Ham Station Grounding for Lightning Protection

Mike Hoskins, W0MJH

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with thanks to Stu Turner for helpful suggestions, example system content and review

Ham Station Grounding for Lightning Protection
Presentation Overview

- Introduction
- Lightning
- Grounding Configurations
- Grounding Materials, Components, Assembly Techniques
- Summary

Presenter Background

- **Relatively new to ham radio: amateur extra license received April 2014**
- **37 yrs experience working as an electrical engineer in RF and uwave integrated circuit development and design**
- **Currently with Analog Devices Inc. developing ultra-wideband (<40 GHz) microwave samplers for high speed A/D converters**

Motivation For This Presentation

- Performed substantial research in lightning protection/grounding in the course of setting up a home HF/VHF/UHF station
- During this work I found that:
  - Grounding/lightning protection is a relatively complex subject
  - There is a significant level of mis-information and/or multiplicity of opinion
  - The average ham cannot usually implement the ideal ground system
  - Practical systems will be something of a compromise based on home layout and available resources (cost, time, etc)
  - There are some key things that can be done to help optimize a practical system

Motivation For This Presentation (Continued)

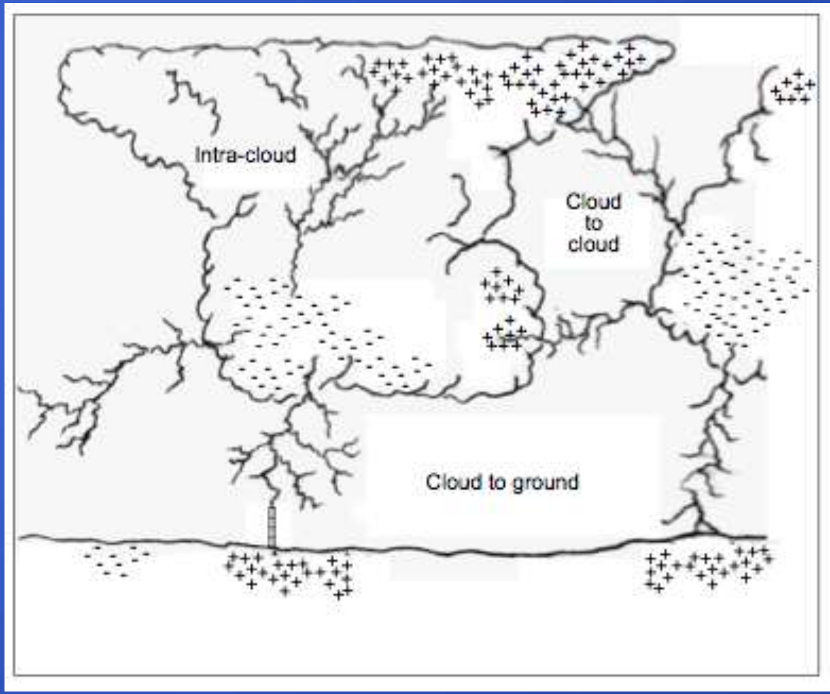
- This presentation strives to:
  - Provide lightning background and appreciation for the difficulty of the lightning problem
  - Summarize the key features and principles of an effective lightning protection ground system
  - Help others achieve an effective system for their particular layout and resources

Ham Station Grounding for Lightning Protection

Lightning

Source of Lightning

- Originates from charged Cumulonimbus Clouds
- Typically involves electron movement from cloud to earth (although positive lightning can occur occasionally)
- Cloud to cloud lighting is most frequent event
- Intense electric field creates ionization channels (plasma) in random sequential steps
- Large current discharges occurs in several repetitive strokes



Ref. 1

Lightning Statistics

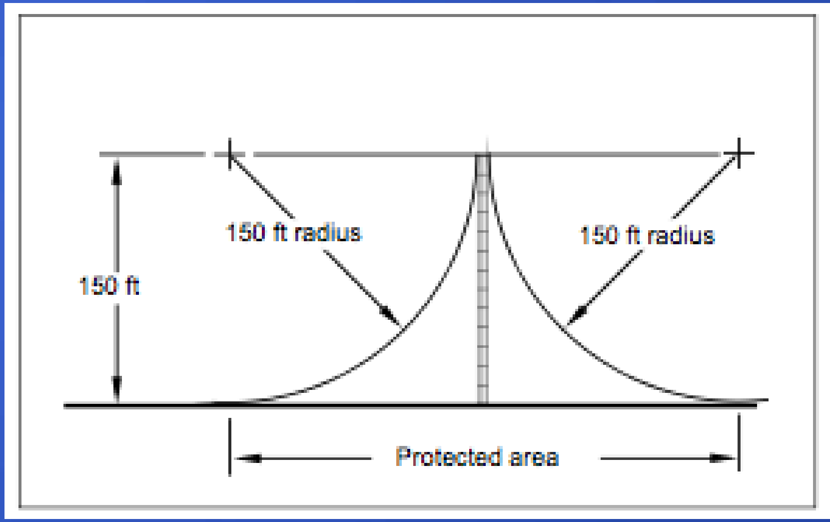
Average US yearly lightning strikes	22,000,000
Number of yearly US insurance claims filled for lightning damage	307,000
Estimated yearly US lightning damage cost	$330,000,000
Continuous worldwide lightning strikes	44 strikes per second
Lightning ionization channel temperature	15,000 to 30,000 °C (About 3 times the surface temperature of the sun)
Average peak current	25,000 Amps
Average strokes per flash	4
Average channel blast wave energy	Equivalent to 200 pounds of TNT

* Based on data from: NOAA and Lightning and Lightning Protection, Hart and Malone

Ref. 1

Lightning Attraction

- Last lightning step leader can be "attracted" by features more than 150 ft above average terrain level
- A lighting rod/tower/mast >150 ft creates a "zone of protection" where probability of strike is on the structure itself
- Warning: Do not stand in the "zone of protection" or depend on it for safety



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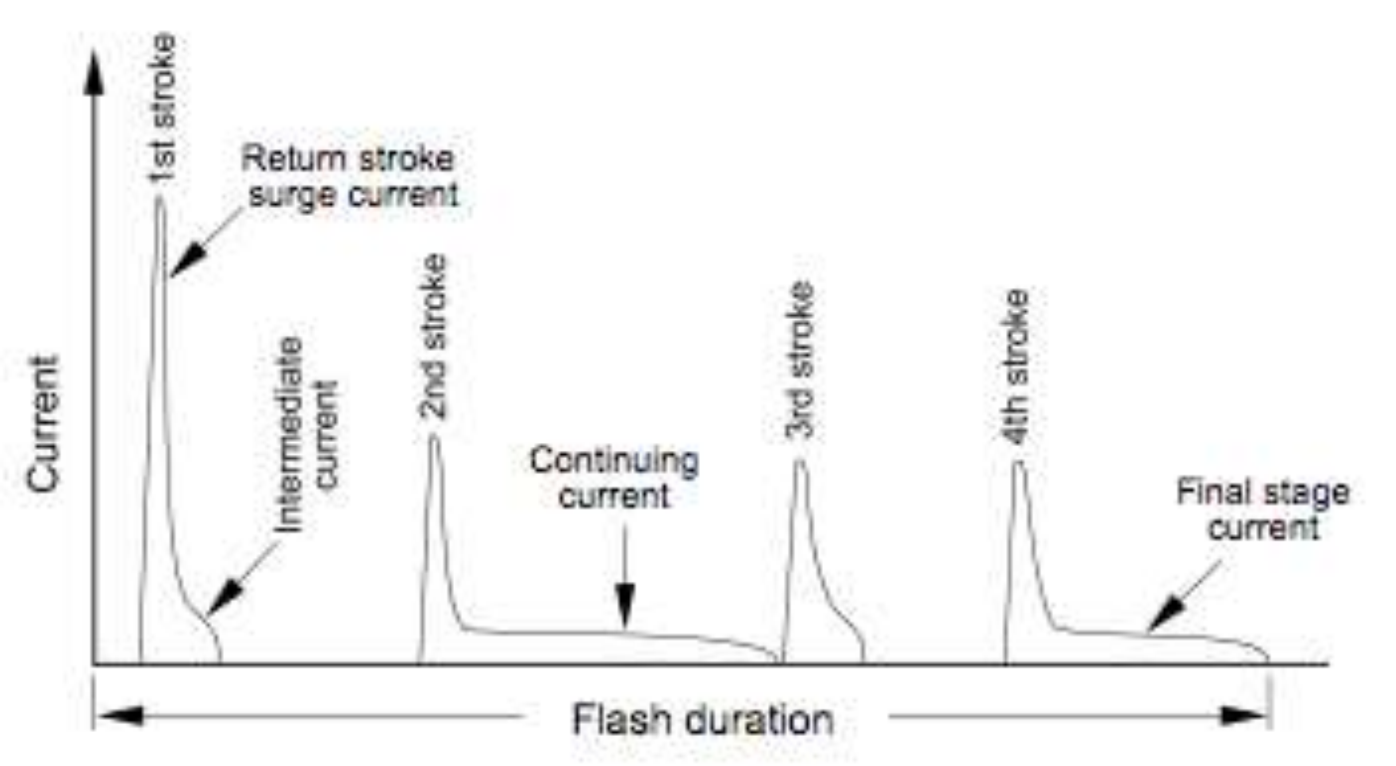
Typical Lightning Transient Waveform



