Dream Beams: Part 2
Forward-Stagger and Interlaced Yagis

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In Part 1, we set up the hypothetical parameters that locked us into one large beam to cover the upper HF amateur bands. Then we examined a much-too-large idealized LPDA to see what nearly perfect radiation patterns might look like within the 13-dBi free-space gain of the continuous coverage array. We next examined a more feasible (in dream-beam terms) LPDA that used 25 elements to achieve just under 9 dBi free-space gain, but once more with very high front-to-back ratios. The last beam we explored was a 5-band 30' quad that used 4, 5, or 6 elements, depending on the band involved. In all cases, we looked at some of the design factors (but not all of them) as well as the resulting performance. For example, on most bands, the quad provided superior gain but inferior front-to-back performance relative to the 57' LPDA.

We omitted discussion of possible Yagi dream beams, saving them for this part of our reveries. Dream Yagis, within the limits of our backyard situation, offer significant design diversity. More significantly and despite our seeming high familiarity with parasitic beams, proper Yagi performance expectations still tend to elude most amateurs. Therefore, we shall begin with a short overview of monoband Yagi performance in beams ranging from 3 to 6 elements. The performance numbers for these arrays will serve as comparators for the more complex Yagi designs that count as dream beams. We shall look at a pure forward-stagger design that covers 5 band on a 63' boom. Then, we shall explore 2 different interlaced designs that offer 3-band coverage using boom lengths between 46' and 53'.

Basic Monoband Yagi Configurations and Performance

Despite the plethora of commercial and homemade monoband Yagis in existence, we tend to loose track of what we can expect from them. For a given boom length, a monoband Yagi provides close to the peak performance that we can obtain and usually exceeds the performance that we can obtain from the same number of elements in a multi-band parasitic beam. Here, performance includes not only gain and front-to-back ratio, but the operating bandwidth of these parameters and of the feedpoint impedance as well.

Yagi gain is more a function of boom length than the number of elements. However, for a given number of elements, there is a limit to the maximum gain. Moreover, additional elements within a given boom length usually allows us to achieve broader passbands for whatever limits we set to the performance values. (In addition, we may use one or more additional elements within a given boom length to tailor certain aspects of the performance, such as reaching peak gain and peak front-to-back ratio on the same frequency and obtaining a desired feedpoint impedance across the design passband. We shall not work with such designs in these preliminary notes.)

Since boom length determines gain, we can normally design a variety of successful monoband Yagis that provide adequate passband coverage using different boom lengths to arrive at different gain levels. **Table 1** lists three 3-element Yagis and two 4-element Yagis to illustrate the principle. The table also includes performance numbers for sample 5-element and 6-element Yagis. The boom lengths appear in feet and as a fraction of a wavelength. The latter number allows you to translate these 15-meter (21.225-MHz) arrays into comparable Yagis for any of the upper HF amateur bands. Gain values are for free space, and the beamwidth values are for the E-plane, which corresponds to horizontal use over ground.

Table 1. Performance of 15-meter Yagis using various boom lengths and element counts

No. of Elements	Boom Length feet	λ	Gain dBi	Front-Back Ratio dB	Beamwidth degrees	Feedpoint Resistance Ω
3	10.1	0.22	7.19	56.21	66	26.5
3	13.3	0.29	7.83	34.52	64	26.0
3	15.1	0.32	8.19	26.32	63	24.7
4	17.5	0.38	8.33	29.07	62	23.1
4	24.3	0.52	8.61	29.34	61	21.7
5	29.5	0.64	10.33	32.83	52	32.7
6	48.1	1.04	11.58	27.10	48	32.8

The table shows only the feedpoint resistance, since all models are resonant within +/-j1 Ω. **Fig. 1** provides to-scale outline sketches of some of the beams in the table to show the relative sizes. Note that the two longer samples compress the distance between the reflector and the driver and between the driver and the first director as a means of achieving an acceptable feedpoint impedance. Once we employ directors in a parasitic design, they tend to control (in the main) the gain and the front-to-back ratio. The reflector's duty by virtue of its length and spacing from the driver is to set the feedpoint resistance and to control the bandwidth at the lower end of the operating spectrum.

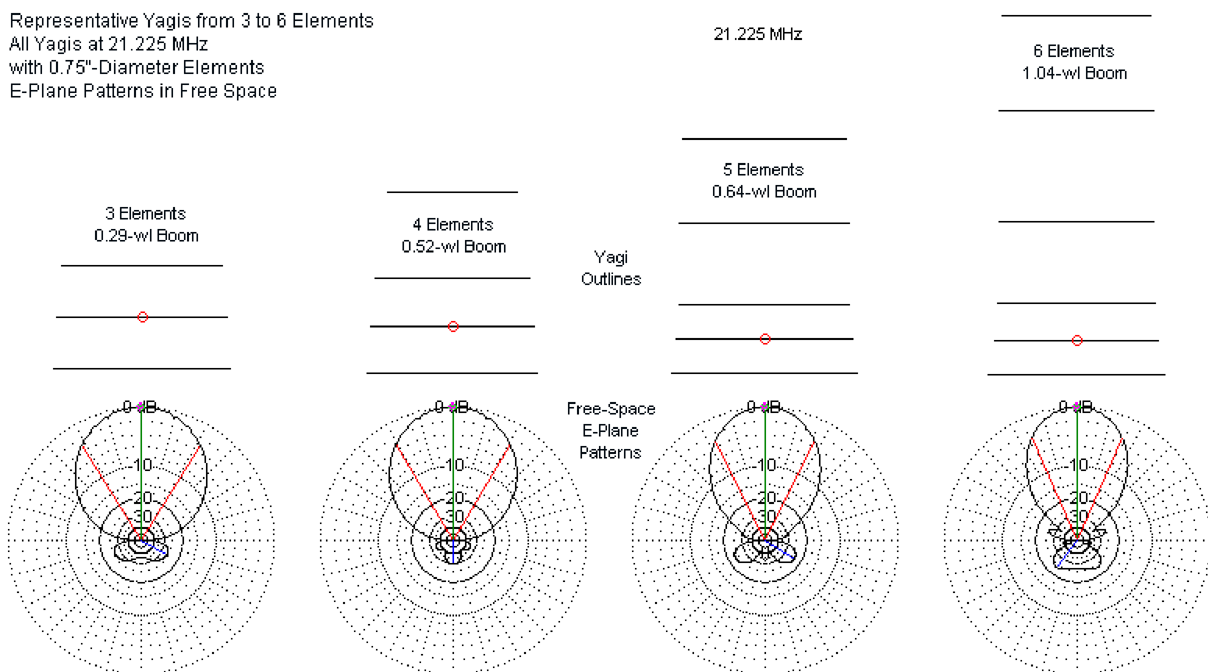
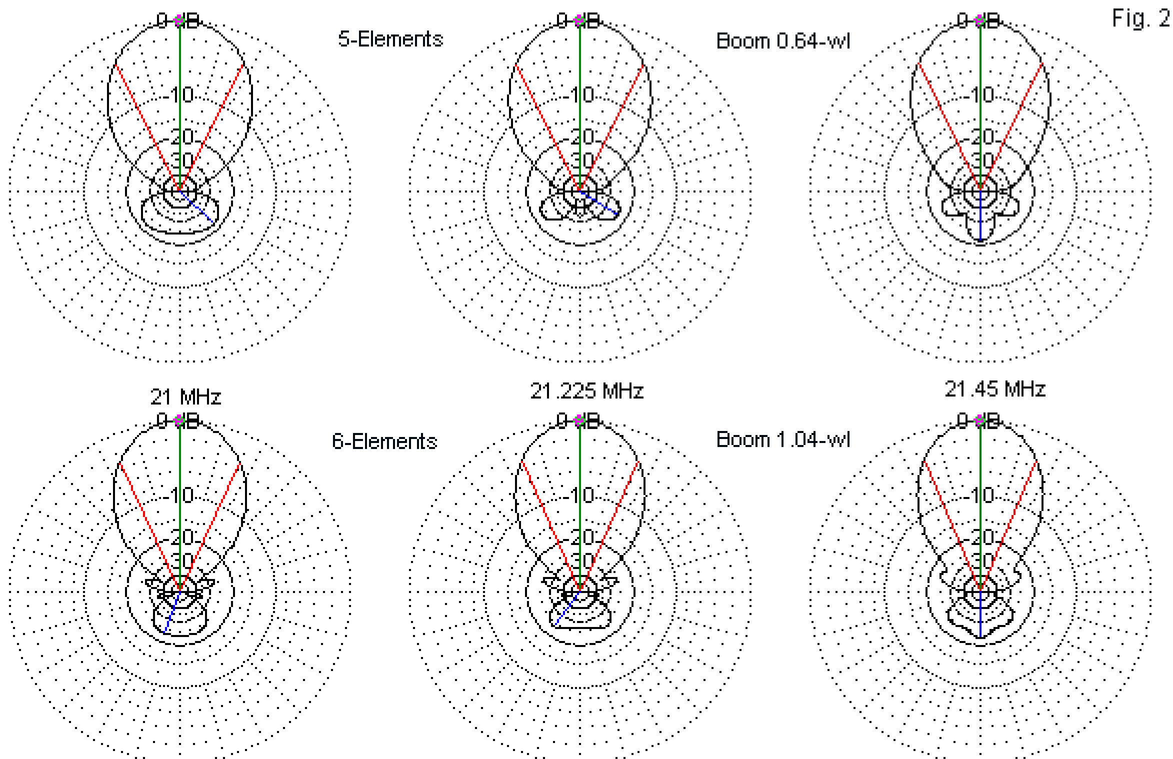


Fig. 1

The amateur standard for the front-to-back ratio for a monoband beam tends to be 20 dB. All of the sample Yagis achieve this value. The very high 180° front-to-back ratio that applies to the shortest 3-element specimen is illusory, since it occurs with two larger rearward sidelobes that resemble those in **Fig. 1** for the medium length 3-element Yagi and the 5-element Yagi. However, the worst-case front-to-back ratio for all of the sample arrays either equals or comes very close to the 20-dB mark, not only on the design frequency, but also across the 15-meter band.

As we change the operating frequency within the range of a given Yagi design, we do not see significant changes in the forward lobe for boom lengths under 1 λ. Forward sidelobes begin to appear under two conditions. For well-designed Yagis, they appear when the boom length reaches about 1 λ. The number of forward sidelobes on each side of the pattern's centerline tends to equal the boom length when we reduce that length to an integer. In addition, across the passband, the form of the sidelobes changes with frequency, as shown in the lower portion of **Fig. 2**. They tend to begin at the lowest frequency as small, thin lobes and become broader as we raise the frequency. Careful measurement would show the 6-element Yagi sidelobes to be strongest at the top of the band, even though the null between each sidelobe and the main lobe is shallower. The second cause of forward sidelobes—not evident in any of our sample designs—comes from pressing the gain potential for a given number of elements.



