The Importance of Exceeding Minimum Grounding and Bonding in Mission-Critical Facilities

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2017
BICSI CANADIAN
CONFERENCE & EXHIBITION
MAY 8-11 • VANCOUVER, BRITISH COLUMBIA, CANADA

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Agenda

1. A Review of National Electrical Code minimum requirements
2. Considerations for sensitive locations and equipment

The Mystery

- The subject of grounding and bonding of electrical systems is often misunderstood
- Related topics are often debated widely
- Are grounded systems safer than ungrounded?
- Many systems are required to be grounded
- Several circuits are *not* permitted to be grounded
- The *NEC*® has ended the debate!

Speaking the Same Language

- Inconsistent use of terms related to grounding and bonding:
  - Is common
  - Results in confusion
- Do terms “grounded” and “bonded” mean the same thing?
- Are they interchangeable?

Speaking the Same Language (cont'd.)

- Is a receptacle on the 27th floor of a building still "grounded?"
- Definition of "*Grounded*" is, "Connected (connecting) to ground or to a conductive body that extends the ground connection."
- Understanding definitions is essential to proper application of the rules related to grounding and bonding

Definitions

- An excellent understanding of definitions is essential to understanding grounding and bonding
- Several definitions have changed from the previous edition of the *NEC®*
- Many rules in the *NEC®* have become more prescriptive to rely less on defined terms

Ground: *NEC*® *Article* 100

- "The earth" consists of many types of soil
  - Soil resistance is determined largely by its content of electrolytes which consist of moisture, minerals and dissolved salts

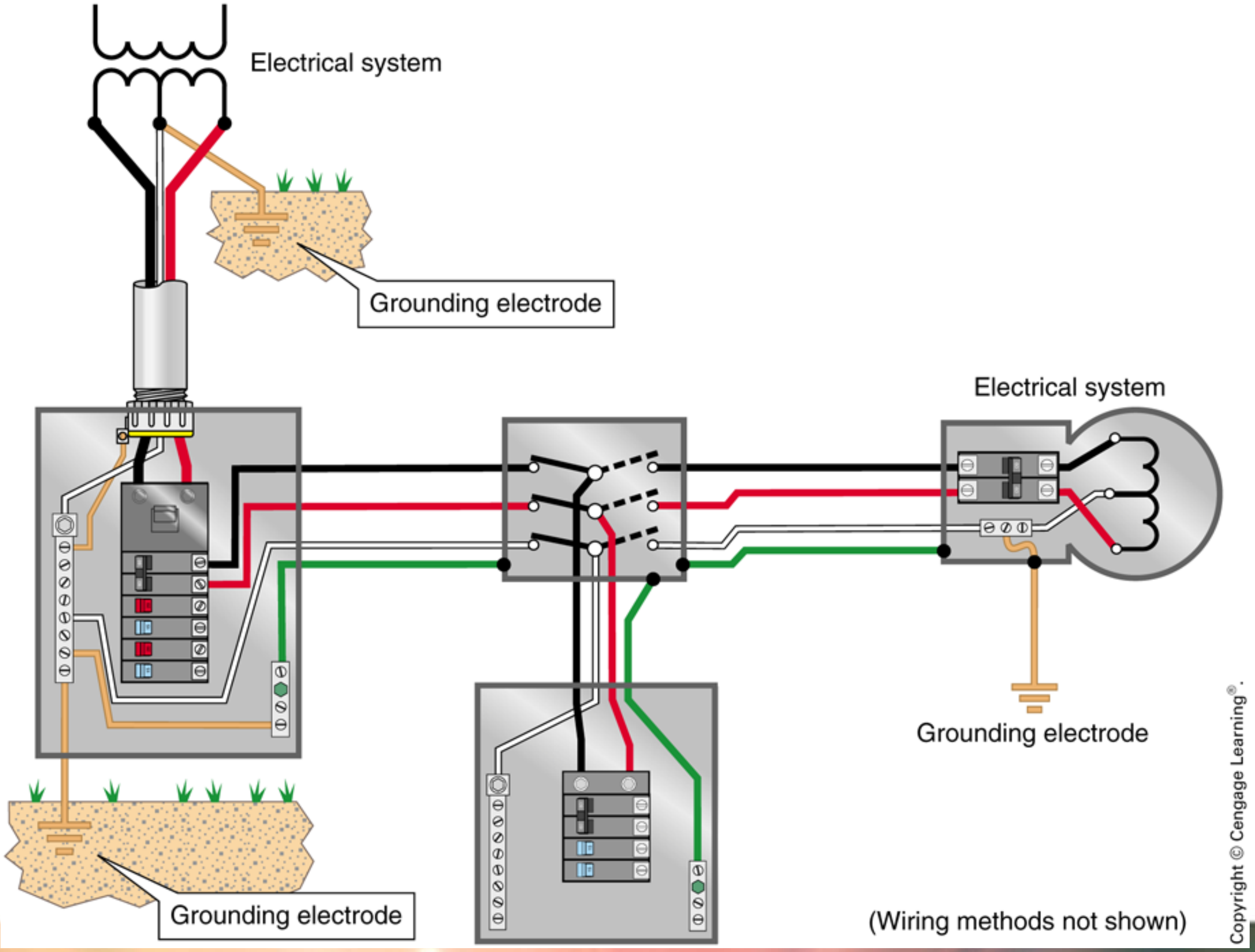
FIGURE I-1 The earth is made up of many different types of soil.

Ground (cont'd.)

- Soil resistance varies from an average of 2370 ohm-centimeters for ashes, cinders, brine or waste to 94,000 ohm-centimeters for gravel, sand, and stones with little clay or loam
- The earth's ability to carry current varies widely
- In the *NEC*®, connections to earth are not permitted for the purpose of carrying current

Grounded (Grounding), *Article* 100

- "Connected (connecting) to ground or to a conductive body that extends the ground connection"
  - Connection to ground is accomplished by means of a recognized grounding electrode (system). See *Parts II* and *III* of *Article 250*
  - Grounded objects such as metal conduit, cables with metallic sheaths and structural metal may "extend the earth connection"


Electrical system
Grounding electrode
Electrical system
Grounding electrode
Grounding electrode
(Wiring methods not shown)
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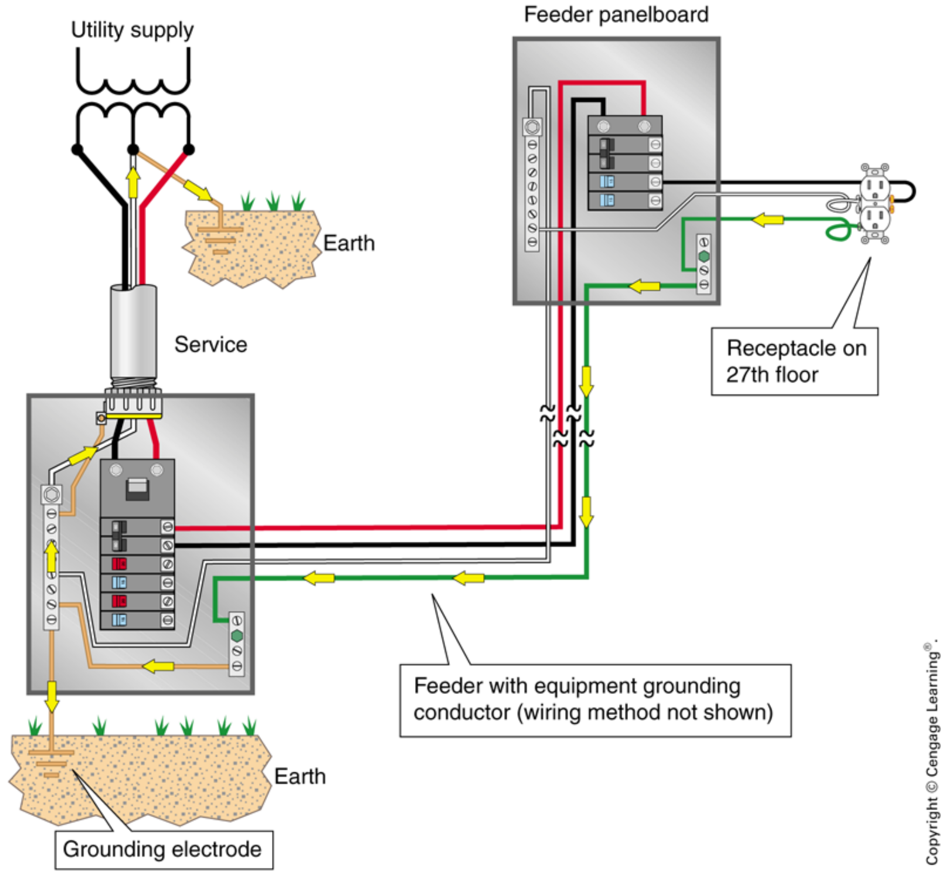

Utility supply
Feeder panelboard
Earth
Service
Receptacle on 27th floor
Feeder with equipment grounding conductor (wiring method not shown)
Earth
Grounding electrode
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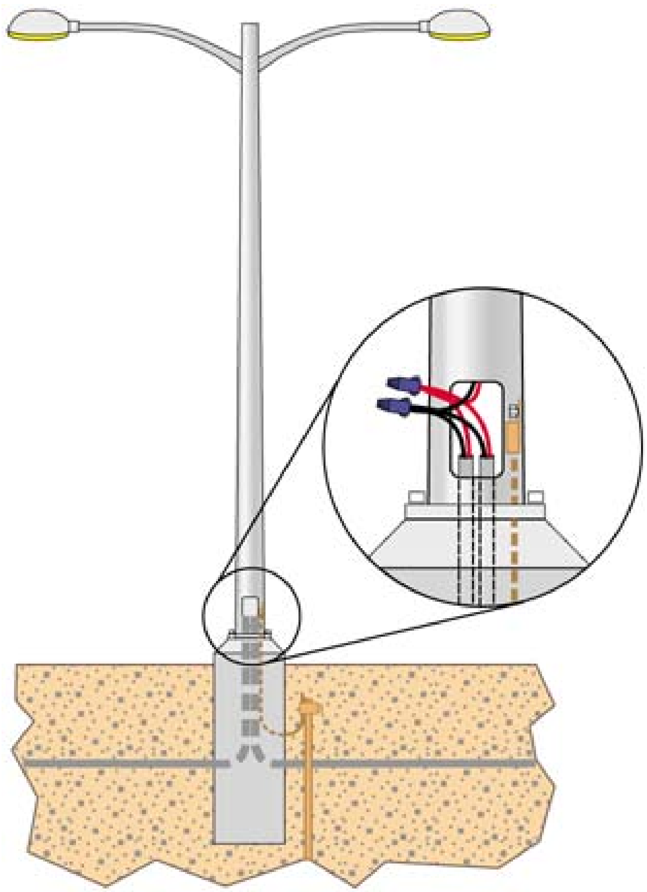
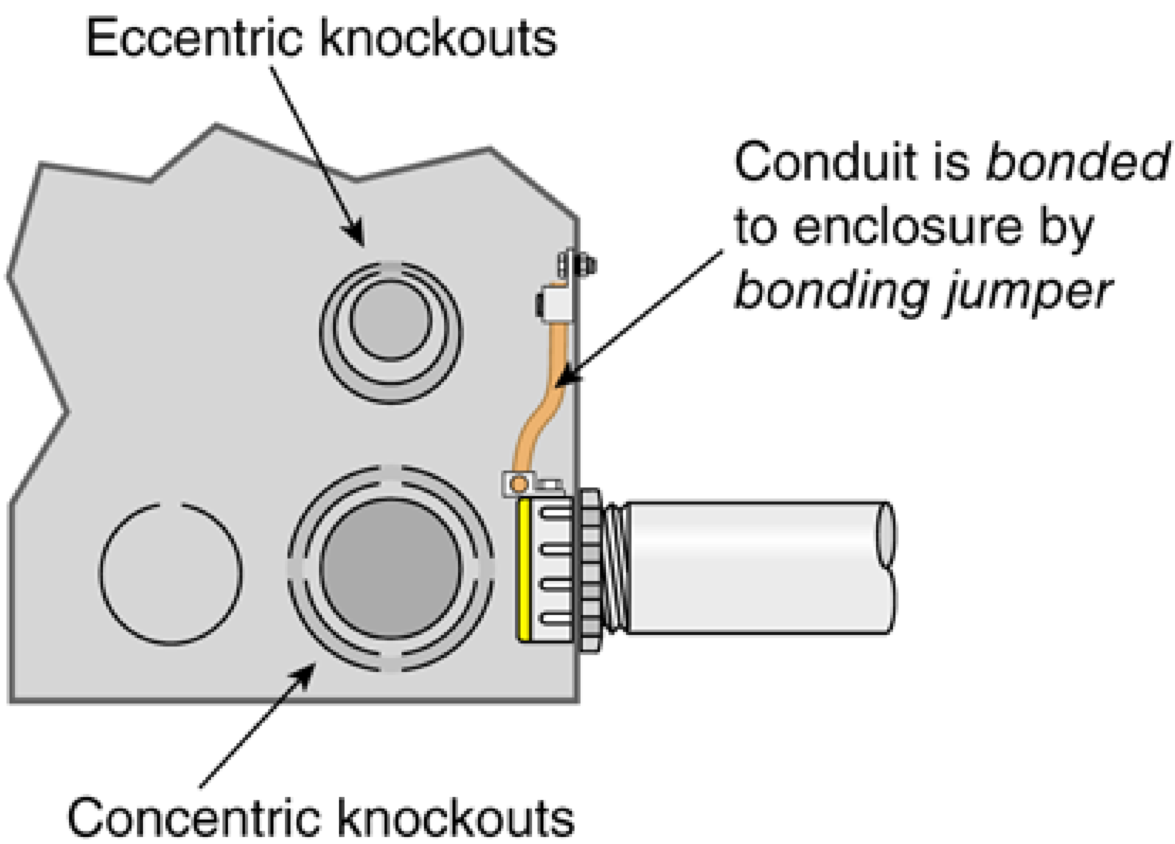


Lighting standard
connected to
ground rod only.
VIOLATION

Bonded (Bonding), *NEC® Article* 100

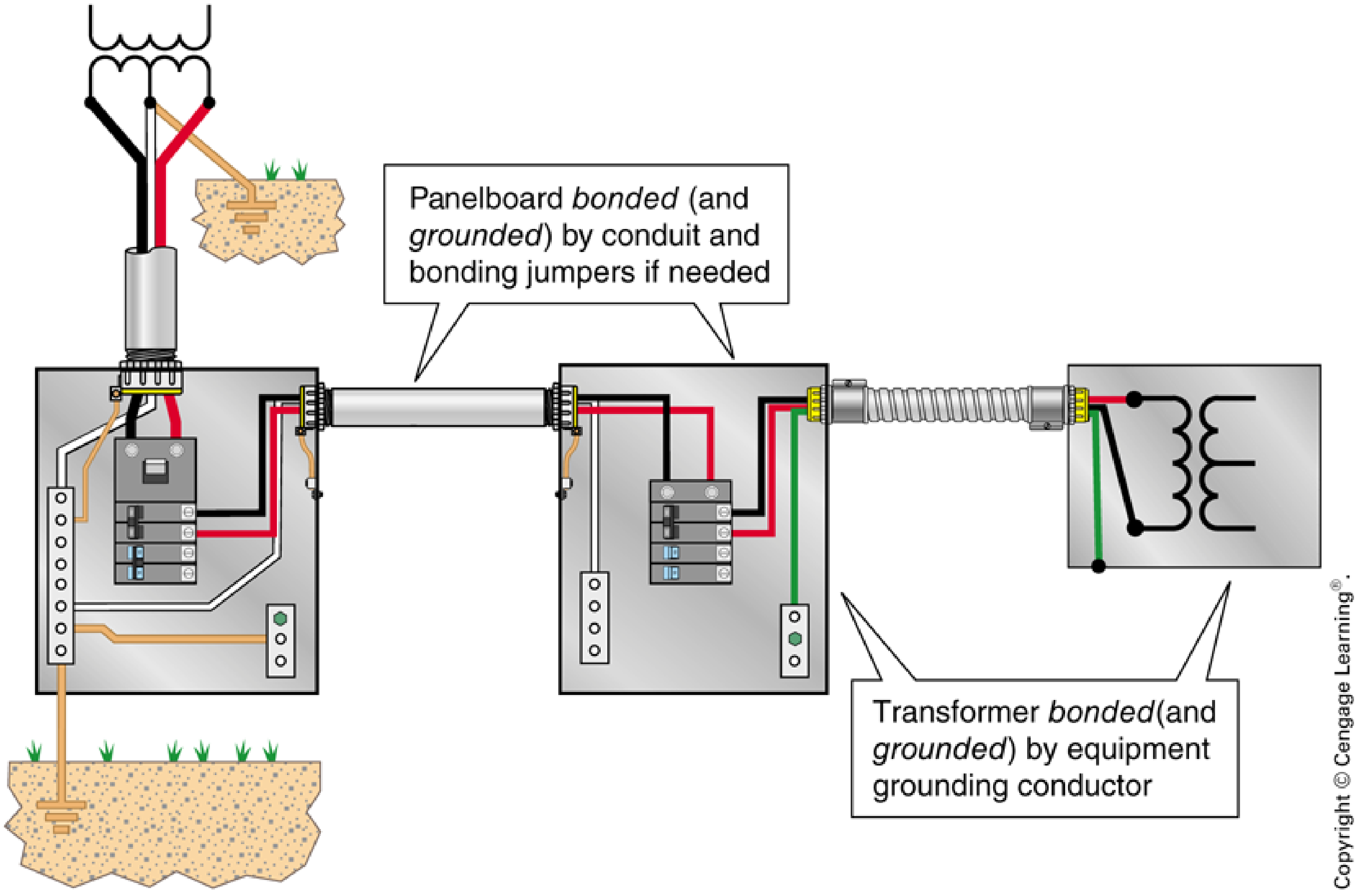
- "Connected to establish electrical continuity and conductivity"
- In its simplest form, the definition means the conductor and connections to connect equipment together and to provide a complete path for current to flow
- Bonding ensures conductivity around suspect connections



Eccentric knockouts
Conduit is *bonded* to enclosure by *bonding jumper*
Concentric knockouts

Bonded (Bonding)

- Conduit or equipment grounding conductor in Type MC or other wiring method are permitted to be used to bond (connect) enclosures together.
- The function of equipment grounding and bonding become inseparable



Panelboard *bonded* (and *grounded*) by conduit and bonding jumpers if needed
Transformer *bonded*(and *grounded*) by equipment grounding conductor
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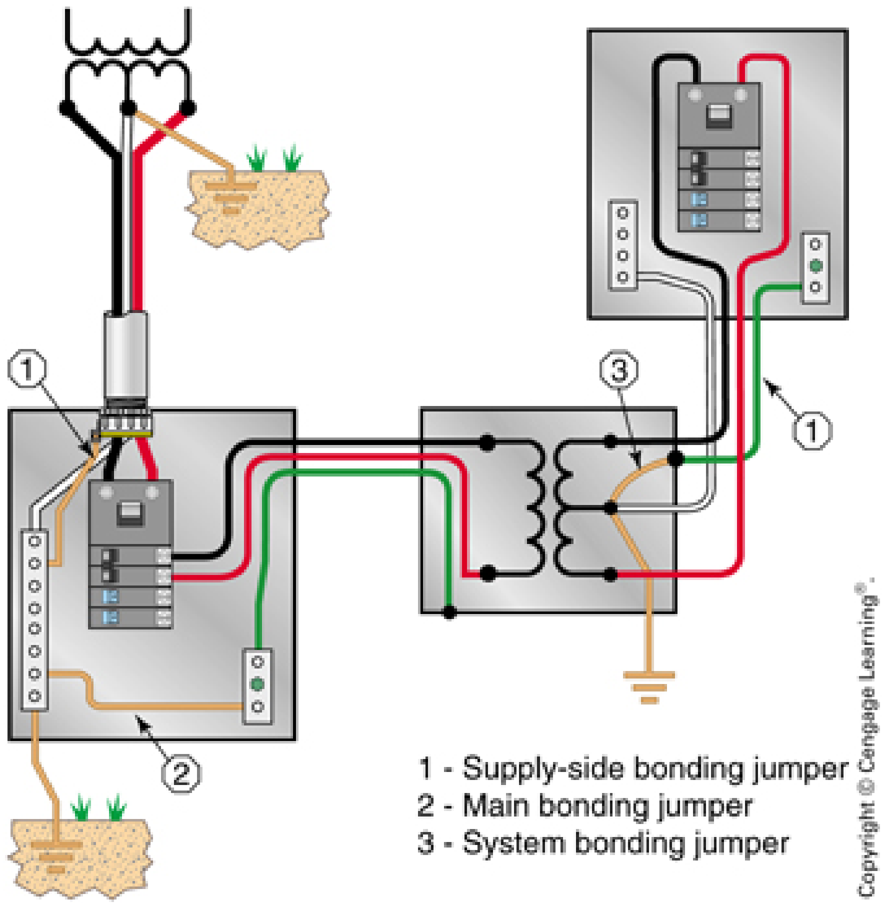
1
2
3
1
1 - Supply-side bonding jumper
2 - Main bonding jumper
3 - System bonding jumper
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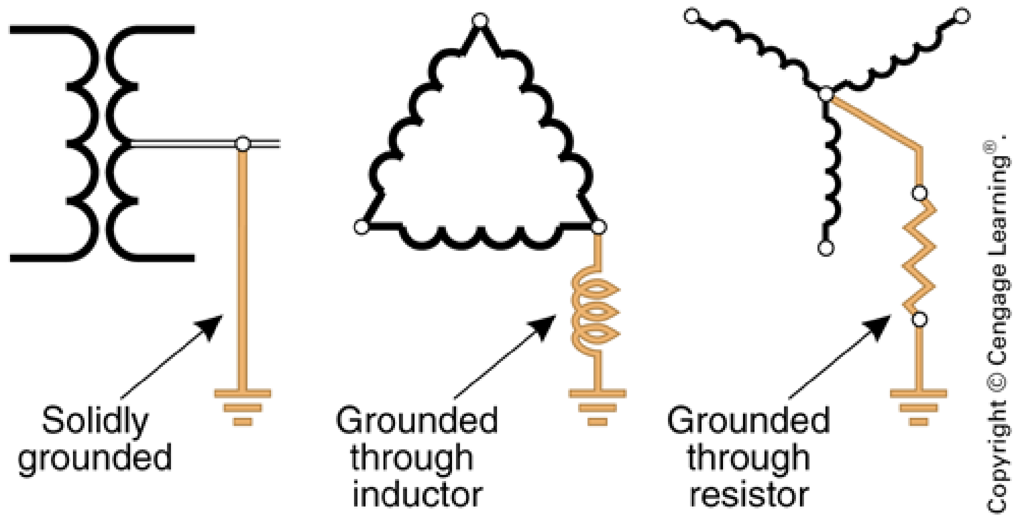
Grounded, Solidly

- "Connected to ground without inserting any resistor or impedance device."
- Considered "solidly grounded" if a resistor or impedance device such as an inductor are not inserted in the connection of the system or equipment to the grounding electrode
- High impedance grounding is covered in *250.36*

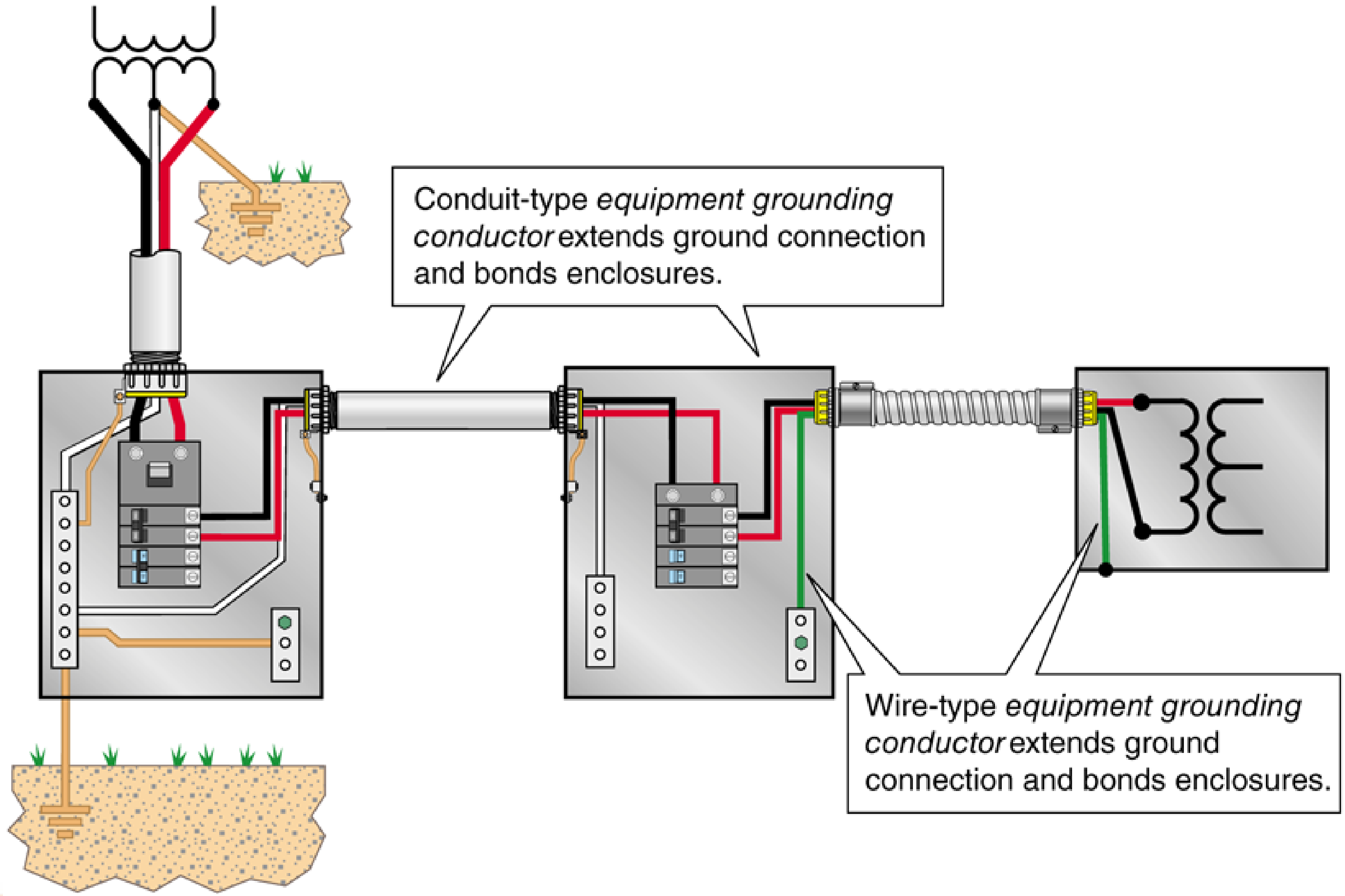
Grounded, Solidly

- "Connected to ground without inserting any resistor or impedance device."
  (Article 100)



Equipment Grounding Conductor (EGC), *NEC® Article* 100

- "The conductive path(s) that provides a ground-fault current path and connects normally non–current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both."


Conduit-type *equipment grounding conductor* extends ground connection and bonds enclosures.
Wire-type *equipment grounding conductor* extends ground connection and bonds enclosures.

Equipment Grounding Conductor (cont'd.)

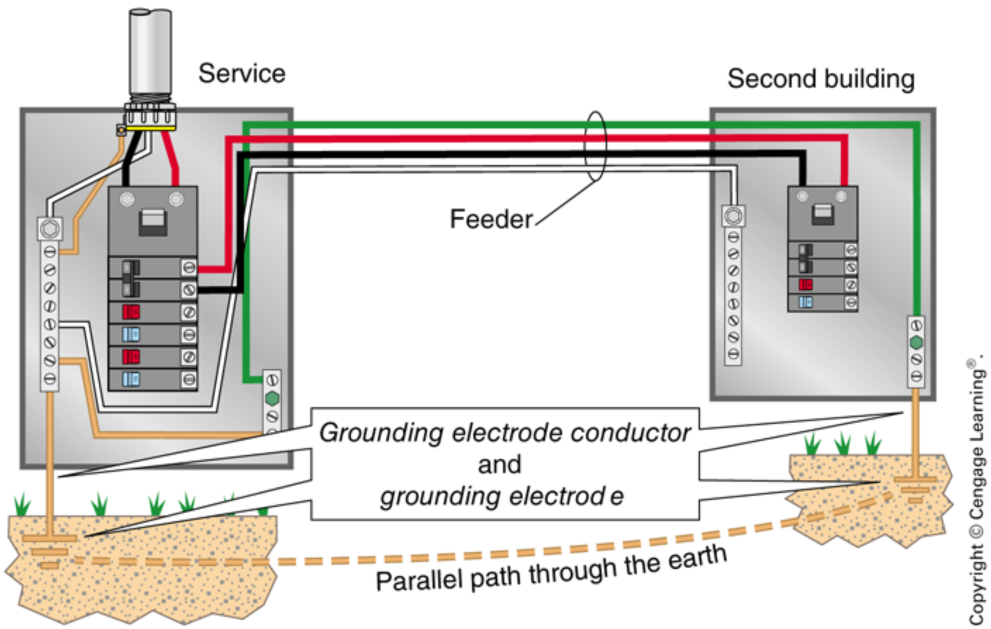
- Conductive ground-fault current path is provided by the EGC
  - Paths recognized include a wire or bus, metallic raceways and metallic cable sheaths
- "Normally non-current-carrying metal parts of equipment …"
  - Equipment grounding conductors do not normally carry current
  - Neutral conductors carry current under normal conditions

Grounding Electrode, *NEC® Article* 100

- Descriptions of grounding electrodes required to be used are in *250.52(A)*
- Grounding electrodes are never used to provide a fault-current path
- Used to make an earth connection
- See Appendix C of this text for testing methods of grounding electrodes

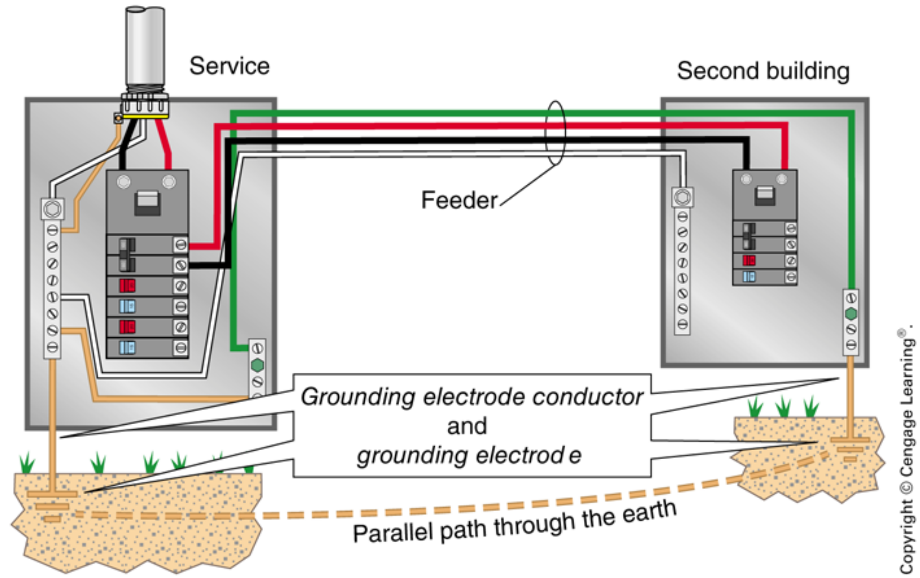
Grounding Electrode (cont'd.)

- "A conducting object through which a direct connection to earth is established."



Grounding Electrode Conductor

"A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system."



Grounding Electrode Conductor (cont'd.)

- Specific rules are provided in *Article 250* for the sizing and installation of grounding electrode conductors, as well as where they are required to be connected to the electrical system or equipment
  - In some cases, specific requirements; in others, considerable flexibility on installation methods

Intersystem Bonding Termination, *NEC® Article* 100

- "A device that provides a means for connecting intersystem bonding conductors for communications systems to the grounding electrode system."
  - Revised for the 2014 *NEC®* and more specific
  - Provides common location for connecting bonding conductors for communications systems
  - Common bonding helps prevent flashover due to elevated voltage events

Intersystem Bonding Termination (cont'd.)

Photograph is reprinted with permission and provided courtesy of ERICO International Corporation

"A device that provides a means for connecting bonding conductors for communications systems to the grounding electrode system."

Effective Ground-Fault Current Path, *NEC® Article* 100

- "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.
- "Facilitates the operation of the overcurrent device or ground fault detectors."

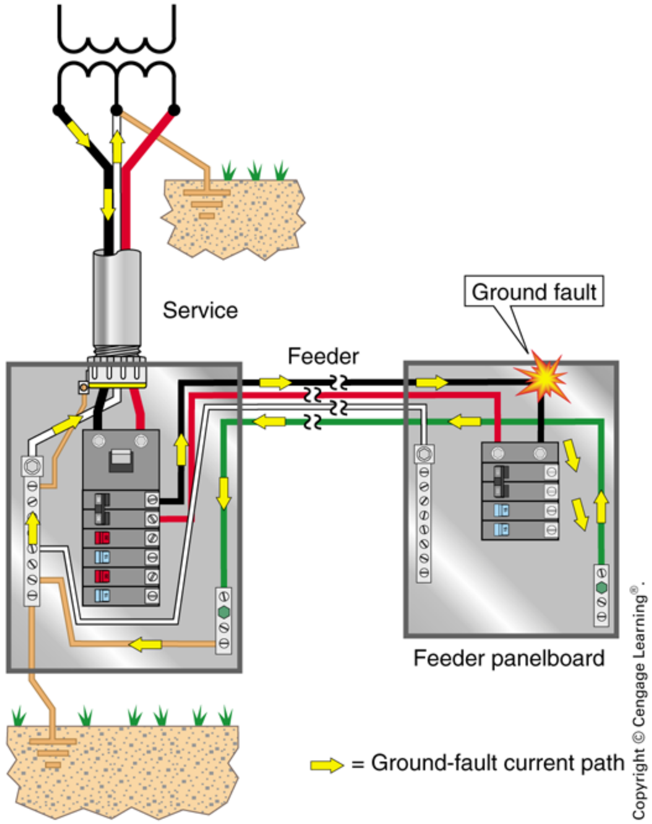


FIGURE I-20 Effective ground-fault current path

Effective Ground-Fault Current Path (cont'd.)

- Intentionally constructed
- Doesn't "just happen"
- Deliberate steps taken to create
- Properly connect all components
- Carries fault-current to facilitate operation of overcurrent device or ground-fault detector

Effective Ground-Fault Current Path (cont'd.)

- Low-impedance
- "Impedance" is total opposition to current flow in ac circuits
- All circuit conductors must be installed in close proximity
- See *250.134* and *300.3(B)*

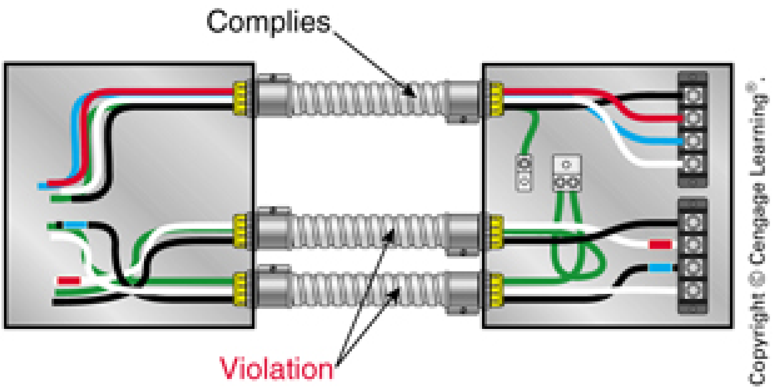


FIGURE 1-21 All conductors of same circuit together

Effective Ground-Fault Current Path (cont'd.)

- All circuit conductors must be installed in close proximity so magnetic lines of force can cancel
- This helps ensure a low-impedance fault-current path

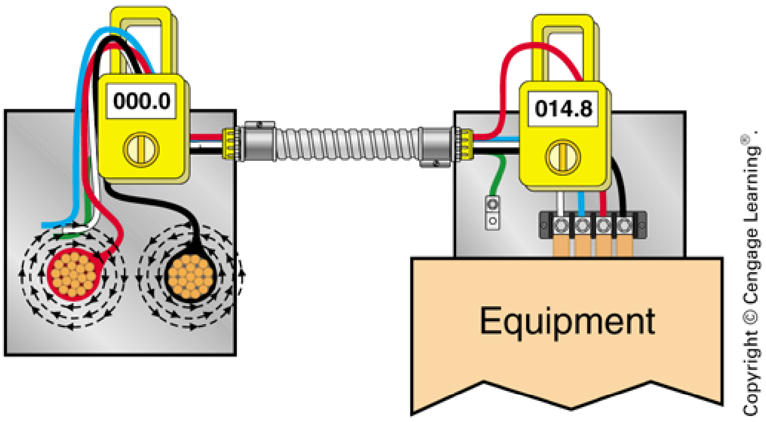


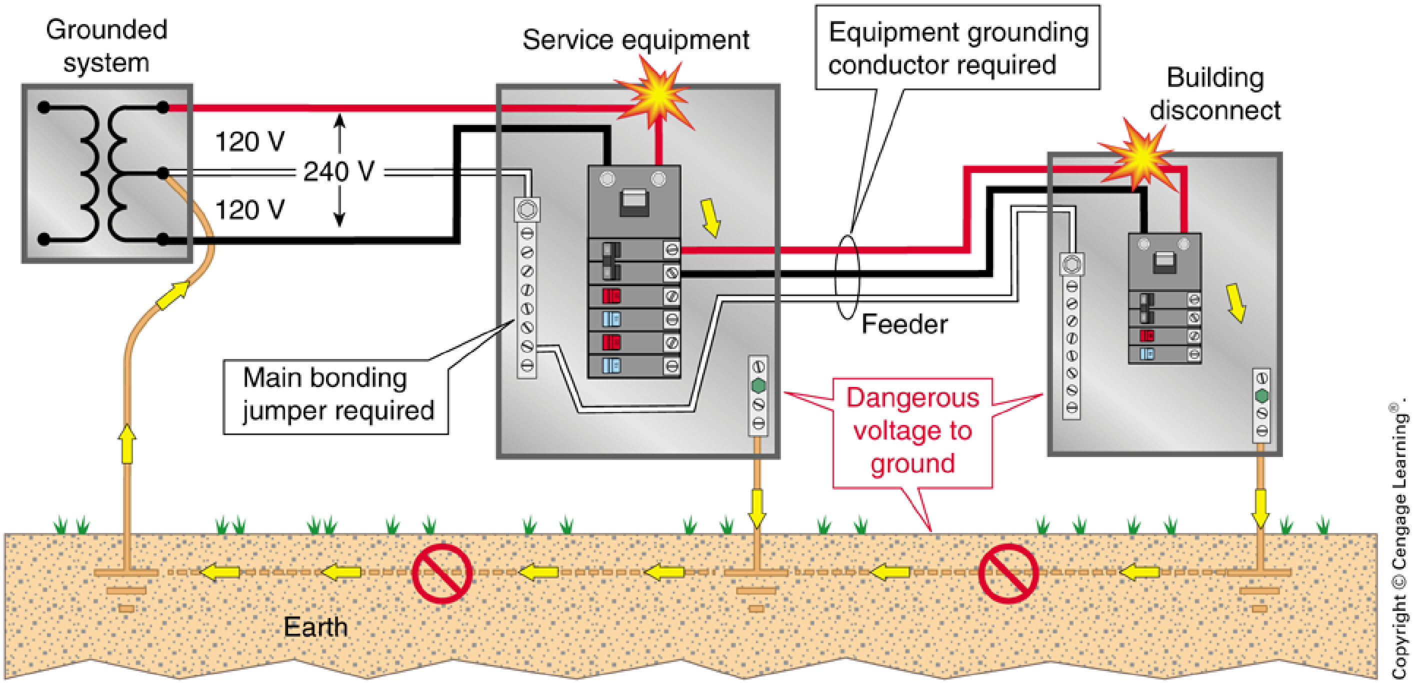
FIGURE 1-22 Expanding and collapsing magnetic lines of force around ac circuits.

Effective Ground-Fault Current Path

- *Continuous* and *reliable*
- Components and connections are intended to last for the life of the installation
- Unless monitored, equipment grounding path can be incomplete without indication
- Does not carry current in normal operation
- Often, a break in the Path is discovered by electric shock after faulted equipment becomes energized

Path Through the Earth

- The path through the earth is in parallel with ground-fault current return path where more than one connection to earth exists
- The earth is not considered an "effective ground-fault current path"
- Connections are made to earth for other purposes, but never to carry fault current
- Path only through the earth will result in electrical equipment presenting a dangerous electric shock hazard


Grounded system
120 V
240 V
120 V
Service equipment
Equipment grounding conductor required
Building disconnect
Feeder
Main bonding jumper required
Dangerous voltage to ground
Earth
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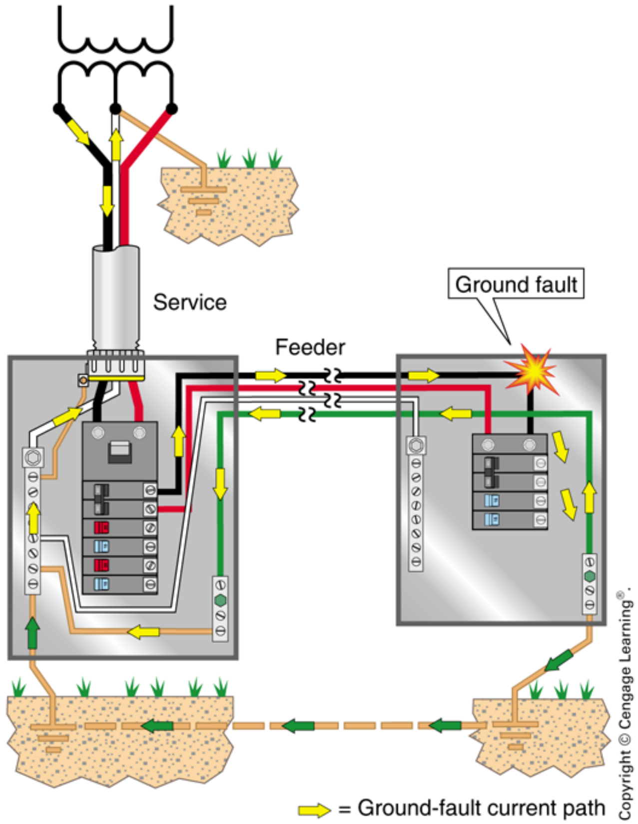
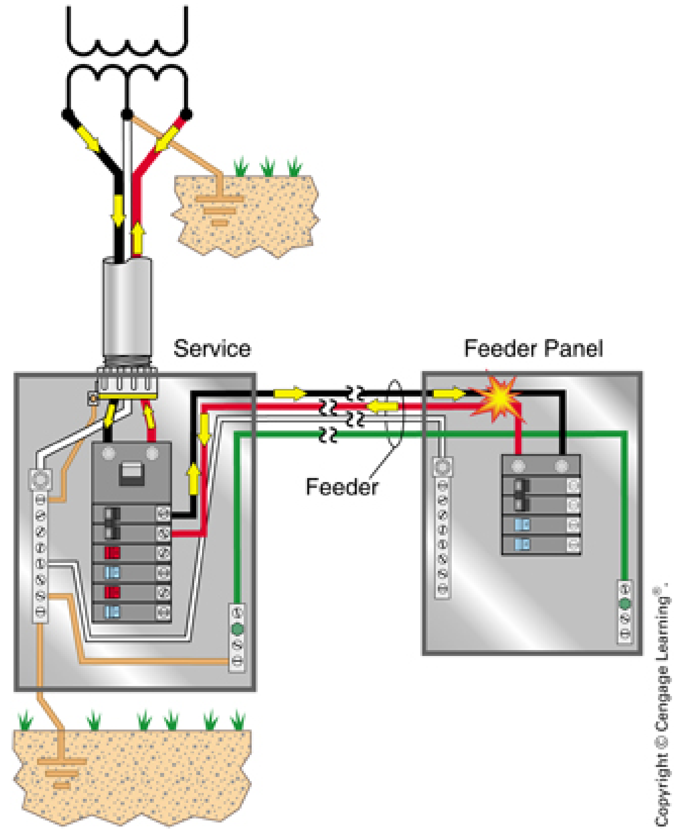
Ground Fault

An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment or earth



Short Circuit

An abnormal connection of relatively low impedance, whether made accidentally or intentionally, between two points of different potential on any circuit

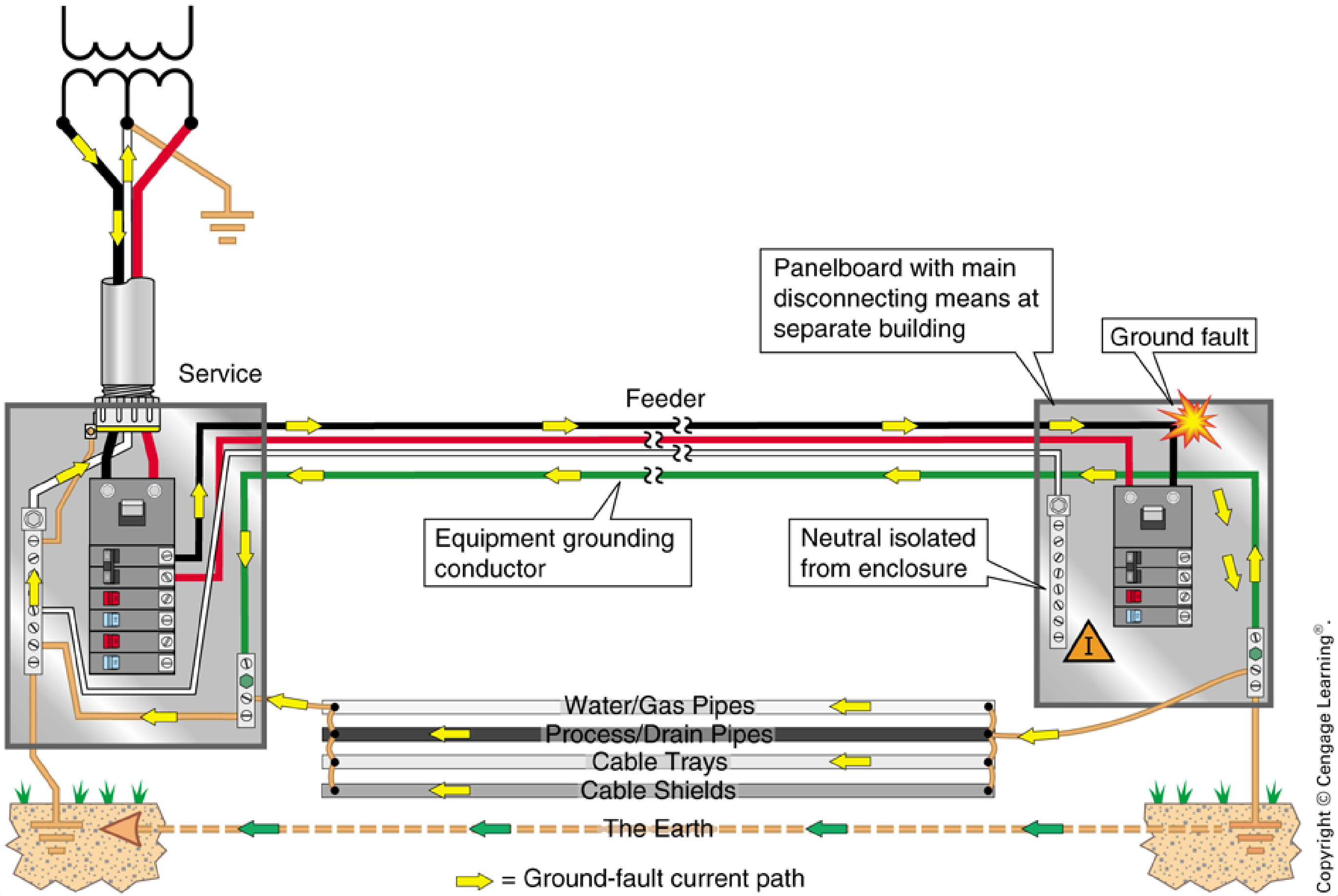


Ground-Fault Current Path, *NEC® Article* 100

- "An electrically conductive path from the point of a ground fault on a wiring system through normally non-current-carrying conductors, equipment, or the earth to the electrical supply source."

Ground-Fault Current Path (cont'd.)

- "Informational Note: Examples of ground-fault current paths could consist of any combination of equipment grounding conductors, metallic raceways, metallic cable sheaths, electrical equipment, and any other electrically conductive material such as metal water and gas piping, steel framing members, stucco mesh, metal ducting, reinforcing steel, shields of communications cables, and the earth itself."


