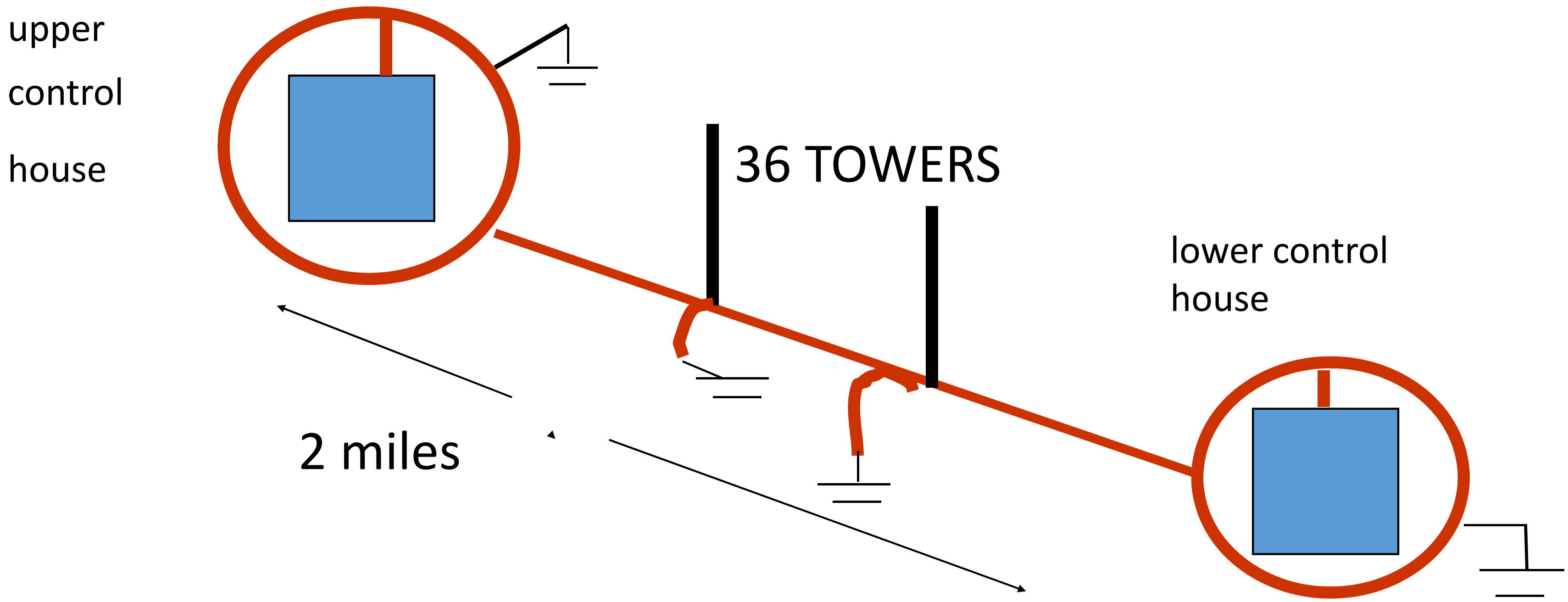
- Ground *system*
- Rod at each tower
- 2 miles of 2/0, each tower connected
- Rings at top and bottom stations
- No outages since!

Exothermic Welding

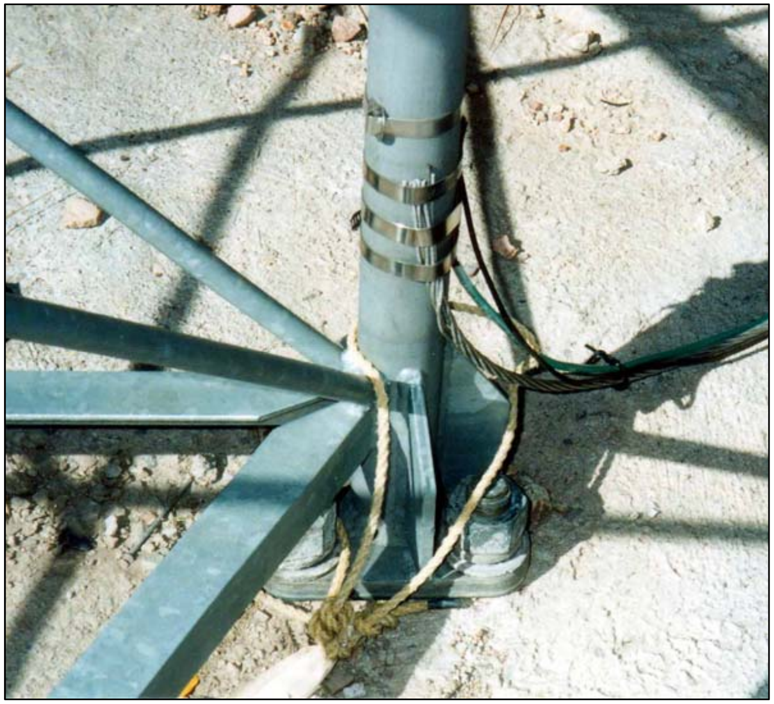
Lower Base Station

Soaking bentonite with water

Angel Fire Result



KKIT - FM



Connection to Electrode

Connection to Water Service

Multi Building Campus Examples

Verestar

Largest satellite facility in North America

Verestar Control Room

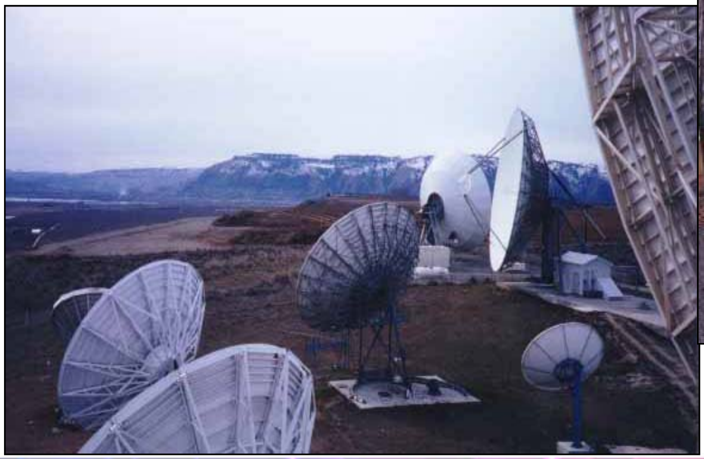
6 buildings

Over 100 acres

Dishes Are Remote

42 satellite dishes

3.5 m to 30 m



Basic Grounding Layout

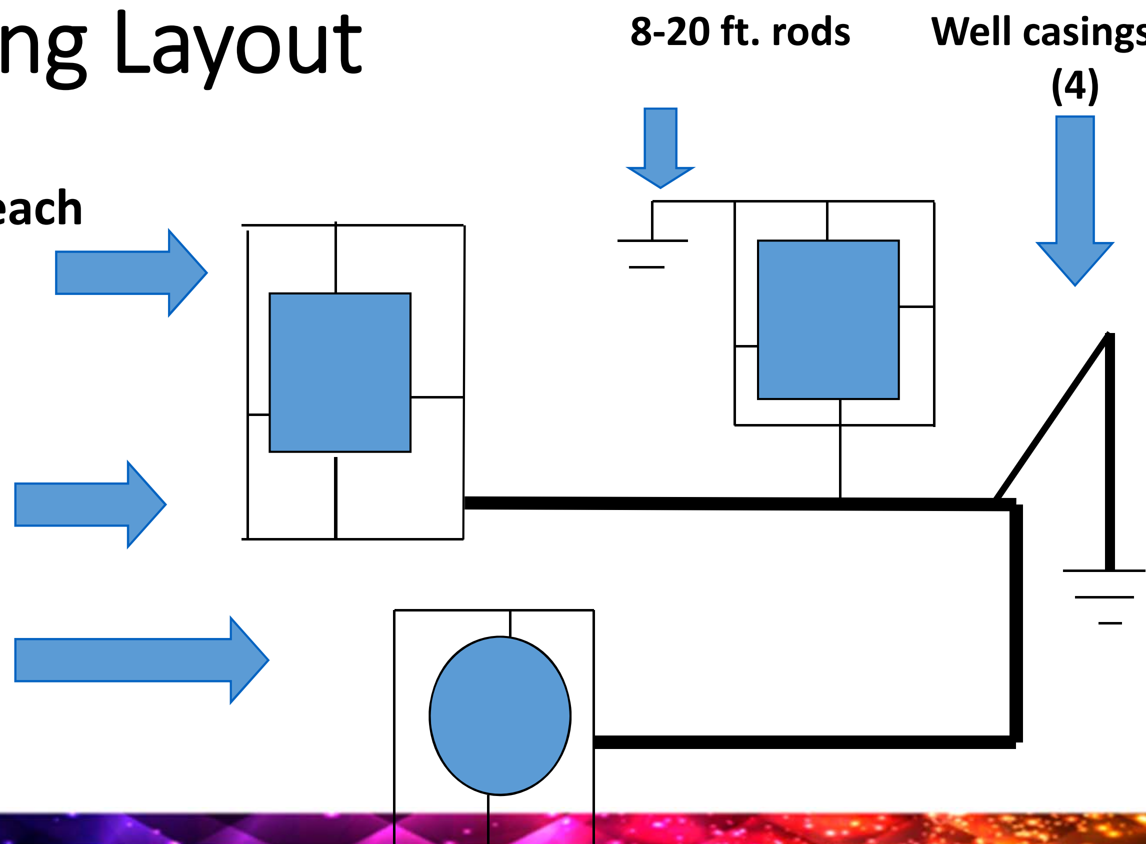
4/0 ring ground around each building (6)

750 kcmil spine

4/0 around each dish

(typ of 42)

<u>2 Ohm standard</u>



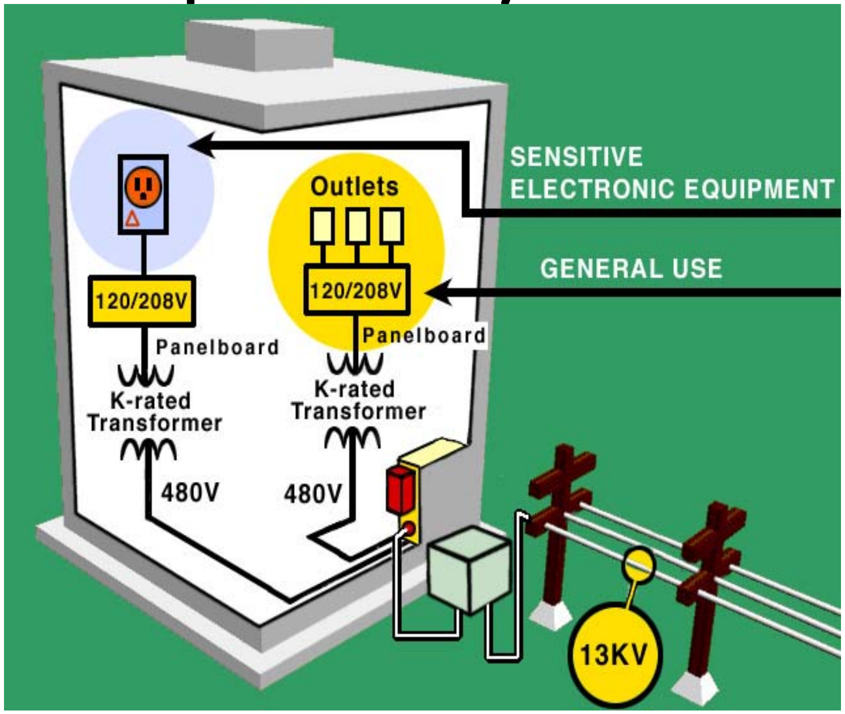
M.I.T. Case Study

Current Interior Design Standards:

Separate computer feeders, panels, and branch circuits

4 outlets per 20 amp. Branch circuit

Separate Systems



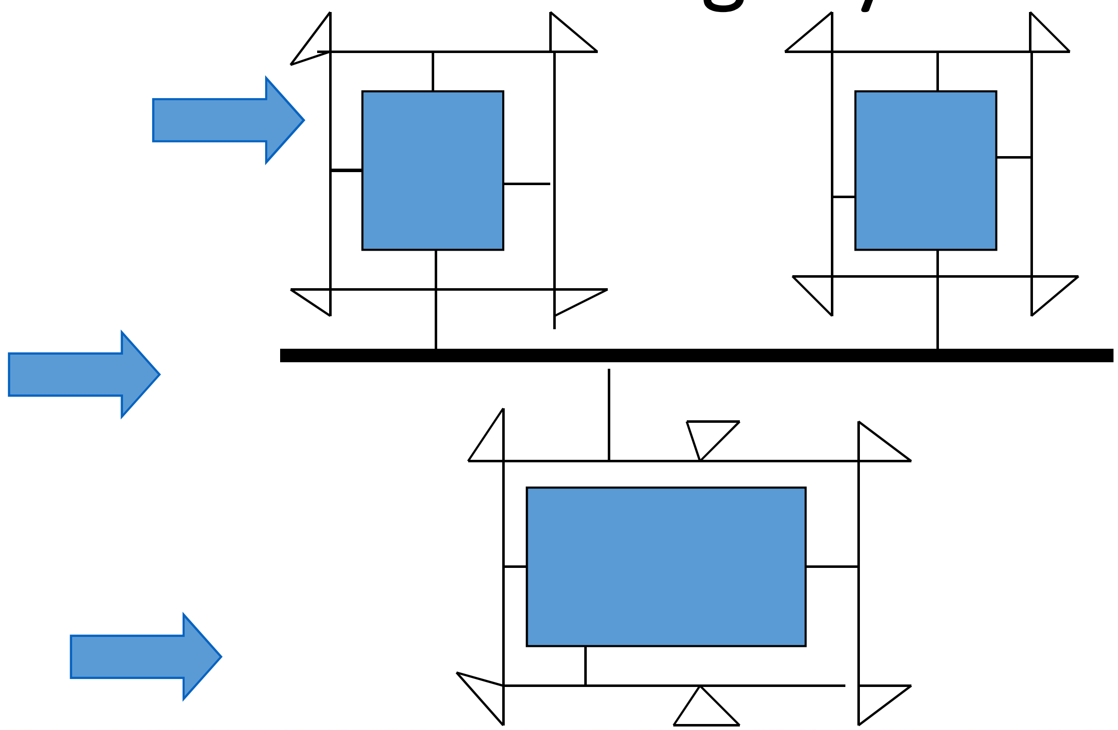
M.I.T. Design Standards

Current Design Standards:

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

M.I.T. Basic Grounding Layout

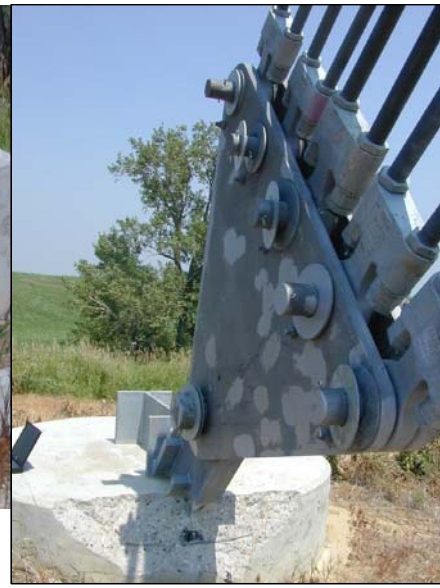
- **500 kcmil ring ground around each building**
- **1000 kcmil spine**
- **Triangulated**
- **20 ft. rods at all corners**



Limitations of Ufer Grounding

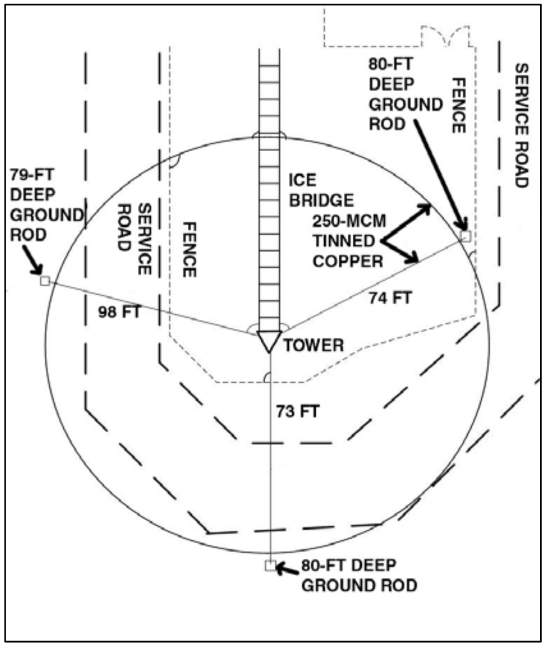
KPTH & KMEG-TV

What Can Happen to a Ufer Ground?

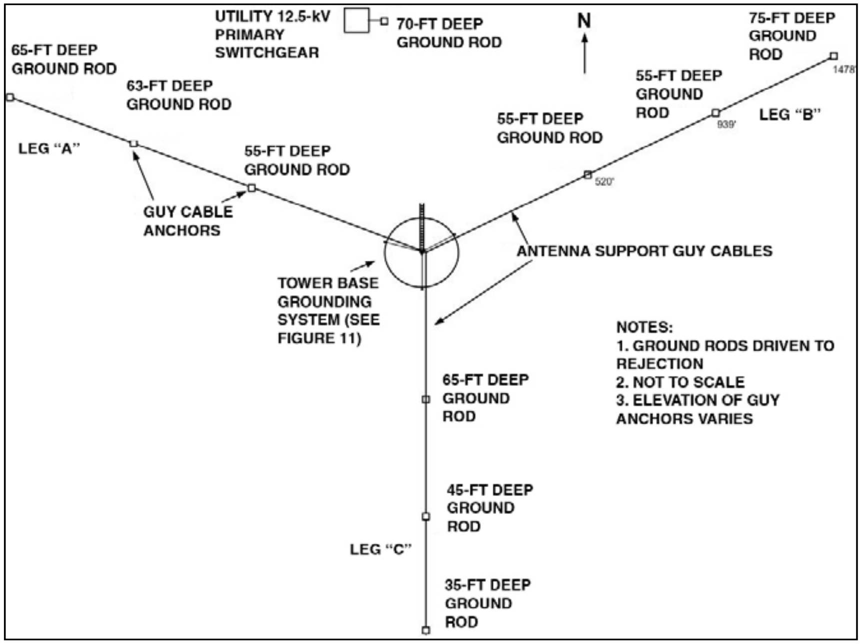

KPTH & KMEG-TV

- 250 kcmil ring around tower
- 80 ft. deep earth electrodes
- Bonded to ice bridge
- Bonded to transmitter



KPTH & KMEG-TV

- Site plan



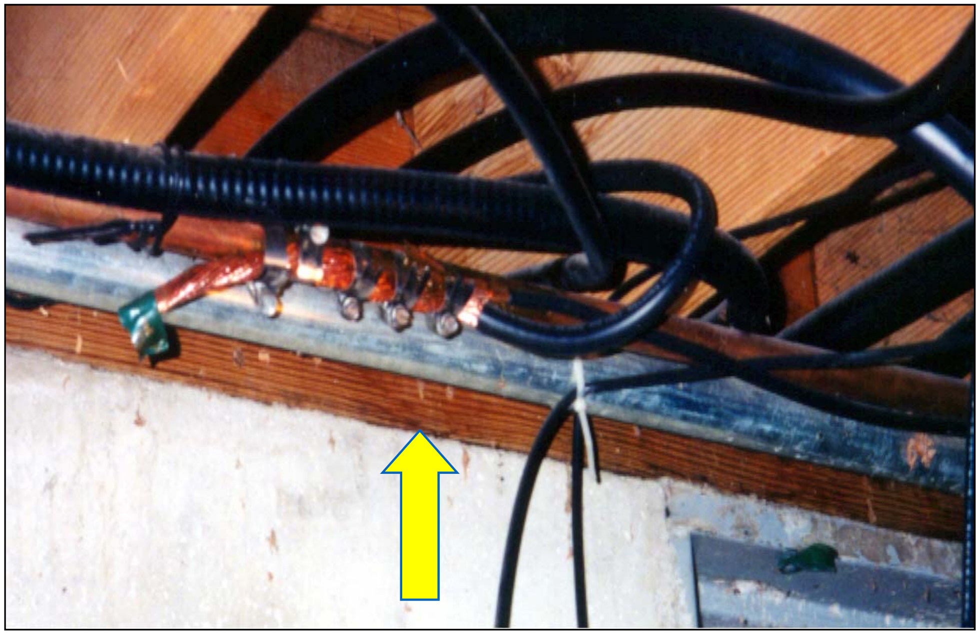
High Water Table Does Not Mean Low R

KROA-FM, Donephin, NE

- **5 ft. water table, near Platte River**
- **Water was “too” clean**

- **Tower hit by lightning**
- **Went off air, equipment damaged / destroyed**

Hose Clamps on Plumbing Tube



Tower Ground Connection

KROA Result of Corrections

- Lightning vulnerability greatly reduced
- Hum on signal disappeared
- Able to rent out to a second station

KROA Lessons

- Pure water is not conductive
- Use only listed connectors
- Use only proper connections, listed proper components
- Pay attention to corrosion

“Clean” Grounds

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.

