Station Grounding

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RevA

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http://www.naøtc.org/

Topics

- Electromagnetic Compatibility (EMC)
- Five Types of Grounds
  1. Safety
  2. Lightning
  3. Static (DC) Bleed
  4. Single Point
  5. RF
     - Antenna
     - Station
- Loops
  - RF
  - Ground
- Examples of Real Problems and Solutions

Electromagnetic Compatibility (EMC)

- The design process that ensures that the "system works" as designed
  when all of the individual boxes are connected as a system
  - "System works" => ***no radiated or conducted noise problems***
  - More than just Radio Frequency Interference (**RFI**) management
    - Grounding is an important part of the EMC design process
    - ***Conducted noise*** is frequently the toughest problem to solve
  - EMC is ***EXTREMELY*** important in satellite system design
    - EMC problems cannot always be fixed at the end of a program
      - $150 M satellite went to the dumpster due to system level EMC (conducted noise) problems that couldn't be fixed
    - **EMC Engineer** must ensure that the entire satellite "system" works
- Few colleges offer any courses on the subject
  - Learning is mostly by OJT

Ham Station Grounding

- Very confusing and frustrating subject to research
  - Complex subject, with numerous variables, and no one solution for all problems
  - Too many "**EXPERTS**", and they frequently don't agree!
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  - Use their own personal experience as proof of their beliefs
  - One "expert" in So. Cal. claims that ***any*** ground is a waste of time and money
    - "He has never had any damage from a lightning strike in over 10 years of operating …"
    - There have been no reports of a lightning strike in the area where he lives for more than 16 years…

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  - The cell phone industry still loses 50 sites (0.01%) a year due to lightning
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Station Grounding is a *SYSTEM DESIGN* Issue

There are at least *FIVE* Types of grounds (in order of importance):

1. Safety
- ***MUST*** have to prevent dangerous 60 Hz voltages from occurring across any two different ground points
- National Electrical Code (NEC) requirement

2. Lightning
- ***Should*** have to dissipate surge energy ***before*** it can enter the house

3. Static (DC) Bleed
- ***Should*** have to dissipate any static charge on antenna ***to ground, before*** connecting to any receiver

4. Single Point
- ***Should*** have for mitigation of any problem loops

5. RF (two types)
- **Antenna:**
  - **May, or may not be needed**:
    - Balanced vs. unbalanced antennas
    - To achieve the correct antenna feed impedance
    - To achieve maximum radiation efficiency
    - Does *not* significantly affect radiation pattern

Station Grounding is a *SYSTEM DESIGN* Issue

FIVE Types of grounds (continued):

5. RF (continued):

- **Station:**
  - **May, or may not be needed**
  - Can sometimes mitigate problems with **RF in the shack:**
    - Unwanted common mode currents on coax
      - A current choke may be a better solution
    - Antenna too close to station equipment
      - 100 ft = good goal for HF antennas
  - Can be hard, or even impossible to achieve

Loops:

- Being able to identify, and deal with **problematic** loops is an important part of an overall **grounding strategy**
- They can cause problems with distortion, and/or 60 Hz hum on the transmitted signal
- **Low frequency ground loops** are often the real cause of what is thought to be "RF feedback"

The only ground that you *MUST* have is a *SAFETY* ground!

Why Are Grounding Problems So Difficult To Solve?

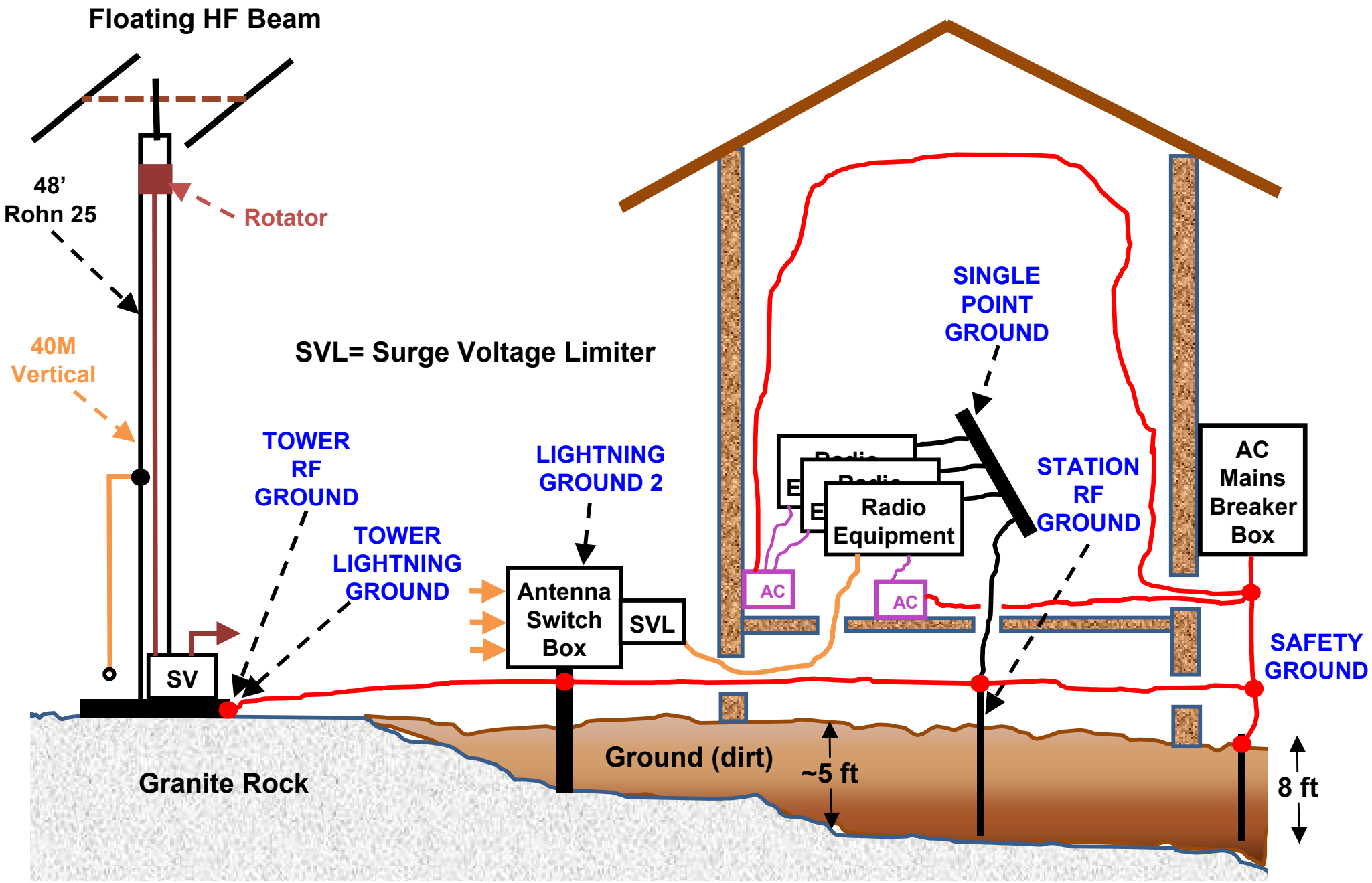
1) There is a conflict between the two different design constraints:

- ***Safety:*** Grounding to prevent electrical shock
- ***Noise:*** Grounding to eliminate unwanted electronic noise
- These two constraints are often not compatible, and their design solutions are frequently in direct conflict
- ***Safety ALWAYS wins***

2) There is ***NO*** absolute ground

- There is always a certain amount of ***resistance*** and ***inductance*** in ever path to any grounding point
- Even if you can get to it (RF-wise), Earth may not be very good RF-wise

N0CU Station Grounding



1. Safety Ground

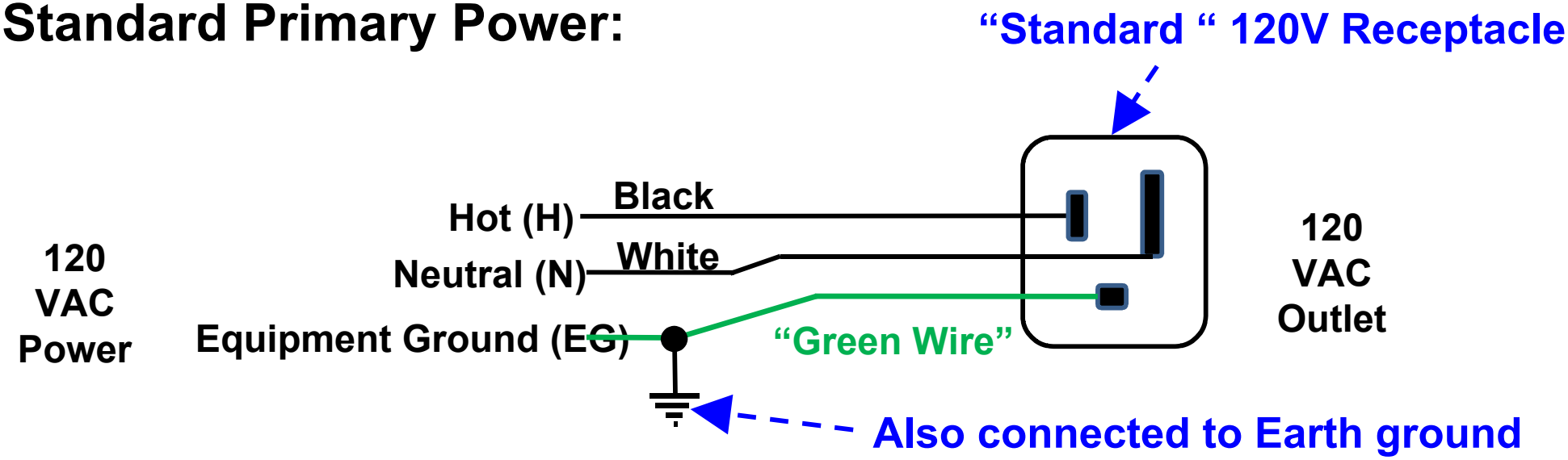
- ***ALL*** grounds must be connected to AC Mains ground (the ***Safety Ground***
  - Usually an 8 ft ground rod at AC Mains entrance box
- This is a NEC requirement
- This is the one point that all experts agree upon
- Be cautious when using isolated AC grounds

Isolated Grounds

Two types of AC Power Grounds:

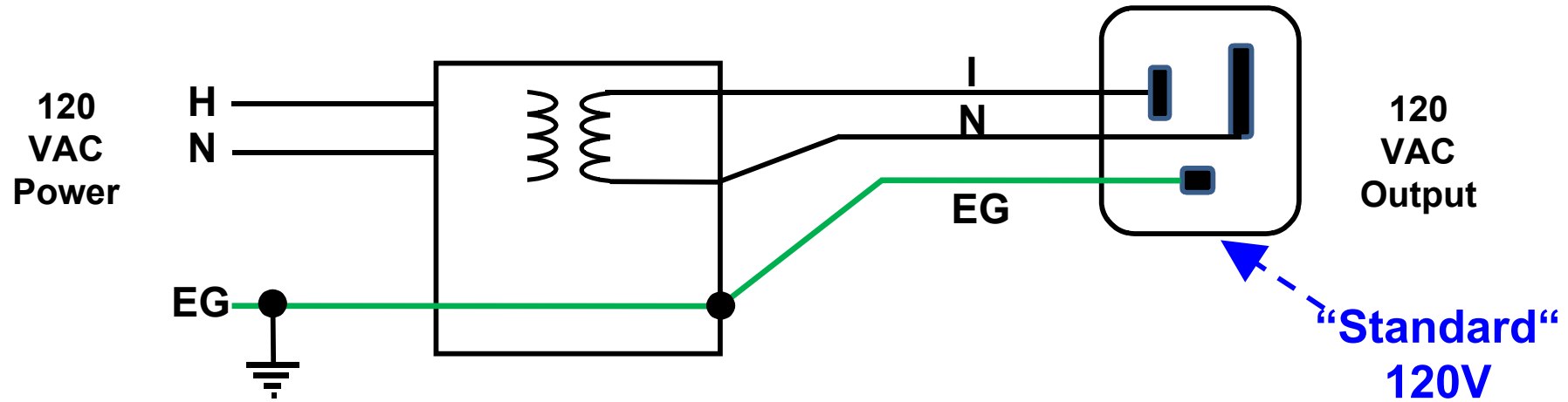
- Isolated Ground (IG)
  - Noise reduction
- Equipment Ground (EG)
  - Safety
  - "Should never carry current"
    - This is only true in an ideal power system that will never see a fau
    - The (EG) needs to be able to carry enough current to cause the circuit breaker/fuse to open during a fault

Standard Primary Power:

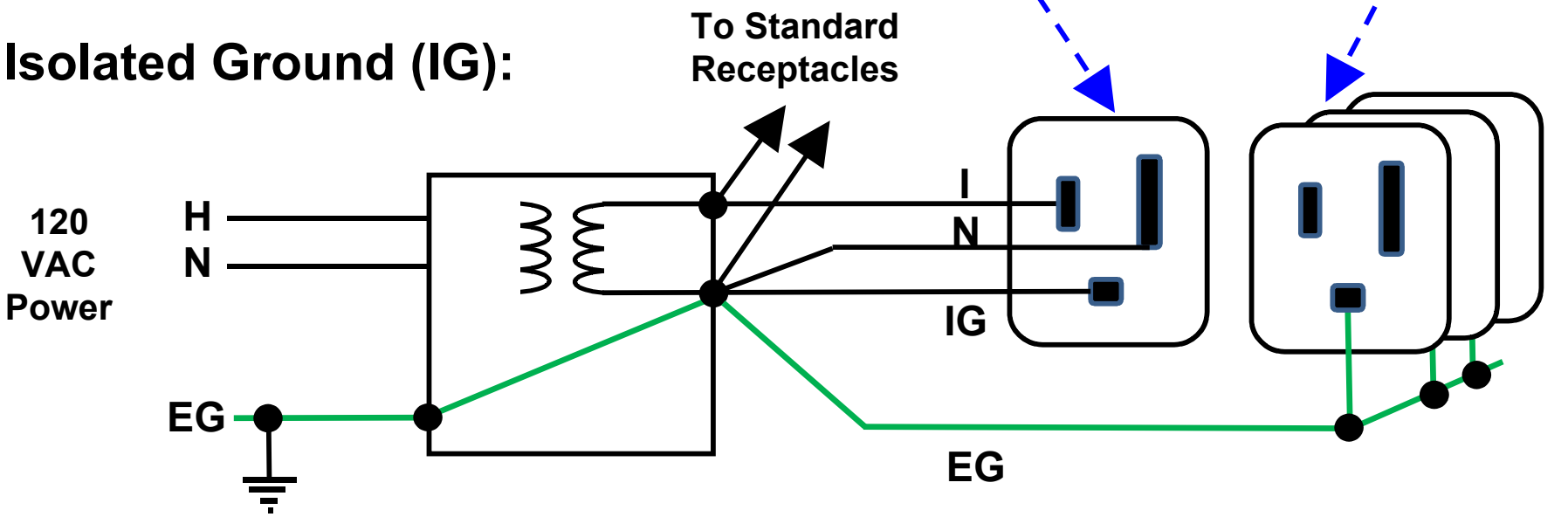


Uninterruptible Power System (UPS) Grounds:

Standard Ground:



Isolated Ground (IG):



Isolated Grounds

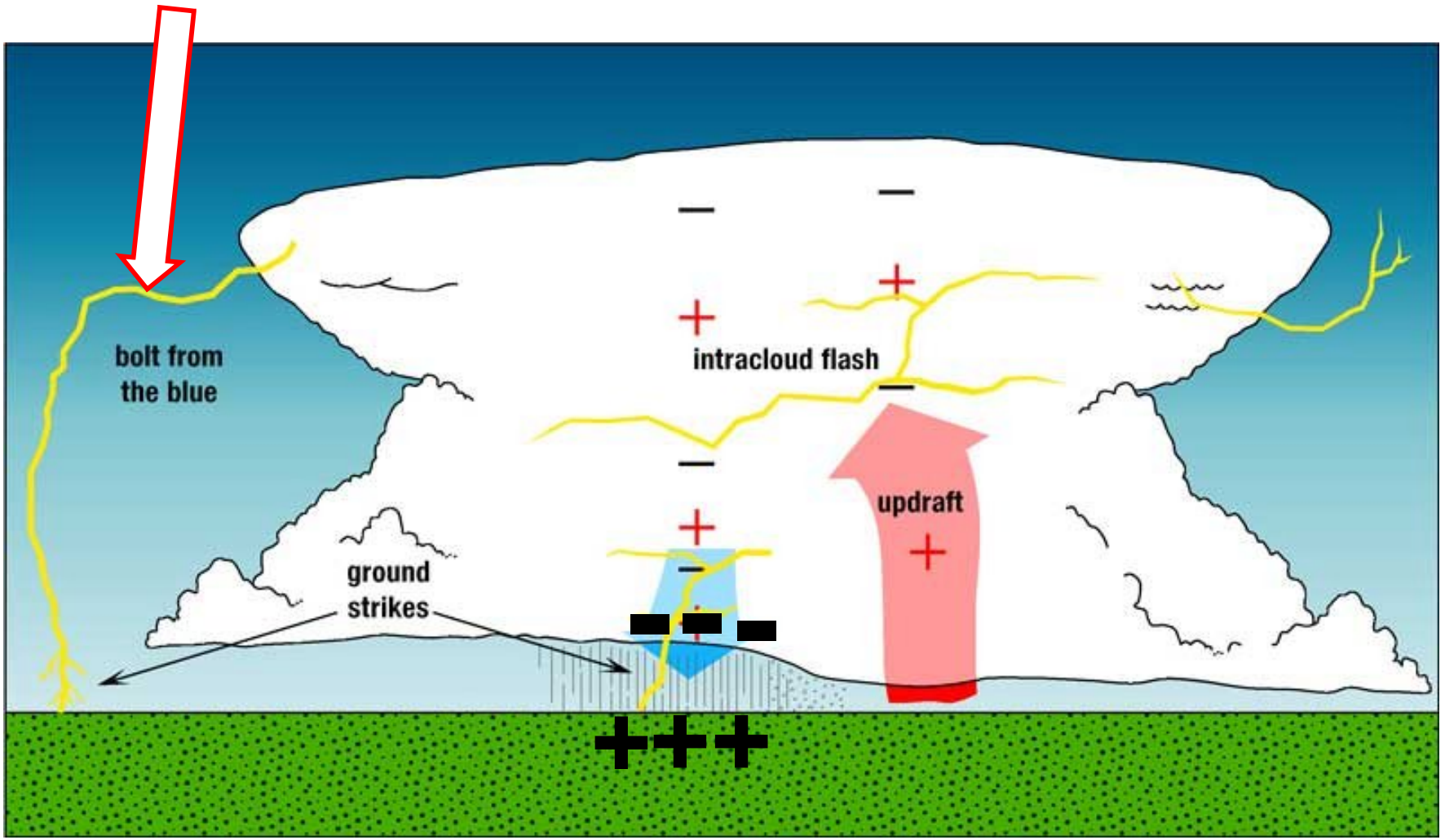
"In most cases, an Isolated Ground (IG) is a waste of money. IEEE 1100, Powering and Grounding Sensitive Electronic Equipment (Emerald Book) states, "The results from the use of the IG method range from no observable effects, the desired effects, or worse noise conditions than when standard equipment bonding configurations are used to serve electronic load equipment [8.5.3.2].""

"Equipment that is *totally isolated* from Earth Ground (EG) is dangerous and can cause injury or death..... There are some reasons to use an isolated ground due to ground loops, but one socket needs to be a solid earth ground."

Lightning Generation

Many different types of lightning

Watch out for this one!



Some facts about Lightning

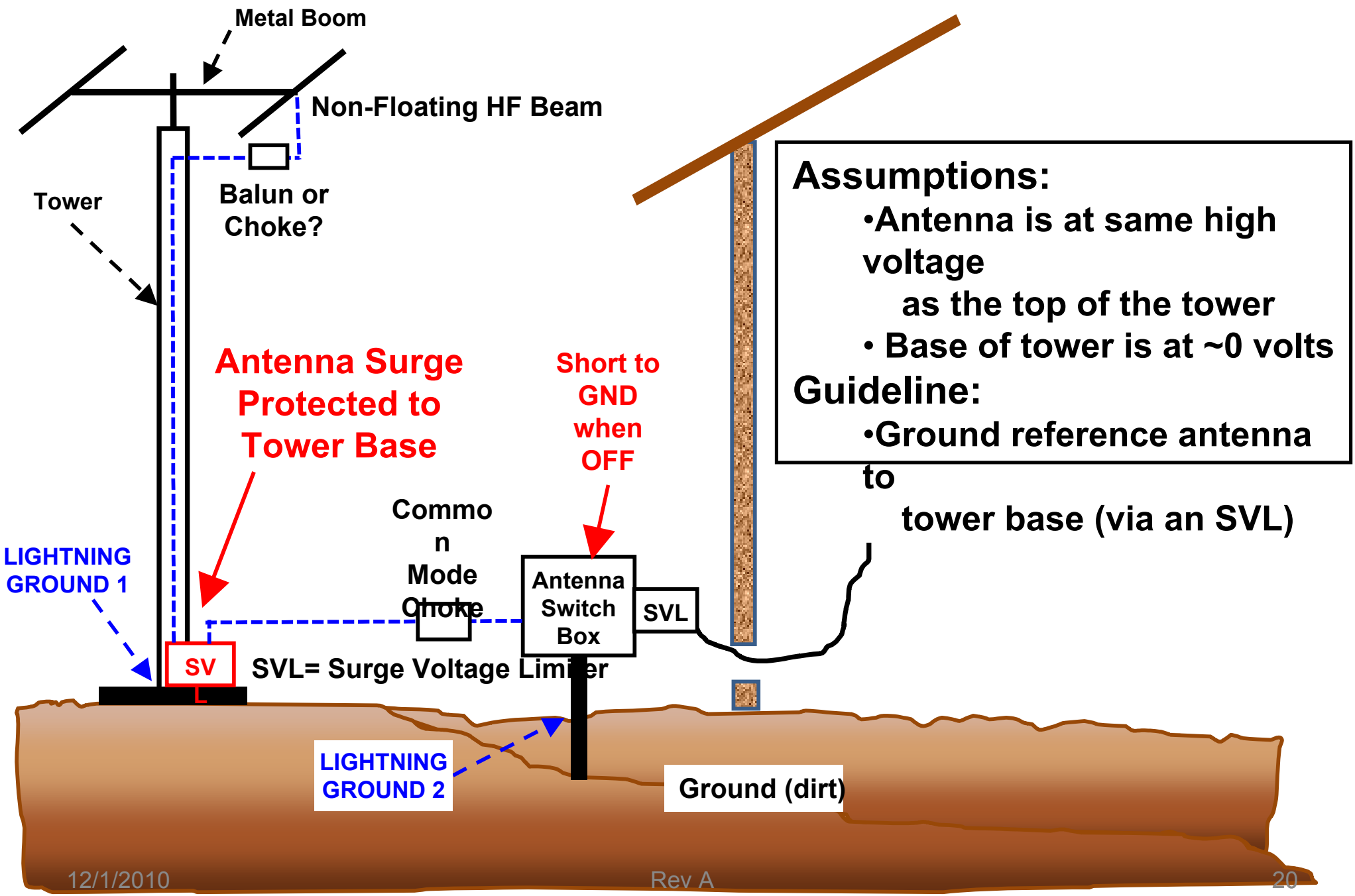
- A lightning bolt can be either **positive or negative**
  - Negative bolts most common (95%)
    - **Streamer** down (invisible) and then the big strike up (visible)
- **Strike Duration:** <30 milliseconds (can have multiple strikes per event)
- **Voltage Risetime:** 2 usec typical (=> significant energy up into the MHz range)
- **Voltage Gradient:**
  - Pre-strike: ***pre*-ionized** path voltage can be >3 megavolts/meter
  - Post-strike: ***ionized*** path voltage is several hundred volts/meter
- **Current:**
  - Most strikes are in the range 5,000 to 20,000 amps
  - The most powerful lightning strike ever recorded in the United States discharged approximately 345,000 amps
- **Power per strike:**
  - Peak power: ~1 trillion watts
  - Energy: ~500 megajoules (~100 W light bulb for 3 months)
- **Air Temperature:** ~30,000 ^{o}F
  - ***Solder instantly vaporizes***
- Grounded metallic objects dominating the area are more likely to be struck by lightning than the surrounding ground or lower structures nearby. This is why:
  - Lightning rods work
  - Towers/vertical antennas are more likely to be struck

2. Lightning Ground

Multi-Level Protection:

- Distribute the energy over a number of different ground points
- **First** Level (when possible):
  - At the likely strike point (tower, vertical, etc)
-
-
-
- **Last** Level:
  - Just outside the entrance to shack or house
- Two levels used at N0CU
  - First level is at the tower
  - Second level is on the outside, at the entrance into the house

Common Antenna Ground



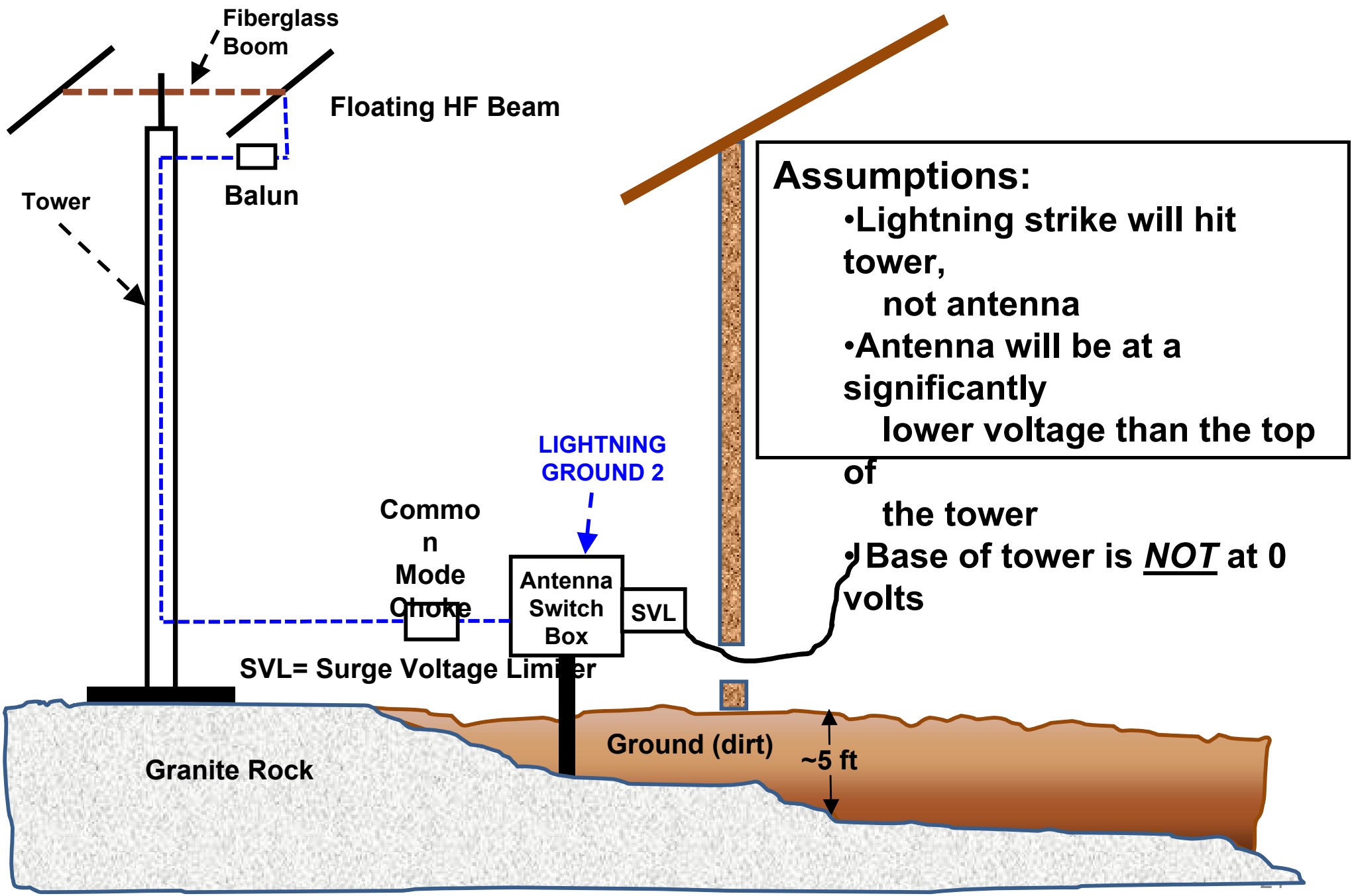
Assumptions:

- Antenna is at same high voltage as the top of the tower
- Base of tower is at ~0 volts

Guideline:

- Ground reference antenna to tower base (via an SVL)

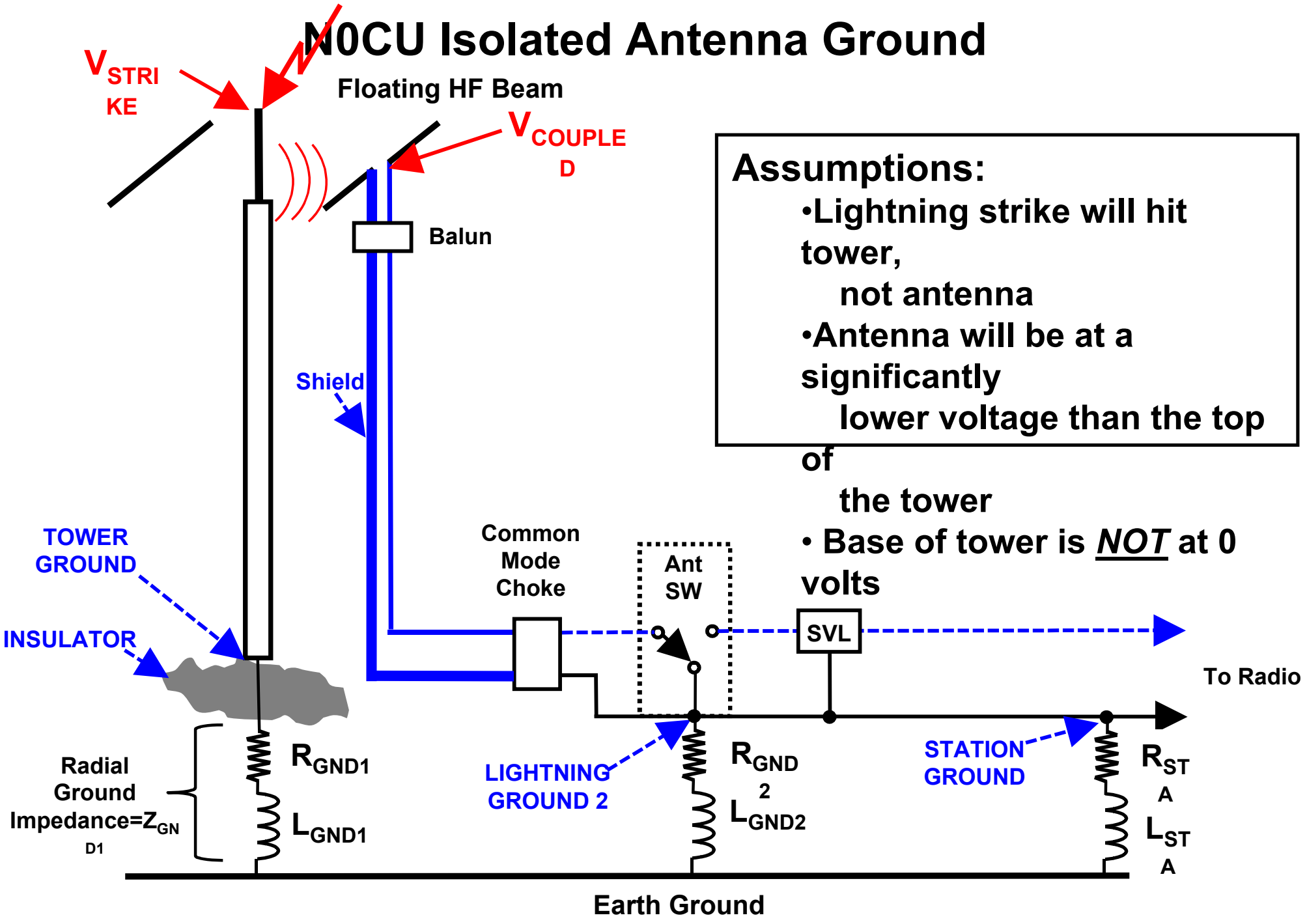
N0CU Antenna Ground



Assumptions:

- Lightning strike will hit tower, not antenna
- Antenna will be at a significantly lower voltage than the top of the tower
- Base of tower is ***NOT*** at 0 volts

