The Counterpoise: The **Other Half** of Your Antenna!

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You Can't Force Current Through a One-Terminal Circuit

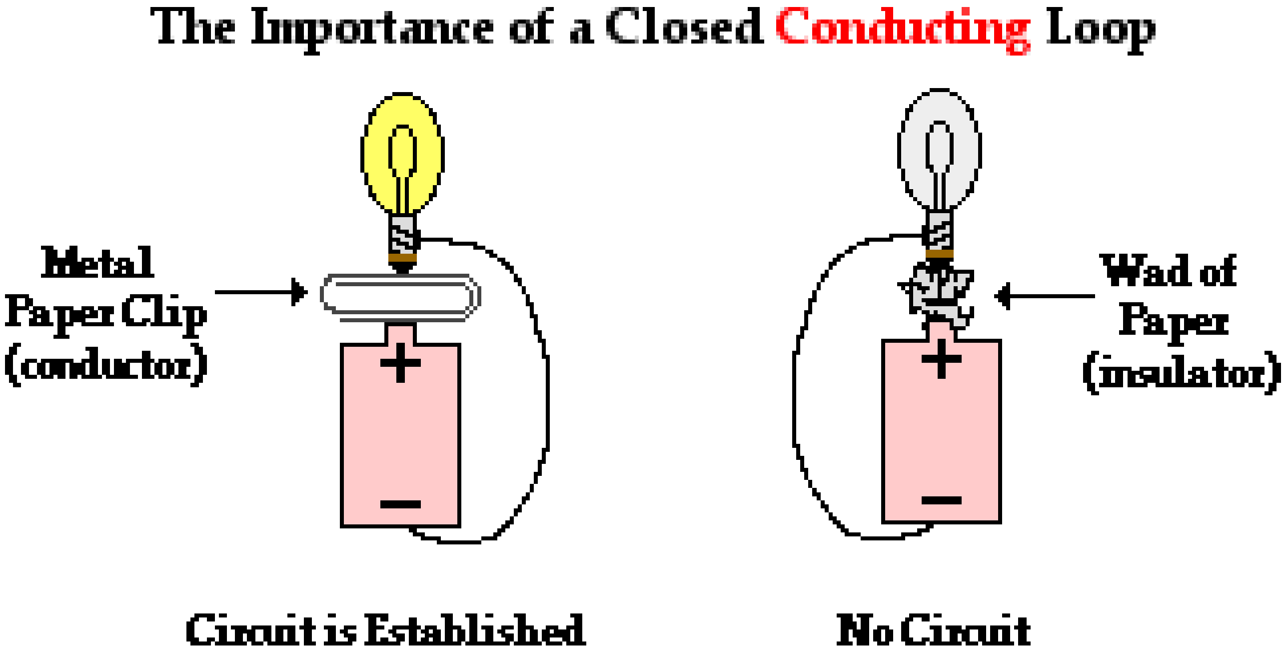
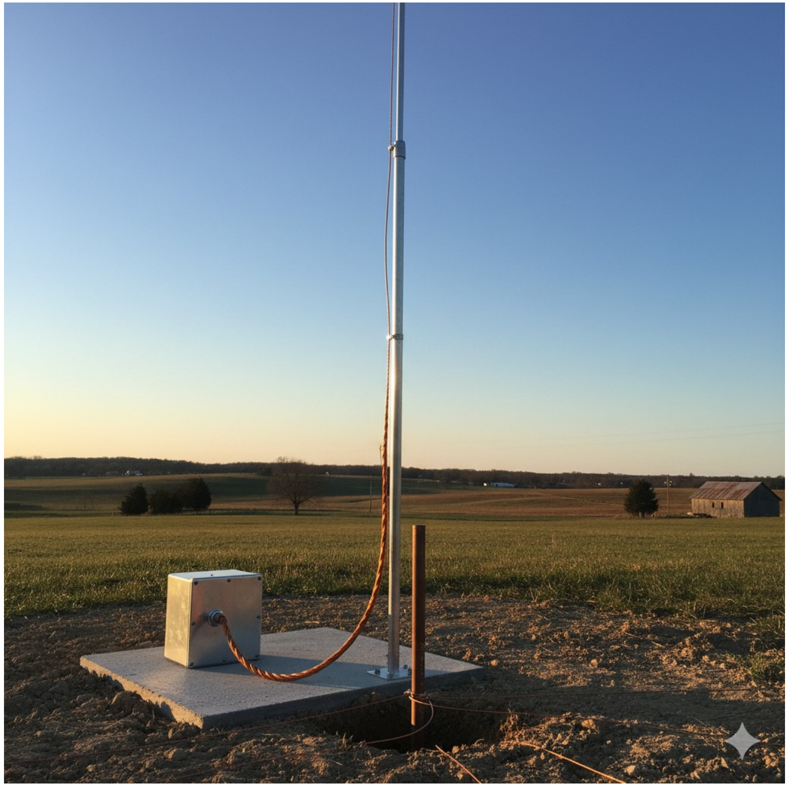


