Ground Is A Myth!

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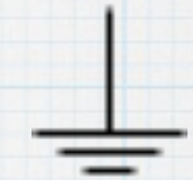
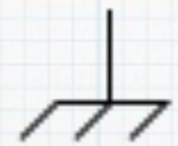
What Is A Ground?

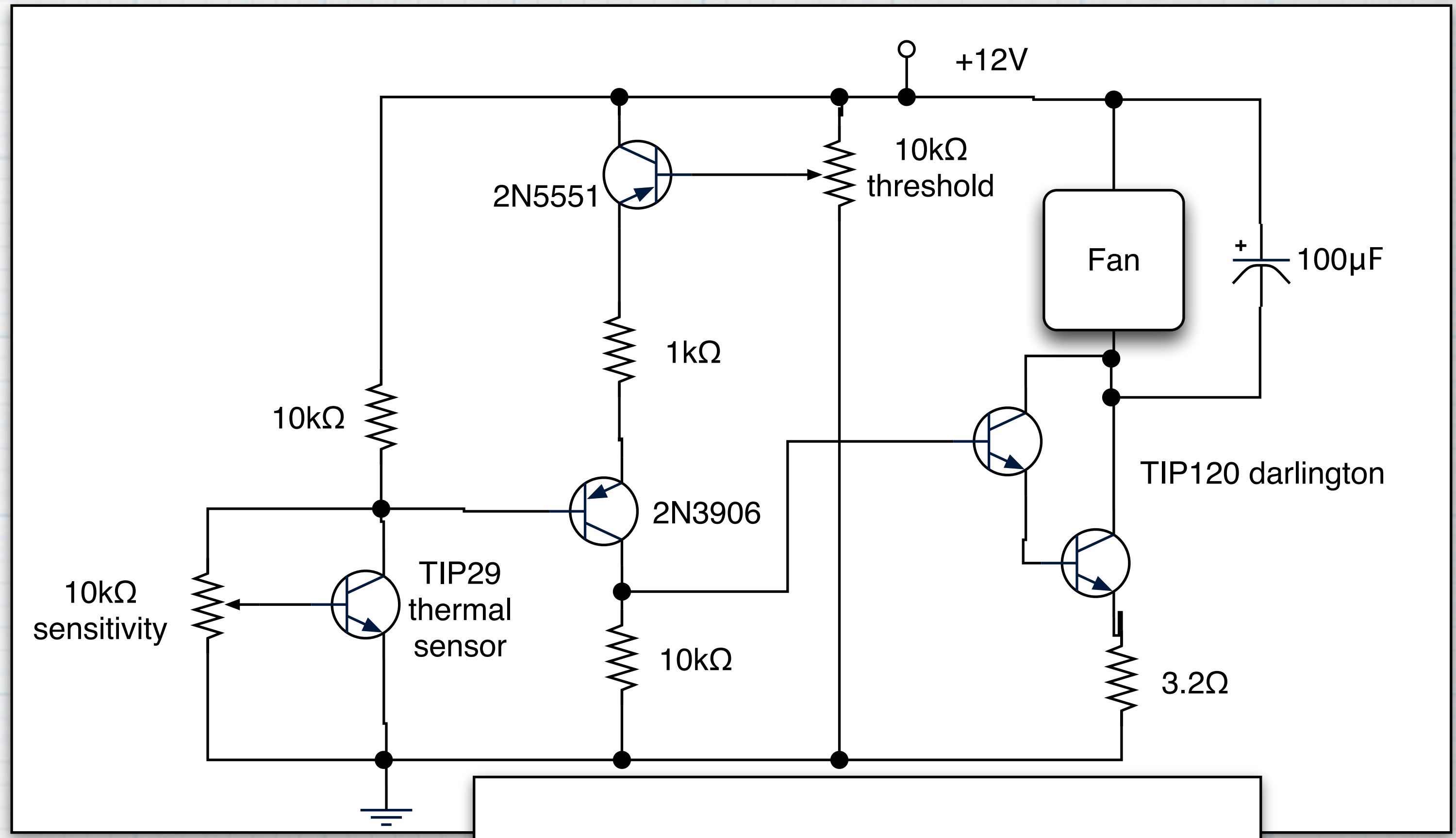


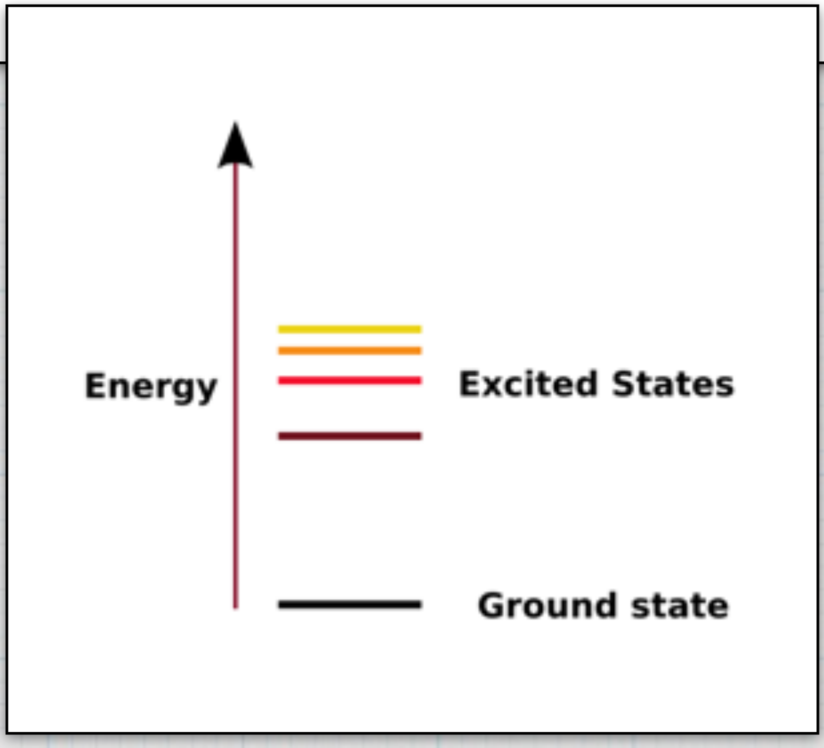


* Haven't you wondered?
* Have you just accepted it?
* Does it have meaning at all?
* Seen on schematics
    * but what does that mean?

It's about a reference point

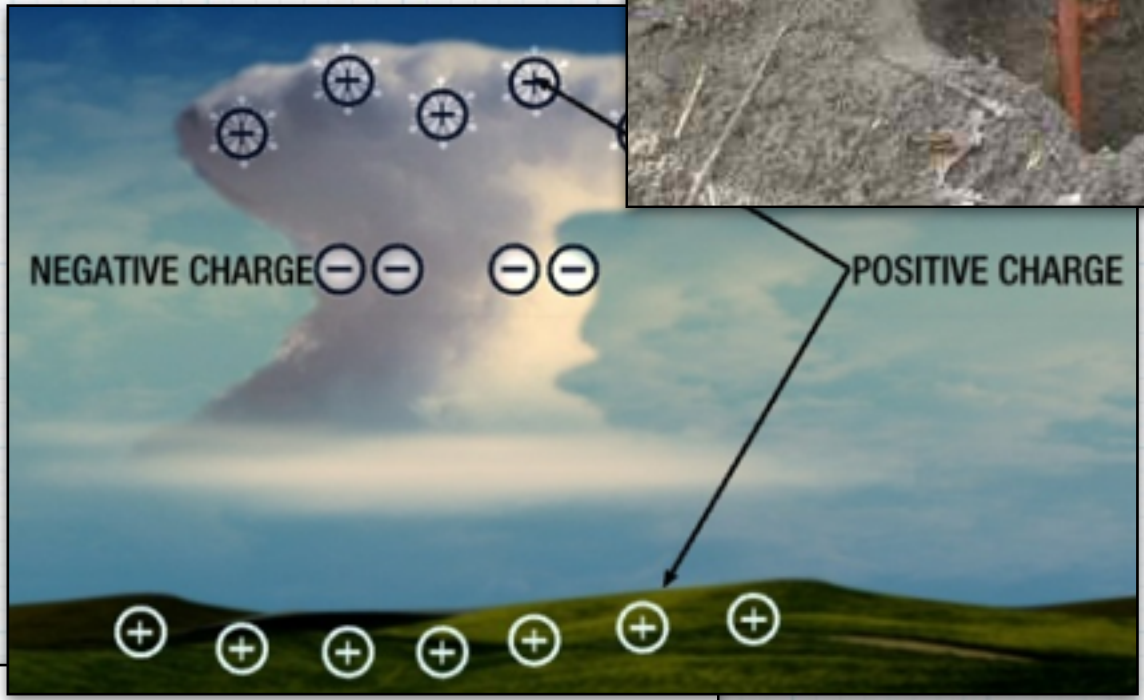
* Ground is an arbitrary zero reference (circuit)
* Might be an energy state
* Might be a common connection
* Implies stability
* Or, perhaps ...

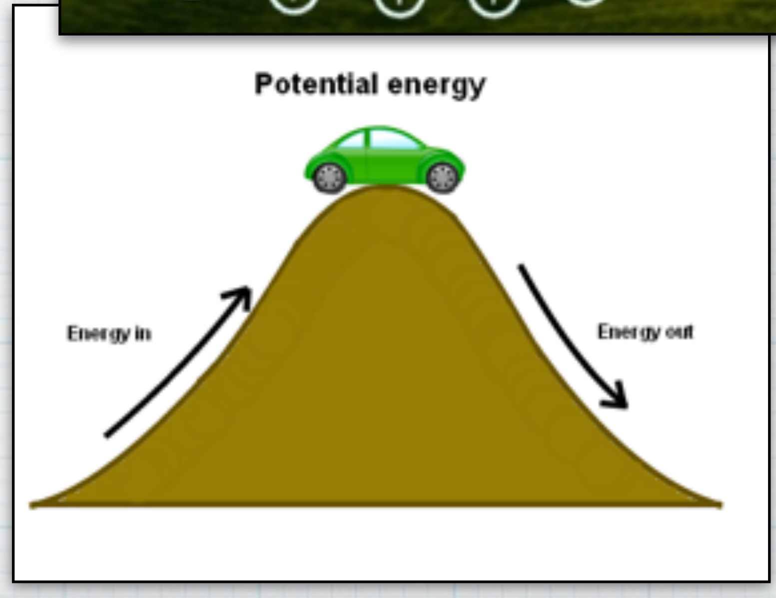




It's about the earth

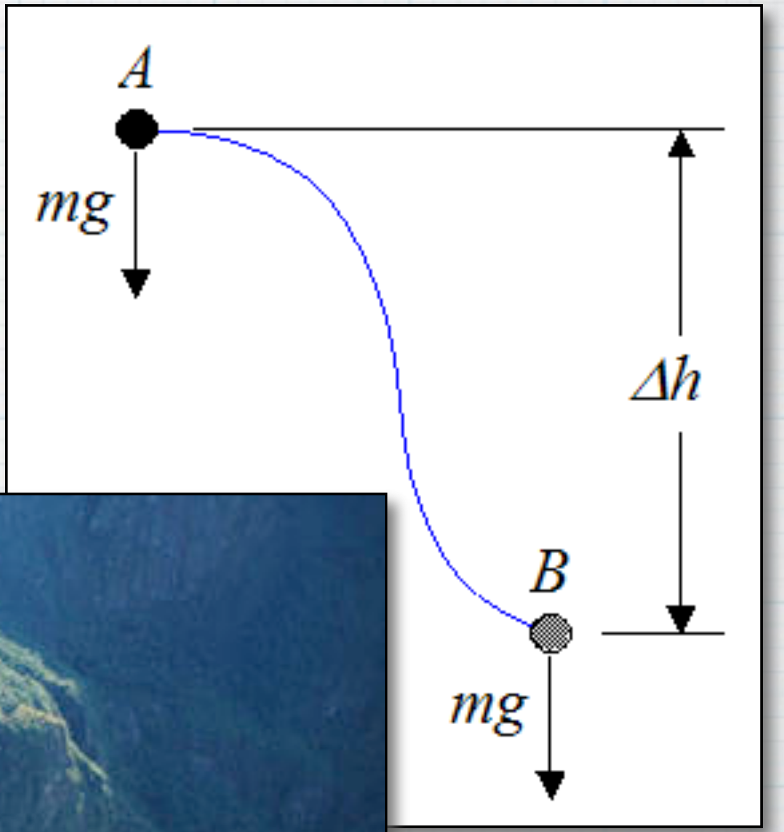
* Physical objects in contact with earth
* Earth's charge state
* Distance from the center of mass
* Gravitational potential energy

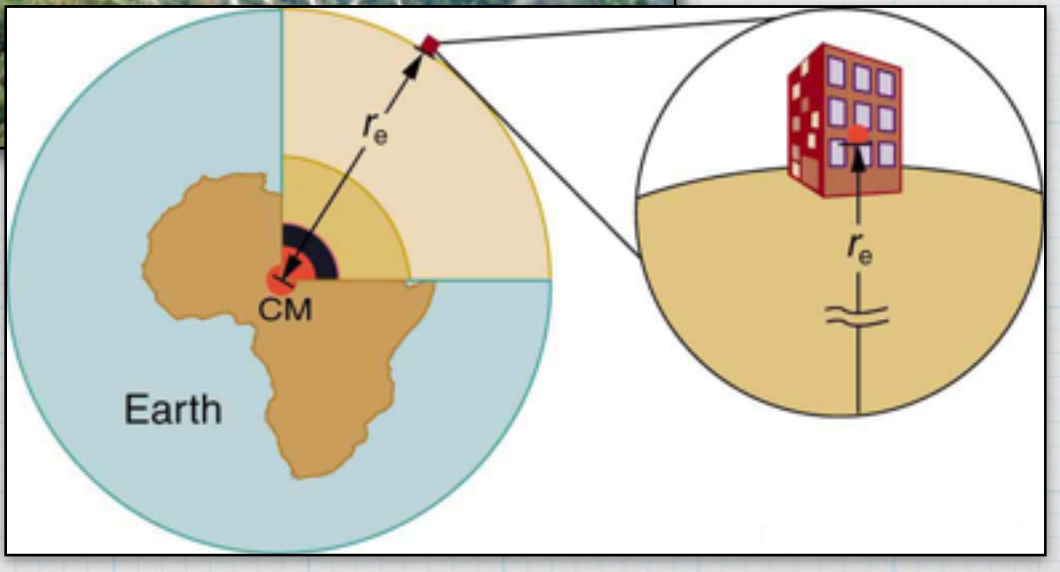




Ground and Gravity

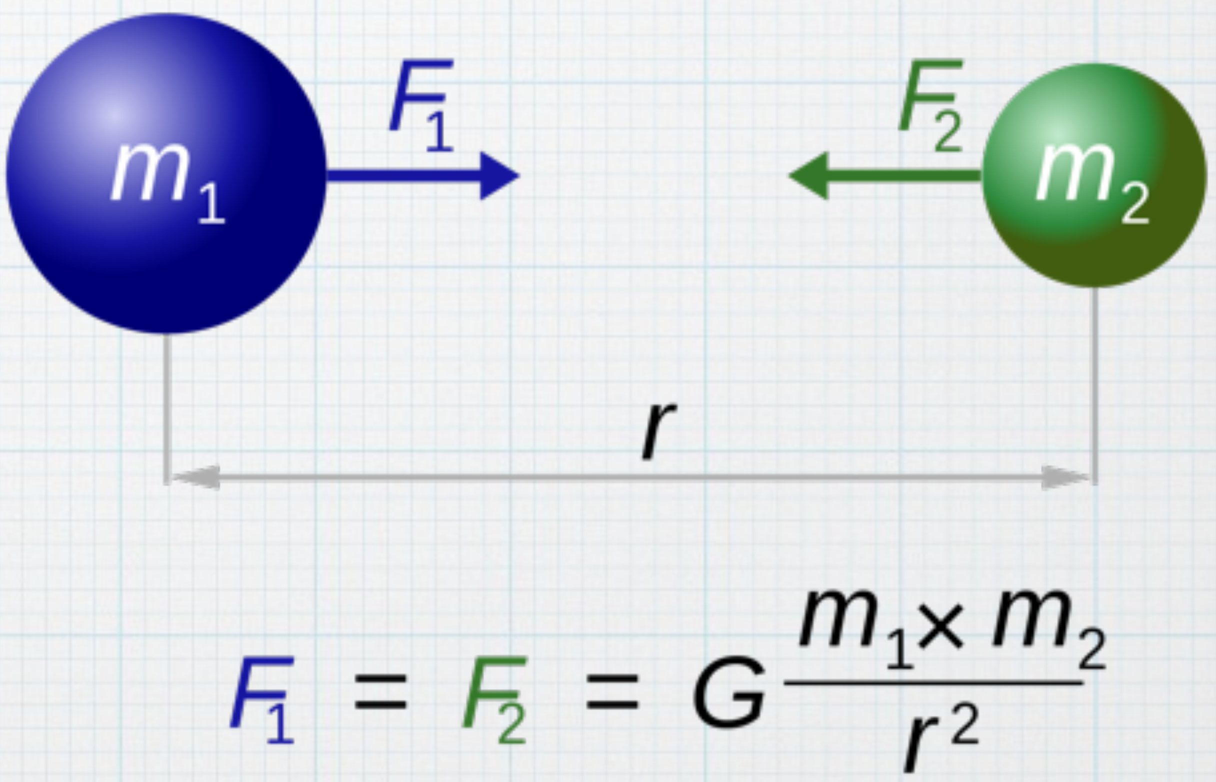
* Gravitational potential energy
* mgh, but what is h?
* Referenced to what?
    * center of mass
    * earth's surface





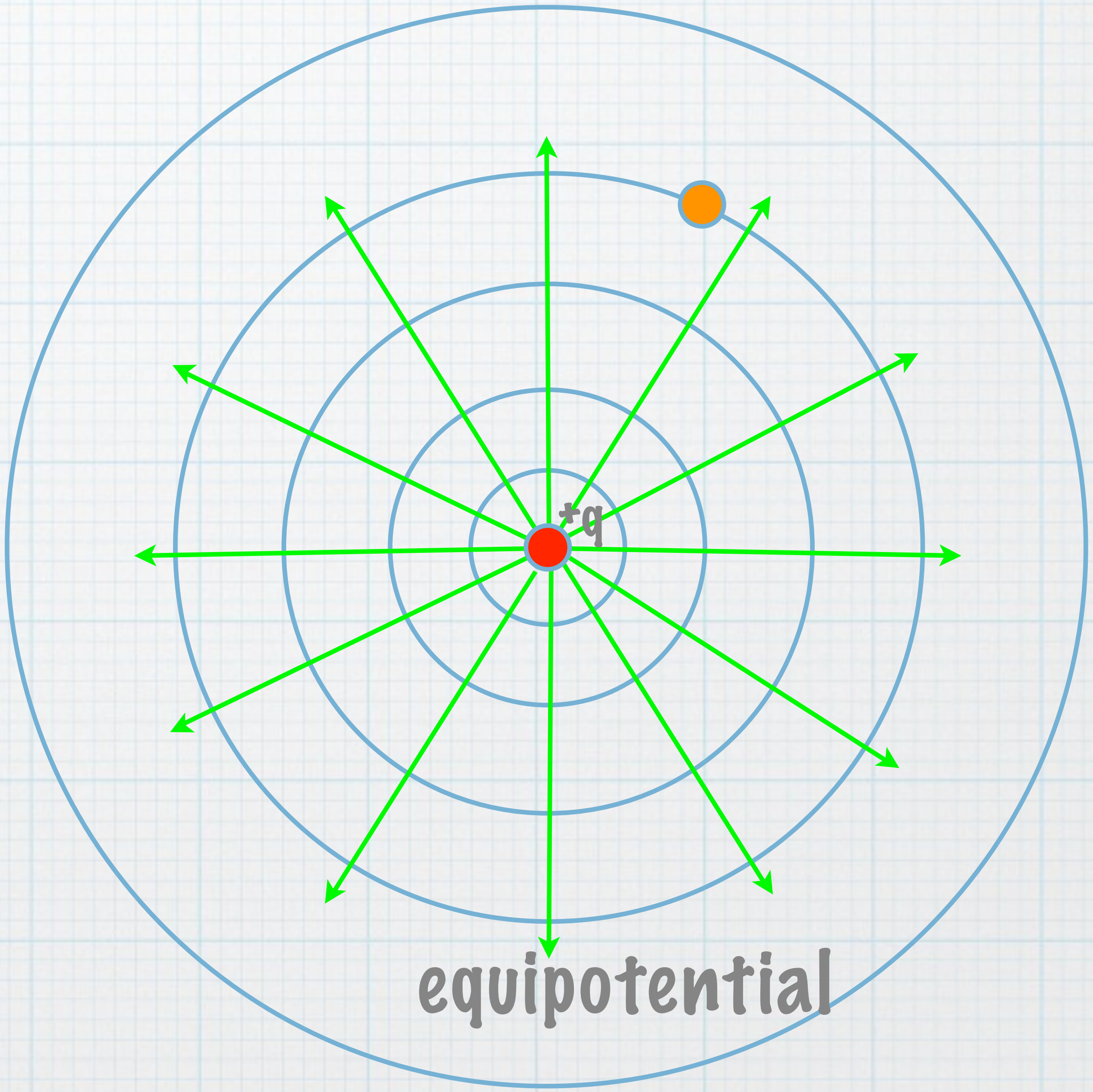
What if there's no earth?

