Grounding & Materials

White Paper

PolyPhaser®

Grounding & Materials

We have discussed the lightning event, how sites get damaged, and how to direct this damaging energy to earth ground. But what (in this context) is ground? Ground is the “sink” for electrons in a negative polarity cloud to earth strike.

The problem is how to disperse the rapidly rising high frequency electron energy into the earth body very quickly, with minimum local ground potential rise.

AC power frequency ground system designs do not always disperse high frequency energies (as in a lightning event) effectively. A 1994 study presented in the U.K. in 1997 compares the performance of adjacent horizontal earth grids at three different frequencies and examines the effect of adding close-in vertical ground rods. The authors conclude that horizontal components with vertical ground rods close in to the point of injection lower the resistance in a predictable way at power line frequencies, but reduce ground potential rise by an additional 27% at 1 MHz!

Ground Theory

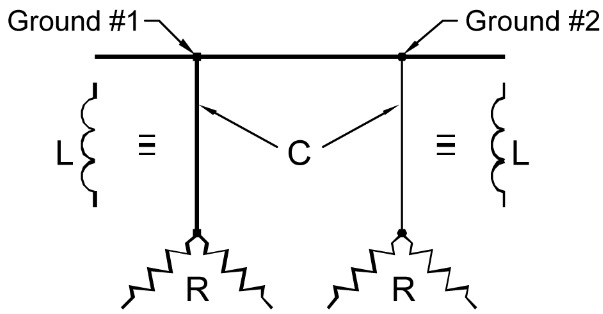
A lightning strike is a local event. If the earth were a metal sphere, a lightning discharge would create a measurable ringing gradient on the sphere. However, the earth’s resistance limits the current and dissipates the energy so the event becomes a mere pebble in the pond scenario. When a lightning strike is delivered to a ground rod driven into average to poor conductivity soil, the rod will be surface charged at a calculable velocity factor. The charge will rise to a level where the concentration of E field lines cause the soil to break down at the rod point. This breakdown will momentarily increase the surface area of the rod. As the charge is being transferred, depleting the source, the E field at the rod tip will decrease below where the arc is sustained. The charge continues to disperse onto the surface of each grain of dirt surrounding the rod. (A charge can exist on an insulator, i.e., a glass rod after being rubbed with a piece of silk.) Because of the irregularity of the granular surface, the bumpy E fields inhibit the charge dispersal beyond a small range (sphere of influence).

If a ground rod is in poor conductivity soil, we can equate this to a rod being suspended in air, so rod inductance must be taken into account. The voltage drop, due to the inductive creation of a large magnetic field is expressed as: $E = L\,di/dt$ - where “di” is the lightning strike peak current, typically 18,000 amps, and “dt” is the rise time, approximately 2μs.

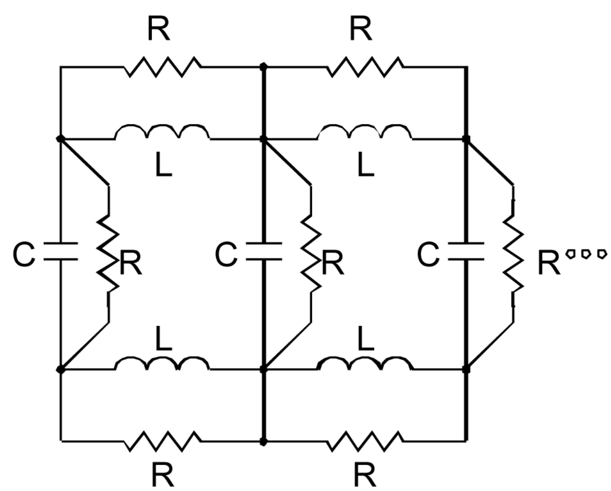
There is a limitation to the length that a single ground rod can penetrate poor conductivity soil on its way to water table and better conductive earth. Unless “shunted” by conductive earth, the series inductance of the rod section in poor conductivity soil, “chokes off” current flow to a possibly more conductive lower section creating a voltage drop along the more inductive top section. The top section of the rod “breaks down” the soil. There will be saturation and local ground potential rise due to this breakdown.

By having two rods connected in parallel, the overall inductance can be reduced. The spacing is important so each rod is able to “dump” into different volumes of earth. This dictates that the rod spacing be rather large (approximately 16 feet for two 8-foot rods in homogeneous soil) so the mutual inductive coupling between the rods would be small. Connecting two rods to the same volume of earth will cause saturation of that volume and limit the passage of any further charge in the given time span of the lightning strike.

Connecting a capacitance meter between two well spaced rods will show capacitance is present in the soil. The soil surrounding each rod is resistively separated from the other. The cumulative resistance represents a poor insulator separating the two electrodes and forms a leaky capacitor.



