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A Beginner's Guide to Modeling With NEC

Part 3—Sources, grounds and sweeps

Once we progress beyond the construction of models and the interpretation of plot patterns, our next set of quandaries revolves around obtaining the best possible results from *NEC* modeling. This month we'll work with three clusters of ideas: the placement of sources, the selection of a ground—including making ground-plane radials—and using frequency sweeps productively. My selection of topics stems from the number of questions I receive from new modelers. These notes will not answer all of them, but perhaps they will promote some useful ways of thinking about sources, grounds, and sweeps in models. As always, we'll stick to *NEC-2*, using both *EZNEC* and *NEC-Win Plus* as our sample programs.

Sources: Where and Why?

Finding the source impedance of an antenna is vital. It gives us a good idea of whether to lengthen or shorten an element if we are aiming for resonance or for a specific reactance needed for a matching network. In nonresonant antennas, the source impedance, when combined with the transmission line we propose to use, can tell us something about the conditions our antenna tuners might see at their terminals.[1]

All of the examples in the preceding installments used a single source or feedpoint located at the center of the driven element. Hence, we needed only to use an odd number of segments on the wire containing the source and specify either the 50% mark or the number of the center segment as the source position. Life was easy, as shown by the "Source 1" designations in Figure 1.

However, not all antennas use a center feedpoint, as evidenced by the entire collection of antennas that we call "OCFs" or off-center-feedpoint antennas. Many of these antennas call for a specific distance either from the wire end or from the antenna center for the source position. As the upper portion of Figure 1 shows, if we use only the minimum number of segments per half wavelength for our wire, we do not stand a chance of placing the source close to the desired position.

The solution is simple: use many segments. It is not unreasonable or problematical to use 101 segments for a model of an OCF antenna that is a half-wavelength long. Suppose that a certain OCF design calls for a feedpoint position that is 14% of the distance from the center outward toward the end of the antenna. This is 86% of the distance from the end of the antenna to the center or 43% of the total distance from one end of the wire to the other. If we specify 101 total segments and place the source on segment 44, it will be 43.1% of the distance from the left end of the wire.

Having enough segments in a model to make fine movements of the source position can come in handy. Suppose that

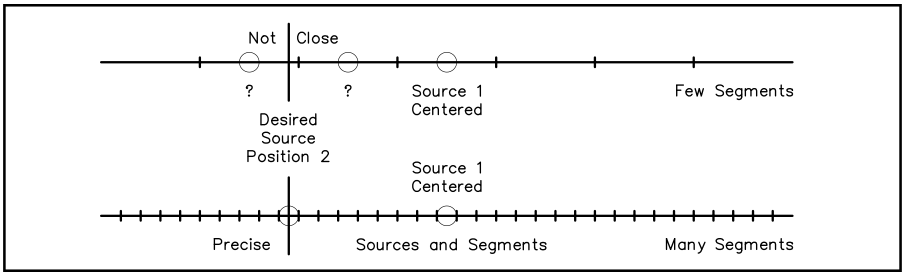

Figure 1—A comparison of low-segment density and high segment density with respect to precisely locating a desired source position.

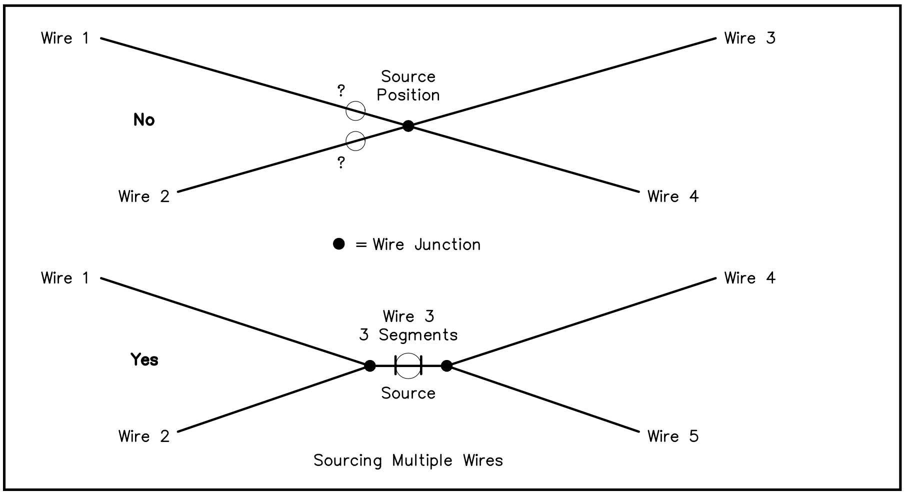

Figure 2—Incorrect and correct ways to model multiple elements with a common feedpoint, using a combined 20-meter and 15-meter dipole.

