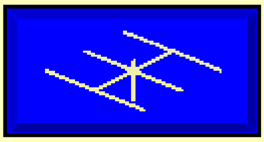


Quagi and Yagi on 2 Meters
Some Preliminary Notes

L. B. Cebik, W4RNL (SK)

As soon as one begins to analyze or design Yagis for VHF, someone (or many ones) will inevitably ask about the quagi, the hybrid parasitic array that usually consists of a quad loop driver and reflector with linear directors. In the past numerous claims have been made about the quagi, most based on operational success stories but without suitable comparisons.

Therefore, I took a step or two into the investigation, and the results appear in these preliminary notes. work is far from done, since I have looked at only some fairly short quagis--in the 11 to 13 foot boom-length range with 7 and 8 elements. I compared them with some Yagis that bracketed the quagi lengths, using models ranging from 9 to 14.5 feet in length and using 8 to 10 elements. The differential in element count for roughly corresponding boom lengths is one of those topics that will bear further study later on.

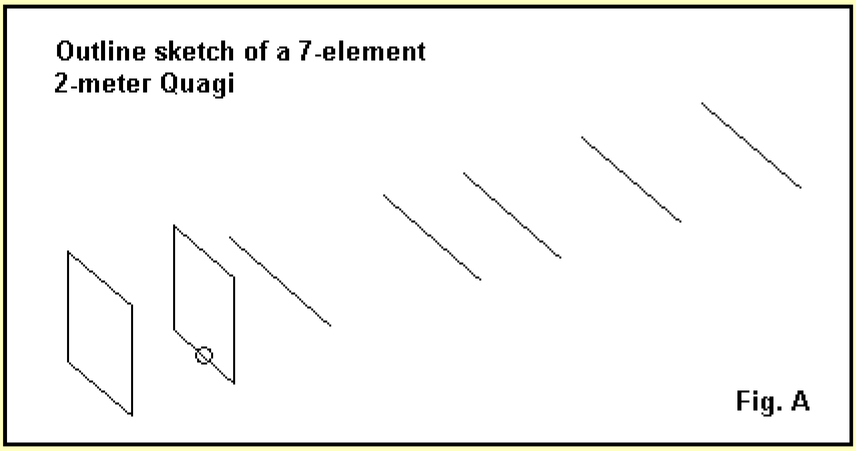
It is clear that I plan to compare the two antenna types over comparable boom lengths. However, every comparison proceeds on the basis of a method and a set of specifications by which to make the comparison. My vehicle of comparison will be NEC-4, which is perfectly adequate to the task, since nothing in either basic quagi or basic Yagi design presses it limitations.

More important perhaps are the categories and criteria of comparison. Many antenna builders of high gain antennas for VHF design for the highest gain over a very narrow bandwidth. This practice meets certain operational needs for point-to-point work. However, my own categories of comparison range over a broader set of categories:

> **1. Operating bandwidth**: I shall be interested in the SWR bandwidth over the entire 2-meter band (144-148 MHz). At VHF, the 2:1 HF standard is often still used, but I shall be interested in how much better than that we can achieve with an array. All arrays in these notes are designed for a direct 50-Ohm feedline connection, which simplifies comparisons.
>
> **2. Pattern control**: The absence of forward side lobes generally yields the widest -3 dB beamwidth possible for a given gain level. The presence of significant forward side-lobes tends to decrease horizontal beamwidth, a factor not generally taken into account in some of the traditional simplistic means of calculating beamwidth from gain. I shall be interested in the level of side-lobe suppression--how far down in dB from the main lobe the strongest forward side-lobes are. As well, I shall be looking at the -3 dB beamwidth.
>
> **3. Front-to-back ratio**: Although many VHF operators ignore the front-to-back ratio due to the relative absence of rearward QRM in many point-to-point operations, a more general set of criteria must attend to this figure. We shall use the 20 dB standard as a marker, giving figures in terms of the 180-degree front-to-back ratio, with special notes on the worst-case value or the averaged rearward value if required.
>
> **4. Gain**: Forward gain will be whatever the array yields, as measured across the passband of 2 meters. We shall be interested not only in the maximum gain to be achieved from an array, but as well in the variation of gain across the test passband. Hence, many of our illustrations will be in the form of performance graphs.

Certainly, anyone who wish to redo the comparisons using other categories or a restricted set of the ones enumerated is free to do so, and the results might look somewhat different from the ones to appear. However, in every such comparison, there should be an initial explanation--like the one above--of the basis for the comparison. Unfortunately, such explanations of the criteria of comparison are still all too often lacking from discussions of large arrays in every frequency range.

Quagis:



Outline sketch of a 7-element 2-meter Quagi

Fig. A

Fig. A is the outline of a 7-element quagi and shows the quad loop driver and reflector, along with the linear directors. Such antennas have been built with wire or thin (up to 3/16" rod or tubing). The use of quad loops for the reflector and driver arise from several considerations:

1. The reflector loop derives from some evidence that even standard Yagis can benefit from multiple reflectors. In effect, multiple reflectors are approximated by the quad loop that provides two reflectors spaced 1/4 wl apart. Although many claims have been made for the multiple reflector arrangement, the chief advantage appears to be in the category of front-to-back ratio.

2. Many older designs of Yagis wound up with very low feedpoint impedances, necessitating the use of matching sections: Tees, gammas, and the like. with a quad loop driver, one can achieve a 50-Ohm feedpoint impedance without the use of additional matching schemes.

3. The combination of driver and reflector loops eases the problem of arriving at a reasonably broad operating bandwidth--at least in terms of SWR. The reflector-driver spacing (as well as the loop circumferences) can be used to set the operating source impedance of the array.

In looking for a suitable quagi to use as a basis for these notes, I turned to the *ARRL Antenna Book*, 18th Edition, page 18-33. There, I found quagi designs that go back to the 1970s. (The same material is on a different page in the 19th Edition.) My modeling efforts required that I reduce the wire size to #14 from the originally specified #12 AWG in order to bring the array to some semblance of performance across the 2-meter band. The following extract from the EZNEC model will provide dimensions:

```
Handbook Quagi                          Frequency = 144-148  MHz.

Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1    W4E2   0.000,-10.770,-10.770  W2E1   0.000,-10.770, 10.770 6.41E-02   7
2    W1E2   0.000,-10.770, 10.770  W3E1   0.000, 10.770, 10.770 6.41E-02   7
3    W2E2   0.000, 10.770, 10.770  W4E1   0.000, 10.770,-10.770 6.41E-02   7
4    W3E2   0.000, 10.770,-10.770  W1E1   0.000,-10.770,-10.770 6.41E-02   7
5    W8E2  20.900,-10.600,-10.600  W6E1  20.900,-10.600, 10.600 6.41E-02   7
6    W5E2  20.900,-10.600, 10.600  W7E1  20.900, 10.600, 10.600 6.41E-02   7
7    W6E2  20.900, 10.600, 10.600  W8E1  20.900, 10.600,-10.600 6.41E-02   7
```

```
8    W7E2  20.900, 10.600,-10.600  W5E1  20.900,-10.600,-10.600 6.41E-02   7
9          36.570,-17.930,  0.000        36.570, 17.930,  0.000 6.41E-02  15
10         69.550,-17.750,  0.000        69.550, 17.750,  0.000 6.41E-02  15
11         86.980,-17.560,  0.000        86.980, 17.560,  0.000 6.41E-02  15
12        112.980,-17.370,  0.000       112.980, 17.370,  0.000 6.41E-02  15
13        138.980,-17.180,  0.000       138.980, 17.180,  0.000 6.41E-02  15
```

The boom length is 11.58' for a relatively low element count of 7.

The thin elements result in deficiencies in performance when measured over the 2-meter passband. (See my "New Quad Notes, especially the item on VHF quads, for fuller notes on the effects of element diameter on quad performance.) Therefore, I also adapted a WB4WEN design for 220 MHz to 2 meters, shortening it to 7 elements and using 1/4" diameter elements. One might build such an antenna out of copper tubing or aluminum rod (or aluminum tubing, if the small diameter material is available). The following partial model description shows the salient features of this array.

```
Modified WB4WEN Quagi                          Frequency = 146  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1    W4E2   0.000,-11.199,-11.197  W2E1   0.000, 11.199,-11.197 2.50E-01   7
2    W1E2   0.000, 11.199,-11.197  W3E1   0.000, 11.199, 11.199 2.50E-01   7
3    W2E2   0.000, 11.199, 11.199  W4E1   0.000,-11.199, 11.199 2.50E-01   7
4    W3E2   0.000,-11.199, 11.199  W1E1   0.000,-11.199,-11.197 2.50E-01   7
5    W8E2  21.000,-10.700,-10.700  W6E1  21.000, 10.700,-10.700 2.50E-01   7
6    W5E2  21.000, 10.700,-10.700  W7E1  21.000, 10.700, 10.700 2.50E-01   7
7    W6E2  21.000, 10.700, 10.700  W8E1  21.000,-10.700, 10.700 2.50E-01   7
8    W7E2  21.000,-10.700, 10.700  W5E1  21.000,-10.700,-10.700 2.50E-01   7
9          36.369, 17.563,  0.000        36.369,-17.563,  0.000 2.50E-01  11
10         67.200, 17.038,  0.000        67.200,-17.038,  0.000 2.50E-01  11
11         83.492, 17.038,  0.000        83.492,-17.038,  0.000 2.50E-01  11
12        107.769, 17.038,  0.000       107.769,-17.038,  0.000 2.50E-01  11
13        132.109, 17.038,  0.000       132.109,-17.036,  0.000 2.50E-01  11
```

The Buchanan array has several features of note. First, boom length is just over 11', a half foot shorter than the Handbook array, although its performance will be superior in every category. Second, for ease of new-builder success, Bill Buchanan designed all but the first director to be of the same length.