Sidelobe Development and Rear Lobe Evolution
as Yagis Grow Longer

Fig. 2 also illustrates what we may roughly call the normal evolution of the rear lobes across the passband. Ordinarily, we design a Yagi so that the peak front-to-back ratio is close to the design frequency in order to obtain roughly similar front-to-back values at the band edges. (Special designs may alter this procedure.) With directors in ordinary Yagi designs, the gain will show a rising value as we increase the operating frequency, usually between 0.5-dB to 1.0-dB, depending upon the exact design. The peak value (except on the wide 10-meter band) will usually occur just above the top end of the band. Past that frequency, the gain decreases rapidly and the pattern will reverse itself as the directors become long enough relative to the operating frequency to become reflectors. Hence the most conservative design is to align the maximum 180° front-to-back ratio with the minimum SWR point relative to the natural self-resonance of the array and allow the gain to increase along the band. The result is usually the set of rearward patterns shown for both beams. Below the design frequency, we have a single bulbous rearward lobe. Above the design frequency, the rearward pattern shows 3 lobes. As the 6-element Yagi shows, the lobes may become somewhat indistinct, since the rearward pattern structure also reveals additional sidelobes as the boom length exceeds 1 λ.

As we look at multi-band Yagis, we shall be very interested in several facets of this preliminary and incomplete account of monoband Yagi behavior. For a given number of elements and an effective boom length (generally, the space from the rear-most to the forward-most element for a band), how does the multi-band gain compare with monoband Yagi gain? Does the array achieve rearward performance that equals or at least comes close to monoband rearward performance? Are the operating parameters equal in bandwidth to those of monoband arrays? If any of the answers given for multi-band Yagis shows a variation from what we expect from monoband Yagis, then a further question arises: why? We shall discover that multi-band design may exceed monoband performance in some categories and lag behind in others. We shall be interested in the reasons for the variance long before reaching a judgment about the differences.

A 5-Band 63' 14-Element Forward-Stagger Yagi

Our first dream Yagi is a 5-band design originally developed by ON4ANT, although the version that we shall examine has evolved a bit to the form shown here. As shown in **Fig. 3**, the antenna requires separate feedpoints for each band, with each feedpoint effectively shorted when another is active. We may immediately notice that some drivers are only 2 elements apart. Hence, the director for one band may become the reflector on another. The 10-meter or forward-most portion of the beam has additional directors to match or exceed the performance on the lower bands.

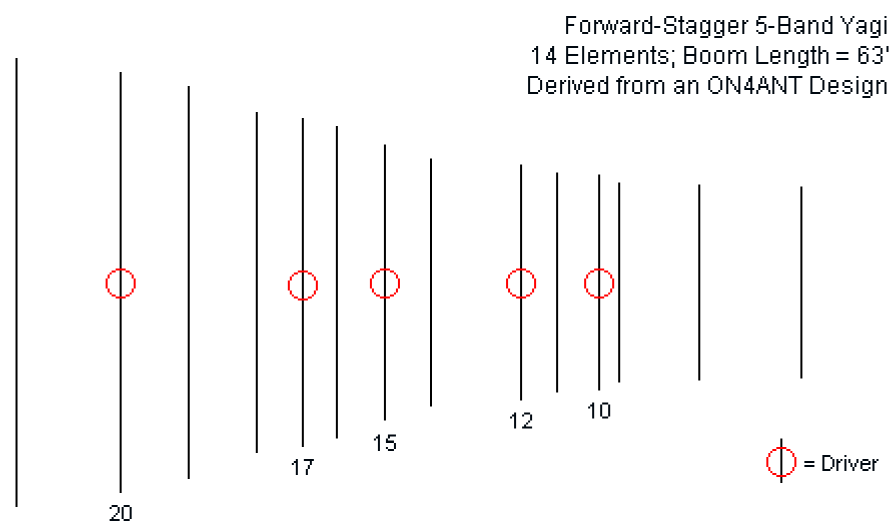
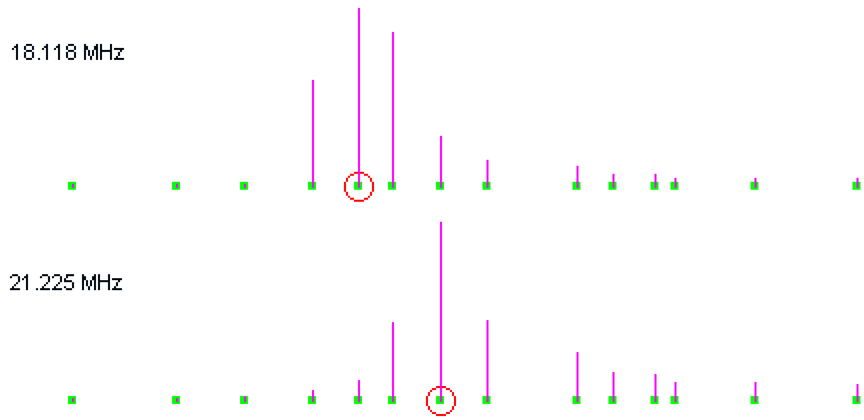


Fig. 3

Unlike the lower bands, 10 meters lacks the benefits of forward stagger design. When we examined the LPDAs, we noticed that all of the elements forward of the most active element was active to a degree, depending on the distance away from the most active element. Even without direct phase-line feeding of elements, we find the same phenomenon operative in a purely parasitic array, although to a lesser extent. To play a role in the forward-stagger process, the forward elements must be shorter than the most active element to become directors, but they must not be too short. Hence, the best forward-stagger design for amateur band use involves all 5 of the upper HF bands. Since these bands are not regularly spaced, we find that the level of effective director action changes from band to band. **Fig. 4** shows the peak current magnitude along the elements on 17 and on 15 meters. In general, an element contributes to an array's gain if its current magnitude is at least 0.1 the peak value of the most active elements, usually the active driver.

Fig. 4



Peak Relative Current Magnitude Distribution on the Forward-Stagger Yagi
17 and 15 Meter Examples

The dual function of many elements modifies the dimensions (length and spacing) of the elements on each side of each band's driver element relative to a monoband design. In addition, the design seeks to cover each band with a relatively clean pattern shape and a 50-Ω SWR that is less than 2:1 across each band. Hence, the performance may vary somewhat from one band to the next for a large collection of reasons, and only one of those reasons will be the degree of forward-stagger activity. For the present design, **Table 2** provides the modeled free-space performance reports. As in Part 1, the table includes band-edge and mid-band data for the three wider amateur bands, but only a single mid-band entry for the two bands that are only 100 kHz wide.

Table 2. Modeled free-space performance of the 5-band 63' forward-stagger Yagi

Band Meters	Frequency MHz	Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ω
20	14.0	8.31	26.15	35.6 – j5.1
	14.175	8.42	24.23	33.7 + j3.0
	14.35	8.55	21.73	30.3 + j12.2
17	18.118	8.42	20.95	33.3 – j7.6
15	21.0	8.91	18.18	36.3 + j12.2
	21.225	9.02	17.81	40.4 + j21.9
	21.45	9.14	17.47	45.2 + j31.1
12	24.94	9.60	30.80	29.2 + j9.5
10	28.0	9.61	19.09	40.3 – j1.7
	28.5	9.94	21.69	31.6 + j12.8
	28.8	10.11	20.20	30.9 + j5.5

Performance values are very comparable to those derived from the 5-band quad that we explored in Part 1. The forward gain falls in the range of 4-element monoband Yagis, with small gain creases from band-to-band as we move upward in the HF spectrum. As shown in the wide-band sweeps for 20, 15, and 10 meters (in **Fig. 5**, **6**, and **7**), the forward gain increases as we increase frequency within each band in normal Yagi fashion. Only on 10 meters do we find the gain peak falling just within the upper end of the band (defined as the first MHz is the total allocation).