Panelboard with main disconnecting means at separate building
Ground fault
Service
Feeder
Equipment grounding conductor
Neutral isolated from enclosure
Water/Gas Pipes
Process/Drain Pipes
Cable Trays
Cable Shields
The Earth
= Ground-fault current path
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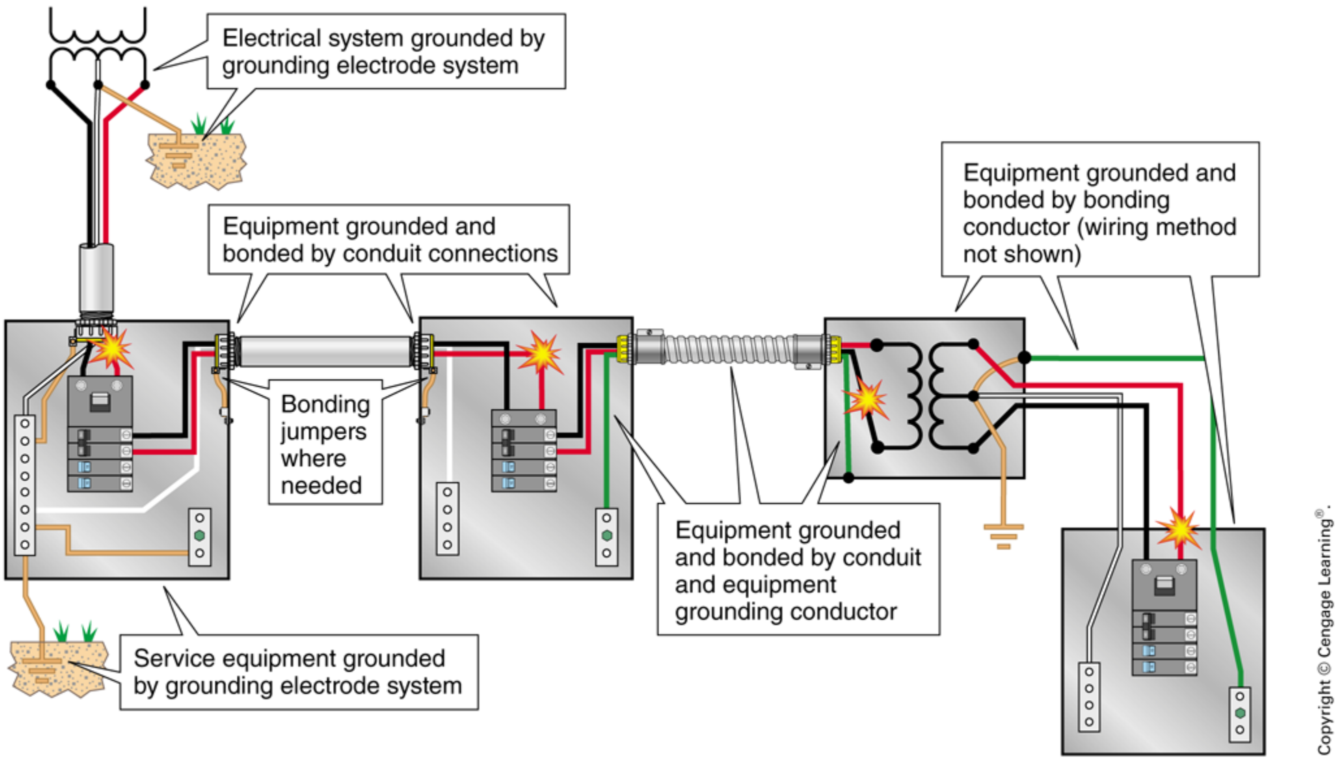
250.4 General Requirements for Grounding and Bonding

- The "prescriptive methods" contained in *Article 250* are to be followed to comply with the "performance requirements" of this section
- *250.4(A)(1)* gives example of performance goal
- No specific measurable requirements are provided

250.4 General Requirements for Grounding and Bonding



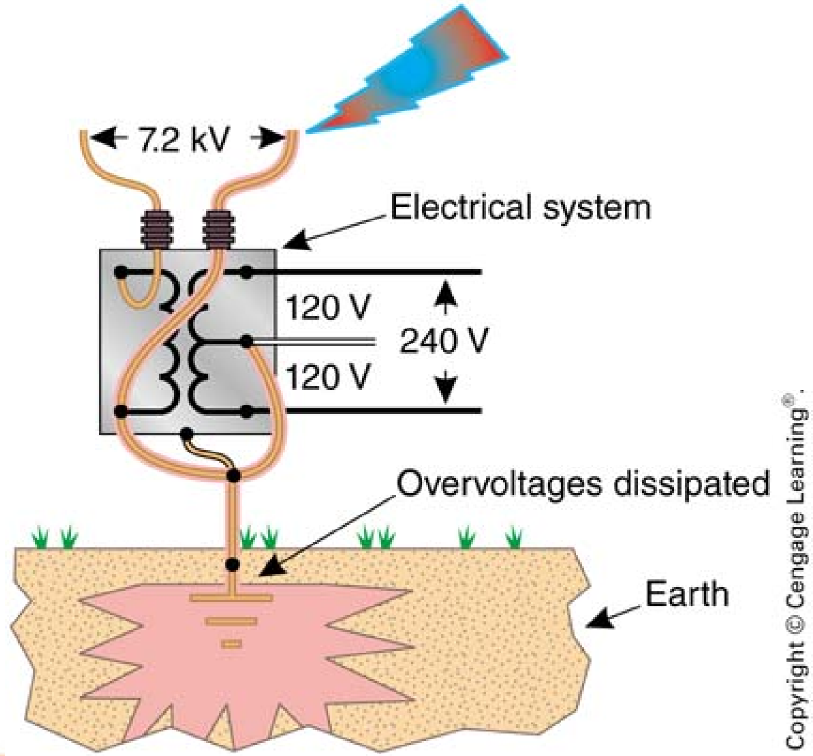
250.4(A) Grounded Systems

- *250.4(A)* provides "performance" rules for grounded systems
- *250.4(B)* provides "performance" rules for ungrounded systems

250.4(A)(1) Electrical System Grounding

- Electrical systems that are grounded are required to be connected to earth in a way that will limit the voltage imposed by
  - Lightning,
  - Line surges
  - Unintentional contact with higher-voltage lines
- Will stabilize the voltage of the system to earth during normal operation

250.4(A)(1) Electrical System Grounding



250.4(A)(1) Electrical System Grounding

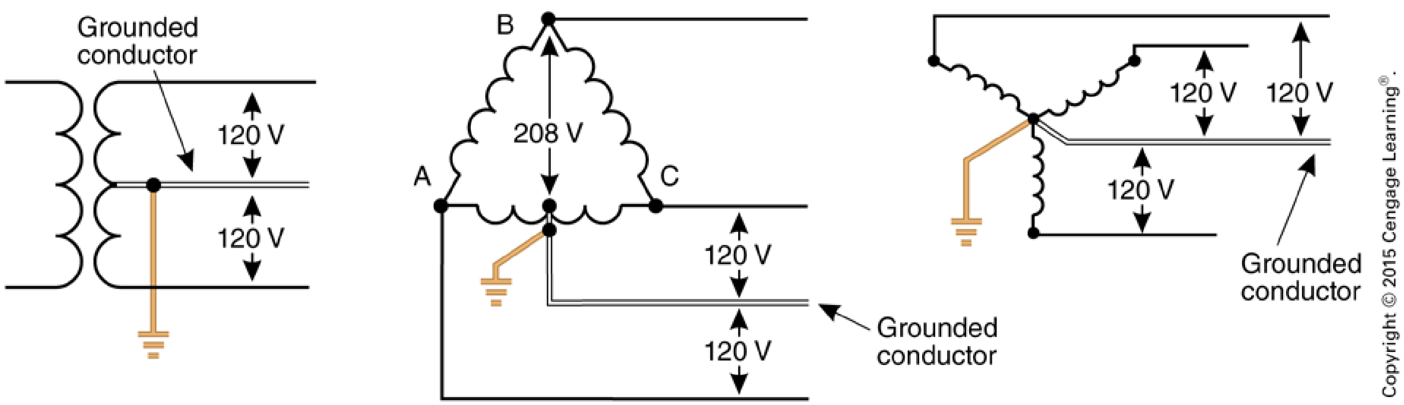
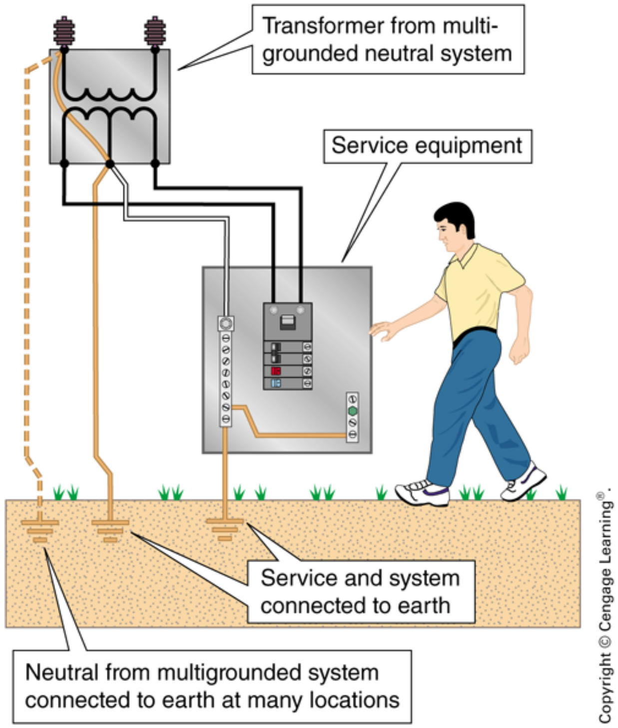


FIGURE 1-3 Typical voltages to ground

250.4(A)(2) Grounding of Electrical Equipment

- "Normally non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are required to be connected to earth to limit the voltage to ground on these materials."



250.4(A)(2) Grounding of Electrical Equipment

A shock or electrocution hazard can occur if there is a break in the ground-fault return path

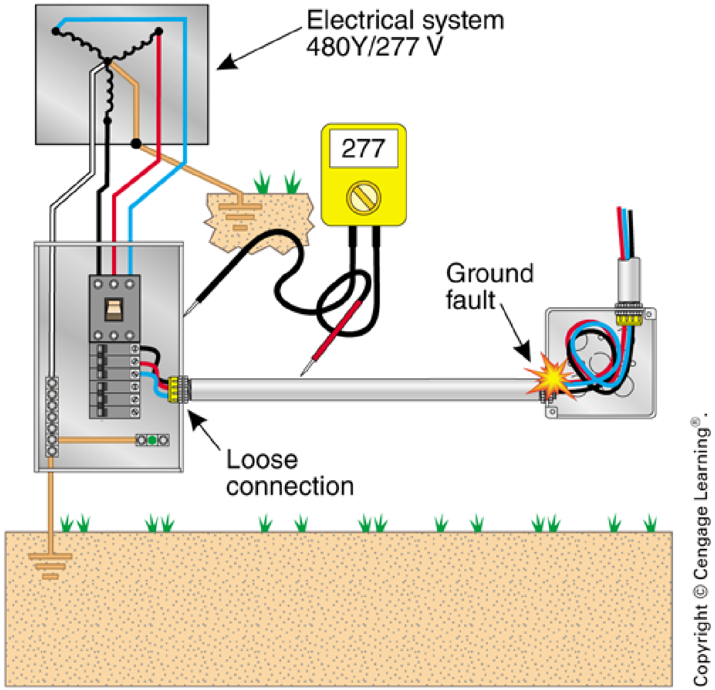


FIGURE 1-5 Break in ground-fault return path

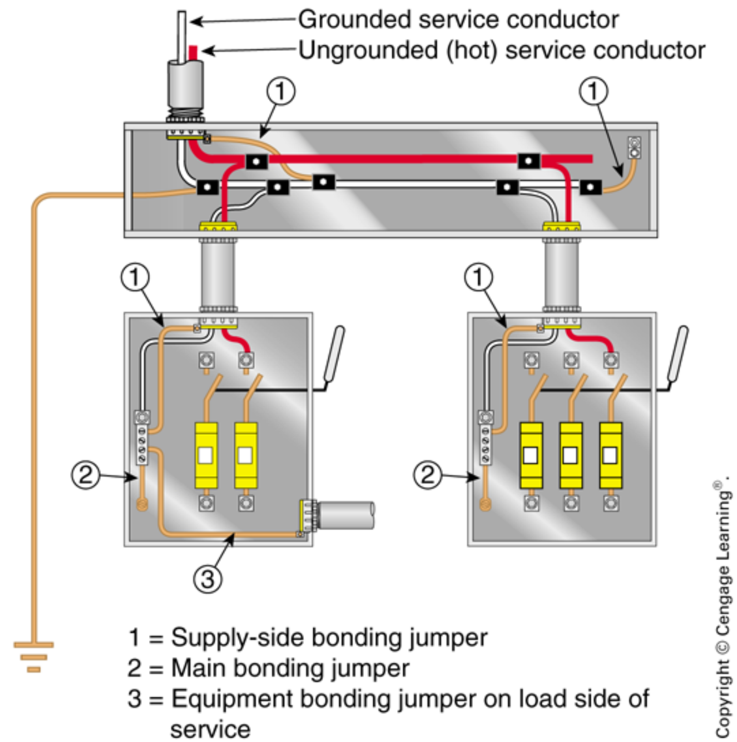
250.4(A)(3) Bonding of Electrical Equipment

- Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are required to be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path

250.4(A)(3) Bonding of Electrical Equipment

In its simplest form, bonding completes a path through which current can flow

- Also keeps connected parts at the same potential
- Eliminates shock hazard



Bonding Jumpers Required

- Instances where required:
  - Loose locknut connections
  - For conduit or cable connections to painted enclosures
  - Service equipment enclosures
  - Around concentric and eccentric knockouts
  - Around knockout reducing washers (if suspect connection)
  - Hazardous (classified) locations
  - Over 250 volts-to-ground

250.4(A)(4) Bonding of Electrically Conductive Materials

Normally non-current-carrying electrically conductive materials that are likely to become energized are required to be connected together and to the electrical supply source to form effective ground-fault current path

FIGURE 1-7 Bonding conduits to panelboard cabinet

250.4(A)(5) Effective Ground-Fault Current Path

- Electrical equipment and other electrically conductive material likely to become energized to be connected (bonded) in a manner that is:
  1. Reliable
  2. Provides a circuit of low impedance
  3. The conductor must be capable of safely carrying the maximum ground-fault current likely to be imposed on it

250.4(A)(5) Effective Ground-Fault Current Path (cont'd.)

- Metal conduit becomes current-carrying conductor when returning fault current to source
- Single loose locknut or loose or broken fitting can result in break in fault path

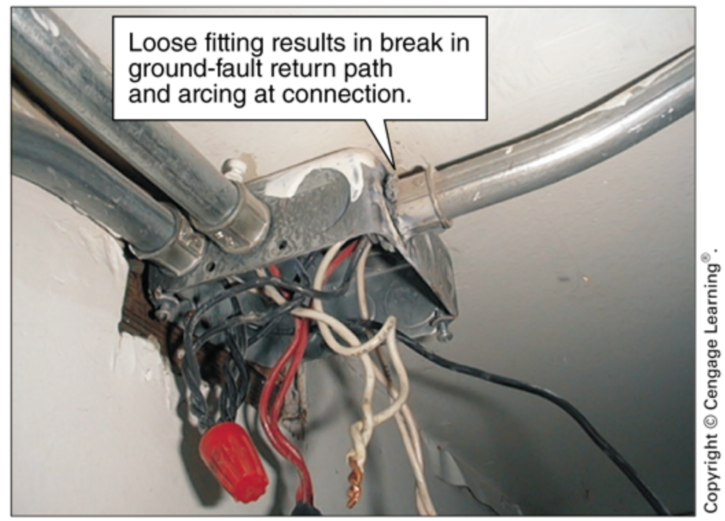


FIGURE 1-8 Loose fitting at box creates shock hazard

250.4(A)(5) Effective Ground-Fault Current Path (cont'd.)

- Ohmic value of low-impedance path not provided in *NEC®*
- Keep all circuit conductors, including ungrounded, grounded and equipment grounding conductors together

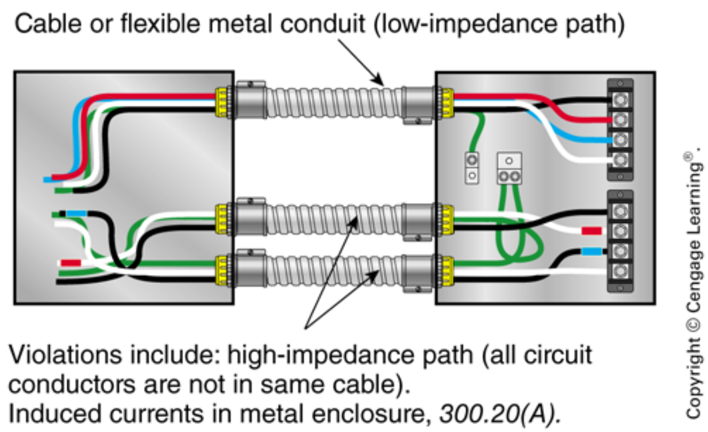


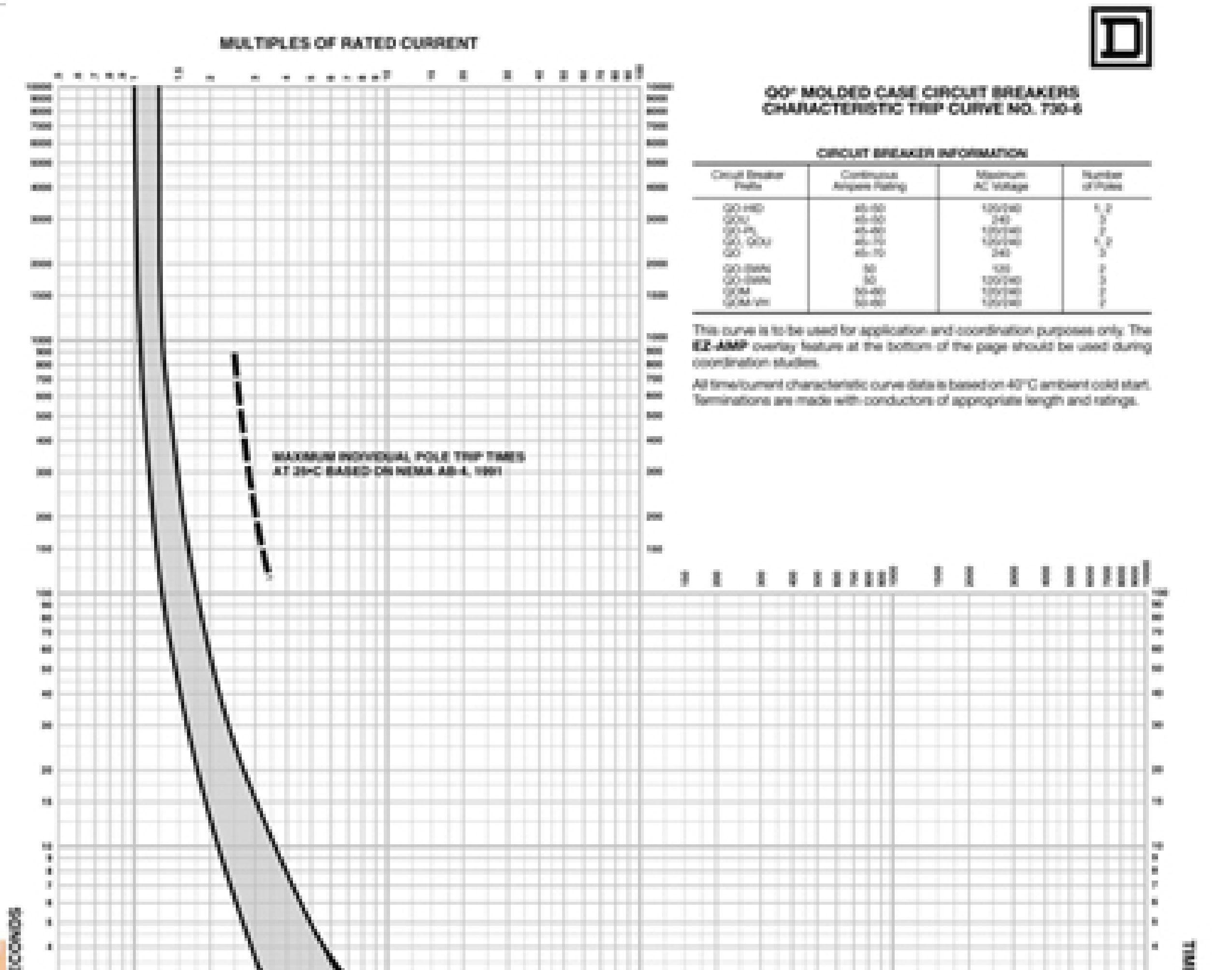
FIGURE 1-9 Low-impedance circuit and violation

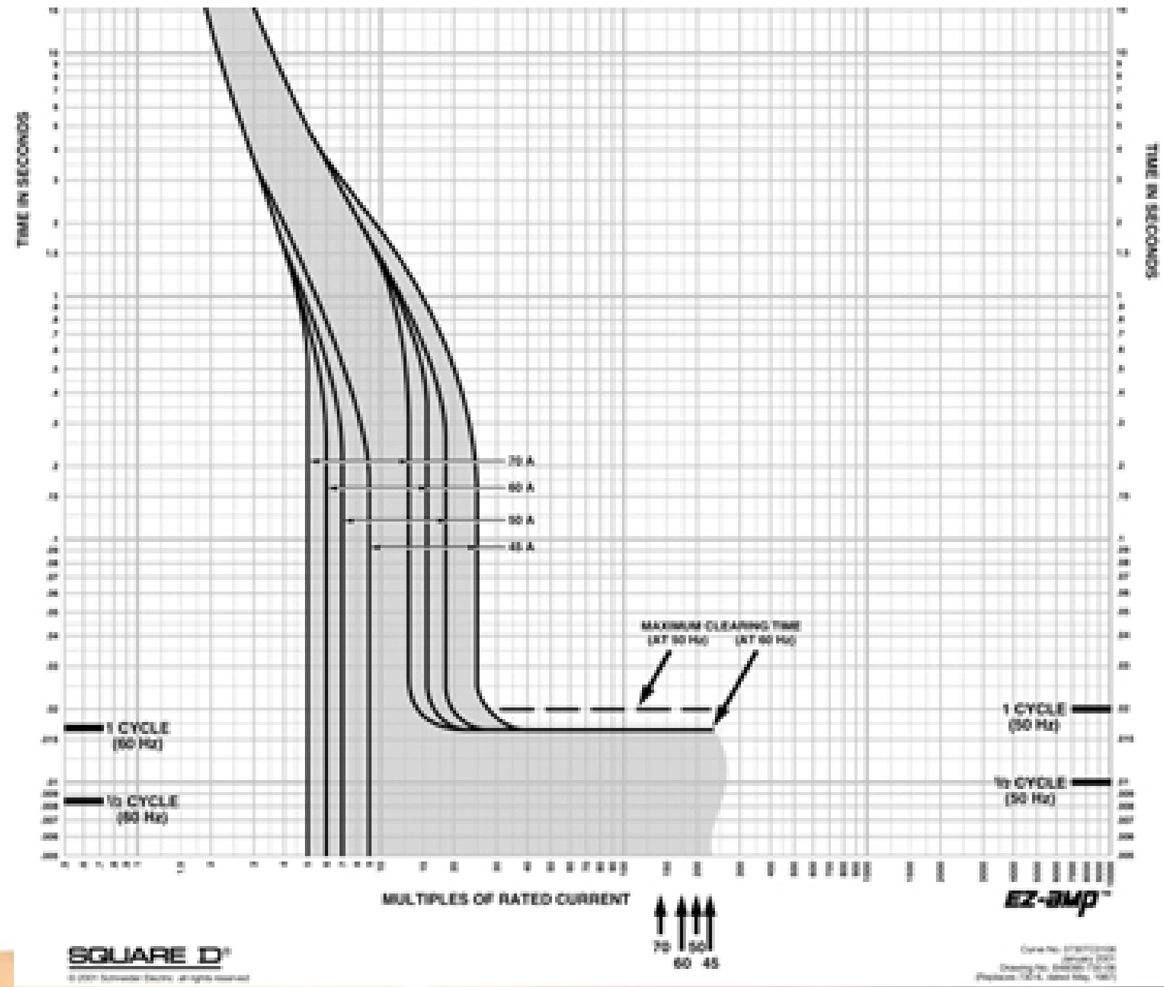
Operating Characteristics of Overcurrent Devices

- Most overcurrent devices such as circuit breakers and fuses are “inverse-time”
- “Inverse time” means the more current that flows, the faster the overcurrent device operates
- Manufacturers furnish time-current curves for the overcurrent devices they manufacture

Operating Characteristics of Circuit Breakers

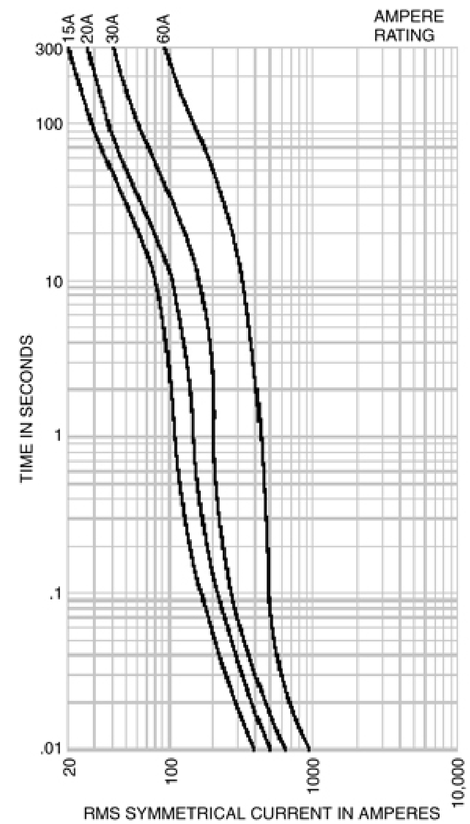
- Vertical line in time-current curve represents instantaneous trip current
- Curved portion represents time-delay mode of circuit breaker
- Width of curve represents the permitted range of time-delay and instantaneous trip operation


MULTIPLES OF RATED CURRENT
QO® MOLDED CASE CIRCUIT BREAKERS
CHARACTERISTIC TRIP CURVE NO. 730-6
CIRCUIT BREAKER INFORMATION
This curve is to be used for application and coordination purposes only. The EZ-AMP overlay feature at the bottom of the page should be used during coordination studies.
All time/current characteristic curve data is based on 40°C ambient cold start. Terminations are made with conductors of appropriate length and ratings.
MAXIMUM INDIVIDUAL POLE TRIP TIMES AT 25°C BASED ON NEMA AB-4, 1991


TIME IN SECONDS
70 A
60 A
50 A
45 A
MAXIMUM CLEARING TIME
(AT 50 Hz)
(AT 60 Hz)
1 CYCLE
(60 Hz)
½ CYCLE
(60 Hz)
1 CYCLE
(50 Hz)
½ CYCLE
(50 Hz)
MULTIPLES OF RATED CURRENT
70
60
50
45
EZ-amp
SQUARE D

Operating Characteristics of Fuses

- Time in seconds are on the left
- RMS Symmetrical current across the bottom
- 60A fuse will clear in about 0.1 seconds for 400-ampere fault



Courtesy of Eaton's Bussmann Business

Keep All Circuit Conductors Together

- Required in *250.134 (B)* and *300.3(B)(1)* through *(4)*
- Low impedance of fault return path will ensure adequate current will flow to provide for rapid operation of overcurrent device
- See “White Paper” report of R.K. Kaufmann in Appendix A of this book

250.4(A)(5) Effective Ground-Fault Current Path (cont'd.)

- The conductor must be capable of safely carrying the maximum fault current likely to be imposed on it
- *Table 250.102(C)(1)* or 12½ percent rule used on line side of service
- *Table 250.122* used on load side of service
- Fault-return path through the earth not permitted as "sole" (only) path

250.4(A)(5) Effective Ground-Fault Current Path (cont'd.)

- Fault current will flow over all paths available (including through the earth)
- The lowest impedance path will carry the most current
- The highest impedance path will carry the lowest current

250.4(B) Ungrounded Systems

- Even though the “system” is not grounded, the enclosures must be grounded and bonded

250.4(B)(1) Grounding Electrical Equipment

- Non-current-carrying conductive materials enclosing electrical conductors or equipment or forming part of such equipment are required to be connected to earth in a manner that;
- Limits the voltage imposed by lightning or unintentional contact with higher-voltage lines and limits the voltage-to-ground

250.4(B)(1) Bonding of Electrical Equipment (cont'd.)

- First ground fault on ungrounded system

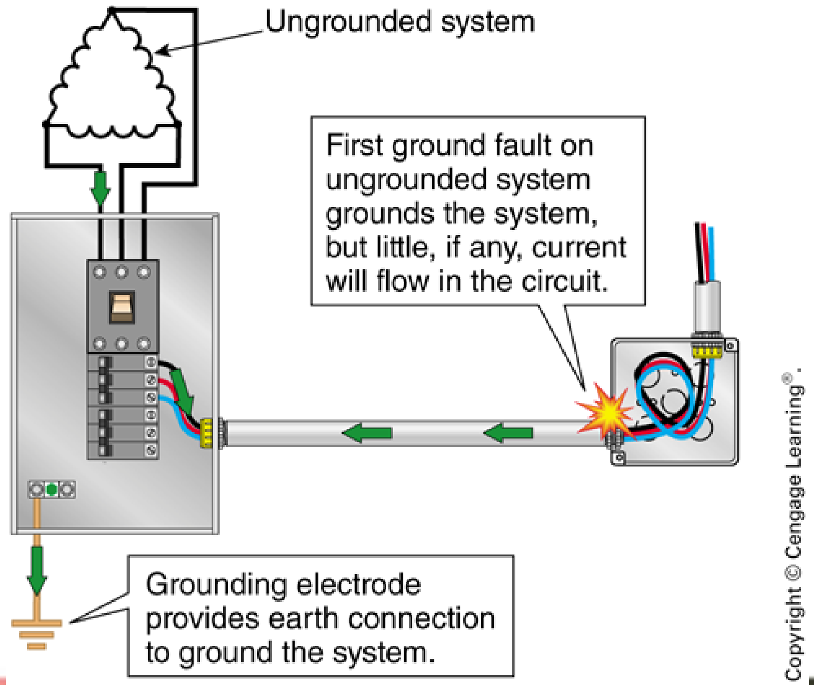


FIGURE 1-12 First fault on ungrounded system

250.4(B)(2) Bonding of Electrical Equipment

- Non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are required to be connected together and to the supply system grounded equipment in a manner that creates a low-impedance path for ground-fault current that is capable of carrying the maximum fault current likely to be imposed on it

250.4(B)(2) Bonding of Electrical Equipment (cont'd.)

- Second ground fault at different location on ungrounded system
- Current will flow from the source to the first fault, over metal paths to the second fault and return to the source

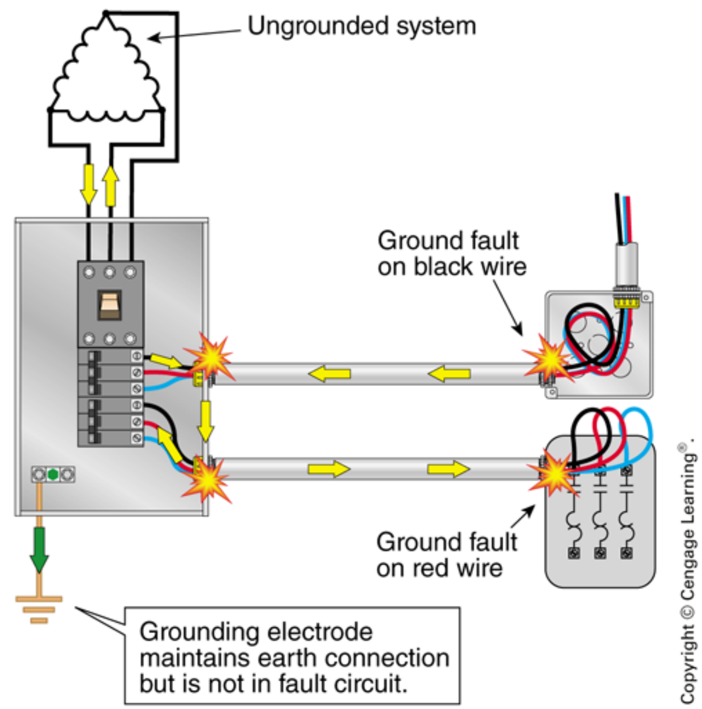


FIGURE 1-13 Two ground faults on different phases of ungrounded system

250.4(B)(3) Bonding of Electrically Conductive Materials

- Electrically conductive materials that are likely to become energized are required to be bonded to create a permanent, low-impedance path for fault current that will carry the maximum fault current likely to be imposed

250.4(B)(4) Path for Fault Current

- Low-impedance path required from any point on the wiring system to facilitate the operation of overcurrent device(s) should a second fault occur
- Earth not permitted as sole (only) equipment grounding conductor
- Earth not considered an effective fault-current path

250.118 Types of Equipment Grounding Conductors

(1) A copper, aluminum, or copper-clad aluminum conductor. This conductor is generally permitted to be solid or stranded; insulated, covered, or bare; and in the form of a wire or a busbar of any shape.

- An insulated equipment grounding conductor is required by several *NEC*® sections

How Large EGC?

- NEC gives the minimum size
  - See the text in the title of Table 250.122 as well as the "Note" below the table

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*

Note to Table 250.122

- The “Note” is mandatory and not an Informational Note

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.

NEC 250.4(A)(5) (Grounded systems)

(5) Effective Ground-Fault Current Path. Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source. The earth shall not be considered as an effective ground-fault current path.

Description of “Path”

- Low-impedance circuit (NEC doesn’t give the maximum impedance of the path)
- Facilitates the operation of the overcurrent device or ground detector for high-impedance grounded systems (NEC doesn’t say how quickly the OCPD must operate
- It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it … (NEC gives the “minimum” size, you may need to size it larger)

NEC 250.4(B)(4) (Ungrounded systems)

(4) Path for Fault Current. Electrical equipment, wiring, and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit from any point on the wiring system to the electrical supply source to facilitate the operation of overcurrent devices should a second ground fault from a different phase occur on the wiring system. The earth shall not be considered as an effective fault-current path.

250.118 Types of Equipment Grounding Conductors (cont'd.)

(2) Rigid metal conduit

(3) Intermediate metal conduit

(4) Electrical metallic tubing

- Good workmanship is essential in providing an effective fault-current path
- The conduit or tubing carry fault current
- Loose connections can interrupt the fault path or cause arcing or sparking

RMC, IMC and EMT

- No maximum length to function as an equipment grounding conductor is given in the *NEC*®
- Maximum “effective” length can be calculated using GEMI™ software
  - Set up software using values for fault clearing characteristics of overcurrent device
  - Available for free download at: https://steeltubeinstitute.org/steel-conduit/resources/gemi-analysis-research/

Maximum Effective Length of Metal Conduit and Tubing

TABLE 6-1

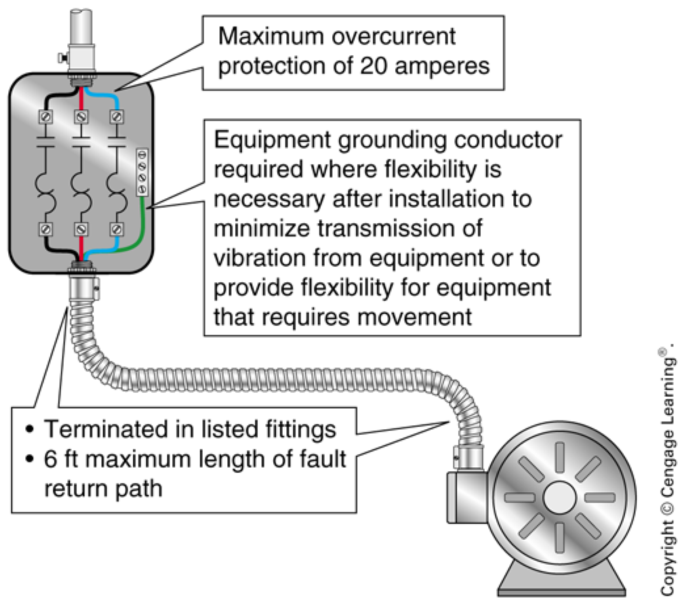
Maximum Effective Length of Metal Conduit and Tubing.

CIRCUIT: 120 V:	TRADE SIZE OF RACEWAY*	EMT		IMC		RMC	
		OC 5×	OC 2×	OC 5×	OC 2×	OC 5×	OC 2×
30 A	½	251	590	282	579	272	555
60 A	¾	250	574	288	564	280	534
100 A	1	250	555	286	537	274	507
125 A	1¼	341	608	356	572	331	543
150 A	1½	291	602	312	563	292	538
200 A	2	294	605	315	561	293	538
250 A	2	266	560	299	525	280	498
300 A	2½	297	584	287	520	274	499
350 A	2½	268	540	268	480	253	461
400 A	3	276	549	269	491	257	471

Typical systems are 120/240 V, 1-phase, 3-wire and 208Y/120 V, 3-phase, 4-wire.
*Trade sizes of conduit in inches, sized for 3 wires.

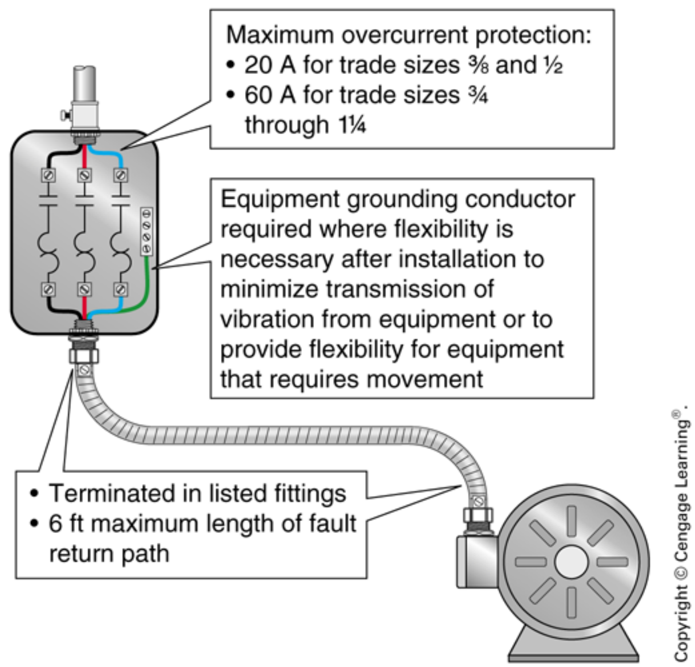
250.118(5) Listed FMC

- Conduit is terminated in listed fittings
- Circuit conductors have OCP max 20A
- Combined length of ground-fault path not more than 6 ft..
- EGC required if installed for flexibility to minimize transmission of vibration



250.118(6) Listed LFMC

- Conduit is terminated in listed fittings
- For trade sizes through ½ in. circuit conductors have OCP max 20A
- For circuit conductors trade sizes ¾ through 1 ¼, OCP maximum 60 A
- Listed LFMC required



250.118(6) Listed LFMC

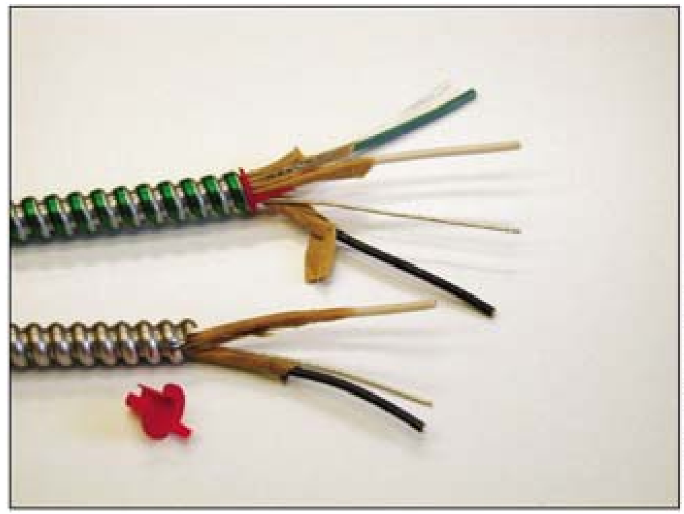
- For circuit conductors trade sizes ¾ through 1¼, OCP maximum 60 A
- Combined length of ground-fault path not more than 6 ft..
- Where installed for flexibility, EGC required
- Unlisted type LFMC is not suitable for grounding
- *350.6* requires LFMC to be listed

250.118(7) Flexible Metallic Tubing

- Fittings must be listed
- Circuit conductors to have not more than 20 A overcurrent protection
- Combined length of ground-fault path with FMC and LFMC is not more than 6 ft..

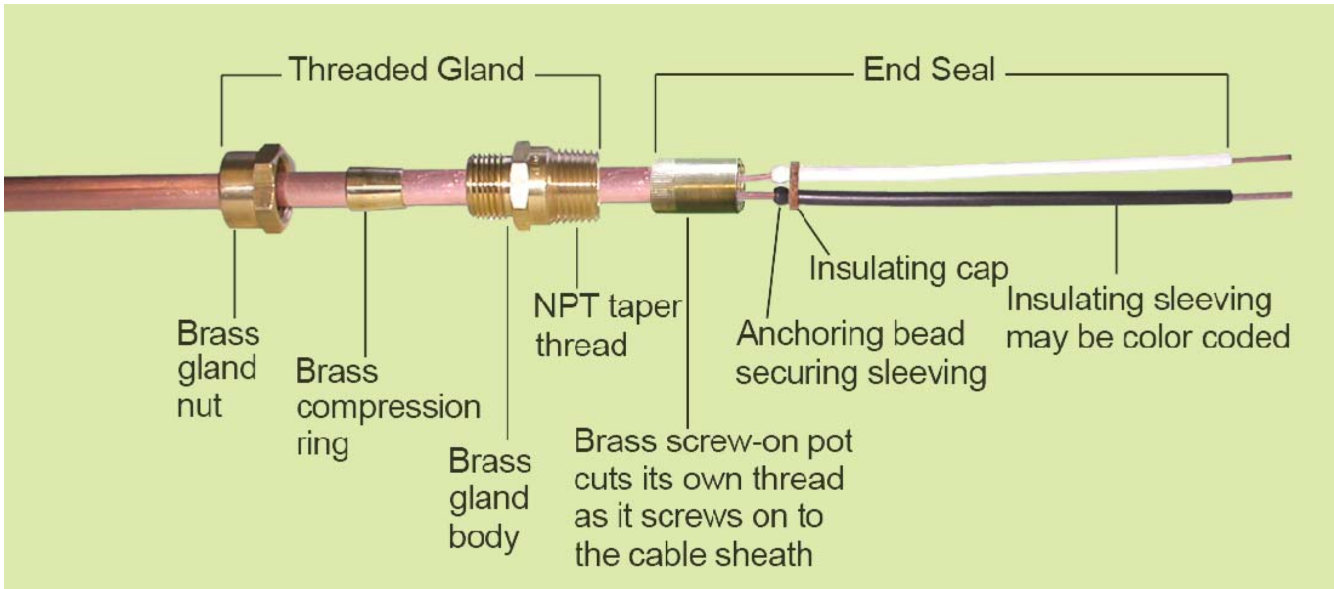
250.118(8) Type AC Cable

- Armor of Type AC cable as per 320.108
- Listed AC cable has a bonding conductor under armor
- Armor and bonding conductor equals ground path



250.118(9) Type MI Cable

- The copper sheath of mineral-insulated, metal sheathed cable



250.118(9) Terminating Single-Conductor Type MI Cable

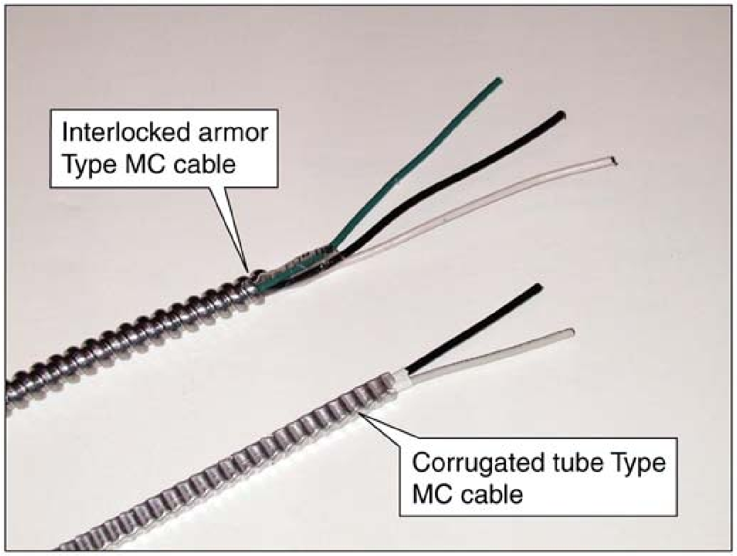
Photo courtesy of Tyco Thermal Controls LLC

250.118(10) Type MC Cable

- Type MC cable that provides an effective ground-fault current path by:
  a. An insulated or bare equipment grounding conductor in compliance with *250.118(1)*, or
  b. The combined metallic sheath and uninsulated grounding/bonding conductor of interlocked metal tape-type MC cable, or
  c. The metallic sheath or combined sheath and grounding conductor of smooth or corrugated tube Type MC cable

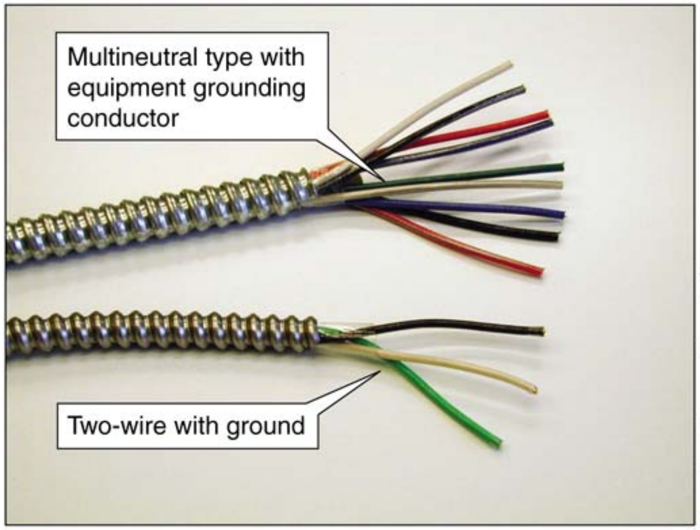
250.118(10) Type MC Cable

- Interlocked and corrugated tube Type MC cables
- Three types of Type MC cable is made:
  - Interlocked armor
  - Smooth tube
  - Corrugated tube



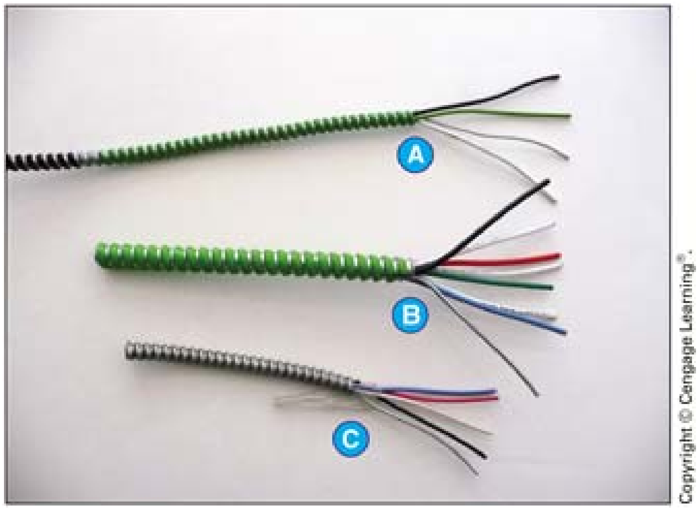
250.118(10) Type MC Cable

- "Traditional" interlocked armor Type MC cable – the armor is not suitable as an equipment grounding conductor



250.118(10) Type MC Cable

- Interlocked armor Type MC cable with a 10 AWG aluminum grounding/bonding conductor in continuous contact with the armor
- Combination is suitable as EGC
- (A) and (B) additional plastic covering on each insulated conductor



(C) plastic wrap around all insulated conductors

Fittings for Type MC Cable

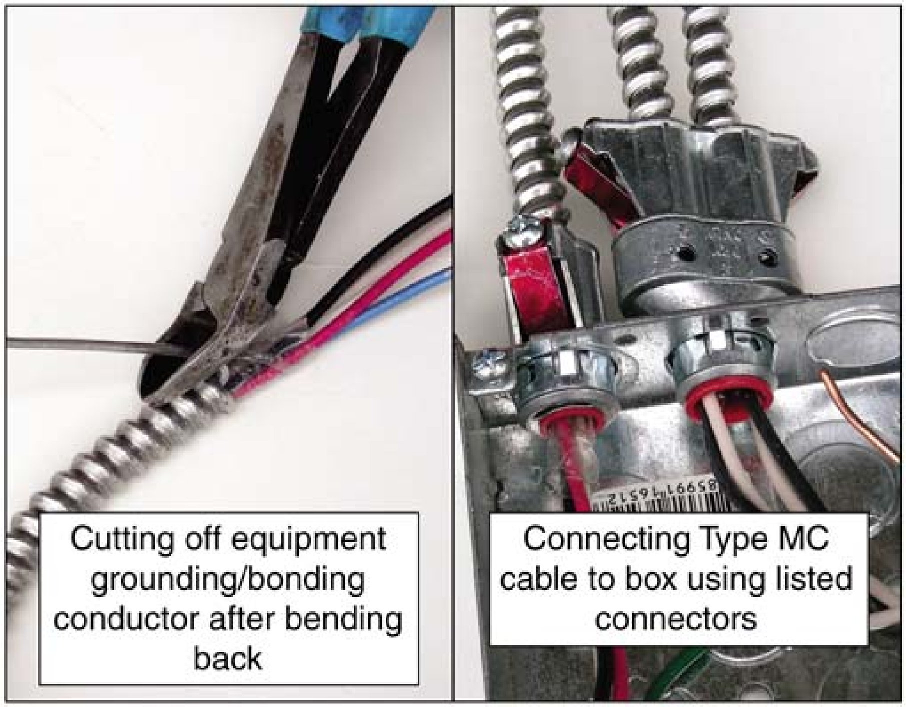
- Use fitting listed and appropriate for variation of Type MC cable being installed
- Select proper size and type of Type MC Cable connector
- Some are permitted for use in concrete
- Grounding (all listed fittings are)
- Marking will indicate suitability for Dry locations and Wet locations
- Use with Armored Cable permitted if marked

Product Markings for Fittings for Type MC Cable

- The range of cable diameters and the type of cable sheath
- The material of the sheath (aluminum, copper or steel)
- “Concrete-tight” if suitable for that use
- ‘For Type AC Cable’ (or equivalent wording)

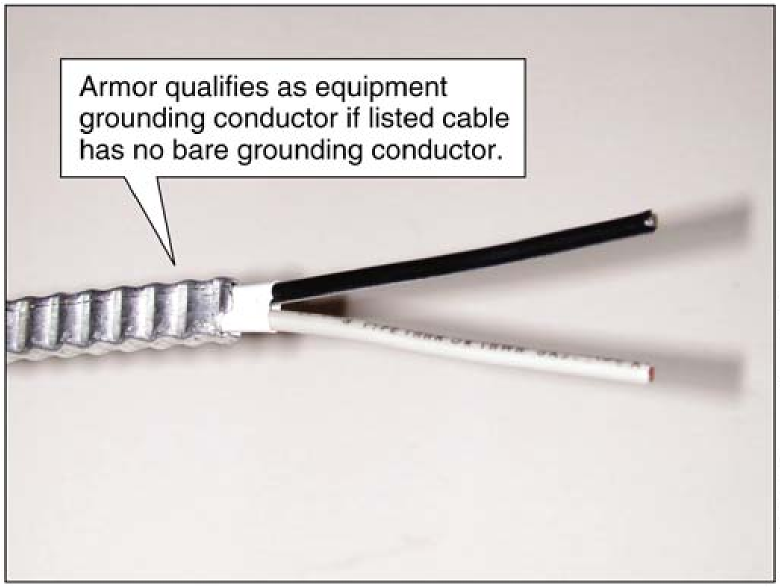
Type of Metal-Clad Cable Abbreviation	
Metal-clad interlocking armor cable	MCI
Metal-clad interlocking armor ground cable	MCI-A
Metal-clad continuous smooth sheath armor cable	MCS

Terminating Type MC Cable Having a 10 AWG Aluminum Equipment Grounding/Bonding Conductor



250.118(10) Type MC Cable (cont'd.)

