Last month we began with identifying some of the components of antenna pattern graphics. In this concluding part we will examine remaining details as well as points of comparison. These patterns are not just pretty pictures. They convey a tremendous amount of information either by inclusion or exclusion, and we should know the difference.

How To Get the Most Out of Antenna Patterns—Part II

BY L. B. CEBIK*, W4RNL

This month we take up with the discussion of antenna patterns by considering what happens to the azimuth pattern when we place our Yagi over real ground.

An azimuth pattern at zero degrees elevation—the horizontal plane—will show nothing. In fact, most NEC-based programs will disallow your attempt to take that pattern. Instead, we take azimuth patterns at some higher angle of interest. The question now is what is interesting.

In the absence of any other considerations, most folks who present azimuth patterns over real ground do so at the take-off angle. Fig. 11 is an illustration using our handy Yagi. The pattern shape is quite similar to the free-space azimuth pattern in figs. 4 through 7. However, there are some important differences.

The free-space azimuth pattern was a true horizontal pattern. The pattern over ground is a cone elevated from the horizontal by the specified elevation angle. Since the take-off angle of this antenna is 14 degrees, the azimuth pattern is a cone 14 degrees above the horizon. You can picture this best by drawing a line straight across the elevation pattern at a point 14 degrees up from the horizontal on each side of the graph.

The pattern shows a front-to-back line. This ratio is not necessarily the maximum front-to-back ratio for the antenna (although it often is). Rather, it is the front-to-back ratio for the chosen angle (14 degrees). Maximum front-to-back ratio (or front-to-rear) may be at some other angle. To get an idea of where it may be—or whether it might be different enough to be notable—simply look at the elevation pattern in the rearward direction. Or, specify some other elevation angles for the azimuth plot.

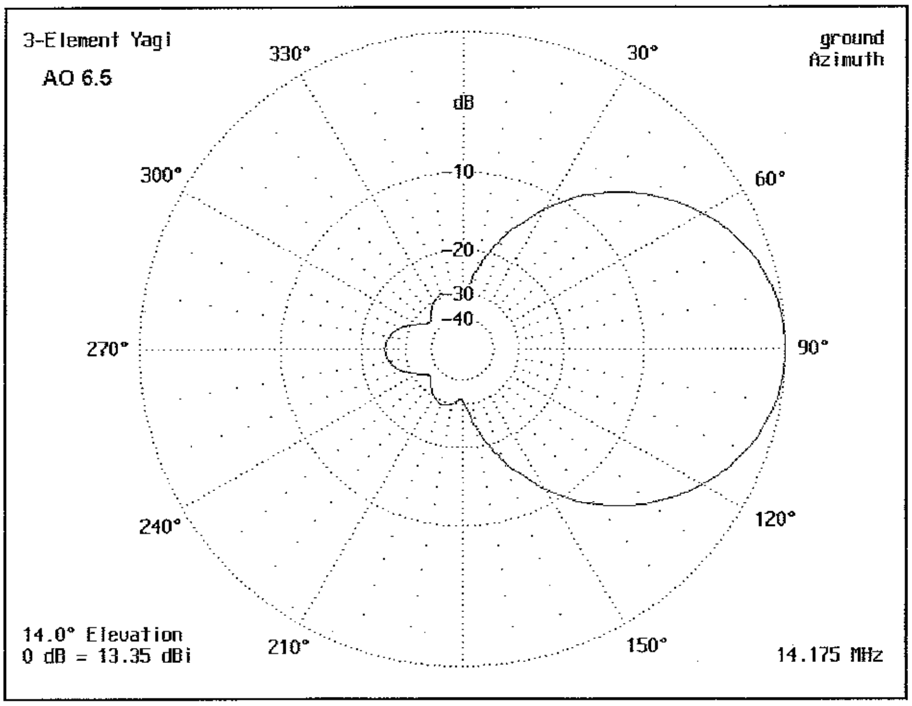

Fig. 11– Azimuth pattern of a 3-element Yagi one wavelength over average ground, at an elevation angle of 14 degrees (elevation angle of maximum radiation).

Although the take-off angle is a handy reference point in many cases, it may not be the most important one. Antenna builders may be more interested in particular paths to the stations they wish to work. If we work a lot of DX, then lower angles—perhaps in the 5- to 10-degree range—might interest us for some paths. In these cases, the antenna modeler and builder might show a lower angle for his or her chosen azimuth pattern. Fig. 12 shows the azimuth pattern for our one-wavelength high Yagi at a 5-degree elevation angle. Note the reduced gain and slight change of pattern shape. In contrast, near-vertical incidence skip is of interest to a number of amateurs, and very high angle radiation may dictate what azimuth pattern they choose. Hence, it

