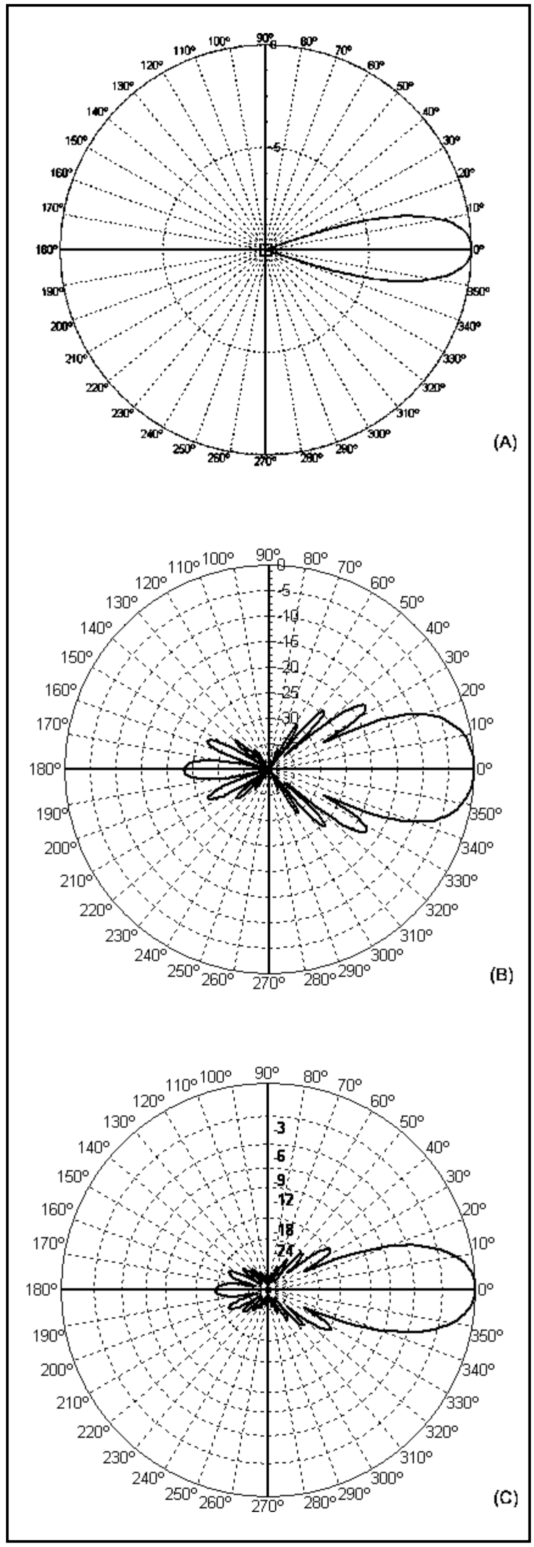
Coordinate Scales for Radiation Patterns

A number of different systems of coordinate scales or *grids* are in use for plotting antenna patterns. Antenna patterns published for amateur audiences are sometimes placed on rectangular grids, but more often they are shown using polar coordinate systems. Polar coordinate systems may be divided generally into three classes: linear, logarithmic and modified logarithmic.

A very important point to remember is that the shape of a pattern (its general appearance) is highly dependent on the grid system used for the plotting. This is exemplified in **Fig A**, where the radiation pattern for a beam antenna is presented using three coordinate systems discussed in the paragraphs that follow.



Linear Coordinate Systems

The polar coordinate system for the flashlight radiation pattern, Fig 10, uses linear coordinates. The concentric circles are equally spaced, and are graduated from 0 to 10. Such a grid may be used to prepare a linear plot of the power contained in the signal. For ease of comparison, the equally spaced concentric circles have been replaced with appropriately placed circles representing the decibel response, referenced to 0 dB at the outer edge of the plot. In these plots the minor lobes are suppressed. Lobes with peaks more than 15 dB or so below the main lobe disappear completely because of their small size. This is a good way to show the pattern of an array having high directivity and small minor lobes.

Logarithmic Coordinate System

Another coordinate system used by antenna manufacturers is the logarithmic grid, where the concentric grid lines are spaced according to the logarithm of the voltage in the signal. If the logarithmically spaced concentric circles are replaced with appropriately placed circles representing the decibel response, the decibel circles are graduated linearly. In that sense, the logarithmic grid might be termed a linear-log grid, one having linear divisions calibrated in decibels.