Illustration Credit: Physicsclassroom.com

Then, How Does Your Antenna Work?

- Many hams think radio waves just fly off of the antenna.
- This is a misconception.



AC gets a *lot* harder than DC Electricity

- Some of us are electrical engineers and scientists, some mainly have an intuitive understanding of DC electricity, if that. Today I’m trying to reach everyone, so, please be patient, wizards!
- It’s a big step to go from DC to AC theory. I’ll go over some of it, as simply as possible.

No One-Terminal Circuits!

- Radio waves can’t just fly off of your antenna, because that would be a one-terminal circuit.
- Rule of electricity: You can not force current through a one-terminal circuit.
- What happens instead?

Antennas Must Always Be Two-Terminal Circuits!

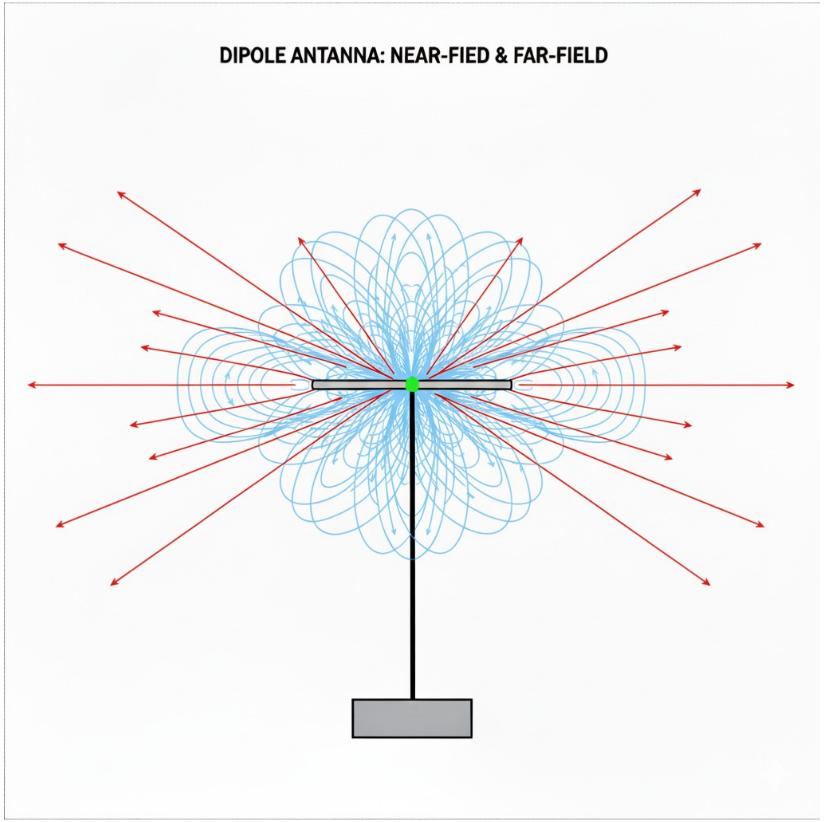
- Current flows from the transmitter to the antenna on the center conductor of the coax.
- Current **must return** from the antenna to the transmitter, to complete the circuit!
- Huh? If all of the current *returns to the transmitter,* how do we transmit anything?

