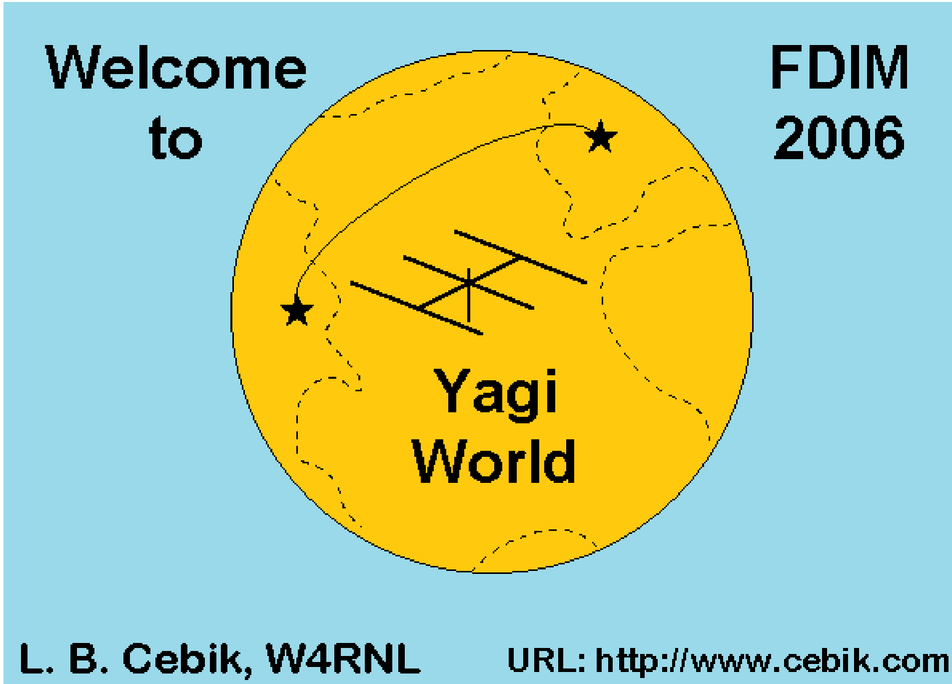
Welcome
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Yagi
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Welcome to Yagi-World

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A typical QRP operator loves simple antennas. However, temptation comes to us all at one or another time. The lure of DX, competition, or simply the desire to have reliable communications with a family member or dear friend is often enough to bring thoughts of directional beams. Among directional antennas, the Yagi-Uda (or Yagi, for short) parasitic array is now the gold standard. That is, the Yagi brings in more gold to antenna makers than any other type of amateur antenna.

Along with the gold, commercially made Yagis carry with them a number of mysteries, called specifications. Like all commercial products, let the buyer beware. If you have some remodeling work done to your home, unless you know the differences between good and bad materials and practices, you may not be able to tell whether the builders did a good or bad job until the work fails. Likewise, unless you know something about Yagis, you may not be able to tell the difference between a good and a bad design until it is too late to correct an error in your buying judgment.

So my premise is simple. Let's survey some of the key elements in Yagi performance to obtain a background against which we can make intelligent judgments about the Yagi that we might buy. Welcome to the world of Yagis.

The Weighty Basics

If you commit to installing a Yagi made by one of the major antenna makers, you usually need also to consider a support structure and a rotator. **Fig. 1** shows some of the man elements of both the overall structure and of a few details that tend to concern Yagi buyers. We shall not pause to cover proper installation of these elements.

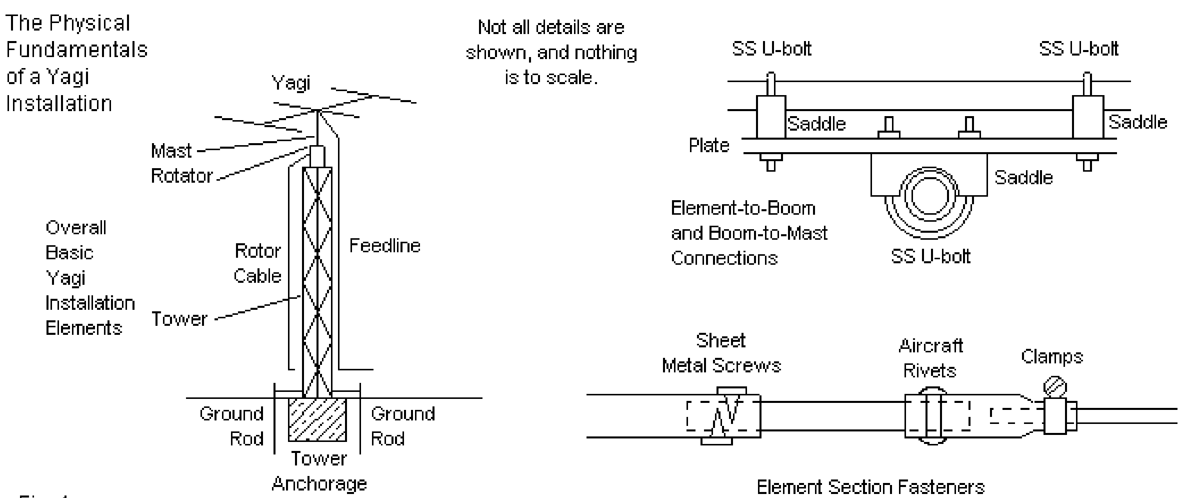


Fig. 1

However, we can note the first of the key Yagi specifications: *weight*. The tower and its method of installation must support the antenna weight. As well, the rotator requires a minimum size for the antenna weight. Do not overlook this critical specification in antenna specification lists, since antenna weights for the very same electrical design can vary considerably. For a given band and antenna design, weight will vary according to the materials used. We can conveniently divide the world into three antenna construction materials.

1. The American Oak: The most common tubular material used in Yagi construction is 6063-T832 aircraft aluminum tubing. In the U.S., the material is readily available for home brew Yagis from a variety of sources. American tubing typically comes in eighth-inch steps, with 0.56" thick walls for perfect nesting from one size to the next. The material is strong and returns to shape after wind forces try to bend it. In fact, making an intentional bend requires special procedures to prevent cracking at the bend.

2. The American Willow: Some antenna makers use thinner wall tubing without loss of strength in the wind. One way to tell if the tubing is thinner than the de facto oak standard is the use of slight diameter reductions at every junction. These antennas can cut the weight of a given design by up to about 1/3rd and include the use of lighter boom material. Willow-based antennas will show more deflection in the wind, but may be as strong as oak-based designs--if we construct the elements properly.

3. The European Ironwood: Today, we have access to many well-designed Yagis made in Europe. Typically, Europeans do not have access to the same sizes of aircraft aluminum that are common in the U.S. Metric aluminum (or aluminium, in the Commonwealth) tends to step in metric sizes with a basic 2-mm wall thickness--about 0.079". For a given element design, the elements will be heavier--up to about 2 times heavier than an equivalent U.S. design. The added element weight calls for a heavier boom with a thicker wall, and the hardware size increases at every step of the assembly. Hence, with few exceptions, European Yagis tend to weigh considerably more than their U.S. counterparts.

The result is a simple question for the total Yagi installation: how much weight are you willing to handle when sizing all of the components to match? Unlike current medical concerns about the U.S. population, lightness in Yagis is not always a virtue, and heaviness is not always a vice. However, a system that mismatches its support, rotating, and antenna components is always a disaster waiting to happen.

Gravity is not the only force acting on a Yagi. Every antenna is subject to *wind loading*. We expect wire antennas to break periodically under forces created by the wind (including the deflection of supporting structures). So we do not bother with wind-load specification. However, we do expect Yagis to last forever, given the size of our investment in them. Therefore, every Yagi carries with it a maximum wind-survival rating and a wind-area. The wind area relates mostly to matching the antenna to the rotator, which has a brake or hold-in-position mechanism that works only until the winds and the antenna area exceed ratings. Then the mechanism lets the antenna rotate, either by design or by the unintentional destruction of an internal part.

The overall wind-survival rating rests on the combination of materials and element construction. The use of tapered element diameters in Yagi construction is no accident. Except at 10 meters and upward, uniform diameter tubing in amateur Yagis would simply snap in high winds. A steady high wind may actually succeed in bending antenna elements. Either case is fatal to antenna performance. By the judicious selection of element segment lengths--aided by computer computations these days--antenna makers can create elements that will survive high winds. Very often, the second section from the element center may extend all the way through the first section to double the wall thickness for extra strength. Yagis for 40 through 20 meters often use this technique to improve the wind-survival rating.

Typically, amateur Yagis have wind-survival ratings from 80 to 120 mph, depending on price and the call to makers for heavy duty versions of their antennas. The U.S. government has readily available maps that list the highest winds expected in every county in the country. Be certain that any Yagi that you buy or build will have a wind survival rating that exceeds the value for your county. Alternatively (or additionally), consider countermeasures against the wind, such as a tower that you can lower when expecting bad weather.

There is one final wind-loading factor: the mast that extends from the rotator to the boom. Even if it is quite short, never use pipe material for the mast. Use a rated tube material. Pipe material is soft and intended to bend under external pressure. Pipe is stiff. It deflects the wind.

When you survey your choices for a given Yagi design, do not neglect the hardware and method of assembly. All hardware should be stainless steel. Galvanized hardware may be suitable for outdoor decking, but not for antennas. Likewise plated steel is forbidden. Besides the problem of rusting, most steel hardware will create bi-metallic electrolysis with the aluminum elements and results in fairly rapid deterioration of the junction. Stainless steel is immune to the effect.

Element and boom saddles should be solid for American oak or willow elements to reduce the chances of element crushing during assembly. Many European designs use muffler-clamp saddles--usually without the teeth on their edges--a practice that is generally satisfactory with the thicker-wall element tubing.

Element section fasteners generally come in 3 varieties and breed some of the longest-standing controversies in antenna work. Where two sections of an element overlap, we can fasten them with sheet metal screws, clamps, or aircraft (not hobbyist) rivets. One maker uses rivets exclusively, and his willow-based designs have shown no unusual problems. Most commonly, standard steps of aluminum handle stainless steel sheet metal screws quite well, although some antenna users report loosening with time. A few makers still use clamps at element section junctions. Be sure to coat the overlapping junctions and fastener contact areas with conductive anti-seizing compound to allow disassembly of the antenna after a few years of service in the weather.

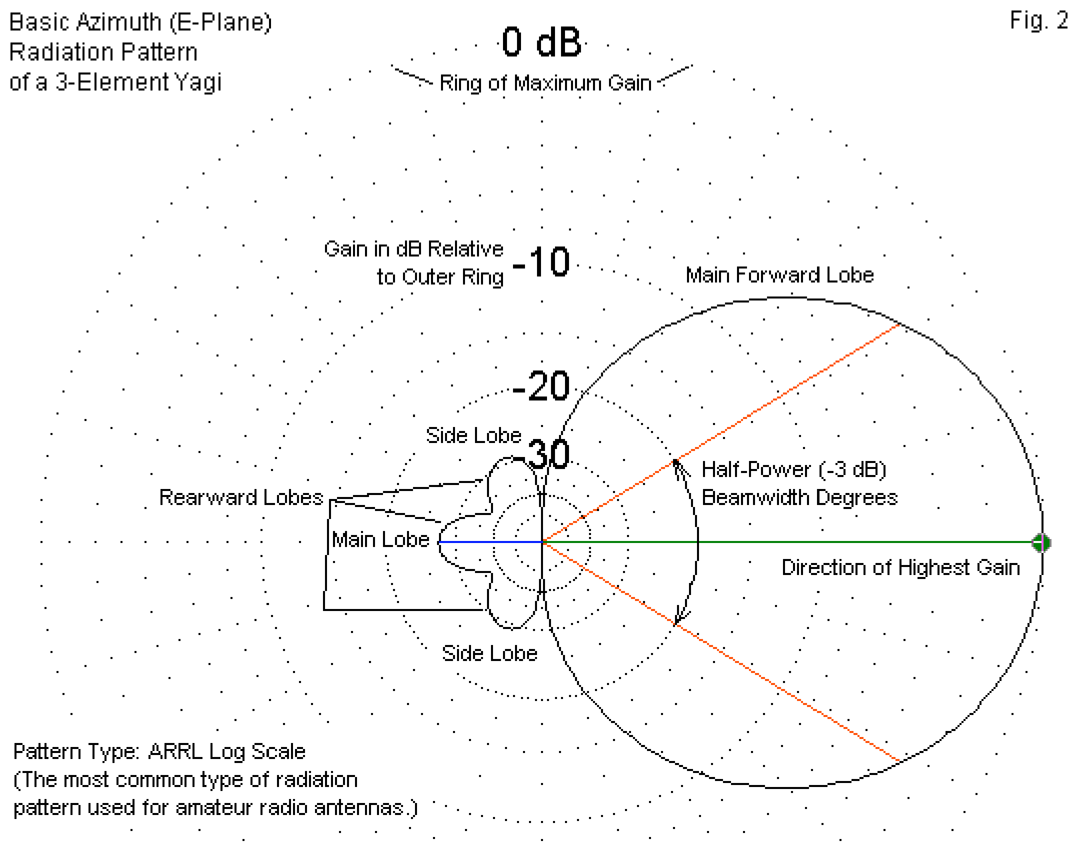
I shall pass over all mechanical and electrical safety measures, as well as means of attenuating common-mode currents, since our goal is the beam itself. Finally, be certain that you schedule and perform periodical preventive maintenance inspections and tests on the same regular (6-month) basis that you use for your trusty wire antennas.

The Maze of Electrical Specifications for Monoband Yagis

To obtain a grasp of basic Yagi specifications, I shall start from scratch and assume no knowledge of the rudimentary terms associated with antenna radiation patterns. Those with modeling or other antenna design and analysis experience may slumber momentarily, but a review has never proven fatal to anyone. **Fig. 2** presents the free-space radiation pattern of a typical long-boom 3-element Yagi. The pattern is technically not an azimuth pattern, because in free space we have no way to distinguish up and down from side-to-side. E-plane patterns are generally in the plane of the elements. (For 3-D quads, they are in the plane of the element portions contributing most to the radiation.)

Conventionally, we represent the radiation pattern on a polar plot, although rectangular graphing is also possible. The plot style most commonly used is called the ARRL log scale, because the power gain levels (recorded here in decibels or dB) use a logarithmic scale from the outer ring down to the center. The center point value is so low that it is nearly infinitesimal. We might have arranged the power level values on a linear scale, but that would force us to select for each pattern a minimum level for the center point--and what we select for the minimum can change the pattern appearance significantly. So we shall stay with the ARRL log scale. (In *QST*, you will see different main rings for values below the outer ring, so always be sure to look at the scale used from outer ring to center point.) Furthermore, the pattern is *normalized* so that the maximum gain of the antenna in any sampled direction just reaches the outer ring. Therefore, every other ring in the pattern shows how much weaker (in dB) the pattern is relative to the maximum gain.