This grid enhances the appearance of the minor lobes. If the intent is to show the radiation pattern of an array supposedly having an omnidirectional response, this grid enhances that appearance. An antenna having a difference of 8 or 10 dB in pattern response around the compass appears to be closer to omnidirectional on this grid than on any of the others. See Fig A-(B).

ARRL Log Coordinate System

The modified logarithmic grid used by the ARRL has a system of concentric grid lines spaced according to the logarithm of 0.89 times the value of the signal voltage. In this grid, minor lobes that are 30 and 40 dB down from the main lobe are distinguishable. Such lobes are of concern in VHF and UHF work. The spacing between plotted points at 0 dB and –3 dB is significantly greater than the spacing between –20 and –23 dB, which in turn is significantly greater than the spacing between –50 and –53 dB.

For example, the scale distance covered by 0 to –3 dB is about $^1/_{10}$ of the radius of the chart. The scale distance for the next 3-dB increment (to –6 dB) is slightly less, 89% of the first, to be exact. The scale distance for the next 3-dB increment (to –9 dB) is again 89% of the second. The scale is constructed so that the progression ends with –100 dB at chart center.

The periodicity of spacing thus corresponds generally to the relative significance of such changes in antenna performance. Antenna pattern plots in this publication are made on the modified-log grid similar to that shown in Fig A-(C).

Fig A—Radiation pattern plots for a high-gain Yagi antenna on three different grid coordinate systems. At A, the pattern on a linear-power dB grid. Notice how details of sidelobe structure are lost with this grid. At B, the same pattern on a grid with constant 5 dB circles. The sidelobe level is exaggerated when this scale is employed. At B, the same pattern on the modified log grid used by ARRL. The side and rearward lobes are clearly visible on this grid. The concentric circles in all three grids are graduated in decibels referenced to 0 dB at the outer edge of the chart. The patterns look quite different, yet they all represent the same antenna response!

The New Look for QST's Antenna Patterns

Antenna radiation patterns can be very useful in Amateur Radio. But using the wrong coordinate system for the plot may obscure important pattern information.

By Jerry Hall,* K1TD

What's the front-to-side ratio of that new vertical phased array featured in *QST*? Perhaps you've noticed, the background grid for antenna patterns appearing in recent issues is new to *QST*. It's designed to let you determine answers to this kind of question easily. If you didn't notice the new coordinate system, you may want to peek again at page 19 of April 1980 *QST*,[1] and at page 32 of the May 1980 issue.[2] Why did we change to this particular grid? Some background information on this system of coordinates appears in the paragraphs that follow.

Let's examine Fig. 1 for a moment. Fig. 1A shows the theoretical azimuth plot of the signal radiated from a half-wavelength horizontal dipole antenna. Fig. 1B is the theoretical azimuth plot of two 1/4-wave vertical antenna elements placed 1/4 wavelength apart and fed equal currents 90 degrees out of phase. These two plots show the type of polar or circular grid-coordinate system which has been used for years in *QST* and other ARRL publications.

What Do These Plots Mean?

How do we interpret patterns? It's not difficult. Imagine that the horizontal dipole antenna is installed above a large, flat desert. At some distance away, say 20 wavelengths or more, we erect a horizontally polarized receiving antenna at the same height as the dipole. We excite our test dipole antenna with a transmitter — a watt or less is sufficient. Now suppose we somehow move our receiving setup in a large circle around the dipole, always keeping our receiving antenna pointed toward the dipole and always staying the exact same distance from the center of the dipole.

As we move around the dipole, the signal picked up by our receiving antenna will change in strength. The strength will be maximum when we are looking broadside at the dipole, and will be minimum (theoretically zero) when we are looking directly at either end of the dipole. The effect would be exactly the same if our receiving position were fixed and, instead, we rotated the test dipole.

The pattern of Fig. 1A tells us exactly this. The azimuth scale, indicated in degrees around the outside edge, shows us the angle of departure of our receiving setup from the reference or starting point. Broadside to the dipole conductor (0- and 180-degrees azimuth in Fig. 1A) we receive maximum signal. Ninety degrees away from broadside, off the ends of the dipole, we receive nothing. At intermediate angles the strength is somewhere between these two extremes. Here is where the circular coordinate system comes into play; we can read these intermediate signal strengths directly from the plot.