[1] Notes appear on page 48.

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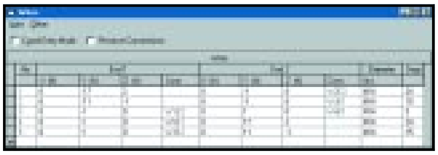


Figure 3—The *EZNEC* wires page for the correct model of the 20-meter and 15-meter combined dipole antenna.

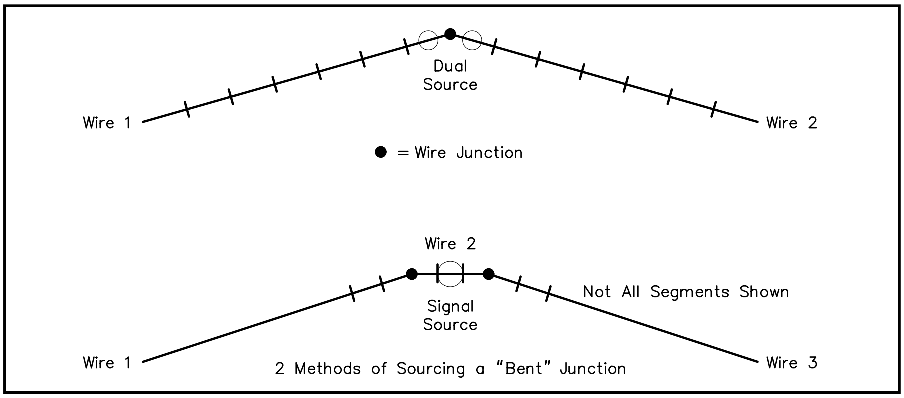


Figure 4—Two methods of modeling an inverted V (and similar elements) in order to obtain a correct source impedance value.

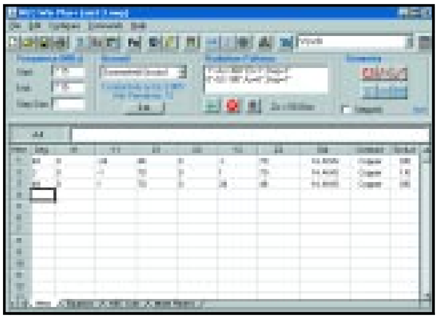


Figure 5—The *NEC-Win Plus* wires page for the 3-wire version of the inverted V.

Table 1

Source Impedance Values for Crossing Dipoles Using an Over-Simplified Model and a Model With a Common Center Wire.

Source Placement:	14.175 MHz Impedance R +/– *j*X Ω	21.225 MHz Impedance R +/– *j*X Ω
Simple Crossed Wire Model		
On 20-meter wire	98.9 + *j*18.5	151.4 + *j*268.0
On 15-meter wire	16.8 – *j*346.1	35.9 – *j*102.7
Central Source Wire Model		
Centered on common wire	57.8 + *j*45.9	111.5 – *j*780.2

we are looking for the point along the wire that yields an impedance closest to 300 Ω. As we move out from the center point, we'll discover that the rate of change of source impedance per segment becomes ever greater. However, with enough segments, we can pinpoint quite closely the 300-Ω feedpoint impedance position.

Antennas very often are not quite so electrically simple as they seem to be from their physical appearance. One common type of antenna combines dipoles for two different band with a common feedpoint, for example 20 and 15 meters. The quick way of picturing this kind of antenna appears in the top sketch in Figure 2. We bring 4 wires together and join them at the center. Now we have the significant question: where do we place the source? We have essentially 2 choices: on the first segment adjacent to the junction on the 20-meter wire or on the corresponding position on the 15-meter wire. Table 1 gives us the source impedance values that we get for 14.175 MHz and for 21.225 MHz for each position for the model.

Which set of values is close to correct? We can't tell. In fact, neither set is accurate. Let's reform the model to match the bottom part of Figure 2. We'll bring the left ends of the 20-meter and the 15-meter elements to a common point that is shy of center. Then, we'll create a short, 3-segment wire that is centered. The right sides of each band's element moves from the junction point on the right of the center wire outward toward the ends. Figure 3 shows the model on the *EZNEC* Wires page.