In the previous example, distributed resistance, inductance, and capacitance have been shown to exist. All can exist simultaneously. The interconnecting of these lumped elements is equal to that of a lossy transmission line or low pass filter. (Since earth R is high compared to the wire R, it is omitted.)



The only condition where both L and C can be eliminated is when R (earth resistance) = 0 ohms. (Here L is the total inductance of both wire, ground rod and the L of earth.)

Because a transmission line can simulate an earth ground system when not in a non-linear arc mode, a Velocity Factor could be calculated once L and C are known.

$$VF = \frac{1}{\sqrt{LC}}$$

However, this assumes the earth is of equally conductive makeup at all depths. If this type of soil were to be found, then calculating the surge impedance would be easy. This condition rarely occurs in nature.

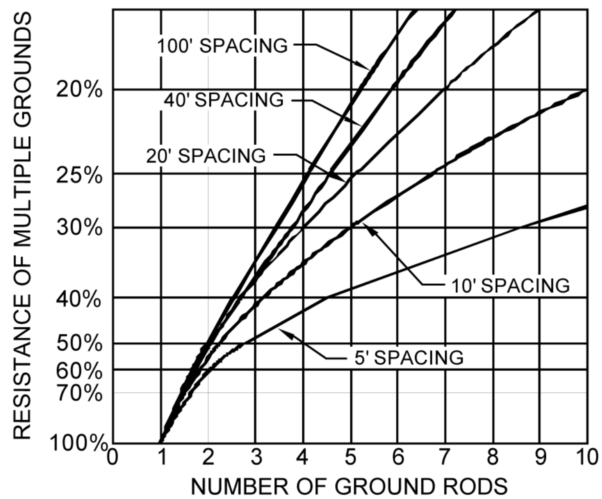
Conventional ground testers are really impedance meters. They operate in the 70 to 300 Hz range and express the measurement in Ohms(Z). They were originally designed for the electric utility industry to measure ground resistance to assure circuit breaker operation should there be a ground fault. If the reactance of 30 feet of wire is <.004 ohms at 60Hz, the same 30 feet could have an inductive (E = L di/dt) voltage drop of over 100kV for a typical 18kA lightning strike.

With no available tester, the question remains: What is the ground system's impedance at lightning's range of frequencies/rise times? Although this impedance is still an unknown, design practices with multiple parallel inductances, such as radials and ground rods, can make a ground system with a faster transient response to quickly disperse lightning's fast rise time pulses.

Ground Rods

Ground rods come in many sizes and lengths. Popular sizes are 1/2", 5/8", 3/4" and 1". The 1/2" size comes in steel with stainless cladding, galvanized or copper cladding (all-stainless steel rods are also available) and can be purchased plain (unthreaded) or sectional (threaded). The threaded sizes are 1/2" or 9/16" rolled threads. It is important to buy all of the same type. Couplings look much like a brass pipe with internal threads and allow two rods to be joined (threaded) into each end.

Theoretically, one ground rod with a 1” diameter driven in homogeneous 1,000-ohm per meter (ohm/meter) soil for one meter would yield 765 ohms. Driving it two meters into the soil would give 437 ohms. Going to three meters, however, does not give as great a change (309 ohms). One would get faster ohmic reduction and easier installation by using three rods, each one meter long, giving 230 ohms compared to that of one rod three meters long. This assumes they are spaced “greater than the sum of their lengths apart”. If the bare interconnecting wire is also buried below the surface, then the ground system may be less than 200 ohms. (Having one deep ground rod, 40 feet or more, even if it reaches the water table, will not act as a good dynamic ground because the top 5 to 10 feet will conduct most of the early current rise and could become saturated. Eddy currents will form in this top layer and cause the rod’s inductance to impede the flow of current to any further depth.)



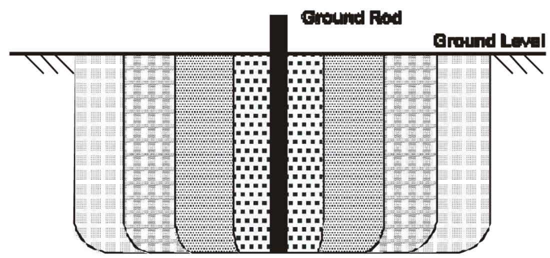
Theoretical resistance change for additionally spaced ground rods.

