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A Beginner's Guide to Modeling with *NEC*

Part 2: The Ins and Outs of Modeling

Last month we developed a basic understanding of what antenna modeling is, and became acquainted with some of the language of modeling. We also gained an orientation to the many parts of a good antenna model, including both the structure and its environment. This month we'll focus our attention on two fundamentals necessary to obtain reliable results from a *NEC* program. The first step is to grow comfortable with translating a physical array of wires or tubes into a set of dimensions that we can enter onto the coordinate system. The other basic element that we need to master is the selection and interpretation of the graphical outputs (the azimuth and elevation plots) from modeling programs. This installment cannot possibly say everything about both of these modeling fundamentals. However, we can hope to start you down a road toward working effectively on your own.

To save space throughout this series, we are limiting ourselves to modeling using the *NEC-2* calculating core, with illustrations from *EZNEC 3.0* and *NEC-Win Plus*. The figure captions will identify from which program the graphics have come.

Wires, Coordinates, and Conventions

One initial "mental block" to getting started in modeling is a certain discomfort with constructing antennas using the Cartesian coordinate system. Adopting a few conventions can dispel much of the uneasiness. By always (or nearly always) doing certain jobs in the same way, the system becomes more natural to use. There may be other equally good ways to do any job, but picking and sticking with one good way is the surest way to initial success.

Let's reacquaint ourselves with the coordinate system. In the horizontal plane, we can define any position—like the end of a wire that is part of an antenna element—by specifying a value for X and a value for Y. Z is the vertical dimension, corresponding to height, whether that is the height of the antenna structure itself or the height of the antenna above ground—or the sum of both in some cases.

When we set up an antenna model, we actually have many choices. We can set the model way over into high values of +X and +Y or into very negative values of each. Where the antenna is located in the coordinate system does not affect the accuracy of calculations. However, we want to strive for consistency, so let's set up the following conventions.

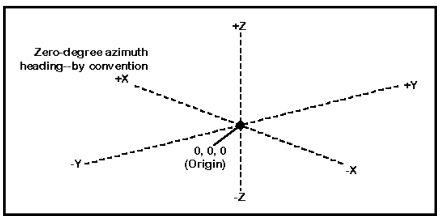

Figure 1—A "3-piece" dipole laid out on the coordinate system. The square indicates the location of the antenna source or feed point. The bold dots indicate a change from one component wire to the next in the overall element.

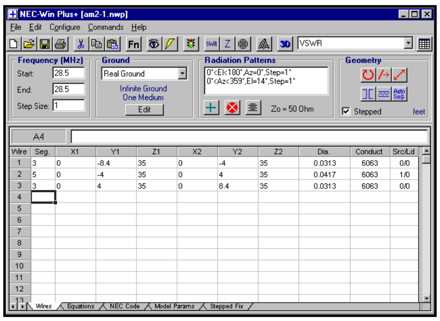

Figure 2—A *NEC-Win Plus* wire spreadsheet for the 3-piece dipole, showing the wire coordinates and other details of the model.

Convention 1: Wherever feasible, we'll split an element into equal parts on each side of a centerline. Therefore, an 8-foot element would have ends that are –4 and +4.

Convention 2: We'll use the Y-axis as the linear element axis. All linear elements will be on or parallel to the Y-axis. Our sample 8-foot element will therefore take values of Y=–4 and Y=+4 for its ends.

Convention 3: We'll use the X-axis for front-to-back dimensions. For single elements, we can use an X-value of zero.

Convention 4: The Z-axis will always indicate height.

Let's work our way through a few examples to see how the conventions work.

Example 1—A 3-piece dipole: Consider a 10-meter dipole (28.5 MHz) made up of two sizes of aluminum tubing ($^1/_2$ inch and $^3/_8$ inch diameters) placed 35 feet into the air. The center section will use the larger tubing. Even though we physically break the tubing in the middle to connect our feed line, we *do not* break the tubing in a model. Use a continuous piece and assign the source to its center. Let's make the centerpiece of half-inch tubing 8-feet long.

Each end of the dipole will consist of $^3/_8$-inch diameter pieces. We would place a bit of each tube inside the centerpiece in a real antenna. However, in a model, we are only concerned with the portion that shows. Let's make each visible end piece 4.4 feet long.