N0CU Isolated Antenna Ground



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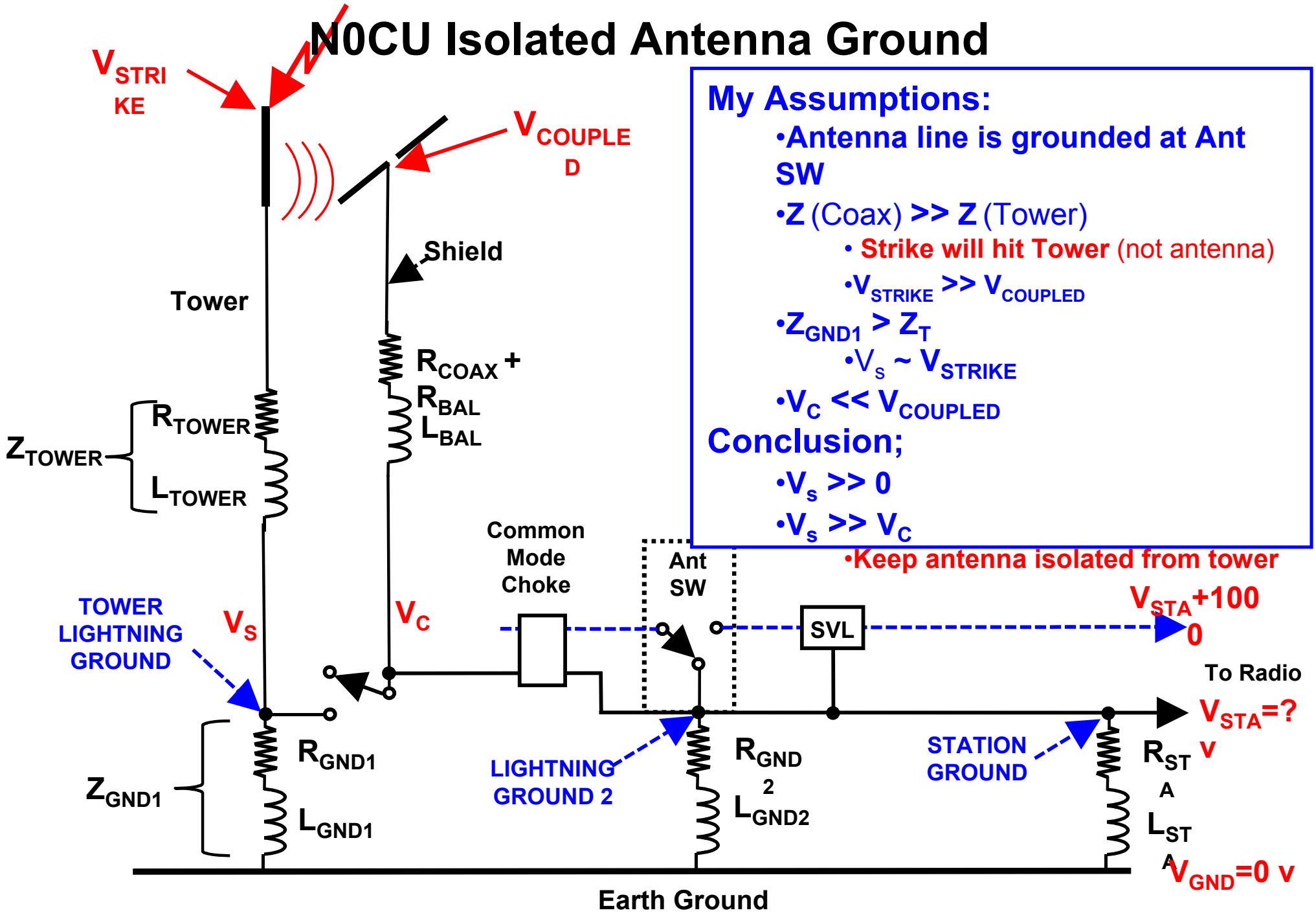

My Assumptions:

- Antenna line is grounded at Ant SW
- Z (Coax) >> Z (Tower)
  - Strike will hit Tower (not antenna)
  - $V_{STRIKE} >> V_{COUPLED}$
- $Z_{GND1} > Z_T$
  - $V_s \sim V_{STRIKE}$
- $V_C << V_{COUPLED}$

Conclusion;

- $V_s >> 0$
- $V_s >> V_C$
- Keep antenna isolated from tower

N0CU Isolated Antenna Ground

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- **Decisions driven by Common Mode**
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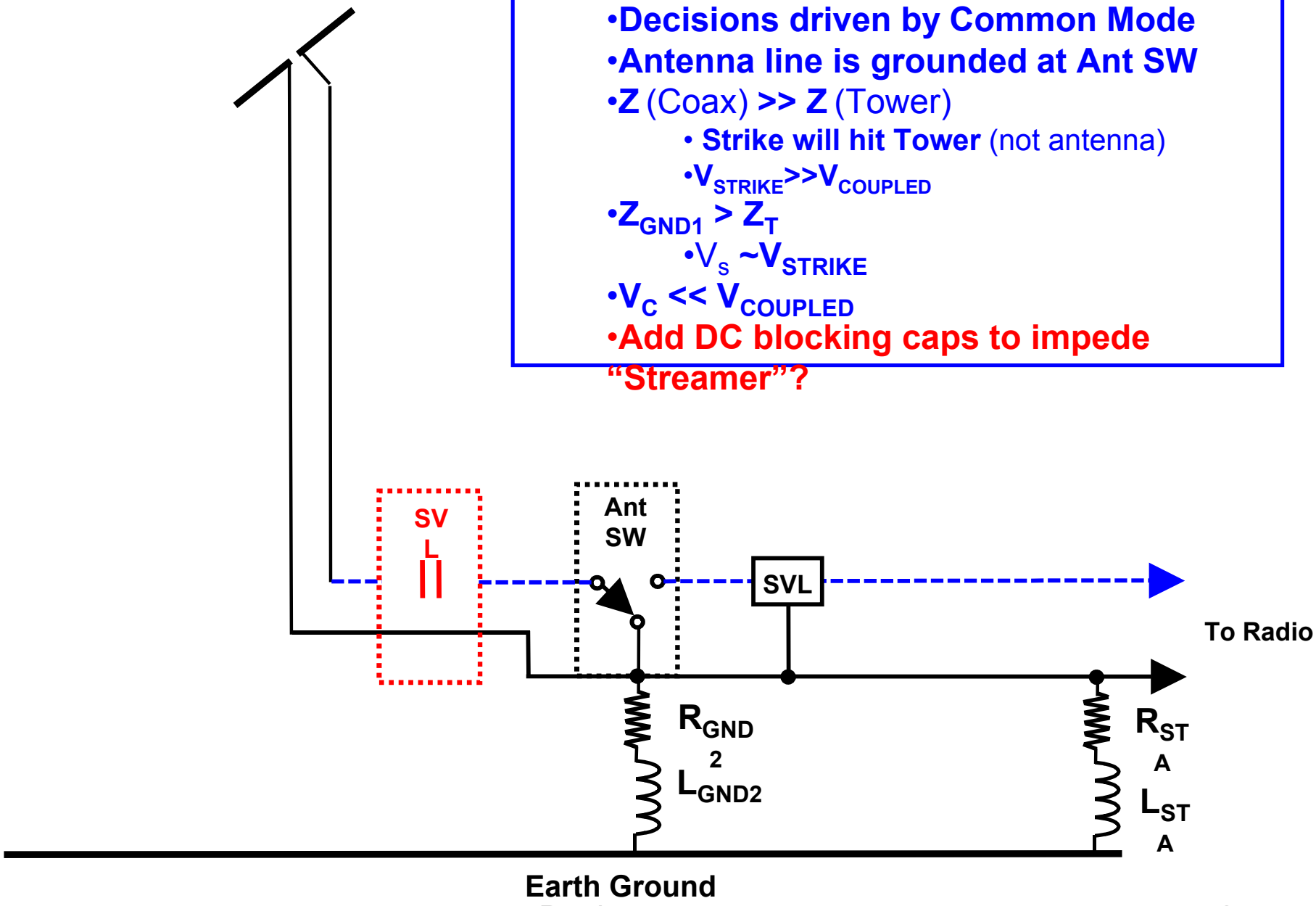
- **Add DC blocking caps to impede "Streamer"?**



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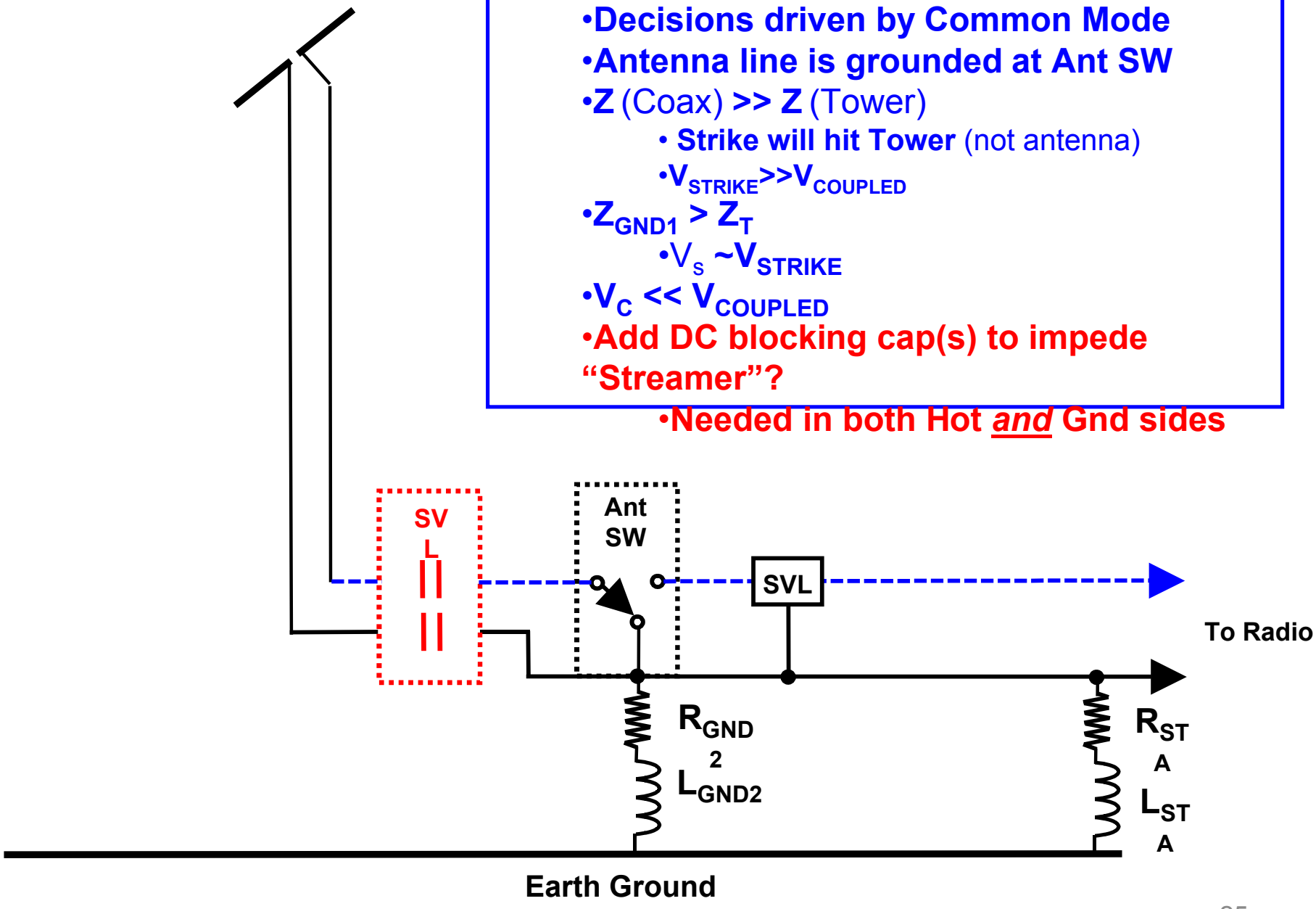
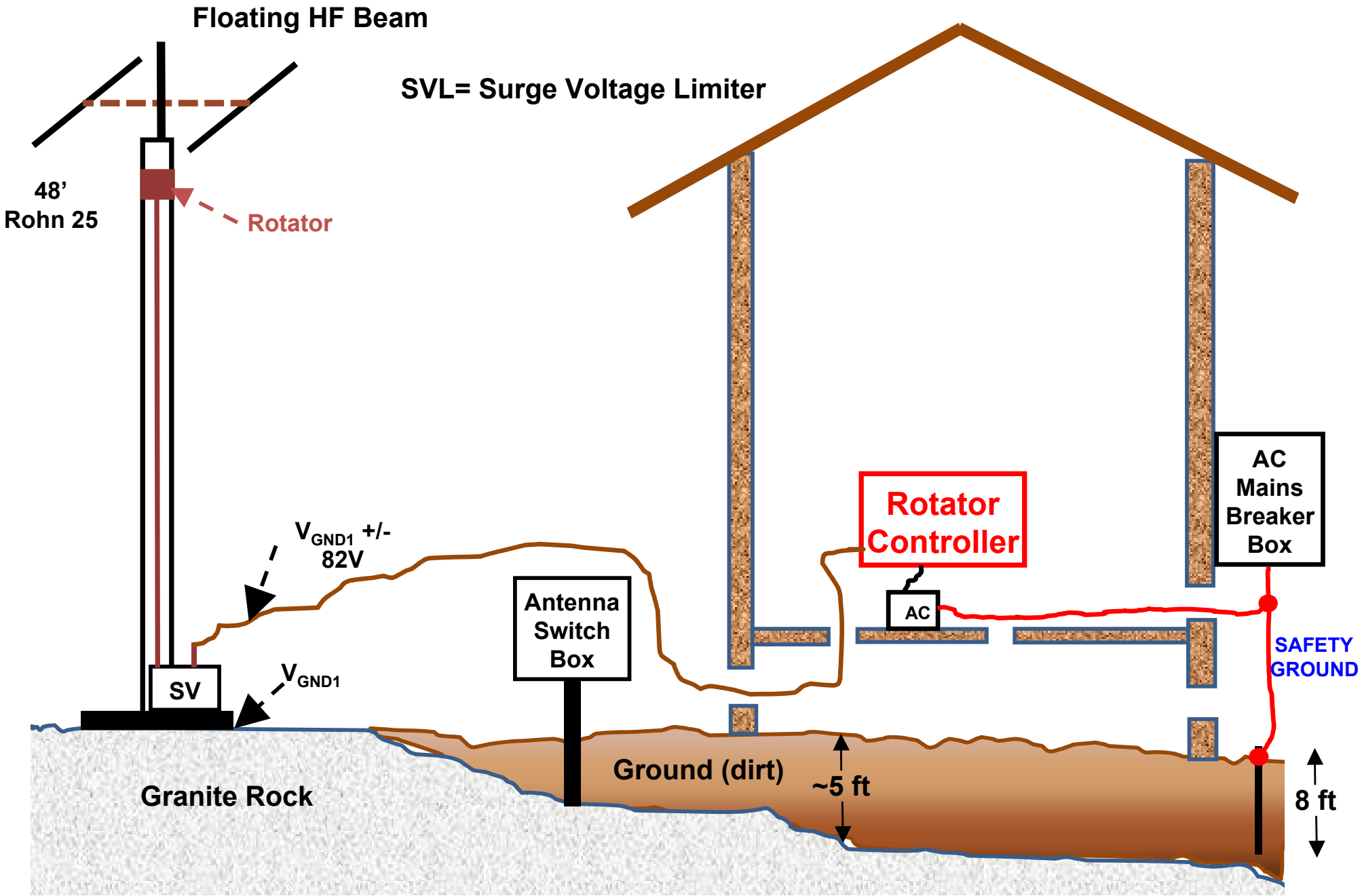
- **Add DC blocking cap(s) to impede "Streamer"?**
  - **Needed in both Hot *and* Gnd sides**



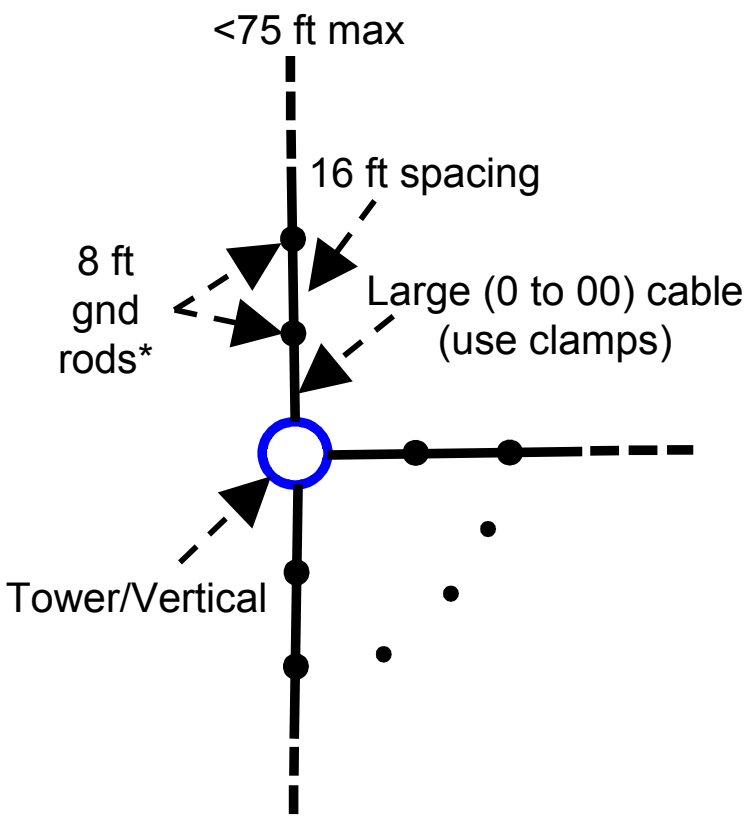
Rotator Grounding???



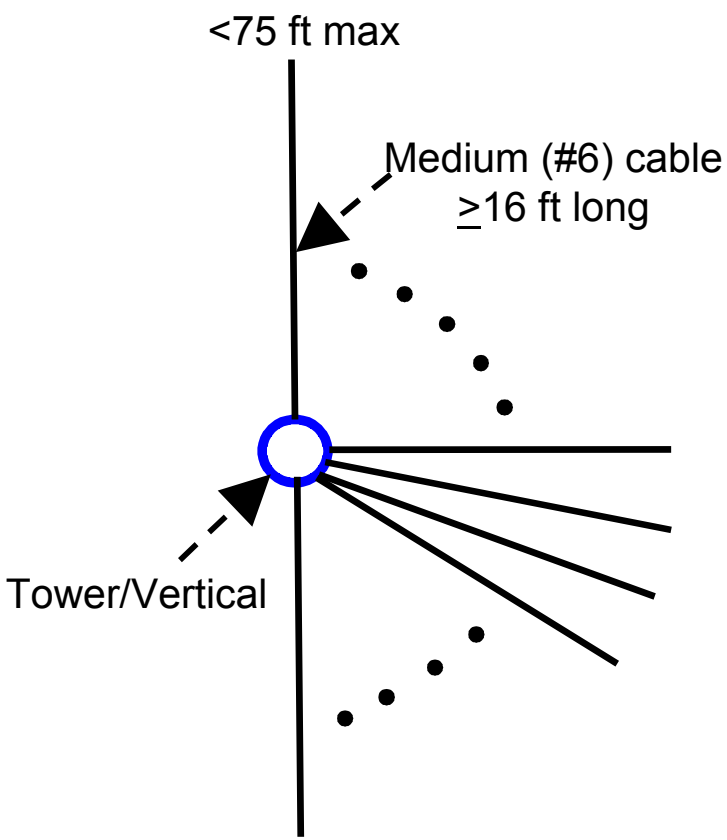
Tower/Vertical Grounding - Lightning

More=Better

Brute Force**



Distributed

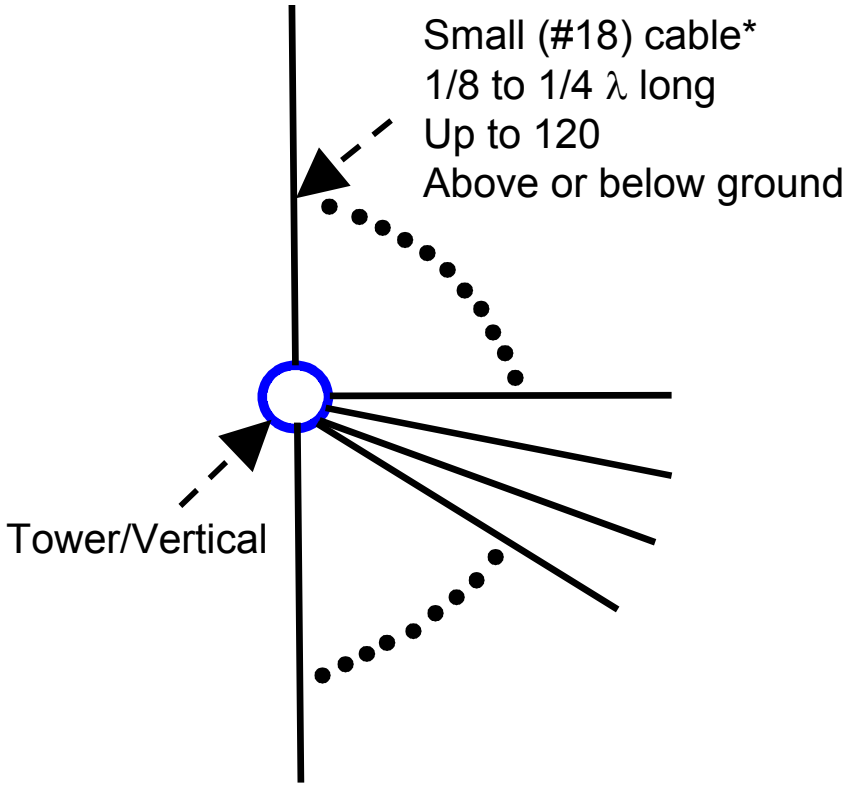


*Can be difficult to get 8 ft down
**May not work well with poor ground conditions

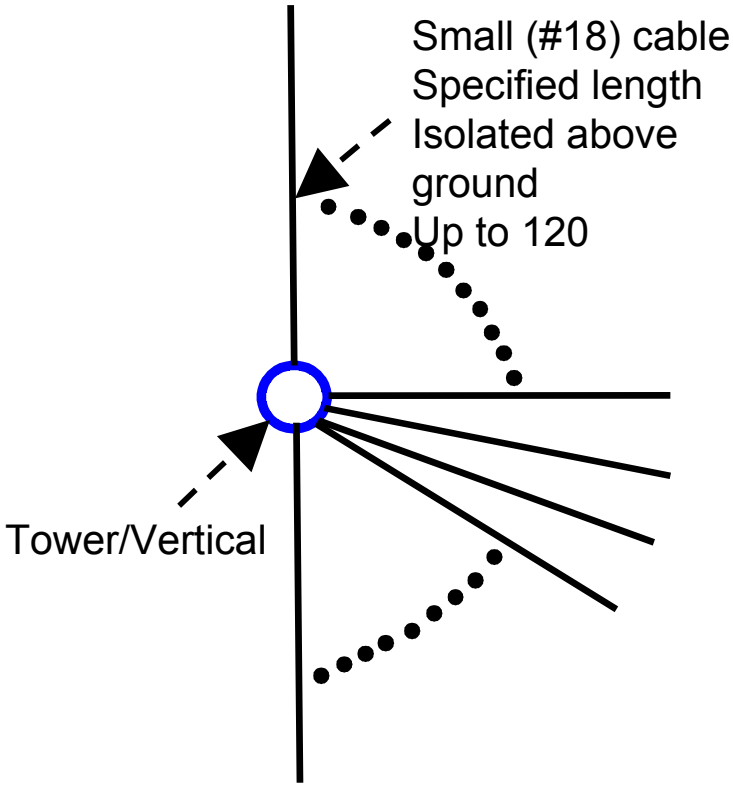
Tower/Vertical Grounding - RF

More=Better

Distributed



Counterpoise

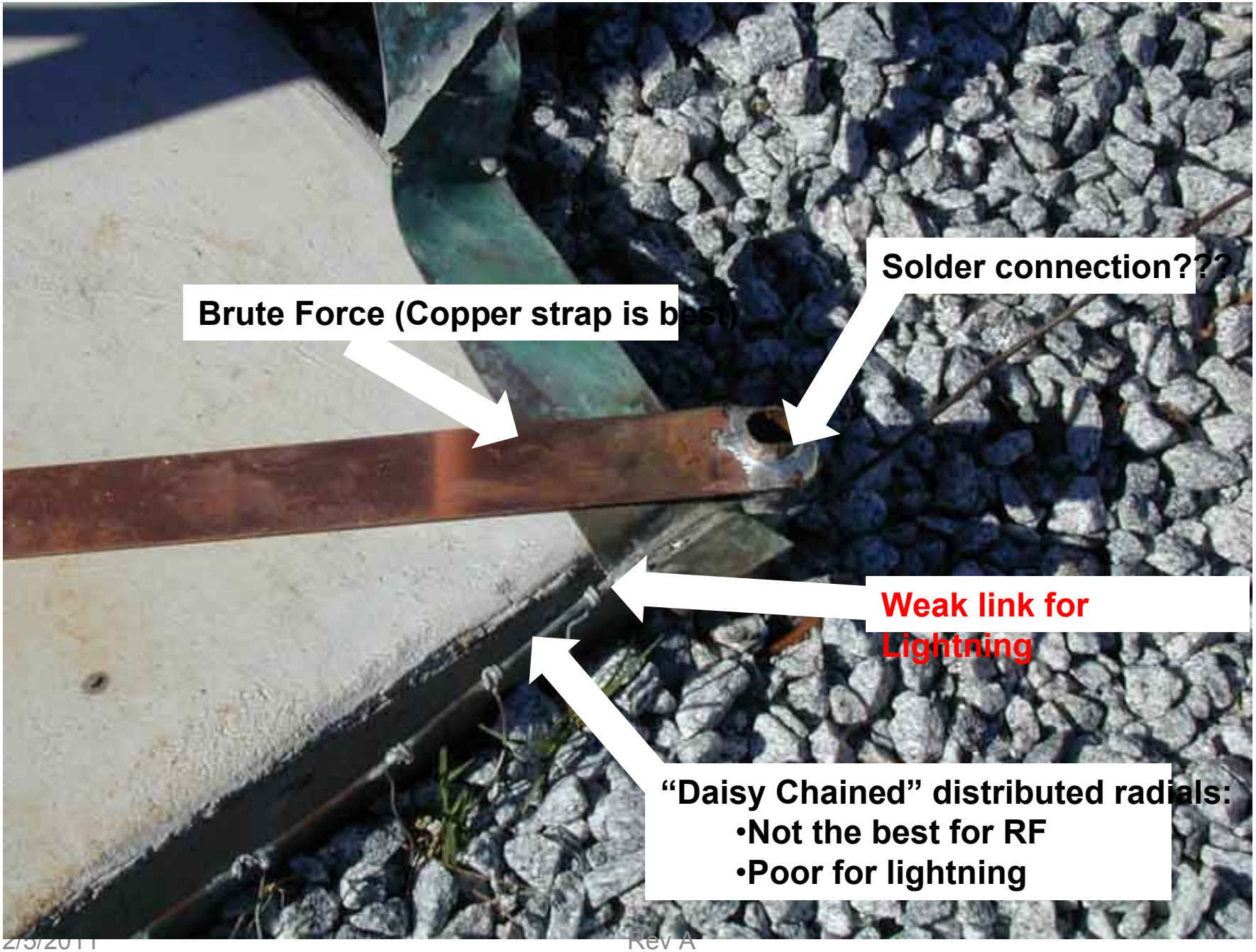


*Galvanized chicken wire also works well

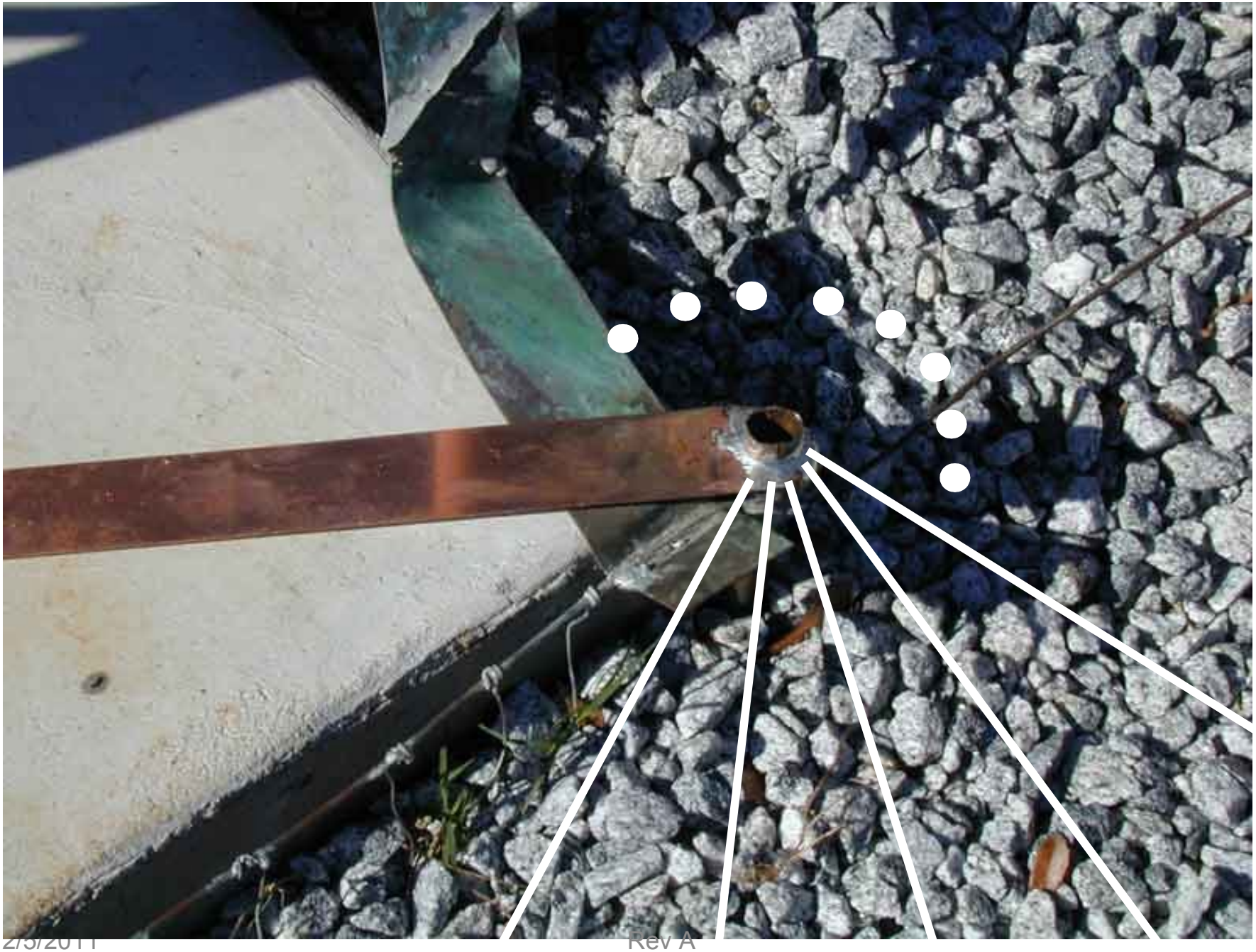
W8JI “Hybrid” Tower Ground

“Hybrid” approach combines some of “brute force”, and some of “distributed”