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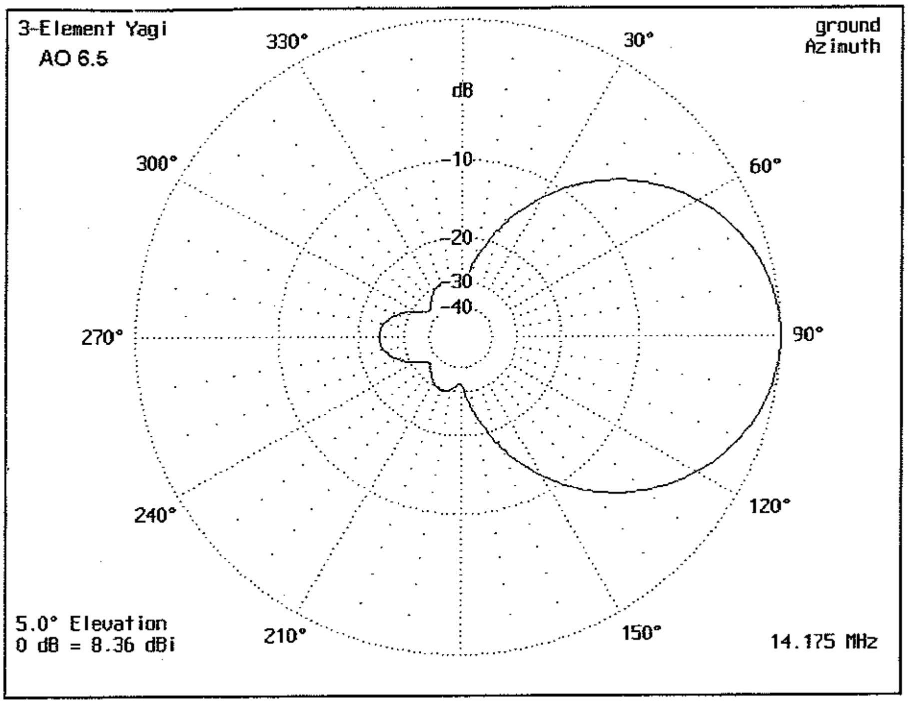

Fig. 12– Azimuth pattern of a 3-element Yagi one wavelength over average ground, at an elevation angle of 5 degrees.

pays always to (1) compare both elevation and azimuth patterns and (2) read any accompanying text to find out why the pattern variables were chosen.

Finally, note that the maximum gain in both our patterns over ground is considerably greater (when taken at the take-off angle) than the same antenna in free space. The signal reflected off the earth is not lost. Rather, it combines with the unreflected signal. At some elevation angles, the two are in phase and add up to a stronger signal—between 5 and 6 dB stronger. At other angles, they are out of phase and cancel, resulting in nulls rather than lobes. In general, for horizontal antennas the number of lobes counting from the ground up to a point overhead (90 degrees up) is about one more than the number of wavelengths in height of the

Gain and Take-Off Angle of a 3-Element Yagi Over Various Soil Conditions

	Ground Type		
	Very Poor (C=0.001/DC=5)	Average (C=0.005/DC=13)	Very Good (C=0.0303/DC=20)
Antenna Height (wavelengths)	Gain (dBi)/ TO angle	Gain (dBi)/ TO angle	Gain (dBi)/ TO angle
0.50	11.7 / 24	12.3 / 25	12.8 / 26
0.75	12.6 / 17	13.1 / 18	13.4 / 18
1.00	13.0 / 13	13.4 / 14	13.7 / 14
1.25	13.2 / 11	13.6 / 11	13.8 / 11
1.50	13.4 / 9	13.7 / 9	13.9 / 9
1.75	13.5 / 8	13.7 / 8	13.9 / 8
2.00	13.6 / 7	13.8 / 7	14.0 / 7

Note: Model used for these representative figures is aluminum and the check frequency is 14.175. As always, modeling is done over flat terrain and does not account for terrain variations. **C** is conductivity as measured in S/m; **DC** is a dielectric constant and has no units. **TO** angle is the elevation angle of maximum radiation and is in degrees above the horizon.

Table I– Representative figures for gain and take-off angle of a 3-element Yagi over various soil conditions.

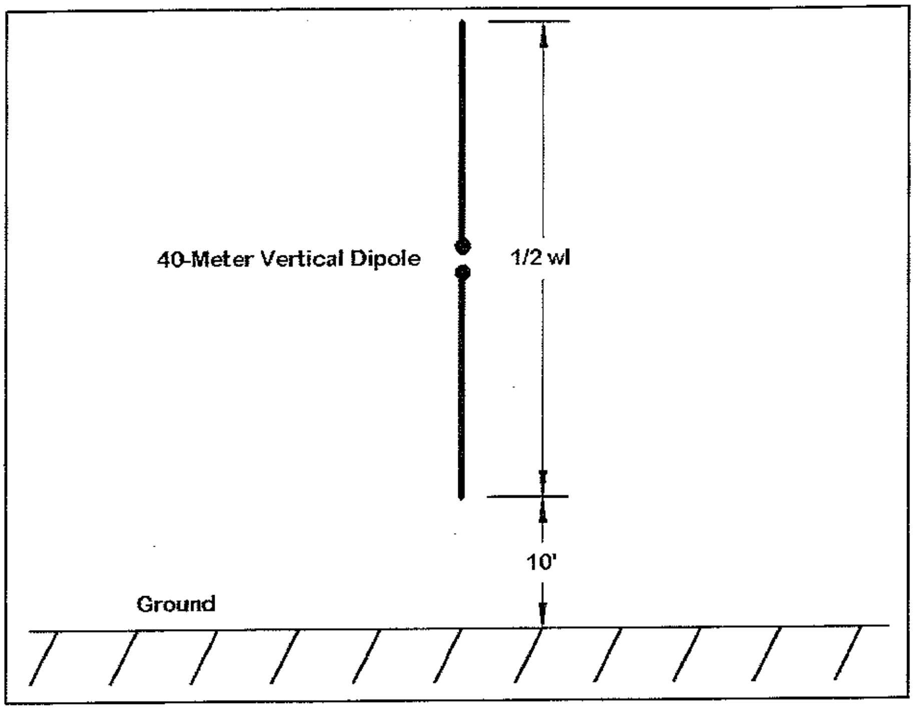

Fig. 13– Vertical dipole for 40 meters placed 10 ft. above ground at the antenna base.

antenna. Remembering this fact will help you both to understand antenna patterns and to anticipate them as you read specifications in the text.