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Lightning Transient Waveform Characteristics

% Of Strikes with Characteristics Exceeding Those Listed

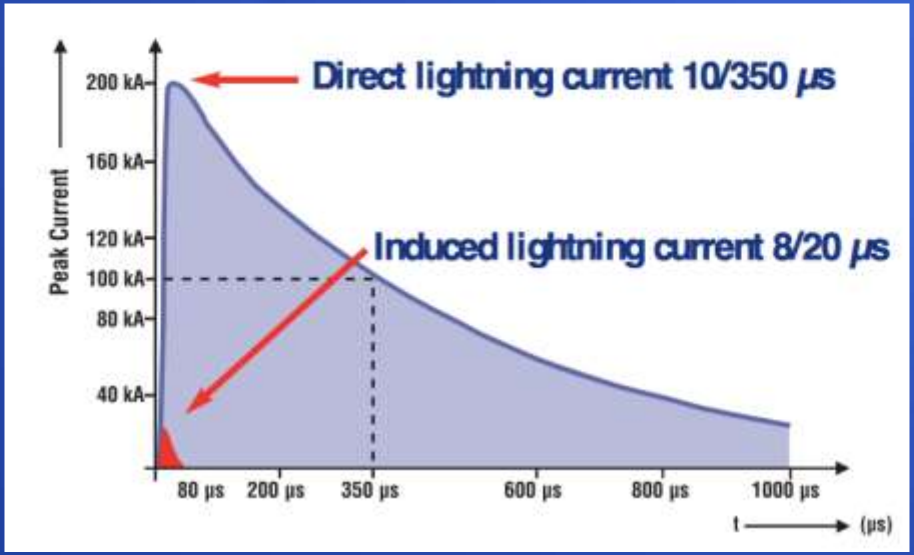
Parameter	90%	50%	10%	Maximum Observed
Crest Current	2 to 8 kA	10 to 25 kA	40 to 60 kA	230 kA
di/dt	2 kA/μs	8 kA/μs	25 kA/μs	50 kA/μs
Single stroke duration	0.1 to 0.6 ms	0.5 to 3.0 ms	20 to 100 ms	400 ms
Interval between strokes	5 to 10 ms	30 to 40 ms	80 to 130 ms	500 ms
Crest rise time	0.3 to 2 μs	1 to 4 μs	5 to 7 μs	10 μs
Number of strokes in the flash	1 to 2	2 to 4	5 to 11	34

* Based on data from: Lightning and Lightning Protection, Hart and Malone - newer data available, but this source is still representative and applicable.

Ref. 1

IEEE 10/350 and 8/20 Lightning Models

- IEEE 8/20 = model for induced lightning transient
- Waveform shows 1st of 3 strokes assumed in model
- 18 kA peak current
- Leading edge current rate of change = dI/dt=2kA/us
- Additional strokes at ~half amplitude



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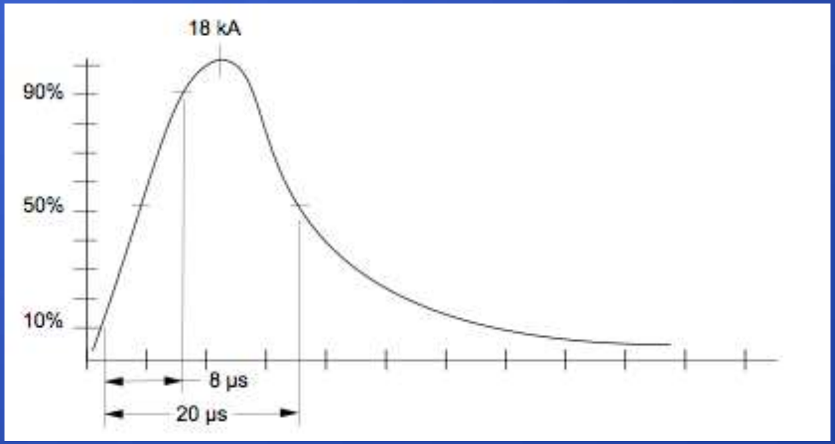
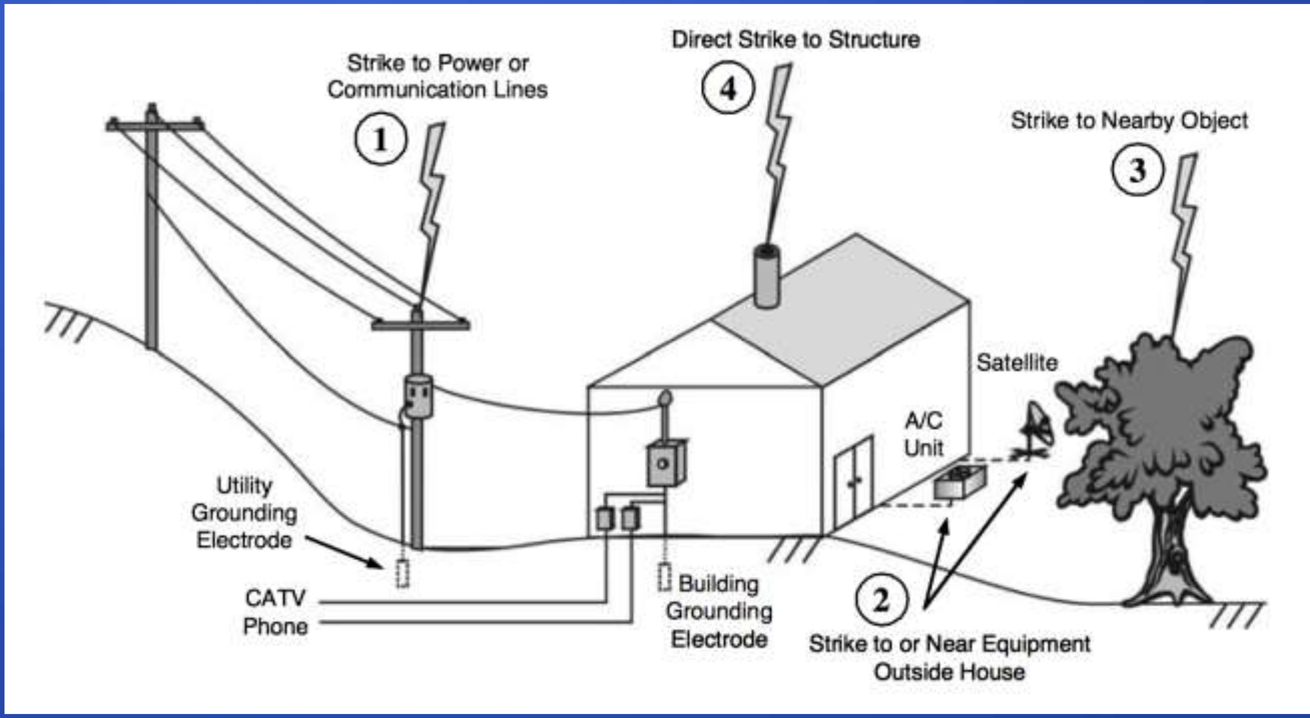
Expanded View of IEEE 8/20 Model



Ref. 1

Mechanisms of Lightning Invasion Numbered by Commonality

- Direct Strikes on Dwelling Rare
- Conduction Through Utilities System Strikes Are Common
- Local Strikes Generate Electromagnetic Fields That Couple to Electrical/Signal Lines
- Main Physical Coupling Mechanisms:
  - Conduction
  - Capacitive Coupling
  - Magnetic Coupling



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The Lightning Problem: Inductive Voltage Drop Example

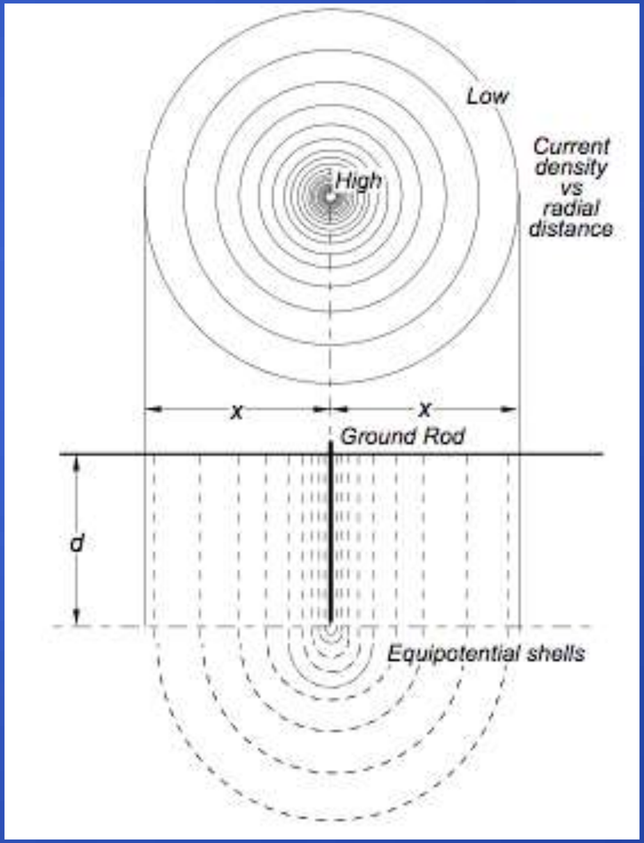
- Use IEEE 8/20 model to calculate induced voltage drop in typical 40 ft long , 4 Ga, Cu grounding wire for antenna mast (assumes perfect ground rod system)
- $V_r = IR$, $V_l = (L\, dI/dt) = L$ (slope of current vs. time curve)
- L=23.3 uH, R=0.0099, I=18kA, dI/dt=2kA/us
- V_r = 178 V @ transient max
- V_l = 46,600 @ transient max
- Interconnect inductance is a key issue due to massive dI/dt

