How Accurately Must We Aim a Beam?

L. B. Cebik, W4RNL (SK)

We may divide the question of beam aiming accuracy into two parts: how accurate we can be and how accurate we must be.

How Accurate Can We Be?

The accuracy with which we can aim a directional beam array depends largely on two factors.

1. The accuracy of the beam assemblies initial alignment: A beam's initial direction depends upon the heading on which we lock down the boom and mast within the rotator and upon the accuracy of the rotator's registry of that direction. Consequently, some installers go to great pains to establish the direction of true North and the departure of the beam from that bearing at the point of installation. Once these values are known, the rotator indicator is also set to this heading. Presumably, when everything is set, we lock down the system. The heading will at least be accurate when the beam is pointed in this initial direction.

2. The accuracy of the beam heading indicator, normally as registered on the rotator control box meter or translated into a computer numerical value. Regardless of the readout system, the accuracy of the heading indication depends upon the accuracy with which the indications system follows the changes of heading relative to the initial alignment.

Many rotator systems use a potentiometer in the rotator motor assembly housing, along with a control voltage from the control box. A perfectly linear potentiometer with no dead region at either end of the turning circumference would provide a very accurate indication of the departure of the beam heading from the setting at initial alignment. However accurate the circuitry for translating the voltage returned by the potentiometer to the control box, the potentiometer itself has an accuracy limit, normally expressed as a potential range of error. A +/-1% error range would translate into a +/-3.6-degree range of heading error. Given the environmental stress under which such potentiometers operate--in terms both of temperature and humidity extremes and of the motor and gear operation--it is dubious that even a 1% potentiometer would long uphold that level of accuracy.

We have presumed that the circuitry that translates the incoming voltage from the potentiometer has no error, an unsafe assumption to be sure. Taking all possible sources together, it is unlikely that a rotating system using a potentiometer in the rotator motor housing and standard sorts of indicator circuitry will be better than +/-3% accurate (and possibly less accurate). This accuracy percentage translates into a possible error of up to +/-10.8 degrees. The error is likely to be variable across the horizon in several ways. First, the error level may shift with the bearing. Second, the error level may shift with the direction of rotation, as the wiper contact changes direction. Third, the error level may shift with changes in temperature and humidity. Fourth, the error level may shift with time and the changing conditions of operation of the potentiometer--not to mention the rotator control box indicator circuitry.

It is not difficult to resolve the voltage returned by the indicator potentiometer down to several decimal places. Translating this voltage into beam headings in tenths of a degree--as read out on a numeric display--is also routine. However, since the basic accuracy of the return voltage is subject to so many potential error-inducing factors, such a display would be more a satisfying illusion than a true registry of the beam's actual heading.

Obtaining a more accurate readout of the beam heading would require an independent measurement system. One such system would include a self-correcting sensing and indicator system of true North or some other preset bearing. It would then measure the difference between the known or reference bearing and the beam heading, possibly taken by real or virtual measurements of the boom vs. the preset heading. Laser interception of the boom and a fixed reference bar could easily achieve 1-degree accuracy for the beam system. However, for almost all installations, the cost would be prohibitive. Likely, it would also require alignment before each use.

In the end, the bulk of amateur operations will have to be satisfied with an accuracy of beam heading read-out somewhere in the +/-1 to +/-5 percent region.

How Accurate Must We Be?

The answer to our second question depends upon several factors regarding the beamwidth of directional antennas. Most amateurs are familiar with the registration of antenna beamwidth in terms of half-power or -3 dB power points. Relative to the bearing of maximum forward gain, we may obtain a beamwidth in degrees by determining the bearings on either side of the maximum gain heading at which the gain decreases by 3 dB.

However, the -3dB beamwidth is too broad for those types of operation most concerned with maximum precision of beam heading readouts. No standard beamwidth currently exists to evaluate the question at hand. Therefore, solely for the sake of discussion and with absolutely no pretense of adoption, I shall create a standard. For standard voice and CW operation, a drop in gain of 0.5 dB is too small to detect. However, for some of the newer modes of operation, such a drop may mean the difference between a signal being received and not being received. A 0.5-dB change of gain represents a change of less than 0.1 S-unit as currently set into meters at 5 to 6 dB per S-unit. Although not detectable in many types of communications, let's take this unit as the hypothetical least detectable change of gain for at least some types of operation.

Using such a standard will allow us to re-evaluate antenna beamwidths by yielding new values. If someone wishes to adopt a more liberal standard, the resulting beamwidths will always be greater than the +/-0.5 dB beamwidth. Hence, any conclusions reached in the following notes can be readily adjusted to the revised standard.