A Yagi pattern has two main parts: the forward and the rearward pattern components. The components consist of one or more lobes (regions that culminate in a maximum strength point), and intervening nulls. For the subject antenna, there is only 1 forward lobe, also called the *main forward lobe*. The rearward components show why we add the word "main" to lobe terms. The rearward portion of the pattern has 3 lobes. With Yagis, we conventionally call the rearward lobe in line with the main forward lobe the *main rearward lobe*. (Note that the main rearward lobe need not be the strongest lobe to the rear, although the main forward lobe is almost always the lobe showing the highest gain level.) Lobes that go off in other directions become *sidelobes*. Forward sidelobes are also possible, but simply do not appear on Yagis this short.

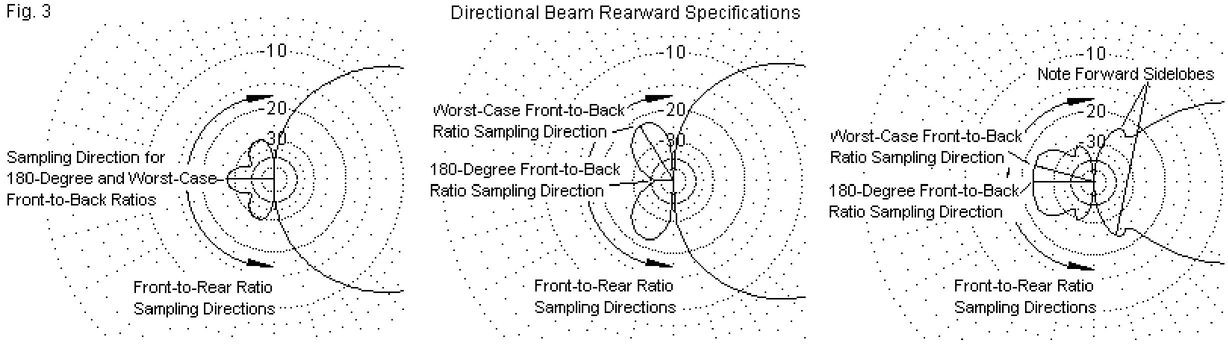


The angular lines in the main forward lobe indicate the directions at which the gain drops by 3 dB relative to the maximum forward gain of the antenna. The other name for these lines is the half-power points. The number of decrees between these lines defines by convention the antenna beamwidth. If we count radiating dotted lines on this EZNEC plot, we shall discover that the beamwidth for the subject antenna is a bit over 60°. Finally, note the deep nulls on each side of the pattern, 90° away from the maximum-gain heading. You will only see nulls this deep on free-space patterns. So if an antenna maker displays patterns having nulls that go all the way to the center-point, you know that he generated them with a free-space model.

One of the most basic antenna specifications that you will find in maker literature is the *front-to-back ratio*. Precisely here we must pause, not only to grasp the terminology, but as well to learn a bit of flexibility in our thinking. First, not everyone uses the basic term in the same way. So we shall find some refinements in the terminology. Second, not everyone who uses the refined terminology uses it in the same way. Our goal is not to say who is right and who is wrong. Instead, our goal is to learn the right questions to ask so that we can find out what a maker means by his use of "front-to-back ratio." **Table 1** and **Fig. 3** will be our guides, but only for part of the journey. Both the table and the graphic present information on the rearward performance of 3 sample antennas. Numbers and pictures do not always determine how people use words. Therefore, we shall proceed along one fork in the front-to-back road, and then we shall backtrack and proceed down the other path. The lesson that we shall learn is not to take at face value everything that appears on a road sign.

Sample Forward-Rearward Power Gain Ratios							Table 1
Antenna	Max Fwd Gain dBi	180 Rear Gain dBi	180-D F-B Ratio dB	Max Rear Gain dBi	Wst-Case F-B dBi	Ave Rear Gain dBi	Front-Rear Ratio dB
3 El Long-Bm Yagi	8.11	-19.01	**27.12**	-19.01	**27.12**	-23.20	**31.31**
3 El Short-Bm Yagi	7.12	-34.72	**41.84**	-14.80	**21.92**	-21.39	**28.51**
8 El Short-Bm Yagi	12.29	-10.71	**23.00**	-10.31	**22.60**	-16.12	**28.41**
Any Front-Rear Ratio in dB = Max Fwd Gain in dBi - Rear Gain (180, Max Rear, or Ave Rear) in dBi							

Fig. 3 Directional Beam Rearward Specifications



3-Element Long-Boom Yagi 3-Element Short-Boom Yagi 8-Element Short-Boom Yagi

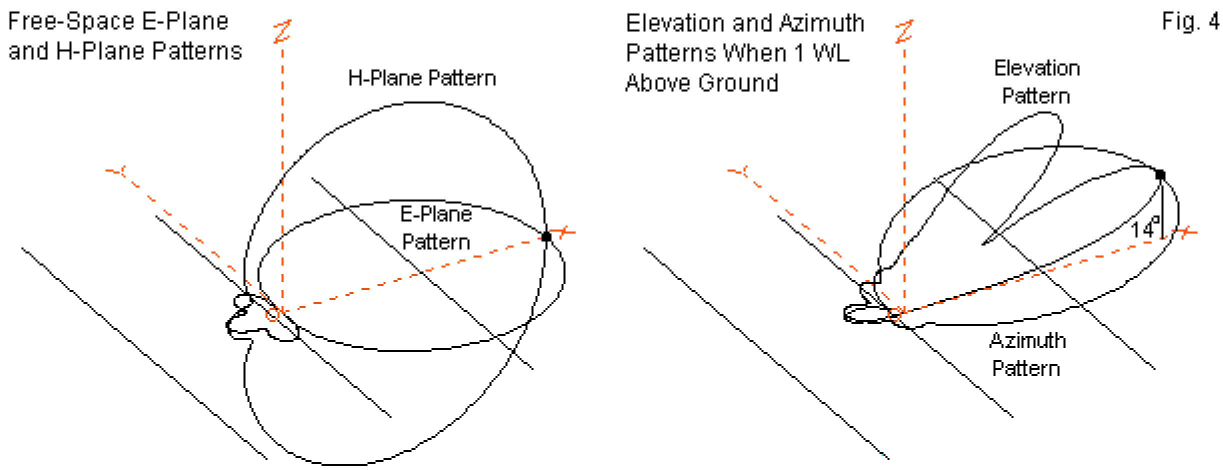
Our first step will be to present some initial definitions (with modifications to come). These definitions will coincide with the labels in **Table 1**. The *180° front-to-back ratio* is the main lobe forward gain (or the maximum antenna gain) minus the gain of the lobe (however big or small) that is 180° away from the heading of the maximum forward gain. This value of front-to-back ratio is most commonly used in general antenna literature and is the one shown in most NEC antenna software. If the main forward lobe is split or does not align with the graph heading, the 180° front-to-back ratio is 180° away from the direction of maximum pattern strength. Hence, the value may not be for a direction directly to the rear of the antenna structure. Since a Yagi is usually symmetrical, the maximum gain will normally be directly forward, and the 180° front-to-back ratio will indicate the relative strength to the direct rear. Note that if we use a normalized scale, we can read the front-to-back ratio directly from the plot--between 25 and 30 dB relative to the maximum gain of the antenna in the leftmost pattern.

In **Fig. 3**, the leftmost pattern comes from **Fig. 2**. The strongest rearward lobe is 180° from the main lobe. However, the center pattern shows a 180-degree gain of very tiny proportions. Hence, the 180° front-to-back ratio is very large (over 40 dB compared to a "mere" 27 dB for the leftmost pattern). Yet, we find rearward lobes that have considerable strength. The line through one of those lobes indicates the direction of maximum strength. It is only about 22 dB weaker than the maximum gain. Some sources call this the *worst-case front-to-back ratio*, and its value is the maximum forward gain minus the highest value of gain in either rearward quadrant. For this antenna, the 180° front-to-back ratio does not give a true picture of the QRM levels from the rear, so some folks prefer to use this figure as a better indicator. The worst-case front-to-back ratio provides the most conservative value for rearward suppression of QRM. The rightmost graphic in **Fig. 3** shows that the 180° and the worst-case front-to-back values do not require separate lobes, even thought the values differ. (We may debate elsewhere whether the 8-element Yagi main rearward radiation is a single main lobe or a junction of 3 overlapping lobes.) When we find the two ratios related to the same rearward lobe, we usually do not find much difference in their value.

We are not done with front-to-back ratios. Each sketch in **Fig. 3** contains an arc going from 90° on one side of the line of maximum gain around the rear to the other point that is 90° from the maximum gain line. Suppose that we add up all of the gain values at the headings that pass through the arc. Next take their average value. Subtract the average gain value to the rear from the maximum forward gain and you arrive at what some call the *front-to-rear ratio*. Others call this the *averaged front-to-back ratio*. **Table 1** performs this task at 5° intervals, which is sufficient for this sampling. If you compare the front-to-rear ratio with the other front-to-back ratios, you can see why an antenna maker might use it. The value is higher than all of the other values (with the exception of the 180° front-to-back ratio for the 3-element short-boom Yagi). The rationale behind using the front-to-rear ratio is that it provides an averaged total picture of the rearward QRM suppression. At least one maker uses this technique for rearward specifications.

The usages listed here, although fairly old, are not universal. For example, ARRL's antenna literature (including the influential *Antenna Book*) uses "front-to-rear ratio" to mean what we have here called the "worst-case front-to-back ratio." You may, of course, select your personal favorite set of terms, but that is unimportant when you are in the market for a Yagi. The key question is this one: what term does each maker use for rearward evaluation, and what does he mean by that term? Until you have that knowledge in hand, you cannot compare beams sold by separate makers.

If all Yagi makers used free-space patterns as the basis for their specification lists, we might have an easy time sorting them out. However, some makers use a ground reference. Therefore, we need to master not only free-space patterns, but patterns taken over ground as well. This process begins by understanding more fully the difference between the two sets of plots. Here we can turn to **Fig. 4**.



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

On the left, we find a 3-element Yagi (our long-boom sample) and the E-plane and H-plane patterns associate with the free-space environment. As noted earlier, the E-plane pattern aligns with the plane formed by the 3 elements. The H-plane pattern is at right angles to the E-plane pattern, when both patterns use the same heading for maximum gain. Note that the patterns meet at the maximum gain point and again at the point that is 180° from the maximum gain heading.

If we place the antenna over ground, both patterns undergo critical shifts in what they show. We change the pattern names to elevation and azimuth, since we now have a ground reference and potential compass headings. The sample on the right places the antenna 1 λ above average ground. Normally, the elevation pattern aligns with the maximum gain heading--but it need not do so. Besides showing multiple elevation lobes, the Yagi's maximum gain now occurs 14° above the horizon, the *take-off angle*. The take-off angle will vary with the antenna height (and, as we shall soon see, with the antenna forward gain). For most purposes, we then obtain an azimuth pattern at the take-off angle, as shown by the dot that indicates a meeting of the two patterns. (Once more, we can take the azimuth pattern at any elevation angle, assuming that we have a reason to do so.) Note that every point on the azimuth pattern outline is elevated 14°, not just the maximum forward gain heading. When we obtain a front-to-back ratio, it implies an azimuth comparison only, so that the sampled rear lobes or lobes are also at the same elevation angle. The comparison may or may not show the point where a rear lobe is strongest or weakest, since that point may occur at a different elevation angle.

Let's add one more final note about pattern conventions. The patterns that we have shown emerge from the exact center of the antenna geometry, not from the driver or any other particular element. The reason that we use this convention lies in the different sizes of the components of each sketch. A far-field radiation pattern extends outward an indefinitely large distance. In fact, the distance is so large that by comparison, the antenna is infinitesimally small. Even a visible dot would be technically too large to indicate the antenna size. If we shrink the antenna to its proper scale for the pattern shown, then it will withdraw uniformly down to an invisible dot at the very center of the pattern. Hence, when we draw the pattern and the antenna so that both are visible, we expand in the reverse direction, and the antenna center becomes the origin of the radiation plot.

Dipole and 3-Element Long-Boom Yagi Forward Gain Values						Table 2
Antenna	FS Gain	1-WL Gn	Refl Gn	FS Gain	1-WL Gn	Refl Gn
	dBi	dBi	dB	dBd	dBd	dB
Dipole	2.13	7.63	5.50	-0.02	5.48	5.50
3 El Yagi	8.11	13.34	5.23	5.96	11.19	5.23
Difference	5.98	5.71	-0.27	5.98	5.71	-0.27
Notes:	Difference = Advantage of Yagi over dipole in the same environment					
	Refl Gn = Gain supplment due to ground reflection; average ground					
	1-WL Gn = Gain at 14-degrees elevation over average ground					
	Antennas use 0.5" diameter aluminum elements @ 28.5 MHz					

We are now ready to tackle the basic concepts of reporting the maximum forward gain of a Yagi. As indicated in **Table 2**, we have a number of choices available, and the shaded entries indicate the ones most commonly used. For reference, I have added a dipole to the 3-element long-boom Yagi that is our fundamental sample.

The most common 21st century power gain reference is *dBi*, meaning the power gain of the antenna in the favored direction as measured in dB over an isotropic source. An isotropic source is one that radiates equally at all elevation and azimuth angles, forming a perfect sphere, if we could model the pattern. Although some folks have developed antennas that radiate in an isotropic manner, the isotropic radiator is a useful tool in calculating power gain, since all power gain numbers use a single standard of comparison. $Power_{dB} = 10 \log_{10}(Power_1/Power_{Ref})$. If the reference is isotropic, then the power gain term is dBi. (If a maker specifies simply dB, then the reference is anybody's guess in the absence of an explanatory footnote.) In the table, a standard dipole made from aluminum and as thick as the Yagi elements has a free-space gain of 2.13 dBi, while the Yagi has a free-space gain of 8.11 dBi. This result gives the Yagi a 5.98-dB gain over an equivalent dipole in free space.