Ground Rod Basics

- During current surge the earth around the ground rod becomes “saturated” lowering it’s resistivity (due to localized underground arcing)
- To first order the current sinking action in the earth becomes negligible at about 1 rod length laterally
- Optimal rod placement/spacing is about equal to 2 rod lengths, thus avoiding overlap of active earth volumes

Top View

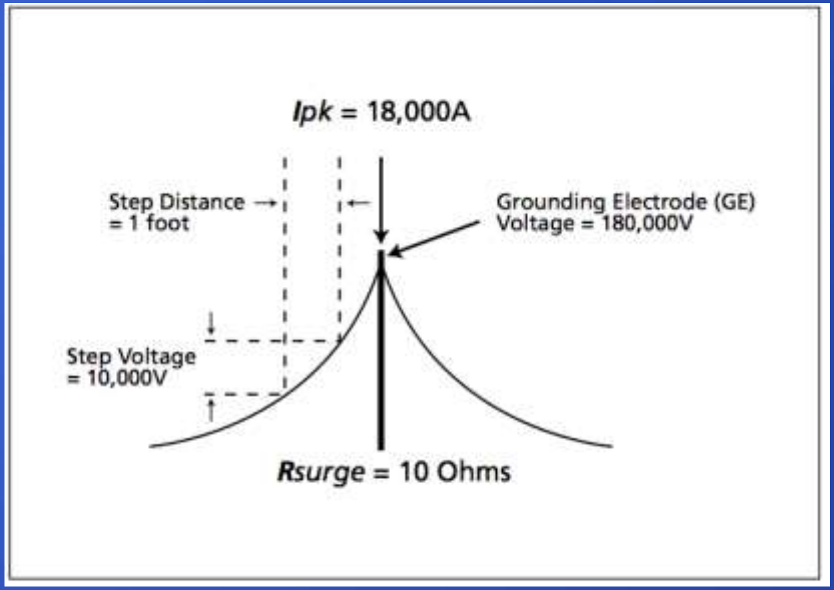
Side View



Ref. 1

The Lightning Problem: Ground Rod Voltage Drop Example

- Use IEEE 8/20 model to calculate voltage drop in typical "good" ground rod during a strike
- V = IR, R=25 ohm nominal, 10 ohm saturated, I=18 kA peak
- V = 180 kV
- Huge voltage gradient in the vicinity of the ground rod



Ref. 1

The Lightning Problem: Mitigation

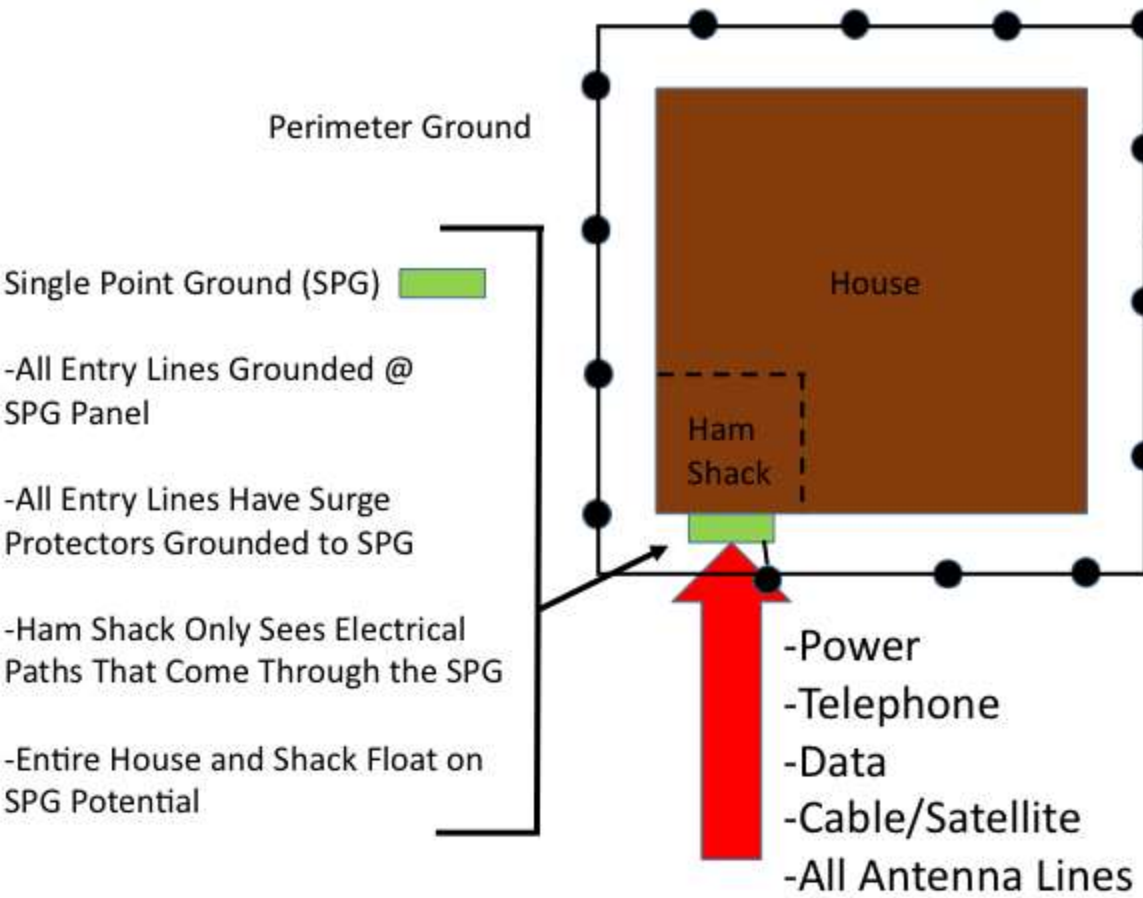
- How can we deal with these huge voltages?
- There is no easy way to achieve large voltage reductions in the ground system (except in very expensive commercial or military installations and even they must use the technique described below for mitigation)
- However, note that birds can sit on high voltage power lines (exceeding 100 kV) and survive
- We must use the same technique: a single point ground system allows all equipment to float up and down at nearly the same voltage so that differences in voltage are minimized
- For this to work, the potential of absolutely ALL wires/interconnects to the ham station must be related to the single point ground (either directly or through surge suppressors)

Grounding Configurations

Ground Terminology/Types of Grounds

- Safety Ground: The green wire in the 3-wire power outlet
  - The NEC requires this to be bonded to any other ground paths involving ground rods/earth grounds
- Lightning Ground: Earth ground connection network for shunting surge currents to earth, preferably with very low RF impedance
- Earth Ground: The imperfect earthen conductor to which lightning surge current eventually flows
- RF Ground: Usually involves connections from radio equipment chassis to earth ground (via single point ground panel) intended to provide low impedance path for RF currents
  - Ties the potential of all equipment chassis to single point ground
  - Reduce potential differences from any RF currents on external surfaces of coax shields (common mode currents)

The Ideal Single Point Ground System



The Ideal Single Point Ground System Attribute Summary

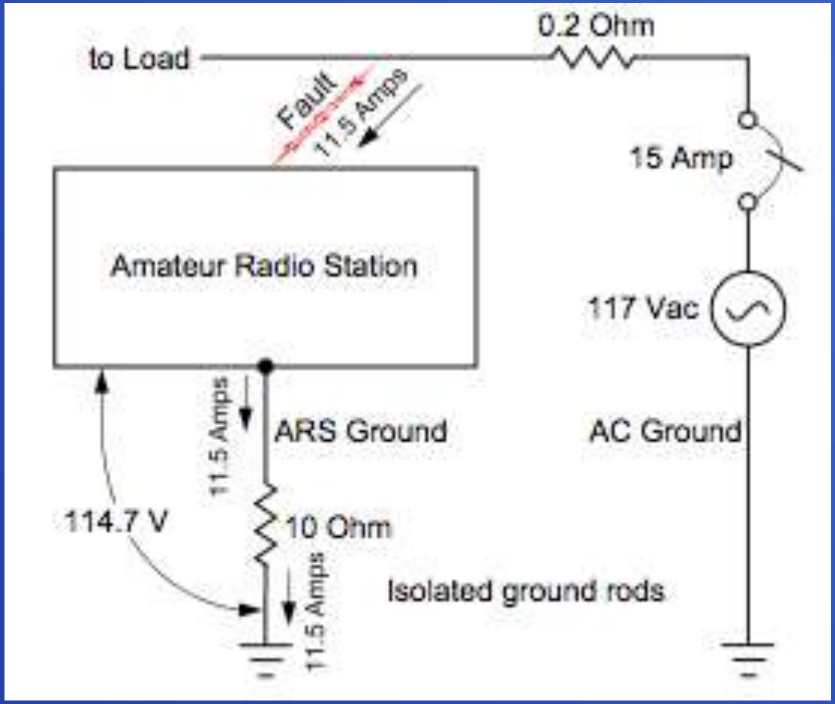
- Power, telephone, cable, data, antennas all enter the house near the same point.
- All utility grounds and antenna coax shields use the same single point ground panel connected with low inductance to a complete perimeter ground rod/strap system
- All utilities and coax are surge suppressed at the single point ground panel
- The house and all it contents will tend to float up and down with the lightning transient
- The surge suppressors will clamp the center conductors and various utility hot/signal leads to a small voltage above the single point ground potential

