Grounding Systems for Amateur Radio Stations

There is quite a bit of talk these days between Amateur **(Ham)** Radio operators about the desirability for **"good grounding systems"** for their home radio stations. I can tell you honestly that this was not so fervently discussed on the radio in earlier decades. My suspicion for this is that there was a better understanding in earlier times, before the advent of our rapid increase in new operators, of the conditions under which a **"grounding system"** would do some good. Lets look at this carefully and critically so that we can assess the desirability of a grounding system for our radio stations.

Safety Grounds vs. Radio Frequency (RF) Grounds

First of all realize that there are two discreet types of ground systems and reasons why a Ham might desire to provide a **"station ground"**. These are for the most part mutually exclusive! In other words one does one job for which it is specifically designed, and one does a different job. You must design your grounding system with this in mind, or one function may inhibit or nullify the other!

One of these grounding systems is what I will generally describe as a **"safety ground"**. This safety ground is installed to reduce the risk of electrocution or radio equipment damage by short circuited **"power mains"**, or from lightening strikes to the antenna or **"feedline"** system. A safety grounding system is certainly a good Ham Radio **"engineering practice",** although it is usually considered as of secondary importance to an **"RF ground"!** In portions of our country where dramatic lightening storms are common this preference is probably reversed. I can tell you that even in the portion of Southern California that I live in, lightening strikes from annual spring storms, or even the thought of accidental **"short circuit"** electrocution are enough of a concern that I have a safety ground system for my station. I have designed it though to operate in conjunction with the RF grounding system I use! Lets talk about the considerations of properly designing an RF grounding system. Through the course of this discussion I will explain how an RF ground can be utilized as a safety ground, and also that a safety ground **should never** be used as an RF ground!

The RF or Radio Frequency Grounding System

A popular misconception is that all radio antenna systems should be grounded to enhance their radio performance. If grounding these antennas was for the purpose of safety, as I have clarified in the earlier paragraphs, this might be true. To think though that grounding an antenna will automatically make it a better communications device is completely wrong! To appreciate this we must think in terms of **"radio frequency wavelength"**, or fractions of wavelength at 1/4 wavelength increments.

On certain lower frequency longer wavelength bands an RF ground is not only a reasonable consideration but, it is fundamental to getting the best communications performance from your radio station. At other higher frequency and shorter **"wavelength bands"** however, RF grounds are either superfluous, or even harmful to overall communications performance! Lets look at this carefully as illustrated in typical and practical scenarios. Keep in mind the concept of thinking about the physical length of the **"grounding conductor"** in relationship to its comparative **"wavelength dimension"!**

The Practical Station Ground

Living in a typical single story ranch style home my choices and availability for a good RF ground installation are relatively simple. The first **"ground rod"** of my grounding system is within 4 feet 2 inches or 1.27 meters of my station equipment. This 50 inch dimension is the entire or total length of the conductor to this first grounding rod. From this first 10 foot deep ground rod, a # 6 AWG. (American Wire Gauge) bare copper wire is buried and runs under ground in a one foot deep trench to a second 10 foot long rod about 15 feet distant. This second rod is then connected to a very elaborately designed grounding system at the base of my antenna tower's foundation. The length of this conductor between the second ground rod and the tower base is 16 feet. The entirety of these ground rods, and the interconnecting conductors, are buried at about 12 inches deep. Take a look at Figure 1 to see this system drawn to scale.