Calibration of the Polar-Coordinate Scale

Let's say we calibrate our test setup with the receiving antenna located broadside to the dipole. We adjust the transmitter power so that exactly 1 millivolt of rf is measured at the receiving antenna terminals. Fig. 1A now becomes simply a plot of the millivolt reading we would obtain at the receiving antenna as it is moved around the circle. The scale is linear, having a range of 0 to 1 millivolt.

If we were to increase our transmitter power to obtain a reading of 1 volt in a direction broadside from the dipole, the plot of the antenna pattern would remain unchanged. Here our coordinate system would simply represent the signal response on a linear scale of 0 to 1 volt. You see, everything is *relative* to the full-scale value of the plot! We could also prepare a plot in *absolute* values of signal strength, such as might be measured in microvolts or millivolts per meter, although very few amateurs have the test equipment needed to perform such measurements. The shape of the pattern would be unchanged.

Even if we were to reverse our transmitter and rf voltmeter locations, using the dipole to receive and our second antenna to "illuminate" the dipole with radiated energy, the pattern would not differ. This is true because the radiation pattern of a given antenna is the same whether it be used for transmission or for reception, assuming that proper terminations are maintained at both ends of the transmission line.

The plot of Fig. 1B reveals the same type of information for the phased vertical array. Imagine here that instead of being located in a desert, we place ourselves and the antenna array on a gigantic sheet of solid copper, a perfect conductor. Of course we now use a receiving antenna that is vertically polarized. As we move our receiving setup in a giant circle around the array (or as we rotate the phased-array system), the signal strength will vary with the angle of departure from the array axis as shown in Fig. 1B. Maximum signal is received when our receiving setup is in line with the two radiating elements and in the direction of the element having the lagging phase (0-degrees azimuth in the plot of Fig. 1B). In the opposite direction on the array axis (180-degrees azimuth) the signal strength is theoretically zero. The circular coordinate scale is again relative, as explained for Fig. 1A.

So what's wrong with this coordinate scale? Why change? A moment's reflection will reveal some good reasons. First of all, none of us ever bothers to trot an rf voltmeter out to the terminals of our antenna to measure signal strengths

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[1]References appear on page 28.