To see what a quagi that is just longer than the Handbook array might do, I added a further director to the 7-element model. This move required a director that is quite a bit shorter than the preceding ones, with adjustments also required to the driver loop circumference. The result is a 13.6' boom length, with the other details shown in the partial model description that follows:

```
8-element Quagi                                Frequency = 146  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1    W4E2   0.000,-11.199,-11.197  W2E1   0.000, 11.199,-11.197 2.50E-01   7
```

```
2    W1E2   0.000, 11.199,-11.197  W3E1   0.000, 11.199, 11.199 2.50E-01   7
3    W2E2   0.000, 11.199, 11.199  W4E1   0.000,-11.199, 11.199 2.50E-01   7
4    W3E2   0.000,-11.199, 11.199  W1E1   0.000,-11.199,-11.197 2.50E-01   7
5    W8E2  21.000,-10.650,-10.650  W6E1  21.000, 10.650,-10.650 2.50E-01   7
6    W5E2  21.000, 10.650,-10.650  W7E1  21.000, 10.650, 10.650 2.50E-01   7
7    W6E2  21.000, 10.650, 10.650  W8E1  21.000,-10.650, 10.650 2.50E-01   7
8    W7E2  21.000,-10.650, 10.650  W5E1  21.000,-10.650,-10.650 2.50E-01   7
9           36.369, 17.563,  0.000        36.369,-17.563,  0.000 2.50E-01  11
10          67.200, 17.038,  0.000        67.200,-17.038,  0.000 2.50E-01  11
11          83.492, 17.038,  0.000        83.492,-17.038,  0.000 2.50E-01  11
12         107.769, 17.038,  0.000       107.769,-17.038,  0.000 2.50E-01  11
13         132.109, 17.038,  0.000       132.109,-17.036,  0.000 2.50E-01  11
14         163.000, 15.500,  0.000       163.000,-15.500,  0.000 2.50E-01  11
```

How these physically comparable quagis stack up against each other will be apparent from the follow performance graphs.

Gain

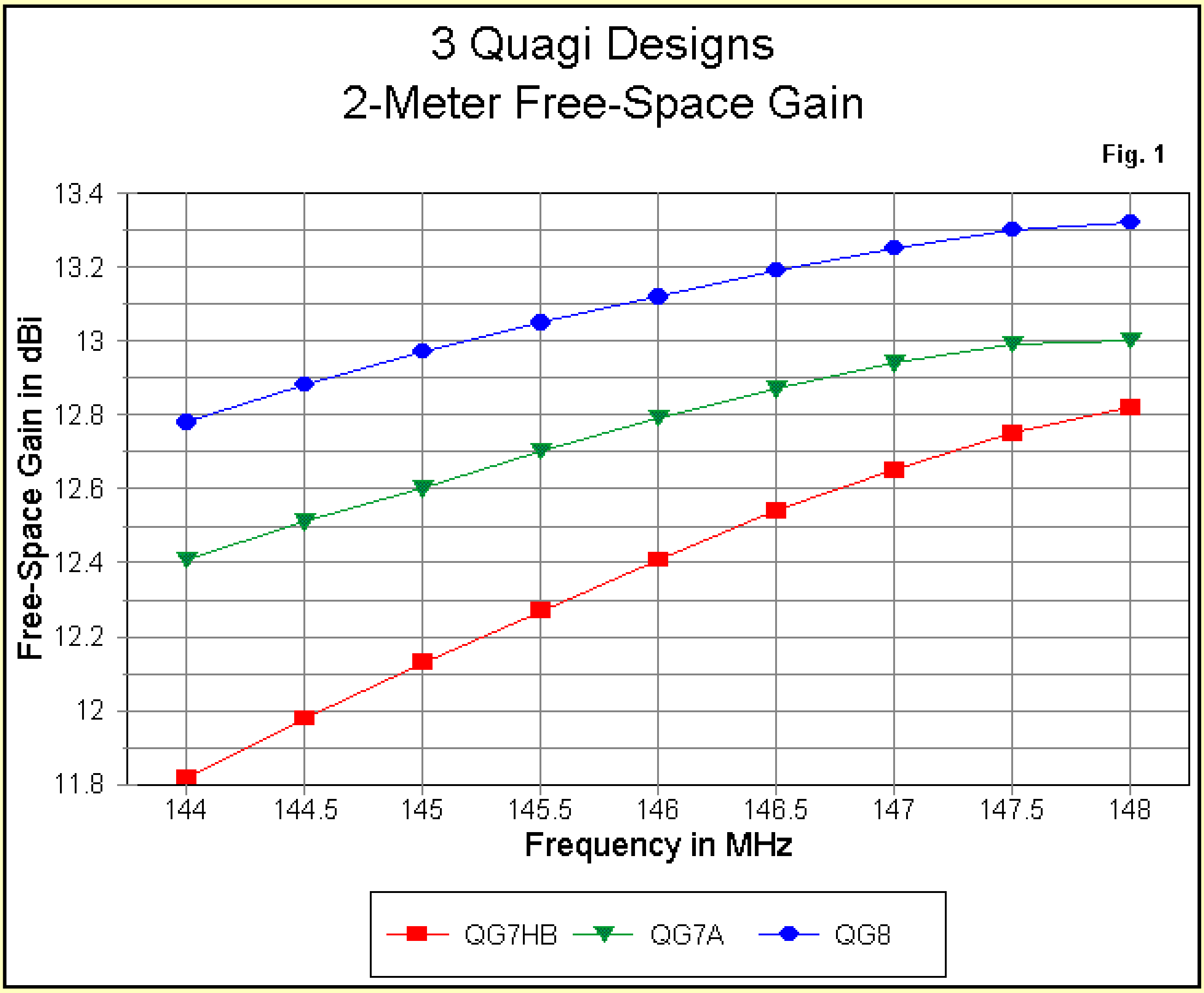
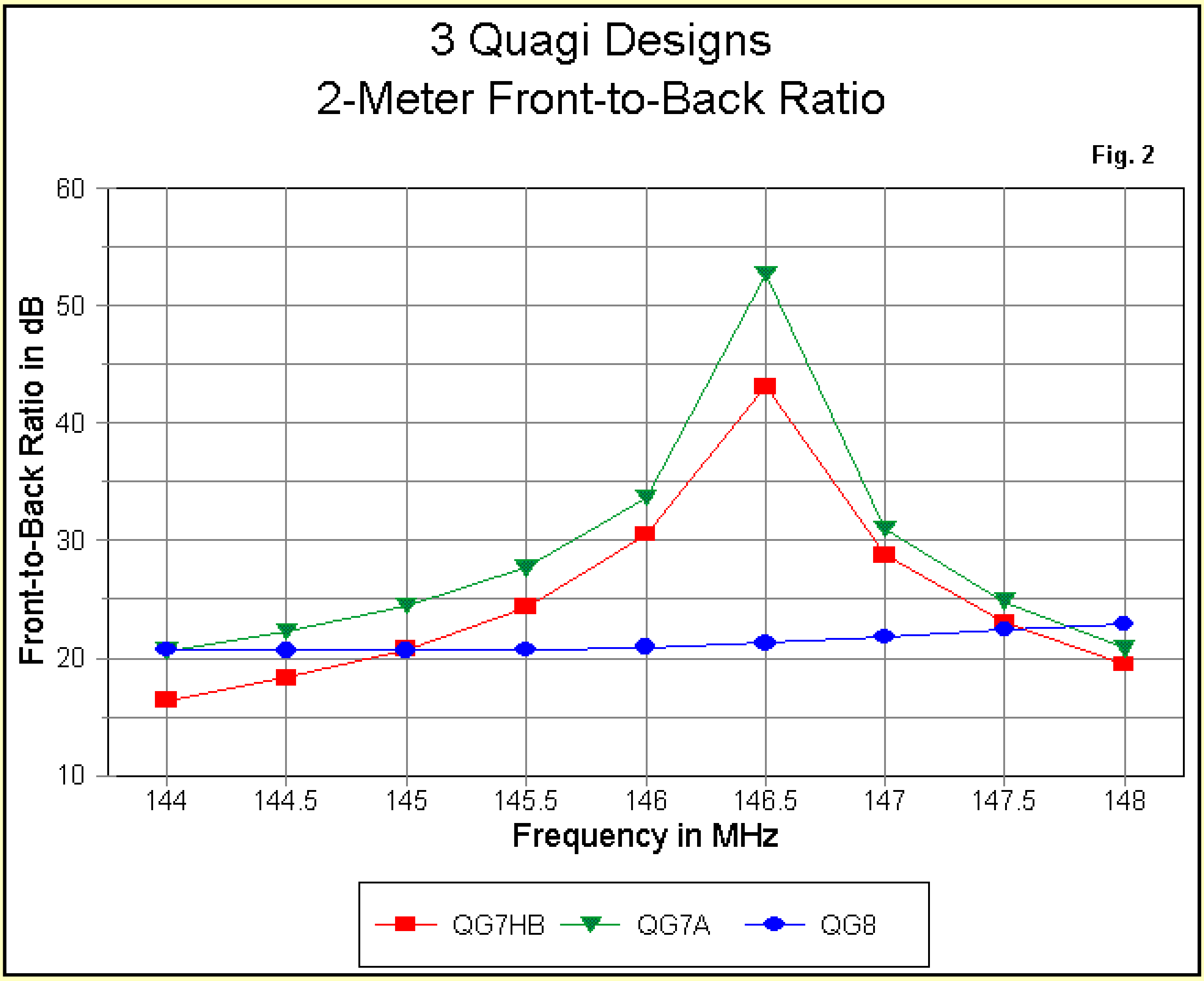


Fig. 1 shows the gain curves of the three arrays across 2 meters. The two quagis using 1/4" elements have curves that are almost congruent, with a 0.3 to 0.4 dB differential--the improvement we derive from the added director. The gain differential from on end of the band to the other is under 0.6 dB. However, the Handbook version, with its thinner elements, not only shows a much lower gain level by 0.4 to 0.5 dB, but as well shows a full 1 dB variation in gain across the band.