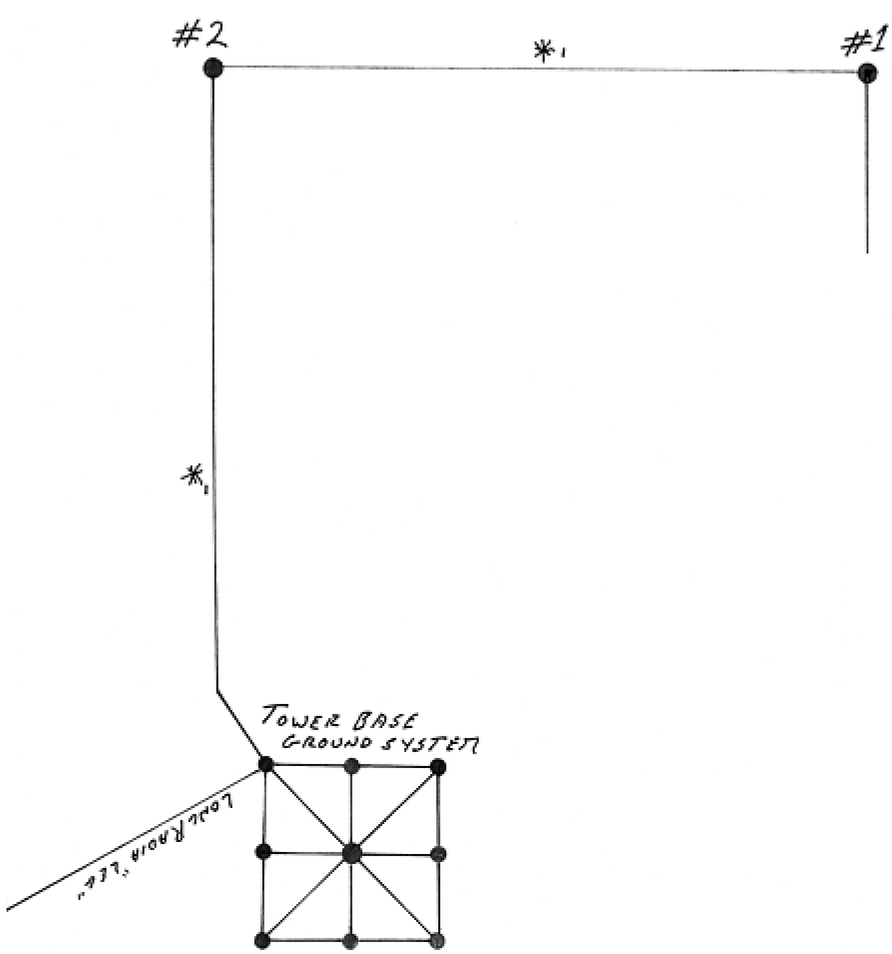

Figure 1.

When you look over this drawing you might think, gee if he says its important to keep the ground conductor as short as possible, why does he have almost 5 meters (15.5 feet) of separation between ground rods. He could have even run a wire from ground rod number 1, straight to the tower base! Well believe me, if I could have, I would have! The combined 15 and 16 foot dimensions surround the perimeter of a building, so that I was forced to take this longer circuitous route! This really though isn’t such a bad happenstance!

Having the ground rods this far apart is actually a desirable feature. What is being achieved by this system is to make a **"large surface contact area"** to earth ground. It also functions to reduce **"ground loops"** as well as is possible. Even though I can’t prevent all ground loop conditions, I can keep them manageable! I had thought that in my original design that I might also place 10 foot deep rods at the points where asterisks are shown. After testing the system on the MF (Medium Frequency) and HF (High Frequency) wave-length bands, I found these additional rods to be unnecessary.

Ground Loops (and the worst case scenario)

Ground loops are the major concern and worry to be dealt with as you lay out an RF ground system! Lets lay out a worst possible case scenario of what would be a terrible way to ground a 20 meter (and all harmonically related bands) home station.

Lets say that our 20 meter Ham has his "Ham Shack" in approximately the middle of his house, up on the second story of the house. He uses a nice low resistance and low inductance flat braided strap (lets let him do at least one thing right), which runs from his 1500 Watt amplifier to a 2 foot deep ground rod in his front yard. This braided conductor runs between the floor of the second story and the ceiling of the lower story. It then runs down the outside of his stucco covered home to the ground rod. Its total length is 33 feet long from the amplifier to the ground rod.

Fifty feet (15.24 meters) of coaxial cable goes up between the walls of the second story, is draped over to the top of his tower, and terminates at his TH6DXX beam on this 65 foot tall tower. Lets break down these dimensions in terms of wavelength, and even look at them as they may appear to form a **"current loop"**!

Our rueful Ham friend is using a ground conductor that is almost exactly one half wavelength long and is raised in the air by the buildings structure. Even if this length were reduced to about a quarter wavelength, it would still very nicely couple energy into other wiring in the house, and also the wire mesh beneath the stucco walls. This other wiring could be telephone wires, television cabling, and the 110 volt power wiring in the house. His coax cables shield is a nice **"odd order harmonic"** radiator, as it is 3/4 wavelength long! The ungrounded tower is about a half wavelength tall.