W8JI "Hybrid" Tower Ground

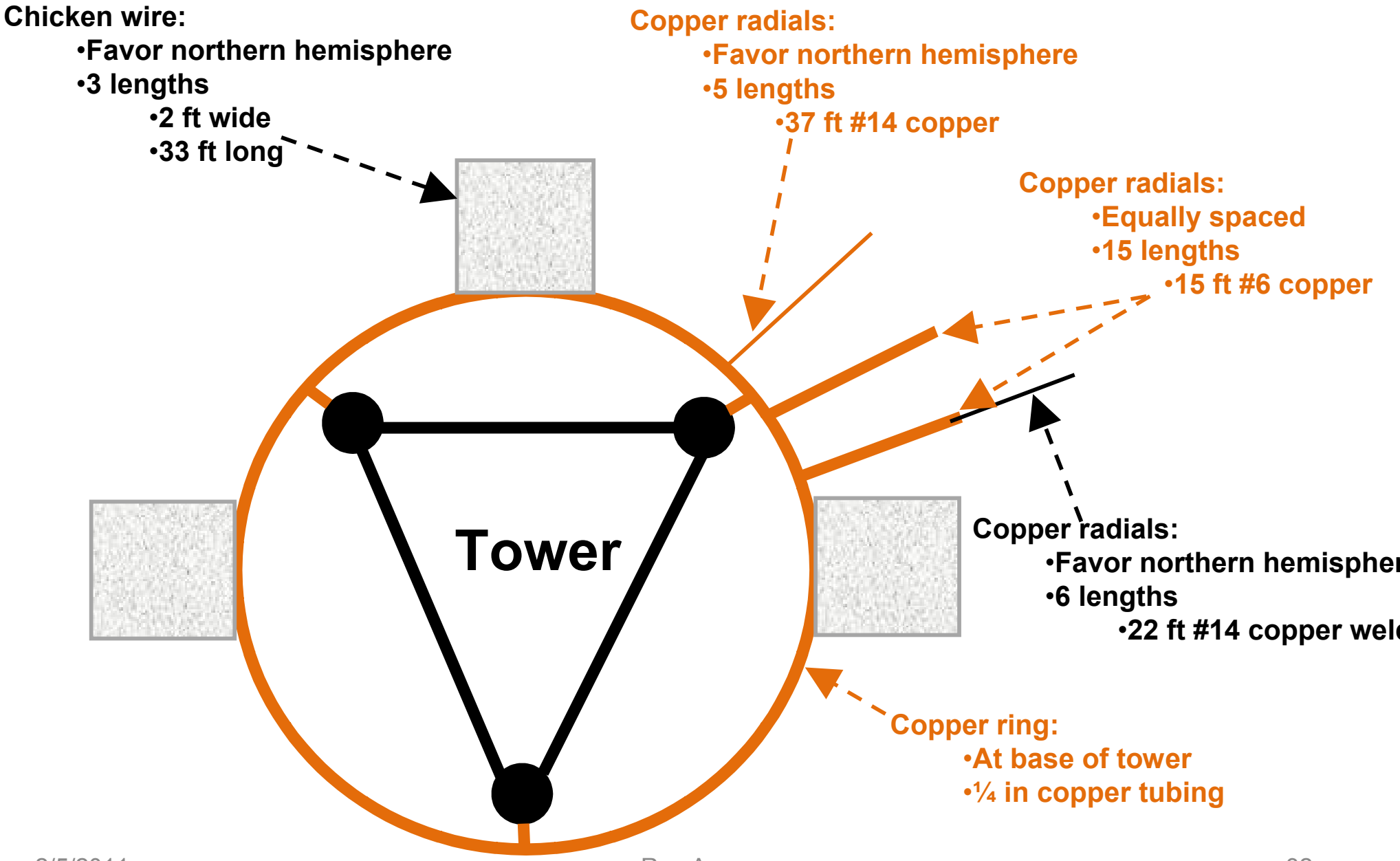


Better “Hybrid” Tower Ground

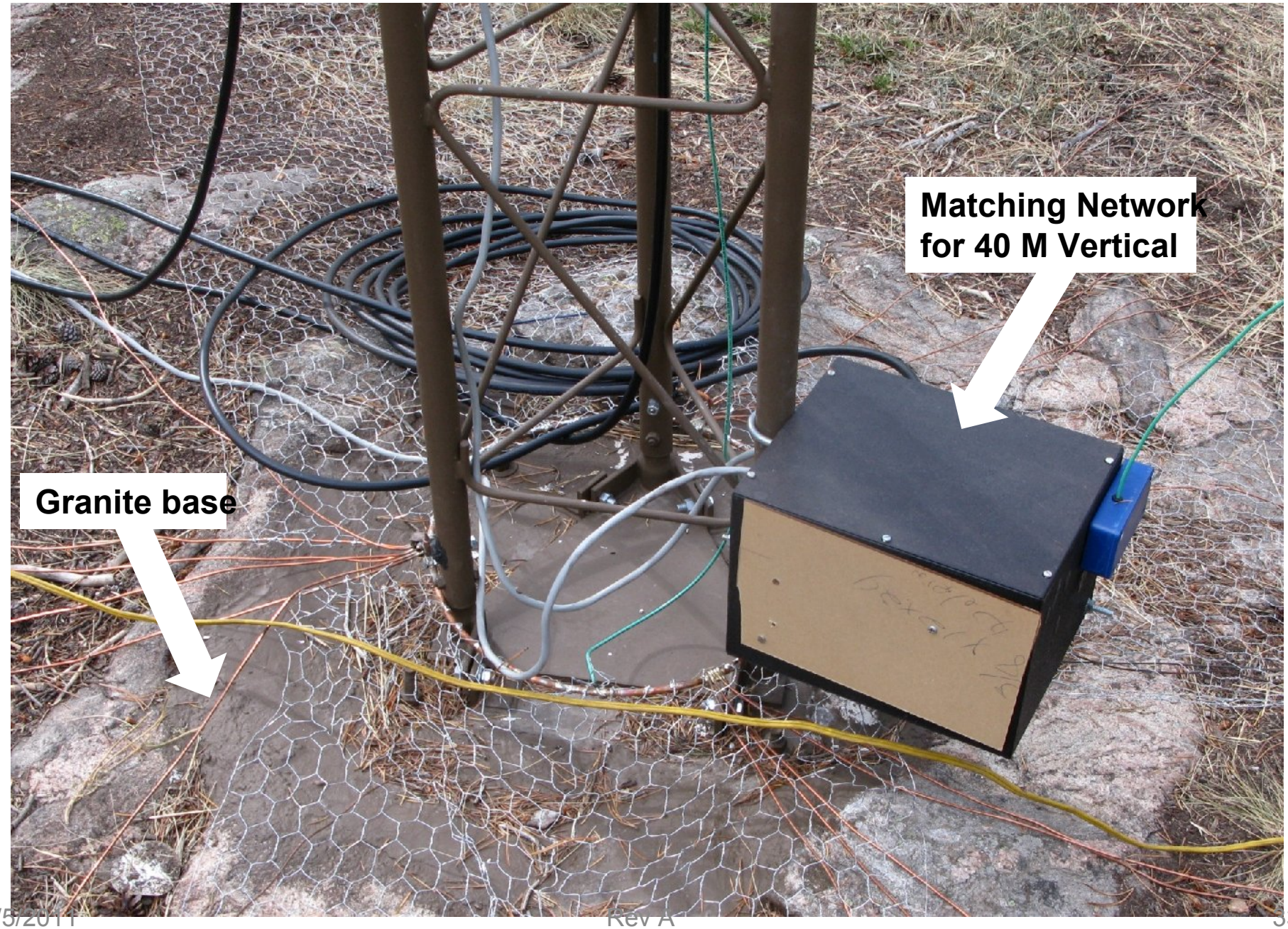


N0CU Tower Ground (Distributed)

Both Lightning and RF ground needed

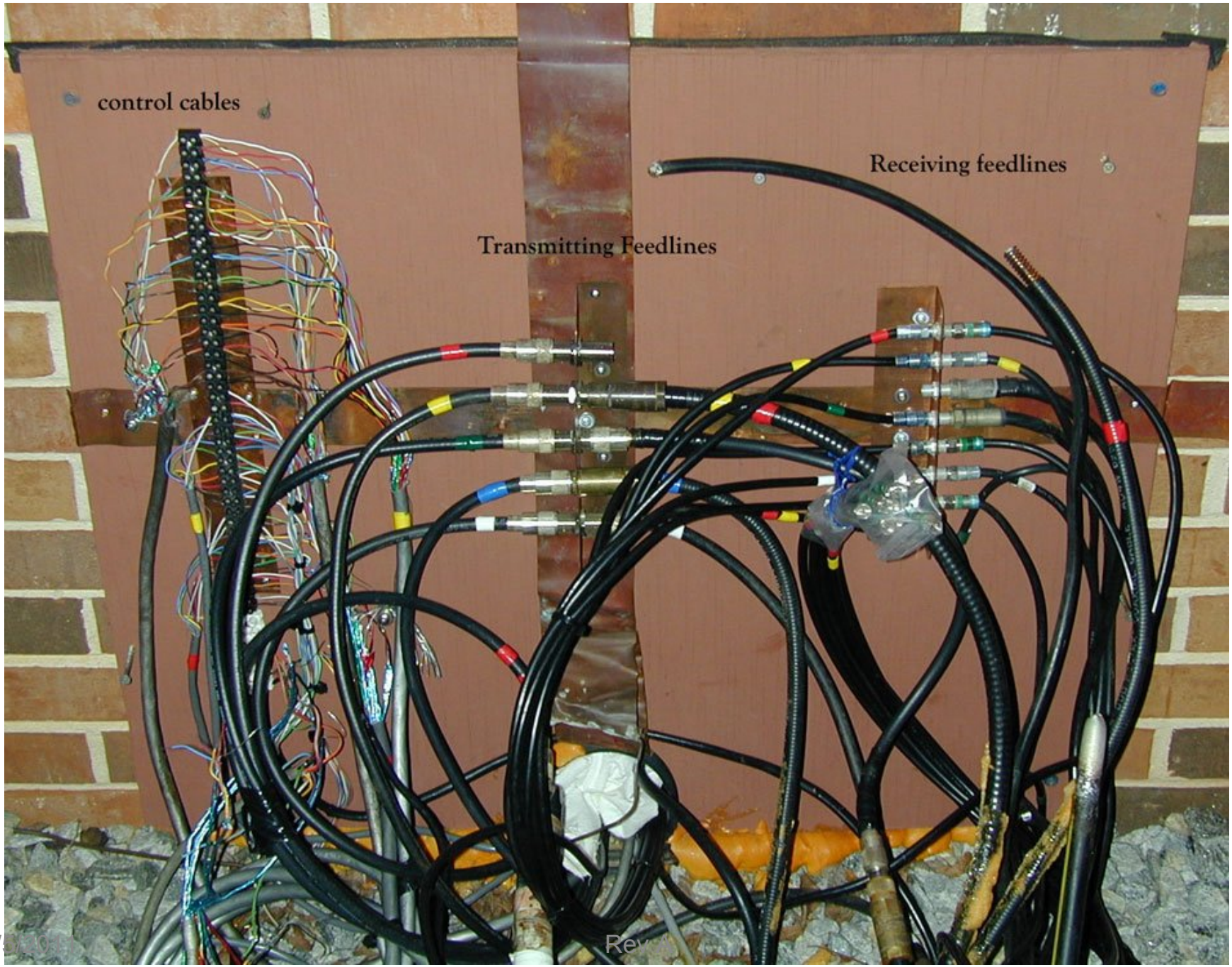


N0CU Tower Ground (continued)



N0CU Tower Ground (continued)

W8JI "Good" Ground at Shack Entrance Point



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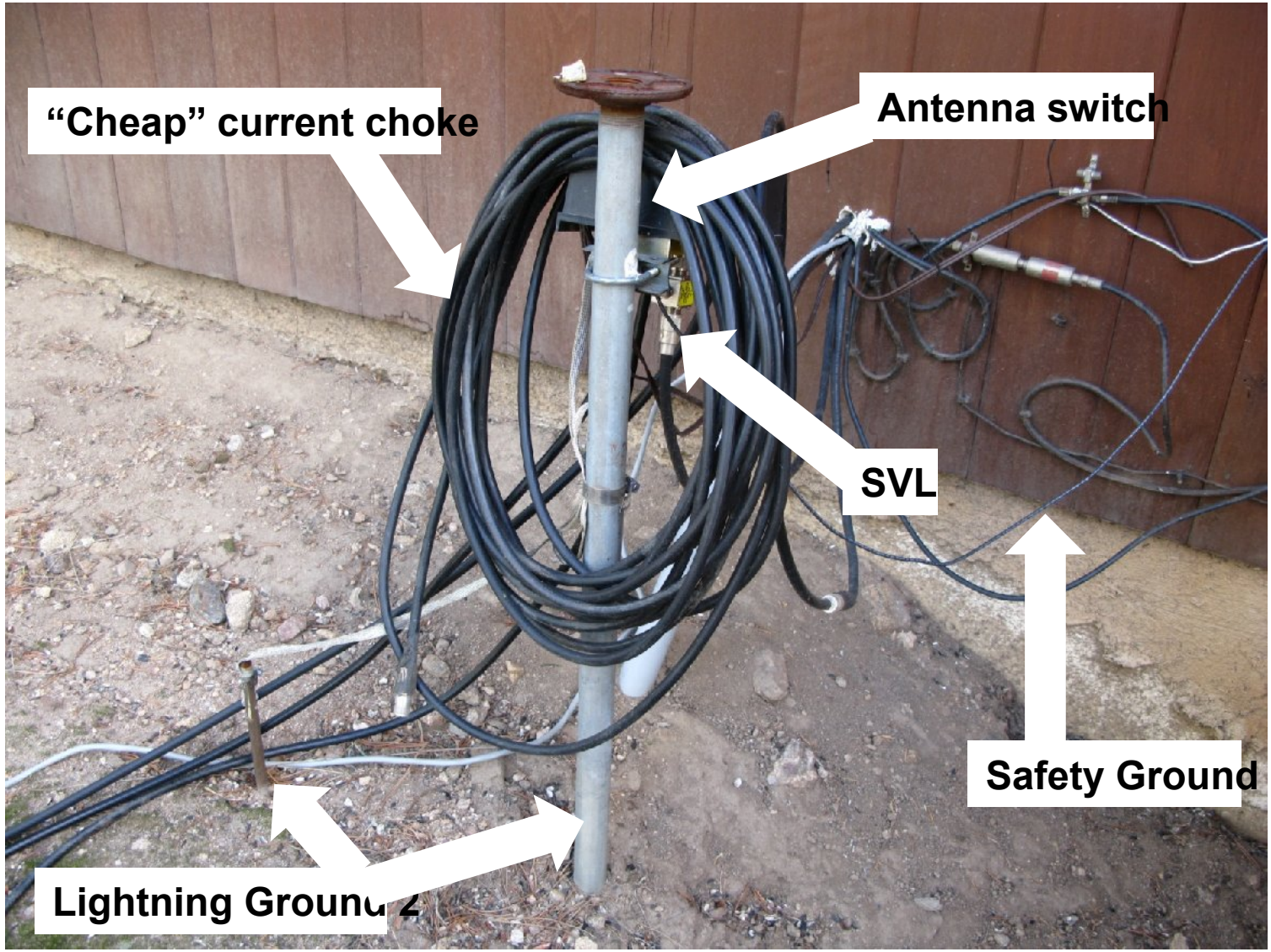
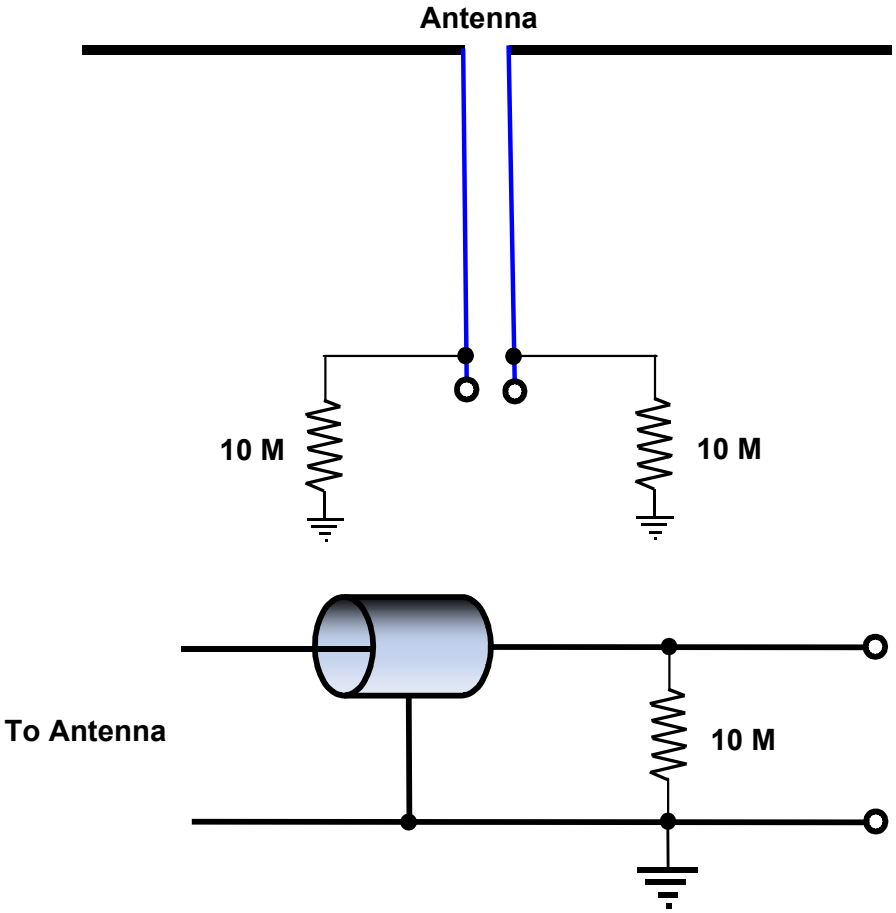


3. Static Ground

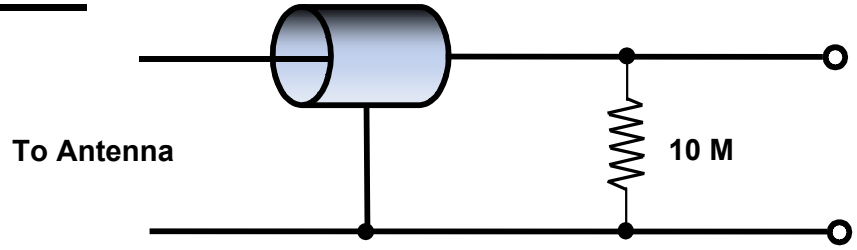
Even a 2 M beam can build up enough voltage to jump the gap on a PL-259 connector!

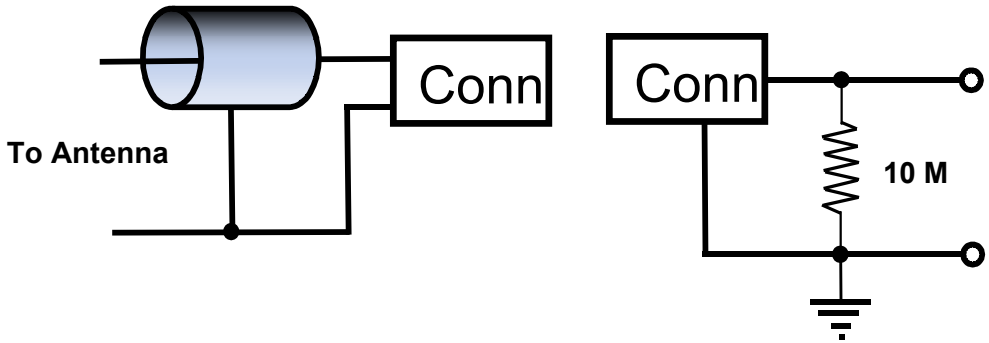
What works!

All static charge must be bled ***to ground***!



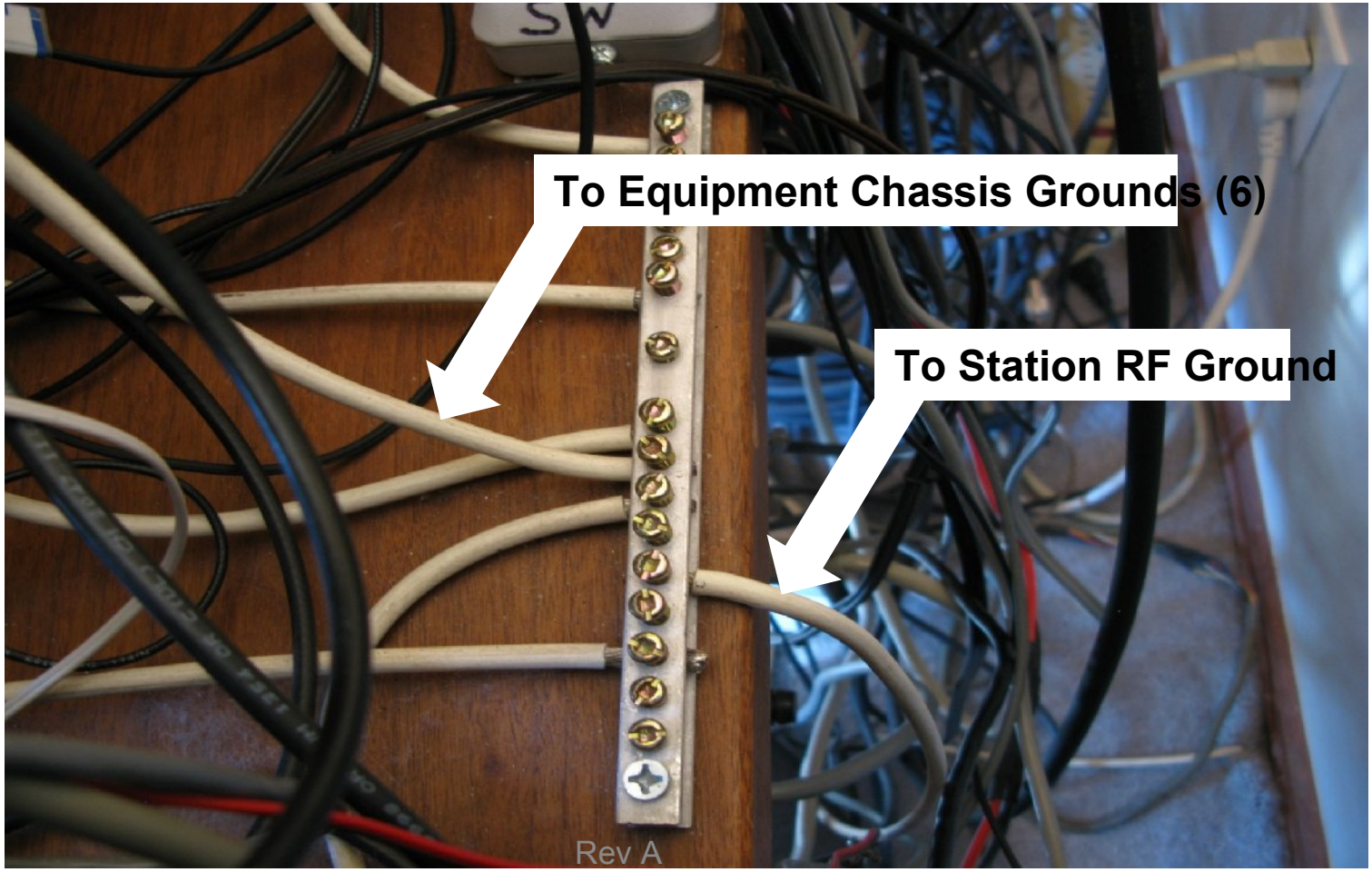
What does *not* work!





4. Single Point Ground (SPG)

- SPGs are used to:
  - ***Reduce the effects*** of audio/RF loops
    - SPGs do ***not*** eliminate loops
  - Improve effectiveness of AC line filters
- Satellites are designed to have <1 milliohm box-to-SPG



5. RF Grounds

- What is meant by “Ground”?:
  - an electrical connection to Earth,
    - For lightning
  - a third conductor in a power distribution system,
    - For safety
  - a common return point within a circuit or piece equipment,
  - the “RF return" for an unbalanced antenna like a vertical or a single ended longwire
  - RF return for common mode currents induced into an antenna feedline
  - ?
- Even a “good” Ground is ***not*** a "sink" into which all unwanted RF and noise can be poured, never to bother us again
  - ***“An electrical connection to an Earth ground is rarely part of a solution to RF or noise problems”***

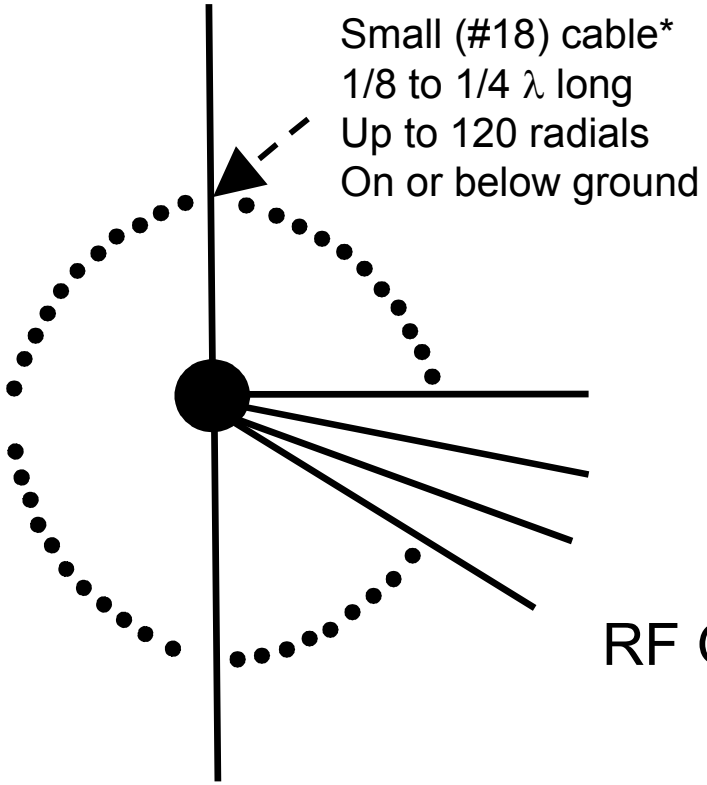
5. RF Grounds

- Antenna RF ground:
  - Needed for **Unbalanced antennas** (ie, ground mounted verticals):
    - A good RF ground is needed to optimize ***match & efficiency***
      - Only affects the "near field" performance (match & efficiency)
        - "Near Field" is 1 to 10^{+} wavelengths from the antenna
      - Does not affect the pattern
    - Distributed set of radials
      - Above ground (counterpoise)
        - Radials may need to be "tuned" for a given band
        - Better for RF
        - Worse for lightning
      - Below ground
        - Better for lightning
        - Worse for RF
        - Corrosion?
      - A ground rod is not an effective ***RF*** ground
    - A **Balanced antenna** should **not** need a good ground in the near field

5. RF Grounds

- Station RF ground:
  - Used to mitigate RF-in-the-shack problems
  - Radials under/near station is the best approach
    - Distributed set
      - Same as for vertical antenna
    - Inductance or resonance of wire connecting radio to the counterpoise can seriously degrade it's effectiveness
      - Tuned (or resonant) ground may help in some situations
        - Also called "***Artificial***" ground
          - MFJ-931 (~$110 new)
            - **3.9/5** on **eHam** (seems to work OK, but poor quality control)
  - A ground rod is not an effective ***RF*** ground

Station RF Ground



RF Ground Resistance vs Number of ¼ λ Radia

#	Ohms
2	28
30	12
120	7

*Galvanized chicken wire also works well

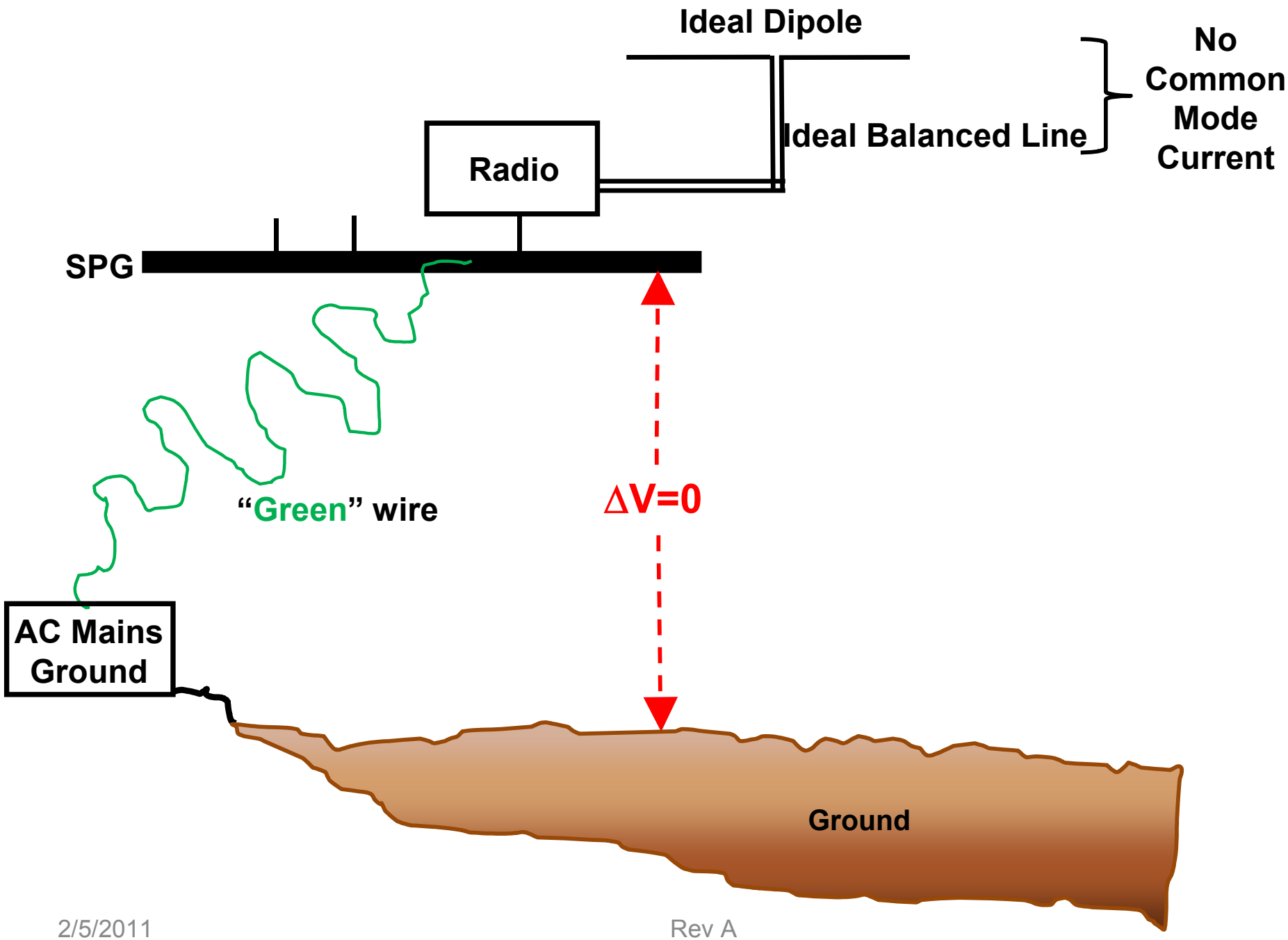
Some Symptoms of RF-In-The-Shack

- Microphone bites (nasty RF shock, usually on the lips)
- Gritty and or fuzzy transmit audio modulation (distortion)
- Malfunction of electronic keyer (sending wrong characters)
- RF shock when touching metallic objects within the shack
- Power supply jitters (the regulated power supply becomes un-regulated!)
- Crazy SWR meter readings
    - Readings that vary as your hand is moved over some equipment
- Desktop computer going crazy
- PC Desktop monitor jitters
- Fluorescent lamp flicker
- Lamps that INCREASE in brightness when transmitting
- Active TTL switch circuit going crazy (turning ON-OFF-ON by itself)
- Inactive panel meters of separate equipment moving on their own
- When transmitting, a distorted audio is heard over the amplified speaker of the PC desktop
- Radio Frequency Interference (RFI)
-
-

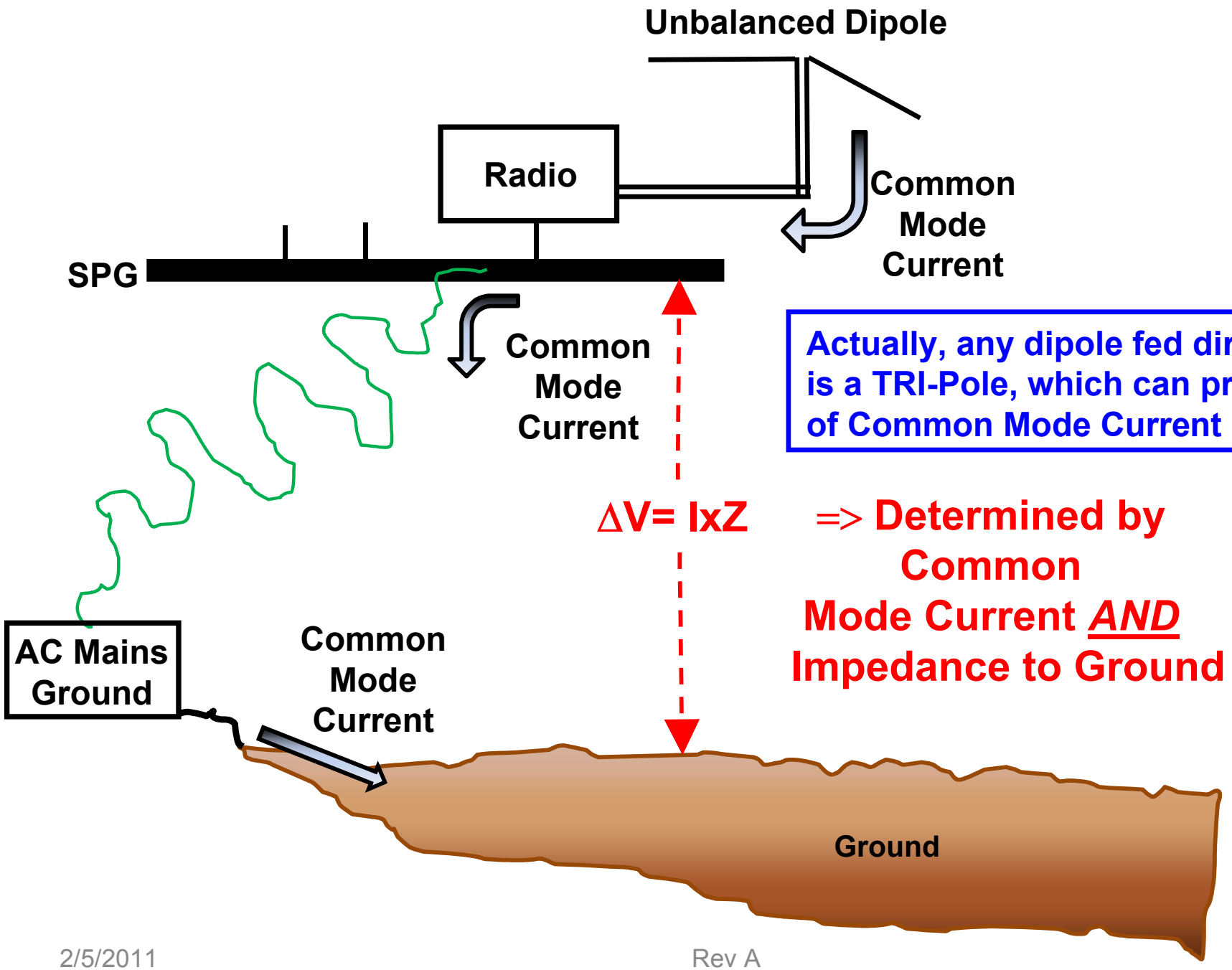
Some Causes of “RF-In-The-Shack” Problems