Practical Single Point Ground Systems

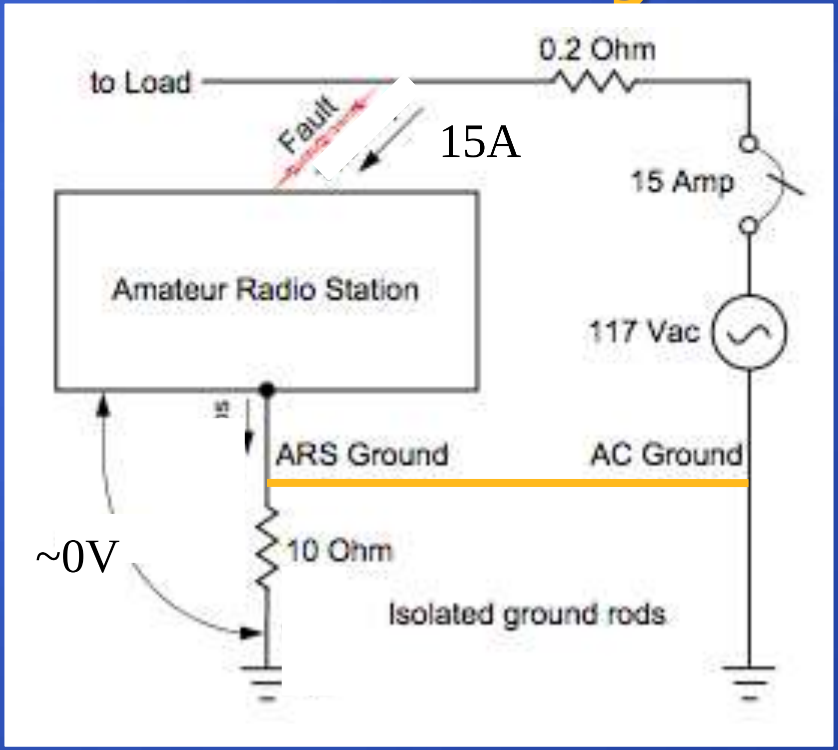
- Ideal configuration can rarely be realized in a residential scenario
  - SPG panel should probably either be near ham shack or utility entrance
  - Utility entrance is typically not a convenient place for our ham shack
  - This means at least one of the 3 will usually be in a separate location
- There are a few practical solutions/configurations that give the next best thing to the ideal configuration

Importance of Bonding - Power Fault Safety (Connecting Power Safety Ground to SPG Panel)

Power to Chassis Fault With No Bonding



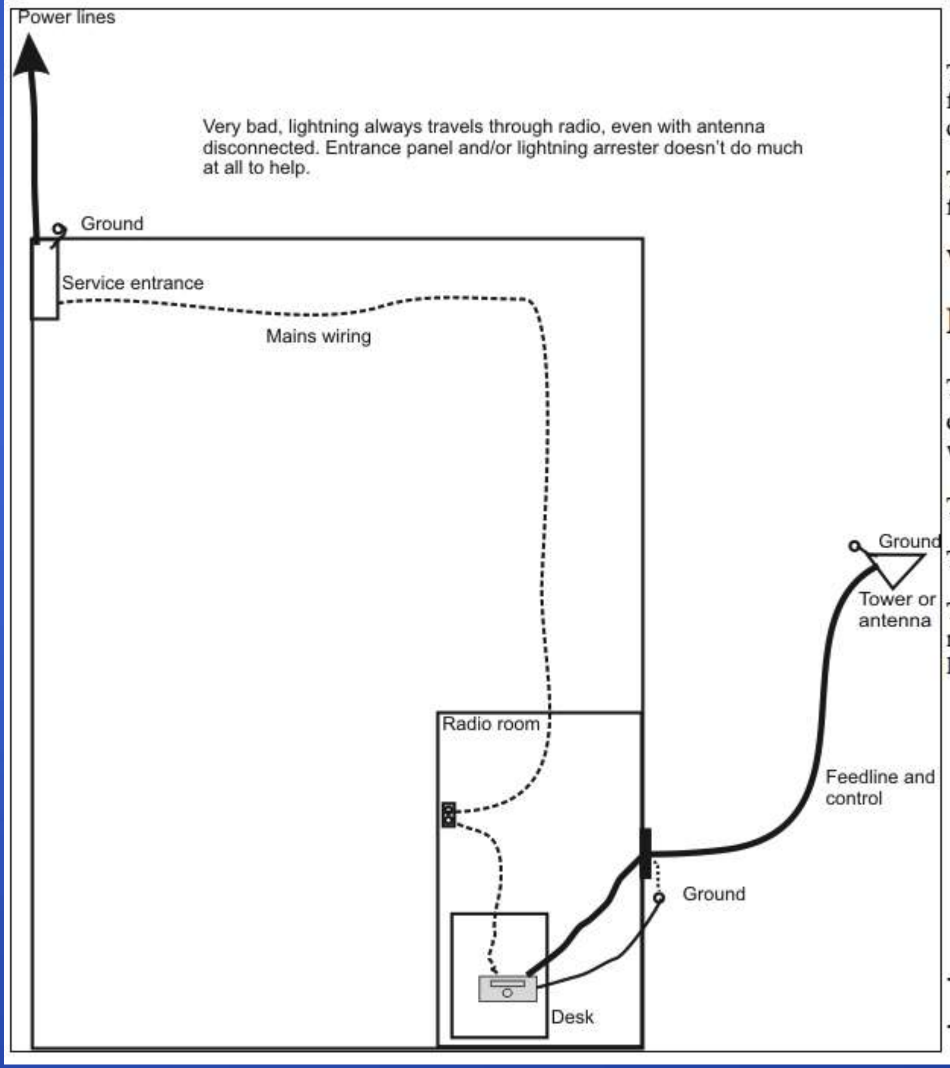
Power to Chassis Fault With Bonding



Ref. 1

Importance of Bonding – Lightning Safety

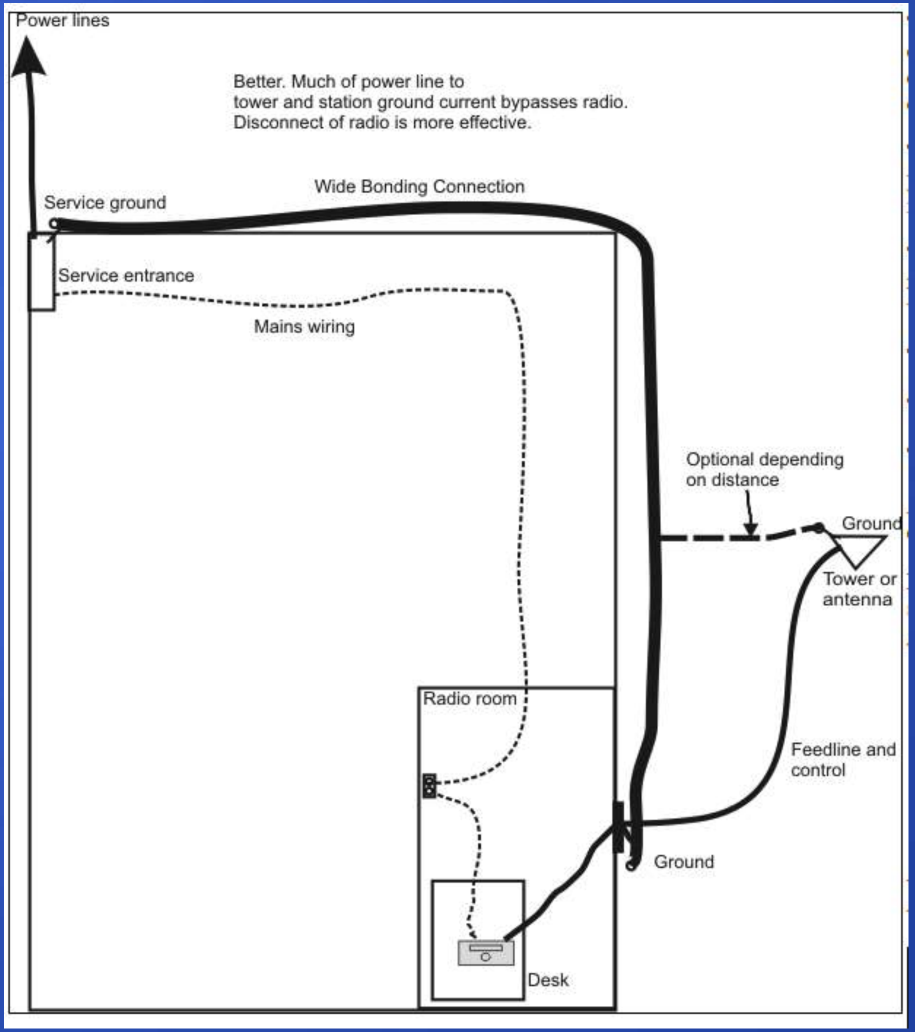
- Most ham station ground rod systems will be lower impedance than the feeble power company ground rod near our power entry panel
- Lightning transient on power line will seek out the best ground path – our SPG panel/strap/rod system
- With no bonding, this path is through our ham equipment – this is very dangerous



