

# GROUNDING FOR THE HAM STATION



HRU-2024

JANUARY 6, 2024

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# KEY POINTS

- Grounding vs Bonding
- Function of Grounding & Bonding
- Lightning Protection
- Specific Code Requirements for Amateur Radio Stations

# DEFINITIONS per 2017 NEC

- GROUND
  - EARTH
- GROUNDING
  - CONNECTED TO GROUND (EARTH)
- BONDING
  - CONNECTED TO ESTABLISH ELECTRICAL CONTINUITY AND CONDUCTIVITY

# FUNCTION OF GROUNDING

- VOLTAGE STABILIZATION (UTILITY)
- PROVIDES AN EFFECTIVE GROUND FAULT CURRENT PATH
  - TO PERMIT OPERATION OF PROTECTIVE DEVICES
- LIGHTNING PROTECTION
  - DIRECT VS INDIRECT STRIKES

# WHAT WILL GROUNDING NOT DO?

- PREVENT ELECTROCUTION
  - ELECTROCUTION IS FATAL!!!
- GROUND FAULT PROTECTION FOR PERSONNEL (GFCI) WILL PROTECT AGAINST ELECTROCUTION
  - MORE ON THIS LATER

# CODES

- STATE
- NFPA-70 (NATIONAL ELECTRICAL CODE) 2017
- LOCAL CODES (CITY, TOWNS, VILLAGES)

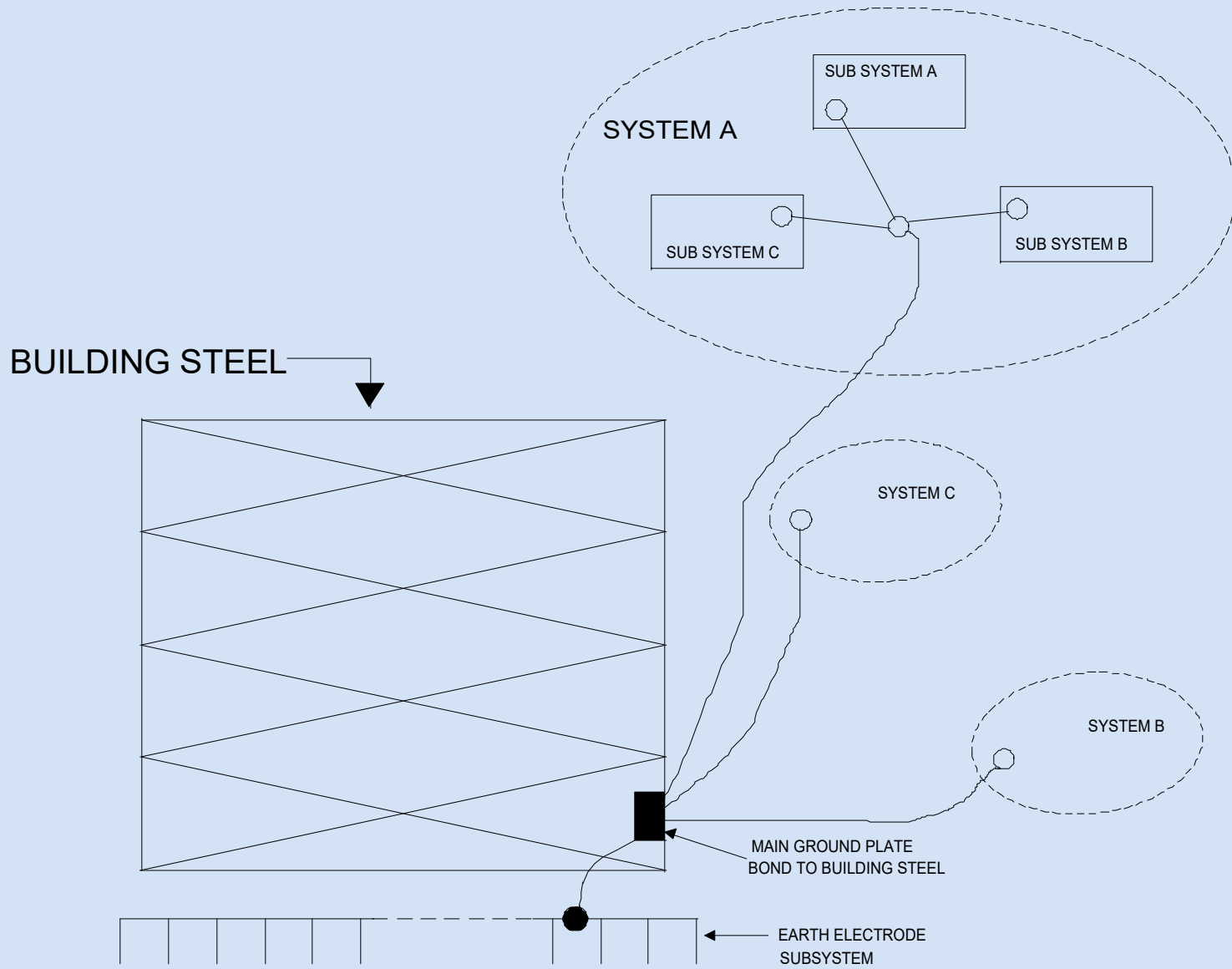
# MATERIALS

- ELECTRODES
- CONDUCTORS
- TERMINATIONS



# GOAL

- EQUIPOTENTIAL BONDING
- SINGLE POINT GROUND
- RESULT
  - MINIMIZE POTENTIAL DIFFERENCES
- WHY?



## SINGLE-POINT GROUND SYSTEM

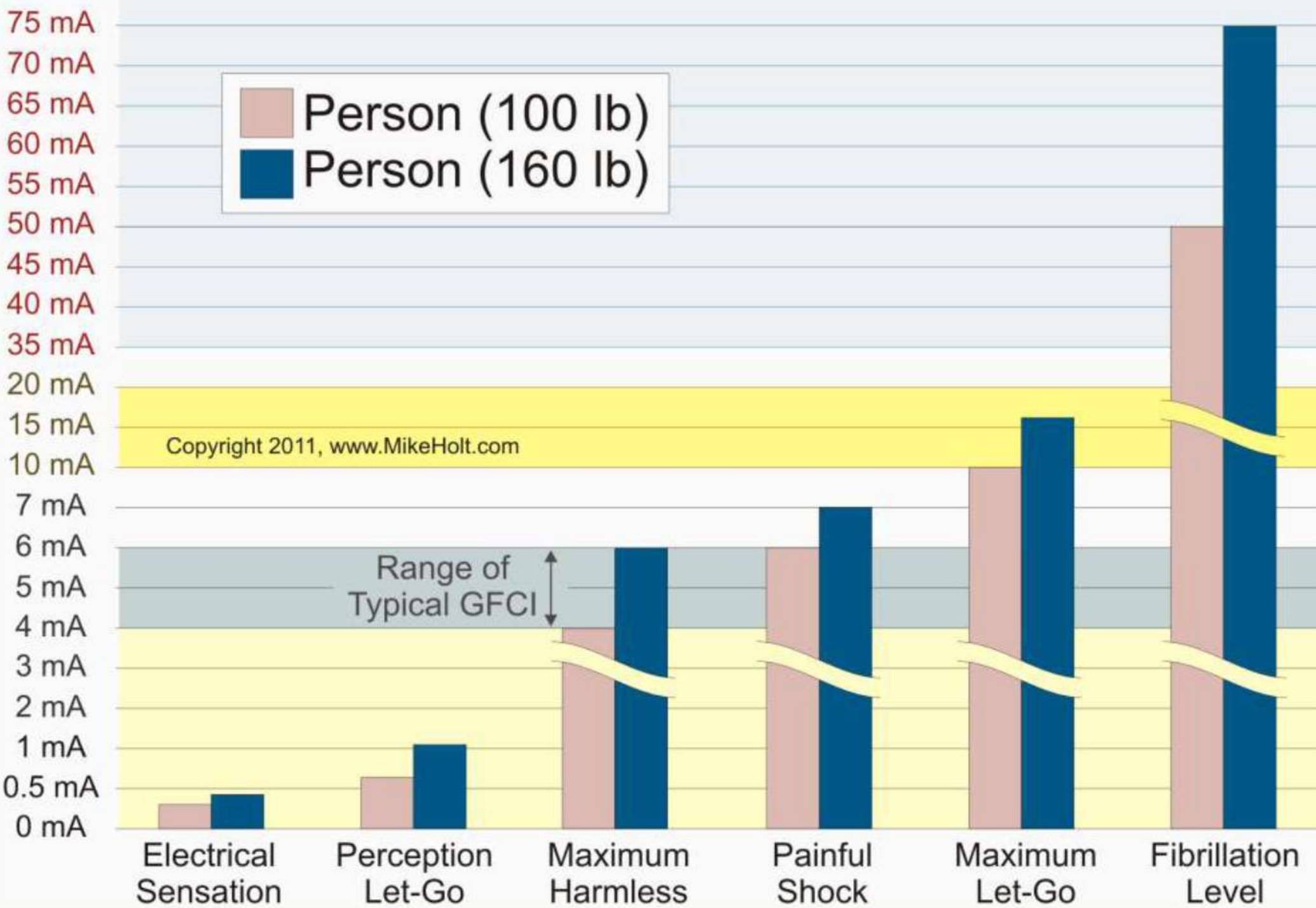
# HUMAN TOLERANCE (TO ELECTRIC CURRENT)

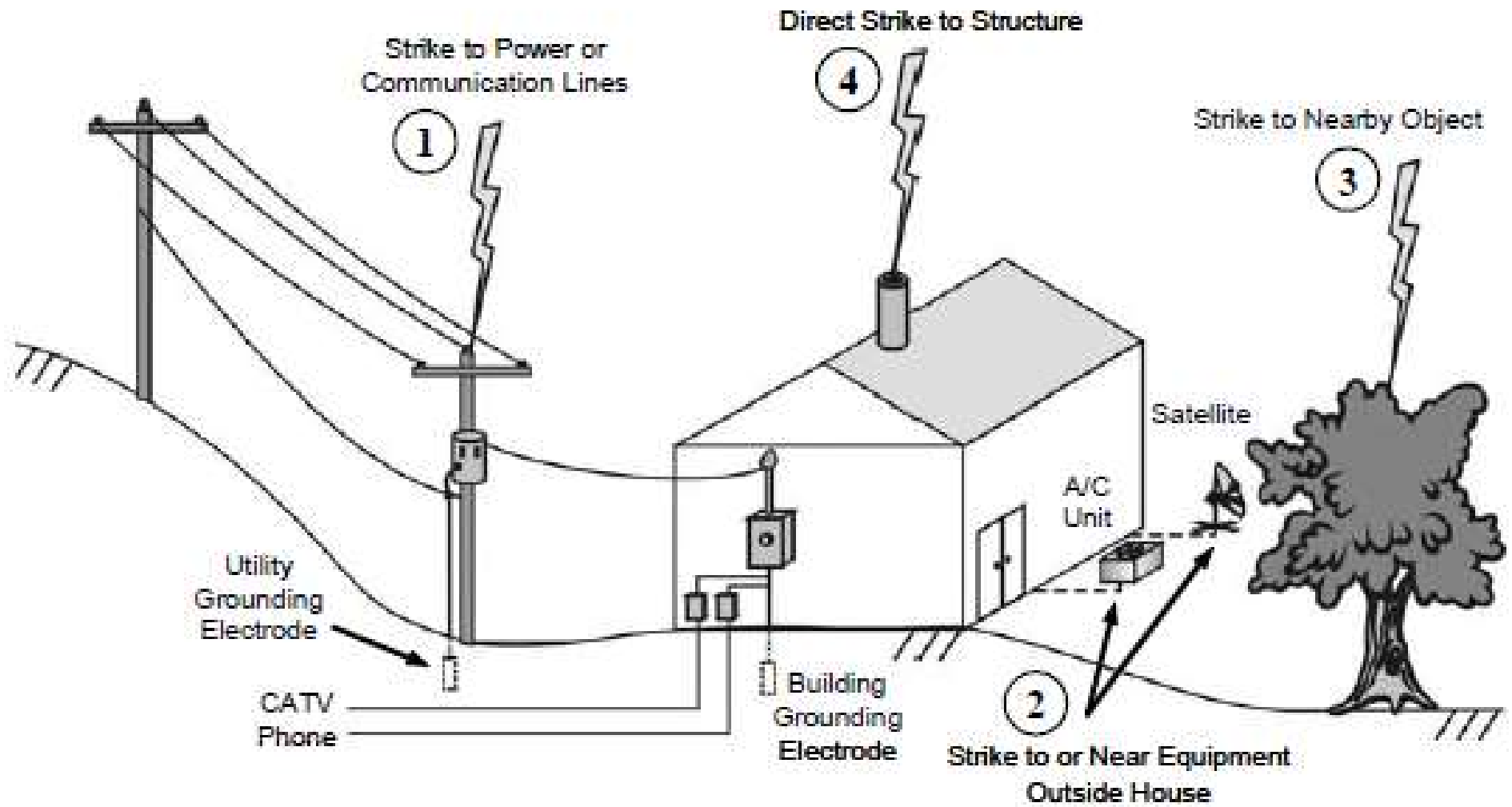
- WORK OF CHARLES DIALZEL
- DIFFERENCES DUE TO WEIGHT
- OVERLAP BETWEEN REACTIONS

Physical Effect	Sex	DC	60 Hz	10 kHz
Slight sensation at contact point	M	1 ma	0.4 ma	7 ma
	F	0.6 ma	0.3 ma	5 ma
Threshold of perception	M	5.2 ma	1.1 ma	12 ma
	F	3.5 ma	0.7 ma	8 ma
Pain; Maintain voluntary muscle control	M	62 ma	8 ma	55 ma
	F	41 ma	6 ma	37 ma
Pain; Loss of voluntary muscle control	M	76 ma	16 ma	75 ma
	F	51 ma	10.5 ma	50 ma
Severe pain; Respiratory difficulty	M	90 ma	23 ma	94 ma
	F	60 ma	15 ma	63 ma
Possible fibrillation after 3 Seconds	M	500 ma	100 ma	
	F	500 ma	100 ma	

**EXPERIMENTAL DATA FROM THE WORK OF CHARLES DALZIEL**

# Electric Shock Values on Humans





# Outside Grounding & Bonding

- Antenna Grounding/Bonding
- Tower Grounding /Bonding
- Building Grounding /Bonding
- Proximity to Other Metallic Objects
- Grounding Field, Rods, Connections
- Protection on Feed to Inside Wiring (antenna, power, telephone, data and fiber cables)

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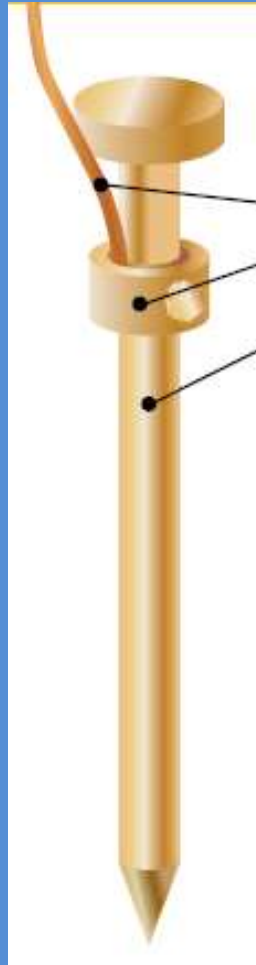




# Materials Required

- Ground Electrodes
- Conductors
  - Flat Conductor vs Round Conductors
- Ground Clamps, Attachments, Welds
  - It's All About the Connections!!!
- Grounding at Building Entry

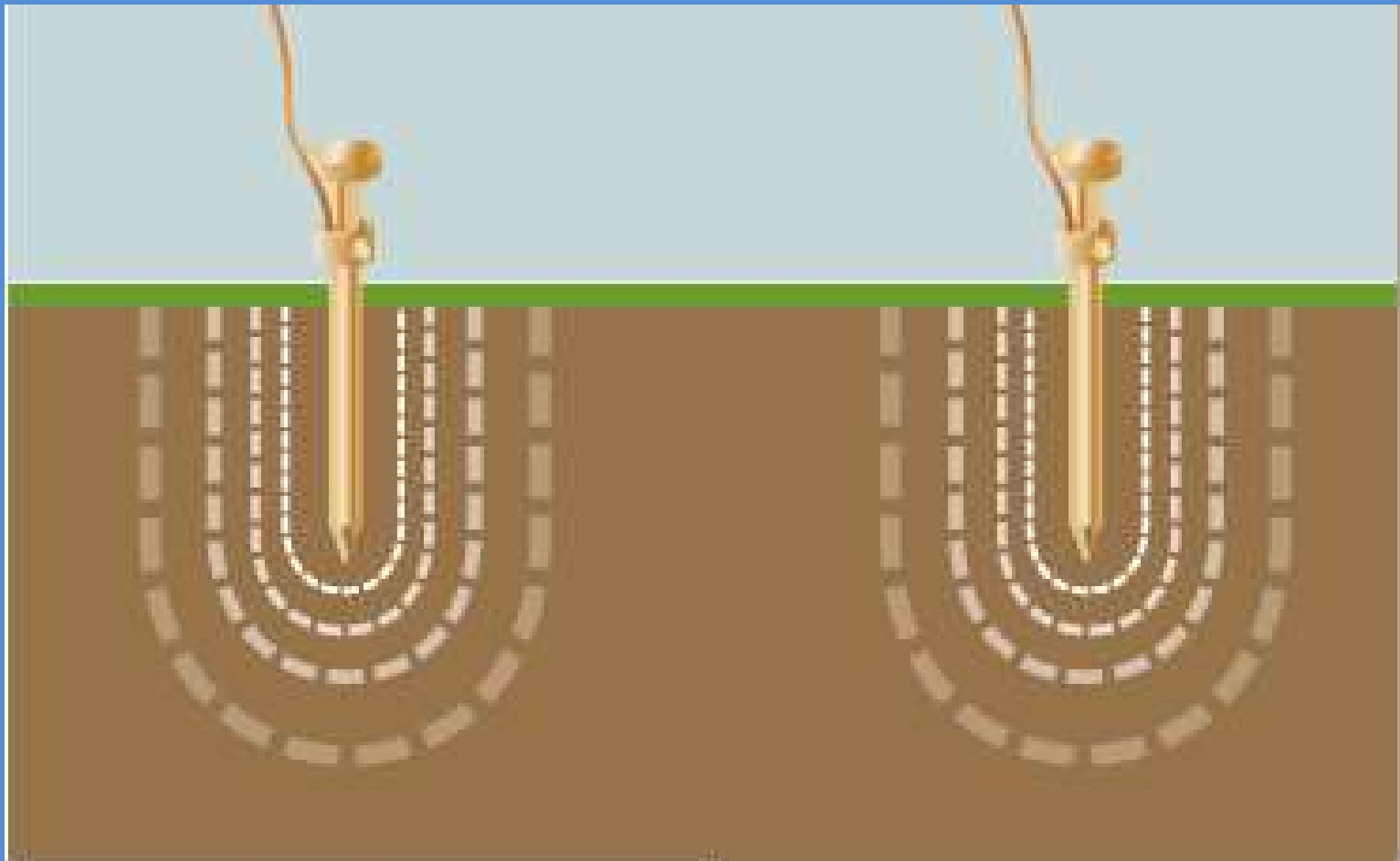
## Components of a ground electrode



Ground Electrode Conductor

Connector

Electrode





# ROD INSTALLATION

- MINIMUM 8 FEET BURIED
  - VERTICAL
  - HORIZONTAL
    - MIN. 2 ½ FEET DEEP
  - ANGLED UP TO 45 DEGREES
- 6 FEET SEPARATION PER CODE
  - 2 X ROD LENGTH PREFERRED!!!

