Short Radials for Ground-Plane Antennas

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Think your elevated radials always have to be full size? N6LF lets you in on some great ideas to lessen the "wingspan" of radials, especially near the beach.

Dean Straw's (N6BV) article[1] in this book describing the 6Y2A operation and beach-front verticals for DXpeditions shows how useful a vertical or vertical array can be—if you can put it over or adjacent to saltwater. For 20 meters and higher in frequency it is practical to use λ/2 verticals with little or no ground plane. For 40 meters and lower in frequency, however, a λ/2 height becomes prohibitive and a λ/4 ground-plane with elevated radials is a more practical form of vertical. Unfortunately, as you go down in frequency the length of the quarter-wave radials becomes very long (approximately 132 feet on 160 meters), and this takes up a lot of area. In addition, most DXpeditions can't place the radials very high off the ground. This results in a number of wires to trip over or strangle on. And if you have several verticals, the beach really becomes an obstacle course!

One way to reduce the problem is to shorten the radials (leaving the vertical part of the antenna as near a quarter-wave as possible) and use either a loading inductor, a top-loading hat or some combination of the two. The question is, "How much do you lose as you shorten the radials?" I took a look at this using *GNEC-4*, a *NEC-4.1*-based modeling program, and the following is what I discovered. Keep in mind of course that all this assumes *NEC* knows what it's talking about!

A 160-Meter Vertical

I have been planning on a beach-front 160-meter vertical for some property I have on Willapa Bay, WA, so I started with that model. While you probably wouldn't try to construct a full-size quarter-wave 160-meter vertical for a DXpedition, the computed results are very similar no matter what band you use with a beach-front vertical. The antenna I am planning will use four elevated radials and will be made of #13 wire. I was planning to use a wooden A-frame made from three Douglas fir trees (as shown in my *QEX* article[2]) to support the antenna. For modeling, the initial lengths of the radials and the vertical were made equal and adjusted for resonance at 1.840 MHz. I then progressively shortened the radials (keeping the vertical height the same) and re-resonated the antenna with a single series inductor feeding all four radials at the feed point.

An inductor Q of 250 was assumed and with a little care this should be readily achievable. In a salt atmosphere you must put the coil in a sealed enclosure, or by morning the Q will be close to zero. I modeled the base of the antenna at 1 foot and at 10 feet, and for comparison used three types of ground: perfect, seawater (ε = 80, the dielectric constant, and σ = 5.0 S/m, the conductivity) and average (ε = 13, σ = 0.005 S/m).

The results are shown in **Figs 1** and **2**. These graphs include both the ground loss and the loss due to the series resistance of the loading inductor. The small wire loss was not included. We can see from Fig 1 the advantage of seawater over average ground: about 4.2 dB more gain for full-length radials. In addition, the peak gain occurs at an elevation angle of 7° for seawater, as opposed to 21° for average ground. As the radial length is reduced the peak gain angle changes very little, but the peak gain goes down. The height of the radials over seawater made very little difference, and the difference between ideal ground and seawater was also very small. The primary difference over seawater is the added loss in the loading inductor.

While Fig 1 shows the peak gain, you can see the variation much better in Fig 2, where the *change* in gain is plotted. Even if you use radials only 40 feet long (0.07 λ!), over seawater the loss is less than 0.2 dB. This is very attractive for DXpeditions. The value of the loading inductor is very nearly the same for all the grounds and heights so that the loss due to the inductor's series resistance is pretty much the same at each radial length. Over average ground, however, the gain reduction is much larger due to in-

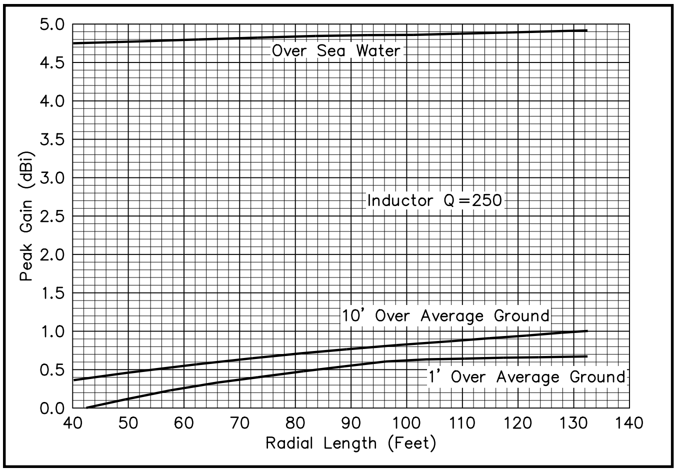

Fig 1—Peak gain for (λ/4-high vertical with four, coil-loaded short radials on 160 meters. The loading coil is assumed to have an unloaded Q of 250. Over seawater, the peak gain doesn't change much, even for quite short radials, while the gain is close to 5 dB less over ground with average conductivity and dielectric constant.