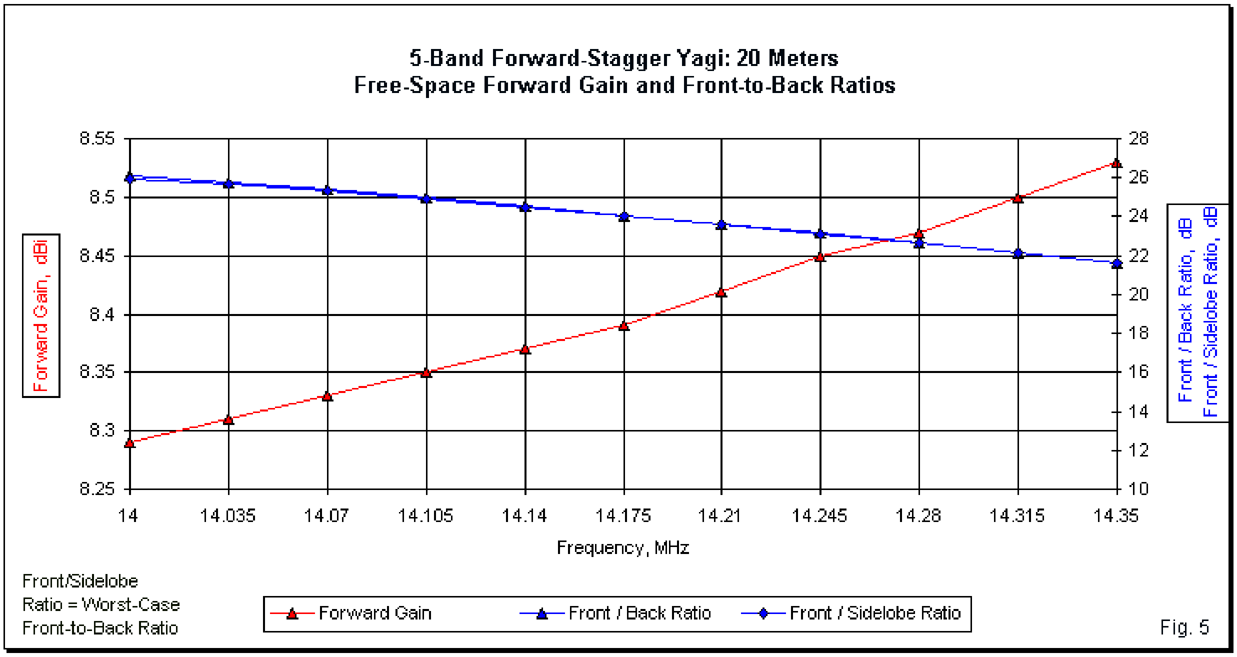


Fig. 5

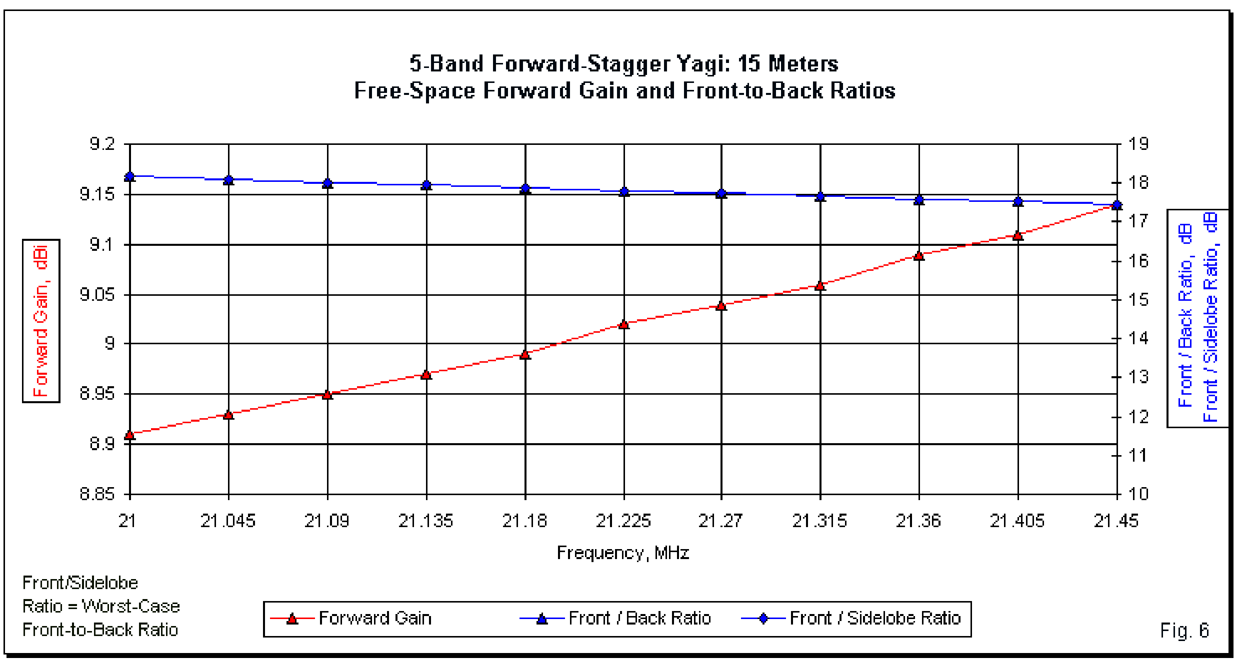


Fig. 6

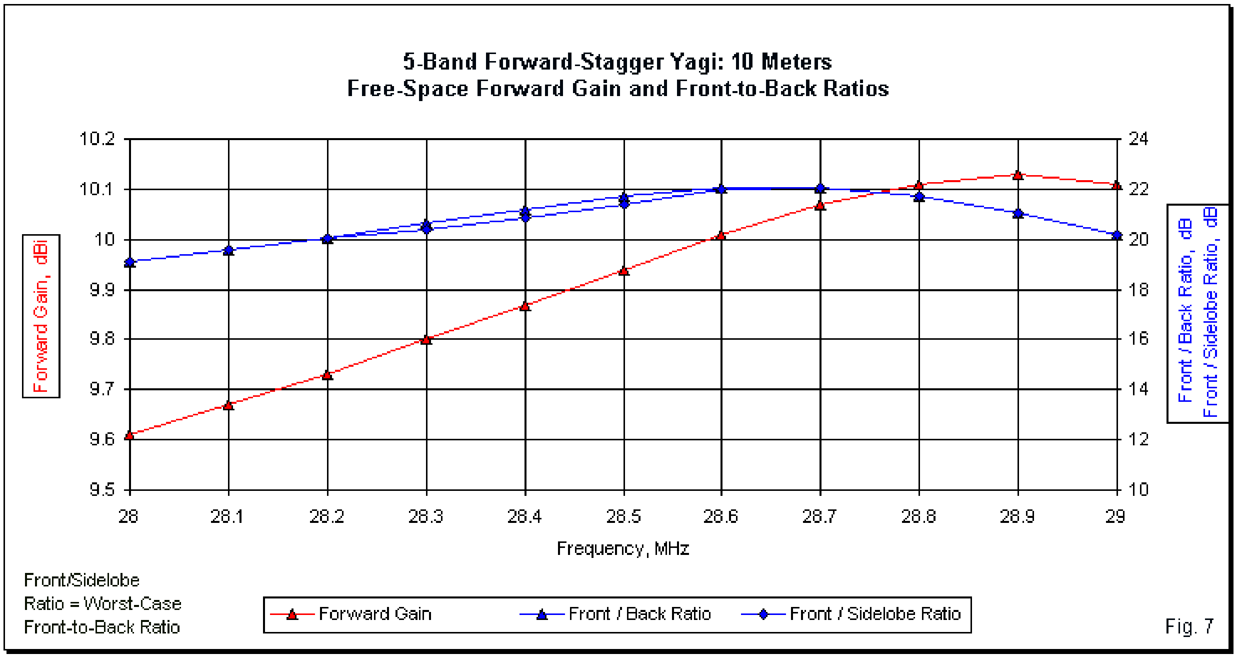


Fig. 7

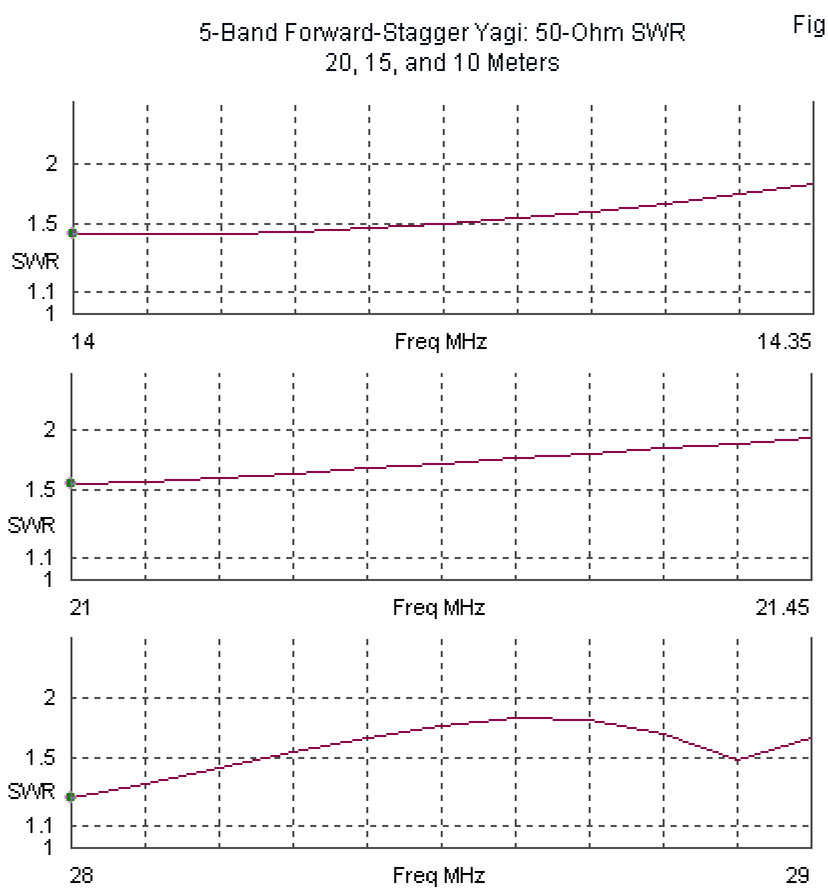


Fig. 8

In one significant performance area, the forward-stagger Yagi outperforms the quad by a considerable margin: front-to-back ratio. Although the sweep graphs show both the 180° and the worst-case values, in virtually all cases, the two lines overlay each other. The range of values on each band is small, providing consistent performance from one band edge to the other. Only on 15 meters in this particular version of the array does the average value fail to meet the 20-dB amateur standard. The average 15-meter front-to-back value is just below 18 dB.

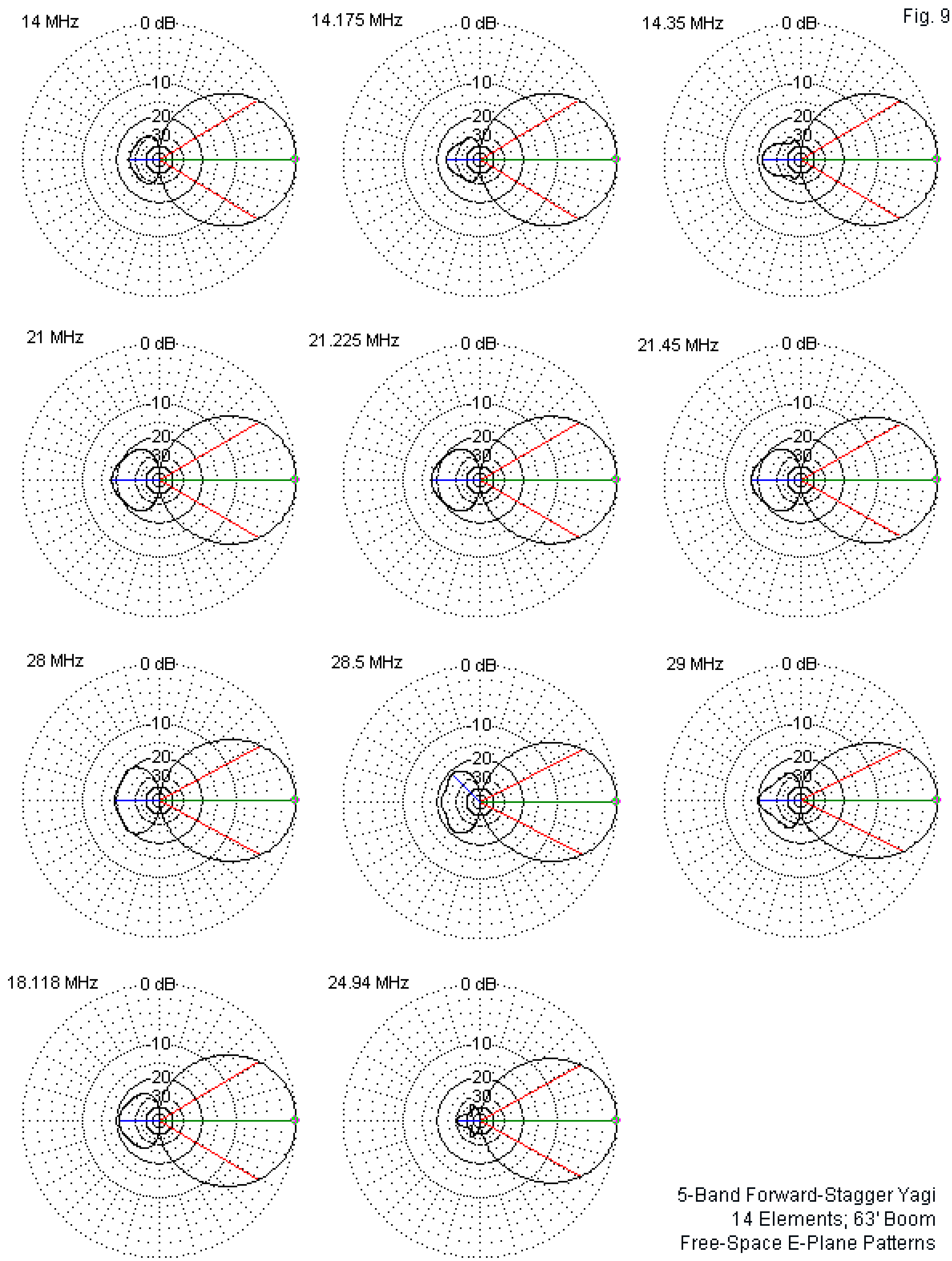
Since the reflector-to-driver spacing determines in large measure the feedpoint resistance, the limitations of overall boom length dictates a smaller spacing than we would expect to find to arrive at a 50-Ω value. Most of the resistance values in the table fall between 30 Ω and 40 Ω. However, it is possible to control the reactive portion of the impedance to derive 50-Ω SWR curves that meet the usual requirements. For each wide band, the SWR is less than 2:1 at the band edges. **Fig. 8** provides 50-Ω SWR sweeps for 20, 15, and 10 meters. On each band, the forward-stagger requirements for pattern formation generally result in a rising SWR across the band, although within the pre-set limits.