* Then there's no reference
* Newton's law of gravitation still applies
    * distance and masses
* Just like voltage / E-field



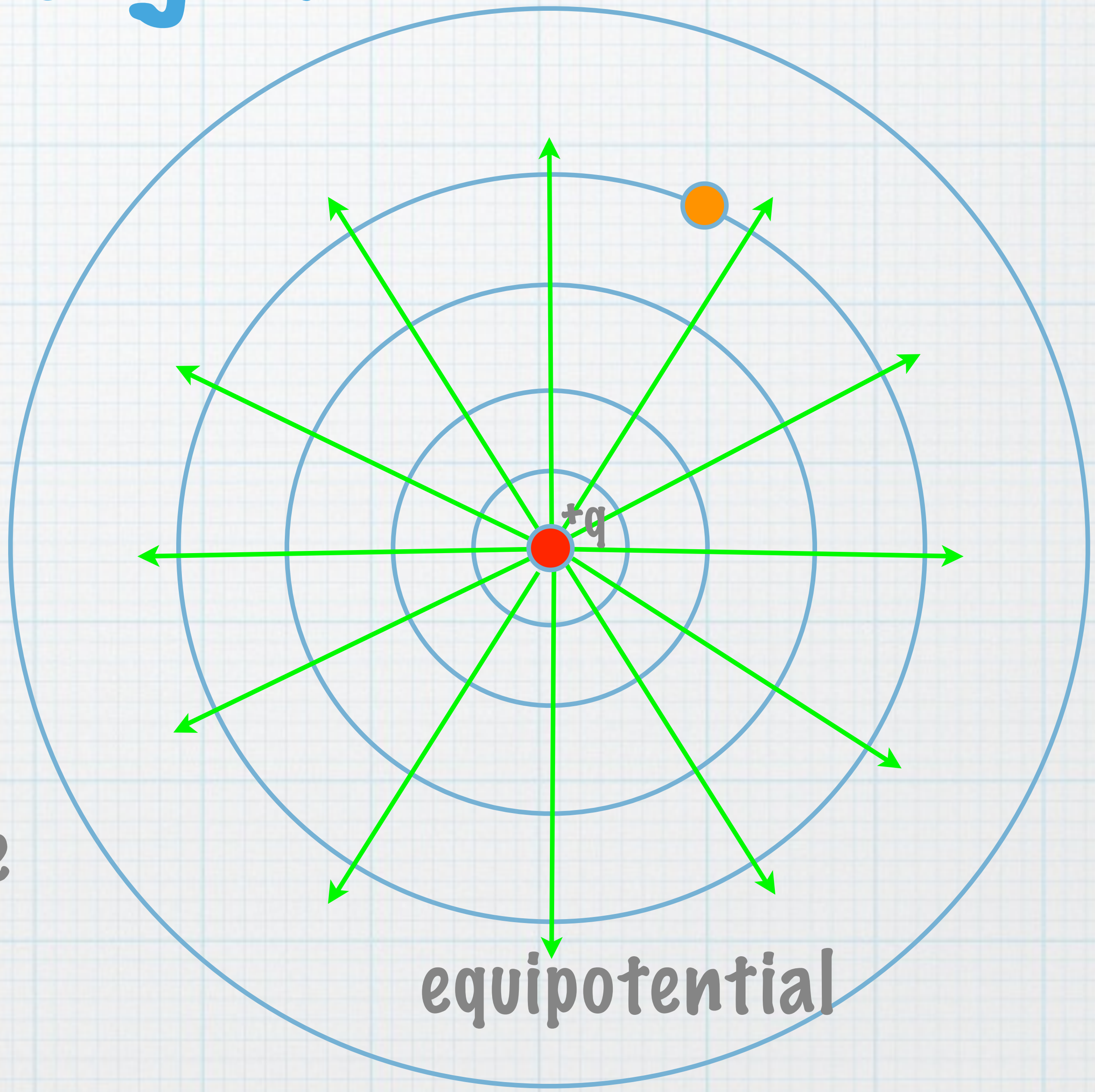
Let's go back to Voltage

* Electric Potential
* Mark your relative position in an E-field
* Says something about Work and PE
  * conservative field
  * path independent



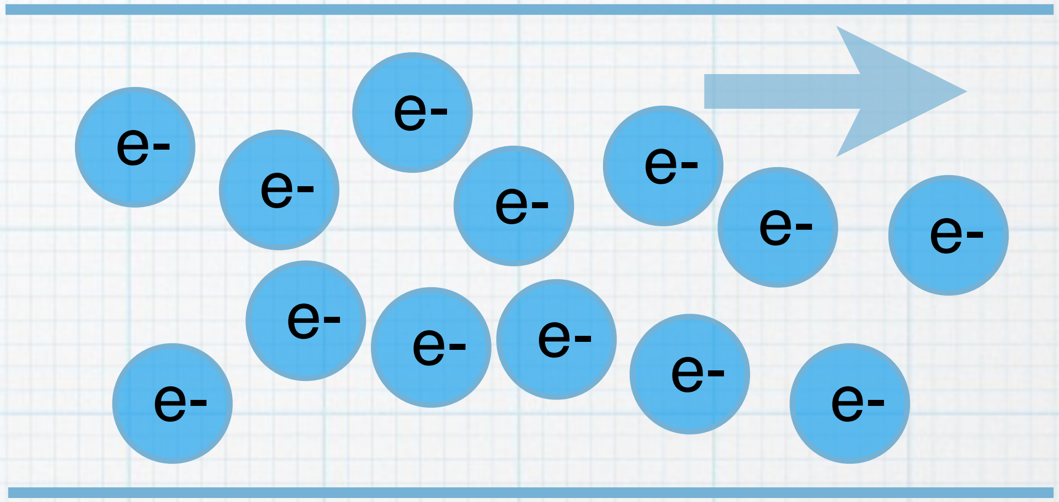
Is there a ground for Voltage?

* Just the difference in position in an E-field
* Where is zero?
    * shift in focus
* Maybe at the edge of the universe



What about Current?

* Is there such a thing as ground for current?
  * Time rate of change of charge
  * Featured in Maxwell
  * Since it's a derivative, there is no reference point



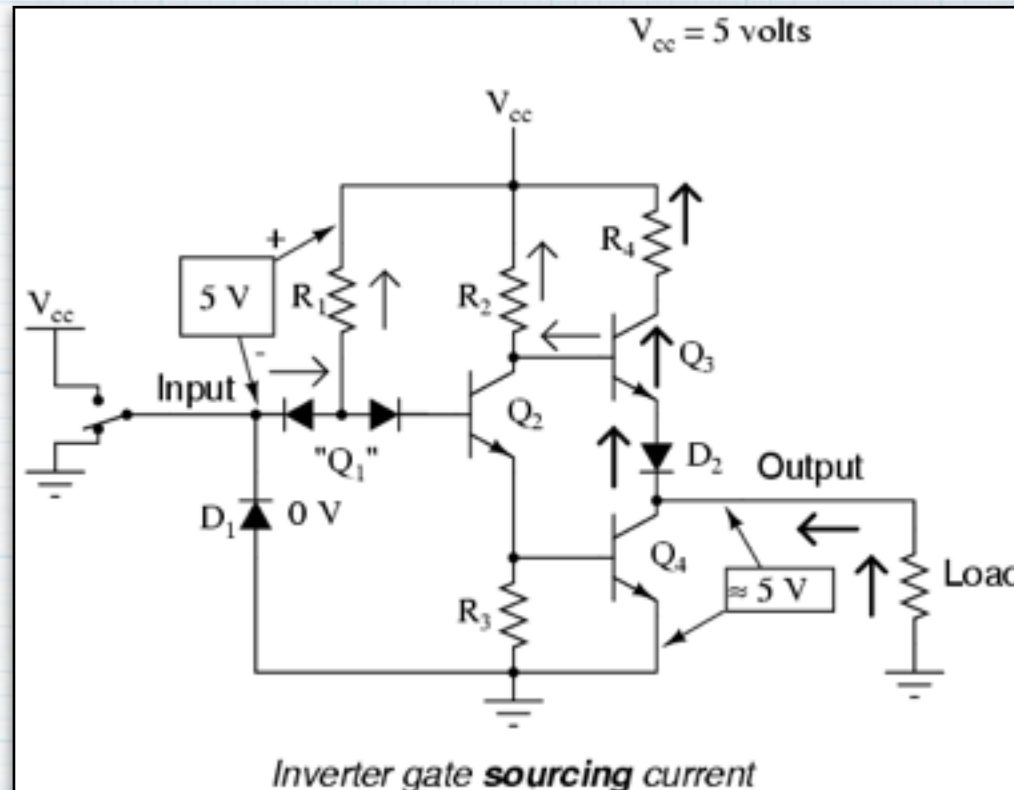
Current = time rate of change of charge dq/dt

$$\oint \vec{H} \cdot d\vec{L} = I + \oint \partial \vec{D}/\partial t \cdot d\vec{A}$$

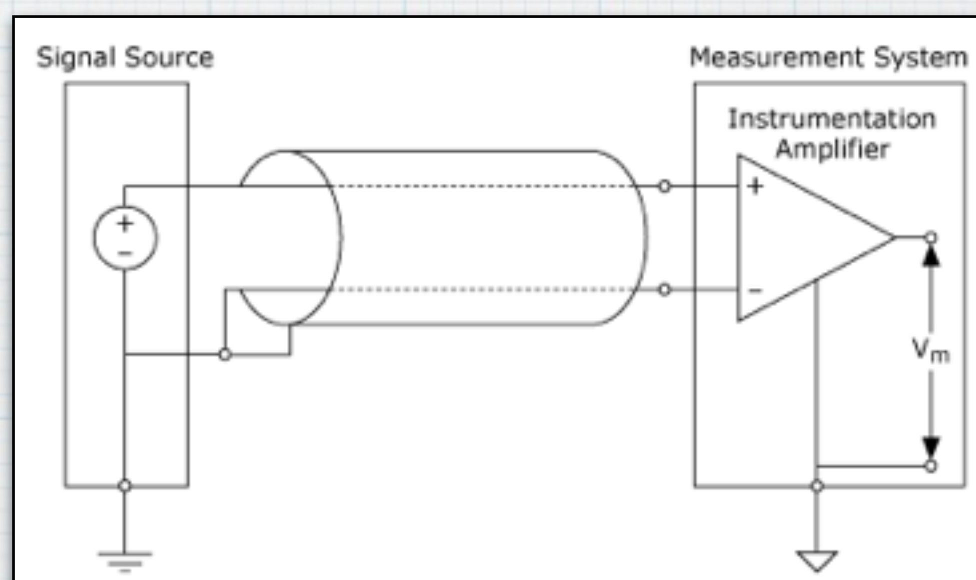
$$\vec{\nabla} \cdot \vec{J} = \partial \rho / \partial t$$

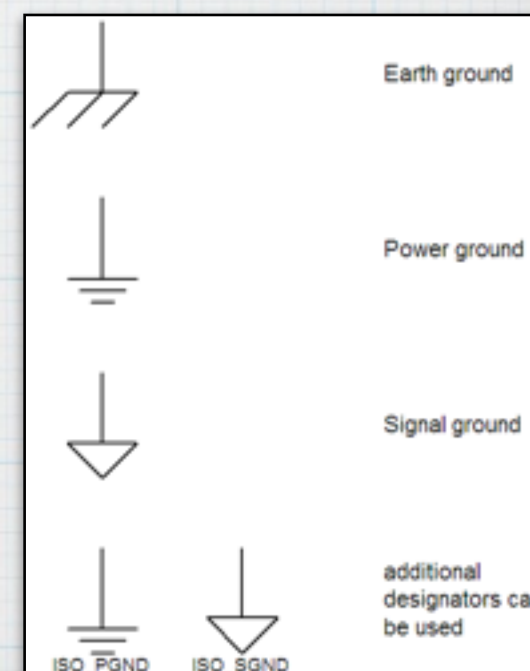
Circuits and Ground

* Common reference
* Chassis connection
* Shielding
* Current return path



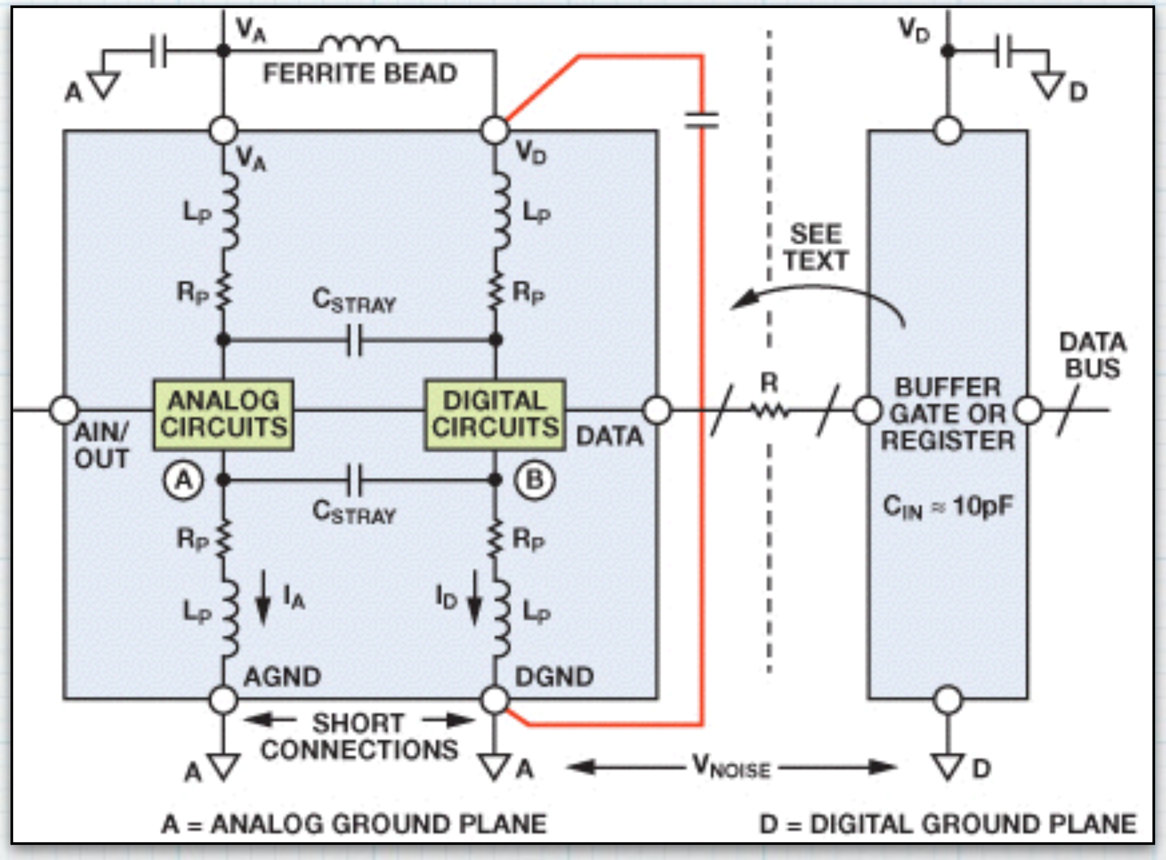
*Inverter gate **sourcing** current*

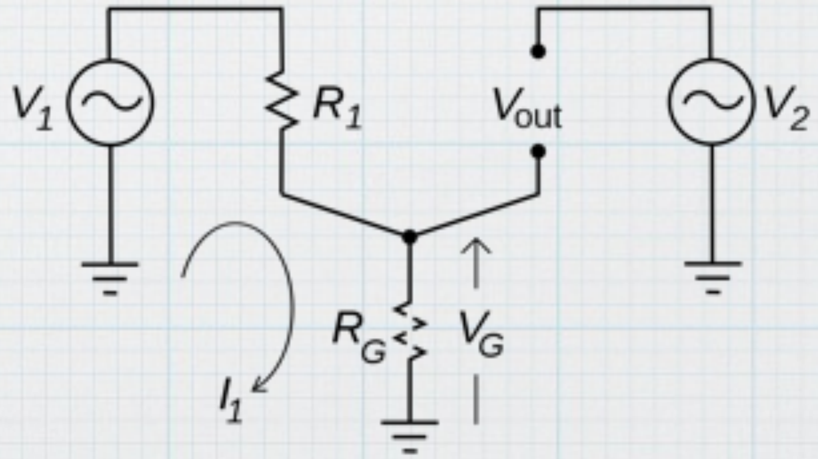




Digital & Analog Ground

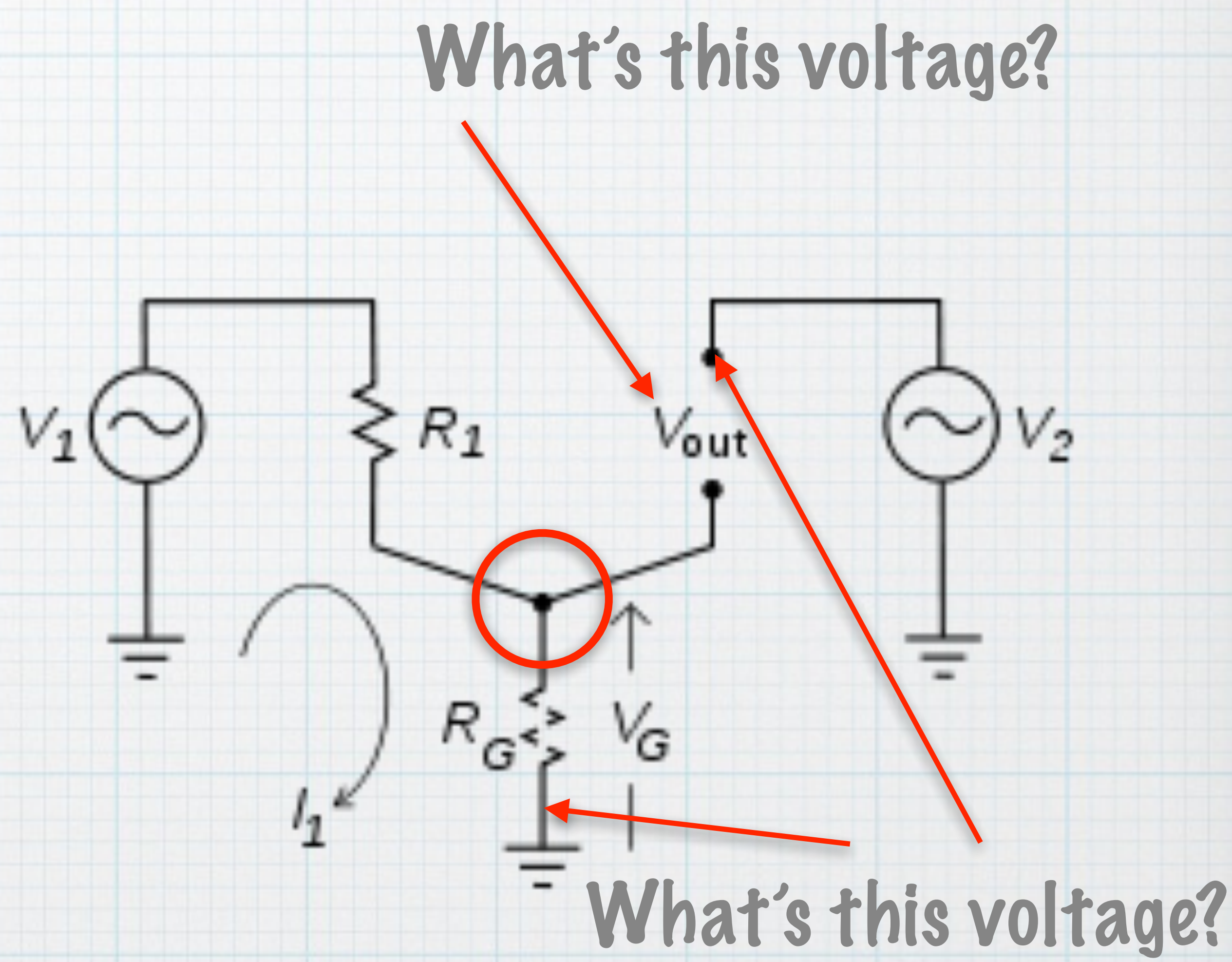
* Split system into two
  * one noisy, high current
  * one quiet, low current
* How do we re-join these?
* What if there's a voltage differential?
  * "ground loop"