Wait, These Things Aren't Connected!

- The center conductor of the coaxial cable goes to the antenna. The shield goes to the ground rod. *They aren't connected.*
- So, how can current return to the transmitter?

There's a Third Component Connecting the Antenna Elements, *Space-Time!*

- Also called "free space", "vacuum", "the air", "luminiferous aether" (when it was thought to be a *substance)*, etc.
- The two elements of a dipole, illustrated, are connected to each other by space-time.
- Blue: magnetic field in space time, Red: electric field.
- Oscillating antenna current induces fields, oscillating ***fields induce current in the antenna.***



How Is Space-Time Part of the Antenna?

- You can think of space-time as an *electronic component.*
- Like a resistor or capacitor, *it has well-defined physical properties that are useful in a circuit.*

Properties of Space-Time

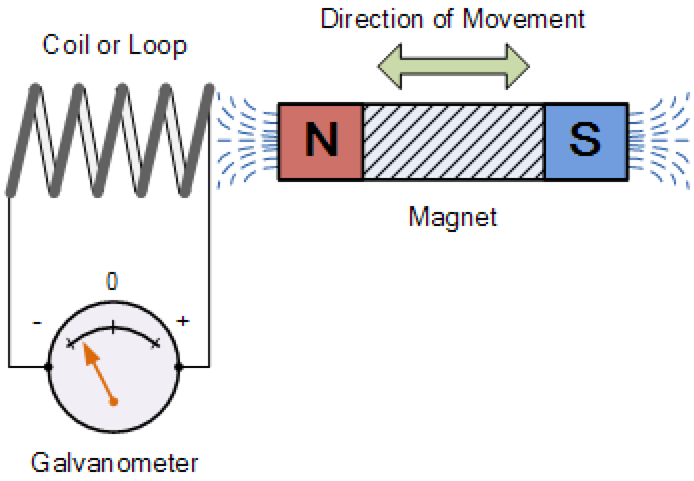
- Magnetic permeability: the ability to support a magnetic field (related to inductance).
- Electrical permissivity: the ability to support an electric field (related to capacitance).
- A propagation speed, the speed of light. Wavelength comes from this (space/time).
- An impedance (377 ohms).

How Antennas Really Work

- Radio waves don’t just fly off of the antenna.
- The antenna creates *fields. Electrical* and *magnetic*.
- The fields are in space-time.
- The two wires of a dipole, and space-time (and the transmitter and feedline) form a complete circuit! *Current returns to the transmitter.*

What Do The Fields Do?

- Just as a moving magnet can induce an electric current in a wire, changing magnetic fields induce electrical fields in space-time, *and vice-versa.*
- The oscillating electric and magnetic fields sustain each other and can propagate over a great distance.
- That’s what radio waves are.



Compromise Antennas

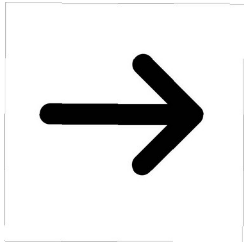
- We’re going to talk about why some antennas aren’t so good. Why?
- A compromise antenna is always better than *no* antenna. But maybe it’s not the best antenna you could have, or you could make a better compromise.
- Most ham antennas are too small, too low height to avoid ground loss, not matched to the frequency, have wires too thin, have a bad counterpoise, etc. These are the ways we compromise.