The reason that the center wire (#3) has 3 segments is that we should always keep the current levels on either side of a source segment as equal as possible. The 3-segment source wire provides a simple solution to this need. Since the source wire is 2 feet long, each segment is about 8 inches long. The remainders of the element wires use lengths approximately equivalent to this value. With these precautions, we can now find the source impedances for the two frequencies on which the antenna operates. As Table 1 shows, the 20-meter wires are just a bit long, but the 15-meter wires are well short of resonant length. Try revising the end values for the 20-meter element to 16.0 and for the 15-meter element to 12.45 (both in feet, of course). Note how changes in the 20-meter wire lengths create large changes in the 15-meter source impedance, while changes in the 15-meter wires have smaller effects on the 20-meter source impedance.

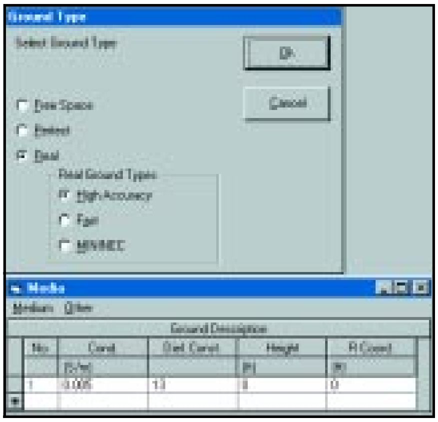
Another common antenna, the inverted **V**, lets us demonstrate that sometimes we can use more than one sourcing technique to arrive at the same goal. Figure 4 shows two ways to model an inverted **V**—and by extension, any other antenna where single elements approach the feedpoint at an angle other than 180-degrees. The top version of the **V** shows the use of a dual source on the segments immediately adjacent to the junction. (Note that this example differs from the preceding one by using only a single element for one band.) Since the source impedance changes very slowly in the center area of a resonant $^1/_2$-wavelength antenna, the two sources together will closely approximate the source impedance at the exact center. For example, *NEC-Win Plus* reads each of the two values as 22.1 – *j*8.1 Ω. The actual source impedance is the sum of the two, adding the resistance and reactance separately: 44.2 – 16.2 Ω. (*EZNEC* has a "split" source option that automatically places the second source on the adjacent segment and which also does the addition for us: the result for the same model is a source impedance of 44.3 – *j*16.5 Ω.)

Alternatively, we can use the short 3-segment source wire technique so that we can place a single source. The bottom of Figure 4 shows the principle, which adds one wire to the model. Figure 5 gives us the NEC-Win Plus wires page, which also shows that once more, we have kept the segment length in the sloping wires about the same as in the center source wire. The impedance numbers yielded by this model are 44.2 + *j*3.6 Ω. The very slight difference in reactance is a result of our having added a tiny amount to the overall length of the wire by adding the source wire.

These sourcing techniques should let us handle with ease most of the antenna geometries that we might encounter.[2] So let our eyes drop to the ground for a while.

Grounds and Ground Planes

We have noted two of the types of ground permitted with *NEC* in past episodes: free-space (also referred to as "no ground") and the Sommerfeld-Norton high accuracy ground. Free-space, of course, eliminates the reflecting surface



Select Ground Type

○ Free Space
○ Perfect
● Real

Real Ground Types
● High Accuracy
○ Fast
○ MININEC

Ground Description				
No.	Cond.	Diel. Const	Height	R Coord
	(S/m)		(m)	(m)
1	0.005	13	0	0

Figure 6—The *EZNEC Windows* boxes for selecting the ground type and for supplying the values for the conductivity and the dielectric constant.