Ground Saturation

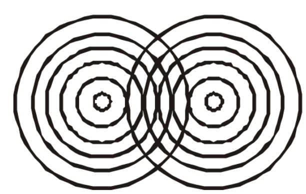
The statement that rods should have a separation, “greater than the sum of their lengths apart,” originates from theory, and the fact almost all ground rods will saturate the soil to which they connect. A ground rod connects to localized, irregularly sized, three-dimensional electrical clumps. Depending on the soil make-up (layering, etc.), the volume of earth a ground rod can dump charge into can be generalized as the radius of a circle equal to the length of the rod at the circle’s center. This is known as the sphere of influence of the rod. The sum of the driven depths of two rods should be, theoretically, the closest that ground rods can be placed. Anything closer will cause the soil (clumps) connected in common to saturate even faster.

A sandy area has a water table at the 10-foot level. Two 10-foot ground rods are coupled and are to be driven to a total depth of 20 feet. A second rod is to be driven no closer than 20 feet to the first, but 40 feet would be according to the “sphere of influence rule. The rule can be looked at two ways:

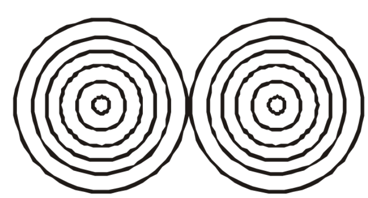
GROUND ROD SPHERE OF INFLUENCE



Incorrect Spacing



Correct Spacing

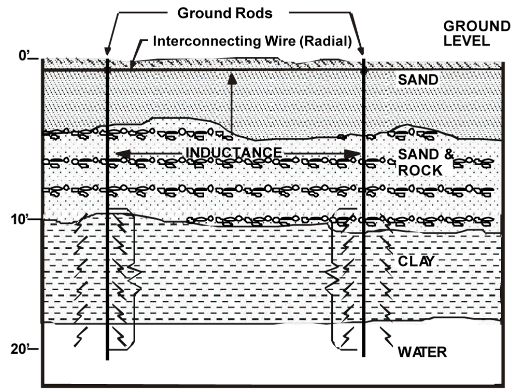


8Ft. Rod - 8Ft. Radius Influence
10Ft. Rod - 10Ft. Radius Influence

(1) Only 10 feet of each 20-foot rod is in conductive soil (the top 10 feet of each rod is in non-conductive dry sand), so 10 feet + 10 feet = 20 feet apart.

(2) Without taking the water table depth into consideration, 20 feet + 20 feet = 40 feet.

Following the rule, the separation in #2 will not work! The interconnecting inductance will choke off the higher frequency components of the surge's rise time and create an L di/dt voltage drop. Due to the interconnecting inductance, most of the surge will never reach the second ground rod. Following #1's spacing, the inductance will be less, but there are two other solutions to this real life problem. First, using copper strap can reduce the interconnecting conductor's inductance. Second, by using chemical salts to increase soil conductivity around the rods and along the interconnect path, the resistance is also reduced. For the best performance, use both solutions together with #1's spacing



Ground System Interconnections

As the spacing between vertical ground rods is increased, the interconnecting wire will be able to launch or leak current into the surrounding conductive earth. Therefore, it can be thought of as a horizontal ground "rod" connecting to vertical ground rods. In highly conductive soil, one should not be concerned about the inductance of such a straight wire because such a wire acts as a leaky transmission line with very high losses to the soil resistance. Therefore, wire size (skin effect) is of little importance, like that of rod diameter mentioned earlier, as long as it can handle the I2 x R of the surge. For highly conductive soil, a #10- AWG (bare) is the smallest wire that should ever be used. This type of soil is not common.

In areas where soil conductivity is poor, such as sandy soil, the #10 buried interconnecting wire approximates an inductance as if suspended in air. This undesirable condition causes it to be highly inductive, preventing strike current (which has a fast rise time) from being conducted by the wire. Ground rods connected in this way are not effectively utilized.

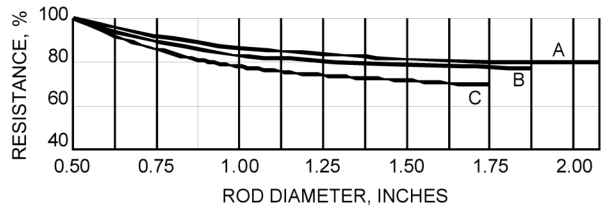
Interconnection Materials

Solid copper strap should be used to inter-connect ground rods in poor conductivity soil, solid copper strap should be used. The strap may be as thin as 0.016". For 1-1/2" wide strap, the cross sectional area will equate to a #6 AWG wire. Greater thickness gains only a little advantage because high frequency currents (1 MHz) penetrate only to a depth of about 0.008" per surface, owing to "skin effect". Although the strap width should be about 1% of its length (e.g., 20 feet x 0.01 = 2.4" wide), 1-1/2" strap is usually acceptable.