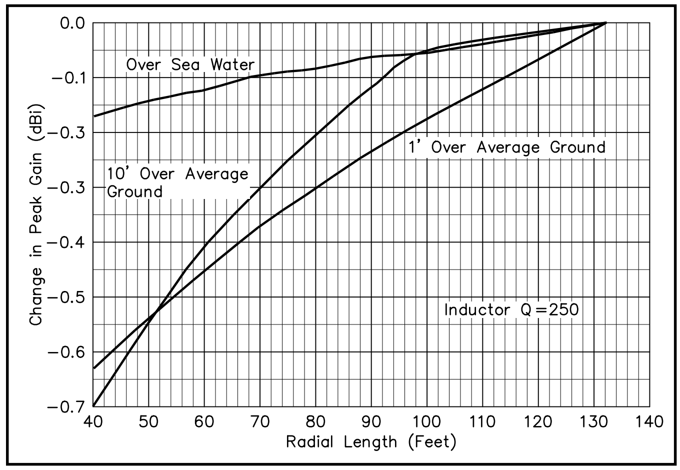

Fig 2—The same data presented in Fig 1, but magnified by showing the change in peak gain versus radial length on 160 meters.

creased ground losses as the radials are shortened.

At some sites the antenna may actually be over seawater, but it is more likely it will be up on the beach adjacent to seawater. How much effect will that have? That depends on two things: the beach's ground characteristics and the distance to the water. If the ground under the antenna is regularly flooded with seawater the conductivity is going to be pretty high. But that may not always be the case, and fairly poor ground characteristics may be encountered—especially on coral islands.

To check this out I modeled the 160-meter antenna site as though it were a circular island located in a sea of saltwater. The island was made up of ground with average conductivity and dielectric constant, and the distance to the saltwater was varied by changing the radius of the island. The results are shown in **Fig 3**. As soon as you move away from the water (that is, you have a larger-diameter island) the peak gain starts to drop and the increased ground loss due to shorter radials shows up.

The message is simple—select a nice salt marsh that is flooded twice a day, or put the antenna out on the reef with water under it! Otherwise, put the antenna as close to the water as practical.

Reducing Losses

We know that the losses due to use of a loading device such as a coil can be reduced by using a higher-Q coil, by moving a loading coil from the base of the antenna to a more optimum location up the vertical radiator, by top-loading or some combination of these.[3,4] For a $^1/_4$-λ vertical with shortened, loaded radials over seawater the ground losses are very small, and even the losses due to base loading of a shortened vertical radiator are small. It is questionable, therefore, whether it is worth the trouble to spend much time trying to minimize the loading loss, except for the case where a vertical's electrical height is much shorter than λ/4.

Unfortunately, short verticals with loading are often used for 80 and 160 meters. On those bands all of the tricks for minimizing losses will have to be used, because shortening the radials as well as the vertical itself can seriously degrade performance, even with a seawater ground.

I looked at modifying the ground plane to see if a more complex radial structure would help. Using eight radials, the difference in ground loss was insignificant. However, the additional radials did reduce the reactance needed to resonate the antenna by almost $^1/_2$. That would reduce the loading coil loss, since a smaller amount of inductance would be needed.

I then looked at tying the ends of the radials together with cross conductors to form a square wagon-wheel shape with four radials. Again, the ground losses were not reduced greatly (≈ 0.2 dB). There appears to be no substitute for long radials if you want that last fraction of a dBi in gain. We really have known this since the 1930s![5,6,7] The reactance, however, was greatly reduced and with the wagon-wheel structure the antenna is resonant—without loading—with a radius of 58 feet, less than half that for normal radials.

Given the fierce corrosion experienced over or near seawater, it would be a good idea to use insulated wire for the radials, some paint on the vertical tubing, conductive joint compound and very careful sealing of all joints and connections.

A Closer Look at Ground Losses

The increase in ground loss with shorter radials is worth a closer look. The additional loss shows up as an increase in feedpoint resistance over that for ideal ground. **Fig 4** is a graph of feedpoint resistance as a function of radial length, without the resistance of the loading inductor. Over seawater the effect of ground loss is very small. It's hard to see it on the graph. Over average ground, however, the effect is very obvious and the loss increases at lower heights.

When generating the data for Fig 3, I noticed that the feedpoint resistance was constant for different values of "island" radius. This is due to the way *NEC* computes impedance, where it takes into account only the first ground characteristic and assumes for this purpose that the ground under the antenna is infinite. For far-field calculations, however, the two ground zones (that is, the ground under the vertical and the seawater surrounding our model island) are taken into account. This means that the ground loss in the model, as reflected in the feedpoint resistance, may be higher than it actually is when close to the water.