As a rule of thumb, the lobes and nulls above the horizon can be calculated by a simple equation:

$$A_e = \arcsin \frac{N}{4h}$$

where $\mathbf{A_e}$ is the angle of the lobe or null, **N** is the lobe or null number counting from the ground up, and **h** is the antenna height in wavelengths or a fraction of a wavelength. For lobes, the value of **N** will be an odd integer (1, 3, 5, 7, etc.), while for nulls, the value of **N** will be even (0, 2, 4, 6, etc.). Our Yagi at a one-wavelength height has lobes at about 14 degrees (the main lobe) and at 49 degrees. This calculation is only a rough guide, since the exact structure of the antenna and the terrain may alter the angles by small amounts.

Does the Good Earth Make a Difference?

Most antenna patterns derived from antenna modeling software presume a flat, uncluttered terrain for the antenna. Because we live in spaces that may be littered with building, objects, and vegetation, and also because our terrain, both near and far, may be anything from flat to mountainous, model patterns only approximate the actual antenna performance we can achieve.

In general, the ground immediately beneath and around an antenna affects antenna efficiency and the feedpoint impedance. The far-field pattern is most affected by the quality of earth several wavelengths from the antenna and beyond.

The quality of the ground beneath an antenna can vary from exceptionally poor to salt-water good. Modeling software records the quality of the earth in a composite of two figures: **conductivity**, which is measured in Siemens per meter, and a **dielectric constant**, which has no unit of measure. For the most part, the larger either of these figures, the better the quality of ground. The range of possible ground conditions is very wide. Average soil has a conductivity of 0.005 S/m with a dielectric constant of 13. Salt-water values are 5.0 S/m and 81. At the other end of the scale, extremely poor soil found in heavy industrial areas may show values of 0.001 S/m and 3. Antenna handbooks usually have tables and maps to help to determine the quality of ground in your area.

The effect of terrain upon horizontally polarized antennas, such as our model Yagi, tends to be slight. To see this point in action, look at Table I, which lists the gain and take-off angles for our model Yagi at various heights above three types of ground: "Very Poor" (0.001 S/m; 5), "Average" (0.005 S/m; 13), and "Very Good" (0.0303 S/m; 20). Note that the take-off angles are very stable, while the gain figures increase only a little as the ground quality increases.

We can make the same point by noting that when the E-plane of an antenna is parallel to the earth, the effects of ground quality are relatively small. However, if the E-plane is at right angles to the earth, the situation changes considerably. This situation of course corresponds to having a vertical antenna.

Using the same three soil types, we can take a simple vertical dipole and illustrate the difference. In this case, I modeled a full-length vertical dipole with the bottom 10 ft. off the ground, as shown in fig. 13. The resulting patterns for the three ground qualities can be combined in a single graphic of the multiple polar plots, as shown in fig. 14. Note that the best ground quality produces the lowest take-off angle and the greatest signal strength, while the worst produces a weaker field strength at a higher angle.

At the same time, notice the absence of strong higher angle lobes in any of the three patterns in fig. 14. You will begin to see why many operators prefer vertical antennas for DX work, especially on the lower HF bands, where getting a horizontal antenna high enough to have a low-angle lobe of maximum radiation is often not feasible.

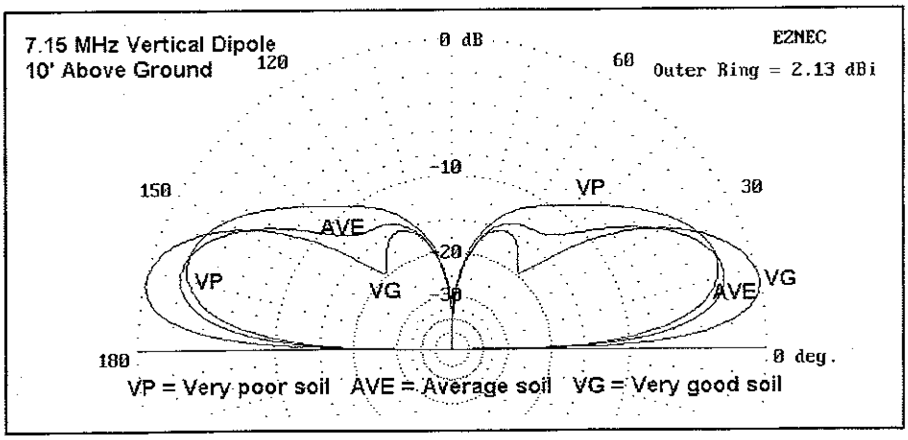

Fig. 14– Elevation patterns for the 40 meter vertical dipole over three different soil types.