Connecting the strap to the rod may be done using a clamp. (An exothermic weld is best but not always available, check with your supplier for an appropriate mold or "one shot") For 5/8" rods and 1-1/2" strap, a clamp offers a way to achieve a mechanically rigid, low maintenance connection. The copper connection must be cleaned and a copper joint compound applied to prevent moisture ingress. Copper clamps that bond straps and rods together in the soil and many other 1-1/2" strap to cable clamps (6AWG to 4/0) are available.

Driving The Sections

Driven rods will out perform rods whose holes are augured or back-filled and not tamped down to the original density. The soil compactness is better around driven rods giving more “connection” to the rod. It will be necessary to purchase a “pounding cap” for hammering threaded rods or a bolt that fits the coupling. By threading the coupling on to the top end of the rod and threading the bolt into the coupling, a “smash proof” hammering point is achieved, saving the rod’s threads.



Three individual tests (A,B,C). Each took a 1/2” Ground Rod which was used as a reference and set to 100%. The Rod size was increased and different results are due to ground conductivity variations.

What type and size of ground rod should be used? Most seem to choose the copper clad 5/8” x 8 or 10 feet. The rod diameter should increase as the number of tandem rod sections and soil hardness/ rockiness increases. The rod diameter has minimal effect on final ground impedance.

Ground Rod Depth

The total depth each ground rod must be driven in to the soil depends on local soil conductivity. Soil resistivity varies greatly depending on the content, quality and the distribution of both the water and natural salts in the soil. It is beneficial to reach the water table, but it is not necessary in all cases.

In higher latitudes, single rods should be long enough to penetrate below the maximum frost depth. In some cases, a total depth of 40 feet or less is necessary, with the average being 15 feet. Depth would also depend on the number of rods and the distances between them.

Rf, Lightning, & Safety Grounds

A single driven ground rod, or one at each leg, is never enough to ground a tower for lightning. The rods will immediately saturate and the local ground potential will rise. There are three types of grounds, each required for different purposes:

• RF ground, such as an antenna counterpoise. A ground plane takes the place of the other half of a normal vertical dipole. A good RF ground plane could be elevated above ground (tuned) and thus cannot be a good lightning ground. If such a ground plane is properly extended and placed in the soil, it will no longer be tuned. It can then be used as an RF noise and lightning sink. Therefore, not all RF grounds are good lightning grounds, but most good lightning grounds are good RF grounds for low frequencies.

· Lightning ground. This ground must be able to sink large amounts of current quickly (fast transient response). The typical frequency range of lightning energy at the bottom of a tower can be from dc to the low VHF range (<100MHz). The ground system must be a broadband absorptive counterpoise over this frequency range.

• Power return or safety ground for ground faults. This is a low frequency (60Hz) ground and may be very inductive to lightning’s fast rise time, yet still be usable for 60Hz.

The signal source for the three-stake fall of potential resistance measurement is a low frequency ac potential, usually around 100 Hz. The electrical safety ground is often not a good lightning ground for that reason.

Radials

Some locations are rocky enough that only the horizontal conductors can be placed below grade. Buried horizontal radials, like those used on vertical broadcasting antennas, make an excellent RF and lightning ground system. Theoretically, four radials each 20 meters (m) long, of #10 gauge wire, just buried will yield 30 ohms in 1,000-ohm/meter (ohm/ m) soil. Eight radials would give about 25 ohms. Eight radials each fifty meters (163 feet each or 1,300 feet total wire) on top of the ground or hardly buried could give about 13 ohms in 1K-ohm/m soil. Theoretically, by adding 2m long rods (if possible) to this system, one on every radial (8 rods total), would calculate the system resistance below 10 ohms. If the rods were spaced every 10m on each radial (32 rods total), then the resistance would go to about 4 ohms. This is the theoretical impedance at 100Hz for 1,000-ohm/m soil, which could be sandy or rocky. A long radial run will not work as well with a fast rise time lightning current pulse as many shorter radials.

There is a law of diminishing returns for radials. As with sprinkler hoses, the amount of water, or in this case lightning energy, at the end of a 75' length radial is so small going further is wasting time, effort, and material. It is recommended radials only have a 75' run (no shorter than 50 feet if possible) and then additional radials from the tower be used to further reduce the surge impedance/ground resistance. The measured earth resistance of the radial system may be decreased, but like ground rods, you will need to double what you have to not quite halve the resistance value. The radial runs should be oriented away from the equipment building as much as possible. In this way, the greatest amount of energy is carried off from the tower and away from the equipment building.

Some have stated "if a radial is like a lossy transmission line, and the energy is not absorbed by the time it reaches the end of the radial, it will reflect back to the tower base." This would seem to indicate there are not enough radials in poor conductivity soil since the soil becomes saturated and will not absorb any more electrons. That is one more reason to install additional radials and rods, not just longer radials.