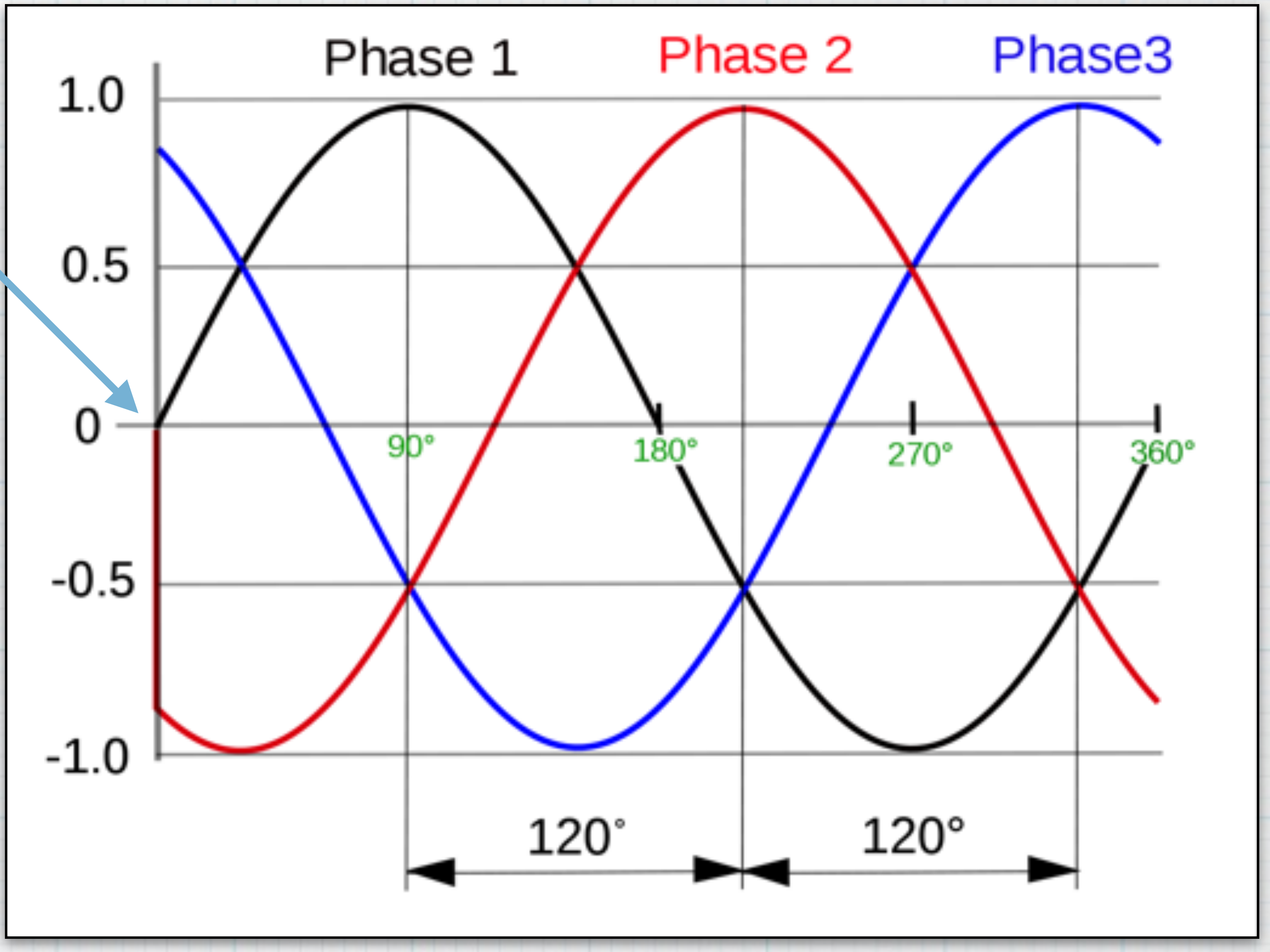
Ground Currents

- Current return path
  - most common use
- If the ground has finite resistance
  - delta V along path
  - it's no longer a reference



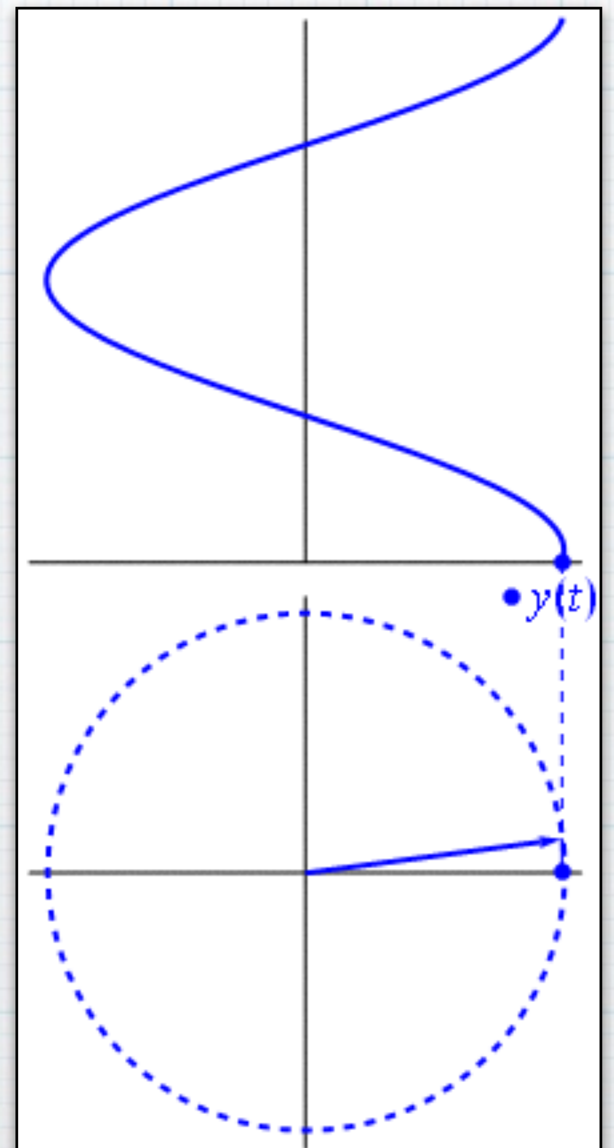
Ground and AC

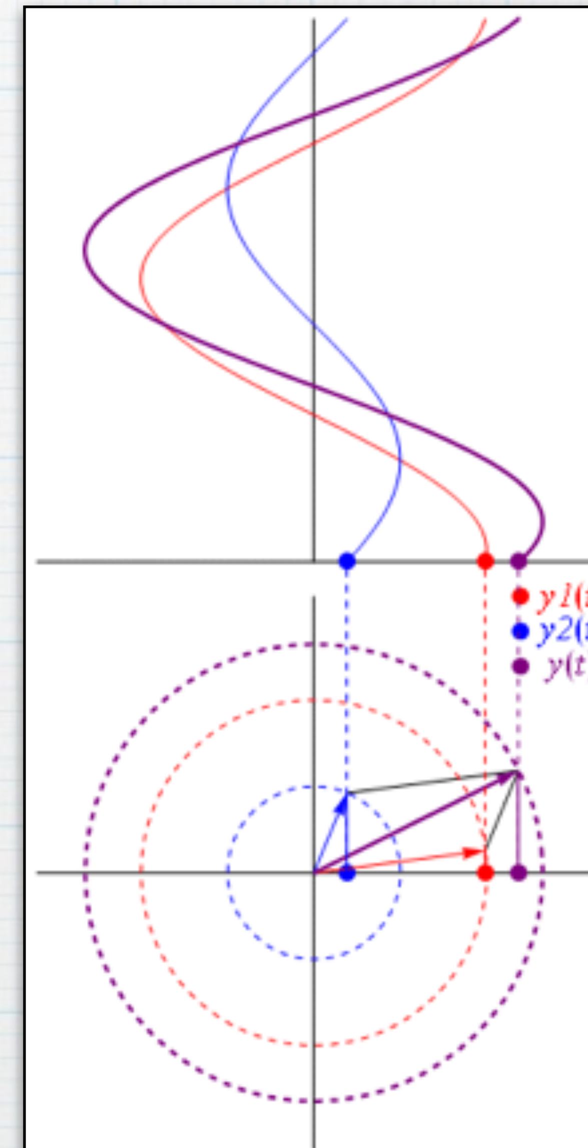
* Very tricky!
* Must be the zero reference for all time
* Signals changing with time: V(t), I(t)
* Consider with three (or more) phases



Diversion: Phasor Notation

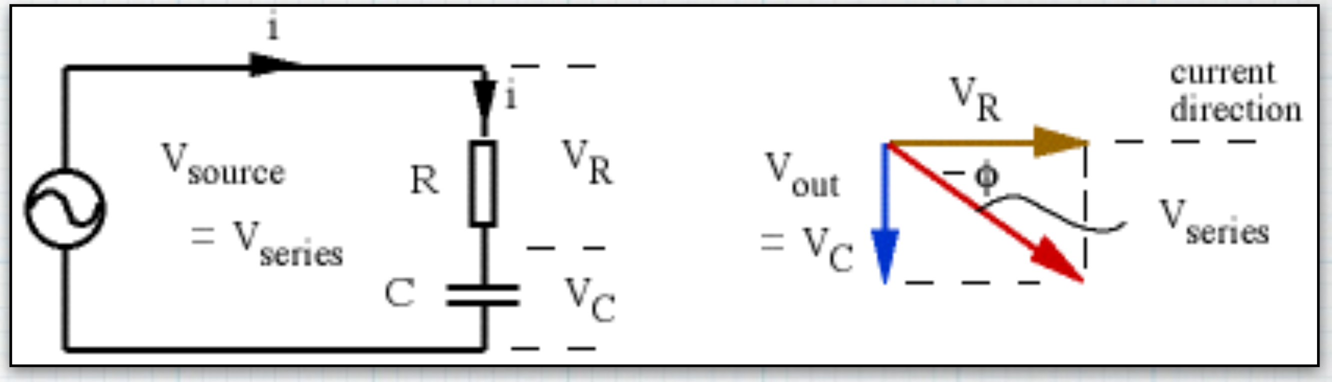
- Vectors used to represent:
  - Voltage, Current, Impedance
    - magnitude
    - phase
- Vectors can rotate with time
  - angular velocity, rad/sec -> ω
  - Complex plane, $e^{-j\omega t}$
- Only for monochromatic signals
- Vector sums simplify calculations

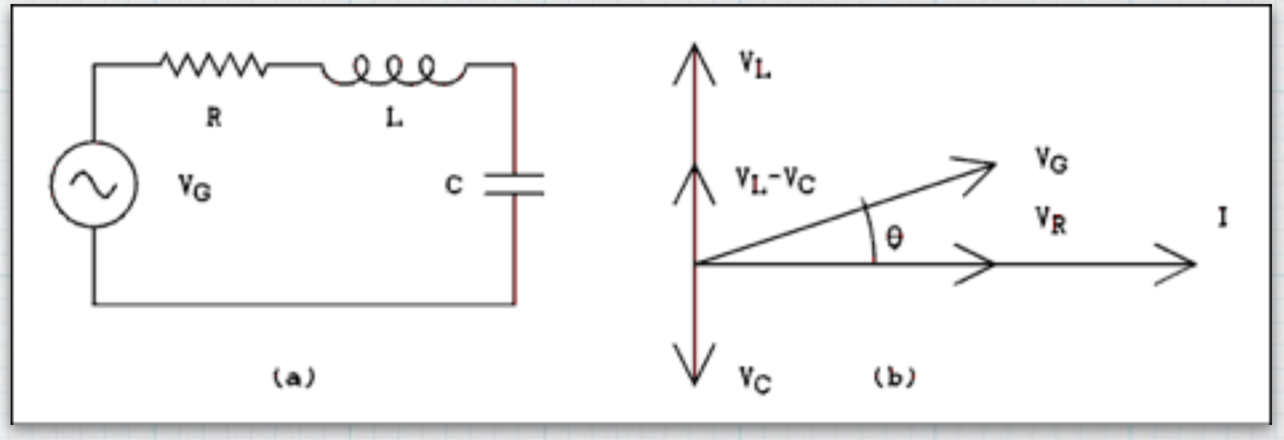




Phasors and Impedance

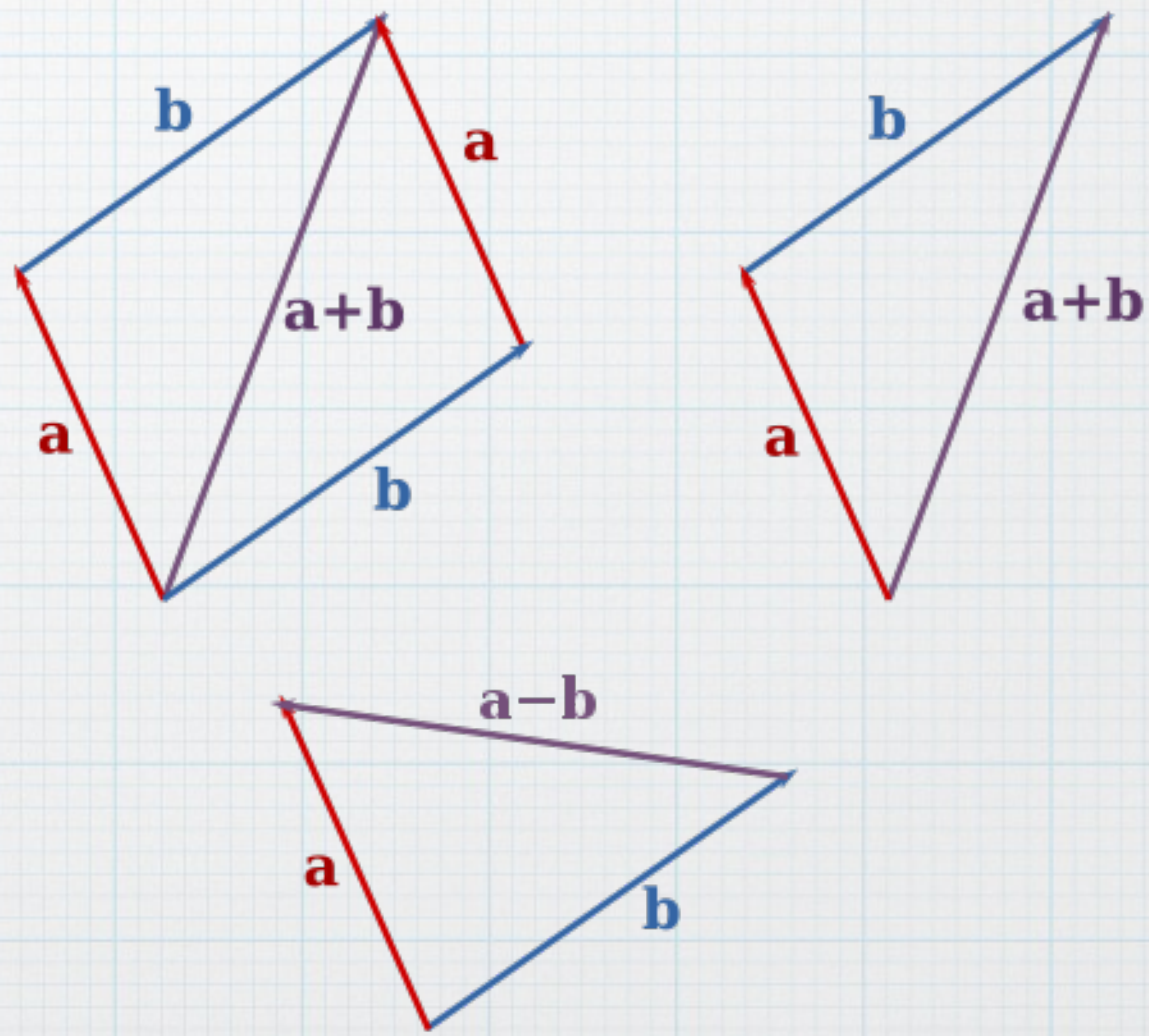
* You might recognize this from ham exams
* Differential equations become algebra, geometry
  * see VIRLCW talk
* Again, only one frequency
  * do not over-apply





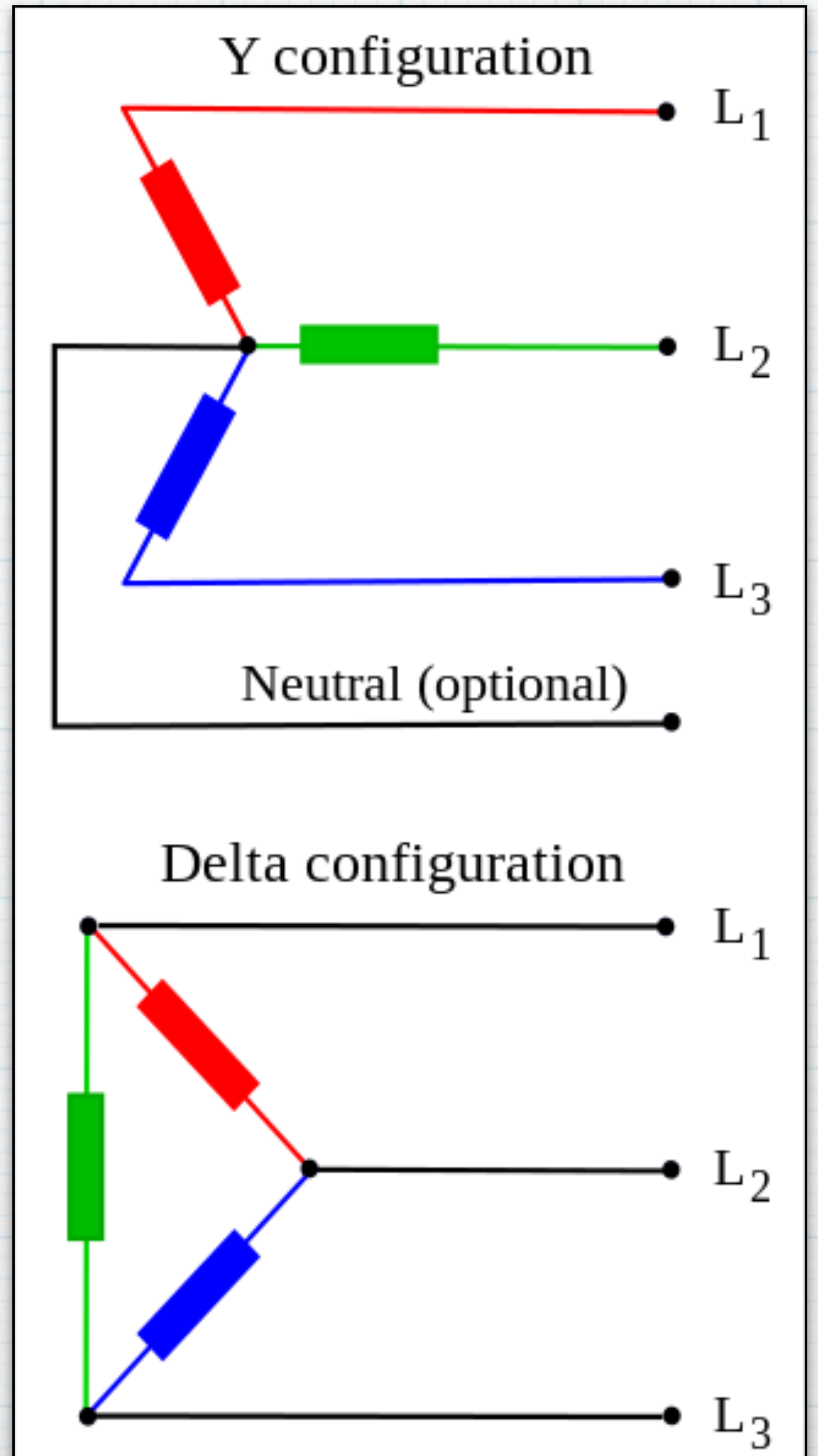
Adding Phasors

* Decompose into their X and Y components
    * Real and Imaginary
* Add these separately
* Resultant components are the new vector
* Tip+Tail, Parallelogram, Tail-Tail

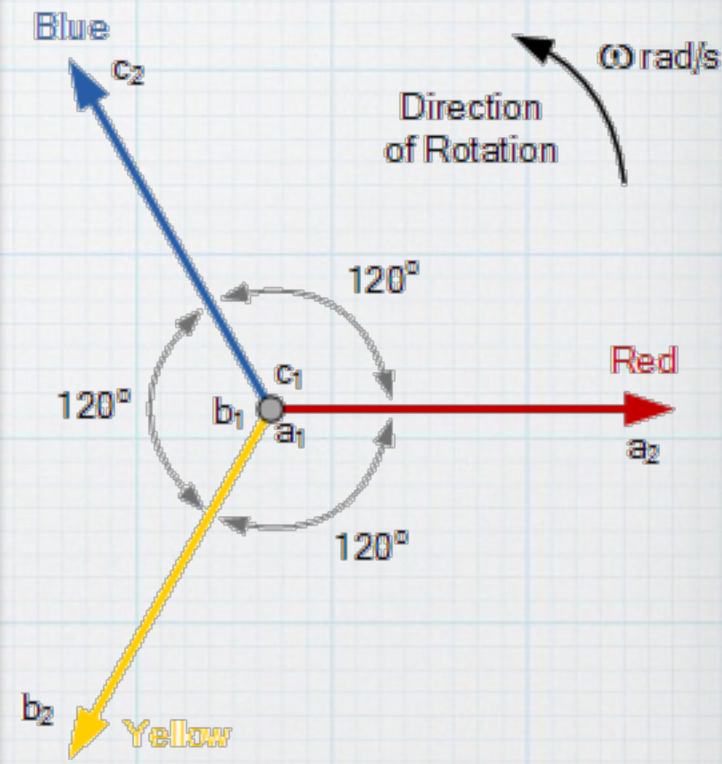


Delta and Wye (Y)

- Delta is un-referenced
- Wye has a reference, or neutral signal
  - no current if phases balanced
  - is this ground?
- Transformable
- How to "ground" a Delta?