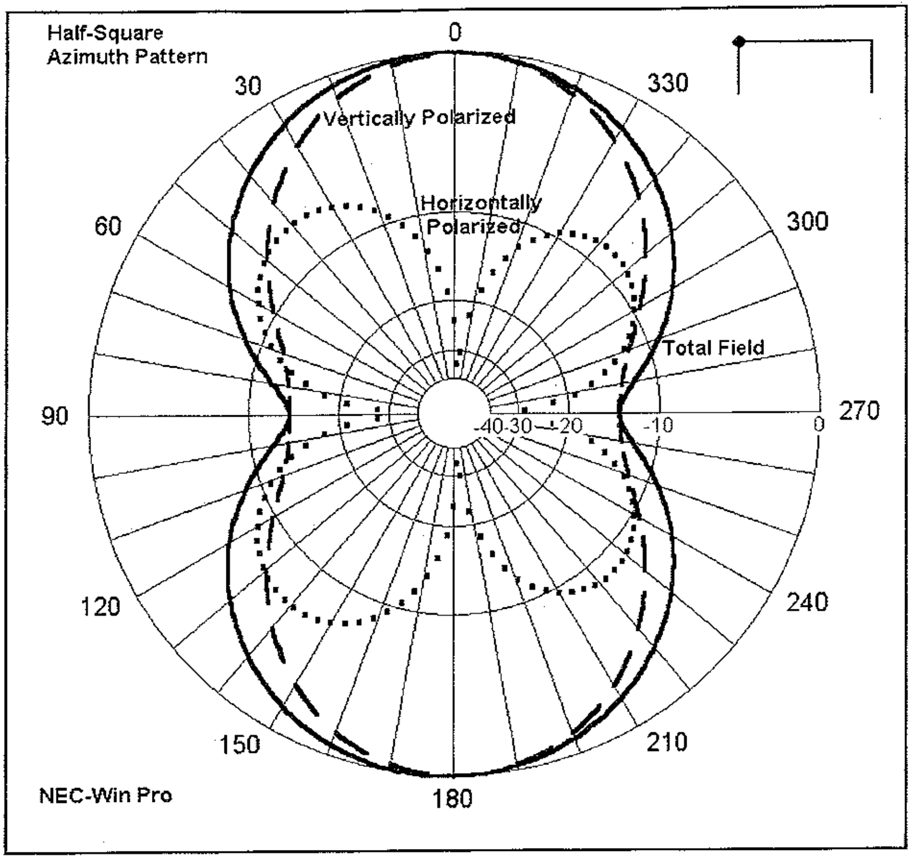

Fig. 15– Azimuth pattern of a half-square antenna at a 16-degree elevation angle over average soil showing the total field and its horizontally and vertically polarized components.

These sample patterns should do more than acquaint you with the terminology and geometry of antenna patterns. They should be the beginning of the development of your expectations when seeing antenna plots of either horizontal or vertical antennas.

Polarization: The Simple And The Complex

Most modeling programs from which antenna patterns emerge can show not only the total far field of the antenna, but also both the vertically polarized and horizontally polarized components of that field. Linear antennas, such as the vertical dipole or the Yagi, tend to have negligible radiation cross polarized to the general orientation of the antenna. However, many antenna types yield both types of radiation. Fig. 15 shows the azimuth pattern at 19 degrees elevation of a half square, the general outlines of which have been superimposed on the plot. Although the maximum gain of the antenna's total field is a function of the vertically polarized radiation, the width of the field is considerably enlarged by the presence of horizontally polarized radiation, which shows itself in the cloverleaf pattern.

At HF, polarization becomes skewed in the ionosphere, and we normally think of the total field as making up the effective far field. However, for many types of loop antennas (quads, deltas, rectangles, etc.), where we feed the antenna can make a difference in the ratio of horizontally to vertically polarized radiation, and this in turn can have an effect on the overall total field of the antenna. Consider fig. 16, which shows elevation patterns of the same delta loop. On the right it is fed at the center of the horizontal wire, while on the left it is fed 1/4 wavelength down from the triangle's apex. The patterns are significantly different, to say the least.

Even where antennas are linear, we should expect pattern differences according to whether they are set up for horizontal or vertical polarization. Consider a small Yagi for 2 meters, elevated about 30 ft. up. Fig. 17 shows the azimuth pattern at the take-off angle for the antenna when it is horizontal and when it is vertical. Vertically, it shows less gain and a much wider beam width than when horizontal. If we want to achieve a vertically polarized pattern the shape of which resembles that of the horizontal Yagi, we have to turn to a different antenna design. Despite its higher gain, we cannot simply press the horizontal Yagi into service, because in line-of-sight, we shall likely