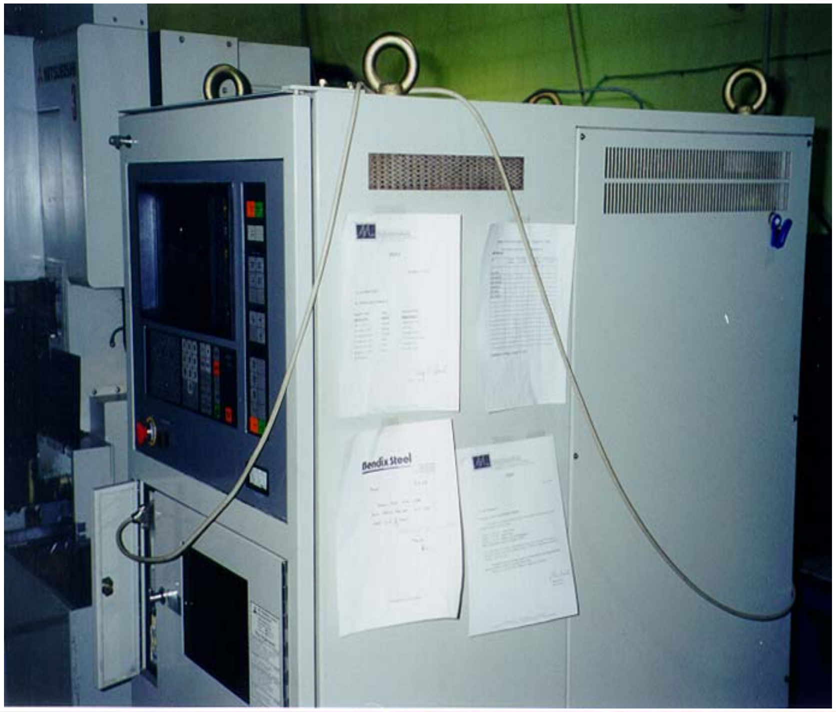
Case Study: “Clean Grounds”

McAfee Tool and Die

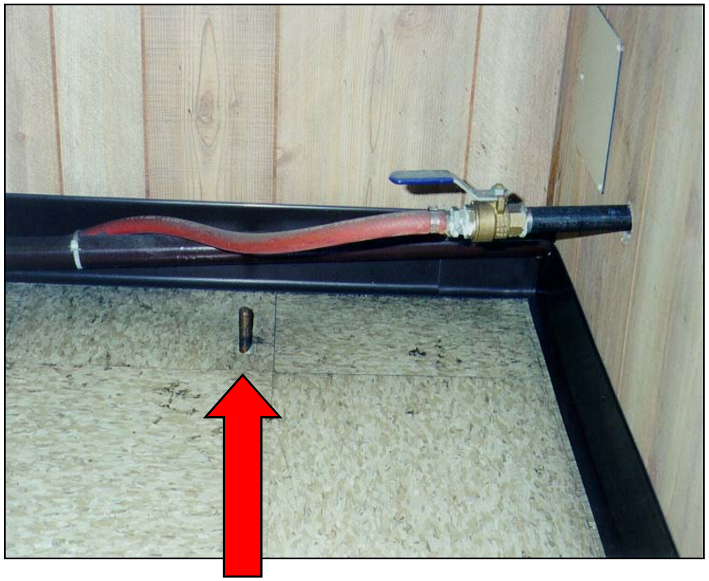
This is a High-Tech Environment

Every CNC Machine is Computer-driven

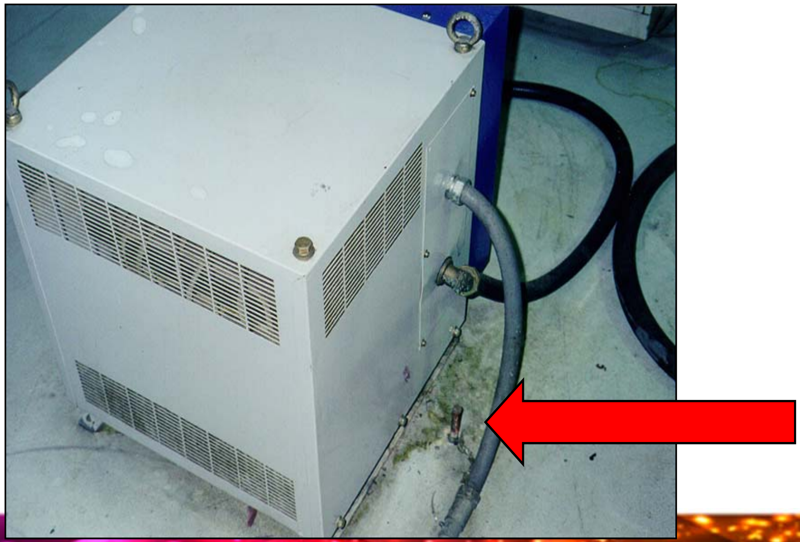
Comm Cable is Unintentional Antenna



So-called "Clean Grounds"

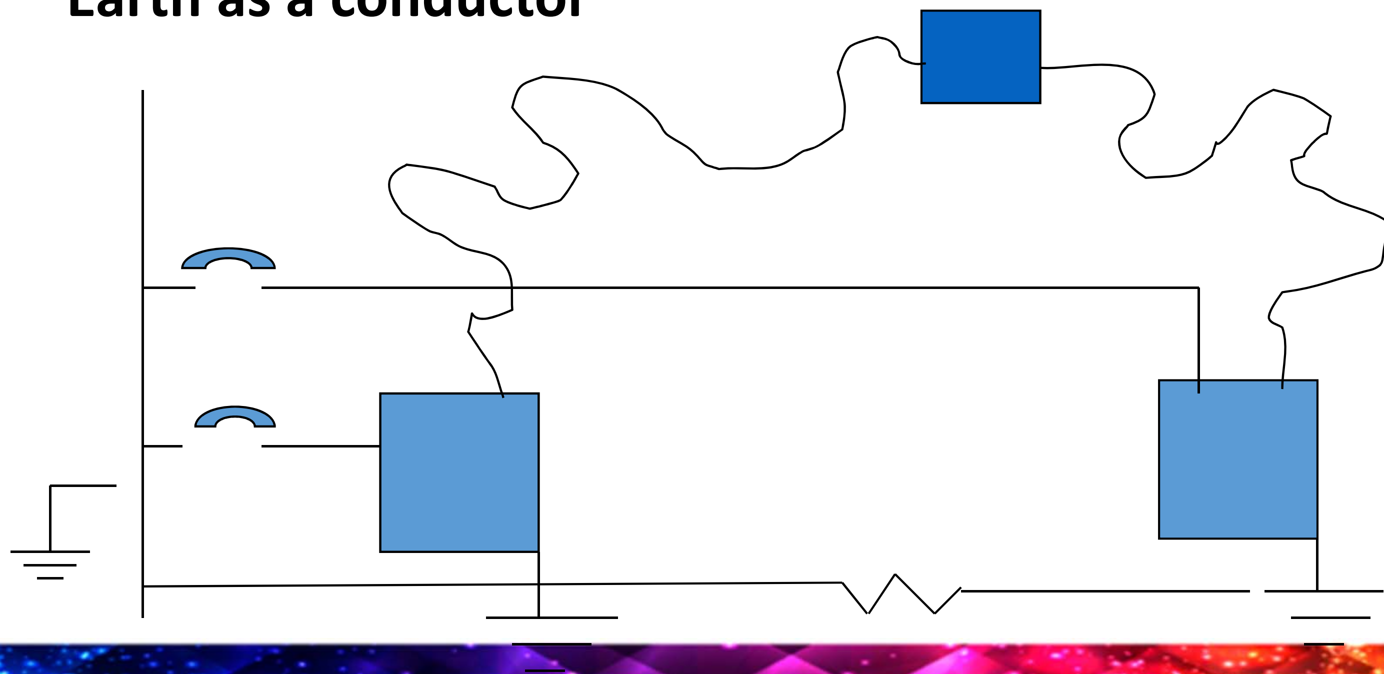


"Supplemental" electrodes abandoned



McAfee Layout

Earth as a conductor

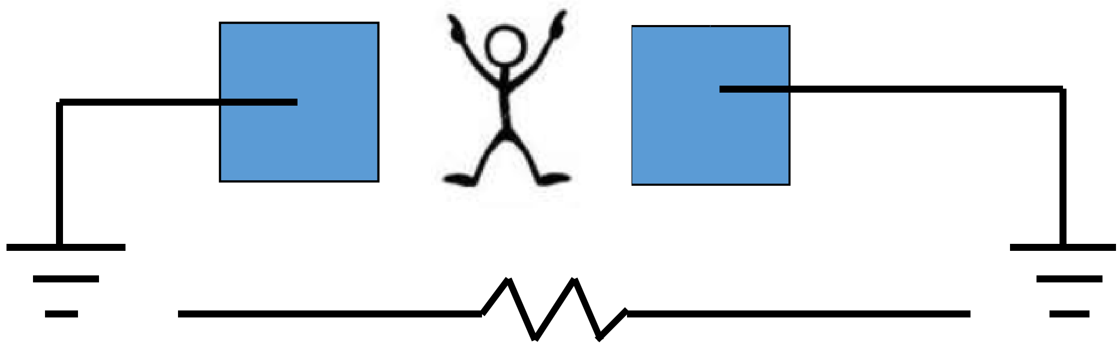


Earth is Not Permitted as a Current Path

No separate grounds allowed

only one grounding system

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



What is an IG?

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

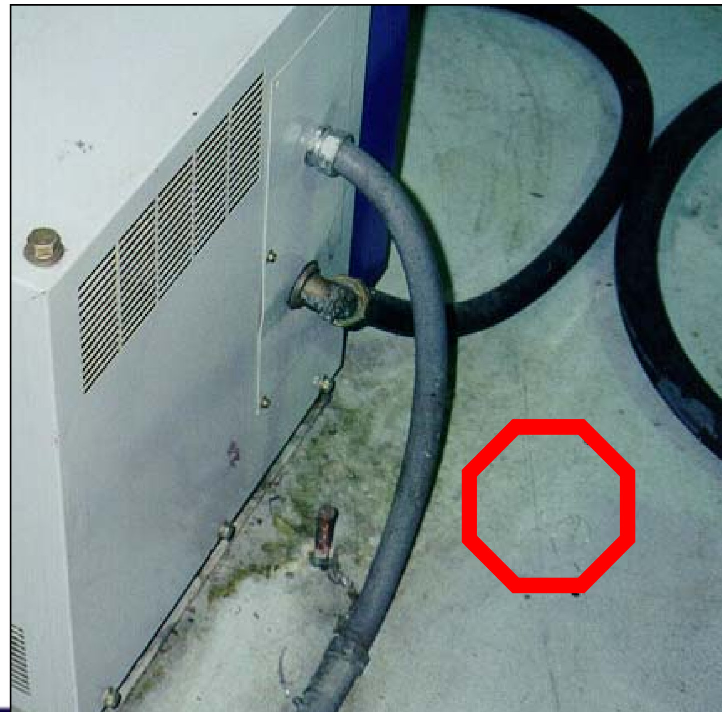
Insulated Grounding

Insulated Grounding (IG)

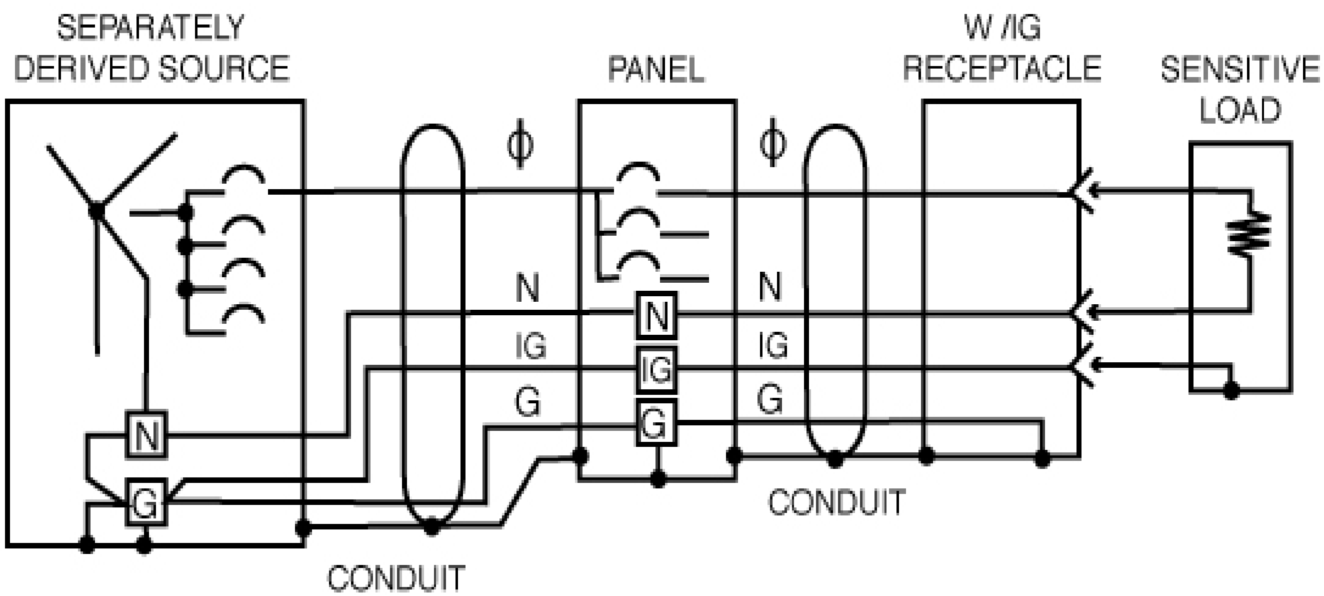
Good idea to install in new circuits

Gives flexibility to use or not

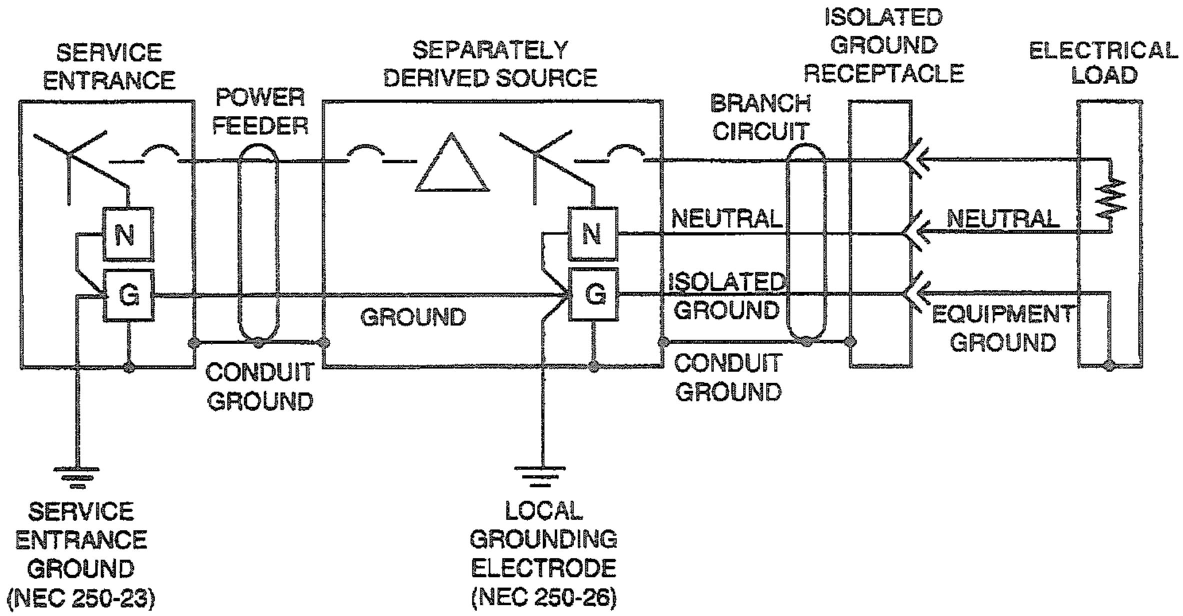
This is NOT IG



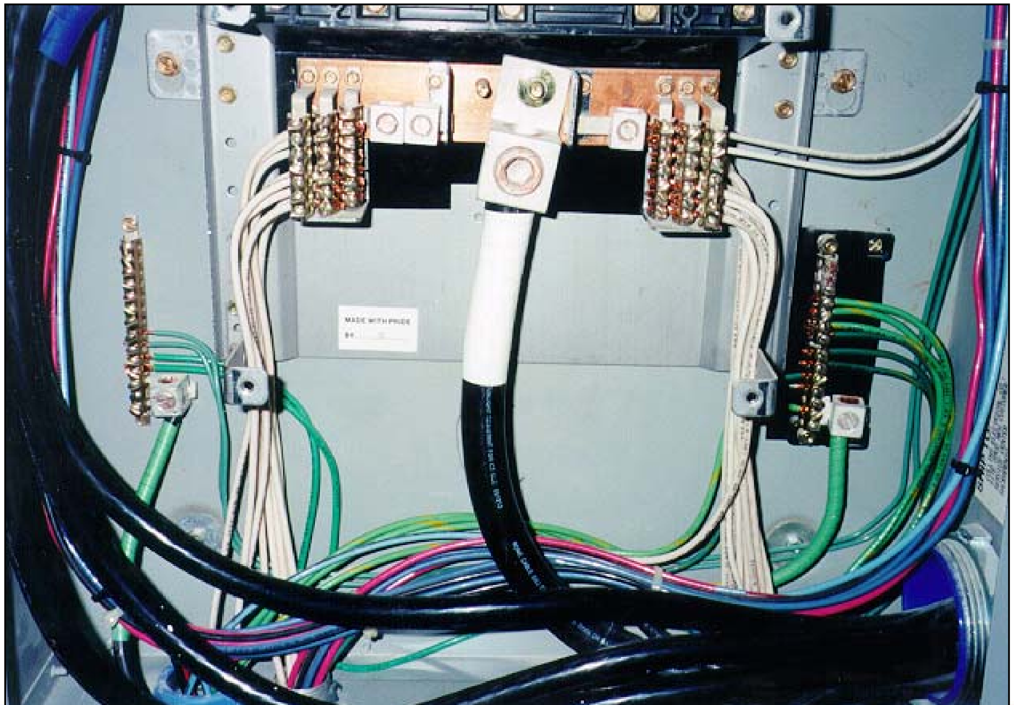
Isolated (Insulated) Grounding



IG Circuit with Transformer

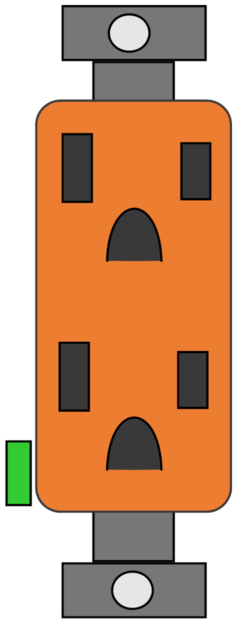


Not Connected to Cabinet



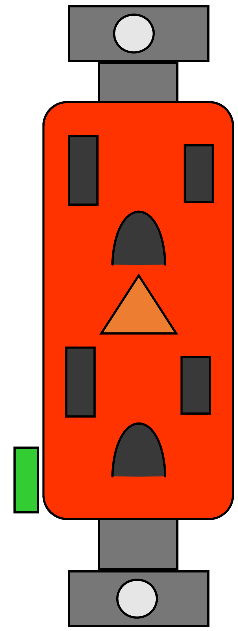
Receptacles

IG or SG?