Ref. 5

Importance of Bonding – Lightning Safety

- This system is improved because it has bonding
- Much of the lightning transient coupled through the power line is shunted to the outside of the house
- But there are still weaknesses:
  - House wiring forms a parallel path which will still carry some lightning current
  - There is no surge suppression on the power to the ham shack

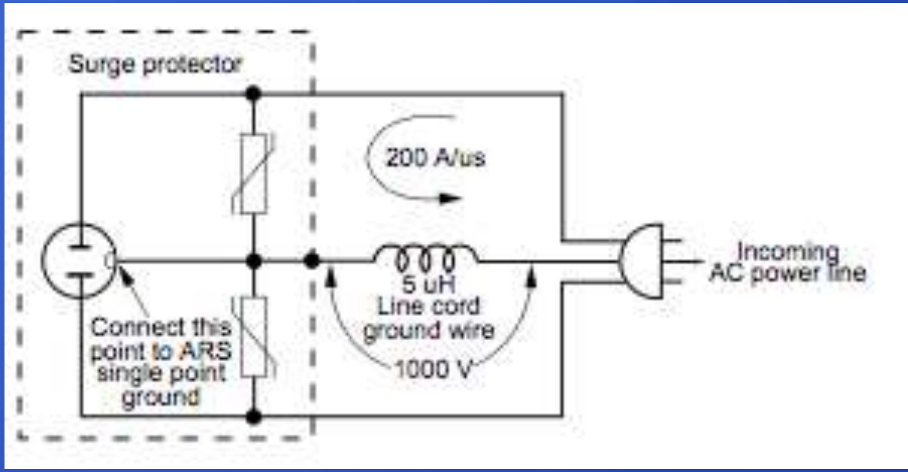


Ref. 5

Power Surge-Suppression Subtlety
Proper Configuration of Surge Suppression Ground is Critical

Scenario: The ham has properly bonded his system and powers his shack off a house wall outlet using a typical UPS or outlet strip surge suppressor

- **If the ground of the surge suppressor is NOT connected to the SPG panel then the house wiring inductance can raise the potential of the shack equipment to very high voltages when the suppressor MOVs trigger during a strike.**
- **ALL surge suppressor output grounds MUST be connected to SPG preferably with very low impedance**

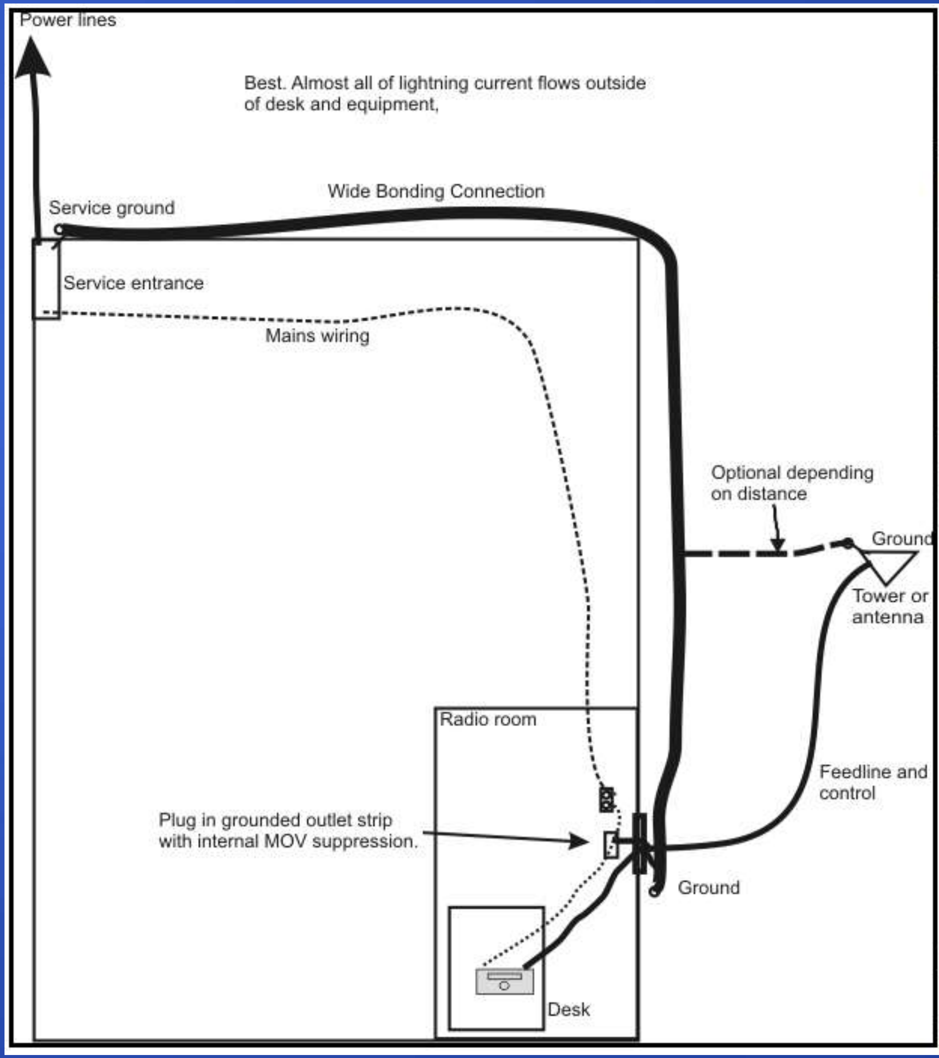


Ref. 1

A Good Configuration Option for Separated Power/SPG Scenarios

- SPG is bonded to power entry
- Shack power is now surge suppressed
- Surge suppressor is grounded to the SPG panel
- All electrical connections to ham shack are referenced to SPG
- Connection from surge suppressor to SPG should be very low impedance
- This is most easily done if the suppressor has a ground plane mount design (e.g. Polyphaser)