On 10 meters, we find two nulls. A review of **Fig. 3** will show that the first director on that band is closely spaced to the fed driver. As a consequence, the director serves as a secondary driver governing pattern formation at the upper end of the passband. We find evidence for this function in the tabular reports of feedpoint reactance. The reactance becomes more inductive up to and beyond mid-band, but then declines at the upper end of the band. The closely spaced secondary driver (and director) serves to broaden the beam’s response over a wider bandwidth relative to a single driver with a widely spaced first director. The technique is widely used in monoband beams. The front-end position of the 10-meter elements allows its use on this band within the 5-band array, although the technique is not applicable to or necessary for the bands below 10 meters.

Fig. 9 provides a gallery of free-space E-plane patterns for the forward-stagger Yagi. Like the tabular data, the plot gallery provides 3 patterns for each wide band and a single pattern for the two narrow bands. Relative to typical monoband Yagi patterns, all of the forward-stagger plots are very well behaved. They contain a single forward lobe with beamwidth values typical for 4-element monoband Yagis: about 62° on average. The forward lobes show no sidelobe development.

The rearward patterns are equally well behaved. All rear lobe structures fall within the sort of variations that we encounter with monoband beams. Below the design frequency for each band, we find a single bulbous lobe. Above the design frequency, we find a tendency toward a 3-lobe structure, although the development is small on almost all bands. The 12-meter rearward pattern differs as a function of both its overall small strength and the activity on the 10-meter elements in the forward-stagger development of the pattern.

Because the 10-meter portion of the array has at least 5 active elements, its pattern differs slightly from the patterns for the lower bands. The average gain is close to 9.9 dBi. This is slightly below the gain for the sample monoband 5-element Yagi (10.3 dBi), but the 5-element set on the forward-stagger array is only about 88% as long as the sample monoband beam. As one consequence of the shorter 10-meter boom length, the beamwidth is about 2° wider (at 55°) than the monoband beams value. The 10-meter front-to-back values, although meeting general amateur standards for performance, do not match the high values shown by the 5-element monoband beam. The root source of the higher rearward radiation levels of the 10-meter section of the large array is the fact that the 10-meter reflector is also the 12-meter director. Hence, its length and position form a compromise between the two bands.



5-Band Forward-Stagger Yagi
14 Elements; 63' Boom
Free-Space E-Plane Patterns

Except for the transition from 20 to 17 meters, every other band transition faces the same compromise required by an element serving as a reflector for one band and a director for the next higher band. Despite the compromises, the forward-stagger Yagi manages remarkably consistent band-to-band performance in every category of concern. Gain values fall in the short-4-element to short-5-element monoband Yagi range with well-shaped patterns. Except for a 2-dB deficiency on 15 meters, the front-to-back ratio reaches the 20-dB amateur standard with normal Yagi rear lobe development. The design—although it has evolved since ON4ANT first shared it with me—is a tribute to his design skills. Perhaps the one major limitation of the array, even within the context of dream beams, is the boom length. At 63 feet, it is the longest of the Yagis that we shall examine. A possible second limitation lies in the absence of interlaced elements. Hence, the gain potential for the array is limited on 10 meters to 5 elements on a 0.56-λ boom. Interlacing allows the use of almost the entire boom to obtain further gain. In exchange for accepting this limitation, the forward-stagger Yagi requires only 14 elements to cover 5 upper HF bands, only 60% to 70% of the number of elements required for the interlaced tri-band designs to which we next turn.

A 3-Band 53' 23-Element Interlaced Yagi

Interlacing elements in a multi-band Yagi is a somewhat tricky process that involves a myriad of compromises and compensatory techniques to arrive at a beam that fits within our dream-beam umbrella. There is an art as well as a science to the development of such beams, which generally are limited to tri-band service. Beyond the level of 3 elements on 20 meters and the boom length associated with that design level, we find very few commercial offerings. We shall look at two different designs, each derived from but in no way identical to a commercial offering. Part of our interest will lie in seeing what aspects of performance each design emphasizes and how the design achieves the desired performance. Part of our interest will also involve different methods of feeding such beams to minimize the number of required feedlines. (The forward-stagger design required 5 separate feedpoints, in most cases requiring a remote relay system on the tower using line length to the drivers that ensured an effective short at the feedpoint on unused drivers.)

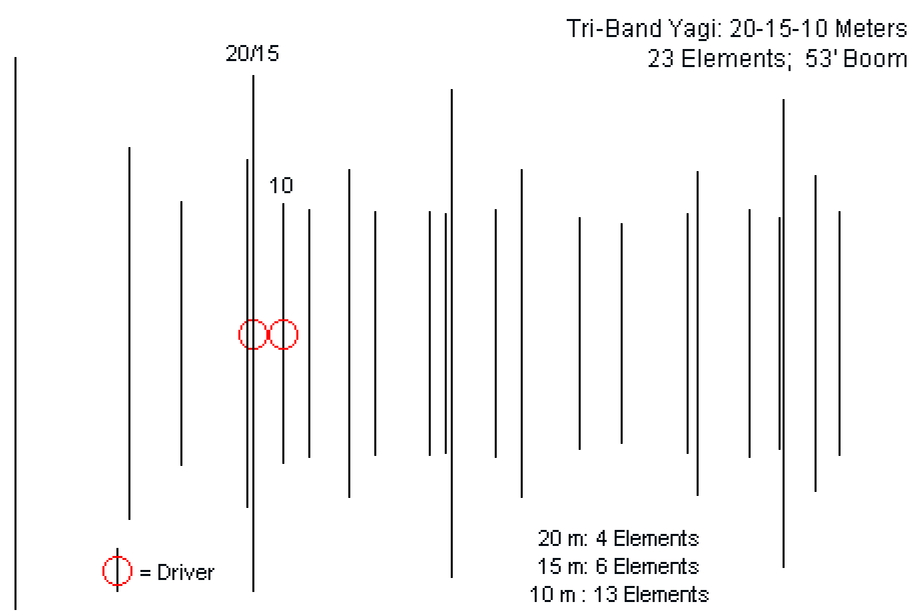


Fig. 10

Fig. 10 shows the first of the designs, a 23-element 53' long array. Effectively, it employs 4 elements on 20 meters, 6 elements on 15 meters, and 13 elements on 10 meters. As we shall discover, the process of interlacing does not make the 10-meter section of the array a true 13-element Yagi, since some of the director serve primarily control functions rather than gain-enhancing functions. The design derives from an non-authorized model of the Force 12 C49, a model I made several years ago. As such, it does not pretend to provide performance data for that commercial beam, and even the commercial design may have changed over the years. However, within our context of dream beams, the model does provide us with some clues to interlaced design principles and to certain methods of feeding large tri-band beams.

Let's begin with the tabular data on the model's free-space performance and then turn to how it delivers that performance. **Table 3** supplies the usual numbers.

Table 3. Modeled free-space performance of the 3-band 53' interlaced Yagi

Band Meters	Frequency MHz	Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ω
20	14.0	9.32	20.58	42.5 – j22.3
	14.175	9.69	34.23	37.3 – j9.4
	14.35	10.20	19.89	30.8 + j9.2
15	21.0	10.62	24.23	80.2 – j15.6
	21.225	11.25	25.54	55.9 + j3.1
	21.45	11.73	24.06	38.2 + j27.5
10	28.0	10.59	36.73	27.2 – j4.0
	28.5	11.89	23.66	49.8 + j15.4
	28.8	10.94	22.38	51.9 – j19.4

One characteristic of the forward gain on 20 and 15 meters that differs from the monoband beams is the rate of change across the band. On 20 meters, the gain increases by 0.9-dB between 14.0 and 14.35 MHz. Between 21.0 and 21.45 MHz, the gain change is 1.1 dB. These steep curves are clear in **Fig. 11** and in **Fig. 12**, the gain and front-to-back sweeps for both bands. The rates are also higher than we find in the forward-stagger Yagi.