This last point about the tower must be viewed carefully. He might want to ground it as an RF consideration, and he might not! Think about it this way. One ground rod is in the front yard at the end of a half wavelength wire. The shield of the coax cable ultimately goes to ground in the back yard at the tower base at an electrical length of about 7 quarter wavelengths (50 + 65 = 115 feet). This makes another sort of odd order harmonic radiator! If you add into this loop circuit the length of the front yard ground rod conductor, the loop circumference becomes 9 quarter wavelengths. Yet another odd order radiator dimension!

My assessment of this Ham's station would inform me that he is throwing away some of the advantage of his beam and the height of his tower because, all of the radiating conductors strung around the house raise the **"angle of radiation"** considerably higher than it could otherwise be! He is also enhancing the prospects of **"audio rectification"** to his own and to neighbors telephones. He is also enhancing the possibility of **"TVI"** to his television, and maybe to the neighbors as well if they all use a cable TV system.

The Absolute Worst Thing To Do

Maybe though this isn't the worst case scenario? The worst case would be the Ham that tries to use the 3rd wire ground within the 110 volt AC power system that runs though out his house. Then he could really couple RF energy around his house and the neighborhood! **Never ever use this 3rd. wire ground as an RF ground!**

How Should our Ham have done it

1) His station should be on the ground floor of the house.

2) His low inductance low resistance grounding conductor should have considerably less than a quarter wavelength of total length between his amplifier and the first ground rod.

3) If the soil or other conditions in his yard allowed only short length rods, he should have used several of them all tied in a line, and ultimately connected to a **"grounding cage"** or rods near the **outside** of the tower's concrete base.

Important Tip: Don't install the ground cage within the concrete! One reason is that it is connected to the earth via the high resistance of the concrete. The other reason is that a lightening strike to the tower may well blow the concrete block to bits!

When Should an RF Ground Be Used and When is it a Bad Thing

With the advent of the many new MF/HF/VHF transceivers on the market these days, Hams are flocking to frequency bands on which they have little or no experience. Additionally because of the licensing structure, one of the most popular Ham bands in use is the 10 Meter band. I'm sure also that within the coming years, 6 Meters will become even more popular. On 6 meters at least, RFI is very simply controlled.

On one of these two mentioned bands, and also on most bands above 20 Meters, television interference from harmonic radiation becomes a concern that grounding will not fix. In fact most practical possibilities for grounding systems at a typical residential home, will enhance this TVI (Television Interference) problem!

Think about it this way, the 2nd. Harmonic of the 28 MHz. band falls right at TV channel 2 (2 X 28 = 56 MHz.)! This is the fourth harmonic of the 20 Meter band (4 X 14 = 56 MHz.)! From this description and the other worst case scenarios that I outlined, you may be thinking, so is he saying not to bother with installing a ground system? Well, that's not at all what I'm saying! I am telling you though that you must appreciate and design your grounding system so that it cannot possibly contribute to either **"fundamental frequency"** radiation, and also not contribute to the re-radiation of harmonics of these upper HF bands.

The prime methods for accomplishing this are to (1) keep the ground conductor shorter than a quarter wavelength on 10 Meters, which is of course the highest frequency HF band. Next we must, (2) make this conductor be at the lowest AC resistance (impedance) possible! We do this by using large surface area (fat) conductors, and **SOLDER** all connections. After soldering, seal them from the eroding effects of weather by using electricians tape and silicon sealers. Anti-oxidizing compounds such as "No-Ox", which are available at most electrical suppliers, are a must for any connection of dissimilar metals! A simpler way to deal with this last mentioned concern is to simply use non-alloy baring copper for the entire system. Copper tubing typically used for plumbing meets all of the above requirement perfectly. Don't use steel or iron pipe for ground rods! Always (3) connect multiple ground rods in a line. This line can bend or zigzag but, it must extend from the nearest to the furthest ground rod or screen in a line. The last physical consideration (4) is to cover as much ground surface area as is practical within the constraints of your yard or acreage. A minimum RF ground system will use at least three 8 foot or longer ground rods. If you can't sink a rod that long, than you must use many more shorter rods, or bury a splayed out radial system of wires. In this last case you must terminate this wire radial screen within less than a quarter wavelength at 29.7 MHz. (which is 94.5 inches or 2.4 meters).

Thinking conversely, if a grounding system becomes a touchy prospect at the higher bands, might it be a better consideration and benefit at the lower bands such as 160 meters? If you answered this question absolutely, you win a gold star, and Ham of the year award!