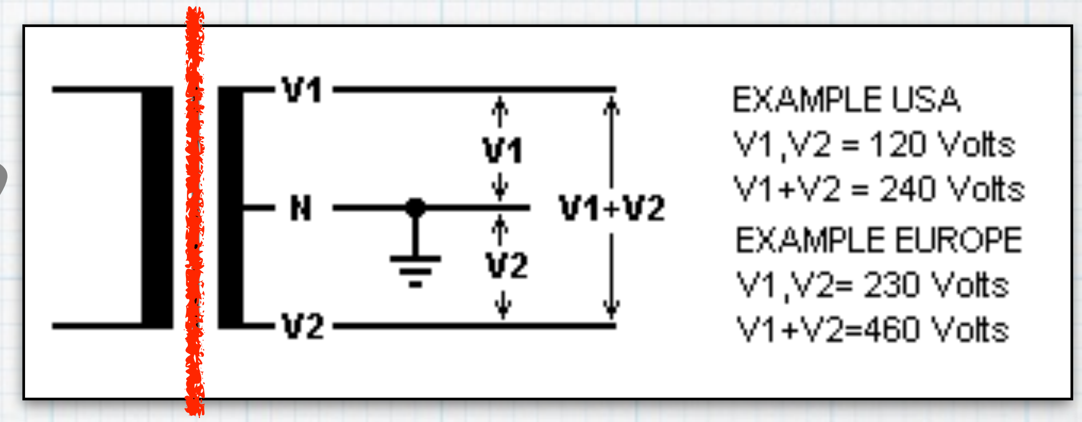
Phasor



Split Phase and Neutral

earth ground?

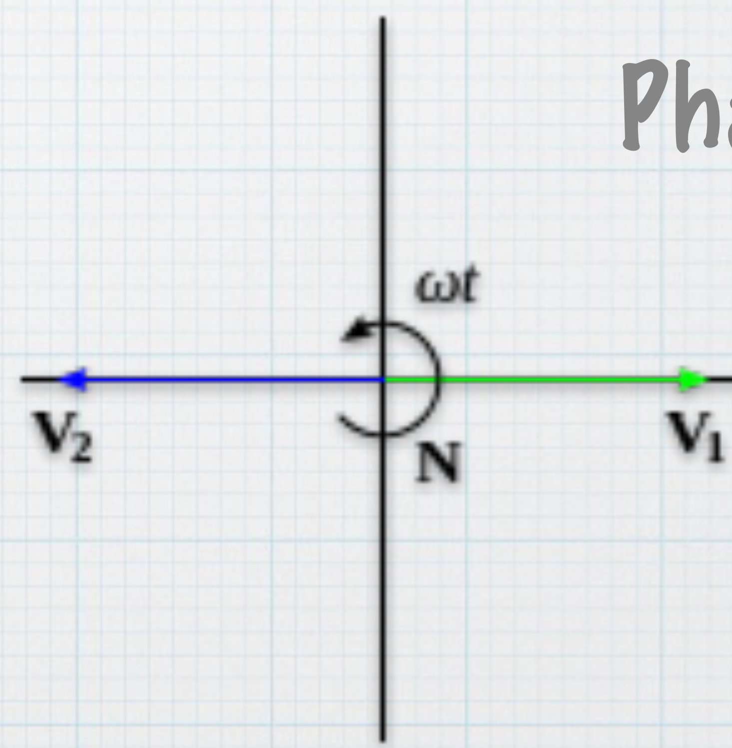
Gnd?



- What is the neutral?
  - center tap
  - is this ground?
- Driven by one phase, isolated - no "ground"

magnetic isolation

Phasor

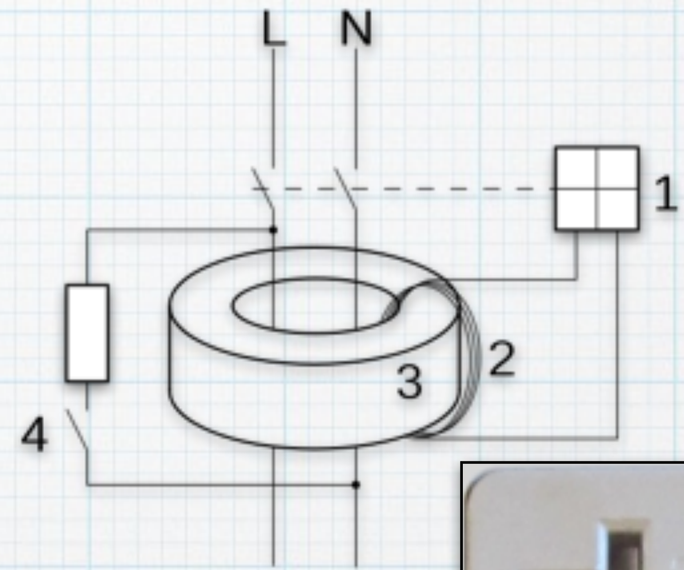


Neutral and Grounding Conventions

- Connected to earth in some way?
- What is the resistance?
  - generally a poor conductor
  - variable: salt, water
- Can we still be hurt?
  - sure

Ground Fault Interruptor

* A workaround
* Looks at current balance
* Doesn't really reference "ground"
  * infers flow to ground, but could be anywhere
  * what is ground?



Ground Conductivity

* Even in the best conditions: 100s of Ohms
* Worst conditions: 100,000s Ohms
* Is this useful or meaningful?
* Is this safe?

	Resistivity (approx), Ω-cm		
Soil	**Min.**	**Average**	**Max.**
Ashes, cinders, brine,waste	590	2,370	7,000
Clay, shale, gumbo, loam	340	4,060	16,300
Same, with varying proportions of sand and gravel	1,020	15,800	135,000
Gravel, sand, stones with little clay or loam	59,000	94,000	458,000

Moisture content	Resistivity Ω-cm	
% by weight	**Top soil**	**Sandy loam**
0	>10^9	>10^9
2.5	250,000	150,000
5	165,000	43,000
10	53,000	18,500
15	19,000	10,500
20	12,000	6,300
30	6,400	4,200

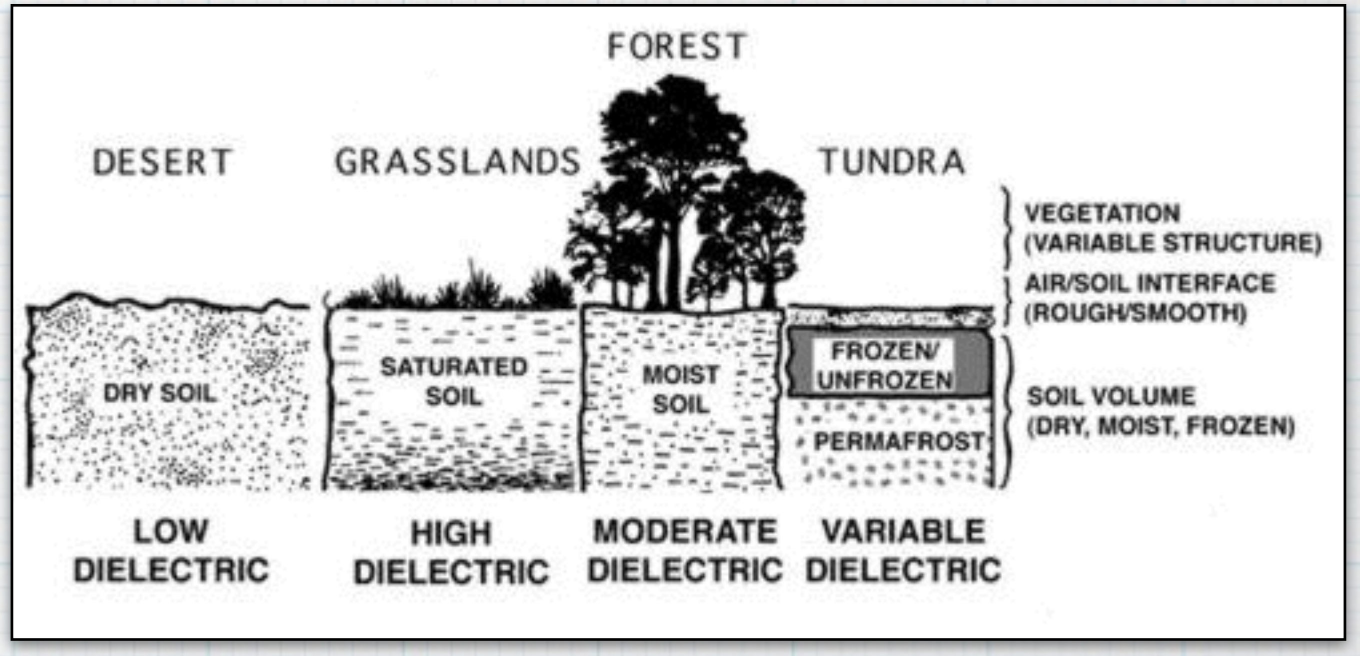
THE EFFECT OF SALT* CONTENT ON THE RESISTIVITY OF SOIL

(Sandy loam, Moisture content, 15% by weight, Temperature, 17°C)

Added Salt (% by weight of moisture)	Resistivity (Ohm-centimeters)
0	10,700
0.1	1,800
1.0	460
5	190
10	130
20	100

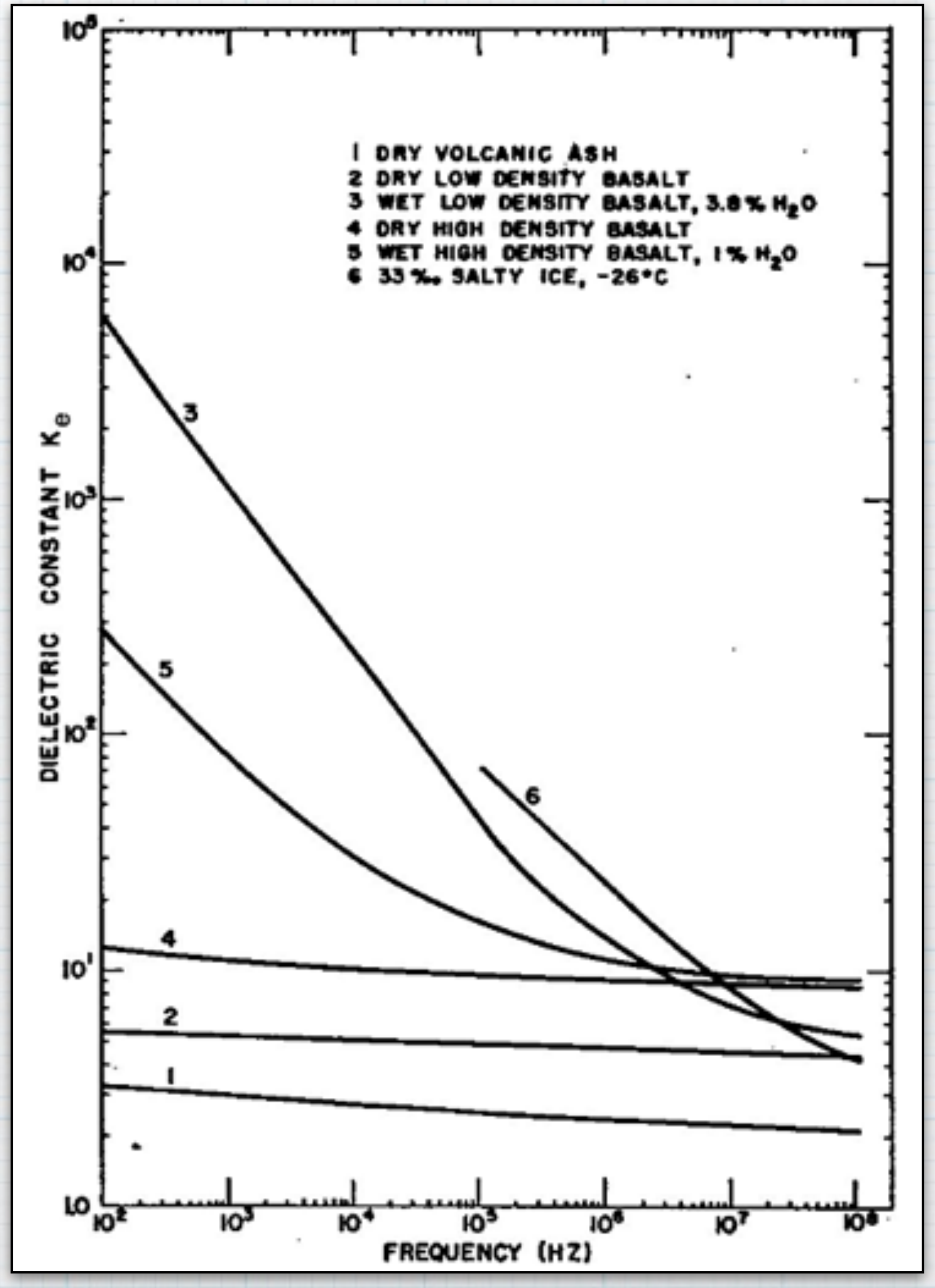
Let's Increase the Frequency

* What is different at HF?
* More coupling, but to what?
* Does this do anything for performance?
* Does this do anything for safety?



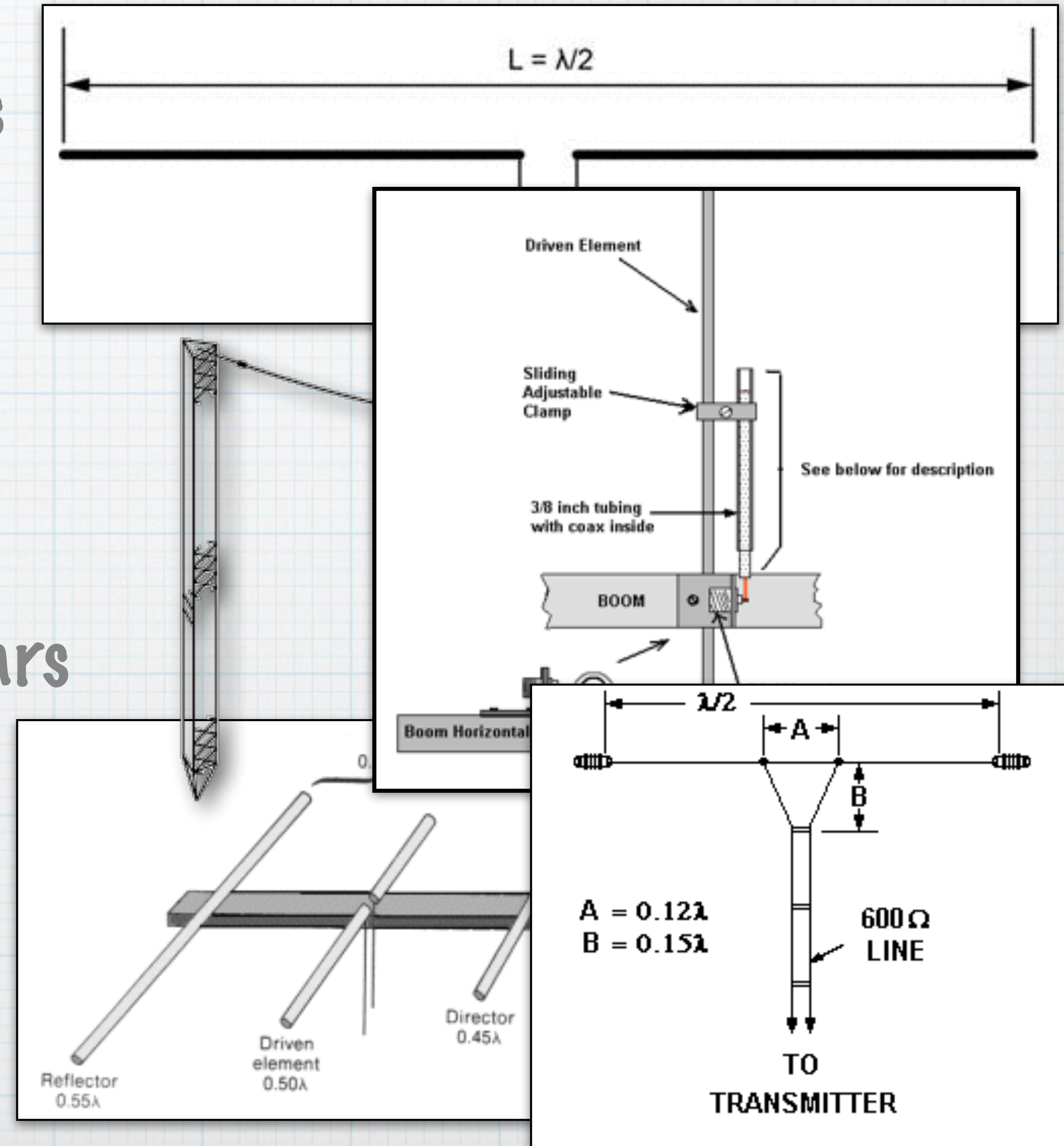
Let's Increase the Frequency

* What is different at VHF?
* Even more coupling, but to what?
* Does this do anything for performance?
* Does this do anything for safety?



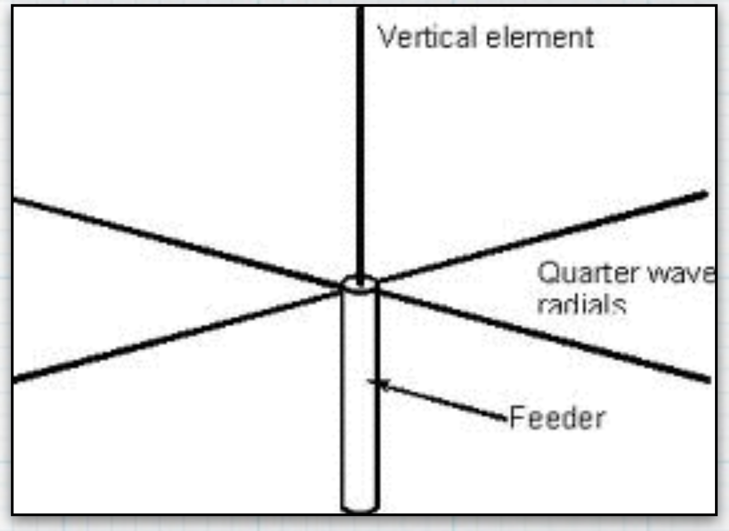
But don't Antennas Need a Ground?

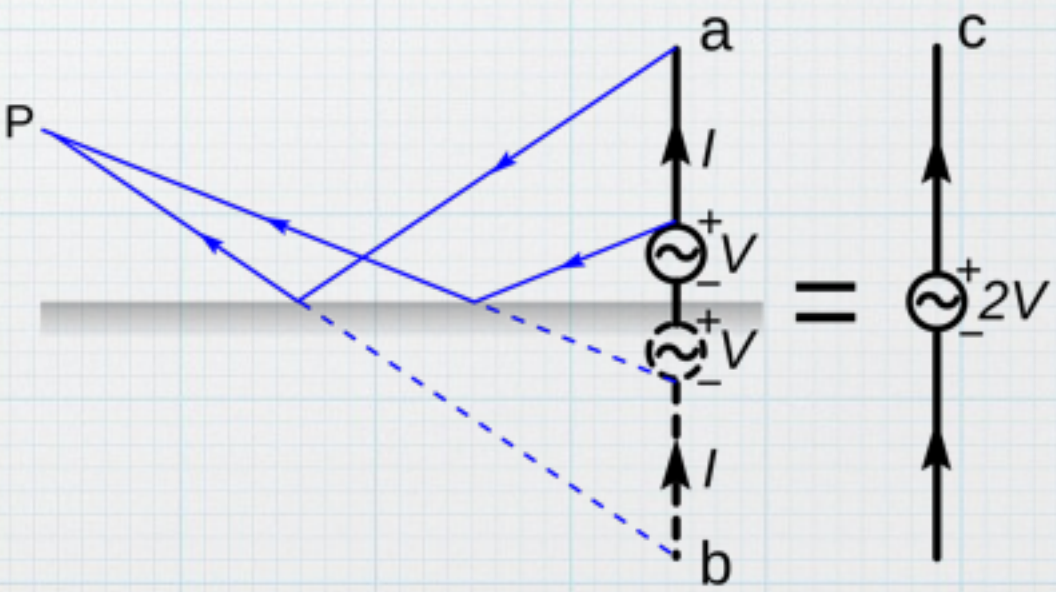
- Balanced antenna needs nothing
- Symmetrical structure favors nothing
- Match doesn't indicate "ground", though it appears assymetic
  - pattern shift



What about Ground Planes?