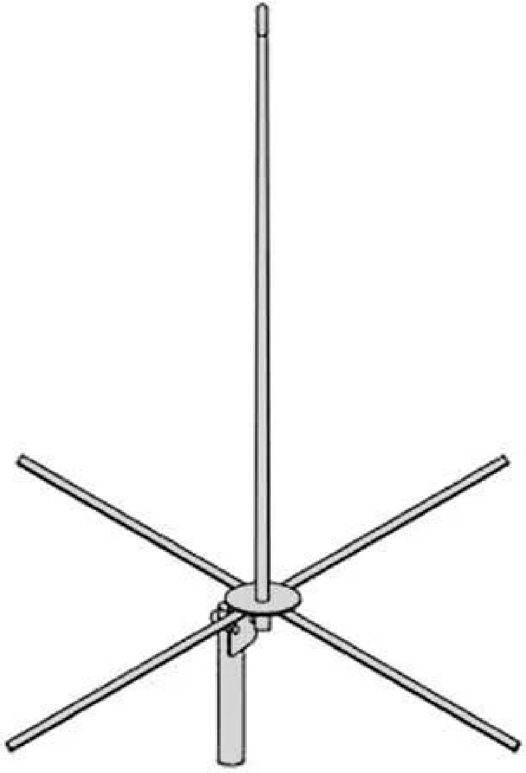
Compromise Antennas (2)

- You will *always* hear from people who won contests with compromise antennas. So, it must be good, right?
- Most antenna manufacturers drink their own kool-aid. Many work entirely by A-B measurement and are not aware of, or at least are unwilling to discuss, how their antennas are suboptimal. Try engaging them online. That goes sour really quickly.

What is a Counterpoise?

- The part of an *unbalanced* antenna that returns current to the transmitter.





Well, What's a Balanced Antenna?

- A balanced antenna has *equal elements* (often wires) for each side of the circuit.
- A dipole has two *equal* wires, so it's balanced. The two wires are in a circuit with space-time (and the transmitter and feedline).
- A loop is a balanced antenna made of *one* wire with both sides connected to the feedline, so it more intuitively makes a circuit, and returns current to the transmitter. Although it makes a circuit on its own, the loop *is still in a circuit with space-time.*

There are Balanced Feedlines Too

- Coax is unbalanced.
- Ladder-line is balanced (new hams may have only seen coax).
- We often use a Balun (BALanced to UNbalanced transformer) to go from unbalanced feedline (like coax) to a balanced antenna.

Unbalanced Antenna

- Verticals, EFHW (end-fed half-wave), and random wire are example of a *un*balanced antenna.
- The “radiating element” and the counterpoise, the part that returns the current to the transmitter, are physically different.
- They can be modeled as dipoles with unequal parts.
- **It’s the unbalanced antennas that often skimp on the counterpoise.**

Misconceptions about the Counterpoise

- "*The counterpoise is not important, because it is not the radiating element.*"
- FALSE! The counterpoise is necessary to return current to the transmitter. ALL of the current must be returned, none flows without returning. The antenna will work poorly unless the current is returned *efficiently.*

Misconceptions about the Counterpoise (2)

- “You only need 0.05% of the wavelength for the counterpoise” (oft-stated for EFHW antennas).
- FALSE! The current will mostly return to the transmitter through the feedline or the ground, not that tiny wire!
- And we’ll talk about what’s wrong with that.

The Importance of Measuring Antennas *Accurately*

- Hams have historically been poorly equipped to measure their own antennas. We only had really indirect methods, like S-meter, the thickness of our QSL pile, and SWR doesn't actually measure antenna performance.

Effect of Lack of Accurate Measurement

- Because antennas were so difficult to measure, *craft knowledge took the place of science,* and there has been a lot of confusion and misconception about antennas. That continues today.
- But today, we have a new method to measure antennas acurately! Let’s talk about how we’ve been doing it, and how we *should* do it.

How Do We Measure Antennas?