- This construction of corrugated tube Type MC cable is suitable as an equipment grounding conductor as a bare equipment grounding conductor is not installed by the manufacturer



250.118(11) Cable Trays

- Cable trays as permitted in *392.10* and *392.60*
- *392.60* Grounding and Bonding. Metallic cable trays are permitted to be used as equipment grounding conductors if continuous maintenance and supervision ensure that qualified persons service the installed cable tray system and the cable tray complies with provisions of this section

250.118(13) Other Raceways

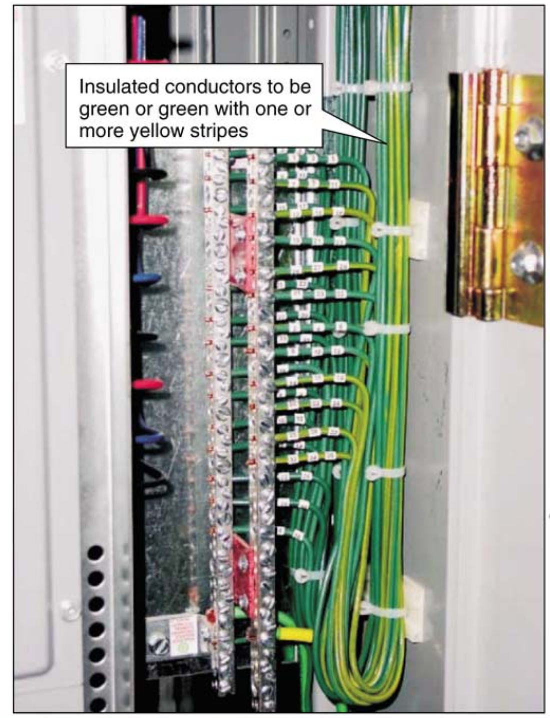
- Other listed electrically continuous metal raceways and listed auxiliary gutters

250.118(14) Surface Metal Raceways

- Surface metal raceways listed for grounding

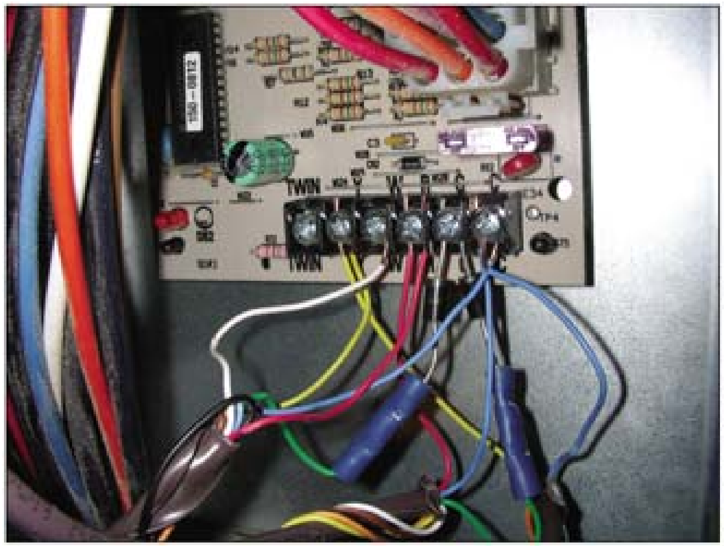
250.119 Identification of Equipment Grounding Conductors

- Permitted to be bare, covered or insulated
- Covered or insulated conductors to have continuous finish that is either green or green with a yellow stripe
- Not permitted to be used as grounded or ungrounded conductor



250.119 Exception No. 1

- Power limited Class 2 or Class 3 cables, power-limited fire alarm cables, or communications cables containing only circuits operating at less than 50 volts are permitted to use a conductor with green insulation for other than equipment grounding purposes



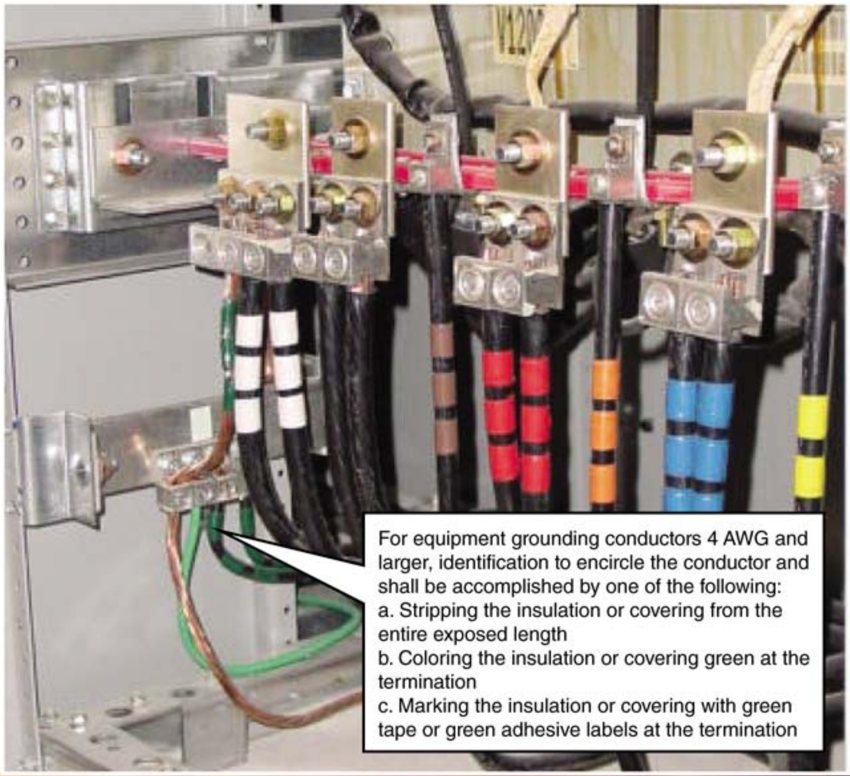
250.119 Exception No. 2

- Flexible cords having an integral insulation and jacket without an equipment grounding conductor are permitted to have a continuous outer finish that is green

250.119 Exception No. 3

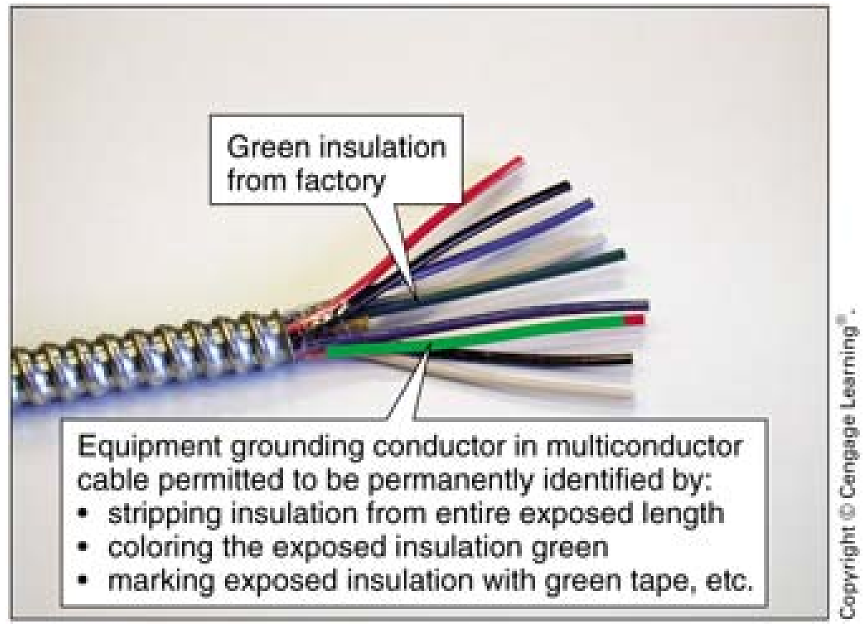
- Conductors with green insulation are permitted to be used as ungrounded signal conductors where installed between the output terminations of traffic signal control and traffic signal indicating heads
  - Signaling circuits must include an equipment grounding conductor 250.118
  - Wire-type equipment grounding conductors must be bare or have insulation or covering that is green with one or more yellow stripes

250.119(A) Conductors 4 AWG and Larger



250.119(B) Multiconductor Cable

- Identification as EGC to encircle conductor by;
  - Stripping the insulation or covering from the entire exposed length
  - Coloring the exposed insulation or covering green
  - Marking the exposed insulation green (tape)



250.120(A) Raceway, Cable Trays, Cable Armor, Etc.

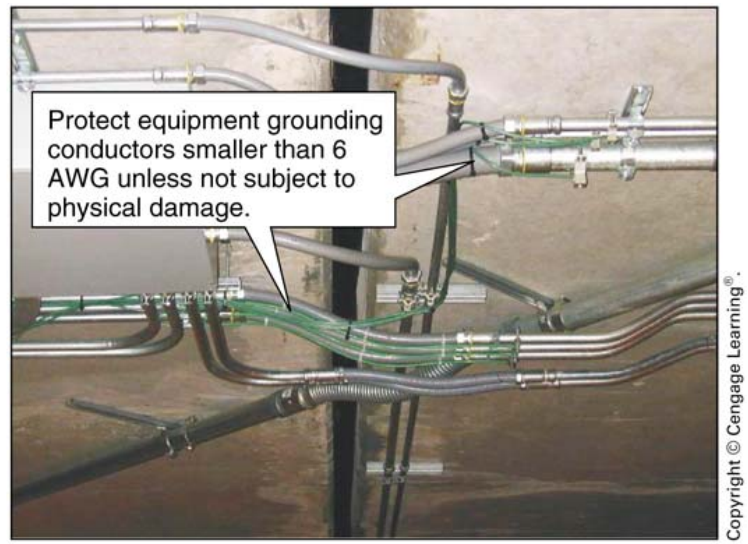
- Use fittings for joints and terminations approved for use with the type of raceway or cable used
- Make all connections and joints tight using suitable tools

250.120(B) Aluminum and Copper-Clad Aluminum

- Bare or insulated are permitted
- Bare conductors are not permitted in direct contact with masonry or the earth or where subject to corrosive conditions
- Aluminum or copper-clad aluminum conductors are not permitted to be terminated within 18 in. of the earth

250.120(C) EGCs Smaller Than 6 AWG

- Protect from physical damage by a raceway or cable armor except where run in hollow spaces of walls or petitions where not subject to physical damage or protect from physical damage



250.121 Use of Equipment Grounding Conductor

- An equipment grounding conductor is generally not to be used as a grounding electrode conductor
- The installation of a wire type grounding electrode conductor that is to serve as both conductors must comply with the sizing, connection and installation requirements of both
- Table 6-2 provides several installation requirements that must be satisfied before a common conductor is permitted to be used

TABLE 6-2

Installation Requirements for Equipment Grounding Conductors and Grounding Electrode Conductors.

EQUIPMENT GROUNDING CONDUCTORS	GROUNDING ELECTRODE CONDUCTOR
Sized from *Table 250.122* based on size of overcurrent protection on supply side.	Sized from *Table 250.66* based on size of conductor on supply side of overcurrent device.
Connects on supply side to neutral at service or equipment grounding terminal bar on load side of service.	Connects on supply side to neutral at service or to system bonding jumper at separately derived system.
Connects on load end to equipment to be grounded, (Bonding results).	Connects on load end to grounding electrode.
Must be installed inside a raceway with circuit conductors or as part of a listed cable which offers protection against physical damage.	Permitted to be installed without raceway enclosure if desired and not subject to physical damage.
Comply with installation requirements in Part VI of *Article 250*.	Comply with installation requirements in Part III of *Article 250*.
Comply with system grounding requirements in Part II of *Article 250*.	Comply with system grounding requirements in Part II of *Article 250*.
	If serves separately derived system, grounding electrode must be in area served by separately derived system.

250.122 Size of Equipment Grounding Conductors

- Generally, size in accordance with *Table 250.122*
- Not required to be larger than the circuit conductors
- If cable tray, raceway or cable armor or sheath is used as the equipment grounding conductor, it must be installed to provide an effective ground-fault return path as provided in *250.4(A)(5)* or *(B)(4)*

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	750
5000	700	1200
6000	800	1200

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.

*See installation restrictions in 250.120.

Comparison Of Table 250.122

Overcurrent Device	Copper Wire Size (AWG)	Percentage of OPD Rating
15	14	100
20	12	100
60	10	50
100	8	40
200	6	27.5
300	4	23.3
400	3	21.3
500	2	19
600	1	18.3
800	1/0	18.8
		(Based on 60C Ampacity thru 100-A. Larger on 75C Ampacity)

Comparison Of Table 250.122

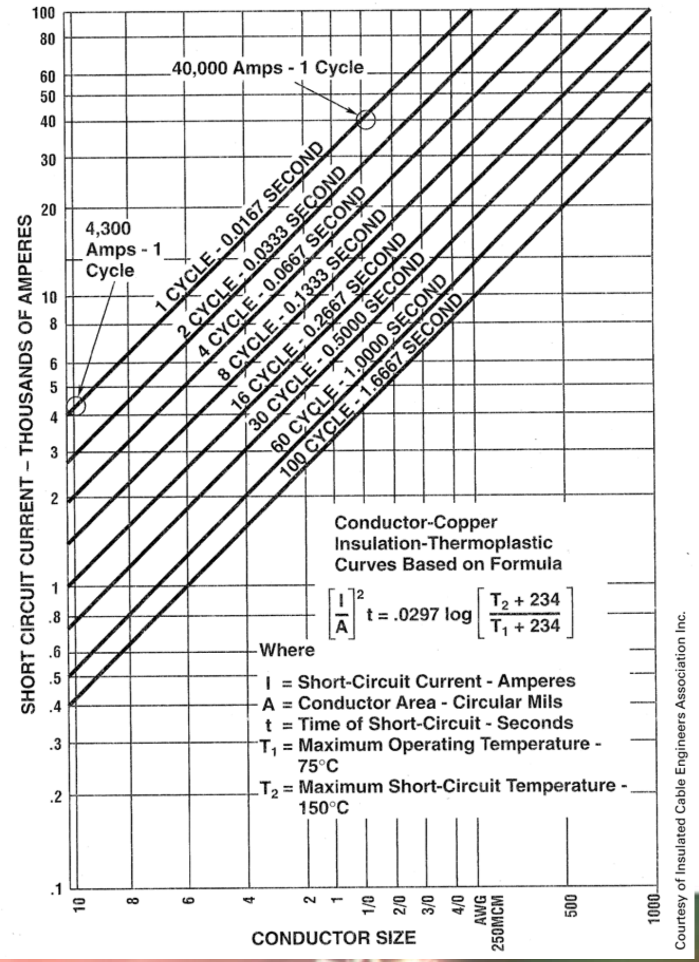
Overcurrent Device	Copper Wire Size (AWG)	Percentage of OPD Rating
1000	2/0	17.5
1200	3/0	16.7
1600	4/0	14.4
2000	250	12.8
2500	350	12.4
3000	400	11.2
4000	500	9.5
5000	700	9.2
6000	800	8.2
		(Based on 75C Ampacity)

Increasing Size of EGC for Available Short-Circuit Current

- The size of the equipment grounding conductor in *Table 250.122* is shown to be the “Minimum Size.”
  - May need to be increased in size using data such as Publication P-32-382 from the Insulated Cable Engineers Association
    - Do not exceed thermal damage curve for equipment grounding conductor
    - The equipment grounding conductor must be large enough so it can carry the fault current delivered by the system until the overcurrent device opens

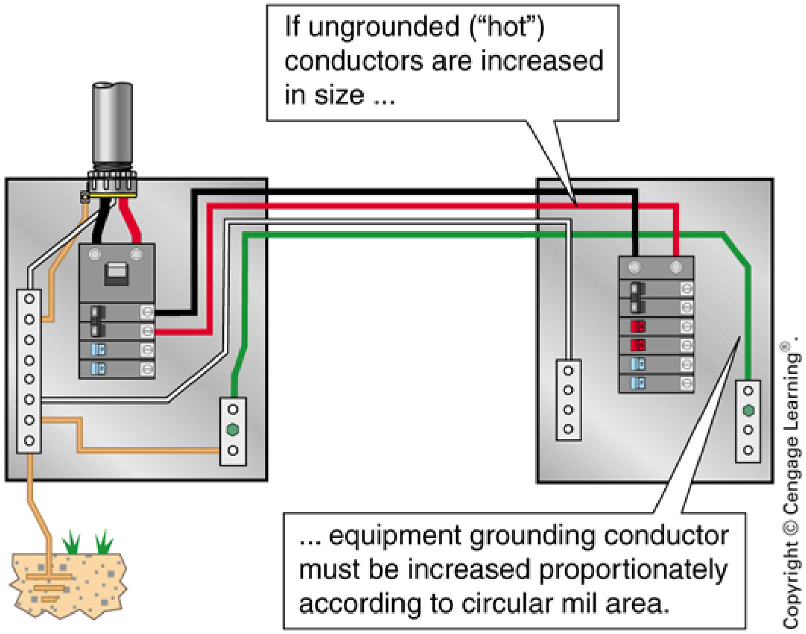
ICEA
P-32-382

- Determine short-circuit current
- Follow line across to diagonal line that gives operating speed of overcurrent device
- Follow line down to equipment grounding conductor size



250.122(B) Increased in Size

If ungrounded conductors are increased in size, wire-type equipment grounding conductors, where used, must be increased proportionately by circular mil area



Common Applications

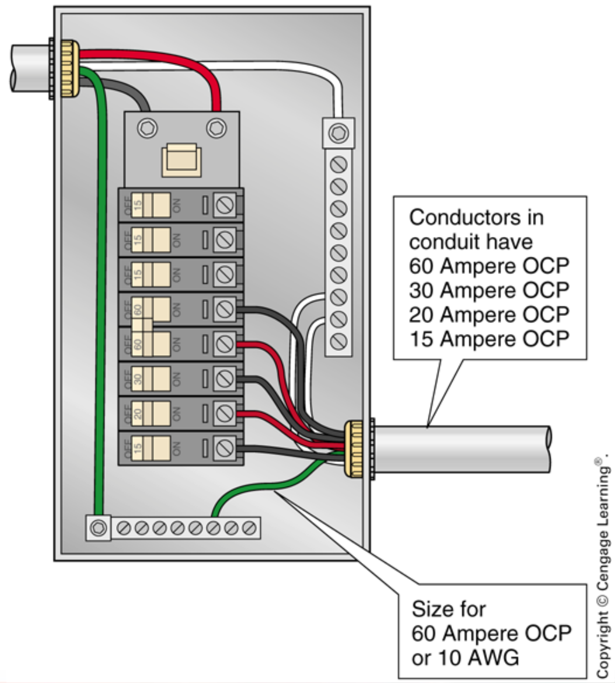
- The phase conductors are typically increased in size for:
  - Excessive voltage drop
  - High ambient temperatures
  - More than three current-carrying conductors in a raceway or cable

Here's How

- 200-ampere feeder installation
  - Normal size – 3/0 AWG copper
  - Installed size 300 kcmil
  - 300,000 ÷ 167,800 = 1.788
    - (167,800 = cm area of 3/0 conductor)
  - Required EGC *NEC® Table 250.122* = 6 AWG
  - Cm area of 6 AWG in *NEC® Table 8, Chapter 9* = 26,240
  - 26,240 x 1.788 = 46,917 cm
  - Next standard size in *Table 8* of *NEC® Chapter 9* = 3 AWG

250.122(C) Multiple Circuits

- Size single equipment grounding conductor for multiple circuits based on the largest overcurrent device for contained conductors



250.122(D) Motor Circuits

- Equipment grounding conductors must be installed in accordance with *(D)(1)* or *(D)(2)*
- *(D)(1)* The equipment grounding conductor is required to be not smaller than the size determined from *Table 250.122*(A) based on the rating of the branch circuit, short circuit and ground fault protection
- The equipment grounding conductor is not required to be larger than the circuit conductors

Here’s How, Motor Circuits

- Size per *Table 250.122* for the rating of branch-circuit, short-circuit, and ground-fault protective device
- 5 hp, 208-V 3-ph motor, *Table 430.250* FLA = 16.7 amperes
- 16.7 A x 1.25 = 20.9 amperes (minimum conductor size)
- *Table 310.15(B)(16)* = 12 AWG (25 amperes)

Here's How, Motor Circuits (cont'd.)

- Circuit breaker used as BC, SC and GF protection permitted to be 250% of FLA or 16.7 x 2.5 = 41.8 A
- Next standard OC device is 45 A
- *Table 250.122,* EGC required to be 10 AWG
- EGC permitted to be same as circuit conductors or 12 AWG

250.122(D)(2) Motor Circuits

- If the overcurrent device consists of an instantaneous trip circuit breaker or a motor short-circuit protector:
  - The equipment grounding conductor is required to be sized not smaller than given by *250.122(A)* using the maximum permitted rating of a dual-element time-delay fuse selected for branch-circuit short-circuit and ground-fault protection in accordance with *430.52(C)(1) Exception No. 1*

Here's How
50 HP, 460-Volt, 3-Phase Motor

FLA from Table 430.250 = 65 A
Conductor minimum 125 % = 65 x 1.25 = 81 A
Select 4 AWG (85 A) Table 310.15(B)(16)
FLA x 175 % for BC, SC & GF = 65 x 1.75 = 113.8 A
Round up to 125 A overcurrent device
Select 6 AWG EGC from Table 250.122

250.112(F) Conductors in Parallel

- Equipment grounding conductor of the wire type are generally not required in metal raceways by the NEC
- Many consulting engineers or plant owners require that an equipment grounding conductor be installed inside the metal conduit
- If an equipment grounding conductor is installed, it must be sized per *Table 250.122*

250.112(F) Conductors in Parallel

- Cables with metallic armor that do not serve as an equipment grounding conductor must have an internal equipment grounding conductor sized not smaller than *Table 250.122*
- Cables with "standard" equipment grounding conductor may not satisfy the sizing rules when installed in parallel

FIGURE 6-27 Equipment grounding conductors in parallel

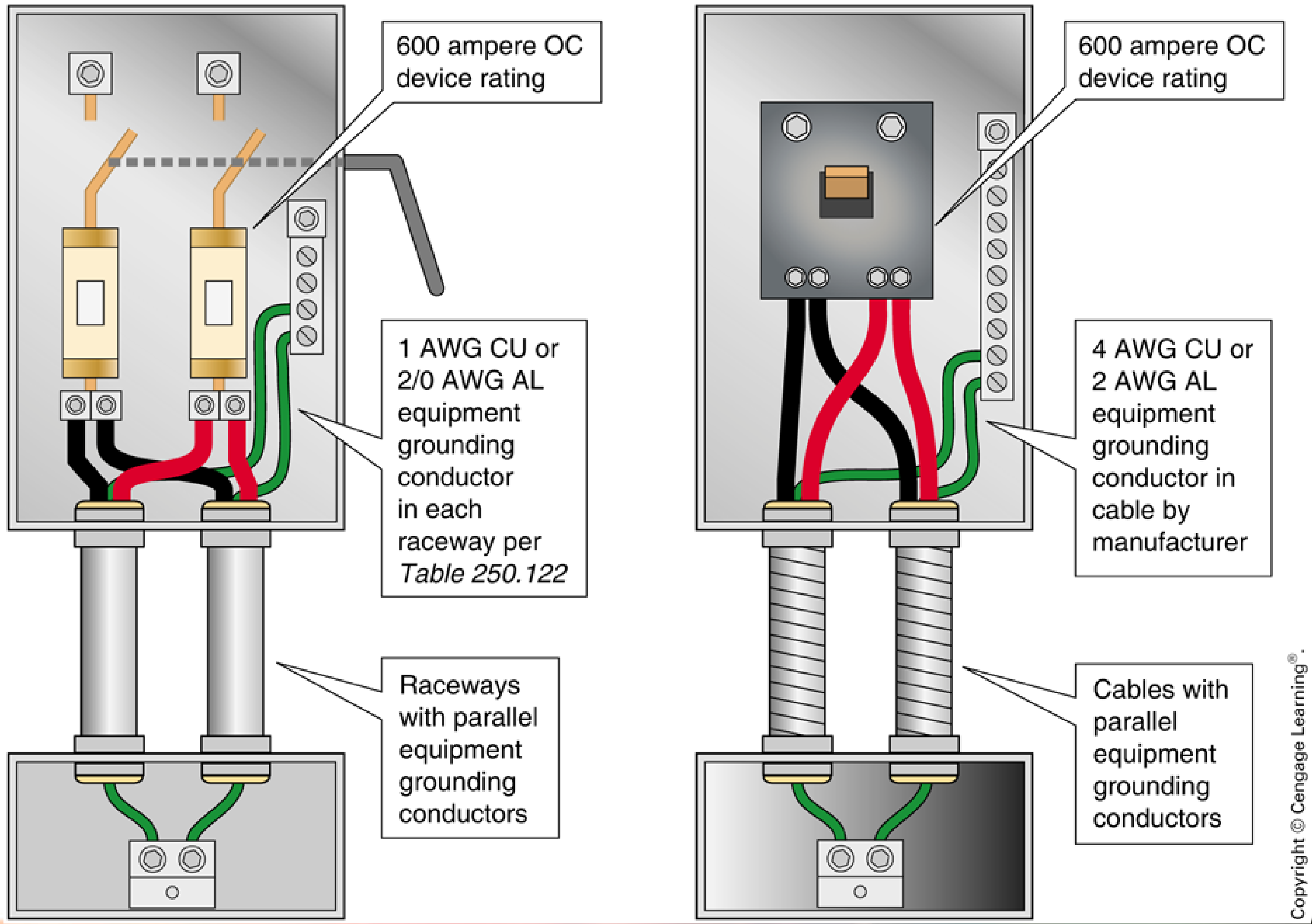


TABLE 6-3

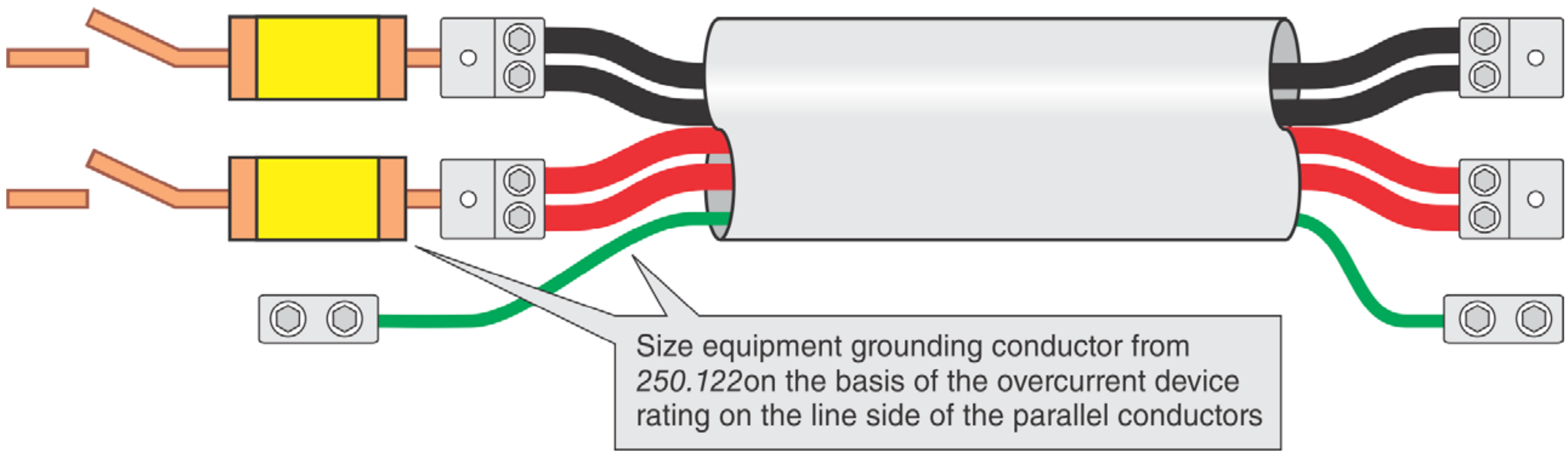
Equipment Grounding Conductors for Cables.

OVERCURRENT PROTECTION	NUMBER OF 200-A CABLES IN PARALLEL	MINIMUM SIZE OF EQUIPMENT GROUNDING CONDUCTOR IN EACH CABLE	TYPICAL SIZE OF EQUIPMENT GROUNDING CONDUCTOR IN LISTED CABLE
200 A	1	6	4
400 A	2	3	4
600 A	3	1	4
800 A	4	1/0	4

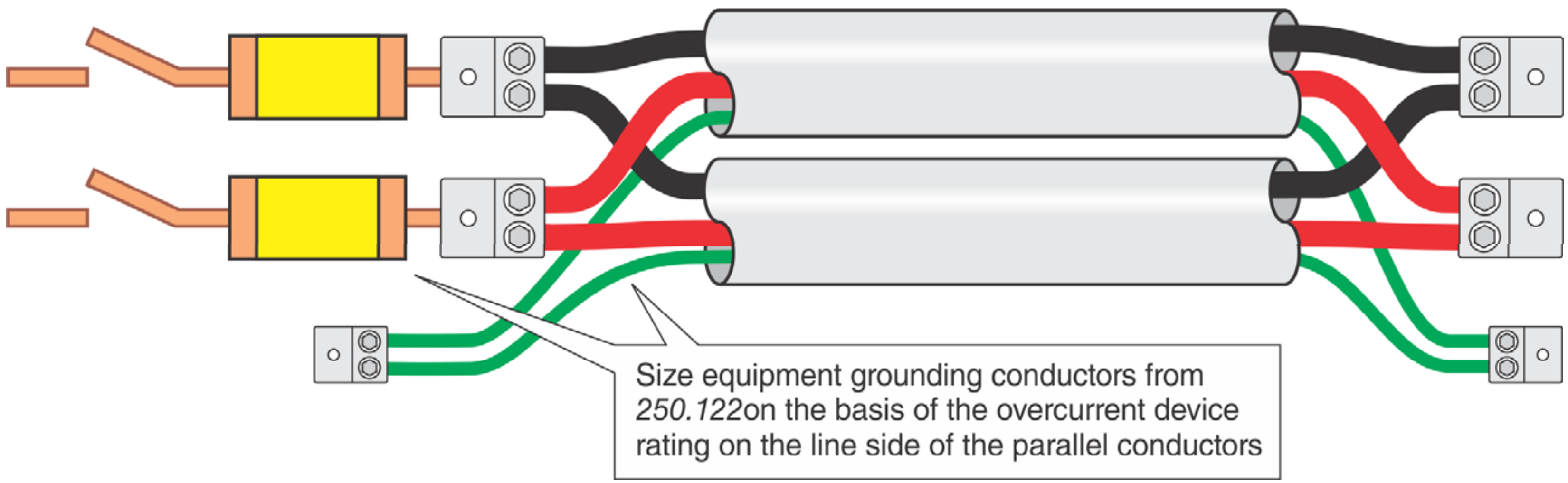
250.112(F) Conductors in Parallel

- If conductors are installed in parallel in multiple raceways or cables as permitted in *310.10(H)*, equipment grounding conductors, where used, are required to be installed in accordance with 250.122(F)(1) or (2)

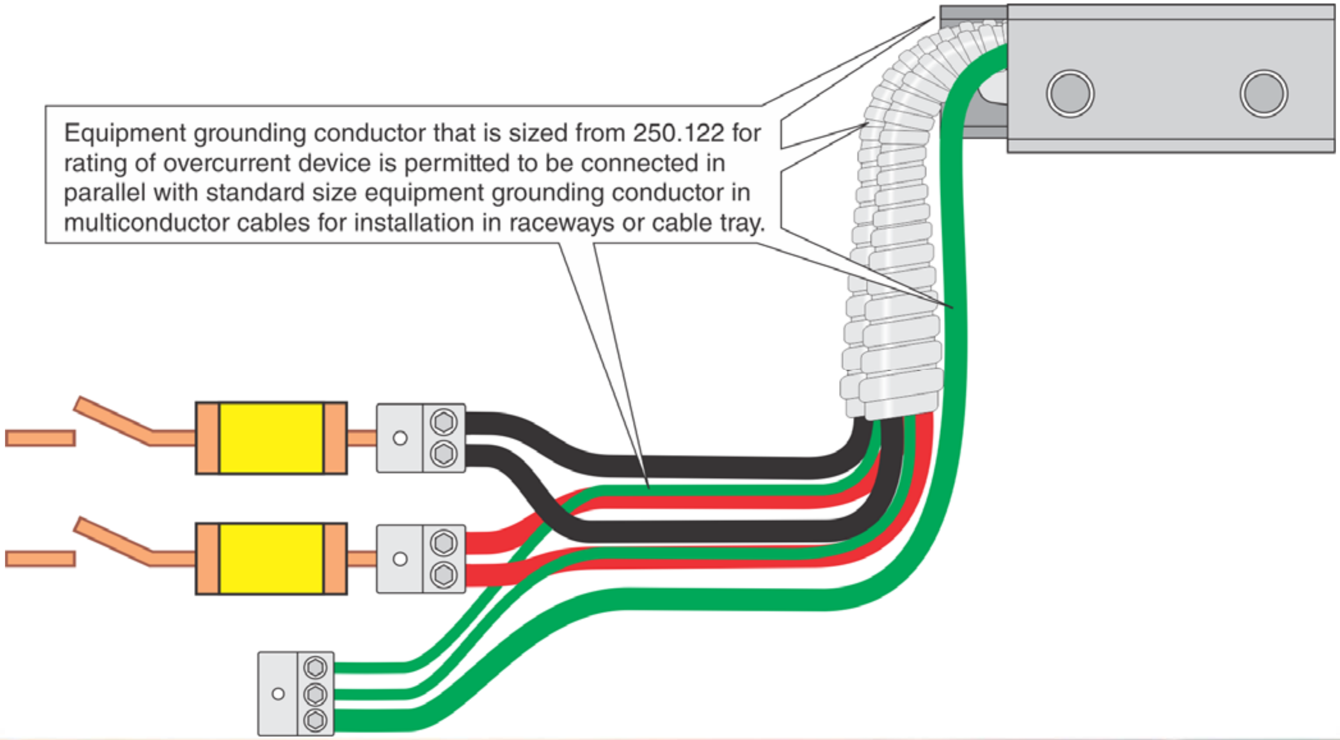
250.122(F)(1)(a) Conductors in Parallel



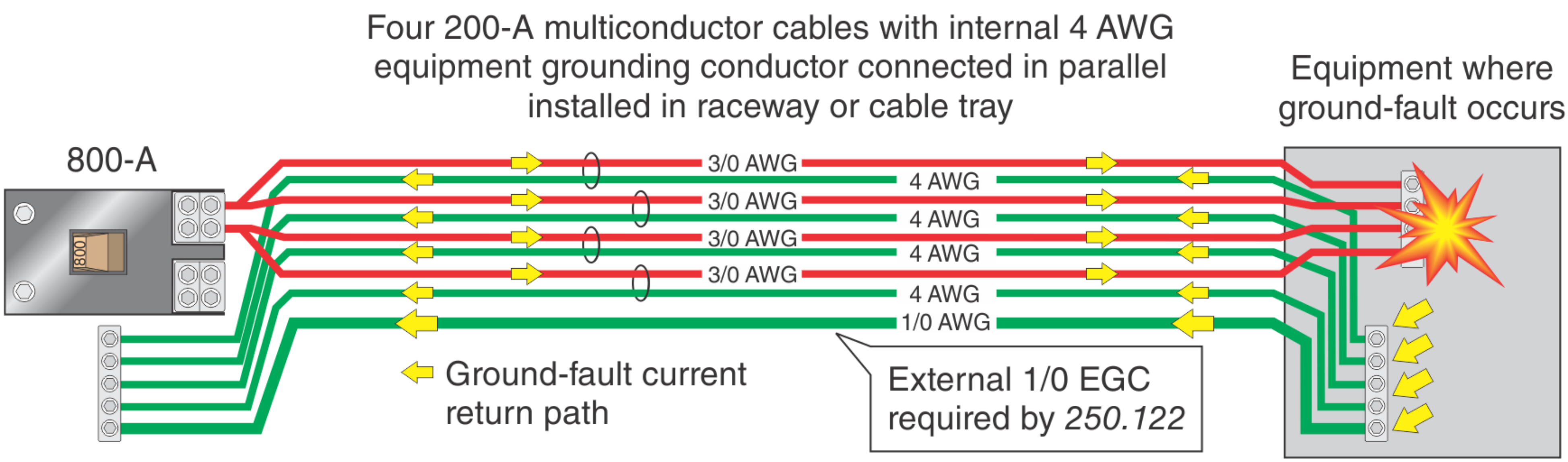
250.122(F)(1)(b) Conductors in Parallel



250.122(F)(2)(b) Conductors in Parallel in Raceway or Cable Tray

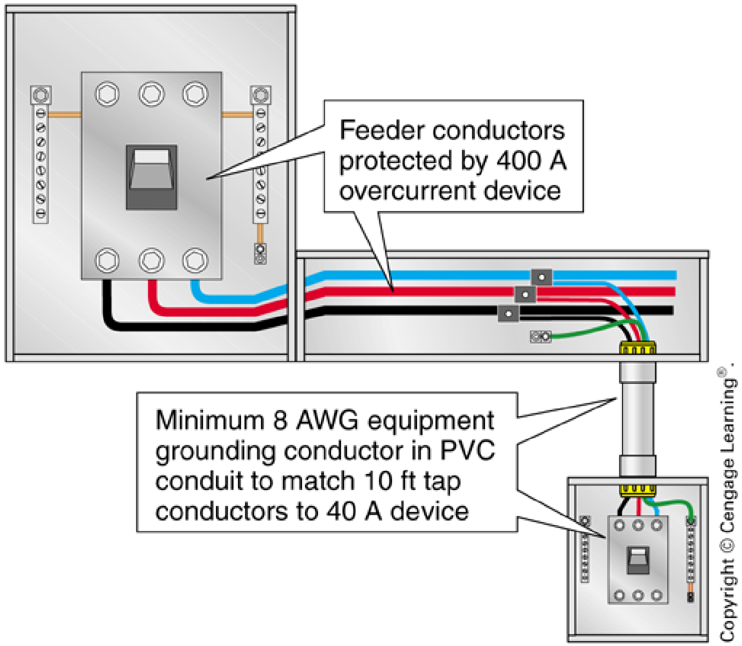


250.122(F)(2)(b) Conductors in Parallel in Raceway or Cable Tray



250.122(G) Feeder Taps

- Equipment grounding conductor for feeder taps sized from *Table 250.122* based on supply OC protection
- Not required to be larger than tap conductors



TIME FOR A BREAK

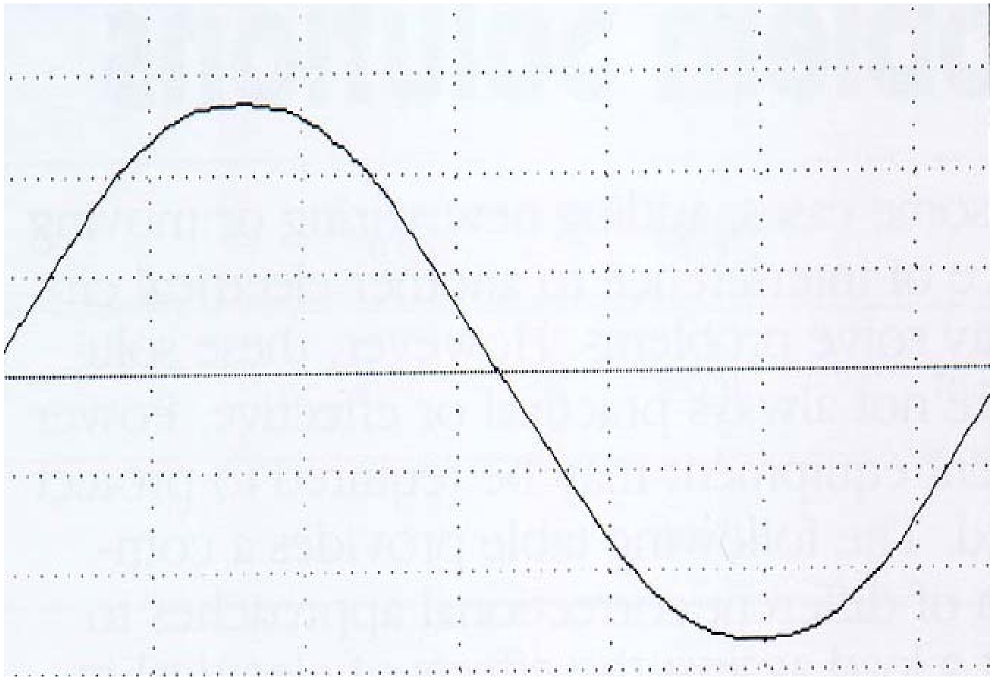
Going beyond the Code after break

What is Poor Power Quality

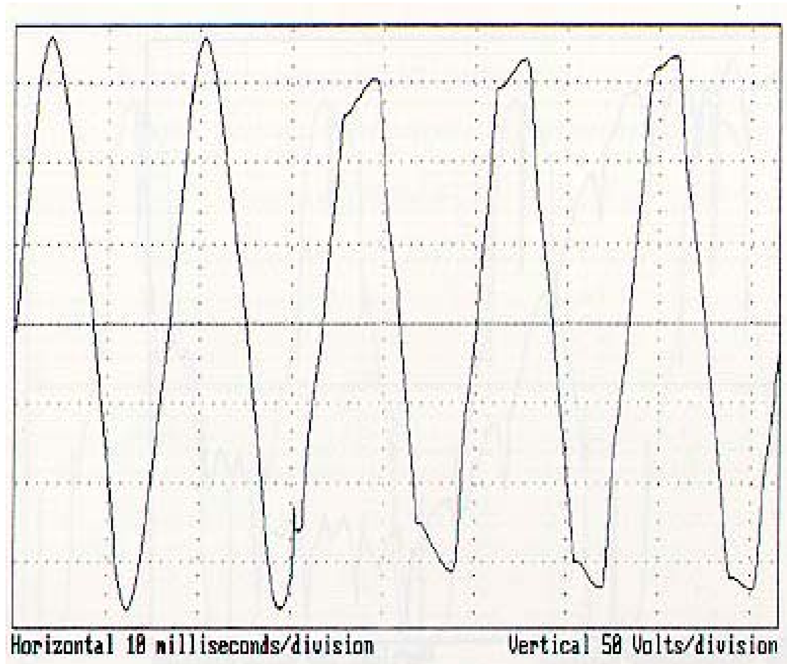
- Poor power quality...

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

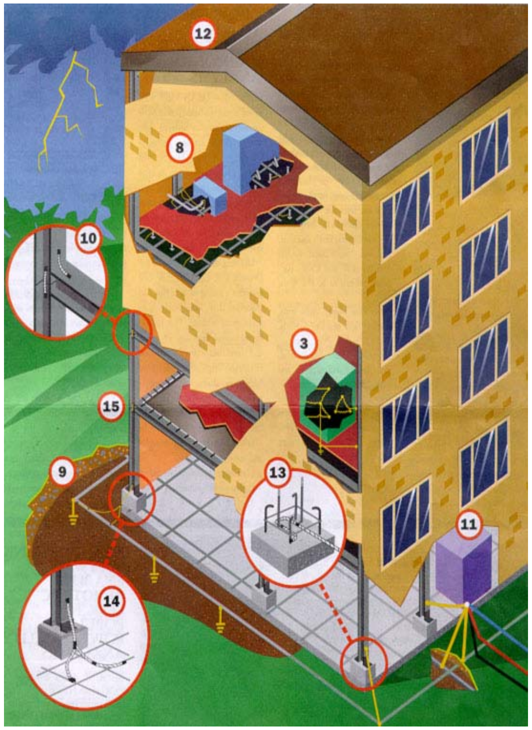
Elements of building infrastructure that can alleviate or cure power quality problems before they affect operations:

Grounding

Bonding

Circuiting

Lightning

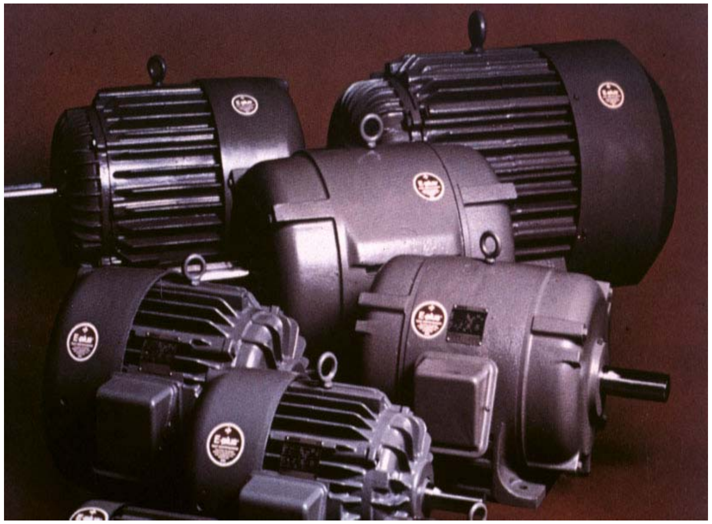


Equipment More Sensitive

- **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

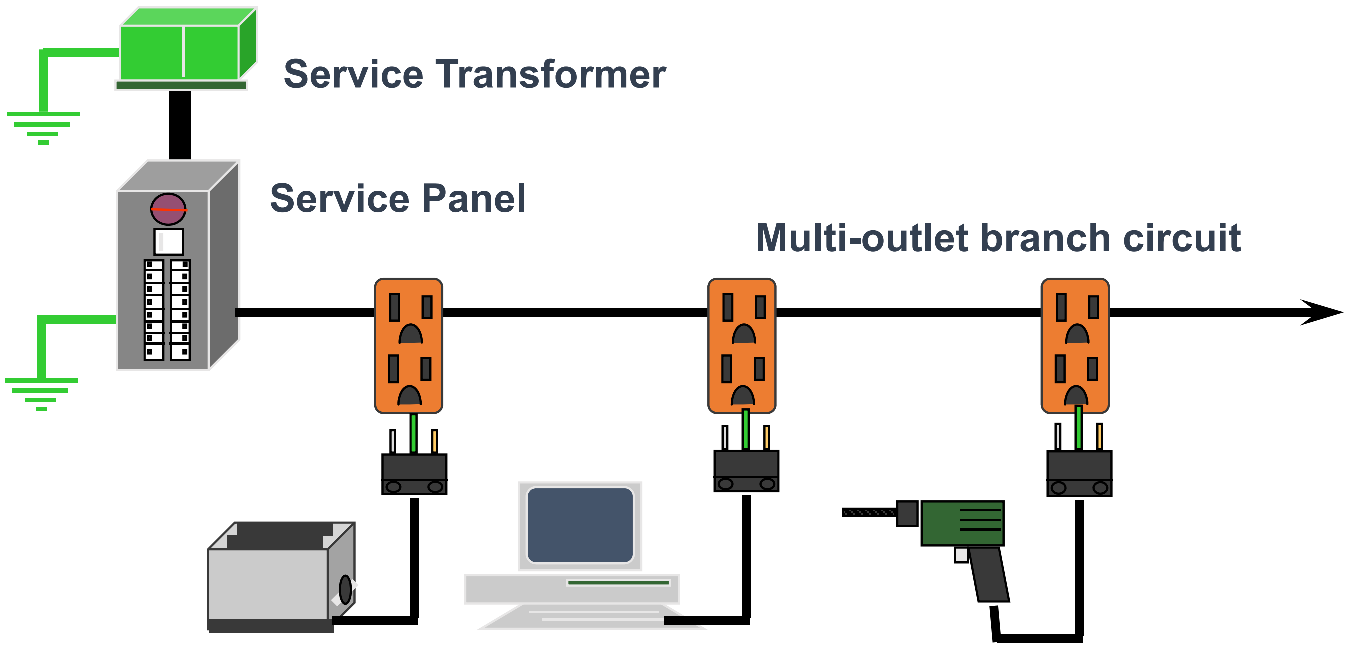
The real cost of poor power quality is in lost productivity (downtime).