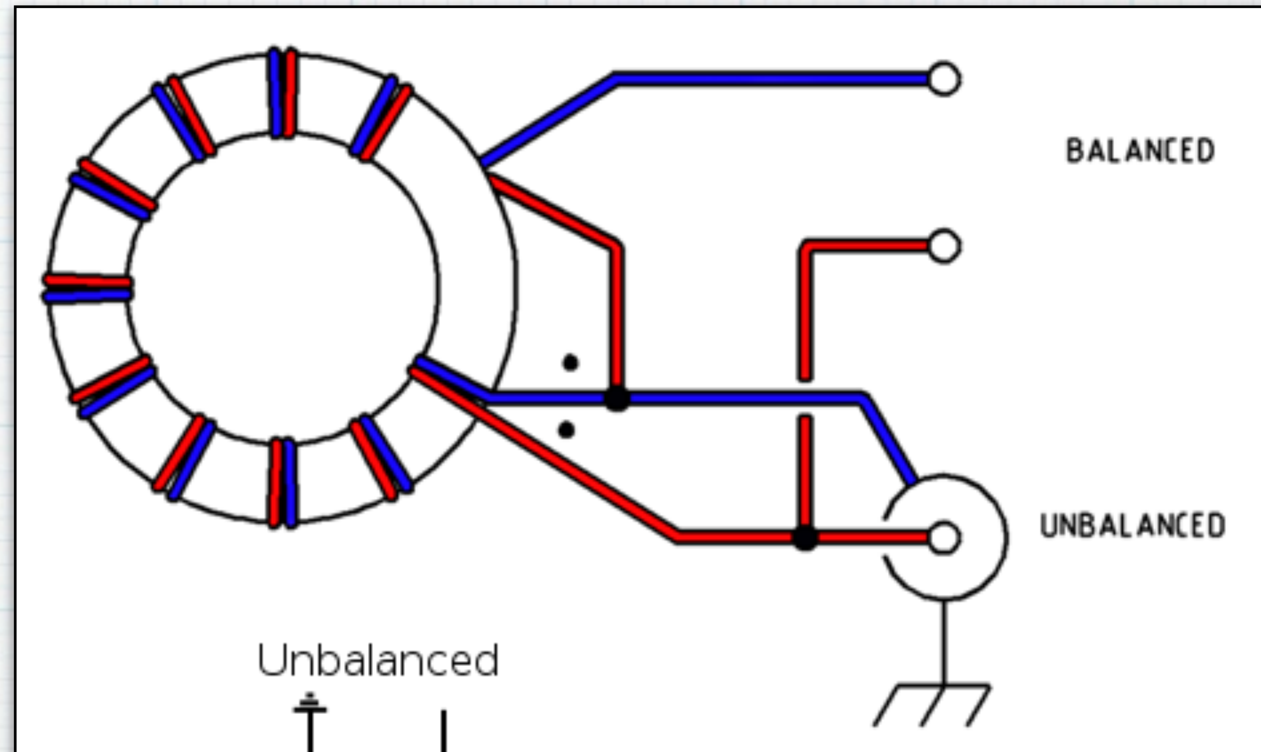
* Creates a mirror for the single radiating element
* More compact
* Easy to use vertically polarized
* Radials might be on the earth
* Is that really a ground?
* Do you need them to be there?
    * no

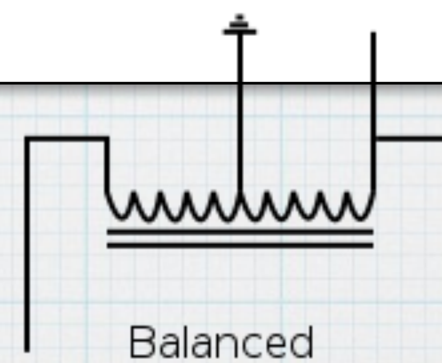


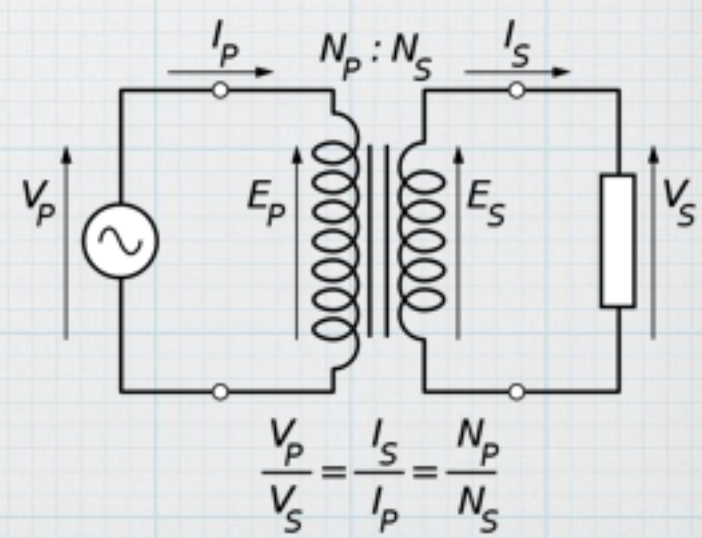


Baluns connect to Ground, right?

* Autotransformer
* Classical transformer
* Both don't care what the unbalanced side is connected to
  * typically a chassis shield
  * not earth ground
  * more about isolation than anything

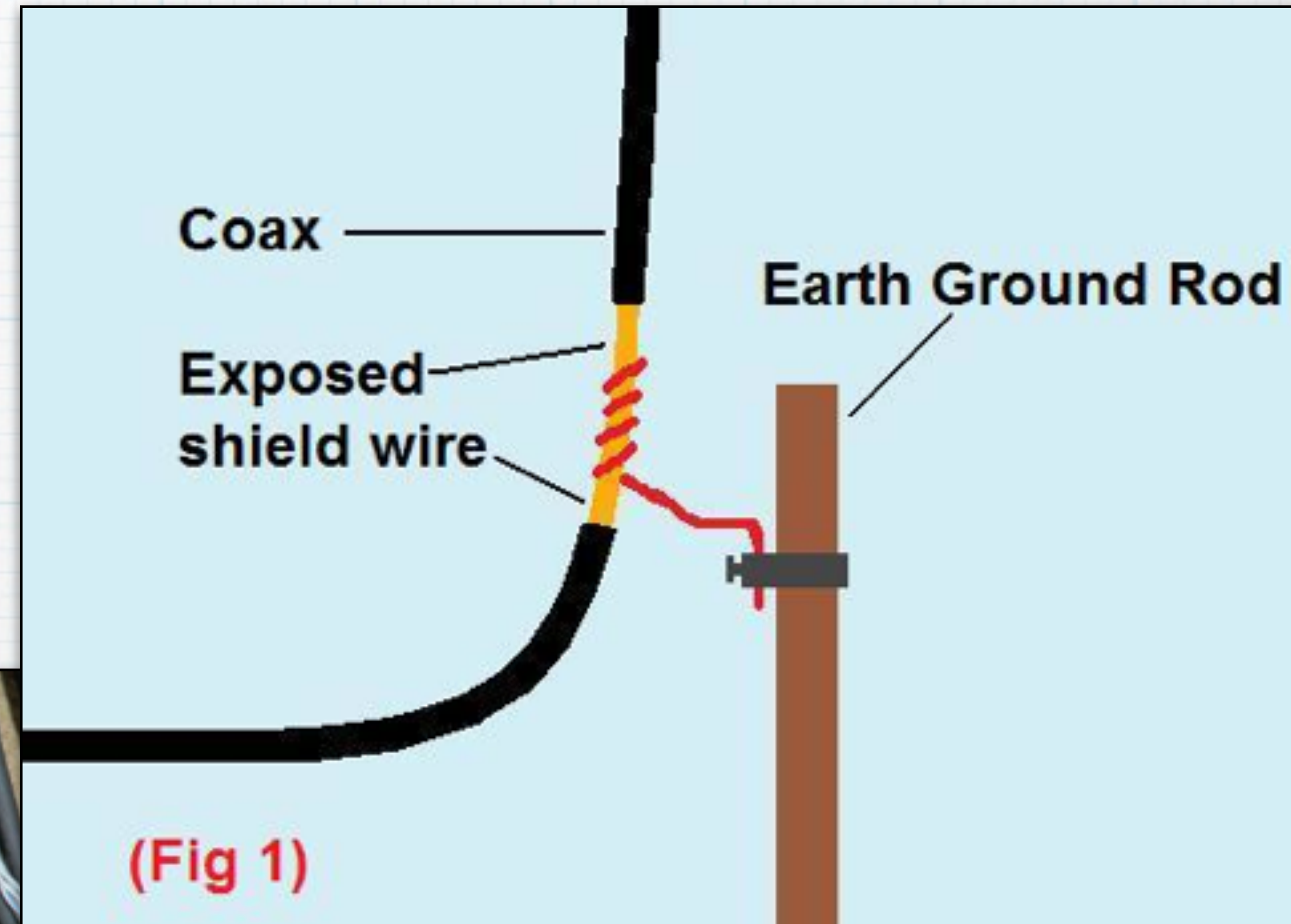


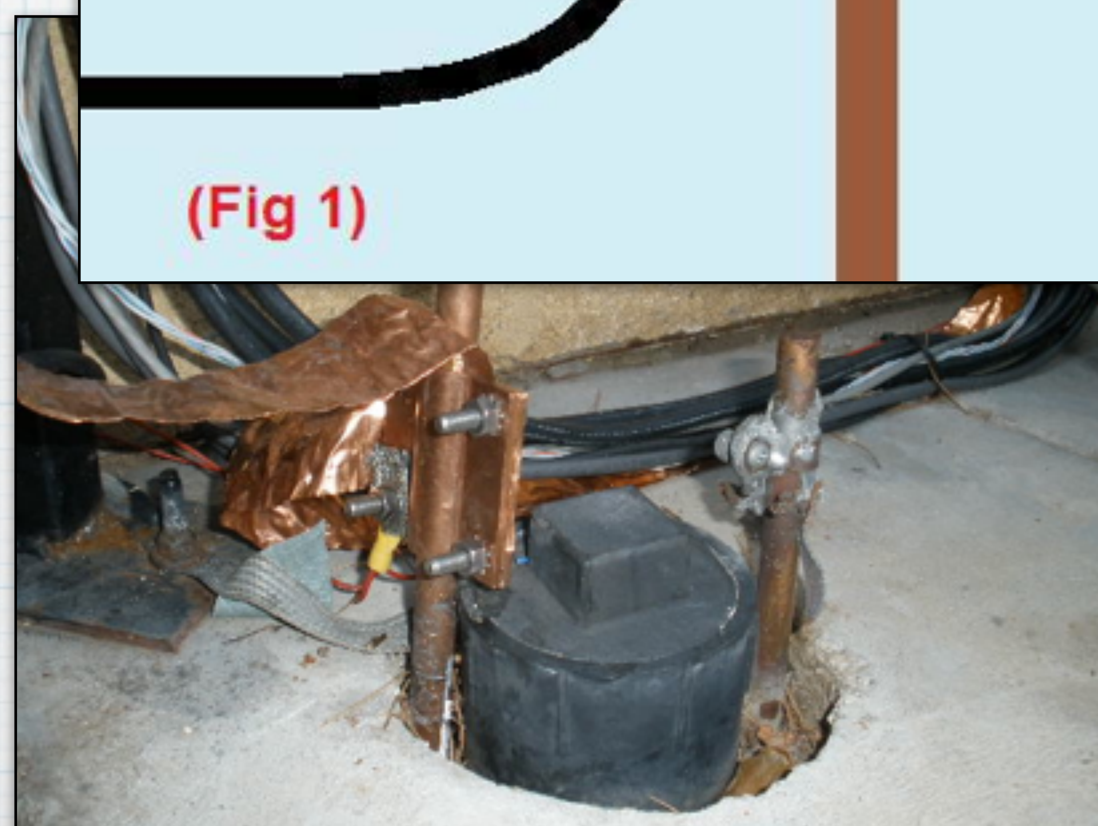




Don't use the Neutral or Safety as the "Ground" !?!

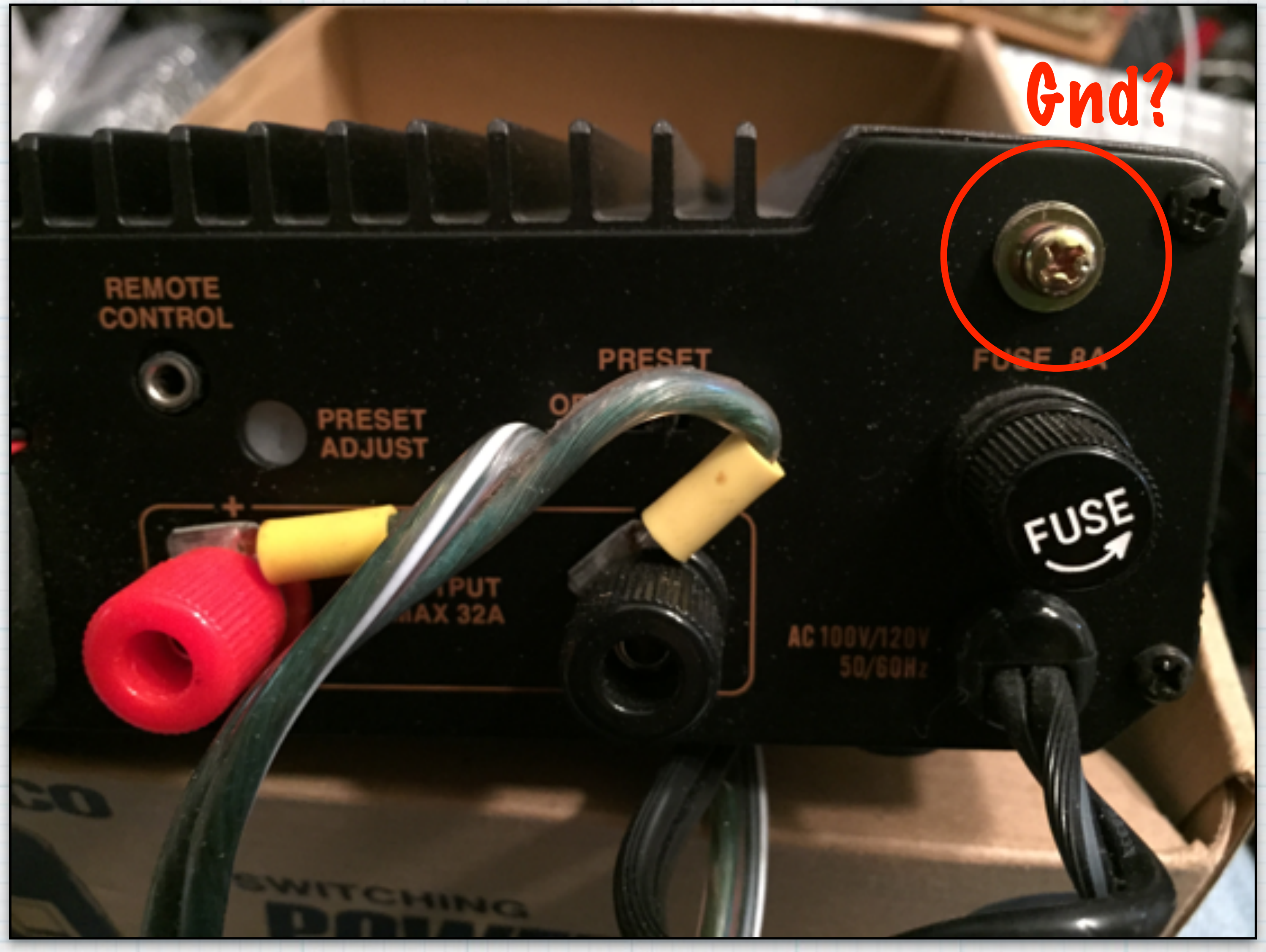
* Amateur Radio Handbook says put in a ground rod
* So, we couple to the earth with a ground rod
* Big undertaking
* But why?





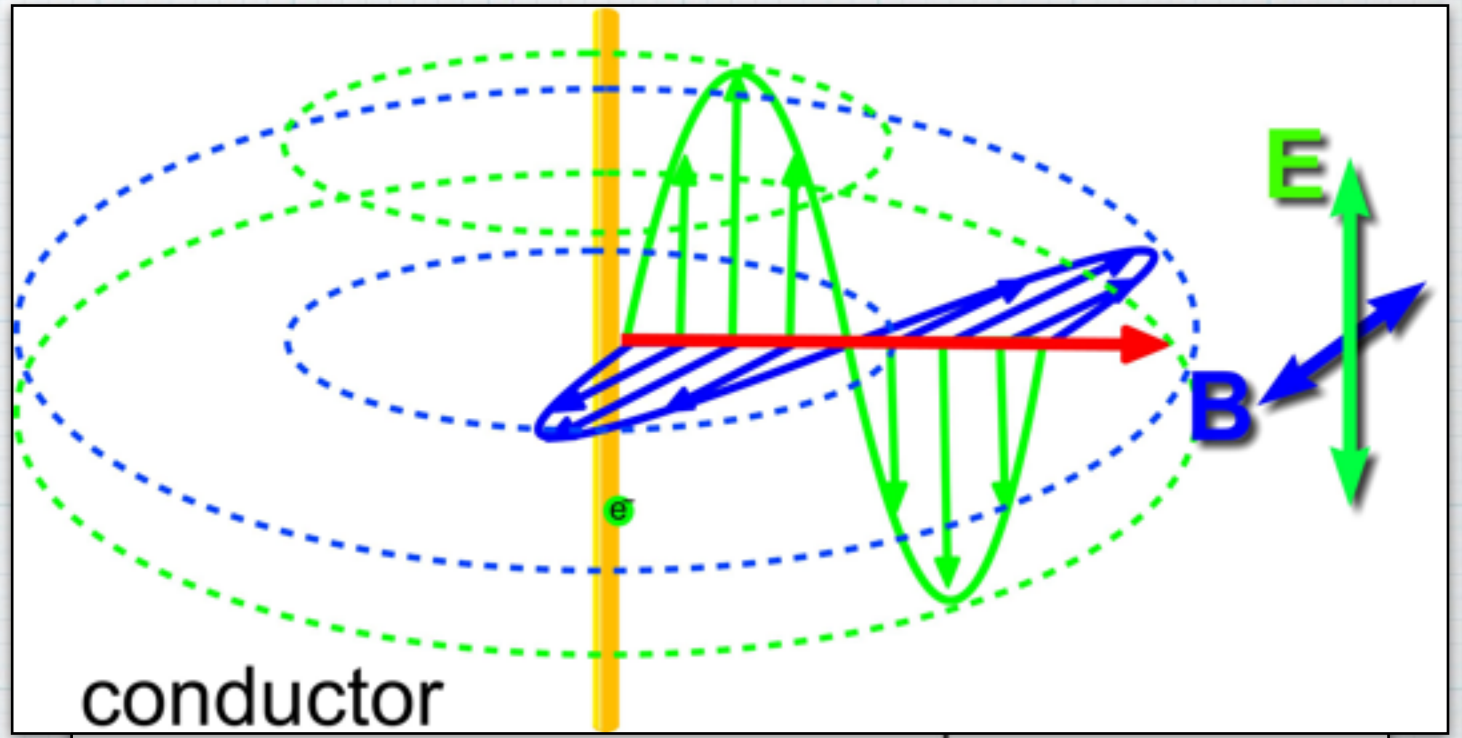
What about the Power Supply and Ground?

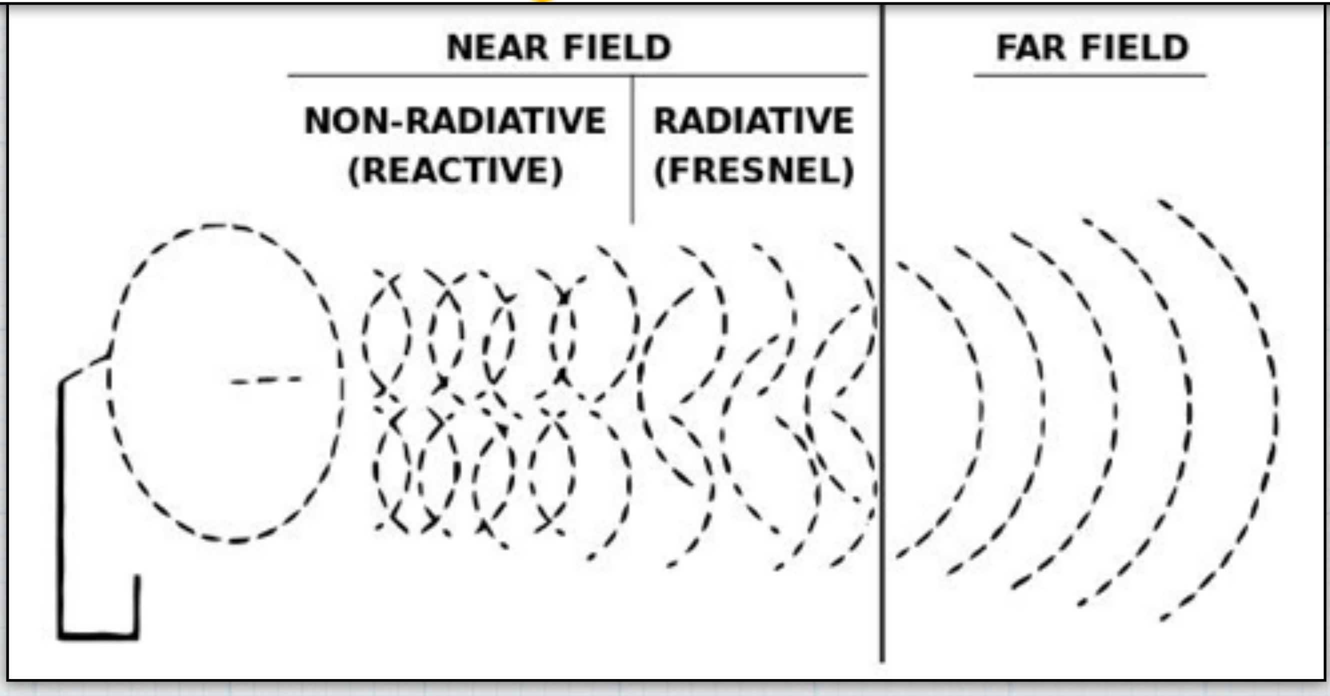
* Now what do we do?
* N grounds?
  * Safety ground
  * Ground rod
  * RF ground
* I'm very confused!