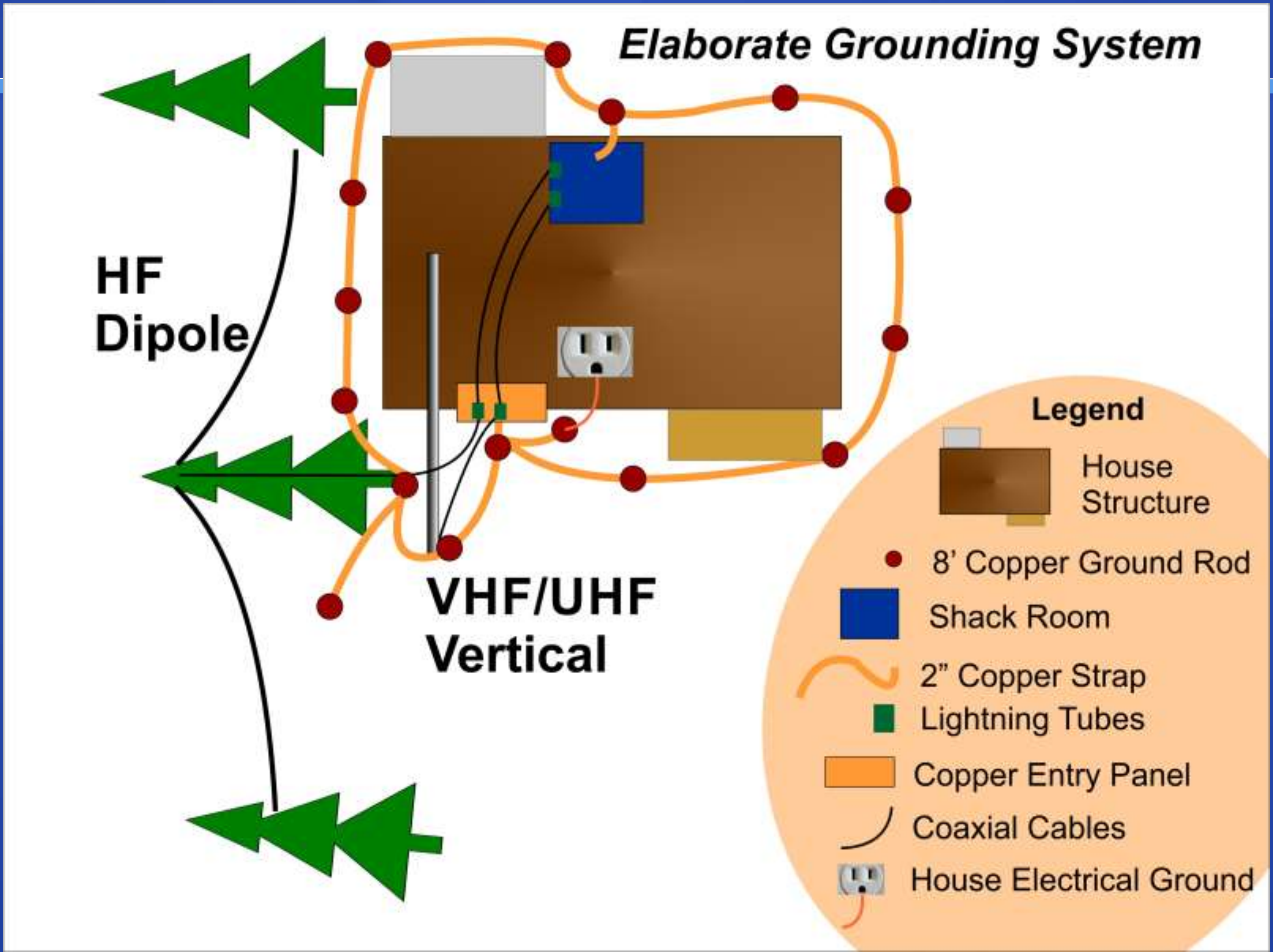
Ref. 5



Options for Addressing Practical Systems Where Power/SPG/Ham Shack are Separated

- Use relatively long bonding connection (preferably at least part of a partial perimeter ground) with SPG referenced power surge suppression in the shack (as in prior example)
- Place SPG/antenna entry at power utility entry point and use a perimeter ground system (or a portion of one) to ground the ham shack (This is Stu's system)
- "Bring the power panel to the SPG" via the installation of an electrical subpanel at the SPG location (this is a Polyphaser recommendation for separated power entry and SPG)
  - A variant of this approach is to implement an external feeder line dedicated to the ham shack (can minimize ground loops if it's buried with the ground rod/strap system in the same trench)

Examples: Stu Turner's System



Examples: Stu Turner's System
SPG Near Power Entry

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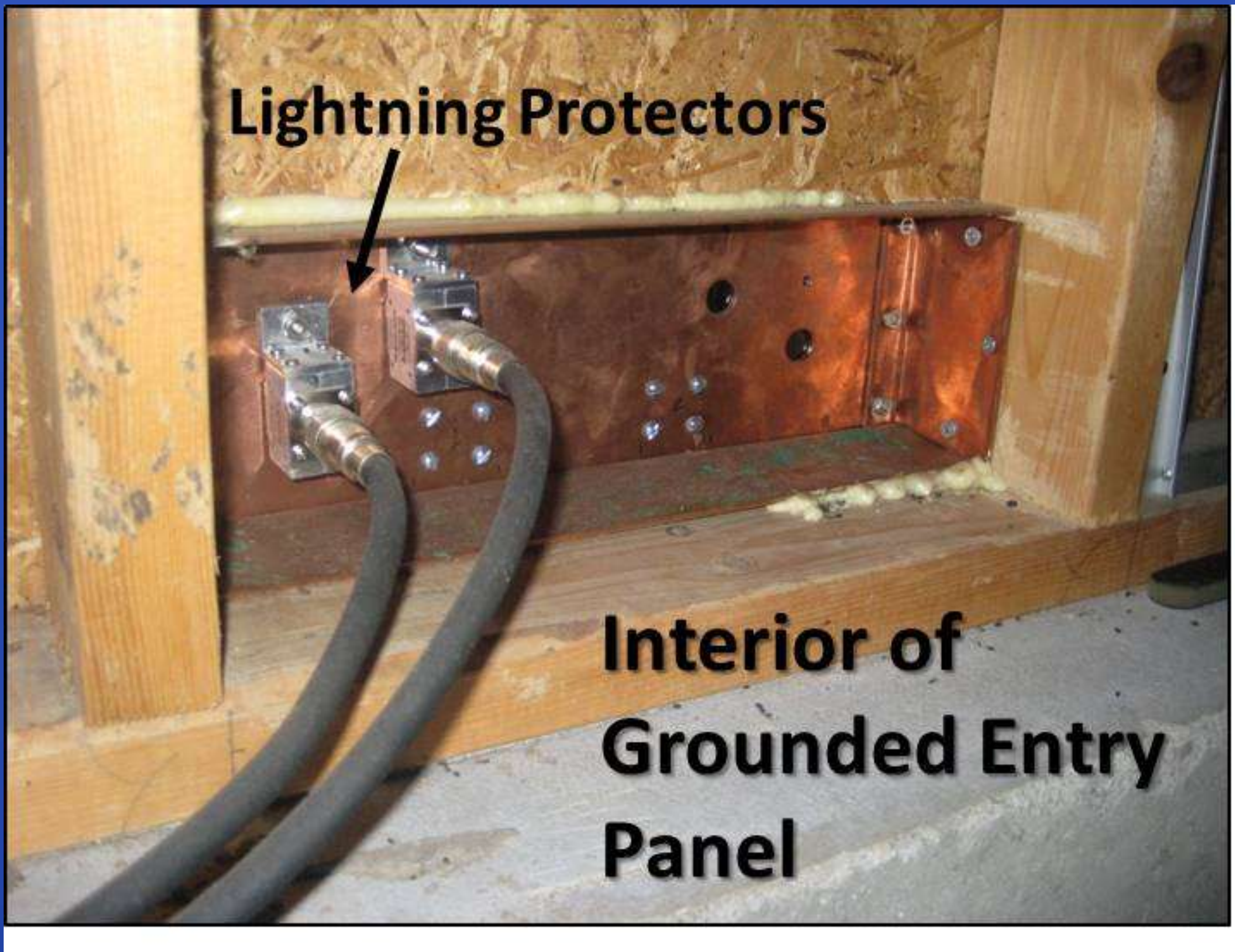
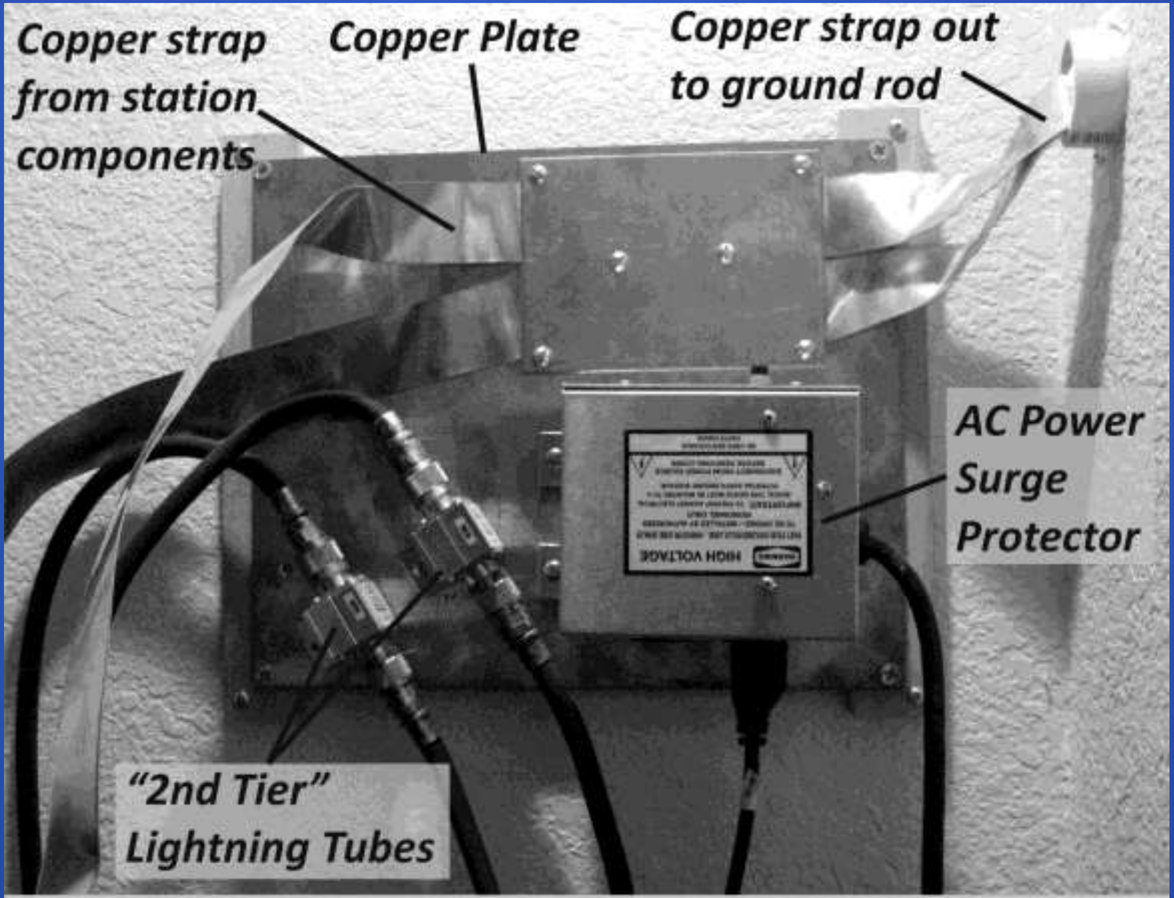
SPG Near Power Entry