- **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**

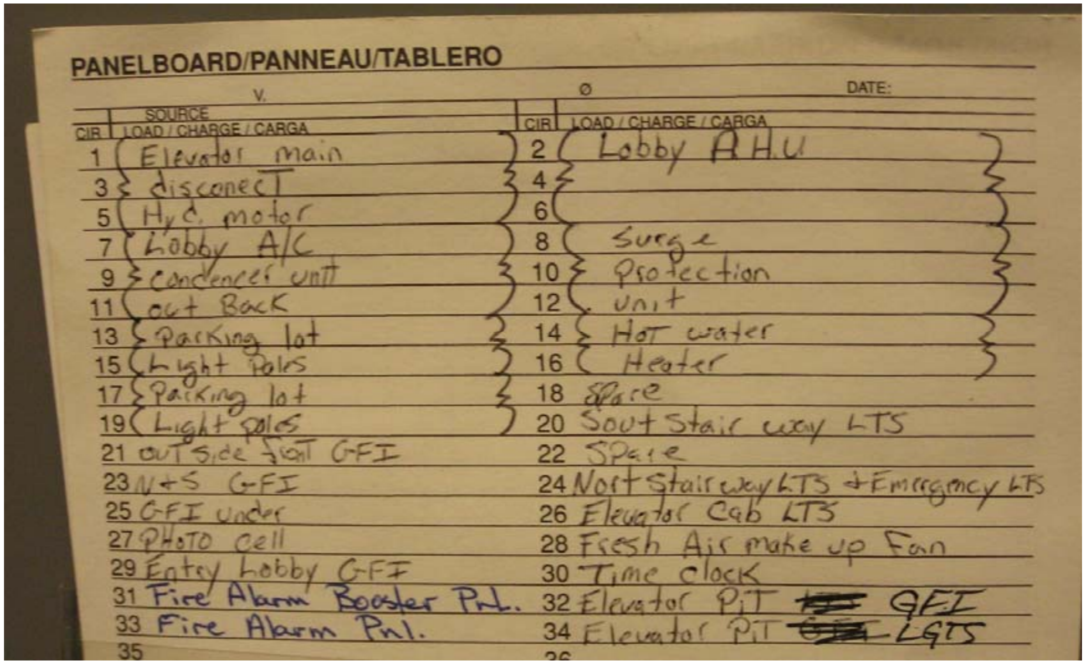
- E Source and Penton

Is the Computer a Problem?

or is it the way it's wired?



Fire Alarm and Parking Lot Lights



Mainly Internal

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

Over 80% are internally caused

source: EPRI

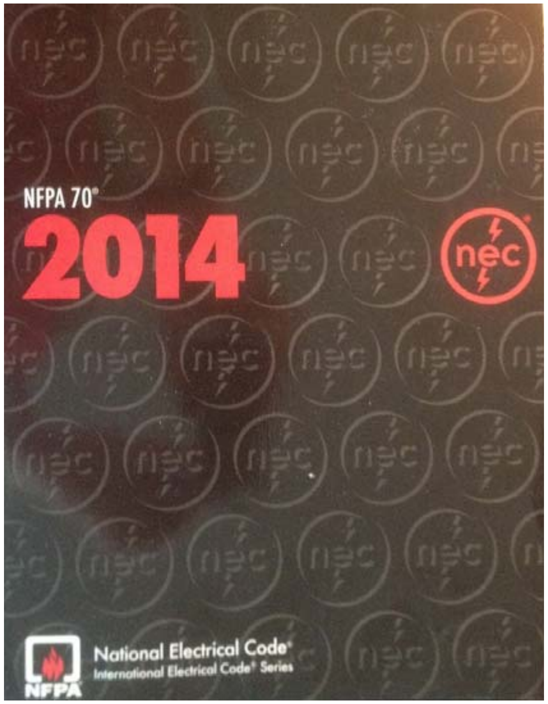
Bare Minimum Needed for Safety

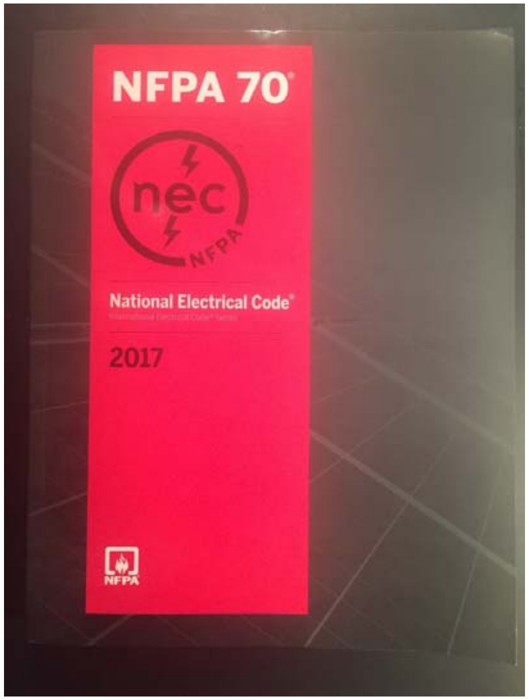
Good starting point, BUT..

Not a PQ Code

Not a lightning Code

Not a good grounding Code





Erratic Operation or Downtime

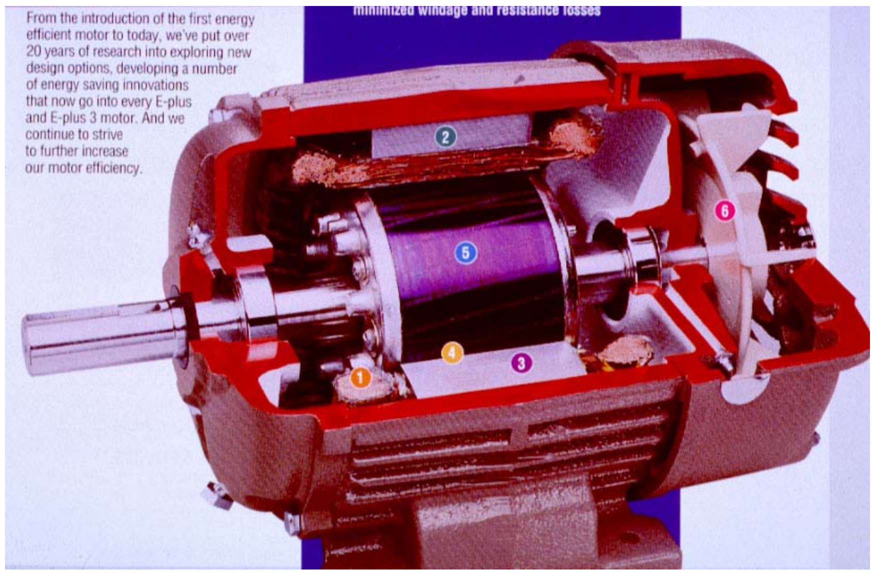
Erratic operation of sensitive electronic equipment (data errors, lockup, false images in medical diagnostics)

Cable Failures

Overheating of phase conductors or neutrals, nuisance tripping

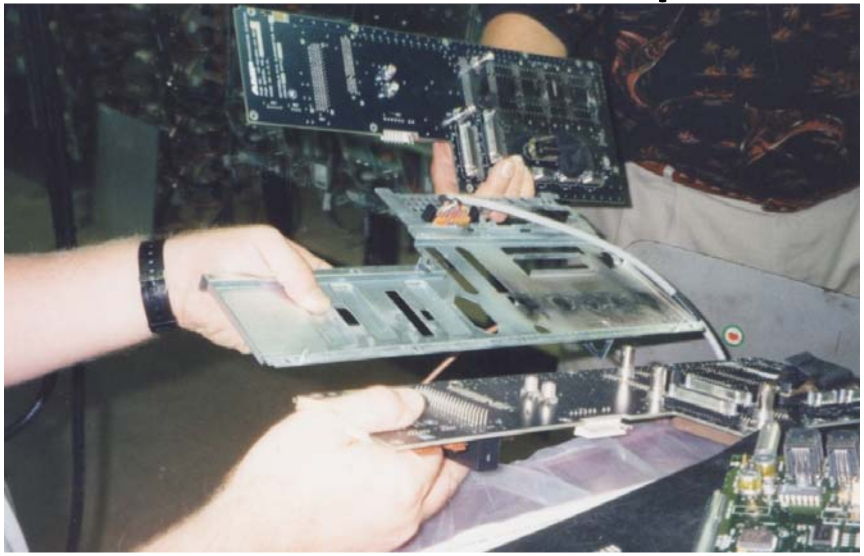
Motor Failures

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.

System or Exterior Grounding

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

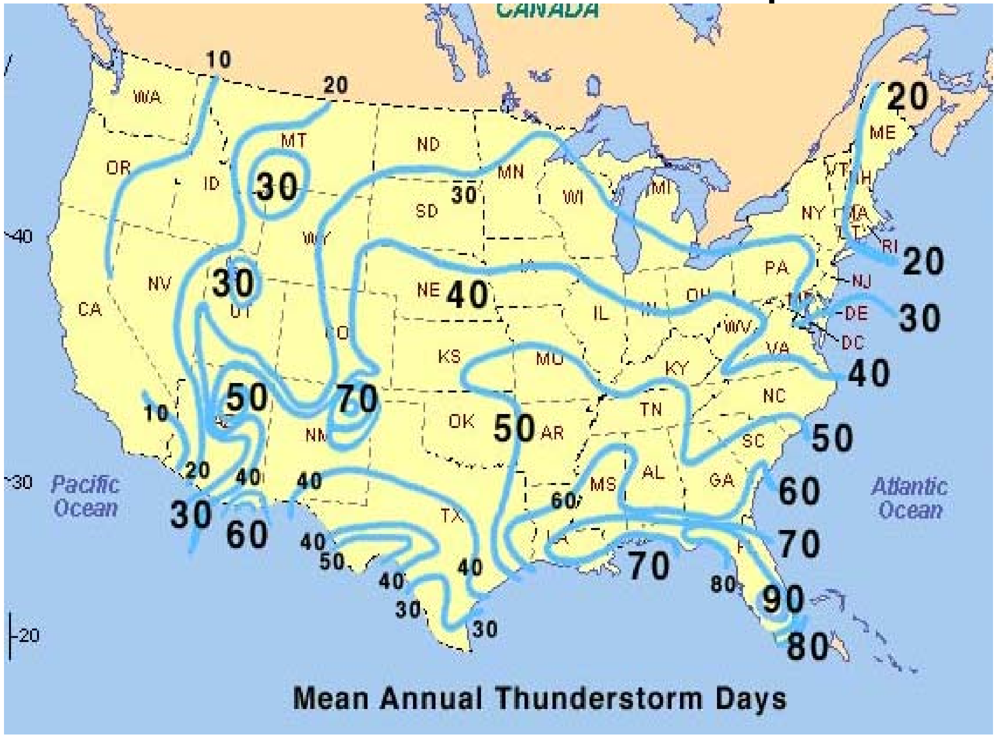
“Bonding”

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

- The two terms are frequently used interchangeably

Exterior Grounding

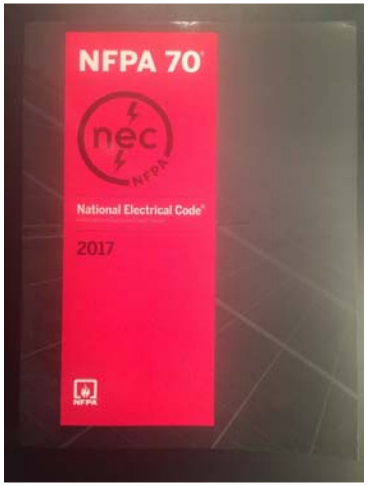
Isokeraunic Map



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:

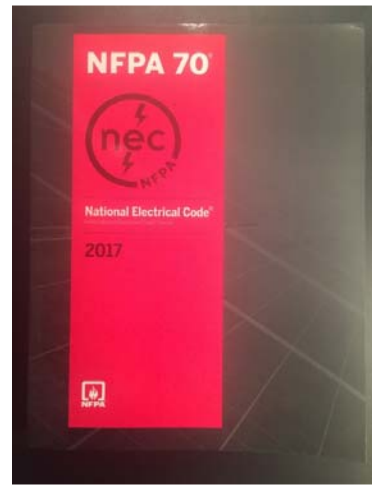
Exception: If a single rod, pipe, or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required.

There are no testing parameters

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

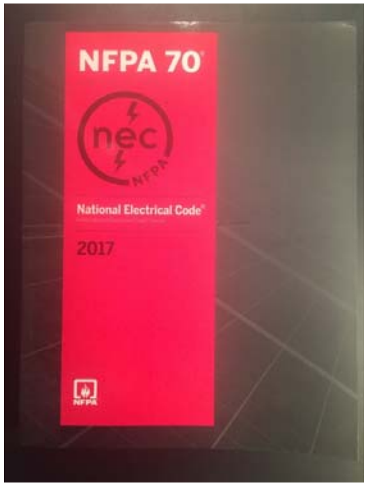
NEC Allows 6 Ft. Spacing

- **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

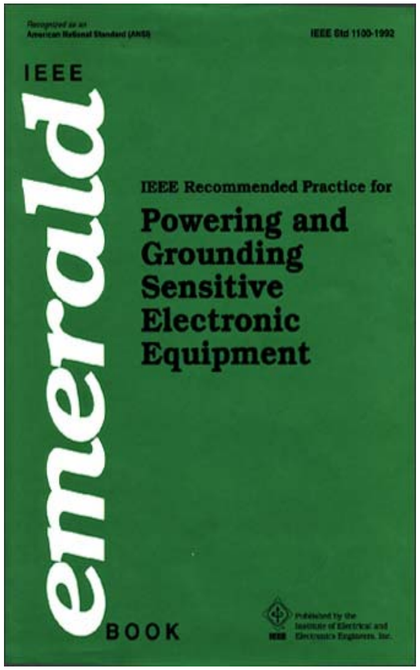
- **250.53 (F) Ground Ring.** The ground ring shall be buried at a depth below the earth's surface of not less than 750 mm (30 in.).



IEEE Emerald Book

- **ANSI/IEEE 1100**

Recommended practices are needed for power quality.

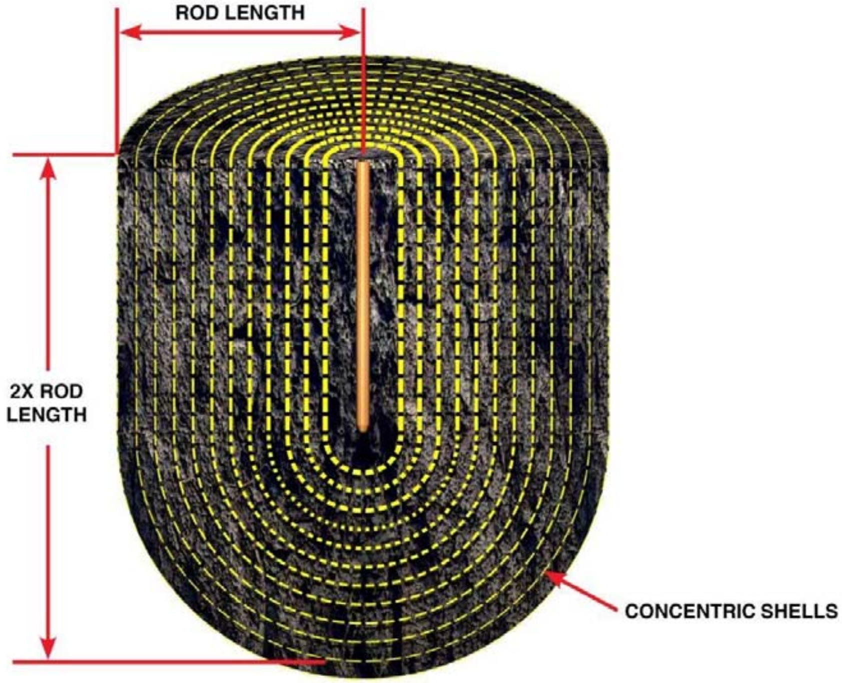


System Grounding

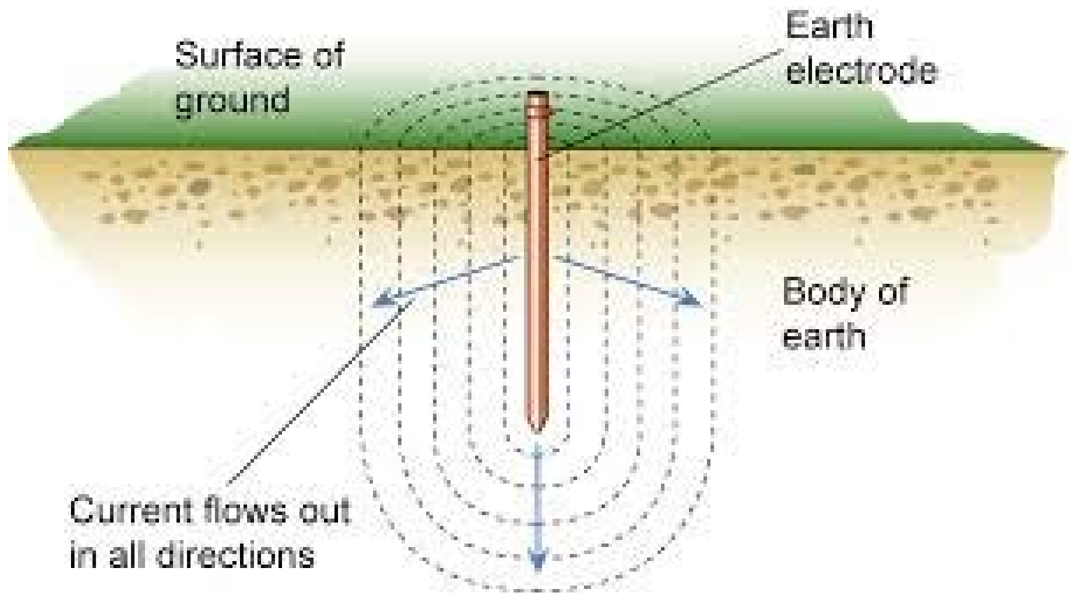
Desired Grounding Resistance:

- **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 ≈ rod length & soil conditions



Current=Voltage/Resistance



2X Rod Length (average) Dependent on Soil Resistivity

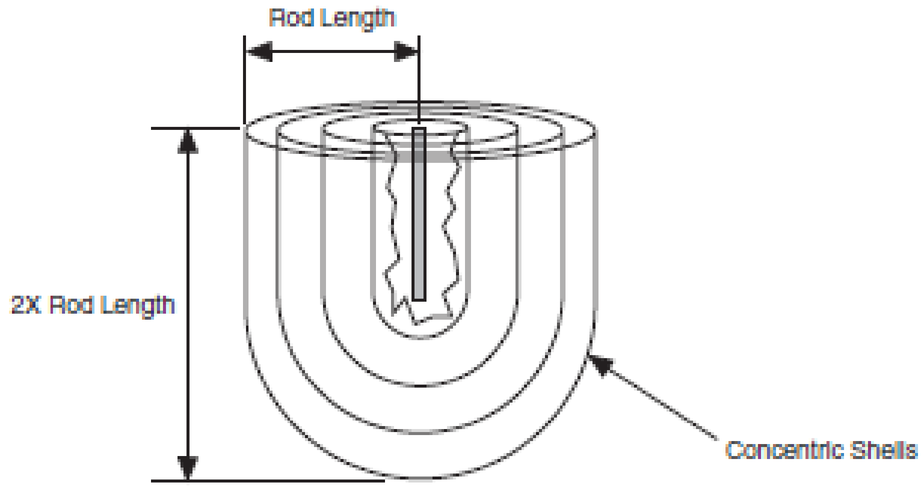
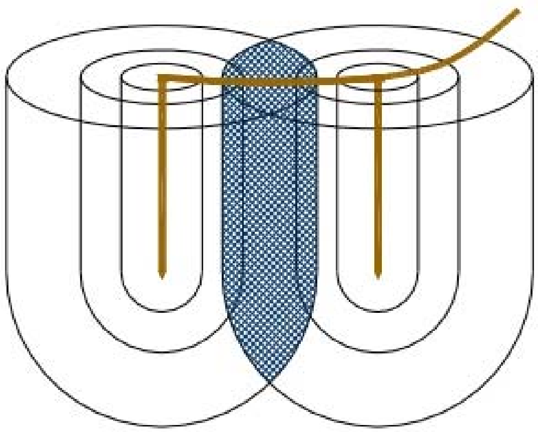


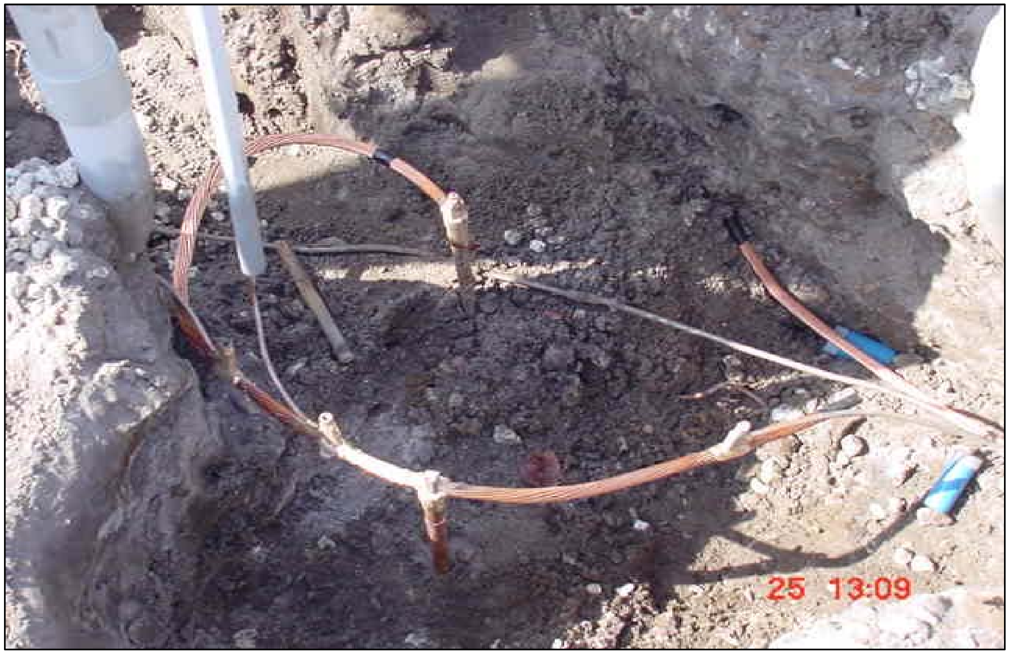
FIGURE 4-5 GROUNDING ELECTRODE SPHERE OF INFLUENCE

Lowering Ground Resistance



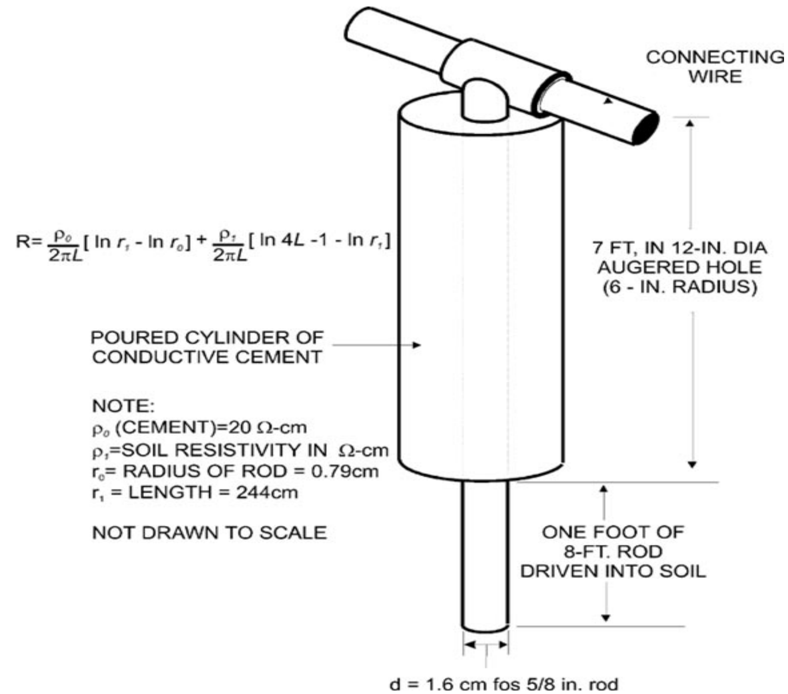
Concentric Shell
Overlap Decreases
Efficiency of
Ground Rod
Resistance

Ground Rod Spacing

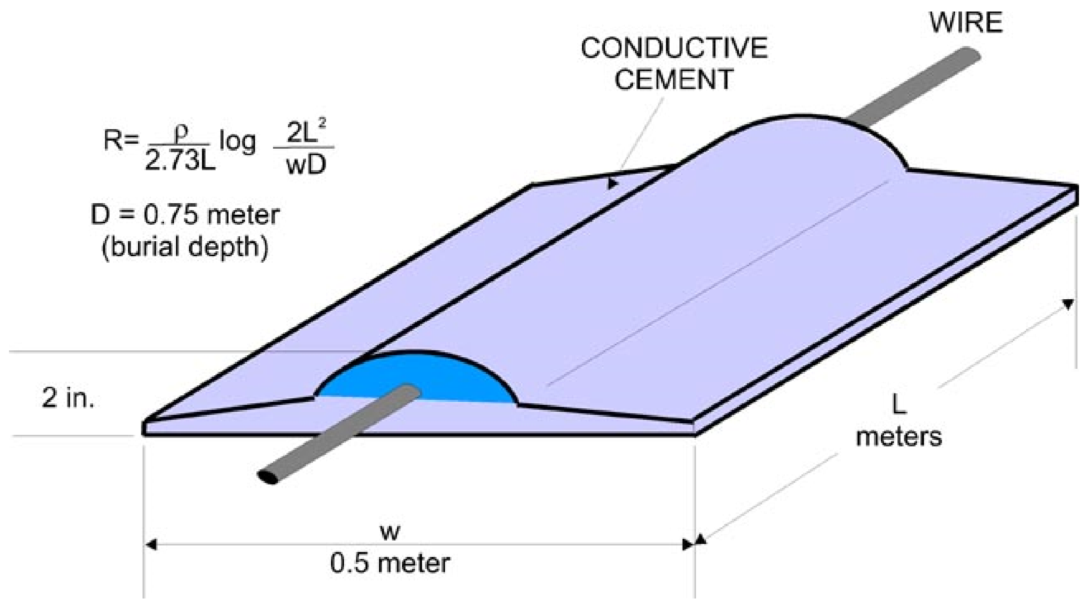


Ground Rod is Embedded in Conductive Concrete

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



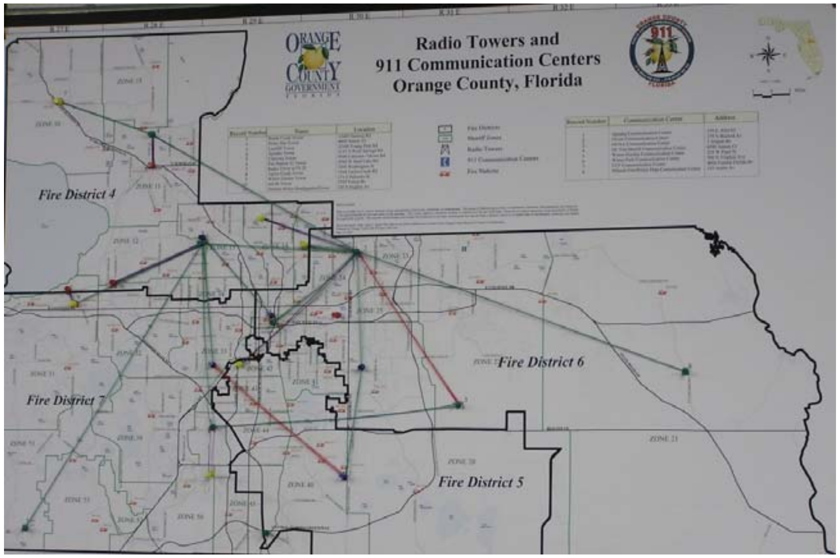
Conductive Cement Effectively Enlarges the Contact with the Earth of the wire.



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

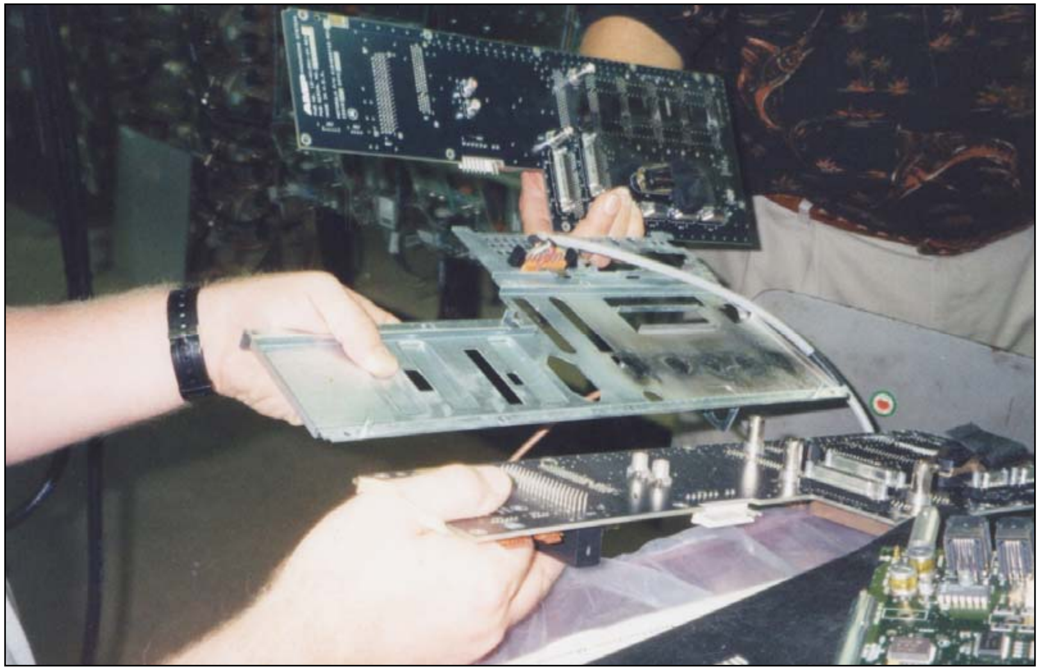
3 sets of 5 guys

Equipment Damages

$100 K/yr damage at Apopka alone

Not including downtime

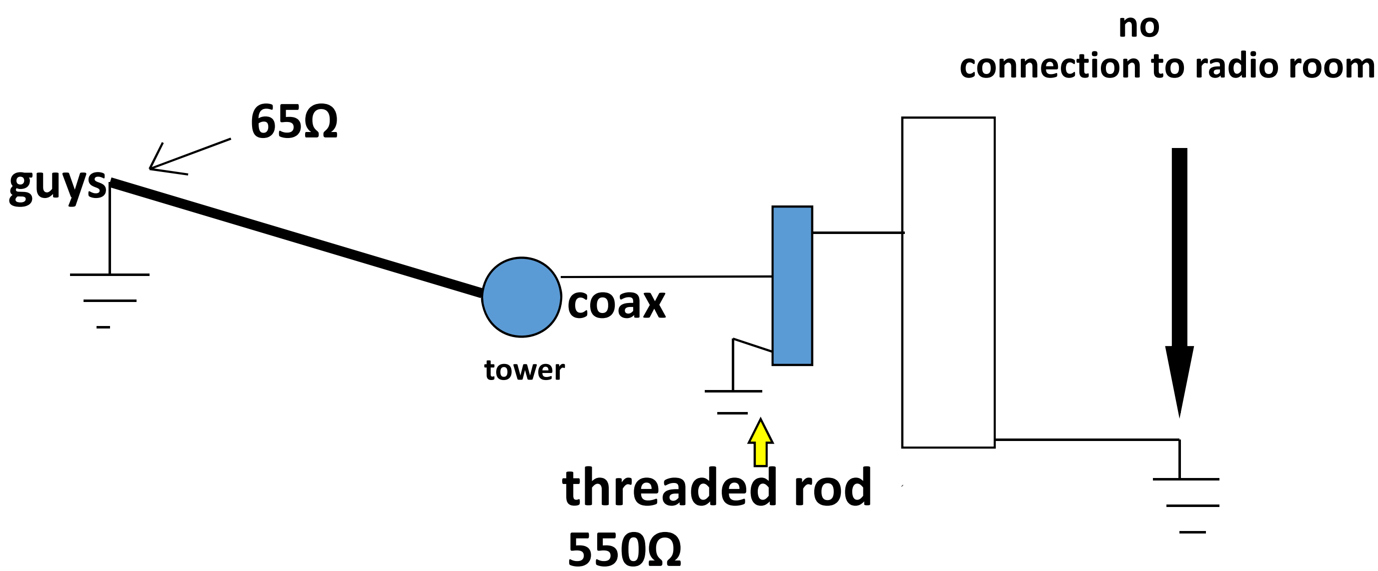
Internal Arcing



Staff Knew They Needed Help

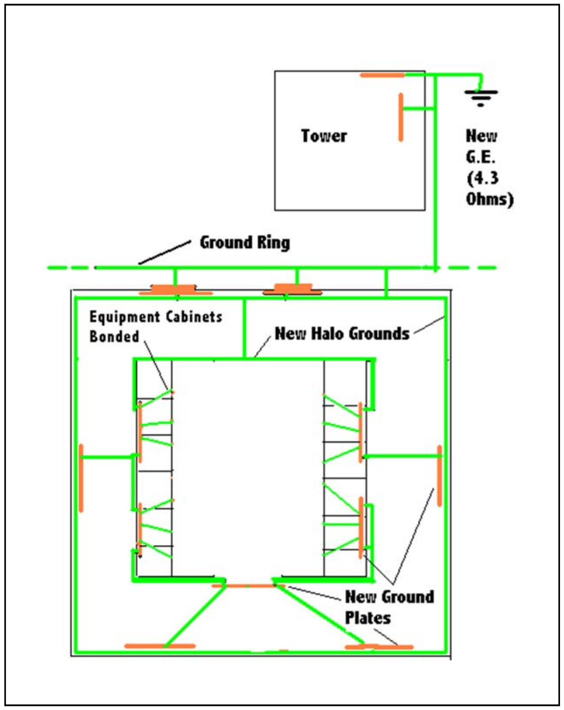
Staff was not expert in power quality, called in knowledgeable professional

3 Independent grounds

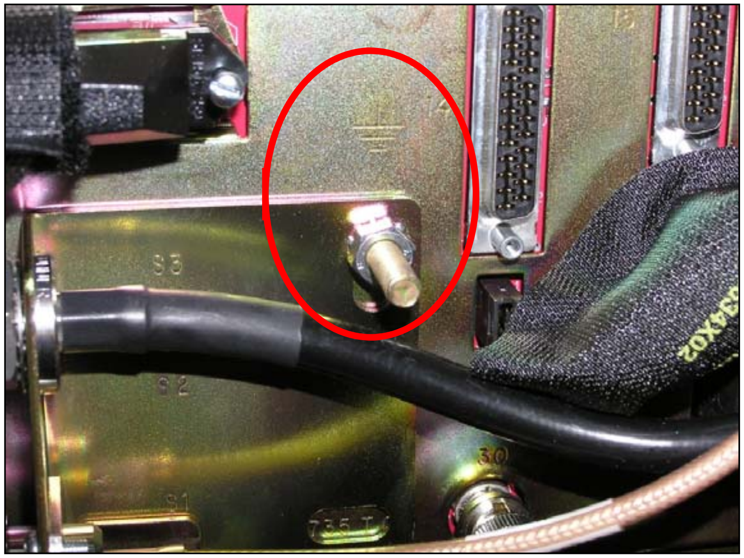


Refitted site

Everything bonded together



Ungrounded Equipment Cabinets



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:

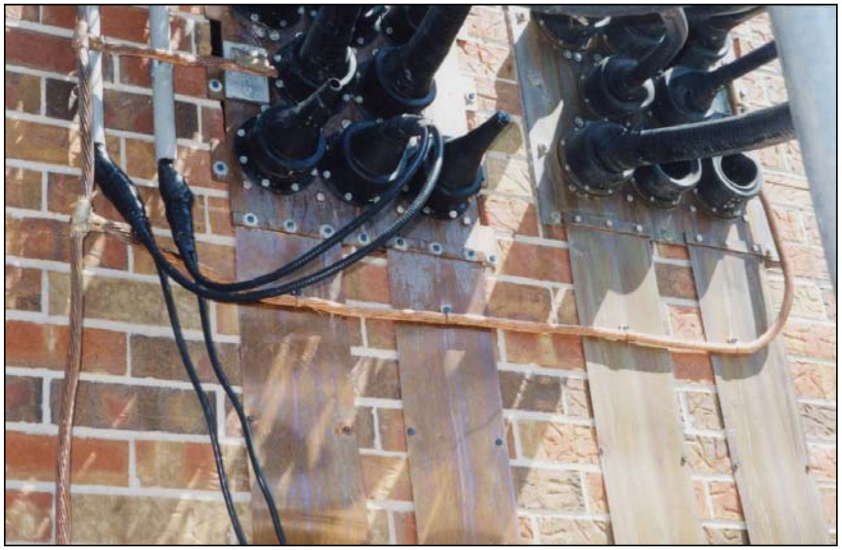
Deep (60 ft..) electrode supplements tower

New Coax Grounding On Tower

for coax grounds then 4/0 to electrode

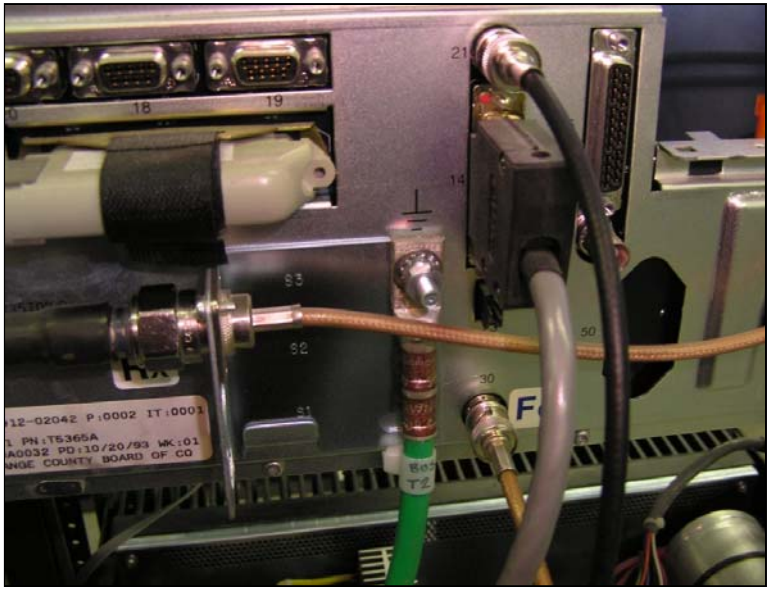
Outside Bulkhead

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

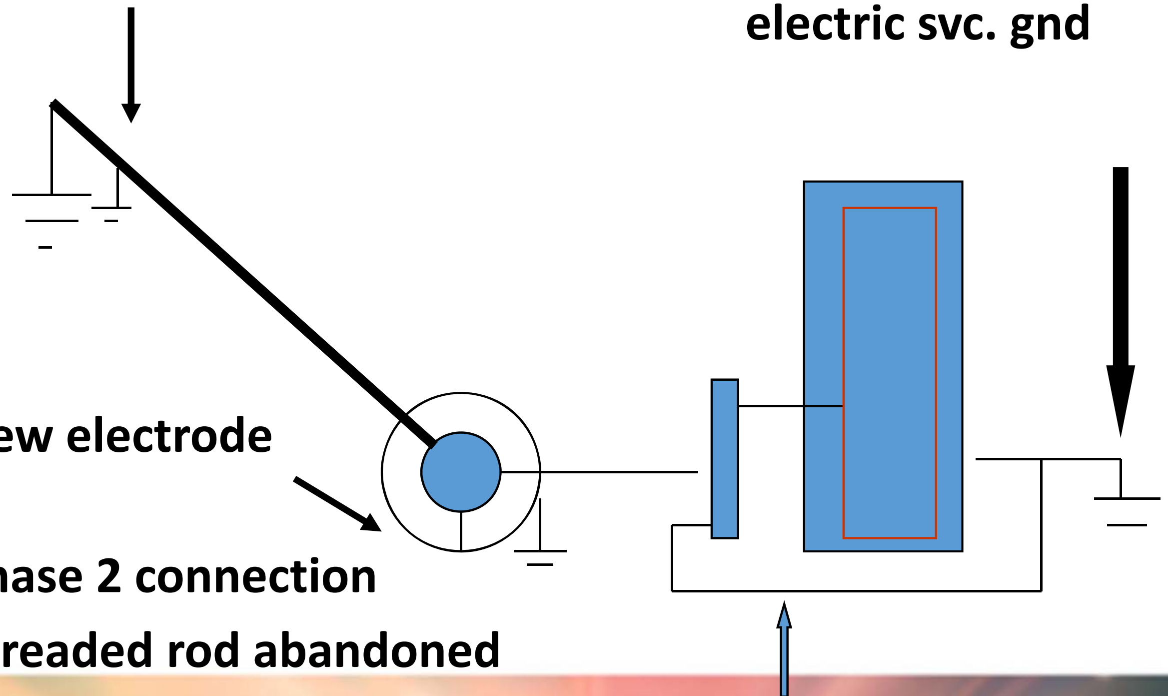
Proper Coax Shield Grounding

- Andrews Cuffs

Apopka

New electrode

electric svc. gnd



New electrode

phase 2 connection

threaded rod abandoned

Reedy Creek

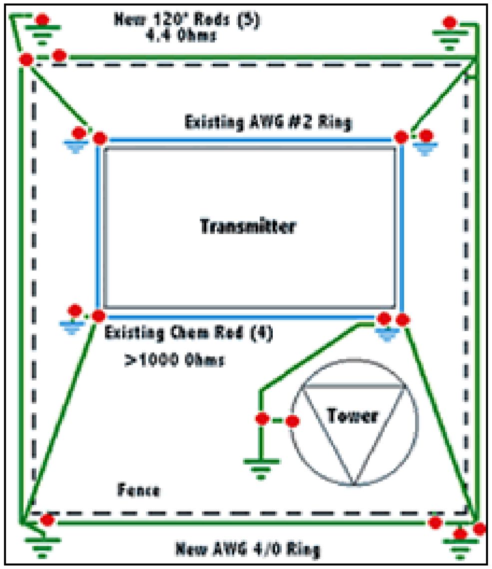
Remote repeater near Disney World

Reedy Creek

More real estate to work with

Reedy Creek

Grounding layout: double rings plus deep electrodes

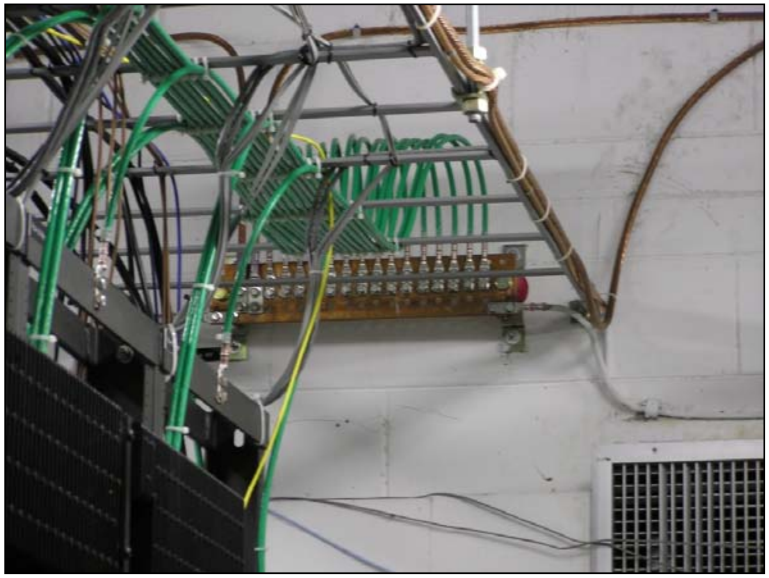


New Resistance 3.5Ω

< 5 ohms independently

Sweeping Turns

Note wide, large diameter turns

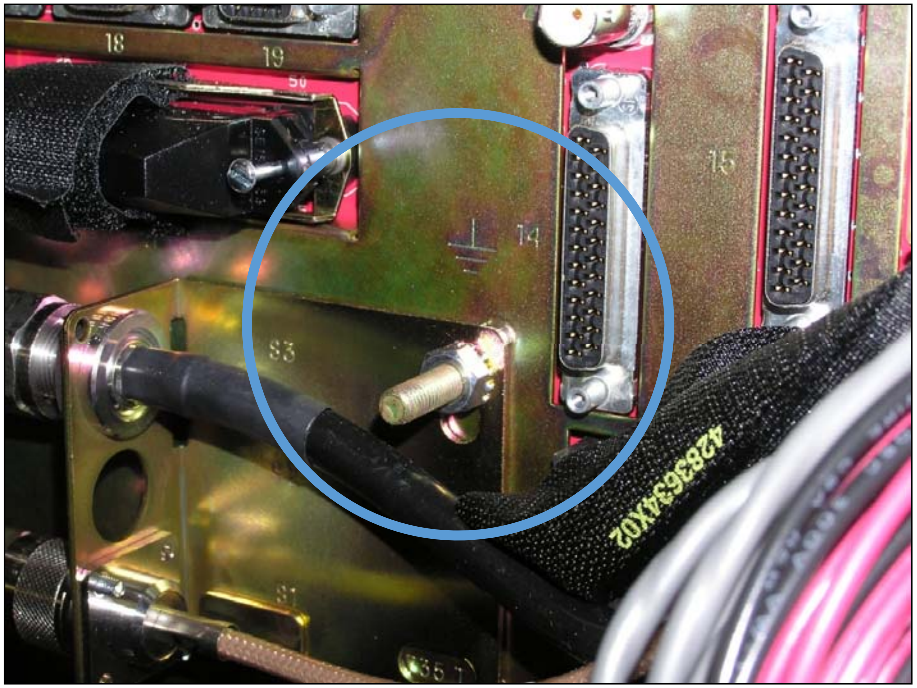


Replaced Connections

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

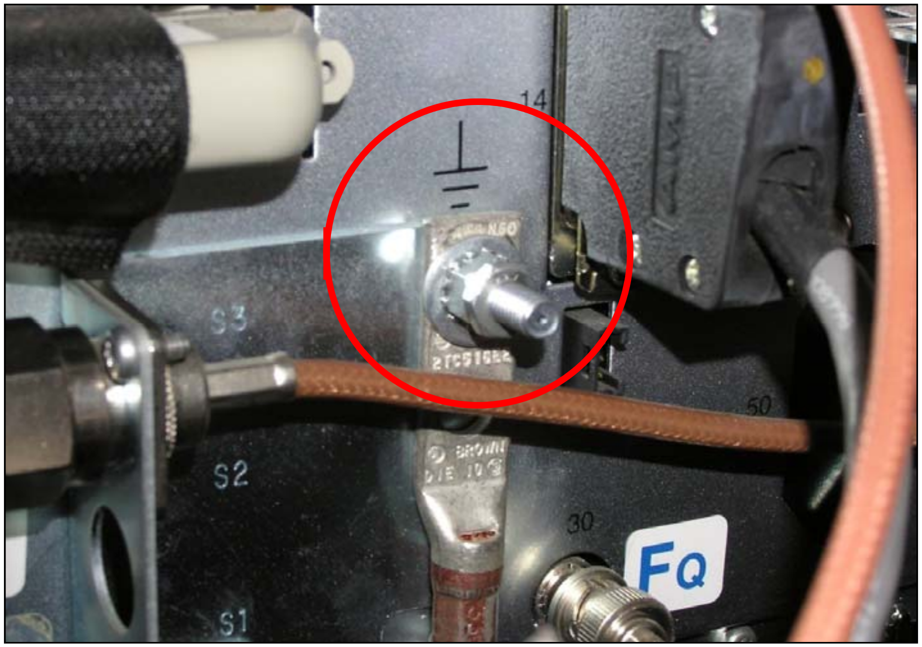
Ungrounded Equipment at Apopka

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

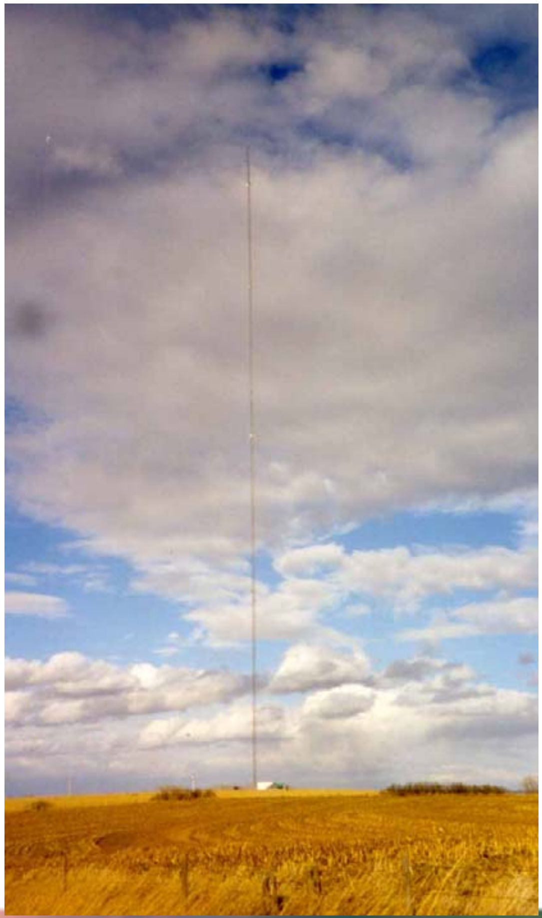
6-mos. to 1 year paybacks common

Retrofit of KGBI - FM

1200 ft.. tower in Nebraska

Numerous lightning hits

Equipment damage and downtime



KGBI - FM

New 4/0 ring around entire site

KGBI - FM

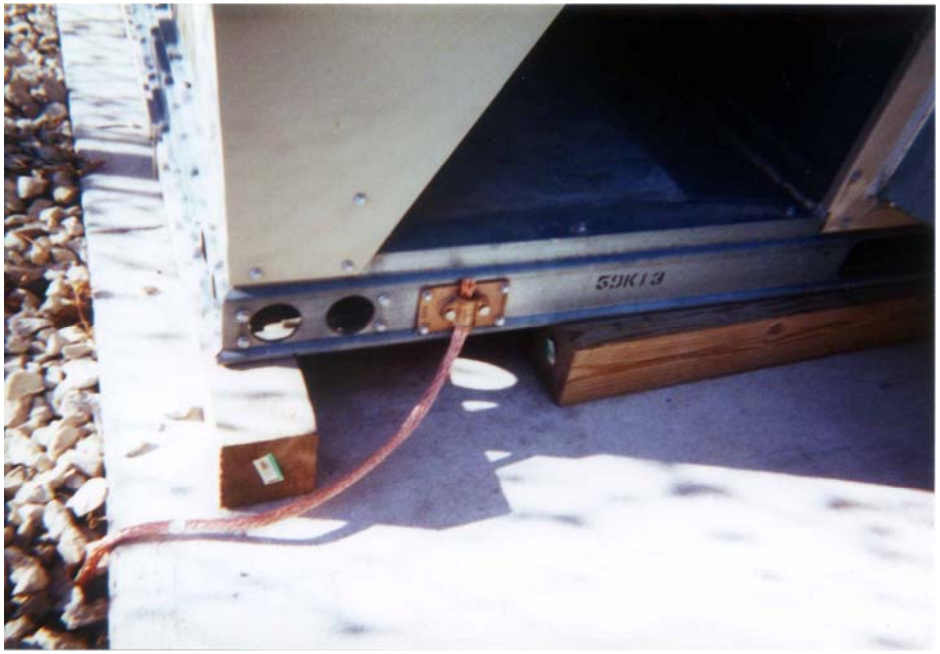
Ice bridge over cables bonded

KGBI - FM

Bonding steel perimeter of roof bonded

KGBI - FM

Bonding HVAC equipment

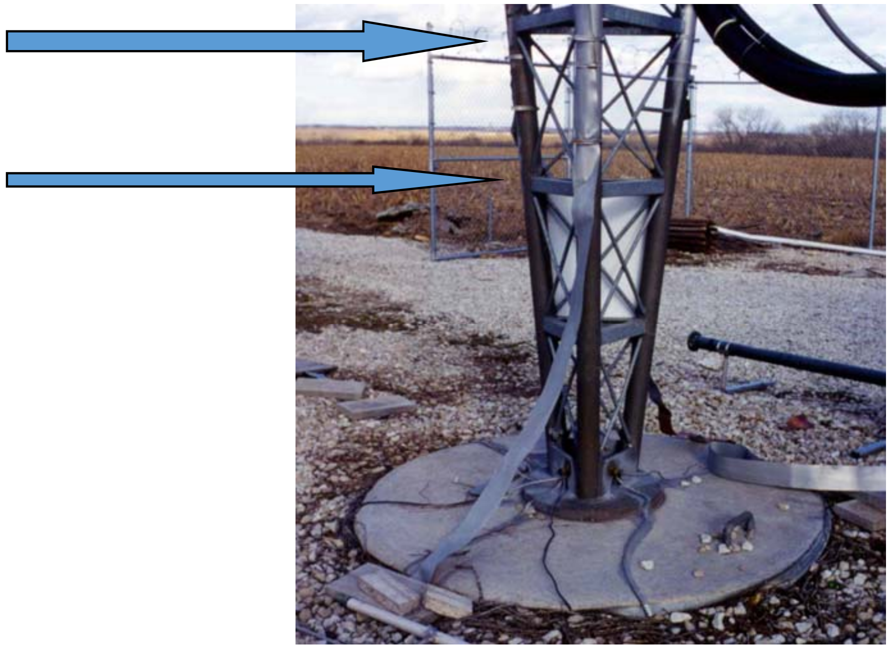


KGBI - FM

Preparation for air terminals

Non-listed Connectors

Old tower grounding

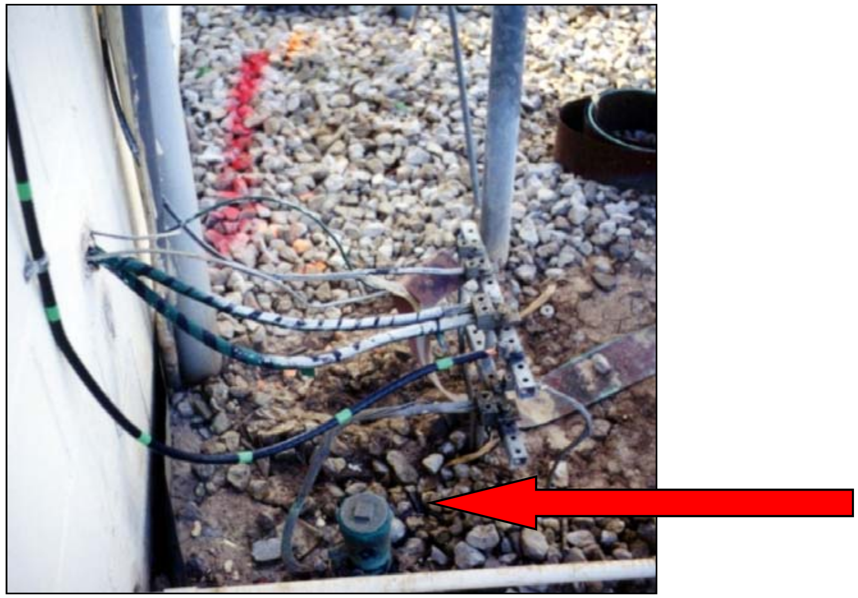


KGBI - FM

New listed mechanical bonding clamps

KGBI - FM

Existing chemical rods to be supplemented



Desired Grounding For Comm.