# UFER GROUNDS

- “CONCRETE ENCLOSED ELECTRODE”
  - MIN. 2 INCHES CONCRETE
  - 20 FT OR MORE BARE, GALVANIZED OR CONDUCTIVELY COATED SHEET, MIN. ½ INCH DIAM
    - OR..20 FT. OF BARE, COPPER WIRE, MIN. 4 AWG
  - REBAR TIES ARE PERMISSABLE
  - EPOXY COATED REBAR IS NOT PERMITTED

# OTHER GROUND ELECTRODES

- METAL UNDERGROUND WATER PIPE
  - IN DIRECT EARTH CONTACT FOR 10 FT
  - MAXIMUM OF 5 FEET FROM ENTRANCE INTO BUILDING



# OTHER GROUND ELECTRODES

- METAL BUILDING FRAMES IF:
  - 10 FEET OR MORE IN DIRECT EARTH CONTACT/CONCRETE ENCASED EARTH CONTACT – OR
  - The bolts securing the structural steel column are connected to a concrete encased electrode by welding, exothermic welding, steel tie wires or other approved means

# OTHER PERMITTED ELECTRODES

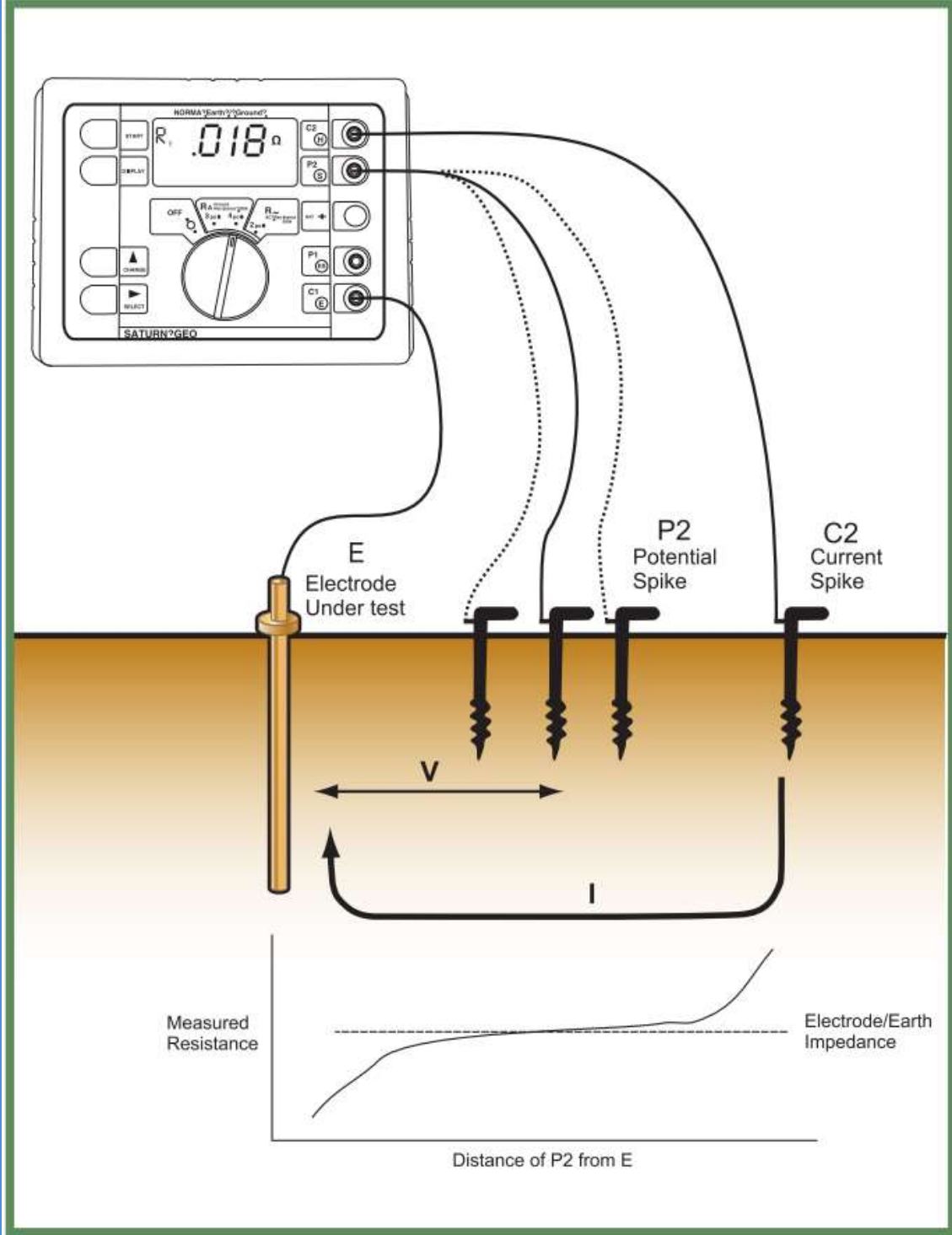
- ROD AND PIPE ELECTRODES
  - PIPE OR CONDUIT  $\frac{3}{4}$  INCH OR MORE
  - STAINLESS STEEL, GALVANIZED STEEL OR COPPER COATED STEEL MINIMUM  $\frac{5}{8}$  INCH DIAMETER...UNLESS
    - LISTED RODS

# OTHER PERMITTED ELECTRODES

- PLATE ELECTRODES
  - MINIMUM 2 SQUARE FEET SURFACE AREA
  - MINIMUM THICKNESS
    - $\frac{1}{4}$  INCH FOR STEEL OR IRON
    - 0.06 INCH FOR COPPER

# TESTING

- Ground Resistance Testing– Fall of Potential Method



## Resistivity Chart of Different Soils

Soil Composition	Resistivity (ohms/cm)		
	Average	Minimum	Maximum
Fills: ashes, cinders, brine wastes	2,370	590	7,000
Clay, shale, gumbo, loam	4,060	340	16,300
Clay, shale, gumbo, loam with varying sand and gravel proportions	15,800	1,020	135,000
Gravel, sand, stones, with little clay or loam	94,000	59,000	458,000

Source: U.S. Bureau of Standards Technical Report 108

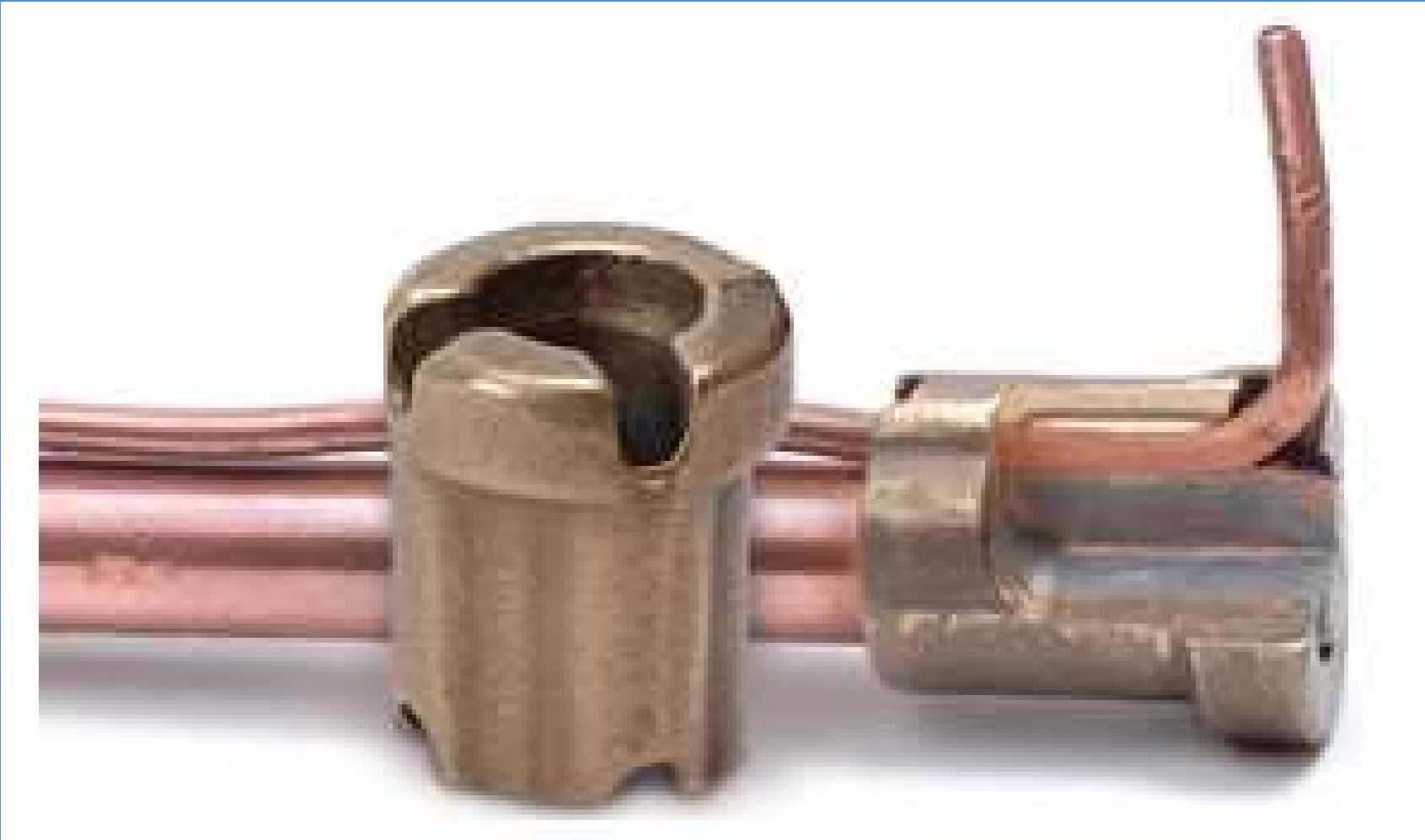
# GROUND ELECTRODE RESISTANCE

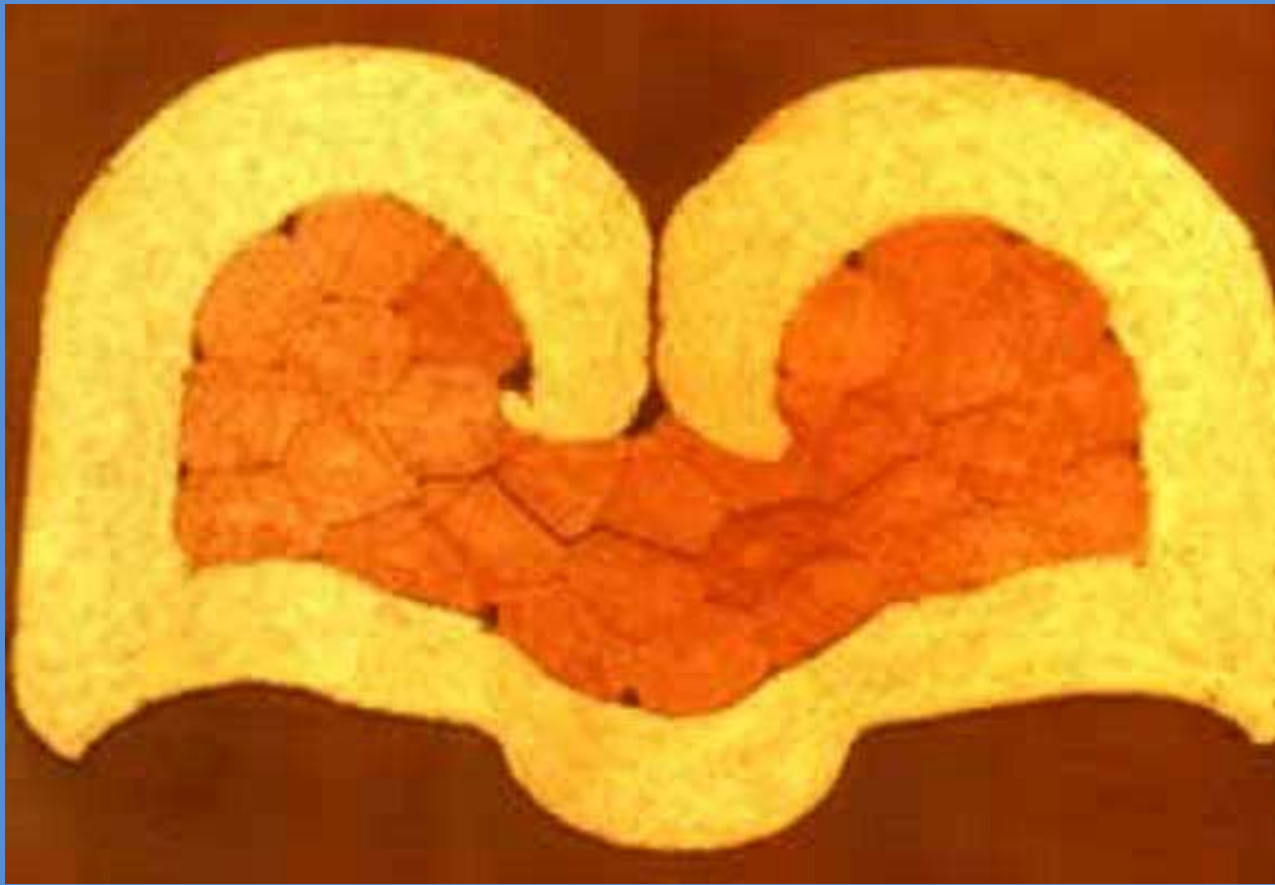
- MAXIMUM 25 OHMS – per NEC
  - OR ADD AN ADDITIONAL ROD (2008 or earlier)
  - Starting with 2011 CODE...
    - INSTALL TWO RODS, UNLESS GROUND RESISTANCE IS LESS THAN 25 OHMS WITH ONE INSTALLED