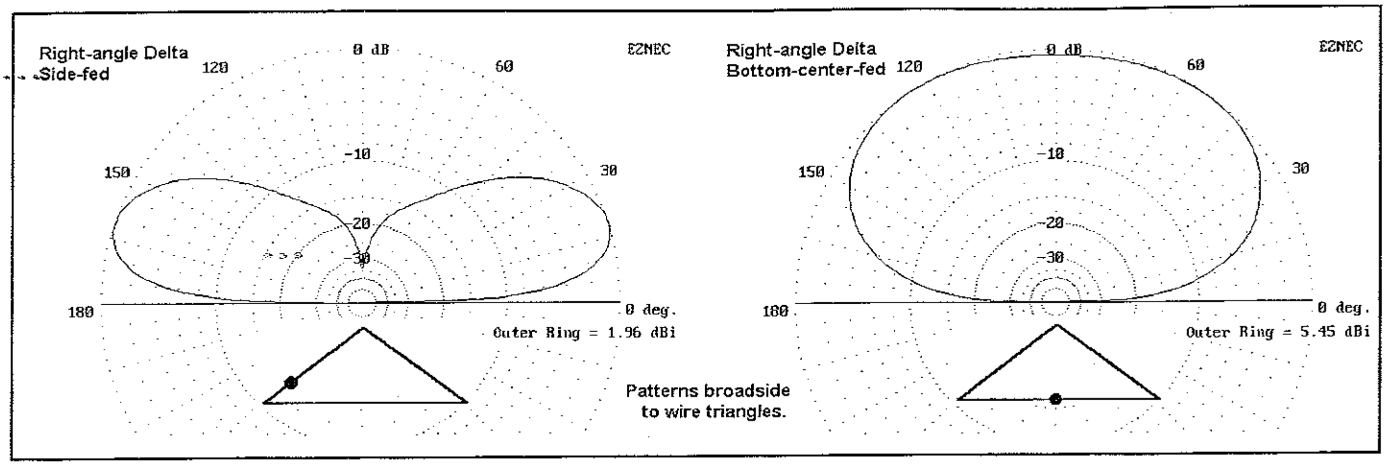

Fig. 16– Elevation patterns of a right-angle delta loop, taken broadside to the loop, for side-feed (for maximum vertically polarized radiation) and for bottom-center-feed.

lose more to cross-polarization losses than the extra gain will give us.

Comparisons, Both Educational and Practical

Now that we know how to read antenna patterns with reasonable accuracy, let's look at some ways in which comparing antenna patterns can assist us in understanding antennas. The following examples are only starters, chosen for their variety. Taking a comprehensive look at antennas is a lifetime's vocation.

1. **The Center-Fed Doublet**: One of the most common antennas is still one of the most misunderstood. Because the center-fed doublet yields a dipole-like pattern at its lowest frequency of operation, many amateurs believe that it provides a dipole-like azimuth pattern at all its frequencies of operation. Generating some azimuth patterns can tell us very quickly whether this belief is true or false.

Let's make our doublet 135 ft. long and use it from 80 meters through 10 meters. We will make it of #14 copper wire and place it at 50 ft. in the air. Ignoring ground clutter and terrain variables, we would get the patterns of fig. 18 on 80, 40, 20, and 10 meters. Notice that the elevation angle of maximum radiation is different for each band. In fact, on 80 meters, because the take-off angle is so high, an arbitrary angle of 45 degrees was selected for the azimuth pattern.

The antenna is 1/2 wavelength long at 80 meters, one wavelength long at 40 meters, etc. For your reference file, you can count the number of lobes and relate them to the antenna length in terms of wavelengths. Also note that as the antenna becomes longer relative to the frequency of operation, the direction of the strongest lobes moves from a broadside direction toward the ends of the antenna.

Besides acquainting you with the antenna patterns on various bands, the azimuth patterns are also useful for practical antenna planning. First, decide which bands are your favorites and, as well, which directions from your station are best for making your most desired contacts. If you have a choice of directions in which

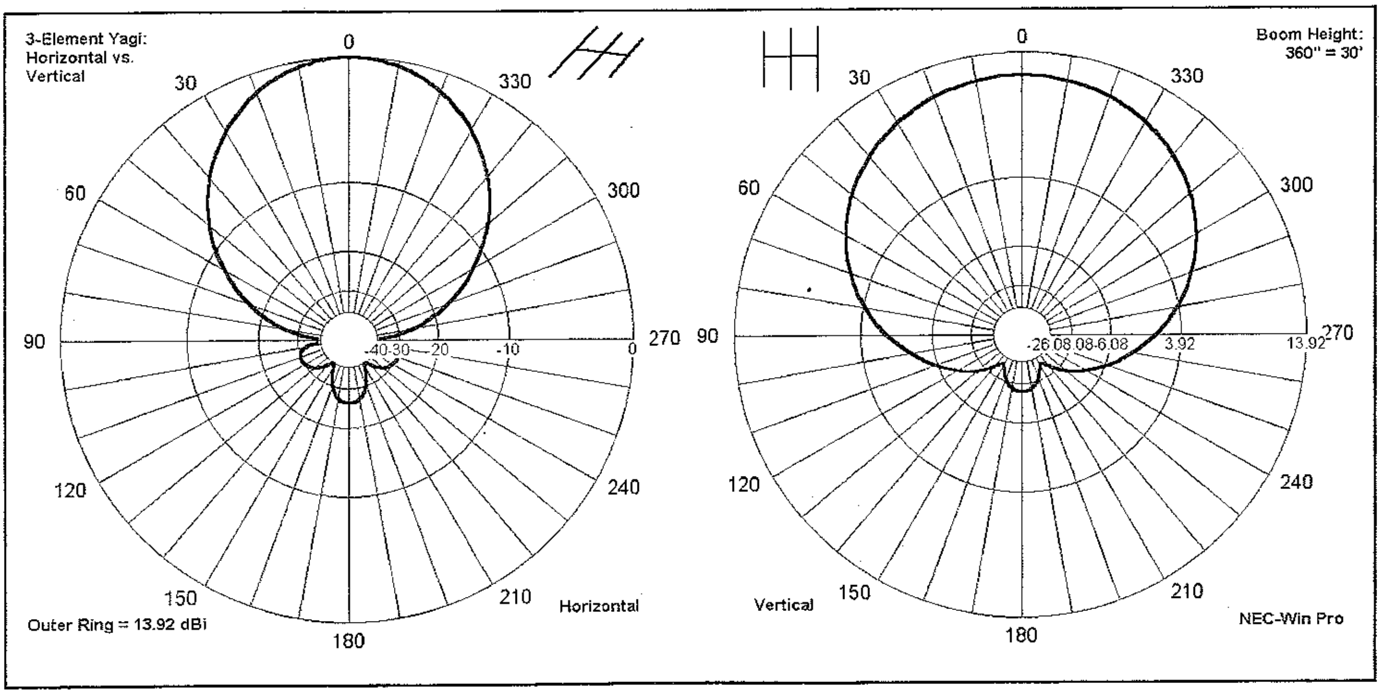

Fig. 17– Azimuth patterns for a 3-element 2 meter Yagi 30 ft. above average soil for both horizontal and vertical orientations of the beam. The outer ring represents the same field strength in both patterns.

to string up the doublet, you can to some measure erect the antenna for maximum signal strength on your favorite bands in your most desired directions. The azimuth patterns can be a useful planning tool.