With a standard at hand, we have only to apply it to typical antennas used by the amateur community. As a sampling, I scanned several dozen beam antennas from my collection of models to determine both the standard -3 dB and the suggested -0.5 dB beamwidths. The standard figure was produced by the modeling software--NEC-4 as commercially implemented. However, the -0.5 dB beamwidth was determined by exploring the azimuth pattern until the gain decreased by half a dB. Since pattern exploration occurs in increments, I chose as the demarcating value the heading on which the gain was at or just above -0.5 dB relative to the maximum forward gain so as not to be too liberal with the recorded beamwidth value.

Using NEC models of beam antennas is convenient, since measurement of the -0.5 dB heading would be difficult, at best. Models presume certain conditions that may or may not be true of real antennas. For instance, the models of standard beam designs all produce symmetrical patterns. The symmetry of the pattern of a real antenna, especially as it increases in frequency and within the tight limits of -0.5 dB points, would be open to question. The models all use free- space gain as the reference in order to fairly compare antennas having vastly different gain values. Over real ground, the take-off angle--or elevation angle of maximum radiation--will vary slightly as we increase the gain of a directional beam, which would make comparisons a bit more difficult.

The table below provides model figures for antennas of 2 types: monoband Yagis and monoband quads. Yagis are far more numerous in the listing--numerous enough not only to show progressions, but as well to show occasional slight departures from progression main lines. The collection of quads is barely large enough to form a progression, but it is sufficiently extensive to allow some comparisons with the group of Yagis.

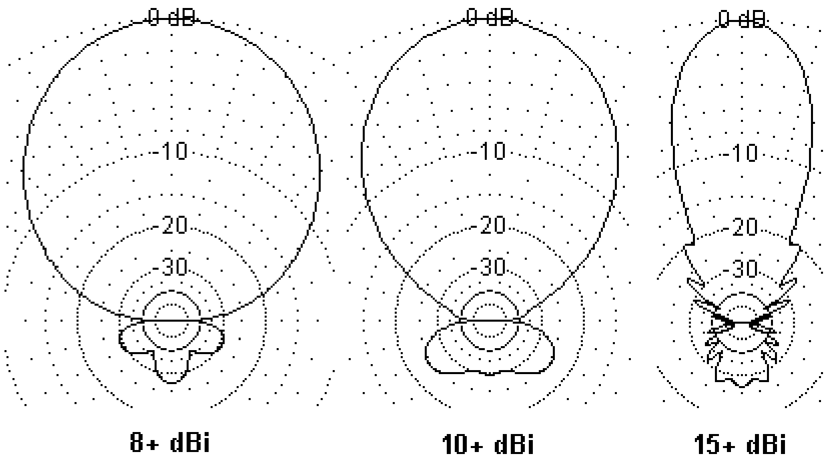
. . . .

Representative Beams and Their Beamwidths

Free-Space Gain dBi	+/-3 dB B/W degrees	+/-0.5 dB B/W degrees	No. Elements
Yagis			
6.13	70.0	28	2
6.27	68.8	20	2
6.48	68.8	28	2
7.12	66.6	26	3
7.80	63.6	26	3
8.11	62.8	24	3
8.48	61.2	24	4
8.90	59.8	24	4
9.25	58.8	24	4
9.71	55.6	22	4
10.05	54.6	22	5
10.21	52.6	22	5
10.22	53.6	22	5
10.23	53.6	22	6
10.23	52.6	20	6
10.28	52.4	20	5
10.53	51.8	20	5
11.07	49.2	20	7
11.33	49.8	20	6
11.89	44.6	18	8
12.25	46.2	18	6
12.54	42.5	18	8
13.27	36.7	16	9
13.33	40.2	16	8
13.89	37.4	16	10
14.21	35.8	14	11
15.22	32.6	14	13
15.68	32.0	14	14
15.68	31.2	12	14
16.27	29.0	12	16
17.62	25.0	10	21
18.59	22.6	10	26
18.66	22.4	8	25
19.64	20.4	8	31
Quads			
7.06	75.0	30	2
7.49	74.0	30	2
8.88	65.4	26	3
9.56	61.6	24	4
9.74	60.2	24	3
9.96	57.8	24	4
10.00	57.0	24	6
11.16	49.6	20	5
11.34	49.2	20	5
11.89	45.2	18	6

. . . .

The table reveals several notable items about gain vs. beamwidth.