If we add up all the pieces, we have a total length of 16.8 feet for the entire element. It will consist of 3 "wires" or pieces. The next step is to place them into the wire spreadsheet. Although we might place them in any order and arrive at correct calculations, let's adopt one more convention.

Convention 5: We'll always work from the left end to the right end of any element. Left will normally mean a value more negative and right will mean a value more positive than whatever reference value we use. This convention will help us locate problems and read the modeling results in a consistent manner.

Now we are ready to determine the coordinates of the ends of each piece of wire. Set the units of measure for the program to feet.

1. Since there is only one element, all values of X will be zero.

2. Since the entire antenna is 35 feet in the air, all values of Z will be 35—assuming that we have selected "feet" as the unit of measure for the antenna.

The only thing left to do is to determine the Y-values. Figure 1 can help us in the task.

4. Since the entire antenna is 16.8 feet long, it will stretch 8.4 feet on either side of the centerline for the Y-axis. If we begin with the left end of the element (–Y2 in Figure 1), we assign the element tip a value of –8.4. The other end of this 3/8 inch piece is 4.4 feet more positive, which gives us –4.0 (for –Y1 in Figure 1). This gives us all of the values we need for the first wire (W1 in Figure 1). End 1 is X=0, Y=-8.4, Z=35. End 2 is X=0, Y=–4.0, Z=35.

5. Wire 2 is the 1/2-inch diameter center portion of the antenna. Since it connects to the second end of Wire 1, its End 1 coordinates are the same as Wire 1's End 2 coordinates. Since it is 8 feet long, then we add 8 to the –4 and arrive at a Y-value for End 2 of +4 (Y1 in Figure 1). Hence, Wire 2 coordinates are these: End 1—X=0, Y=–4.0, Z=35; End 2—X=0, Y=+4.0, Z=35.

6. Wire 3 is the far right tip of the element. Since it connects to the centerpiece, its End-1 coordinates are the same as the Wire 2 End-2 coordinates. The length of Wire 3 is 4.4 feet, which we add to the 4-foot position of the Wire 2 end. This gives us an End-2 Y-value of +8.4 for Wire 3's second end (Y2 in Figure 1). Hence, Wire 3 coordinates are these: End 1—X=0, Y=+4.0, Z=35; End 2—X=0, Y=+8.4, Z=35.

We have completely defined the element, despite its complex structure. Figure 2 shows the *NEC-Win Plus* wire entry spreadsheet for the element, where the X1, Y1, and Z1 columns represent End 1 values for each of the 3 wires. X2, Y2, and Z2 represent the end 2 values for each wire that composes our dipole element. We must add some other information to complete our model. Each line has an element diameter value. In *NEC-Win Plus*, this value is in the same units as the wire lengths, so we divide the diameters by 12 to get their values in feet. We chose aluminum for our material, and the "Conduct" (conductivity) column records 6063-type aluminum. (There are other types.) The "Src/Ld" column shows that we have a source on the center wire, and we'll assume that it has been correctly placed at the center of the wire.

Do not neglect the "Seg." column. We wish to have at least 10 segments per half-wavelength of element. A dipole is about a half-wavelength long, and the total number of segments is 11—within our specification. The center wire containing a source has an odd number of segments, meaning that the source segment can be precisely at the antenna's center. We may also note the frequency entry and the ground entry as fitting our original specification. We also note some radiation pattern requests that we'll explore a bit later. For now, we see a symmetrically specified dipole element composed of 3 wires.[1]

Example 2—A 3-element Yagi: Our second example will demonstrate the utility of adopting the convention by which we set elements symmetrically about a centerline. Consider a 3-element Yagi composed of 1/2-inch diameter elements throughout. This specification means that we'll have only one wire per element, but also that we'll have 3 elements. The Yagi will be for 6 meters, 51 MHz, to be more exact. We'll place the antenna at a height of 240 inches (20 feet).

This model will be in inches. The element lengths are these: Reflector—114.36 inches; Driver—108.96 inches; Director:—102.44 inches. To make sure that the shorter elements are inset at their ends by the same amount on both ends—relative to longer elements—we'll build each element symmetrically around the same centerline. By convention, the centerline is the X-axis, with each element being set up parallel to the Y-axis. Each Y-value for the positive and negative values will be half the total length: Reflector—57.18 inches; Driver—54.48 inches; Director—51.22 inches.