Since the radial system is emulating a solid plate. The capacitance of this plate to true earth will determine the amount of charge that can be transferred. The resistance will dictate the time constant in which the plate will be elevated (saturated) above earth. Adding more radials with ground rods will increase the surface area (capacitance) and decrease the resistance.

Ufer Grounds

When building a new site, some radio installations do not take advantage of what is known as the Ufer ground. This grounding technique can significantly reduce the overall ground system impedance. The Ufer technique can be used in footings, concrete building floors, tower foundations and guy anchors.

The Ufer ground can be both a good lightning ground and safety ground. Under a ground fault condition, more total energy will be conducted to ground than during a lightning strike, due to the longer time required to clear the fault. Lightning has a very high peak energy, but the duration is very short. The Ufer has been proven to handle both without failure.

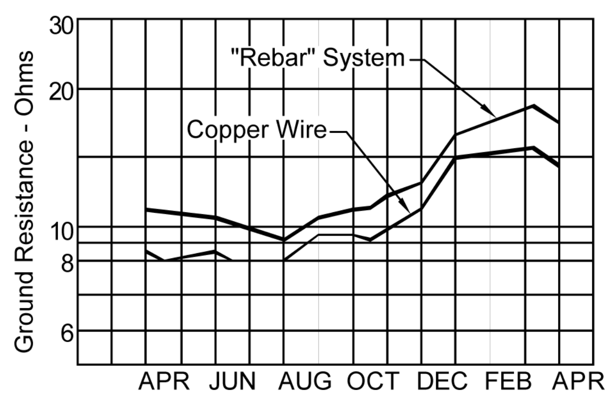
Herbert G. Ufer, for whom the technique is named, worked as a consultant for the US Army during World War II. The Army needed to earth ground bomb storage vaults near Flagstaff, Arizona. Since an underground water system was not available and there was little annual rainfall, Mr. Ufer came up with the idea of using steel reinforcing rods embedded in concrete foundations as a ground. After much research and many tests, it was found that a ground wire, no smaller than a #4AWG conductor, encased along the bottom of a concrete foundation footing, would give a low resistance ground. A 20-foot run (10 feet in each direction) typically gives a 5-ohm ground in 1000-ohm-meter soil conditions.

Ufer Ground Tests

One of the most important tests performed was under actual lightning conditions. The test was to see if the Ufer ground would turn the water inside the concrete into steam and blow the foundation apart. Results indicated that if the Ufer wire was 20' minimum and kept approximately 3" from the bottom and sides of the concrete, no such problems would occur. (A Ufer ground should always be used to augment the lightning grounding system and not be used alone. Radials, or radials with ground rods, should be used together with the Ufer. For those who are afraid to use the Ufer, think about this: The heating of the concrete is more likely if the current is high or concentrated in a given area. This is known as current density "J". The more surface area there is to spread out the given current, the less the current density. Your tower's anchor bolts are already in the concrete. If the ground system is poor, the current density surrounding the bolts could be high, turning any ambient moisture to steam, and could blow apart your concrete. If the rebar is tied in to the "J" bolts, the area is increased and the current density is reduced. (Corrosion will be reduced as well.)

A Ufer ground could be made by routing a solid wire (#4 AWG) in the concrete and connecting to the steel reinforcing bar (rebar). Theoretically, the outermost sections of the rebar structure should be bonded together, not just tied. If tied, a poor connection could cause an arc. Because arc temperatures are very high and are very localized, they could cause deterioration of the concrete (cracking and carbonizing) in that area.

Although possible, this has not been the case in practice. The wire ties are surprisingly effective electrical connections. "One might think that the ties would fail under fault conditions. However, it should be remembered that there are a large number of these junctions effectively in parallel, cinched tightly." (IEEE Seminar Notes 1970.)



Graph of Rebar Versus Copper Wire

The use of large amounts of copper cable coiled in the base of the tower (for a Ufer "effect") has been shown to cause flaking of the concrete and could, over time, also cause de-alloying of the rebar. This can occur due to the concrete's pH factor. The use of copper conductors, such as radials and ground rods, outside the concrete, has not shown these problems.

Using a small amount of copper wire, such a radial "pigtail" connection (short run in the concrete) will not adversely affect the rebar during a typical 30- year tower life.

Choosing The Length

The minimum rebar length necessary to avoid concrete problems depends on the type of concrete (water content, density, resistivity, etc.). It is also dependent on how much of the buried concrete's surface area is in contact with the ground, ground resistivity, ground water content, size and length of bar, and probable size of lightning strike current. The last variable is a gamble! The 50% mean (occurrence) of lightning strikes is 18,000 amperes; however, super strikes can occur that approach 100,000 to 200,000 amperes.