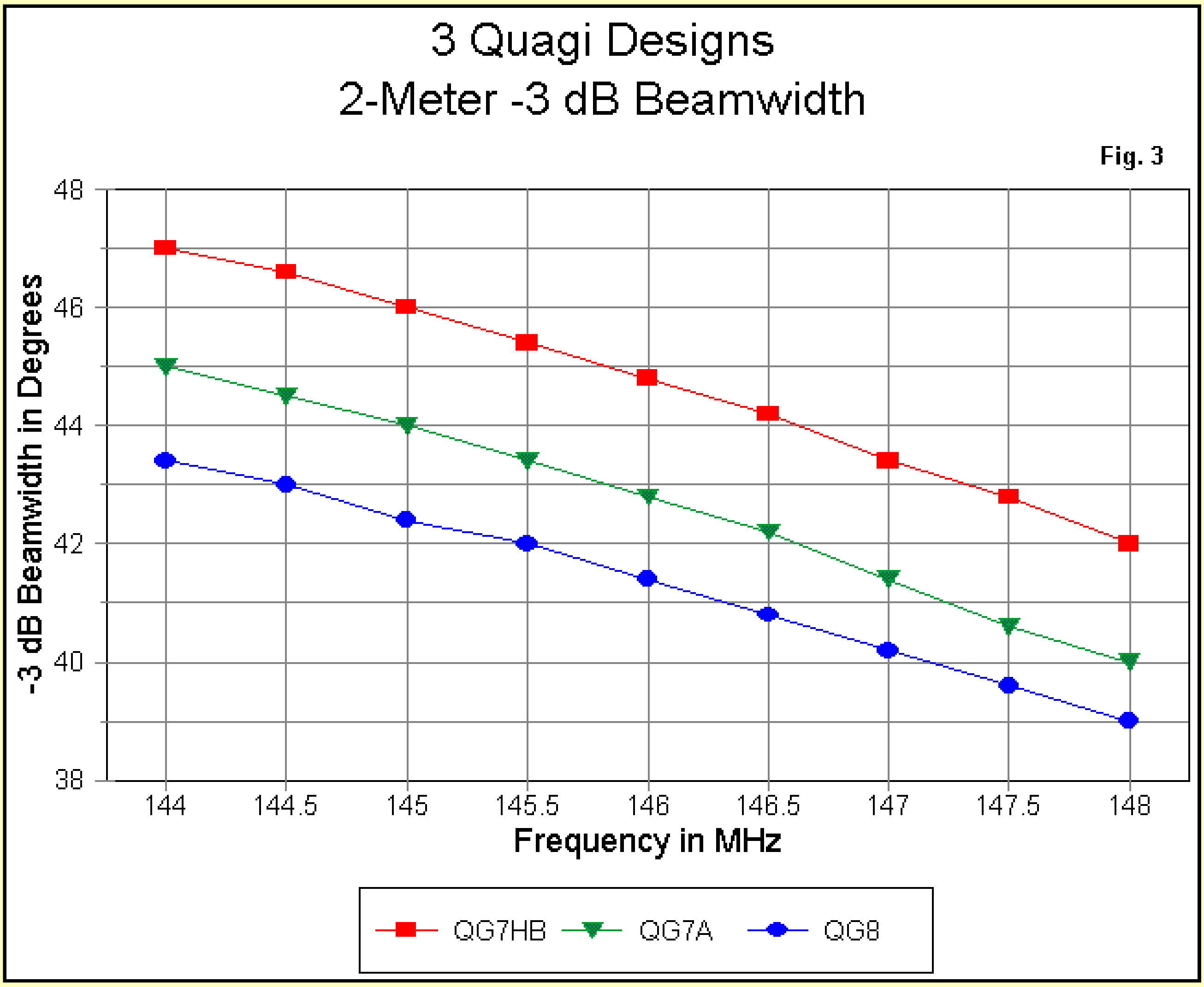
Front-to-Back Ratio



The Handbook array and the 7-element WB4WEN-derived quagi show similar front-to-back curves, as displayed in **Fig. 2**. The 180-degree figures are generally representative of front-to-rear performance, since the deep null just above the center of the band is accompanied by a reduction in rear side lobes. However, the Handbook quagi drops below 20 dB at the lower end of the band. Of course, in parasitic design, it is fairly straight forward to move the peak front-to-back ratio to a favored portion of a given band. However, note that above the peak value frequency, the value drops more rapidly than below the peak value frequency.

The 8-element quagi was designs for a relatively constant front-to-back ratio across the band with all values above 20 dB, whether we are speaking of the 180- degree front-to-back ratio or an average or worst case value. Should a builder wish to bring the higher gain at the upper end of the band down to the low-end point-to-point operating region of 2 meters, the array can be scaled slightly larger to preserve all of the other operating characteristics.

Pattern Control



The -3 dB beamwidth, shown in **Fig. 3**, is a partial measure of pattern control. The decrease in beamwidth across the band is partially a function of the increasing gain across the band, although the drop in beamwidth is somewhat greater than the increase in gain. In this regard, the arrays are comparable, although the Handbook array has the widest beamwidth.

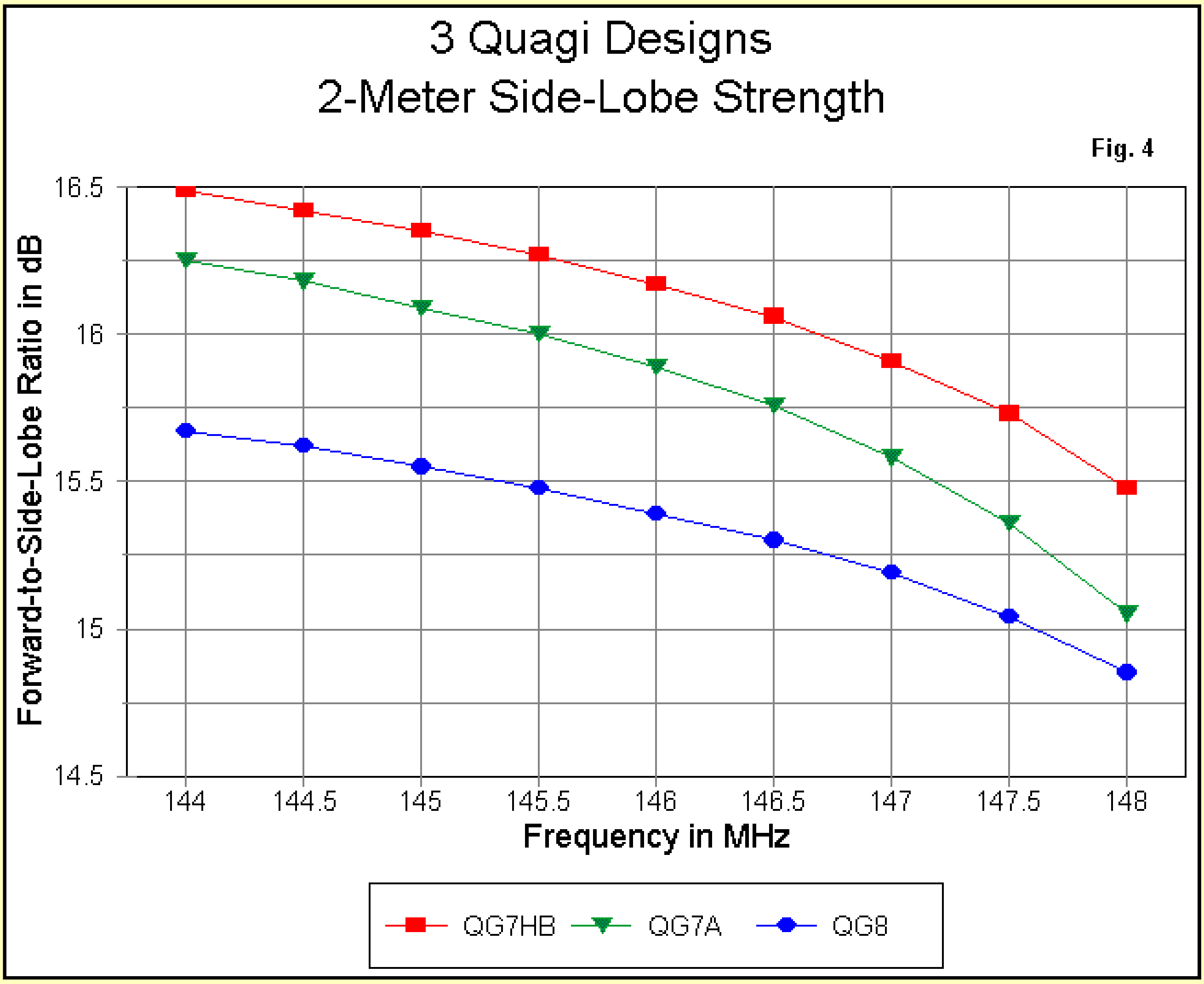


Fig. 4

Not all of the beamwidth differential among the arrays is solely a function of gain. **Fig. 4** shows the Forward-to-Side-Lobe ratio in dB. The Handbook array shows considerably higher side-lobe reduction than the two WB4WEN designs (partly a function of using equal-length directors). Suppression of side lobes tends to increase the beamwidth.

To this point in my look at quagis, I tend to find that most designs (which are more numerous than the ones examined here) show stronger forward side lobes than the best Yagi designs. In a broad and incomplete summary, quagis have values range from 11 to 17 dB, while most Yagis run from 16 to nearly 20 dB.