- *Antenna measuring field:* A huge empty field with the antenna in the middle, and a moving tower at a distance from which far-field signal strength can be measured.
- At VHF and up, practical in terms of space, cost, and time spent. At HF, size and cost can be astronomical.
- Advantages: Can be very accurate.

How Do We Measure Antennas? (2)

- *A-B testing:* Compare two antennas with the cooperation of a distant station.
- Advantages: uses the equipment you already have.
- Problems: *Too many variables to give a good answer,* for example propagation and fading; the antenna pattern, which can have many lobes; etc. ***So, it’s easy to deceive yourself.***

Self Deception

- This is the phenomenon of your car running better after it’s been through the car wash. What actually happens is you *like* your car better that way.
- You want your antenna to be good, so it’s easy to deceive yourself when using poor methods of measurement.
- Good scientific methods of measurement protect you from self-deception.

How Else Do We Measure Antennas

- *SWR:* Indicate the reflected power at the transmitter.
- Advantages: Uses the equipment you already have, and very easy to do.
- Disadvantages: **SWR is *not* a measure of the antenna radiation at all!** So, you *are* deceiving yourself. We'll discuss why.

How Do We Measure Antennas (4)

- *Theoretical Modeling*: A mathematical model of a real-life phenomenon.
- Advantages: Can be done before the antenna is built, easy to change and re-try, tells us a lot. Uses the computer you already have.
- Problems: Misses real-world issues, so you can deceive yourself. Math can be inscrutable.

How *Should* We Measure *Real* Antennas?

- *Drones* are the solution!
- Programming a drone to fly to many points on a 1000-foot hemisphere around your antenna, sampling the signal strength at each point, is *within reach of the more technical hams today.*
- Advantages: most accurate method within reach.
- You should still model before building.

Commercial Antenna Testing Drone!

Antenna Measurement with a Drone, Continued

- Disadvantages: making a sampling antenna that works through a 90° change in angle (from beside to above), or *adding a servo to turn it.*
- Electrical noise from the drone and environment.
- RFI *to* the drone. Use low power.
- Reflection from the environment (but this is a real-world part of your antenna performance).
- Neighbors and regulation, risk of losing the drone.

The Only Accurate Measurement

- *The only accurate antenna measurement is radiated field strength at a distance, measuring many points to take the antenna pattern into account.*
- You *only* get this with a drone, or a measuring field.
- Consider it like putting a thermometer in the refrigerator, vs. just going by how the food tastes. The goal is the food, but only the thermometer helps you understand how you are getting there.

Radiation and Loss

- Some of the power that goes to your antenna ends up as *radiation.* In other words, radio waves. This is the useful part.
- The rest ends up as *loss.* This becomes heat, although you probably don't notice the heat.

Where Does Loss Come From?

- **Mainly, the Ground.**
- In an unbalanced antenna, the ground is almost always the *main* path for current return to the transmitter. The soil has resistance, and it's part of the circuit, so power is lost there.
- A balanced antenna at a practical height for most hams will radiate into the ground.

Dipole Height and Loss

- A dipole ¼ wavelength from the ground or less has the ground as a lossy reflecting element. It could be considered *a two-element beam pointing straight up.* Both reinforcement and cancellation of the signal happen, distorting the expected antenna pattern.
- Adding multiple parallel ground radials under that dipole would make it a good NVIS antenna.
- ½ wave high is better if NVIS isn’t your goal. The higher you can get it, the more like a *theoretical* dipole it will perform.