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

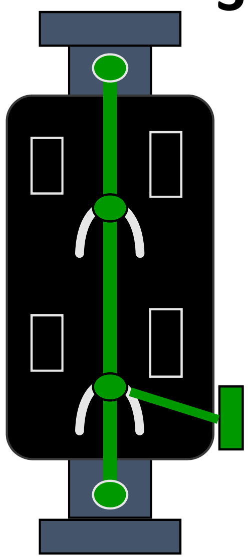
IG



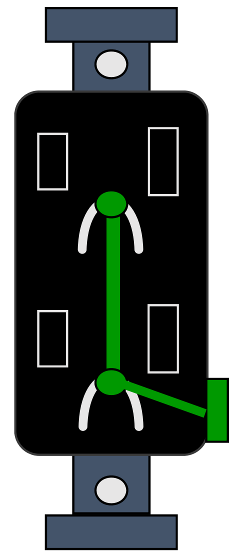
Receptacles

Do you see the difference?

SG

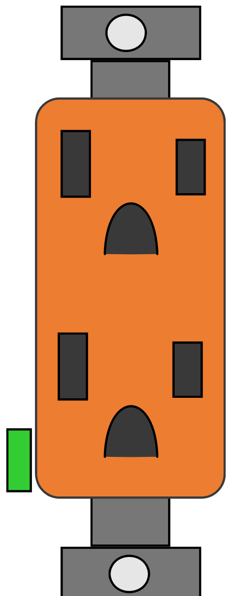


IG

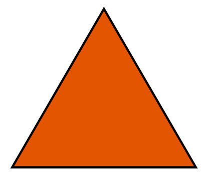


Receptacles

IG or SG?

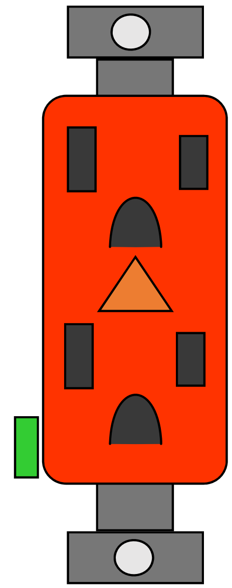


An orange color delta

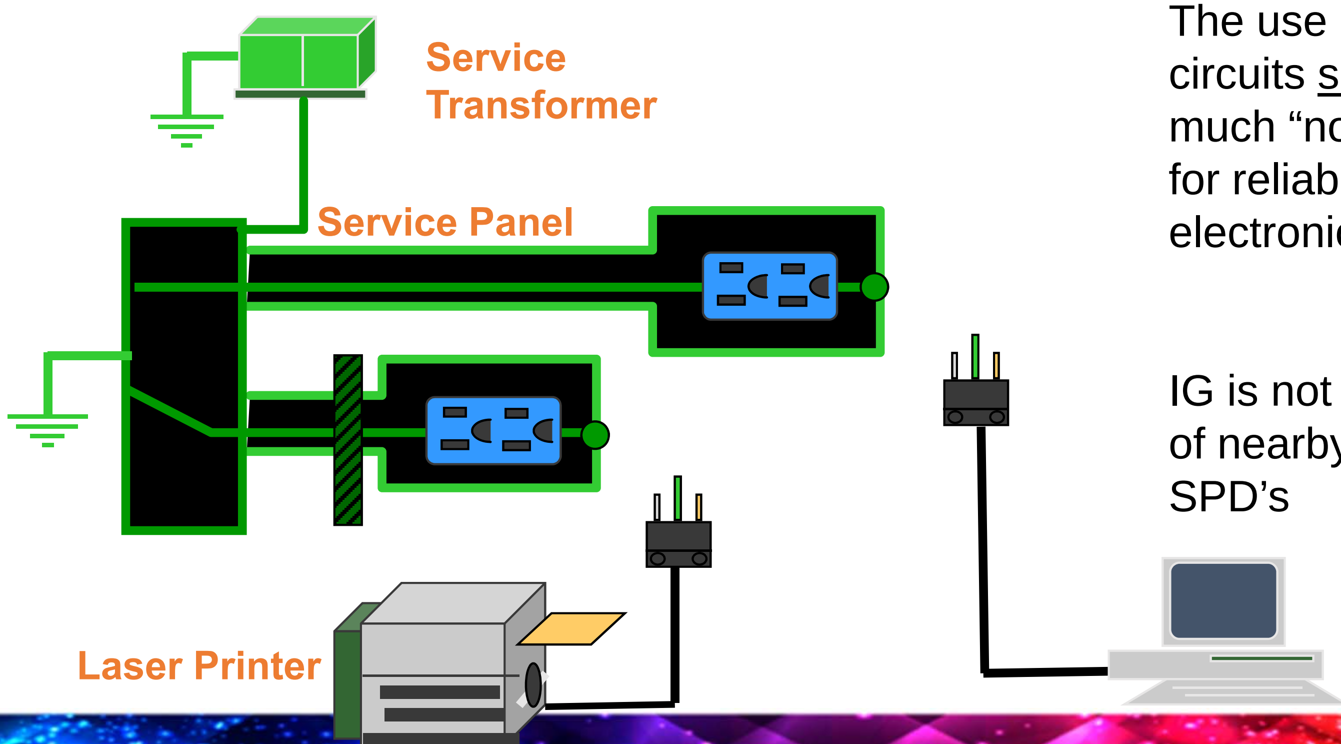


is required to be
embossed on the face

IG



Why use IG?



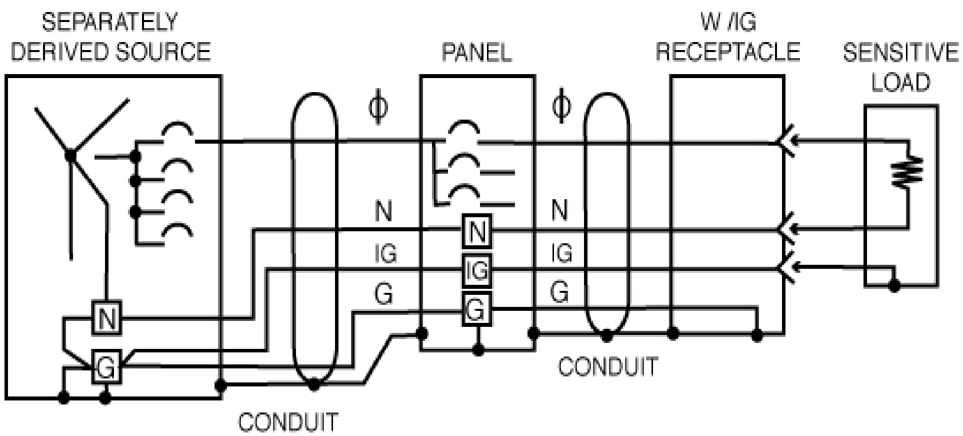
The use of solidly grounded branch circuits <u>sometimes</u> results in too much “noise” on the branch circuit for reliable operation of the electronic loads.

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

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.



Let’s Take a Break

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.

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

- Learn about high performance bonding.
- 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.

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?

- 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.

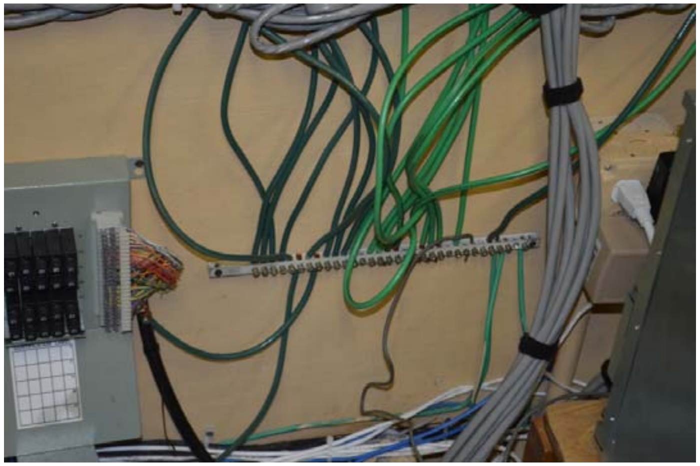
The lightning arrestors for this phone system are not bonded to a path to ground.   This is a life safety issues as well as a formula for equipment damage.

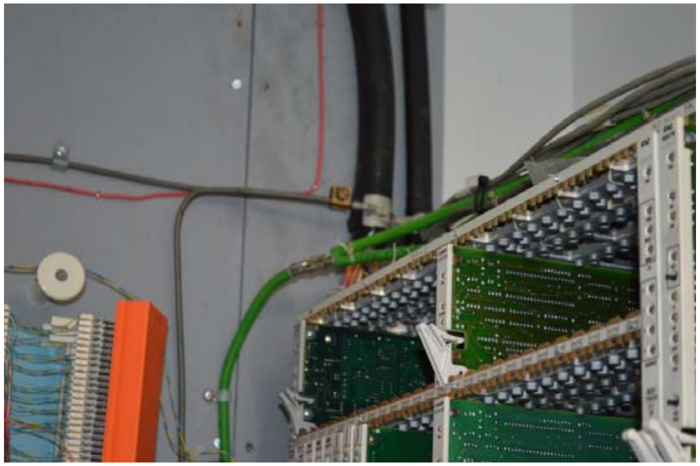
This Met Code When Installed!

- As a result it meets code today!
- But, is it satisfactory?

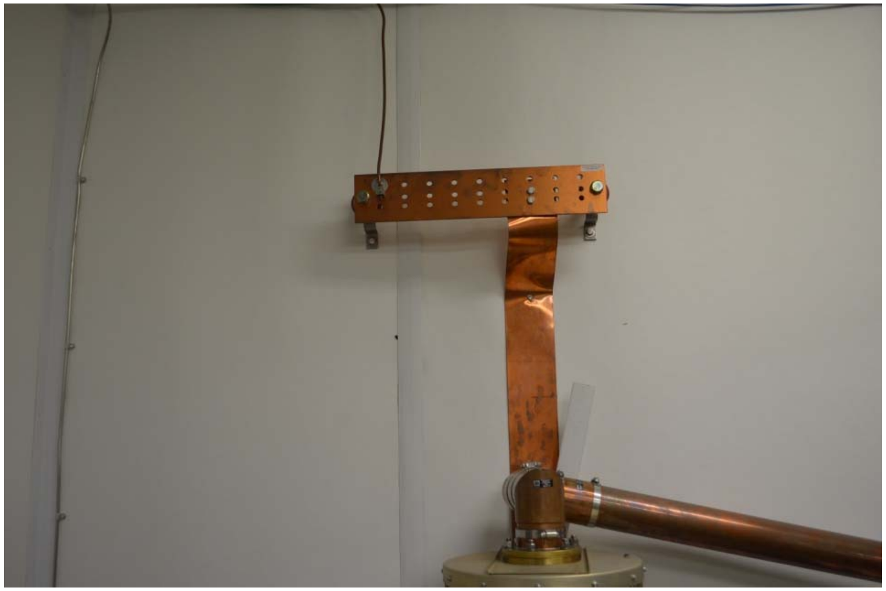
Want Your Name on This Job?

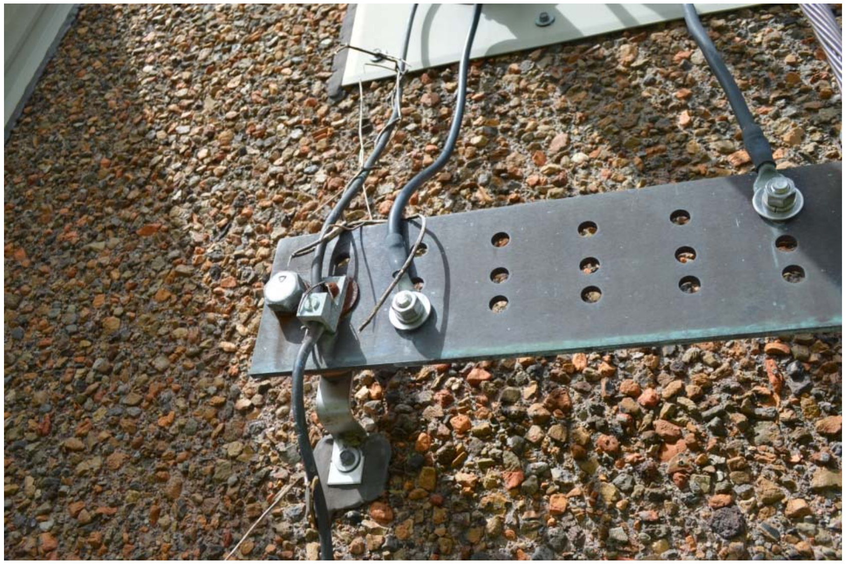
This is one of many electrical systems in a HUGE resort's in central FL.
MS1's Bond is shown to the left, MS2's Bond is show above…(missing).
THIS PASSED INSPECTION





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 he wanted to make sure the critical equipment was grounded properly so he had additional ground rods, ground bonding bars added.

Wonder Who Approved This?

Want your new HD, Smart, Flat Screen TV on this ground? How about the fire alarm in a Children's hospital?

Tape Holding the Ground Bonding?

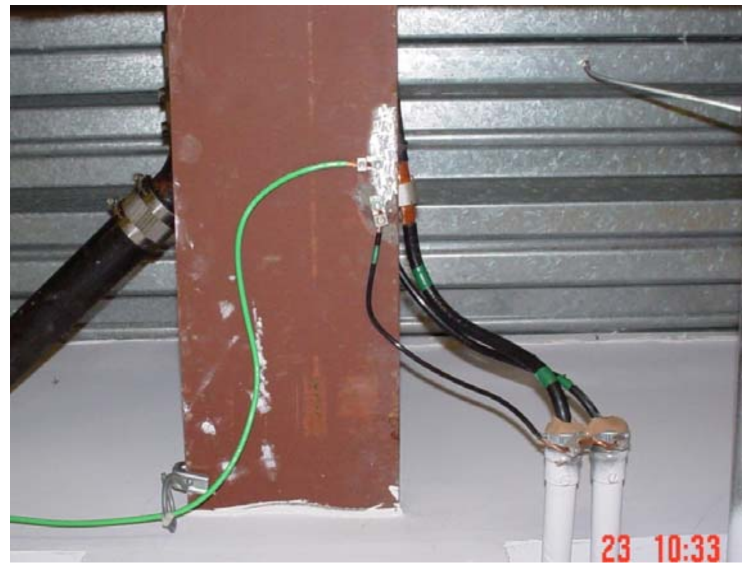
This Was At a 9-1-1 Center

Very Expensive Copper Theft!

Nice bonding job….. to What?

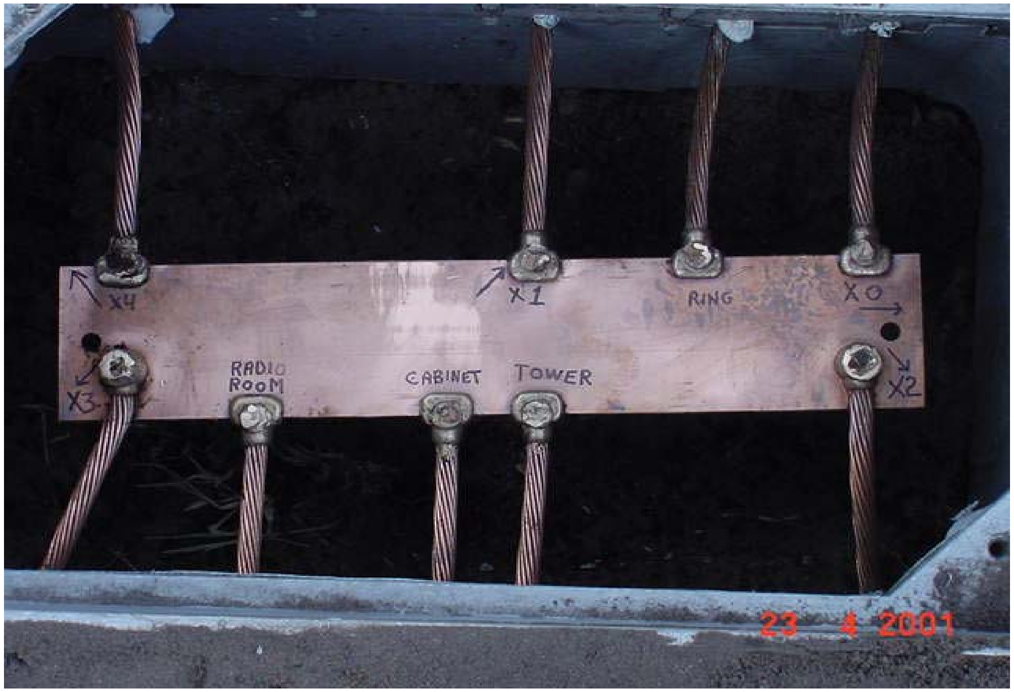
Bonding to Building Steel

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

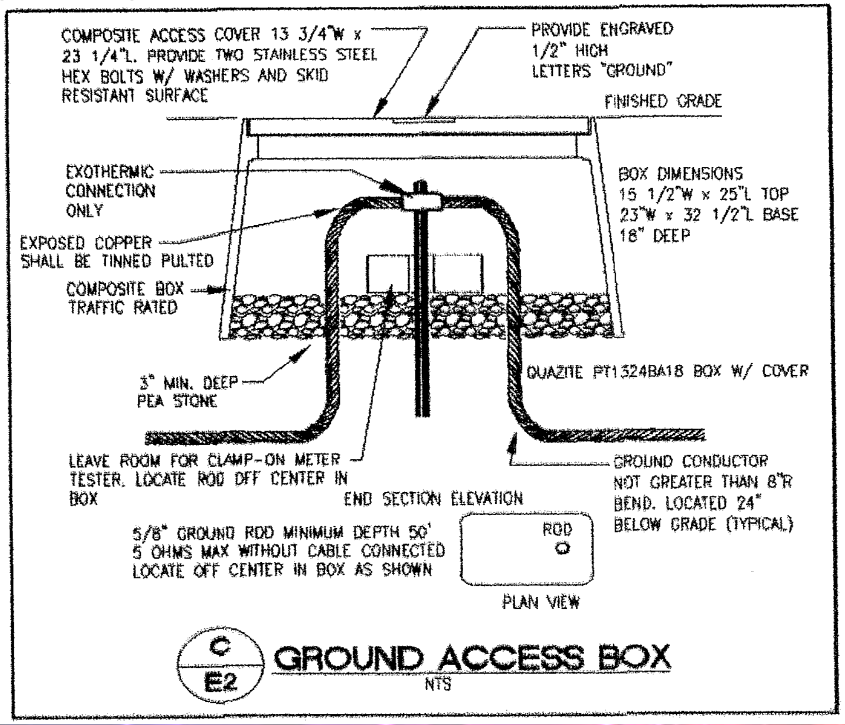


What is wrong here?

What should be done here?



A proper Ground Test Well



Lightning vs. Concrete Footer

Path in but not a good one out!