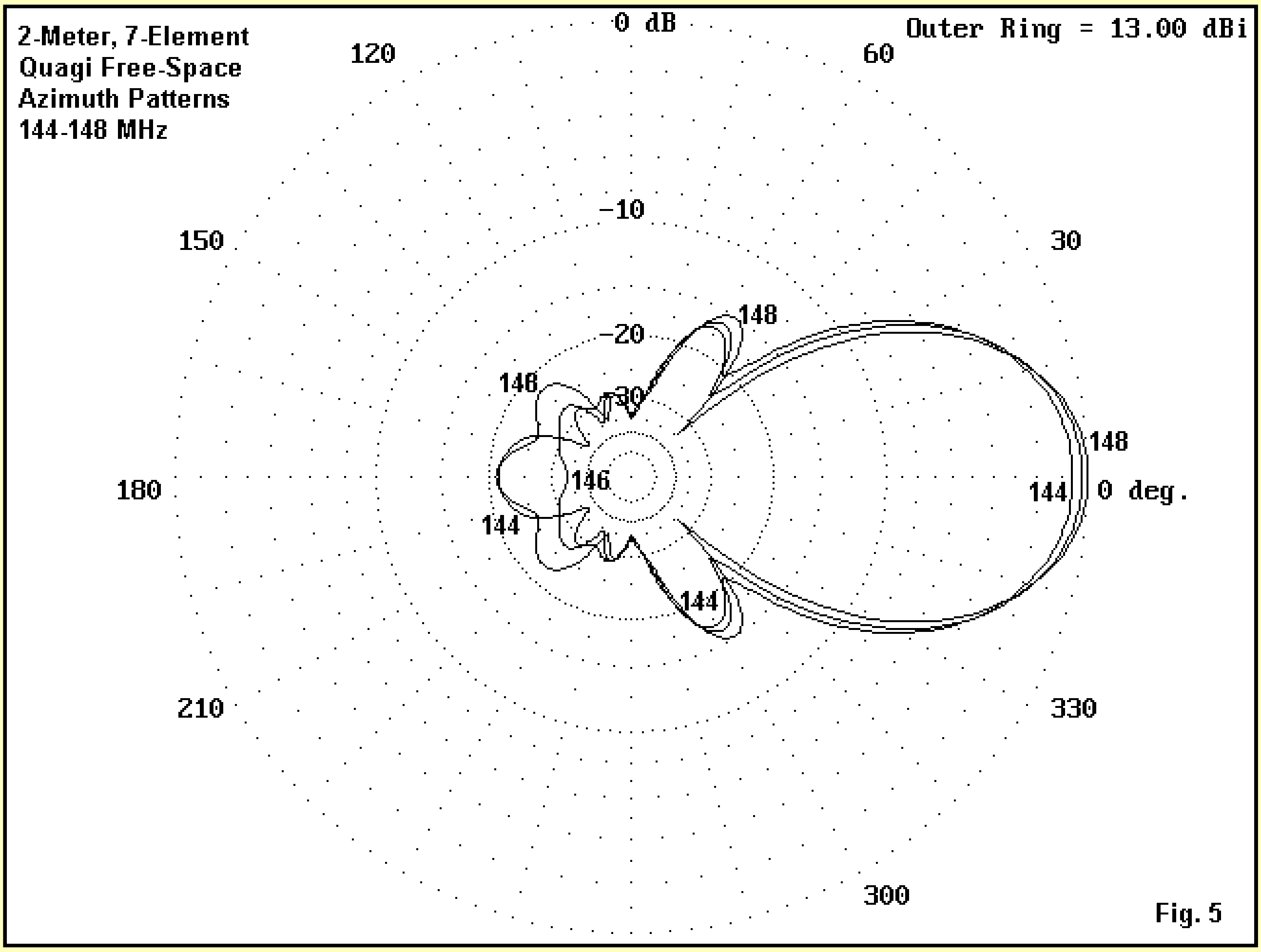
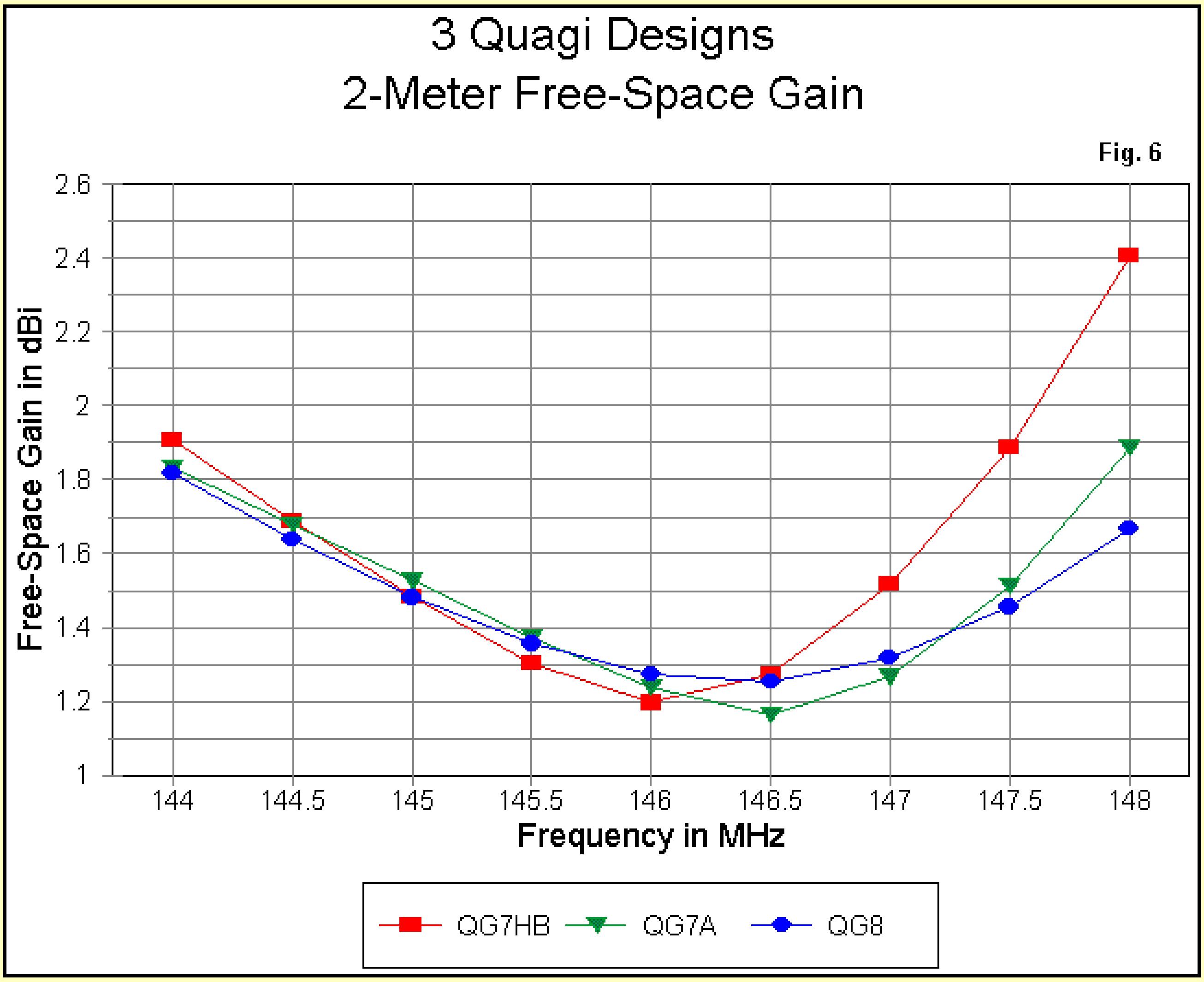


Fig. 5 shows overlaid patterns for the 7-element WB4WEN-derived quagi. The patterns illustrate the forward side-lobe development of the array--and the other quagis as well--as gain increases across the band. Note also the confirmation of the reduction in overall rear gain near the peak 180-degree front-to-back ratio frequency.

SWR Bandwidth



Unfortunately, the thin-wire Handbook array does not provide under 2:1 50-Ohm SWR across the entire 2-meter band, as shown in **Fig. 6**. However, this achievement was likely not among the design goals for the array. Both of the other quagis provide under 1.9:1 50-Ohm SWR values across the band, partly as a result of the use of larger-diameter elements.

The quagis, especially the 2 updated designs, represent perfectly usable arrays for either spot or general 2-meter use. They are capable of good gain and generally acceptable performance figures in most categories of comparison. However, part of our initial exploration is to see how they might stack up against pure Yagis.

Yagis

There are many types of long-boom Yagis, ranging from the classic DL6WU designs to more recent efforts to improve upon that standard. For the comparison here, I have used three members of a family of OWA Yagis that I designed in an effort to achieve reasonable levels of pattern control. Their gain levels for a given boom length may be up to 0.3 dB below those of classic DL6WU designs, but they are broad-band antennas in every sense of the term. **Fig. B** shows the general outline of one of the series.

8-el OWA Yagi 146 MHz   Frequency = 148 MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

--------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in) Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

```
1         -20.450,  0.000,  0.000       20.450,  0.000,  0.000 1.88E-01  21
2         -19.750,  8.792,  0.000       19.750,  8.792,  0.000 1.88E-01  21
3         -18.501, 13.471,  0.000        18.501, 13.471,  0.000 1.88E-01  21
4         -18.164, 25.379,  0.000        18.164, 25.379,  0.000 1.88E-01  21
5         -18.199, 40.722,  0.000        18.199, 40.722,  0.000 1.88E-01  21
6         -18.106, 61.382,  0.000        18.106, 61.382,  0.000 1.88E-01  21
7         -17.600, 86.489,  0.000        17.600, 86.489,  0.000 1.88E-01  21
8         -16.600,113.000,  0.000         16.600,113.000,  0.000 1.88E-01  21
```

The 8-element array is about 9.4' long. The use of 8 elements in this space derives in part from the OWA driver section and in part from the need for enough directors to effect pattern control.