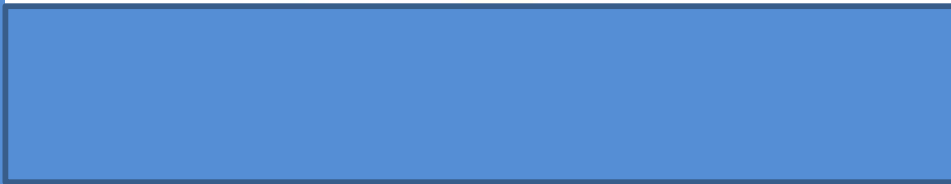
IT'S ALL ABOUT THE CONNECTIONS



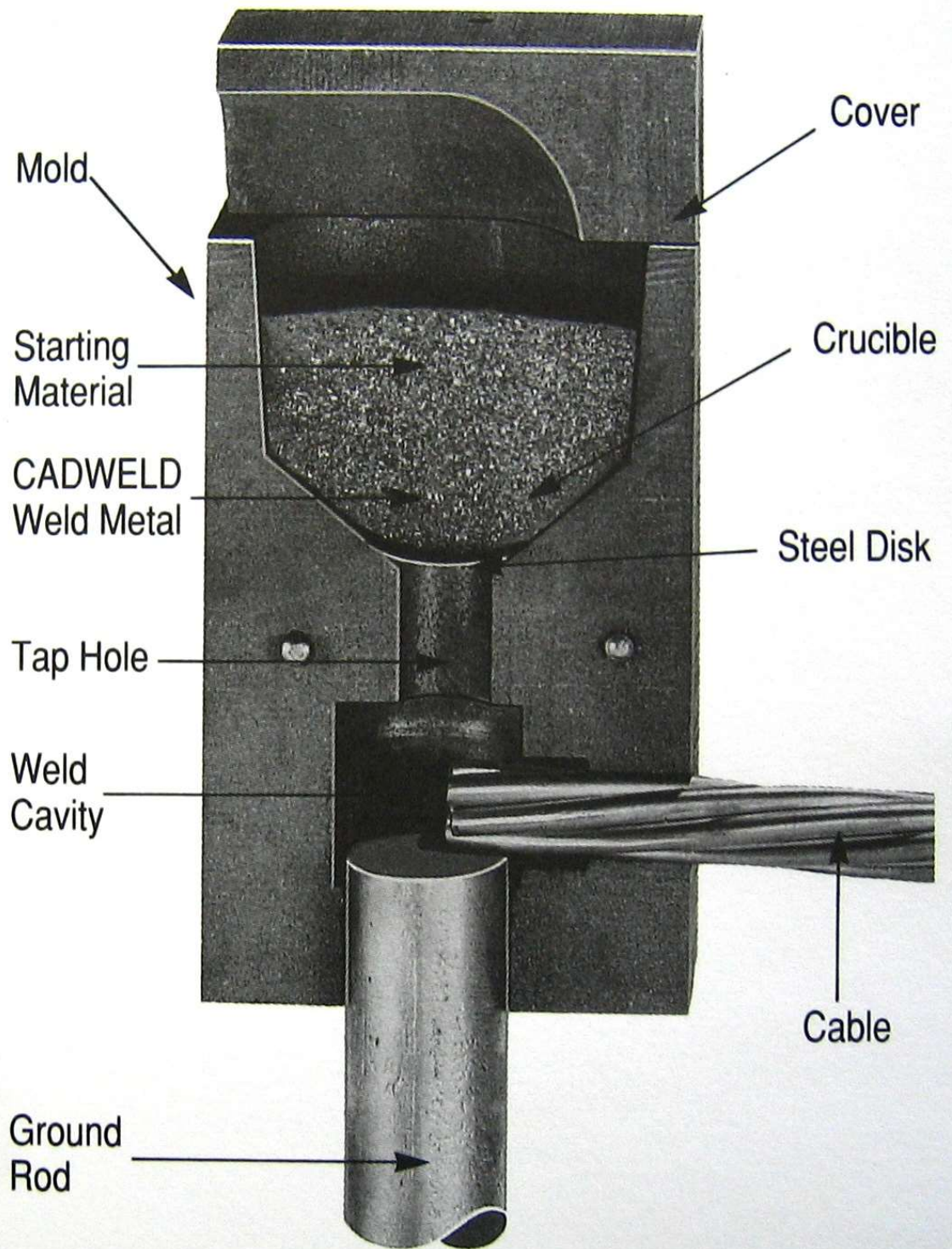


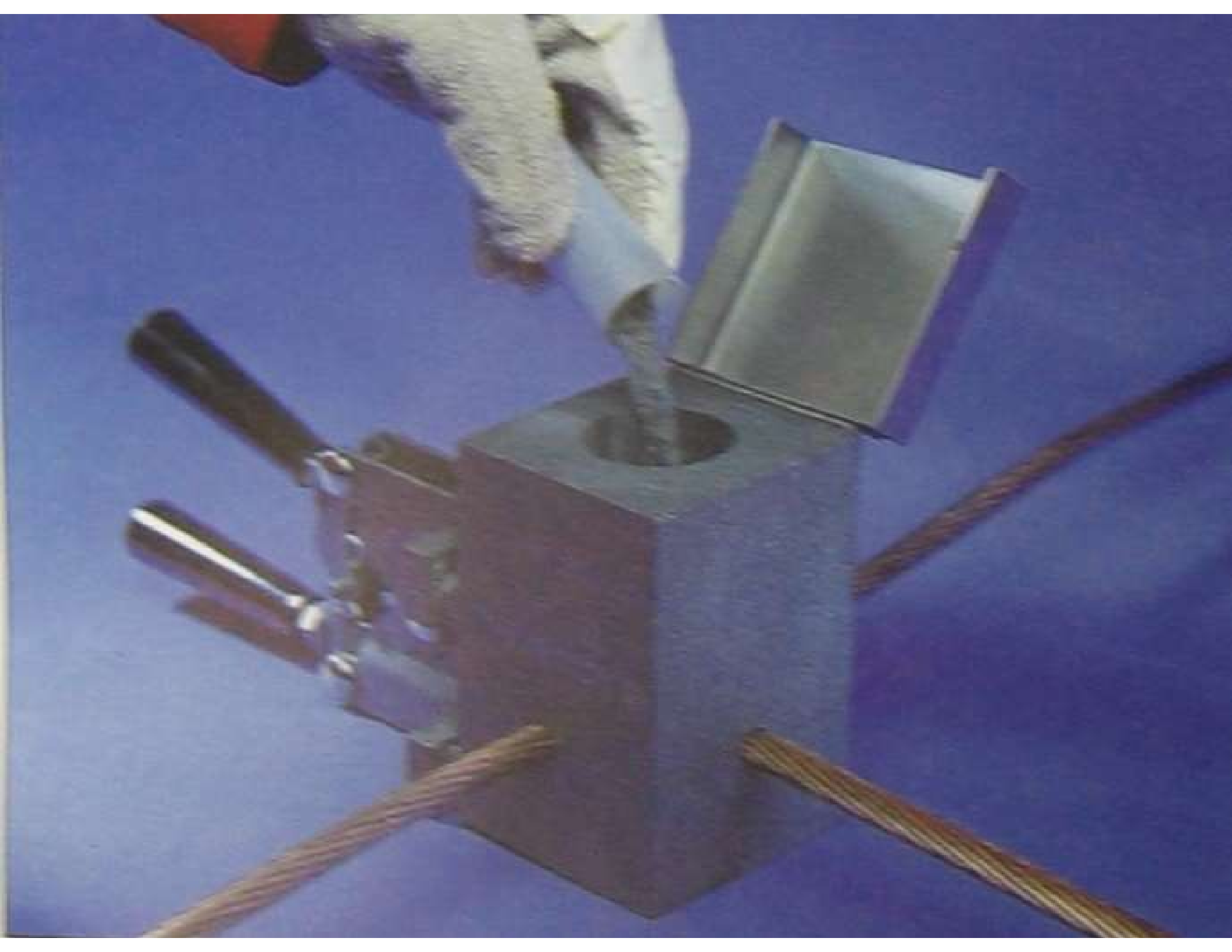


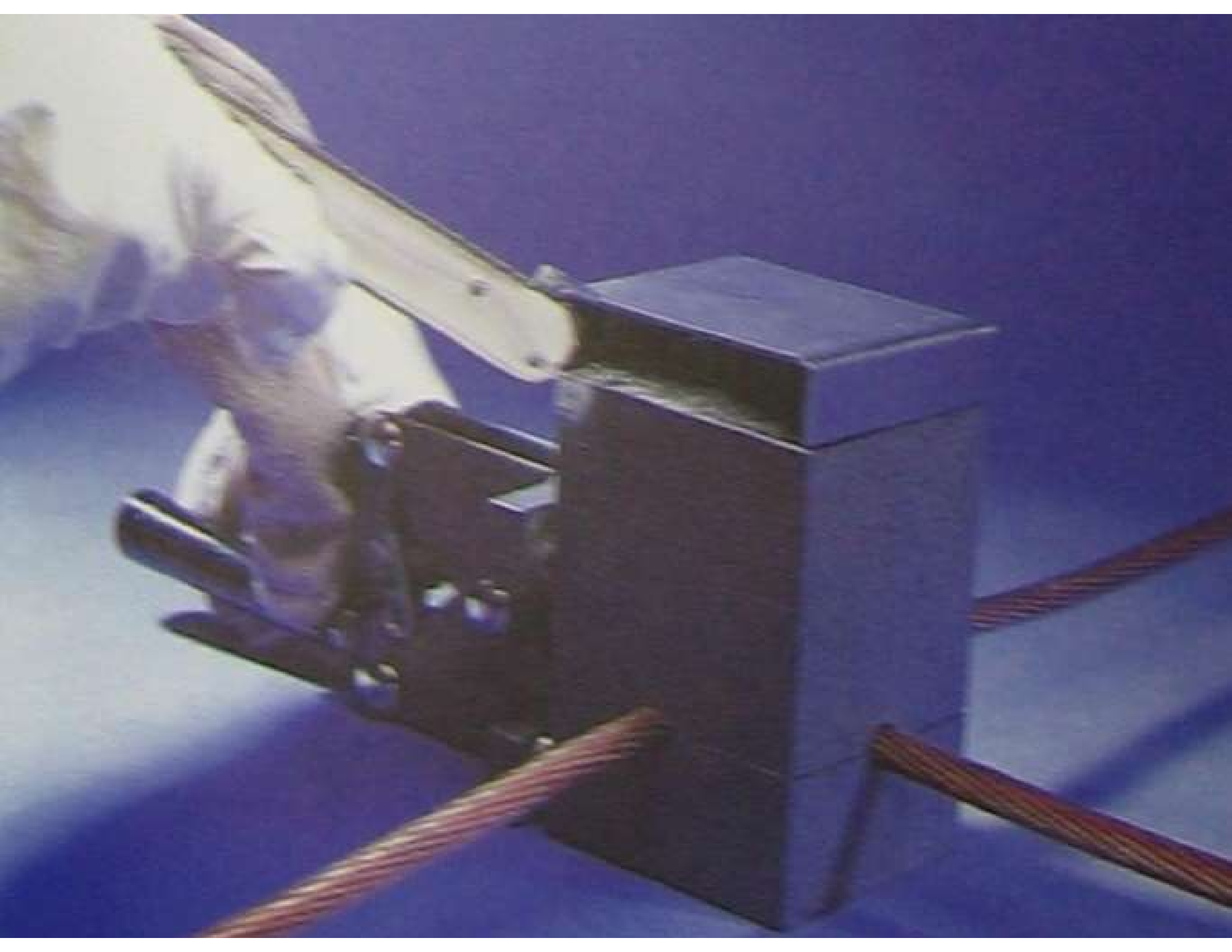
















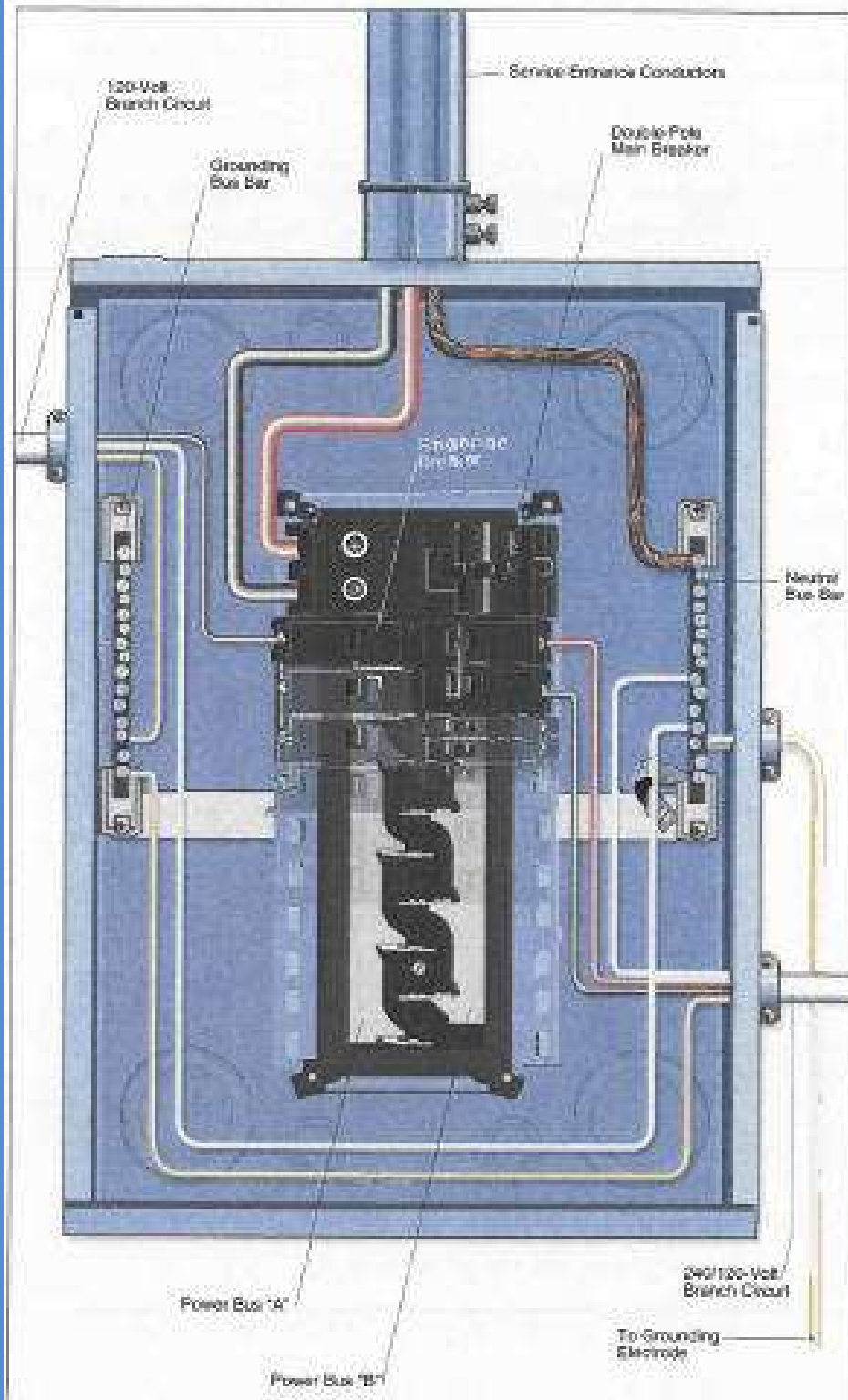
# CADWELD ONE-SHOT





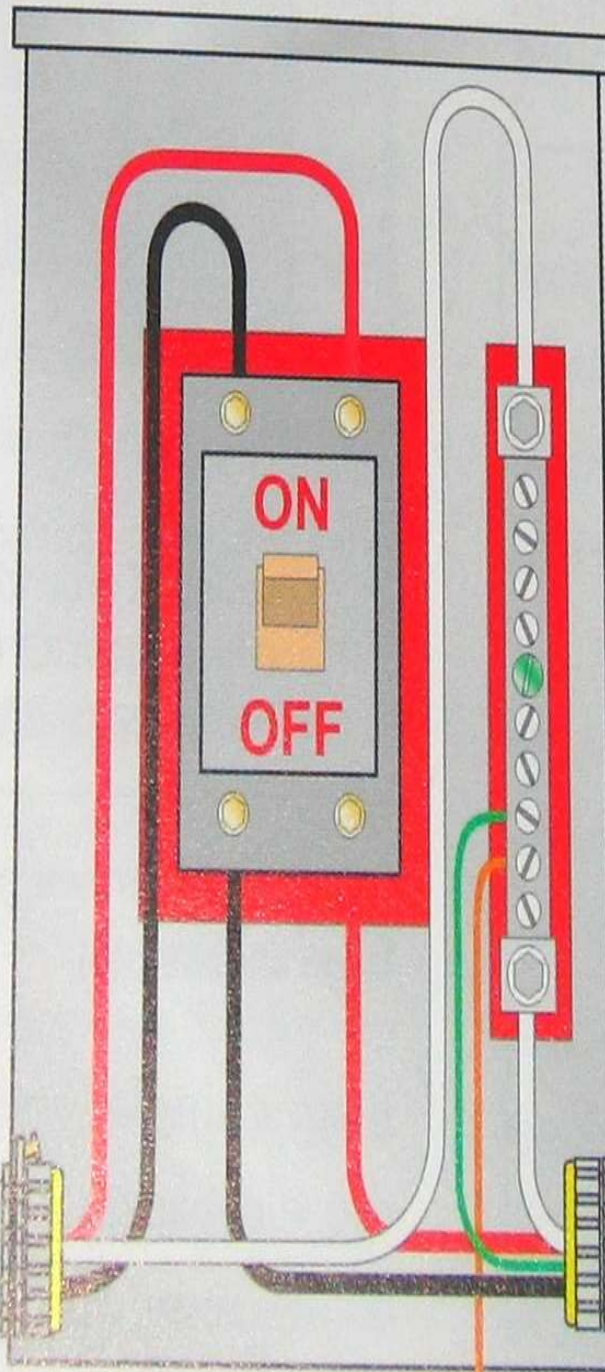
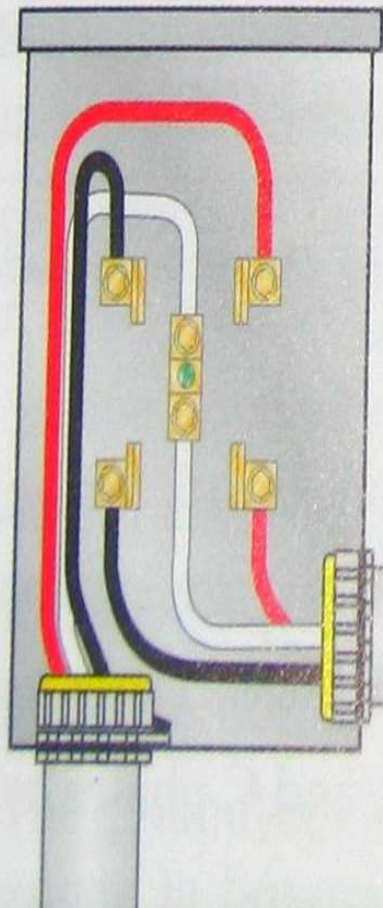
# MAIN BONDING JUMPER