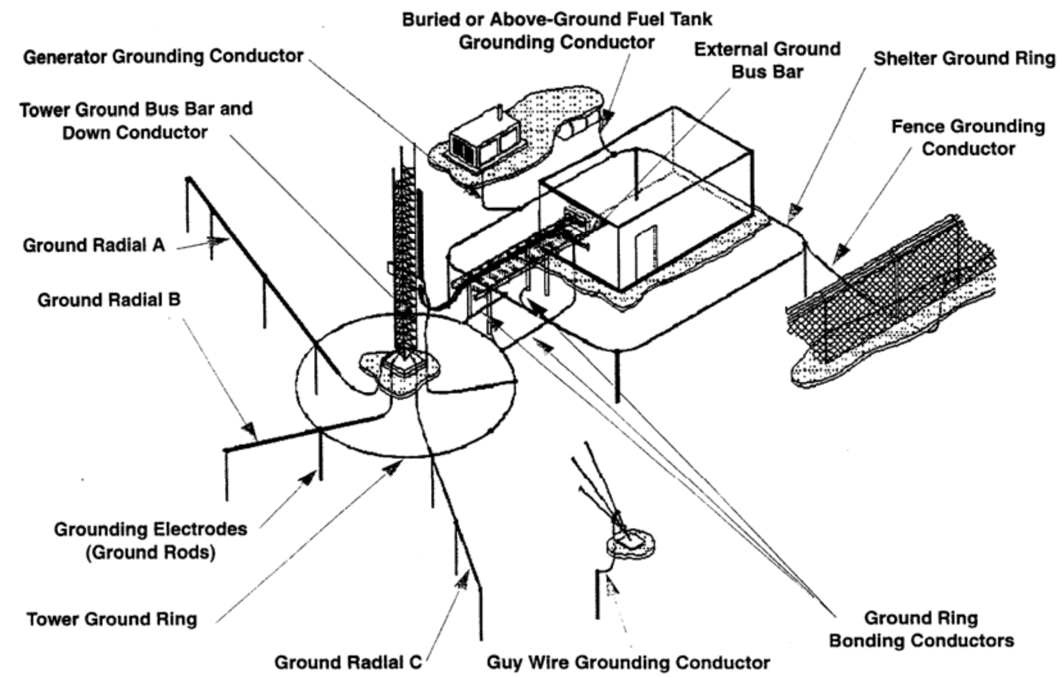


FIGURE 6-1 TYPICAL TYPE B EXTERNAL GROUNDING ELECTRODE SYSTEM

KGBI - FM Result

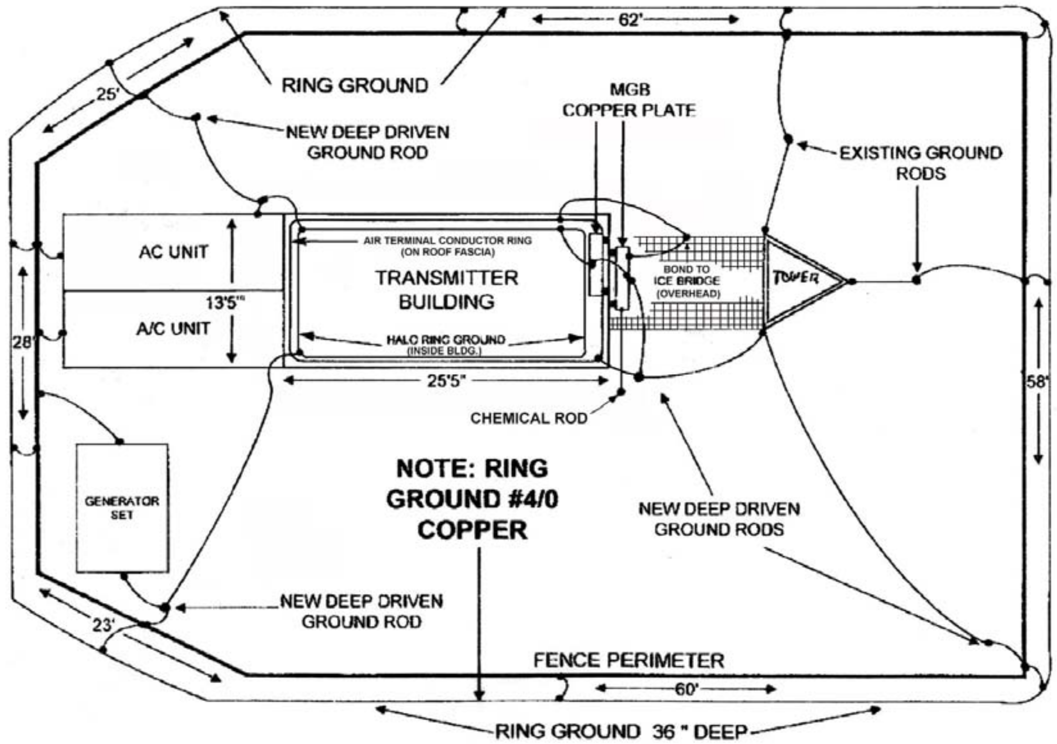
Cost under $40K

No downtime since

No equipment damage since

No audio hum since

Rented site



System Grounding Example

Can save big $$

Mt. Washington, NH

Mt. Washington, NH

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

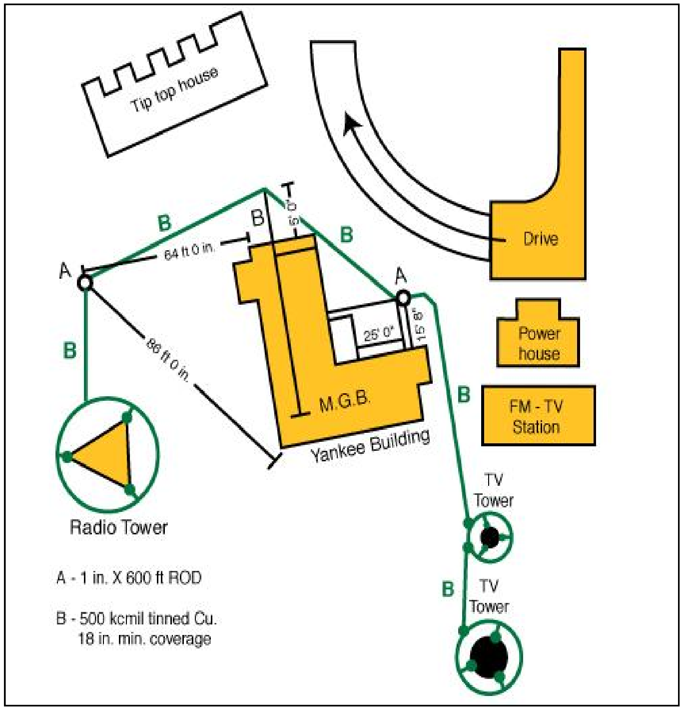
Backfill with bentonite grout

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 4 years since improved grounding

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

Angel Fire Ski Resort

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

Angel Fire

Grounding for communications cable

Terminus of messenger wire (only grounding between towers)

System Was Not Integrated

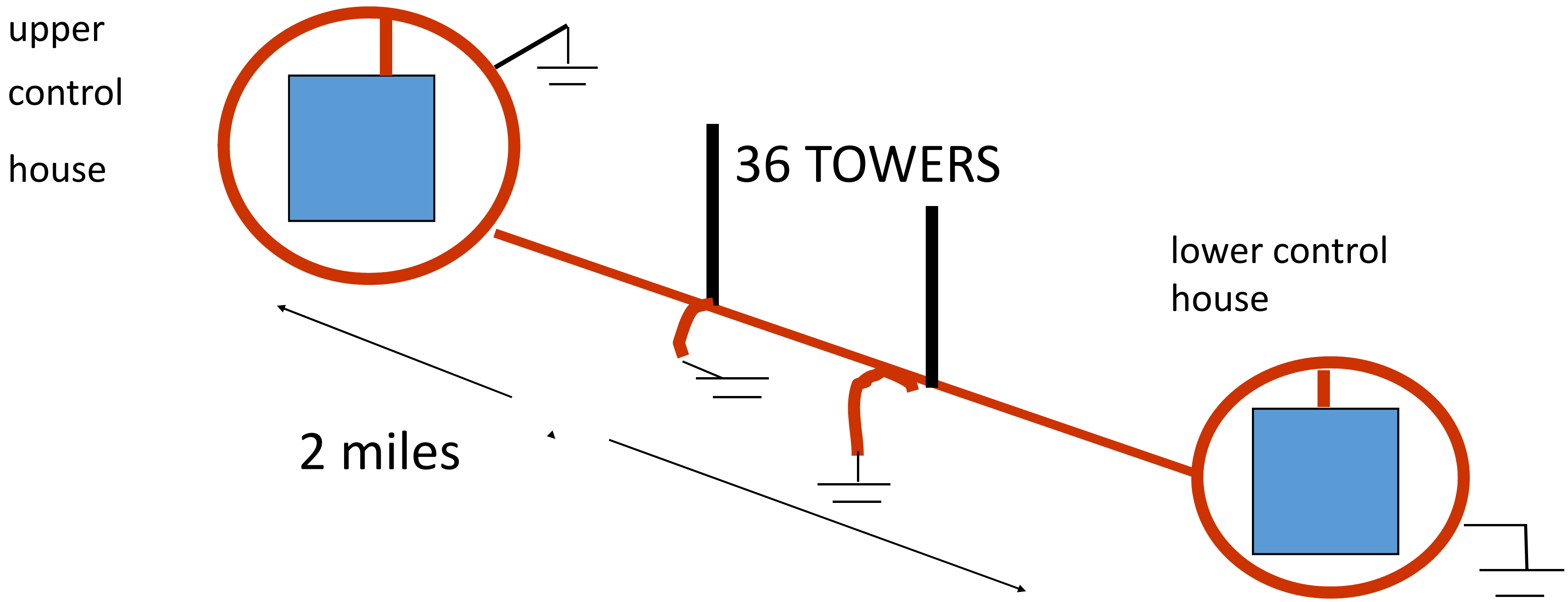
- Ground *system*
- Rod at each tower
- 2 miles of 2/0, each tower connected
- Rings at top and bottom stations
- No outages since!

Exothermic Welding

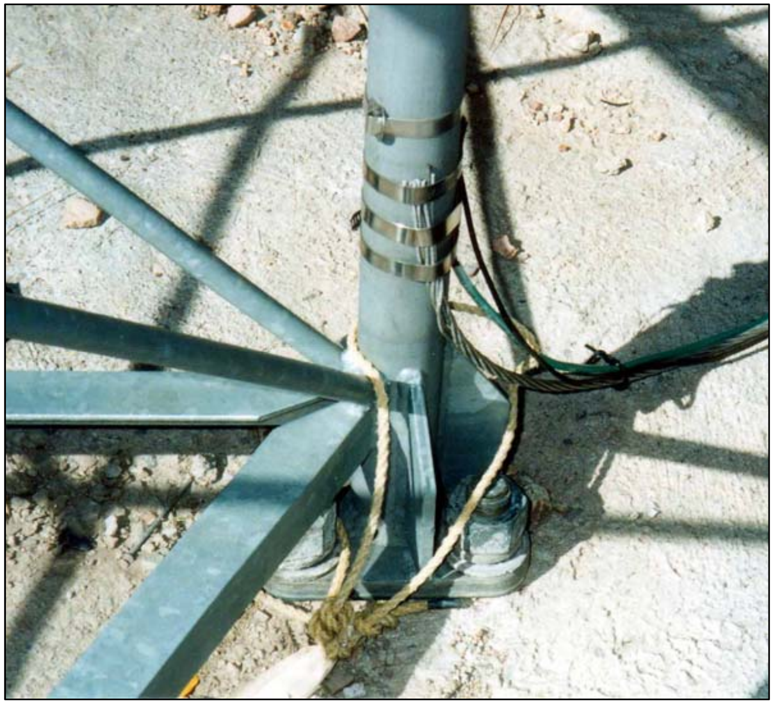
Lower Base Station

Soaking bentonite with water

Angel Fire Result



KKIT - FM



Connection to Electrode

Connection to Water Service

Multi Building Campus

Verestar

Largest satellite facility in North America

Verestar Control Room

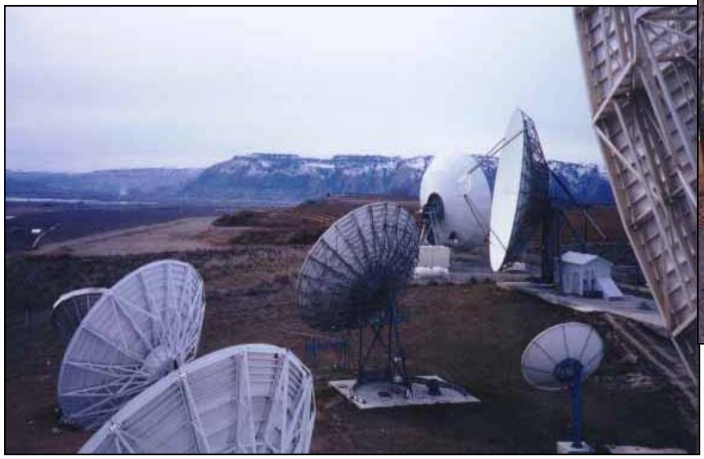
6 buildings

Over 100 acres

Dishes Are Remote

42 satellite dishes

3.5 m to 30 m



Basic Grounding Layout

8-20 ft. rods

Well casings (4)

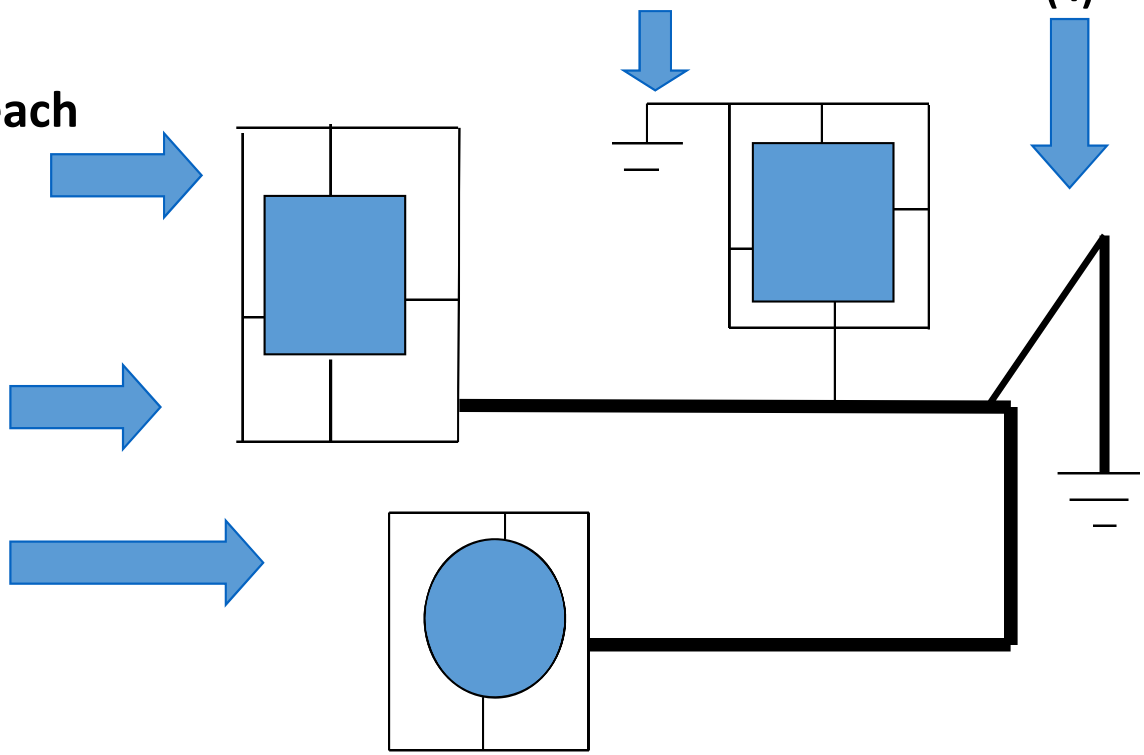
4/0 ring ground around each building (6)

750 kcmil spine

4/0 around each dish

(typ of 42)

2 Ohm standard



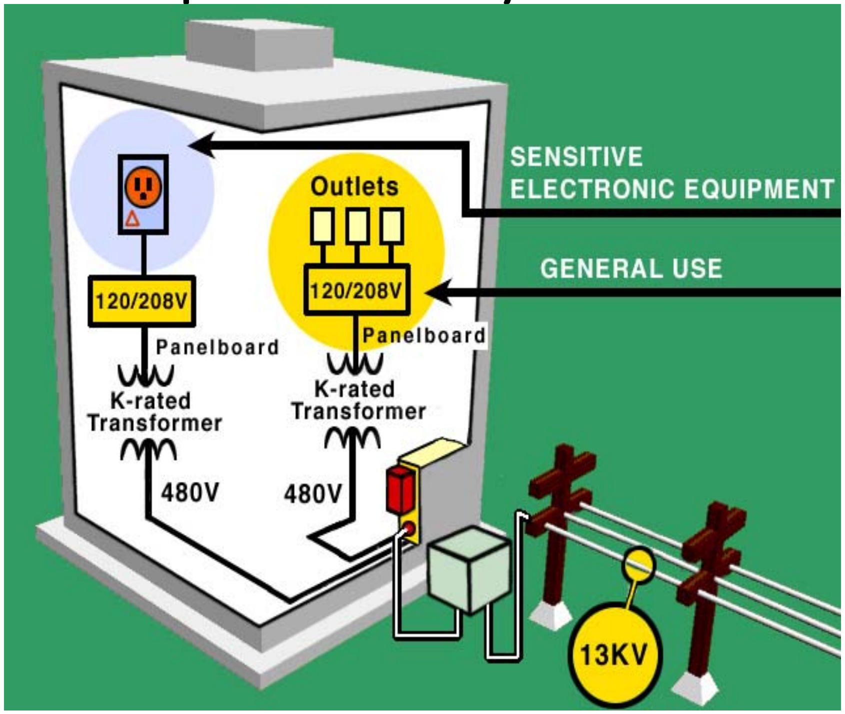
M.I.T. Case Study

Current Interior Design Standards:

Separate computer feeders, panels, and branch circuits

4 outlets per 20 amp. Branch circuit

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**

System Grounding

- **Ground Ring System:**
- **500 MCM surrounding building**
- **1000 MCM “spine” between buildings**
- **36”-42” depth (below frost line)**
- **Tripled ground rods at each corner**
- **Tripled ground rods if span exceeds 200 ft..**

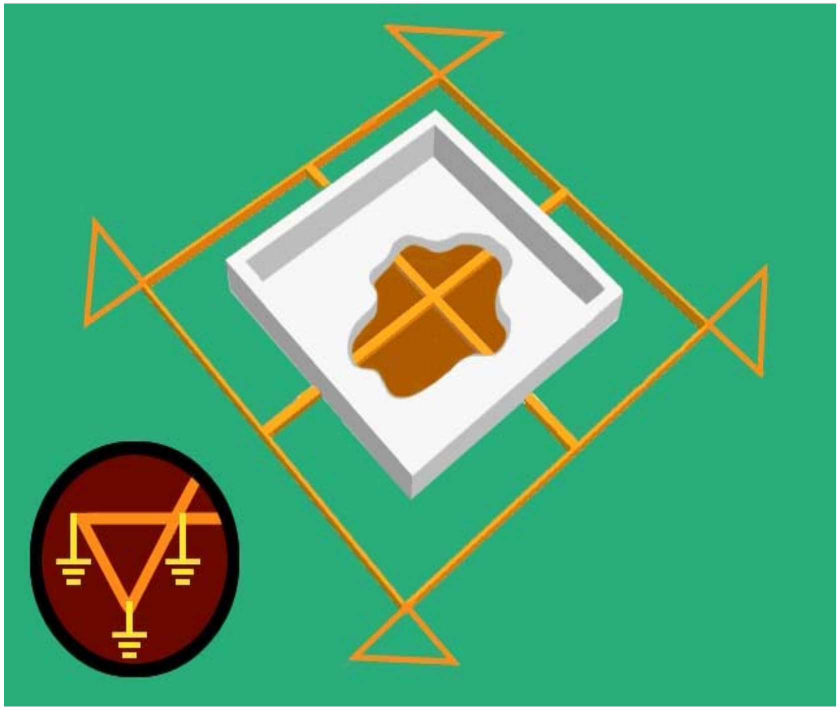
System Grounding

For slab – on- grade construction:

Ring ground

Triple rods at corners

Criss-cross under slab



Bonding

Connection of equipment cabinets that are not normally energized

KPTM-TV

4800 kW station

Studios in Omaha, NE

Built 2 Towers Near Studio

KPTM-TV

- **Lightning strikes damaged $1,000’s of equipment, took station off the air.**

KPTM-TV

Tower was not bonded to studio

3-ohm resistance

2 electrodes at 125 foot deep

KPTM-TV

Satellite dishes were not bonded to studio

Note crowded site

Installed Master Ground Bus

Re-bonded all interior and exterior equipment:

- Equipment racks
- Satellite dishes
- Towers

to new MGB

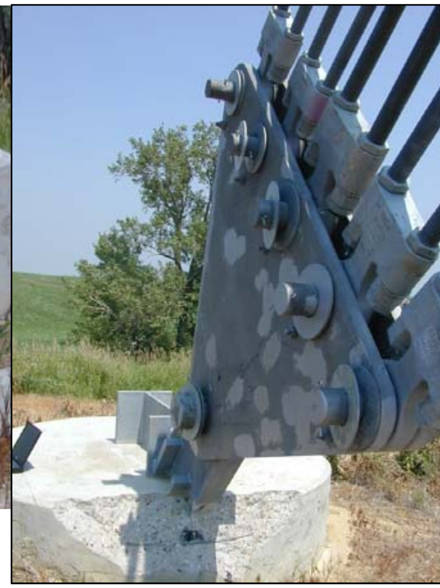
- No damage
- No downtime

KPTM Results

- Spent about $40K
- No equipment damage since
- No time off the air
- Able to sleep at night

KPTH & KMEG-TV

What Can Happen to a Ufer Ground?



KPTH & KMEG-TV

- Transmitter equipment bonded

KPTH & KMEG-TV

- Exterior equipment bonded

Findings

- Up to 200 Ω at guy anchors
- Guy wires connected to one 8-ft rod with #2 AWG wire
- Utility service 190 Ω
- Ice bridge was not bonded to ground system

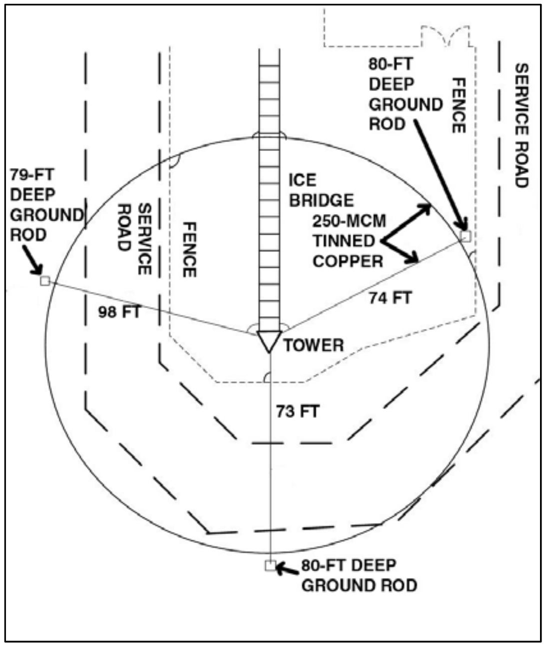
Inadequate Guy Wire Grounding

KPTH & KMEG-TV

- Ice bridge bonded
- Tower bonded
- 250 kcmil ring ground
- 3-80 ft. deep rods

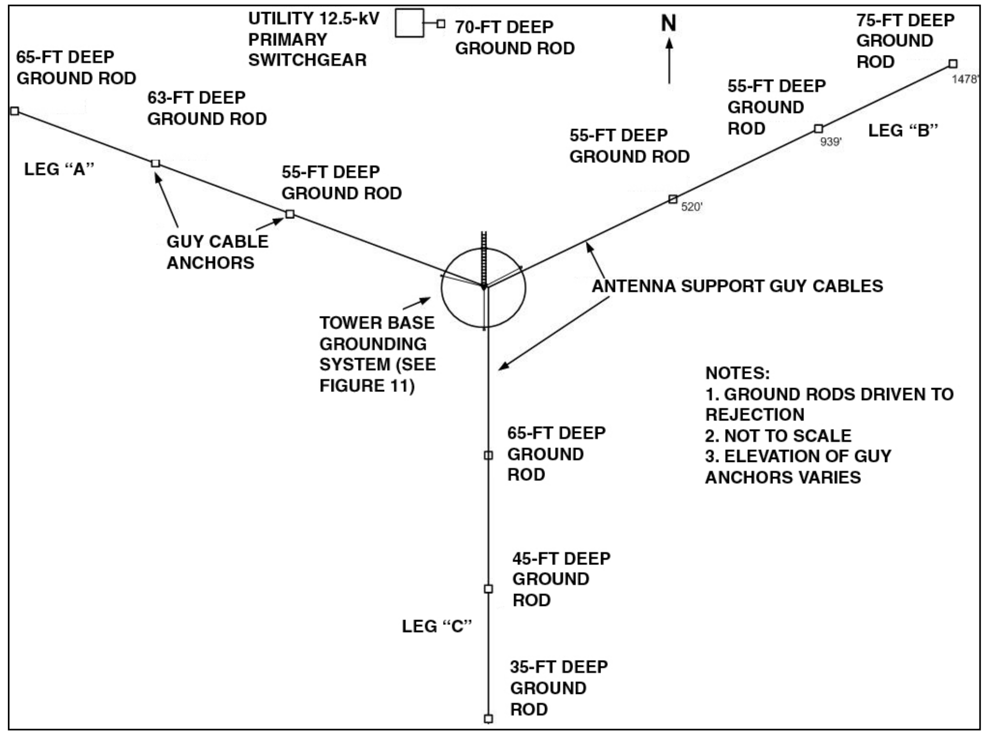
KPTH & KMEG-TV

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



KPTH & KMEG-TV Tower

- Site plan
- 45 to 75 Ft deep
  electrodes on guys
- Every one of the new rods measures < 2 Ω



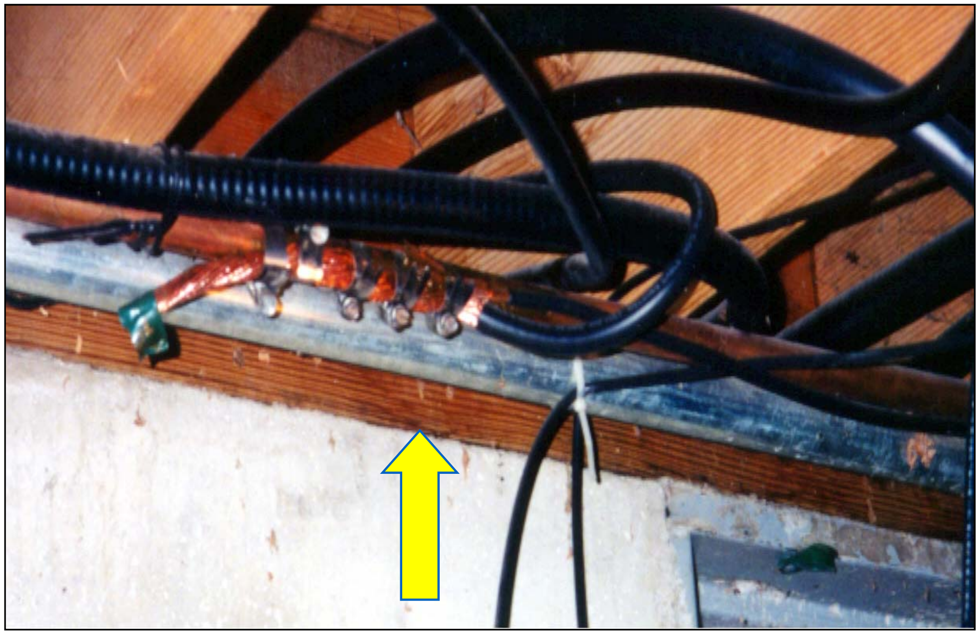
High Water Table Does Not Mean Low R

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

“Clean” Grounds

Shift Gears

- Let’s talk about Isolated Grounds

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

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.

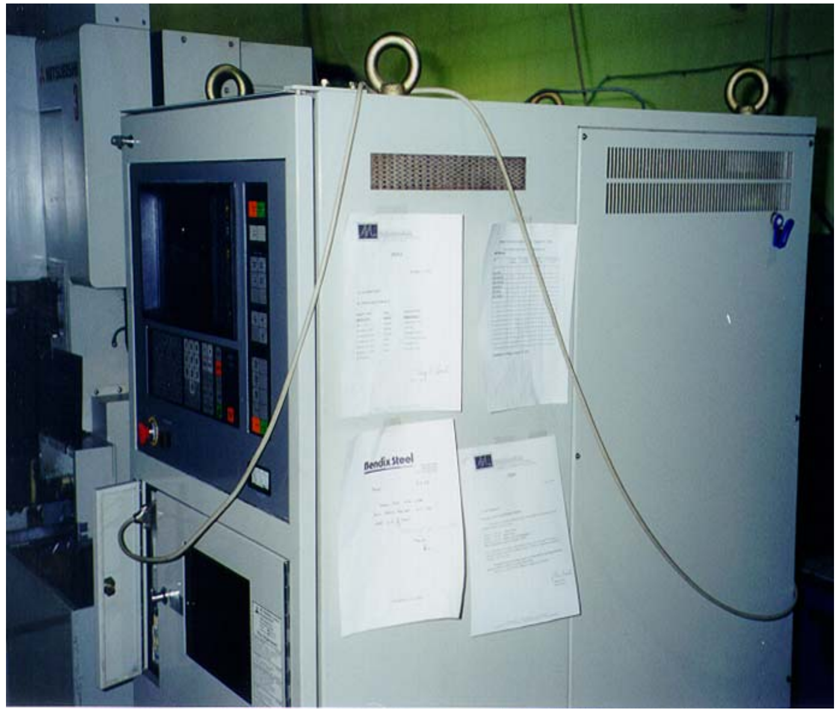
Case Study: "Clean Grounds"

McAfee Tool and Die

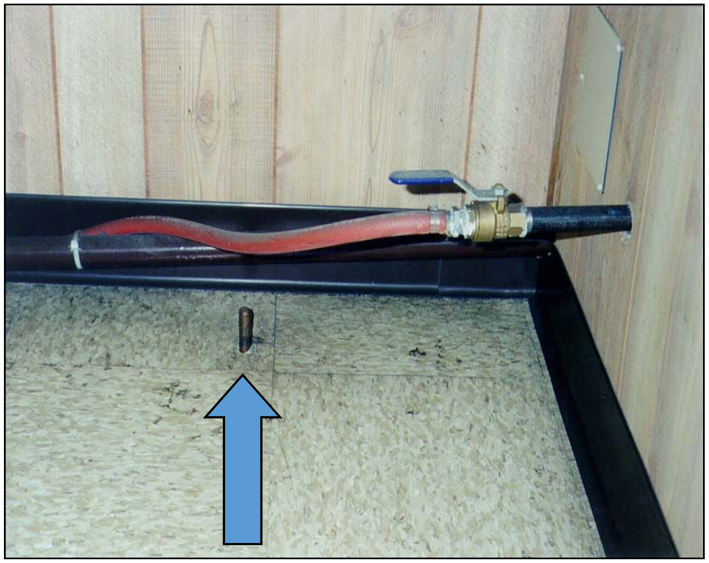
This is a High-Tech Environment

Every CNC Machine is Computer-driven

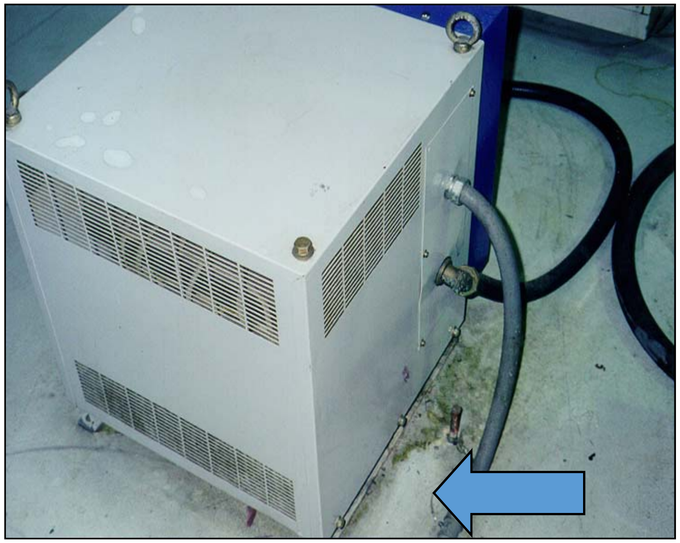
Comm Cable is Unintentional Antenna



“Clean Grounds”

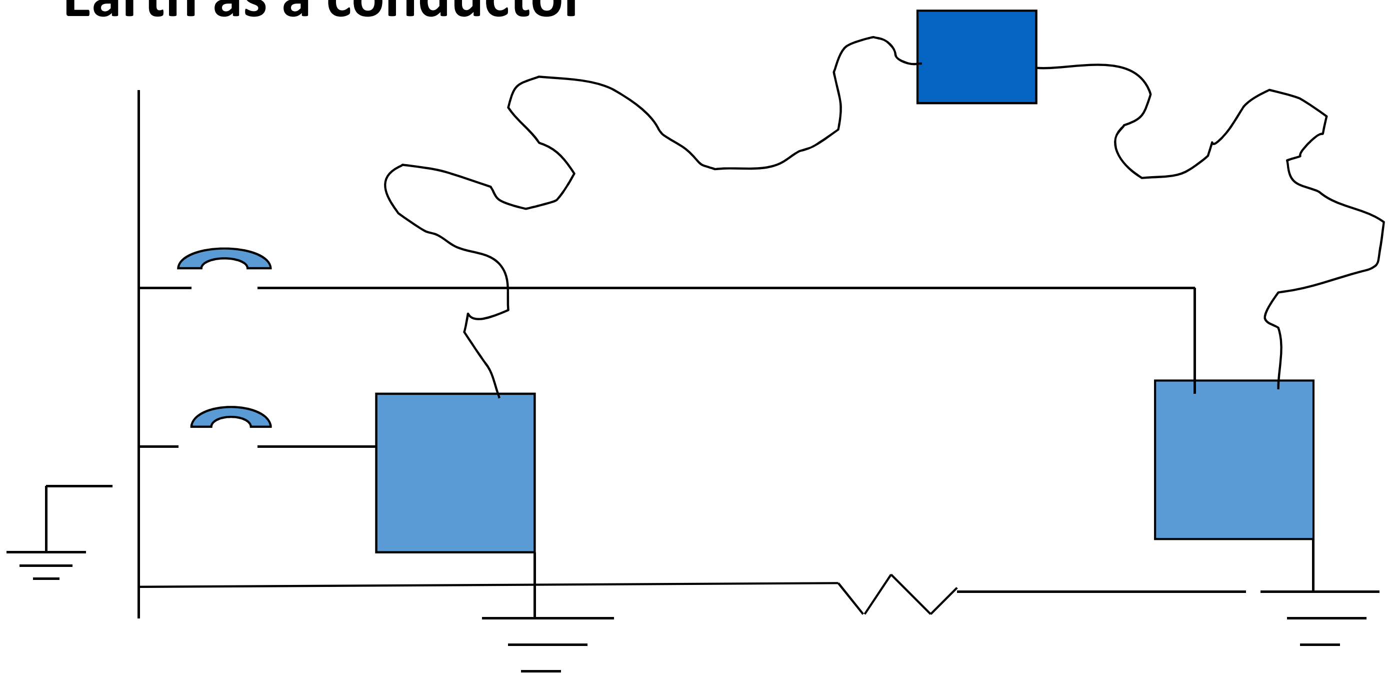


“Supplemental” electrodes abandoned



McAfee Layout

Earth as a conductor

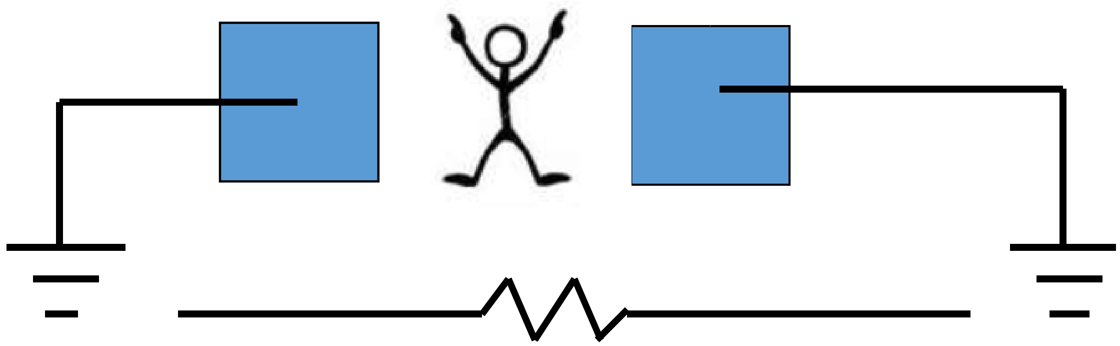


Earth is not a current path

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?

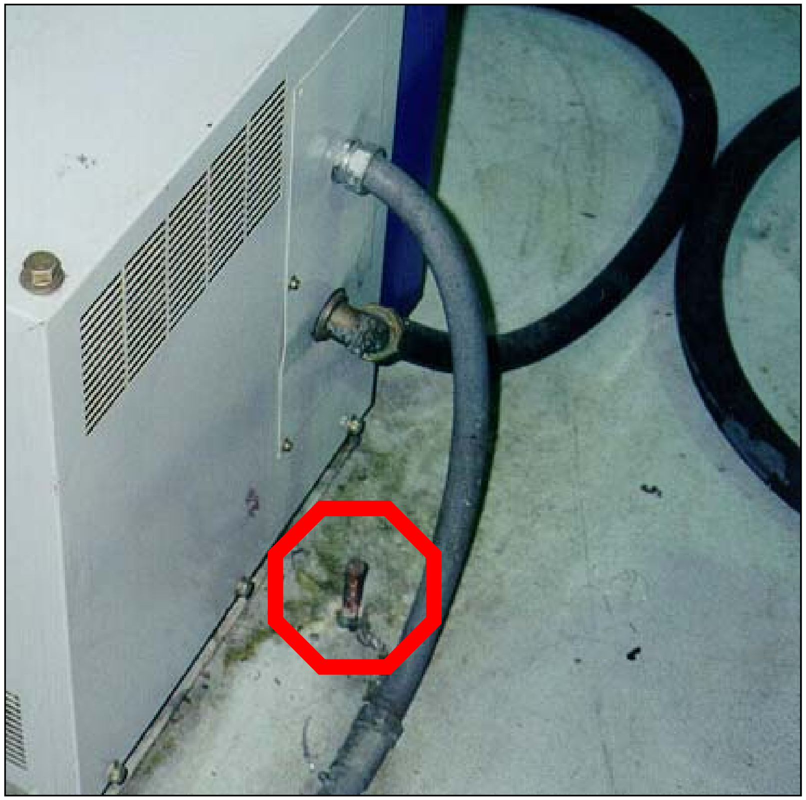
Insulated Grounding

Insulated Grounding (IG)

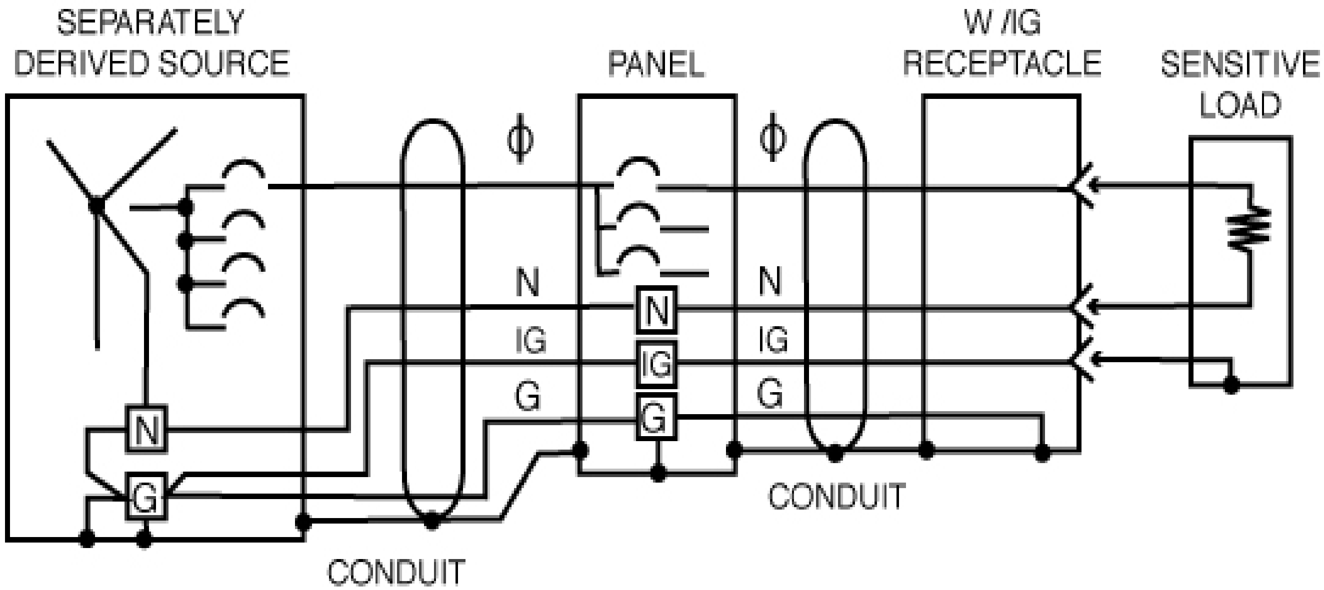
Good idea to install in new circuits

Gives flexibility to use or not

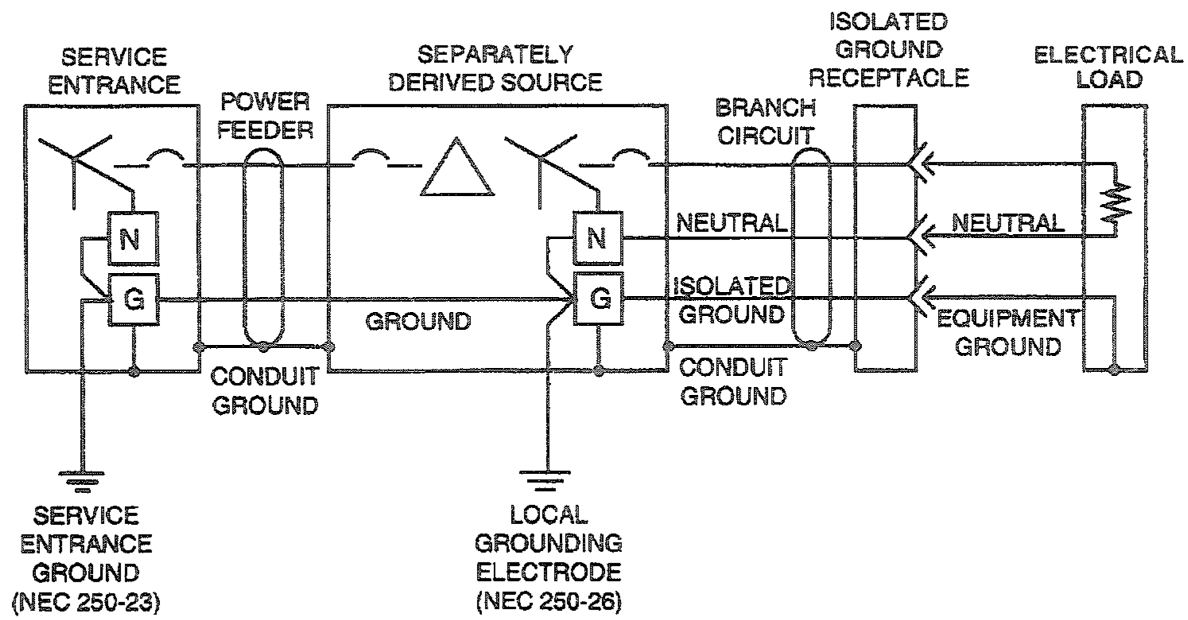
This is NOT IG



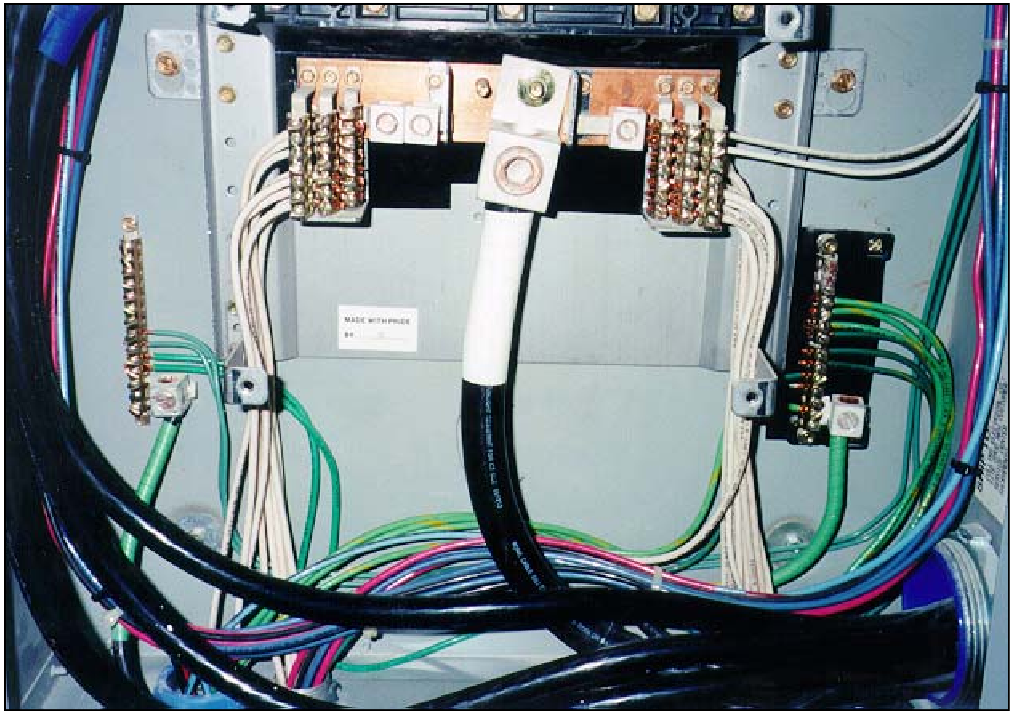
Isolated (Insulated) Grounding



IG Circuit with Transformer

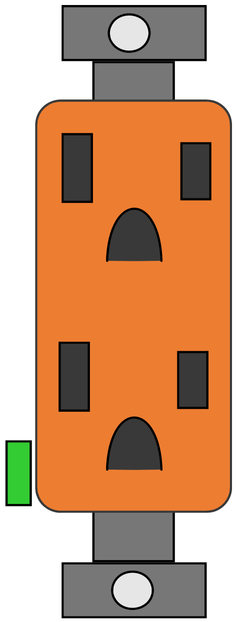


Not Connected to Cabinet

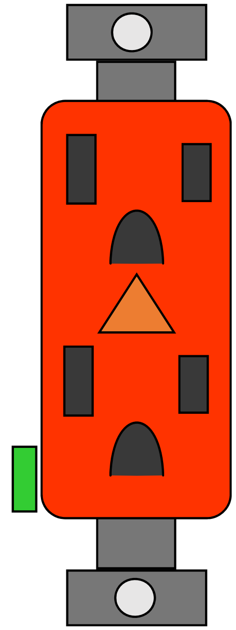


Receptacles

IG or SG?