On lower frequency bands, both RF noise level, and also **"ground wave"** signal propagation become an important concern. Just to give you a clue, AM broadcast stations invest huge amounts of money in designing and installing their antenna grounding systems. Of course, we are nearby neighbors, almost kissing cousins you might say of the Broadcast band that ends just below 160 meters! On this band doing everything you can to enhance the signal is preeminent within the stations design. It even becomes easier to install a good grounding system than it is to install good antennas!

Think about it. Even if you could put an antenna that is 260 feet long, 100 feet above the ground, it would still be only .19 wavelengths above the ground. That would be the equivalent of installing a 2 meter antenna at about 15.6 inches above the ground! My 160 meter **"Zep"** is 48 feet up at its highest point, this equates to .18 wavelengths. This actually places the **"high current point"**, which is main working point of the antenna, at 37 feet. Thirty-seven feet is about .14 wavelengths above the ground at 1.8 MHz. Pretty low, little more than 1/10th of a wavelength! By contrast, a good ground system is easy! Good RF ground systems really come into their own, as far as showing worthwhile value, on the bands below 30 meters!

Lets wrap up these concepts

An RF ground can be used as a safety ground but, a safety ground is often the worst sort of RF ground.

Multiple ground rods provide the most earth area covered, and consequently, the best sort of grounding system.

If soil is so rocky that even hydrologically installed ground rod tubes aren't possible, a screen or web of wires below the ground surface will work well. Always use metalurgically sound, true copper wire. No alloys! Cover the largest surface area possible.

Tip: These wires can be installed in a radial fashion, by making slits in the earth or lawn with a sidewalk gardening edger. You then stuff bare copper wire in the slits. In this sort of installation wire size can be reduced to save cost. Use large enough wire to provide good physical strength, lets say #16 AWG.. Be certain that it is **"soft copper"**. A good test is to heat the wire with a gas flame, a propane cigarette lighter works great. If the wire is truly soft copper non-alloy wire, it will quickly turn green, then black, and loose all of its tensile strength. Another test would be to bury a piece of this wire for a week or more. When you dig it up, if it shows signs of oxidation or pitting, its not pure copper!

A ground cage surrounding a tower foundation provides a good final terminus point for the grounding system. It also provides for the prospect of **"shunt feeding"** the tower as a multi-band vertical antenna.

Why use a Ground Cage

For the Ham that is dedicated enough to our avocation to want the best engineered station possible, an antenna tower of considerable height is a must! The best radios in the world will not out perform poorer radios using an efficient antenna!

If you are going to install a tall tower (at least a half wavelength tall in the center of the HF spectrum) your going to have to dig a deep hole for the towers concrete base. The kind of tower I'm speaking of as a minimum will require at least a 6 foot deep hole that is 3 feet per side. I think its advisable though to install a foundation for a larger tower. You never know, you may someday want a nice 90 or 120 foot tall tower. This sort of tower requires at least a 9 foot deep hole that is 4 or 5 feet square. After such a hole has been dug, putting in a ground cage is simple!

First install the longest feasible ground rod in the center of this hole. Hopefully this rod will be at least 8 feet long. Even if you can't install a rod this long into the center bottom of the hole, a shorter rod still adds its length to the wire cage that will reside in the hole.

The cage itself is fabricated from #8 AWG. copper wire. You may visualize this cage as 8 lengths of wire that extend upward from the central ground rod, and reside at each corner of the hole, and the four sides of the hole. It is best to keep the wire contiguous however. If you were to section it into individual lengths, its net resistance (or AC impedance) would be higher than if it is kept as a continuous length. I hope that my verbal description will reveal an assembly that extends 17 feet into the ground (assuming a 9 foot deep foundation hole, and 8 foot rod) and covers a large surface area around the sides of the hole.

After this wire assembly is in place, install the towers steel work base frame. Next before filling the hole with concrete, install plastic sheeting over the wire. Now when the hole is filled with concrete, the plastic sheeting will insure that the wire is pressed against the dirt sides of the hole, and not encased by concrete. Two ends of the wire can be left to extend above the top of the hole. These will later be attached to the bottom of the tower.

