# How Wide is Wide?

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Unlike the question, "How high is up?" our question has an answer. In fact, the question has many answers. The first step is deciding what we are referring to by the word "wide." Since our subject is antennas, there are two possibilities: beamwidth and bandwidth. Let's choose the latter as the more intriguing. Let's further refine the expression with a qualifier and call the operative term "operating bandwidth." That expression should give us room to get into trouble.

## The Width of the U.S. Amateur Bands

As background, we may look at the U.S. amateur bands from 160 meters through 70 cm and define the bandwidth of each. One common way to arrive at the width of each band is to divide the width of the band from the lowest frequency to the highest by the band's center frequency--and multiply by 100 to arrive at a percentage. 20 meters is 350 kHz wide, with a center frequency of 14.175 MHz (or 14175 kHz to use constant units of measure). The result is 2.47%. **Table 1** provides bandwidth values for each of the amateur bands within the indicated scope of our survey.

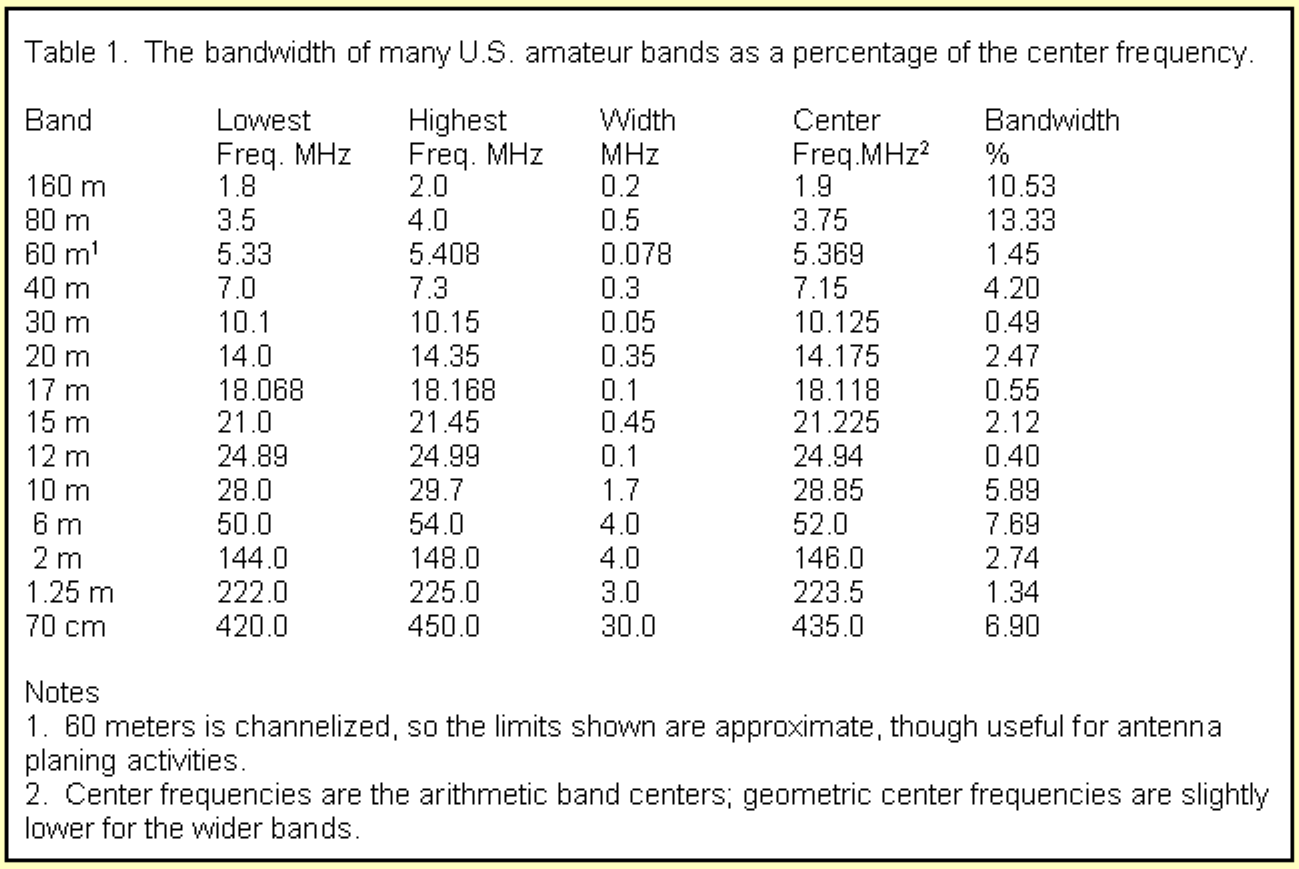


Table 1. The bandwidth of many U.S. amateur bands as a percentage of the center frequency.

| Band | Lowest Freq. MHz | Highest Freq. MHz | Width MHz | Center Freq.MHz[2] | Bandwidth % |
|---|---|---|---|---|---|
| 160 m | 1.8 | 2.0 | 0.2 | 1.9 | 10.53 |
| 80 m | 3.5 | 4.0 | 0.5 | 3.75 | 13.33 |
| 60 m[1] | 5.33 | 5.408 | 0.078 | 5.369 | 1.45 |
| 40 m | 7.0 | 7.3 | 0.3 | 7.15 | 4.20 |
| 30 m | 10.1 | 10.15 | 0.05 | 10.125 | 0.49 |
| 20 m | 14.0 | 14.35 | 0.35 | 14.175 | 2.47 |
| 17 m | 18.068 | 18.168 | 0.1 | 18.118 | 0.55 |
| 15 m | 21.0 | 21.45 | 0.45 | 21.225 | 2.12 |
| 12 m | 24.89 | 24.99 | 0.1 | 24.94 | 0.40 |
| 10 m | 28.0 | 29.7 | 1.7 | 28.85 | 5.89 |
| 6 m | 50.0 | 54.0 | 4.0 | 52.0 | 7.69 |
| 2 m | 144.0 | 148.0 | 4.0 | 146.0 | 2.74 |
| 1.25 m | 222.0 | 225.0 | 3.0 | 223.5 | 1.34 |
| 70 cm | 420.0 | 450.0 | 30.0 | 435.0 | 6.90 |

Notes
1. 60 meters is channelized, so the limits shown are approximate, though useful for antenna planing activities.
2. Center frequencies are the arithmetic band centers; geometric center frequencies are slightly lower for the wider bands.

The bandwidth numbers are useful in some contexts. For example, a precisely scaled antenna from one band would have the same coverage in terms of the bandwidth on the new band. Precision scaling means scaling the element length(s), diameter(s), and spacing (if relevant). If we scale an antenna known to cover one of the wider bands for a narrower band, we can be sure that the antenna will cover the new band. If we begin with an antenna for a narrower band, we cannot be certain that a scaled version will cover a wider band.

Next, with a bit more trepidation, let's subdivide the range of bandwidths that emerged for the U.S. amateur bands. The following categories have no validity in general antenna literature, but will be useful for discussion within these notes. If the bandwidth is less than 1%, we may refer to a narrow bandwidth. If the bandwidth is between 1% and 4%, we may refer to a medium bandwidth. In the table, we may call bandwidths greater than 4% wide bandwidths.

Our concern over bandwidth derives from a subset of the antennas that we typically use. For example, someone who uses a center-fed (or off-center-fed or end-fed) wire cares very little about bandwidth. He or she simply "dials in" the correct settings of a tuner for maximum effectiveness (usually meaning a good SWR match at the transceiver). The operator measures bandwidth in terms of how many times the tuner requires resetting as the frequency moves up or down one of the bands.

The bandwidth categories evolve from general expectations that we have for relatively standard Yagi antenna designs, where the elements are aluminum tubes in the upper HF range. A 0.5" 10-meter element for 10 meters would require a 2.0" diameter on 40 meters. The normal tapered-diameter schedules for full-size 40-m elements in amateur installations virtually never approach this value. So practical antenna scaling may not meet the table's presumption of perfect antenna scaling. As a result, horizontal 40-meter antennas based on designs that easily cover 20 or 15 meters usually suffer declining performance or full failure to perform at one or the other 40-meter band edge.