- WHAT DOES IT DO?
- WHAT DOES IT LOOK LIKE
  - SCREW
  - BUS BAR
  - CABLE

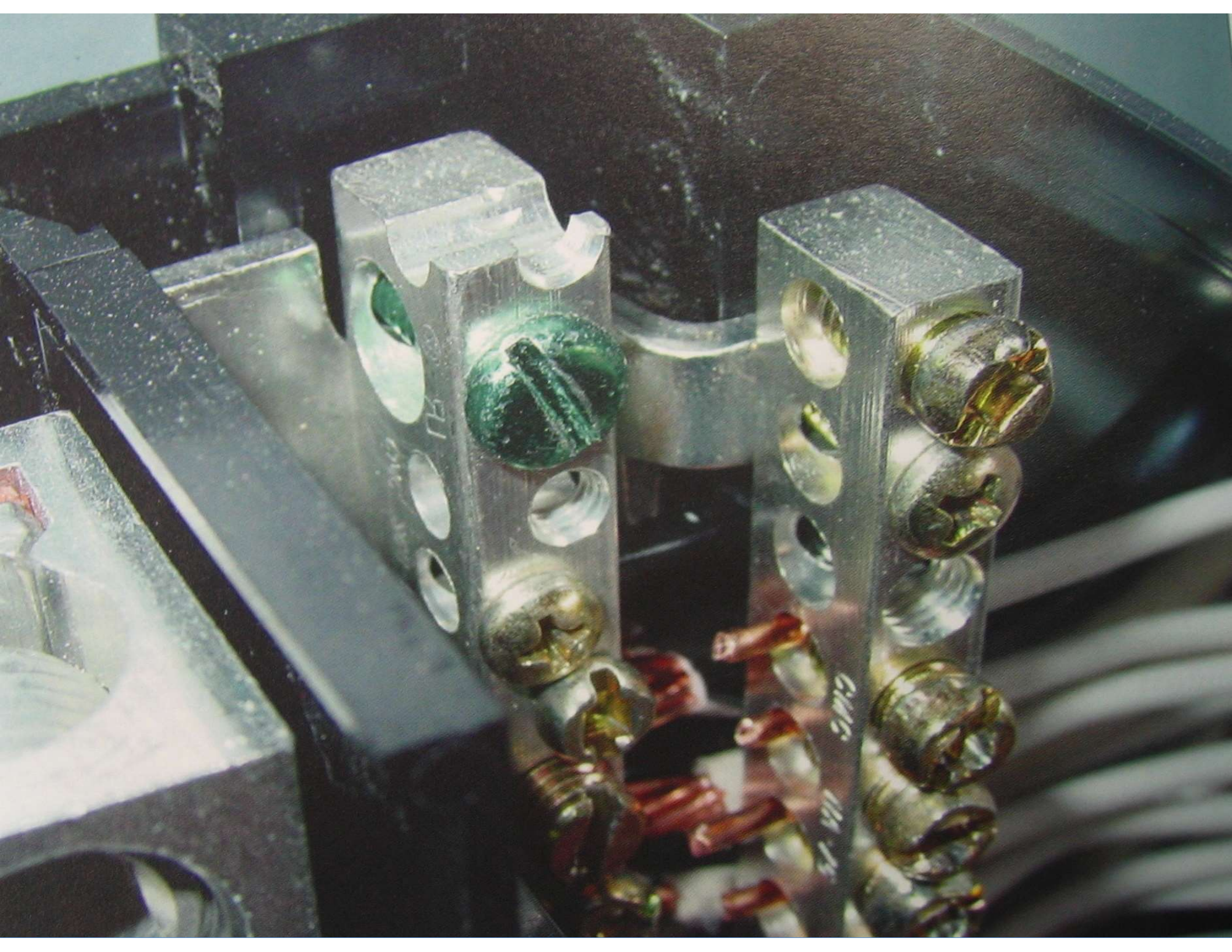


Service disconnect

Meter enclosure



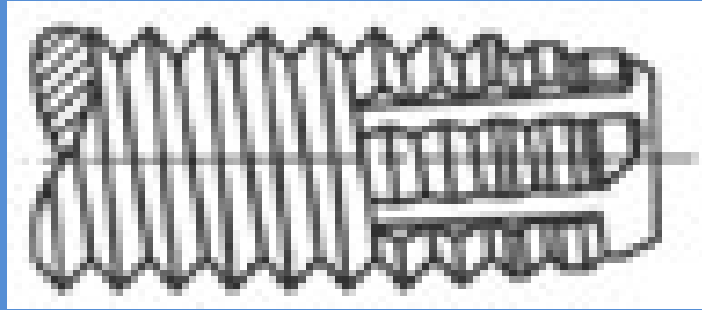
Panelboard



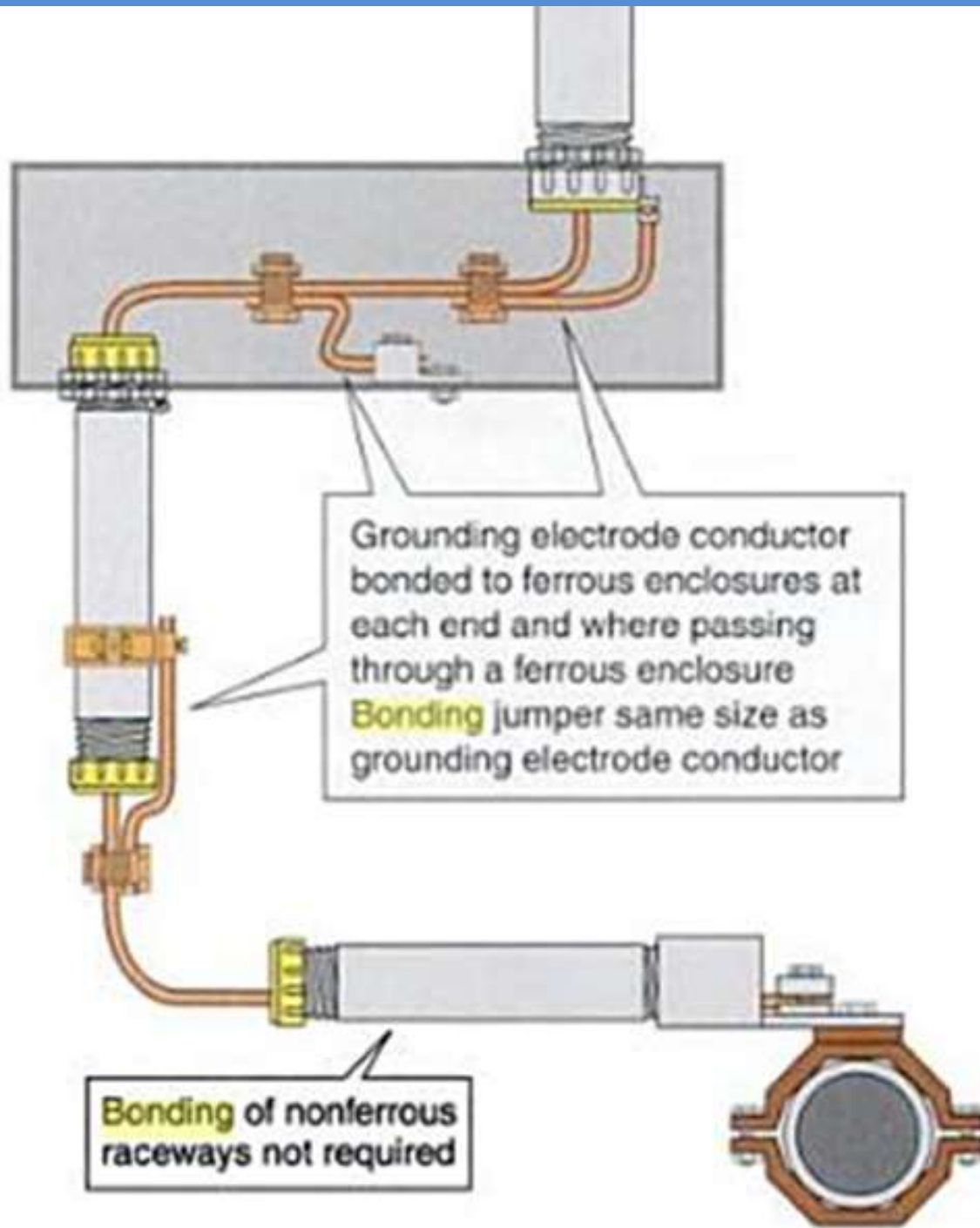
# A NOTE ABOUT HARDWARE

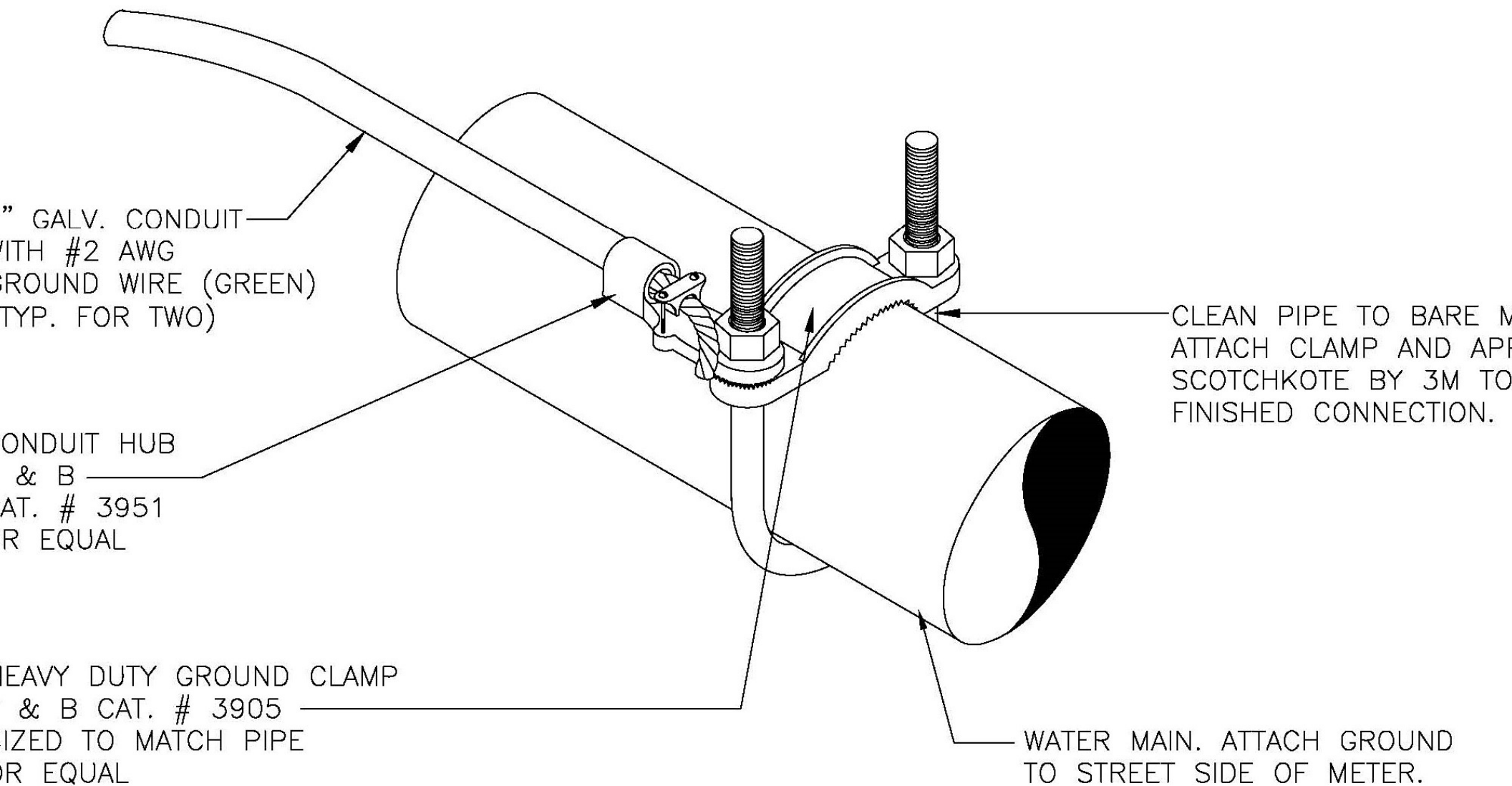
- MINIMUM TWO THREADS  
ENGAGED...OR....SECURED WITH A NUT
- ACCEPTABLE TYPES
  - AND UNACCEPTABLE TYPES





- CAUTIONS WHEN RUNNING A GROUNDING CONDUCTOR THROUGH FERROUS METAL CONDUIT (STEEL)





2  
5

# GROUND at WATER MAIN DETAIL

N.T.S.

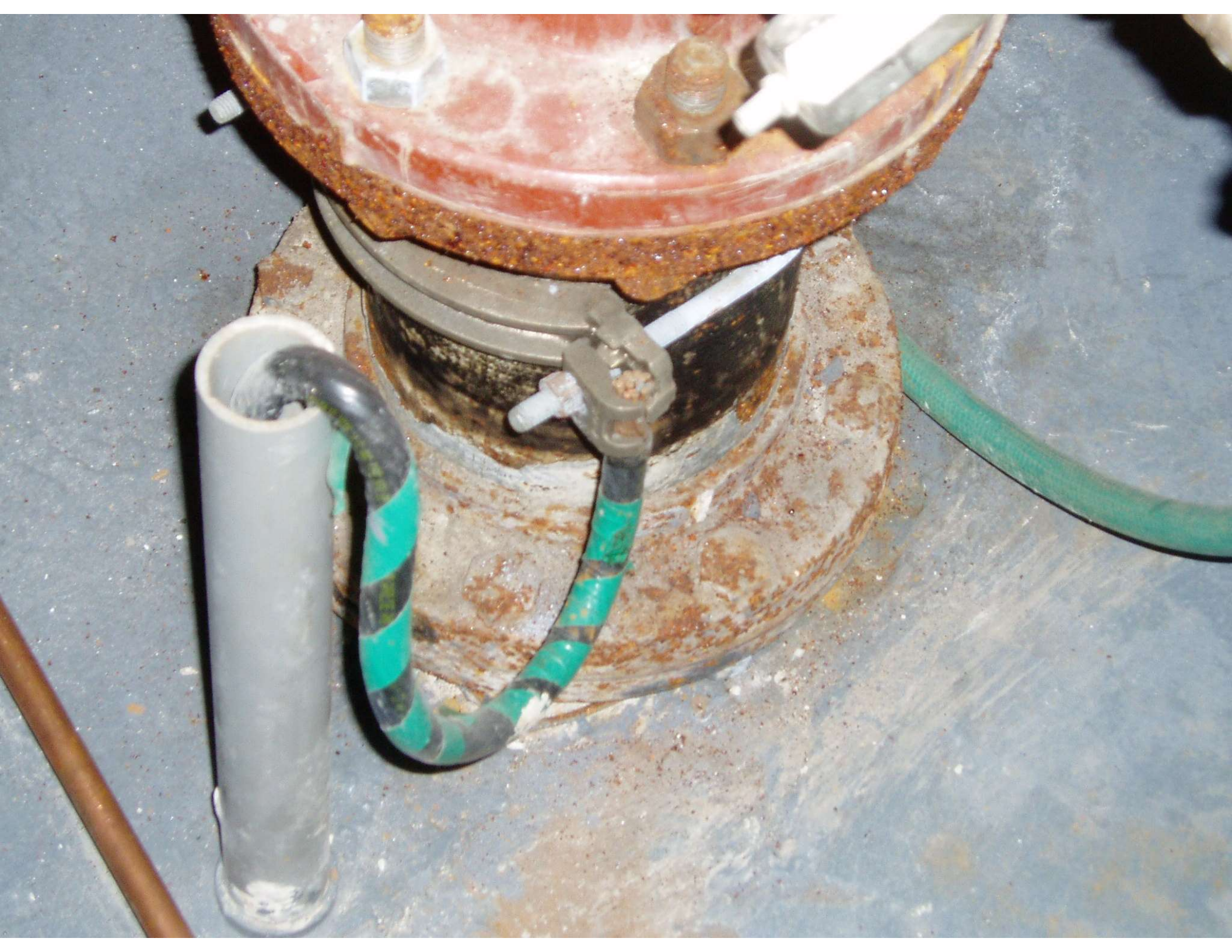
(TYPICAL FOR EACH GROUND LINE)

# WHEN GROUNDING/BONDING CONDUCTOR PASSES THROUGH FERROUS METAL ENCLOSURE



# FOR LARGE GROUNDING CONDUCTOR IN CONDUIT

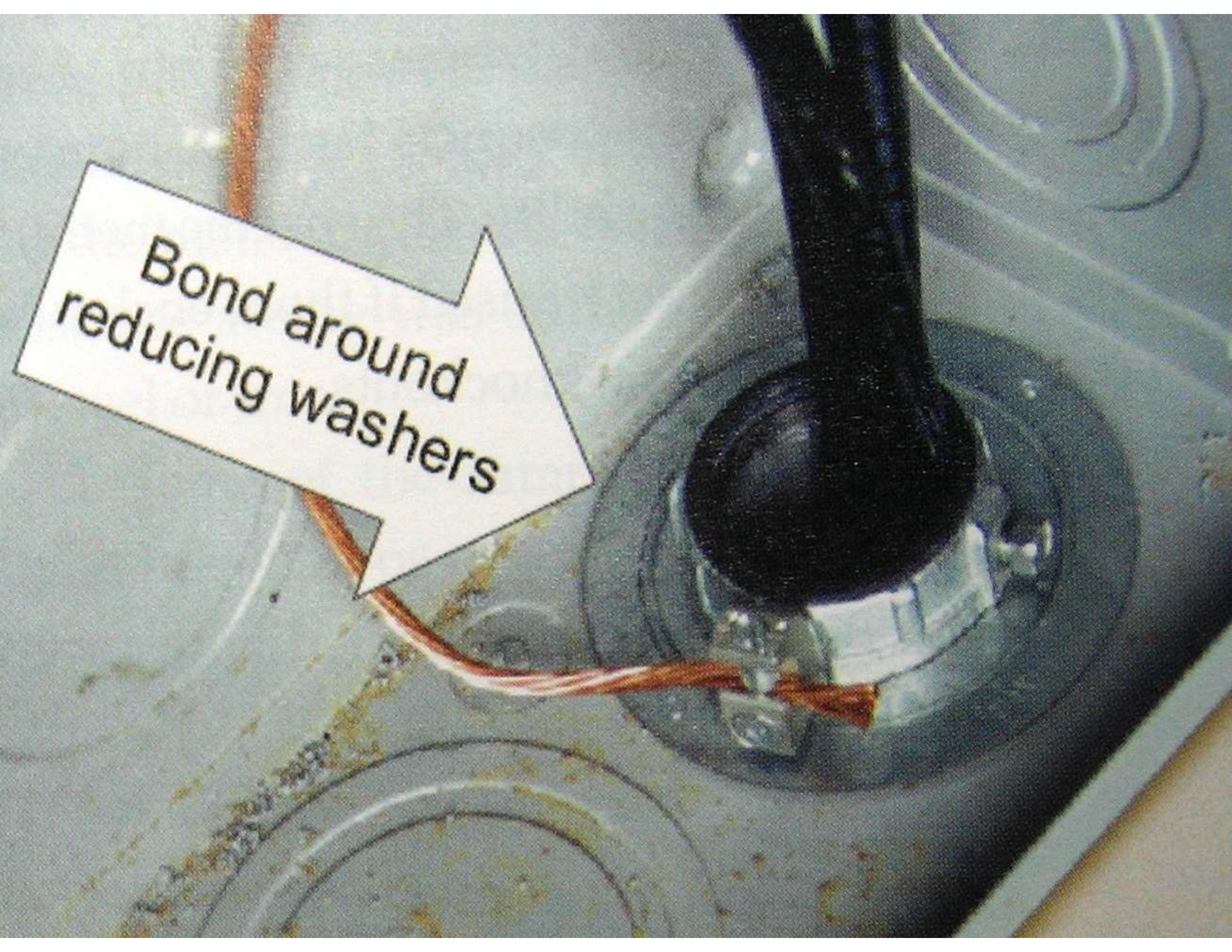


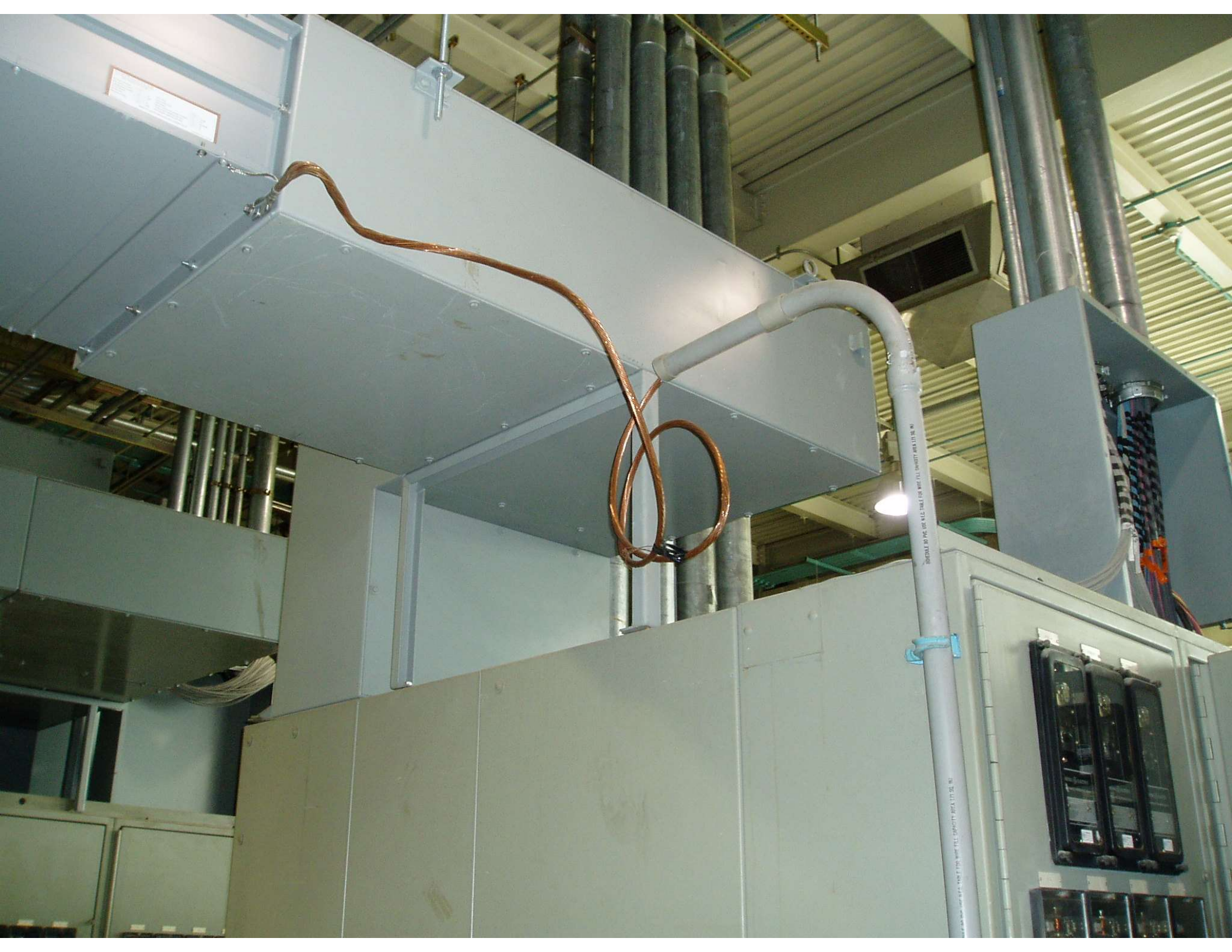






Bond around  
reducing washers







A cylindrical metal component, possibly a valve or part of a larger machine, is wrapped in white tape. A red label with white text is wrapped around the middle of the cylinder. The label reads "DO NOT TAP BEYOND THIS POINT". The component is mounted on a metal base with several bolts. A green cable is connected to the component. The background is a concrete wall.