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

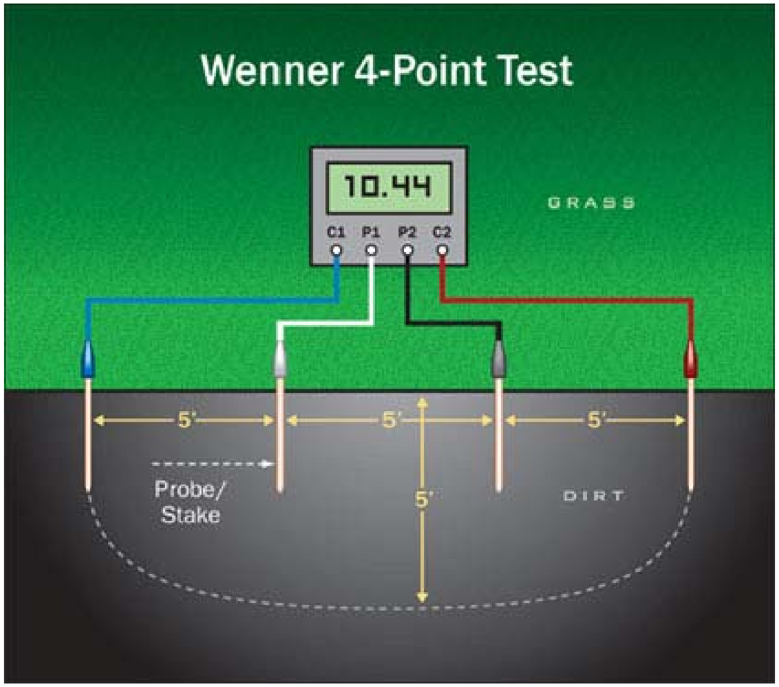
- Should be the requirement for the ground rod system of every electrical system.
- Ufer grounding & bonding is in addition to the 5-Ohm ground rod system.
- The maximum resistance of a lightning protection system ground rod should be 5-Ohms.
- All this added together, properly bonded will assure the 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

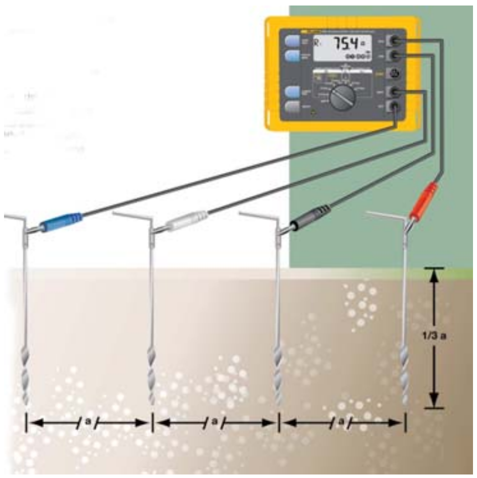
To determine the resistivity of the soil, the Wenner four-point measurement method (my choice of the two options), it corresponds to IEEE Std. 81.

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

Note the distance between probes!



Long-form Wenner Formula



Four Point Soil Resistivity Test layout. Wenner Method:

ρE = measured apparent soil resistivity (Ωm)
a = electrode spacing (m)
b = depth of the electrodes (m)
RW = 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

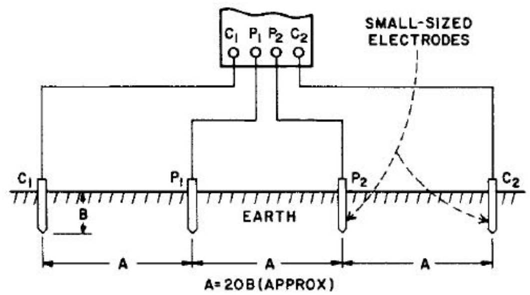


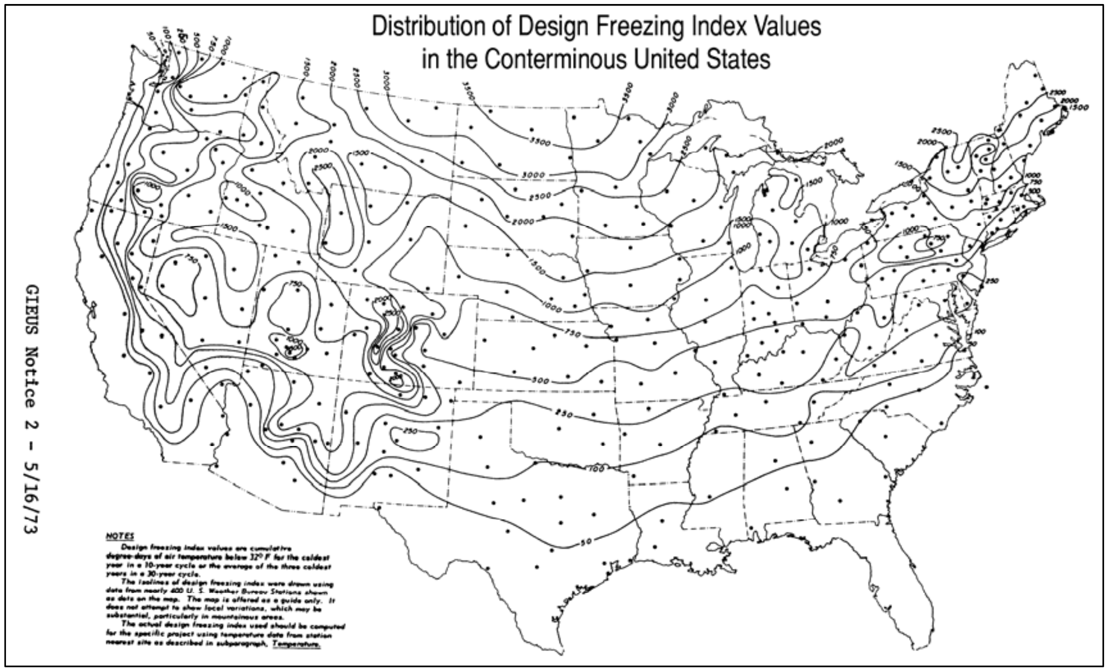
Fig. 1: Four-terminal method of measuring earth resistivity

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.

Temperature & Grounding



The “Depth” Require to Reach:

SOIL RESISTIVITY	LENGTH FOR A 5-Ohm GROUND	LENGTH FOR A 10-Ohm GROUND
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

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.

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

Temperature and Resistivity*

Temperature		Resistivity
C	F	Ohm-cm
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.

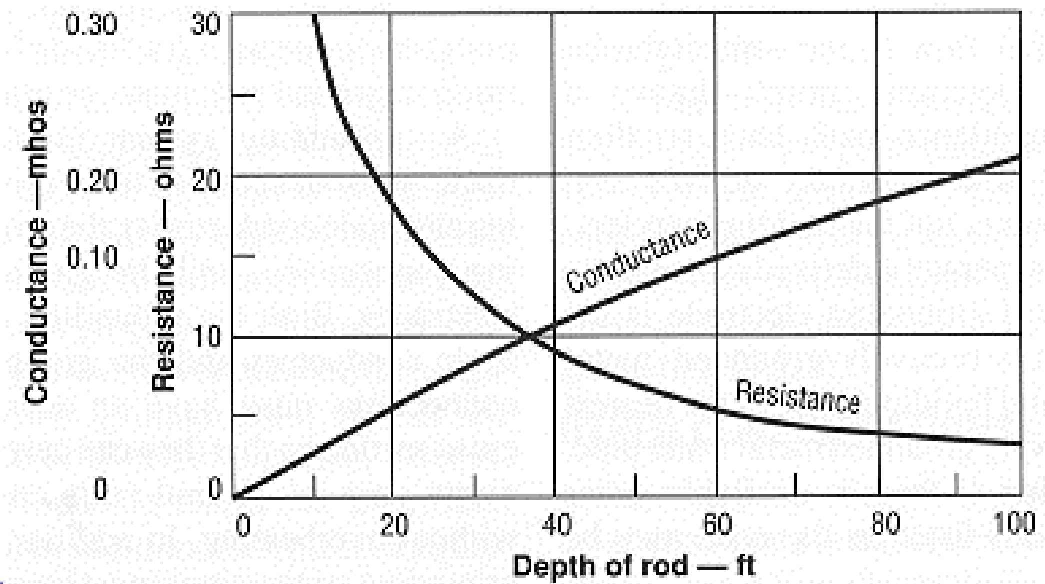
Resistivity of Various Waters

Classified Water	Ω −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)

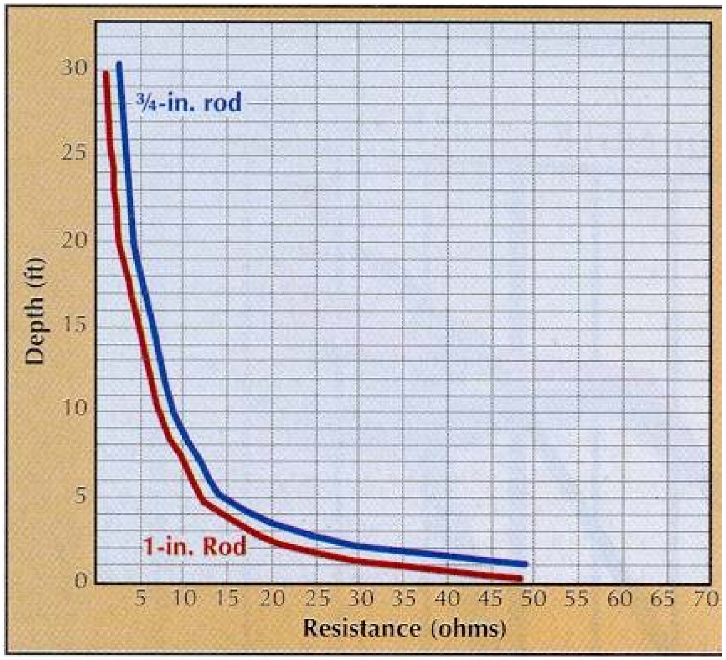
Depth of Rod

- 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 ¾" 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 is two version. 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

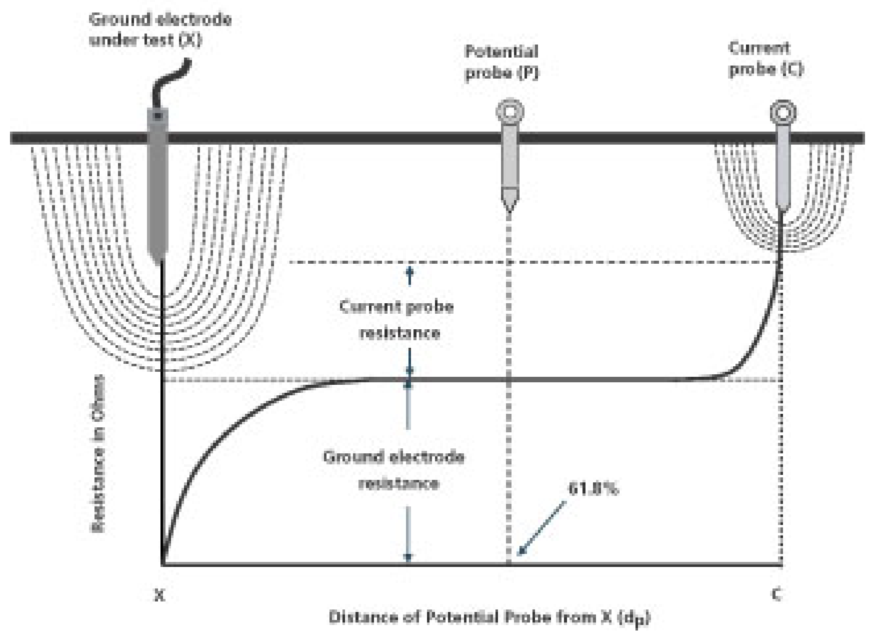
After training on both types this list is logical.
The Fall-of-Potential Checklist

- 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



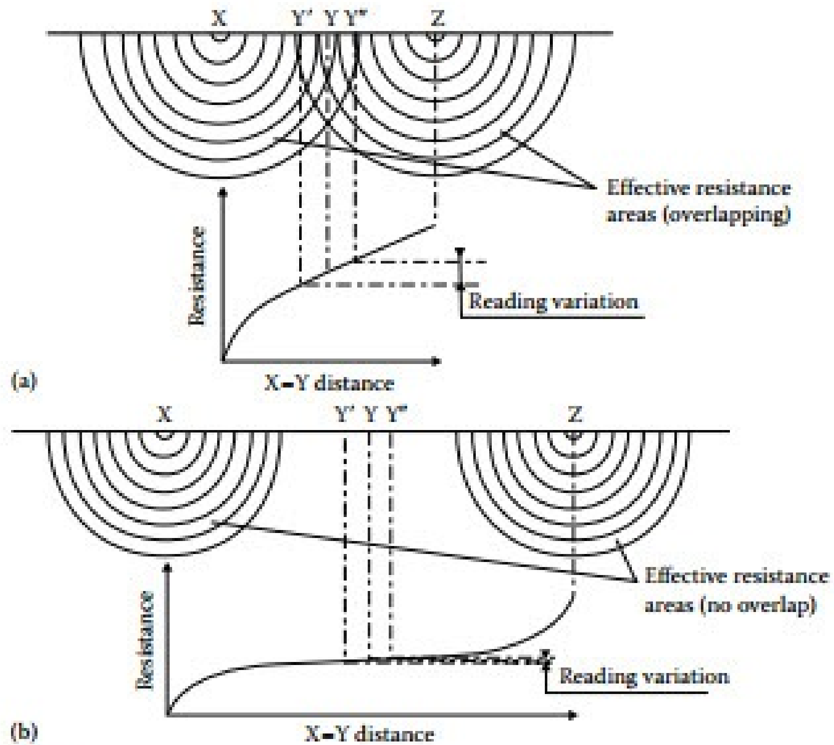
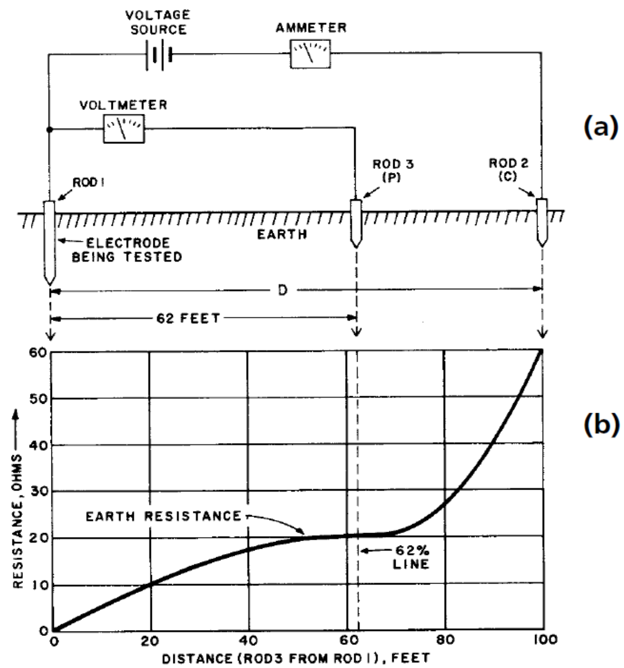


FIGURE 11.17
Effective resistance areas (cylinders of earth) (a) overlapping and (b) not overlapping.

“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

Fall-of-Potential Ground Testing



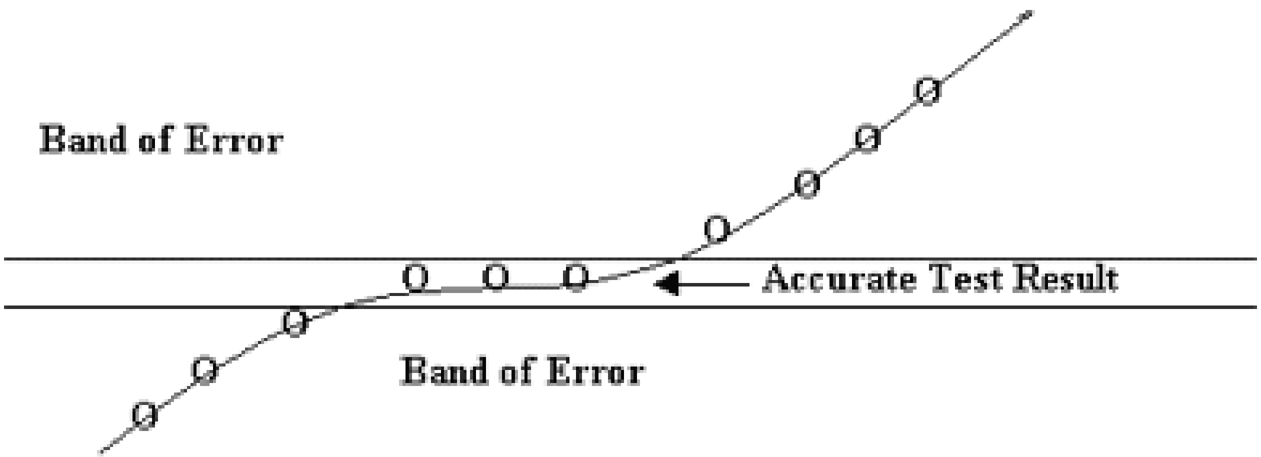
ı. 10: Principle of an earth resistance test

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

Depth Driven	Distance to "Y"	Distance to "Z"
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



Lowering Ground Resistance

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

Grounding vs. Bonding

- Art. 250's requirements for grounding and bonding, which begin in 250.4, can be broken down into two groups: Grounded & Ungrounded systems.
- Grounded systems [250.4(A)] Grounding (Earthing) metal parts of electrical equipment in or on structures.
- Ungrounded systems don’t have a winding grounded at the supply transformer. That is the only difference.
- Grounded or Ungrounded you MUST bond enclosures and equipment together.
- The difference in Ungrounded systems you are bonding the equipment together, rather than each other and the source. (The bond to the source is missing.)

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.
- Bonding must be installed with the capability to channel the flow of lightning energy to earth ground with no equipment damage.
- Bonding must be logical…. It is not just a green wire connected to something.
- NO cross contamination.

Bonding Installation

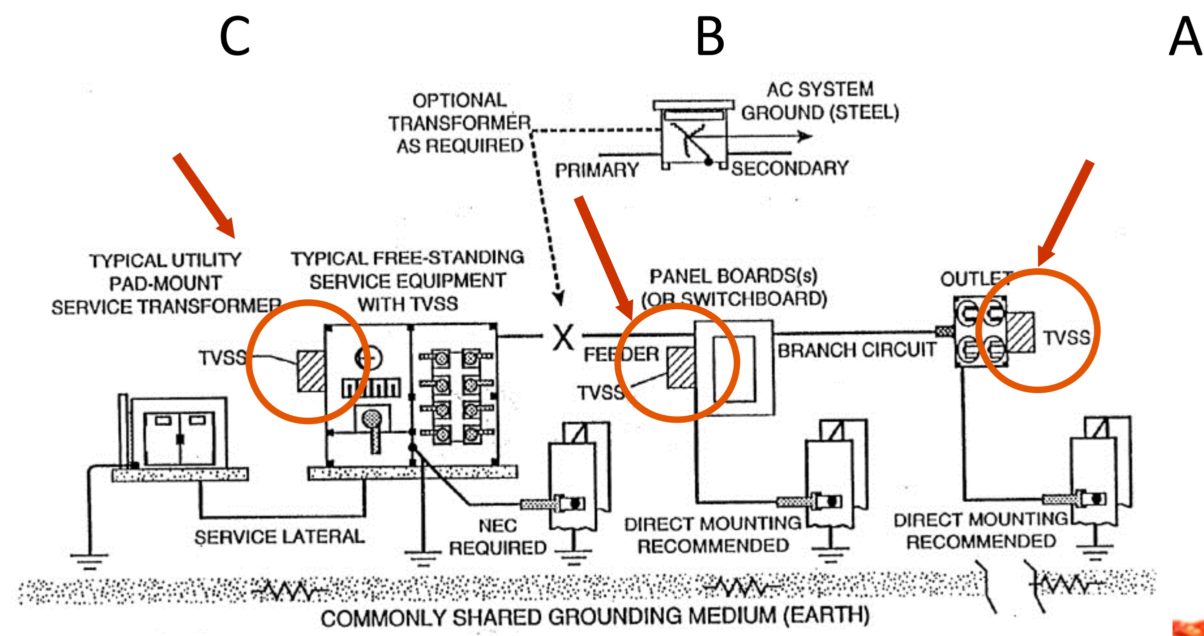
- Electrical service entrance ground bonds should be to a common bonding bar that is both robust and provides a low impedance path to earth ground.
- All bonds should be exothermic welds or double lugs and made using conductive grease and robust hardware. (lock washers, double nuts, etc.)
- This bonding 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.