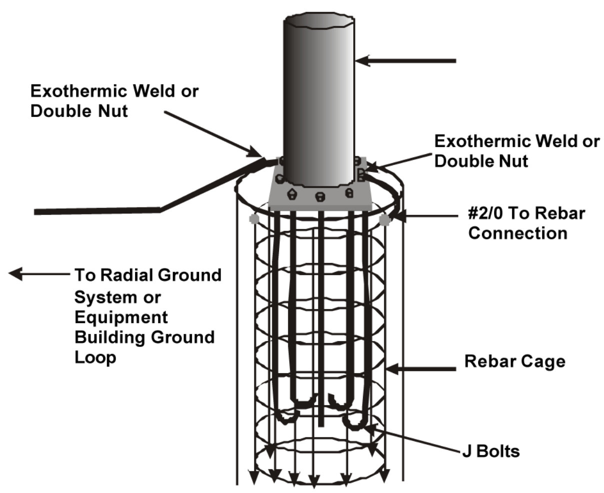
Conductor	Diameter Inches	Surge Amps/Ft
Rebar	.375	3400
Rebar	.500	4500
Rebar	.625	5500
Rebar	.750	6400
Rebar	1.000	8150

The chart shows how much lightning current may be conducted per foot of rebar for (dry mix) concrete. Take the total linear run of wire and multiply it by the corresponding amperes per foot to find out how long the ground conductor must be to handle a given strike current. Only the outside perimeter rebar lengths of the cage should be totaled.

Protection to at least the 60,000-ampere level is desirable. This offers protection for 90% of all lightning strike events. A Ufer is only to be used together with a radial, or radial and rod ground system.

How It Works

Concrete retains moisture for 15 to 30 days after a rain, or snow melt. It absorbs moisture quickly, yet gives up moisture very slowly. Concrete's moisture retention, its minerals (lime and others) and inherent pH (a base, more than +7pH), means it has a ready supply of ions to conduct current. The concrete's large volume and great area of contact with the surrounding soil allows good charge transfer to the ground.



Sample tower base Rebar Assembly with #2/0 stranded copper pigtails used to interconnect Tower Ufer Ground to Equipment Building Ground, Ground Rods, Radials, etc.

Materials

Rods may be clad with copper to help prevent rust, not for better conductivity. Of course, copper cladding is a good conductor, but the steel it covers is also an excellent conductor when compared to local ground conductivity.

The thickness of the copper cladding is important when it comes to driving the rod and when the rod is placed in acidic soil. Penetrating rocky soil can scratch off the copper and rust will occur. Rust, an iron oxide, is not conductive when dry, but it is fairly conductive when wet. In acid ground conditions, such as in an evergreen area, the copper will be attacked. The thicker the copper cladding, the longer the rod will last. Some have elected to tin all copper components in an attempt reduce corrosion. Actually, this is not a bad idea. Tin will protect the copper in acid soil. The tin will be sacrificed in alkaline soil, but the copper will remain.

A swimming pool or garden soil acid/base tester can be used to determine the soil pH. Any ground system will need to be checked and maintained on a regular basis to assure continued performance.

About Corrosion

Corrosion is an electromechanical process that results in the degradation of a metal or alloy. Oxidation, pitting or crevicing, de-alloying, and hydrogen damage are but a few of the descriptions of corrosion. Most metals today are not perfectly pure and consequently when exposed to the environment will begin to exhibit some of the effects of corrosion.

Aluminum has an excellent corrosion resistance due to a 1-nano-meter-thick barrier of oxide film that forms on the metal. Even if abraded, it will reform and protect the metal from any further corrosion. Any dulling, graying, or blackening that may subsequently appear is a result of pollutant accumulation.

Normally, corrosion is limited to mild surface roughening by shallow pitting with no general loss of metal. An aluminum roof after 30 years only had 0.076mm (0.0003 inch) average pitting depth. An electrical cable lost only 0.109mm (0.0043 inch) after 51years of service near Hartford, Connecticut. Copper, such as the C110 recommended for Bulkhead Panels, has been utilized for roofing, flashing, gutters and down spouts. It is one of the most widely used metals in atmospheric exposure. Despite the formation of the green patina, copper has been used for centuries and has negligible rates of corrosion in unpolluted water and air.