The alternative standard for power gain measurement is *dBd*, meaning the power gain of the antenna in the favored direction as measured in dB over a theoretic dipole. A theoretic dipole is composed of lossless wire that is infinitesimally thin. It has by calculations from basic antenna theory a gain of 2.15 dB over an isotropic source. Hence, the difference between dBi and dBd is always exactly 2.15 dB. In free-space, the Yagi has a gain of 5.96 dBd, but the thick aluminum dipole has a gain of -0.02 dBd. The gain of the Yagi over the thick dipole in free space remains 5.98 dB. Although the use of dBi seems less confusing, the dBd measure is still popular with some antenna makers, especially in Europe. In the U.S., makers who model or measure their beam performance over ground still favor dBd.

Let's move our antennas to exactly 1 λ above average ground and re-model them. The Yagi shows a maximum gain of 13.34 dBi and 11.19 dBd. The lower number might sound more conservative, but it hides a deceit, since it seems to imply that the gain of the Yagi is 11.19 dB over a dipole. However, a real dipole at the same height has a gain of 7.63 dBi and 5.48 dBd. The thick dipole has a gain of 5.48 dB over a dipole. We shall be stuck in a conundrum unless we clearly specify that the real dipole has gain over the theoretical foundation of dBd measurements. In fact, over ground, whether we use dBi or dBd, the Yagi has a gain of 5.71 dB over a real dipole at the same height over the same ground quality.

In free space, the Yagi showed 5.98-dB gain over the real dipole, but 1 λ over average ground, the gain advantage dropped to 5.71 dB. Although the difference is too small to be operationally detected, we still must wonder what happened to the 0.28 dB. The answer lies in the basic antenna losses and the ground losses that result in the reflection amount that we add to the direct gain. As we shall soon see, the higher the initial gain and the larger the number of elements in our Yagi, the lower grows the increment of additional gain that we accrue by placing the antenna over a fixed ground at a fixed height.

Some makers give their maximum gain values in free-space terms, using either dBi or dBd. Other manufacturers model or measure their antenna forward gain values at some height above ground. They may or may not specify the ground quality, and they may give the height in terms of feet or other physical measure or in terms of wavelengths above ground. If the frame of reference is not clear in a specification sheet, then you have some questions to ask before you start making comparative performance judgments. As well, our brief notes only provide a modicum of translation guidance. For example, if one maker gives specifications for 70' for all antennas, that height is 1 λ only on 20 meters. It is 2 λ on 10 meters. If another maker uses a 1-λ height for all specifications, then you can easily compare 20-meter Yagis, but not 10-meter Yagis.

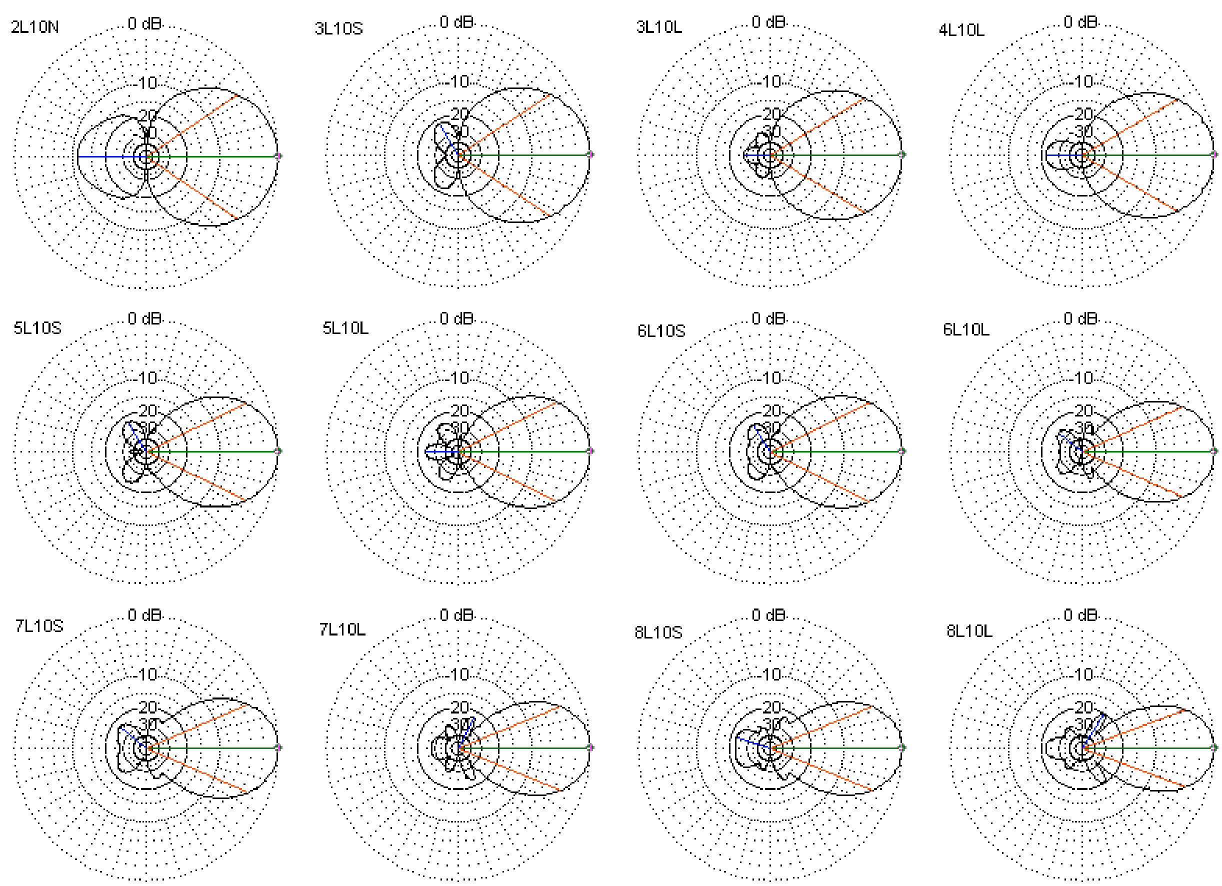
Further confusion enters the playing ground because too few amateurs contemplating their first Yagi know what to expect from the antenna. To provide a partial remedy for this situation, **Table 3** presents some free-space modeling figure for Yagis ranging from 2 to 8 elements. The table lists the forward gain in dBi, the 180° front-to-back value, the horizontal (or E-plane) beamwidth, and the rough feedpoint impedance.

Typical Free-Space Performance Data						Table 3
Elements	Boom WL	Gain dBi	180-FB	H BW	Feed Z	M or D
2	0.125	6.27	11.23	69	33+1	M
2	0.140	6.21	11.05	69	40+2	D
3	0.217	7.12	41.87	67	27+0	M
3	0.286	7.8	34.71	64	27+2	M
3	0.325	8.11	27.11	63	26-1	M
4	0.368	8.44	25.57	61	20-0	M
4	0.522	8.84	22.19	60	22-0	M
5	0.637	10.25	36.79	52	33-1	M
5	0.792	10.33	23.92	53	42+9	D
6	0.698	10.29	29.27	53	46-2	D
6	1.029	11.54	31.41	48	29-1	M
7	1.043	11.53	27.42	47	46+8	D
7	1.376	12.34	27.68	44	31-1	M
8	1.407	12.29	23	44	49+13	D
8	1.724	13.23	21.99	40	37+1	M
Notes:	Boom WL = Boomlength in wavelengths					
	Gain dBi = Forward Gain in dBi					
	180-FB = 180-degree front-to-back ratio in dB					
	H BW = Half-power beamwidth in degrees					
	Feed Z = Feedpoint impedance as R +/- jX Ohms					
	M or D = Intended for M = matching network or for D = a direct					
		50-Ohm coax connection				

Yagi designs come in many forms, so understanding the remaining table data requires a few notes. First, we may design Yagis with a fixed number of elements over a range of boomlengths. Even the 2-element driver-reflector Yagis have one boom length for maximum gain and front-to-back ratio, and another that is more suitable for a wide-band match with a direct 50-Ω cable connection to the driving element. The 3 element Yagi shows 3 variations in ascending boomlengths as measured in wavelengths. For longer Yagis, I have selected a relatively short-boom and a relatively long-boom model. At 6 elements and up, the short-boom models use design principles to provide stable wide-band performance and a direct 50-Ω coax connection (with the usual common-mode attenuator, of course). The final column indicates whether a manufactured beam of a given type would employ a matching network between the driver and the coax (M) or simply make a direct connection (D). Matching networks are neither good nor bad in themselves. They do provide a few more components to go bad in the weather, not to mention additional connections to corrode. But good manufacturing techniques can result in long-term reliable assemblies.

The tabulated monoband Yagis intended for a matching network show impedance values very close to resonance. In such cases, one might use a quarter-wavelength matching section to arrive at 50 Ohms. By making the element shorter, we do not disturb the performance of Yagis that have at least 3 elements, but we do set up a capacitive reactance in the driver that is suitable for both a beta (hairpin) or a gamma match. I have seen no evidence (amid much manufacturer palaver) that any one system is intrinsically better than another. Remember that the matching network affects only the SWR performance of the antenna and not its gain or other basic performance properties.

The data show increasing gain values (within limits from one model to the next). As gain increases, the horizontal beamwidth decreases. **Fig. 5** provides a gallery of free-space E-plane patterns (almost the same as azimuth patterns above 1 λ antenna height). The collection shows the progression of forward patterns shapes as the gain grows higher. Note especially the emergence of forward sidelobes: minuscule in 5L10L but ever more definite in the L-type patterns as the number of elements goes from 5 to 8. Of course, the boomlength also increases in this same range.



Selected Free-Space E-Plane (Azimuth) Patterns for 2- to 8-Element Yagis

Fig. 5

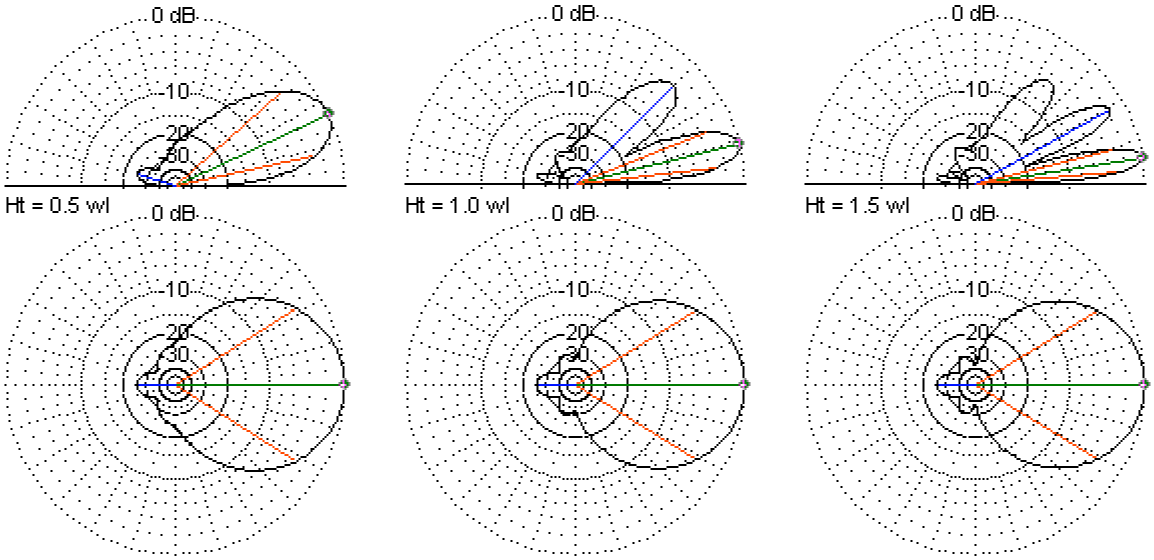
The S-series of Yagis shows lesser sidelobe development. The weaker forward sidelobes do not result so much from the shorter boomlength, but from the special arrangement of elements, the same arrangement that allows for direct 50-Ω feed connections with no intervening matching network. The tabular data also show that we pay a small gain price for the privilege of forward lobe shaping and performance stabilization.

Typical Yagi Performance 1-WL Above Ground						Table 4
Elements	Boom WL	El Ang	Gain dBi	180-FB	H BW	Feed Z
2	0.125	14	11.63	12.57	70	35+0
2	0.140	14	11.58	12.44	70	42+1
3	0.217	14	12.41	29.29	67	27-1
3	0.286	14	13.06	33.52	64	26+2
3	0.325	14	13.34	25.23	63	25-1
4	0.368	14	13.63	24.19	62	20-0
4	0.522	14	14	21.71	61	22+0
5	0.637	13	15.28	33.33	53	33-2
5	0.792	13	15.44	23.72	53	42+8
6	0.698	13	15.33	29.24	53	46-2
6	1.029	13	16.45	29.15	48	29-1
7	1.043	13	16.4	26.24	47	46+8
7	1.376	13	17.12	27.28	44	30-1
8	1.407	13	17.02	21.56	43	49+13
8	1.724	13	17.74	22.19	39	36+0
Notes:	Boom WL = Boomlength in wavelengths					
	El Ang = elevation angle of maximum radiation in degrees					
	Gain dBi = Forward Gain in dBi					
	180-FB = 180-degree front-to-back ratio in dB					
	H BW = Half-power beamwidth in degrees					
	Feed Z = Feedpoint impedance as R +/- jX Ohms					

Table 4 moves the same set of typical Yagi designs from free space to a position 1 λ above average ground. To the table, we add a new column to record the take-off angle. The angle drops by 1° as we move from 4 to 5 elements--or more precisely, from a half-wavelength boom to one that is about 5/8-λ long. Gain tends to be more a function of boom length than of the exact element count, although to obtain a beam with adequate feedpoint impedance and operating bandwidth, the variation in element numbers for a given gain level and boomlength is minimal. We have already seen that tailoring the elements on a given boomlength for special performance properties may also exact a small gain penalty.

Re-examine the patterns for the 3-element long-boom Yagi in any of the early figures. I called attention to the deep insets or nulls 90° either side of the main lobe bearing. **Fig. 6** provides supplementary elevation and azimuth patterns for the same beam at different heights above ground: 0.5, 1.0, and 1.5 λ. The elevation patterns will be virtually identical for all of the Yagi designs in the tables. We acquire a new elevation lobe for each half wavelength of height. The lobes do not suddenly appear at each height. Rather, they emerge as an increase in gain straight up and as we move the antenna a bit higher, they tilt over in the forward direction. A corresponding tilt also occurs in the rearward direction, but the rear elevation lobes tend to be too small for us to bother noticing.