- Antenna feedlines that have high levels of "***common-mode current***“
- ***Antennas*** that are ***too close*** to the operating position
  - A common rule-of-thumb for HF antennas is ***100 feet*** from station
- Equipment with improperly designed/defective:
  - Enclosures
  - Interconnections
  - Input or output ports
  - Internal grounding

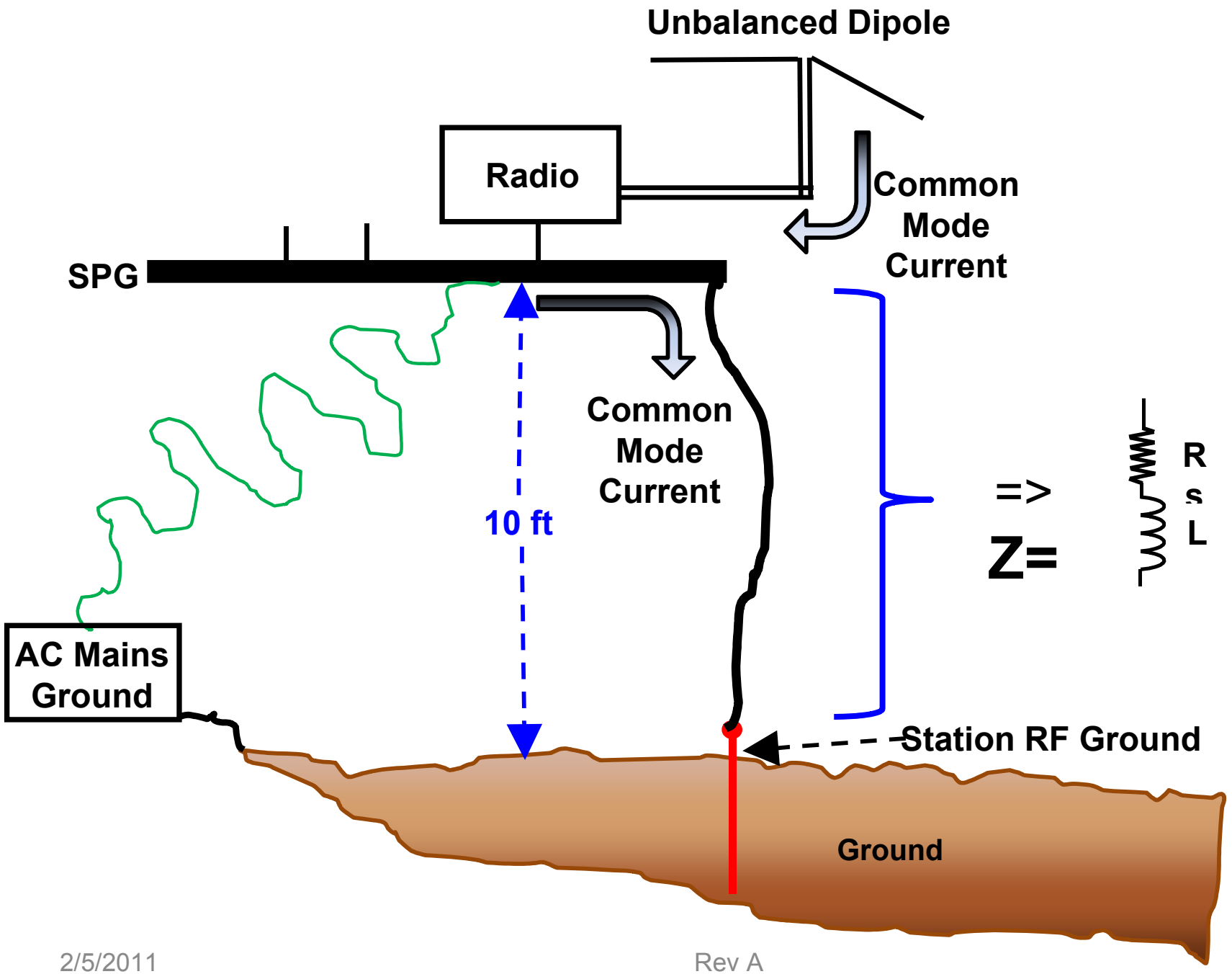
Common Mode Current



Common Mode Current



Station RF Ground



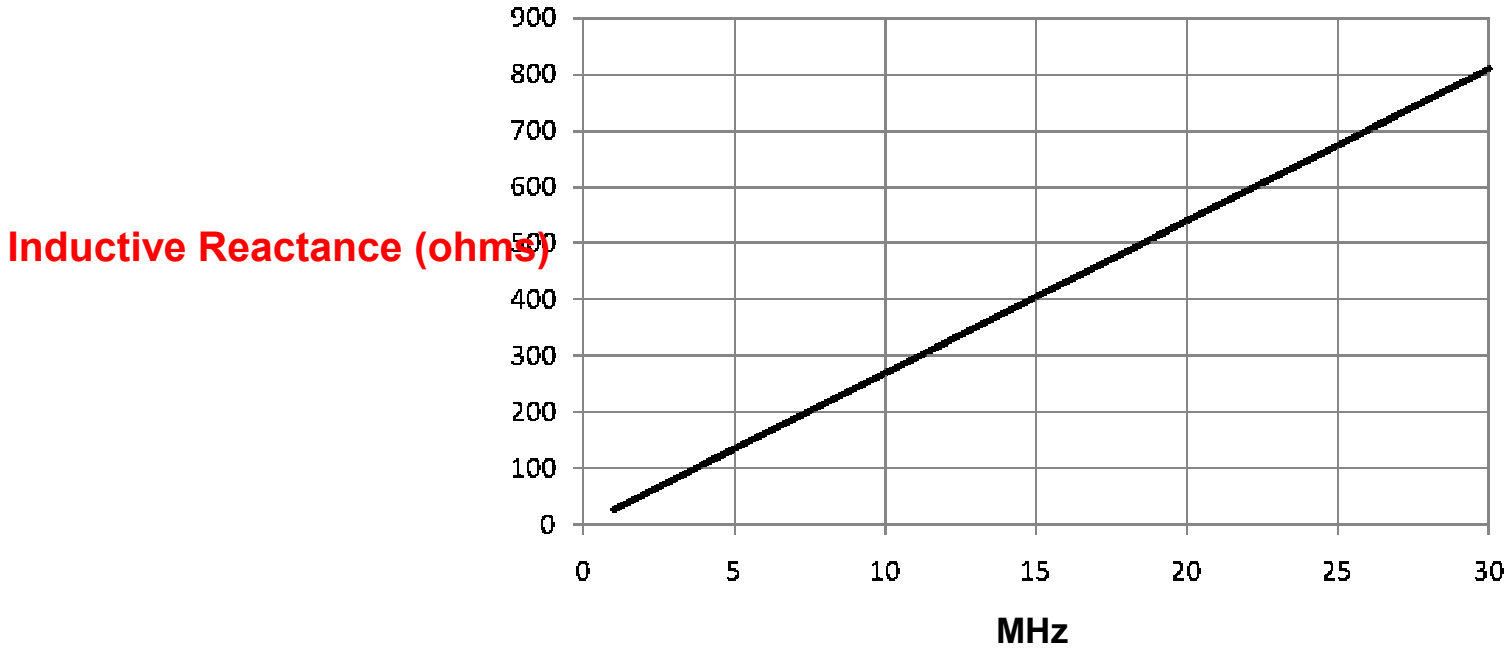
RF Impedance of a Wire

Inductance of a *non*-*resonant* straight wire:

$$L = 2l\left[2.303\log(4l/d) - 1 + \mu/4 + (d/2l)\right]$$

For ***10 ft*** of **0.2 in** diameter cable:

L = 4.3 uH



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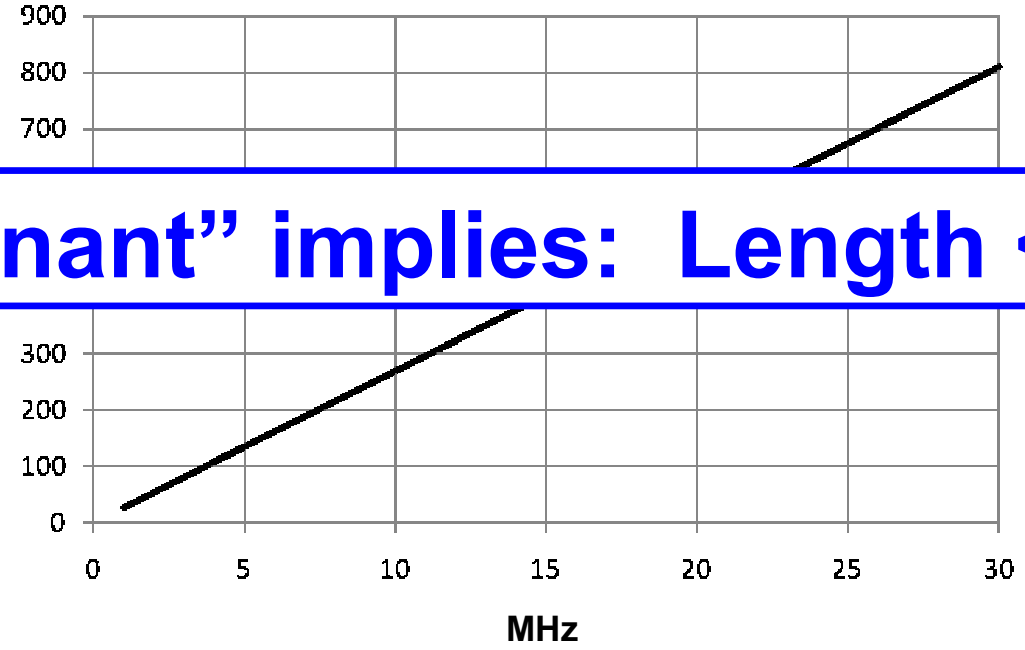
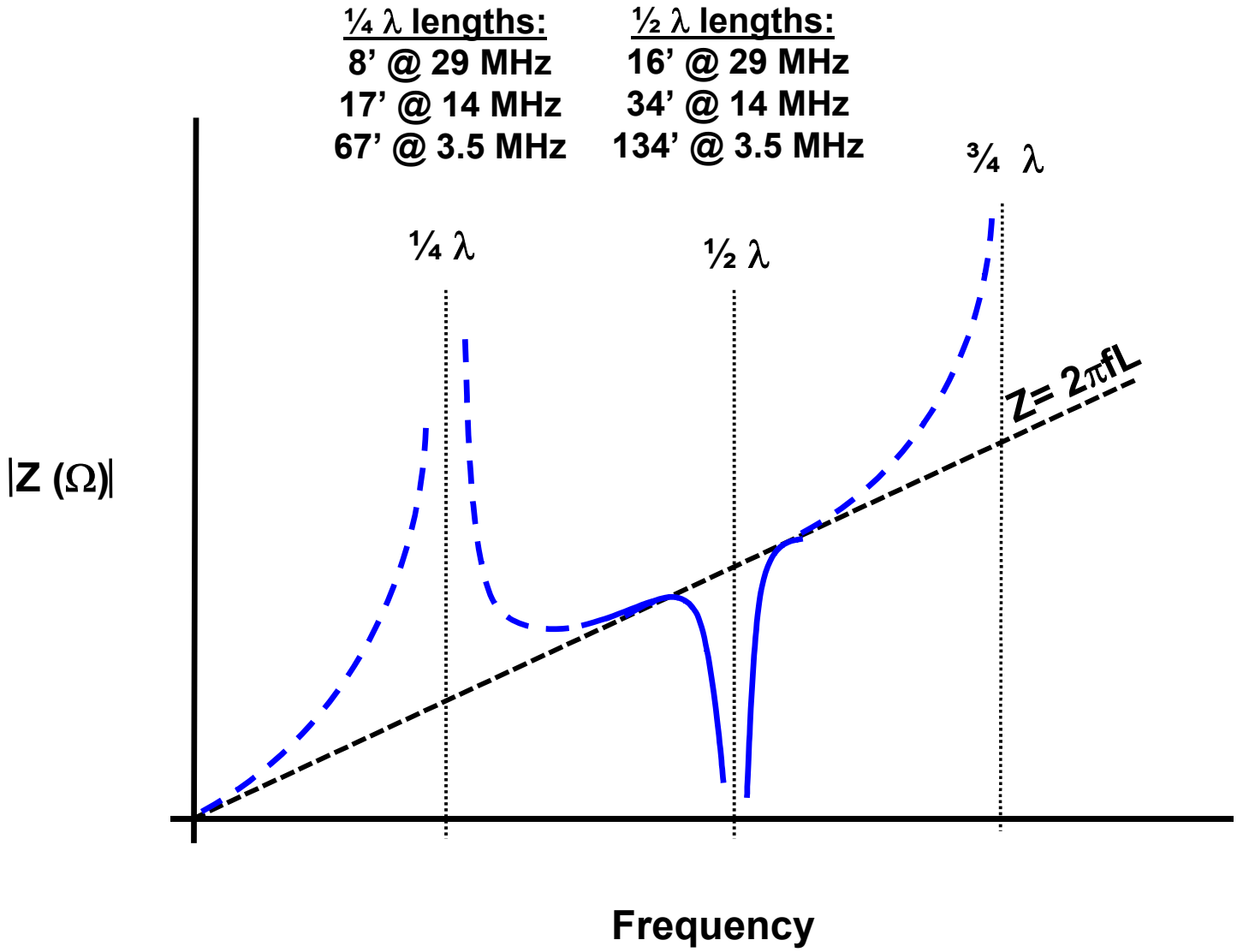
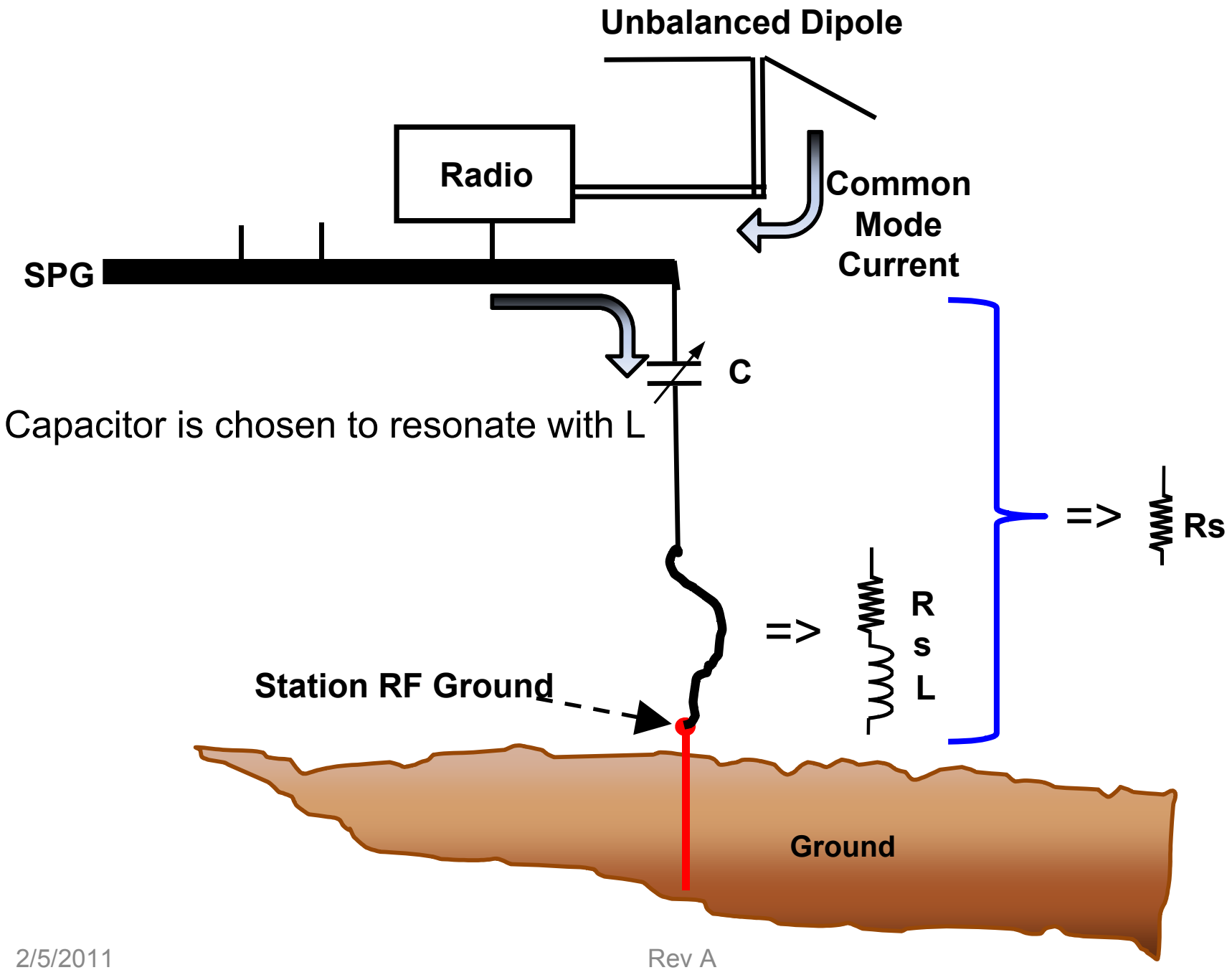


"Non-resonant" implies: Length < 1/10 λ

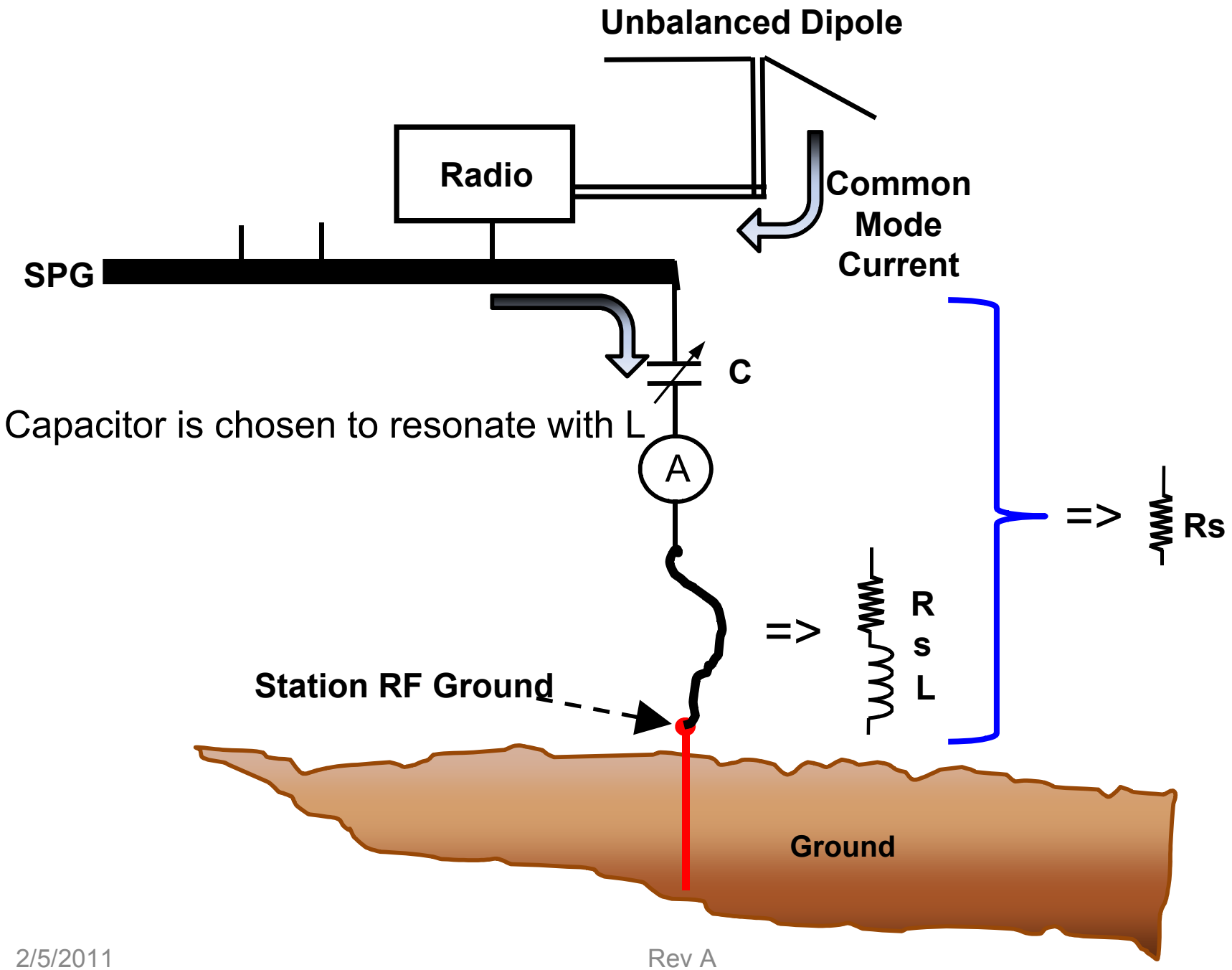
Impedance of a straight wire connected to *ground*:



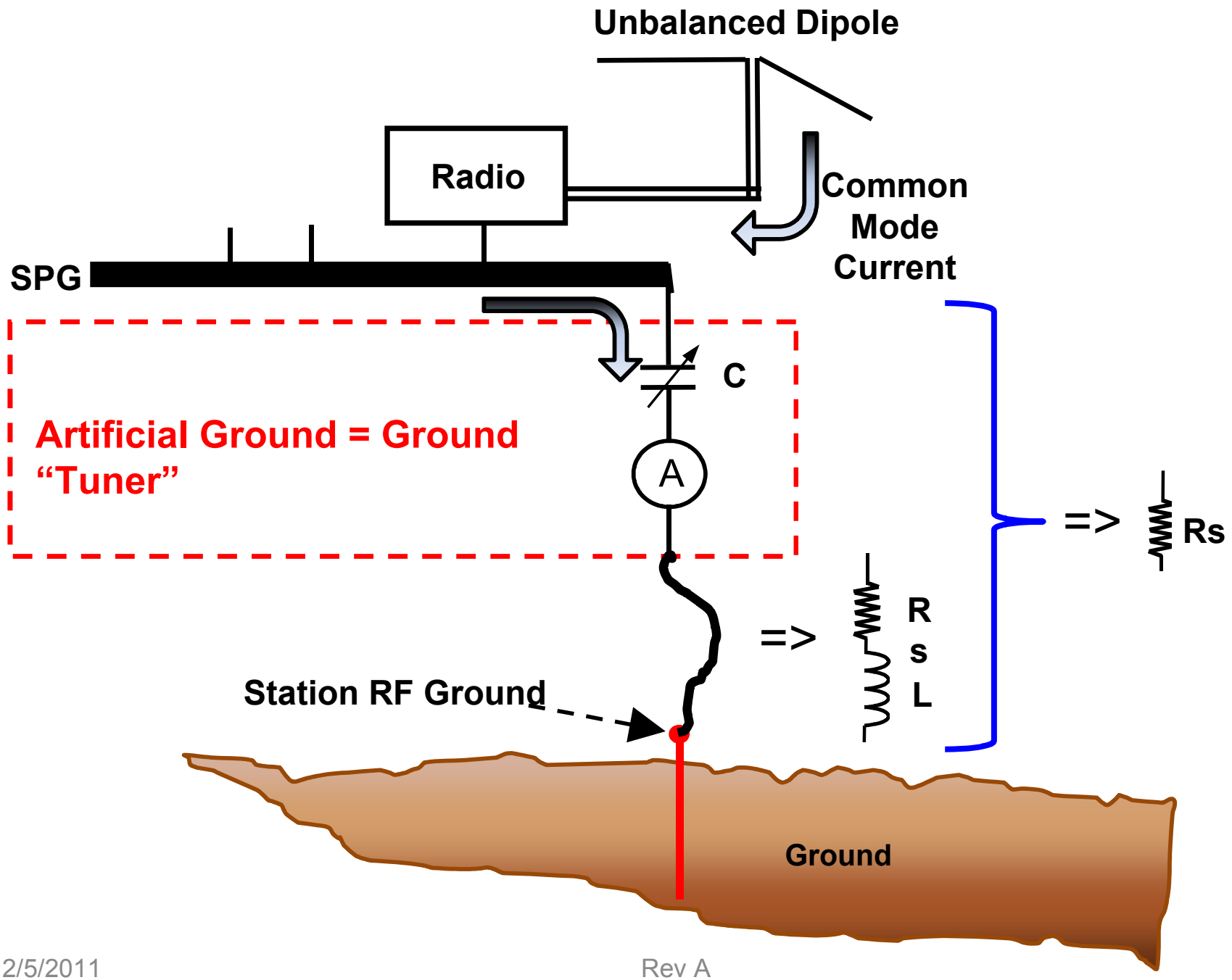
Resonant Ground



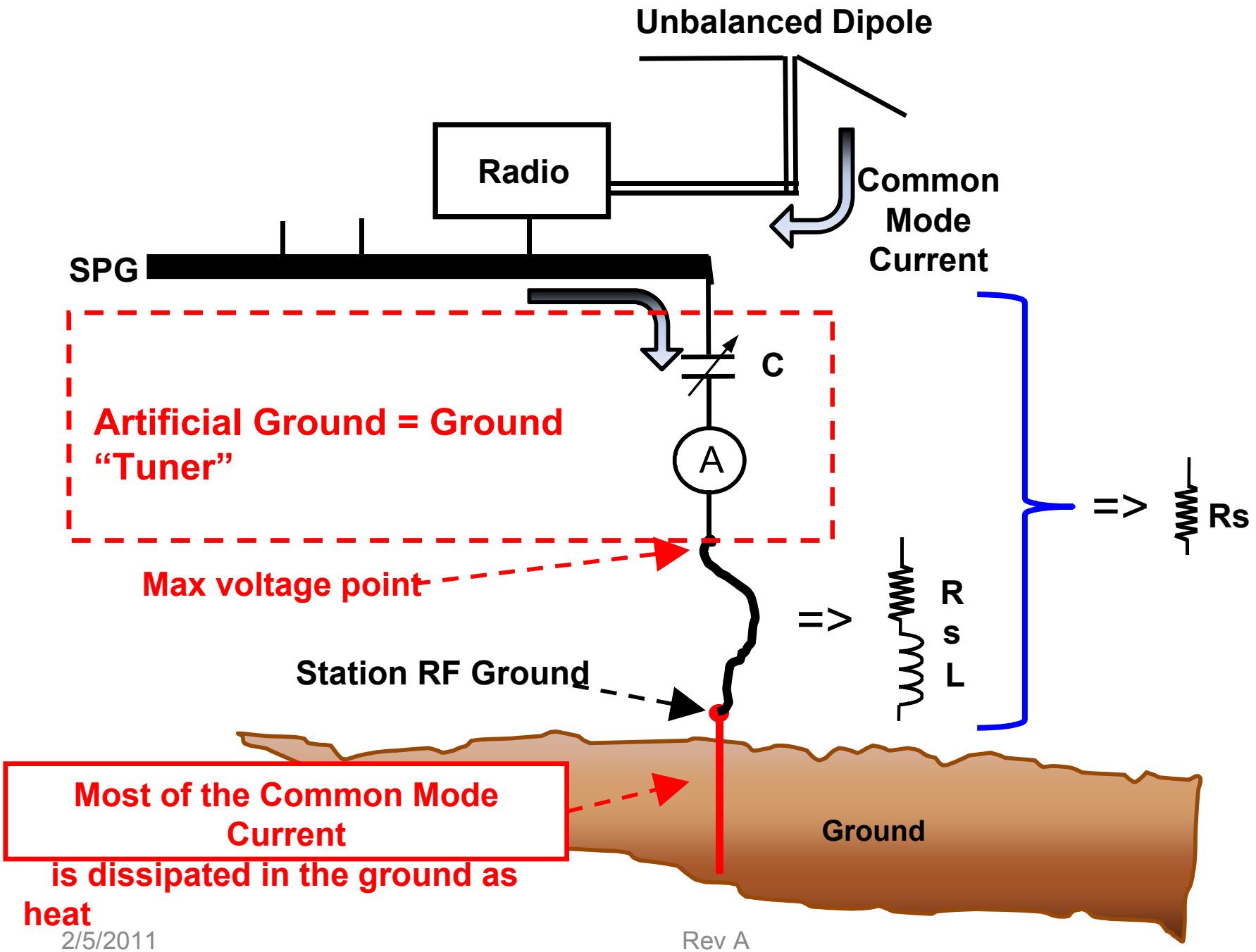
Resonant Ground



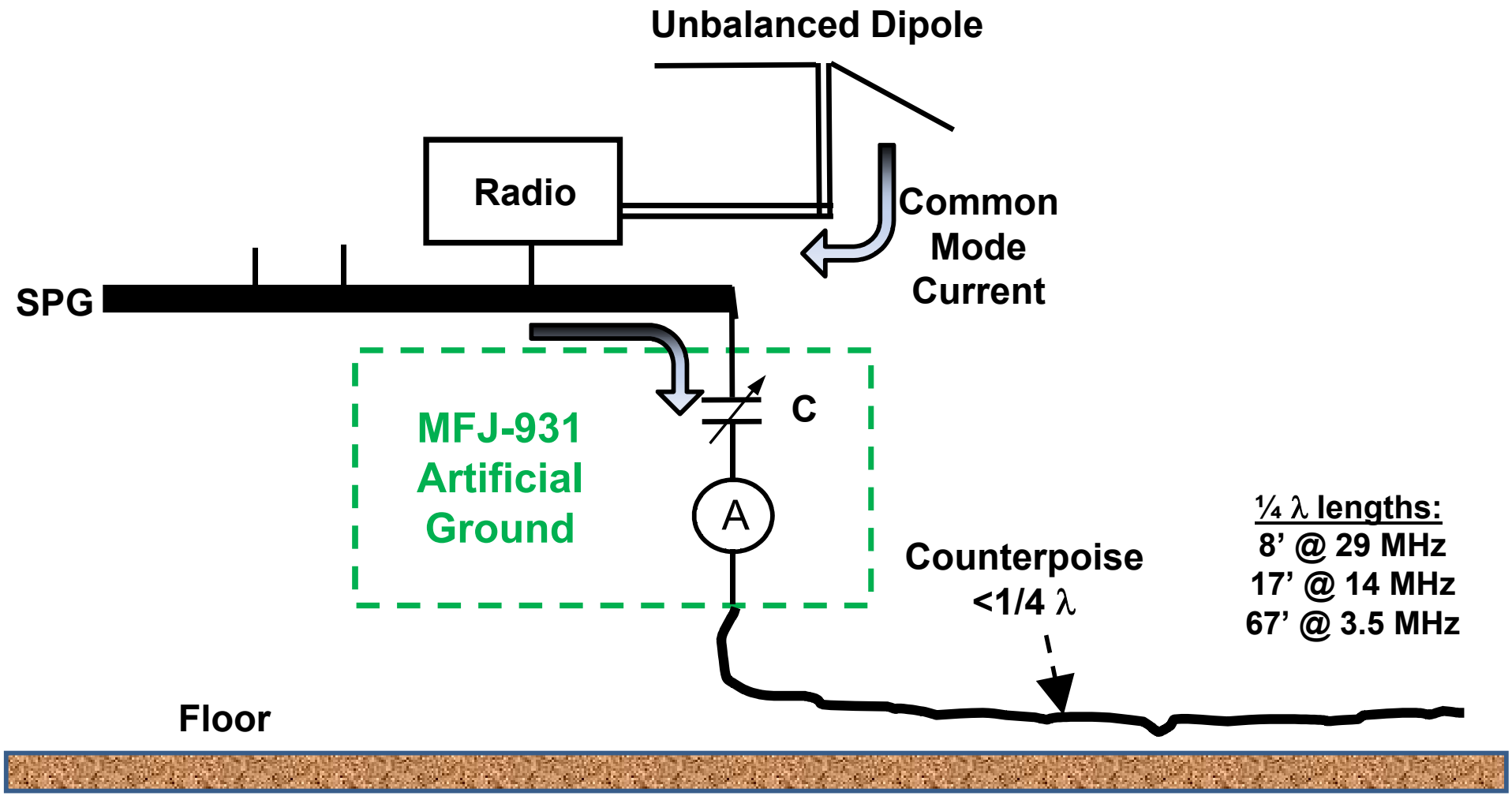
Artificial Ground



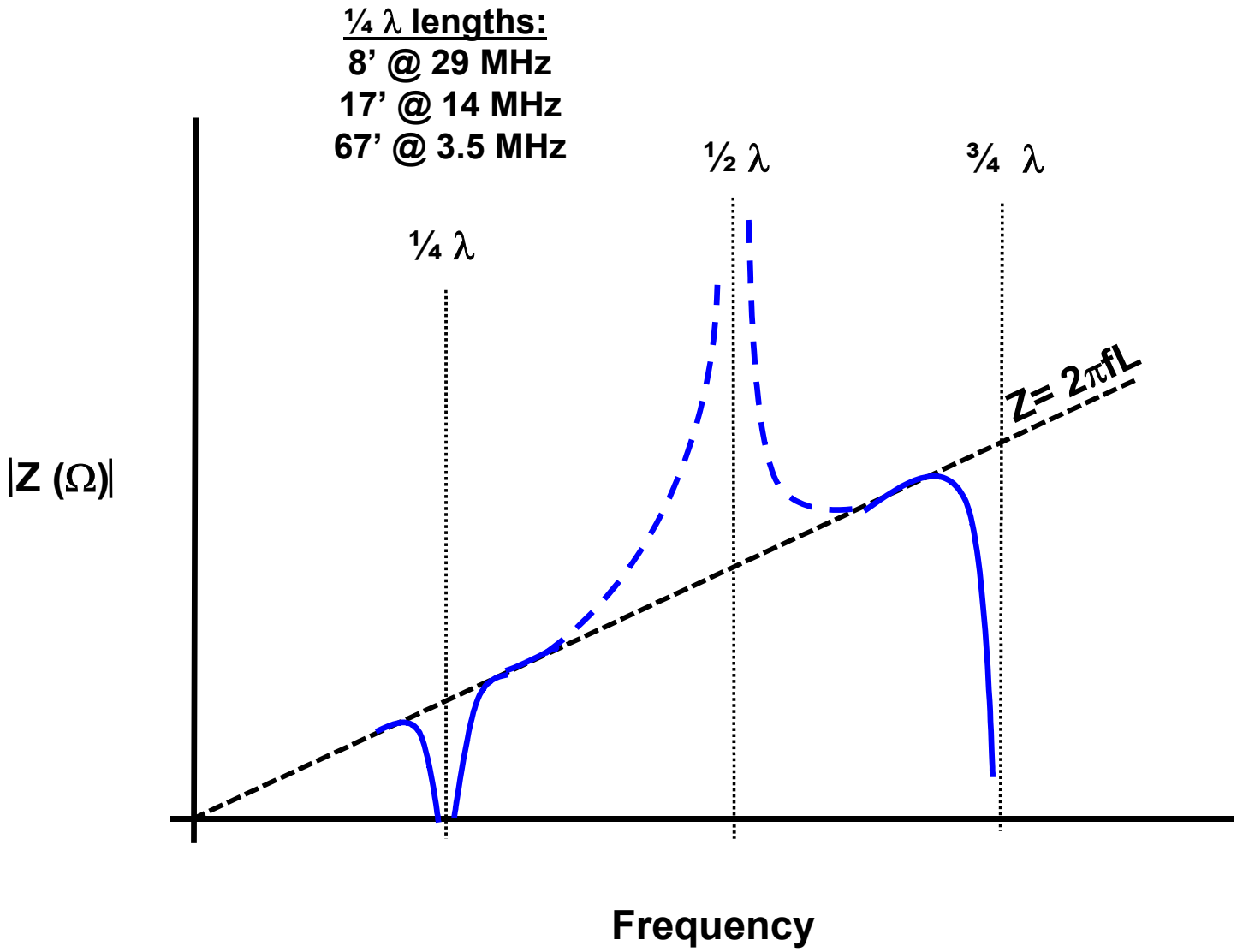
Artificial Ground



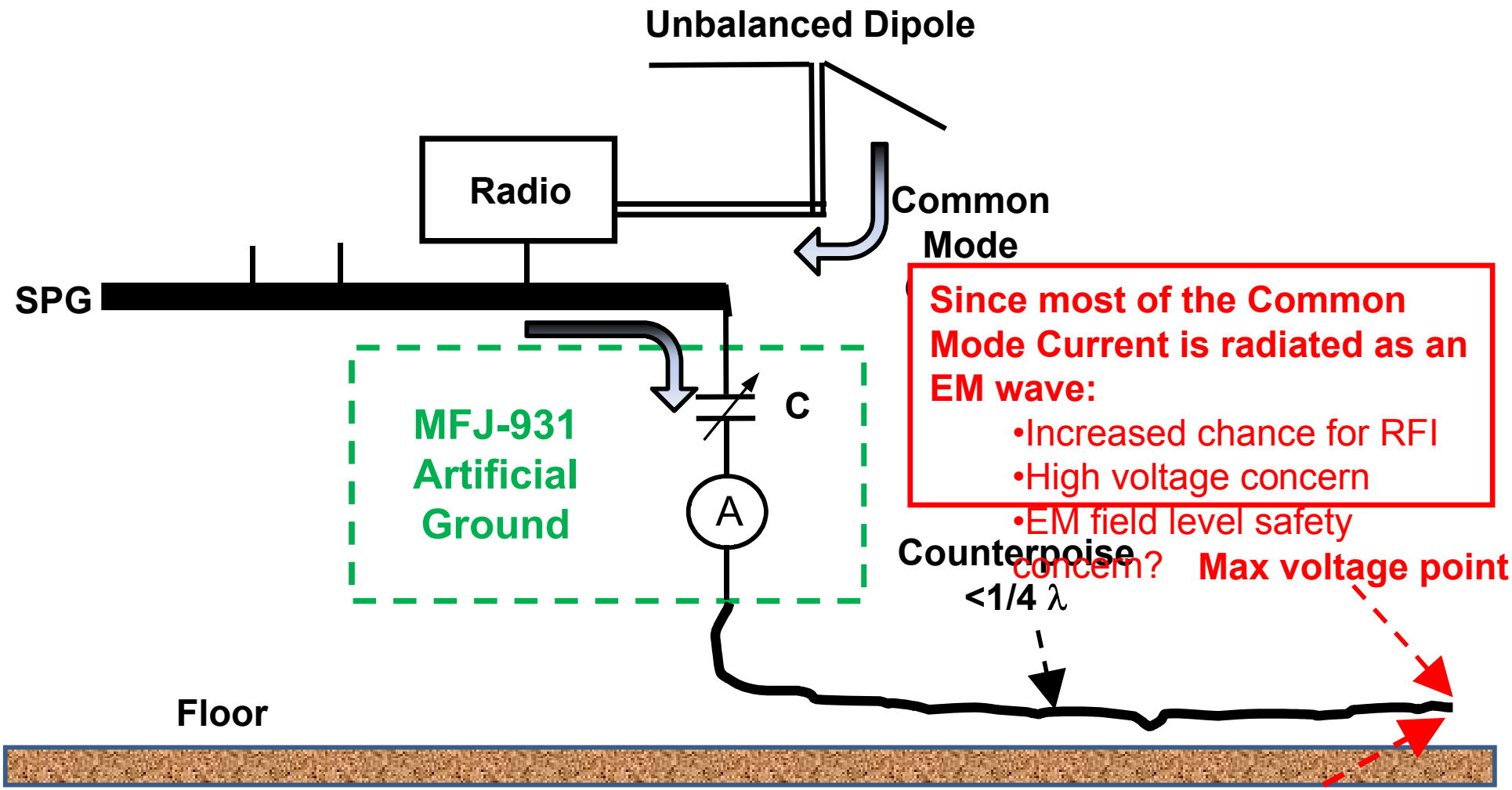
Artificial Ground



Impedance of an open-ended straight wire:



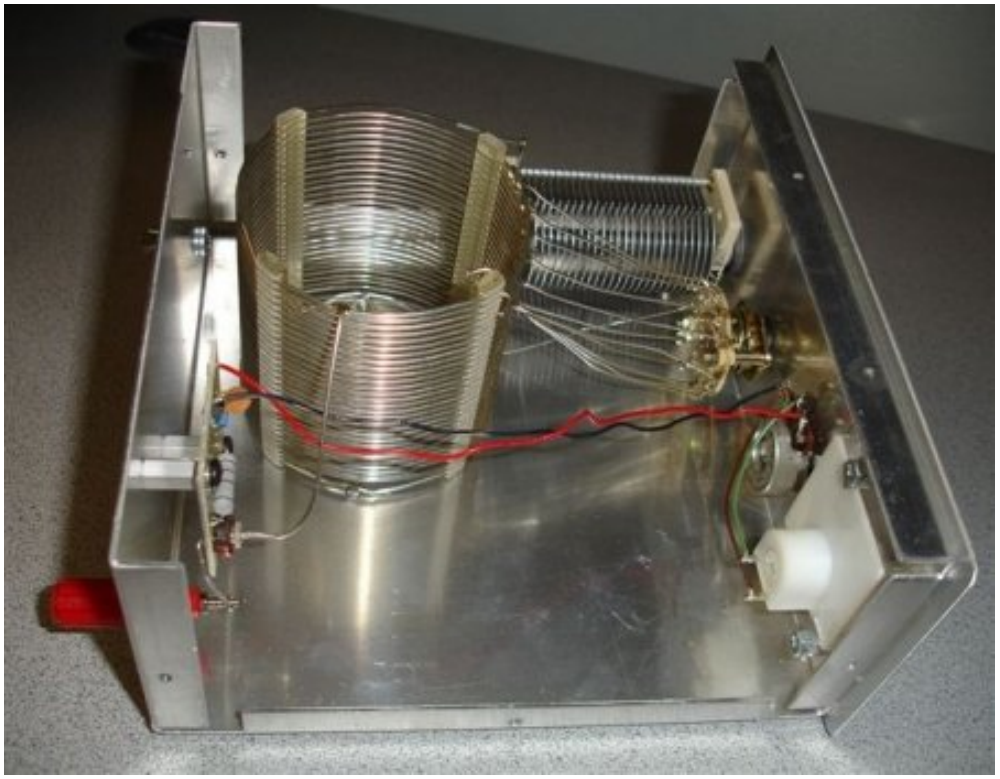
Artificial Ground



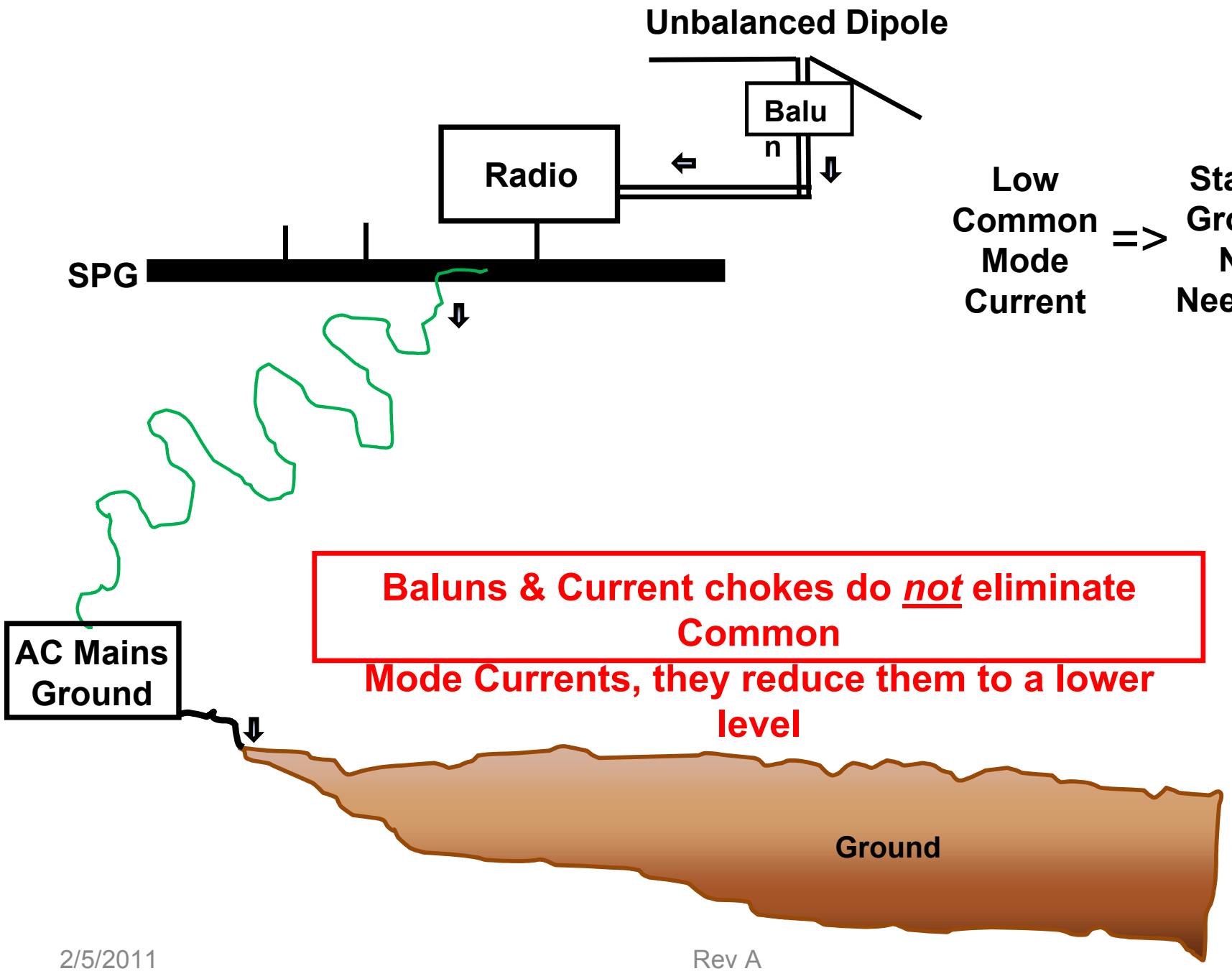
MFJ Operation Manual Caution Note:

DANGER: Touching the wire while keying can cause RF burn and is potentially fatal. Watch out for children and pets.

MFJ-931 Artificial Ground



Choke/Balun = Better Solution than a Station RF Ground



Station RF Ground

Bottom Line:

- Since most, but not all, RF-in-the-shack problems are caused by improper antenna implementation:
  - Maintain balanced (or unbalanced) impedances at all interfaces
  - Maintain adequate separation between antennas and station equipment
- The quality of the RF ground is usually not the *primary* issue
- The best cure for RF-in-the-shack problems:
  - Keep all equipment at the same potential (ie, a good SPG), and
  - Keep all unwanted RF currents outside the shack

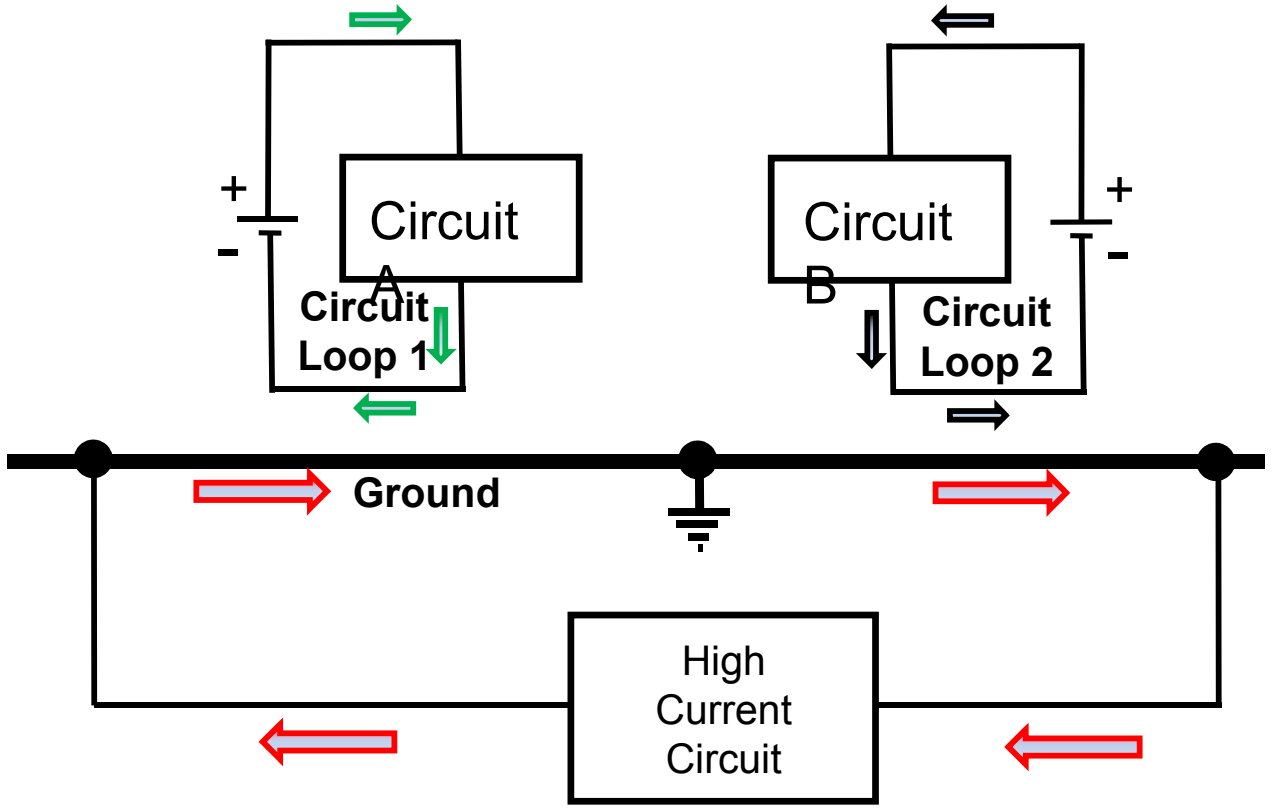
Loops

- **Circuit Loops** always exist (by definition)
  - "GOOD" Loops vs. "BAD" Loops
- Problems with Loops can arise when:
  - 1) Two or more Loops share a ***common impedance***, ***and*** there is a current flow that generates ***a common voltage in those circuits***
    - Usually more of a problem at low frequencies
  - 2) There is ***sufficient Loop AREA*** to pickup ***interfering RF signals***
    - Usually more of a problem at high frequencies
    - The larger the Loop, the greater the chance of a problem
- Unwanted **Ground Loops** almost always exist, but don't always cause a problem
  - A Ground Loop is defined as ???
    - A circuit with more than two connections to "Ground"
- Problem Loops don't always involve a "Ground" Loop
- "RF Feedback" is frequently assumed to be the cause of distorted transmit audio when a low frequency ground loop is the real

Loops (continued)

Two isolated Loops

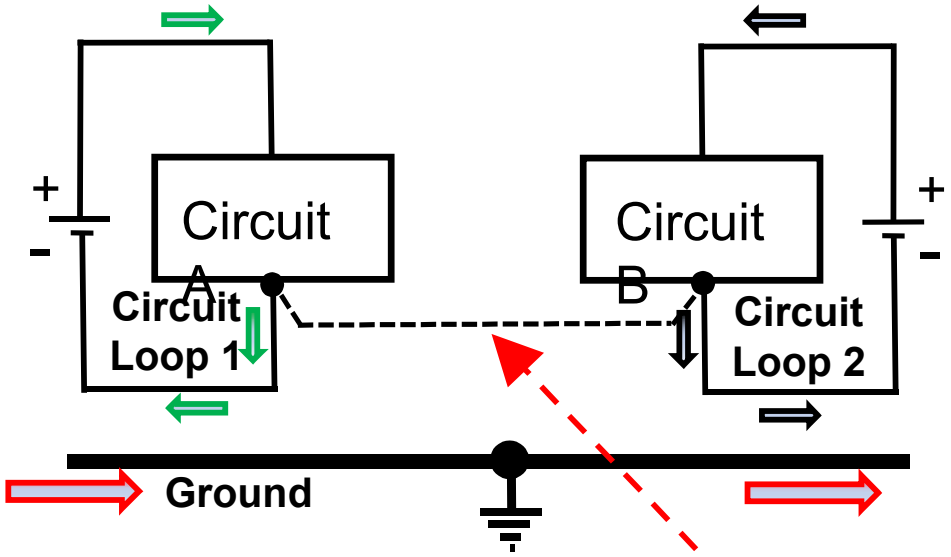
- **No unwanted coupling**



Loops (continued)

Two connected Loops

- **No unwanted coupling**

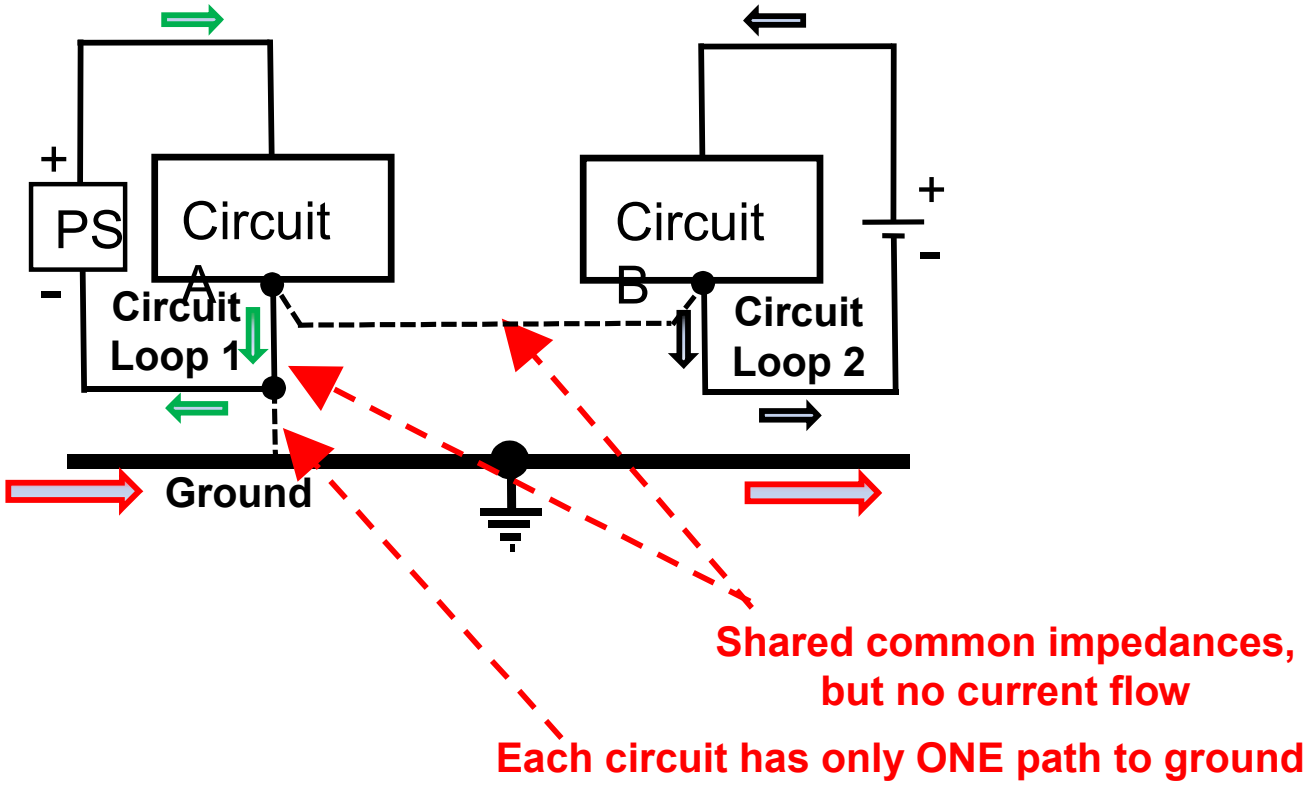


- **Shared common impedance, but no current flow**
- **Current flow requires a closed loop around a voltage source**

Loops (continued)

Two connected Loops connected to ground

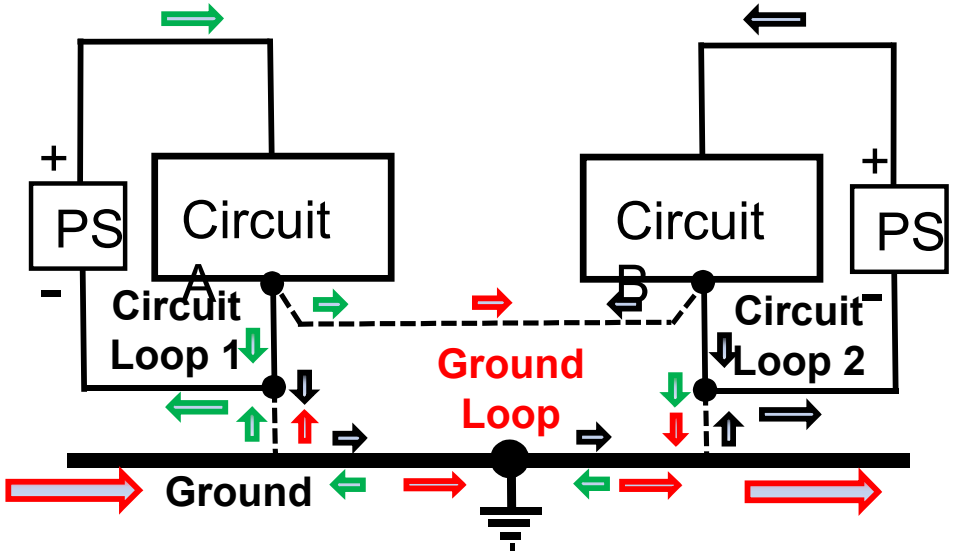
- **No unwanted coupling**



Loops (continued)

Two Mutually Coupled Loops with a Ground Loop

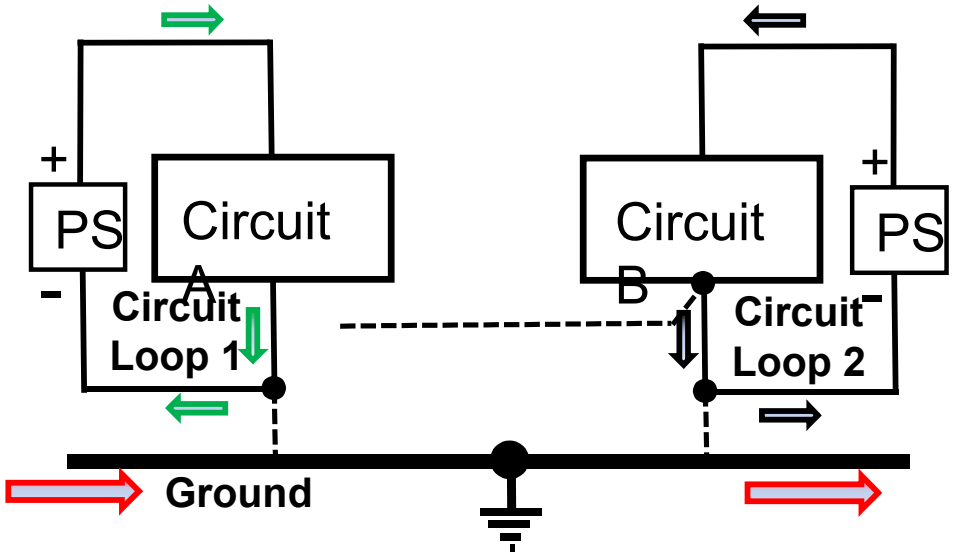
- **Possible problems from any/all of three sources**
  - **Division of circuit return currents**
  - **Loop antenna for RF pickup**
  - **Injection of noise voltages from ground currents**



Ideally, no circuit has more than one path to ground!
(Rarely achievable)

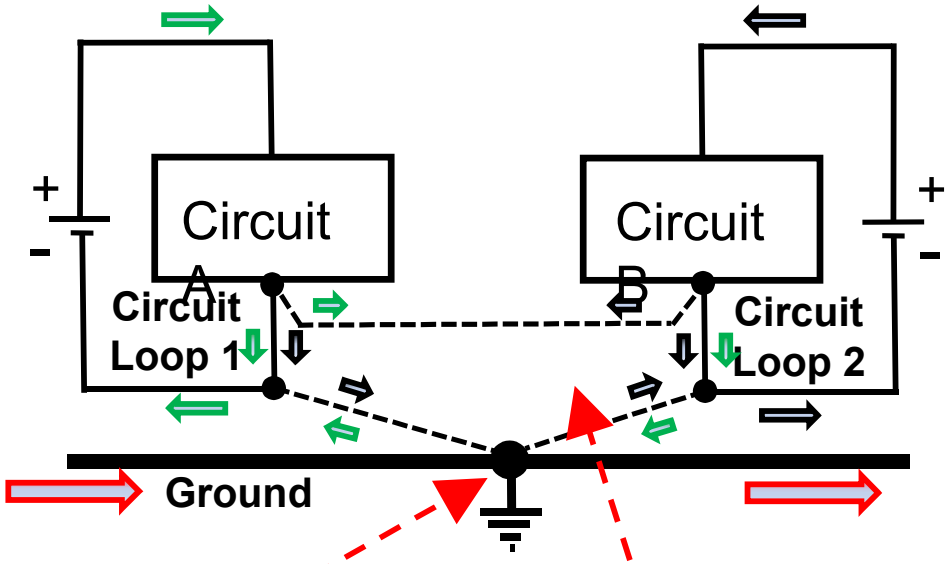
Loops (continued)

- To mitigate problems:
  - **"OPEN" the loop**
    - Sometimes used in audio and low frequency circuits
    - Not a good approach for RF applications



Loops (continued)

- To mitigate problems:
  - **"ISOLATE" signal paths from ground noise**

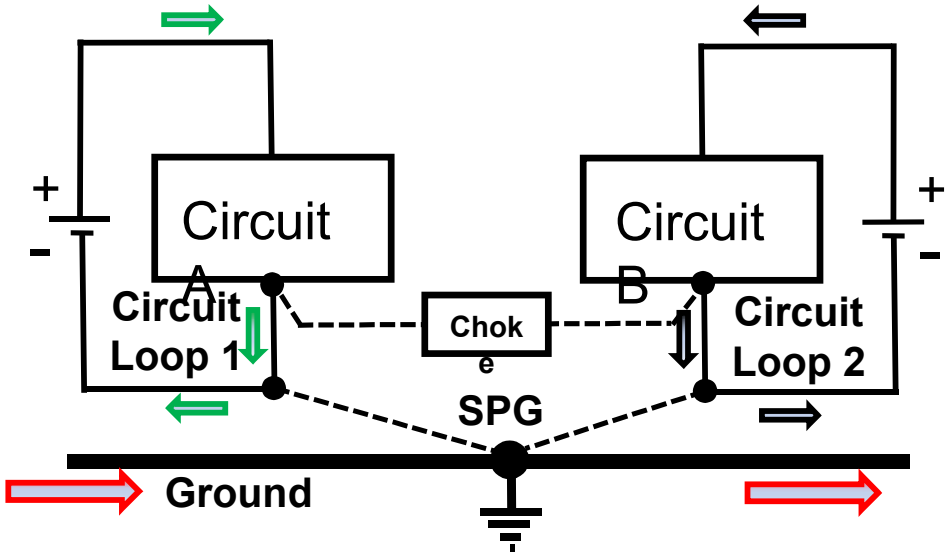


Single Point Ground (SPG)

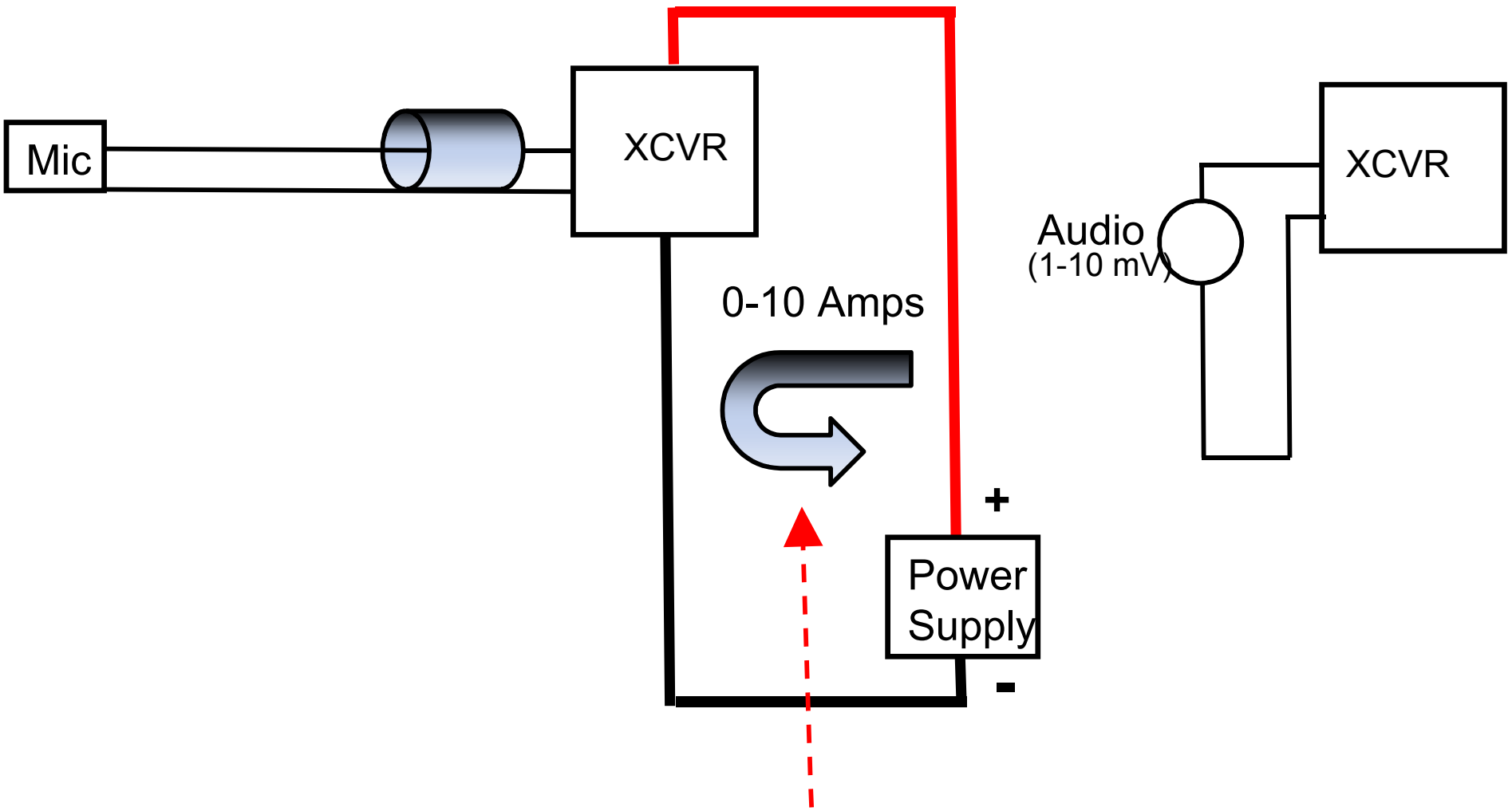
I don't consider this loop a Ground Loop.
To me, it is a Grounded Loop.