LESS NOBLE ↑	Magnesium	Aluminum	Zinc	Iron	Cadmium	Nickel	Tin	Lead	Copper	Silver	Palladium	Gold
MAGNESIUM	0.00	-0.71	-1.61	-1.93	-1.97	-2.12	-2.23	-2.24	-2.71	-3.17	-3.36	-3.87
ALUMINUM	0.71	0.00	-0.90	-1.22	-1.26	-1.41	-1.52	-1.53	-2.00	-2.46	-2.65	-3.16
ZINC	1.61	0.90	0.00	-0.32	-0.36	-0.51	-0.63	-0.64	-1.10	-1.56	-1.75	-2.26
IRON	1.93	1.22	0.32	0.00	-0.04	-0.19	-0.30	-0.31	-0.78	-1.24	-1.43	-1.94
CADMIUM	1.97	1.26	0.36	0.04	0.00	-0.15	-0.27	-0.28	-0.74	-1.20	-1.39	-1.90
NICKEL	2.12	1.41	0.51	0.19	0.15	0.00	-0.11	-0.12	-0.59	-1.05	-1.24	-1.75
TIN	2.23	1.52	0.63	0.30	0.27	0.11	0.00	-0.01	-0.47	-0.94	-1.12	-1.64
LEAD	2.24	1.53	0.64	0.31	0.28	0.12	0.01	0.00	-0.46	-0.93	-1.11	-1.63
COPPER	2.71	2.00	1.10	0.78	0.74	0.59	0.47	0.46	0.00	-0.46	-0.65	-1.16
SILVER	3.17	2.46	1.56	1.24	1.20	1.05	0.94	0.93	0.46	0.00	-0.19	-0.70
PALLADIUM	3.36	2.65	1.75	1.43	1.39	1.24	1.12	1.11	0.65	0.19	0.00	-0.51
GOLD	3.87	3.16	2.26	1.94	1.90	1.75	1.64	1.63	1.16	0.70	0.51	0.00

← LESS NOBLE

Noble Metal Table: Accelerated corrosion can occur between unprotected joints if the algebraic difference in atomic potential is greater than $\pm$ 0.3 volts.

Joining copper to aluminum or copper to galvanized (hot dipped zinc) steel with no means of preventing moisture from bridging the joint would result in corrosion loss over time. This is the accelerated corrosion (loss) of the least noble metal (anode) while protecting the more noble metal (cathode). Copper, in this example, is the more noble metal in both of these connections. See the Noble Metal Table (below) for a ranking of commonly used metals.

Where the copper connection is with galvanized steel, the zinc coating will be reduced allowing the base steel to oxidize (rust), which in turn will increase the resistance of the connection and compromise the integrity of the mechanical structure. Aluminum will pit to copper leaving less surface area for contact and the connection could become loose, noisy, and possibly arc under load.

Using a joint compound covering and preventing moisture from bridging the metals can prevent joint corrosion problems. The most popular compounds use either graphite or copper particles embedded in a grease. As the joint pressure is increased, the embedded particles dig into the metals and form a virgin junction of low resistivity, void of air and its moisture. The use of a joint compound has been adopted as the recommended means for joining coaxial protectors to bulkhead panels for non-climate controlled installations. Copper joint compound is supplied for bulkhead panel ground strap connections. This compound has been tested with a "loose" one-square-inch copper to copper joint, and can conduct a 25,500 ampere 8/20 waveform surge with no flash over and no change in resistance (0.001 Ohms). Moving the loose joint after the surge found no change to its resistance.

The connection of a copper wire to a galvanized tower leg should be avoided even if joint compound is used. The problem is the limited surface area contact of the round wire with the (round) tower leg. Consider using two PolyPhaser TK series stainless steel isolation clamps. The TK clamps will help increase the surface area of the connection and provide the necessary isolation between the dissimilar metals. Use joint compound on exposed applications of the TK clamps. For a more effective connection, use copper strap in place of the wire with one TK series clamp. Other connectors are commercially available where the two dissimilar metals are already bonded together.

Silver oxide is the only oxide known to be conductive. (This is one reason why quality N-type coax connectors are all silver with gold center pins.) Copper oxide is not conductive. The proper application of joint compound will prevent copper oxidation.

If copper clad ground rods are used, be sure the oxide layer is removed. Tinned wire should not be used together in the ground with copper ground rods. Tin, lead, zinc and aluminum are all more anodic than copper. They will be sacrificial and disappear into the soil. It is recommended that all components be made of the same external material (all tinned or all copper).

Doping The Soil

Salts may be added to increase the conductivity of the soil, but it is a temporary solution that must be renewed every year to maintain the elevated conductivity. Chemical ground rods can help capture the precipitation and direct it through the salts, creating a saline solution dispersed into the surrounding soil. It can also be fed from a timed drip system, if domestic water is available.

Chemical additives, such as Rock Salt, Copper Sulfate and/or Magnesium Sulfate, will help reduce the R (resistance) value so some dissipation can occur. (Remember, power is I2R.) This will dampen the ringing, transform the surge energy into heat and increase the size (volume) of the ground system. The latter two chemicals are less corrosive than Rock Salt. Magnesium Sulfate will have much less of an environmental impact than the other salts. All salts will lower the freezing point of the soil moisture, which is important at higher elevations. About 2 kilograms (kg) of salts will dope 2 meters of a radial run for one year. About 5 kg (minimum) is necessary for each ground rod. Make sure the salts are watered in or they may be blown away.