The following spacing separates the elements from each other: Reflector-to-driver space—37.8 inches; Driver-to-Director space—40.14 inches. How shall we place the elements along the X-axis? There are numerous schemes. Some modelers like to start with the reflector at X=0 and place all other elements ahead of this position with +X values. Some modelers like to take the entire distance from the reflector to the director and place the model symmetrically on the X-axis. We'll adopt for our starting convention a third popular convention:

Convention 6: Place the driver for any multi-element array at X=0. Place the reflector at a negative value of X that equals the driver-to-reflector spacing. Place all directors at positive values of X equal to the spacing from the driver to that director.

To keep the elements readily identifiable, we should also adopt a convention for the order in which they appear on the wire table.

Convention 7: Order the wires beginning with the reflector(s), the driver(s) and the director(s) for each self-contained array.

With these new conventions in mind, we can develop the values for our wire spreadsheet. Set the units to inches. Use Figure 3 as an aid.

1. Start with the driver, but make it Wire 2. X2 in Figure 3 will be 0. The values for Y (–Y2 and +Y2 in Figure 3) will be the half-length of the driver element. The value of Z for this and all other wires in this model will be 240.

2. The reflector (Wire 1) will have values for Y (–Y1 and +Y1 in Figure 3) that are the half-length of the reflector. Since the reflector is behind the driver, the value of X (–X1 in Figure 3) will be –37.8.

3. The director (Wire 3) will have values for Y (–Y3 and +Y3 in Figure 3) that are the half-length of the director. Since the reflector is ahead of the driver, the value of X (+X3 in Figure 3) will be +40.14.

The resulting wire spreadsheet, in *EZNEC* form, appears in Figure 4. Be sure to set all of the frequency, source, material, and radiation pattern values appropriately. By making the Y-values for each element symmetrical about a centerline, we align the model as the antenna would be aligned on its boom. By using a positive value for the director on the X-axis, we assure ourselves of a pattern where the forward lobe points at zero degrees on a standard azimuth pattern. In

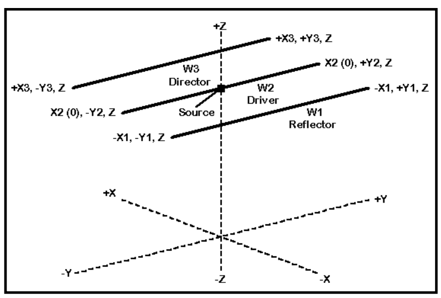

Figure 3—A 3-element Yagi laid out on the coordinate system.

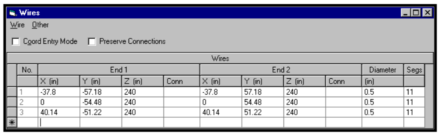

Figure 4—An *EZNEC* wire spreadsheet for the 3-element Yagi of example 2, showing the element end coordinates, wire diameter, and segmentation.

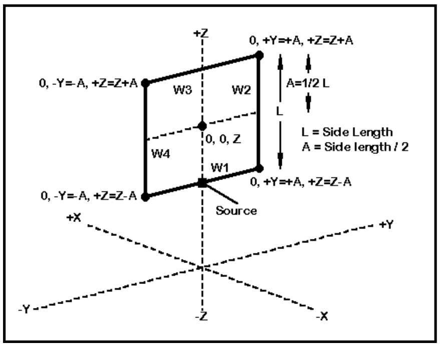

Figure 5—A single quad loop for 146 MHz laid out on the coordinate system.

the end, each convention that we adopt and use consistently contributes to being able easily to sort out the components and have reasonable expectations about the results.

Example 3—A single quad loop: So far, we have dealt with antennas that extend their structures only in the X and Y plane. Let's look at a quad loop in order to become comfortable dealing with antennas that extend into the Z dimension. We'll model a single quad loop for 146 MHz that is set up for broadside operation—where the main signal strength comes off each side of the plane of the loop. The loop will be about 87.04 inches in circumference, which makes it about 21.76 inches per side. The loop will use standard insulated spider construction (which means that we do not model the support arms). The center hub will be 20 feet or 240 inches off the ground.