Kinds of Loss in Your Antenna

- **Ground Losses Dominate.** This varies with each installation, but typically 25 ohms resistance in returning current to the antenna.
- Electrically-short antennas: Effective radiated power dimishes approximately with the **square** of the ratio of the element's electrical length to ¼ wave, no matter how well you load it with your tuner. So, a half-size antenna is ¼ as effective.
- Resistance losses. Made worse by the *skin effect,* because *only the skin of the wire carries RF, not its whole diameter.*
- At 10 meters, 100 feet of wire: 24 AWG (American Wire Gauge): 20 ohms. 12 AWG: 5 ohms. This is *much higher than* the DC resistance of the same wire. *Diameter matters!*

Kinds of Loss (2)

- Dialectric Loss: complex (several different causes) loss in the insulating portion of your feed-line.
- Transformer loss: also a number of factors.
- **But ground loss almost always dominates.**

Measuring Radiation and Loss

- An antenna has *radiation resistance*, the effective resistance that comes from the work of radiating radio waves.
- An antenna has *loss resistance*, the resistance that comes from all of the losses in your antenna system that make heat rather than do real work.
- The second is often larger than the first.

Measuring Radiation and Loss (2)

- We generally arrive at loss resistance and radiation resistance through theoretical modeling, but can derive it from accurate field-strength measurements.

This is Why **SWR Lies**

- SWR measures the matching of the impedance of the transmitter and feedline to the antenna's impedance, including its radiation resistance and loss resistance.
- **You are measuring the SWR match to the *loss,* often more than to the *radiating* portion.**

SWR **Lies!** (2)

- With a fixed antenna (not a tuner or SteppIR), the flatter the SWR is over a wide band, the more suspicion that you are mainly matching the loss.
- A 52 ohm resistor is likely to have perfect 1:1 SWR and not radiate at all.
- Impedance matching is important. It’s just not a radiation measurement.

So, This is Why We Need The Counterpoise

- The counterpoise helps us to reduce the ground loss, the resistance of the soil in returning current, *by replacing the soil with a more conductive wire*. This reduces the loss resistance.
- *Elevated* radial wires can provide an efficient current return without involving the actual soil.
- Conductive radial wires on the ground help to avoid the effect of the soil’s resistance.

Mobile and Marine Counterpoise

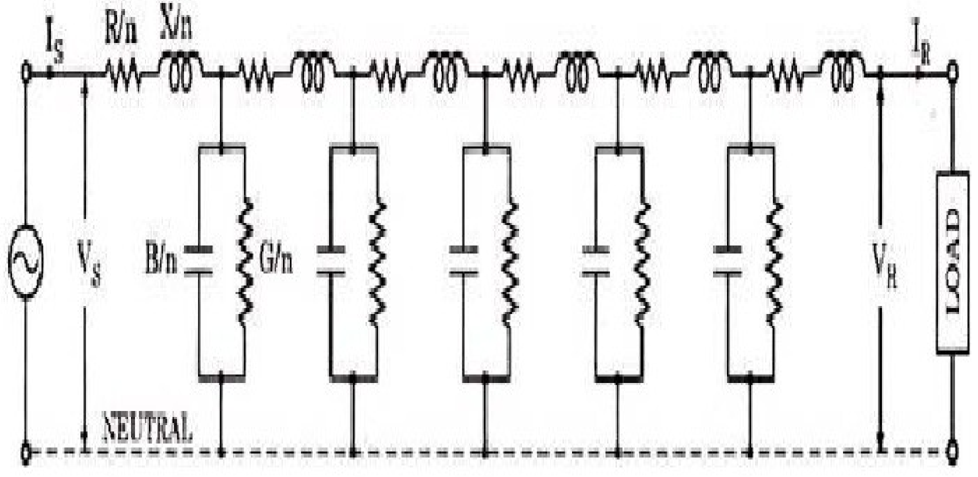
- Automotive antennas almost all use the metal of the vehicle as a counterpoise. Magnetic ones capacitively couple to the roof of the car. Permanent ones electrically couple through their mount.
- Mobile antennas need a counterpoise, so don’t work well without a big piece of metal under them.
- At VHF, fiberglass boats generally use vertical dipoles, or the feedline as a counterpoise. Marine HF gets complicated enough for its own talk.

Two Kinds of Radials

- *Resonant* radials are cut to ¼ wave for a particular frequency, and couple efficiently to the overall circuit of the antenna and space-time at that frequency. They must be elevated from the ground.
- Unresonant radials work over a broad bandwidth but require more material, space, and work.