**DO NOT TAP BEYOND THIS POINT**

# ARTICLE 250.102(B) OTHER PIPING

- ALL METAL PIPING INCLUDING GAS PIPING WHICH CAN BECOME ENERGIZED SHALL BE BONDED TO THE SERVICE GROUND
  - GAS PIPING CAN NOT BE USED AS A GROUNDING ELECTRODE
  - THE GAS PIPE BONDING CONNECTION, IN GENERAL, MAY BE EFFECTED BY THE EQUIPMENT GROUNDING CONDUCTOR OF THE EQUIPMENT LIKELY TO ENERGIZE THE PIPING

# GAS SYSTEMS WITH CSST PIPING

- NATIONAL GRID “BLUE BOOK” APPENDIX F GIVES THE REQUIREMENTS FOR GROUNDING/BONDING OF CSST PIPING

# CSST GAS PIPING

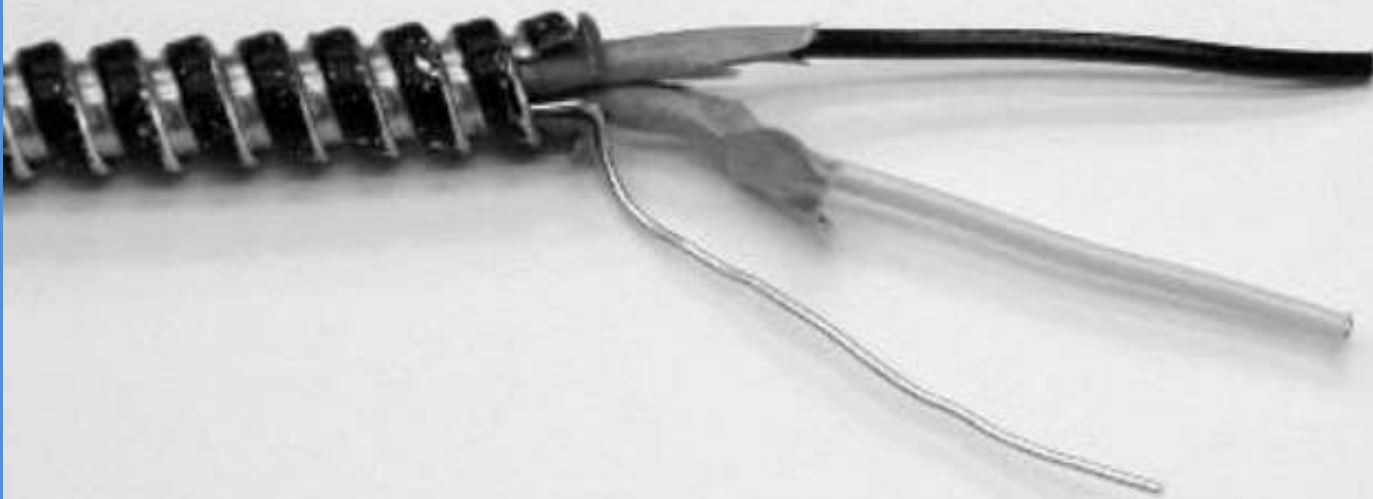
- “G2411.2.2 Bonding clamp. The bonding jumper shall be connected to the gas piping system with a bonding clamp that is listed for the material of the bonding jumper and for the material of the component of the gas piping system to which the bonding clamp is attached.
- The bonding clamp shall be attached to the gas piping system at a point which is inside the building or structure in which the gas piping is installed, on the downstream side of the gas meter or regulator, in an unconcealed and readily accessible space, and as close as practicable to the point where the gas service enters the building or structure.
- The bonding clamp shall be attached to a segment of metallic fuel gas pipe which
  - (a) is a component of the gas piping system,
  - (b) is electrically continuous with all CSST components of the gas piping system,
  - (c) is made of steel or wrought-iron,
  - (d) complies with Section G2414.4.2 of this code and with all other applicable provisions of Section G2414 of this code, and
  - (e) is not less than 3 inches (76 mm) in length.
- Neither the CSST nor the brass hexagonal nut on the CSST fitting shall be used as an attachment point for the bonding clamp

GROUNDING WHEN  
USING TYPE AC AND  
TYPE MC CABLE



# BASIC DEFINITIONS

- GROUNDED CONDUCTOR – Conductor that is intentionally grounded
- EQUIPMENT GROUNDING CONDUCTOR – Connects normally non-current carrying metal parts with the grounded conductor, the ground electrode conductor or both



Type AC  
Cable



Type MC  
Cable

## Preparing AC Cable for Termination



**Method 1 - Bend back over anti-short**



**Method 3 - Back-wrap under anti-short**



**Method 2 - Bend back under anti-short**

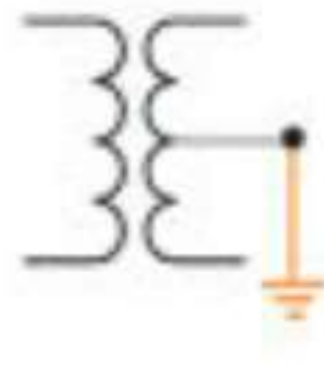
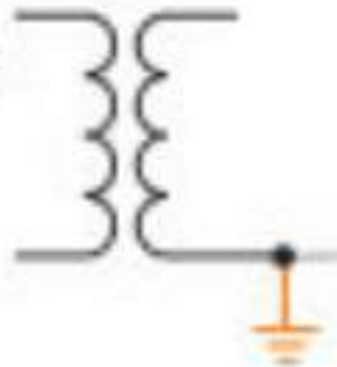


**Method 4 - Back-wrap over anti-short**

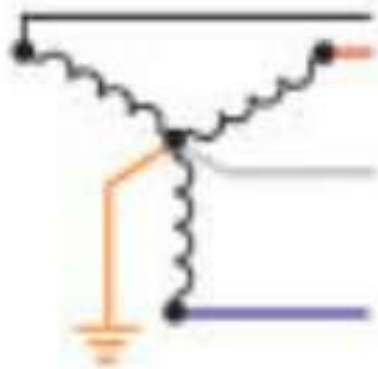
	<b>Type AC Cable</b>	<b>Interlocked Armor Type MC Cable</b>
Number of Conductors	No more than 4 plus EGC.	No limit
Size of Conductors	14 AWG to 1 AWG	18 AWG to 2000 kcmil

# THE GROUNDED CONDUCTOR

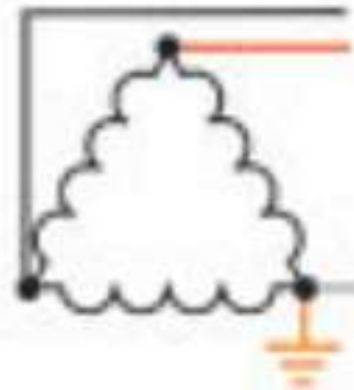
Single-phase, 2-wire:  
one conductor  
(either one)



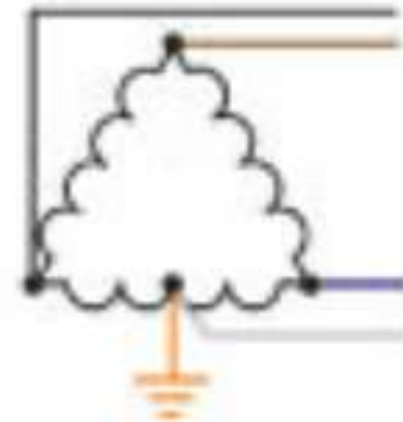
Single-phase, 3-wire  
the neutral conductor



Multiphase system with  
one common wire,  
The common conductor

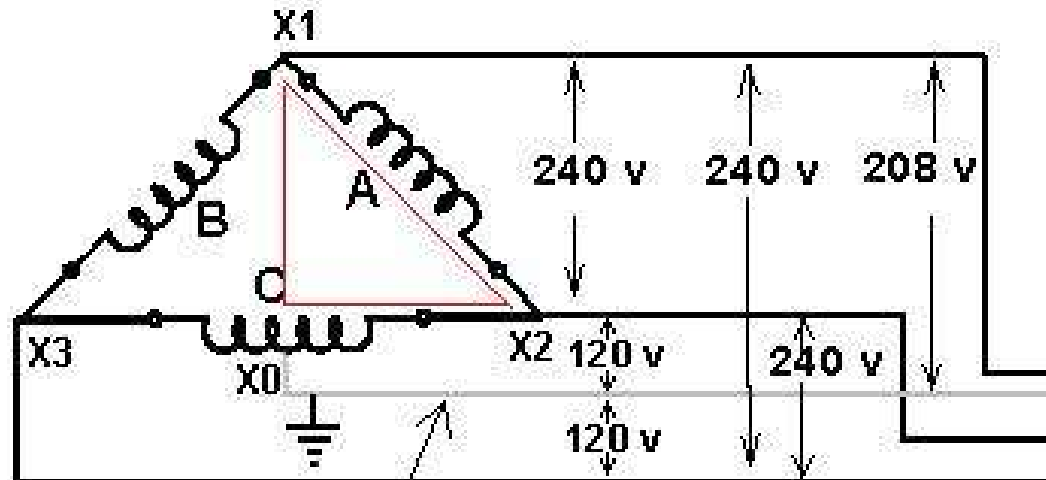


Multiphase systems  
that are corner  
grounded conductor,  
one phase conductor

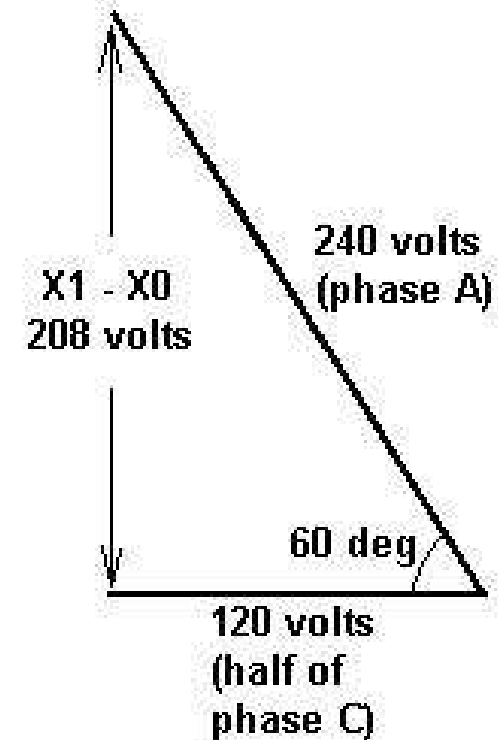


Multiphase systems in which  
the midpoint of one  
transformer winding is used  
as a neutral conductor,  
the neutral conductor

This represents the secondary windings of a DELTA connected 240 volt transformer



Neutral conductor



$$\begin{aligned}
 \text{High Leg Voltage} &= \sqrt{240^2 - 120^2} \\
 &= \sqrt{57600 - 14400} \\
 &= \sqrt{43200} \\
 &= 207.84 \text{ volts}
 \end{aligned}$$

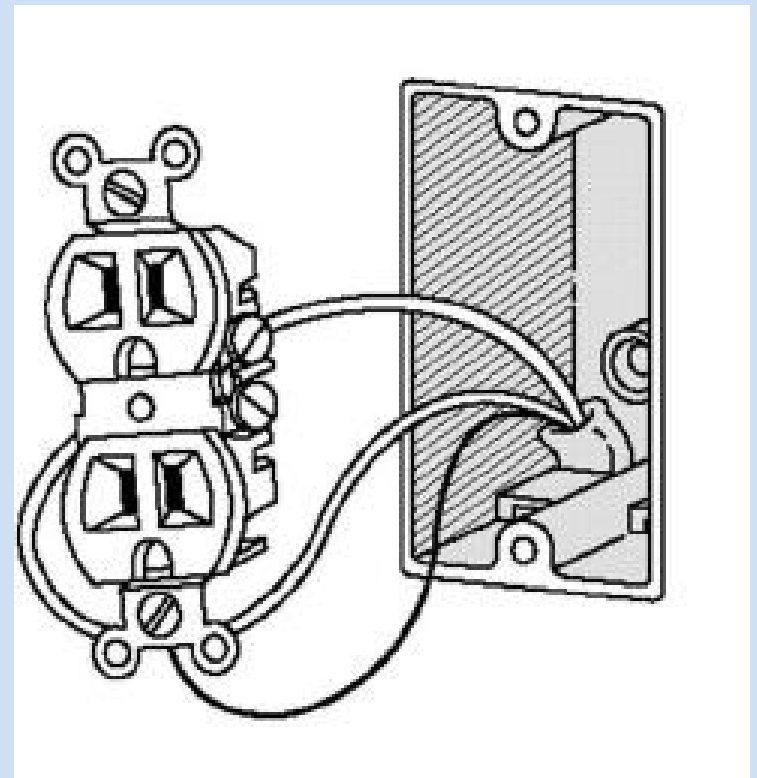
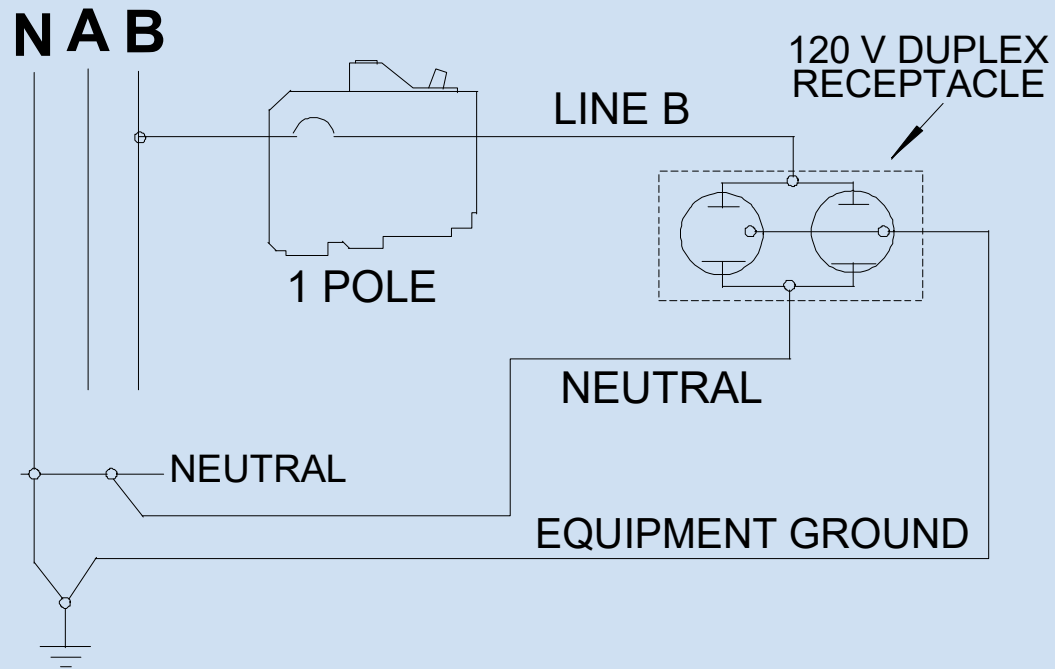
# RECEPTACLE GROUNDING