First, the value of X for this model will be zero throughout. The loop wires will extend along the Y-axis and parallel to the Z-axis. However, the model opens up two questions about loop construction that we can answer with new conventions and with the aid of Figure 5.

Convention 8: Model a loop as a continuous series of wires such that End 2 of Wire 1 is also End 1 of Wire 2, etc.

Convention 9: Model the loop with Z initially equal to zero, and later add the "hub" height to each value of Z in the model.

As Figure 5 shows, the two conventions give us an orderly progression of development and a technique for specifying the dimensions. Since the length (L) of a side is 21.76 inches, the values of +Y and –Y will be half the side length—or A=10.88 inches. Initially, we'll also use the value of A for +Z and for –Z, that is, 10.88 inches.

1. Assign values for Y and for Z for each end of each wire (in order), using the half-length of the side, referring to Figure 5 for guidance. Wire 1, for instance will have the following values: End 1—X=0, Y=–10.88, Z=–10.88; End 2—X=0, Y=+10.88; Z=–10.88. Wire 2 will have these values: End 1—X=0, Y=+10.88, Z=–10.88; End 2—X=0, Y=+10.88; Z=+10.88. Wire 3 will have these values: End 1—X=0, Y=+10.88, Z=+10.88; End 2—X=0, Y=–10.88; Z=+10.88. Wire 4 will have these values: End 1—X=0, Y=–10.88, Z=+10.88; End 2—X=0, Y=–10.88; Z=–10.88.

2. Add the "hub" value of Z to the values developed to arrive at the final dimensions. The new values for Z alone will be as follows: Wire 1, End 1—Z=229.12, End 2—Z=229.12; Wire 2, End 1—Z=229.12, End 2—Z=250.88; Wire 3, End 1—Z=250.88, End 2—Z=250.88; Wire 4, End 1—Z=250.88, End 2—Z=229.12.

The values, plus the other model setup data, appears on the wire spreadsheet in *NEC*-Win form in Figure 6.[2]

By combining the conventions and techniques we have shown here, you should be able comfortably to model virtually any single antenna array, no matter how many elements or which way they point. However, the task requires an orderly procedure in each case. Very often, it is more efficient to do all of the preliminary work of setting the wire end coordinates on paper.[3]

Patterns, Patterns, and More Patterns

Once the model is satisfactory, our next inclination is to race through setting the other necessary parameters, run the model, and see what the pattern looks like. In this episode, I shall race with you, bypassing for the moment all of those less exciting but vital features. We'll land upon a potentially confusing set of graphical outputs. My aim will be to see if we cannot make a little initial good sense out of them.

Let's begin our adventure in free space. Among the ground options, we'll find a label that reads either "Free Space" or "No Ground." Setting the option here places the antenna in what amounts to outer space with nothing to reflect the radiation except possibly the elements themselves. In some programs, the radiation pattern itself is automatically set for

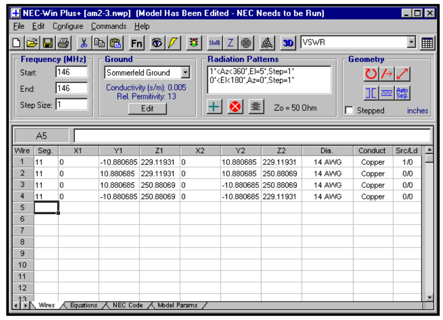

Figure 6—A *NEC-Win Plus* wire spreadsheet for the 2-meter quad loop, showing the wire coordinates and other details of the model.

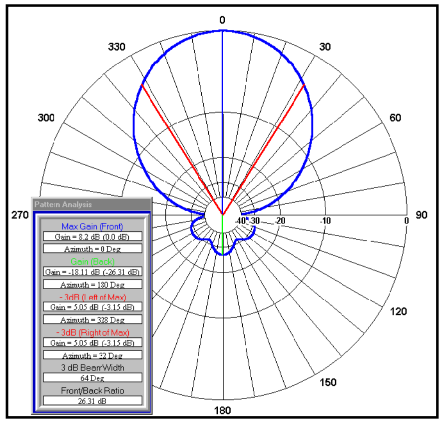

Figure 7—A *NEC-Win Plus* free-space azimuth pattern for the 3-element 6-meter Yagi.

full 360-degree patterns in both the azimuth and the elevation directions. However, other programs require the user to enter the start and stop degree numbers, along with increment between steps in the pattern tracing. The pattern itself is graphically developed outside the *NEC* core by simply connecting the dots that form the *NEC* data points. Hence, the smaller the increment, the smoother the pattern outline. One degree usually suffices for HF antennas at all reasonable heights, while 0.1 degree is sufficient for most VHF and UHF antennas.