The forward lobes of the azimuth patterns appear to be virtually the same. As we raise the height of the antenna, the gain slowly increases as the take-off angle decreases. However, the most notable gain increases occur from near ground level to about 1-λ high, as the ground exerts ever-weaker effects upon performance. The most dramatic affects of ground proximity involve the rear lobes and the side nulls of the free-space pattern. The closer the antenna is to ground, the shallower are the side nulls. At a height of 0.5 λ, the nulls do not appear. Instead we have only a squaring of the pattern on the way to the rear sidelobes. As we continue to raise the antenna, the side nulls appear and grow stronger. However, even at a height of 1.5 λ, the nulls are considerably weaker than in the free-space pattern. These phenomena, even though not especially important to effective operation, are evidence that the ground does influence the performance of horizontal antennas.



3-Element Long-Boom Yagi Elevation and Azimuth Patterns
at 3 Heights Above Ground

Fig. 6

Earlier, we noticed that the added gain due to ground reflections was greater for the dipole than for the 3-element long-boom Yagi. We now have the data to show that the trend is continuous as we increase both the boomlength and the element count of our sequence of Yagi models. Although we may find a small trend reversal between any 2 steps in **Table 5**, the general trend is continuous. As the boomlength grows longer, the added gain due to ground reflections grows less for antennas at a fixed height over a fixed ground quality. Had we added the dipole to this list, we would have seen a full 1-dB decrease in ground-reflection gain for the 1-8-element sequence.

Yagi Gain: Free-Space vs. 1-WL Above Ground				
Elements	Boom WL	Gain FS	Gain 1WL	Diff dB
2	0.125	6.27	11.63	5.36
2	0.140	6.21	11.58	5.37
3	0.217	7.12	12.41	5.29
3	0.286	7.8	13.06	5.26
3	0.325	8.11	13.34	5.23
4	0.368	8.44	13.63	5.19
4	0.522	8.84	14	5.16
5	0.637	10.25	15.28	5.03
5	0.792	10.33	15.44	5.11
6	0.698	10.29	15.33	5.04
6	1.029	11.54	16.45	4.91
7	1.043	11.53	16.4	4.87
7	1.376	12.34	17.12	4.78
8	1.407	12.29	17.02	4.73
8	1.724	13.23	17.74	4.51
Boom WL = Boomlength in wavelengths				
Gain FS = Forward free-space gain in dBi				
Gain 1WL = Forward gain 1 WL above ground in dBi				
Diff dB = Gain increase due to ground reflections in dB				
				Table 5

The sequence of beams has something in common. They all are designed at the middle of an HF ham band (in this case, 28.5 MHz). The gain values are not necessarily peak values, since at the design frequency, each beam is a compromise aiming at the best combination of gain, front-to-back ratio, and SWR bandwidth. The gain values give you a ballpark number to use in reading antenna maker specification sheets. Once you translate them into the terms that the maker uses, you can detect values that are grossly under- or over-stated. Normally you will see higher values for antennas with the same number of elements and comparable boomlengths. Makers like to site the optimistic peak gain within the operating passband rather than the mid-band or average gain value.

Even knowing the gain specification and the finer points of its meaning still leaves us short on information. The gain number is a single number. It does not tell us the gain everywhere in the band. That information requires a graph that gives the gain curve across the band. Sometimes, those curves can be very different. **Fig. 7** is case in point, as it contrasts the gain curves between beams 5L10L and 6L10S. In fact, 6L10S has the shorter boom, just below 0.7 λ. 5L10L uses a boom that is nearly 0.8 λ. In addition, 5L10L uses a standard older Yagi design with a lower feedpoint impedance. In contrast, 6L10S uses an element configuration that stabilizes many of the performance dimensions. The graph shows how different the gain curves can be between 2 design techniques.

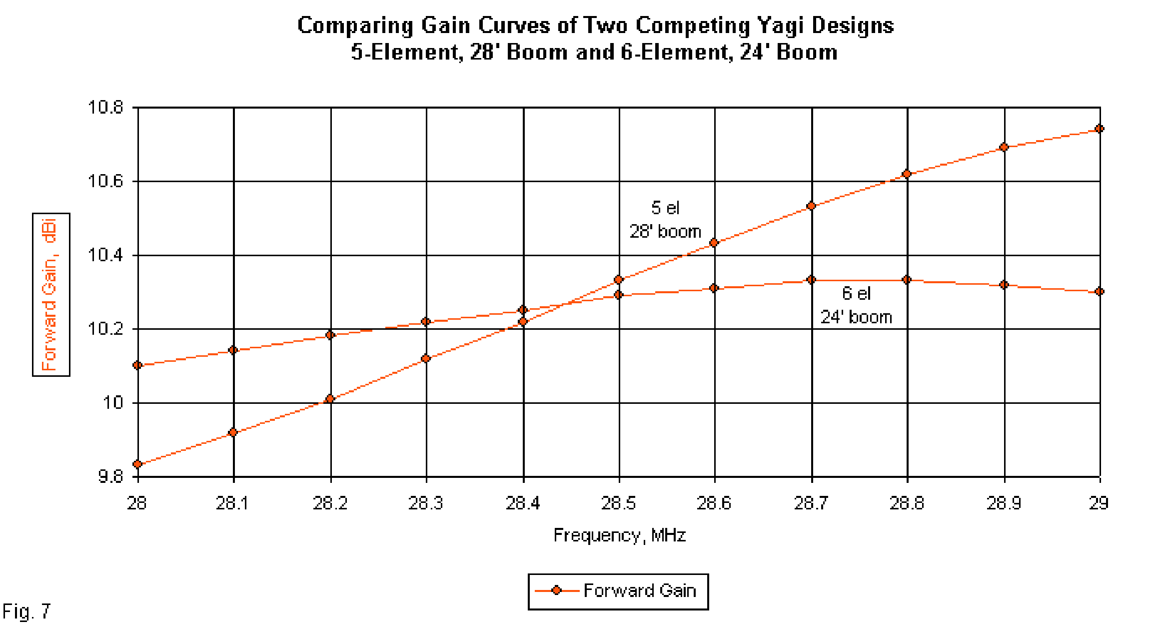


Fig. 7

Typical of standard Yagi design for any parasitic beam with 1 or more directors, 5L10L shows a rising gain pattern across the first MHz of 10 meters. The total gain variation across the band is 0.9 dB. If I were selling the antenna, I might be tempted to state that the antenna peak gain is 10.74 dBi (in free space). The 6-element beam has a peak gain of 10.33 dB, but only varies by 0.2 dB across the entire band. The average gain values do not tell us much, since the 5-element Yagi has an average gain of 10.31 dBi, while the 6-element versions averages 10.25 dBi. The only vehicle for effective evaluation of the gain all across any amateur band (with the possible exception of the narrow non-harmonic or WARC bands) is a detailed graph of the gain.

Although the test models emerge from modeling on 10 meters, the same data would apply to any HF Yagi having the same number and configuration of elements on the same length boom as measured in wavelengths. The one exception to this generalization is the performance at the band edges. Most of the other bands below the first MHz of 10 are slightly narrower. Hence, the band-edge to band-edge performance differences may be somewhat less dramatic.

We can find differences in front-to-back performance that also depend upon graphs that cover the entire operating passband for a Yagi. Let's compare the 180° front-to-back ratio for the same 2 antennas. **Fig. 8** gives us the data.

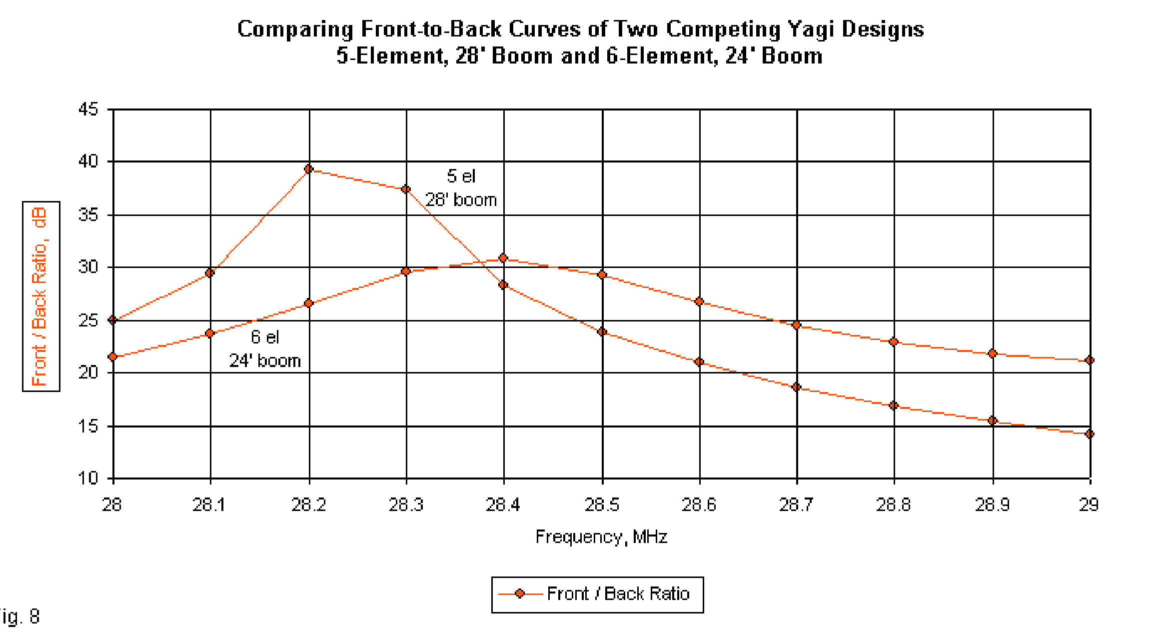
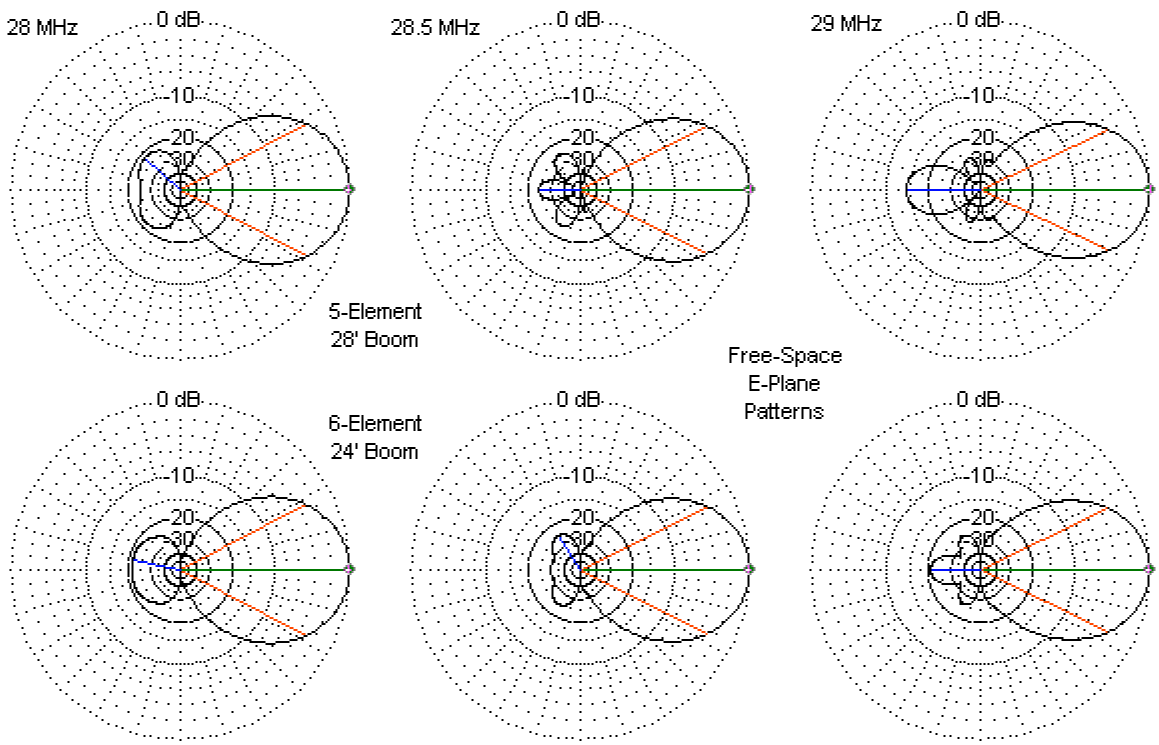


Fig. 8

We can make the 5-element Yagi stand out by citing the peak front-to-back ratio: about 39 dB. However, the 180° front-to-back ratio varies across the band from the peak value down to 14 dB. In contrast, the 6-element beam shows only a 9-dB variation in front-to-back ratio, varying from a low of 21 dB to a high of over 30 dB. In this comparison, the average front-to-back ratio values would tell us very little, since they are within about 0.8 dB of each other.

We can easily jump to the conclusion that the graph shows the 6-element Yagi to be superior. That judgment has no meaning, since it does not tell us in what respect the beam is better. The 6-element beam is superior in the smoothness of its operating curve across the band. However, if we need the front-to-back ratio at the low end of the band, then the 5-element beam wins the comparison. Part of comparing beams rests on deciding what you want from a Yagi and where you want it. Nevertheless, we could not even begin to make the comparison unless we have the detailed data graph. Given the current prices of monoband beams, demanding performance curves for the band in question is not merely reasonable. If the maker wants your money, he will send the curves or show you where they are available on the web. If he will not go this far to support your purchase, then I might have strong questions about his reliability in standing behind the product.

If you can obtain the antenna manual in advance, you likely can model each Yagi that is a candidate. Modeling will not only confirm the maker's claims, but can also put a pattern face on the raw numbers. **Fig. 9** presents band-edge and mid-band free-space E-plane patterns for the two Yagis that we have been using for our sample gain and front-to-back curves. In many ways, at least through the middle of the band, there are no decisive radiation pattern traits that would lead us to select one over the other beam. The high-end patterns might tip the scale--if using the upper portion of the band is sufficiently important. (On 20 and 15 meters, the high-end performance would determine how well the design works in the most active SSB portion of those bands.) The 5-element beam shows that it is near the limits of performance at the listed boomlength. The front-to-back ratio has fallen off, resulting in a sizable main rear lobe. In addition, we can notice the emergence of forward sidelobes. These sidelobes are not serous, unless we allow for manufacturing variations. In contrast, the 6-element high-end pattern shows the same cleanliness that characterizes the patterns for frequencies lower in the band.



Comparing Azimuth Patterns of Two Competing Yagi Designs
5-Element, 28' Boom and 6-Element, 24' Boom

Fig. 9

Even if these patterns do not lead us to a decision about which hypothetical beam to purchase, they are still worthy of study. The more we know about the antennas that we buy or build, the more reasonable will be our expectations of them.