Improve Bonding Installations

- Bring footer rebar out of the footer in an 18” radius bend to 1’ above the floor adjacent to the service entrance.
- A minimum of two 20’ sections of rebar should be 1’ apart. (more is better)
- The Ufer bonds to be exothermic wields with 4/0 bare copper.
- Connect the 4/0 copper bonding bar with high compression double lugs (or exothermic wields).
- Connect the X/O bond to the bonding bar.
- Connect all outside services (CATV & Telecom) bonds with home runs to the bonding bar.

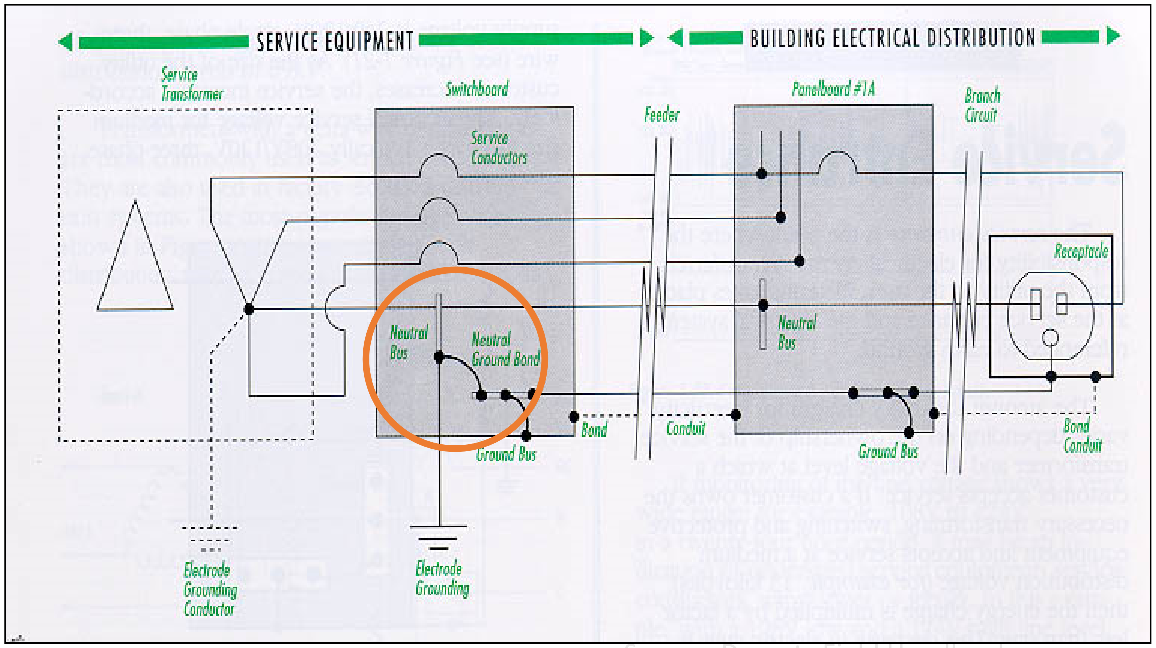
SPD (TVSS) Placement

Use Surge Suppressors in a “system "approach.



Series Installed Surge Suppressors for critical circuits!

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



- Source: Dranetz Field Handbook

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.

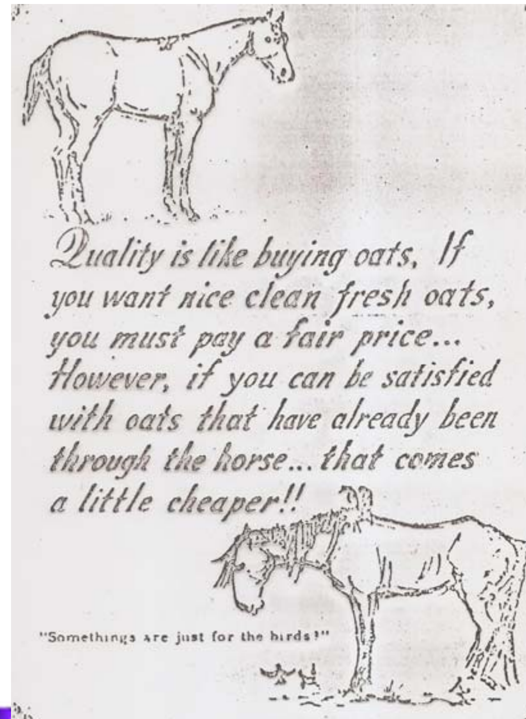
Lightning Protection Systems

- 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?

Improper Bonding

- The building's metal studs are a ground reference path for the metal equipment cabinet of the system to attach to them.
- The case ground wire connects the control board to the ground reference of the metal studs.
- The electrical ground and the metal studs become a ground loop.
- Lightning strikes the building or nearby the building and electrical energy flows between the grounds.
- ZAAAAAP! System(s) down!

SPD Quality = Performance



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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.

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.

The SPD Layered or System Installation

- Ahead of the main means of disconnect.
- Automatic transfer switch both line & load.
- To protect the main
- To protect all distribution panels.
- To protect critical circuits.
- To protect circuits that exit the facility.
- To protect elevators.
- To protect point of use devices.

General Wiring Practice

- **Surge Suppressors should be connected to a <u>full size</u> grounding conductor**

- **By “full size” I mean equal to the phase size**

Minimal Wire Length Is Critical

Wire Length is DELAY!

But NOT a local ground rod!

Code Violation & more!

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.

Installation Conditions

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

Poor Location Example

Proper grounding can be done.

Mt. Washington, NH

Mt. Washington, NH

Two 600 feet deep copper rods placed in 8 inch diameter well casings

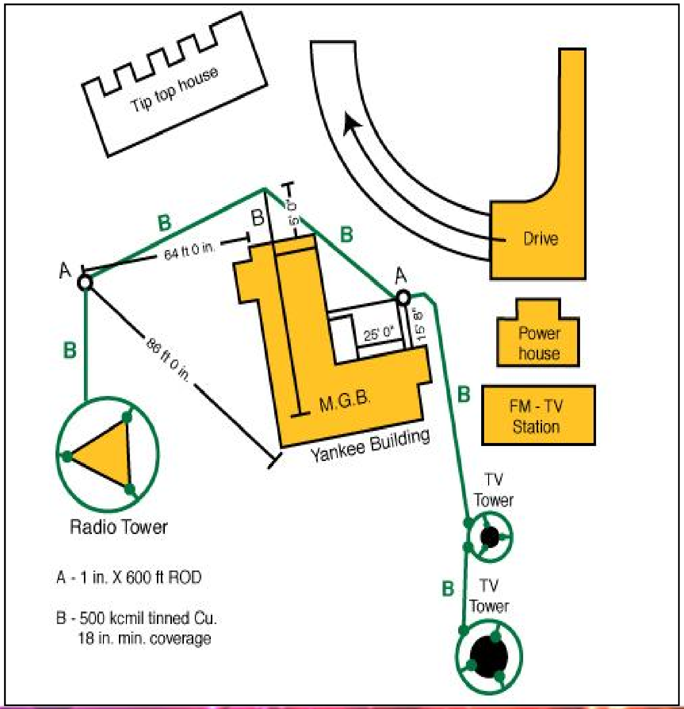
Backfill with bentonite grout

Interconnect with 500 kcmil copper cable

Achieved 6 ohm resistance

Site Layout

- **500 kcmil**
  ring grounds (B)
- **2-600 ft. deep vertical**
  electrodes (A)



Deep Electrodes

Through a mountain

Cost-effective

<u>Before:</u>

3-4 major events in 2 years (lightning)

$120,000 average equipment damage per year plus lost ad revenue (station downtime)

<u>After:</u>

<u>No damages</u> or disruptions in >10 years since improved grounding

Source: R. Cushman, Chief Engineer, WMTW-TV

System Installation Options

- Geographic conditions should be considered when connectivity of devices within a system is determined.
- Distance of the connection must be considered.
- Device location (inside or outside) the facility will impact the connectivity option considerations.
- System expansion plans will impact the initial system installation.

WRZN

Multiple things to learn

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

Fire & Security Alarms

- Plan the layout – consider wire run options.
- Networks are nice, however long wire runs increase exposure to lightning damage.
- Avoid problems – use shielded wire.
- Understand how to bond the shield.
- Avoid ground loops – know your connection.
- Isolate if you are not 100% sure.
- Select the right technology.

General Guidelines

Circuitry
Voltage Drop
Full Size Conductors
General Principals

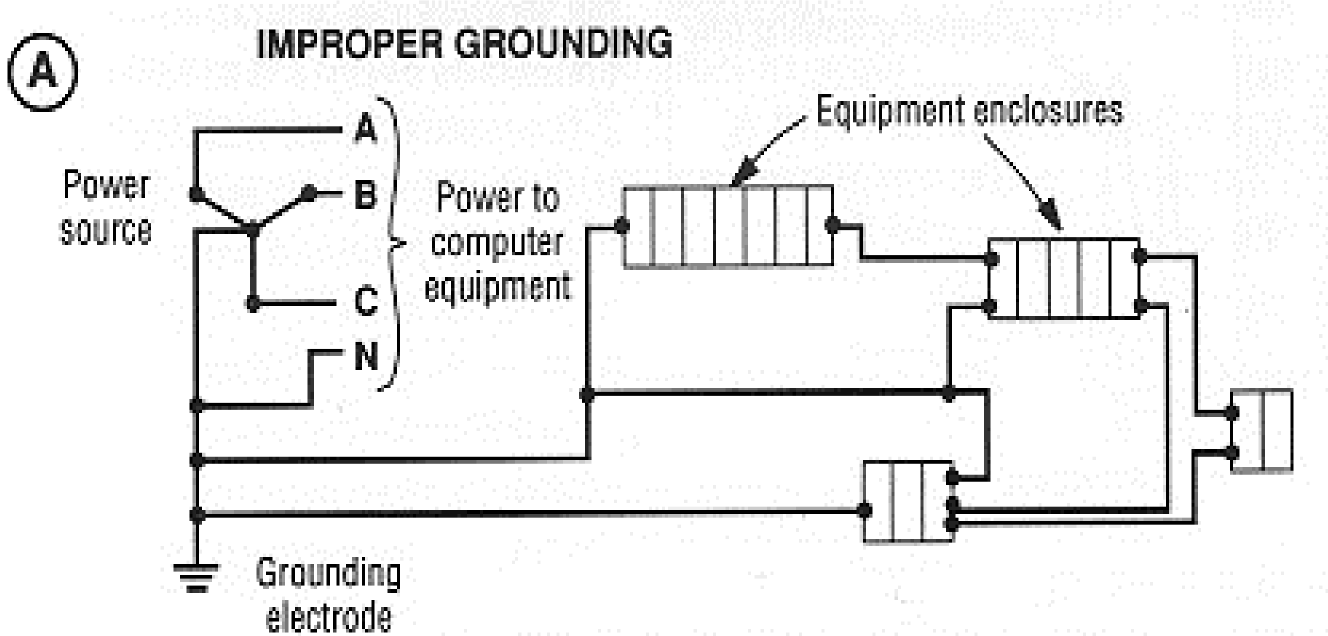
Source: Dranetz Field Handbook

Avoiding Ground Loops

There should be ONE central point connecting the interior wiring to the ONE exterior grounding electrode system

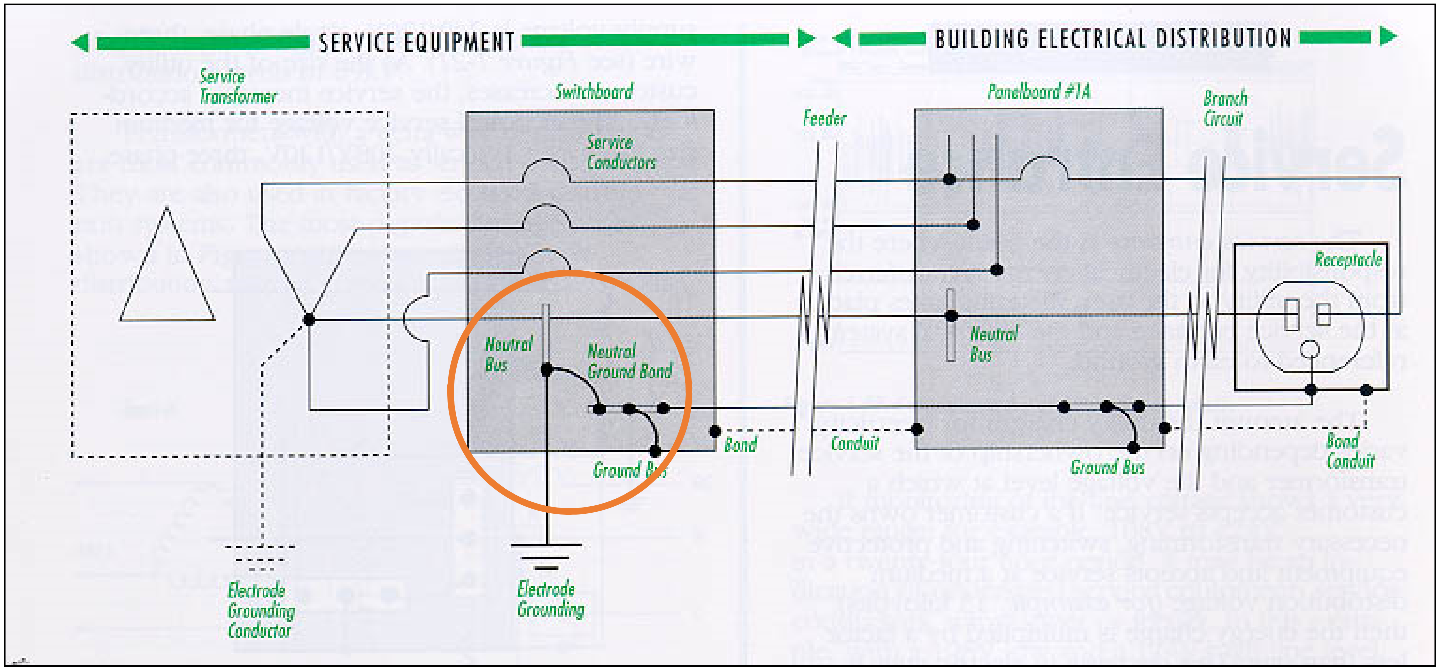
Source: Dranetz Field Handbook

Avoid Ground Loops



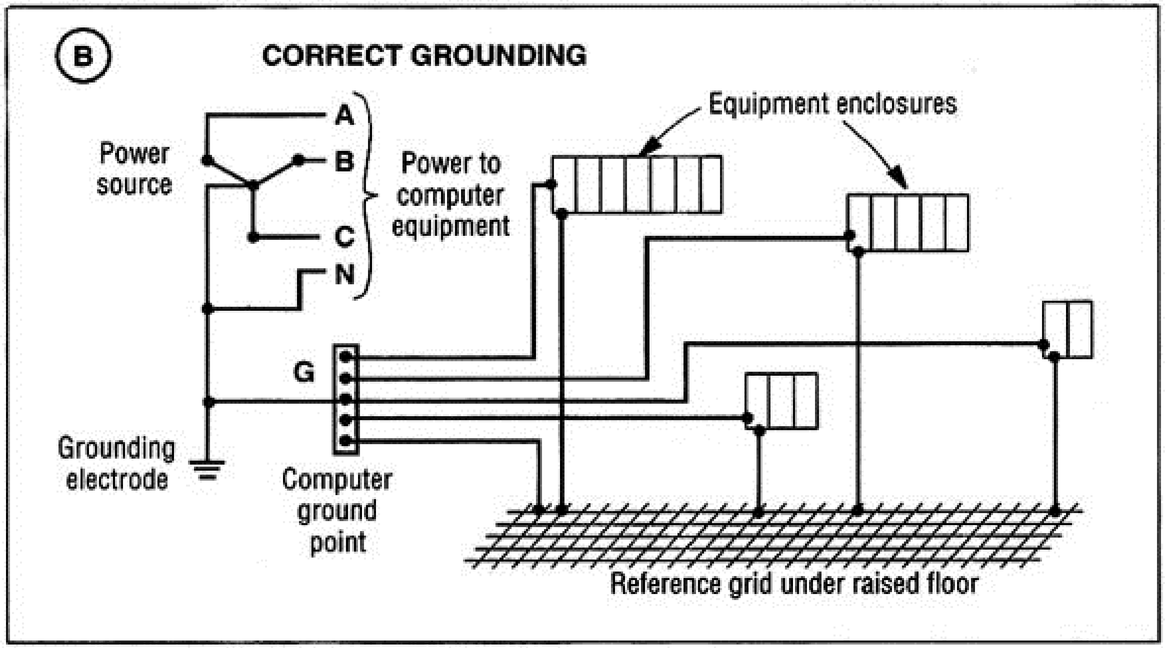
Never use the earth as a ground path

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



- Source: Dranetz Field Handbook

Example of "star" grounding

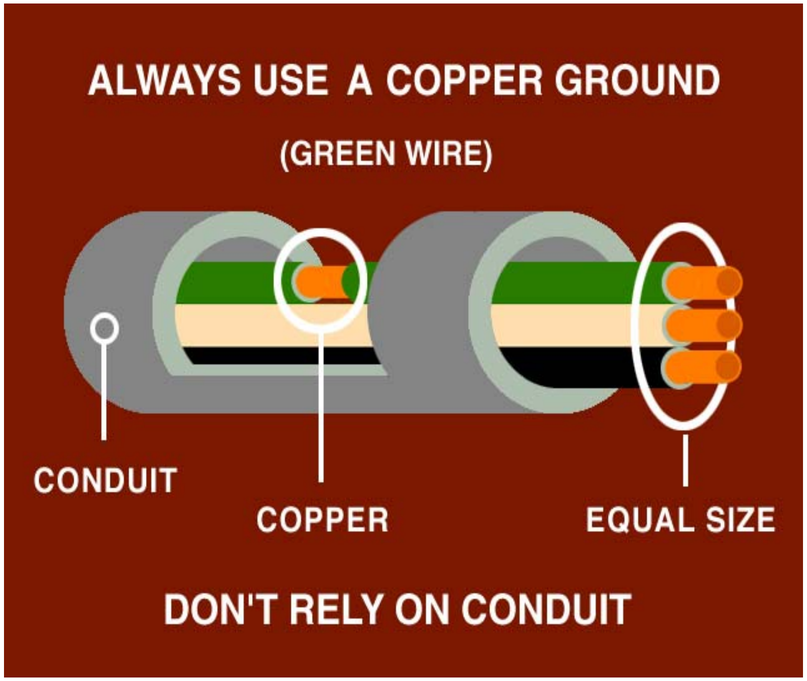


Source: EC&M Guide to Quality Power

Avoid Conduit as a Ground Path

Can you imagine a joint every 10 feet?

Full Size Equipment Grounding

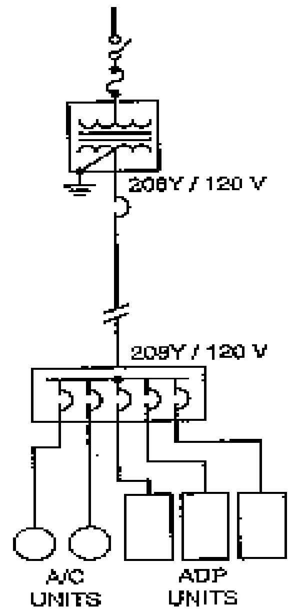


Will That Conductor “Fuse”?