The two most fundamental ways to get free-space patterns is to take azimuth and elevation patterns at zero-degrees, that is, along the X and along the Z axes. Figure 7 shows a *NEC-Win Plus* azimuth pattern, along with its analysis box. We may note the free-space gain as a rough measure of the antenna design quality, along with the front-to-back ratio, a measure of rearward QRM suppression. Equally notable is the -3 dB or half-power beamwidth (64°) of the antenna in the horizontal plane.

The elevation plot (Figure 8) of the antenna in free space comes from *EZNEC* and also includes the available analytic data. Note that the gain and front-to-back ratio are identical to those in the azimuth plot, despite the difference of programs. Both use *NEC*-2 calculating cores and hence, both will yield numbers that are coincident or very close to coincident. Most notable is the –3 dB beamwidth in the vertical plane, which is over 98° between half-power points.

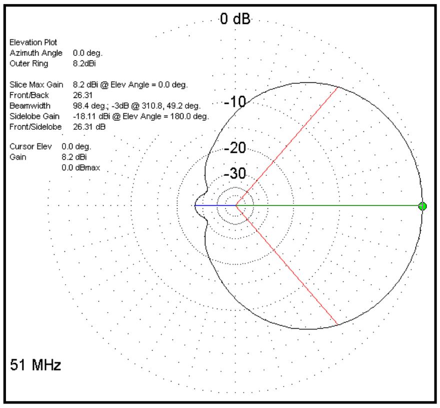

Figure 8—An *EZNEC* free-space elevation pattern for the 3-element 6-meter Yagi.

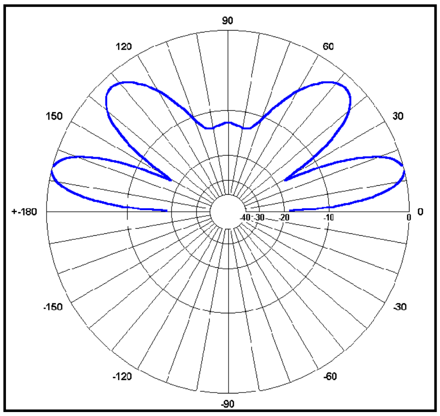

Figure 9—A *NEC-Win Plus* elevation pattern for the 10-meter dipole 1 wavelength above ground.

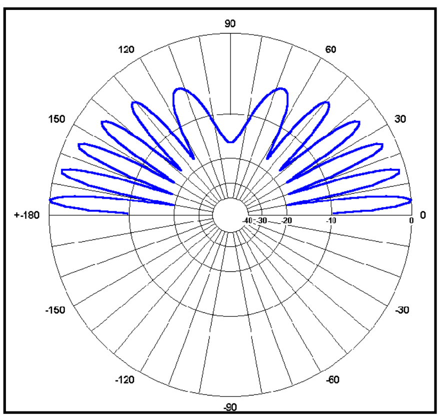

Figure 10—A *NEC-Win Plus* elevation pattern for the 2-meter quad loop 4.1 wavelengths above ground.

Our real antennas, of course, have a ground beneath them that plays a role in the reflection of signals. So let's move from free space back to our Sommerfeld-Norton ground. For all of the horizontal antennas that we'll look at in this episode, we will choose average ground with a conductivity of 0.005 S/m and a relative dielectric constant (permittivity) of 13. Changes in the ground constant values have only small effects on the performance of horizontal antennas, so using "average" ground will work nicely for most beginning analyses.