So far, we have said nothing about the impedance performance of the antennas that we have surveyed as typical representatives in the HF range. For this specification, most makers are all too happy to shows 50-Ohm SWR curves. At worst, they assure us that the SWR is under 2:1 at the limits of the passband and often that the design-frequency SWR is 1:1. What makers rarely tell us is how they obtained the numbers. If a beam requires an impedance matching network, we know that it must be in place. However, the specification sheets rarely tell us whether the SWR applies at the antenna terminals or after some intervening length of coax. If we can infer the use of coax--as we can for at least one maker who specifies Yagis above 70' over ground--we usually do not know what coax he used to make measurements. All of these considerations make a difference in the claims that we can make about Yagi performance.

To demonstrate the difference, I provided the 3-element long-boom Yagi with a quarter-wavelength matching section so that the impedance at 28.5 MHz was 50.00 - j0.007 Ω. Then I ran a frequency sweep and recorded the impedances and 50-Ω SWR from 28.0 to 29.0 MHz in 0.1-MHz increments. The next step involved using the program TLW that comes with *The ARRL Antenna Book*. For the impedance at each frequency, I connected a 75' length of coaxial cable and read out both the impedance and the SWR. I repeated the exercise for 3 different 50-Ω cables: low-loss LMR400, common RG-213, and equally common RG-8X, the so-called low-loss thinner cable. However, the 3 cables show increasing losses from LMR400 through RG-213 down to RG8X. Each cable has a different velocity factor, so the electrical length of each cable in the tests differed slightly. However, the test focused on using a physically constant length of cable.

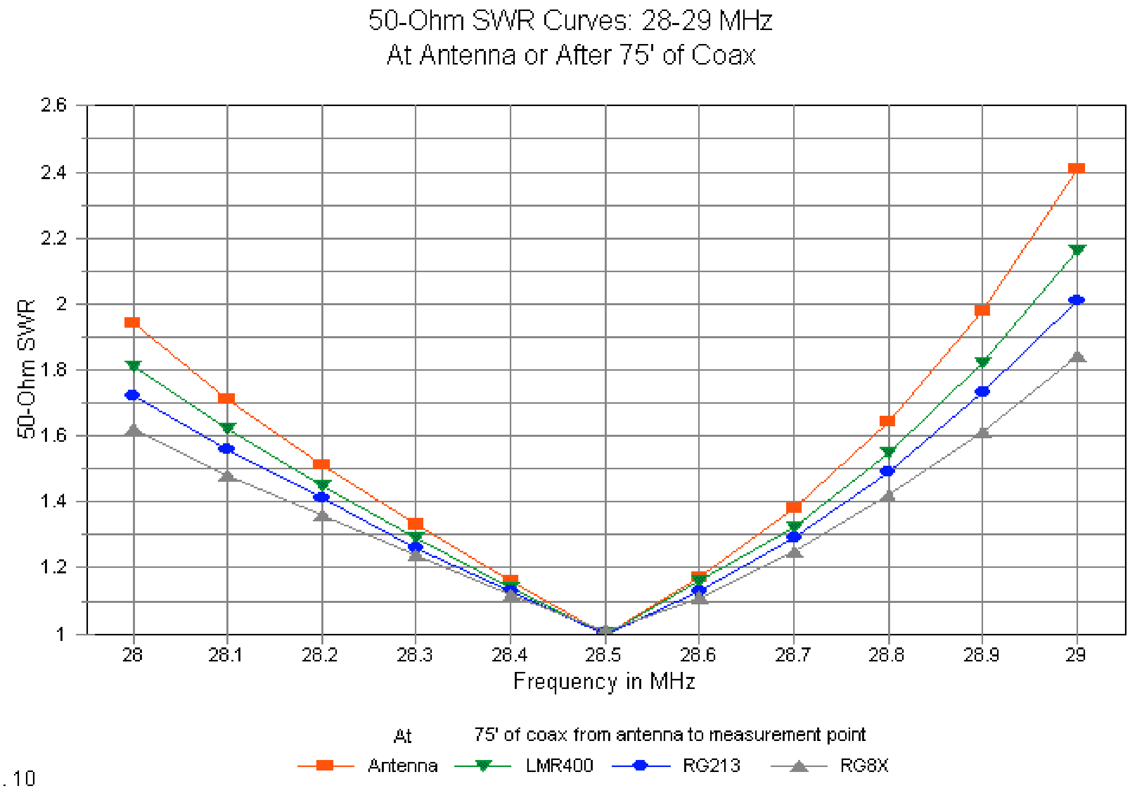
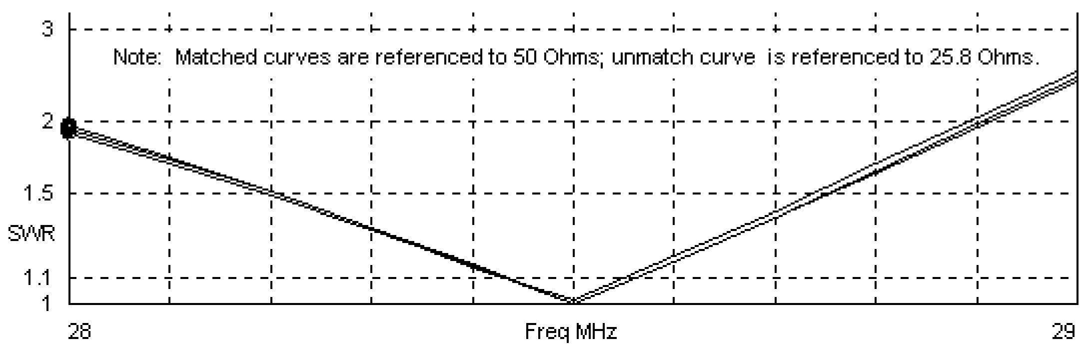


Fig. 10

The results of the test appear in **Fig. 10**. The steepest SWR curve belongs to the antenna terminals with no cable. Since every cable has some loss, all cable curves are broader than the cable-less curve. The curves become broader as the cable loss increases. The only curve that manages an SWR under 2:1 across the entire passband is RG-8X, the lossiest of the collection. (Very lossy RG-58 would show an even broader SWR curve. As cable loss increases, less power reaches the antenna.)

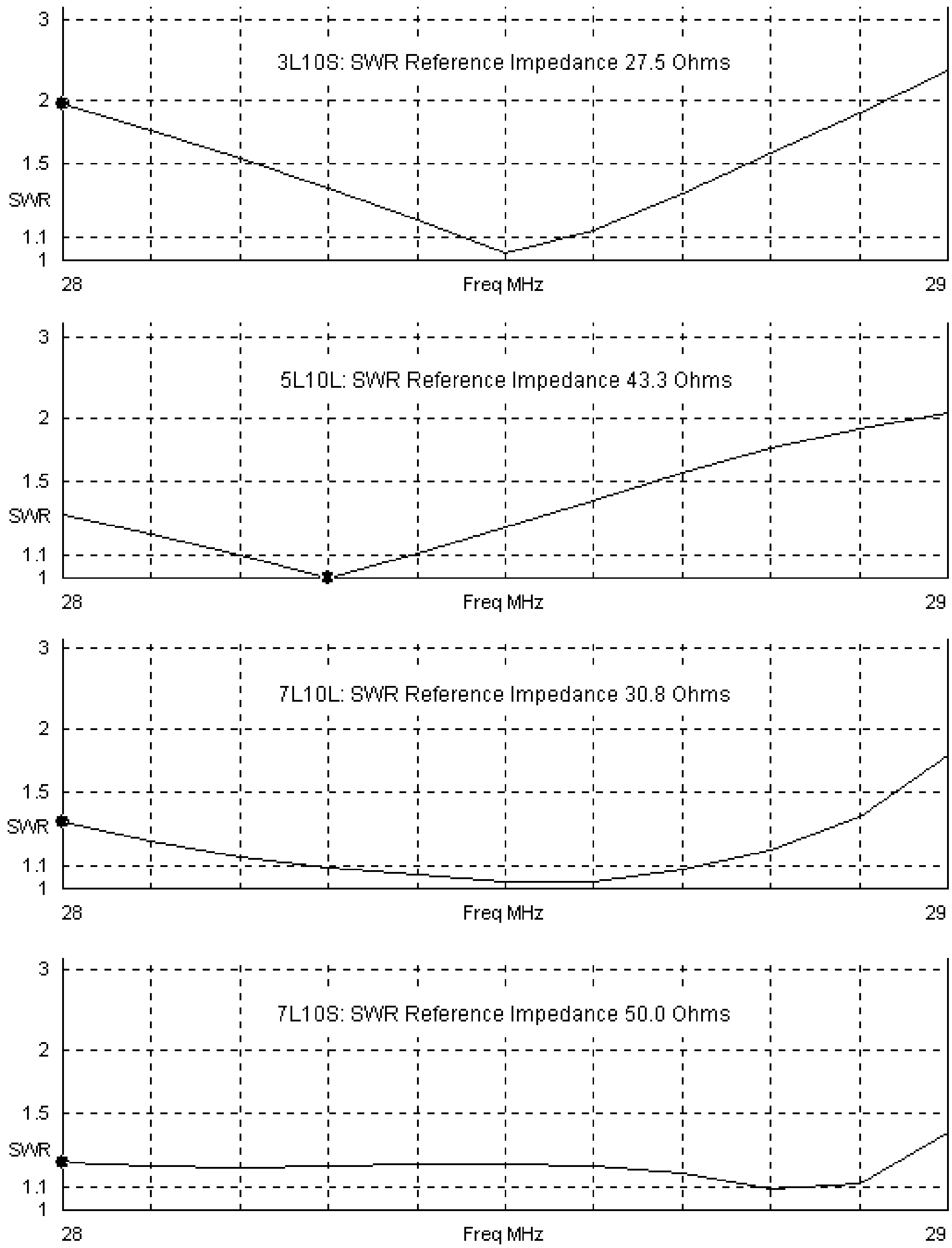
A number of 10-meter Yagi designs only rate their antennas to 28.8 MHz, on the presumption that activity ends at that point. This practice also eases design problems, since an 800-kHz 10-meter passband is equivalent to a 600-kHz passband on 15 meters and a 400-kHz passband on 20 meters. Therefore, scaling a single Yagi design up or down will satisfy the monoband Yagi needs of all upper HF bands.



Overlaid SWR Curves of the 3-Element Long-Boom Yagi with No Match,
with a Beta (Hairpin) Match, and with a Quarter-Wavelength Matching Section

Fig. 11

Note that the SWR curve is quite sharp and rises more steeply above the design frequency than below it. The curve properties are quite normal for virtually any Yagi of standard design that has at least one director. The rate of change of SWR above and below the design frequency is normal regardless of the type of matching section used. **Fig. 11** shows overlaid SWR curves for the sampled 3-element Yagi without a match and with 2 different types of matching sections: a quarter-wavelength line and a beta or hairpin match. Some curves shown by antenna makers are so smooth that one has to wonder how much loss the measuring system has.



Sample SWR Curves for Typical Yagis of Various Lengths Fig. 12

Not all SWR curves are alike. **Fig. 12** samples some variations. At the top, the 3-element short-boom Yagi has a typical small-Yagi curve, very much like the one for the long-boom 3-element Yagi. The second curve--for the 5-element long-boom Yagi--shows favoritism for the lower end of the passband. Indeed, some commercial Yagi designs will ask the user to select the desired portion of the band and adjust the assembly measurements to produce the SWR curve that most favors the selection. As Yagis grow longer, we find that designers use broadband techniques, since they normally do not change the total boom length by much. Hence, the 7-element long-boom Yagi provides a shallow SWR curve, although the reference impedance tells us that it still needs a matching network for a 50-Ω cable.

The last curve in the set is typical of the Yagis receiving special design considerations for a direct connection to 50-Ω cable. The design produces no frequency at which the impedance is exactly 50 Ω, but it remains very close to 50 Ω across the entire band. Hence, the SWR never quite reaches 1.4:1 anywhere within the first MHz of 10 meters. The curve serves as a counterweight to placing too much emphasis on commercial claims that a Yagi's SWR is 1:1 at the design frequency. Often, there are good reasons for not having a perfect 1:1 SWR at the design frequency if we can hold the SWR very low across a wide band of frequencies.

We have reached the end of our basic introduction to the world of commercial monoband Yagis. We have covered enough information to allow you to understand and even translate maker specifications into a uniform set of information so that you can compare antennas before buying. The data on typical short- and long-boom Yagis designs, both in free space and 1 λ above ground provides a set of ballpark values so that you can evaluate gain claims. You may extrapolate probable values for boomlengths and element counts that do not appear on the list. If you cannot translate a maker's claims and terms into values that make sense relative to the data tables, you should send inquiries to the maker. His patience and helpfulness during the decision process is often a good indicator of probable after-sale support to you.

As an exercise, I am providing the following sample specifications drawn from the literature of various antenna makers. Since this is only a sample, I have not listed explicit maker names. Furthermore, specifications change over time, so the list will soon be dated. In some cases, the meaning of a specification is clear as given. In other cases, other portions of the literature will make it clear. However, sometimes, nothing may clarify a listed specification except an explicit question to the maker. Every antenna maker wants to present his products in the most favorable light. Your job is to change the rose-colored advertising glow into the bright white of clarity and full information. If you need motivation, scan the price lists for monoband Yagis.