A combination of practical material limitations and total bandwidth has established conventions for band utilization. We find the 80-meter band subdivided into the 80-meter CW band and the 75-meter phone band, each requiring separate antennas (or antennas with switched element lengths, loads, or other means of changing the range). On 160, we find a relatively narrow DX window, with antennas designed to cover only that region. 10-meter antennas tend to cover the first MHz of the band--and sometimes, only the first 800 kHz of the band. In the VHF and UHF region, we find many high performance narrow-band antennas for use only within specific small parts of the bands. FM repeater users generally expect to use relatively simple, omni-directional, vertical antennas. Hence, high performance horizontal antennas on 6 meters tend to cover only a half MHz at the low end of the band. The upper 3 MHz of the band call for ground-plane monopoles, J-poles, and a few collinear vertical designs.

How we handle the wider amateur bands thus has at least two dimensions: operator decision or preference on the one hand and design capability on the other. We shall be interested in what various antenna designs--especially parasitic beams--can achieve by way of operating bandwidth.

## Operating Bandwidth

Before we look at antenna types that will cover the various amateur bands, let's probe the idea of operating bandwidth for a parasitic beam. For many amateurs, the 50-Ohm SWR seems to be the only factor involved in setting the operating bandwidth. For general-purpose communications, a 2:1 SWR maximum serves as a usable standard. Avid DXers and contest operators tend to prefer a 1.5:1 limit to prevent fold-back circuits in high power amplifiers from reducing or cutting off the power output.

There are numerous other considerations that go into a final judgment of an antenna's operating bandwidth. We can focus on just two aspects of antenna performance and enlarge our thinking considerably. How well the front-to-back ratio holds up across a given band contributes to many decisions about whether to use a particular antenna design. Amateurs tend to use a 20-dB standard for the front-to-back ratio of Yagis with at least 3 elements. The figure represents a minimum value that we expect to achieve at all frequencies within the band. (I shall pass over the question of which front-to-back figure to use: 180°, worst-case, or average front-to-rear ratio.)

Matters of gain can be even more complex. Much commercial antenna literature cites only a single number. It does not matter whether the number is the peak gain or the average gain, because neither figure tells us anything about the antenna's gain behavior across the intended passband. Only a detailed table of samples or a graph for the entire band will give us an adequate portrait of the gain performance. Very likely, these ideas will grow more meaningful as we look at some sample designs. The samples will emerge from my stock of antenna models. All make use of very standard techniques, even though the models themselves may not be in final form, ready for the home workshop. For example, some HF Yagis will use uniform-diameter elements rather than tapered-element schedules. However, all present very reasonable pictures of actual antenna performance.

*Example 1*: A 4-Element Yagi and a 3-Element Quad Beam for 20 Meters. We may begin with a pair of contrasting parasitic beams for the medium width 20-meter band. The 4-element Yagi uses a 437" boom, while the quad's boom is about 387" long. The Yagi uses 1" diameter elements, while the quad uses AWG #12 wire elements. We expect most extant beam designs to cover all of 20 meters. Both the standard 4-element Yagi and the 3-element quad provide SWR values of less than 2:1 across the band, as shown in **Figure 1**. The quad uses a 75-Ohm standard, while the Yagi uses a beta match to arrive at a 50-Ohm SWR reference. **Table 2** provides sampled data from the models across the band.

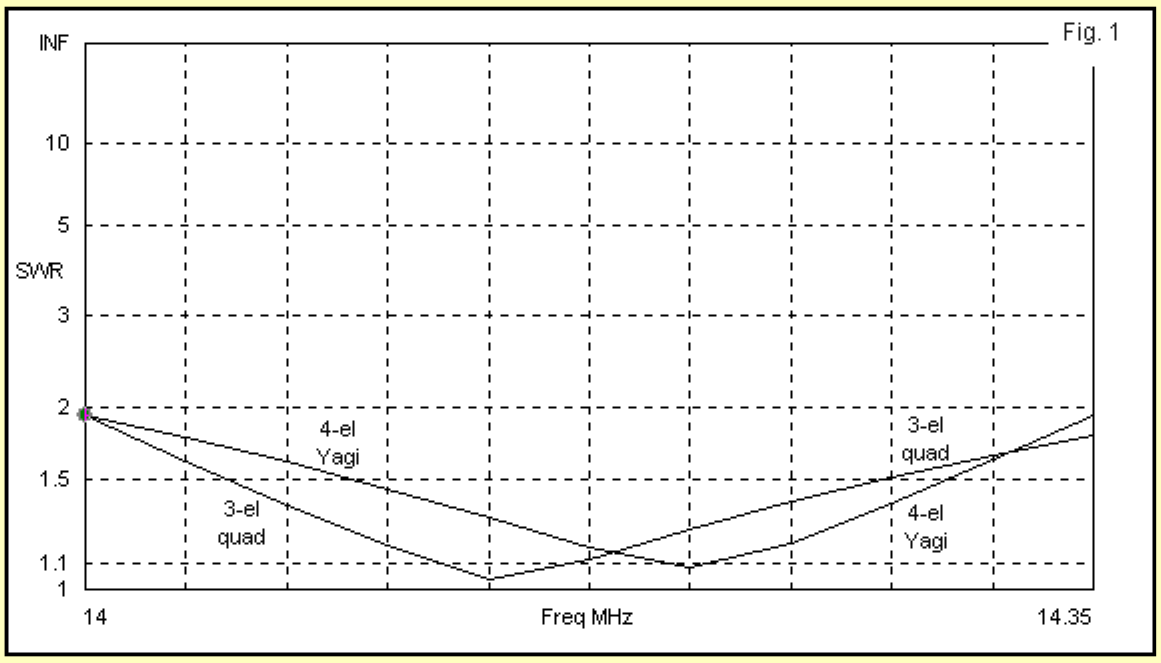


Fig. 1

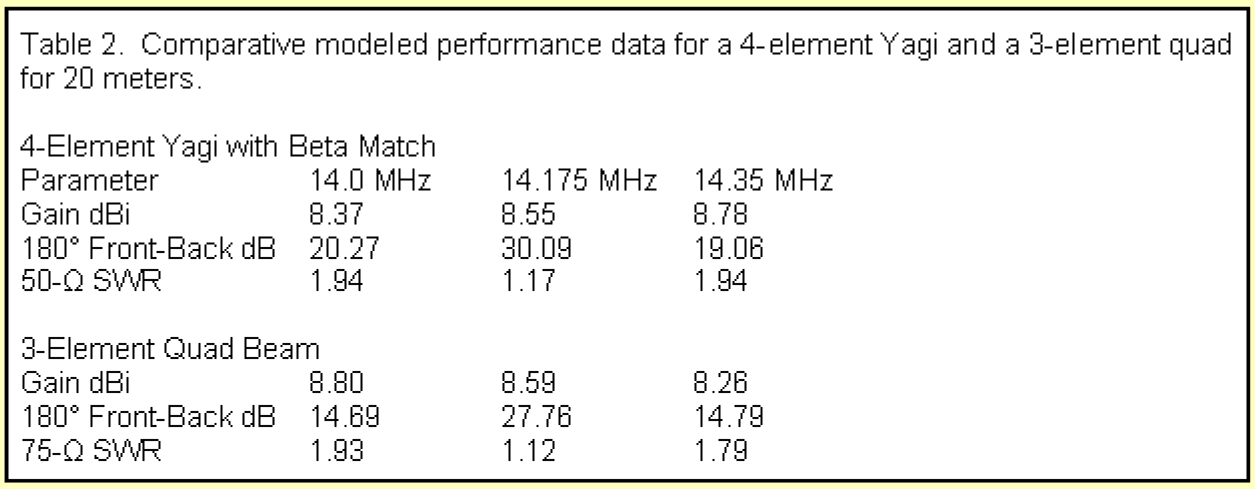


Table 2. Comparative modeled performance data for a 4-element Yagi and a 3-element quad for 20 meters.