General Wiring Practice

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

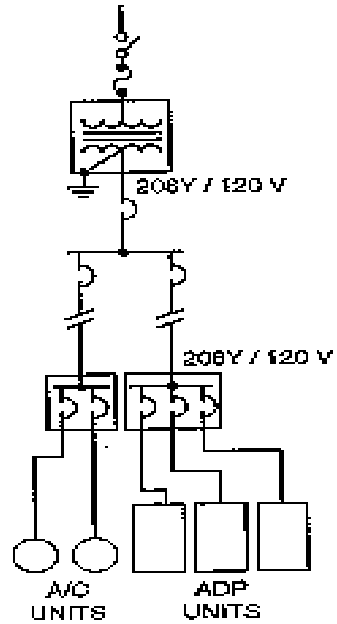
Typical Wiring Method



a) WORST!

source: IEEE
Emerald Book

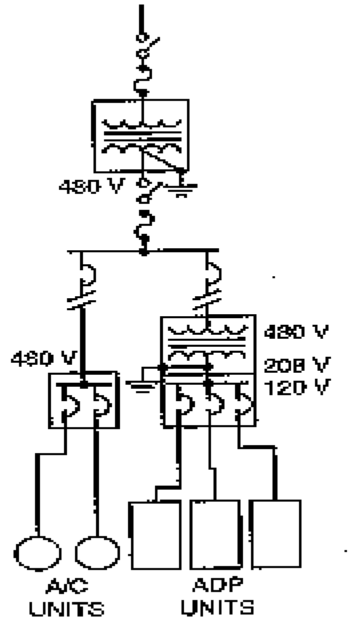
Slightly Better Wiring Method



b) FAIR!

source: IEEE
Emerald Book

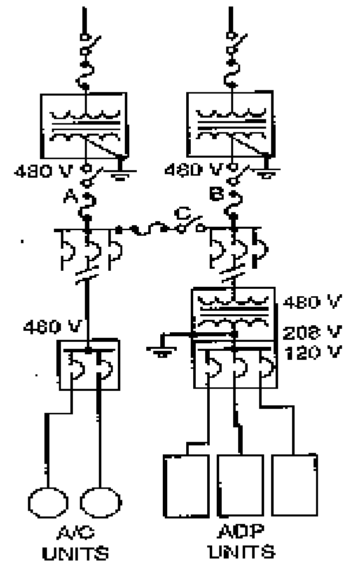
Much Better Wiring Method



c) BETTER!

source: IEEE
Emerald Book

Optimal Wiring Method



d) BEST!

source: IEEE

Emerald Book

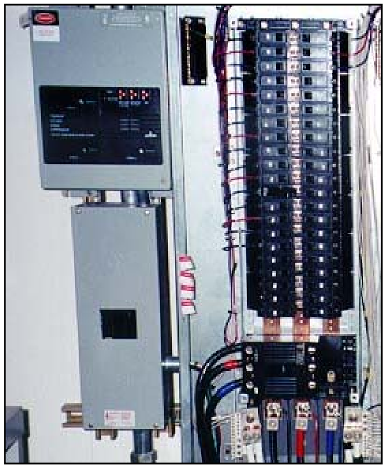
General Wiring Practice

- **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 <u>full size</u> grounding conductor**

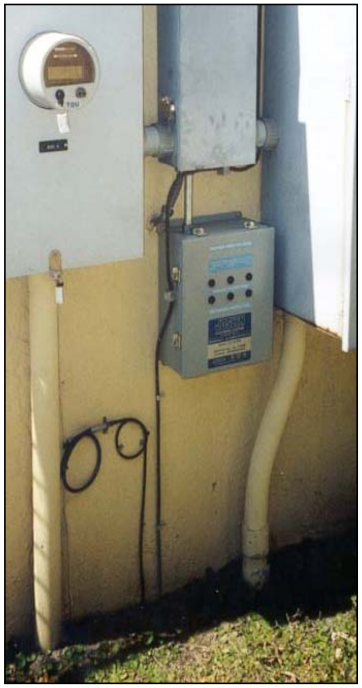
- **- at the service**
- **- at the panelboard**
- **- at the load**



General Wiring Practice

Surge Suppressors:

Must be well-grounded to work



General Wiring Practice

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**

Caveat

MOV's can degrade with use!

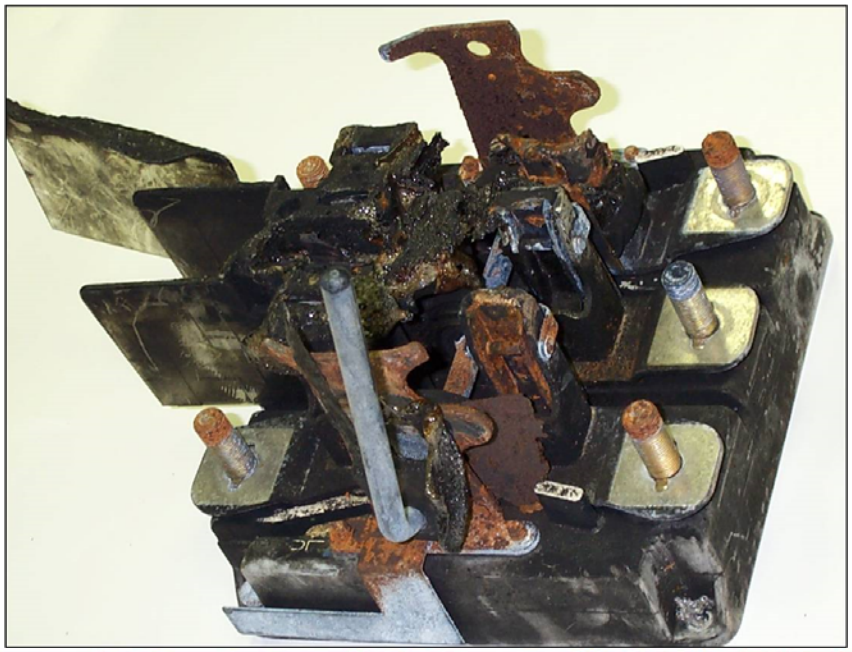
Suncoast Schools FCU

SunCoast FCU

Data Center Inside

Lightning Hit Service Drop

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



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.

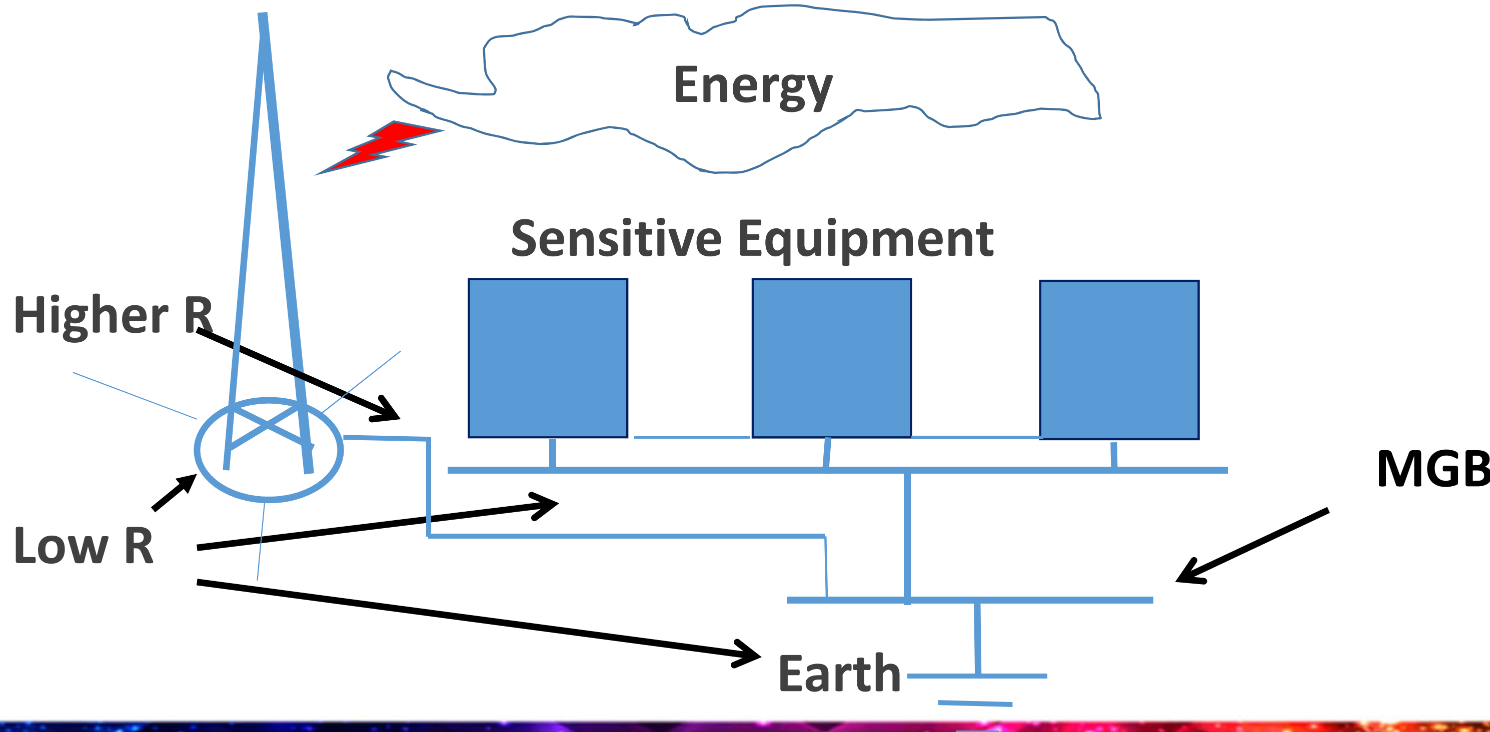
Suncoast's Data Center

No downtime

No equipment damage

Cost around $40,000

Think of a "current divider"



Desired Grounding

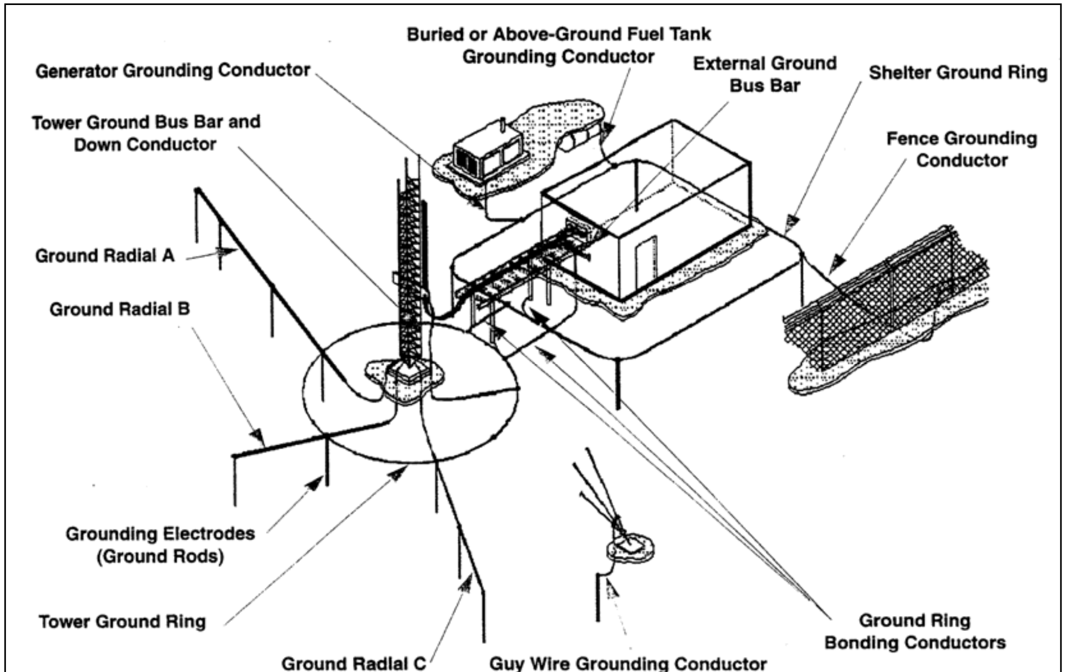


FIGURE 6-1 TYPICAL TYPE B EXTERNAL GROUNDING ELECTRODE SYSTEM

Example of Current Divider

Macomb County, MI 9-1-1

Note Tower in Rear

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Gas and Water Services Bonded

Labeled So No One Removes

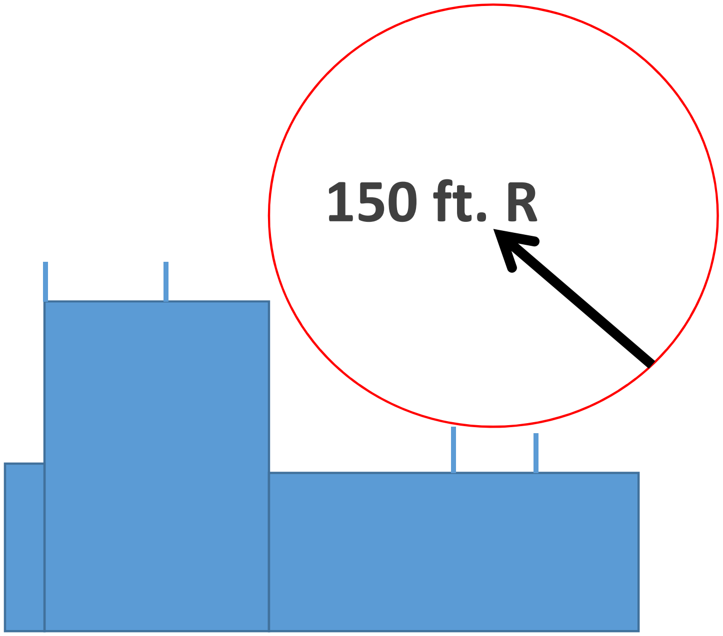
Conductor Welded to Base, Not Tower Leg

Coax Braid Bonded on Vertical Run

Then to Strap at Bulkhead

Inside Radio Room

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**

One Summer Street, Boston

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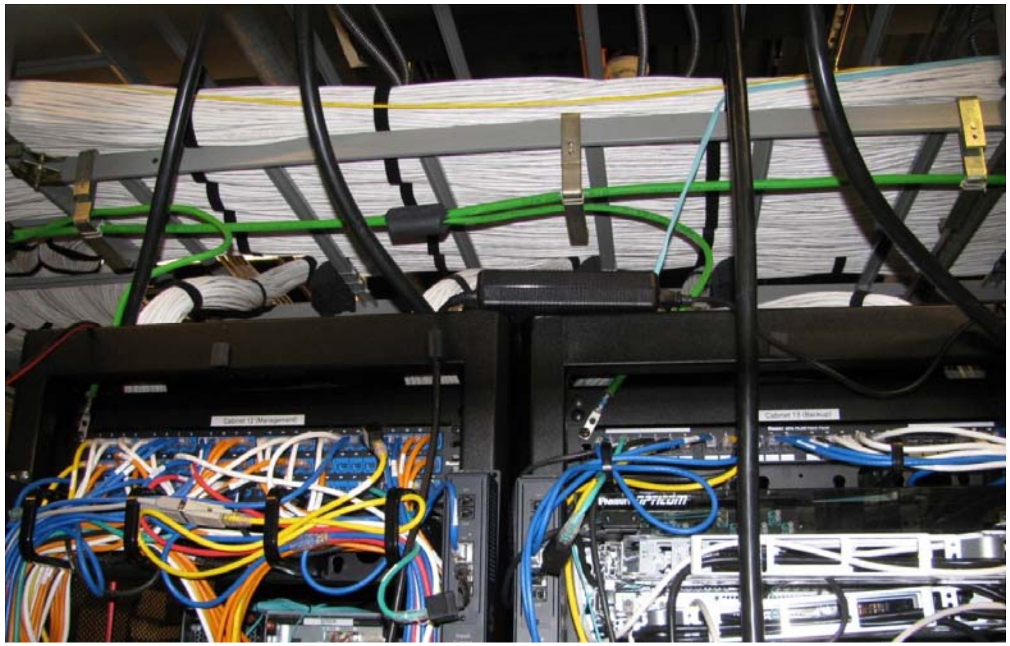
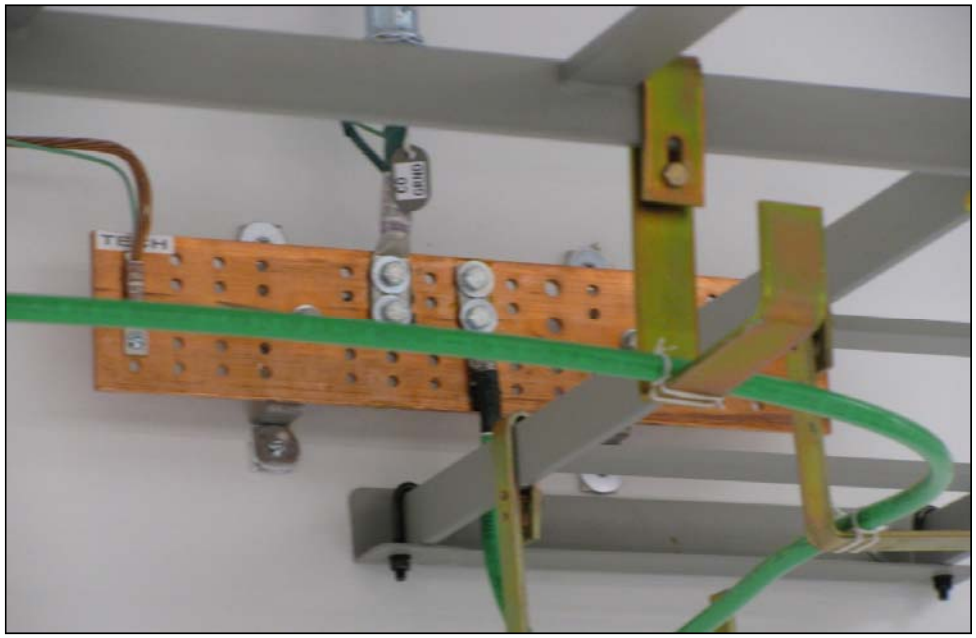
Each Rack Tied to Overhead Bus



Rows of Racks to Ground Bus



Separate Conduits to Master Ground Bus

Master Ground Bus (MGB)

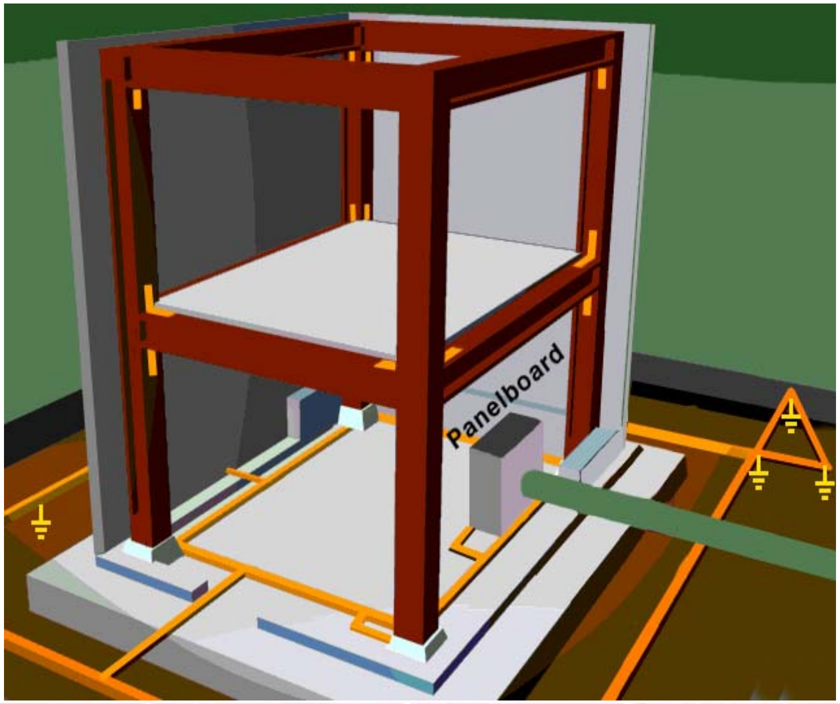
- Note that all conduits are labelled.

- MGB located at lowest point in building.