# Receptacle Grounding

120/240 Vac  
SOURCE

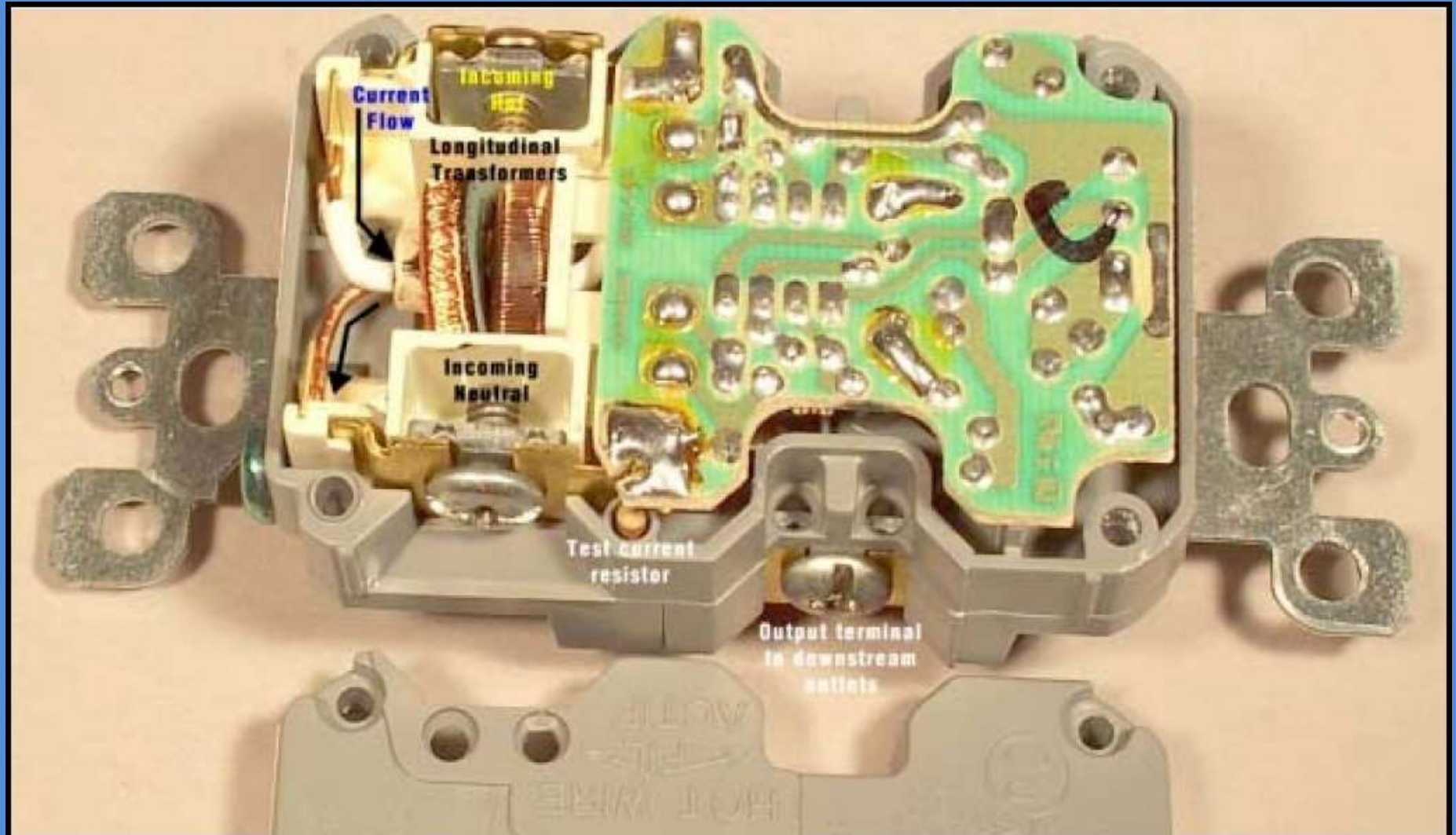


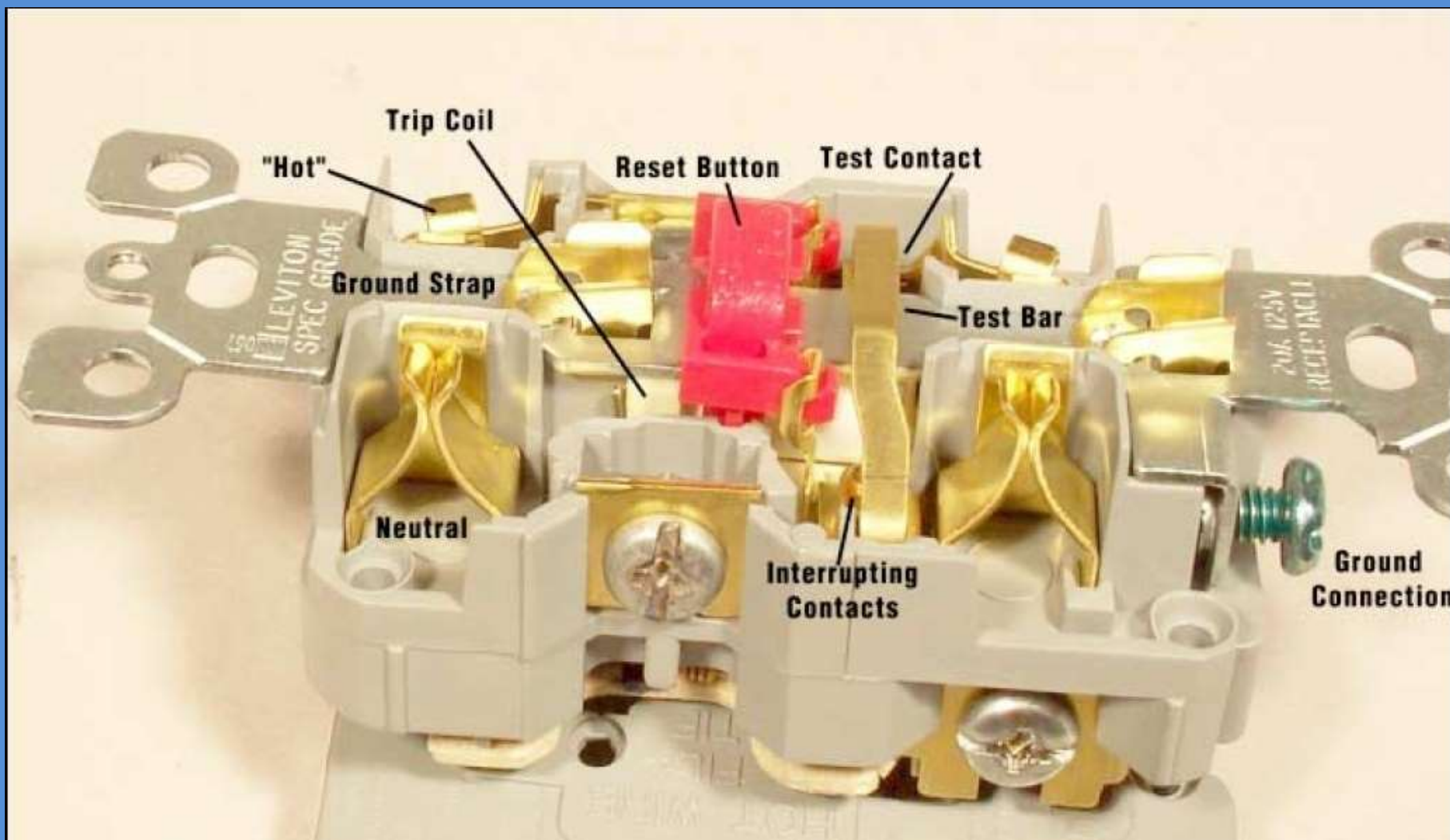
# GFCI REQTS EXPANDED FOR 2014

- Article 210.8 (A) – **210.8 (D)**
  - All 125V Single Phase, 15A and 20A Dwelling Unit Receptacles Located:
    - NOTE: 2020 NEC CHANGED TO INCLUDE 125V THROUGH 250V RECEPTACLES

- Bathrooms
- Garages/Accessory Bldgs at or Below Grade
- Outdoors
- Crawl Spaces – At or Below Grade
- Unfinished Portions of Basements Not Intended as Habitable Space
- Kitchen – Serving Countertop Surfaces
- Within 6 Ft From Top Inside Edge of Bowl of Sink
- Boathouses
- Within 6 Ft of Outside Edge of Bathtub or Shower Stall
- Laundry Areas

# GFCI RECEPTACLE

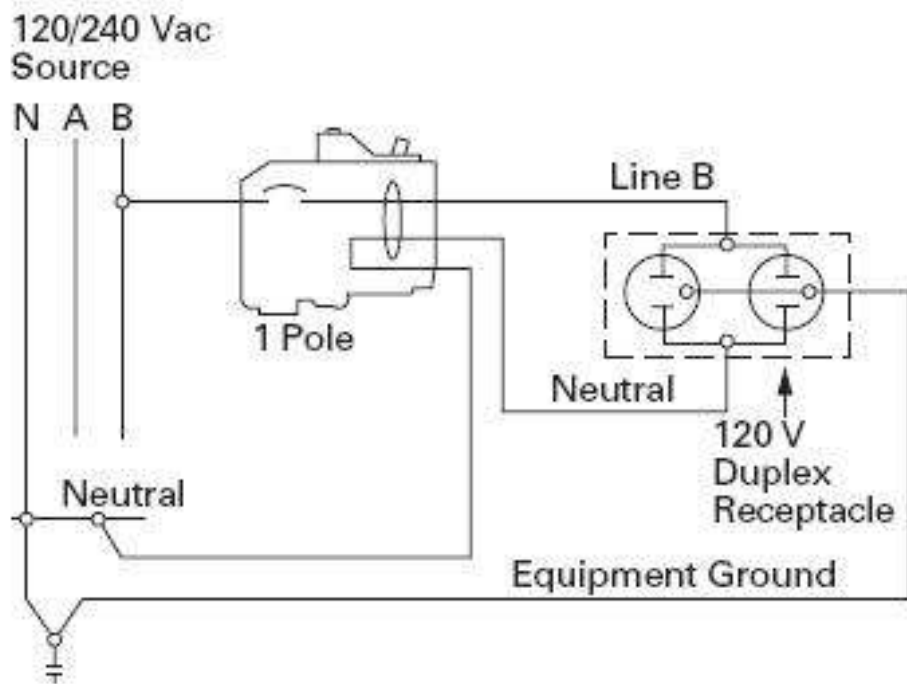




# RELIABILITY OF GFCI

- MUST BE REGULARLY TESTED
- CURRENT DESIGNS WILL “FAIL SAFE”
  - IF THE PROTECTIVE CIRCUITRY IS NOT FUNCTIONING CORRECTLY IT WILL NOT PERMIT RESETTING
  - IF THE RECEPTACLE IS WIRED INCORRECTLY IT WILL TRIP AND NOT ALLOW RESET
- NEW MODELS HAVE “SELF TESTING” FEATURE

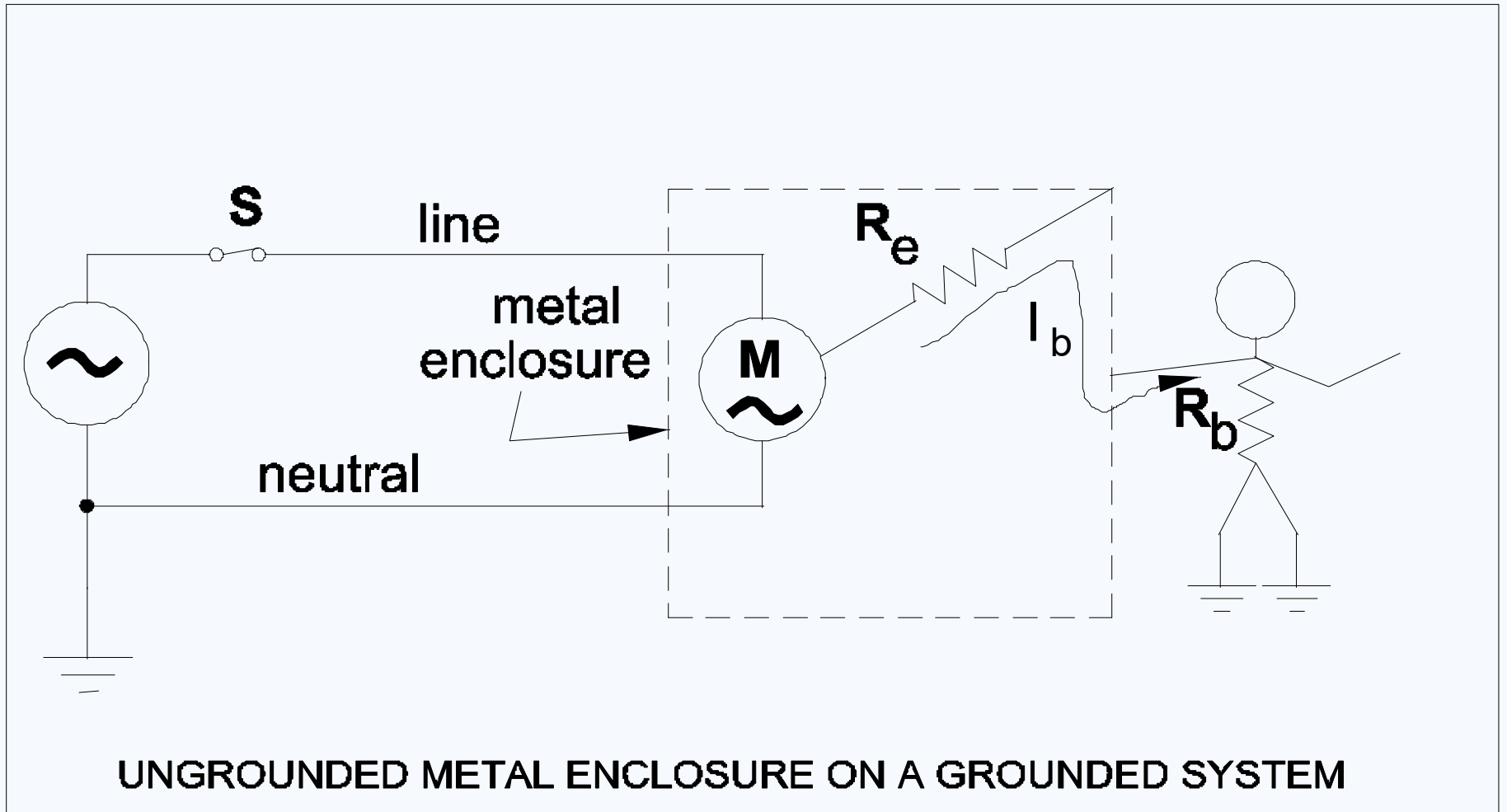
# The GFI Circuit Breaker

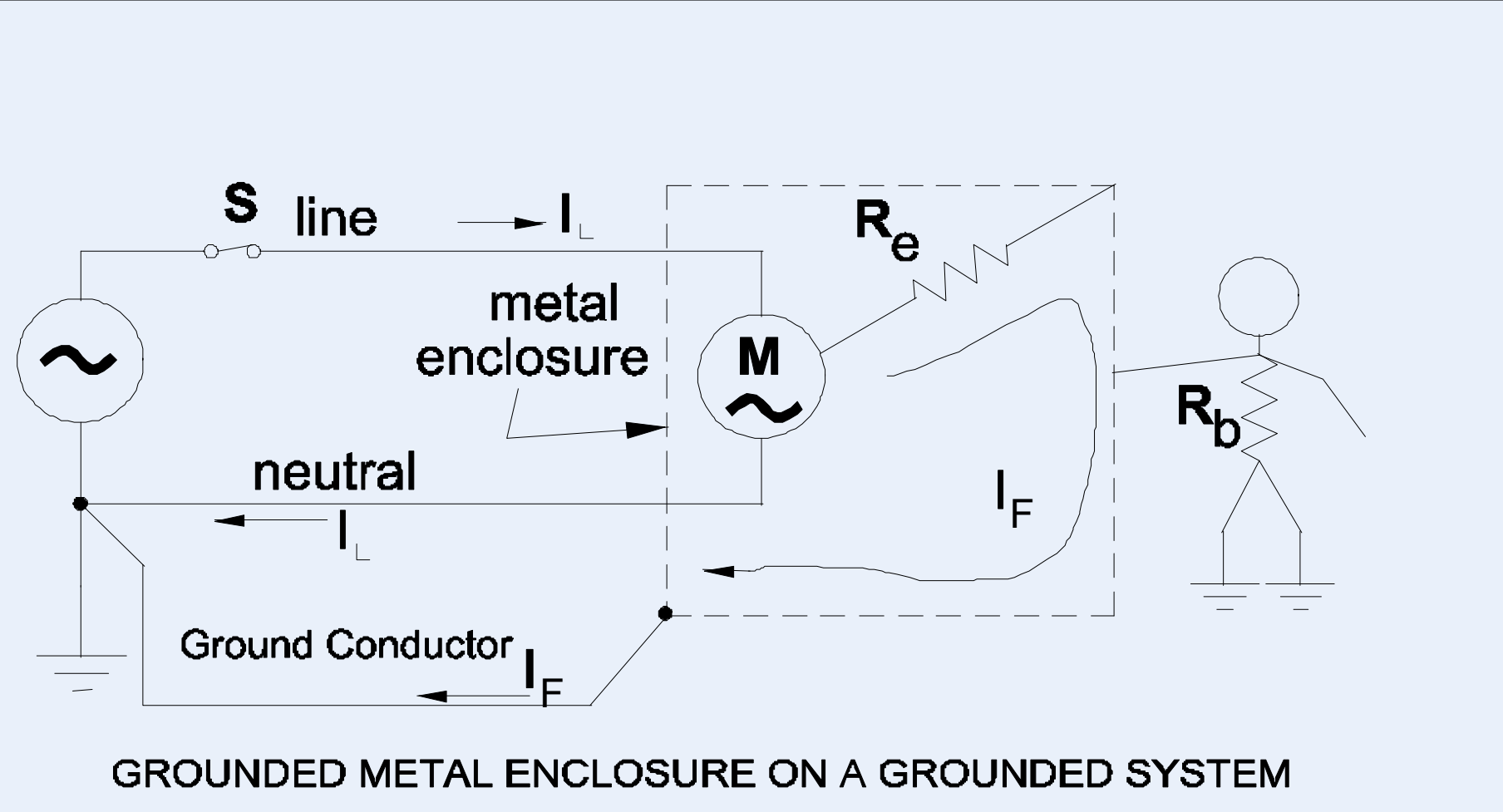


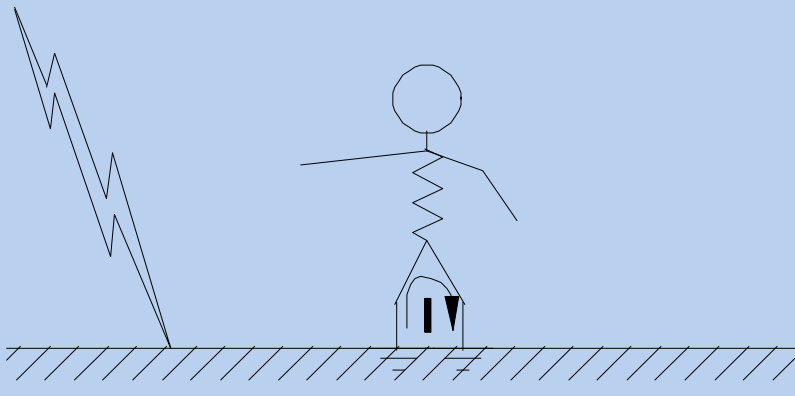




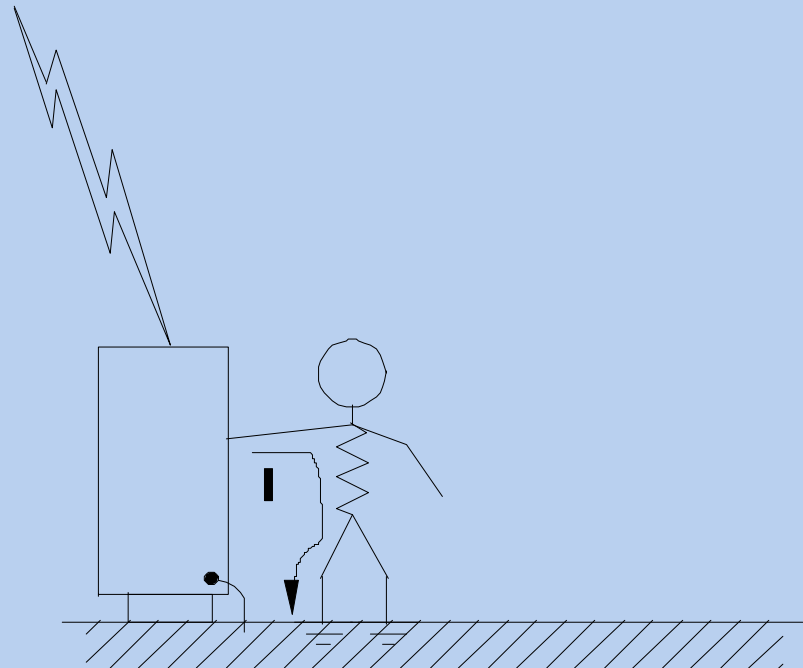
# WHY AN EQUIPMENT GROUNDING CONDUCTOR?







**STEP POTENTIAL**



**TOUCH POTENTIAL**

# Additional Grounding Rules

- Prevention of Disconnection
- Equipotential Bonding Paths

- ANTENNAS AND “RF” GROUNDS

- STRICTLY FOR RF PERFORMANCE, THE “GROUND PLANE” OR COUNTERPOISE CAN BE SMALLER GAUGE WIRE THAN FOR PROTECTIVE GROUNDS
- HOWEVER.....
  - SINCE ALL “GROUNDS SHOULD BE TIED TOGETHER, AND SINCE THE ANTENNA GROUND WILL SHARE SOME PORTION OF A LARGE FAULT CURRENT, DO NOT UNDERSIZE THE CONDUCTORS USED.