NEC can provide a direct calculation of total ground losses using the so-called "RP" card. This card sets the parameters for radiation patterns and can provide a calculation of average gain. An example is given in the Appendix.

Conclusions

If you are lucky enough to be near or on seawater, you can drastically reduce the size of your elevated ground-plane. With a little

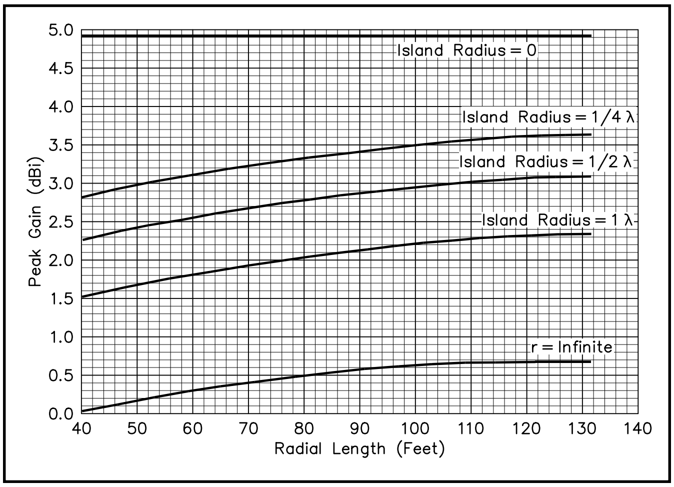

Fig 3—Peak gain for a (λ/4-high vertical with four, coil-loaded short radials on 160 meters, but this time where the antenna is located on a circular island in a saltwater ocean. Three different radial heights are shown over average ground. The radius of the circular island is equal to the length of the shortened radials in this model. Obviously, you should mount your antenna and radials over—or at least as close to—salt water, as you possibly can!

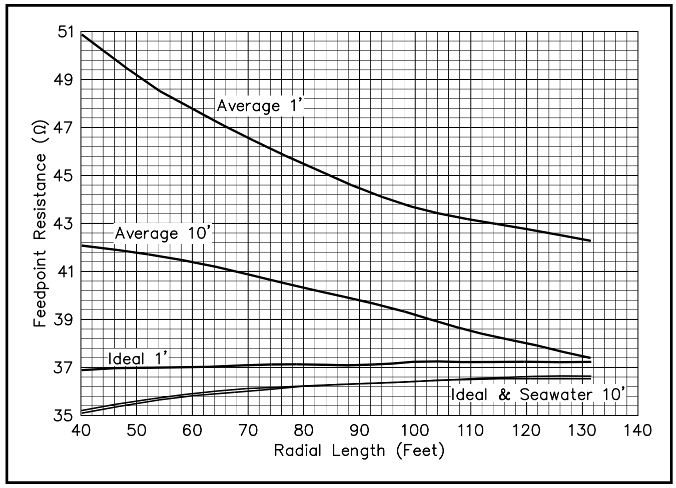

Fig 4—Feed-point resistance as a function of radial length and radial height above ground. Here, the loss resistance of the loading inductor is removed. The effect of ground loss over soil is large compared to that over salt water.

care, loss due to the loading components can be small, on the order of a few tenths of a dB. If you must place the antenna over poorer ground, such as the beach, you should try to get as close to the water as possible and keep the radius of the ground-plane radials greater than λ/8. You can, of course, use a smaller ground plane if you are willing to accept the reduced peak gain.

And here is another important consideration: Even with λ/4 radials, you should decouple the feed line from the antenna with a common-mode choke (balun). As the radials become shorter this becomes even more important, since the voltage between the base of the antenna and ground increases.

References

[1]D. Straw, N6BV, "Antennas Here Are Some Verticals on the Beach...," Elsewhere in this book.

[2]Rudy Severns, N6LF, "Another Way To Look at Vertical Antennas," *QEX*, Mar/Apr 1999.

[3]J. Belrose, VE3BLW, "Short Antennas for Mobile Operation," *QST*, Sep 1953; see also subsequent *ARRL Mobile Manuals*.

[4]B. Brown, W6TWW, "Optimum Design Of Short Coil-Loaded High-Frequency Mobile Antennas," *The ARRL Antenna Compendium, Vol 1* (Newington: ARRL, 1985), pp 108-115.

[5]G. Brown, "The Phase and Magnitude of Earth Currents near Radio Transmitting Antennas," *Proc IRE*, Feb 1935, Vol 23, No. 2, pp 168-182.

[6]Brown, Lewis and Epstein, "Ground Systems as a Factor In Antenna Efficiency," *Proc IRE*, Jun 1937, Vol 25, No. 6, pp 753-787.

[7]J. Devoldere, ON4UN, "Antennas and Techniques for Low-Band DXing," (Newington: ARRL, second edition 1994), Chapter 9, Fig 9-40 and supporting text.