Gain vs. Beamwidth: The General Trend
The Higher the Gain, the Narrower the
-3 dB and -0.5 dB Beamwidths

Fig. 1

1. The general trend: As shown in **Fig. 1**, the general trend in each group of directional beams is a narrower beamwidth for a higher gain. This fact has been known since beam antennas first appeared in the dim recesses of radio history. However, few amateurs have a due appreciation of the quantification of this phenomenon. Therefore, the table is worth reviewing. Note also that, within limits, the gain-beamwidth relationship is independent of the number of elements within an array. Rather, the gain derived from the beam is the chief determinant of both -3 dB and -0.5 dB beamwidth--or anything in between. Indeed, the exact boom length is also secondary to the beamwidth, since some nearly equal-gain arrays have differences in operating bandwidth: narrower bandwidth arrays can often achieve a peak gain on a shorter boom. Of course, excessively widening the beamwidth standard can easily let the check points encounter secondary lobes-- although not for the reasonably well-behaved patterns in **Fig. 1**--and thus empty the figure of meaning.

For the most part, HF operators work with antennas with less than 12 dBi free- space gain, in other words, less than 8-9 elements on a long boom. The majority work with antennas yielding between 7 and 9 dBi free-space gain. Consequently, the available -0.5 dB beamwidth will be at least 20 degrees (+/- 10 degrees of the desired heading for most operators. Even those working with beams capable of 12+ dBi free-space gain will have a -0.5 dB beamwidth of 18 degrees.

The situation differs as we increase gain, as is common in VHF and UHF operation. Beamwidths at the -0.5 dB level shrink to single digit levels, increasing the difficulty of accurately aiming an array. Indeed, independent references are often needed to precisely position a very high gain array on its target.

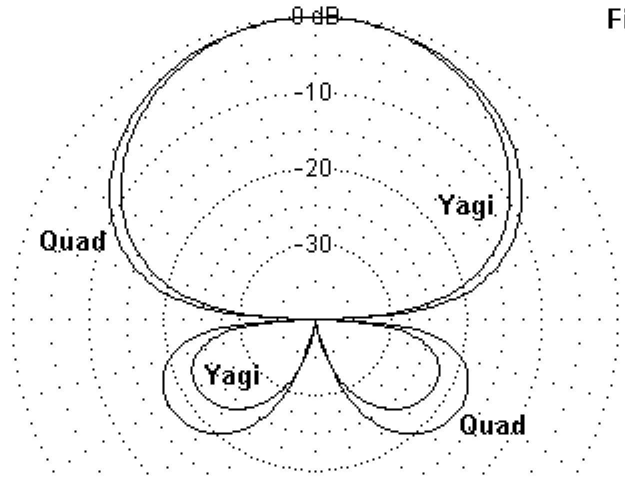


Fig. 2

Yagi vs. Quad Beamwidth
for Equal-Gain Arrays
Plotted on Linear Scale

2. Quad vs. Yagi beamwidth: At every level sampled where the gain of a quad array could be roughly equated with the gain of a Yagi array, the quad exhibited wider -3 dB and -0.5 dB beamwidths. As shown in **Fig. 2**, the difference is most dramatic at lower gain levels: the plots show antennas with 7+ dBi free-space gain levels. The linear plot is necessary to display the two patterns clearly.

As the gain of the array increases, the differential in beamwidth between Yagis and quads decreases. However, it never disappears entirely within the range of arrays sampled here for the quads. However, since no quad with a free-space gain above 12 dBi was used in the listing (since I do not have any in my collection of models), there may well be a point at which the differential disappears from view.

What applies to the differential between Yagis and quads also applies to other types of arrays. It is always unwise to assume from a glance at an azimuth pattern that a directional beam has a certain order of beamwidth at any level used as the standard. Careful checking of each design is necessary to know for certain.