IG



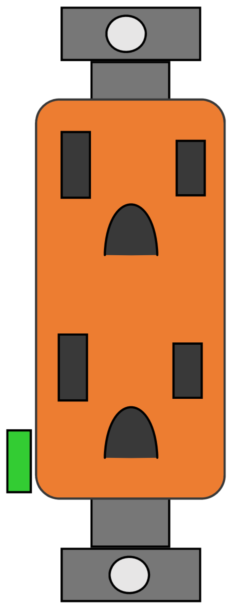
Either receptacle may be any color under the most recent NEC editions.

Receptacles

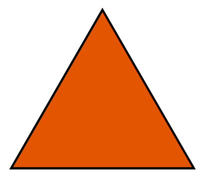
Do you see the difference?

Receptacles

IG or SG?

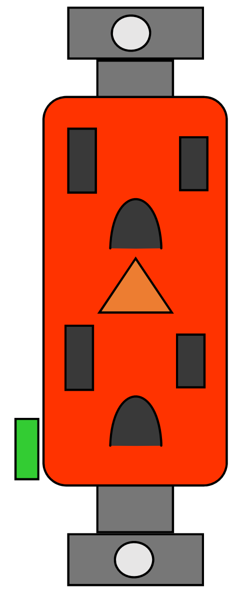


An orange color delta

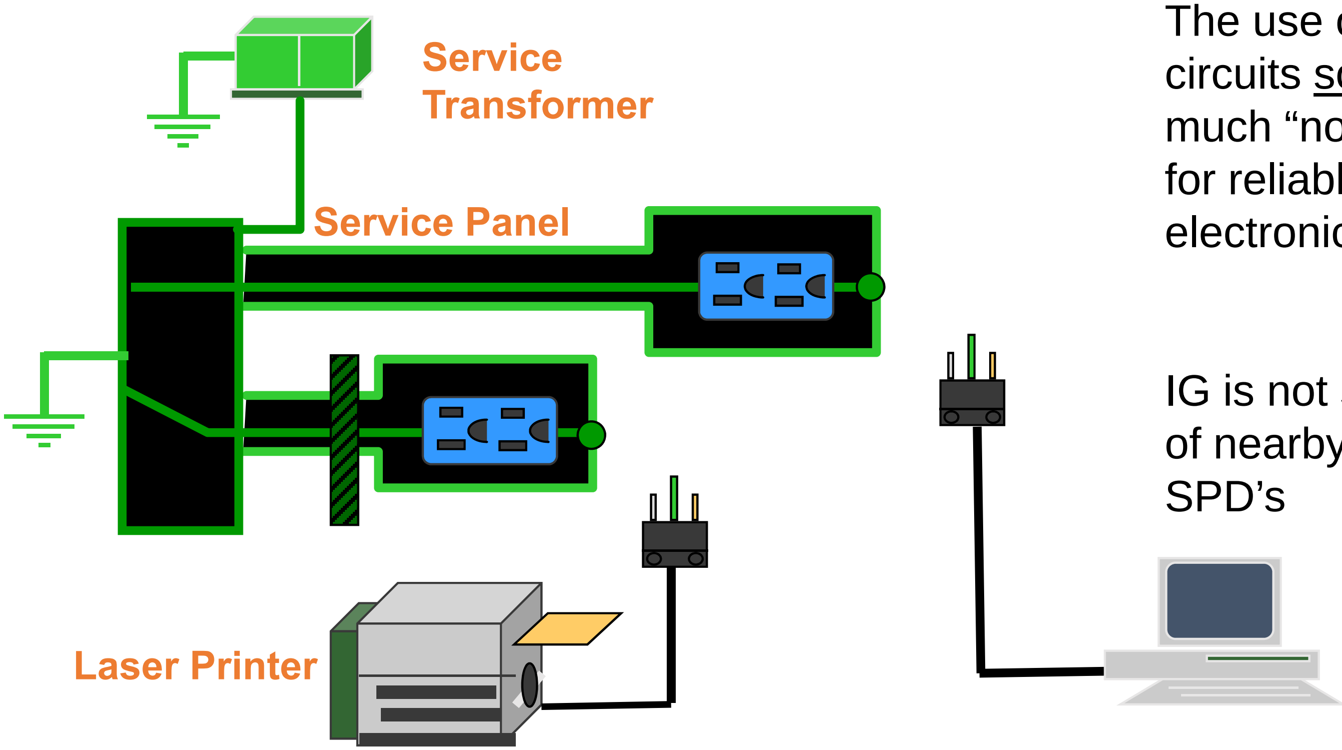


is required to be embossed on the face

IG



Why use IG?



The use of solidly grounded branch circuits 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

Isolated Grounding

CAVEAT:

- **50% of the time, IG helps situation**
- **50% of the time, IG hurts situation**
- **50% of the time, makes no difference**

Be flexible, use what works best in a particular circumstance

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.
- The customer votes with their wallet!

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.
- With many projects there are 6-phases.

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

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

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.

Next We'll Talk About

- 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.
- 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.

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.

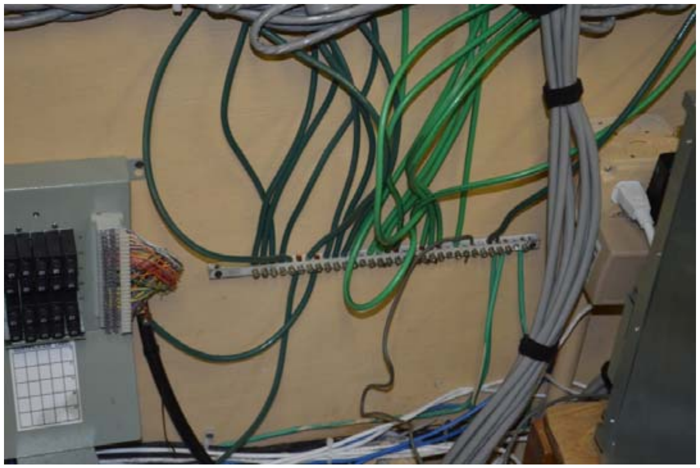
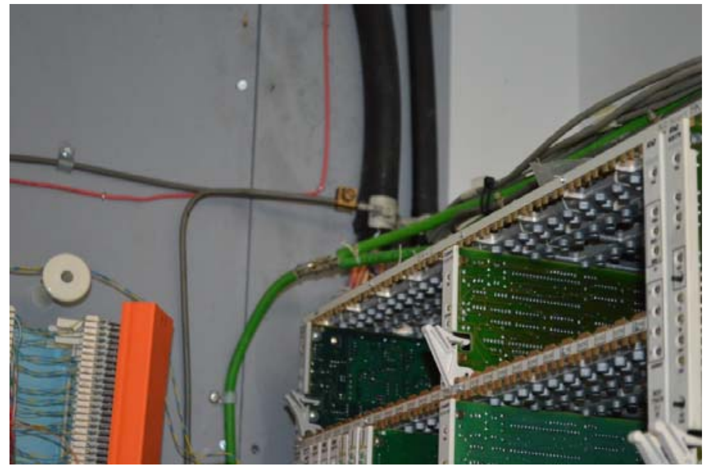
The lightning arrestors for this phone system are not bonded to a path to ground.   This is a life safety issues as well as a formula for equipment damage.

This Met Code When Installed!
As a result it meets code today!

Want Your Name on This Job?

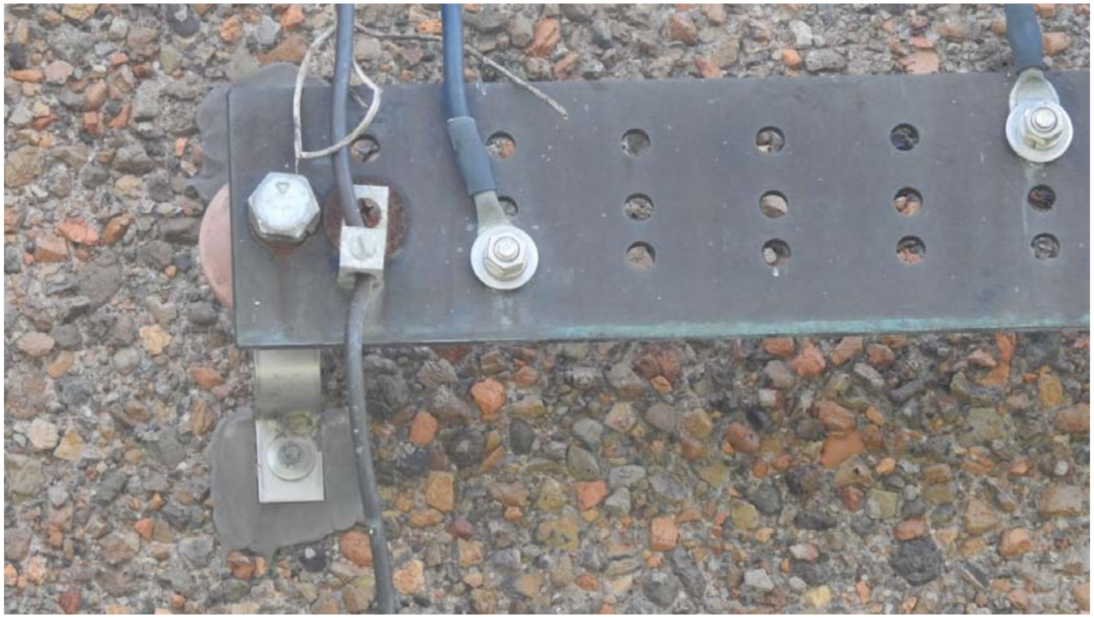
Large Resort in Florida

- Missing bond caused equipment damage, now in court

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 Busbar Was a Good Idea



- But what about the connections?

FM Radio Station Tower

#1 The difference in ground potential with the photo, a minimum of 4.
(the phone company cable has a ground reference)

#2 Look at the daisy chain connection from the telephone cabinet to the rod!

#3 Note the connections are all single lugs.

#4 No Penetrox / Noalox between the lugs and ground bonding bar.

#5 Note the bar is over and very close to a bundle of communication cables.

#6 Multiple conductors on the RHS Lug……

#7 Improper lug for the wire size on the lug in position #2 (L-R)

#8 Note the size of the ground conductor and the lug size in position #3.
The installer solved not having the proper lug, just cut some of the conductors until the wire fits the lug you have….. Oh, what quality!!!

#9 Only one lug is correct for the wire size…..

#10 The "flow" is not aimed in the direction of the ground rod (forget it is wrong to have a ground rod) the flow is wrong….. Must be from the equipment to the drain (the earth).

#11 Solid wire, not stranded is used for 4 of the 5 ground bonds.

#12 The connection to the rod is a cable that is stranded and NOT the proper size the clamp used.

#13 The clamps are exposed to physical damage.

Wonder Who Approved this job?

- Want your new HD, Smart, Flat Screen TV on this ground? How about the fire alarm in a Children's hospital? (no, I am not kidding)

Liked the split bolt, how about the tape job on the ground bonding?

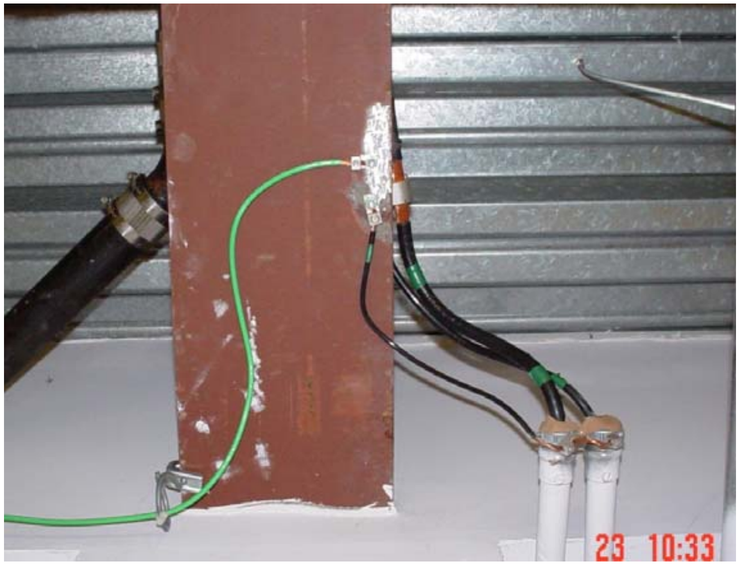
Lightning Damage to 911wonder why?
(Monitor your grounding!!!)

Very Expensive Copper Theft!

Nice bonding job….. to What?

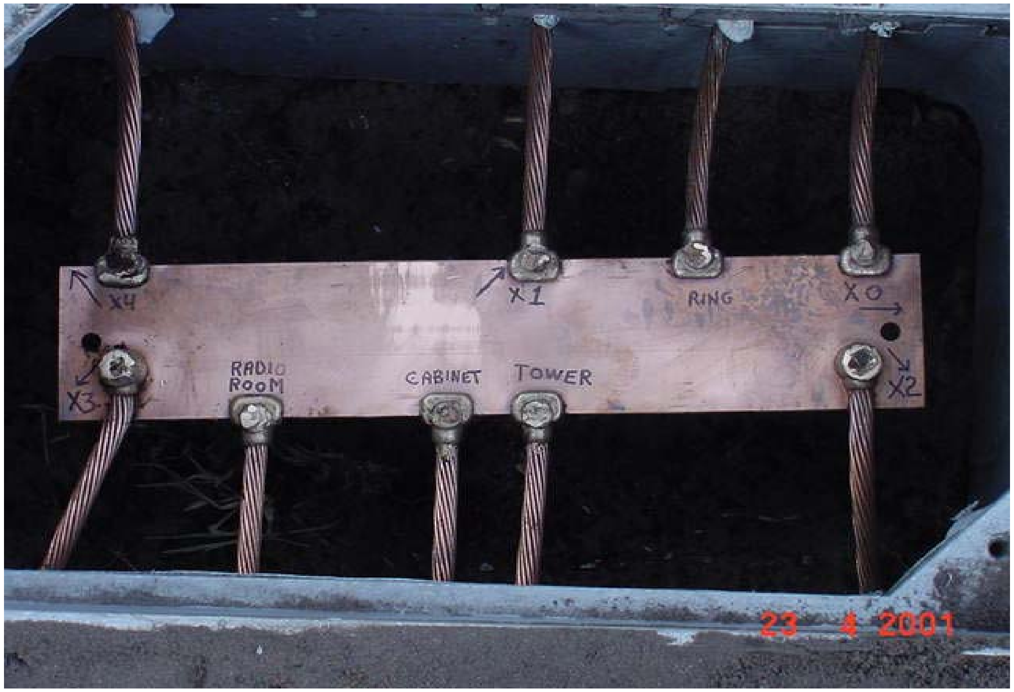
Bonding to Building Steel

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

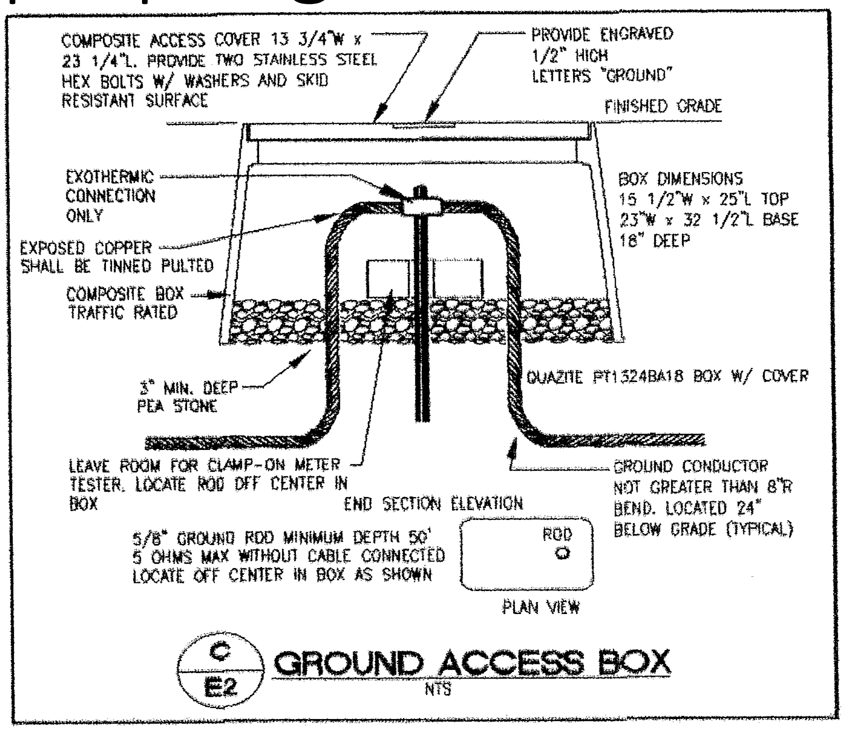


What is wrong here?

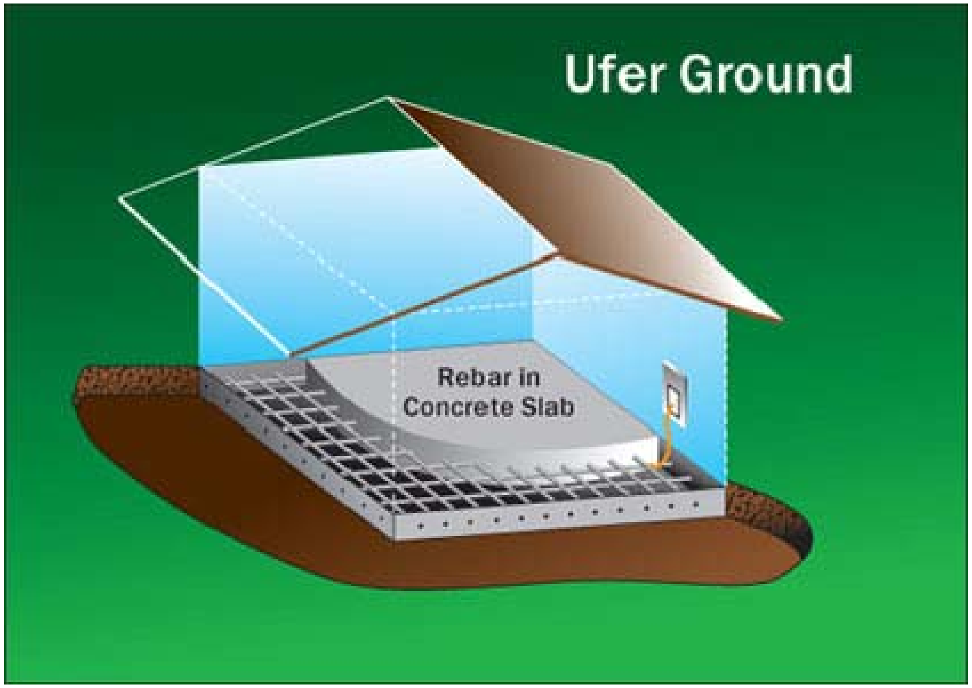
What should be done here?



A proper ground test well



What is wrong with this picture?



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.

Good Place For Another 10 Min. Break

Testing Ground Systems

- 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”.

Testing Equipment

- EARTH RESISTIVITY is measured with a 4-point Wenner tester
- Resistance is measured with a 3-point Fall of Potential tester or a clamp-on meter
- Many meters can do both

AEMC 6470 –B

Megger DET4TD2

AEMC 6417

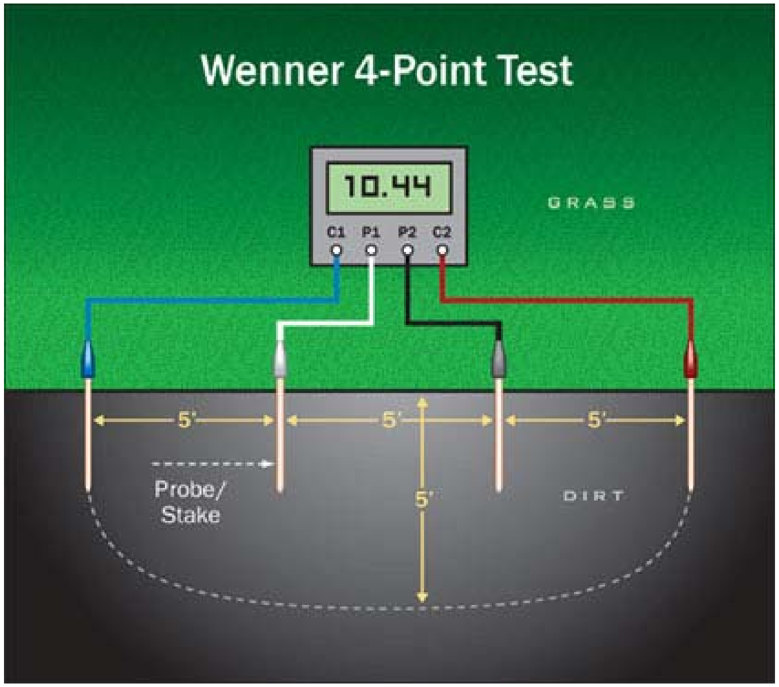
Megger DET24C

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!

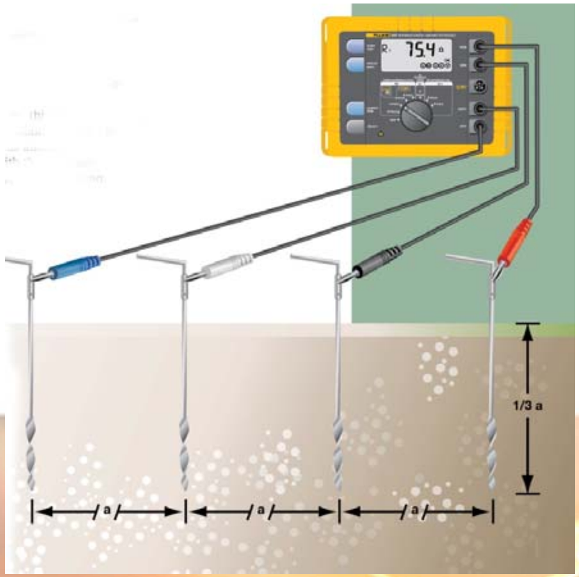


Four Point Soil Resistivity Test layout.

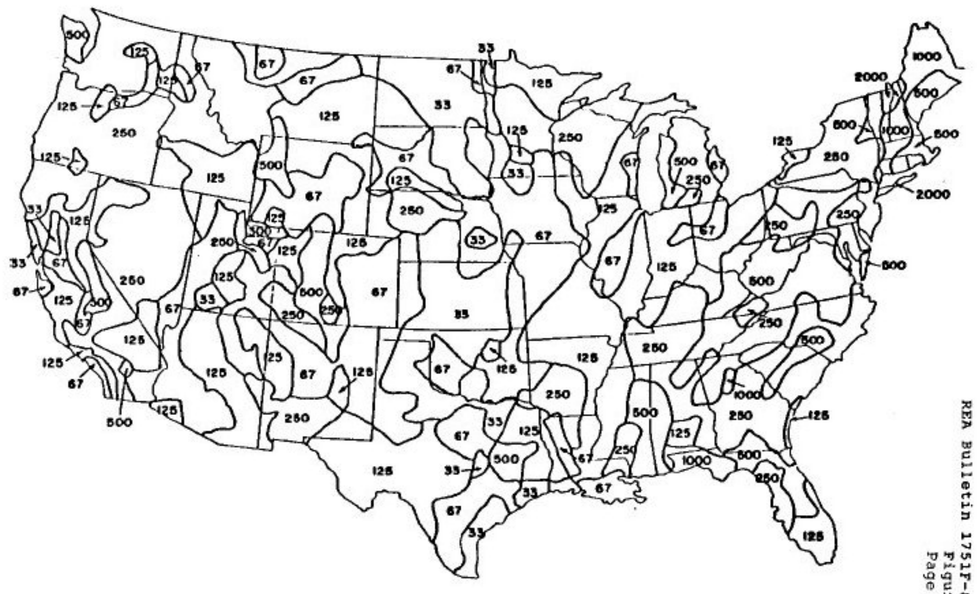
Wenner Method:

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

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.



Earth Resistivity

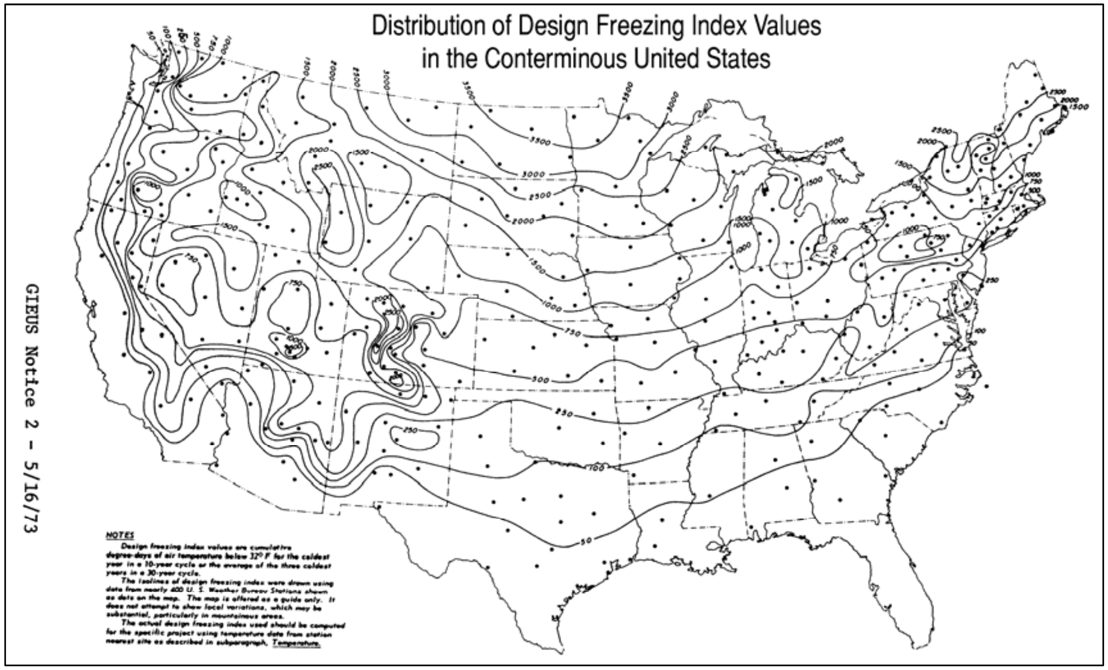


REA Bulletin 1751F-802
Figures
Page 59

FIGURE 2

Estimated Average Earth Resistivity in U.S. (ohm·meters)

Temperature & Grounding



The "Depth" Required 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

Fall-of-Potential Tester 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°.
- Do you have access to enough area or real estate to allow completion of two additional tests for the stake type tester? (Including this requirement for 4-Point soil resistivity testing is proper.)
- 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 by “San-Earth” or “Conducrete” the testing may (will) not be accurate.

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.

The formula for determining ground system impedance

Grounding System Impedance (Z) = $\sqrt{R^2 + {X_L}^2}$

Where R is the Grounding system Resistance

X_L is Grounding system Reactance given by $(XL) = 2\pi f L$

f is the frequency of current

L is the inductance offered by the installed Grounding System

This Chart Influenced by Temperature and Moisture

Resistivity (approx.), ohm-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.

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)

Combined Resistance Of n No Of Electrodes

$$R_n = R\left[\frac{1 + \lambda a}{n}\right]$$

In which $$a = \frac{\rho}{2\pi RS}$$

Where

R=resistance of one rod Ω

S = distance between adjacent rods m

ρ = resistivity of soil Ω-m

λ =is a factor selected from Table 2 or 3 of BS 7430

'n is the no of electrodes as given in Tables 2 and3

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.

Ohms Law

- I = E/R
- Current is “I”
- Voltage is “E”
- Resistance is “R”
- The most current will flow when R is minimal
- So you can have all the voltage you can imagine and if the “R” is close to “0” you have “0” damage. Current, the “I” causes damage.

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.

Single 10' Ground Rod

The resistance of this ground rod on a home and is lower than the ground of many critical facilities.

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.
- In order to understand your needs you should have the knowledge of both tools and how to properly use and operate them.
- Take the training to use both types. Understand how to use both tester properly.
- Then you are ready to make a decision of what you need and make the investment in Fall-of-Potential Ground Rod Tester(s).   NOT Before

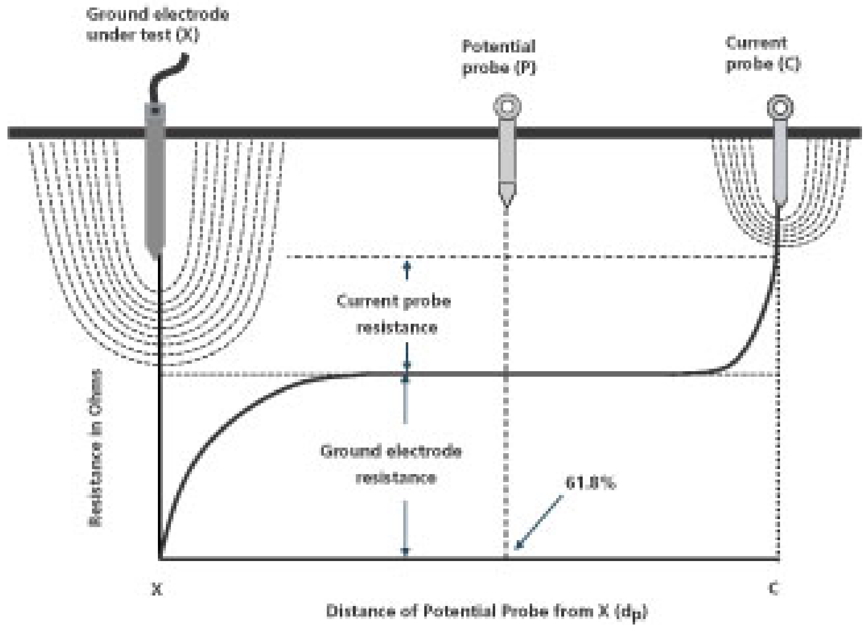
After training on both types this list is logical. The Fall-of-Potential Checklist

- 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.

After training on both types this list is logical. The Fall-of-Potential 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 soil moisture “volumetric water content in soil” if it exceed the “norm” then the test is invalid in “moist” soil conditions.
- Test and record; the soil temperature, moisture content, PH, salt content on the testing report form.
- Confirm if any ground enhancement material was used when the grounding was installed. If anything other than Bentonite or conductive concrete by; “San-Earth” or “Conducrete” the testing will not be accurate.

Ground Rod Fall of Potential Testing & Concentric Shells of Earth



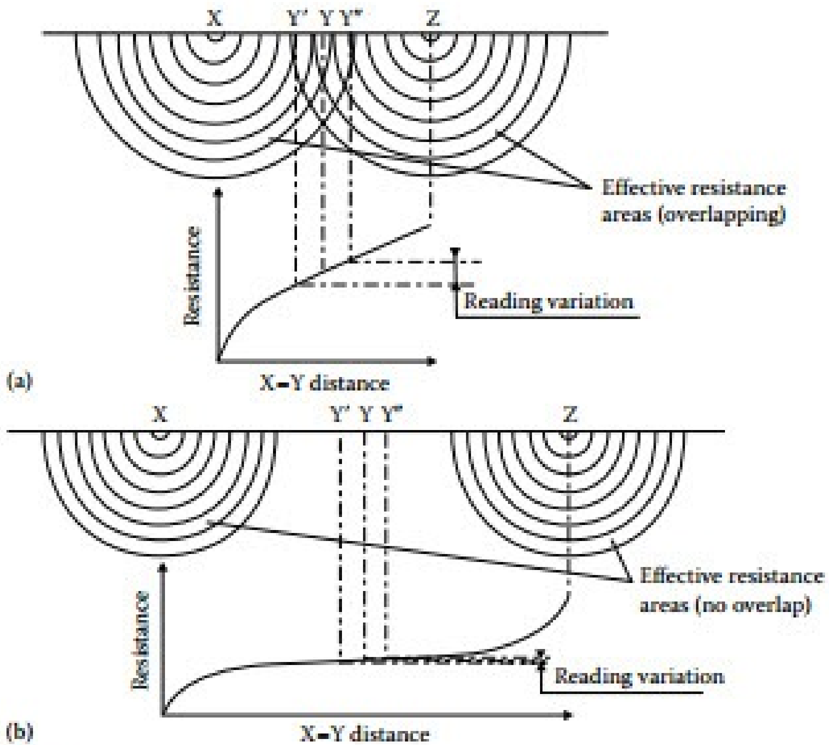


FIGURE 11.17
Effective resistance areas (cylinders of earth) (a) overlapping and (b) not overlapping.

Fall-of-Potential Ground Testing

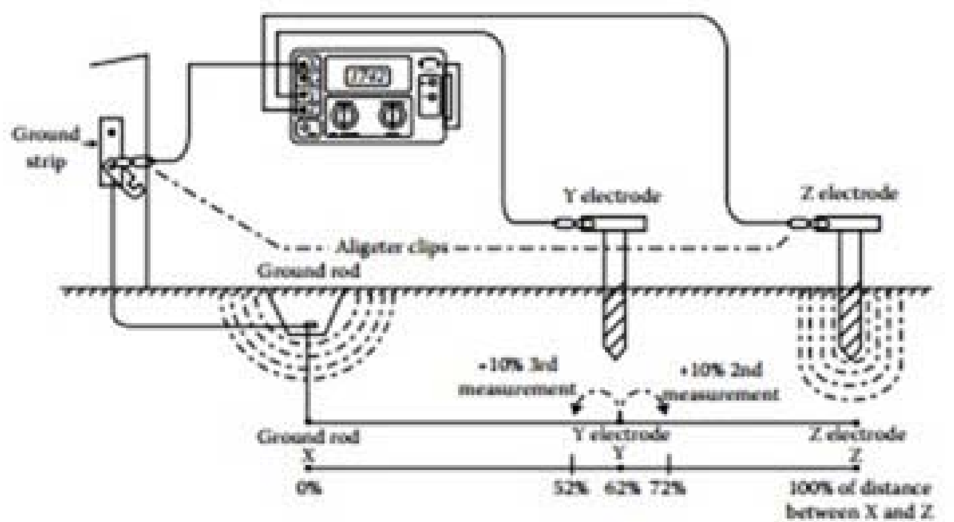


FIGURE 11.18
Fall-of-potential method showing potential rod location at 62% distance from the electrode under test.

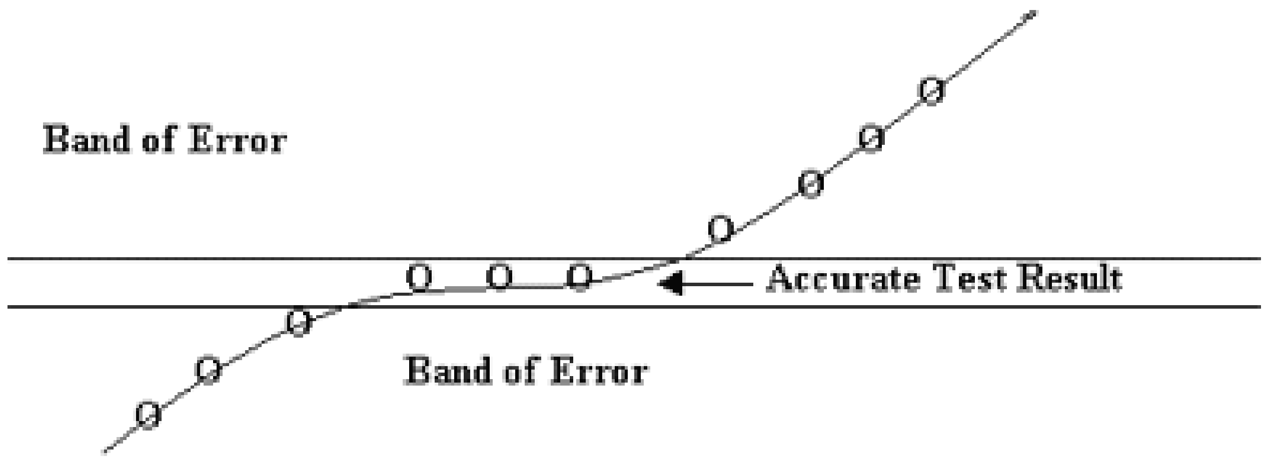
Distance in feet to the Auxiliary Electrodes Using the 62% Method**

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.

Multiple Electrode System		
Max Grid Distance	Distance to Y	Distance to Z
6 ft.	78 ft.	125 ft.
8 ft.	87 ft.	140 ft.
10 ft.	100 ft.	160 ft.
12 ft.	105 ft.	170 ft.
14 ft.	118 ft.	190 ft.
16 ft.	124 ft.	200 ft.
18 ft.	130 ft.	210 ft.
20 ft.	136 ft.	220 ft.
30 ft.	161 ft.	260 ft.
40 ft.	186 ft.	300 ft.
50 ft.	211ft	340 ft.
60 ft.	230 ft.	370 ft.
80 ft.	273 ft.	440 ft.
100 ft.	310 ft.	500 ft.
120 ft.	341 ft.	550 ft.
140 ft.	372 ft.	600 ft.
160 ft.	390 ft.	630 ft.
180 ft.	434 ft.	700 ft.
200 ft.	453 ft.	730 ft.

Band of Error
Fall-of-Potential



Lowering Ground Resistance

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

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.

Sodium Bentonite

- Sodium Bentonite has superior swelling capacity when compared to Calcium Bentonite.
- Sodium Bentonite has extremely low hydraulic conductivity to water.
- Sodium Bentonite has a “valence” of +1. (Calcium Bentonite +2)
- Sodium Bentonite can absorb up to 5-times it weight in water.
- Sodium Bentonite can swell up to 13-times it dry volume.
- Sodium Bentonite (30%) can be mixed with concrete to lower the resistance of a Ufer ground.

Calcium Bentonite

- Calcium Bentonite has a lower swelling capacity when compared to Sodium Bentonite (10-20%).
- Calcium Bentonite has 15% higher hydraulic conductivity to water than Sodium Bentonite.
- Calcium Bentonite has a “valence” of +2)
- Calcium Bentonite can absorb less than 5-times it weight in water.
- Calcium Bentonite can swell up to 11-times it dry volume.
- Calcium Bentonite is superior to Sodium Bentonite in corrosive soil conditions.
- Calcium Bentonite can be mixed with concrete to lower the resistance of a Ufer ground.

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.

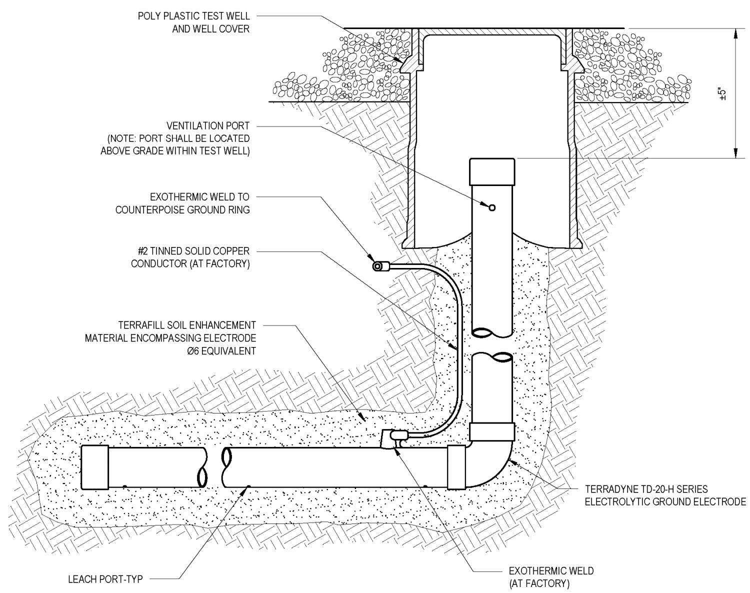
Benefits of Bentonite

- 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 recommended

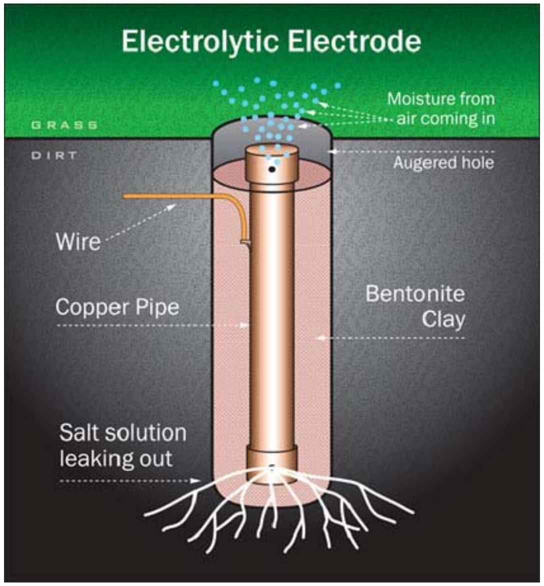
Chemical Ground Rods

- Sustainable grounding is installation to a high standard and maintenance.
- You can use disposable technology such as chemical ground rods if you are aware of the limitations and recognize what must be done to use them.
- If you make the choice to use “chemical ground rods, ground enhancement material or any other “alternative” option, you must have a testing plan in place and a program to make sure what you have is working.
- Lacking that, you should not use any technology including chemical ground rods, GEM, etc.

Chemical Ground Rods



A Chemical Ground Rod in Action
a copper pipe full of salt will last how long?



Chemical Electrodes

Salt-filled pipe after 7 years

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.

Ground Enhancement Material

- Such material is marketed as the best way to lower the resistance in difficult grounding conditions.
- The material is a product that is a “waste” or by product of a manufacturing process.   It may not be 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” like Rock Salt or fertilizer of some type.
- Carbon “enhanced” or based products are know to be corrosive and not recommended.

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…. Doubt that statement? See the next slide.

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 wields or double lugs and made using conductive grease and robust hardware. (lock washers, double nuts, etc.)