[8]GNEC-4 Users Manual, Nittany Scientific, Airline Highway, Suite 361, Hollister, CA 95023.

[9]Gerald J. Burke, Numerical Electromagnetics Code—"NEC-4, Part I: Users Manual (NEC-4.1)," Lawrence Livermore National Laboratory, Jan 1992, UCRL-MA-109338 Pt I, pp 76-78.

Appendix

The average gain for a lossless antenna in free space is 1.0 (or 0 dBi). For a lossy antenna the average gain will be lower by the amount of the total loss. If you model using ideal conductors and lossless loads, then the reduction in average gain directly reflects the ground loss. Inserting the correct parameters for average gain can be a little tricky, however, until you get used to it. For example, when modeling an antenna over ground, instead of averaging over the surface of a sphere, the averaging is done over a hemisphere. Because the total power is radiated into only half as much space, the gain of a lossless antenna will be 2.0 (or 3.01 dBi).

You have to keep track of these things as you go along. As a check on my "card" entries (following the terminology for the FORTRAN-based NEC-4 software) when starting a new analysis, I make the ground perfect and the conductors lossless. I thus should get an average gain very near 1.0 or 2.0, depending whether I'm modeling in free space or over ground. If all is well, then I insert the real ground constants and proceed with the modeling.

The RP card has the following format:[8,9]

RP I1 I2 I3 I4 F1 F2 F3 F4 F5 F6

where:

I1 = Selects the mode of calculation; I1 = 0 for this example

I2 = Number of values of theta at which the field is to be calculated

I3 = Number of values of phi at which the field is to be calculated

I4 = An integer consisting of 4 digits (XNDA), each of which has a different function

X = Controls antenna output format; X = 1 for this example

N = Causes normalized gain to be printed; N = 0 for this example

D = Selects either power gain or directive gain; D = 0 for this example

A = requests calculation of average gain; A = 2 for this example

F1 = Initial theta angle

F2 = Initial phi angle

F3 = Increment for theta

F4 = Increment for phi

F5 and F6 are not needed for this example.

Greek letter θ (theta) is the angle measured from zenith (directly overhead) downward. For a free-space antenna, θ will vary from 0° to 180° and for an antenna over ground, the range is 0° to 90°. Greek letter ϕ (phi) is the angle moving counter-clockwise (viewed at the antenna from the X axis towards the Y axis) rotating around the Z axis. The range of ϕ is 0° to 360°. The number of values for theta (I2) and phi (I3) will be the range selected divided by the increment (F3 or F4) plus 1. The number of values must be an integer.

The number of increments of theta and phi must be large enough to cover the entire field, unless there are known symmetries that can be exploited to reduce the number of calculation points. For example, a free-space antenna will require a sphere, and an antenna over ground will require a hemisphere. For the case of an elevated-radial, ground-plane antenna with four radials, the field will repeat every 90° of phi. It is thus only necessary to compute one quadrant of the hemisphere. The accuracy of the averaging will depend on the number of points over which the gain is averaged. Fewer points mean less accuracy but much faster computation. The way you check your setup is to calculate the average gain for a lossless system, with perfect ground, no wire loss, etc. Under those perfect conditions the average gain ideally will be 1.0 or 2.0. The difference in the actual calculation is the error due to specification of overly coarse steps in the angles. The error in dB, for antennas over ground, can be expressed as error = 10 log (average gain/2). This gives the error directly in dB. Typically, I accept an error of 0.01 dB.

I usually start with 2° increments and go up or down after checking the lossless gain. The number of field points generated with $^1/_2$° increments can be quite large and noticeably slows the computation even on a workstation. This great a resolution will seldom be needed but you should always check an ideal version of the antenna model before proceeding with a real ground and lossy antenna.

In some cases where the field does not vary greatly with either θ or ϕ you can use larger increments in one plane to reduce the computation time. For example, with a four-radial ground-plane antenna, the field variation with ϕ, at a fixed θ, is quite small and usually needs only two values for ϕ—, that is, 0° and 90°. This greatly reduces the computation time. However, for a two-radial antenna, the pattern is asymmetrical and you must use smaller increments for ϕ.

A key point is to recognize that the number of points (I2 and I3) must be adjusted to give total coverage of the desired sector (sphere, hemisphere, or quadrant) when the increments (F2 and F3) are selected. Don't forget to include one extra point for the ends.

My RP card looks like this for one quadrant and 1° increments:

RP 0 91 91 1002 0 0 1 1

With four radials and only a small error this can be reduced to:

RP 0 91 2 1002 0 0 1 90

For an antenna over ground with a pattern symmetrical about the X axis:

RP 0 91 181 1002 0 0 1 1

The average gain will appear at the end of the output file in terms of absolute gain. You can convert it to dB by using 10 log (absolute gain) or 10 log (absolute gain/2).