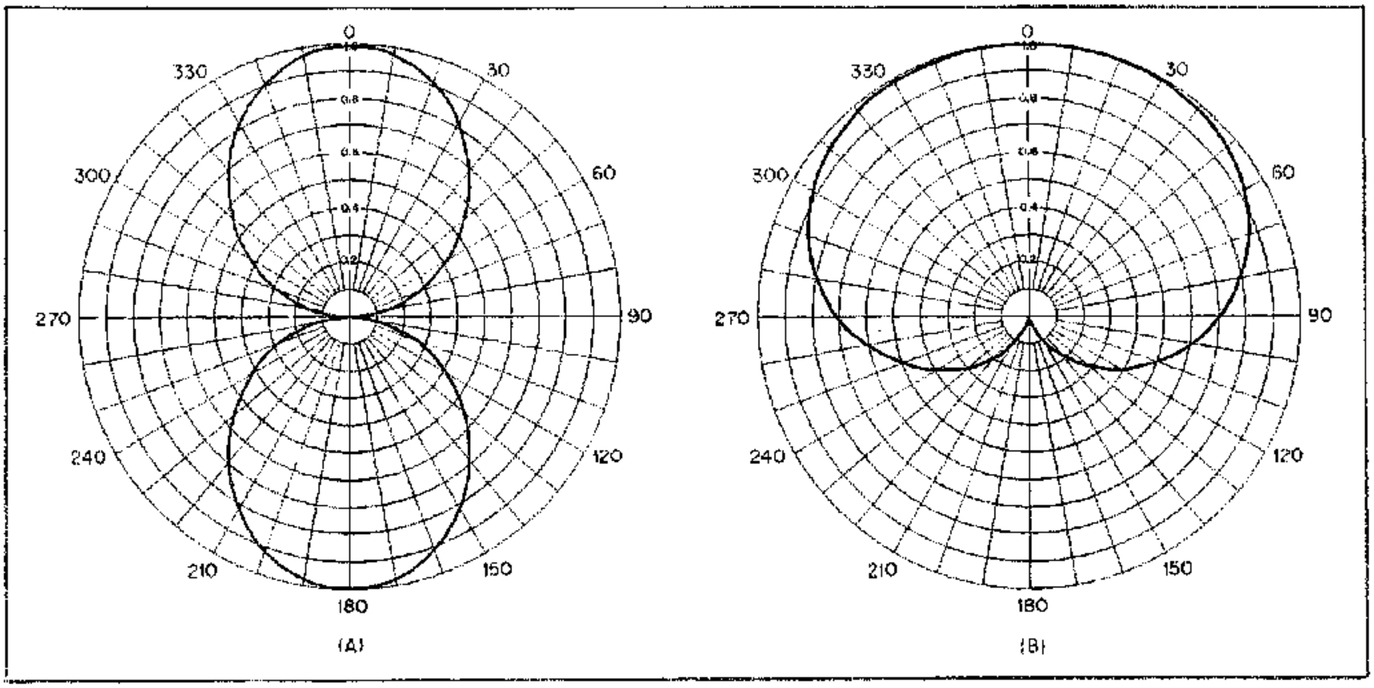

Fig. 1 — At A, a theoretical azimuth plot of the signal radiated from a horizontal half-wavelength dipole. The axis of the conductor lies along the 90/270-degree line on the chart. At B, the theoretical azimuth plot of two 1/4-wave vertical elements spaced 1/4 wavelength apart and fed 90 degrees out of phase. The two elements of the array lie along the 0/180-degree line, with maximum signal being radiated in the direction of the element that is lagging in phase. In these plots the linear system of concentric circles represents signal strength in voltage units, with zero at the center.