2. **Directional Beams and Elevation Patterns**: In the maze of antenna materials, we often find it difficult to see how antennas are related. For example, in a number of talks I have given to beginners in amateur radio, questions have arisen about how dipoles and various size Yagis may be kin to each other. The questioners are often surprised by how close the relationship is.

One simple demonstration I have used is to combine the elevation patterns of a dipole, a 2-element Yagi, and a 3-element Yagi, all at the same height. A representative version of this pattern combination appears in fig. 19. I have added labels to the portions of the curves that might get confusing.

From the figure, two significant features appear. First, all three antennas have the same lobes and nulls at almost identical angles. Second, the symmetry of the dipole pattern fore and aft of the vertical center line disappears steadily as the parasitical elements direct the main lobe in one direction. Hence, both kinship and differences appear at once.

Combining curves is something that an antenna modeler can do with ease. The casual reader of amateur magazines may see only individual patterns. However, by examining either the graphic or the text for further information on gain, front-to-back ratio, and other features of the antennas, one can get a pretty good view of two or more antennas in combination. In fact, one can transpose the pattern of one antenna upon the other for greater clarity. However, be sure that the transposed patterns are truly comparable before transposing them.

3. **Directional Beams and Azimuth Patterns**: There is a myth that pervades amateur radio—that is, for every operating purpose whatsoever, always choose the highest gain, highest front-to-back antenna you can afford. Like all myths, this one has some truth, but not all truth.

To sort out what is true and what is false in the myth, let's combine in one graphic the azimuth patterns for a good 2-element Yagi and a good 3-element Yagi. We will place both at one wavelength in height so that the elevation angles for the patterns will be the same. The result is shown in fig. 20.

Obviously, the 3-element Yagi has superior gain and front-to-back ratio. As such, it may indeed be the better antenna for serious DXing, where we wish to maximize our signal to the distant receiving station and suppress as much as possible all the potential QRM from the sides and rear of our station. However, serious DXing is not the only important type of amateur operating activity.

Many contesters and net operators do not want to suppress signals completely from the sides and rear. They wish to know that someone worth working is present, but not so loud as to interfere with the current station being worked. Hence, they tend to prefer antennas with some front-to-back ratio and some gain, but not the ultimate in each. For their type of operation, the 2-element Yagi may in fact be the preferred antenna.

In this example, I have given a choice of only two antennas. However, the basic principle can be applied to a host of antenna types. A comparison of antenna patterns, when placed against a list of operating goals and the needs one has to achieve those goals, can be a valuable tool in antenna selection.

4. **Truth—Pattern Shape and Pattern Detail**: The shape of an antenna pattern is not the whole story, and one easily can