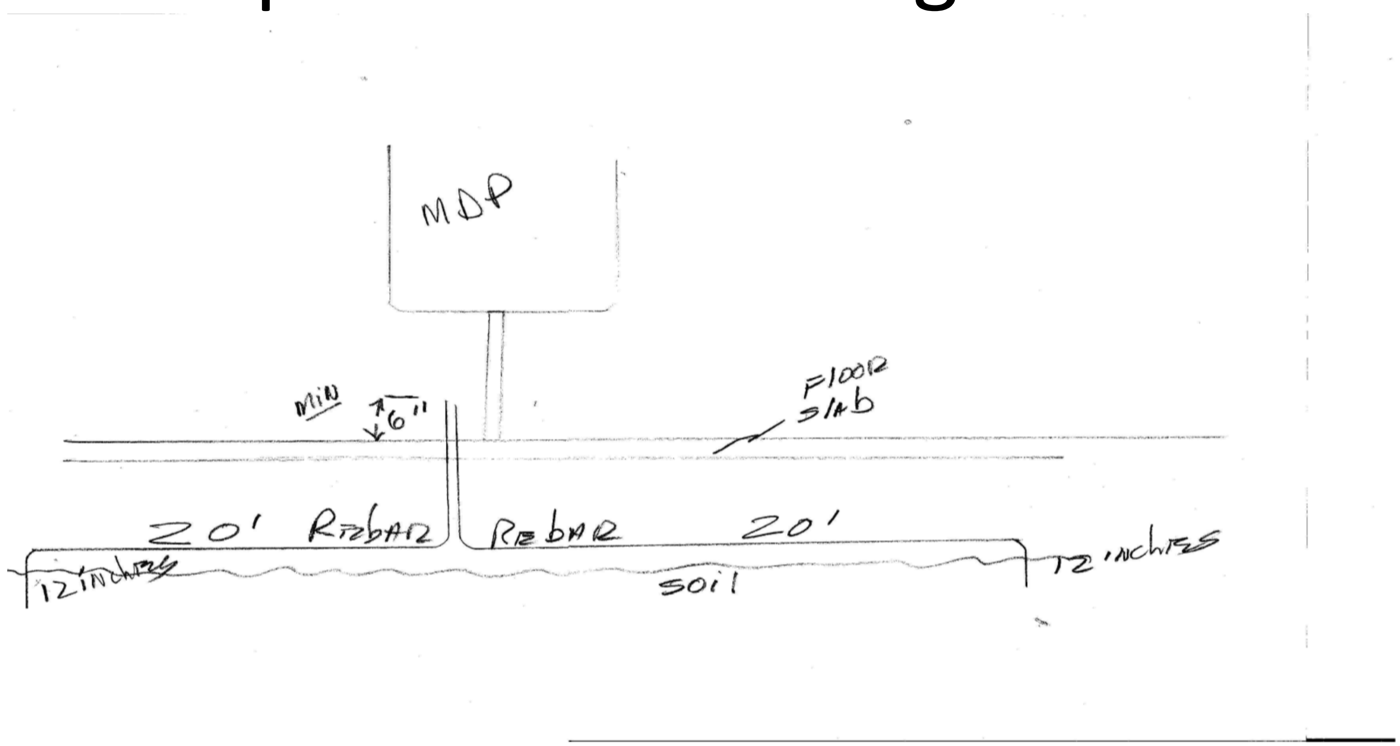
Bonding Installation

- 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 <u>all</u> outside services (CATV & Telecom) bonds with home runs to the bonding bar.
- Bond: plumbing, water, gas pipe, lighting protection, building steel, standpipe(s) or fire sprinkler piping, static bonds (computer room), etc. to this bonding bar.
- Make all bonds to flow to the earth; ground rod system (plate, mesh, etc.) and the Ufer bond. (Flow to earth is down & out)

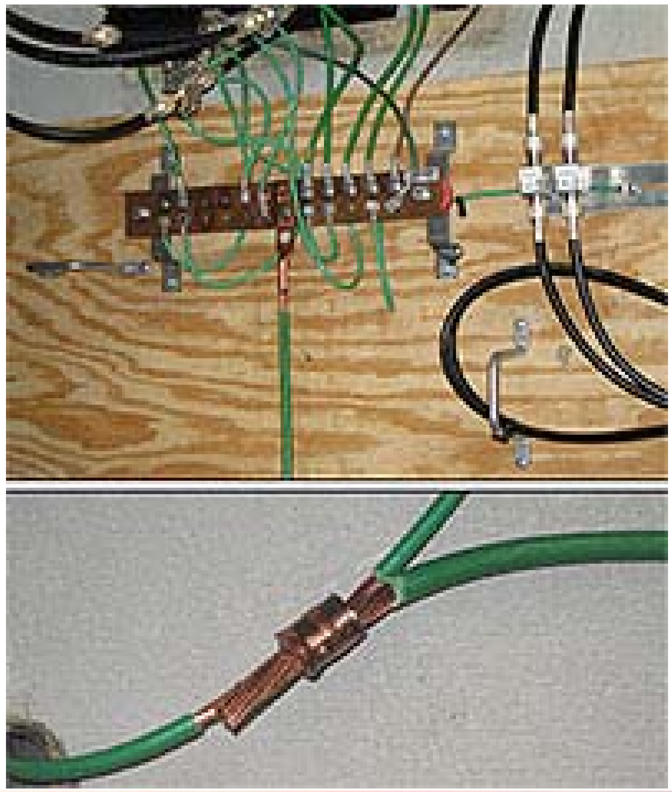
Improved Ufer Design



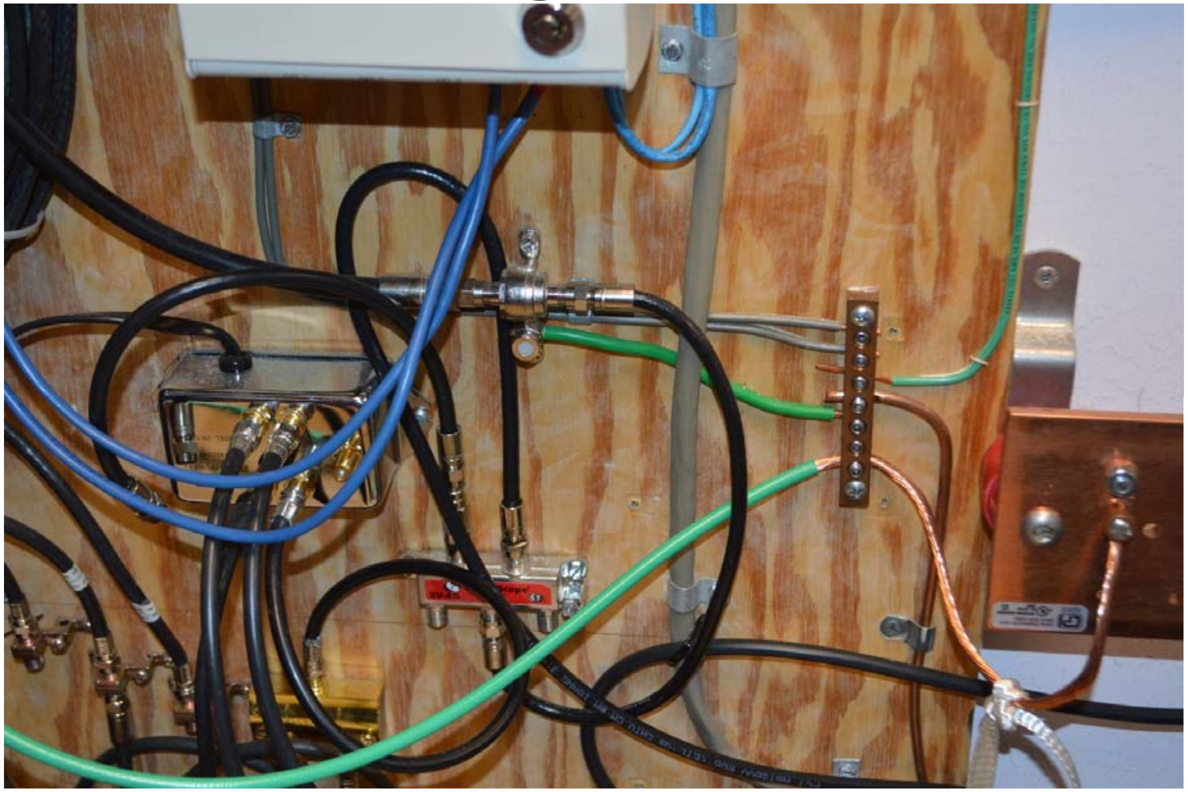
Ground Bonding

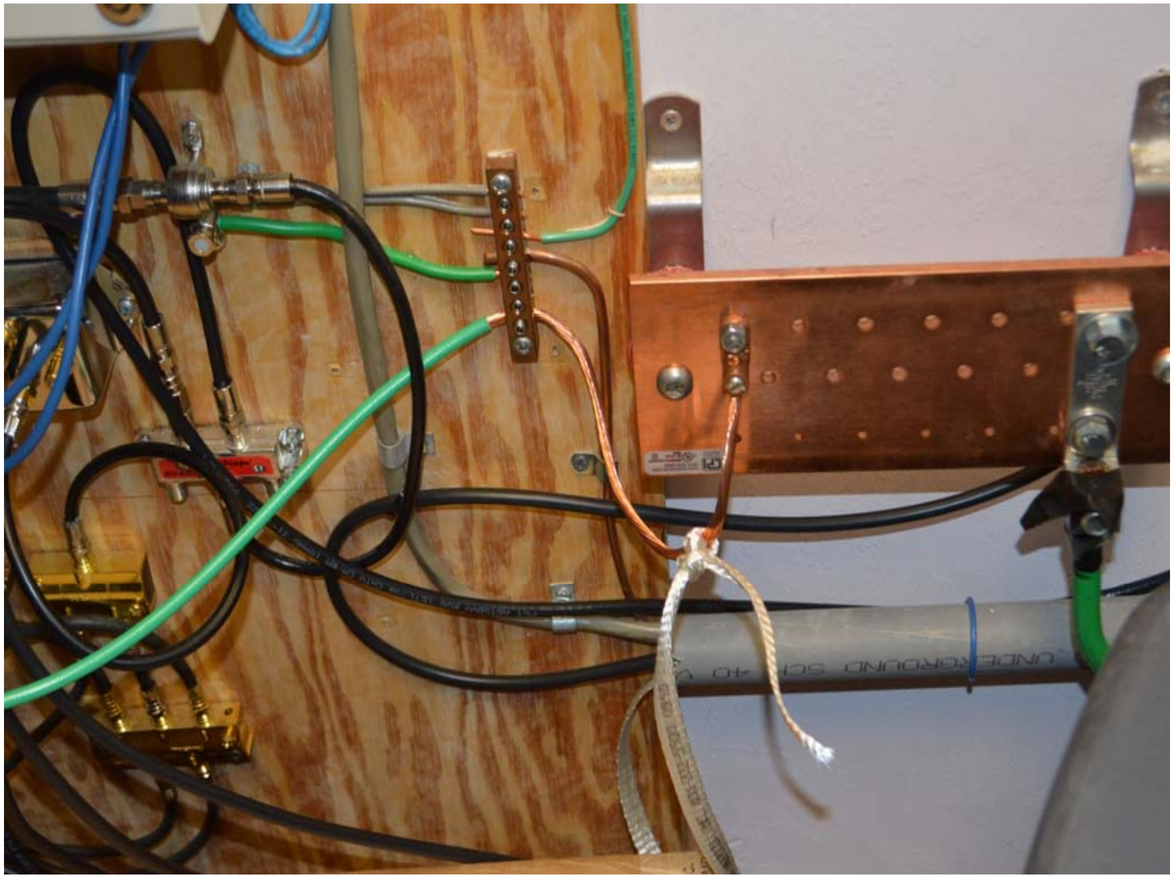
- The next series of slides will give you answers to some of the questions you have on the why some of your equipment may have been damaged by lightning.

What is wrong in the Photo?

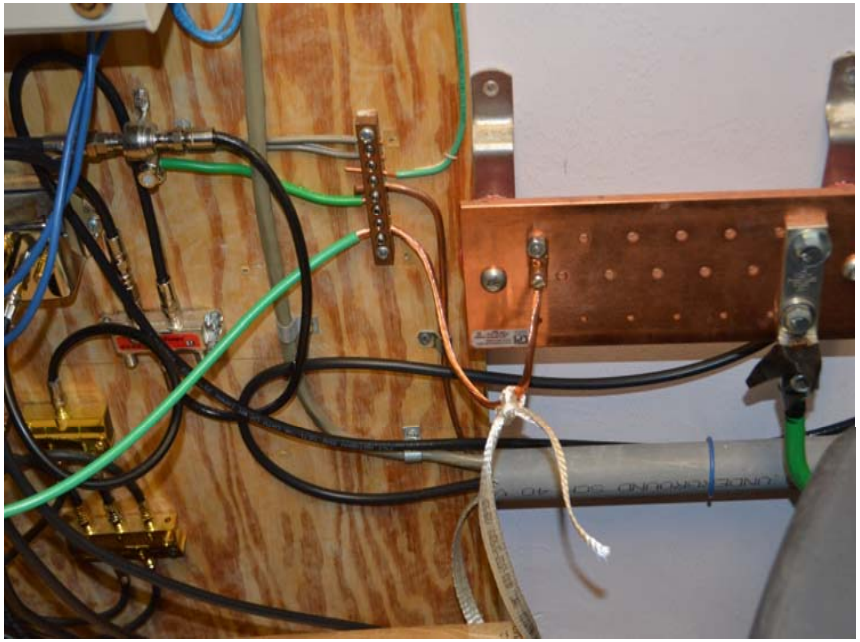


What is Wrong in This Picture?





Can you find more?
Ground loops between devices.
Coax ground bonds…. 11 are missing.
Sweep bends are missing.
Most wire is solid, not stranded.
Single lug bonds, no surface area.
Telecom & coax bonds are mixed.
Grounding and no conductive grease.
Daisy chain method of ground bonding.
Follow the wires, how many go don't go to the ground bonding bar???
Ground bonds to not "flow" to the grounding system…change directions.
No labels to know which ground bonding wire goes to what.
All wires are solid conductors not stranded conductors.
Critical equipment ground bonds mixed with coax and Telcom bonds.
(The above is a formula for lightning to damage equipment!!!!!)



Remember the two types of "Grounding"

- **System Grounding**

- **Equipment grounding (bonding)**

Causes of PQ Problems

INTERNAL:

- **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**
- **etc.**

Transformers

- NEC requires transformers ground bonds be made to building steel and pipe systems.
- NEC requires the steel or pipe system be continuous and contiguous.
- Networked systems ground reference will be to the same “pipe” or “steel”.
- The only exception is when the ground bonding path is not continuous and contiguous.

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?
- What impact will this have on your systems?

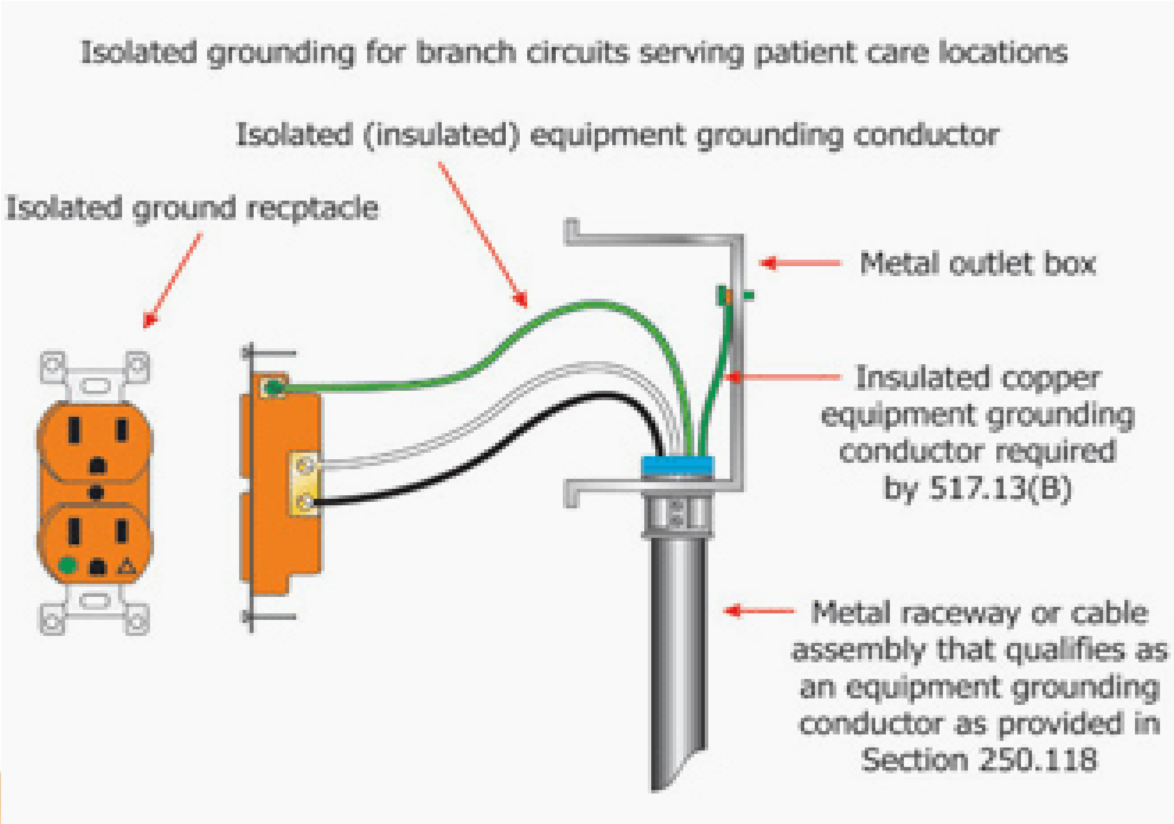
Improper Bonding

- The buildings 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!

How Will IG Circuits Help?

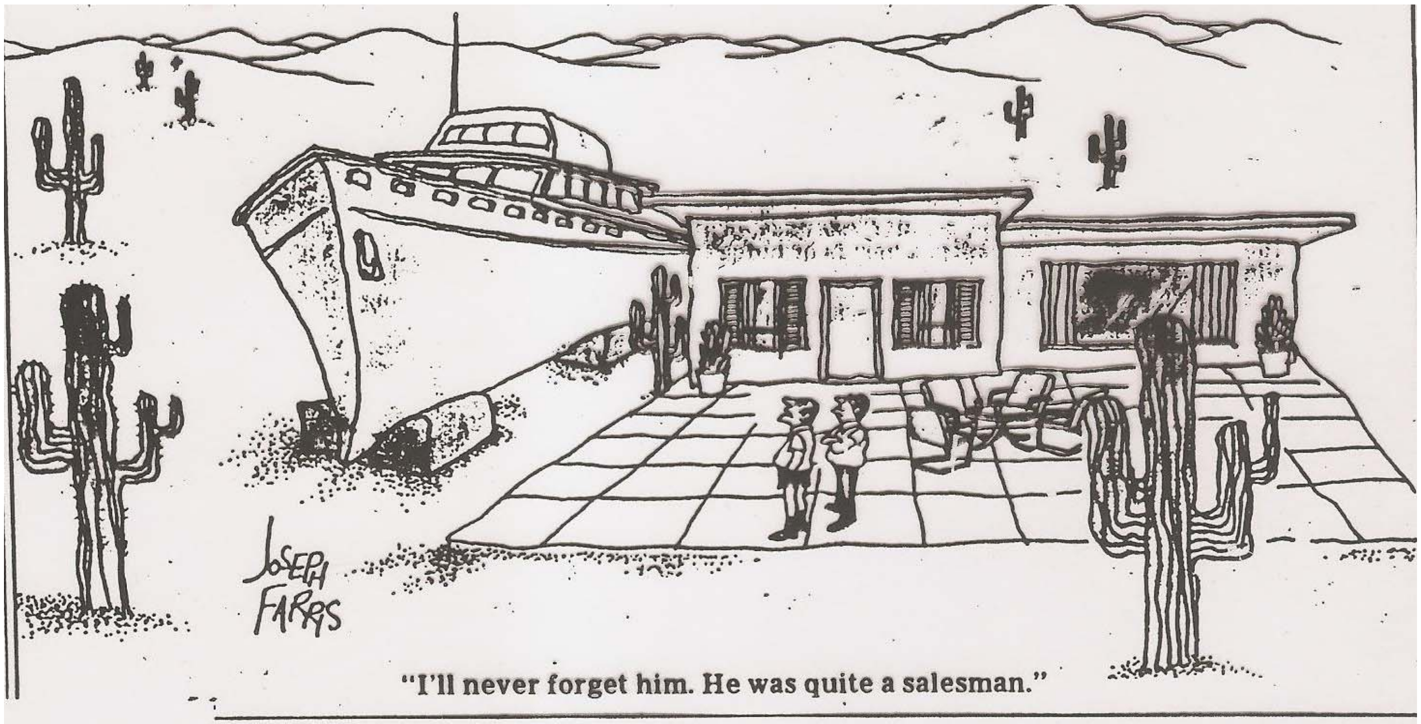
- Case ground is also the ground reference of your installed systems.
- In addition to protecting the wire conduit is also a shield from EMI & RFI.
- Building steel, conduit and all other metal objects in a facility can become charged and become a current path during a lightning strike.
- IG ground along with the phase and neutral conductors are protected from this induced energy by the conduit, gutter work and metal housing of the electrical system. The case ground wire is not bonded to the IG wire except at the X/O (neutral / ground) bonding point.

- As permitted by **NEC 250.146(D)** and **NEC 408.40** Exception, consider installing an isolated grounding system to provide a clean signal reference for the proper operation of sensitive electronic equipment.



(photo credit: iaeimagazine.org)

Surge Protection Devices (SPD)

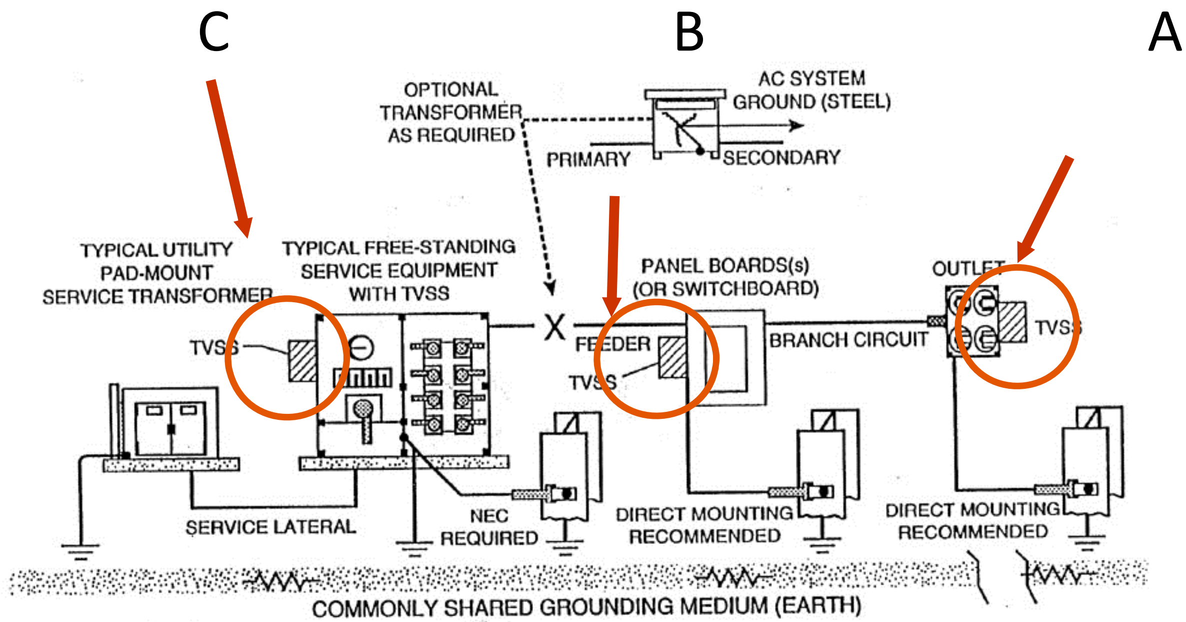


Surge Suppressors

- Used to be known as TVSS, Transient Voltage Surge Suppressors
- Now called Surge Suppression Devices
- NEC Art. 285 for non-hazardous locations

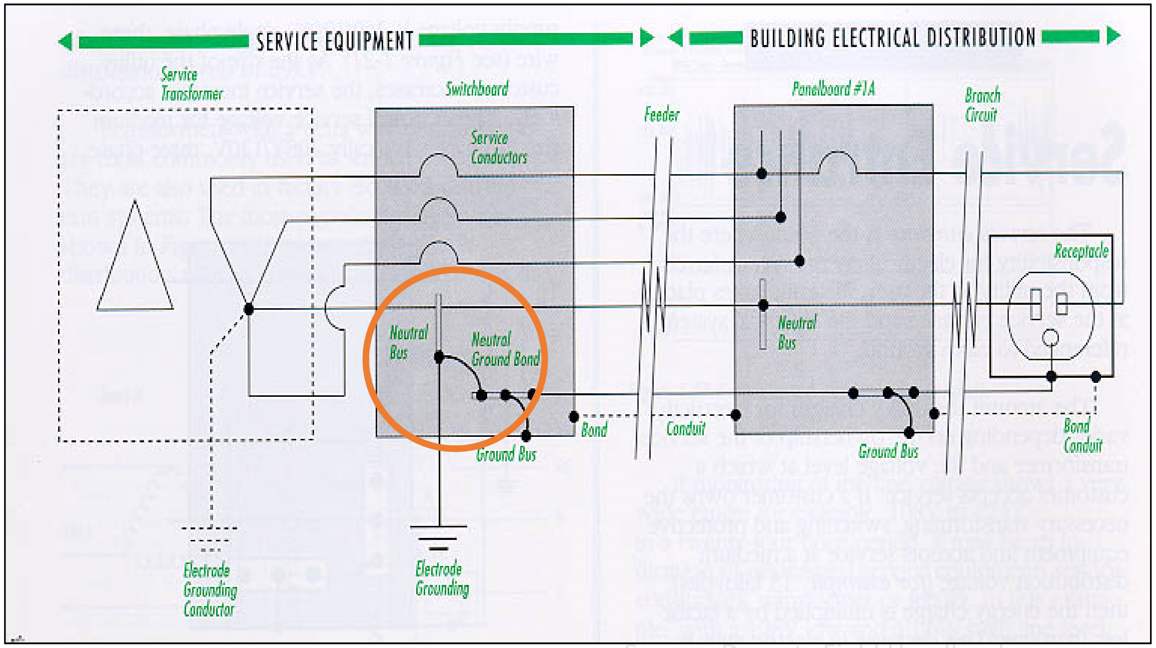
SPD (TVSS) Placement

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)



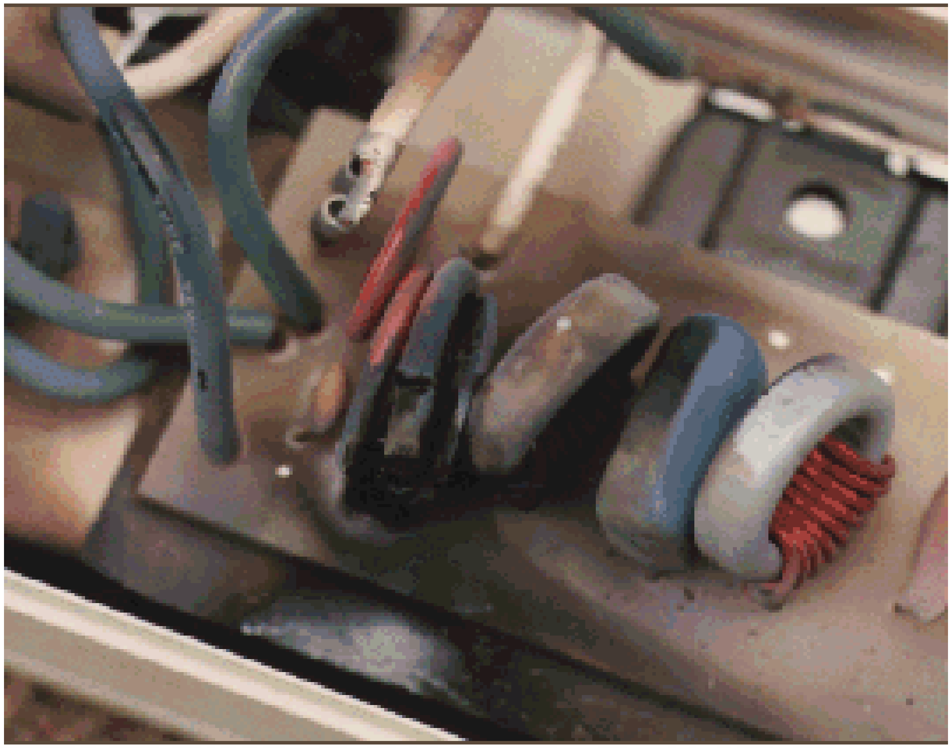
- Source: Dranetz Field Handbook

MOV Based SPD

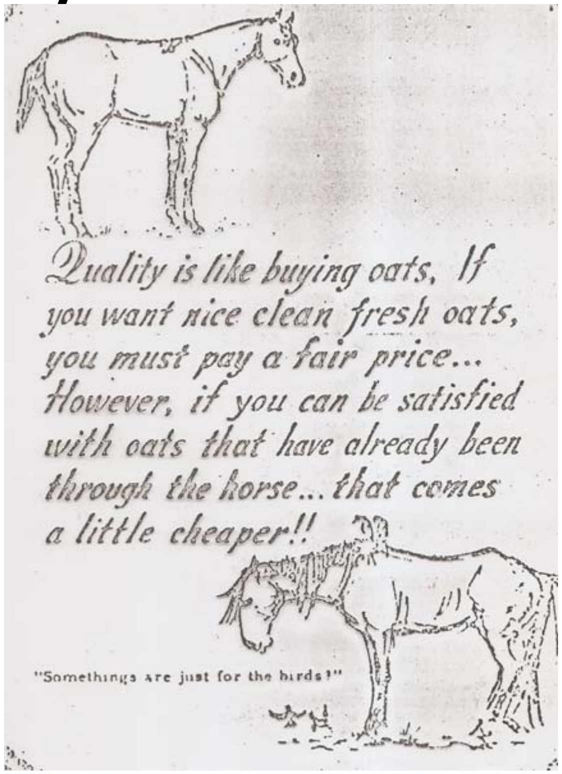
- SPD “must” have a ground to be UL Listed.
- That is true of all “low voltage SPD”
- Low voltage defined as listed to UL-497.
- Some UL listed AC Power SPD do not have a ground connection. They are “Type 1” as their “drain” is neutral…. And there is no ground involved….

MOV

A Failed MOV



Quality = Performance



AC Power Surge Protection Devices

- SPD are classified by UL based upon how they are installed and their installation.
- 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.

Installing Hardwired SPD What is Important.

- Location of the SPD.
- Position of the SPD.
- Wire length between the SPD & connection.
- Wire type, stranded vs. solid wire.
- Wire installation – no sharp bends.
- Conductor twisting - lower wire impedance.
- Breaker or fuse ratings.
- Proper torque for all connections.
- Connections - <u>*NO WIRE NUTS*</u>!!
- Written inspection, testing and maintenance program.

MOVs

- MOVs are bi-directional components.
- So if one is on a line (AC Power, System, etc.)

It will be connected to another “reference”.

- That reference could be neutral, ground, another line, etc.
- Simply put: A surge can come from any of those connections!!!! (Bi-directional)

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

General Wiring Practice

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

Minimal Wire Length Is Critical

Wire Length is DELAY!

NOT a Local Ground Rod!

Code Violation & more!

Only One Ground Reference

- Systems must only have one ground reference.
- NO passive grounds.
- You have to love the “out” marked on the can. It should say “incoming!!!!”

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. Beware of cross-contamination.
- Be sure they have also protected their services.

AC Power Source

Is the electrical system serviced annually?
Is the power source stable enough for proper equipment operation?
Is a power backup system needed?
Any disruptive circuits on your power panel?
Any outside circuits powered by your panel?
Is the panel surge protected properly?
Are the upstream panels surge protected?

Access – Video – Fire – Security - Environmental

- To the customer, all are critical systems.
- All should have the highest level of protection possible.
- Protection starts with a proper installation.
- The installation should be flexible, as technology changes so should the system.
- Technology must be proper & sustainable for the application and installation.
- The system must be installed so it can be serviced.

Systems Installations

- Installation Conditions
- System Power Options
- System Installation Options.
- System Communication Options.
- Connections to communication utilities.
- Inter system connections.

Installation Conditions

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

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.

System Power Options

- AC Power Source, should be a dedicated, isolated ground circuit from a clean power panel if a 120VAC system.
- What do you do if it is not?
- Is a back up power source required or needed.
- Is there a generator involved.
- Is the system smart and does it communicate?
- Is the system network based.

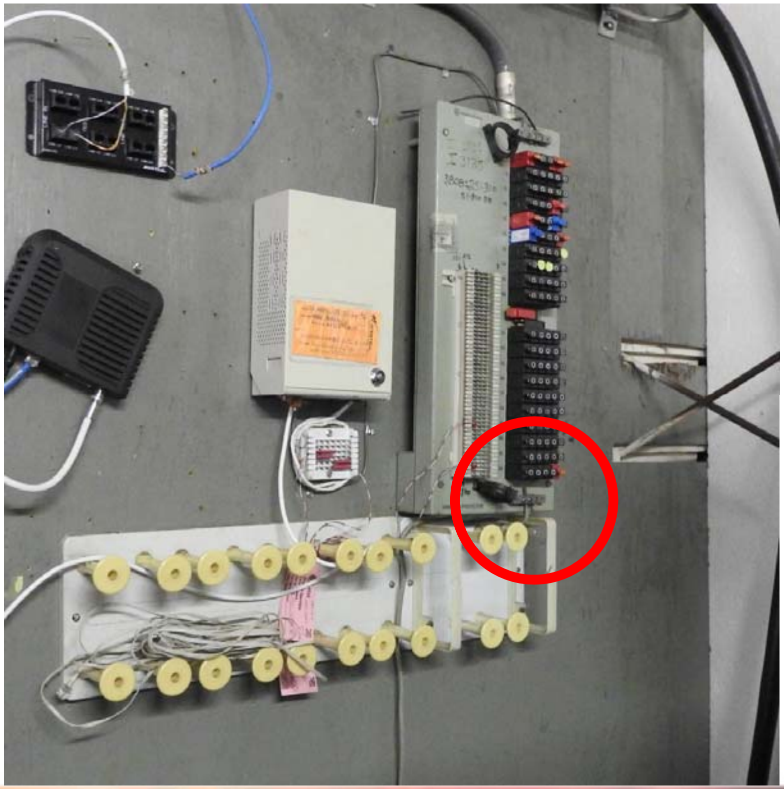
System Topology - Communication

- System component or device communications.
- Inter system communications.
- Connections to the outside world.
- Shielded vs. Unshielded wire.
- RF Communications.
- Fiber Optics.
- Cellular
- Phone lines

Connection to Communication Utilities

- Phone lines, what you need to know to avoid the worst possible problems they can cause.
- Cellular Communications, good, bad and ugly.
- RF to a central station. Is the option available locally. What is involved.
- Networked devices, options and considerations.
- Wi-Fi – the good, the bad & the ugly.

Beware Telephone Lines



Inter System Connections

- Integration is the watchword in the security industry.
- Network applications continue to be introduced and in the long term it will be how security is controlled.
- The term you need to be aware of is "the bleeding" edge of technology

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.

Video Security Systems

- Stand Alone Systems
- Networked Systems
- RF Systems
- Wi-Fi Systems
- Hybrid Systems
- Camera Options
- Connectivity Options

Camera Options

- Coax
- Twisted Pair Video
- POE Mode A
- POE Mode B
- Fiber Optics
- RF Transmission
- Wi-Fi

Coax Systems

- With RG-59U - 800 feet coax limit.
- With RG-6U - 1,100 feet coax limit.
- With RG-11U – 1,600 feet coax limit.

Twisted Pair Video

- Passive systems to about 1000 feet.
- Combination to about 1500 feet.
- Active systems to about 3000 feet.
- The low cost option if “wired” is required.
- The key is the UTP baluns.
- Shielded wire used for TPV must have low parasitic capacitance, below 20pF per foot.

POE Mode A & B

- POE & lightning prone environments.
- Main difference is pin numbers for power vs data
- Not always labelled
- Not all equipment may be compatible with a mode
- Wired Limits – 24 volts about 150 feet.
- Wired Limits – 48 volts about 300 feet.

Fiber Optics

Down side:

- Not always cost effective.

Upside

- Very secure, frequency & type of signal
- Multiplexing
- High Resolution
- Distance is not an issue.

RF Transmission

- Low cost compared to wired systems
- Significant distances, 3 miles or more
- 2.5GHz can transmit up to 40 miles
- High data transfer rates 150Mbps+
- Security issues, jamming, hacking
- System limitations.

Wi-Fi

- Advantages: low cost, simple installation & mobility
- Primary disadvantage: low security
- Unsecured unless encryption devices added
- Secured systems are still a hackers dream
- Interference issues
- Slower speeds / resolution issues

Environmental Systems

- Environmental controls have the same issues as security systems
- Environmental systems can be connected to other systems and networked
- All connections to your system can be problematic.
- Before you connect know your options
- If the connection will be problematic consider some "non" wired connection

We Took a Hit, Now What?

- When you are ask to respond to a customer that has (they think) been struck by lightning or has suffered lightning damage what do you say or do?
- What do you do when you arrive?
- What questions do you ask?
- What do you look for?
- How best to find the “smoking gun”.

The First Steps after a "HIT"

- Talk to the client and ask questions.

❑ Why do they think they were "hit"?
❑ In their words what happened?
❑ Was equipment lost or damaged?
❑ Make a list of everything that was impacted.
❑ Now compare that to the electrical distribution system.
❑ Find out where in the electrical system was the majority of the damage or impact of the event.

- Test the grounding!
- Inspect the lightning protection system (if installed).
- Inspect every SPD installed.
- Gather information and then call an expert in lightning damage mitigation.

Another Break

Next Section

- Review and some data center cases

- Source: Dranetz Field Handbook

General Guidelines

Circuitry
Voltage Drop
Full Size Conductors
General Principals

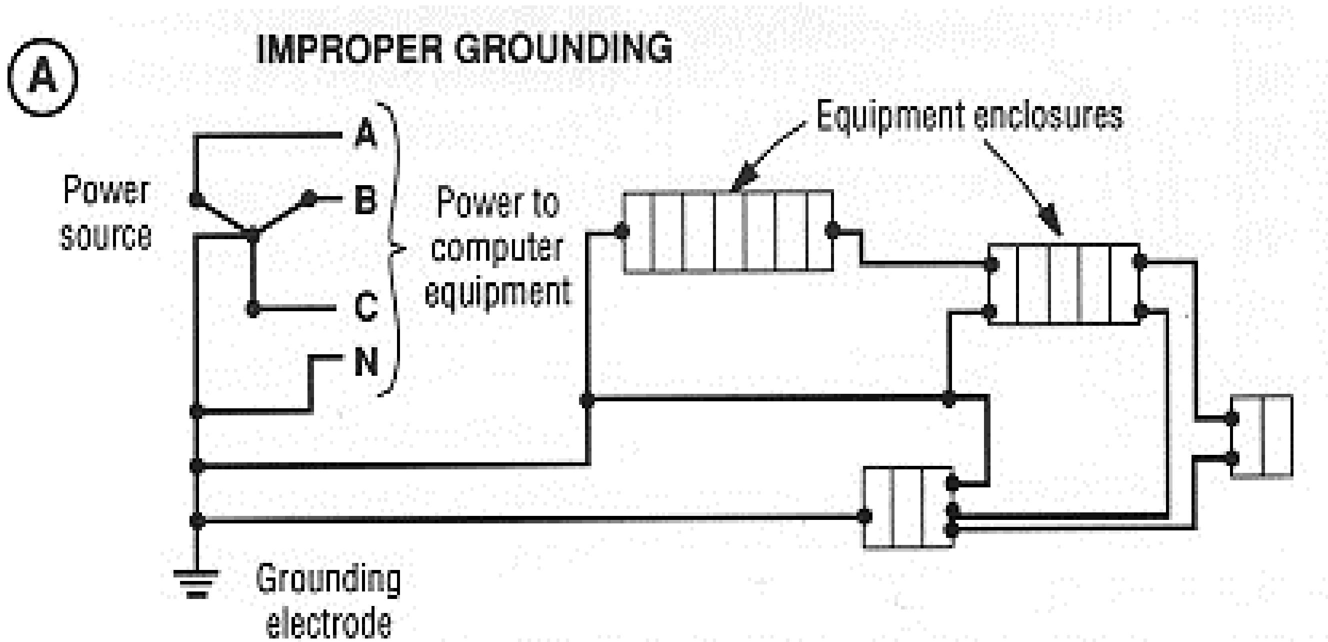
- Source: Dranetz Field Handbook

Avoiding Ground Loops

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

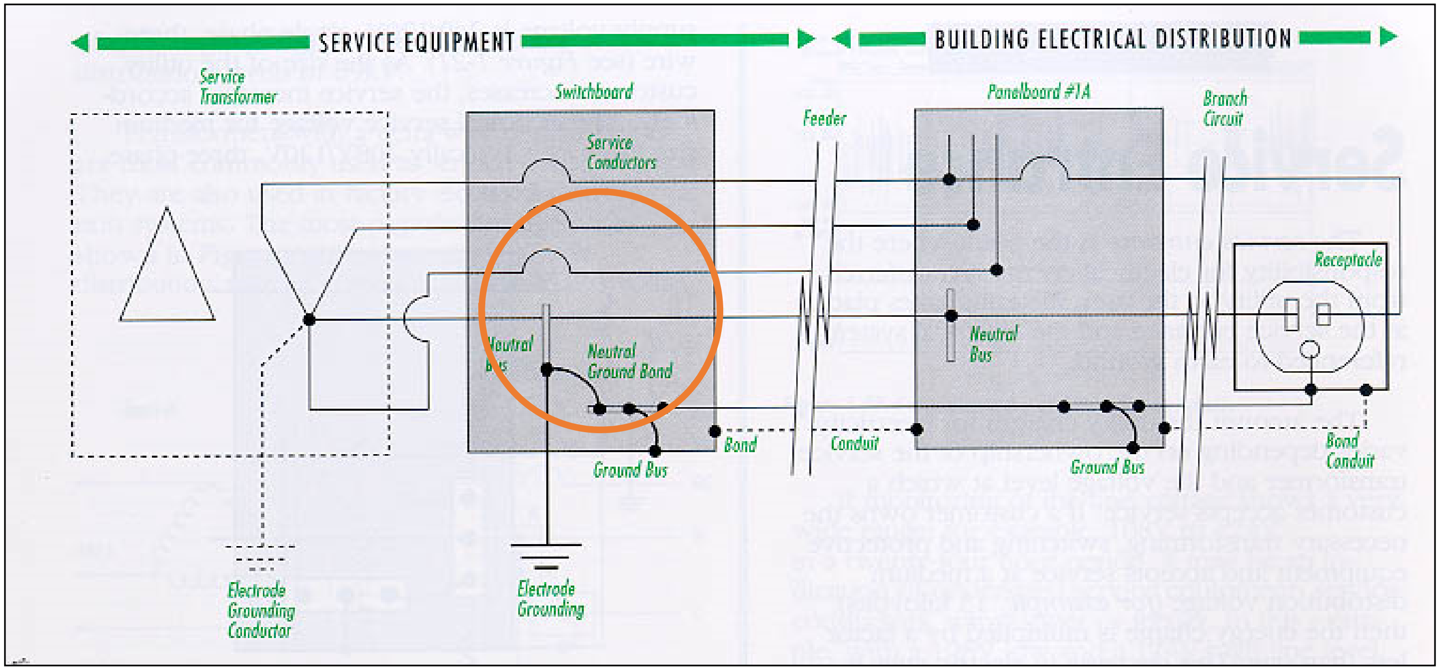
- Source: Dranetz Field Handbook

Avoid Ground Loops

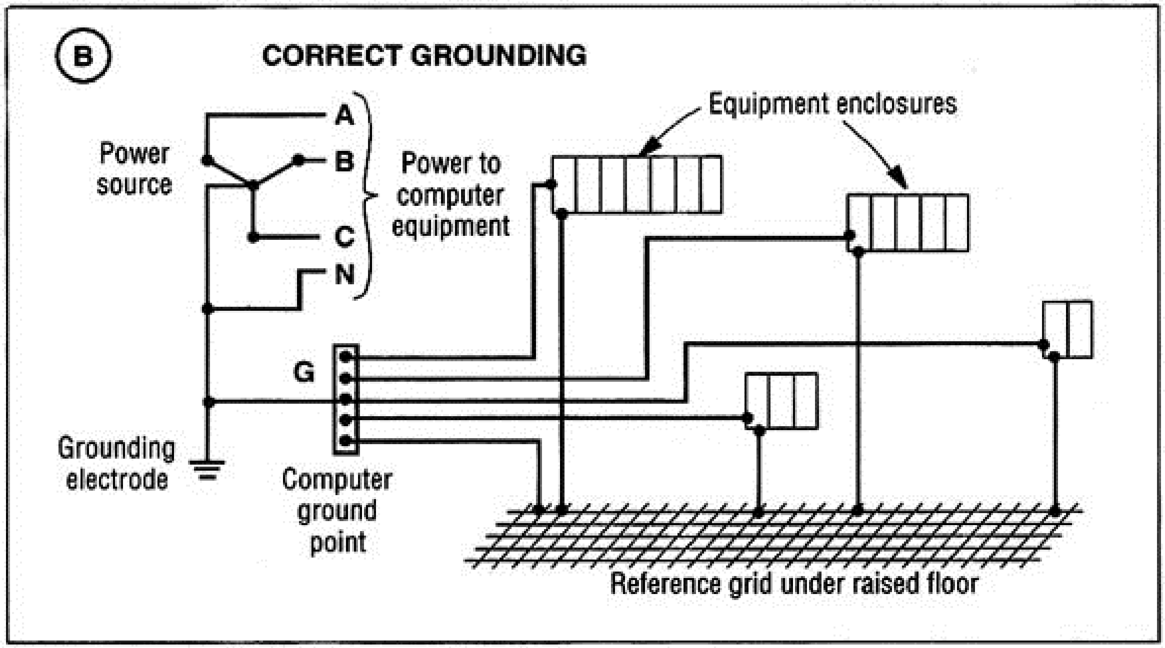


Never use the earth as a ground path

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



Example of "star" grounding

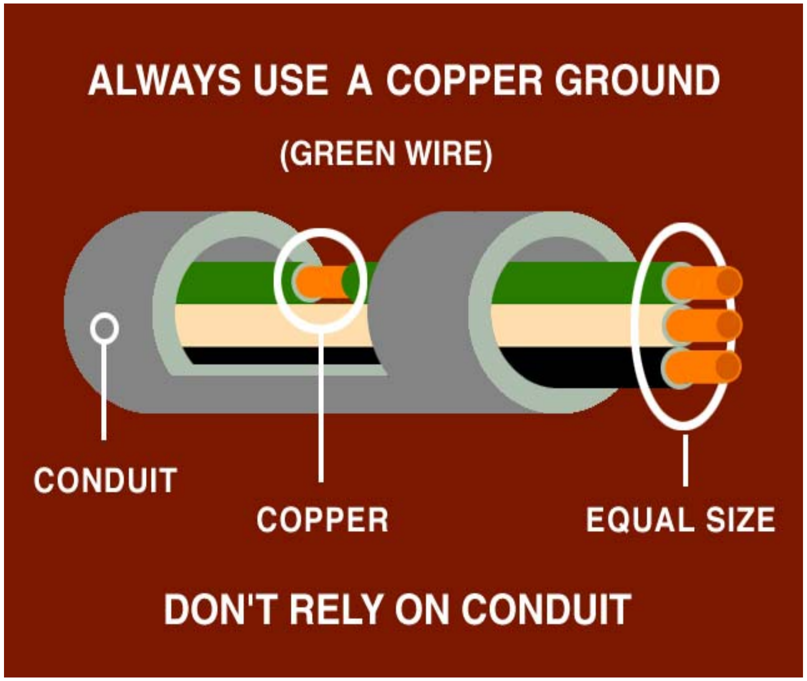


Source: EC&M Guide to Quality Power

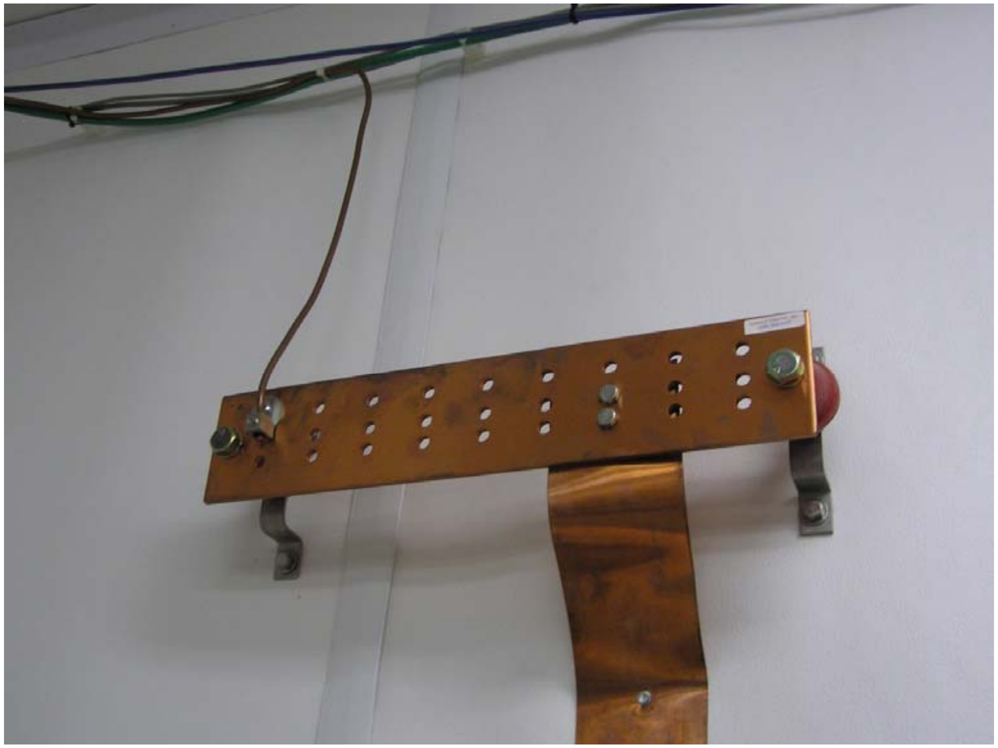
Avoid Conduit as a Ground Path

Can you imagine a joint every 10 feet?

Full Size Equipment Grounding



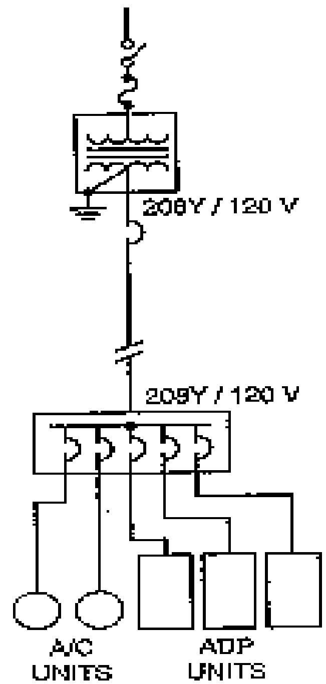
Will That Conductor "Fuse"?



General Wiring Practice

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

Typical Wiring Method

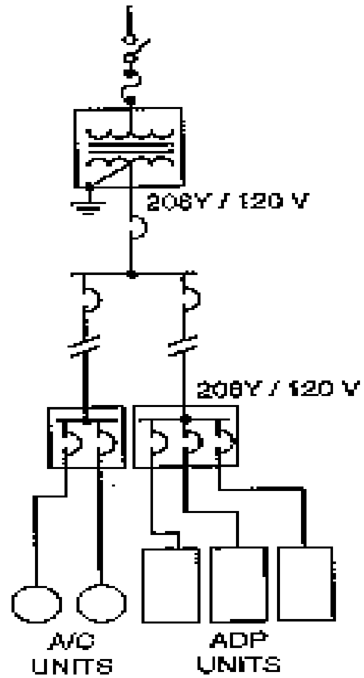


a) WORST!

source: IEEE

Emerald Book

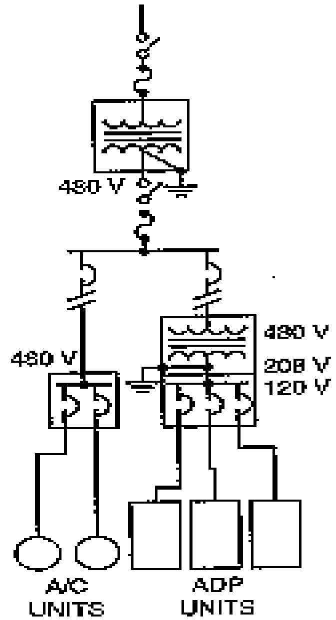
Slightly Better Wiring Method



b) FAIR!

source: IEEE
Emerald Book

Much Better Wiring Method

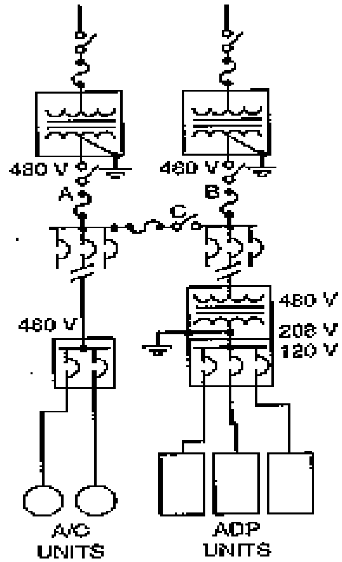


c) BETTER!

source: IEEE

Emerald Book

Optimal Wiring Method



d) BEST!

source: IEEE
Emerald Book

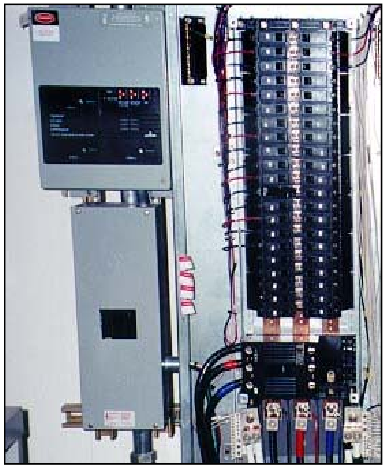
General Wiring Practice

- **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

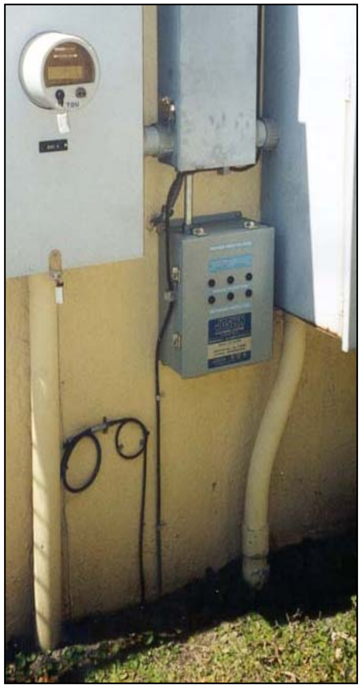
- - at the service
- - at the panelboard
- - at the load



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!