Is your head spinning yet?

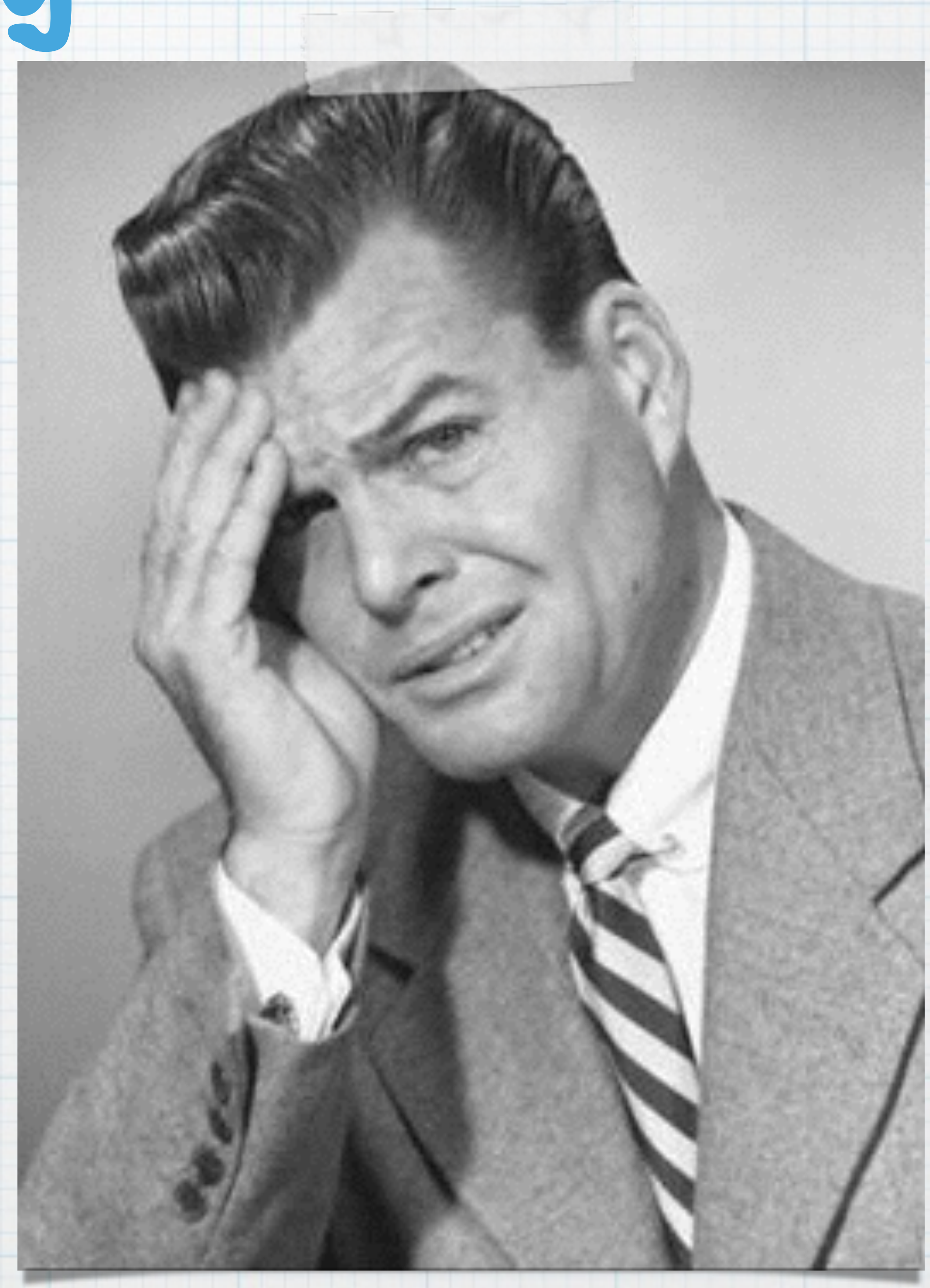
* Where is ground?
* What is zero volts?
* Ask again in an RF field
    * spatially dependent
    * temporally dependent
    * induction





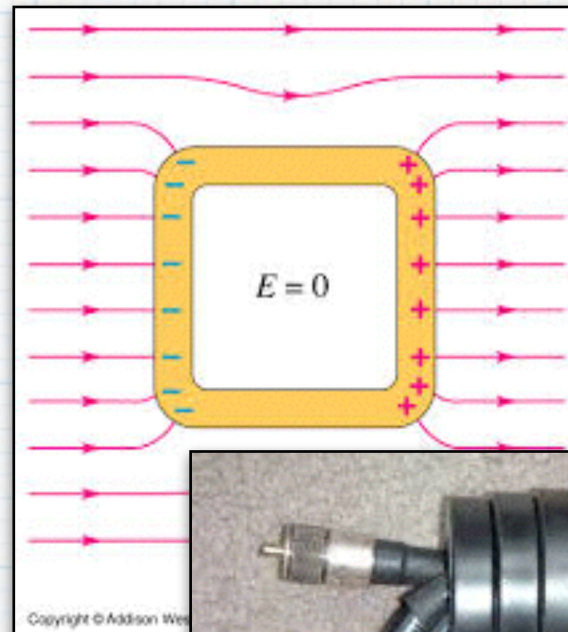
This is an impossible thing

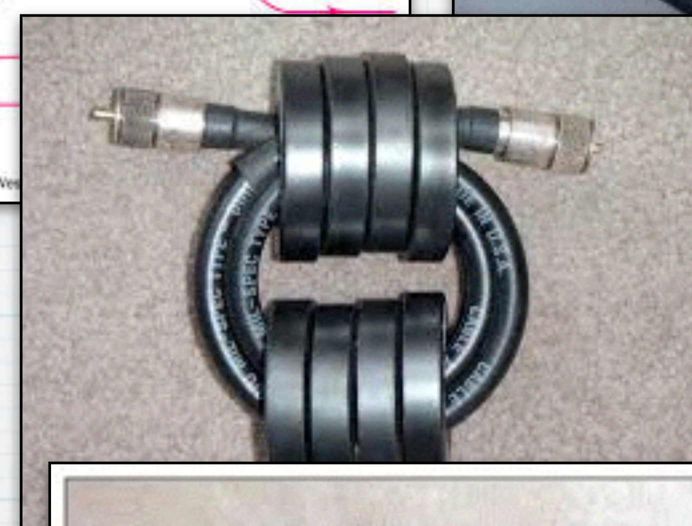
* There is no ground!
* Everything is relative
* Everything is in motion
* The best we can do is differentially stabilize at certain points

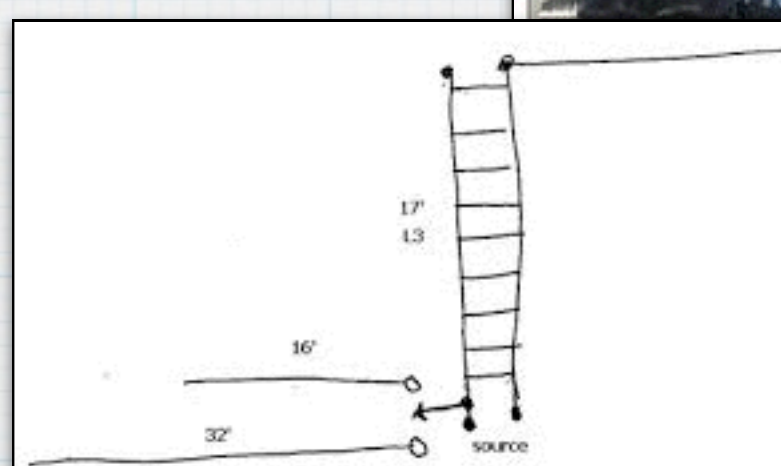


So, now what?

* Shield
* Isolate
* Stabilize

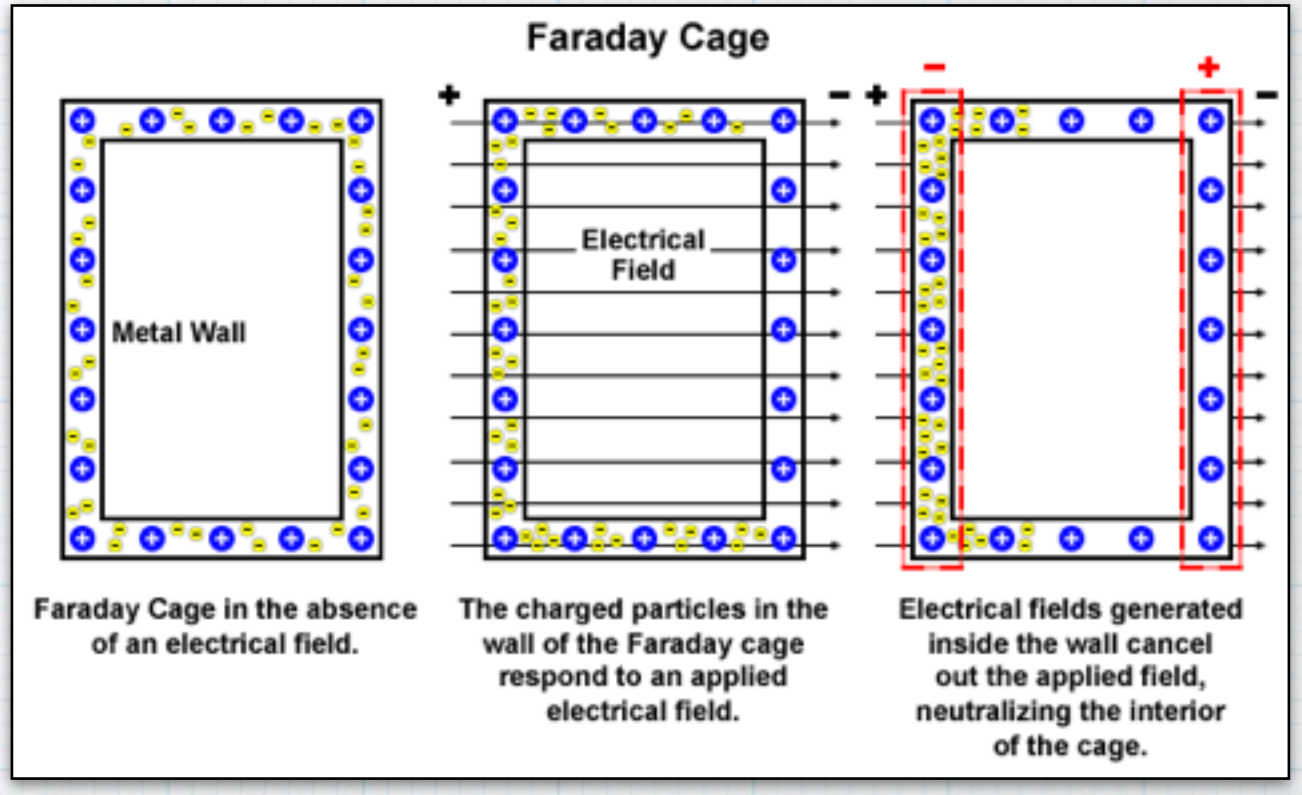






Shield - Faraday

* Enclose in conductor
  * keeps fields from inducing V or I in bad places
  * changes "ground"
* Avoid leakage fields in or out
* Avoid currents in other "grounds"
  * safety, neutral



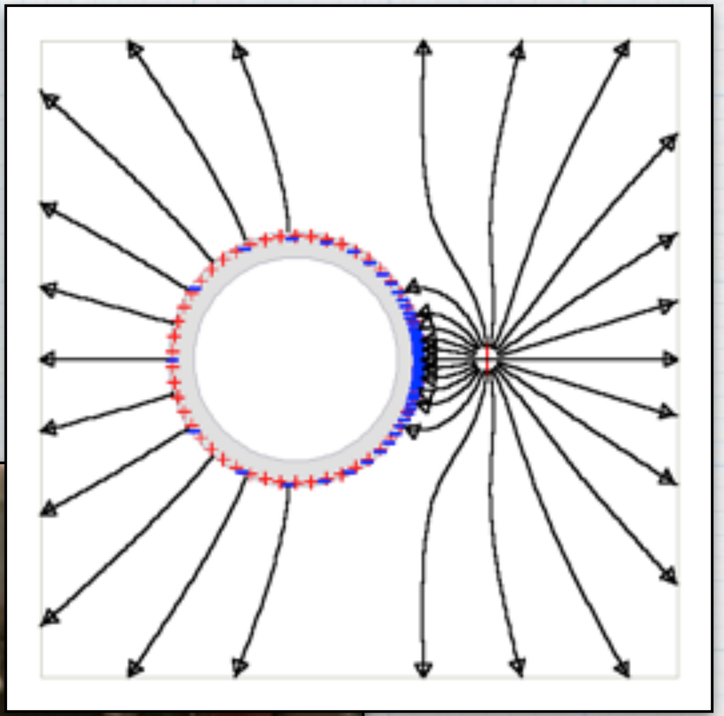
$$\oint \vec{E}\cdot d\vec{L} = -\oint \partial\vec{B}/\partial t \cdot d\vec{A}$$

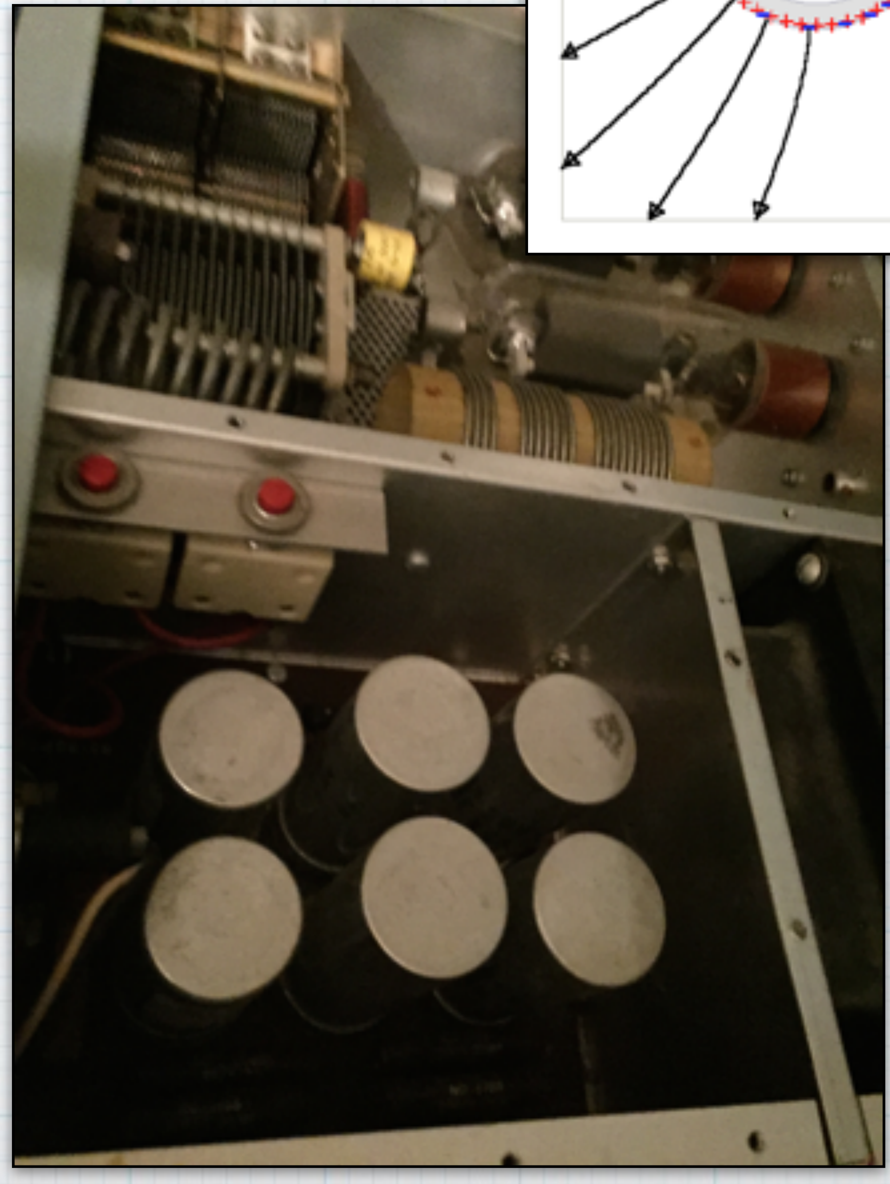
$$EMF = -d\Phi_m/dt$$

$$\oint \vec{H}\cdot d\vec{L} = I + \oint \partial\vec{D}/\partial t \cdot d\vec{A}$$

Shield: Example

- Faraday shielding between systems and subsystems
- Tight connections
  - high conductivity
- Drive the E-Field to zero





Isolate

- Differential signal paths, avoid common mode
- Reduce leakage fields
- Restrict components to their primary function
- Create high impedances where current shouldn't flow
  - avoid currents in bad places

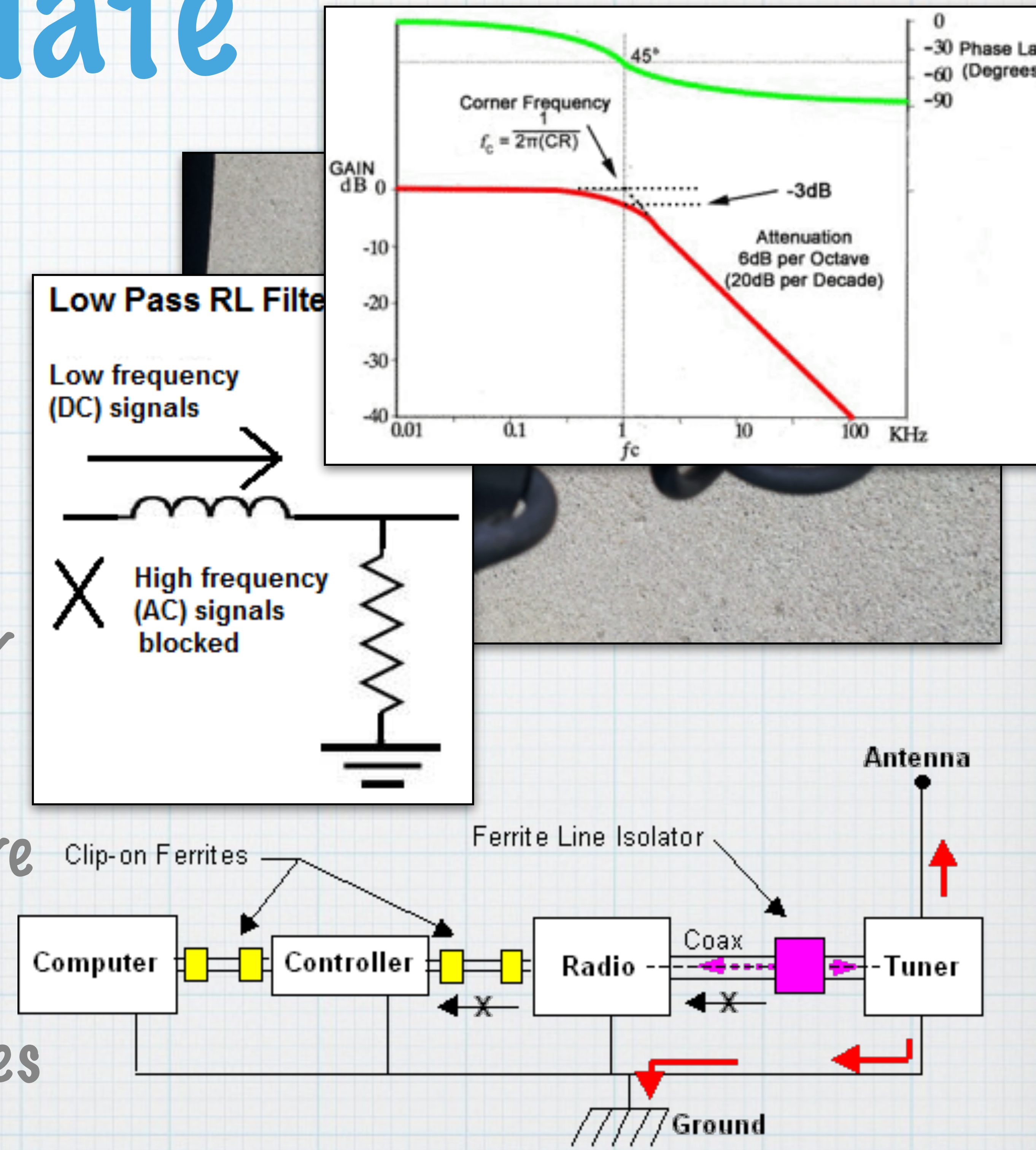


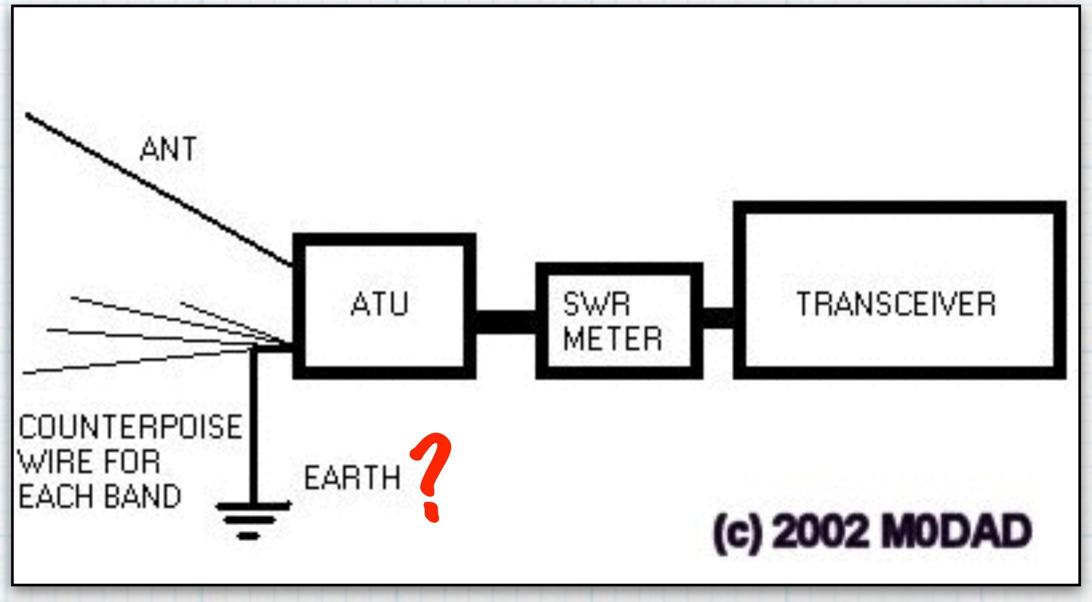
Fig 3: This is the same configuration as above with ferrite chokes added to block the alternative ground paths. Differential signal currents in the coax are not effected by the ferrite, but common-mode ground currents are blocked.