A Random Sample of Mono-Band Yagi Specifications

Maker	H	H
Band	10	20
No. Elements	3	3
Boom Length (ft)	8 (0.23 λ)	16.5 (0.24 λ)
Weight (lb)	15	32
Gain (free space)	7.5 dBi	7.15 dBi
F-B	FR: 24 dB max	FR: 23 dB max
SWR	1.25:1 at resonance	<1.5:1 at resonance

Maker	C	C	C
Band	10	10	20
No. Elements	3	4	4
Boom Length (ft)	10 (0.29 λ)	16 (0.46 λ)	32.7 (0.47 λ)
Weight (lb)	11	18	55
Gain	8.0 dBd (unspecified)	10.0 dBd (unspecified)	10.0 dBd (unspecified)
F-B	30 dB (unspecified)	30 dB (unspecified)	30 dB (unspecified)
SWR	1.2:1	1.2:1	<1.5:1

Maker	M	M	M
Band	10	20	20
No. Elements	4	4	5
Boom Length (ft)	24 (0.69 λ)	34.7 (0.5 λ)	44 (0.63 λ)
Weight (lb)	20	36	105
Gain (free space)	8 dBd	7.34 dBd	8.1-8.5 dBd
F-B	FR: 22 dB typical	FR: 23 dB typical	FR: 24 dB typical
SWR	1.25:1 typical	1:1 at resonance	1:1 at resonance

Maker	F	F	F
Band	20	20	20
No. Elements	5	6	7
Boom Length (ft)	36 (0.52 λ)	44 (0.63 λ)	58 (0.84 λ)
Gain (at 74')	7.3 dBd net	7.8 dBd net	8.4 dBd net
F-B	FR: 23 dB average	FR: 23 dB average	FR: 23 dB average
SWR	<1.6:1	<1.4:1	<1.5:1

Tri-Band Yagi Compromises

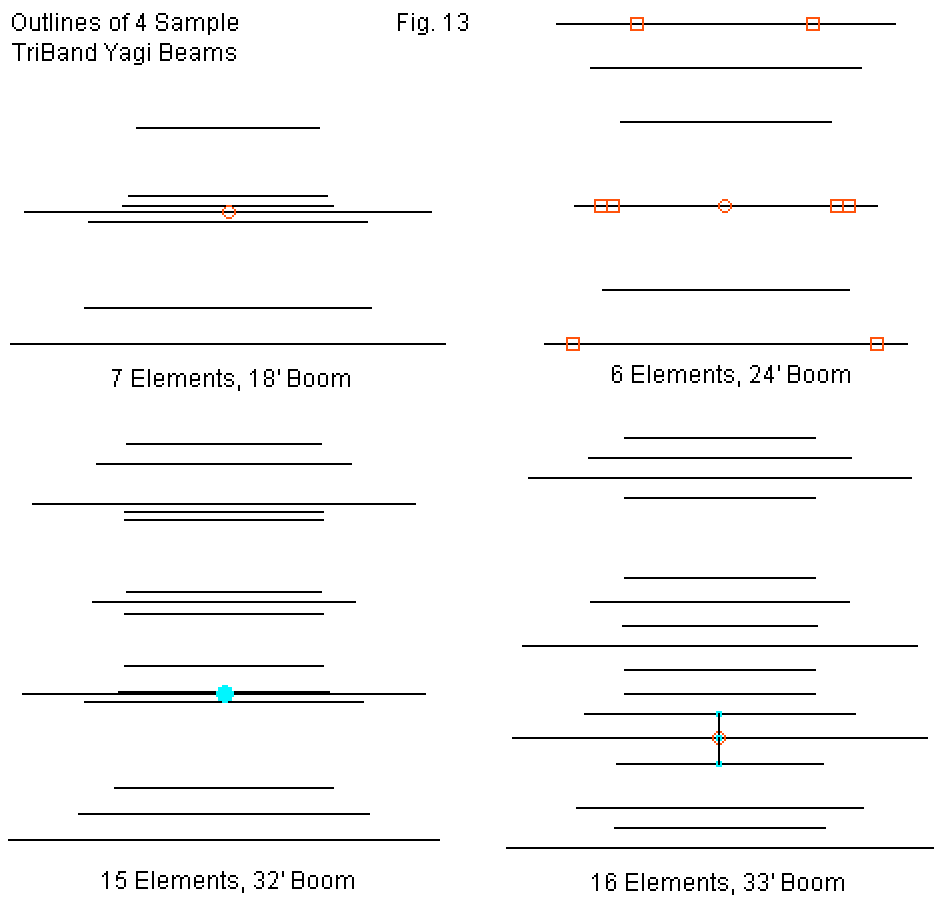
Just when I though our work might be complete, someone asked, "What about tri-band Yagis?" The idea of obtaining Yagi performance for three different bands on one boom has great appeal. Anyone with a computer and antenna modeling software might develop a quite reasonable monoband Yagi. But squeezing full performance out of interlaced elements for 3 bands involves far more than 3 times the labor of a monoband Yagi.

Let's see what might be involved in tri-band design. Suppose that we want to have a 3-element Yagi. If we select a monoband design, then a given design on 20 meters will have a boom that is twice as long as the same design on 10 meters. The earliest tri-band Yagis simply chose a compromise spacing and threw traps into the elements so that they would show a resonant point on 10, 15, and 20 meters. In the 1970s and 1980s, every Yagi builder assumed his beam reached full theoretical performance, and so the gain claims for these 3-element compromise arrays were unbelievably optimistic. With the advent of computer modeling software, designers went back to the drawing boards.

Today's tri-banders tend to look nothing like those of past decades. Very few use traps, although some older designs are still available. Nevertheless, tri-band designs involve compromises. For example, modern trapless designs tend to add 10-meter elements to fill a boom and therefore obtain better than 3-element performance on that band. However, with a common driver or set of driver elements, one of the 10-meter directors tends to want to be just where the 20-meter director lies. A 20-meter director will tend to dominate the 10-meter pattern and change the 10-meter passband to reduce the operating range at the high end of the band. One corrective is for the designer to add an extra director so that 2 10-meter directors bracket the 20-meter director to neutralize the dominance factor. So we cannot determine performance simply by counting elements on each band (although we always do just that as a matter of course).

As well, we now see a variety of different ways to provide a common feedpoint for all 3 bands. A single driving element with traps appears in some designs. One maker uses a log-cell driver section, a set of driving elements connected very much like the elements in a log periodic dipole array. We also find separate driving elements for each band, but there are at least 2 arrangements. One system makes a direct connection between drivers, using a short length of parallel transmission line. An alternative method uses open-sleeve coupling so that only the 20-meter driver has a connection to the feedline. By careful selection of the length and close spacing of each "slaved" driver for the other bands, high efficiency coupling occurs, although it is difficult to obtain full band coverage from a slaved driver. All of the systems work, but the trapped driver is perhaps the least efficient. However, traps do reduce the total number of elements needed by a tri-band for a given boomlength, since some elements may do double or triple duty.

We cannot survey tri-band Yagis in the same systematic way that we used to observe monoband Yagi performance. At best, we can review some samples to observe probable performance curves to understand what compromises various tri-banders might entail. **Fig. 13** shows the samples that we shall use. They have roots in past commercial designs, but are not identical to them. For authoritative performance data for any beam resembling these four samples, consult the antenna maker.



The tri-band Yagi designs fall into 2 groups of 2. At the top are trapped and trapless designs for antennas having relatively short booms. 24' is about the length of a long-boom 3-element monoband Yagi for 20 meters. The bottom pair of designs use different feed systems and different element arrangements, but both have very comparable boom lengths, a little under a half-wavelength at 20 meters. That length falls between the boom lengths for the short and the long 4-element monoband Yagis. In fact, you may wish to consult **Table 3** from time to time as we proceed. The table provides the free-space gain and front-to-back data for monoband beams, along with the boom length for each entry. To convert a physical boomlength into its equivalent in wavelengths, do the following simple math. On 10 meters, divide the physical length by 34.5. On 15 meters, use 46.7. The 20-meter divisor is 69.4. These numbers show the length of a wave at the approximate mid-band frequency of each band. However, we should not use the entire boomlength for all of our calculations.

Let's start with a comparison between the 2 shorter beams. We do not aim to evaluate them as better or worse. Instead, our goal is to understand why they perform as they do. For example, **Fig. 14** presents the gain curves on each band for the 2 antennas. Each curve divides each band into 10 equal parts, so the frequency spread is the total band size. Hence, the increments between sampling points are not equal from band to band.

The first notable feature for the shortest 7-element, 18' antenna is that the curves for 20 and 15 are very similar, with slow downward slopes, but the curve for 10 meters has a very steep upward slope. If you examine the outline in **Fig. 13**, you can identify the 2 active 20-meter elements and the 2 active 15-meter elements. Each pair forms a driver-reflector 2-element Yagi, and the gain curves for those bands fit typical monoband performance for wide 2-element spacing. However, the 10-meter elements are all directors, and so the curve is upward with frequency increases. For each band, the effective boom length for the individual bands is only about half of the total boomlength.

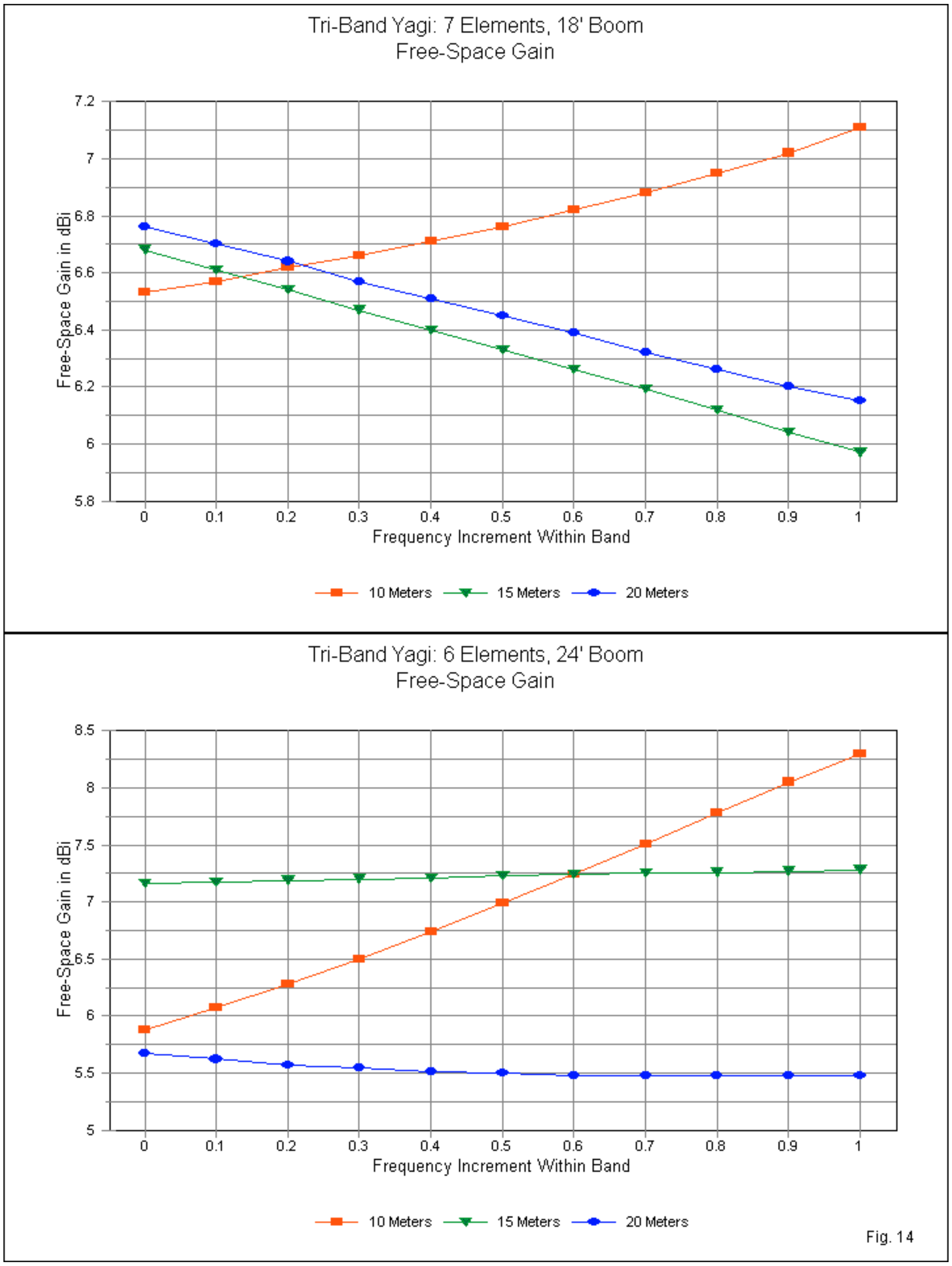


Fig. 14

The lower part of **Fig. 14** shows gain curves for the 24' trapped model. The 4 elements on 10 meters show a steep upward gain slope. The three 15-meter elements have long-boom spacing, but there is a trap on each side of the driver. So the performance is more akin to a short-boom monoband Yagi. Where traps take their greatest toll is on 20 meters, where we find 2 traps on each side of the driver and single traps on each side of the parasitic elements.

Fig. 15 shows the 180° front-to-back curves for the 2 antennas. The 7-element antenna shows comparable 20- and 15-meter values that are on a par with 2-element monoband Yagis. The curve for 10 meters shows higher values, but still under the 20-dB value that is typical for a well-designed monoband short-boom 3-element Yagi. Since we have 2 major elements on 20, 2 on 15, and 3 on 10 meters, the beam obtains about all that we can expect from its design.