We'll begin with the 3-piece dipole that we modeled at 28.5 MHz. The antenna has a height of 35 feet, about 1 wavelength above ground. Let us take an elevation pattern, shown in Figure 9, a *NEC-Win Plus* graphic. Note that the pattern now breaks into lobes and nulls, that is, stronger and weaker directions of radiation as calculated for various elevation angles. Compare Figure 9 to Figure 10, an elevation pattern for the 2-meter quad loop that became our third case study of model construction. The quad loop elevation pattern has broken into many lobes and nulls, with the lowest one very near the horizon.

The key difference between the two antennas is not their shapes, but their heights. Height is not measured in feet or inches in this case. In fact, the quad loop is only at 30 feet hub height, whereas the dipole is 35 feet up. Instead, we measure height in terms of wavelength. The 10-meter dipole is 1 wavelength up, while the quad loop is about 4.1 wavelengths high. The higher the antenna in wavelengths, the more lobes and nulls to its elevation pattern.[4]

Let's return to the Yagi that we left in free space. Remember that the 6-meter antenna is 20 feet or 240 inches above the ground. Let's look at a 3-D pattern of the antenna above ground. Figure 11 provides the view in *EZNEC* form. Allowing for the blunting of the curves by virtue of the larger sampling increment, we still see an amazing pattern. It bears some resemblance to the dipole by virtue of having two main elevation lobes. The 2-lobe pattern results from the antenna height, which is close to 1 wavelength above ground. However, almost all of the energy is displaced along the X-axis forward of the antenna structure. In contrast, the dipole had equal amounts of energy in both directions broadside to the wire along the X-axis.

We can refine our view of the antenna pattern by calling for a 2-D elevation pattern. The *EZNEC* elevation pattern in Figure 12 smooths the lobe shapes by using a 1-degree increment between data points. As well, the rear lobes that had been obscured under a mass of 3-D close-spaced lines are now clear. An elevation pattern over ground provides other significant information, for example, the vertical beamwidth and the elevation angle of maximum radiation—the "take-off" angle. In reality, of course, terrain features may modify the actual take-off angle.

Although the elevation pattern for our Yagi has changed radically in the move from free space to a position over the ground, the azimuth pattern does not change shape appreciably for horizontal antennas. Compare Figure 7 with Figure 13, the azimuth pattern for the Yagi at a 13-degree elevation angle over average earth. The pattern shapes are virtually identical, even to the 64-degree –3 dB (half-power) beamwidth. What has changed is the forward gain of the antenna. It now records 13.35 dBi, compared to 8.2 dBi in free space: a 5.15 dB pick-up due to ground reflections. But remember that the forward lobe of the antenna in the free-space elevation pattern was smooth. Over ground, the added power in the main

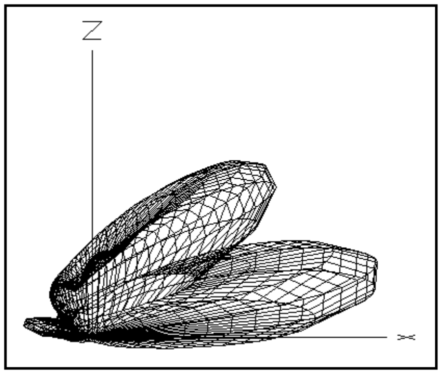

Figure 11—An *EZNEC* 3-D radiation pattern for the 3-element 6-meter Yagi 1 wavelength above ground.

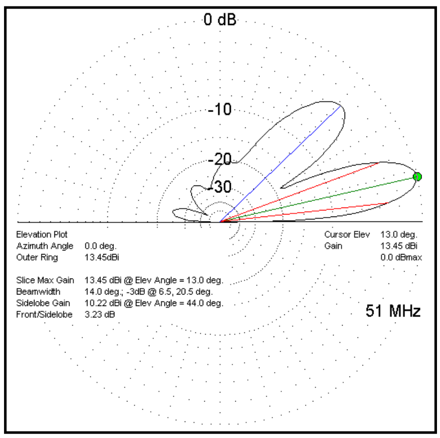

Figure 12—An *EZNEC* elevation pattern for the 3-element 6-meter Yagi 1 wavelength above ground.

lobes, of course, is offset by the reductions in power in the null areas.

NEC measures all pattern gain figures in dBi, which is decibels over an isotropic source. Since *NEC* has no built-in antenna range on which to use a real antenna standard for comparisons, it uses a mathematical standard. The isotropic radiator is defined as one radiating equally well in all directions (relative to a sphere that theoretically surrounds it). It is up to the individual modeler to make comparisons among antennas in order to figure out, for example, how much more gain the Yagi has than a dipole in the same setting.