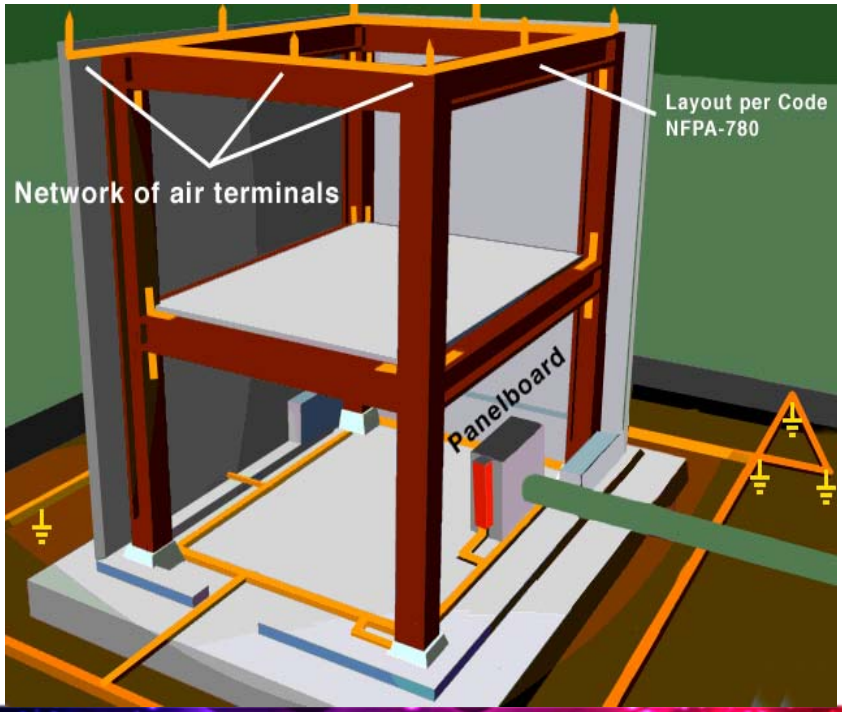
Never Rely on Conduit for Ground

- Always use a full-sized separate copper ground conductor

Start With Ring Ground

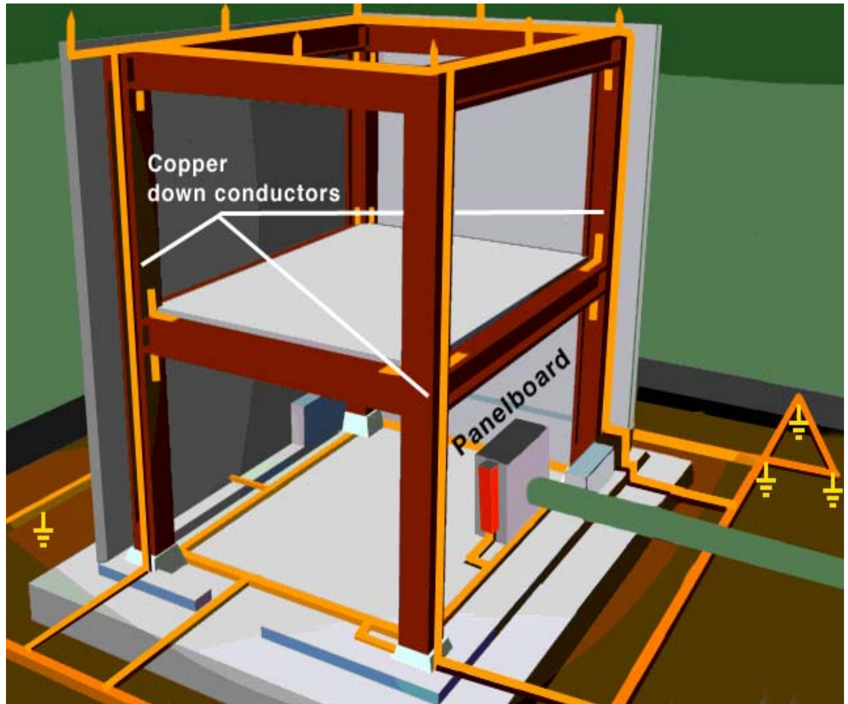


Network of Air Terminals

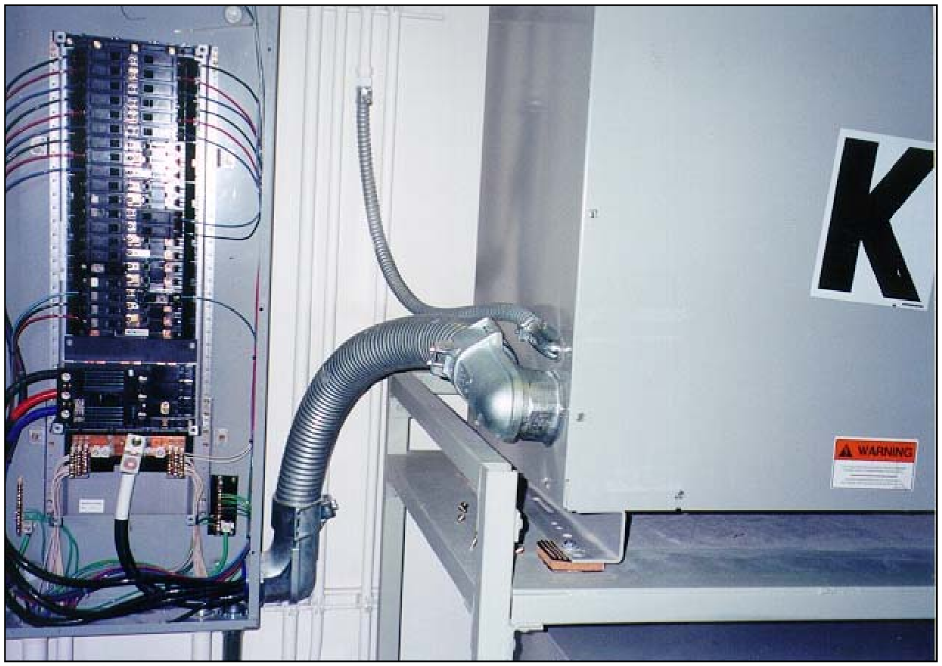


Heavy Duty Down Conductors

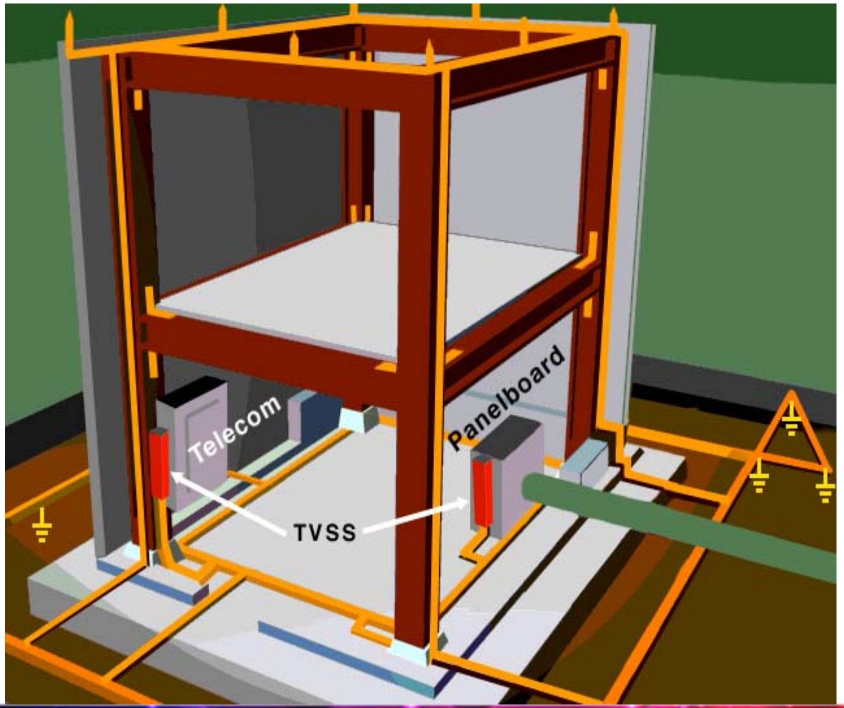
Not steel framing



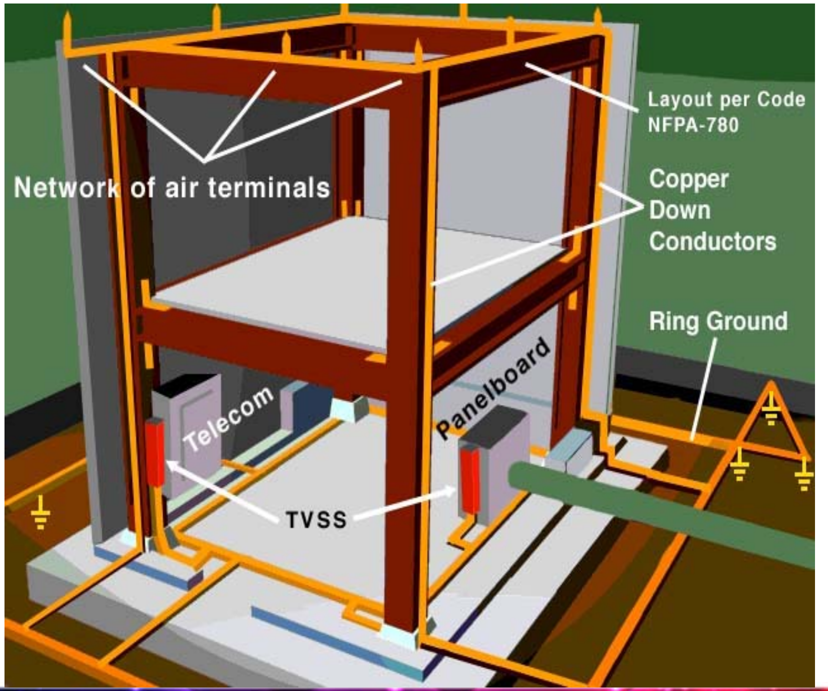
Do Not Use Building Steel



Surge Suppression



Overall Result



System Grounding

There should be ONE and ONLY ONE point connecting the neutral to the exterior grounding electrode <u>system</u>

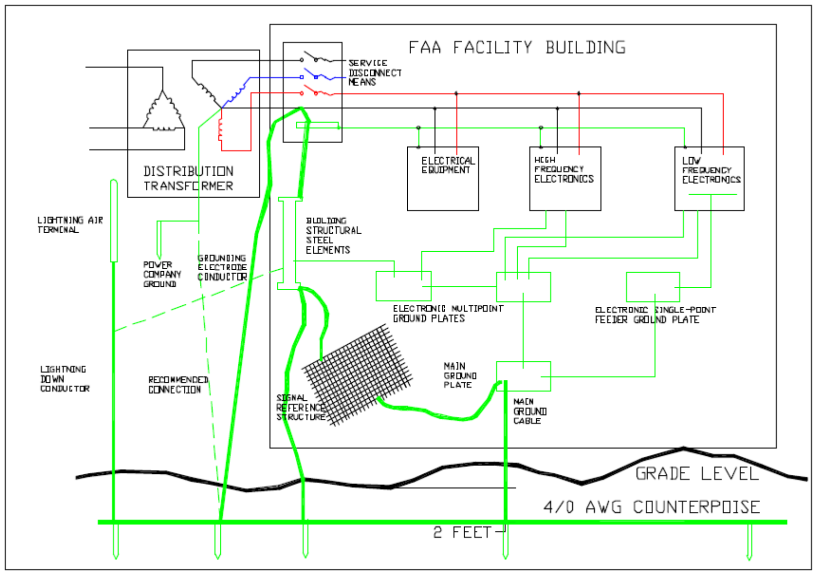
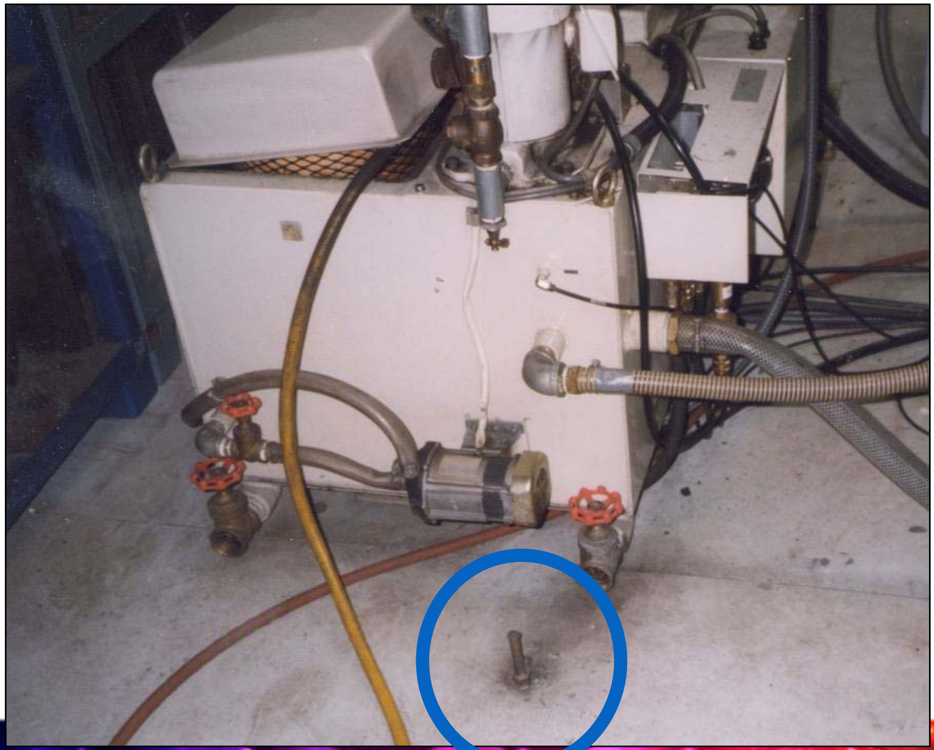


Figure 6. Facility Grounding System

No “independent” grounds



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.**

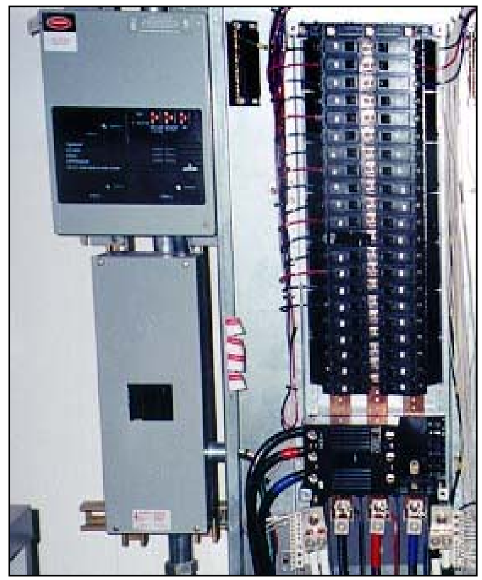
  wire gage, circuit length

Surge Suppressors

Keep leads as short as possible

Surge Suppressors (SPD's)

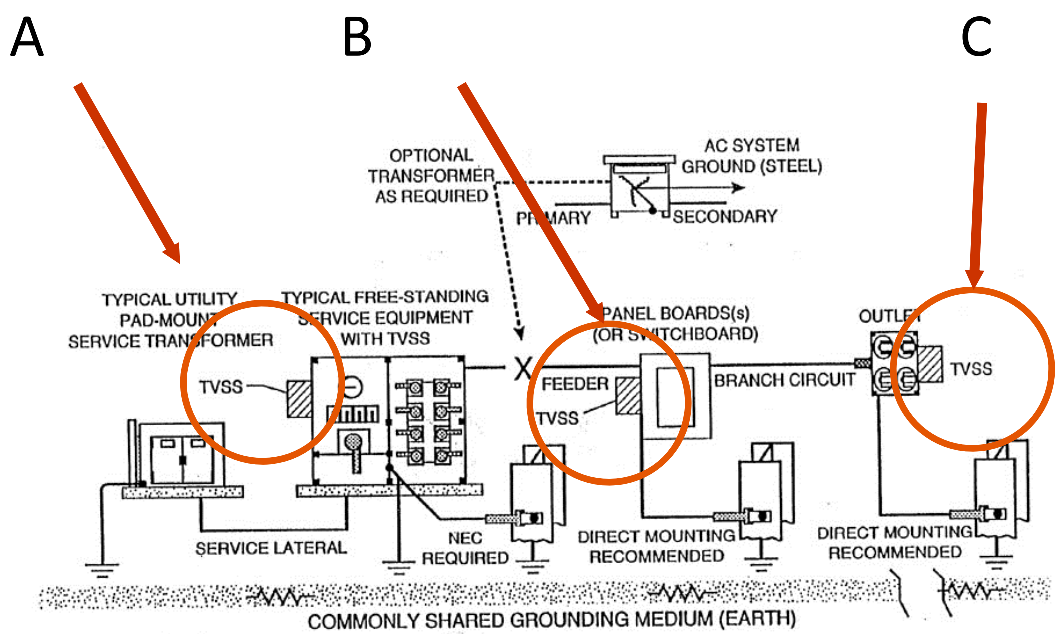
- at the service
- at the panel board
- at the load



TVSS Placement

Use Surge Suppressors in 3 places

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



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

At the Device Level

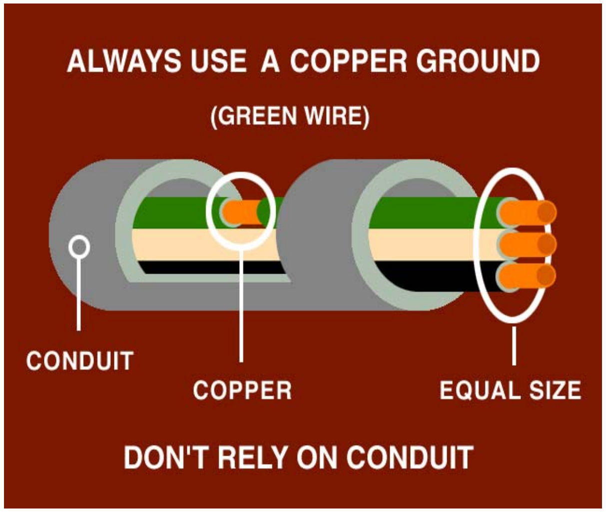
Type 3 devices

25 kA per mode min.