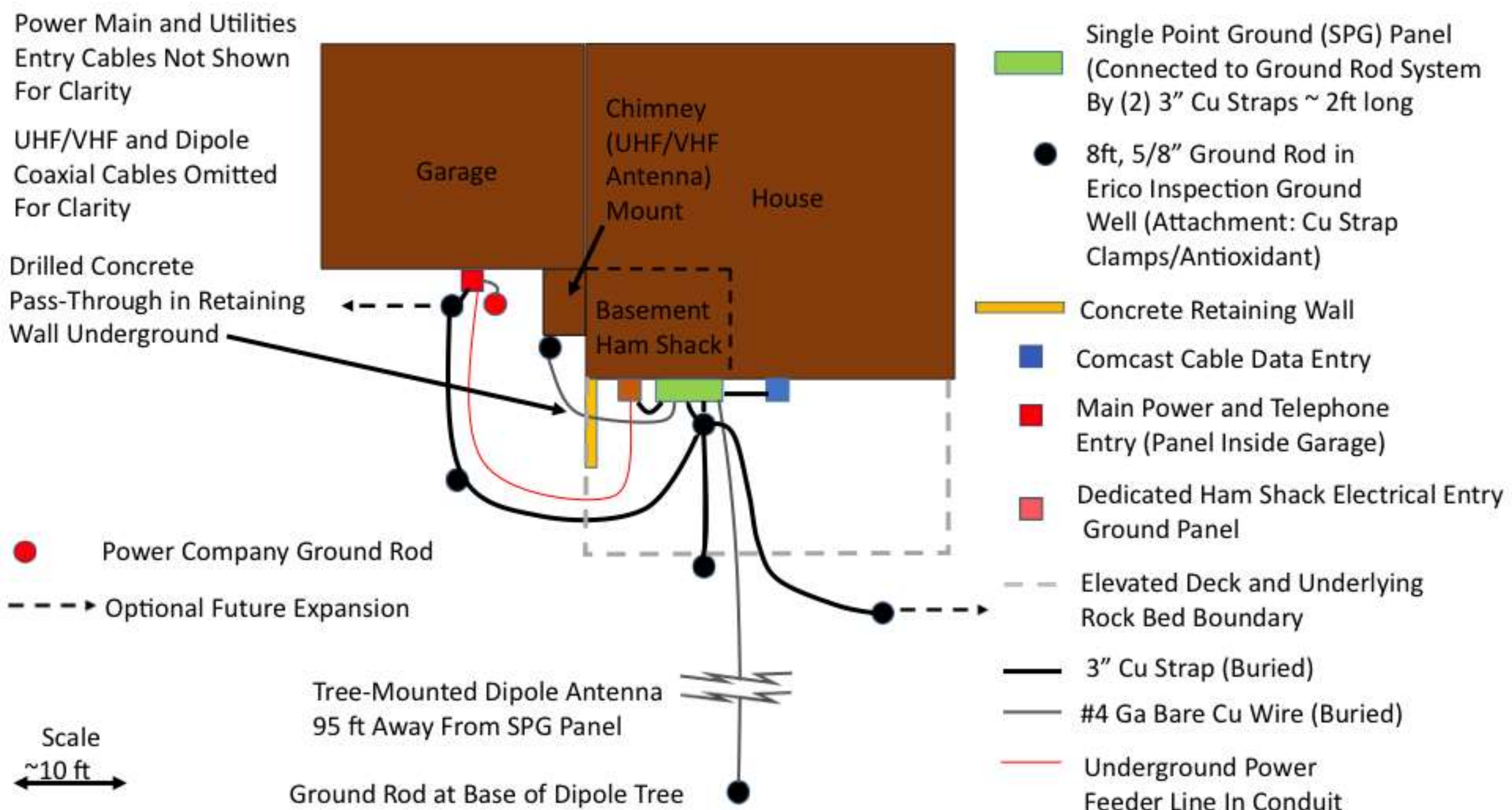


Examples: Stu Turner's System Ground Panel in Ham Shack

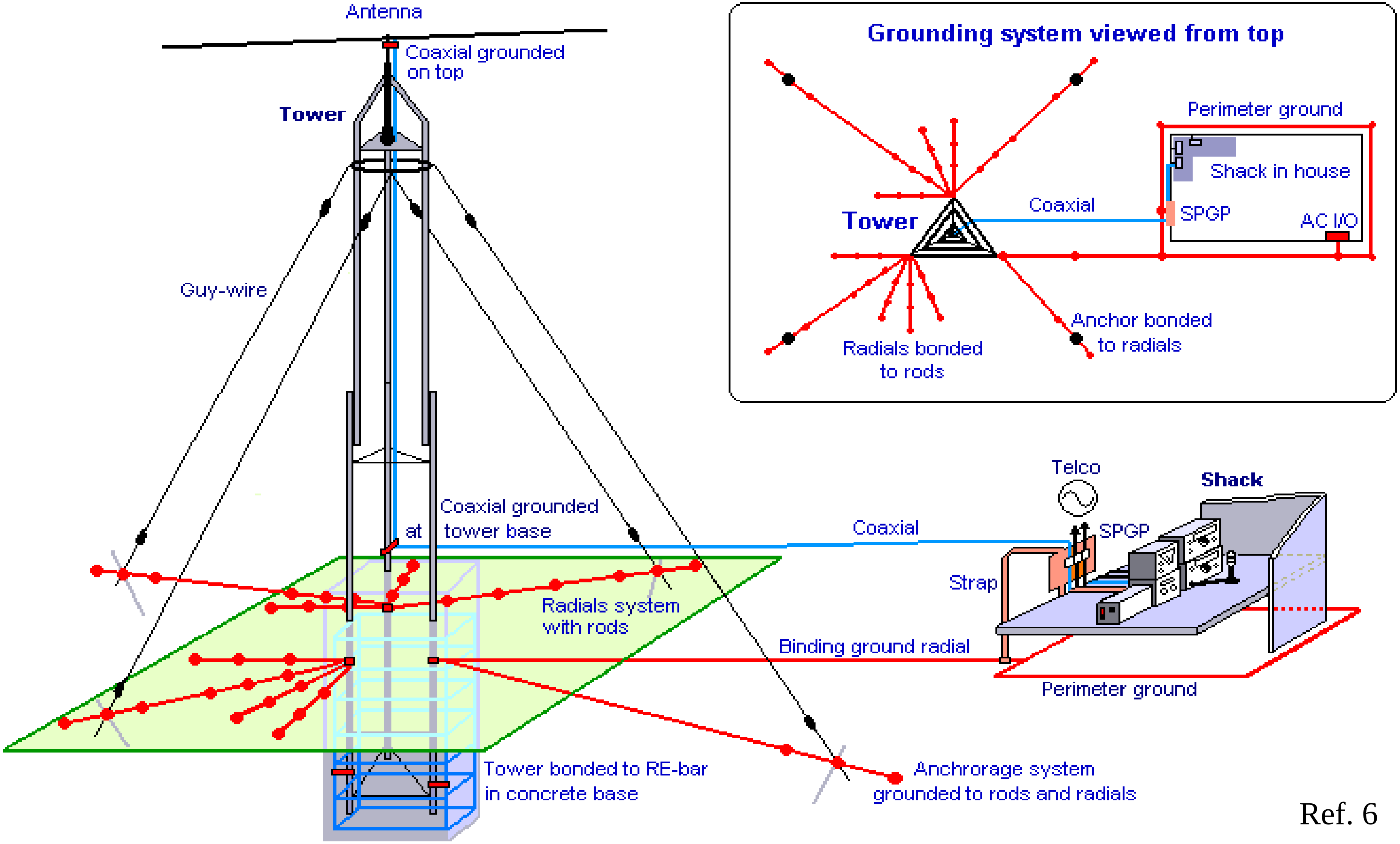


An example wall-mounted single point ground panel with a second set of in-line coaxial lightning protectors and AC surge protector ground-mounted to panel, as well as ground straps from station component chassis.