4-Element Yagi with Beta Match

| Parameter | 14.0 MHz | 14.175 MHz | 14.35 MHz |
|---|---|---|---|
| Gain dBi | 8.37 | 8.55 | 8.78 |
| 180° Front-Back dB | 20.27 | 30.09 | 19.06 |
| 50-Ω SWR | 1.94 | 1.17 | 1.94 |

3-Element Quad Beam

| | | | |
|---|---|---|---|
| Gain dBi | 8.80 | 8.59 | 8.26 |
| 180° Front-Back dB | 14.69 | 27.76 | 14.79 |
| 75-Ω SWR | 1.93 | 1.12 | 1.79 |

At mid-band, both antennas show a free-space forward gain of above 8.55 dBi. However, the two antennas have very different gain curves, as revealed in **Figure 2**. Like most standard-design Yagis with at least one director, the 4-element beam shows a rising gain characteristic as we increase frequency within the passband. In contrast, the quad shows a decreasing gain value as we increase frequency. I chose these particular models because they pass at the middle of the band. Hence, neither has any particular average gain advantage.

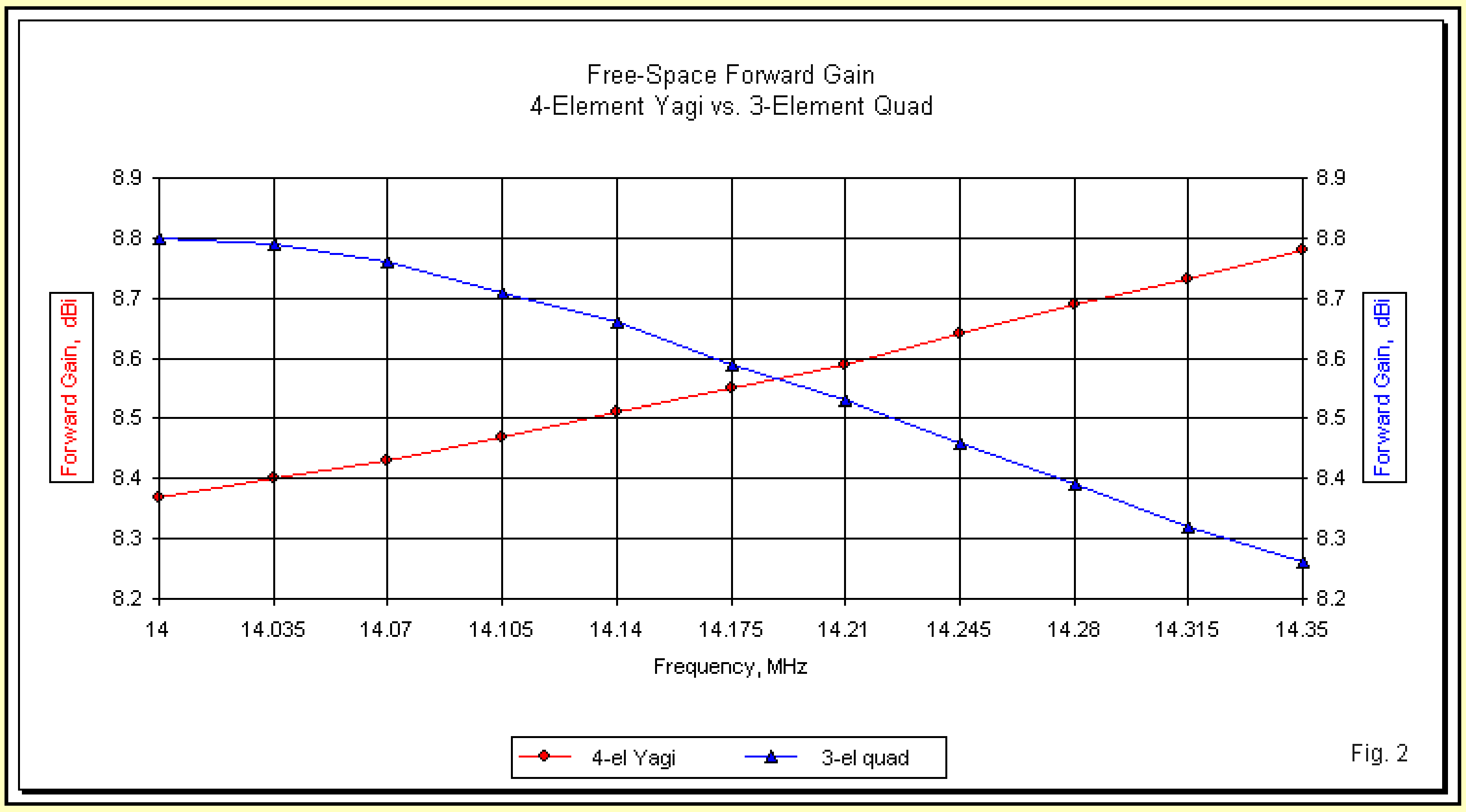
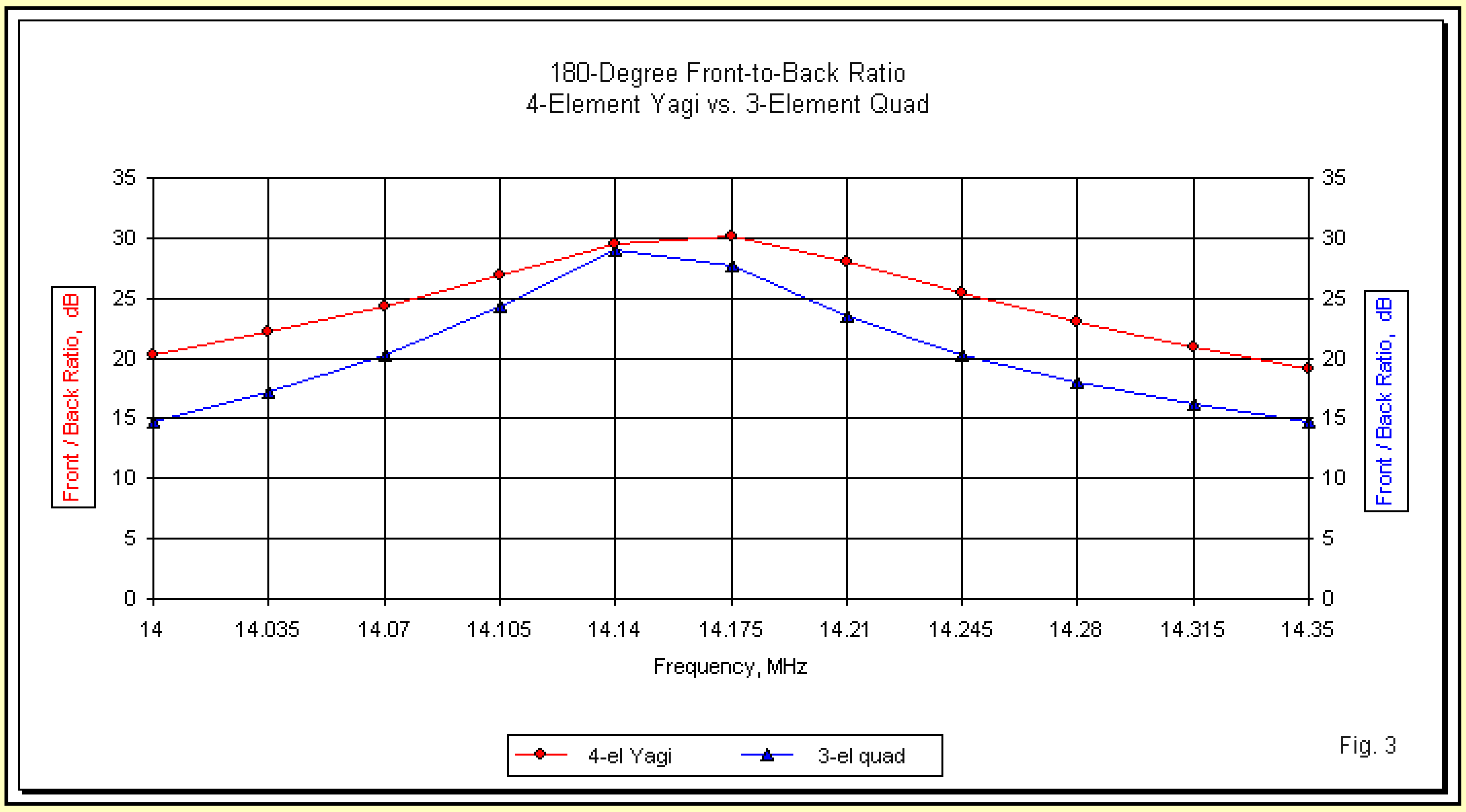