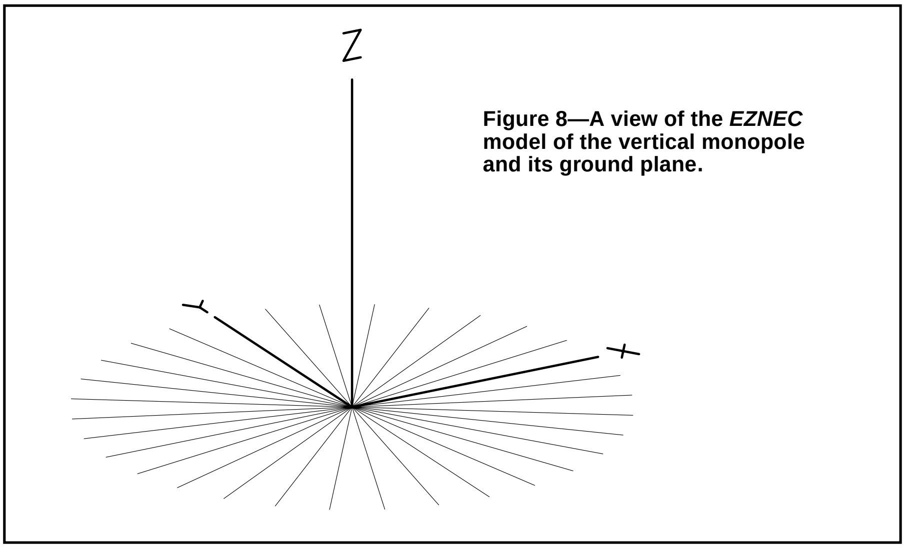


Figure 8—A view of the *EZNEC* model of the vertical monopole and its ground plane.

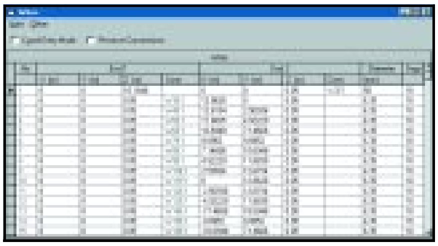


Figure 7—A partial *EZNEC* wires page for a 40-meter vertical monopole with a 32-element ground plane system.

Table 2

Commonly Used Soil Quality Designations and their Corresponding Values of Conductivity and Permittivity

Type	*Conductivity (Siemens/meter)*	*Permittivity (dielectric constant)*
Very Poor	0.001	5
Poor	0.002	12
Average/Good	0.005	13
Very Good	0.0303	20
Salt Water	5.0	81

that we call ground so that antennas have a limitless sphere for their expanding radiation patterns.

Actually, *NEC* provides 3 types of ground, shown in Figure 6, the *EZNEC* boxes for both ground type and value. "Perfect" ground is sometimes useful for preliminary modeling of vertical antennas that touch the ground—akin to using free space for highly elevated antennas. The "real" ground possibilities include the fast or "reflection-coefficient" ground—which is inaccurate below about 0.1 wavelength antenna height—and the preferred Sommerfeld-Norton ground, which is accurate down to about 0.001 wavelength of antenna element height. (*EZNEC* provides the NEC-user with the *MININEC* ground system, but it has limited use for most modelers.) Modern fast computers let us zero in on the high accuracy ground for all of our work that places the antenna over earth.

Since all of our models so far have been horizontal, we have simply used the program default "average" ground values. However, as modeling becomes more serious or if we have a vertical antenna, it becomes increasingly important to select ground values that most closely approximate the conditions for the antenna we propose to build. Table 2 provides a short list of commonly used values, and a listing in *The ARRL Antenna Book* supplies many more.[3] However, looking up local values or testing one's own ground is always more precise than a table of general values. For most hams, measuring conductivity is usually more feasible than measuring the soil dielectric constant.

The two numbers—conductivity in Siemens per meter and the relative dielectric constant (permittivity—no units)—together combine in engineering equations for the calculation of the effects of ground on antenna radiation, both in terms of reflections and of losses. However, *NEC* ground calculations presume a uniform soil beneath the antenna. At lower HF frequencies and below, the stratified nature of the soil beneath the antenna and its more distant area where the fields are reflected may play a role in advanced modeling. For the beginner, selecting one of the standard categories usually suffices for reasonable accuracy.

There is a second type of ground important to modelers, the radial ground plane we establish beneath our vertical antennas. Although we commonly place the radial wires either directly on the ground or slightly beneath the surface, *NEC* cannot model any wire on or under the ground. However, for a close approximation of ground plane action, we can construct a model of a radial system very close to the ground. The normal limit of close approach is about 0.001 wavelength, which amounts to under 2 inches at 40 meters. Some modelers have successfully experimented with ground planes as low as 0.0001 wavelength above the surface, although in every case, we must allow for the radius of the ground plane wire. The surface of the wire should not touch the ground.