50 kA if critical load

Use Grounding Conductor

Always use a <u>full size</u> copper equipment grounding conductor – do not rely on conduit

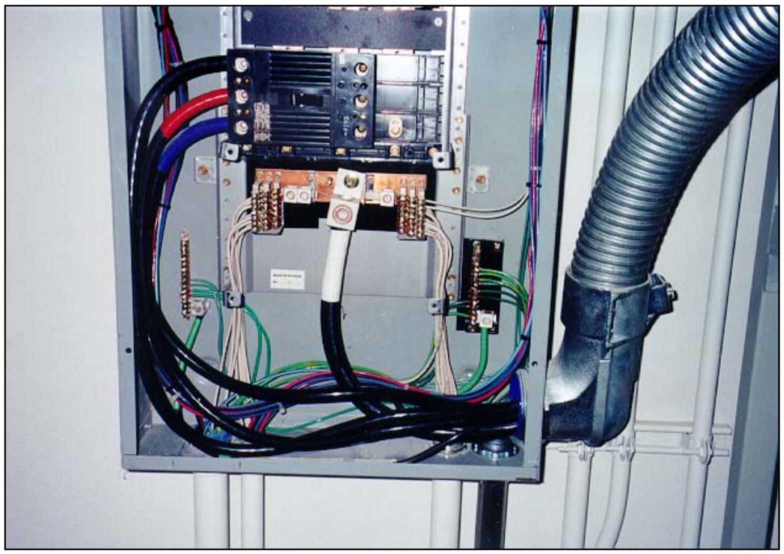


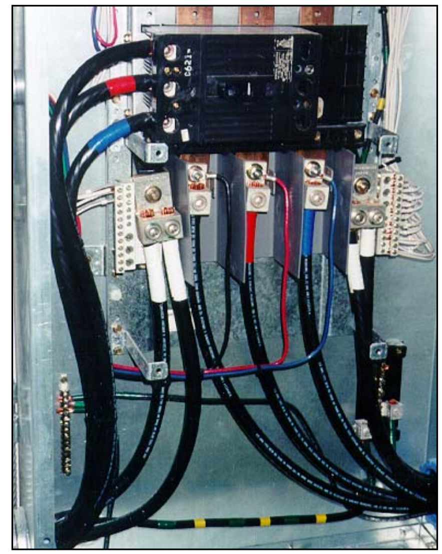
Trap Harmonics

Shielded isolation transformer sometimes helps Isolate harmonics

To Handle Harmonics

Use a 200% rated neutral or separate neutrals per phase



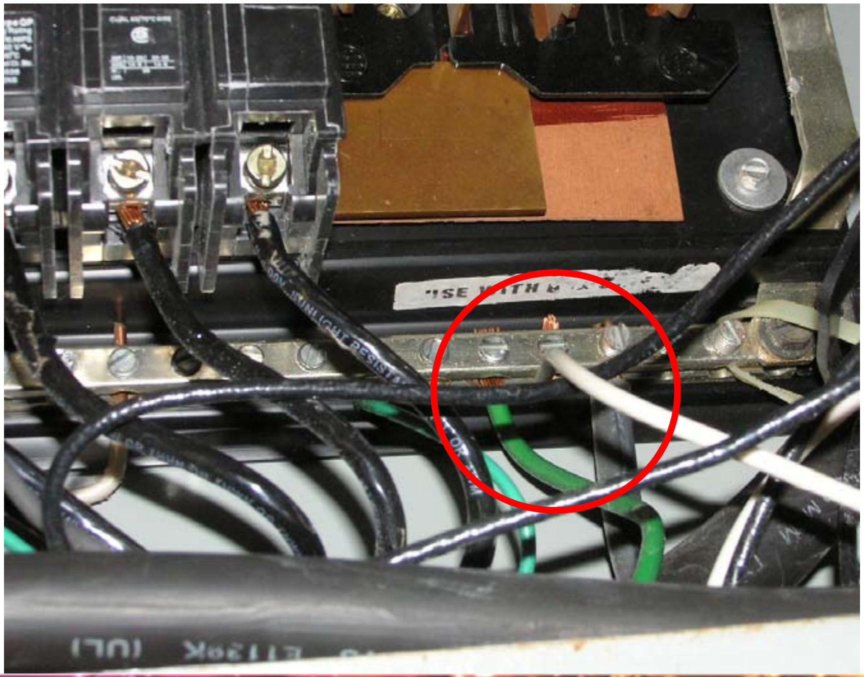


N-G Bonds

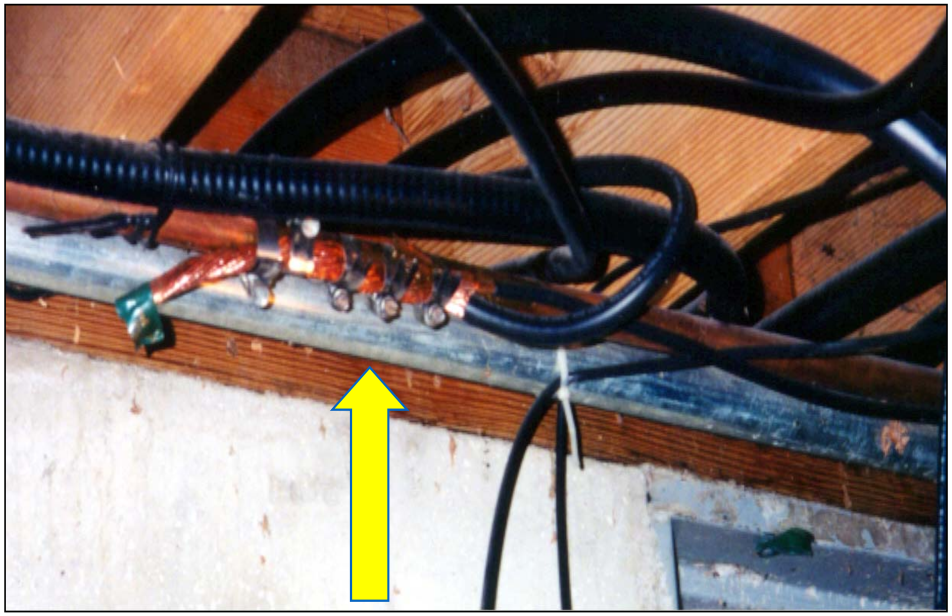
Interior:

- **Check neutral – ground voltage**
  - **- could mean harmonics**

- **Check for ground current**
  - **- illegal N-G bonds**



Use Only Listed Connectors



- Automotive hose clamps
- Water tube conductor

Limit Voltage Drop

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

Environment Considerations

- Automotive hose clamps
- Undersize conductors
- Rust
- Different metals

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

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

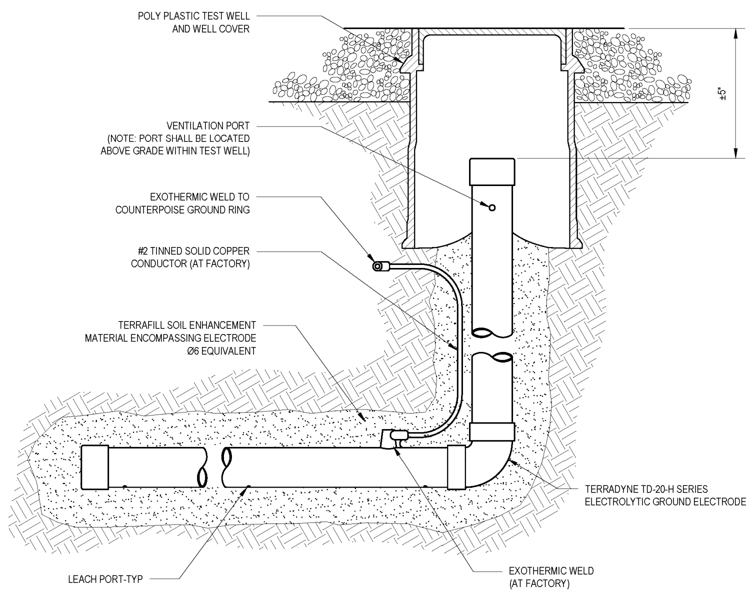
Augured Hole with Rod & Bentonite

- 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 wielded 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 the only Ground Improvement Material approved and recommended by the Copper Industry. (re: copper.org)

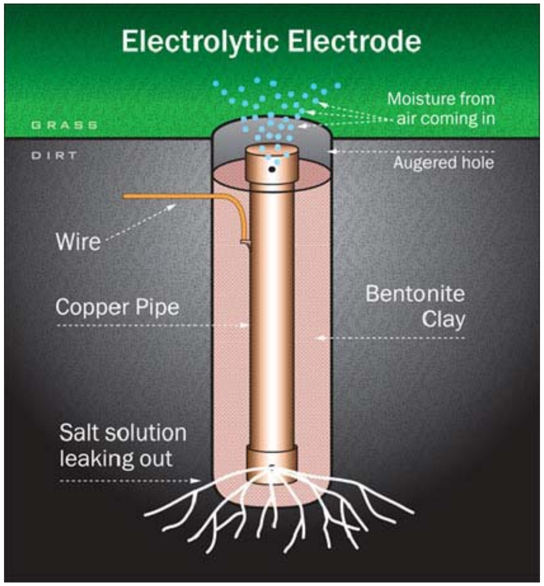
Chemical Ground Rods



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 a Copper pipe full of salt will last how long?



Chemical Electrodes

Salt-filled pipe after 7 years

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. GEM does 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.

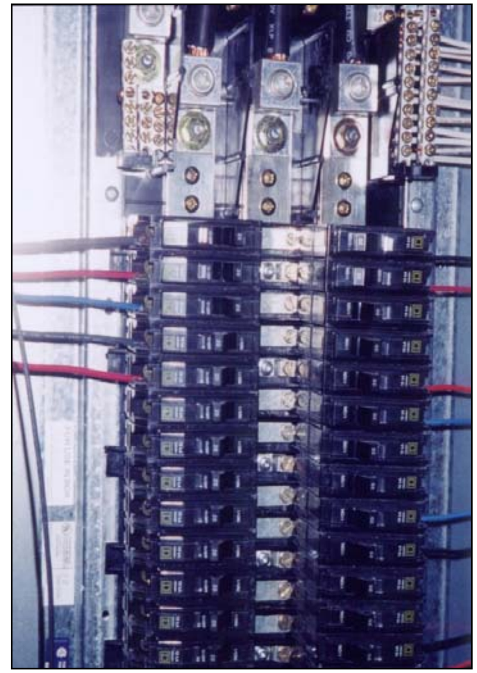
Galvanized Rod After 7 Years

Galvanized Rod

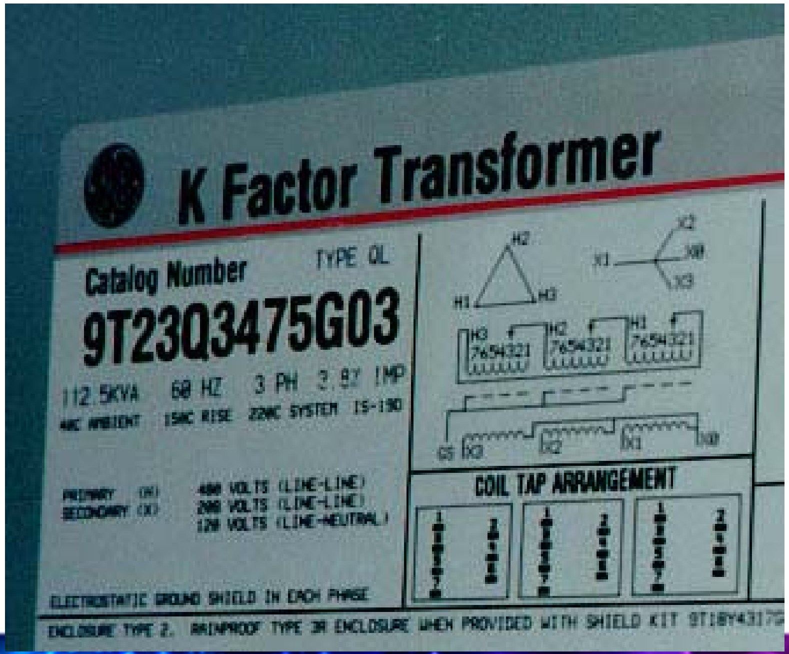
¾ inch to pencil-thin

Use bolt-in Circuit Breakers

Twist-lock plugs/receptacles



Harmonic rated panels and transformers

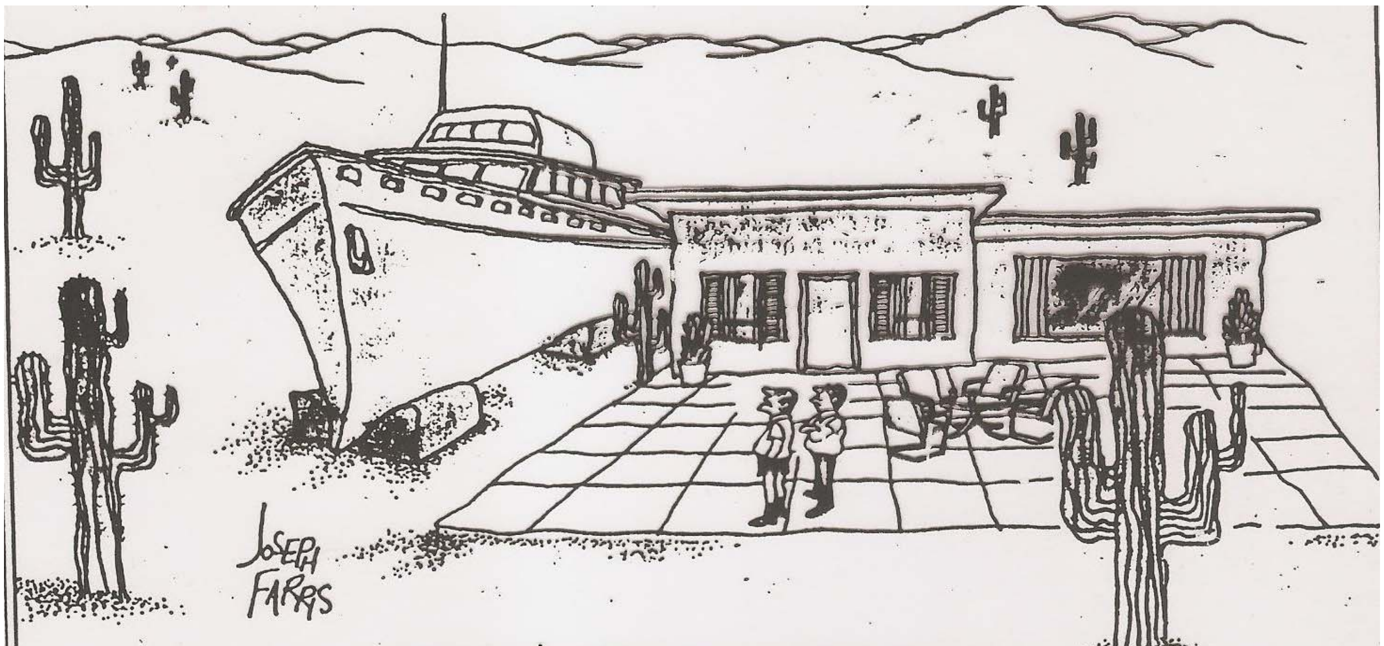


First Step

Get the wiring and grounding right

This may solve the problem at minimum cost!

Buy What I Sell



"I'll never forget him. He was quite a salesman."

Grounding System Must be Checked

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

Is Ufer Actually Grounded?

Bonded to rebar?

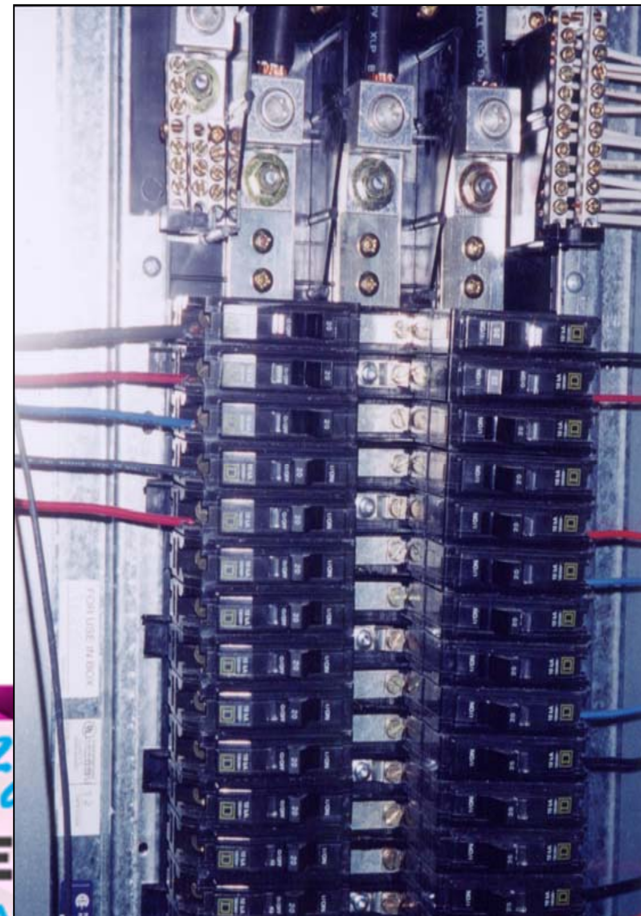
Building Steel Was Not Grounded

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

Sumter County 911

Review

- **Interior:**
- **Bolt-in circuit breakers**
- **Twist-lock plugs/receptacles**



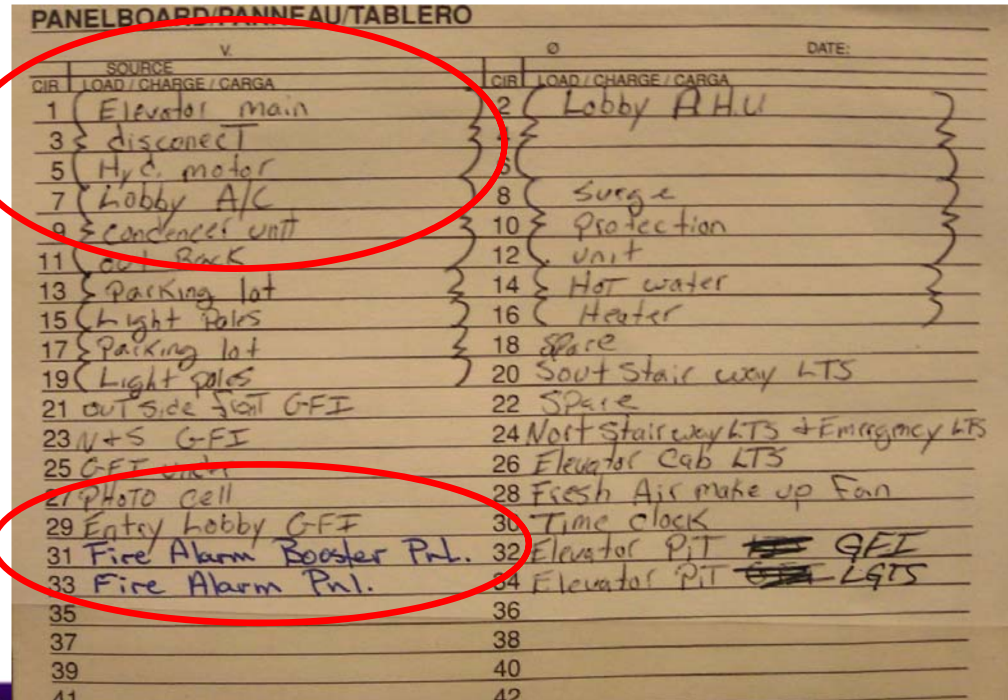
Does Lightning Flow Up?

Telephone grounding

Are connections proper?

Look for paint or other insulation

Do Not Mix Load Types



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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.

Tips

This stuff isn't taught in school.

"A man's got to know his limitations."

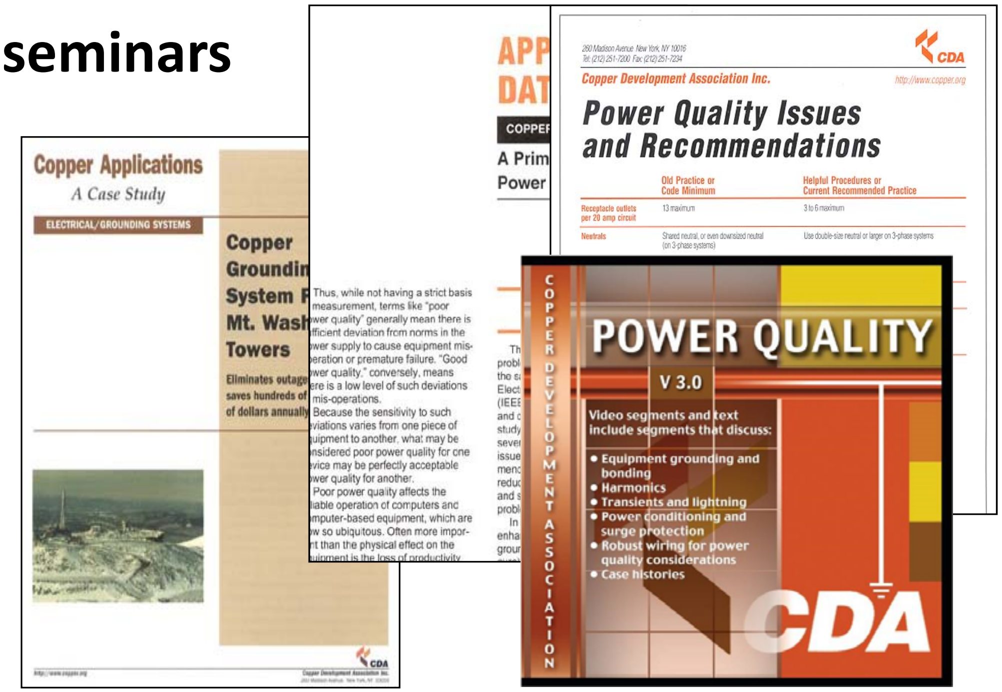
- Clint Eastwood as Dirty Harry

Call in a professional when there is doubt.

Free Educational Seminars

- **www.copper.org/electricalseminars**

- **Case Histories**
- **Recommendations**
- **Bibliography**
- **CD-ROMs, DVDs**



Thank You!

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