Fig. 2

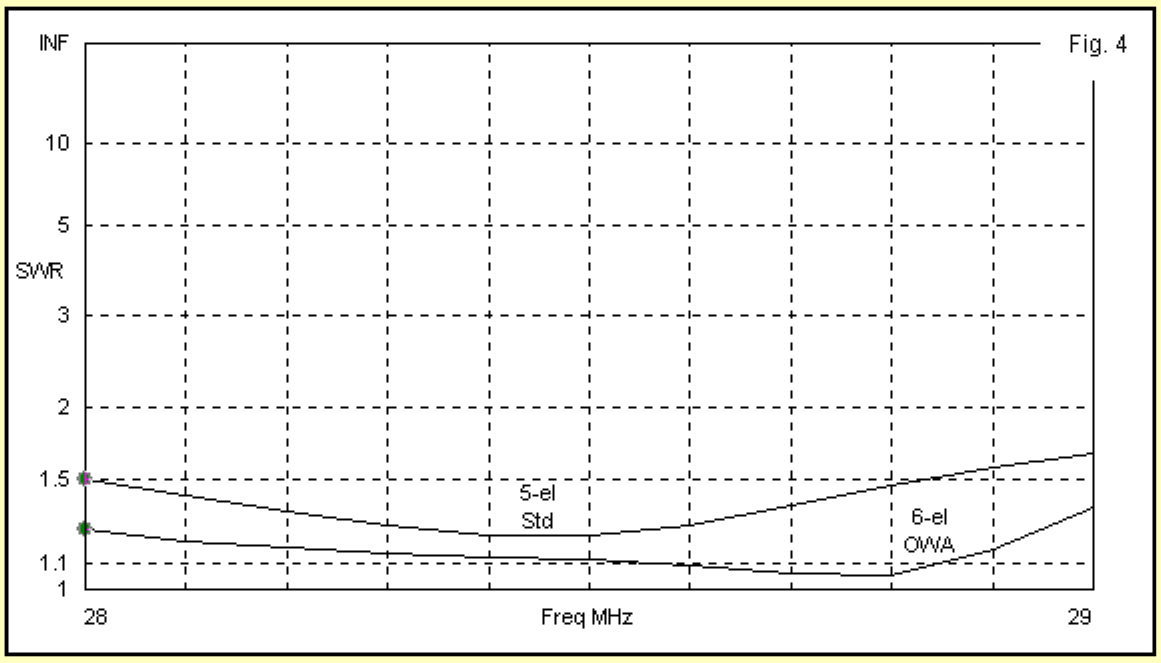
Still, we may concern ourselves with two aspects of these curves. First, what is the total change in gain across the band. For the Yagi, the gain difference is just above 0.4 dB, while for the quad, the difference is a little over 0.5 dB. Only a particular operator with a good sense of what the desired operation requires can decide if these numbers are acceptable or not. Second, we may note where the highest gain values occur. Apart from other reasons for selecting one of the 2 antennas, the quad favors the CW end of the band, while the Yagi favors phone operation. Note that the questions we may usefully pose about antenna gain performance are simple, and the answers may be easy--if only we take the time to pose them.



The front-to-back performance of the 2 sample antenna designs appears in **Figure 3**. The Yagi just about meets the front-to-back standard of 20-dB minimum, using the 180° values across the band. However, the quad meets the standard only for about half the total bandwidth. The quad design used here emerged from a series of 3-element quad designs expressly aiming for maximum operating bandwidth. As with most quad beams, the SWR bandwidth--when measured against our normal amateur standard--exceeds the front-to-back bandwidth by a considerable margin. Whether or not a particular operation needs a 20-dB minimum front-to-back ratio is once more an operator decision.

*Example 2*: A 5-element Standard-Design Yagi and a 6-Element OWA Yagi for 28-29 MHz. When we design parasitic beams for 10 meters, we usually design them only for the first MHz of the band--from 28.0 to 29.0 MHz. The reduced passband still has a bandwidth of 3.51%, making it considerably wider than 20 or 15 meters. Many highly capable designs for 20 meters strain to achieve a good set of performance values across the most active part of 10 meters. Let's compare a 5-element Yagi of standard design to a 6-element OWA design. Both antennas use 0.5" elements. The 5-element array has a 333" boom, partly because it increases the driver-reflector spacing to produce a near-50-O feedpoint impedance. The OWA design, pioneered by NW3Z and WA3FET, packs its elements onto a 288" boom.

The boom lengths and the number of elements call for a small comment. Ever since the appearance of the groundbreaking work of Jim Lawson, W2PV, a sound bite has pervaded Yagi articles: gain is a function of boomlength rather than the number of elements. As true as this statement may be, it is no excuse for using too few elements to achieve all of the characteristics that one needs from a given Yagi design. As we shall see in the OWA design, extra elements may not increase gain over the longer-boom 5-element Yagi, but they can shape the performance curves across the operating bandwidth of the antenna.



As shown in **Figure 4**, the 5-element design achieves a very acceptable 50-Ohm SWR curve. However, by judicious spacing among the reflector, the driver, and the first director, the OWA SWR curve is superior and meets the most stringent fold-back circuit requirements. **Table 3** provides sample numbers for the rest of the performance categories on which we are focusing. Note that the 5-element design has a very good front-to-back ratio, but tails off in this category at the upper end of the 10-meter activity region.

Table 3. Comparative modeled performance data for a 5-element Yagi and a 6-element OWA Yagi for 28-29 MHz.

5-Element Standard-Design Yagi

| Parameter | 28.0 MHz | 28.5 MHz | 29.0 MHz |
|---|---|---|---|
| Gain dBi | 9.80 | 10.32 | 10.74 |
| 180° Front-Back dB | 25.15 | 23.74 | 14.09 |
| 50-Ω SWR | 1.50 | 1.22 | 1.66 |

6-Element OWA Yagi

| Parameter | 28.0 MHz | 28.5 MHz | 29.0 MHz |
|---|---|---|---|
| Gain dBi | 10.11 | 10.31 | 10.33 |
| 180° Front-Back dB | 20.06 | 30.29 | 20.03 |
| 75-Ω SWR | 1.24 | 1.11 | 1.36 |