- ADDITIONALLY.....
  - WHILE CROSS CONNECTIONS OF RADIAL GROUND WIRES (FROM THE BASE OF A TOWER, FOR EXAMPLE) DO LITTLE TO HELP RF PERFORMANCE...THEY STILL ACT TO EQUALIZE STEP POTENTIALS DURING THE EVENT OF A LIGHTING STRIKE OR POWER FAULT



- WHAT DOES THE CODE HAVE TO SAY ABOUT AMATEUR INSTALLATIONS – TRANSMITTING AND RECEIVING?

- ARTICLE 810 OF THE NEC (NFPA-70)
  - COVERS TRANSMITTING AND RECEIVING EQUIP.
    - INCLUDING ANTENNAS AND SUPPORT STRUCTURES
  - REQUIRES GROUNDING OF TOWERS AND MASTS
    - UNLESS IN “ZONE OF PROTECTION” USING “ROLLING BALL METHOD”
    - REQUIRES BONDING TO SERVICE GROUND
      - INTERSYSTEM BONDING DEVICE OR GROUND ELECTRODE CONDUCTOR
  - REQUIRES MINIMUM CLEARANCES BETWEEN ANTENNA/FEEDLINE CONDUCTORS AND POWER CONDUCTORS AND STRUCTURES.
    - MIN. 2 FEET IF OVER POWER CONDUCTORS (<250 V)
      - PROHIBITED IF OVER 250 V
    - PASSING UNDER IS PROHIBITED, IF PRACTICABLE

- CLEARANCE TO BUILDING MIN. 3 INCHES OR INSULATOR WITH 3 INCH CREEPAGE DISTANCE
  - EXCEPT WHEN IN CONTINUOUS METALLIC SHIELD
- ENTRANCE TO BUILDING THROUGH INSULATING BUSHING OR HOLE WITH 2 INCH CLEARANCE
  - EXCEPT WHEN IN CONTINUOUS METALLIC SHIELD

- SPLICING AND TERMINATIONS
  - MECHANICALLY SECURE
  - APPROVED MEANS
- CONDUCTOR ROUTING
  - GROUNDING/BONDING CONDUCTORS TO BE DIRECT AS POSSIBLE...NO SHARP BENDS
- CONDUCTORS AND ANTENNA MASTS NOT PERMITTED TO BE SECURED TO SERVICE MAST
- MECHANICAL PROTECTION
- IF IN FERROUS RACEWAY..BONDING AT EACH END

- CONDUCTOR MATERIAL
  - BONDING/GROUNDING CONDUCTORS
    - MIN.10 AWG Cu/8 AWG Al...EXCEPT
      - ELECTRODE BONDING MIN. 6 AWG Cu
- ANTENNAS
  - HARD DRAWN Cu, Cu CLAD STEEL
    - MEDIUM DRAWN Cu IF <35 FEET
  - Cu MIN. 14 AWG (<150 FT.)10 AWG (>150 FT)
  - Cu CLAD STEEL
    - 14 AWG (<150 FT) 12 AWG (>150 FT)

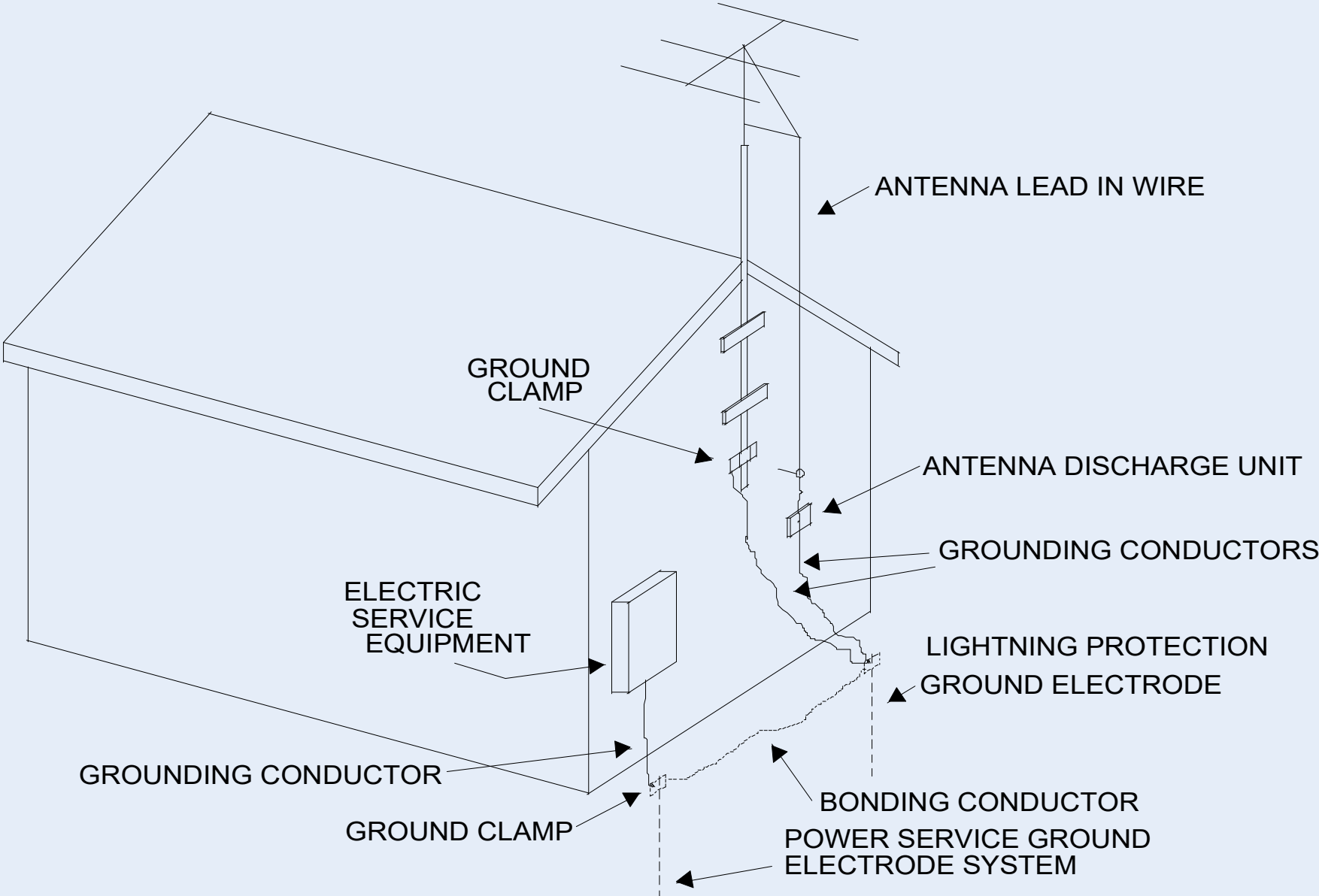
- SURGE PROTECTION – LEAD IN CONDUCTORS
  - IF NOT PROPERLY GROUNDED SHIELDED CABLE
    - LISTED
    - BONDED TO INTERSYSTEM BONDING DEVICE OR
      - SERVICE GROUND
      - GROUND ELECTRODE CONDUCTOR
      - GROUNDED INTERIOR WATER PIPE (W/I 5 FEET OF ENTRY)
- ANTENNA DISCHARGE UNITS
  - GENERALLY ONLY FOR OPEN WIRE FEEDERS
    - SHIELDED COAX, IF SHIELD IS PROPERLY GROUNDED DOES NOT REQUIRE
      - GROUNDING OF UNUSED CABLES RECOMMENDED

- TRANSMITTER REQUIREMENTS (>350 VOLTS)
  - METAL ENCLOSURE-BONDED TO GROUND'
  - EXTERNAL METAL CONTROLS CONNECTED TO EQUIPMENT GROUNDING CONDUCTOR
  - ACCESS DOOR INTERLOCKS WHERE >350 VOLTS ACCESSIBLE INSIDE

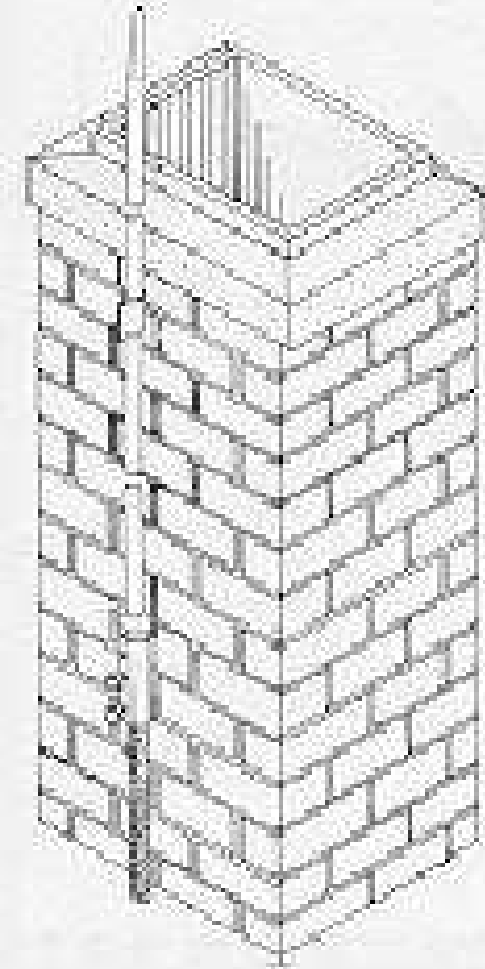
- CODE EXCERPTS....ARTICLE 810
- <http://www.nfpa.org/codes-and-standards/free-access>
- [www.mikeholt.com](http://www.mikeholt.com)
  - Select “Code Forums”