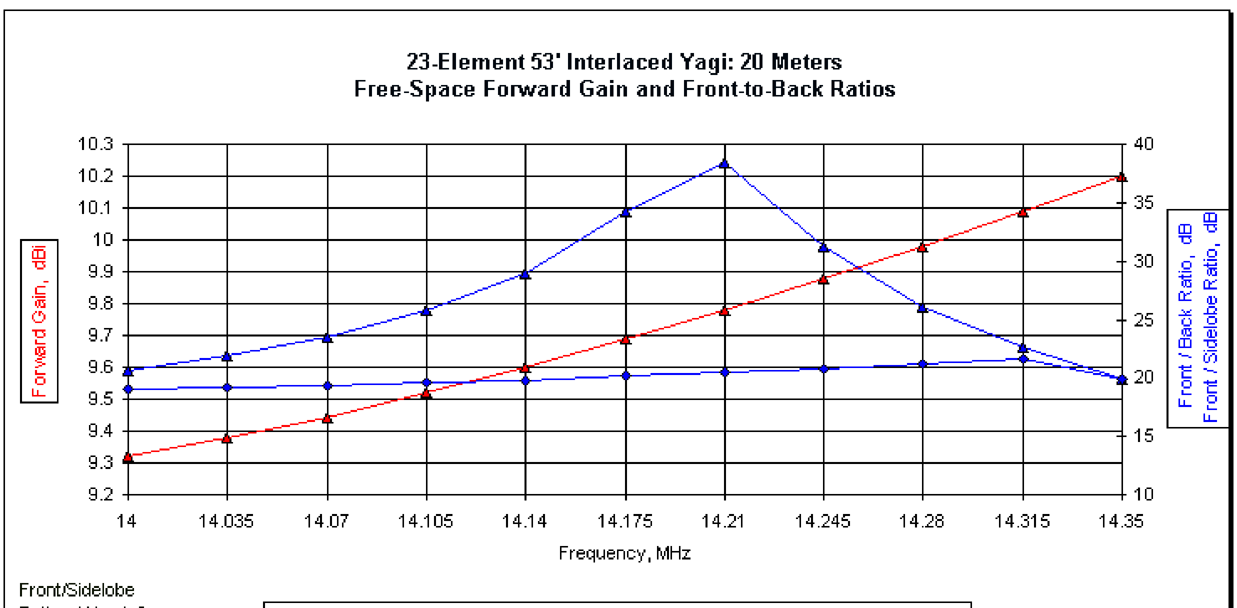


Fig. 11

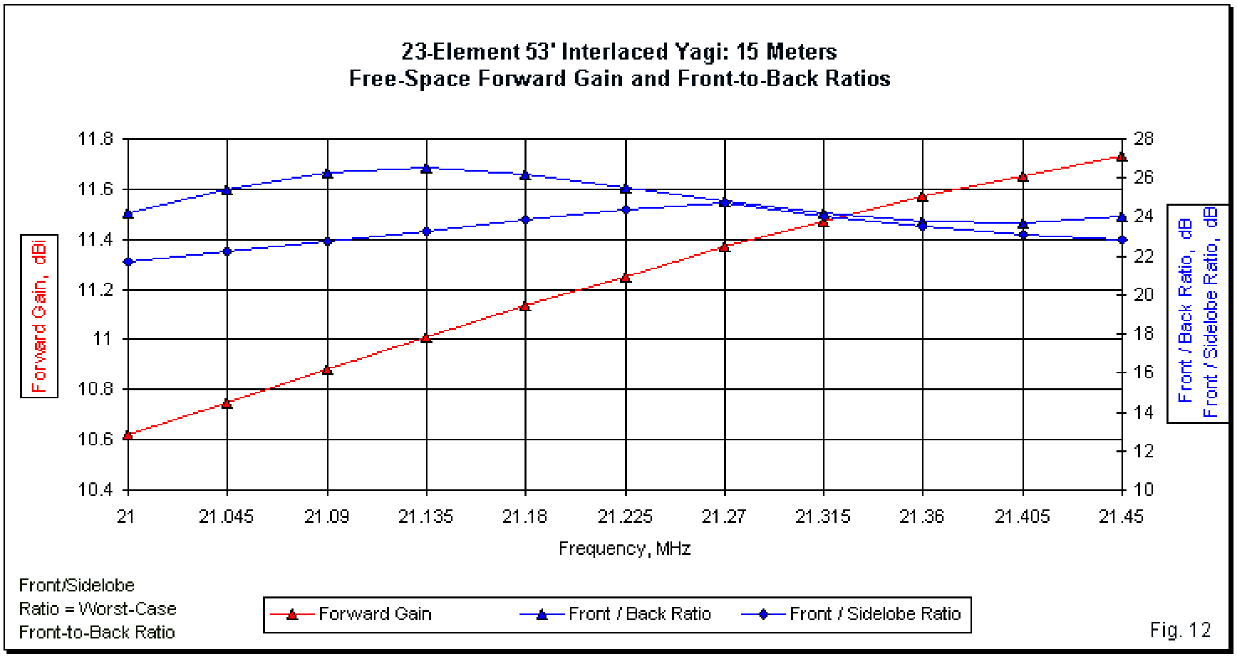


Fig. 12

The lower 2 bands also show gain levels that are approximately appropriate for the number of elements and the boom length when compared to monoband beams. The 4-element 20-meter section is about 0.7-λ long, which is longer than the long-boom 4-element monoband Yagi. The 20-meter interlaced gain in this model is about 1-dB higher as well. On 15 meters, the 6 elements use about 0.95-λ of boom, and the gain approximates the value shown by the 6-element monoband beam at 1.04-λ of boom. We have not referenced these values to any forward stagger effects for two reasons. First, with interlaced elements, the relative current peak values on individual elements are not as clear an indication of gain-enhancing director action as they are in the pure forward-stagger Yagi. Second, a number of elements, especially on 10 meters, exert influence on the operating bandwidth more than they affect forward gain.

As interlaced tri-band beams go, the front-to-back ratios have remarkably good values, with an average of greater than 20 dB on both bands. The sweep graphs show both the 180° and the worst-case values. Although the worst-case graphed values tend to meet the usual amateur standard for rearward performance (about 20 dB down), the differential suggests the presence of rearward sidelobes that lessens the relevance of the 180° value as a clear performance marker.

So far, we have bypassed the 13-element 10-meter section of the antenna. It occupies about 1.2-λ. However, the gain values describe an arc across the band, as shown in **Fig. 13**, with a peak value just above mid-band. The peak is just above the value attained in a monoband Yagi with 6 elements and a shorter boom. In fact, many of the 10-meter directors serve as control elements to allow full-band performance on 10 meters. The 20-meter elements are especially pernicious, because they are close to 1-λ long on 10 meters. On 10 meters, they are not only active; they also tend to control 10-meter performance by lowering both the upper and lower frequency limits of good pattern formation and feedpoint impedance. Placing 10-meter elements close to the 20-meter directors tends to return passband control to the entire set of shorter directors, but without adding significantly to the forward gain. You may observe the 10-meter director placement in **Fig. 10**. Once the control elements are in place, they may require an extra director to avoid large spacing values on 10 meters, a situation that often narrows the operating bandwidth. In addition, when interlacing elements, each higher band requires a director ahead of the forward-most director for the next lower band to prevent the longer element from acting as a reflector on the upper band and thereby depressing the forward gain. Hence, the forward-most elements follow the pattern of 20-15-10 from back to front.

The graph shows only the 180° front-to-back ratio. On 10 meters, the boom length is sufficient for the development of forward sidelobes that are stronger than any of the rearward lobes over at least part of the band. Therefore, the front-to-sidelobe ratio no longer indicates worst-case rearward performance.

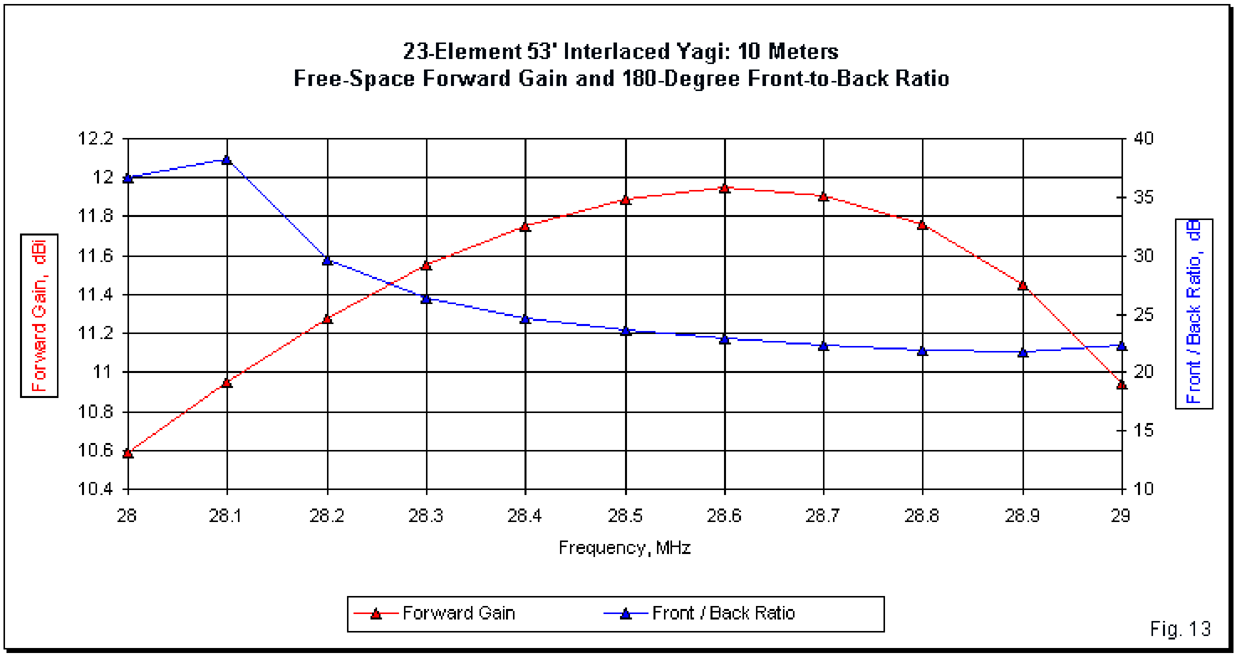


Fig. 13

The feed system for the first of our interlaced Yagis is especially interesting for the combination of elements that it uses. The 20-meter driver serves both 20 and 15 meters. As shown in **Fig. 10**, the 15-meter driver is a slaved driver placed immediately behind the fed driver. Slaved drivers generally have a narrower operating range than directly fed drivers. Therefore, in the tabular data, we find a relatively wide—but completely usable—40-Ω excursion of the feedpoint resistance (compared to only 11 Ω on 20 meters). The curves for both bands appear in **Fig. 14**. Notice that the 15-meter curve shows a high range of SWR values, even though, as a percentage bandwidth, 15 meters is narrower than 20 meters. Any physical implementation of a master-slave driver system requires careful attention to the length of both elements and the spacing between them. These values may change slightly from just a shift from uniform-diameter elements in the model to equivalent stepped-diameter elements in the antenna itself.

The master-slaved driver arrangement serves 15 meters well enough in obtaining an acceptable SWR curve for that band, but the system proves (in this model) inadequate to the needs of 10 meters, which is nearly twice as wide as 15. Therefore, the model uses a separate feedline for 10 meters, along with a first director that is fairly close to the 10-meter driver. The distance is not close enough to form a secondary driver capable of giving the SWR curve (shown in **Fig. 14**) a double null, but it is close enough to extend the operating range of 10 meters all the way to 29 MHz.