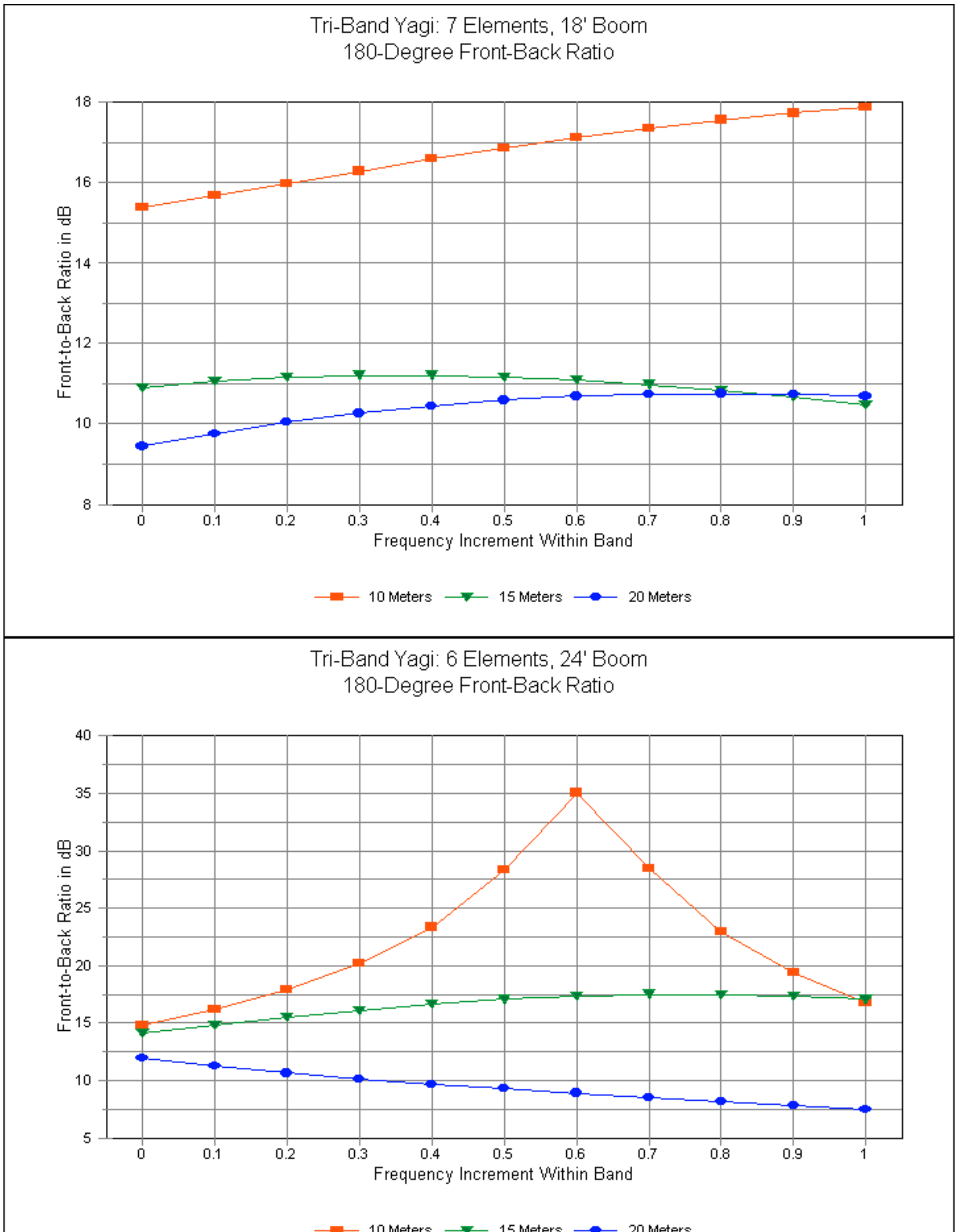


Fig. 15

The trapped 24' Yagi shows generally superior front-to-back ratios on 10 and 15 meters, although 15 meters has an average value under 20 dB. The sharp peak in the 10-meter curve is movable with slight adjustments to the element lengths inside the traps. On 20 meters, the multitude of traps at work reduces the ratio for the 3 active elements down to 2-element Yagi levels. In general, the compromise element spacing of most tri-band beams usually results in reduced front-to-back performance relative to monoband Yagis with the same boomlength between the limiting active elements.

Fig. 16 supplies modeled 50-Ohm SWR curves for the 2 sample antennas. The upper curves for the 7-element, 18' design shows one recurring challenge for open-sleeve coupling in tri-banders: reduced operating bandwidth. The challenge shows up on 15-meter, where the beam covers only about 80% of the band at 2:1 SWR or better.

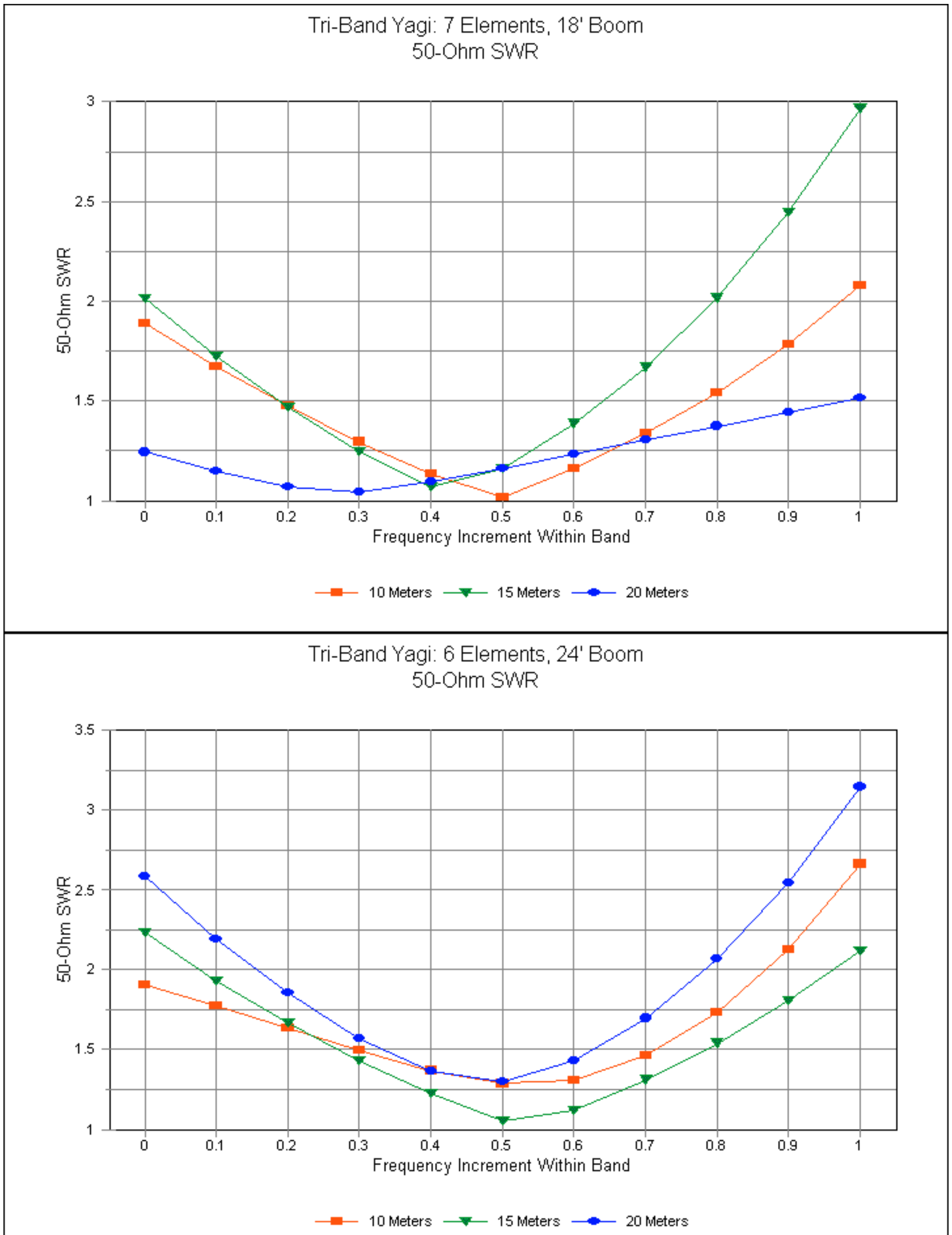


Fig. 16

The lower set of curves for the trapped models shows 2 facts. First, the 20-meter curve is not accurate, since the actual beam has a matching section not used in the model. The matched curve would reach very close to 1:1 at mid-band and simple be lower overall. Traps shorten the overall element lengths for the lower bands, creating challenges for full band coverage. The 10-meter curve shows a sharpness that reflects the sharp front-to-back curve. One property common to many trapped designs is the need to favor either the lower end or the upper end of the wide ham bands.

Let's turn to our 2 long-boom tri-band candidates. **Fig. 17** provides the gain curves for the 2 designs. The 15-element, 32' version uses open-sleeve driver coupling. It provides very smooth gain curves for 15 and 20 meters, using 3 elements on 20 and 4 on 15. The 4th element on 15 meters does not so much add to gain as it compensates for the smaller bandwidth of the slaved driver. The 10-meter section has 8 elements and shows a very steep rising slope to accompany the enhanced average gain values.

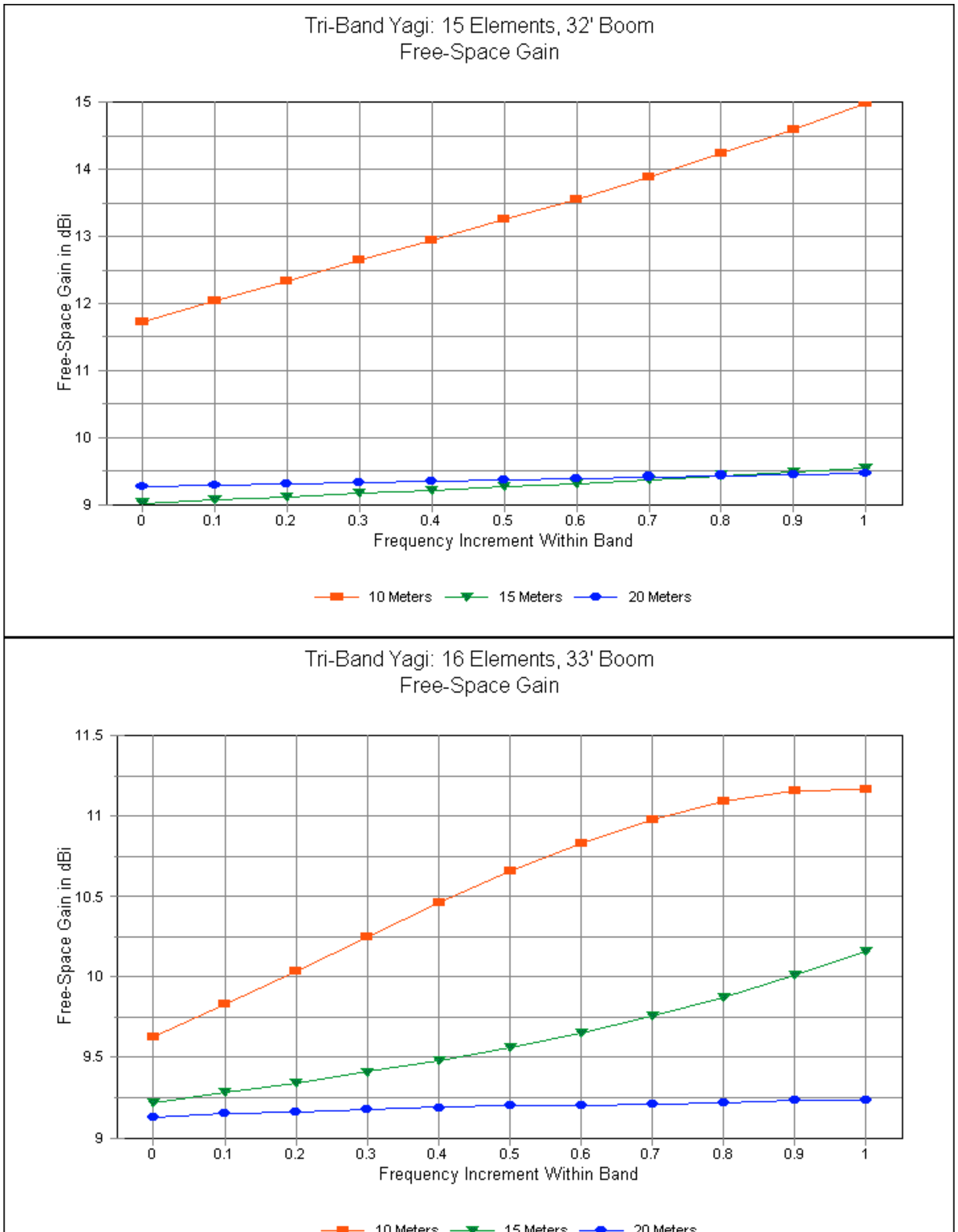


Fig. 17

The lower curves represent probable performance from the 16-element, 33' boom Yagi that uses direct coupling between drivers. The 3 20-meter elements provide a gain curve almost identical to the curve for the other design. However, 15 meters shows improved gain performance from its 4 elements, but not evenly across the band. The 10-meter curve is more modest for the same number of elements (8) that we find in the other design, but the slope of the gain curve is less steep. We should note in passing that, although we refer to elements for each band, almost al elements are active at least at low levels on all bands.

We have noted that tri-band Yagis generally cannot match the front-to-back performance of monoband beams. The top part of **Fig. 18** gives us strong evidence of this fact. Only on 2 of the 3 bands does the 15-element design exceed the 20-dB level, and then for only part of the band. If you want to use a tri-band Yagi, you will just have to live with the lower levels of rejection of rearward QRM.

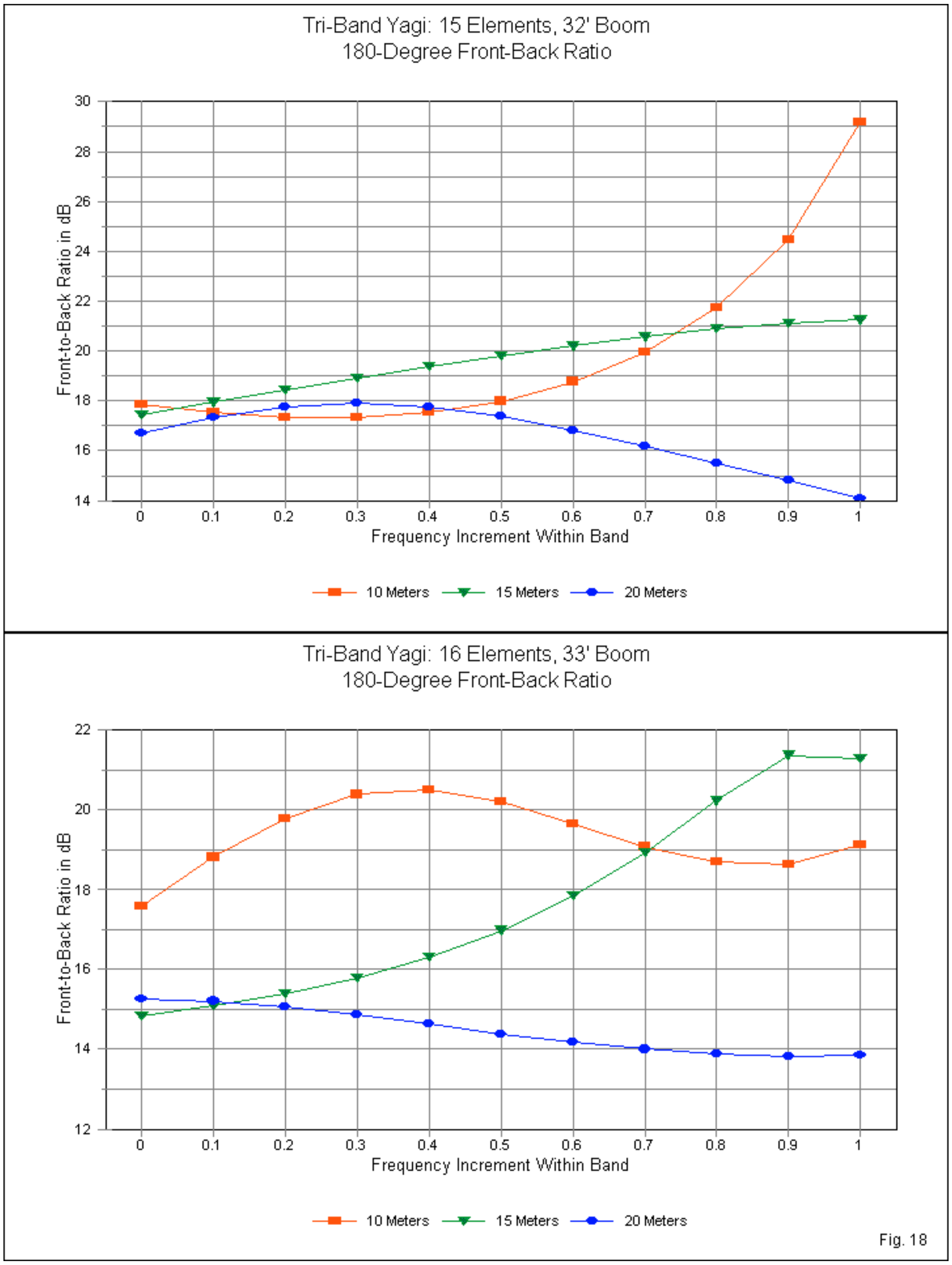


Fig. 18

The longer 16-element design shows the same limitation of front-to-back values, although with more erratic curves than we find in the 15-element design. The likely source of the lower values in the front-to-back category lies in the fact that tri-band Yagi designers generally give higher priority to two other key properties of their antennas: forward gain and operating bandwidth. In most designs, the front-to-back ratio is secondary, and designers generally are satisfied with values that average about 15 dB or better. If you examine the monoband specifications extracts, you will see that 15-dB front-to-back ratio--under any interpretation of the term--is 5 to 8 dB lower than typical monoband values.