Loops (continued)

- To mitigate problems:
  - **"ISOLATE" signal paths from** ground noise and **unwanted coupled signals**
    - Choke solution is hard to implement for low frequency noise

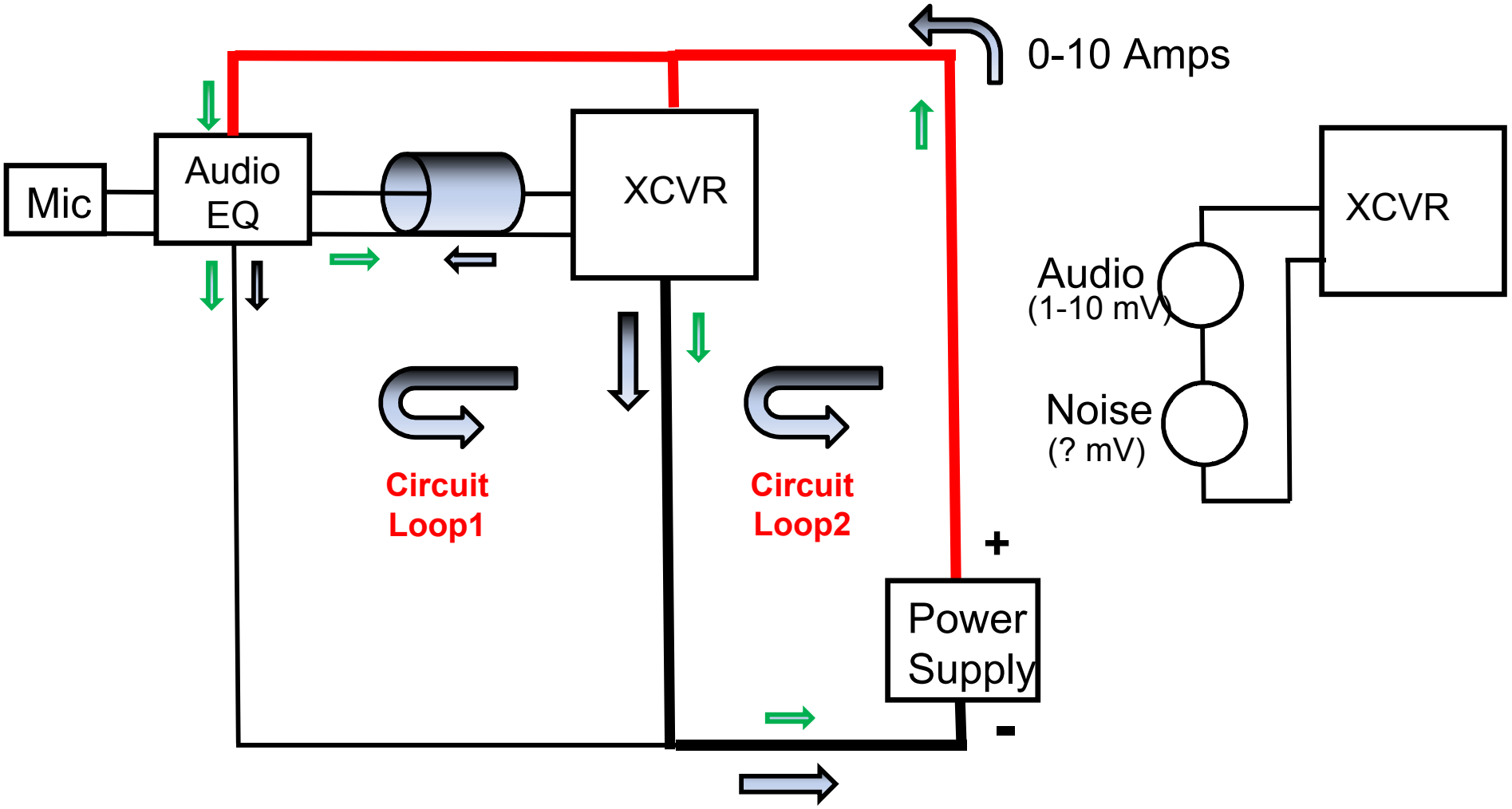


Low Frequency (Audio) Ground Loops



With SSB transmissions, this current varies with modulation

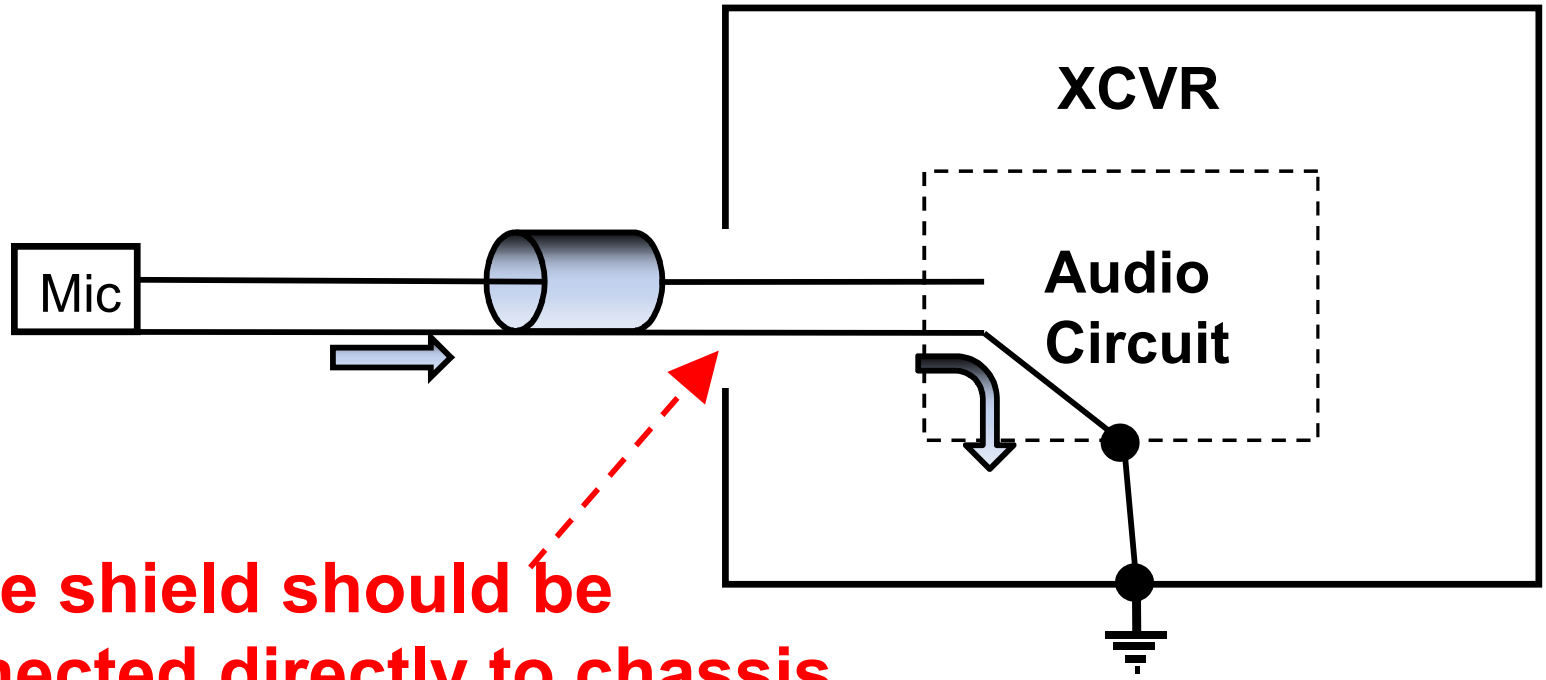
Low Frequency (Audio) Ground Loops



Low Frequency (Audio) Ground Loops

The "Pin 1 Problem":

- Well known in the Audio community
- Common problem in some older Ham gear



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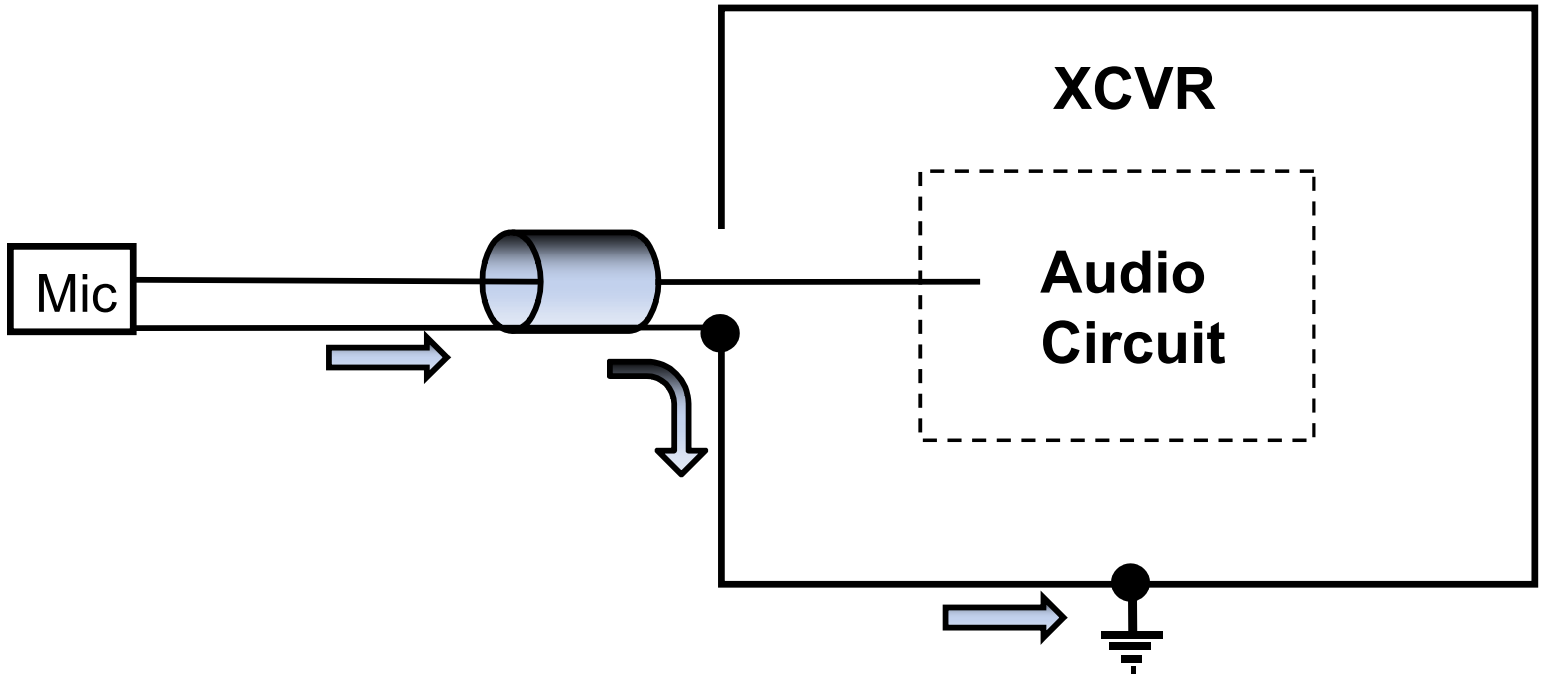
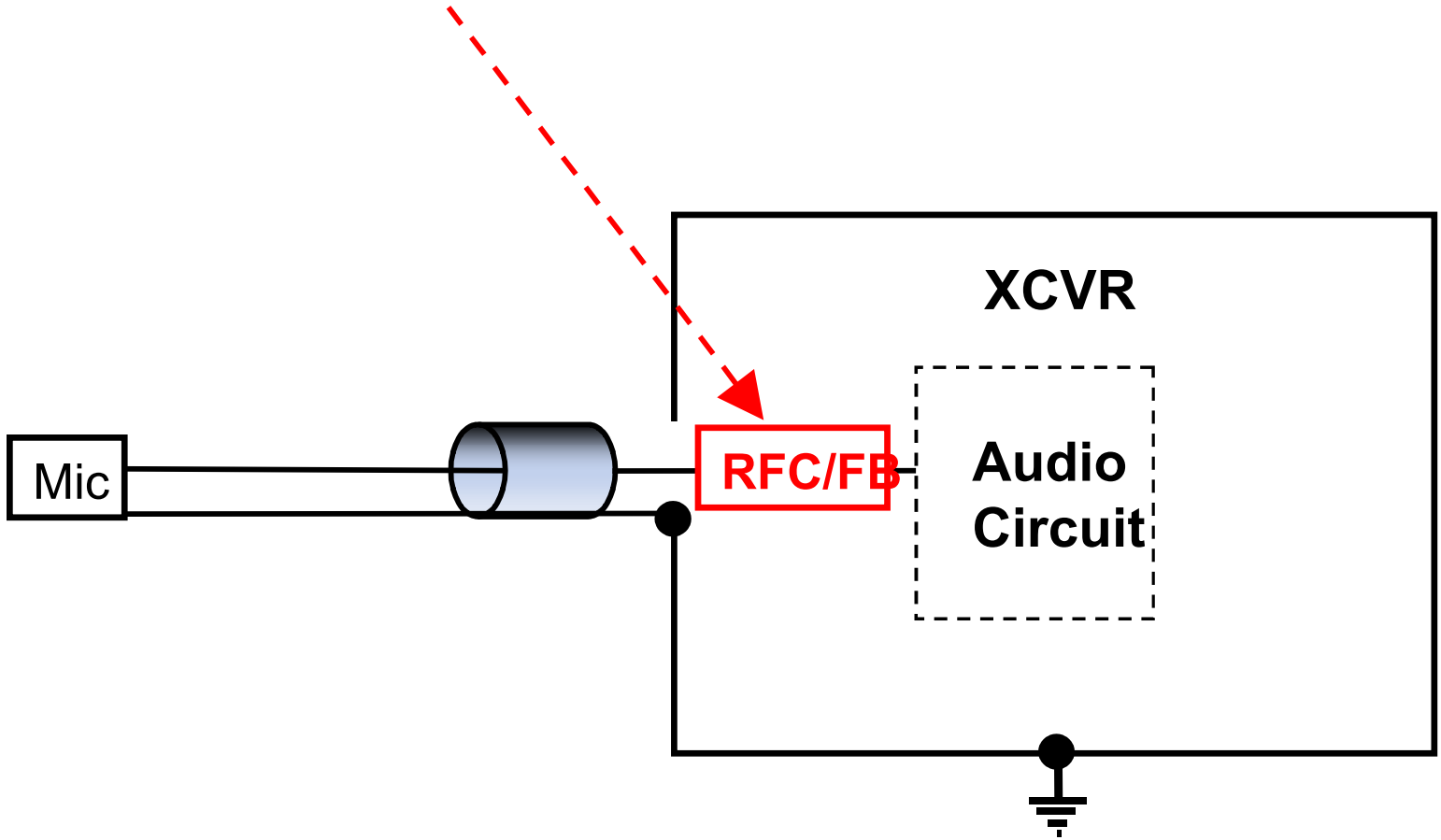
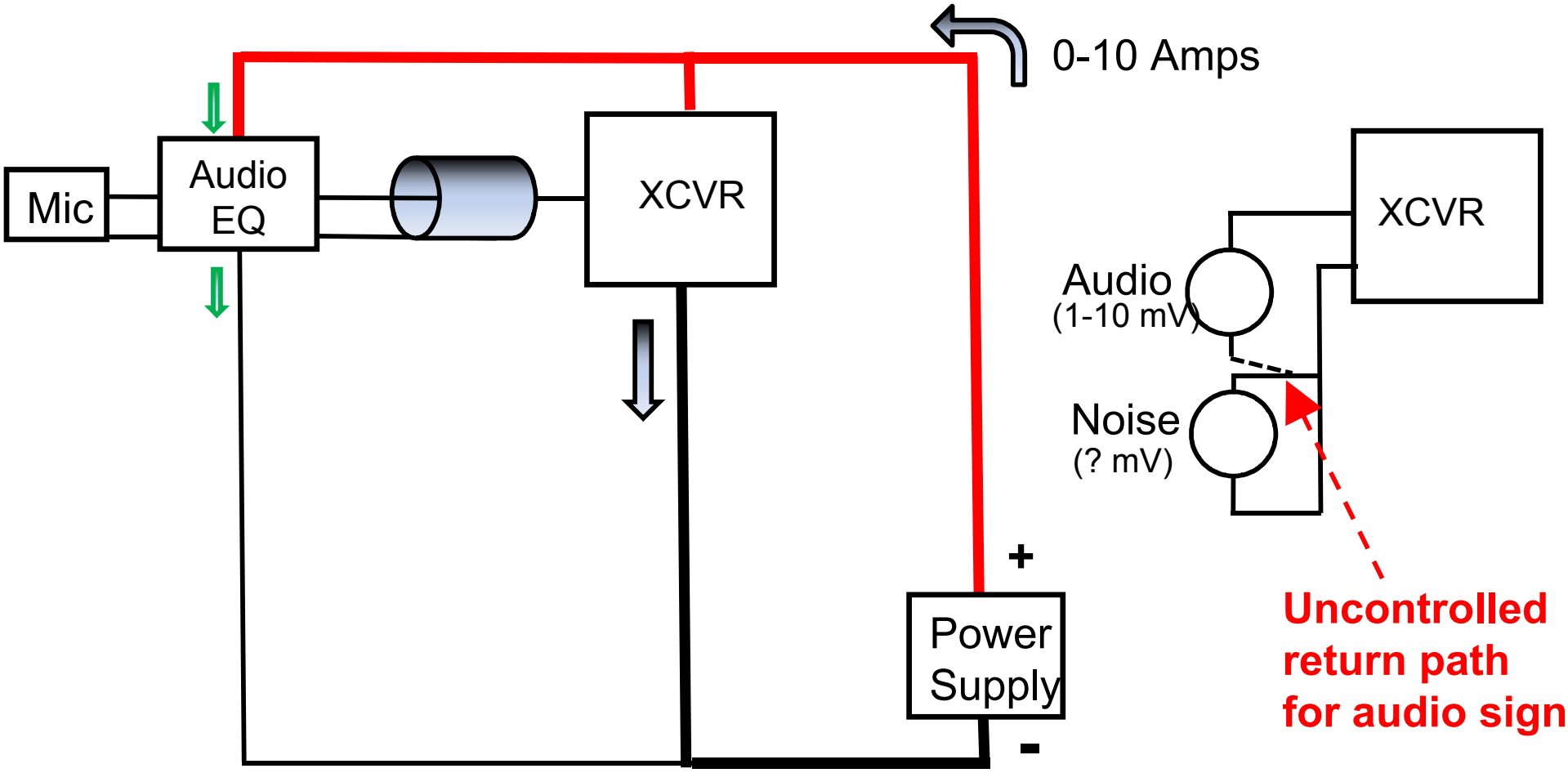


Low Frequency (Audio) Ground Loops

For Problems with RF Pickup, try a Ferrite Bead or RF Choke

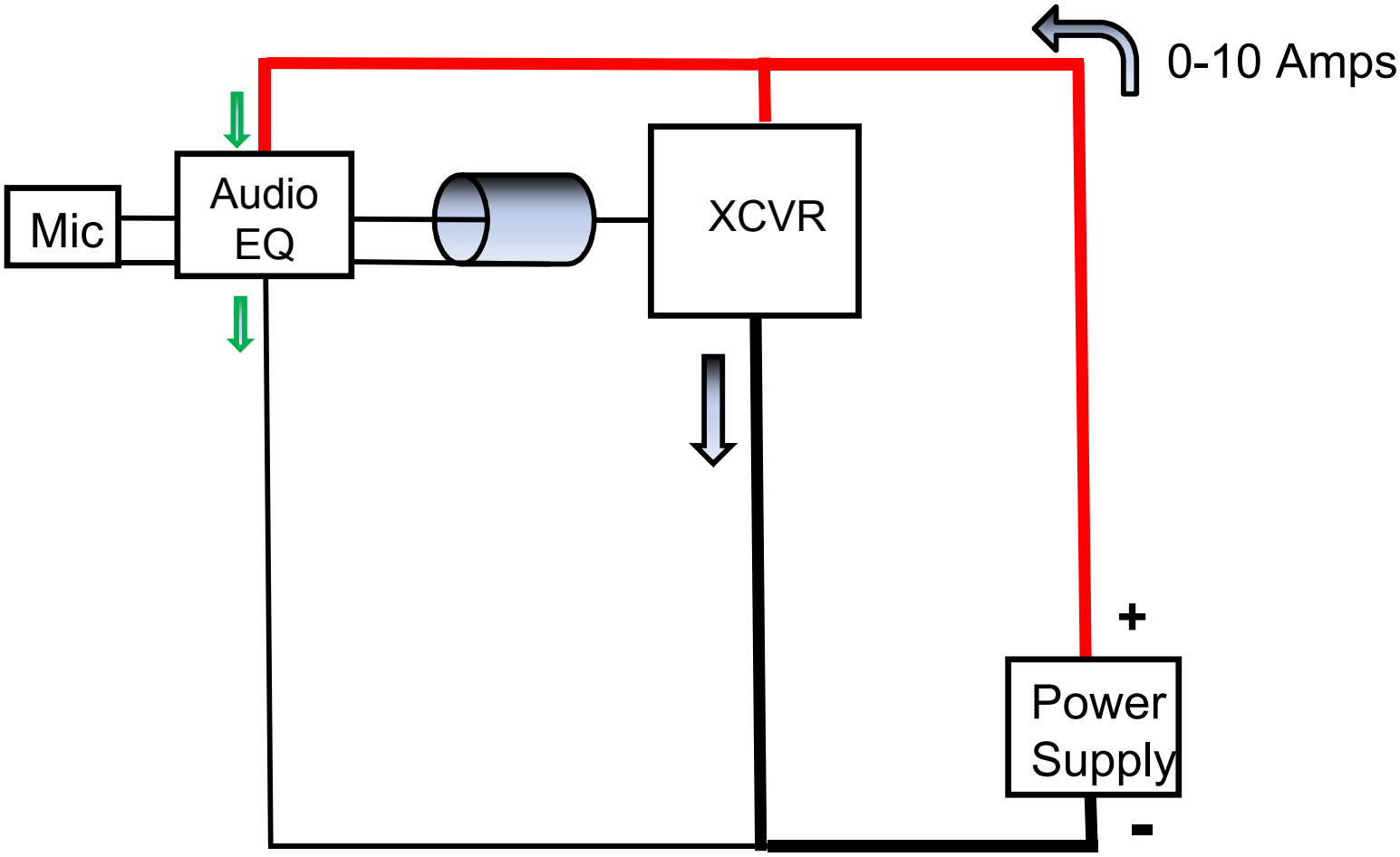


Low Frequency (Audio) Ground Loops



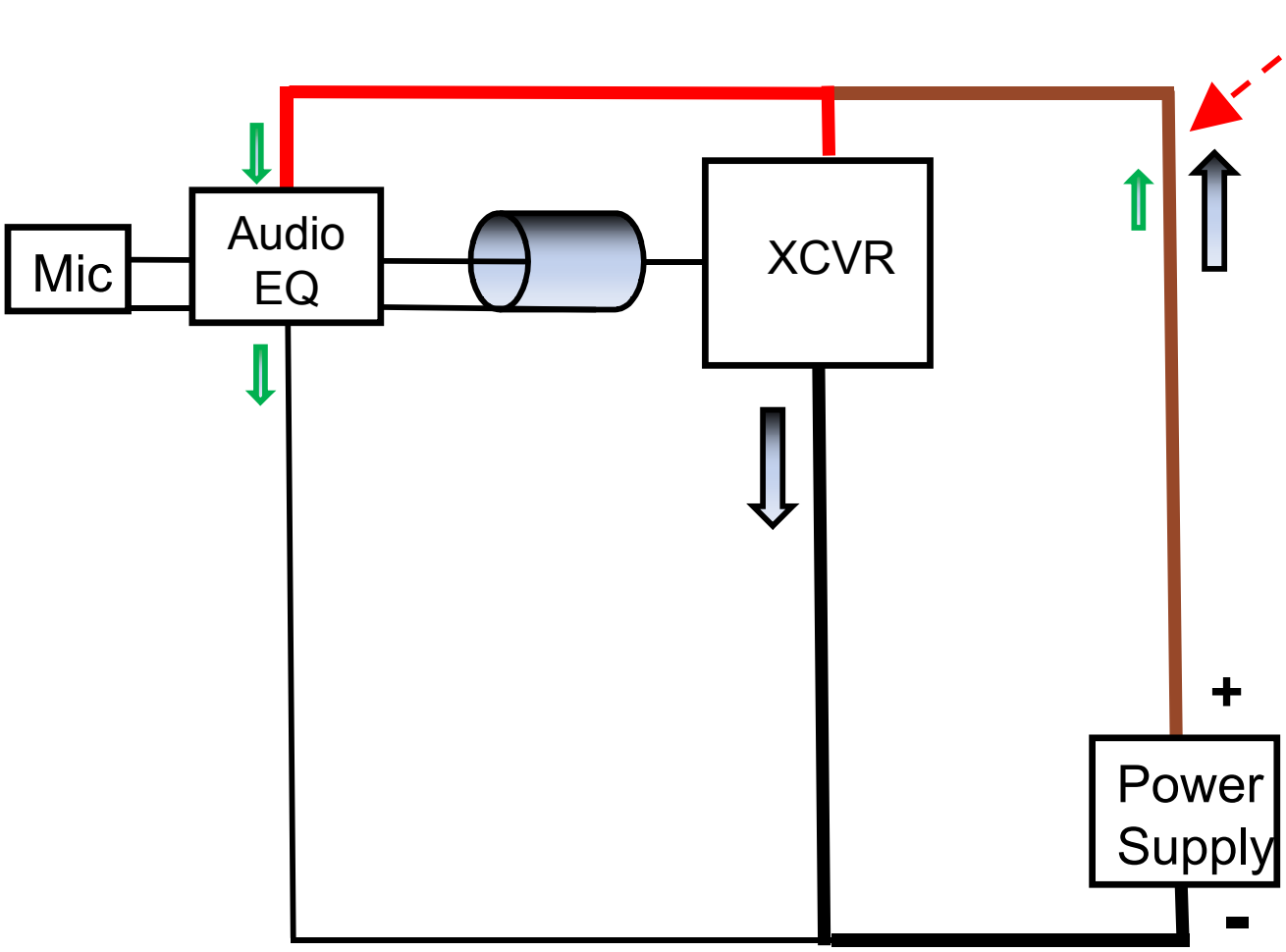
- To mitigate problem, try **opening one end of the shield** on the audio cabl
- In satellite design, ***only RF cables are grounded at both ends!***
  - At Lockheed/Martin, a corporate VP must approve any exception

Low Frequency (Audio) Ground Loops



Is there still another potential problem area?

