An-Ten-Ten-nas

INFORMATION to help you decide on the best antenna for *you!*

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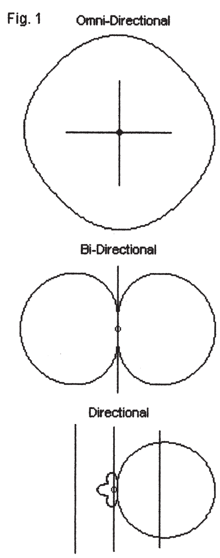
In each issue of the News, we shall try to clarify a significant cluster of ideas used in antenna work. Our object is to help you make the best decisions about the antennas you buy or build without imposing our own prejudices on you. The more you understand, the better your choices will be.

No. 59: Some Basic Concepts for Directional Antennas

In the course of our quarterly discussions of antennas, we have used many terms as a matter of course. Perhaps we should pause to be sure that we are all using the same terms in the same way. Nothing helps understanding more than a firm grasp of what the basic words mean. In this episode, we shall look at ideas and concepts that underlie the way we talk about directional anatennas and their radiation patterns.

1. What do we mean when we say that an antenna is directional? We generally describe the directionality of an antenna's radiation pattern using one of 3 words, shown in **Fig. 1.**



3 Common Terms that Describe Antenna Patterns

If an antenna radiates equally well in all directions--or closely approximates equal radiation strength--then we say that the antenna is *omni-directional*. The turnstile antenna at the top provides a squared-off or nearly perfect circle, so it qualifies. Almost all verticals used alone or collinearly (end-to-end) are omni-directional. In contrast, a horizontal dipole provides a 2-way or *bi-directional pattern*. There are many bi-directional wire arrays with gain, such as the lazy-H or the 8JK flattop.

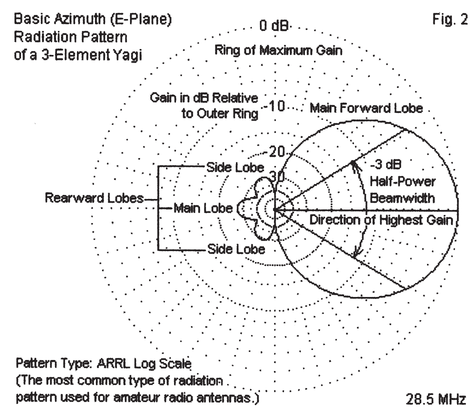
If an antenna, like the Yagi at the bottom of **Fig. 1**, directs a major part of its radiation one way, with only smaller amounts of radiation in other directions, then we have a *directional* antenna. Note that the Yagi has some rearward radiation (if we take the large lobe as being forward), but it is small compared to the main radiation region. There is no sharp line between these divisions. We can have some differences in the lobe strength of bi-directional antennas and directional antennas sometimes have fairly large rearward lobes. So the categories are for general cataloging and not for precise specification.

Not all antennas are directional (by category), but all antennas have *directivity*. Let's place an antenna in free space and measure (or calculate) the power density in every direction around the sphere. Next, take the average of all the readings. We obtain the average power density. Next, measure the power density in the direction where it is strongest. The ratio of the two numbers is the directivity of the antenna. Only an isotropic radiator has a directivity of 1, since by definition it radiates equally well in all directions in free space.

The *gain* of an antenna is the directivity multiplied by the *power efficiency* of the antenna. Power efficiency is simply the ratio of the radiated power to the power supplied to the antenna. For example, if we make the antennas in **Fig. 1** out of copper or aluminum, we shall suffer a small loss of power in the resistivity of the metals. If we use various loading schemes to shorten our antenna elements, then the power efficiency goes down further.

For antennas above real ground, we can also calculate a value for the *radiation efficiency.* Radiation efficiency takes into account not only losses in the antenna, but also the losses from the ground. Some radiated energy results from the energy directed toward the ground but reflected upward again. However, the ground "eats" or absorbs some energy, and so the antenna in its situation becomes less efficient overall. Horizontal antennas over ½ λ above ground achieve radiation efficiencies well above 70%. However, ground-mounted vertical antennas may drop below 30%.

2. How do we represent various aspects of an antenna's radiation pattern? One of the common ways to show the most important features of an antenna's radiation is the radiation pattern or plot. Directional patterns have resulted in an evolving language to describe the pattern parts. **Fig. 2** shows some of the pattern parts for a directional Yagi antenna.



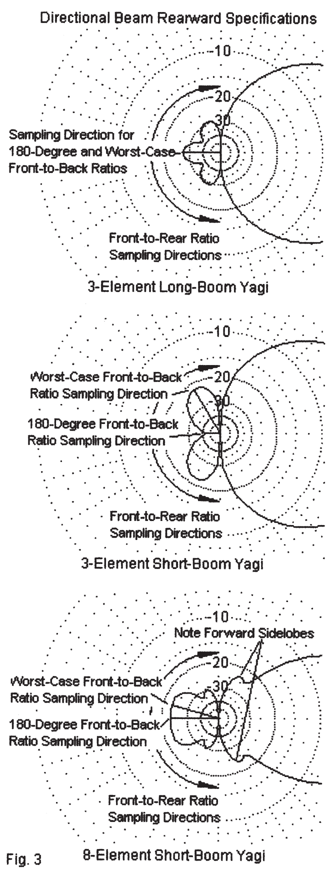
The direction of highest gain defines what is forward, namely, the *main forward lobe*. On each side of the direction of highest gain there are points at which the power level is half the maximum value. The angular distance in degrees between these points defines the *half-power* or *-3-dB beamwidth.*

Note that the pattern shown uses some conventions. First, it is *normalized*. A normalized pattern brings the direction of maximum gain to the outer ring of the polar plot. We take all other readings as amounts below the maximum gain. Second, the pattern expresses gain in dB rather than as a simple power ratio. The power in dB is 10 times the common log of the ratio of the measured or calculated maximum power to some standard power. The most common (but not the only) power standard is the power radiated by an isotropic radiator. (Contrary to some who call the isotropic radiator a 'mere' theoretical concept, we can construct antennas whose radiation patterns are very close to isotropic.) Hence, we generally show power as values in dBi or decibels over an isotropic source.