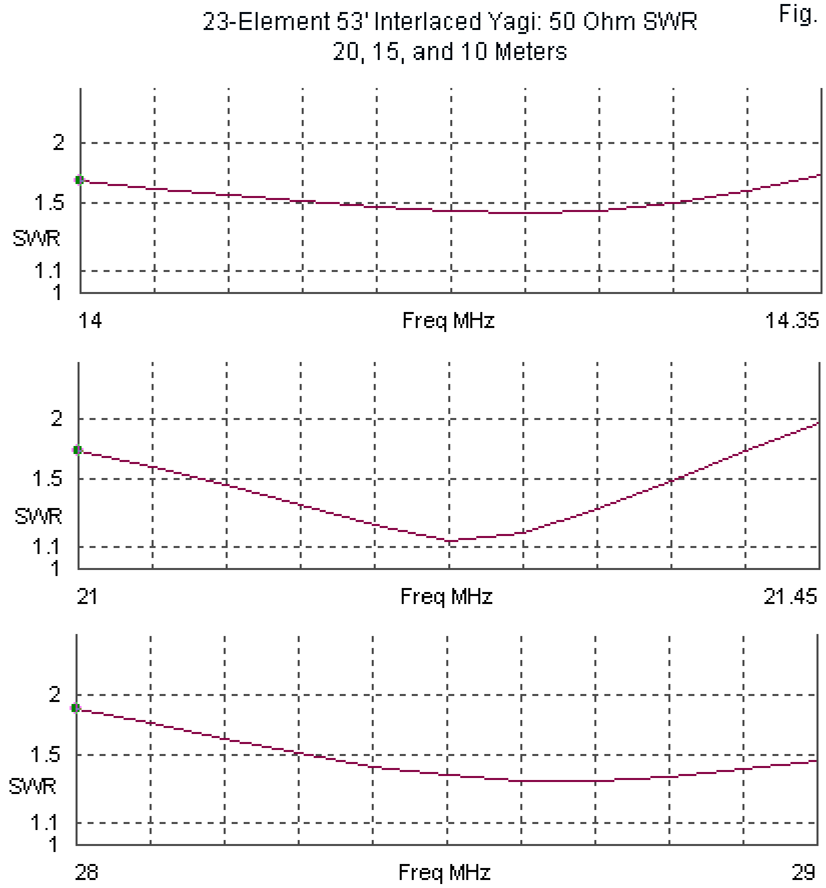
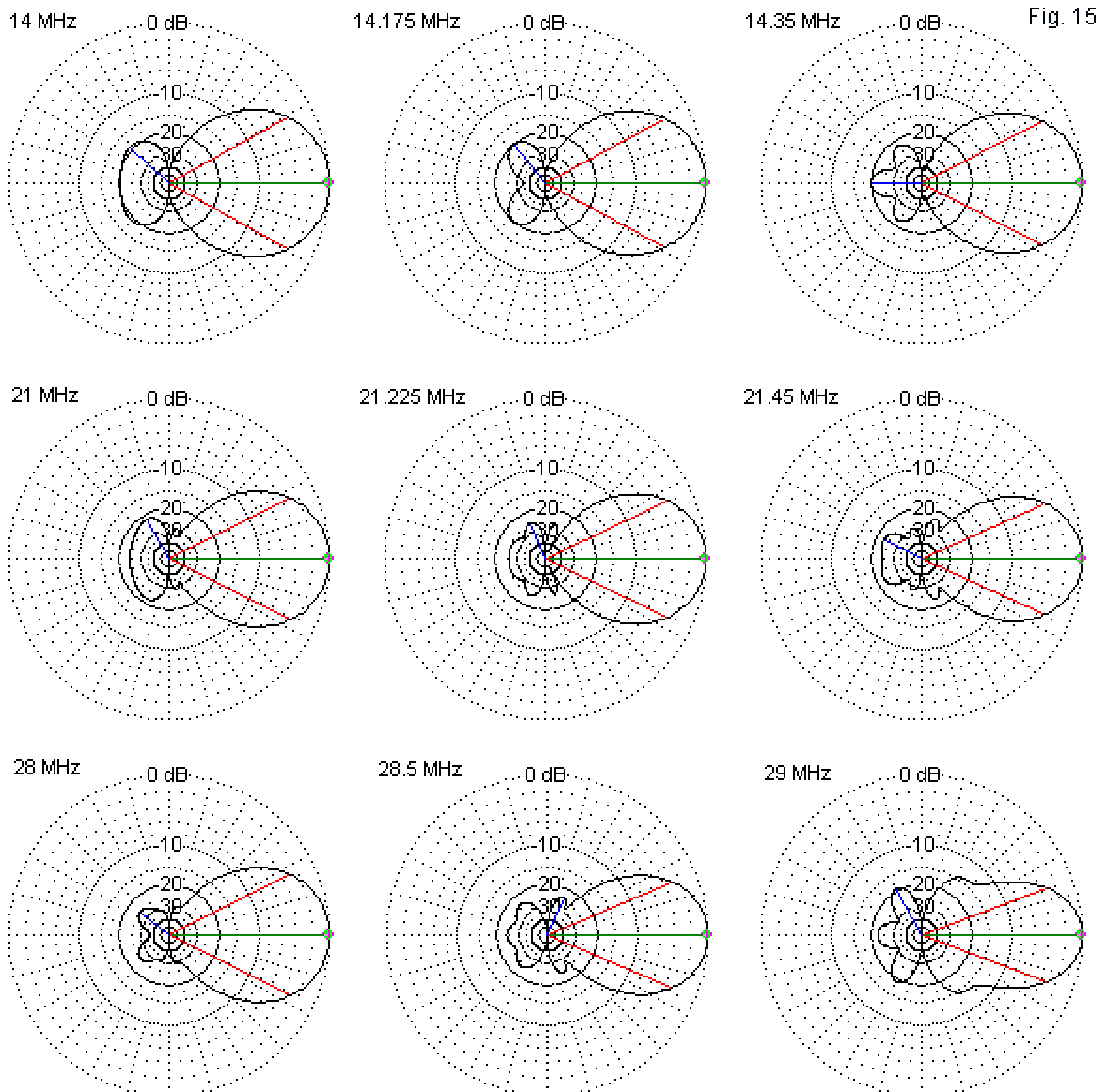


Fig. 14

The pattern development for the three bands differs among them. A gallery of free-space E-plane patterns appears in **Fig. 15**. With its shorter boom (as measured in wavelengths), the 4-elements on 20 meters produce quite expected patterns, with a single forward lobe across the band. The beamwidth averages about 57°, which falls between the monoband values for 4 and 5 elements, as does the 20-meter gain. The rearward lobe structure follows the normal Yagi pattern of a single lobe below the design frequency and three lobes above it.

On 15 meters, the boom is long enough to show the emergence of forward side lobes that grow as we increase the operating frequency within the band and thus increase the boom length slightly over the same frequency span. The rearward lobes are generally tightly confined, especially above the lowest end of the band. Nevertheless, the patterns do not precisely coincide with rearward patterns for any of the monoband beams. In fact, they tend to follow patterns that are more typical of much longer Yagis.

The 10-meter forward lobe patterns show more distinctly the development of sidelobes and their evolution into side “bulges.” Their growth rate is significantly higher than we find on 15 meters with an increase of about 15-dB in strength across the band. The shifts in pattern shape do not adversely affect the basic directional function of the beam, but may have a small affect on the reception of off-axis signals. Although not as clearly resolvable into main and side lobes, the rearward pattern shows a spreading with increased operating frequency on 10 meters. The worst-case front-to-back ratio drops from about 30-dB at the low end of the band to less than 20-dB at the high end.



23-Element 53' Boom Interlaced Yagi: Free-Space E-Plane Patterns

The 53' 23-element interlaced Yagi counts as a high performance array of its type. 20- and 15-meter performance closely matches monoband Yagis with the same number of elements and boom length. The special needs of 10-meter operation require us to set aside a tight comparison with monoband Yagis, since so many of the 10-meter directors serve control rather than gain-enhancing functions. However, the band-by-band performance levels are roughly equal to those of the 5-band quad on the wider amateur bands. Both beams have some areas calling for finicky adjustment, but we shall not here debate the relative merits of the two beam types. The interlaced Yagi exceeds the performance levels attained by the longer forward-stagger array, but at a cost of 9 additional elements. In return, the interlaced beam offers a more compact feed system.

A 3-Band 46' 20-Element Interlaced Yagi

Our second interlaced Yagi (and final dream beam) employs 20 elements on a 46' boom. The array has 5 20-meter and 5 15-meter elements, with 10-elements devoted to 10-meter functions. **Fig. 16** shows the outline of the array. In the forward reaches of the antenna, 10-meter directors surround pairs of longer elements consisting of a 20-meter and a 15-meter director. As we move toward the rear of the array, the driver placement alters this system. The 10-meter driver is behind the 20-meter driver, while the 15-meter driver has a forward position. That arrangement places the 10-meter reflector behind the 15-meter reflector. As well, it requires the use of separate 10-meter control directors for the 20-meter and the 15-meter first directors. Nevertheless, the system allows us to reduce the 10-meter director count relative to the previous model. Still, the array adheres to the principle that the forward-most elements must appear in the order of length (20-15-10) from back to front so as to prevent gain reductions on one or more bands.

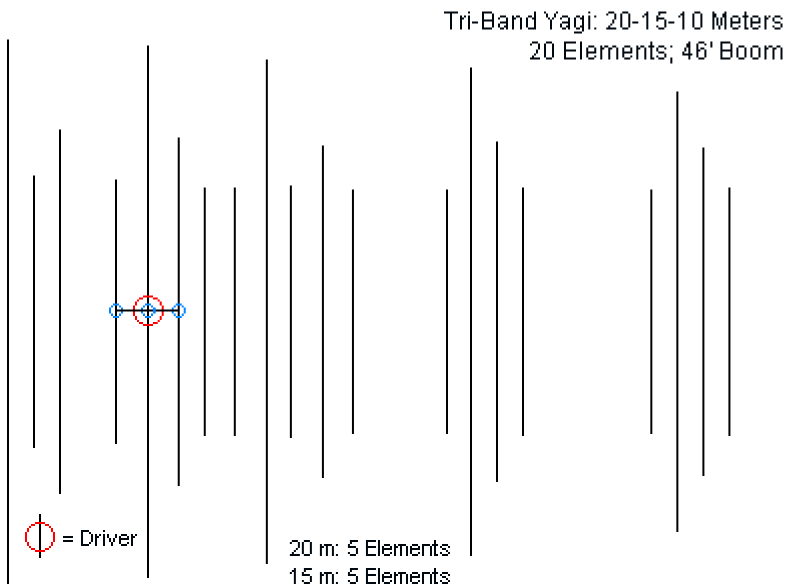


Fig. 16

The alternate interlaced design is also interesting for its feed system. The feedline goes to the 20-meter driver. The 15-meter and the 10-meter drivers receive energy via a 50-Ω direct (not reversed) phase line. The line length is short enough that very little impedance transformation occurs along it. In fact, the amount is so small that simply adjusting the driver length can compensate. Of course, the impedance at the 20-meter feedline terminals is a parallel combination of the active element impedance and the off-band impedances. But, the off-band impedances are generally high enough to allow us to achieve good 50-Ω SWR performance on all bands and with a broad impedance curve.

The design has its origins in my personal modeling of an Optibeam offering, but with major differences. The commercial antenna maker does not offer any beam in this boom-length class. Hence, they are in no way responsible for any differences between my dream-beam model and their well-respected antenna offerings. Whether my long-boom 20-element array provides any enhancements over any commercial antennas will require a comparison with an authorized model for the commercial beam. **Table 4** provides the numerical free-space reports for my 46' model,

Table 4. Modeled free-space performance of the 3-band 46’ interlaced Yagi

Band Meters	Frequency MHz	Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ω
20	14.0	9.56	14.87	38.5 – j5.7
	14.175	9.64	17.77	42.4 – j3.5
	14.35	9.75	22.02	40.5 + j7.4
15	21.0	9.67	14.30	34.1 + j3.4
	21.225	10.20	14.70	58.3 + j5.7
	21.45	10.76	17.72	68.0 + j1.2
10	28.0	10.27	18.01	39.0 – j0.8
	28.5	11.65	21.23	52.1 – j1.5
	28.8	12.32	17.88	69.6 + j4.7

The average forward gain on 20 meters is about the same as for the 53’ interlaced beam, even though the 20-meter boom length is about 0.1-λ shorter. The extra 20-meter element in the present model not only aids the development of gain, but also reduces the gain change cross the band. The 20-meter sweep graph in **Fig. 17** shows a gain change of less than 0.2-dB, compared to about 0.9-dB for the previous model.