Low Frequency (Audio) Ground Loops



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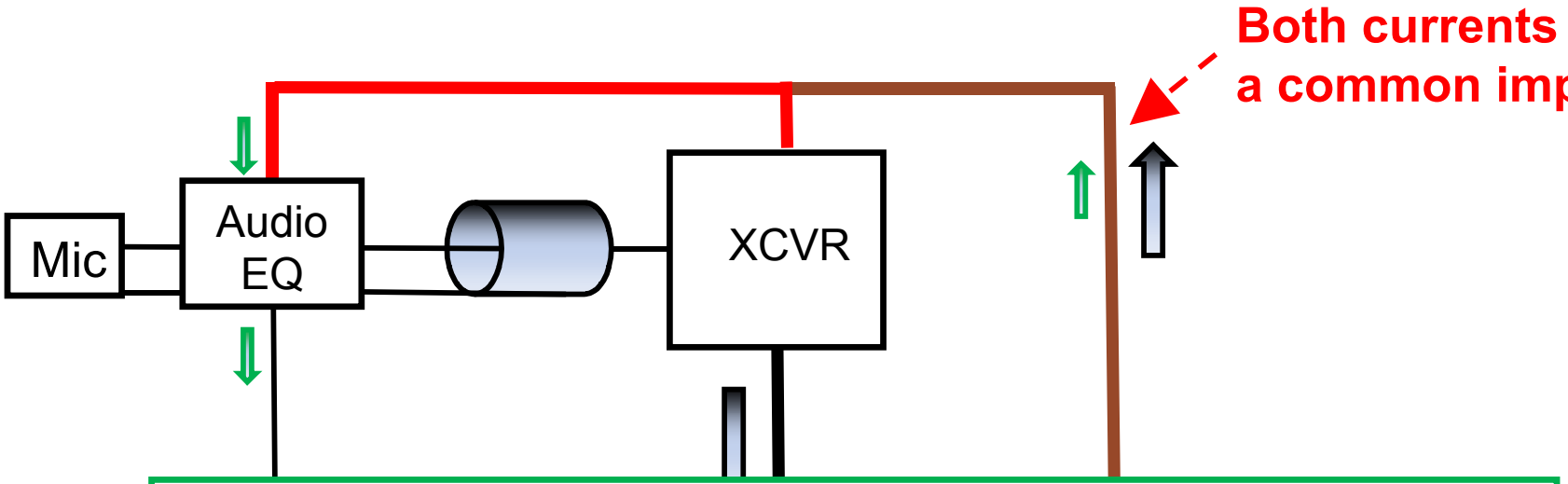
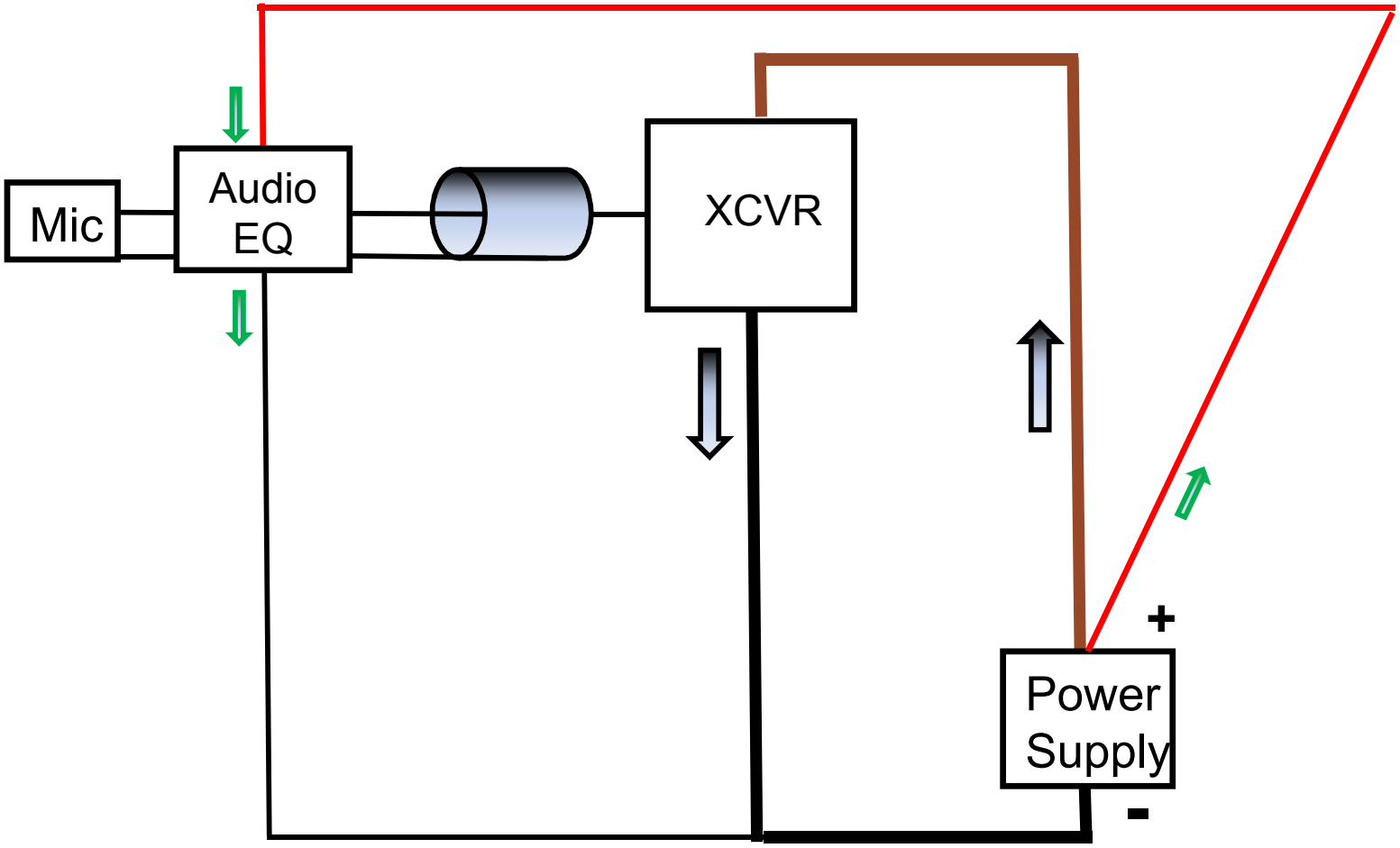


Possible solutions for this problem are:

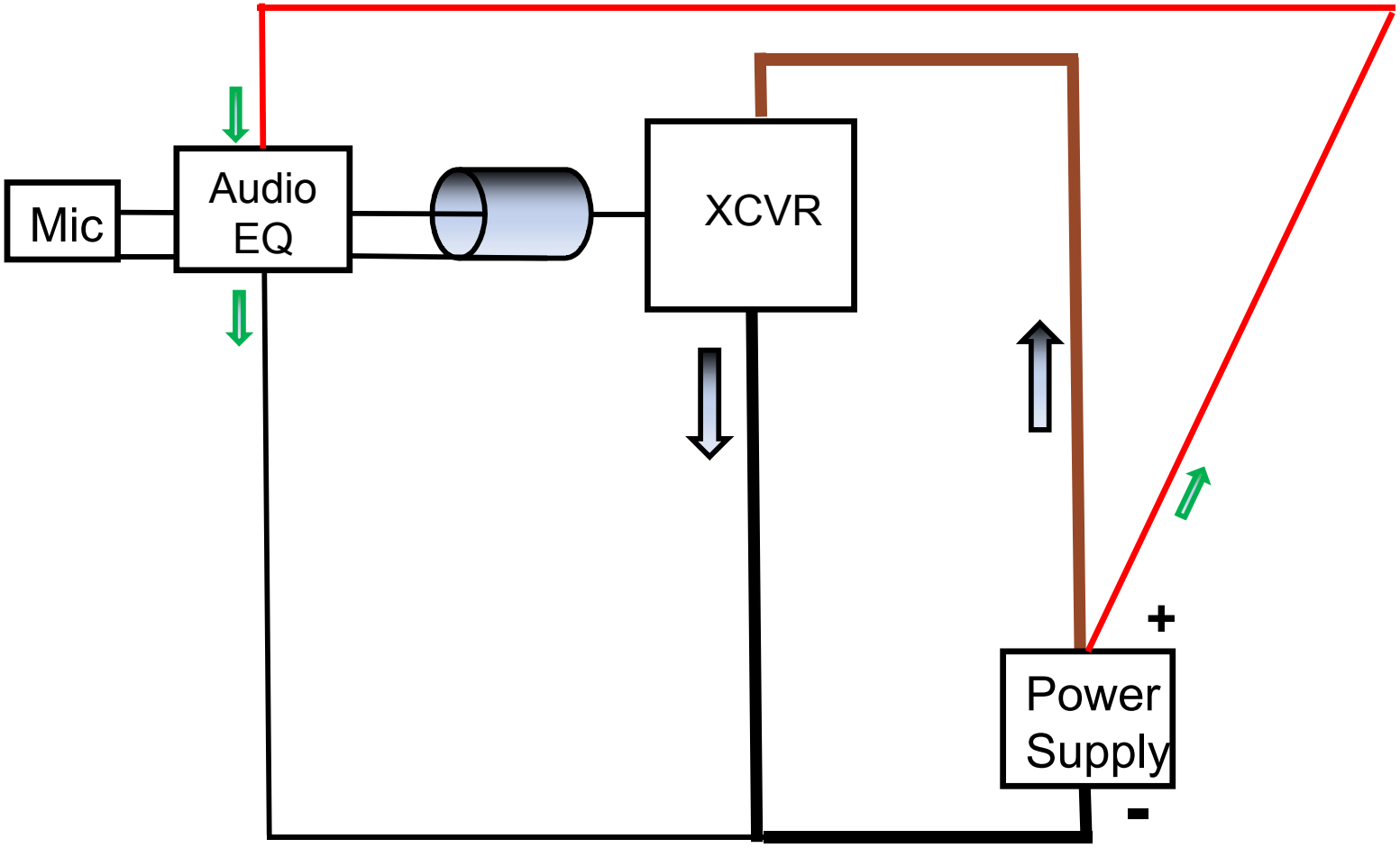
- Improve DC voltage regulation
- Improve DC voltage filtering
- **Minimize common impedance**

Low Frequency (Audio) Ground Loops



Common impedance minimized

Low Frequency (Audio) Ground Loops



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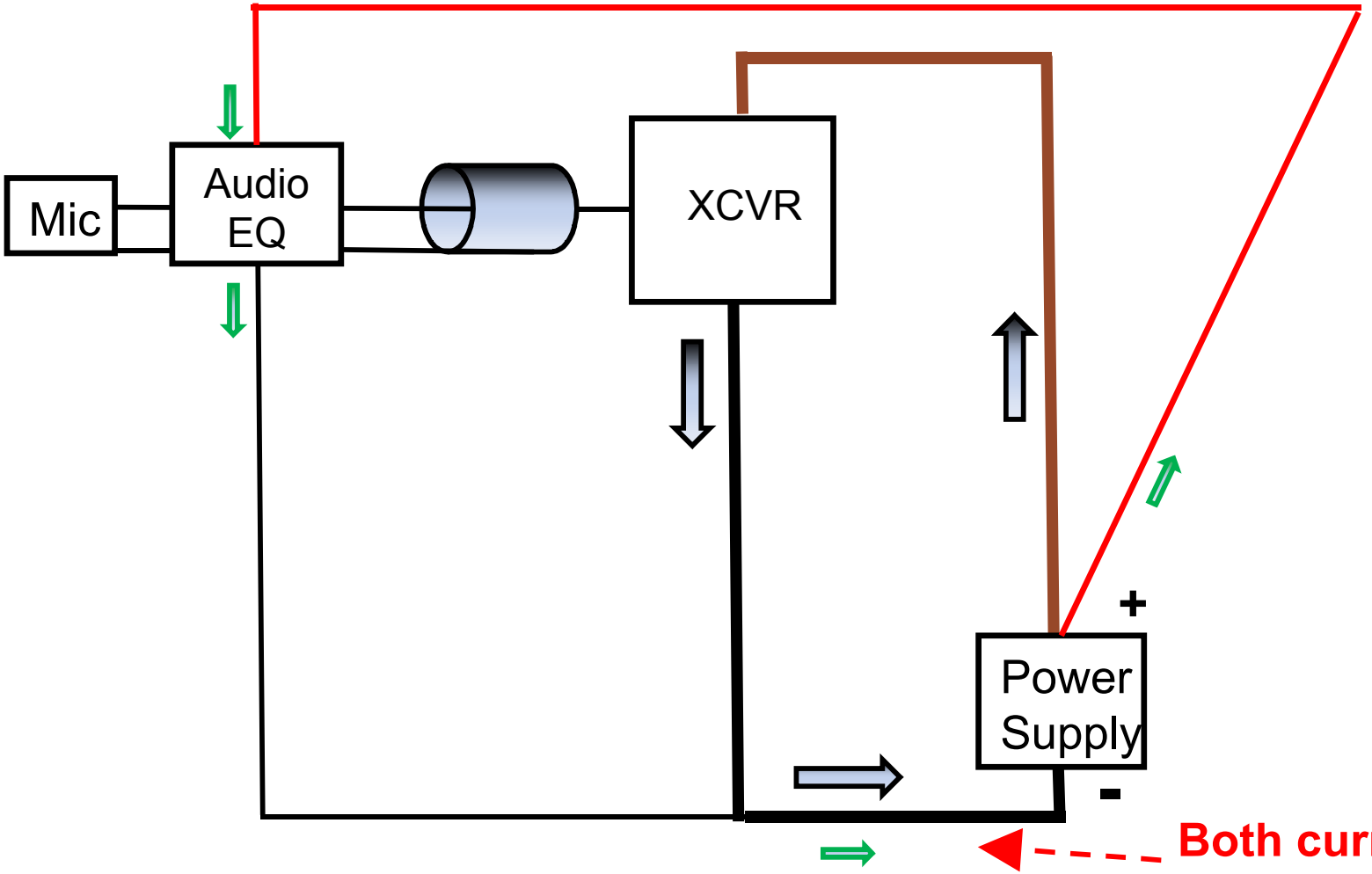
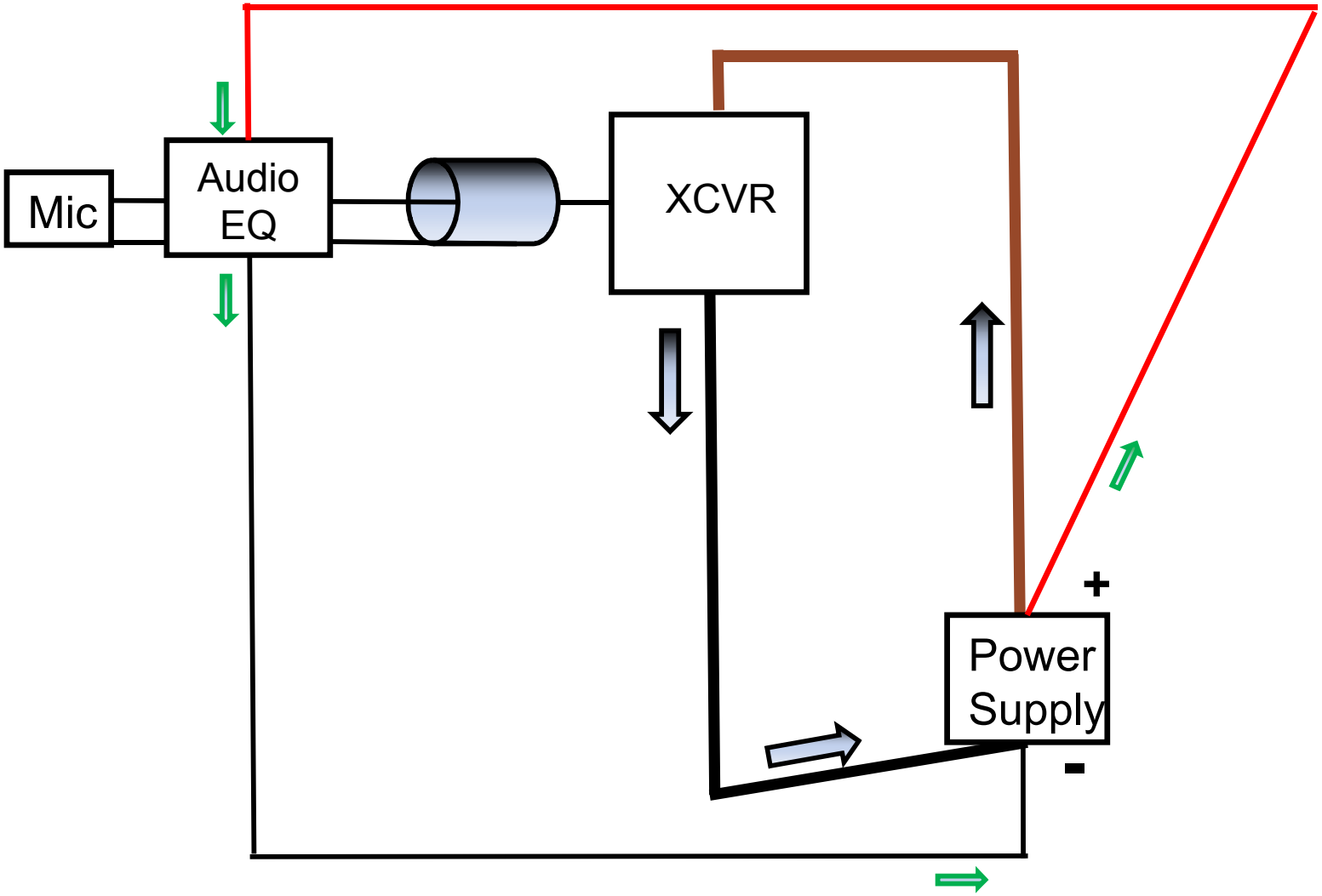
Low Frequency (Audio) Ground Loops

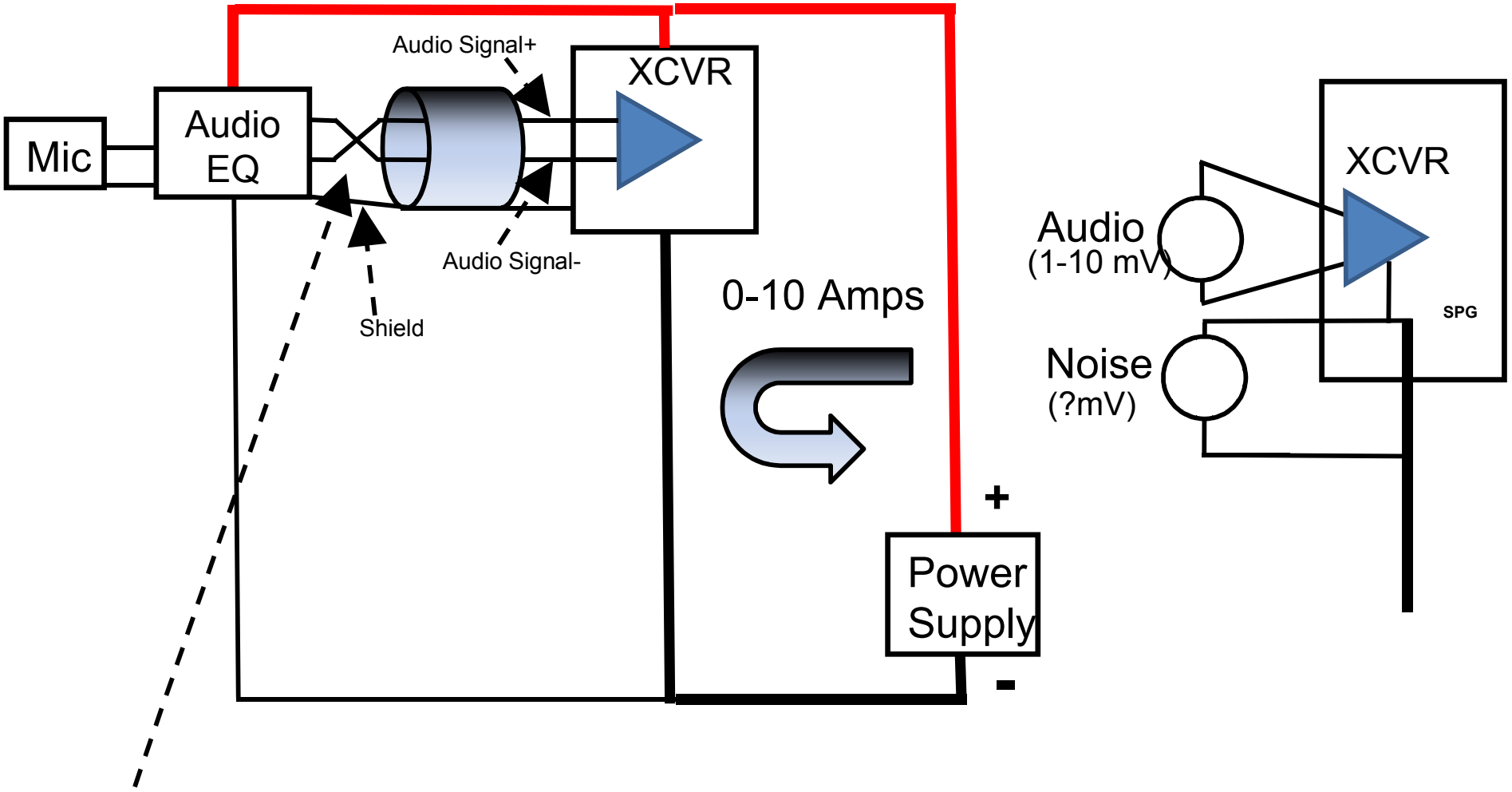


Low Frequency (Audio) Ground Loops



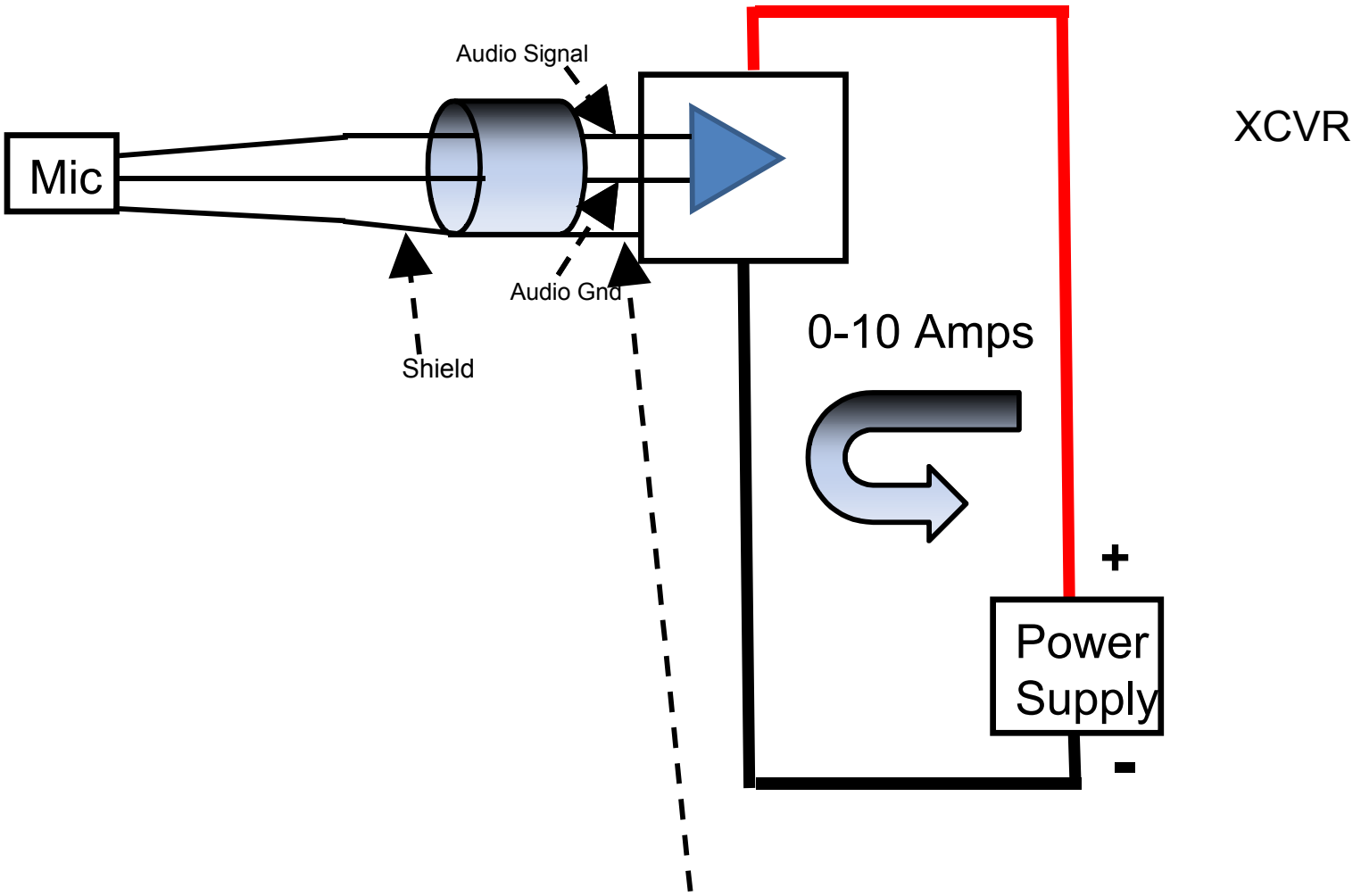
Still have two Loops, but the common impedances have been minimized

Low Frequency (Audio) Ground Loops



- Balanced, differential line with twisted, shielded pair is the ***best*** solution
  - Rarely used in Amateur equipment

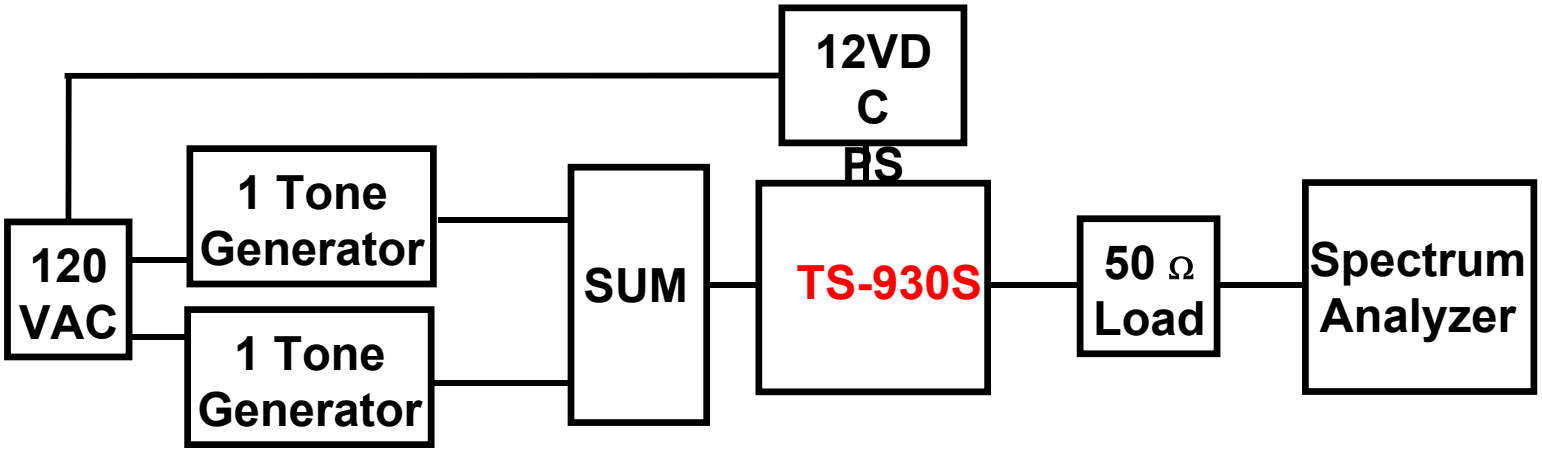
Low Frequency (Audio) Ground Loops

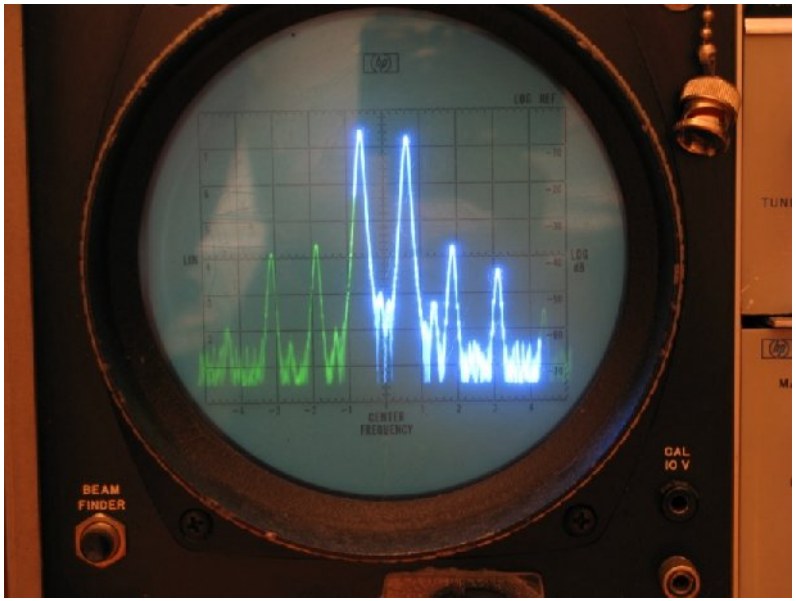


Separate grounds are used in newer Amateur equipment

Audio Ground Loops- 2 Tone Test on TS-130S

Carrier at 14.175 MHz and 100 watts output





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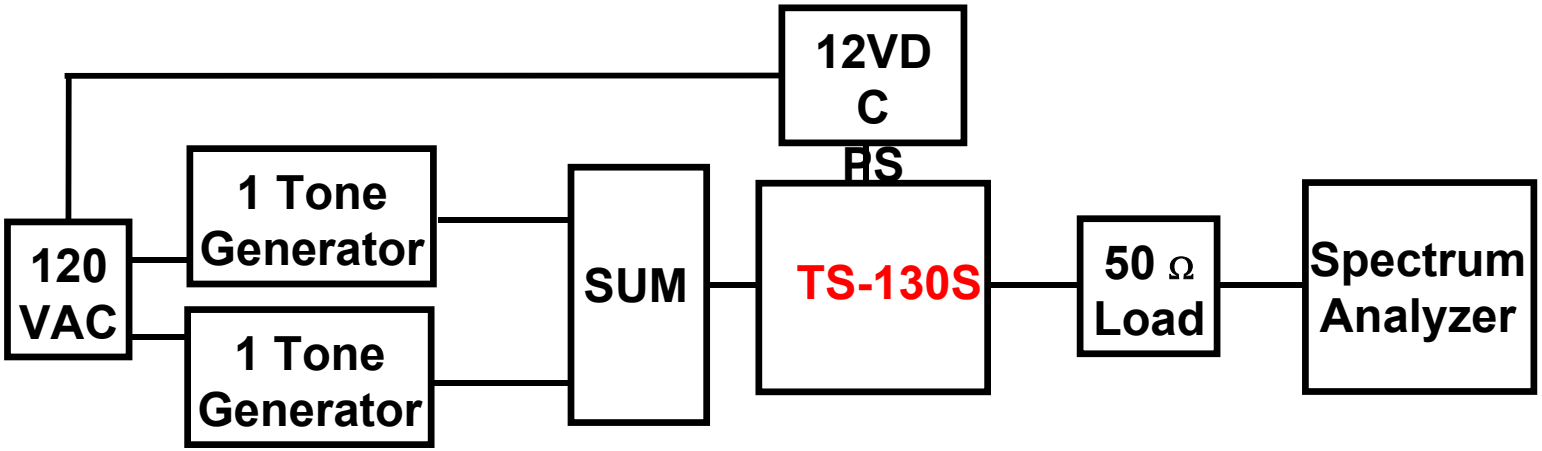

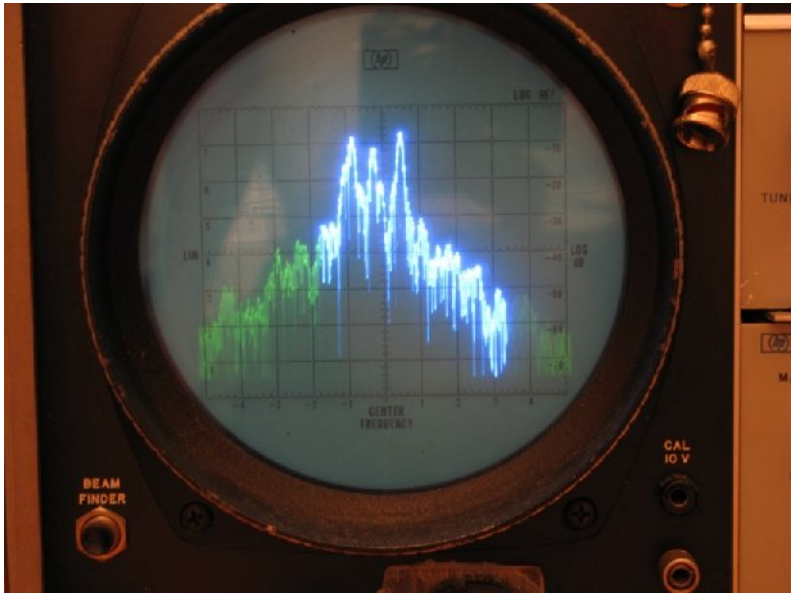

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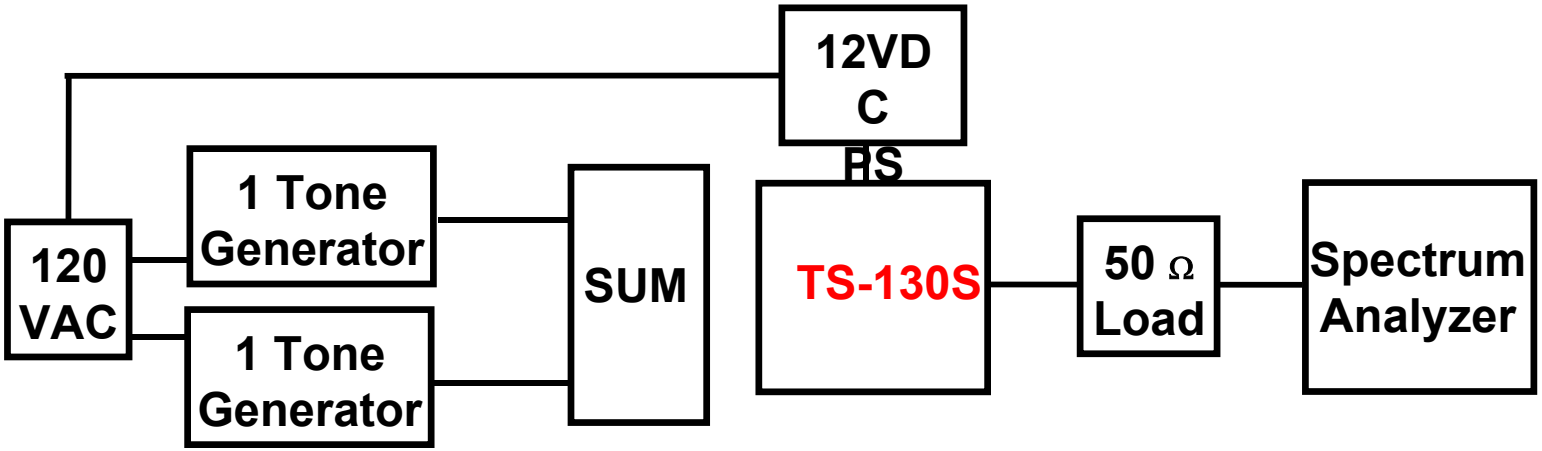