(The dBd standard, or decibels over a dipole, is passing out of vogue, although some antenna makers still use it. The dBd standard is neither more nor less theoretic than the isotropic standard, since by definition, the gain value in dBd is 2.15 less than the gain value in dBi.) Third, the scale used to display is the *ARRL scale*, which records relative gain values logarithmically so that all pattern are uniform. A *linear scale* requires one to select maximum and minimum values, and the choice of minimum gain value can radically change the appearance of a pattern.

3. What is a front-to-back ratio? The rearward pattern for the Yagi in **Fig. 2** is more complex than the forward pattern. It has 3 lobes. The main lobe is the strongest one and happens to be centered. As well, we find two smaller lobes, one on each side of the main lobe. One term that we often hear and read in connection with rearward performance is the *front-to-back ratio.* This term raises a forest of ideas and terms, almost none of which have uniform use in the antenna field. **Fig. 3** illustrates part of the reason.

We can define the front-to-back ratio as the power ratio--in dB--between the maximum forward gain and some selected rearward gain value. One common comparator is the rearward gain directly opposite the direction of maximum forward gain. This gives us the *180° front-to-back ratio*. We might easily select the strongest radiation in the rear quadrants, regardless of exact direction. In the top part of the figure, the 180° value and the new value are the same. However, in the middle part of the sketch, the 180° figure is very high due to the direct rear null. However, the angling lobes are stronger, so the new figure is lower. In the lowest part of **Fig. 3**, the 180° direction and the direction of the strongest rearward radiation appear on the same general lobe structure, but in somewhat different directions. (Note that in the lowest figure, the forward lobe has begun to develop sidelobes, a common feature of the forward pattern structure when the boom length is over 1 λ.)

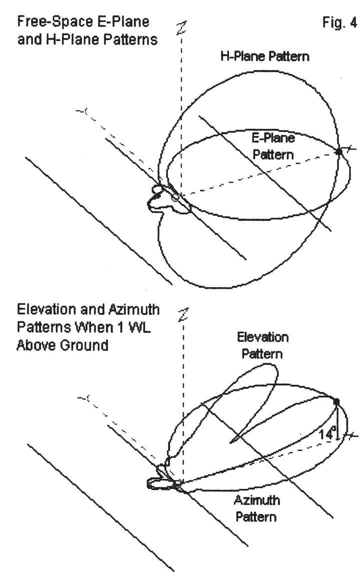


I have so far not named the new figure. Many sources call the new figure the *worst-case front-to-back ratio*. In other circles, such as *The ARRL Antenna Book*, the named applied to this figure is the *front-to-rear ratio*. However, you may note that all 3 parts of **Fig. 3** have a semi-circular arrow. For some purposes, antenna engineers take rearward readings at regular intervals and then take the average of these readings. When we compare the average of the rearward gain values with the maximum forward gain we obtain a third ratio, one that many call the *front-to-rear ratio*. A few call this value the *averaged front-to-back or front-to-rear ratio.*

One reason for mentioning this terminological morass is that you may find any of these values under any of their possible names in the specification literature for commercially made antennas, especially Yagis. So until some industry standard appears, you will have to decipher the claimed specifications of virtually any directional antenna that you contemplate buying.

4. What is the meaning of E-plane and H-plane, and how do these planes differ from azimuth and elevation? Before we leave the subject of antenna radiation patterns and values, let's add one more layer to our pile of terms. In free space, we cannot validly use terms like up and down or horizontal and vertical. Wherever possible, we use the terms *E-plane* and *H-plane* to distinguish major aspects of a radiation pattern. For linearly polarized antennas, like Yagis, the E-plane is the plane that parallels the surface that we would create by filling in the spaces between elements. The H-plane is at right angles to the E-plane. The left portion of **Fig. 4** shows E-plane and H-plane patterns for the 3-element Yagi in free space. Note that the patterns do not have the same shape or beamwidth. H-plane patterns are generally broader than E-plane patterns.

When we place an antenna over ground, we shift to new terms: *azimuth* and *elevation*. The elevation pattern is a semi-circle limited by the earth's surface and peaking at the overhead or *zenith* angle. Although we can take the pattern in any direction, the prime elevation pattern is along the axis of strongest antenna radiation. Note that the strongest elevation lobe is at an angle with respect to the ground. When we take an azimuth pattern, we generally think of a horizontally oriented pattern. We can use any angle with respect to ground, but the most common pattern is at the elevation angle of maximum radiation, that is, the *take-off (TO) angle*. Since the same angle applies at all azimuth headings, we are actually taking a conical pattern and projecting it on a flat surface. At low angles, the projection does not create significant distortion.



Radiation Patterns to Determine Forward Gain for a 3-Element Long-Boom Yagi Free Space and 1 Wavelength Above Ground

These are not the only terms that you will encounter when meeting directional, bi-directional, and omni-directional antennas. However, they certainly are a large enough collection for one episode.