As we add more elements to a tri-band Yagi that uses open-sleeve coupling, we can more easily obtain full-band coverage with under 2:1 SWR. The 50-Ω SWR curves for the 15-element antenna appear at the top of **Fig. 19**. Only on 10 meters does the beam miss full coverage, but it does manage 90% coverage.

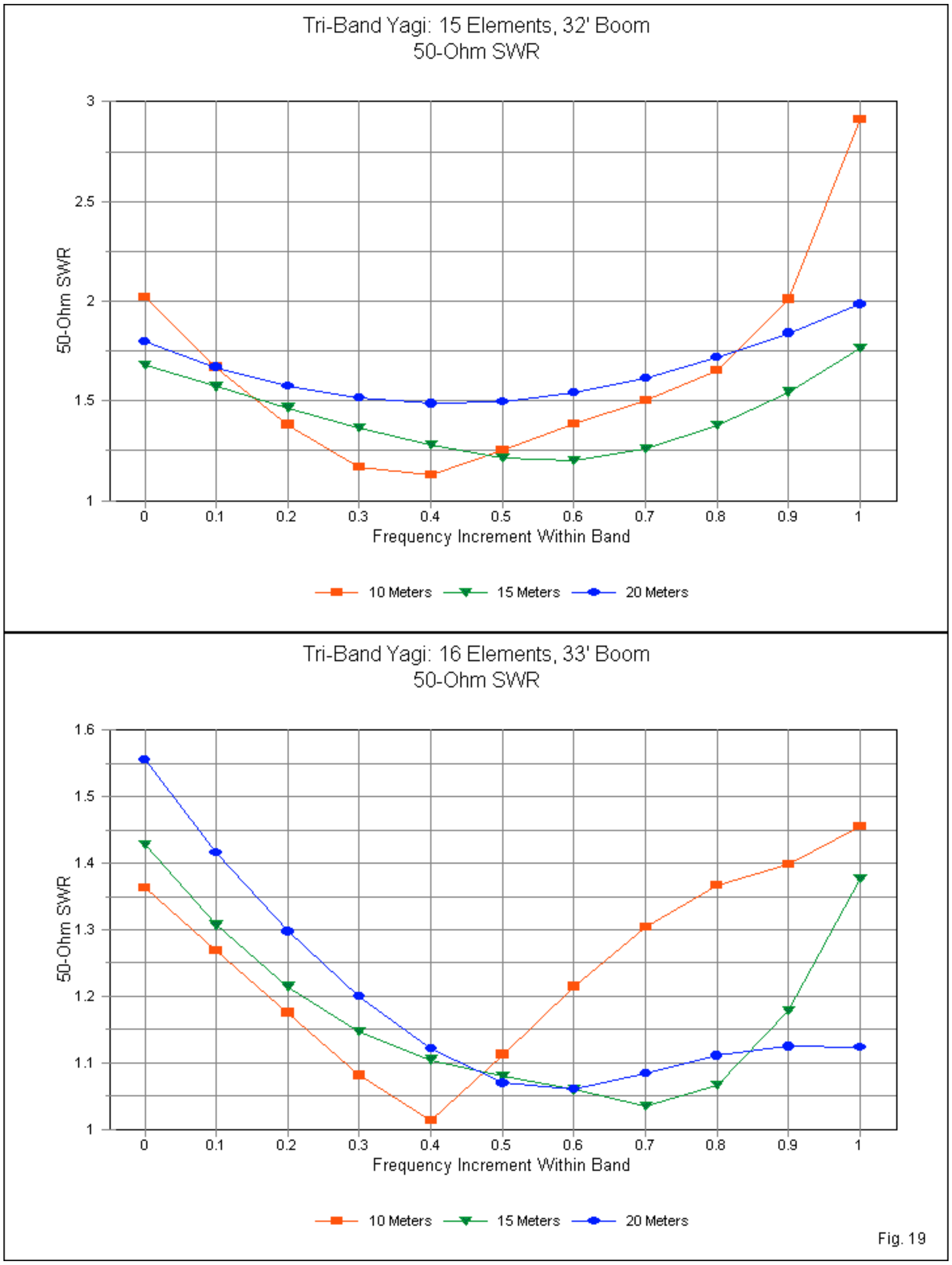
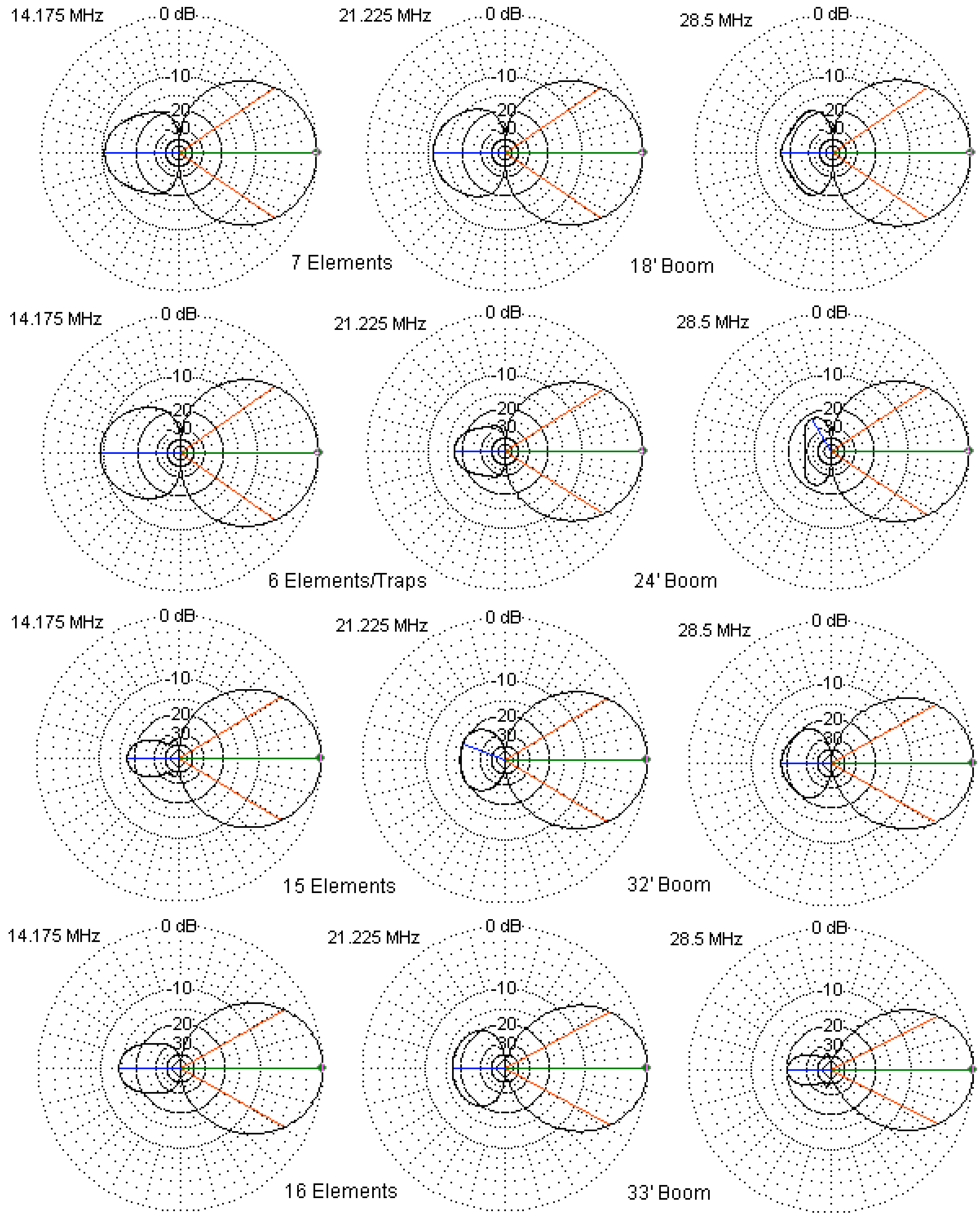


Fig. 19

Direct coupling of the drivers does ease the problem of obtaining a low SWR across each of the HF bands covered by the antenna. The lower part of **Fig. 19** shows excellent curves when measured by tri-band standards. (Remember that we cannot expect of a tri-band Yagi the same smooth performance curves that we obtained from the short-boom 6-, 7-, and 8-element monoband Yagis.)

All of the tri-band Yagis that we have sampled produce well-behaved patterns, as shown in the gallery of free-space E-plane (azimuth) patterns in **Fig. 20**. The graphic provides a pattern for the center of each band. The forward lobes have no emergent sidelobes. The range of rear-lobe shapes is as modest as the front-to-back performance. Since all of the patterns are normalized, they give no hint of gain difference among the beams and bands.



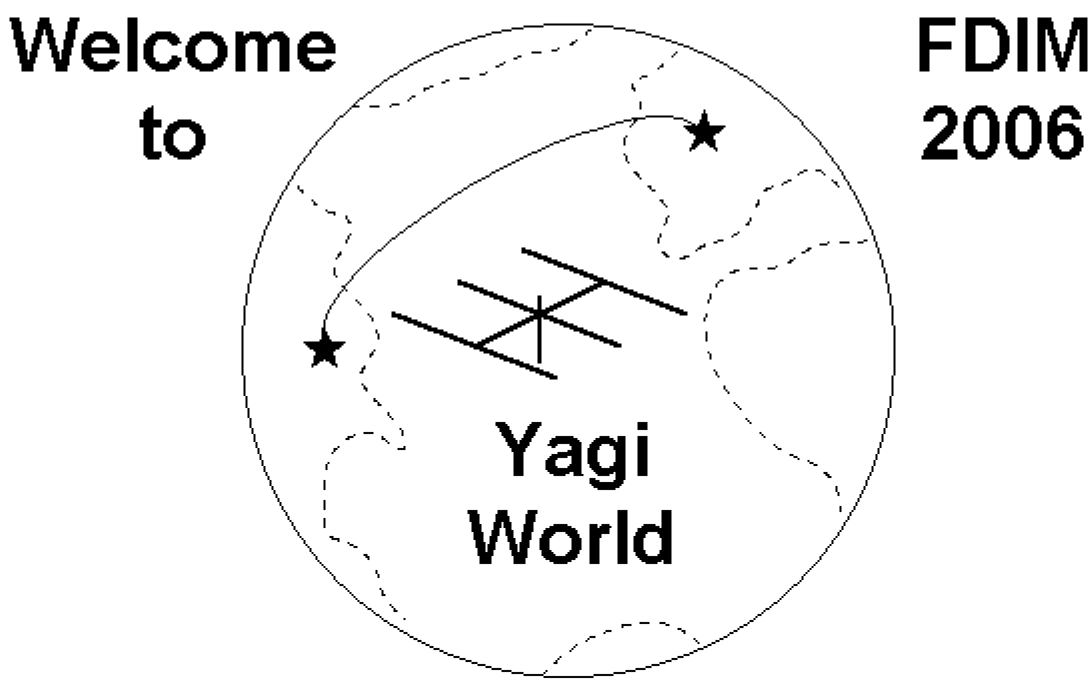
Short, Medium, and Long-Boom Tri-Band Yagis
Mid-Band Free-Space E-Plane Patterns

Fig. 20

Does our brief survey hold any lessons for us, if we contemplate them as an alternative to one or more monoband beams? Indeed it does. Tri-band Yagis generally show slightly lesser gain performance on at least one band relative to the number of major elements and the boomlength for that band. For trapped models, the gain deficit usually shows up on 20 meters, where the most traps are actively at work shortening the overall element length. Because the front-to-back ratio usually takes a backseat behind gain and operating bandwidth during the design process, it suffers most of all, although the values obtained may be entirely satisfactory for many types of operation. Finally, obtaining a satisfactory SWR curve for all 3 bands may prove to be a major challenge, especially for smaller tri-band beams.

Our samples show some of the compromises that you may find in many tri-band designs. Expect variations from these samples in any multi-band antenna that you may consider. You may not initially see the compromises when you read specification sheets, since they will look just like the monoband extracts, except with 3 sets of performance values. Very often, the values cited will be the peak performance values for a band. Even if the maker uses more modest average values, you cannot tell from a single number for a band what sort of curve that the values form across any of the bands covered by the antenna. Once more, you need to pester the maker until you have all of the data that you need for an informed decision. If you do not receive the requested data, then begin to suspect that you may also not receive post-purchase support when installing and maintaining your antenna.

I cannot make the decision among candidates for you. Every antenna decision involves matters of operating needs and desires, not to mention budget. An HF Yagi installation is a major investment of energy and money. All that these notes can do is to provide some basic information on how to correlate specifications expressed in different ways by different makers, along with some cautions. In fact, we can sum up the cautions in 2 classic words: *caveat emptor*, or let the buyer beware. On the other hand, there are a number of very fine antennas out there, if you get the incurable bug to go Yagi.



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