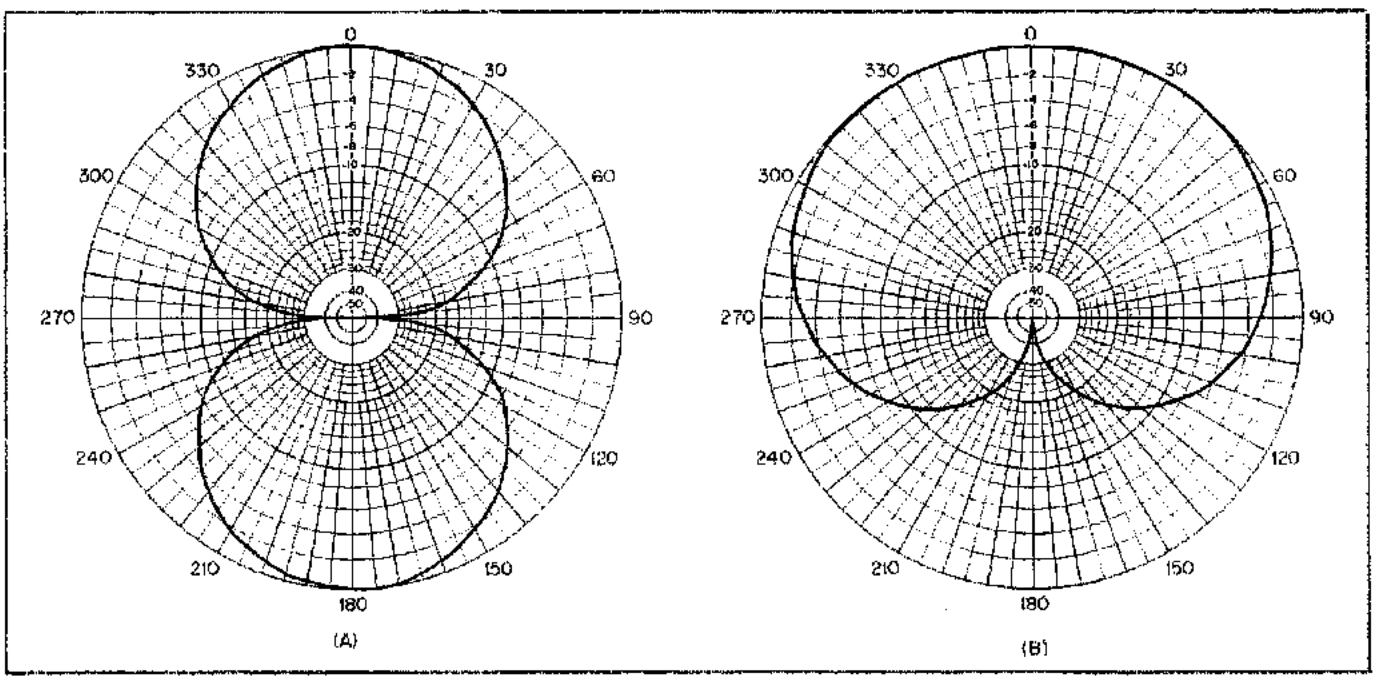

Fig. 2 — "New look" azimuth plots for the same antennas plotted in Fig. 1. The patterns have a slightly different shape but are quite recognizable to those who may be familiar with various antenna patterns. The log-periodic system of concentric circles represents signal strength in decibels relative to that in the direction of maximum radiation, with −100 dB at the center.

because of the impracticality. As a result, we're just not accustomed to thinking of signal strengths in terms of rf millivolts, microvolts, or whatever, especially when everything is relative. Instead, most of us have become accustomed to thinking in terms of decibels, or dB. Receiver manufacturers have made it extremely easy for us to think in decibel terms, with every communications receiver that has more than bare essentials sporting an S meter. Nearly all of these meters indicate S units to S9, and indicate decibels above S9. How many times have you heard this kind of an expression? "You're 40 dB over S9 here, solid copy!"

The two plots of Fig. 1 don't give us much help directly if we're looking for relative information in dB. What's the front-to-side ratio of the phased vertical array? Or how much is my signal down at a particular DX station if he is 60 degrees away from broadside of my fixed dipole? Sure, we can find the answers to these questions by taking information from the plot and applying the familiar equation, $dB = 20 \log E_1/E_2$. But why not plot the pattern on a coordinate system of decibels in the first place, and save *all* that trouble? This was the thinking which went on in our minds at ARRL headquarters as we were considering the change.

The New Look

Now please examine Fig. 2. These pattern plots are for the same antennas as those of Fig. 1. The only difference is that the plots are made on a nonlinear polar-coordinate system graduated in decibels.

We pondered various decibel-coordinate systems for quite a while before arriving at the chosen one. A linear scale in dB is easy to work with when making plots, for example, but has one serious drawback which I'll explain. In a real situation, a change from 0 to −3 dB in signal strength is far more significant than a change from, say, −20 to −23 dB. But on a linear dB scale these two changes would be represented by the same scale distance. No, we wanted something where a change from 0 to −3 dB was portrayed with a larger scale distance than −20 to −23 dB, which in turn should be represented by a larger distance than −50 to −53 dB.

A log-periodic coordinate system was the answer, where the graduations vary periodically with the logarithm of the signal strength (in voltage units). To cover the desired decibel range without severely distorting the pattern shapes from those of voltage plots (as shown in Fig. 1), we chose 0.89 for the periodicity constant. In plain English, here's what that means. The scale distance covered by the outermost 2-dB increment, 0 to −2 dB, is a particular length, approximately 1/10 the radius of the chart. The scale distance for the next 2-dB increment is slightly less, 89.0 percent of the first, to be exact. The scale distance for the third 2-dB increment is 89 percent of the second, and so on, each 2-dB increment becoming progressively smaller toward chart center. The scale is constructed so the progression ends with −100 dB at exact chart center. In amateur practice, signals of 50 or 60 dB and more below the reference level will normally be so weak as to be insignificant, so we deemed the small size of the −50 dB innermost circle as shown in Fig. 2 to be quite acceptable for our purposes. The coordinate system we've adopted may not be suitable for some laboratory work, where better definition at greater dynamic ranges may be desirable.

We think you'll appreciate this new look for antenna patterns. The "look" is designed for ease of pattern interpretation, in terms we're accustomed to using as amateurs. What's the front-to-side ratio of that new vertical phased array featured in *QST*? Well, if it happens to be the array patterned in Fig. 2B, you can readily determine the answer — 3 dB. QST

References

[1]Eggers, "An Analysis of the Balun," *QST*, April, 1980.

[2]Belrose, "The Half Sloper — Successful Deployment is an Enigma," *QST*, May 1980.