Transmission Lines

- Current going through a wire is not as simple as you might think. It behaves as a long reactive (inductive and capacitive) network. This is due to interaction with materials around the wire, and with space-time.
- **This is called a transmission line.**
- By AbhiMukh97 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=80542783



Practical Transmission Lines

- Coaxial cable, and ladder-line, are deliberately-constructed to be transmission lines, and to have a well-defined impedance along their entire length.

(photo credit: W7FG)

Transmission Lines

- Original understanding of transmission lines developed with the electric telegraph.
- AC power distribution uses transmission lines, and their issues are motivating a switch to long-distance distribution using DC.

Propogation Speed

- The propogation speed through a transmission line is *slower* than the speed of light in vaccuum. It's the speed of oscillating electricity going through that network of inductances and capacitances.
- This is true for *all matter.* Matter interacts with light and electricity going through it; slowing it down.
- We call this difference in speed the *velocity factor.*

Velocity Factor

- Light travels at 186,000 miles per second **in *vacuum.***
- Electricity travels more slowly through matter because of its interaction with the matter.
- This difference is the *velocity factor.*
- Bare copper has a velocity factor around 0.95 .
- This effects the *electrical length* of the wire, and the size you cut it to match a wavelength.

Ground Radial Velocity Factor

- Ground radials will be electrically longer than the same wire in the air, as the effect of the ground reduces their velocity factor. A 1/8 wave radial on the ground may be electrically closer to ¼ wave.
- This effect changes with ground conductivity, and rain. Because we can't count on it, we just use a lot of radials.
- A Beverage-on-ground antenna is electrically longer because of this effect.

Skimping on Elevated Radials

- Most VHF/UHF base antennas have radials much smaller than ¼ wave, that might provide an adequate impedance match, but a poor current return.
- Actually, some or most of the current is returning through the feed-line,or through the mast to ground, making this more of a vertical dipole.

Skimping on Elevated Radials (2)

- Where's the counterpoise? It's the PCB, any conductive part of the case, and you!
- "Tails", wires shorter than your height, connected to the shield part of the antenna connector, are useful for improving range.

EFHW and the Tiny Counterpoise

- An EFHW can be a decent antenna *if a lot of the current returns to the transmitter through the coax shield, transmitter, operator, your computer, etc.* The pattern will be distorted and you will get RF in the shack. This will happen as long as you don't clip on a choke at the *transmitter* side of the coax. A choke or isolating transformer at the *antenna* end *doesn't prevent the coax from acting as a counterpoise,* consider it as equivalent to a counterpoise wire connected to the transmitter ground.

EFHW and Tiny Counterpoise (2)

- If you carefully choke the coax at both ends so that the 0.05 wave counterpoise is all you have for current return, the current will mostly return to the transmitter through the ground. Signal will be about 10 dB down due to ground losses.

The Tiny Counterpoise

- What does the 0.05 wave “counterpoise” on an EFHW actually do?
- It mostly acts as a capacitor to ground.
- This provides some load to the matching transformer (usually 1:49) so that it can drive the antenna.

Skin-Effect Note

- *Common-mode* return current picked up by your feedline is on the **outer** skin of the coax. A clip-on choke can effect this.
- The return of current *from the antenna,* to the extent that you have that, is on the **inner** skin of the coax. A clip-on choke *does not effect it.*
- Because of the skin effect, the inner and outer skin are effectively two separate conductors! They are connected at the end.

Final Note on EFHW

- Because of many factors, such as capacitance and other coupling at the transformer, and from the feedline shield to ground at both sides of a choke, etc. *the EFHW can not be expected to perform as theoretically modeled.* This is often to your advantage.

HF Vertical Antenna and Radials on the Ground

- Importance of this counterpoise is acknowledged by many hams.
- But there are a number of commercial antennas with tiny counterpoise, with questionalble results.