The design philosophy behind this beam places less emphasis upon peak front-to-back ratio values than we found with the previous design. The average ratio is about 18 dB, with a rising value as we increase the operating frequency. In general, then, the 5 20-meter elements provide very stable operation over the entirety of 20 meters.

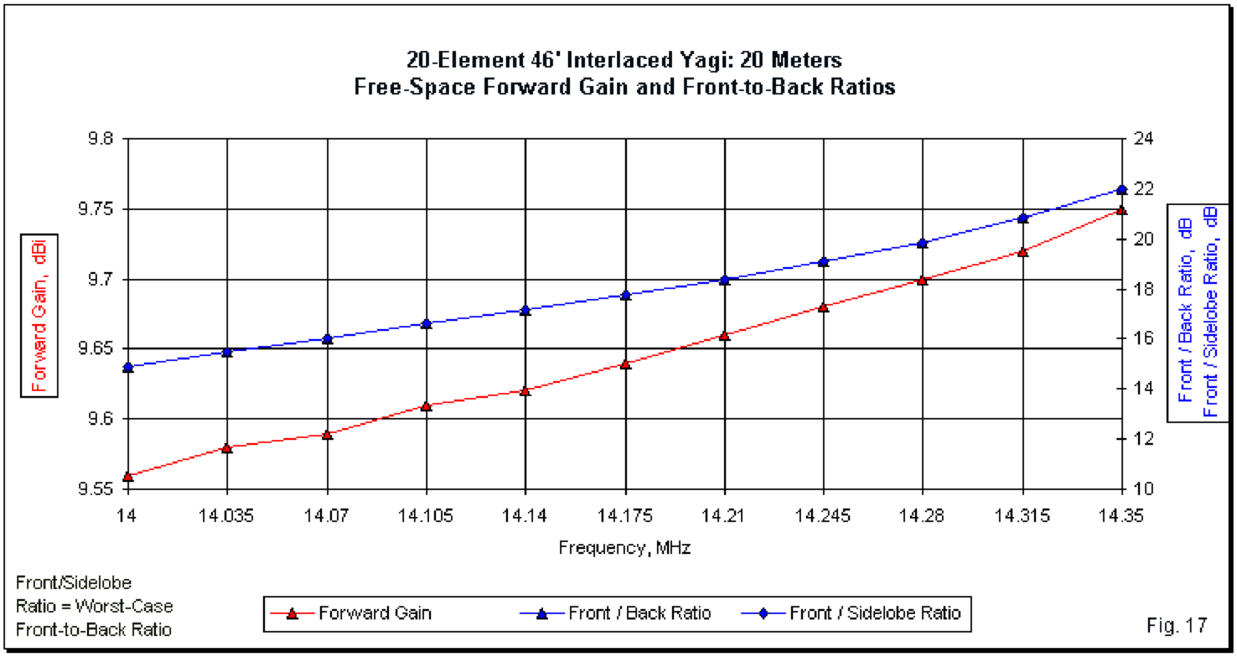
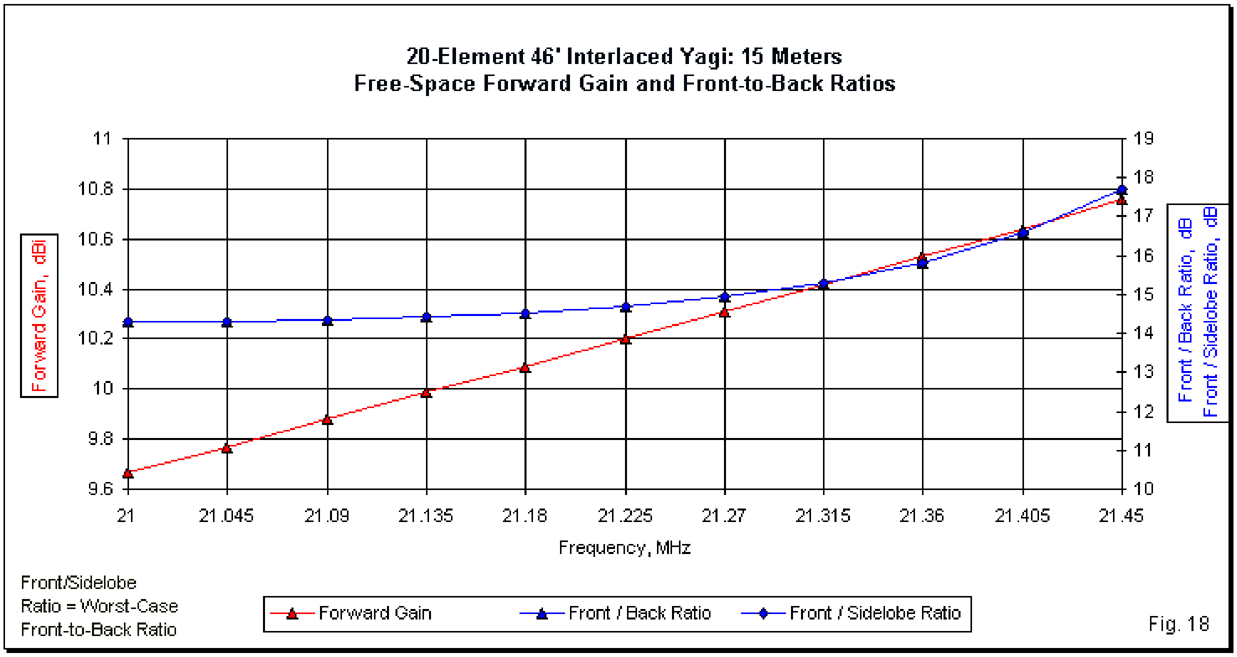
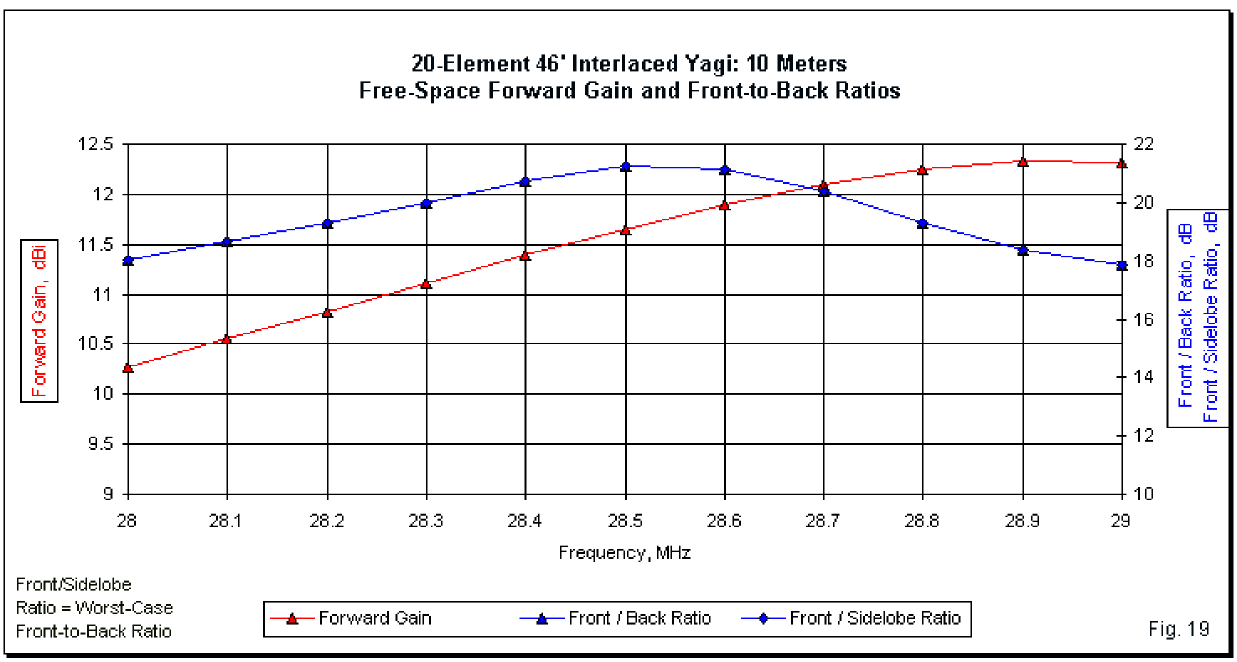


Fig. 17

We find some of the same characteristics on 15 meters. However, the gain is not as stable, since the array uses 5 elements on a boom that is just under 0.9-λ. The gain change of about 1.1 dB is similar to the performance of the earlier interlaced Yagi, but the average gain is down about 1 dB due to the use of a shorter boom.

Once more, the front-to-back ratio remains stable across the band, as shown by the sweep graph in **Fig. 18**. The average value is about 16 dB. Like the 20-meter front-to-back curves, the 180° and the worst-case values are exactly coincident from one end of the band to the other.





The 10-meter band is wide enough to show the peak gain at 28.9 MHz in **Fig. 19**. Due to the large bandwidth, the gain range is about 2 dB from one band-edge to the other. The front-to-back ratio, with coincident 180° and worst-case values, is very stable and varies between about 18 dB and 21 dB. With close to same boom length for 10-meter elements as we found in the previous interlaced design, the present design has very comparable gain values, despite using 3 fewer directors.