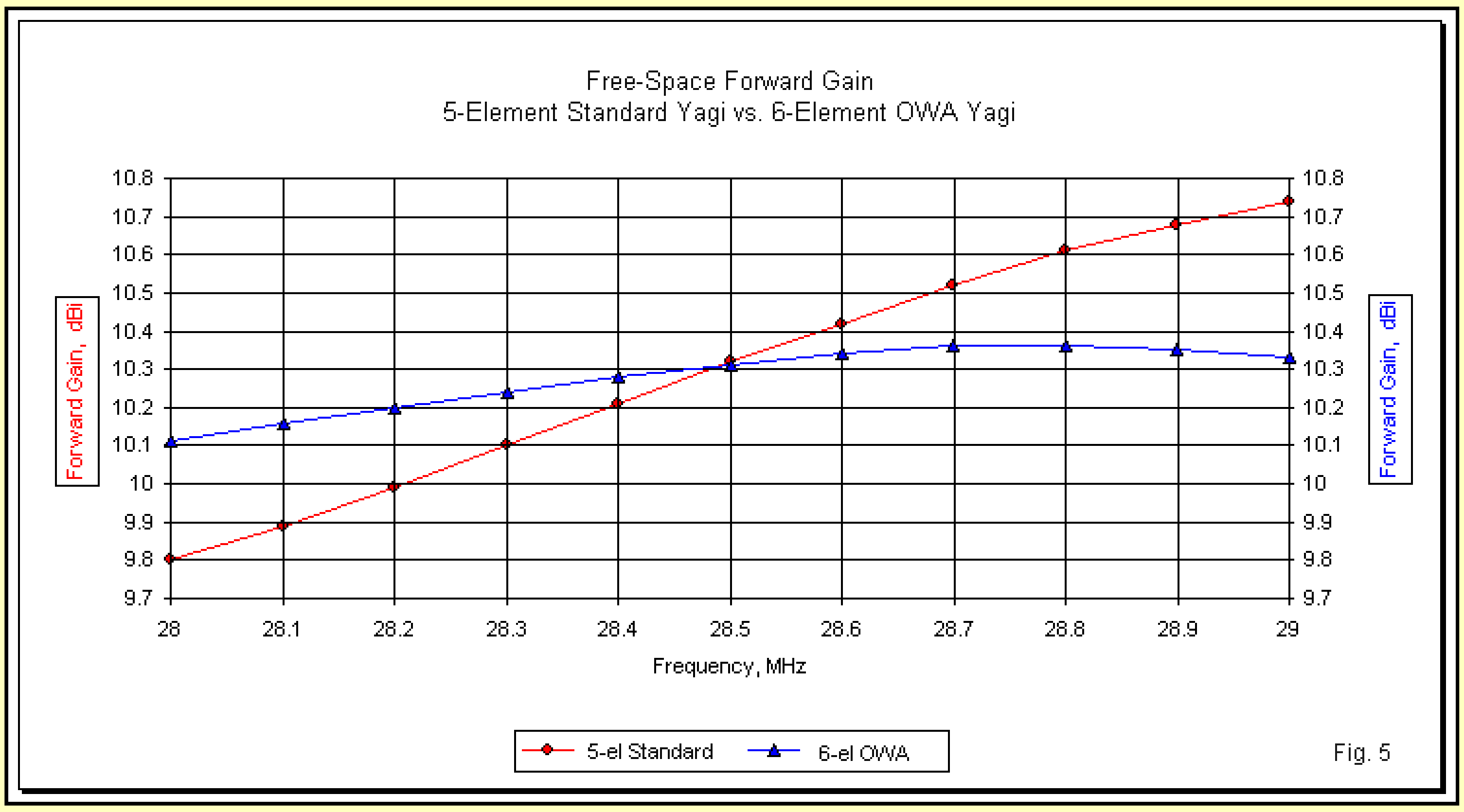


Fig. 5

More important than the front-to-back behavior is the shape of the gain curves that appear in **Figure 5**. Nothing in the 5-element standard-design Yagi controls the steep gain increase with rising operating frequency. The total gain differential across the band is nearly a full dB. In contrast, the extra OWA element and the arrangement especially of the second and third directors place the gain peak within the passband. One result is more even gain across the band. The total gain range is a mere 0.23 dB.

*Example 3*: A Log-Cell Yagi for the Entire 10-Meter Band. The OWA design is only one of many techniques for increasing the operating bandwidth of a parasitic beam. Suppose that we wanted a beam that would cover the entirety of 10 meters, that is, cover nearly a 6% bandwidth. The OWA design would strain at the 60+% increase in required bandwidth. However, a well-designed log-cell Yagi can handle the task with relative ease. Our sample uses a 5-element log cell designed according to LPDA rules. It adds parasitic elements, namely, a reflector and a director. The resulting 7-element array uses a 337" boom with 0.75" diameter elements. **Table 4** provides sample modeling results across the band. The band-edge 50-Ohm SWR values mark the highest values for the array.

Table 4. Modeled performance data for a 10-meter log-cell Yagi with a 5-element log cell plus a director and a reflector.

| Parameter | 28.0 MHz | 28.85 MHz | 29.7 MHz |
|---|---|---|---|
| Gain dBi | 9.84 | 10.00 | 9.86 |
| 180° Front-Back dB | 28.37 | 28.08 | 27.15 |
| 50-Ω SWR | 1.52 | 1.28 | 1.49 |

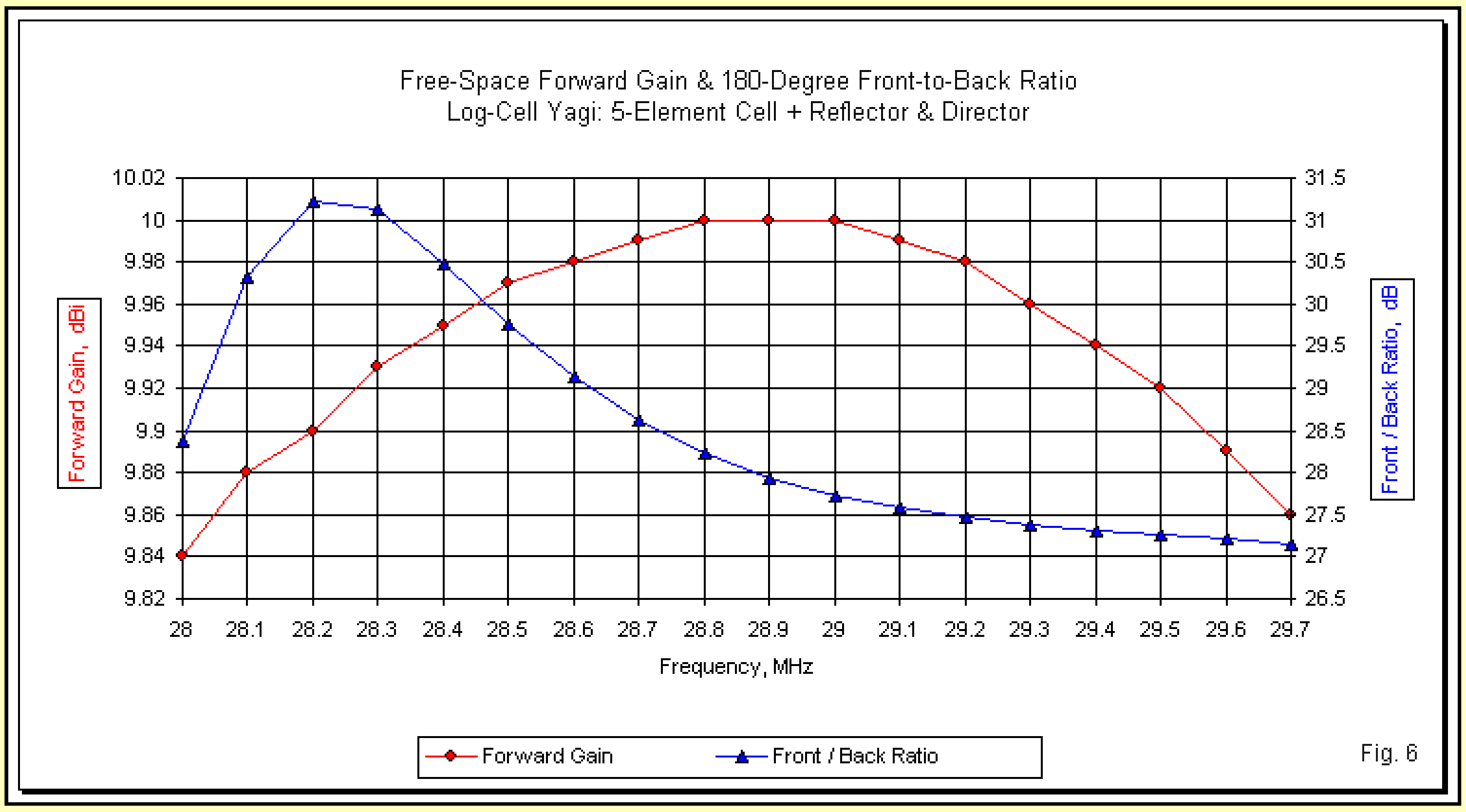


Fig. 6

**Figure 6** provides the gain and front-to-back curves for the antenna design. The peak in the front-to-back ratio may give the impression that the bulk of the band shows a poor ratio until we read the right-hand Y-axis and discover that the minimum front-to-back ratio is 27.15 dB. The use of a log cell as a driver does not generally enhance array gain relative to standard-design Yagis of the same boom length. However, it does provide strong control of the gain curve. As the graph shows, the antenna's peak gain occurs close to the band's center. As well, the gain changes by only 0.16 dB across the entire 1.7 MHz spread.

*Example 4*: A Short-Boom 3-Element Yagi with Phased Drivers for 6 Meters. We tend to call parasitic arrays with driver cells designed according to LPDA principles and equations "log-cell Yagis." However, we often use 2 or 3 phased driver elements that we arrive at by trial and error (or success, as the case may be). Such antennas often bear the label "phagi," in keeping with our penchant for snappy antenna names. Let's look at one example to see what a casually designed phased driver pair might be able to do to enlarge the operating bandwidth of an antenna. 6 meters is a good band for a compact simple Yagi used vertically to provide some gain and wide directivity within the 3 MHz used for FM operations.