The rod at the bottom center of the hole also provides a solid anchor, to keep the steel work from "floating" or moving about while the concrete is being poured. To accomplish this use Nylon rope and turnbuckles to tension down the steel frame. Nylon rope is used so that no metal work encased within the concrete is electrically connected to the ground system. High voltage static or lightening will now flow only to dirt earth surrounding the concrete. Raise the steel frame above the dirt bottom of the hole with cement foundation piller blocks. If the ends of the steel frame contact the dirt at any point, they will eventually rust and totally disintegrate!

Let's review the best things to do

1) Always use the shortest and largest surface area conductor feasible. This can be wide metal strap material, or large diameter wire or tubing.

Helpful Tip: I use 1/2 inch diameter copper tubing as my ground conductor between rod #1 and the radios. The **"ground bus"** at the back of the radio bench is yet another piece of tubing, with short braided cables soldered to it for attachment to the radios, amplifiers, and antenna **"Trans-Match"**. The ground rods themselves are also copper tubing which were hydrologically sunken (this is a technical way of saying, hook up a garden hose to the tube and let the water suck it into the ground). This method will push aside even grapefruit size rocks as it burrows into the ground.

Copper tubing is much less expensive per foot than is large diameter copper wire (I wish I had thought of that when I installed my system, because it's easier to solder as well). It has a larger diameter than most wire which lowers both its impedance and inductance. It can be easily soldered together using plumbing fittings, just as you would install water pipes. If you want to make a real bang up job of things use Silver solder to lower the impedance even more! Seal and weather proof all soldered joints!

2) Use several ground rods, and cover a large surface area. A large surface area is more important than ground rod depth! Longer rods are desirable though when possible. If it is possible, place ground rods in an area that is often irrigated. Wet soil improves soil conductivity, and helps reduce radio frequency noise.

3) Think about and sort out possible ground loops on various wavelength bands. Design your system to avoid ground loops on any band on which you operate.

Terms you should become convivial with, and use in your conceptual thinking process

Angle of radiation: The term "angle of radiation" and "signal gain" are virtually the same thing. A good antenna that is high in the air, and also isolated from other random radiators provides the lowest radiation angle, and consequently, the furthest signal propagation.

Audio rectification: This is the condition that prevails when transistor and diode circuitry within telephones or other audio devices are within the "near field" of a radio signal. This same sort of diode junction detection can even be observed with the false switching of infrared detector outdoor lighting. In this last example, the RF signals forward bias the lamps switching circuitry.

***Current loop:** Any time a wire or assembly of wires form a loop, a current generator is formed. Whenever you impose generated current across a resistance, you produce voltage. In the case of this articles premise, this voltage represents unwanted signal radiation!

Feedline: This term depicts the generic and proper description of conductors that connect an antenna to the radio station. This "feedline" might be either coaxial cable, balanced "Ladder line", or even single conductor line (as in the feed system for a "Windom" antenna, and also "G-line").

Fundamental frequency: The fundamental or prime frequency at which an oscillator or "Exciter" operates. An example might be an oscillator or Exciter operating at 3.5 MHz. (See Harmonic)

Ham: The name by which radio experimenters identified themselves, prior to the implementation of Amateur Radio pursuant to the Federal Radio Bureaus, "Communications Act of 1934".

Harmonic: The multiple of some fundamental frequency. The second harmonic of

3.5 MHz. is 7.0 Mhz., or 2 X 3.5 MHz. = 7.0 MHz.

High current point: Radio frequency currents reverse every half wavelength. The high current point of maximum signal radiation is at the center of a half wavelength antenna.

Good engineering practice: Amateur Radio operators are required by law to construct and maintain their radio stations to the best "state of the art" good engineering practice.

Good grounding system: A grounding system that provides the lowest possible resistance or Alternating Current (AC) impedance, has the lowest AC inductance possible, and is designed so as to limit the re-radiation of fundamental or harmonic frequency energy.

Ground bus: A common point connection terminus that embodies the design criterion of a good grounding system.

Grounding conductor: This is the connecting link between the radio station equipment bus, and the nearest point of earth grounding connection.

Ground rod: The term used to describe the simplest device associated with any sort of electrical "earthing" practice.

***Ground loops:** Intrinsically the same thing as a Current Loop.

Grounding system: The entirety of a conceived and engineered plan for providing "earthing" perameters for radio or other electrical requirements.

Ground wave: One electrical component of the physics of low frequency radio propagation. In Amateur Radio practices, the 160 band is the only wavelength band that exhibits significant ground wave signal propagation.