Examples: W0MJH System



Overall View of Ground System With Antennas



Ref. 6

Grounding At the Antenna

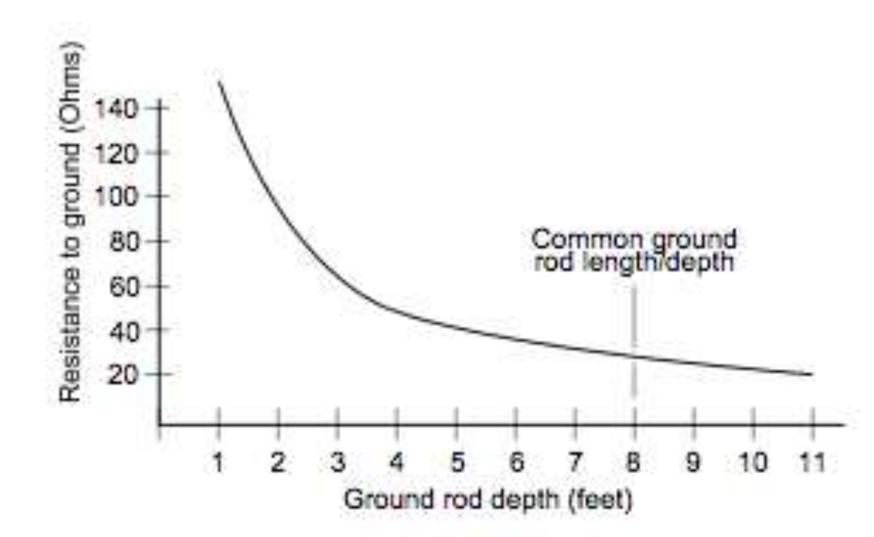
- Antenna Support Structure Philosophy
  - Ideal approach: All support structures are metal (conductors)
    - Polyphaser official stance
  - Pragmatic Approach: Use what your have! i.e. trees
    - Steve Morris, Renowned Tower Expert (Author of the highly respected book Up the Tower)
- Most experts seems to agree:
  - Coax should be attached to ground conductors at top and bottom of structure which are earth-grounded at base of structure
  - Ideally a metal mast/lightning rod should protrude above all antennas by several feet to help route lightning strikes to the down-ground conductors (and not the antenna or coax)
  - All antenna earth grounding networks should be connected to SPG panel despite the long distances involved

Ham Station Grounding for Lightning Protection

Grounding

Materials, Components, Assembly Techniques

Grounding Materials
Ground Rod Electrical Characteristics



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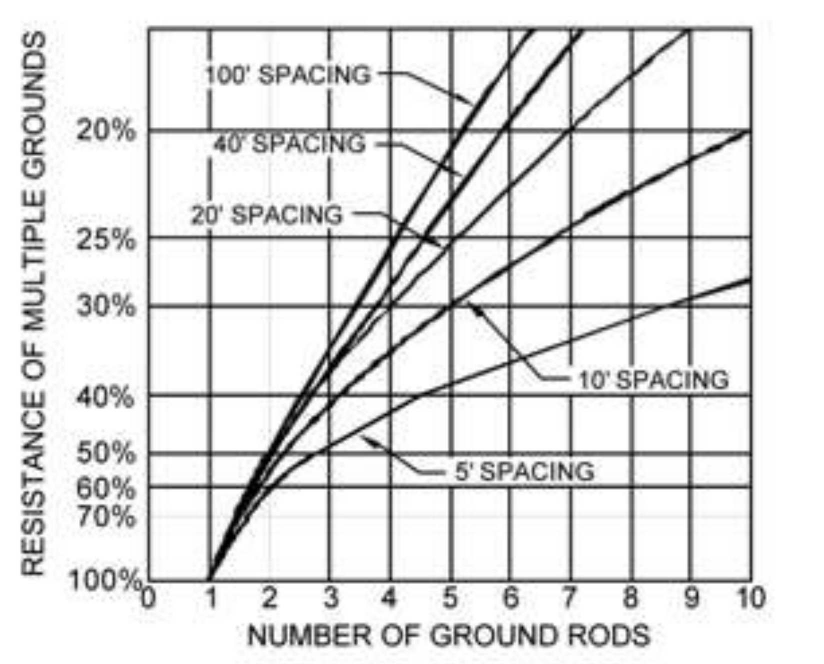

Theoretical resistance change for additionally spaced ground rods.

Ref. 8

Practical Facts About Ground Rods

- Typical rod construction: Cu plated steel
- 8ft length is cost efficient length
- 5/8” is cost efficient diameter
- Available at Home Depot for reasonable price
- More rods reduces grounding impedance faster than using longer rods
- After 50ft length, a string of rods/strap has dissipated the majority of the lightning transient – there’s no point in running a string much longer than 50 ft unless doing perimeter ground

Ground Rod Effectiveness Dependent on Soil Type

Medium	Resistivity (Ohm-cm)[A]		
	Minimum	Nominal	Maximum
Rocky soil	10^3	5×10^4	10^5
Dry sandy	3×10^4	5×10^4	5×10^5
Clay, shale, gumbo, loam	3×10^2	4×10^3	2×10^4
Gravel, sand stones	5×10^4	10^5	10^6

Ref. 1

Cu Wire and Strap Inductance in Free Space for Typical SPG Panel to Ground Rod Separation

Interconnect	Inductance (uH) per 3ft
#4 Wire	0.913
2” strap (0.064 thick)	0.74
3” strap (0.064” thick)	0.67
4” strap (0.064” thick)	0.62

Comment: At first glance it appears that there’s little benefit in using wider strap and the difference between wire and strap seems small:

But there’s more to the story…

Conductors/Interconnects

- Cu strap is preferred over Cu wire, particularly if buried
- The inductance per unit length comparison in free space is misleading because there are beneficial effects with buried strap
  - Much larger surface area for soil contact – increases shunt conductance to the soil
  - Sharp edges increase/concentrate the electric field thus supporting enhanced soil arcing more easily
  - Buried strap creates much better distributed RLC lossy transmission line thus dissipating the transient more effectively
- The conductance surface area advantage also applies to comparisons of different strap widths

Components and Assembly Techniques Ground Rod Interconnect Attachment

- General Comment: Huge magnetic-induced stresses occur on all conductors in a lightning ground system during the transient – all connections must have solid physical attachments to hold the system together
- Key Attachment Techniques for Ground Rod to Wire/Strap
  - Erico CAD-Weld Exothermic Connections
    - Easy to assemble, very strong, impervious to corrosion when buried but inconvenient to find for anything beyond wire connections
  - Physical clamps with antioxidant compound
  - Some hams extol the benefits of high temp, brazed silver solder (melting temp over 1000C) but most official stances discourage even high temp brazing
  - Never use regular electronic solder for any lightning ground connection
  - Do not use braided strap connections for outdoor use - the high conductor surface area results in corrosion-related degradation (Ref. 7)
- Must pay attention to galvanic series compatibility of materials
  - Stainless steel hardware IS compatible with Cu but always use antioxidant

Components and Assembly Techniques Driving Ground Rods

- Some people have used a “water drilling” technique to install ground rods or copper pipe (ARRL even had related articles)
  - NEC and Polyphaser only advocate installing force-driven rods
- If you have many rods to drive, consider using a demolition hammer rented from Home Depot (example Makita 1214C)
  - Use unit rated >18 ft-lbs/blow (typical 1900 blows/min)
  - Total tool weight tends to track blow force
  - You can also rent a small shovel attachment (for free with the hammer) at the same time - makes digging a breeze in our tough Colorado soil
  - You will need a ground-driver-bit – order online or you’re welcome to borrow mine
  - This tool will sink most 8 ft rods in less than 30 seconds and blow its way through moderate rocks in short order

Components and Assembly Techniques
Surge Suppressors

- Surge suppressors come in two basic types
  - Shunt suppressors (gas tubes, MOVs, Si Avalanche Diodes)
  - Series suppressors (more expensive, low AC current rating)
- Some Quality Manufacturers for Coaxial and Power Suppressors
  - Polyphaser, Industrial Communication Engineers (I.C.E)
- A well outfitted ham shack may need several types of suppressors all tailored to the specific function
  - Power
  - Antenna Coax
  - Antenna Rotor Control or Remote Tuner Control
  - Telephone/Data
  - Remember:
    - All Connections To the Ham Shack Require Proper Grounding/Surge Suppression With Respect to the SPG
    - One connection violation can destroy the "ham shack floats on SPG" principle

Components and Assembly Techniques
Helpful Info

- Consider using ground inspection wells
  - Protect ground rod/connections from soil corrosion/elements
  - Allow easy testing/maintenance-inspection of connections
  - Support easy system expansion if/when time and resources permit
  - Erico is one manufacturer for these
- Where to get grounding components?
  - Georgia Copper (Cu of all types in bulk quantities)
  - DX Engineering (wide selection of components/materials)
  - Ham Radio Outlet (Denver store ships really fast!)
  - KF7P Metalwerks (make very nice SPG entry panels)

Ham Station Grounding for Lightning Protection Summary

- The key to effective lightning protection is strict adherence to a single point ground configuration
  - The voltages induced by direct strike or induced transients are usually not controllable to reasonable levels even with good ground systems
  - Whole house and ham shack should float on the SPG voltage
  - SPG tends to force all ground/shield potentials to same value
  - Surge suppressors hold the hot or signal leads to within the clamp voltage of the SPG voltage
  - To be successful ALL connections into the ham shack must be referenced to SPG
    - Note: A concrete basement floor may be an unexpected “ground” connection into the ham shack!

Ham Station Grounding for Lightning Protection References

1. Amateur Radio Station Grounding and Lightning Protection, W5BWC Electronics, www.bwcelectronics.com (this is an excellent and thorough review of the subject)

2. The ABCs of Lightning, Dehn Inc. Application Note

3. How to Protect Your House and Its Contents From Lightning, IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits, IEEE Press 2005

4. Grounding System and Lightning/Ground Fault Protection, Samlex America Application Note

5. W8JI.com (extensive and accurate discussions of ham station grounding, this site is well respected and often quoted by others)

6. http://www.astrosurf.com/luxorion/qsl-lightning-protection4.htm

7. Up the Tower – The Complete Guide to Tower Construction, Steve Morris K7LXC, 2009, Champion Radio Products, ISBN #978-0-615-28514-6

8. Grounding and Materials, Polyphaser White Paper, (also see whitepapers on many related aspects) http://www.smithspower.com/brands/polyphaser/services/media-library/white-papers