Fortunately, both *EZNEC* and *NEC-Win Plus* include automated radial makers. We need only specify the center point, the number of radials, the number of segments per wire, and the wire diameter. (Some programs require that you set up the first radial and then the others become copies spaced the correct number of degrees apart.)

Figure 7 shows the first 14 radials (plus the vertical 40-meter antenna) of a 32-radial system. We could, of course, calculate the end coordinates of each radial with a little sine and cosine work from trigonometry, but the automated radial maker is much faster. In general, one should limit the number of junctions at a single point to about 30, since *NEC* can become less accurate as the angle between wires at a junction becomes too small. However, the rate of error increase is small and *NEC* appears to handle 32-radial systems with ease.

The radials in Figure 7 are dimensioned in meters (with the wire size in millimeters). The height of the radial sys-

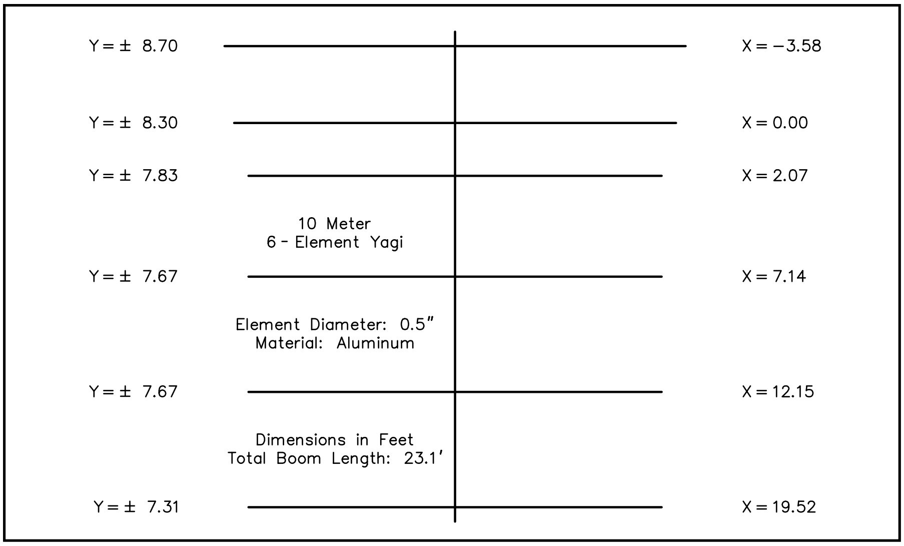


Figure 9—An outline sketch of a 6-element Yagi used in the frequency sweep exercise.

Table 3

A Summary Table of Modeling Results from a 28 to 29 MHz Frequency Sweep of a 6-Element Yagi *NEC* Model

Frequency (MHz)	*Gain (dBi)*	*Front-to-Back Ratio(dB)*	*Source Impedance*	*50-Ω VSWR*
28.0	9.95	18.4	33 – *j* 6	1.54
28.1	9.98	19.9	35 – *j* 4	1.44
28.2	10.01	21.4	37 – *j* 2	1.36
28.3	10.04	22.9	39 – *j* 0	1.30
28.4	10.08	24.5	40 + *j* 2	1.25
28.5	10.11	25.8	42 + *j* 3	1.22
28.6	10.14	26.4	43 + *j* 5	1.19
28.7	10.16	26.1	45 + *j* 6	1.18
28.8	10.19	25.2	46 + *j* 6	1.17
28.9	10.21	23.9	48 + *j* 7	1.15
29.0	10.22	22.7	49 + *j* 6	1.13

tem is 0.05 m or 50 mm, which is just under 2 inches. I have used these dimensions as an alert: you will undoubtedly encounter models in both metric and in English units, so gaining some facility in translating between the two systems is very useful to every modeler.

Figure 8 is a view of the overall antenna model, showing the 1/4-wavelength vertical element along the Z-axis together with all 32 1/4-wavelength radials. Each wire has 10 segments, with the source segment being the lowest one on the antenna wire. The model's 330 total segments may seem large, but on modern PCs, the run time is quite fast. If your program permits the model size, you might wish to increase the number of segments per wire by a factor of 1.5 to 2. The resulting model would place the source a bit closer to the radial junction to improve the precision of the output.

We have chosen a complex radial system as our example, although much modeling will be done with simpler systems. Many upper HF models will use as few as 4 radials elevated far above ground. However, once you master the radial-maker in your program, as well as the limiting conditions that we have noted, then no radial system will be too complex to model.