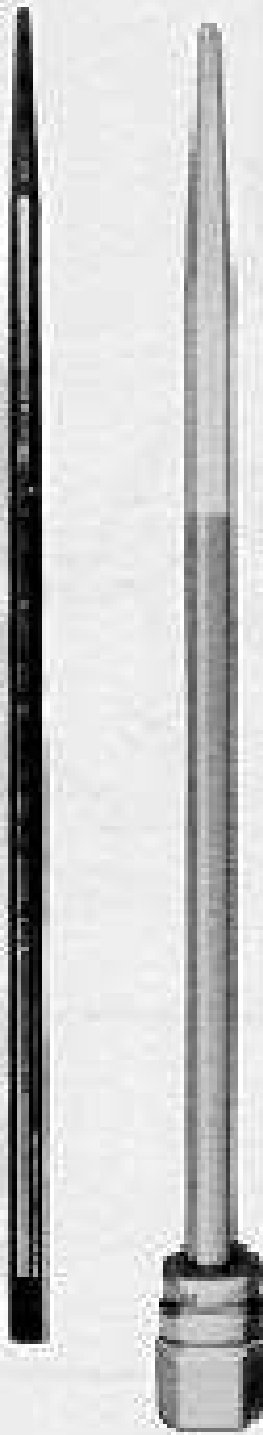
# TYPICAL ANTENNA GROUNDING SYSTEM



# LIGHTNING PROTECTION



**CHIMNEY AIR TERMINALS**



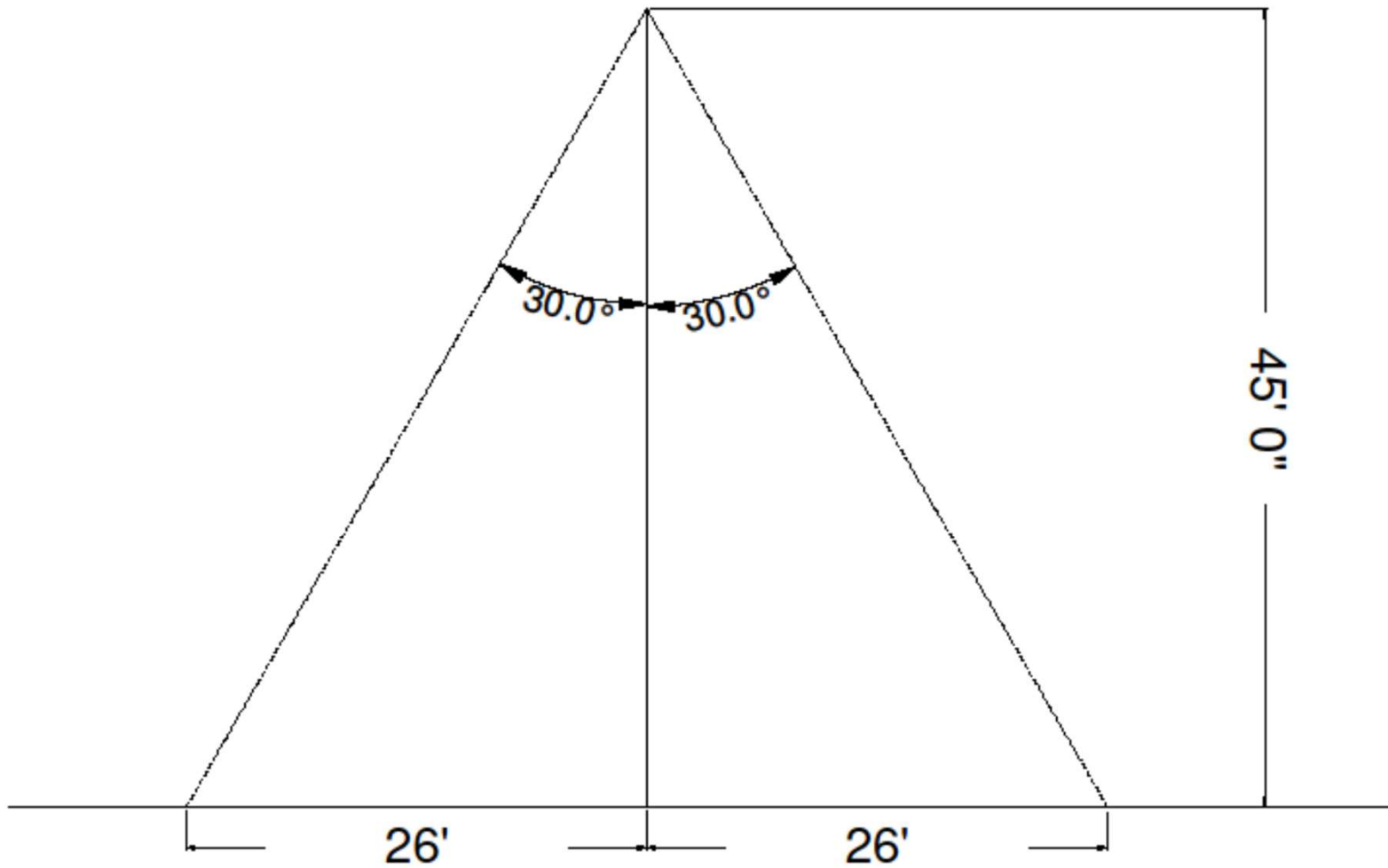
**COPPER AIR TERMINALS**

- AMATEUR RADIO STATION AIR  
TERMINAL



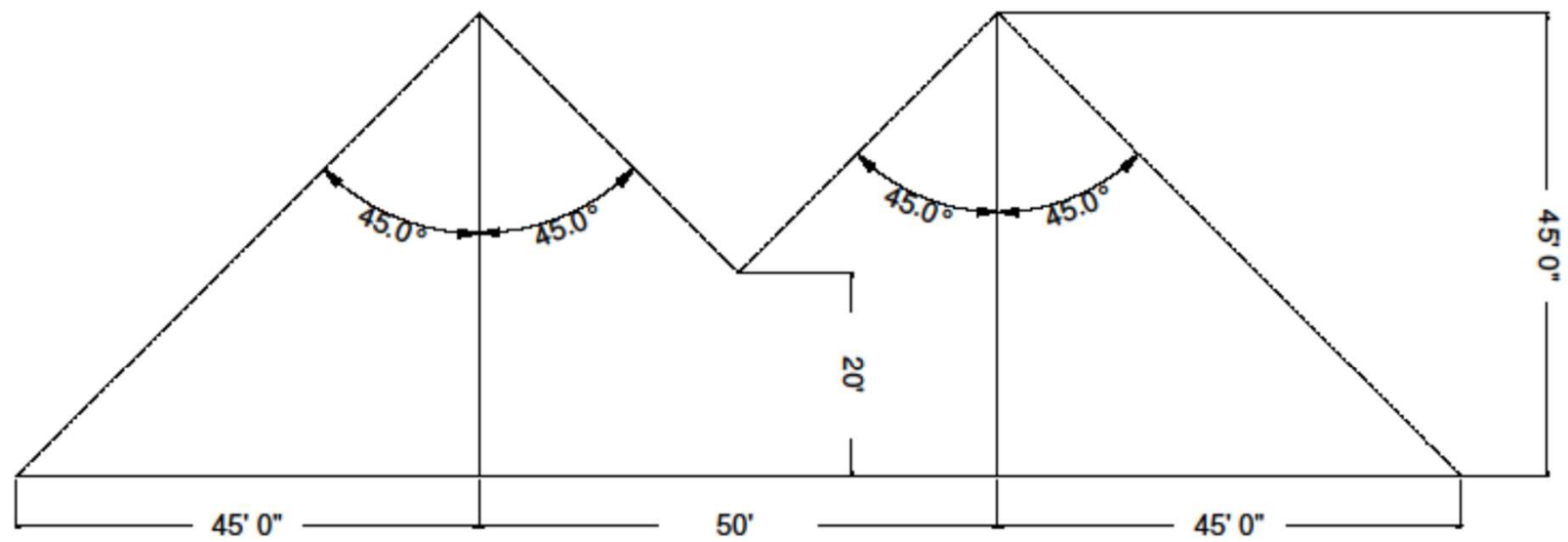
# HOW TO DETERMINE PROTECTION ZONE

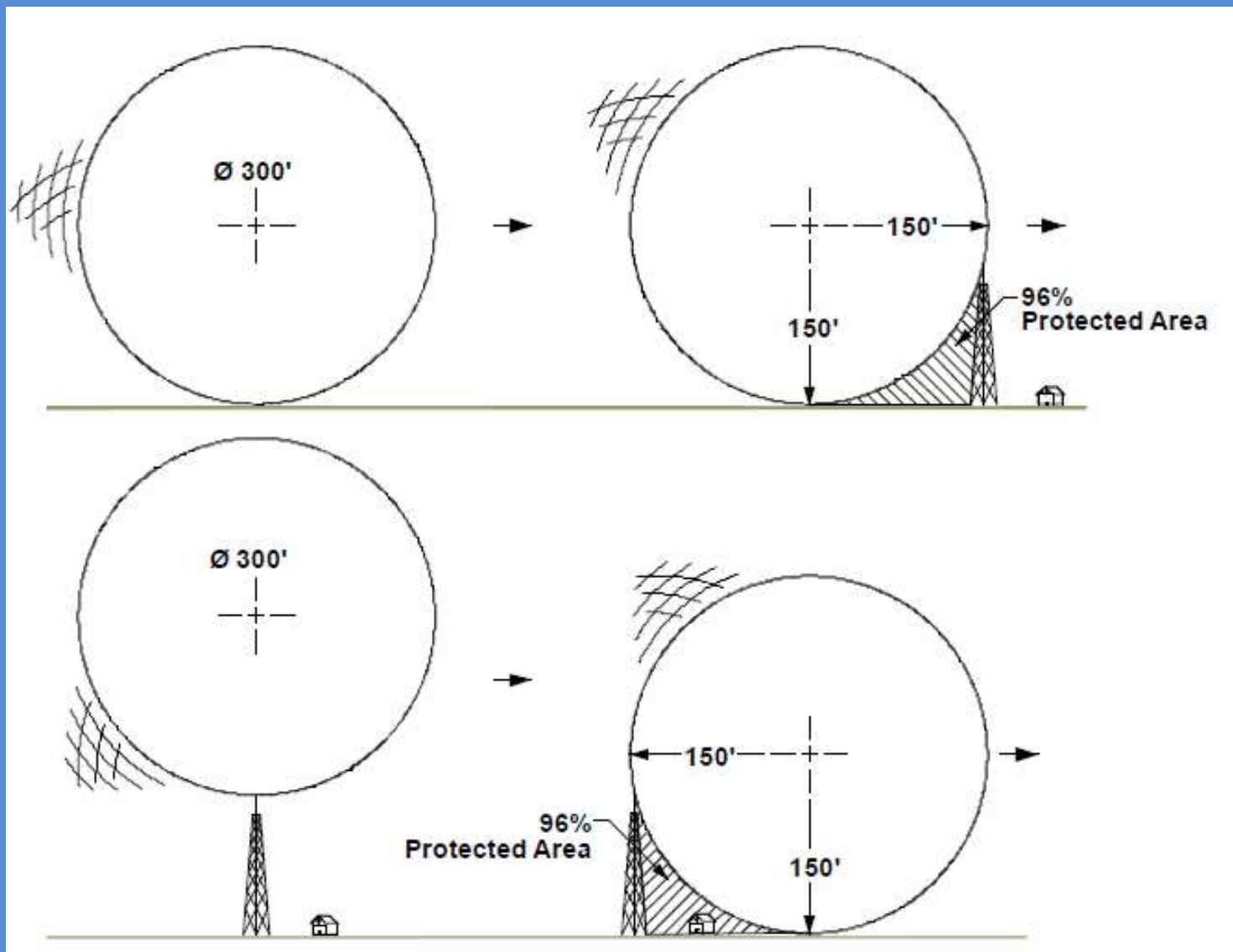
# "CONE OF PROTECTION" ONE MAST/TOWER





**"CONE OF PROTECTION"  
TWO MASTS/TOWERS**





## S

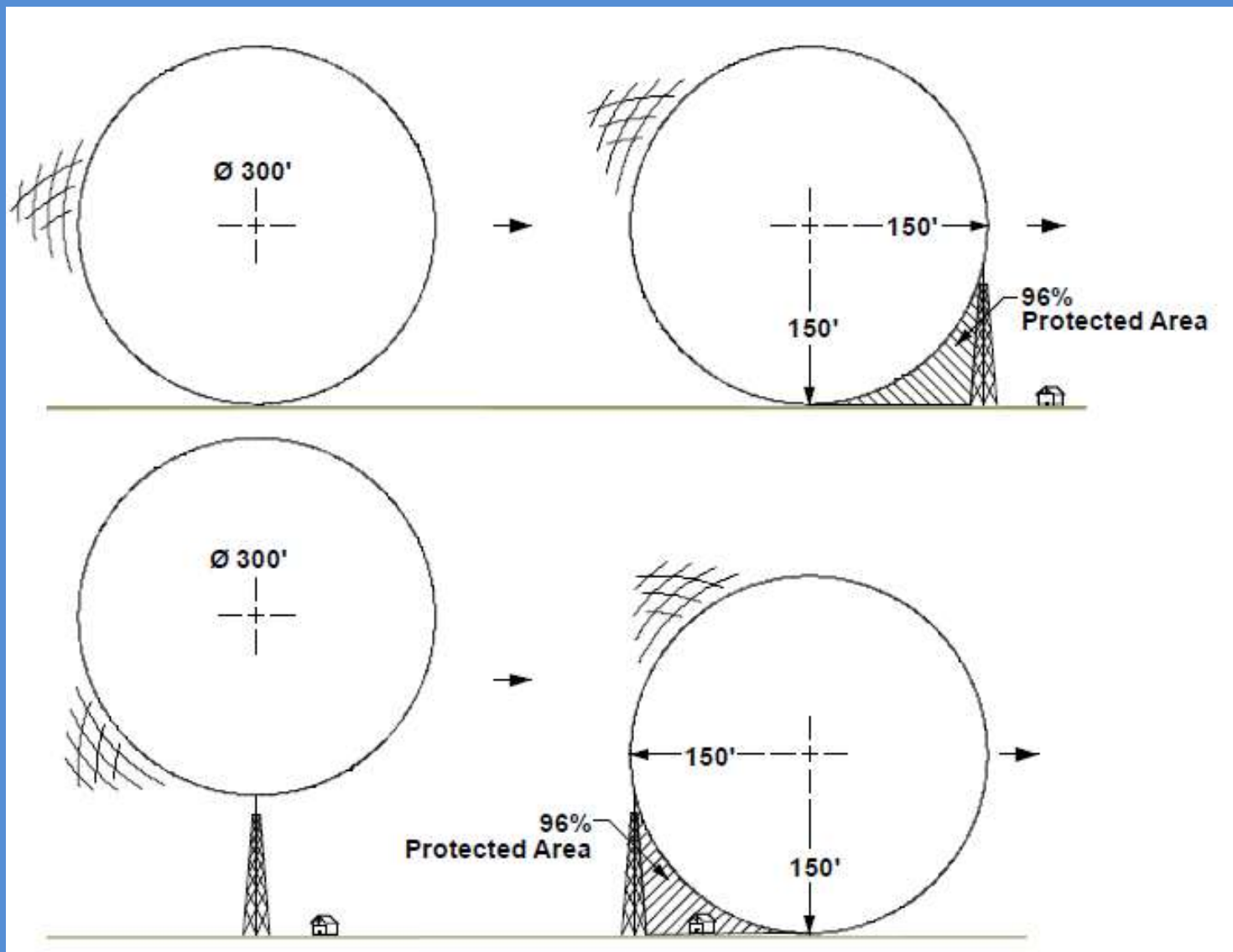
Strike distance refers to the length of the last stepped leader (in feet), and therefore defines the radius of the “rolling sphere” which rolls over the ground and shielding electrodes. Any equipment that exists in the path of this rolling sphere is considered unprotected. It is calculated according to Eq 5-1B of IEEE 998-1996:

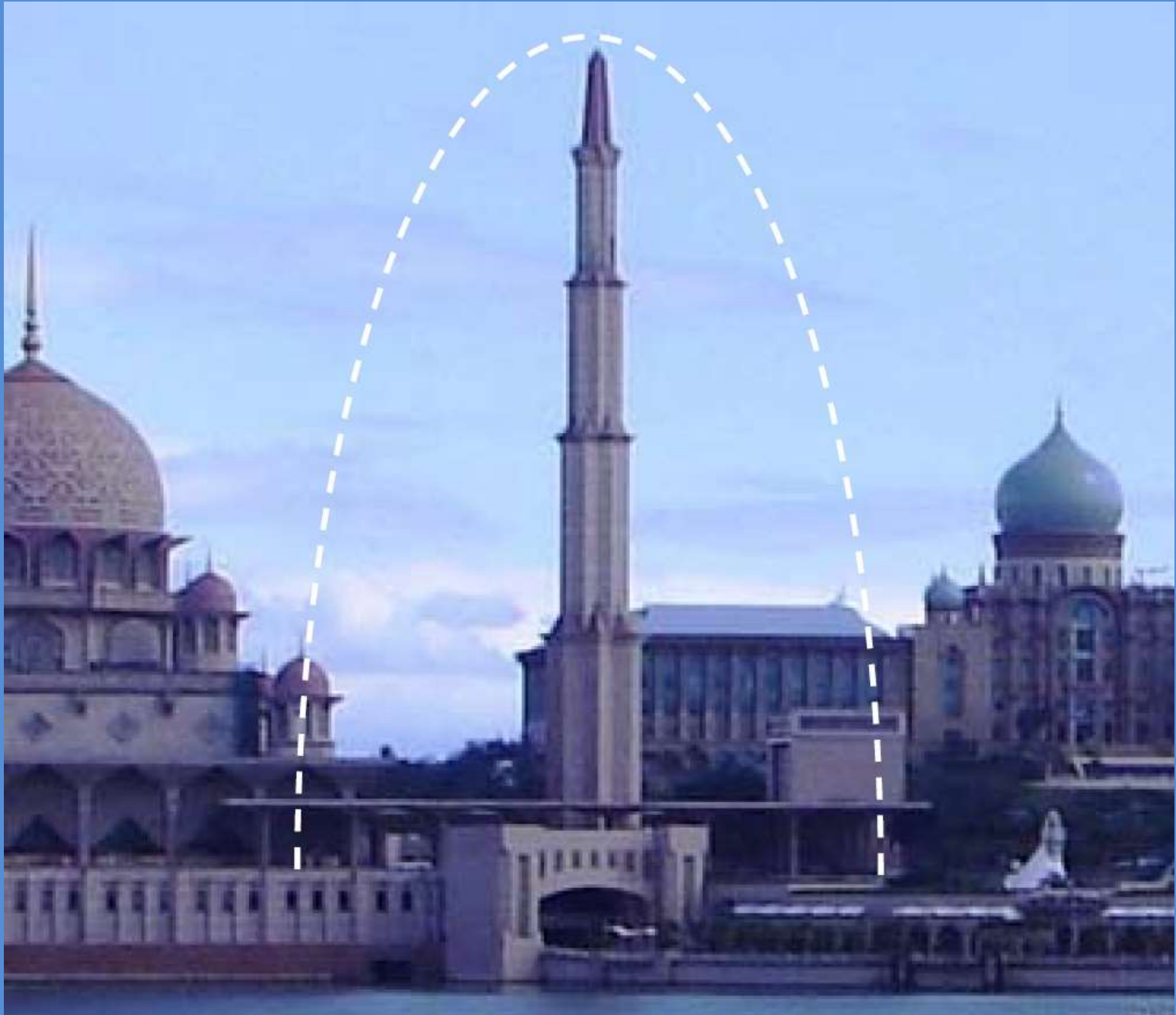
Strike distance:

$$S = 26.25kI_s^{0.65}$$

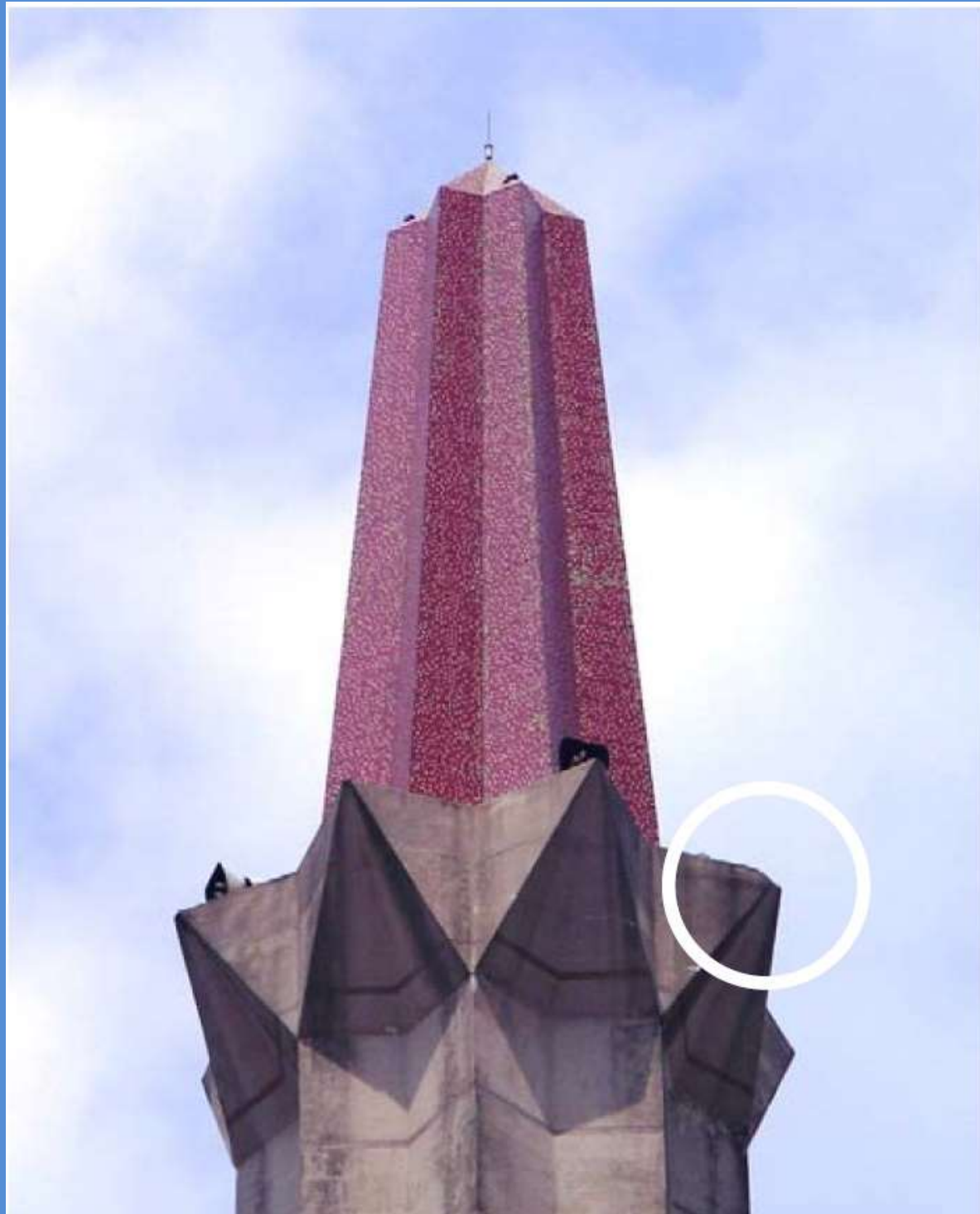
where

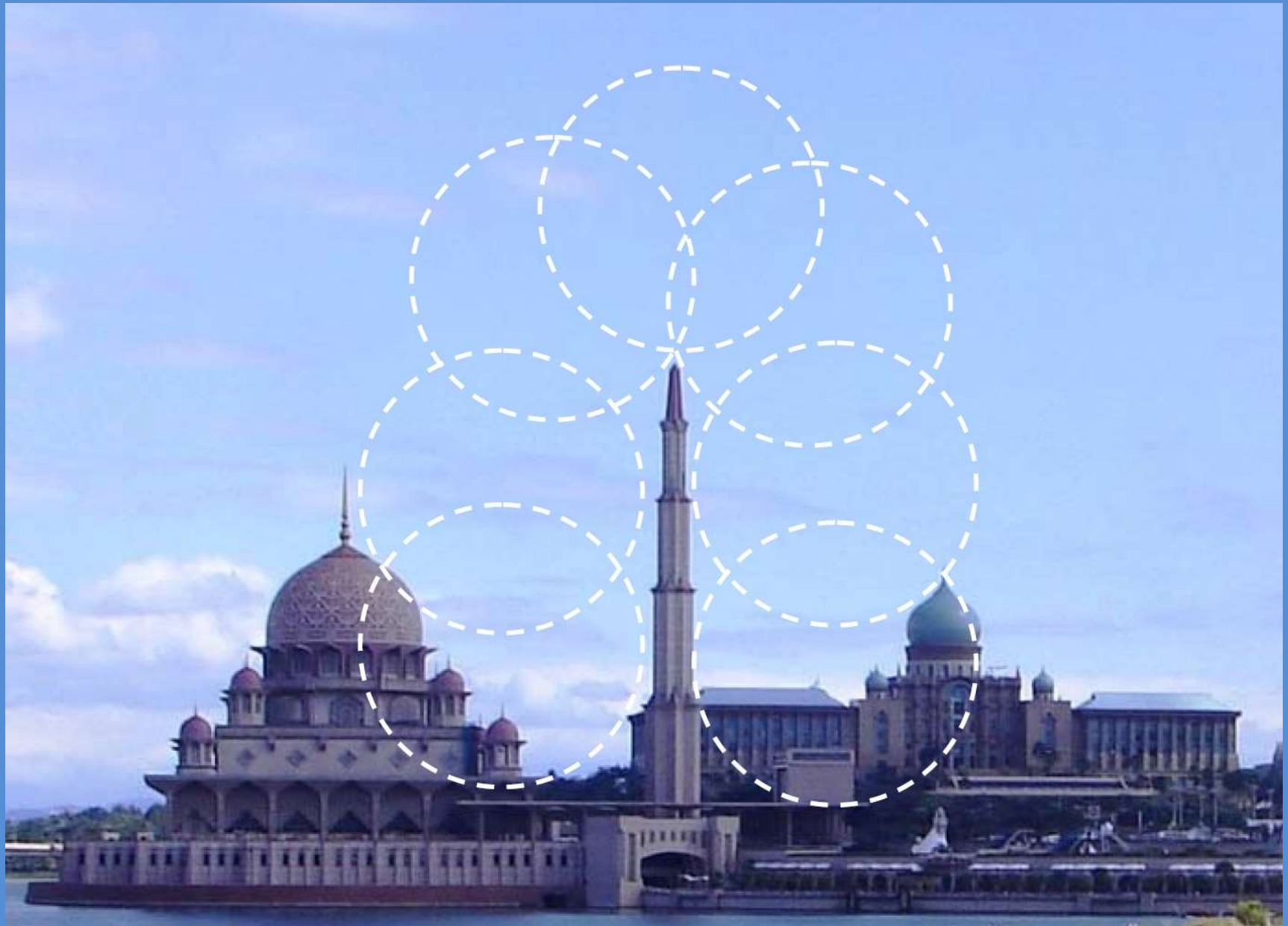
- $k$  is a coefficient to account for different striking distances for masts and wires. It is 1.2 for strikes to masts and 1 for strikes to wires
- $I_s$  is the stroke current in kA













# Summary

- Ground rods should be spaced 1 to 2 times their depth.
- Use coupled longer ground rods rather than more rods.
- Ground resistance s/b as low as possible and not more than 25 ohms.
- Ground antenna at the roof, low point of vertical cable drop, before entry into the building.
- Any metal object within six feet of ground system s/b grounded to the ground system.
- Stay clear of gas piping.
- No sharp bends in ground conductors, focus ground path down toward earth.
- Ground/Bond everything together. Wire so that no other grounds have to be removed to remove one piece of equipment.
- Be careful with equipment with polarized plugs.
- Check system integrity often.

# REFERENCE SOURCES

MIL-HDBK-419A  
29 DECEMBER 1987

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SUPERSEDING  
MIL-HDBK419  
21 JANUARY 1982

# MILITARY HANDBOOK

## GROUNDING, BONDING, AND SHIELDING FOR ELECTRONIC EQUIPMENTS AND FACILITIES

VOLUME 1 OF 2 VOLUMES  
BASIC THEORY



AMSC N/A

EMCS/SLHC/TCTS

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# STANDARDS AND GUIDELINES FOR COMMUNICATION SITES



# QUESTIONS?

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