By systematic modeling and comparisons, *NEC* yields useful information to us, information that might not arise by more haphazard methods and approaches. However, gain, front-to-back ratios, and beamwidths are not the only information that we can systematically develop with a modeling program. Now that we can model almost anything we wish, it is time to refine our modeling further. Next month, we'll explore some of the mysteries of sources, grounds, and frequency sweeps in an effort to clean up some relevant details.

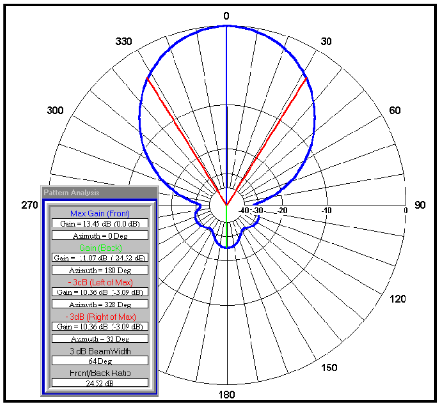

Figure 13—A *NEC-Win Plus* azimuth pattern for the 3-element 6-meter Yagi 1 wavelength above ground at a 13-degree elevation angle.

Notes

[1]Those who wish to experiment with their modeling software might wish to perform the following investigation. I noted that the model may be placed anywhere within the plane of the X and Y coordinate system (leaving Z as a constant) and that it would yield the same results. Here is a 3-step process to verify this note.

1. Change all values of X by the same amount (for example, changing all Xs to +36 or to –95).
2. Change all values of Y by adding the same amount (for example, adding +27 or –105).
3. Combine the changes of both X and Y. For each change, run the model and check the radiation pattern and source impedance.

[2]There are ways to simplify quad loop construction available to the user of either *EZNEC* or *NEC-Win Plus*. In *EZNEC*, there is a provision for changing the antenna height, a means of altering all of the values of Z simultaneously. The easiest way to change the dimensions of a quad loop is to determine the center or hub height in advance. Then construct the modeling using values of +A and –A (as defined in the text) to make up the loop. Finally, change the height by the value predetermined for the hub. The upper and lower wires will then be properly placed above and below this height. To alter the coordinates, reduce the height by the hub value, which places the loop center back at zero. Then enter the new values of –A and +A, and change the height back to its raised hub value again.

In *NEC-Win Plus*, there is a "model-by-equation" facility within which we can define the values of A and of the hub height (which we might call B). On the wire entry page, we then enter –A, +A, –A+B, and +A+B for the loop corner positions in the appropriate boxes on the spreadsheet. We can then change the dimensions (or the height) of the antenna simply by changing the value of the variables. Those interested in modeling by equation are invited to look at a four-part tutorial that appeared in the May through August editions of *AntenneX* (**www.antennex.com**) and which is available even to non-subscribers. Alternatively, the 4 parts are also at my site as columns 27 through 30 in the "Antenna Modeling" series (**www.cebik.com**).

[3]A form suitable for model planning (with front and back sheets) can be downloaded from the ARRL Web site in Adobe PDF format at **www.arrl.org/notes/qst/am2-f.pdf**.

[4]We can estimate the number and angle of the lobes for most horizontal antennas from the antenna height alone.

$$\theta = \arcsin \frac{A}{4h} \qquad \text{(Eq 1)}$$

where θ is the angle for a particular lobe, and h is the antenna height in wavelengths. An "arc sin" value means to use the inverse and then the sine button on your calculator. To find the angle of a lobe, use odd numbers for succeeding lobes, where 1 is the first lobe, 3 is the second lobe, etc. For nulls, use even numbers for A, where 2 is the first null, 4 is the second, etc. Of course, you reach the total number of lobes when the angle approaches or reaches 90 degrees.

Since the 10-meter dipole is 1 wavelength up, its first lobe is at about 14 degrees and its second is about 48 degrees up. For the 2-meter quad loop, the first lobe is about 3.5 degrees up, while the second is about 11 degrees. These estimates are more accurately calculated by the *NEC* core, so the numbers it yields would take precedent over estimates.

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