Frequency Sweeps: Why and How?

One of the initial tendencies of most modelers is to model for perfection at a specific design frequency. For example, if we model a Yagi, we try to arrive at the maximum possible gain, the highest front-to-back ratio and resonance—all on one frequency. We then sometimes mistakenly think that our work is done.

However, amateur antennas only rarely are used at a single frequency. Instead, we normally use them across a band of frequencies, such as all of 20 meters or the first MHz of 10 meters. The modeler's work is not complete until the antenna is checked and analyzed at reasonably close spot frequencies across the band of use. Fortunately, *NEC* is designed for "frequency sweeping."

How we sweep and what a sweep might tell us can be illustrated with a single model, shown in outline form in Figure 9.

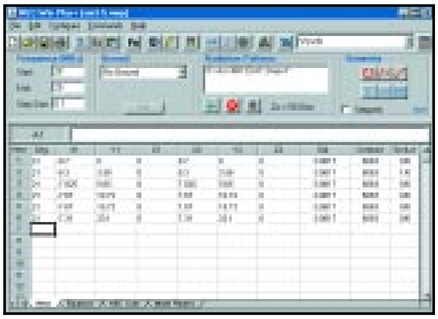


Figure 10—The *NEC-Win Plus* wires page showing the set-up of the 6-element Yagi model along with frequency sweep data.

The 6-element high performance Yagi looks more complex in the sketch than its models looks in Figure 10, a *NEC-Win Plus* main page. Here, we see all 6 elements, their diameter (in feet), their aluminum material, and the source located on the second or driven element. If we look to the top of the page, we see that the model will be run in free space, with only a simply azimuth pattern chosen. *NEC's* output tables will produce all data for each frequency swept, including the source impedance (and the program's calculation of the 50-Ω SWR), the currents on each element segment, and the radiation pattern values used in the output plot.

How we set up the sweep is shown in the upper left corner of Figure 10. We select a start and stop frequency, as well as an increment. In this case, we'll obtain all values for the range of 28 to 29 MHz at 0.1 MHz increments. (Interestingly, this system has resulted from user preference. Raw NEC actually specifies a start frequency, the number of steps to be swept, and the increment of increase for each step. Commercial implementations make the transition from user-input to NEC core invisible.)

If we run the sweep, then we can obtain a truly overwhelming volume of data. Most users reduce the volume to a set of select values. Most commonly gleaned are the gain, the 180° front-to-back ratio, the source impedance, and the SWR relative to a user-preset standard. Occasionally, we might add the –3 dB beamwidth to the collection, and sometimes the currents along the element may be important. However, in the beginning, the data in Table 3 will satisfy most requirements.

Note that in the table, I have recorded values in different levels of precision, some with more operational significance than others. For example, no one can tell the difference on the air between 9.95 and 9.98 dBi free-space gain. However, in making up tables from *NEC* output data, it is often useful to use the level of numerical precision that shows most clearly

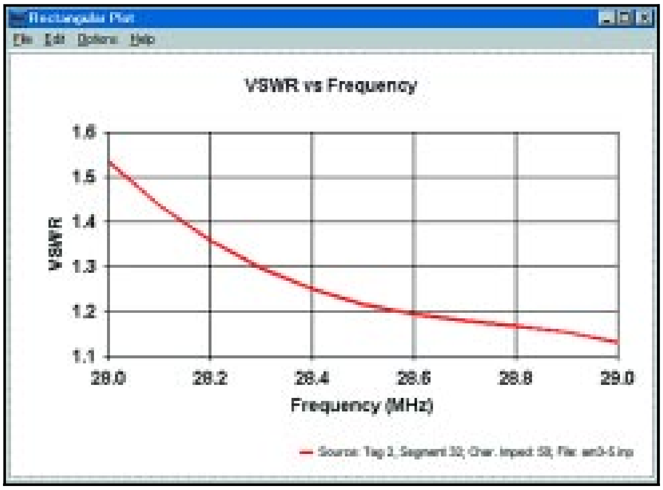


Figure 11—A *NEC-Win Plus* 50-Ω SWR plot from 28 to 29 MHz for the 6-element Yagi.