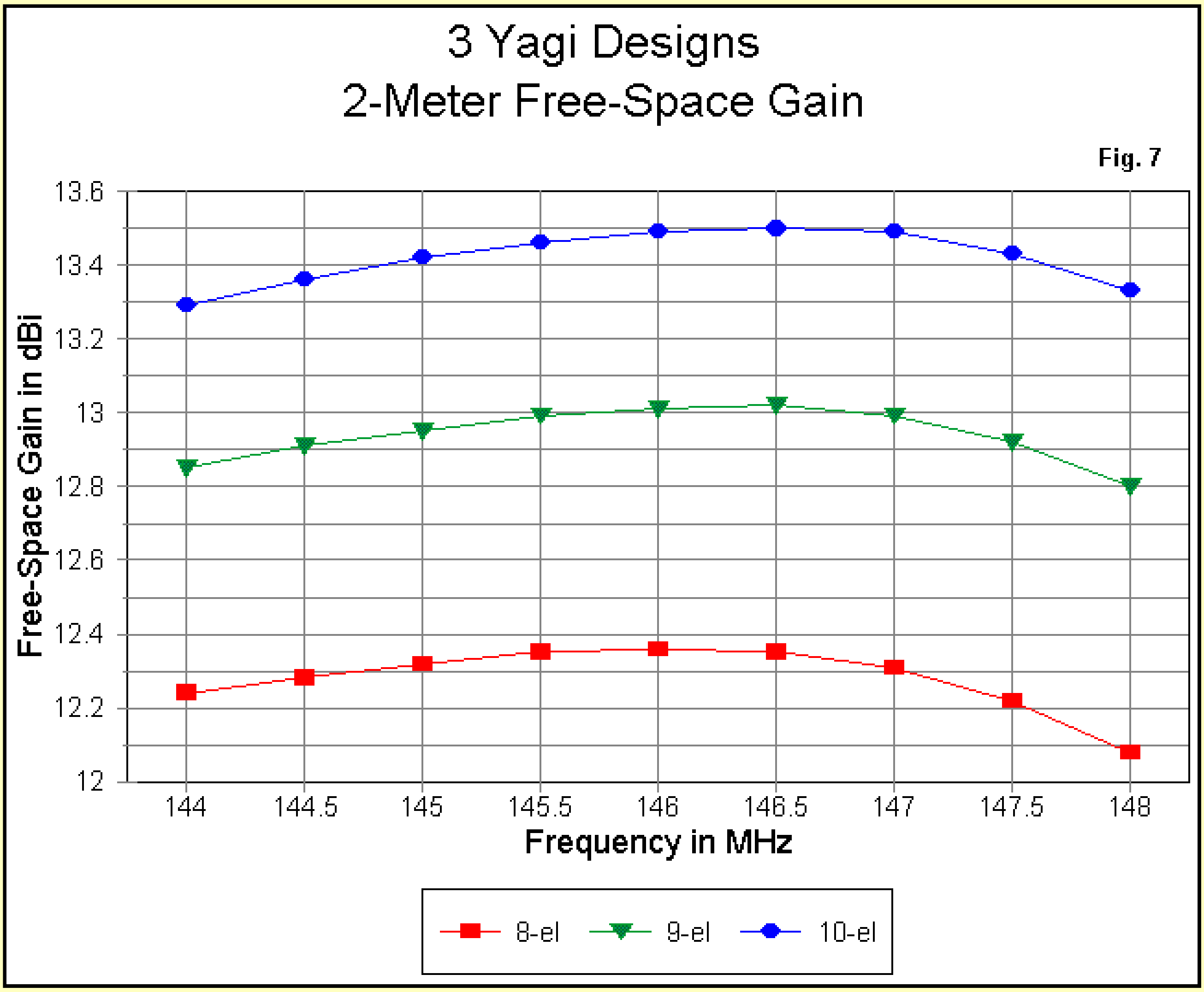
```
9-el OWA Yagi 146 MHz                              Frequency = 146  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1         -20.450,  0.000,  0.000       20.450,  0.000,  0.000 1.88E-01  21
2         -19.750,  8.792,  0.000       19.750,  8.792,  0.000 1.88E-01  21
3         -18.501, 13.471,  0.000        18.501, 13.471,  0.000 1.88E-01  21
4         -18.164, 25.379,  0.000        18.164, 25.379,  0.000 1.88E-01  21
5         -18.199, 40.722,  0.000        18.199, 40.722,  0.000 1.88E-01  21
6         -18.106, 61.382,  0.000        18.106, 61.382,  0.000 1.88E-01  21
7         -17.600, 86.489,  0.000        17.600, 86.489,  0.000 1.88E-01  21
8         -17.150,116.000,  0.000         17.150,116.000,  0.000 1.88E-01  21
9         -16.100,144.000,  0.000         16.100,144.000,  0.000 1.88E-01  21
```

The 9 element array is 12' long. Hence, the 8- and 9-element arrays bracket the 7-element quagis in boom length. Since Yagi gain tends to be a function of boom length, we would expect the Yagis to have gain levels just below and just above the quagis of intermediate length. However, as we shall see, raw gain value is not everything to the design of a parasitic array.

```
10-el OWA Yagi 146 MHz                              Frequency = 148  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1         -20.450,  0.000,  0.000       20.450,  0.000,  0.000 1.88E-01  21
2         -19.750,  8.792,  0.000       19.750,  8.792,  0.000 1.88E-01  21
3         -18.501, 13.471,  0.000        18.501, 13.471,  0.000 1.88E-01  21
4         -18.164, 25.379,  0.000        18.164, 25.379,  0.000 1.88E-01  21
5         -18.199, 40.722,  0.000        18.199, 40.722,  0.000 1.88E-01  21
6         -18.106, 61.382,  0.000        18.106, 61.382,  0.000 1.88E-01  21
7         -17.600, 86.489,  0.000        17.600, 86.489,  0.000 1.88E-01  21
8         -17.150,116.000,  0.000         17.150,116.000,  0.000 1.88E-01  21
9         -16.800,146.600,  0.000         16.800,146.600,  0.000 1.88E-01  21
10         -15.400,174.000,  0.000         15.400,174.000,  0.000 1.88E-01  21
```

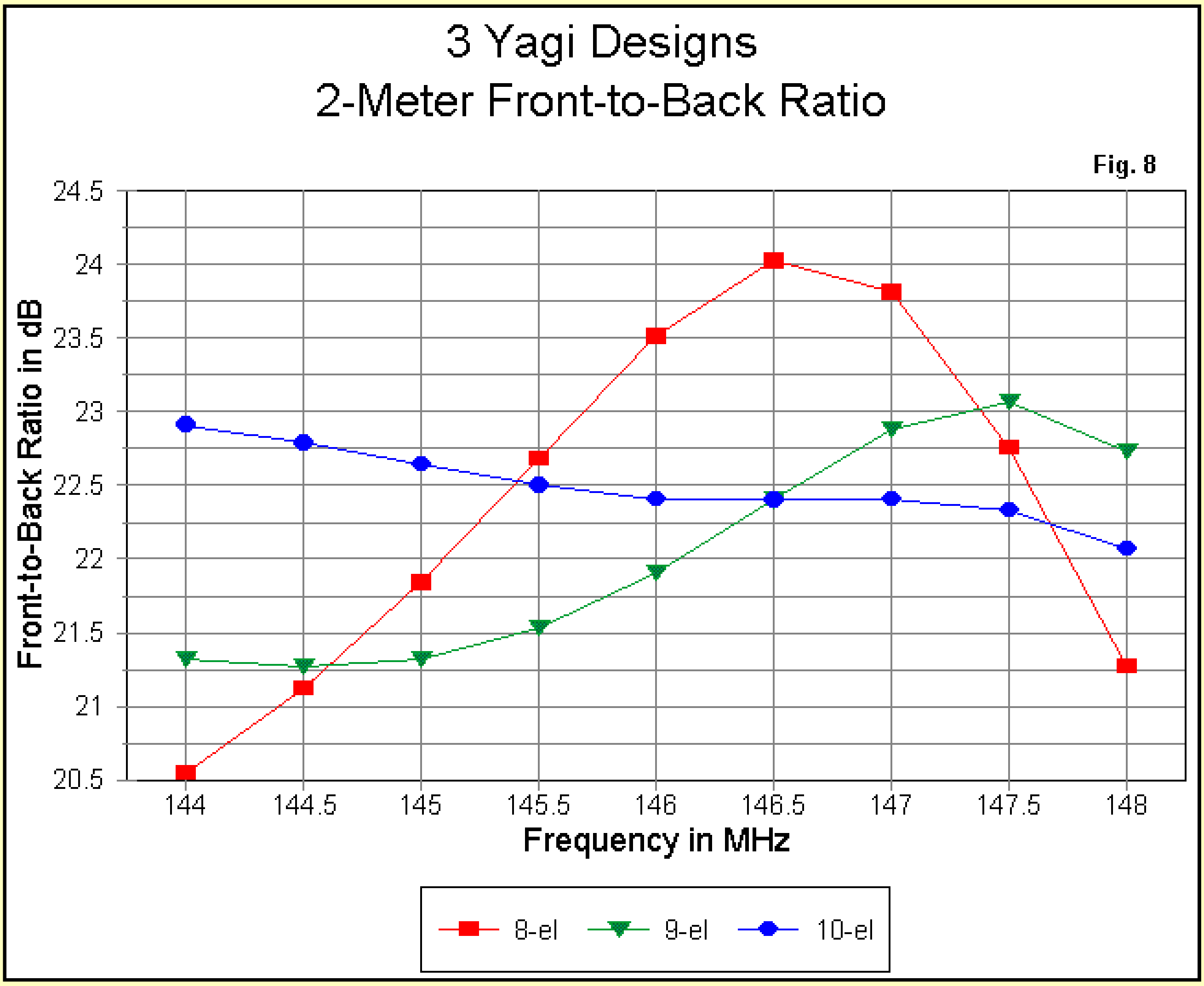
The 10-element Yagi is 14.5' long. Its gain value should be just above that of the 8-element quagi, at least in theory. All of the Yagis use 3/16" diameter elements. As well, elements 1-7 are identical. Indeed, the entire family--from 7 to 12 elements--was developed using that same core elements with each added director requiring adjustment of only the two forward-most directors to stabilize performance. Details of the entire collection and its theory of design will appear sometime in 2002 in *antenneX*. For now, our first step is to make a few comparisons among the Yagis set forth here.