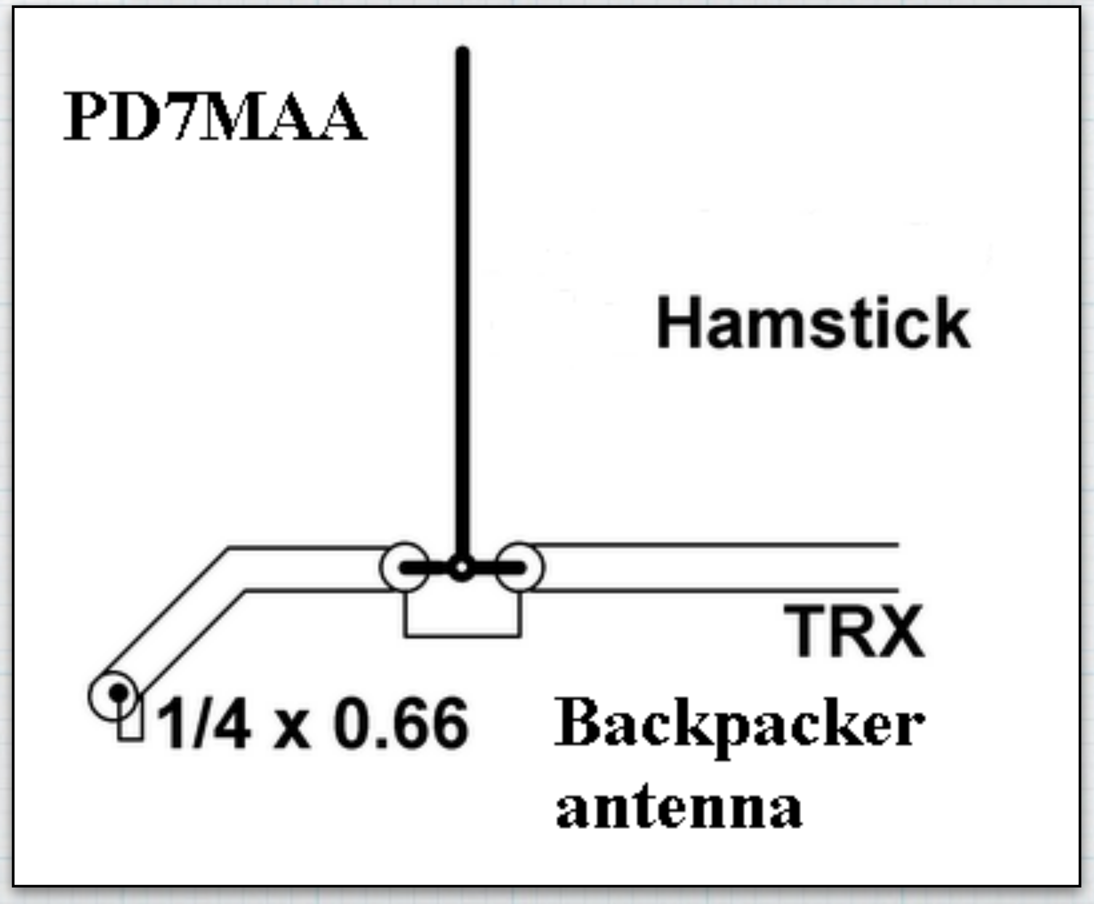
Isolation: Example

- Ferrites everywhere
- Wrap as many times as you can
- Pay attention to the ferrite mix

Stabilize

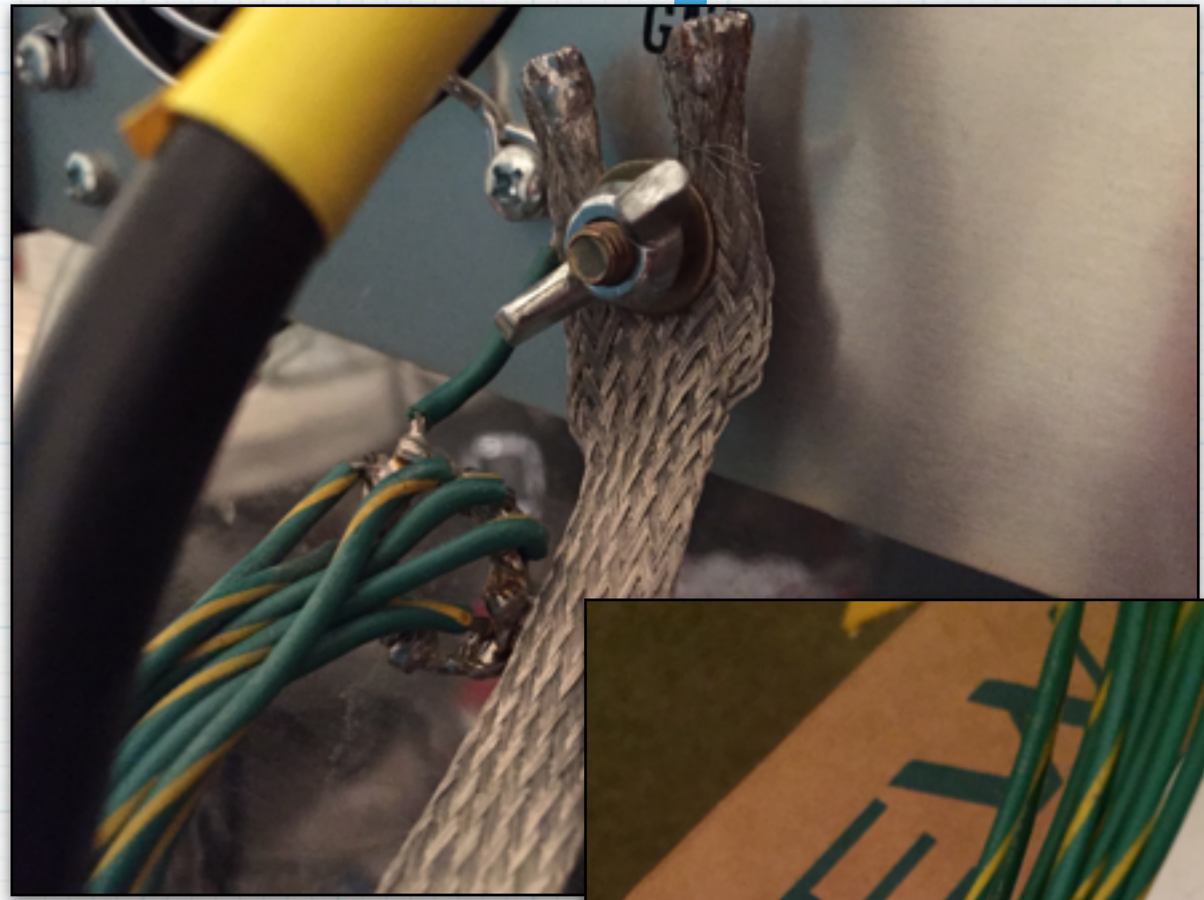
* Use low impedances
  * reduce voltage differentials
  * reduce E-field gradients / differentials
  * can be antenna enhancements





Stabilization: Example

* One wire per band
* Bundle them together
* High voltage at wire ends
    * fold over and tape



Wither Ground Rods

* Outside of lightening, you're wasting your time
* Can make things worse!
  * noise
  * RF losses
* On a portable antenna: disconnect it

My 2nd Floor Station: 800 Watts

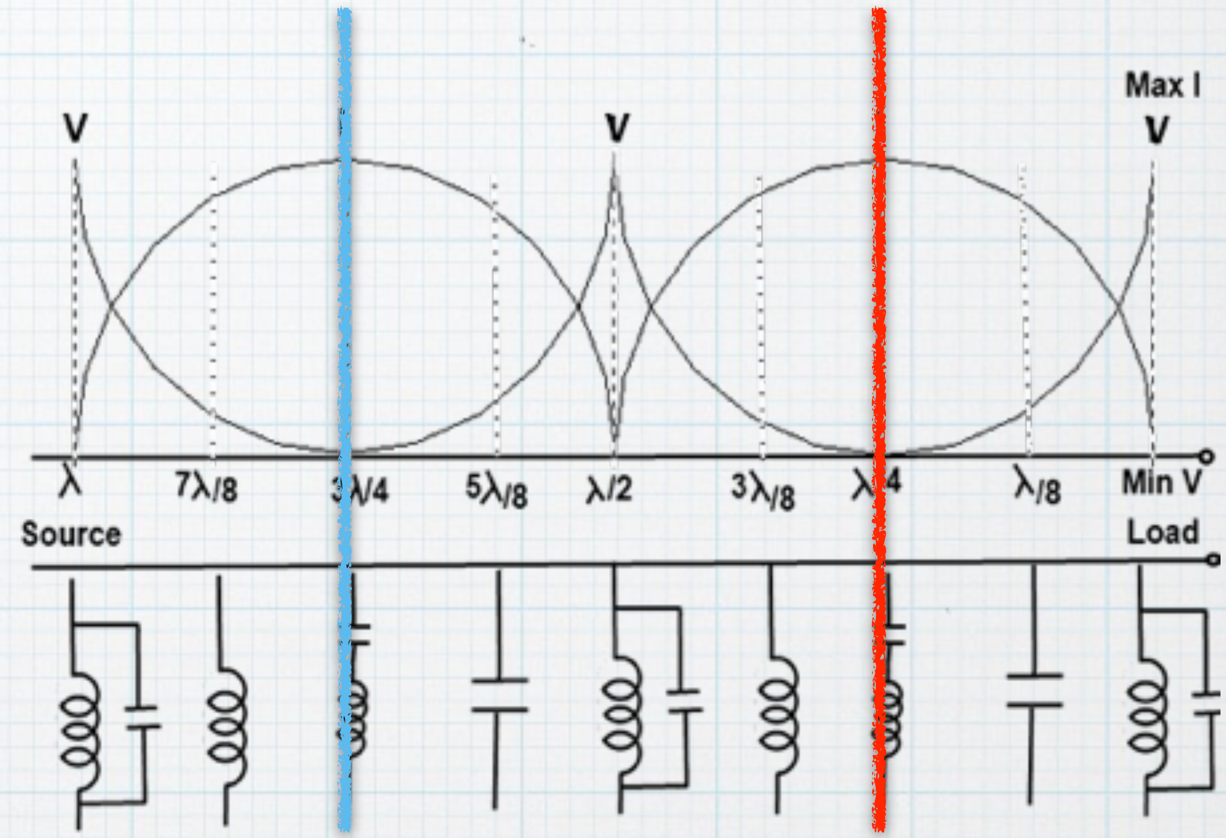
* Helically wound vertical dipole
* Tuner (manual or auto)
* AL-811H Amplifier
* IC-7600
* No ground!

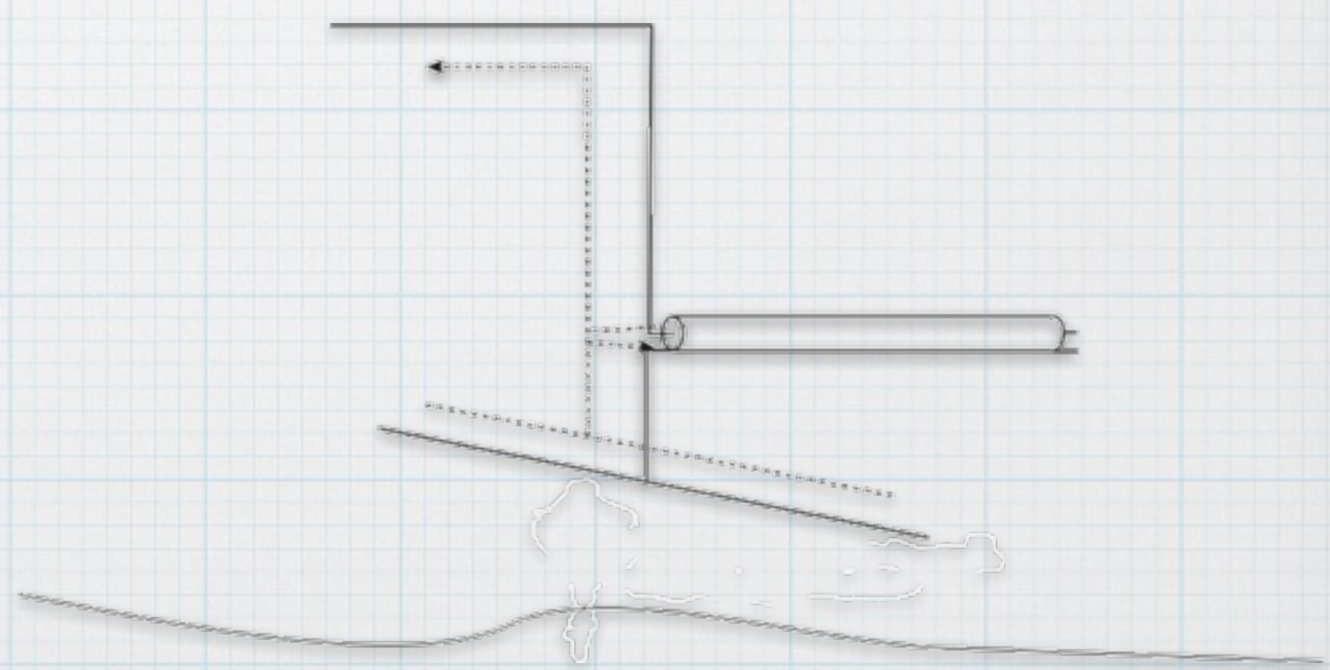
But how, you ask?

* Shielding: all components are individually shielded
* Isolation: ferrites form inductive isolators keeping common mode currents from flowing
* Stabilization: counterpoises on all bands

What is a Counterpoise?

- A 1/4 wave monopole
- The low impedance point of an open antenna or transmission line
- Must match operating frequency
- Can be bundled
- Watch for high voltage!



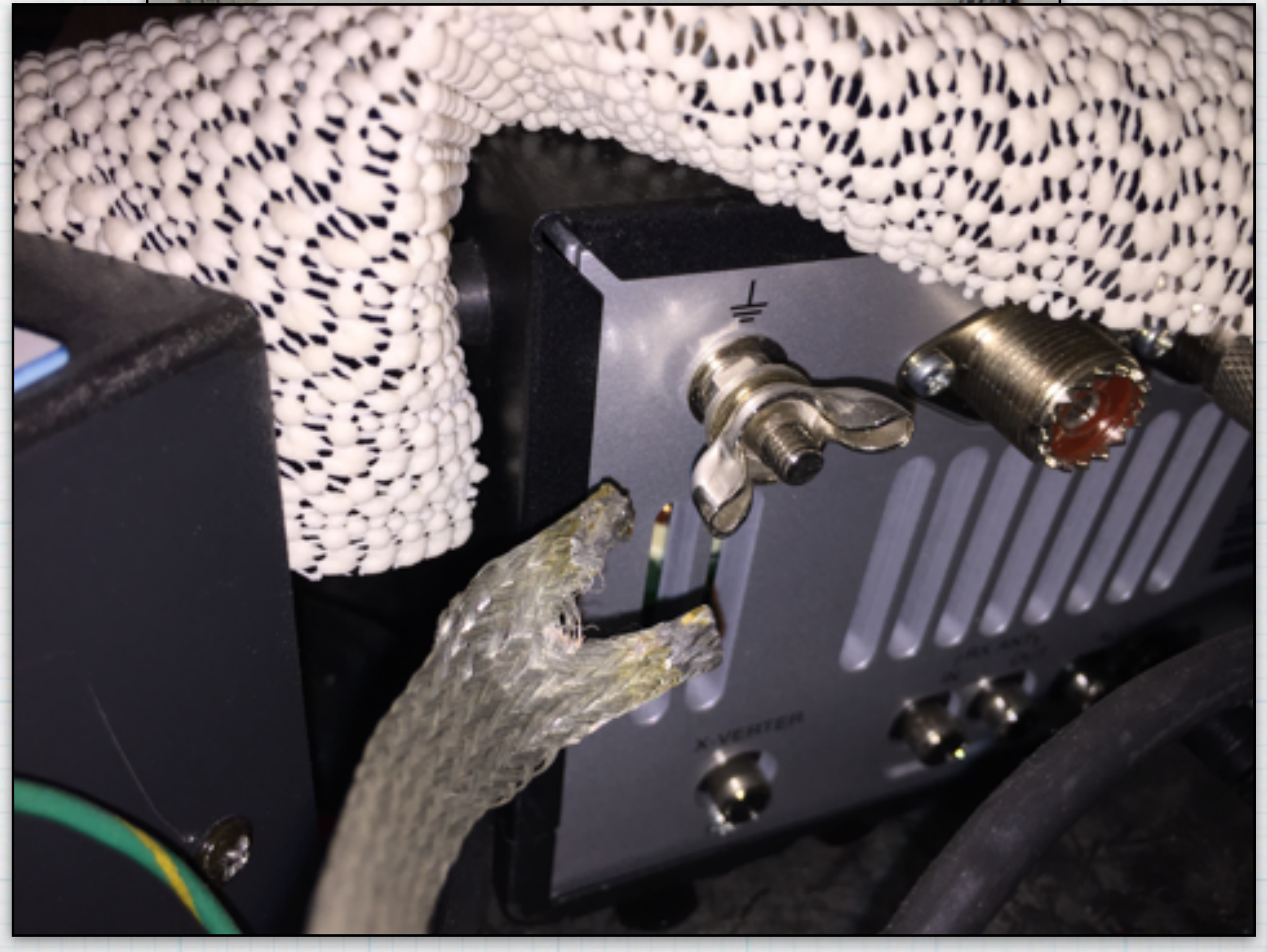


Radials on the Ground

* Like a counterpoise
  * detuned by the earth
* Provide the mirror
* Should be as complete as possible: 16 to 64
  * lower loss resistance
  * remember - earth is lossy

What about the “ground” lugs?