Encapsulation of radials in conductive gels or carbon materials is an alternative where little or no soil exists. Commercial products are available for this use. Acrylamide gel, Silicate gel, and Copper ferrocyanide gel are listed here in the order of increasing conductivity; however, all involve toxic and/or hazardous materials. An easy alternative is to use concrete to make a Ufer ground.

On Rocks And Mountains

If soil is rocky enough that radials are sometimes in air while spanning between rocks, the accumulated inductance along the runs will choke off the surge currents. In this situation, numerous slightly shorter lengths of solid flat strap radials have been effective. The copper strap's sharp edge will concentrate the E fields that are present due to the existing L di/dt voltage drop and breakdown or arc onto the surface of the rock or soil.

On solid bare rock, strap arcing will help spread out the charge onto the rock's surface. A strike is usually an onslaught of electrons with like charge. Electrons repel and want to spread out. In doing so, they lose energy due to the resistances involved. Since little conductivity is present on dry bare rock, there will be little spreading in the time frame of a strike. If rain occurs before the event, then the surface of the rock will be quite conductive and the charge will spread out, losing energy in the process. The more it spreads, the more energy is lost as the charge density is reduced. The use of the Ufer ground technique at the tower base and at the guy anchors will help spread the charge.

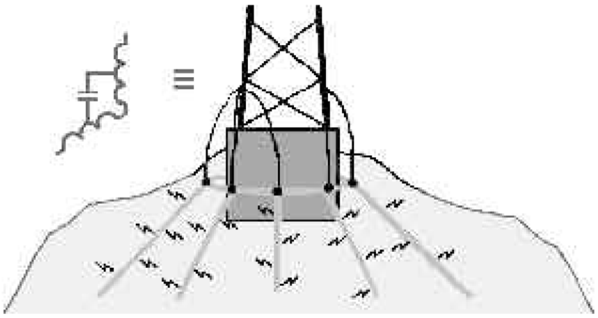
Be aware that low-frequency ringing may occur since the entire grounding scheme is being excited. Think of such a site as a giant vertical (parasitic) antenna being excited by a broadband (arc) noise generator (the lightning strike). The ringing will further stress the I/O surge protectors, such as the power line and telephone line protectors.

A Mountain Top "Nonresonant Counterpoise"

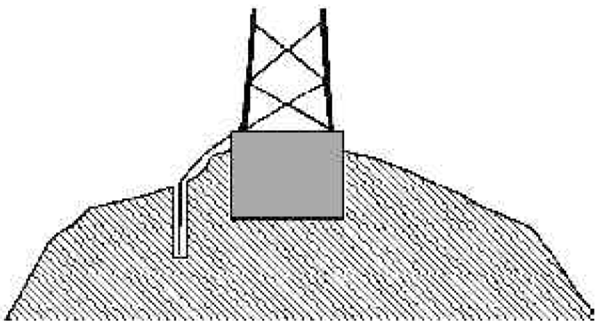
By placing several copper straps in the soil or on the rock, a counterpoise is created much like those used on AM broadcast tower sites. Even though the mountain is an insulator, the radials charge up like a capacitor and spread out the charge onto the surface. The sharp edges of the strap will help breakdown the air and form arcs onto the surface of the rock.

This action will not affect the equipment and is beneficial, since like arcing in the soil, it will reduce the elevated potential of the entire ground system. We are still dealing with a theoretical antenna (the tower) and a ground plane (the radials) which can "ring" when excited by an arc. Random lengths cut to odd multiples/divisions of the tower height are recommended as part of the circuit to reduce the possibility of "ringing." Increasing the rock's surface conductivity will dampen and dissipate the strike energy. This may be as simple as having light rain just before the strike event.

Avoid the concept of drilling holes in a mountain top and filling it with conductive material (a "conductive hole?"). Most mountain locations do not have fissures in the rock which allow water to collect, making the fissures conductive. (A consultant in South America recommends setting an explosive charge in the bottom of such a hole to "fissure" the rock. Consider this at your own risk!)



A Non-resonant Counterpoise



Drilling and backfilling a single ground rod not recommended without additional grounding components.

Solid rock is not going to be any more conductive in a hole than on the surface. Consider what happens in the hole after it has some electrons in it? Since the electrons repel one another, few will enter the hole. Like water, the electrons will spill on to the surface of the rock and spread out. Unlike water, the repulsion of electrons will mean fewer are needed to fill the hole and, once filled, the spreading on the surface will have an added force. The best way to disperse the electrons is by having a radial ground system. Commercial products are available to encapsulate the radial in a conductive concrete-like substance.