Gain



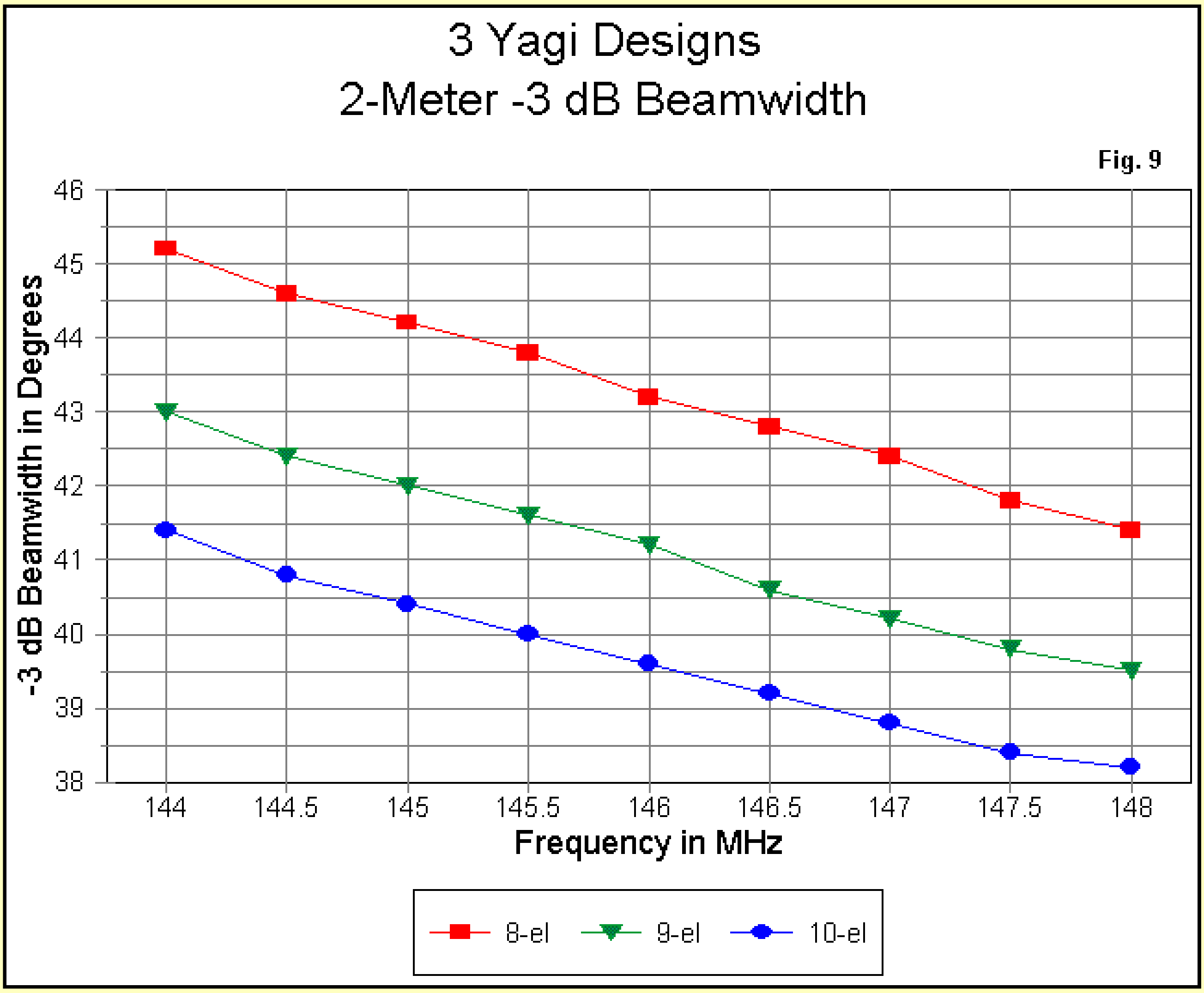
Yagi design can be set to place the maximum gain of the array within the operating passband, as shown in **Fig. 7**. This practice results in the least variation in gain across the band. As we increase the number of elements, the variation in gain decreases. The range is about 0.25 dB in the 8-element design and only 0.2 dB in the 10-element version.

Front-to-Back Ratio

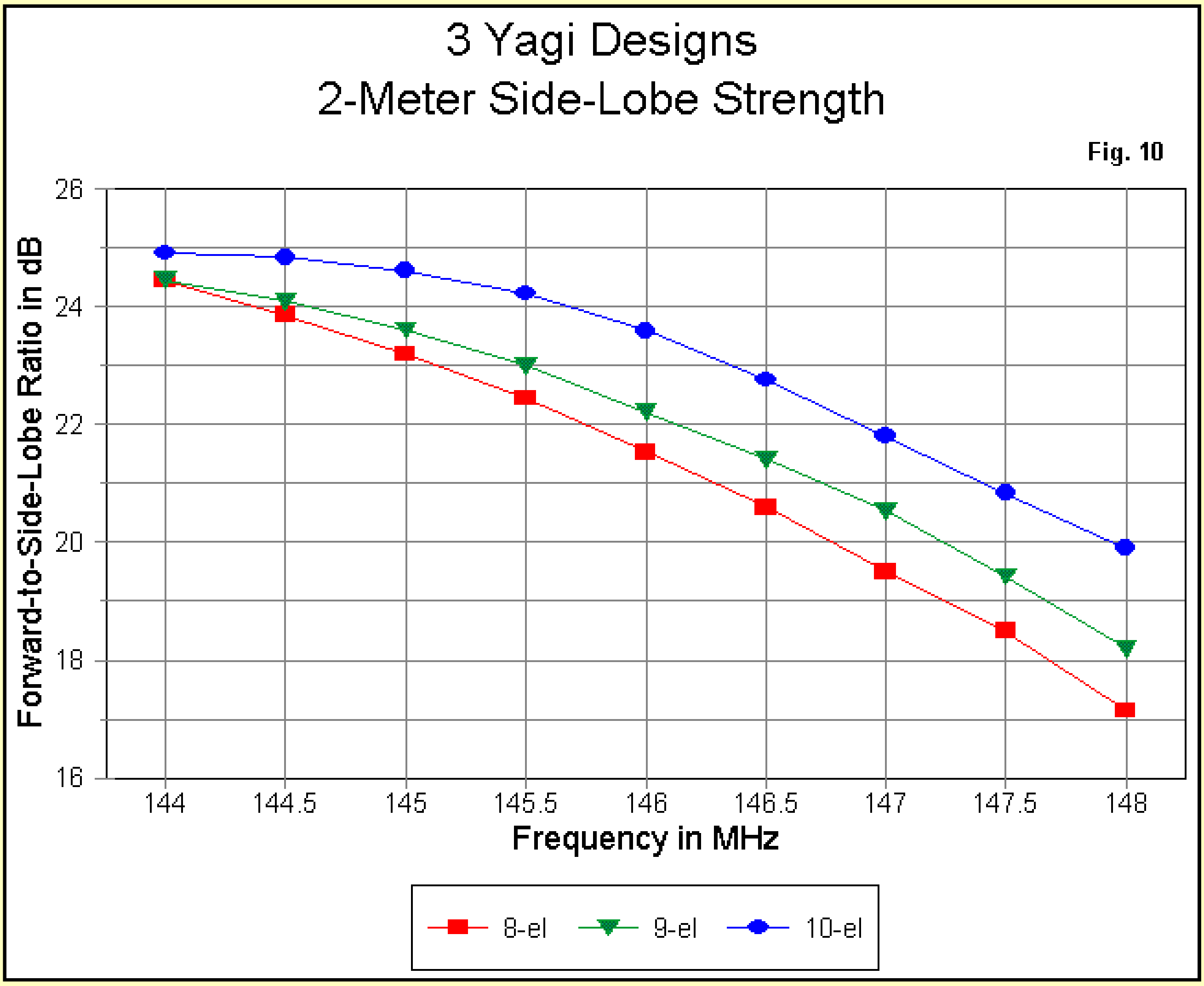


The graph of front-to-back curves in **Fig. 8** appears to be a maze of lines. However, note the very small range of values on the Y-axis--only 4 dB total. Had I graphed the curves on a larger scale, say 20 dB total, the lines would be difficult to distinguish from each other. In general, the graph simply demonstrates that all 3 of the Yagis achieve a 20 dB front-to-back ratio across the entire band. Nor part of the rearward pattern exceeds the -20 dB mark relative to the gain of the forward lobe.

Pattern Control



The first step in looking at pattern control is to examine the -3 dB values for beamwidth in **Fig. 9**. Like the values for the quagis (in **Fig. 3**), the curves all show a relative constant rate of decrease across the operating passband. However, if we refer to **Fig. 7**, we see that at the upper end of the band for all three antennas, the gain is decreasing slightly. Thus, beamwidth is not solely a function of gain.



The graph of relative side-lobe strength in **Fig. 10** shows in part why the beamwidth continues to decrease even though gain no longer increases. For all three designs, maximum forward side-lobe suppression is greatest at the low end of the band. It decreases across the band. The stronger forward side lobes tend to narrow the beamwidth of the array, regardless of gain. Hence, parasitic array beamwidth is a function of at least two (if not more) factors: gain and forward side-lobe strength.