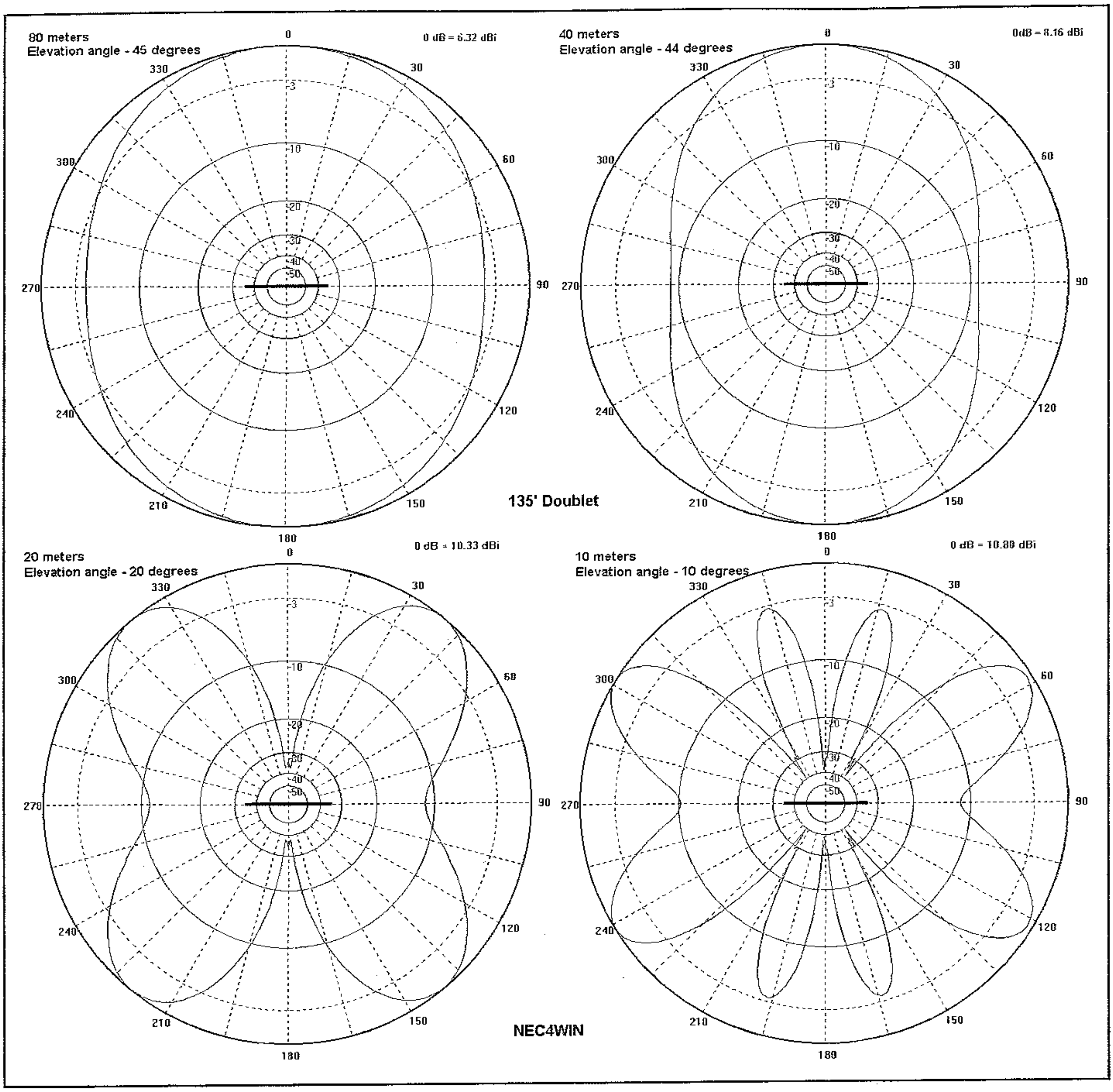

Fig. 18– Azimuth patterns for a 135 ft. doublet 50 ft. above average soil when used on 80, 40, 20, and 10 meters. In each case, the doublet is oriented left-to-right in the pattern graphic.

fall into traps of hasty interpretation. To illustrate the point, let's look at fig. 21 and fall into one kind of trap together.

Part (A) of the figure shows the free-space azimuth pattern of a 2-element Yagi. The main lobe is, as expected, quite round with a good beam width. The rear quadrant shows a very high 180-degree front-to-back ratio. In most respects, this pattern appears to be superior to the free-space pattern shown in part (B), where the 180-degree front-to-back ratio is under 20 dB.

Part (C) of the figure springs the trap. The patterns in parts (A) and (B) are overlaid, demonstrating the far lower gain of the initial pattern. In fact, the gain for (A) is only 3.8 dBi, while the gain for (B) is nearly 6.6 dBi. In addition, the 180-degree front-to-back ratio for (B) is a little under 19 dB and is the worst case of the entire rear quadrant. By contrast, the 29 dB 180-degree front-to-back ratio of (A) covers only a small part of the rear quadrant and drops to a worst-case value of just over 16 dB.

Without the added data, we might not have realized that the performance of the two antennas was so radically different. Even without the pattern overlay, the data for both the forward and rear quadrants of the antenna pattern make those differences clear. In fact, (A) is based on a model of a highly loaded and shortened 10 meter beam, while (B) is based on a model of a full-size 10 meter beam with phasing line connecting the two elements.

When comparing antenna patterns, be certain that you have a complete data set before you start the work of comparison. As we have seen, free-space patterns are not directly comparable, even though similar, to patterns over ground. When comparing patterns taken over ground,

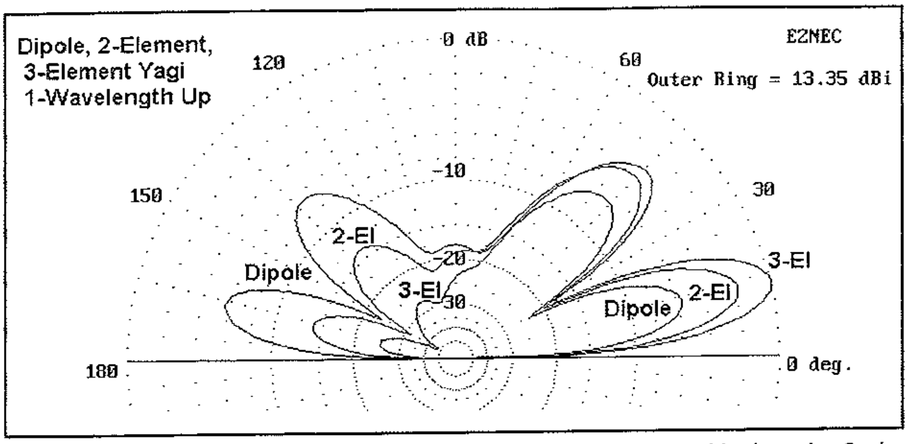

Fig. 19– Composite elevation patterns for a dipole, a 2-element Yagi, and a 3-element Yagi, each placed one wavelength above average soil.