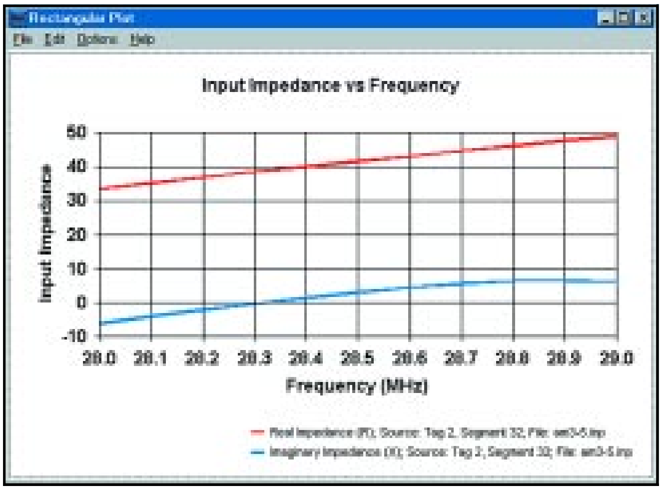


Figure 12—A *NEC-Win Plus* graph of the source resistance and reactance values from 28 to 29 MHz for the 6-element Yagi.

the trends in the figures. For the source impedance data, whole numbers are sufficient. For the front-to-back date, a single decimal place works well, while some of the gain trend might be lost if we used fewer than 2 decimal places. Use the level of precision that coincides with the task at hand. *NEC* will always supply more precision than we can ever use, and our performance requirements may be looser than those we may want to impose on the data for study purposes.

From the table, we can detect certain trends. For example, the peak front-to-back ratio occurs above the mid-band point of 28.5 MHz. (Very often, for the highest front-to-back ratio at the band edges, the peak value for a Yagi should be a little below the band center.) At the same time, the gain increases all across the band, but that is natural to Yagis having one or more directors.

Graphing some of the trends is useful, and some programs have built-in graphing facilities. Figure 11 shows the *NEC-Win Plus* 50-Ω SWR graph, which gives us the same data as Table 3. We begin to see that the peak front-to-back ratio at 28.6 MHz coincides with the fact that the minimum SWR occurs at the upper end of the design range for the model. The *NEC-Win Plus* graph of the source resistance and reactance adds further confirmation. The source resistance only approaches 50 Ω at the high end of the range, although reactance should not be a problem, since it peaks at 7 Ω and then descends again.

The picture we get from the frequency sweep is that our design work is not finished. For optimal operation of the antenna from 28 to 29 MHz, we would like to increase the element lengths just a bit to better center the maxima and peaks in the sweep table. Perhaps moving the peaks downward by about 0.2 MHz might give us a minimum of 10 dBi gain, a minimum front-to-back ratio of 20 dB across the band, and a peak 50-Ω SWR value of about 1.35:1.

The more you get into the habit of frequency sweeping your antenna models, the more insight you will gain into various designs. Trends in performance can be as important as peak performance data in telling us how antennas of various types do their work. Some sweeps may cover wide frequency ranges at greater intervals—for example, when checking the performance of a log periodic dipole array (LPDA) from 14 MHz through 30 MHz. Other sweeps may use very small intervals over restricted frequency ranges—for example, determining at what frequency (or frequencies) the 50-Ω SWR passes the 2:1 point for a 40-meter antenna and deriving from that an operating bandwidth.

In this part of our series, we have covered considerable ground: source placement, grounds and ground planes, and frequency sweeps. Part 4, will cover even more ground, as it corrals a number of topics: loads, transmission lines, model tests, and limitations of *NEC*. However, by the time the last installment appears, you may have already obtained a modeling program, read the manual, practiced a lot, and be way of ahead of me.

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Notes

[1] The new *ARRL Antenna Book*, just released in its 19th edition, has an excellent program for using the source impedance along with most kinds of feed lines to show the impedance at the antenna tuner end of the line, whatever length of line we specify. Written by Dean Straw, N6BV, *TLW* also provides a wealth of other data for the antenna system builder.

[2] In our look at sources in this episode, we won't focus on whether we are using a voltage or a current source. However, we'll work though an exercise in the last episode of the series that will show at least one situation in which choosing one type of source over the other makes our work easier.

[3] See Chapter 3 of the 19th Edition of *The ARRL Antenna Book* for a good treatment of the effects of the earth on antennas, and especially pages 3-6 for a picture of ground values applicable to various parts of the US.