* Connect them together
    * flat braid (low inductance)
* Connect that to the counterpoise bundle
* Stabilizes the equipment chassis within the RF fields (E-field)
* Avoid RF burn
* Connect to ground rod?
    * probably a bad idea

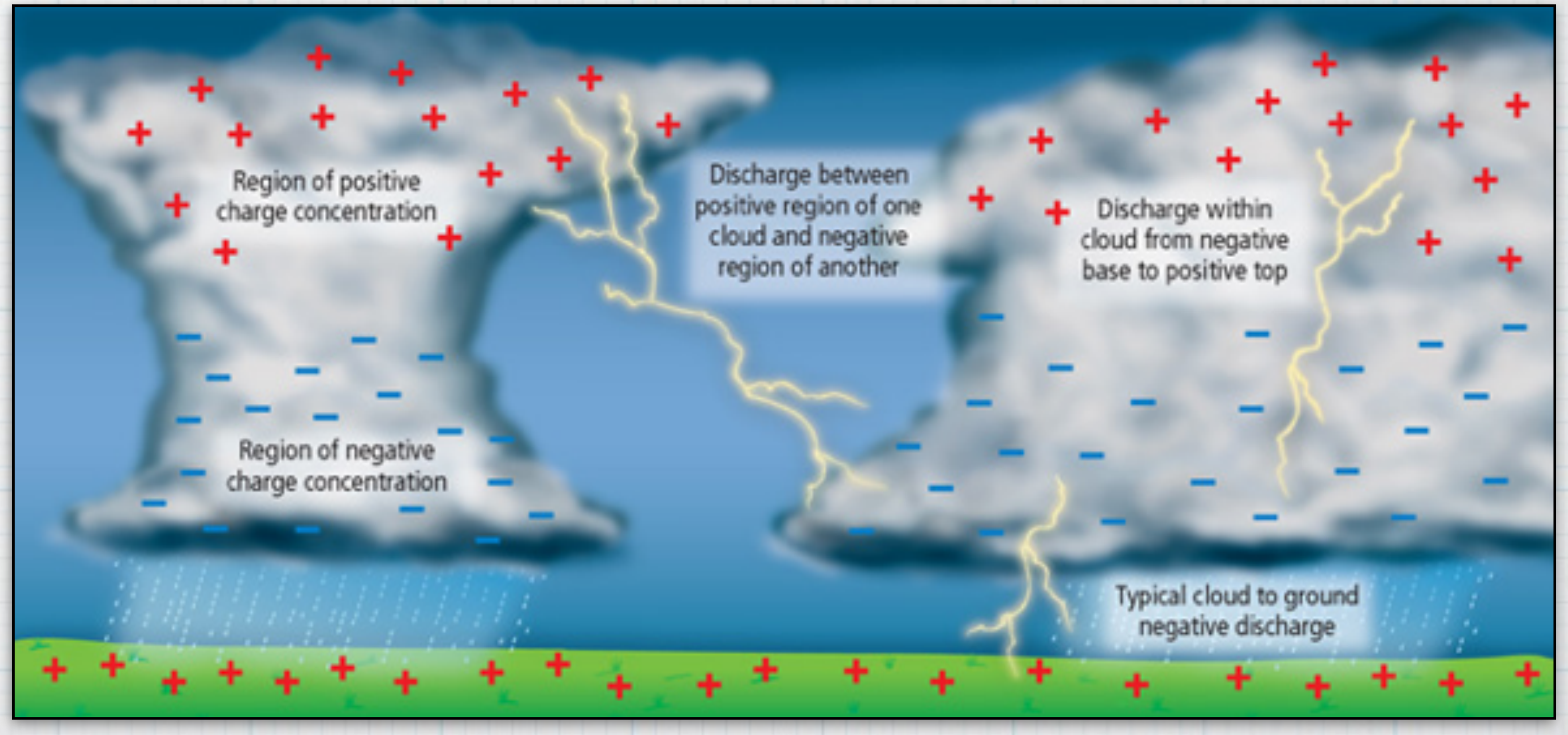


What Applies To Your HT?

* No apparent ground
* Where's the other half of the antenna?
* Let's add one
  * counterpoise
  * not a "ground"
  * several dB improvement

Lightning: A Case for Ground (sort of)

* Back to DC
* Large charge differential builds
* Covers earth's surface
  * relatively wide area
* Want safe discharge

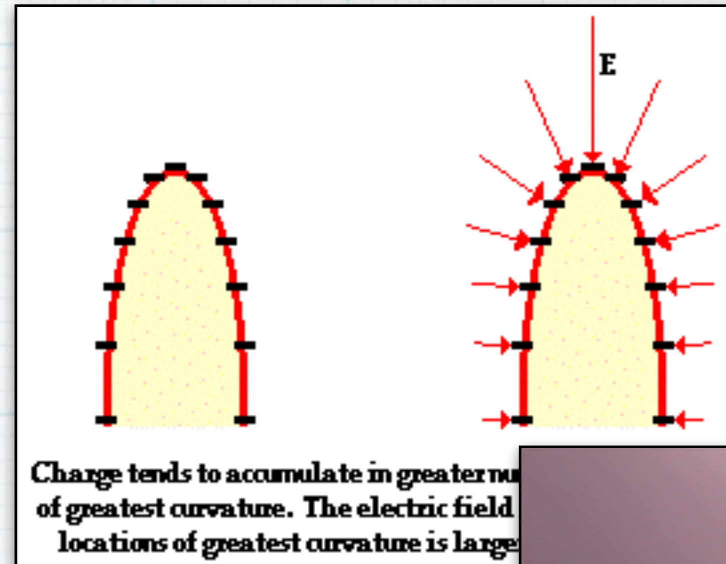


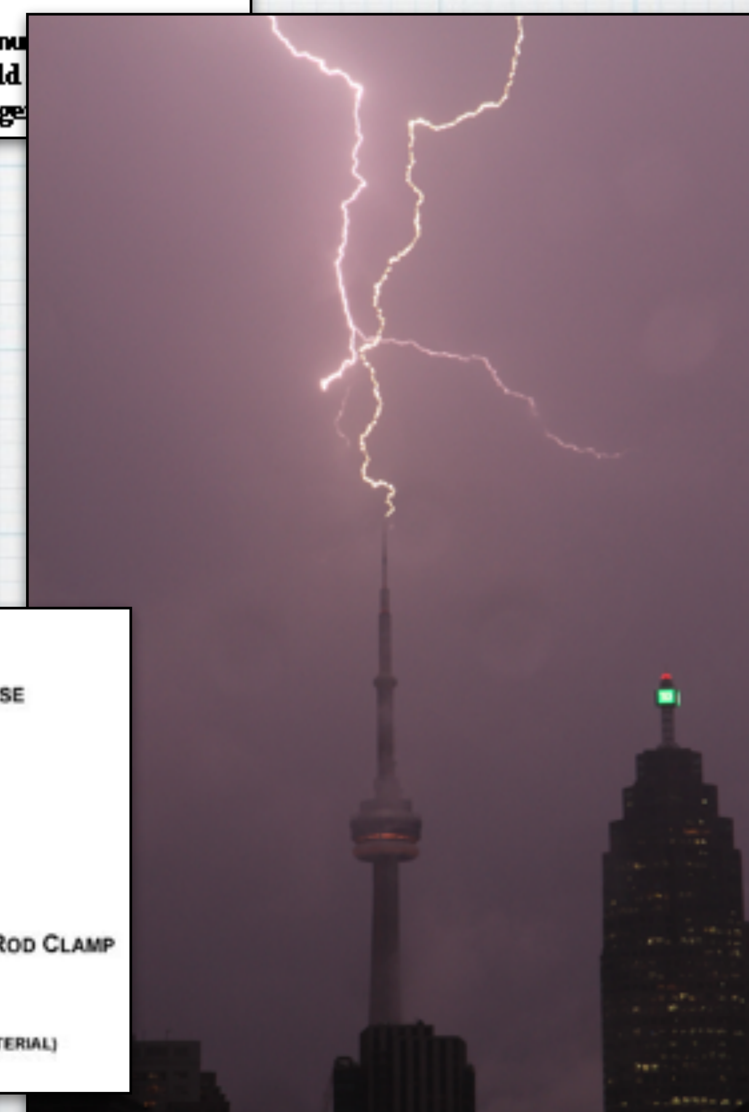
Lightning Strike

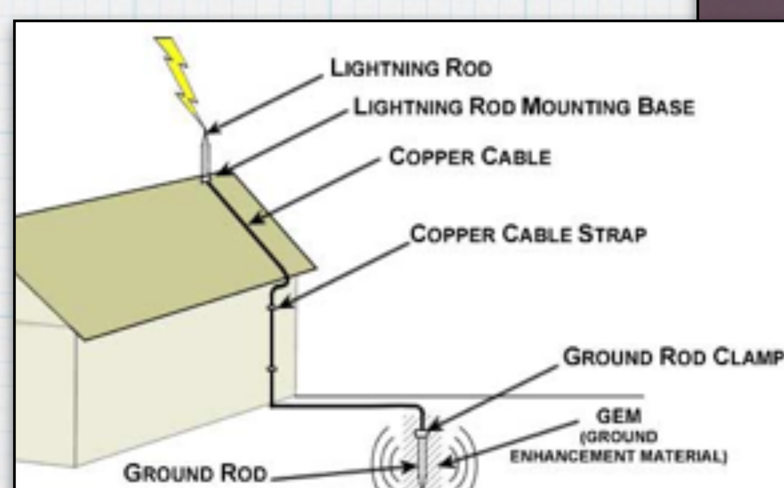
* Plasma forms from intense E-field
* Ions are conductor for charge carriers
* Charge equalizes
* Hopefully doesn't equalize through your shack

Lightning Rod

* Sharp tip has many charge carries
    * mutual repulsion minimized
* Conducts to earth's surface efficiently
    * charge equalization

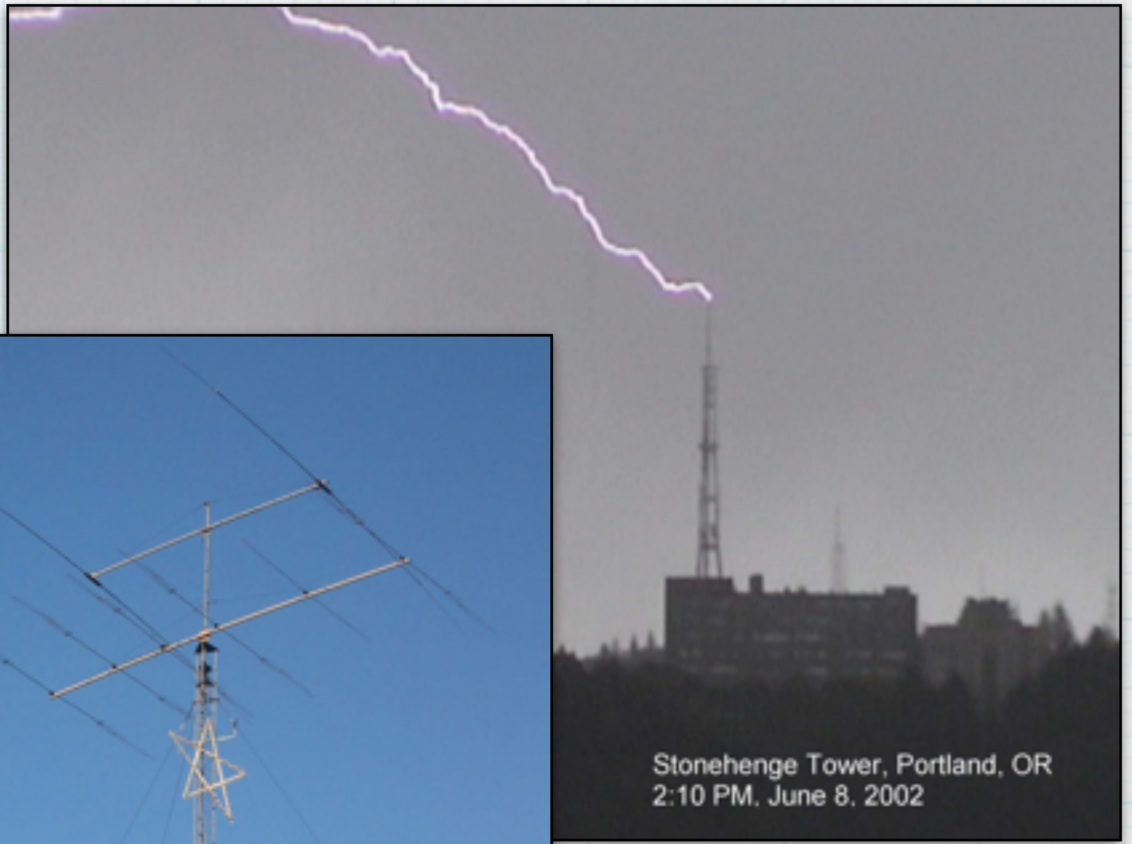






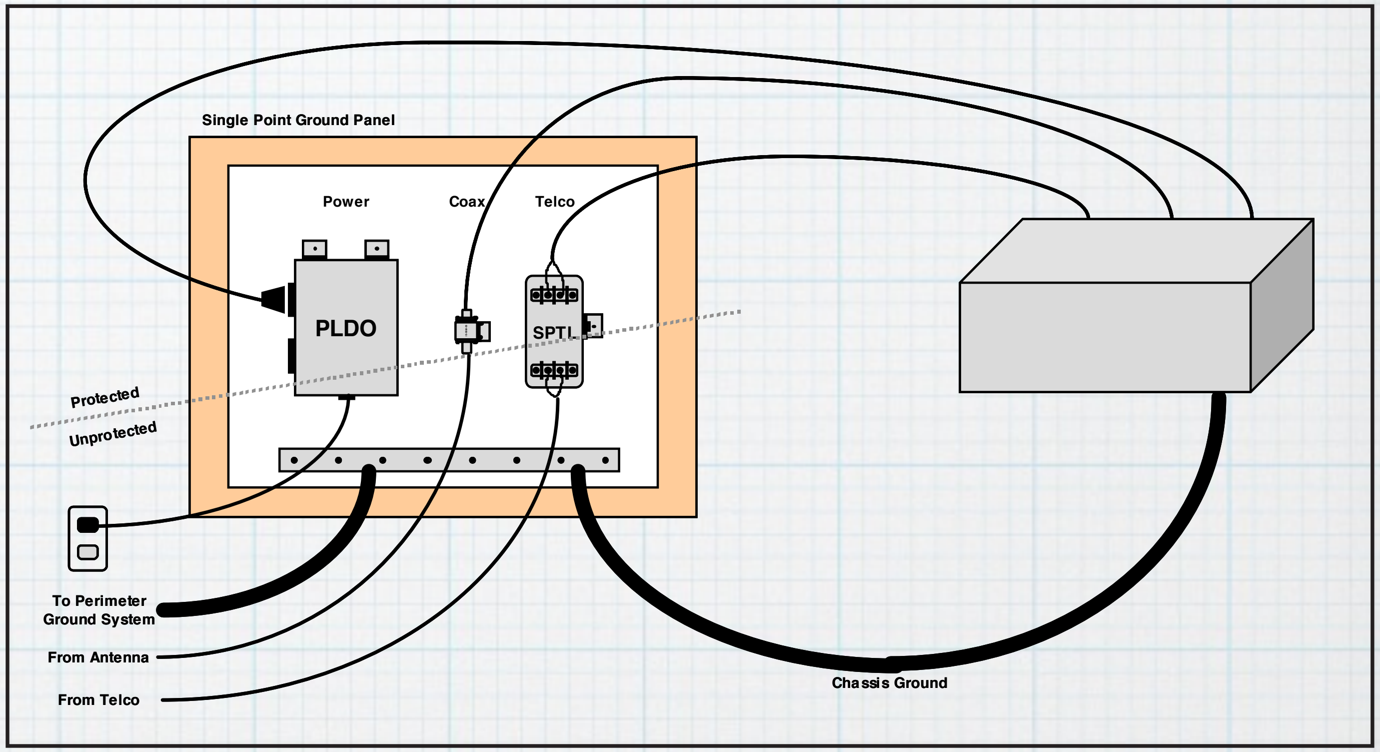
Antennas Are Like Lightning Rods

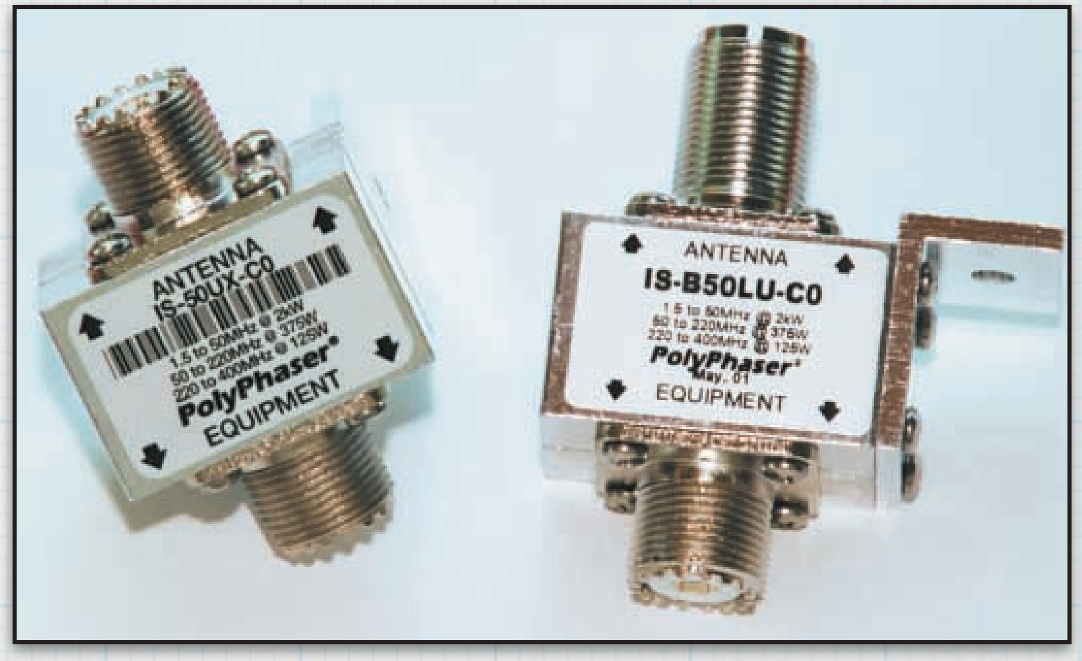
- Altitude and connection to earth's surface makes E-field intense
- Many sharp edges
- Efficient conductors
- Ought to be grounded for lightning, not RF



Should Antenna coax go to station "ground"?

- Bad idea for lightning
  - bring that current flow inside your house?
  - likely to kill your transceiver
  - damage other gear
- Ground the coax first through protection device
- Do this outside or near the outside



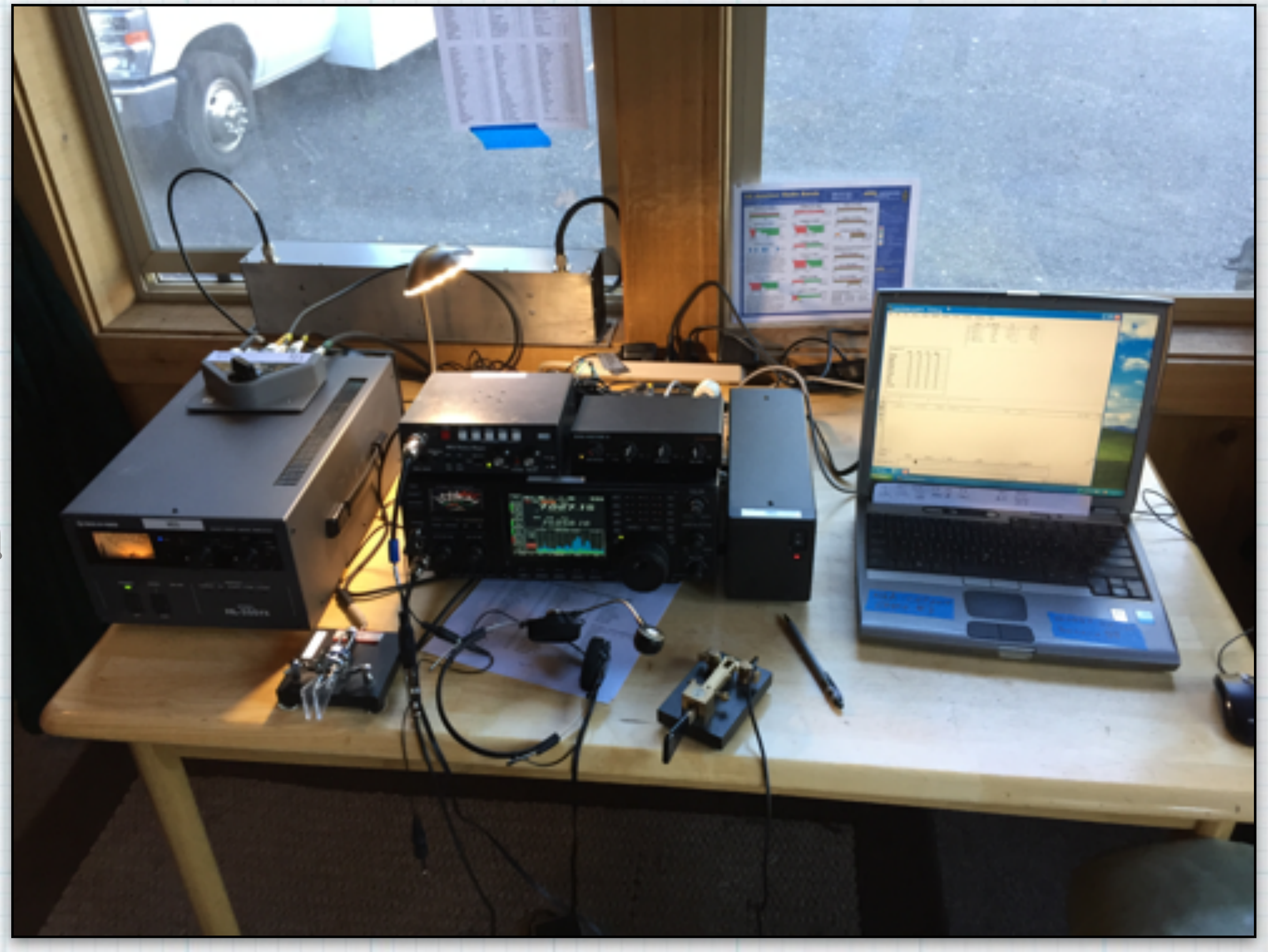


So, what happened to Ground?

* It evaporated!
  * except for lightning
* It's all relative
  * there is no reference
* The earth is not reliable
  * dirt is a crummy conductor
  * it's a crummy dielectric too

What can we hams do?

* Shield our equipment from RF fields
* Isolate the various components from each other: balanced currents
* Stabilize everything within the RF field
* Ditch those ground rods (except for lightning)
* Have fun on the radio



Questions?

Thank You