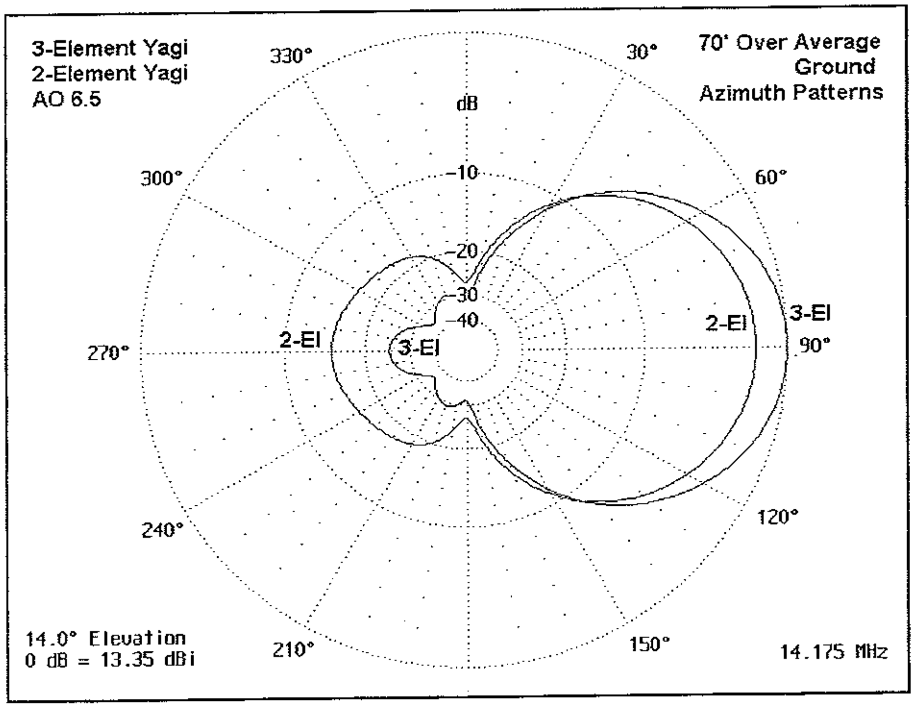

Fig. 20– Composite azimuth patterns at 14 degrees elevation of a 2-element Yagi and a 3-element Yagi, each one wavelength above average soil.

be certain the heights are comparable and the ground types are similar. Wherever antennas are of different types, examine both the azimuth and elevation patterns of each. These considerations become very important when trying to make purchase decisions among commercial beams. The manufacturers do not present their information with a common format, and therefore comparisons are very difficult, even where patterns are offered.

Antenna patterns do not tell anything like the whole story with antennas. We have already seen the need to place the performance figures in juxtaposition with our operating goals and needs. In addition, we shall have to factor in considerations such as cost, weight, available space, installation complexity, and maintenance, not to mention the legalities which are becoming an increasing burden to antenna installation.

In the End, There is No End

We barely have scratched the surface of the things we can learn from antenna patterns when we learn to read them accurately and carefully. By examining the azimuth and elevation patterns for single antennas, we can gauge their performance in terms of gain, front-to-back specifications, lobes and nulls, beam width, and polarization composition. We also can compare antennas, both within a single type and among types, analyzing high- and low-angle lobes, lobe direction and shape, and numerous other properties.

In the end, the information you can gain from antenna patterns will help you make intelligent decisions about the best antenna for your station location. When combined with all of the other types of information you can and should gather, the more information you draw from antenna patterns, the more satisfying your ultimate decision is likely to be. ■

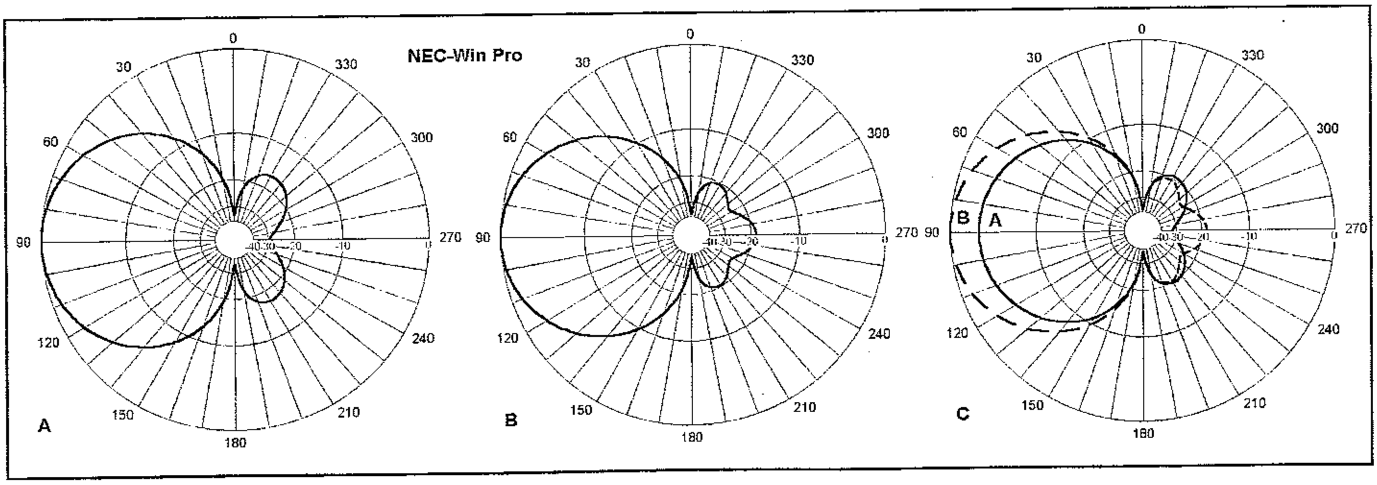

Fig. 21– Azimuth patterns for two 2-element Yagis (A and B) along with a composite pattern graphic of the two (C), with each antenna one wavelength above average soil.