Standard-design wide-band Yagis that will cover all of 6 meters already exist. The two samples shown in **Figure 7** are adaptations of 10-meter designs that Bill Orr, W6SAI, first presented in Ham Radio during the 1980s. The 3-element version is interesting because it uses a boom length that one might find in a higher-grain, narrower-bandwidth Yagi. However, as evident in the data in **Table 5**, the gain of the wideband Yagi is about a full dB lower--the price paid for increased operating bandwidth.

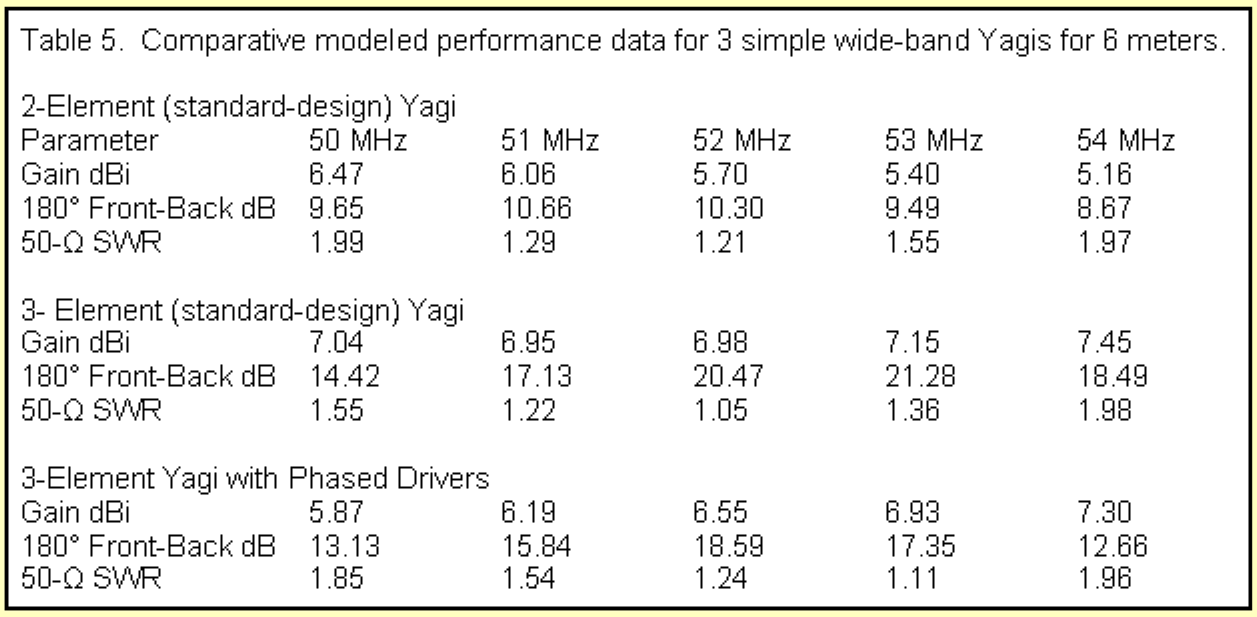
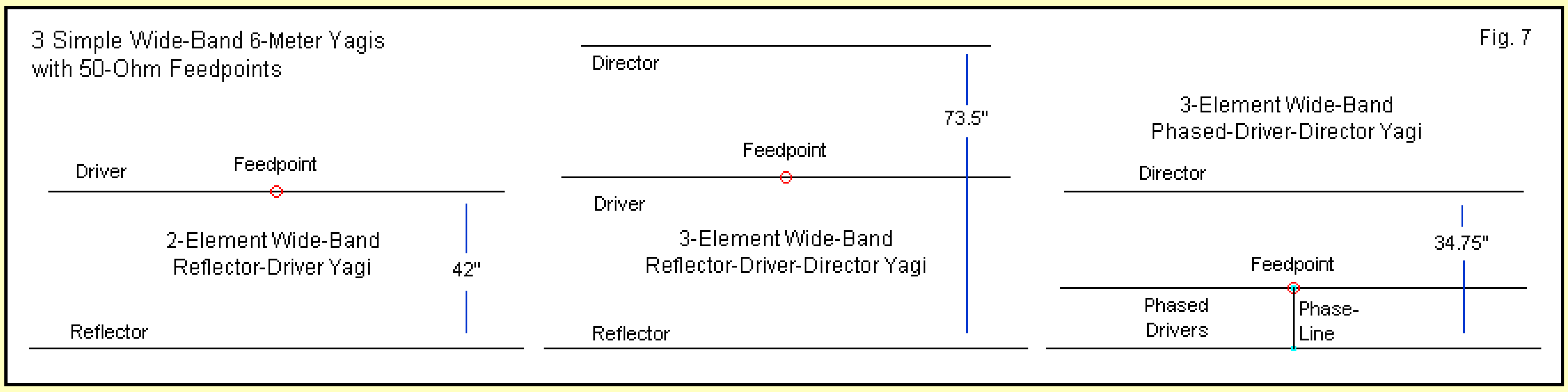


Table 5. Comparative modeled performance data for 3 simple wide-band Yagis for 6 meters.

| 2-Element (standard-design) Yagi | | | | | |
|---|---|---|---|---|---|
| Parameter | 50 MHz | 51 MHz | 52 MHz | 53 MHz | 54 MHz |
| Gain dBi | 6.47 | 6.06 | 5.70 | 5.40 | 5.16 |
| 180° Front-Back dB | 9.65 | 10.66 | 10.30 | 9.49 | 8.67 |
| 50-Ω SWR | 1.99 | 1.29 | 1.21 | 1.55 | 1.97 |
| 3- Element (standard-design) Yagi | | | | | |
| Gain dBi | 7.04 | 6.95 | 6.98 | 7.15 | 7.45 |
| 180° Front-Back dB | 14.42 | 17.13 | 20.47 | 21.28 | 18.49 |
| 50-Ω SWR | 1.55 | 1.22 | 1.05 | 1.36 | 1.98 |
| 3-Element Yagi with Phased Drivers | | | | | |
| Gain dBi | 5.87 | 6.19 | 6.55 | 6.93 | 7.30 |
| 180° Front-Back dB | 13.13 | 15.84 | 18.59 | 17.35 | 12.66 |
| 50-Ω SWR | 1.85 | 1.54 | 1.24 | 1.11 | 1.96 |

The smaller 3-element Yagi with the phased pair of driver elements on the far right of **Figure 7** is actually an extension of a 2-element driver-director Yagi. This class of Yagi has a high peak gain but a very narrow beamwidth. I tend to recommend them for use on the narrow amateur bands, such as 30, 17, and 12 meters, although they have other specialized uses as well. The enlargement of the driver section of the antenna does not materially increase the boom length ahead of the drivers, and so the overall length is less than the boom needed by the 2-element wide-band driver-reflector Yagi. All three Yagi designs use a tapered-diameter schedule consisting of 0.5" and 0.375" element sections.



The data table shows that the phased drivers do not quite equal the performance of the wide-band 3 element Yagi. However, the performance curves are closer to that antenna than to the 2-element curves. As well, the 2-element gain shows its downward progression with rising frequency, in contrast to the nearly parallel upward gain curves of the 3-element Yagis. Hence, for the intended application--FM simplex and repeater operation--the phase-fed dual driver of the sample short-boom Yagi seems a natural. Unlike either the OWA Yagi or the log-cell Yagi, the 3-element phagi has too few elements to control all of the relevant operating parameters.

*Example 5*: An 8-Element Utility Yagi for 70 cm. Almost as wide as 6 meters, the 70-cm band has a bandwidth of 6.9%. Very long-boom Yagis, such as the DL6WU "trimming" series and other comparable designs, manage to cover the entire band with something to spare. The undulations of gain, front-to-back ratio, and SWR are fascinating to observe, but all three aspects of operation remain under relatively good control. Wide operating bandwidth is a boon to the home antenna builder, since limitations of precision tend not to void the basic performance of the antenna. The question that we might pose here is whether we can cover all of 70 cm with a relatively short utility antenna, say, using 8 elements. In this frequency range, the boom length would be about 53".