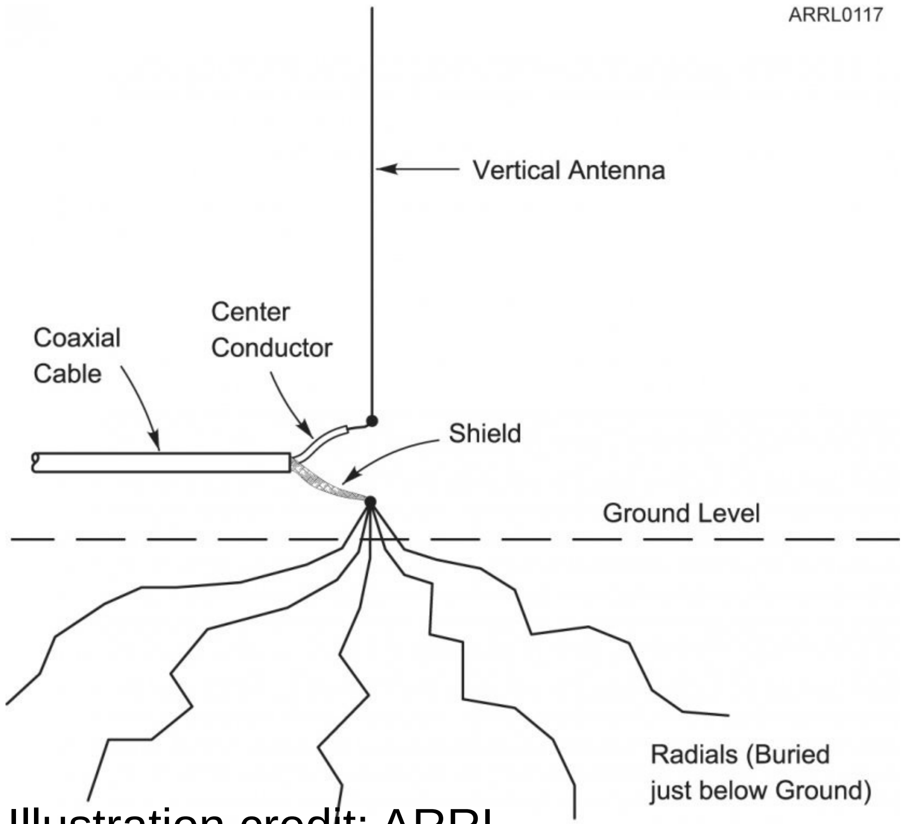


Illustration credit: ARRL

What Is It About 120 Radials?

- In an AM broadcast site application, FCC has historically required 120 radials, each ½ wave long, *or* theoretical modeling of the grounding system.
- This originated in a 1937 technical paper.
- 120 ½ wave is overkill for all but the most zealotly perfectionist of radio amateurs.

Diminishing Returns

- A length of ¼ wave at the lowest expected frequency is considered good for Amateur applications. This is still 65 feet for 80 meters, and a 130 foot square lot, so compromise might be necessary. There is diminishing improvement with additional length.
- As the number of radials increase, there is diminishing improvement. 16 is a good minimum, you can feel good about 32, there isn't a limit.

HF Vertical with Elevated Radials

- In contrast to on-ground radials, 3-4 elevated radials, cut to resonance, for *each band* you expect to operate (sometimes considering harmonics), are considered sufficient.

In Closing: So, The Counterpoise is Important

- The counterpoise is as important as the part of the antenna you think of as the “radiating element”, and takes part equally in making the radiation!
- Unfortunately, the counterpoise requires space and work, so it is often ignored, to the ham’s disadvantage.

The Counterpoise is Important (2)

- Any antenna a ham is likely to encounter other than a loop or dipole will need a counterpoise.
- Compromise antennas tend to skimp on the counterpoise, in part because buyers think the radiating element is most important. It isn’t.

Contact the Speaker

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