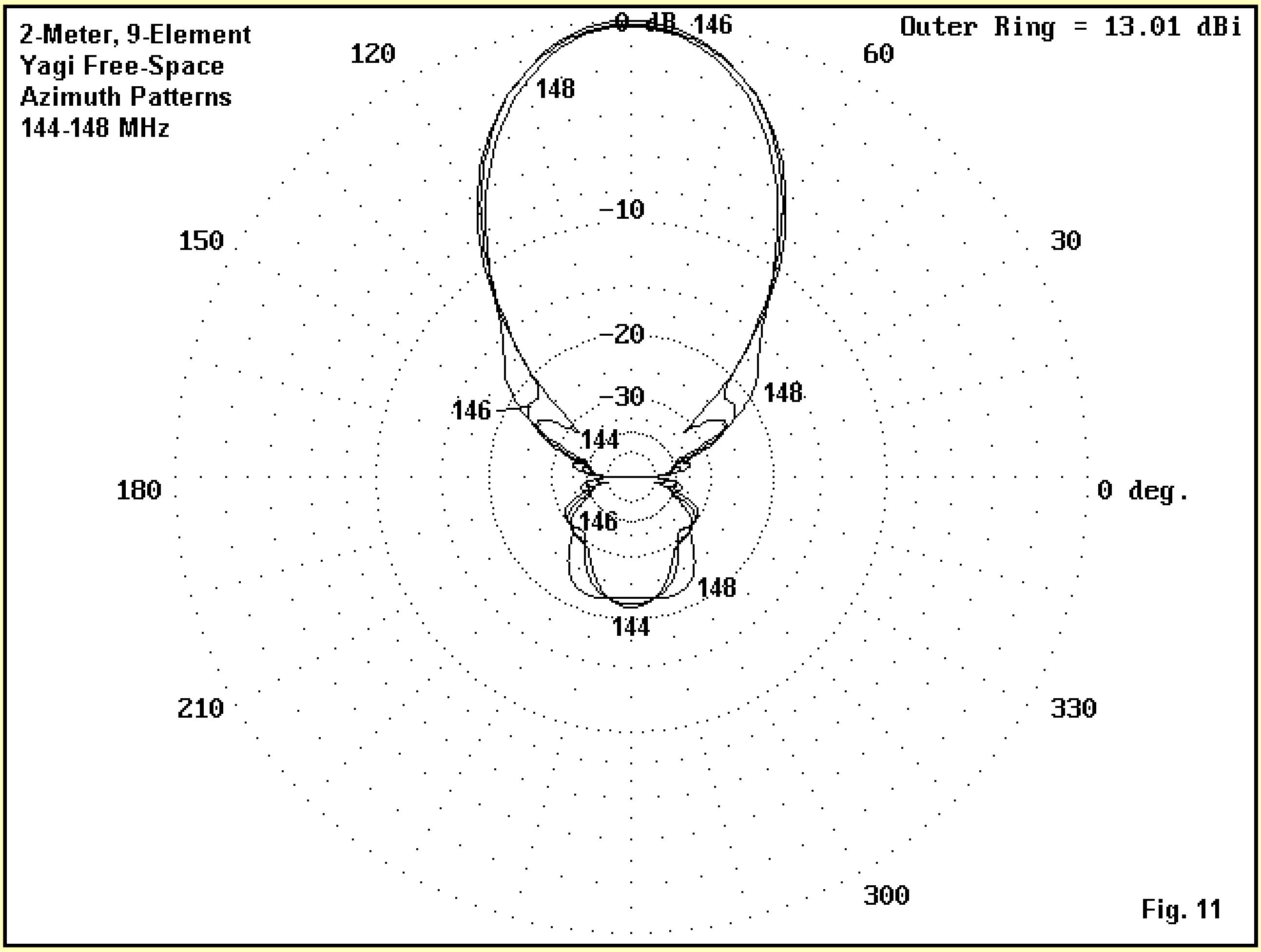
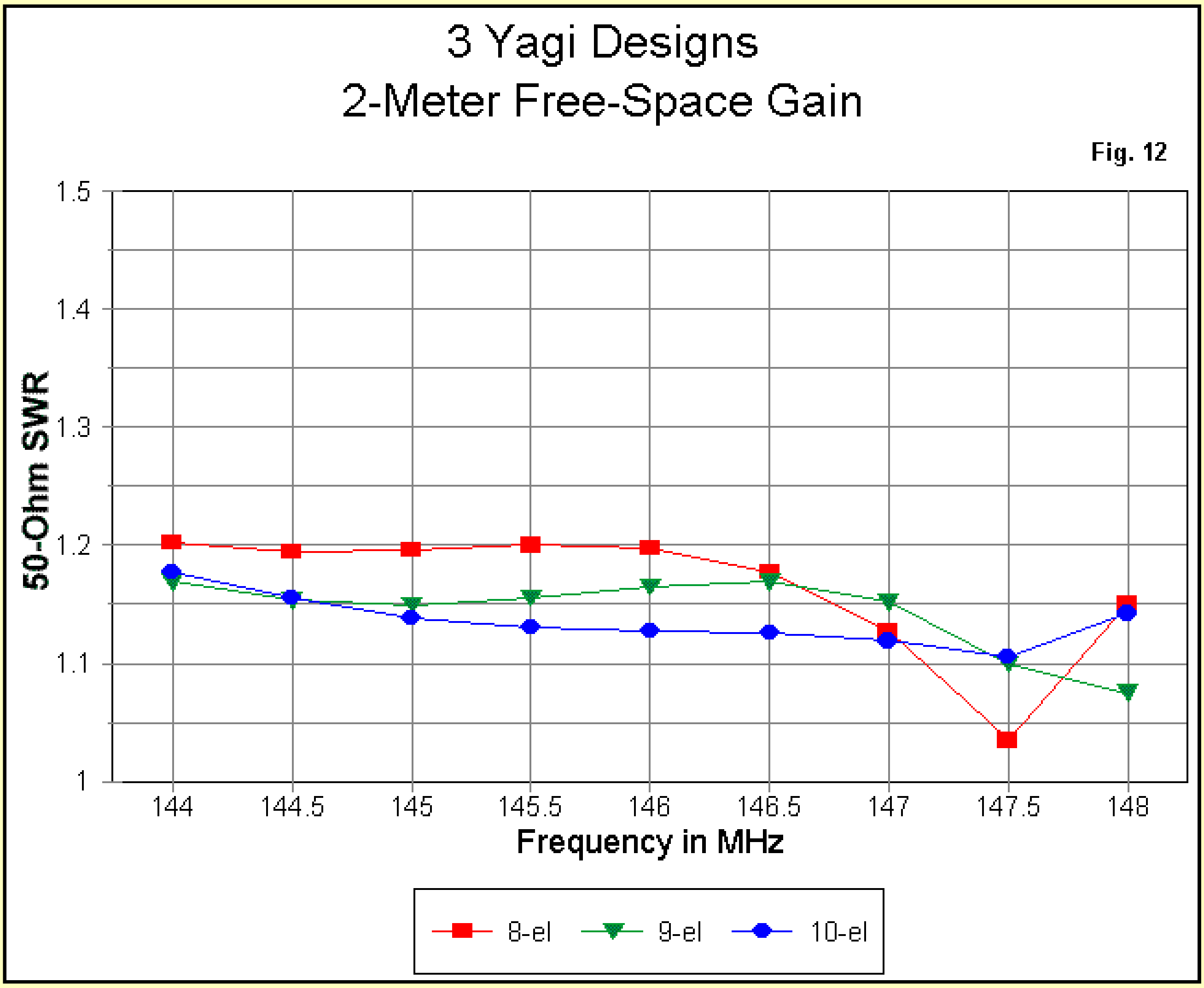


Fig. 11 shows the overlaid free-space azimuth patterns of the 9-element version of the Yagis used here for comparative purposes. The patterns are typical of those for all three Yagis. Of especial note is the fact that forward side lobes can be disguised and hence not recognized in casual observation. The overlaid patterns show how a definite forward side lobe at 144 MHz becomes a seemingly simply bump in the pattern at 148 MHz. However, that side-lobe has effects that are just as definite as the clearly evident strong side lobes of the quagis. Note the main forward lobe at 148 MHz: it is clearly narrower from the -10 dB point onward than the other main forward lobes.

SWR Bandwidth



The family of OWA Yagis was designed for relatively constant performance characteristics across the 2-meter band, including gain, front-to-back ratio, side-lobe suppression, and SWR. The highest value of 50-Ohm SWR shown in the graph in **Fig. 12** is about 1.20 to 1. A mark of OWA performance is a double dip in the SWR curve--a weak dip low in the band and a deep dip near the upper end of the band. Either dip can be disguised, as is the large dip in the 9-element Yagi, which actually occurs between 147.5 and 148 MHz.

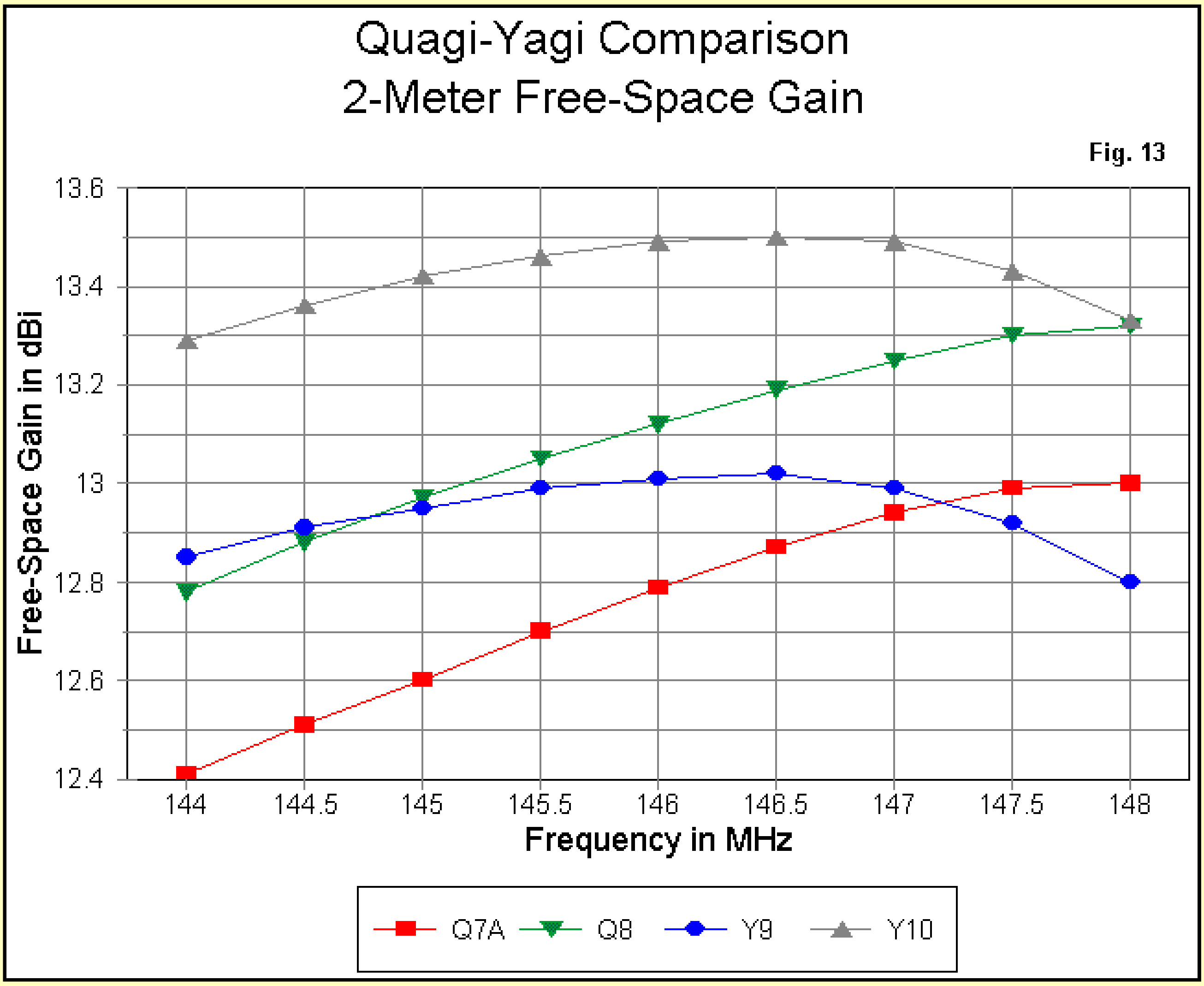
In general, the Yagis shown here represent a quite usable family sub-group that meets all of the design goals set for them

Some Relevant Comparisons and Some Remaining Questions

In comparing the quagis to this family of Yagis, it is unnecessary to overlay SWR patterns. The fundamental design principles used in the Yagi designs ensured a flatter set of SWR curves and any of the quagis. Indeed, it is unclear at this point in the investigation whether one can design a quagi for equivalent SWR performance, although it is likely that improvements in the current quagi SWR curves are possible with redesign. However, that work is for the future.