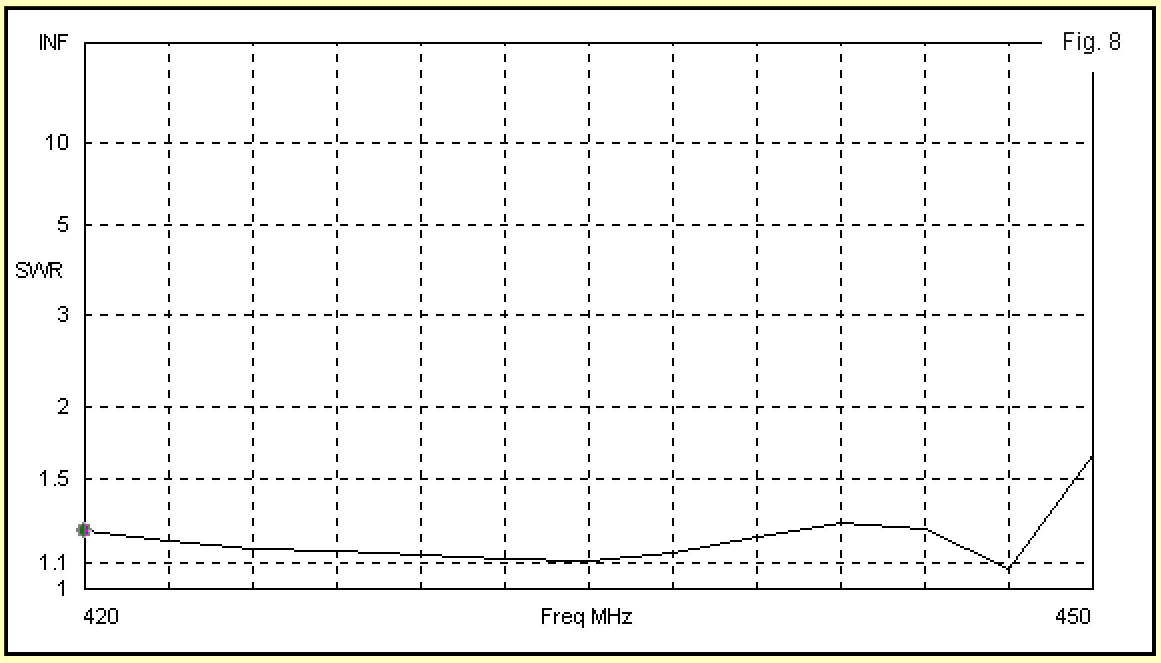


Fig. 8

The project is quite feasible under 2 conditions. First, we should use fat elements, about 0.5" or so. Second, we should expect some variability of performance across the band. Other than that, we may use a fairly standard Yagi design. **Figure 8** shows the 50-Ohm SWR curve of our sample antenna, which reflects the application of OWA principles stretched about as far as I dare.

Table 6. Modeled performance data for a 70-cm 8-element wide-band utility Yagi.

| Parameter | 420 MHz | 430 MHz | 440 MHz | 450 MHz |
|---|---|---|---|---|
| Gain dBi | 12.92 | 13.31 | 13.59 | 12.99 |
| 180° Front-Back dB | 16.27 | 14.95 | 19.61 | 20.91 |
| 50-Ω SWR | 1.24 | 1.13 | 1.21 | 1.65 |

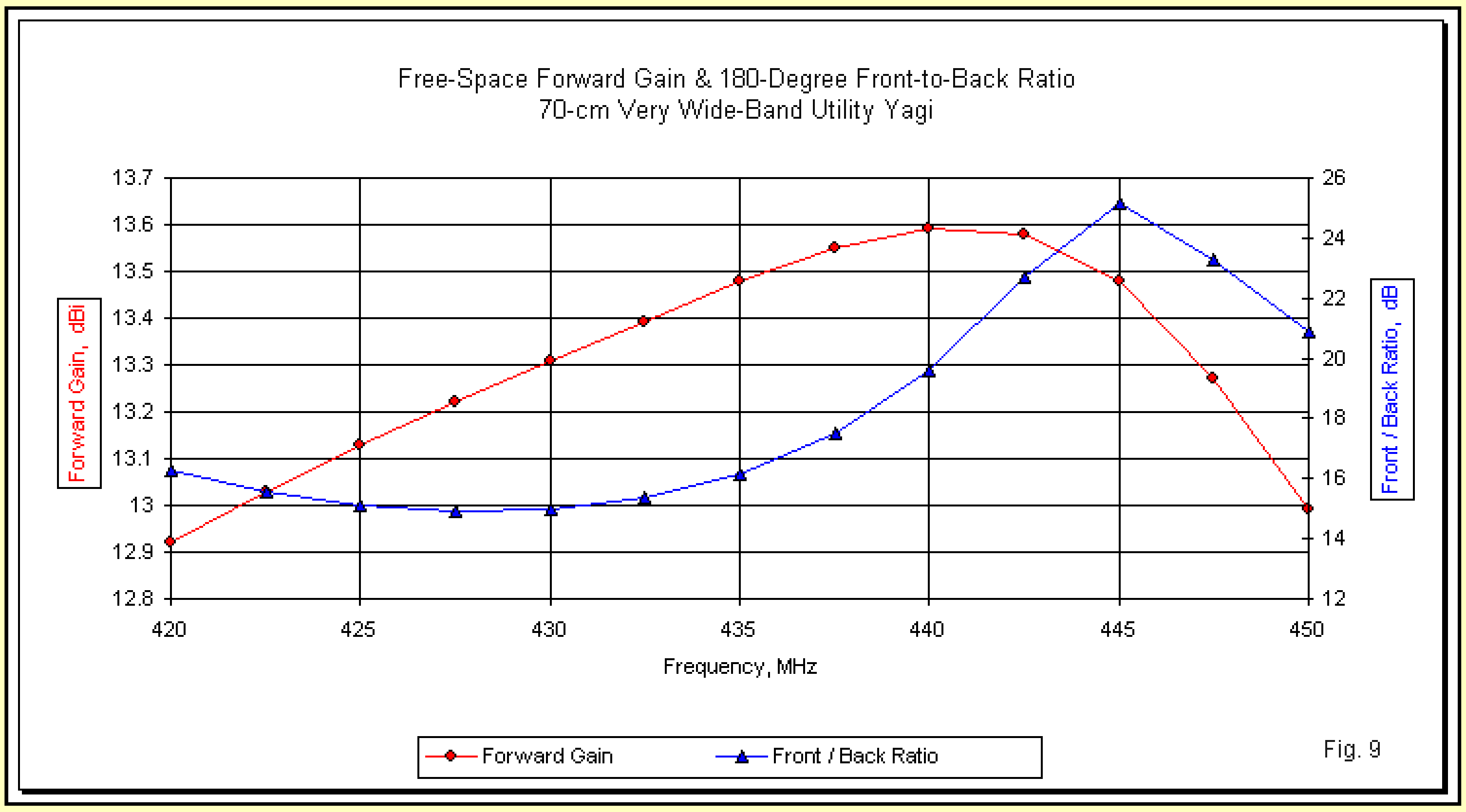


Fig. 9

Sample data from across the band appear in **Table 6**. The gain and front-to-back curves are in **Figure 9**. The gain curve shows that it is possible to place the gain peak within the passband and to control the range of variation within about 0.5 dB. The gain level is close to what is standard for narrower-band Yagis with the same number of elements. However, over the wide operating bandwidth, we cannot fully control all facets of performance to the same level. The front-to-back curve dips to slightly less than 15 dB, which is adequate for the designated use as a utility beam for either horizontal or vertical installation.

*Example 6*: An 8-Element Wire LPDA for 3.5-4.0 MHz. Yagi designs are capable of considerably wider-band performance than we generally give them credit for--if we are willing to pay the price in terms of using more elements for a given boom length or using special driver sections. I have stretched one design to cover a 26% bandwidth with an acceptable SWR curve and modest, though usable performance. However, when we turn to the 80-meter amateur band, the 13% bandwidth combined with a need to use relatively thin wire presents a daunting challenge. One solution is to use a full LPDA for the band. With 8 special wire elements and an 86' virtual boom length, such an array can provide about 7 dBi free-space gain with a front-to-back ratio that remains above 20 dB across the band. Since such an array is a major undertaking, I have not hesitated to use virtual 2" elements composed of dual wires (shorted at the phase-line and the outer end) spaced anywhere from 8" to 12" apart along their length.