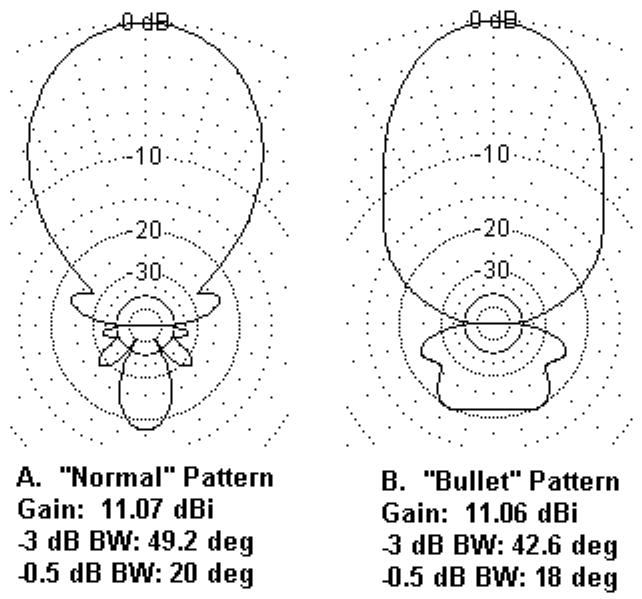


Fig. 3 Pattern Shape Effects on Beamwidth

3. Exceptions to the trend: Within the list of directional arrays, there are a few exceptions to the general progression of gain vs. beamwidth correlations. Moreover, the progression would not graph out as a smooth curve for either the - 3dB or -0.5 dB levels. **Fig. 3** demonstrates why the curve would be irregular. Not all patterns are the smooth ovals that we associate with "perfectly designed" parasitic arrays. Although the curve on the left resembles in its main forward lobe outline the middle pattern of **Fig. 1**, the forward secondary lobes make it difficult to know for sure whether the main lobe has been distorted from the most "well-behaved" condition. Hence, ripples in the general progression are bound to occur wherever secondary forward lobes are present.

As the right side of **Fig. 3** demonstrates, even when the secondary lobe structure seems invisible, it may exert an effect on the beamwidth. For equal-gain antennas, the "bullet" pattern to the right has a narrower beamwidth by noticeable amounts at both levels of interest in these notes. The widening of the pattern as the bearings approach the side nulls is an indication of secondary lobe formation.

In fact, changes in the azimuth pattern that can affect the beamwidth may occur across the operating bandwidth of an antenna, even though gain changes are small to negligible. For well-designed arrays with limited operating bandwidths, such differences are likely to be only of academic interest. However, they do exist and may play a role in performance wherever designs are pressed beyond their limits.

Some Tentative Conclusions

The second portion of these notes was designed to graphically and tabularly demonstrate the relationship between gain and beamwidth for a span of array gains that cover most amateur operations. However, the basic question for the second part of these notes was how accurate our beam aiming must be to achieve the strongest signals between locations. If we combine the notes for the two portions of this preliminary investigation, some tentative answers emerge.

1. For lower gain, wide beamwidth arrays--typical of most (but not all) HF operations--excessive concern with the precise heading of a beam seems to be beyond the level of necessity. The potential errors of heading indicators are offset by the very wide -0.5 dB beamwidth--in most cases, better than 20 degrees. Unless on the cusp of detectability, most changes of 5 degrees in beam heading will not yield any change in signal strength that will show up on a meter. For this class of arrays, simply point at "Europe" or "Southeast Asia" (for the U.S. operator) will be accurate enough, although a final tweaking to compensate for unquantified indicator system errors may be useful. For voice and CW operations, where the -0.5 dB standard for detectable signal strength change is too stringent, the available beamwidth before a change of beam direction would make a difference can be considerably wider.

2. For very high gain system with inherently narrow beamwidths, such as those above 12 dBi free-space gain, the indicator system error and the -0.5 dB beamwidth begin to merge. For such systems, adjunct aiming accessories are certainly warranted as a matter of course for each change of beam direction. Such auxiliary systems may involve manual or automated fine aiming relative to signal strength, or they may make use of adjunct directional aids derived from precise navigation work.

3. For the intermediate level system with free-space gain levels between 8 and 13 dBi, we have a situation that is difficult to define in terms of operational actions. When used for casual or slow-rate operations, manual system tweaking based on signal strength of the target station (and possibly QRM from other competing stations) often suffices. However, for high-speed and competitive operations with definite target stations, even an operating assistant may not be able to keep pace with the need for adjusting headings to be as precise as necessary for the highest efficiency. It is in these kinds of cases that we find appropriate concern with precision installation settings, indicator system error levels, and (automated) adjunct heading adjustments.

However, system error potential and antenna beamwidth alone--even when all normal variables are taken into account--do not tell the full story. To these factors we must add the propagation conditions and paths that exist at any given moment of operation. This final collection of variables can sometimes (but certainly not always or even most of the time) void the best results of the most precise system that does not rely on careful listening and re-aiming for the strongest signal.

In the end, each operator must make his or her own decisions on how much effort to place into each phase of the problem of aiming a directional array. These notes--especially the beam data--are designed to help with, but not substitute for, the process through which each station operator must go in directing his or her array.

Go to Amateur Radio Page