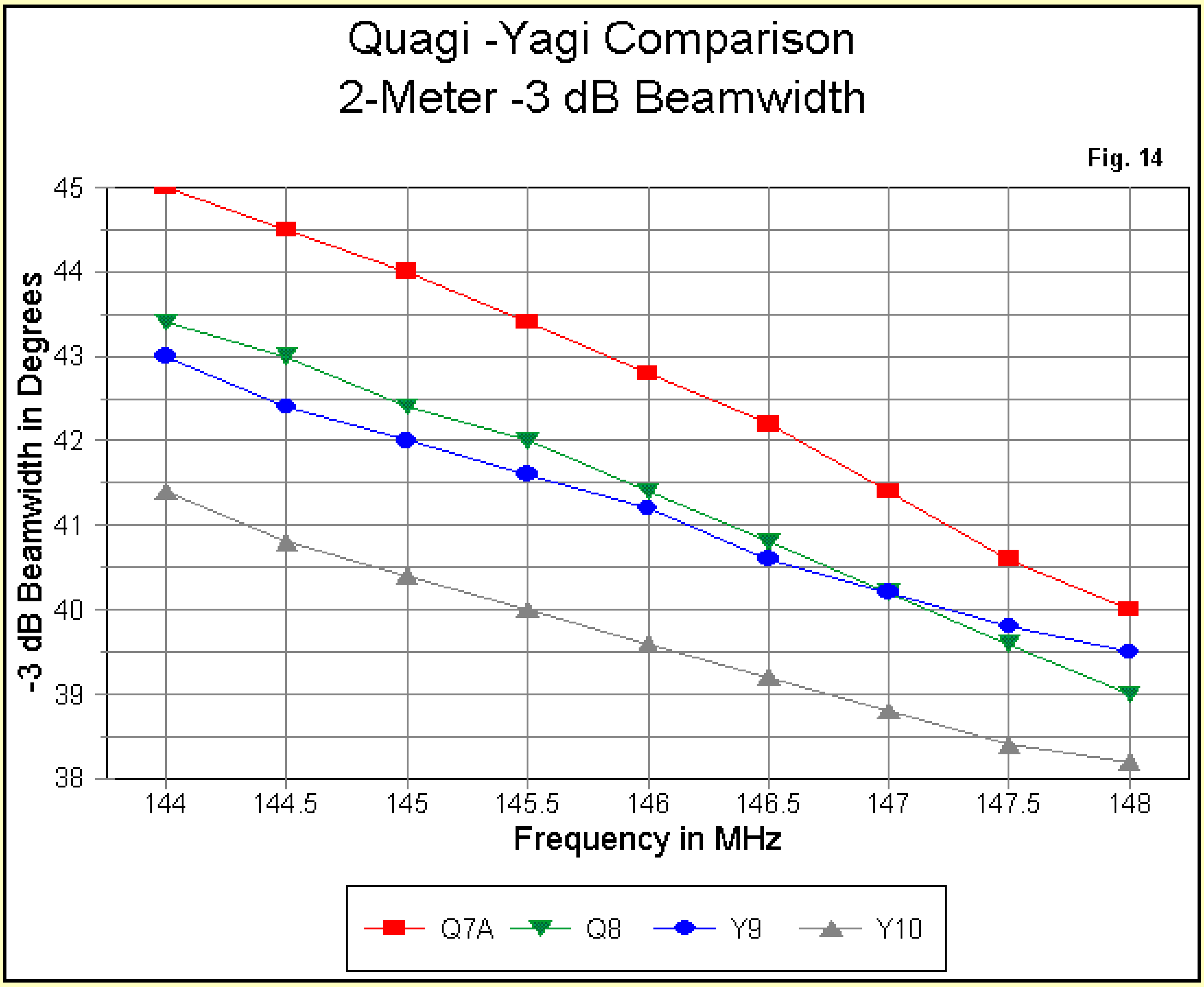
Likewise, the front-to-back curves also need no overlaying, since all but the Handbook array meet the 20 dB standard.

For the remaining comparisons, we shall use the 2 updated quagis (11' and 13.6') and the 9- and 10-element Yagis (12' and 14.5'). Adding in all of the antennas would make the graphs confusing.

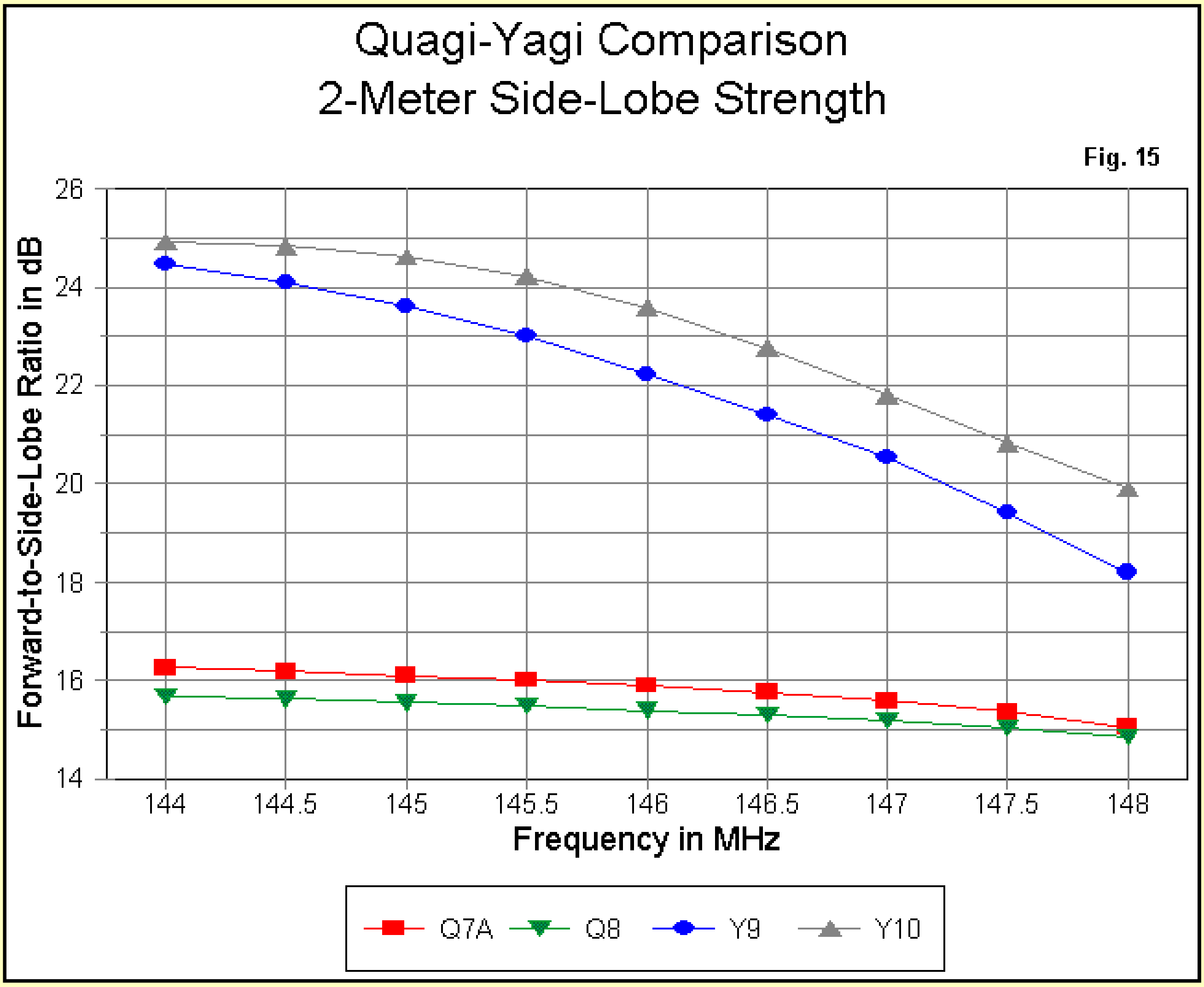


In **Fig. 13**, we can see the different gain curves for the two types of antennas. The Yagis, with their longer booms, have higher average gains, although the quagi gain values rise to meet the Yagis at the upper end of the band. That rise--in contrast to the relatively even gain of the Yagis across the band--suggests that further design work may be possible to better center the quagi gain peak within the band. However, centering the gain within the operating passband often has the effect of reducing maximum gain by 0.1 to 0.2 dB from its out-of-band peak. Only further design work will tell of one can equalize quagi gain in the way in which Yagi gain can be equalized.

Despite the differences in the curves, it is clear that for a given boom length, the quagi has no especially advantage over a Yagi. At least, this holds true for the quagi versions so far analyzed. Whether a real gain improvement over a comparable Yagi is possible with a quagi design remains to be seen.



The comparative -3 dB beamwidth curves in Fig. 14 are especially interesting from the perspective of pattern control. The 8-element Quagi and the 9-element Yagi have closely matched curves. The quagi gain surpasses that of the 9-element Yagi for most of the band, suggesting that it should have a narrower beamwidth. However, a glance at **Fig. 15** shows that the Yagis decrease their forward side-lobe suppression more rapidly than the quagis, which tend to have uniformly strong forward side lobes. Hence, where gain would increase the beamwidth of the Yagi, the development of side lobes of significance reduces it.



However, neither gain nor side lobes fully account for the close tracks of the 8-element quagi and the 9-element Yagi. It presently appears--subject to further exploration of quagi designs--that the quagi design itself yields for a given boom length a "naturally" wider beamwidth than a comparable Yagi. It is not clear at this stage of investigation what factors are at work--the loops, the special director set, etc.--or to what degree.

This initial investigation, thus, has ended by raising more questions than it has answered. Perhaps the only fairly definite conclusion we can reach is that, all other things being equal, quagis and Yagis have similar gain potential for given boom lengths. With proper design, either antenna can be designed for a front-to-back in excess of the standard (20 dB). Likewise, both can be designed for under 2:1 50-Ohm SWR throughout the operating passband. Whether the quagi can rival the OWA SWR figures remains to be discovered.

In the realm of pattern control, beamwidth and side-lobe suppression remain open questions for further design or design analysis--depending on what designs come my way and what I may be able to concoct. Whether adding further elements will allow better gain centering and pattern control is, again, a matter for further investigation.

Moreover, I have stayed with rather modest boom lengths so far. It is not clear what the development of very long-boom quagis may hold by way of performance characteristics.

Finally, remember that these notes are based on a set of analysis categories and criteria that may or may not be applicable to a given operating circumstance. I tend to think in fairly broadband terms. If you think in other terms, feel free to develop a comparable analysis from your own perspective. Nothing has been claimed as an absolute, and alternative perspectives are not only fair, but also welcome.

Go to Amateur Radio Page