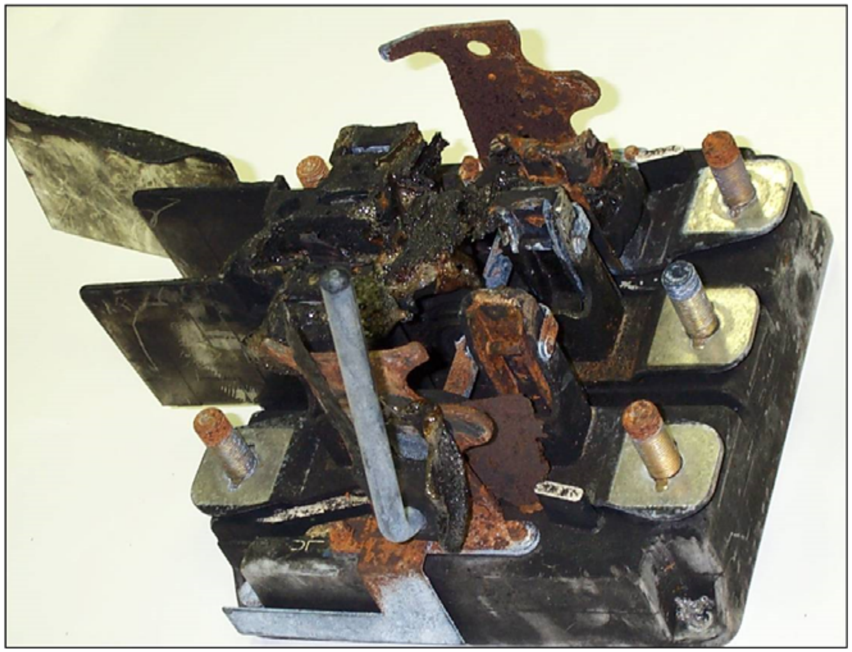
Suncoast Schools FCU

Data Center Inside

SunCoast FCU

Lightning Hit Service Drop

Data Center 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 Went To Earth

- 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.

- Low impedance grounding
- Full size grounding conductor – Not Allowed Down Size

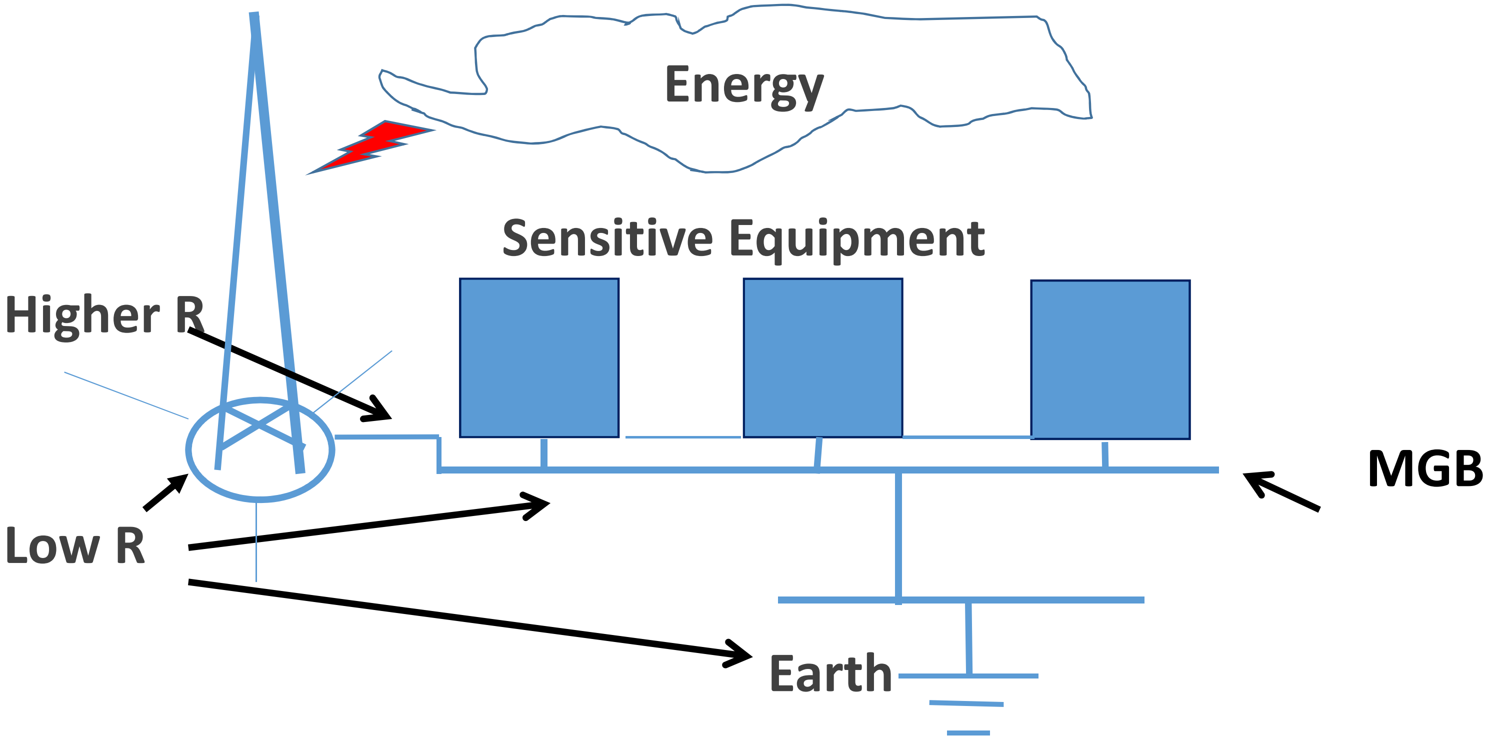
Suncoast's Data Center

No downtime

No equipment damage

Cost around $40,000

Think of a “current divider”



Desired Grounding

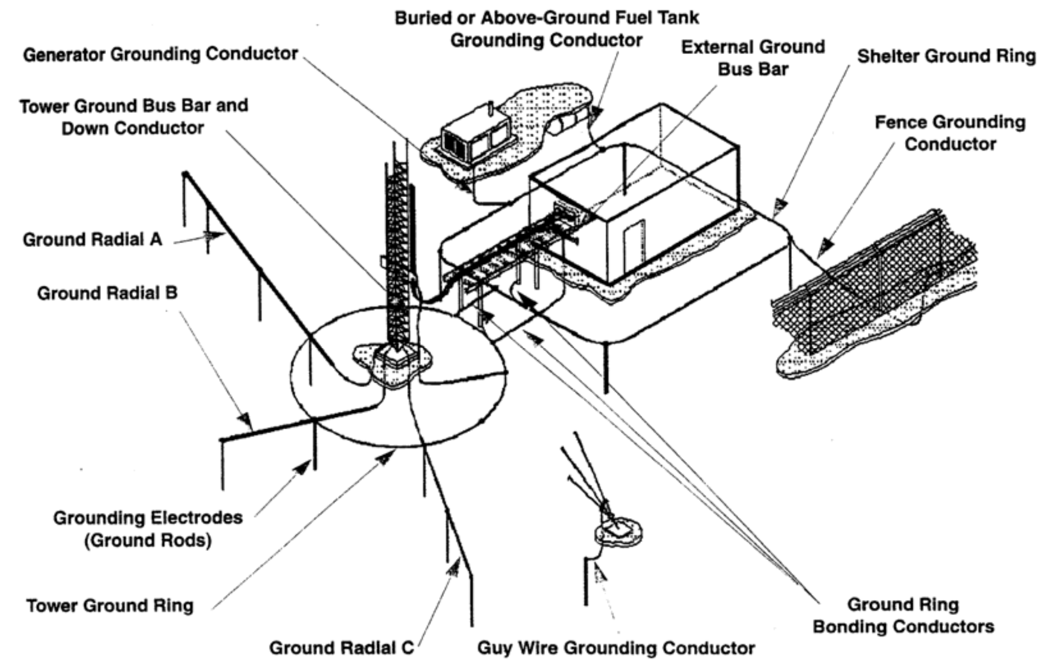


FIGURE 6-1 TYPICAL TYPE B EXTERNAL GROUNDING ELECTRODE SYSTEM

Example of Current Divider

Macomb County, MI 9-1-1

Note Tower in Rear

Gas and Water Services Bonded

Labeled So No One Removes

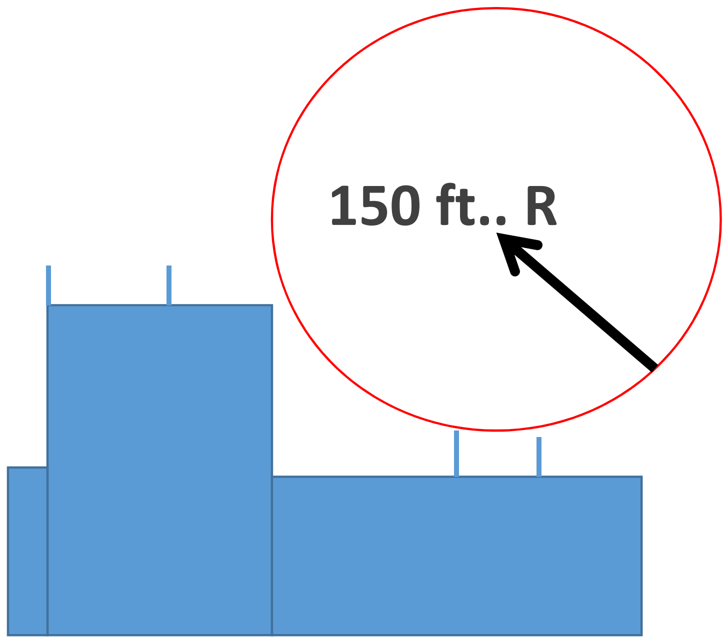
Conductor Welded to Base, Not Tower Leg

Coax Braid Bonded on Vertical Run

Then to Strap at Bulkhead

Inside Radio Room

Rolling Ball

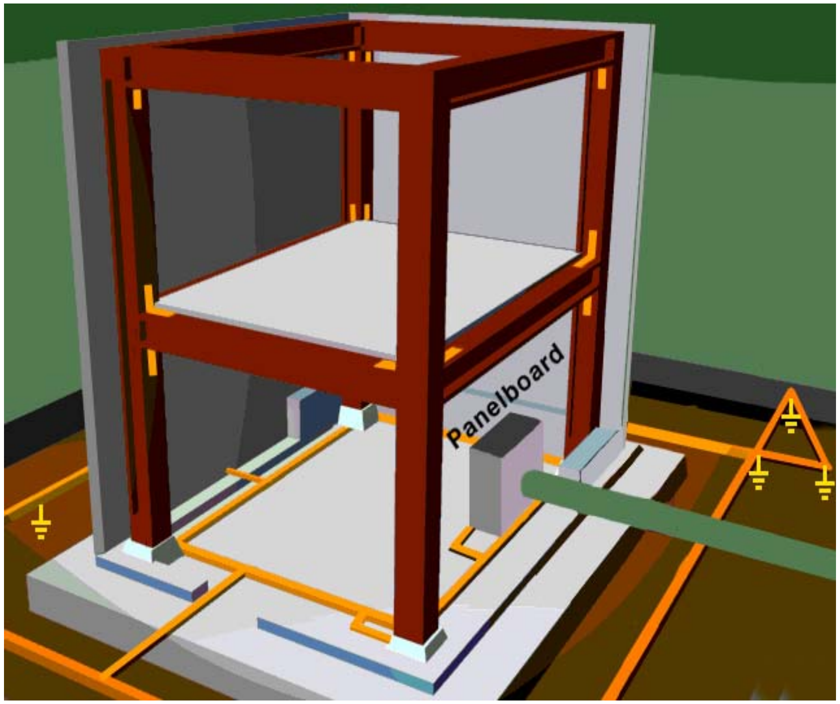


Costs

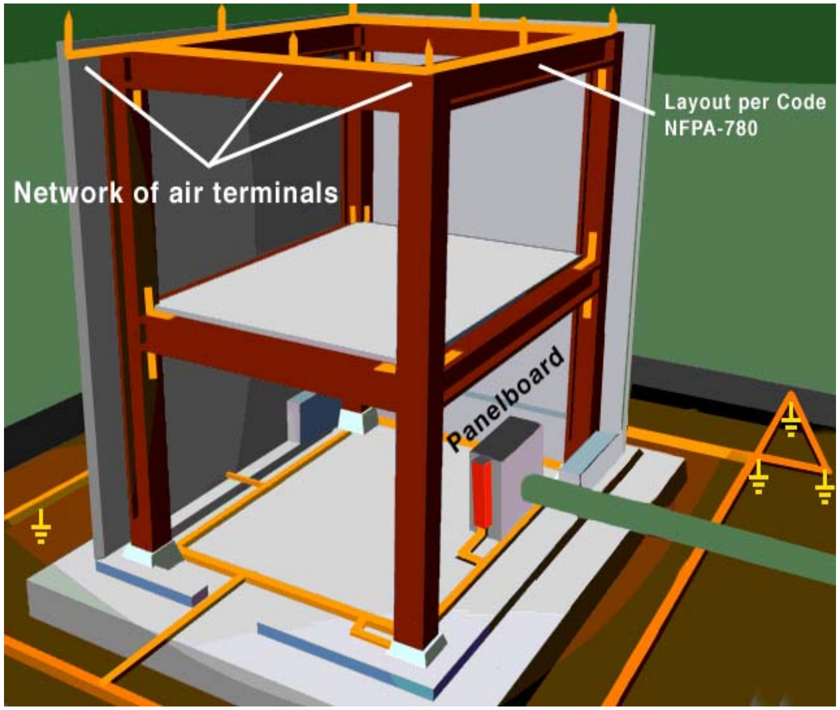
- **Cost of materials is CHEAP compared to labor, equipment, downtime**
- **Cost for all PQ improvements:**
- **Adds about 1 to 1-1/2% to the overall cost of construction, but….**

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

Start With Ring Ground

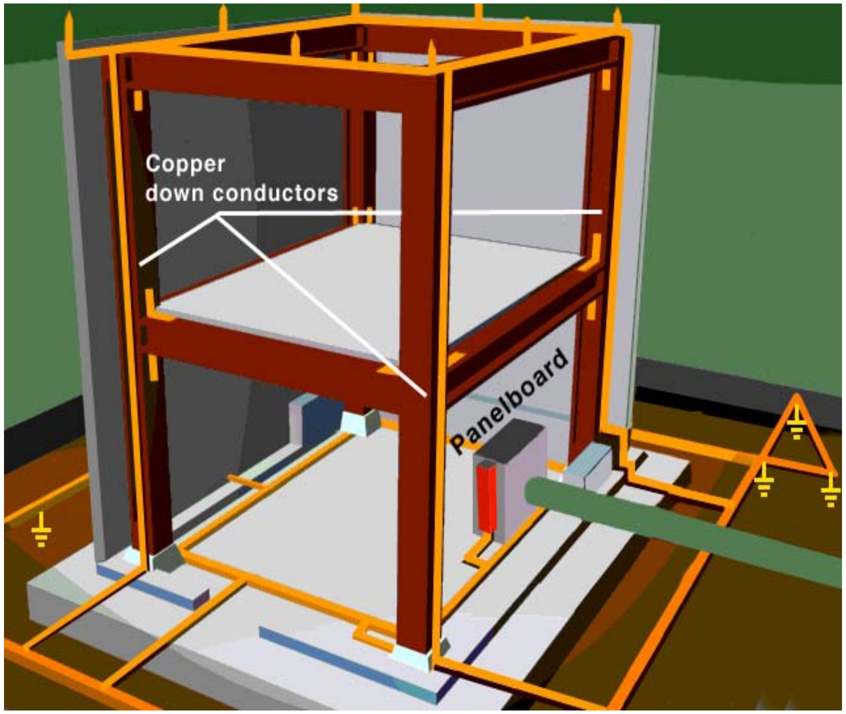


Network of Air Terminals

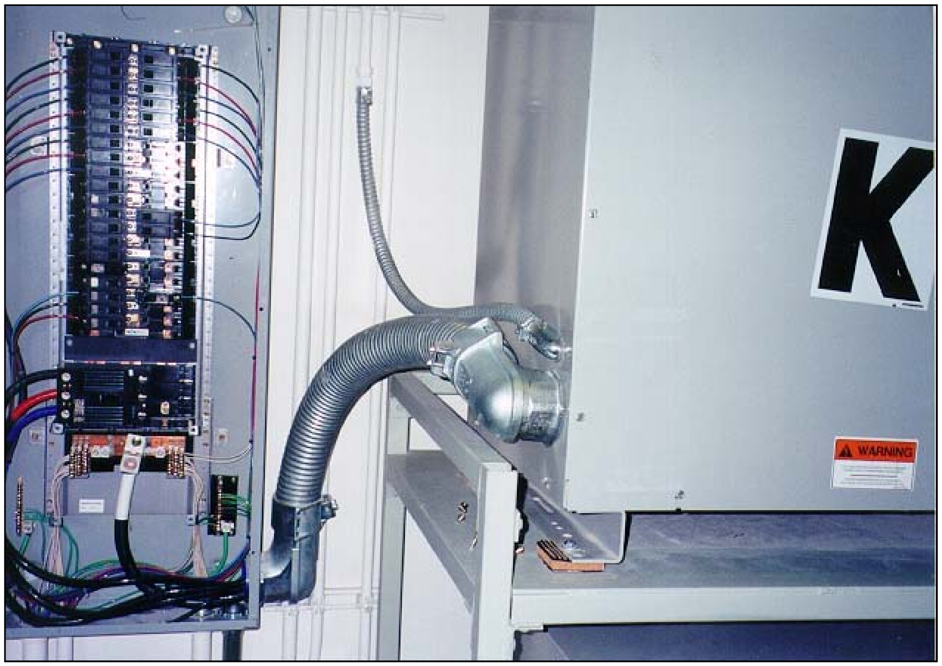


Heavy Duty Down Conductors

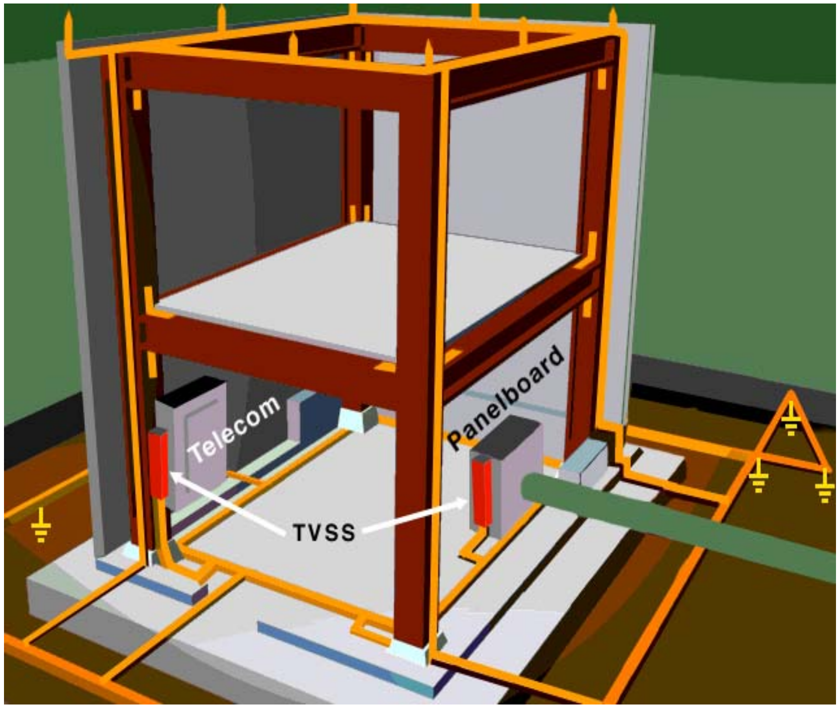
Not steel framing



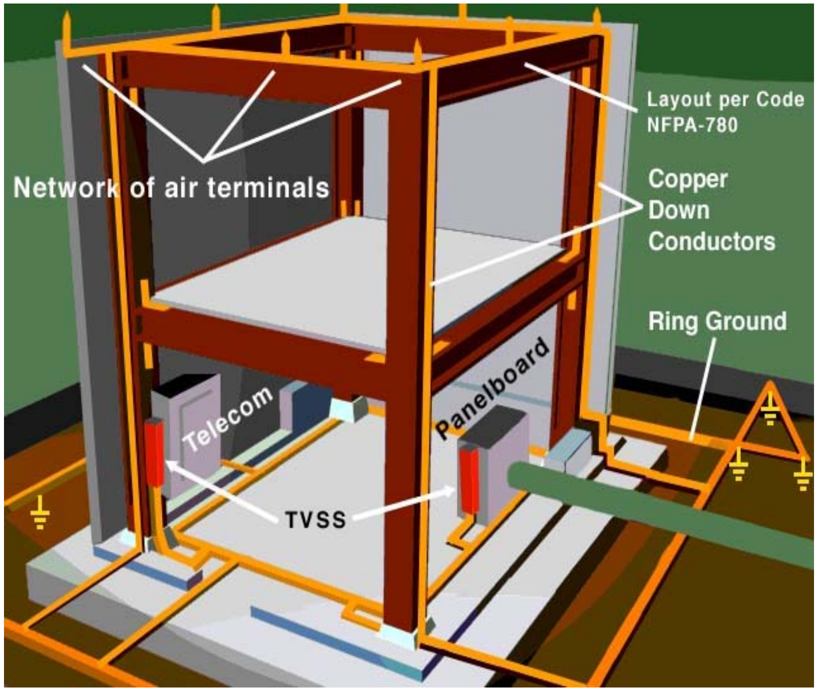
Do Not Use Building Steel



Surge Suppression



Overall Result



System Grounding

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

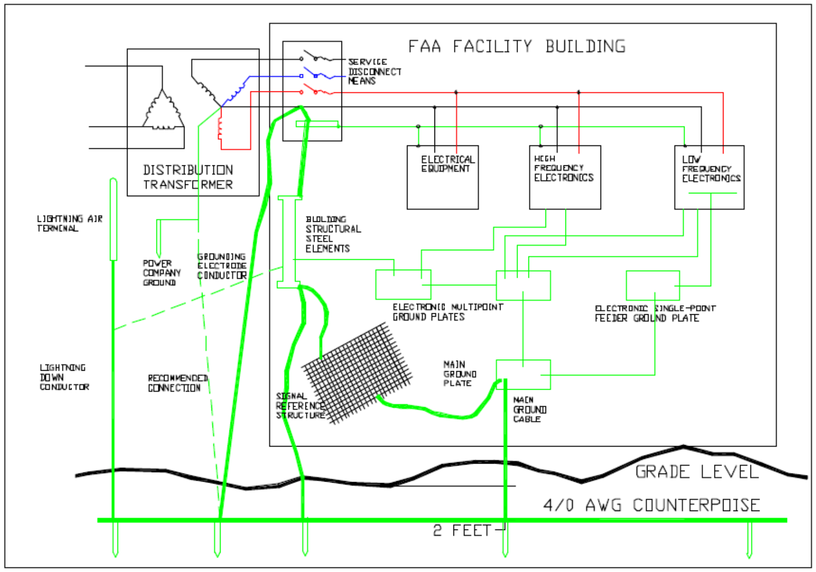
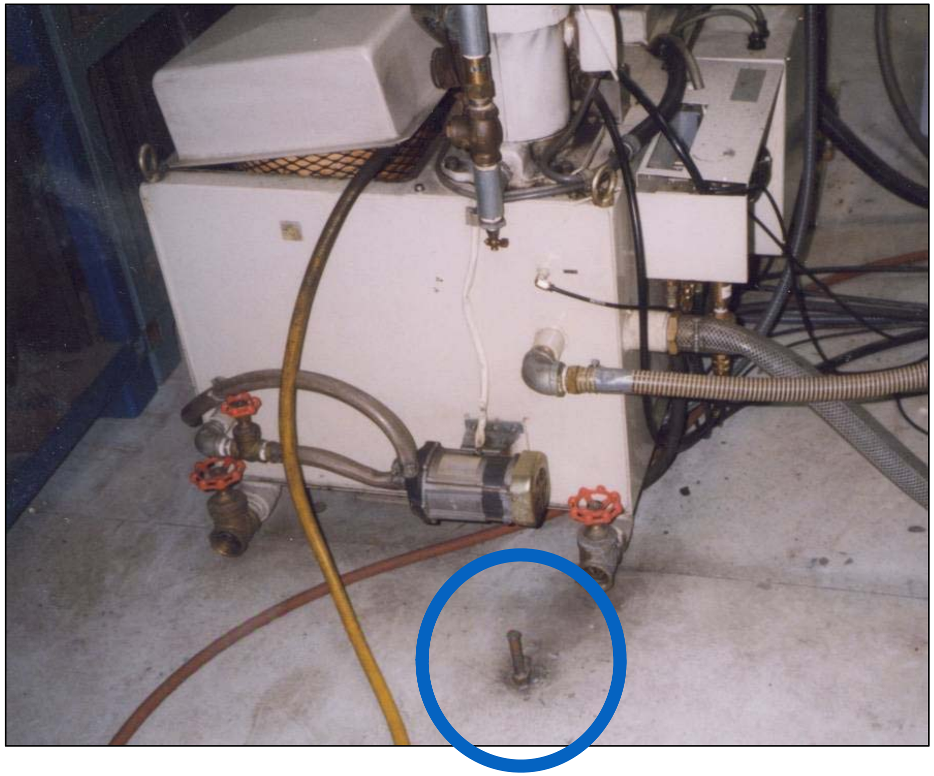


Figure 6. Facility Grounding System

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.**

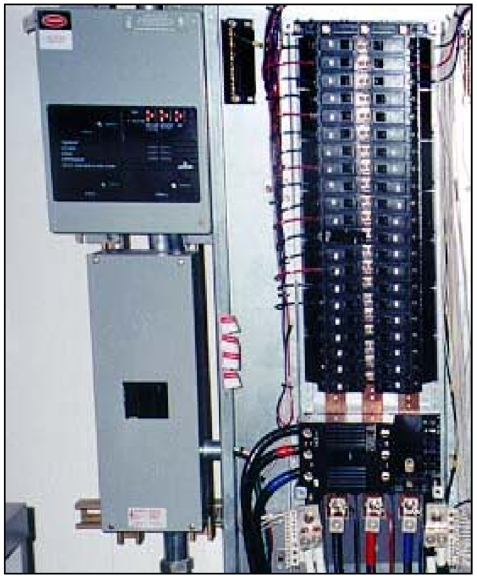
  wire gage, circuit length

Surge Suppressors

Keep leads as short as possible

Surge Suppressors (SPD's)

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



At the Service Level

Type 1 devices

150 kA per mode minimum

At the Feeder Level

Type 2 devices

75 kA per mode minimum

At the Device Level

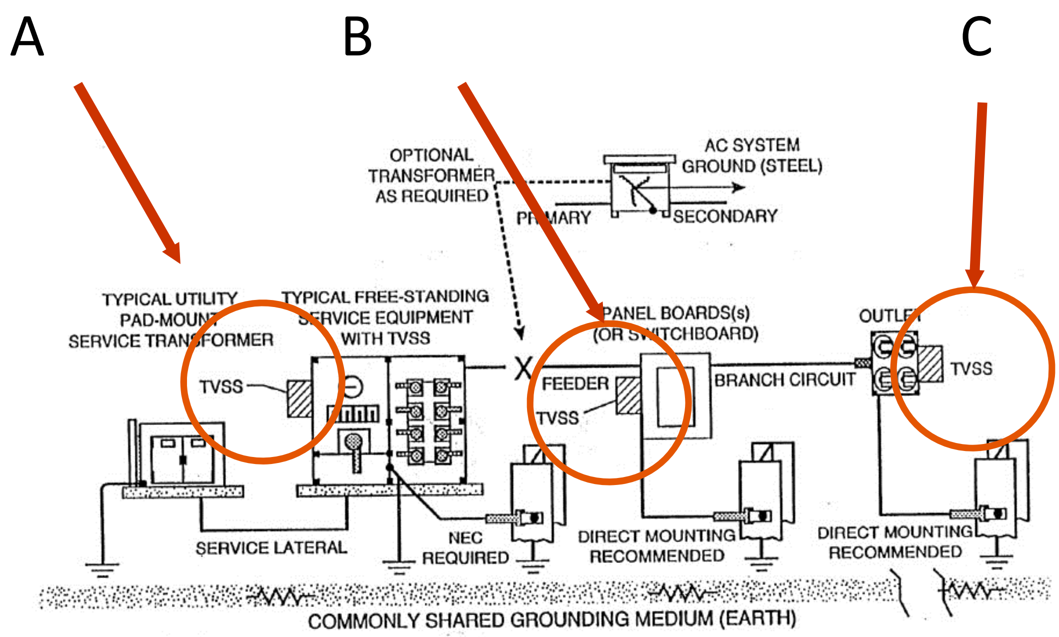
Type 3 devices

25 kA per mode min.

TVSS Placement

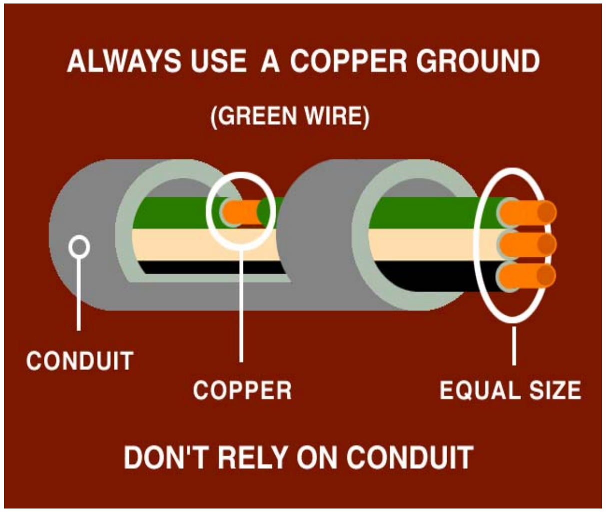
Use Surge Suppressors in 3 places

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



Use Grounding Conductor

Always use a full size copper equipment grounding conductor – do not rely on conduit

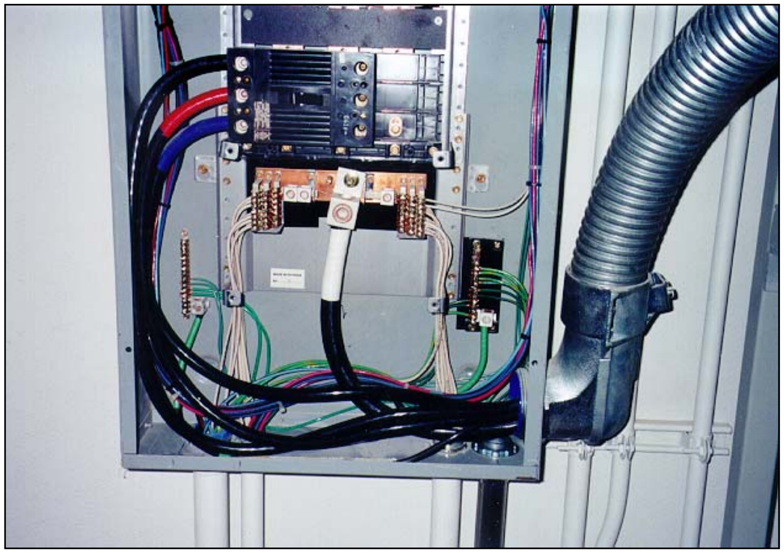


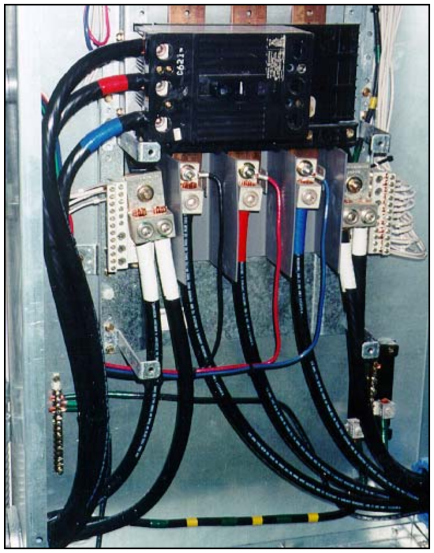
Trap Harmonics

Shielded isolation transformer sometimes helps Isolate harmonics

To Handle Harmonics

Use a 200% rated neutral or separate neutrals per phase



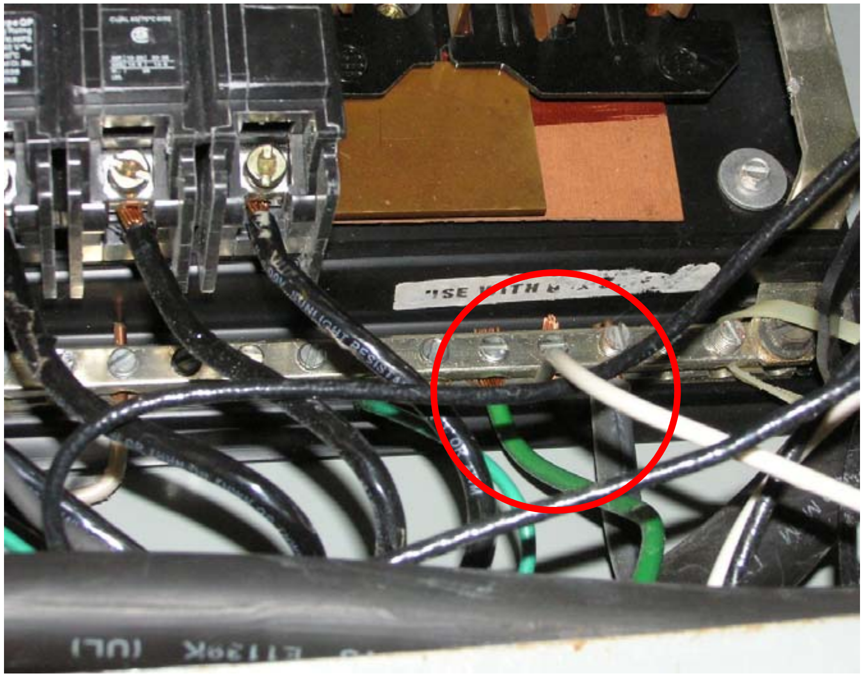


N-G Bonds

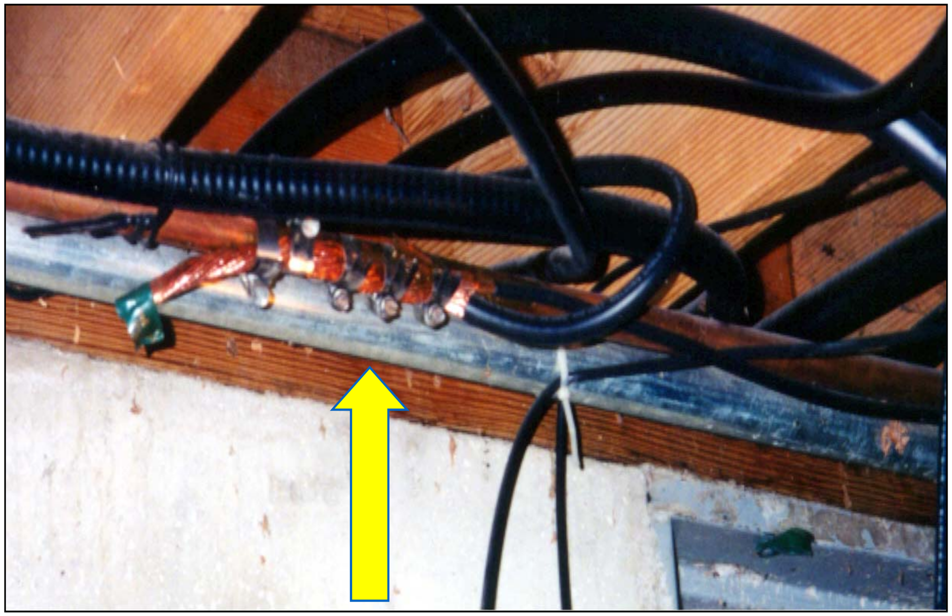
Interior:

- **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

Rusty Water Pipe Bonding

- Automotive hose clamps
- Undersize conductors

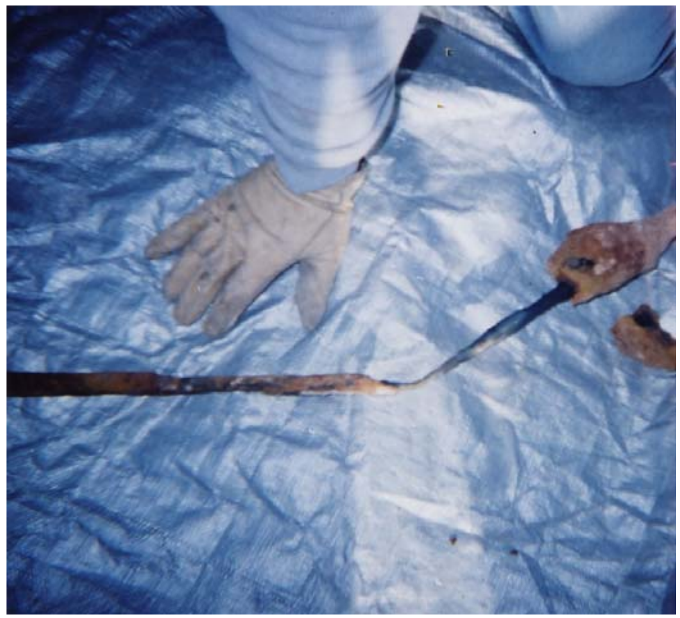
Choice of rod types

Pick the right rod for the
soil conditions

Galvanized Rod After 7 Years

Galvanized Rod

¾ inch to pencil-thin

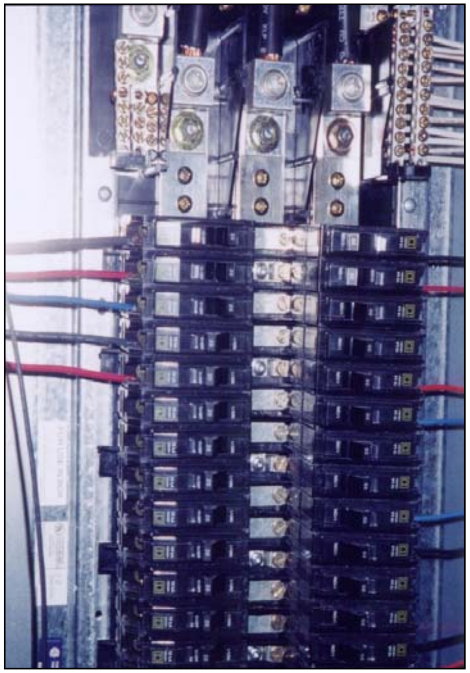


Chemical Electrodes

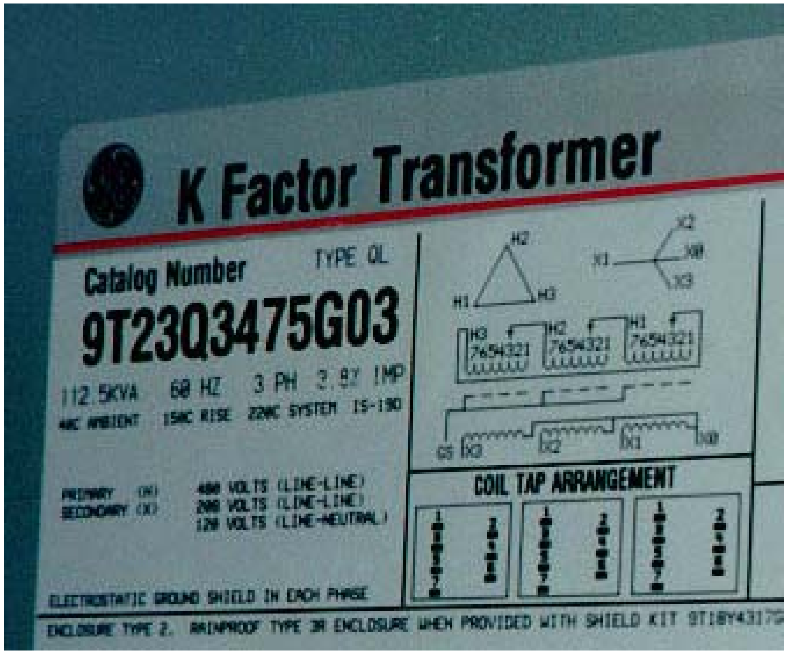
Salt-filled pipe after 7 years

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!

Backfill

Bentonite is the recommended backfill

Be wary of anything containing graphite (very corrosive)

Grounding System Must be Checked

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

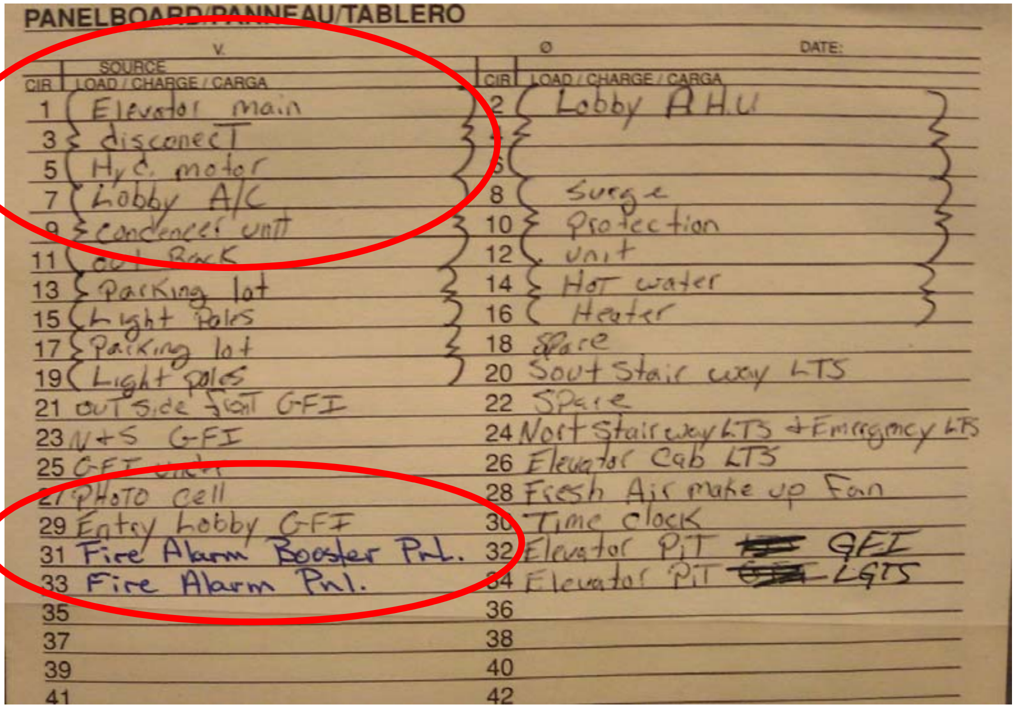
Is Ufer Actually Grounded?

Bonded to rebar?

Are connections proper?

Look for paint or other insulation

Do Not Mix Load Types



PANELBOARD/PANNEAU/TABLERO

V. Ø DATE:

SOURCE

CIR	LOAD / CHARGE / CARGA	CIR	LOAD / CHARGE / CARGA
1	Elevator main	2	Lobby AHU
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	Space
19	Light poles	20	Sout Stair way LTS
21	outside front GFI	22	Spare
23	N+S GFI	24	Nort Stairway LTS + Emergency LTS
25	GFI [illegible]	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	
37		38	
39		40	
41		42	

Data Center Example

“We like to maintain a

maximum of two ohms … and that’s checked once a year to make sure it hasn’t risen.” – CoSentry Data Center

500 kcmil Ground Ring Surrounds Building

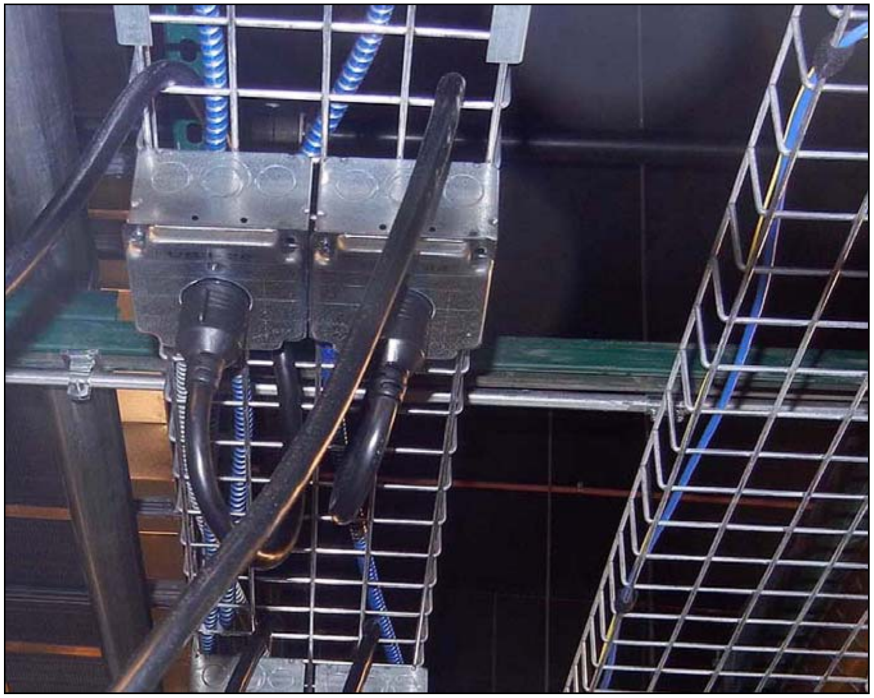
- Inspection well about every 100 feet with 10 ft. vertical electrode

Dual Electric Circuits

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

A and B Circuits

Dual Feed to Cabinets



Cabinets to Overhead Bus

Bus Grounds Collected at SGB

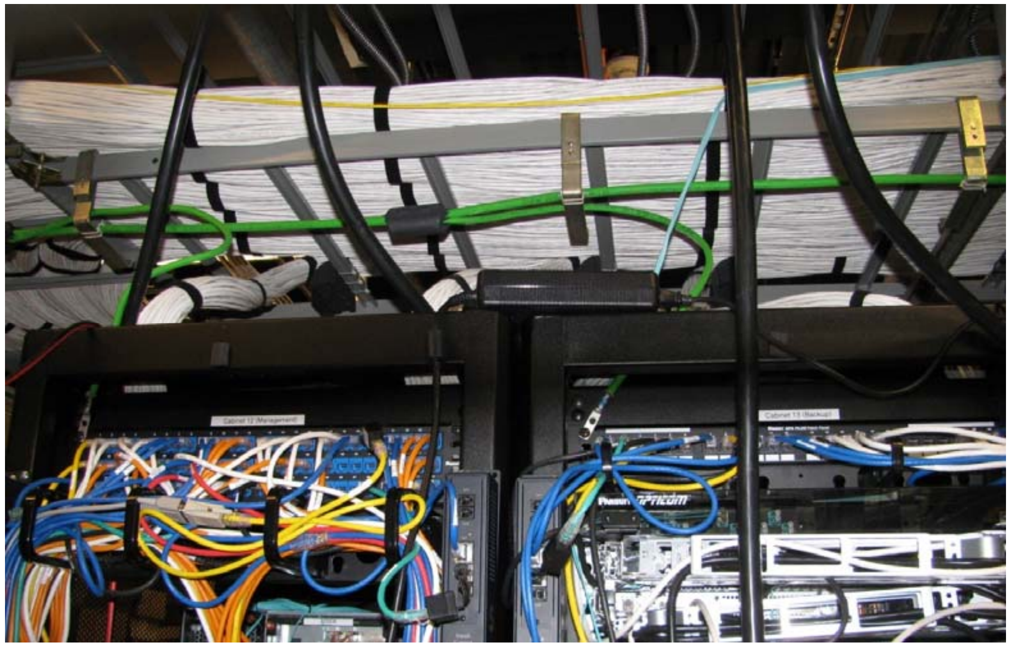
From SGB to MGB

Another Data Center

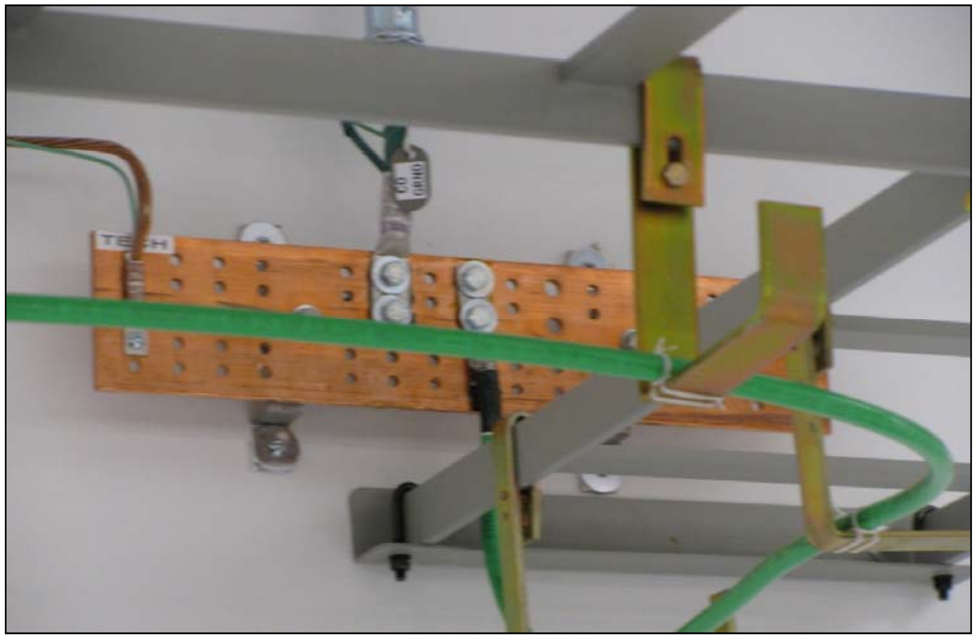
One Summer Street, Boston

2 Vaults, 5 MVA each

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

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

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 <u>expect</u>,**
   you only get what you <u>inspect</u>.

3. **Have a written plan and procedures.**
   Insist contractors follow it.

3. **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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