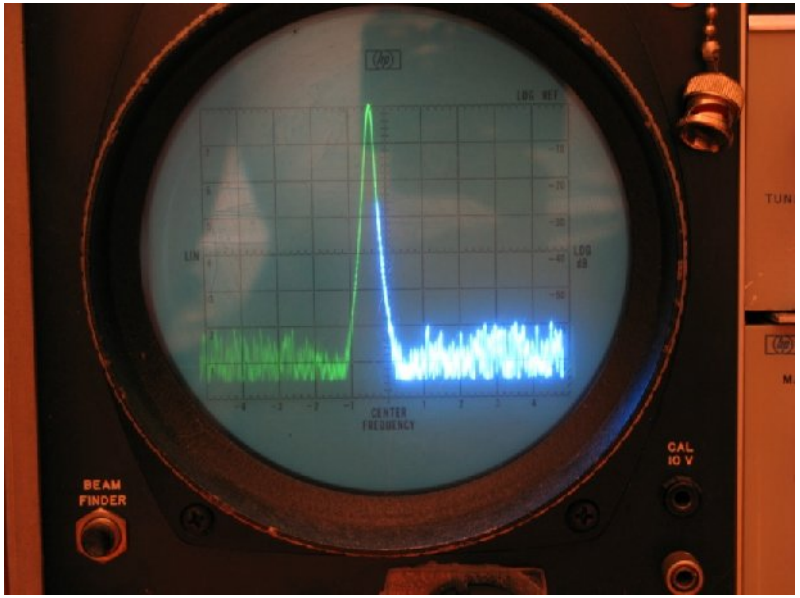

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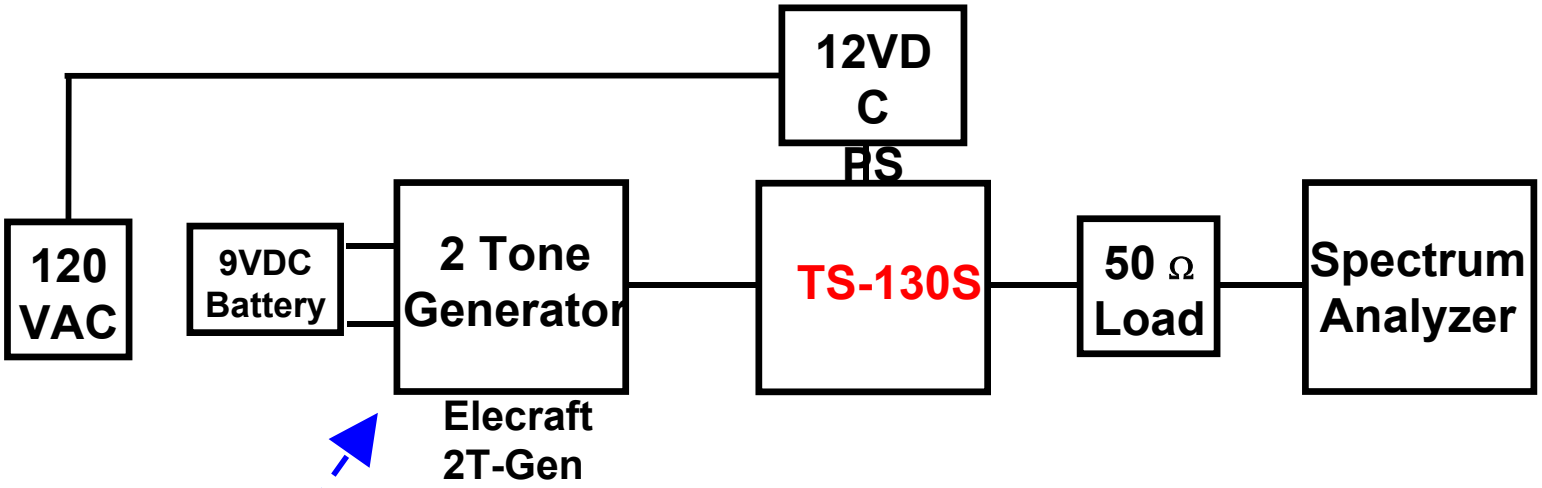
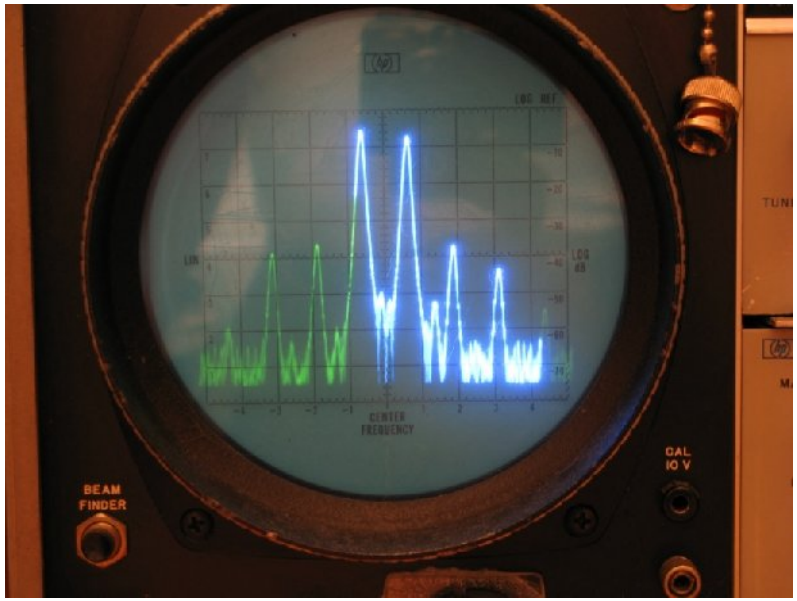
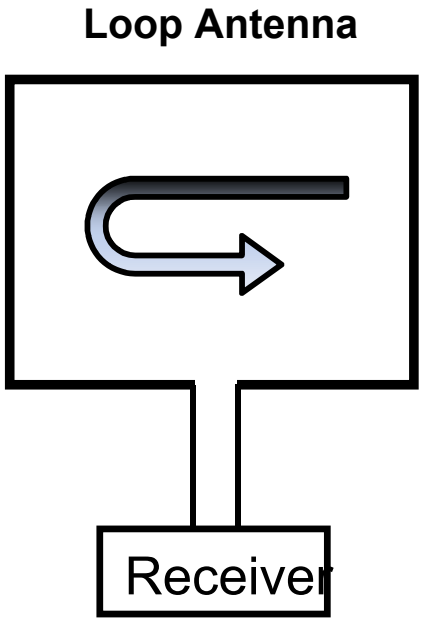
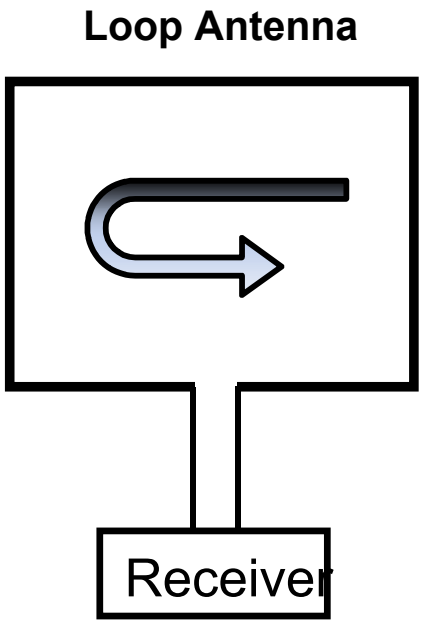


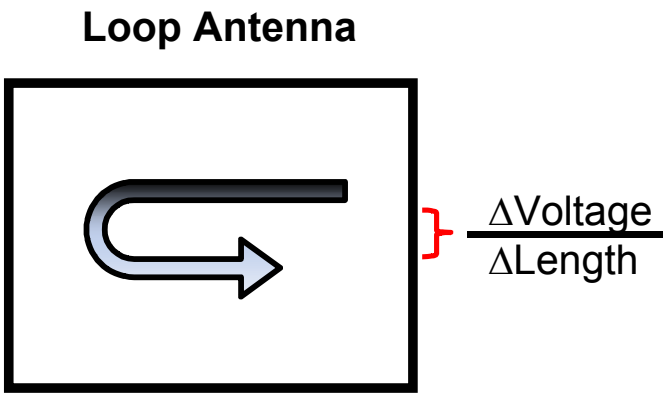


Loop Antenna

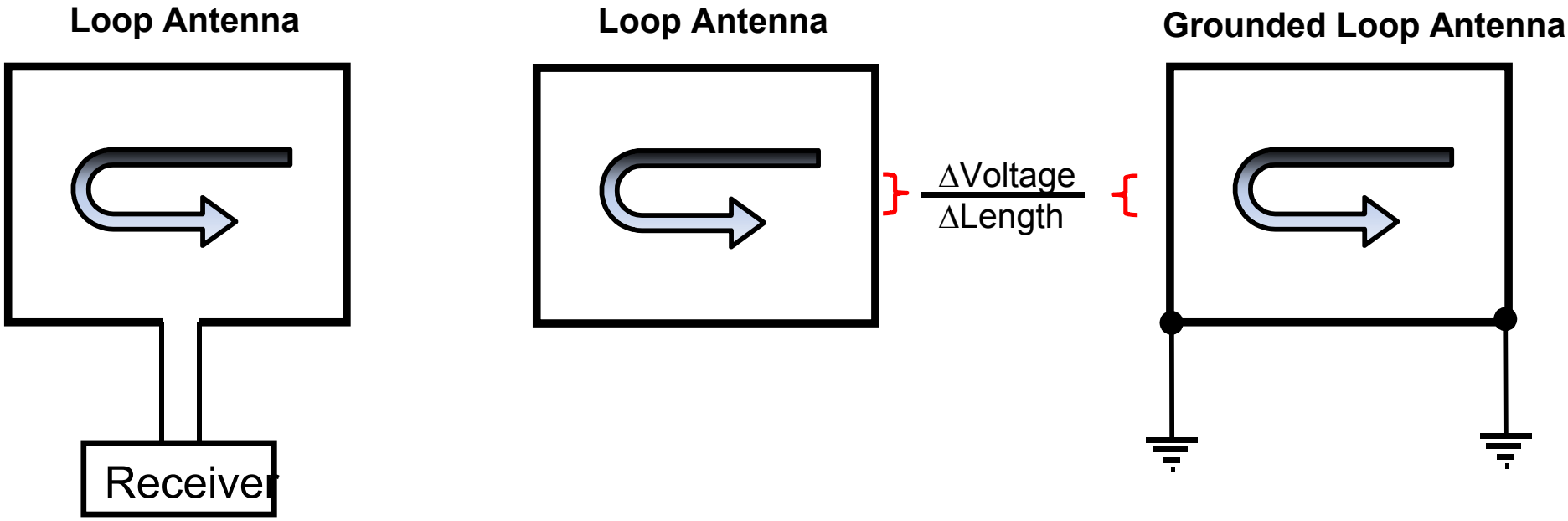


RF Loop





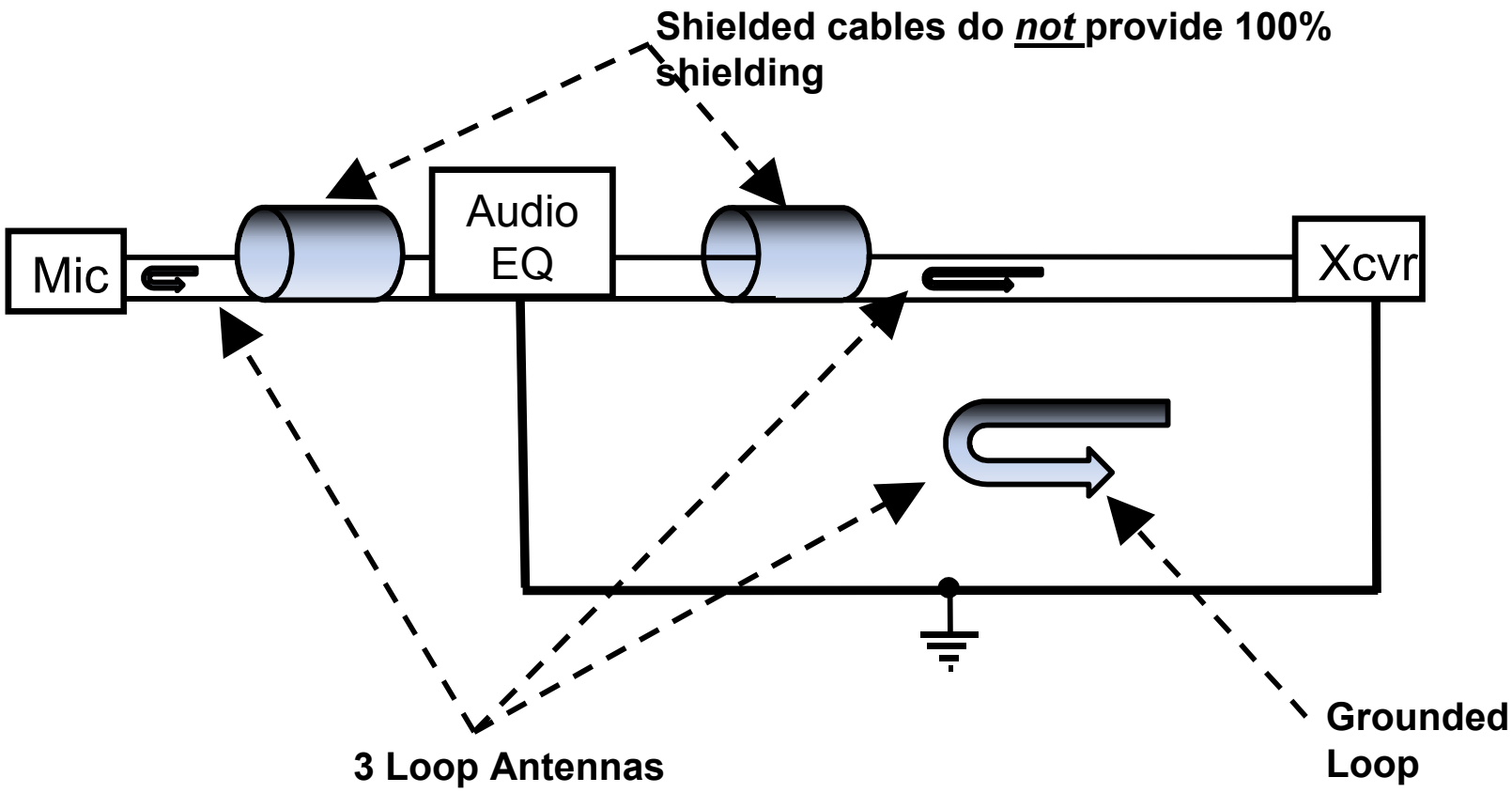
RF Loop



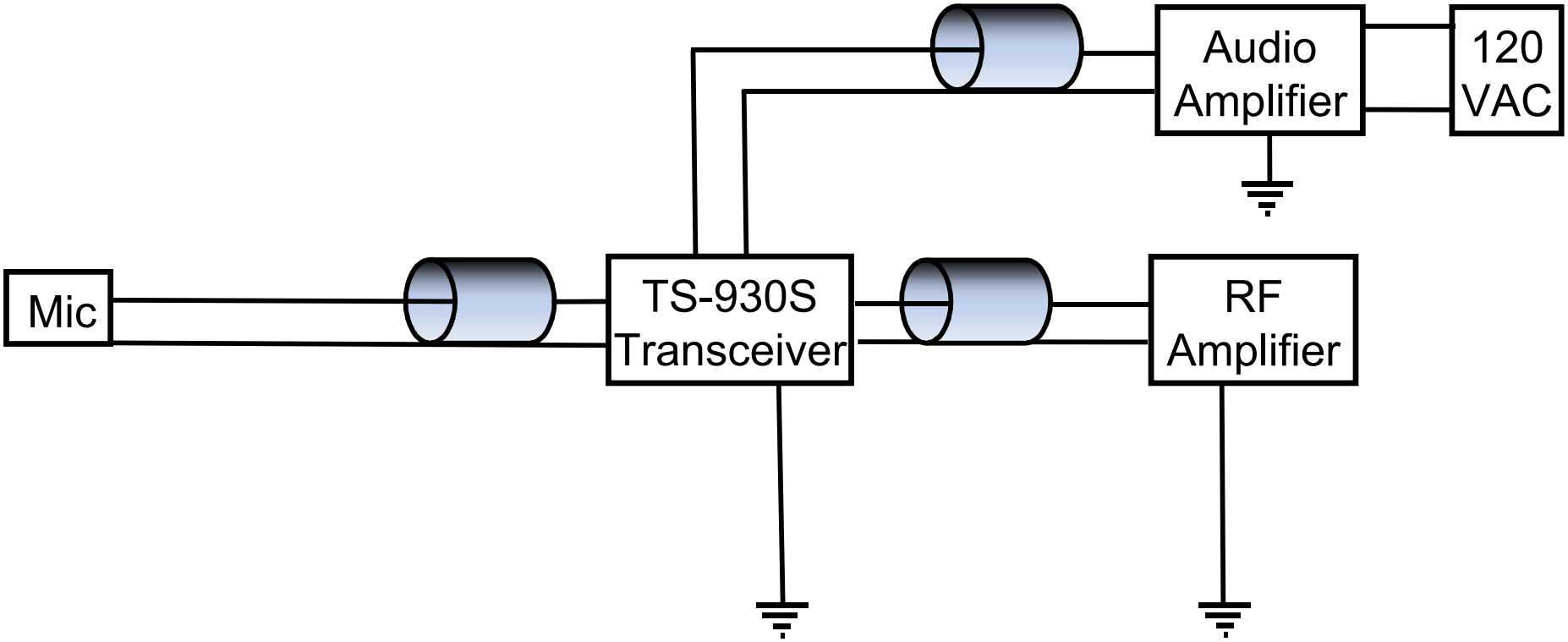
The larger the Loop *AREA*, the better the Antenna

Unwanted Loop Antennas

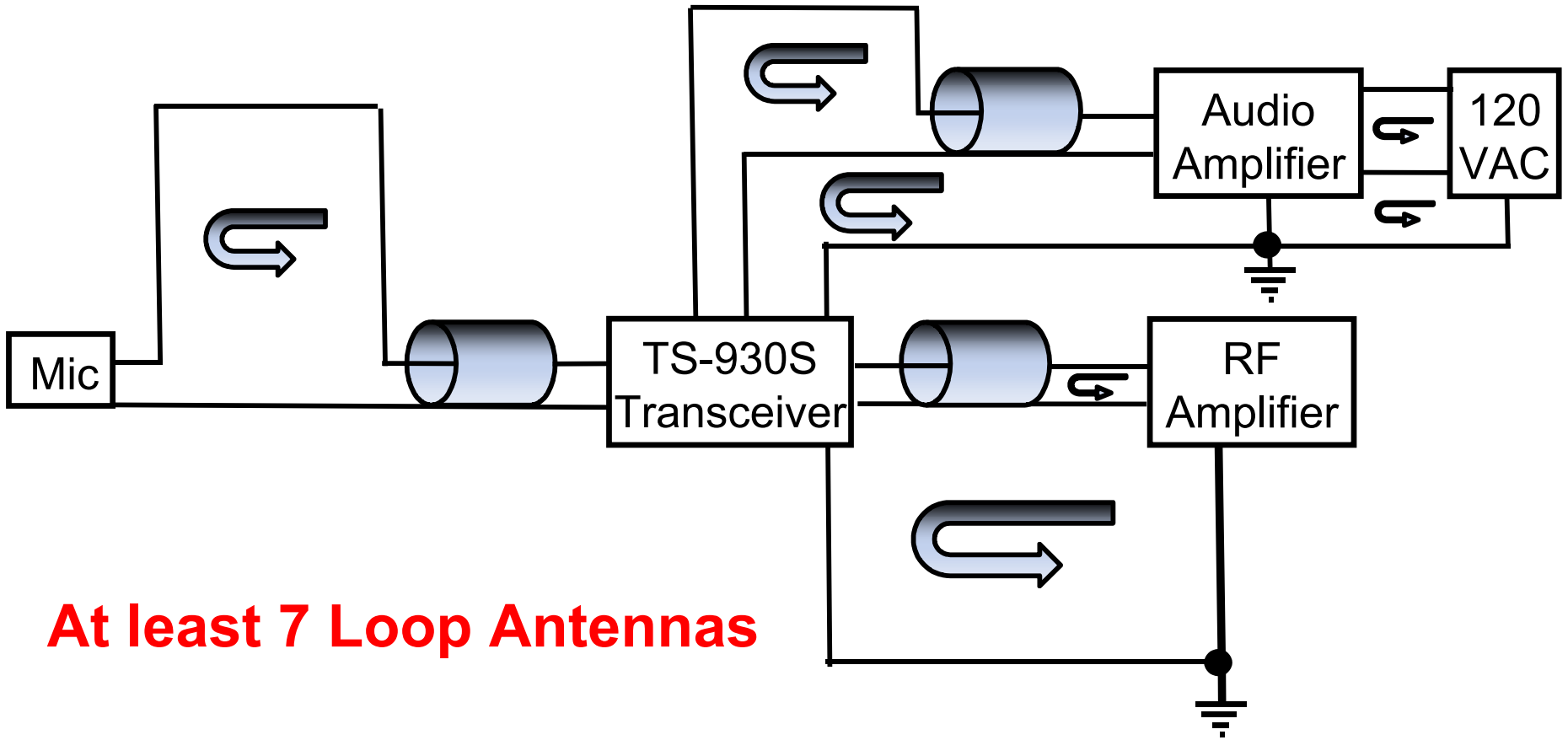
- Unintentional loop antenna can pick up unwanted Electromagnetic energy
- To eliminate => **"RF ISOLATE"** the loop



Problem Loops at N0CU

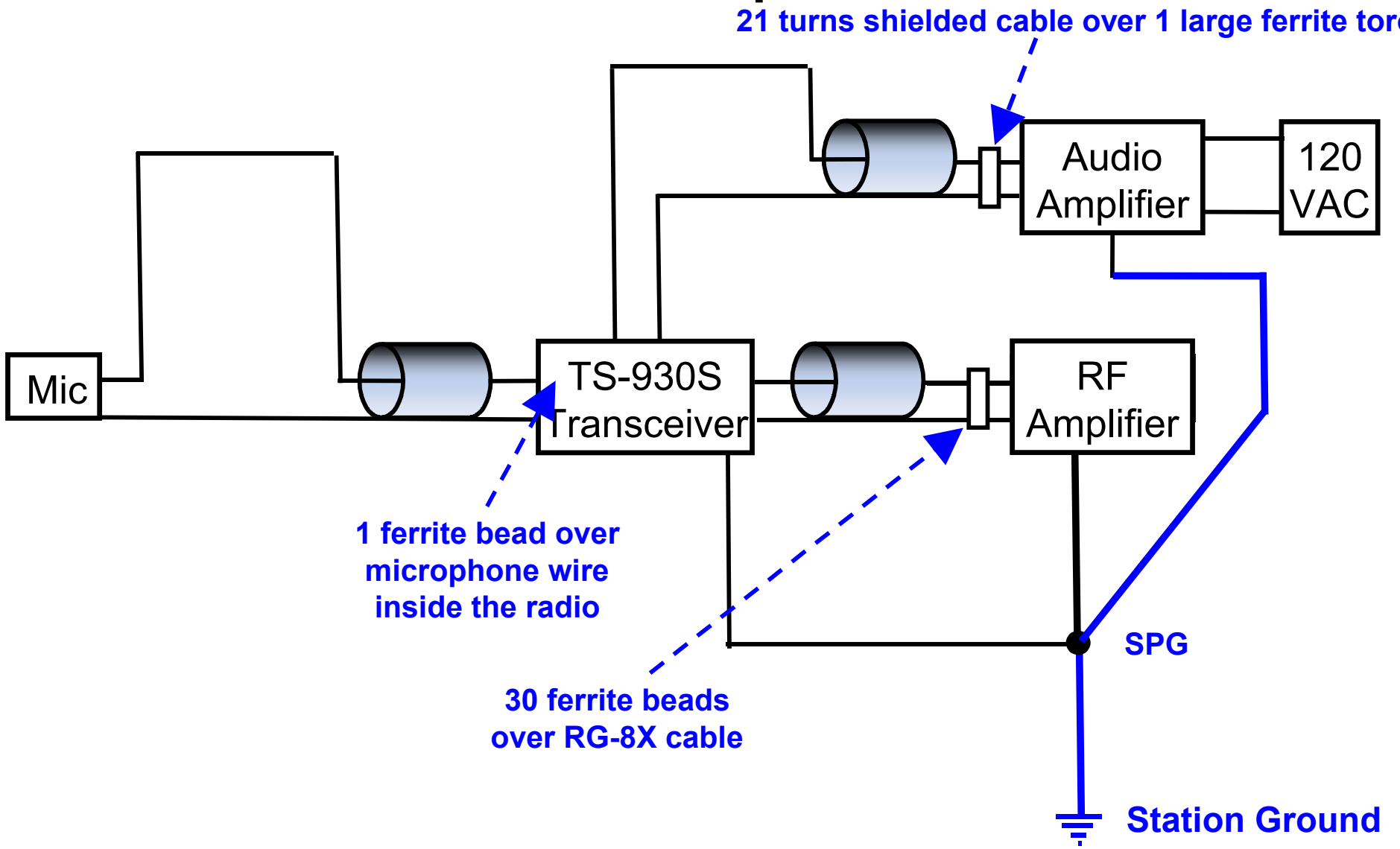


Problem Loops at N0CU

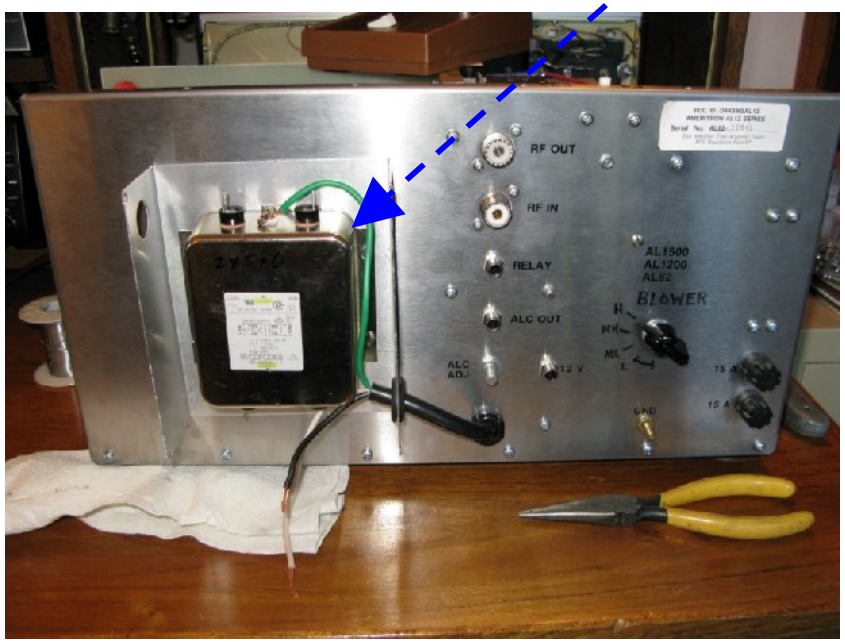


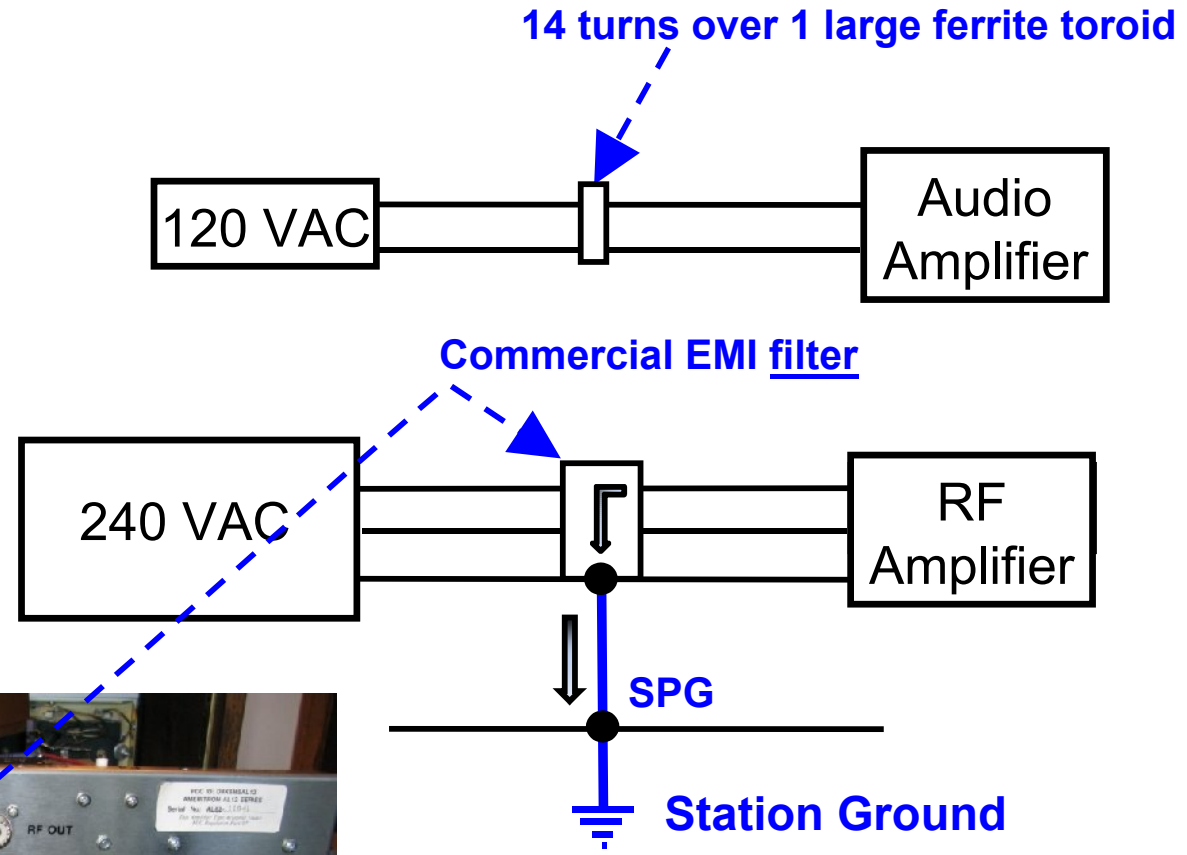
At least 7 Loop Antennas

Fixes for Problem Loops at N0CU



Fixes for Problem Loops at N0CU - continued





Choke = single inductive element
Filter = multiple L/C components

“Beads” and Cores

Come in many:

- Sizes
- Shapes
- Mixes
  - Determine the useful frequency range
  - “Current” and “Parasitic” chokes usually made of a high loss Ferrite
    - Good for making ***lossy inductors***
  - Pay attention to power limitations (due to losses)

Other Info

- Adding additional grounds can ***INCREASE*** the current surge on the house wiring in the event of a lightning strike on a nearby AC power line
  - Is the a problem????
  - "**Bleeding" off the charge**" techniques only ***increase*** the likelihood of a strike
- **Isolation**:
  - RF current chokes
  - AC power line filters:
    - Linear amplifier
    - All other equipment
- **Surge Voltage Limiters** (SVLs) aka "**Lightning Arrestors**"
  - ***Must be sized appropriately*** for frequency and the RF power level used
  - Metal Oxide Voltage Suppressors (**MOV**s)
    - Fast risetime
    - Limited power dissipation capability
  - Gas Discharge Tubes (**GDT**s)
    - Slow risetime
    - Significant power dissipation capability
  - These devices ***CAN FAIL OPEN*** after taking a strike
    - ***Hard to tell when you are no longer protected***
  - ***Do <u>not</u> provide 100% protection*** against a direct strike

Specifications for PolyPhaser IS-B50HN-C0-MA

Mount Type: Bulkhead
Frequency Range: 1.5 MHz to 400 MHz
Protected Side Connector: N Female
Surge Side Connector: N Male
Turn On Voltage: ±1200 Vdc ± 20 %
VSWR: ≤ 1.1:1 @ 2 MHz to 400 MHz
Insertion Loss: ≤ 0.1 dB
RF Power: HF **3 kW**
VHF 500 W
UHF **250 W**

Replaceable Gas Discharge Tube (GDT)

Summary

- ***Always use the SAFETY Ground***
- **Bleed static from each antenna *to Ground***
- **Consider using a SPG** (even if you don't have a Station RF Ground)
- **Regarding Lightning Grounds:**
  - **Install a multi-level protection system when possible**
  - **"Best Protection is Disconnection"**
    - Antenna lines (before they enter the house)
    - Disconnect AC power lines from equipment
  - **"Second Best Protection is Disconnection"**
    - Disconnect antenna lines from radios
      - ***Do not lay near the radio***
    - Use "shorting" antenna switches on the outside of the house/shack
    - Use an SVL at the antenna switch output and on rotator lines
    - Disconnect AC power lines from equipment
  - Use extra caution regarding "**Bolts from the Blue**"
  - **100% protection is not achievable** with present technology
  - Even a "Good" ground can be very expensive by Ham standards

Summary - continued

- **Regarding RF Grounds:**
  - Every station has different requirements and constraints
    - Most stations should not need a ***Station*** RF ground
    - If in doubt => Where is “Ground” on the Space Station?
  - Experimentation is the best way to find out what is needed
    - If you are not experiencing any RF related problems, continue with what you have until a problem arises
    - A fix may only work for awhile, then come back, or a new problem may emerge
- **Keep in mind:** interference with consumer electronics may ***not*** be something you can fix at your station