Large surface contact area: In the context of this article, this term implies the best "current conductivity" to earth ground. In Alternating Current (AC) circuits (ergo radio) large surface contact provides both low inductance, and low impedance. (See also "Skin Effect")

Near field: The near field of radio frequency energy is that radiated energy within a several wavelengths of an antenna or other radiating source.

Odd order harmonic: The direct definition relates to the third, fifth, seventh, ninth, eleventh, and thirteenth multiples of a fundamental signal etc. A readily available example of an odd order harmonic in Amateur Radio practice is the means by which a 441 MHz. signal can be generated from a 147 MHz. source (147 X 3 = 441). Another way of saying this is, the 70 centimeter band falls at the 3rd. Harmonic of the 2 meter Amateur Radio wavelength band. Odd order harmonics are easily propagated in contrast to "Even Order" harmonics which will self cancel.

Power mains: The generic description of the primary power distribution source (117 Volt Alternating Current, or 220 VAC etc.)

Radio frequency wavelength: The unit of radio signal measurement that embodies both the legal requirement of Amateur Radio station operation, and also depicts the physics by which radio signals propagate. Radio wavelength is determined by deviding frequency into the velocity by which that signal energy travels. Where V = Velocity or 300,000,000 meters per second, and f = Frequency (of oscillation) of the frequency in use. Example: V f = λ 300 / 50 MHz. = 6 meters

RF ground: A grounding system that by inference implies the qualities of low impedance, and low inductance.

Safety ground: A grounding system that by inference implies only a better electrical path to ground than the person or equipment being protected.

Skin effect: Alternating Currents, such as radio frequencies, flow only on the outside surface of conductors. By inference in this application, larger surface area equates to lower impedance and improved conductivity.

Short circuit: The situation that arises when a person or other conducting object is exposed to an electrical circuit between that circuits source and load. The "short circuiting" object in this case, becomes the interim load.

Shunt feed: In the context of this article, this implies a system for "feeding" radio signal energy into a grounded metal tower, to make that tower function as an antenna.

Soft copper: The term soft copper refers to copper that is not produced with other metal content. In other words, it is just plain copper, not an alloy.

Hint: To expand upon the conceptual idea contained within the use of such metals, think about the concept of using other metals of low resistance! Just as a thought teaser, if the cost was not so exorbitant, would using silver plating on antennas or other RF conductors be desirable?

Station ground: A radio station grounding system where both electrical safety precautions as well as radio frequency transmission optimization have been provided.

Trans-match: This is the proper term for a transmitter to antenna system impedance matching coupler. This is often errantly referred to as an "Antenna Tuner". If the word Antenna *System* Tuner was inserted, the errant quality of the term would be mitigated.

Wavelength bands: A political distinction for allotting and cataloging portions of radio frequency spectrum. This term though embodies the physics by which radio signals propagate. (See: radio frequency wavelength)

Wavelength dimension: This term refers not only to unitary or single units of frequency wavelength such as 10 meters or 2 meters, it more importantly refers to thinking in terms of a dimension length. Example: 10 feet is .28 wavelengths at 28 MHz. (or a bit longer than a 1/4 wavelength).

The formula to calculate this is:

V f =

300 / 28 MHz. = 10.7 meters

10.7 X 39.37 = 421.8 inches

421.8 / 12 = 35.15 feet

10 feet / 35.15 = .28 wavelength

Where V = Velocity of signal propagation, or 300,000,000 meters per second, and 39.37 = 1 meter as measured in inches

This same 10 foot physical length of wire becomes .253 wavelengths (still a bit over a quarter wavelength) at the 12 meter band, .508 wavelengths on the 6 meter band, and 1.46 wavelengths on the 2 meter band.

For our purposes in this article, anytime a piece of wire at your station approaches a 1/4 (.25) wavelength or longer, it isn't a ground conductor anymore! In fact it becomes a **"radiating element"**, or you might say an antenna in its own right. This is bad news for a ground system!

Radiating element: a radiating element is any metallic conductor that is within the **"near field"** of a radio frequency energy source. This is usually specific length component elements of an antenna. It can be any piece of metal that is a significant percentage of the energizing wavelength frequency. Examples of such **unwanted** radiating elements might be, rain gutters, wire guy lines, or grounding conductors, any of which would have to be a quarter wavelength or longer at the energizing frequency.

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