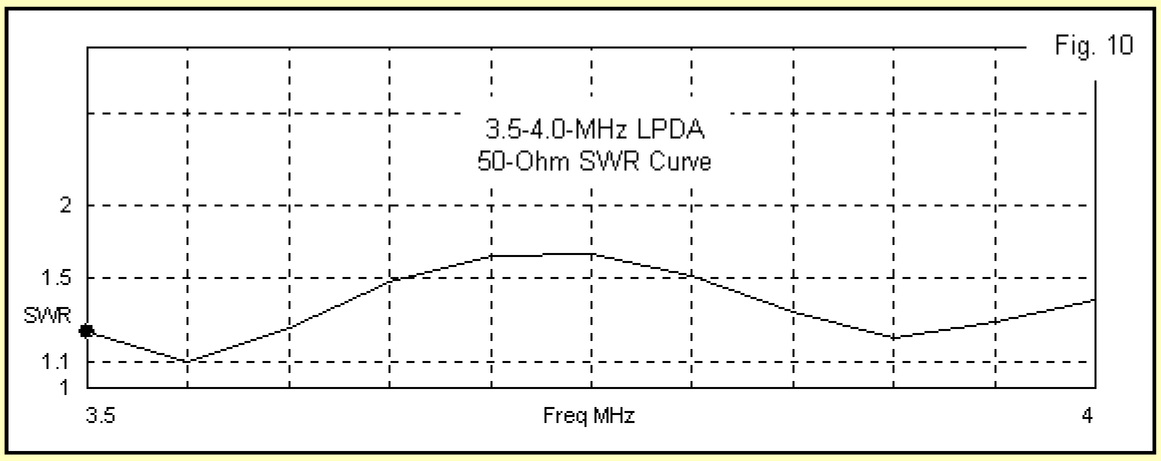


Fig. 10

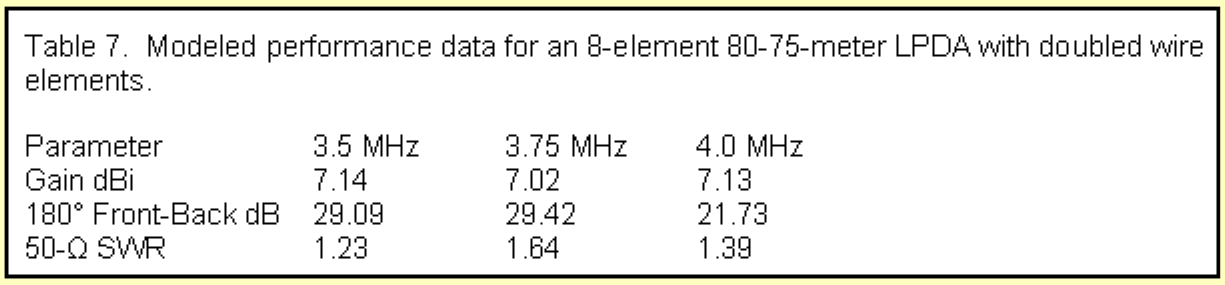


Table 7. Modeled performance data for an 8-element 80-75-meter LPDA with doubled wire elements.

| Parameter | 3.5 MHz | 3.75 MHz | 4.0 MHz |
|---|---|---|---|
| Gain dBi | 7.14 | 7.02 | 7.13 |
| 180° Front-Back dB | 29.09 | 29.42 | 21.73 |
| 50-Ω SWR | 1.23 | 1.64 | 1.39 |

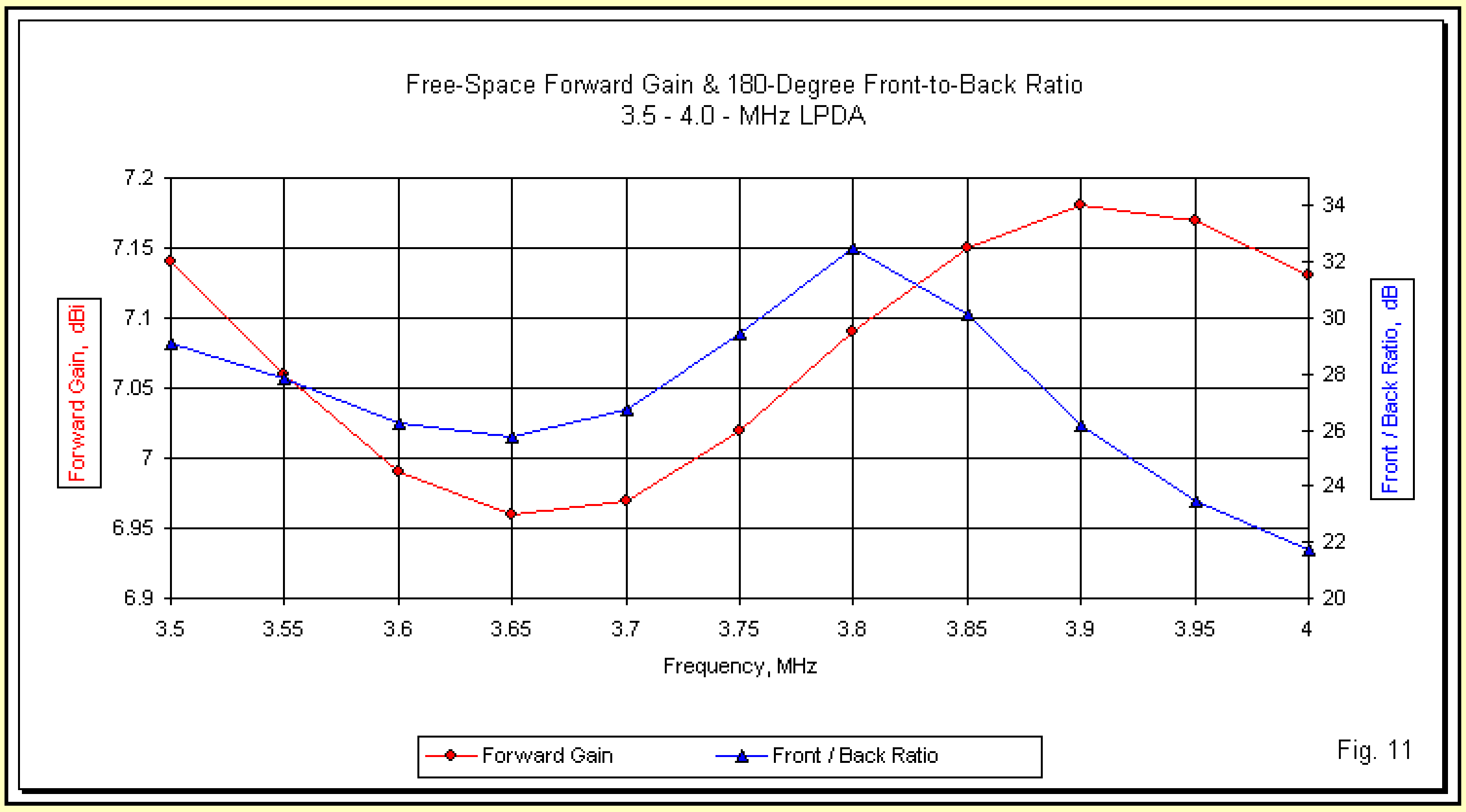


Fig. 11

**Figure 10** shows the modeled 50-Ohm SWR curve, and sample data appears in **Table 7**. The gain and front-to-back curves are in **Figure 11**. All of the curves show a particular trait inherent to LPDAs. The curves undulate across the passband, but the peaks and nulls do not coincide with each other. Many newcomers to phased element design (including LPDAs) believe that the phase line provides a direct source of energy to the elements. While this belief is true, it is equally true that the elements exhibit mutual coupling. Hence, an LPDA (and any phased-fed collection of elements) is a form of parasitic array, at least in part. The balance among the energy sources for the elements undergoes continuous change as we change frequency. As one consequence, the operating parameters change with frequency. A good LPDA design is one that minimizes the level of change, although some change is inevitable in even the most ideal designs.

Our sample antennas have had two goals. One purpose was to show that it is possible by a variety of techniques to enlarge the operating bandwidth of a directional array. We have only touched a few of the many techniques available. The second aim was to expand our appreciation of the concept of operating bandwidth so that SWR becomes only one of many equal parts in the equation. We have many options in deciding which aspect of performance deserves primary attention, and equally many options in the techniques by which we achieve acceptable performance over a wide operating bandwidth.

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