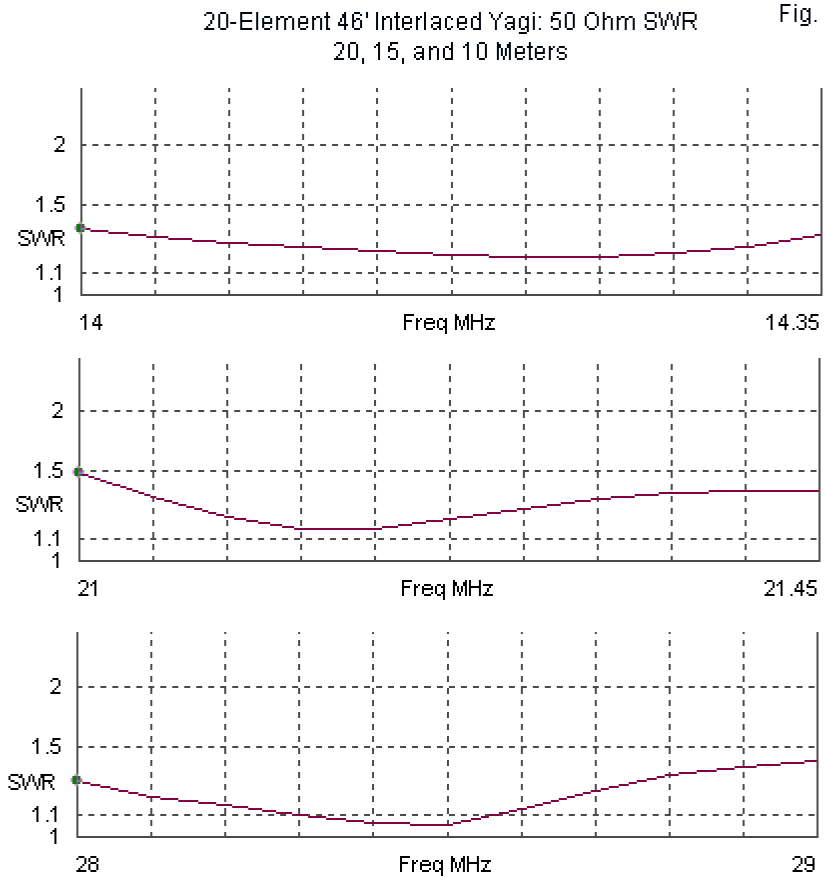
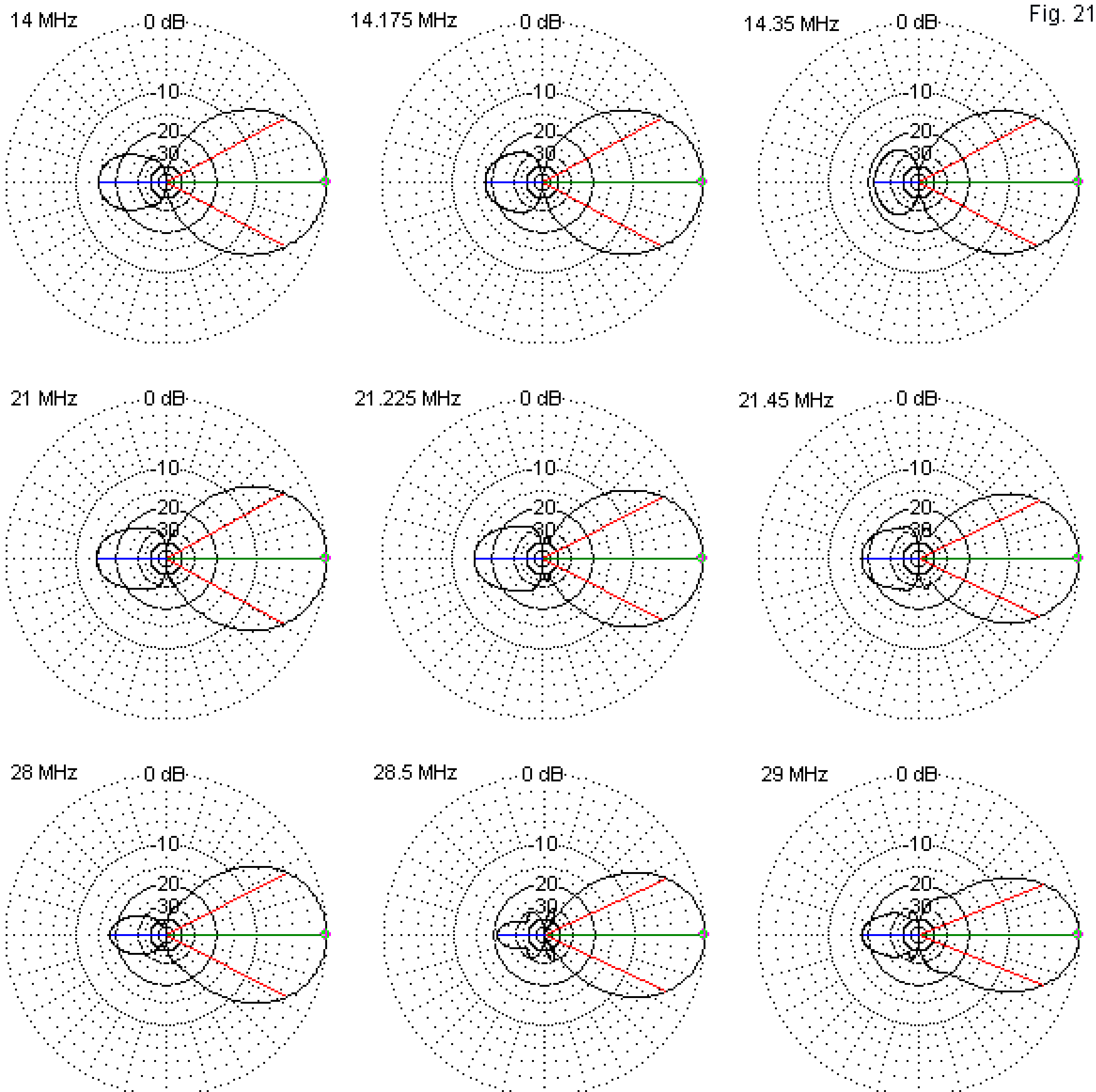


Fig. 20

If the 46' Yagi design yields some front-to-back ratio to the 53' design, it captures honors with respect to impedance and SWR values, as revealed by **Fig. 20**. In the tabular data, note that the reactance never exceeds +/-j7.5 Ω at any operating frequency. The variations in the feedpoint resistance create 50-Ω SWR curves that remain at 1.5:1 or below across all of the 3 bands. The direct connections among the feed points using the 50-Ω phase line provide very wide coverage on all bands with the correct element length and spacing values.

The shorter overall length of the present design, along with element positioning that does not strive for maximum possible front-to-back ratios, results in a set of remarkable “clean” free-space E-plane patterns. The gallery is **Fig. 21**. We find almost vestigial forward and rearward side lobes on 15 and 10 meters, but at strengths that are too low to affect the beam's performance in any way. Even on 10 meters, where the array is nearly 1.3-λ long, the side “bulges” are 25-dB down from the main lobe.

The 46' interlaced design provides gain that is consistent with the boom length on each band when compared to monoband Yagis. For the bands covered, the gain values are comparable also with the 5-band quad performance. The Yagi sacrifices front-to-back ratio for improved SWR curves and well-behaved E-plane patterns on all bands. These factors tend to make final field adjustment of the array less finicky than for some other designs. Finally, the design offers the use of a single feedline without need for switching systems.



20-Element 46' Boom Interlaced Yagi: Free-Space E-Plane Patterns

Conclusion

Although we have examined a few advantages and disadvantages of each dream beam along the way, the point of these notes is not to select one above the others. Instead, the goal has been to describe and sample some of the possibilities for a single, large, high-performance beam to cover all or most of the upper HF amateur bands. We have examined a 25-element 57' continuous-coverage LPDA, a 24-element 30' quad with 4 to 6 elements per band, a pure forward-stagger Yagi on a 63' boom with 14 elements, an interlaced 53' tri-band Yagi with a combination of feed methods, and a 46' interlaced tri-band Yagi with a single feedpoint. Each design has its strong points and its disadvantages relative to forming an "ideal" single upper HF antenna. Along the way, we were able to sample some of the design principles and limitations that given each type of array.

Although we might make a chart of what I might believe to be the key features, the chart would not fit your dreams or your construction preferences. My chart would initially list a number of items:

1. Coverage (continuous, 5-band, 3-band)
2. Boom length
3. Number of elements
4. Performance level on each band (relative to Yagis of sample boom lengths)
5. Operating bandwidth of forward gain, front-to-back ratio, and 50-Ω SWR
6. Quality of forward and rearward E-plane patterns
7. Number of required feedpoints
8. Level of sensitivity of final adjustments

To this list, you may add any further interests and concerns that haunt your dreams of beams.

The models for each of the beams that we have discussed in both parts of this exploration used NEC-4 to arrive at the free-space data reports. NEC-2 would also be very serviceable, since all models have been reduced to using uniform-diameter elements. Any physical implementation would require a translation of the antenna dimensions to reflect the stepped-diameter element construction commonly used in the upper-HF range. The dimensions of the beams for each part appear at the end of the text. Although some of the designs have roots in my personal models of commercial designs, the models do not reflect the performance of any commercially made beam. In most cases, I have highly modified the original model, which was not an authorized model in the first place. My use of models having such origins stems from a desire to show different methods and principles of organizing and feeding multi-band arrays.

Our work has had a secondary purpose. For each dream beam, we have viewed both tabular and graphical data that sampled performance across each of the bands covered. (The exceptions were the two 100-kHz bands, 12 and 17 meters.) When evaluating a beam design, whether to be built or purchased, single numbers are normally insufficient to reveal the array's characteristics. For any of the wider amateur bands, beams may show small to large changes in their performance—whether we are interested in the gain, the feedpoint impedance, or the rear lobe structure and strength—and a multi-band beam may have different characteristics on each band. Between two designs seemingly covering the same overall territory, large changes of performance may show up on different bands. Therefore, the only way to obtain a clear picture of multi-band antenna performance is to have accurate sweep data for every band, whatever the size of the antenna from 2 to *n* elements per band. Alas, for most commercial offerings, such data is not readily available.

How do you end a dream? The simplest way, from my perspective, is simply to end the text. If you are prone to reveries about antennas that lie outside the range of what is practical for a given back yard, you can return to these designs, and you may add designs of your own invention. These notes have only scratched the surface of what might be possible. Suppose, for example, that we could install the idealized 40-element LPDA on a warm (Caribbean, Mediterranean, or Pacific) rotatable island surround by salt water (and everything else we might personally add to the dream). If you like to dream, then dream big.

Dimensions of Beams Discussed

15-Meter Monoband Yagis								
3-Element Short			**3-Element Medium**			**3-Element Long**		
Element	Length	Spacing	Element	Length	Spacing	Element	Length	Spacing
1	23.73	0.00	1	23.18	0.00	1	23.11	0.00
2	21.71	4.03	2	22.31	6.62	2	22.06	6.99
3	20.71	10.08	3	20.96	13.25	3	20.76	15.07
4-Element Short			**5-Element**			**6-Element**		
Element	Length	Spacing	Element	Length	Spacing	Element	Length	Spacing
1	23.10	0.00	1	23.44	0.00	1	23.63	0.00
2	22.31	4.67	2	22.40	4.44	2	22.36	4.67
3	21.27	9.33	3	21.58	8.64	3	21.50	9.56
4	19.48	17.50	4	21.40	18.80	4	20.95	20.47
4-Element Long			5	20.68	29.52	5	20.78	35.26
Element	Length	Spacing				6	20.04	48.12
1	23.05	0.00	Notes:	1. All dimensions in feet				
2	22.17	6.37		2. Spacing is from the rear element (Element 1)				
3	21.23	12.89		3. All elements 0.75" diameter				
4	17.54	24.31		4. Design Frequency: 21.225 MHz				

14-Element, 63' Forward-Stagger Yagi				
Element	Length	Spacing	Diameter	Drivers
1	36.00	0.00	1.25	
2	33.74	8.30	1.25	20 m
3	31.50	13.81	1.25	
4	27.23	19.22	1.00	
5	26.38	23.00	1.00	17 m
6	24.93	25.62	1.00	
7	22.28	29.56	1.00	15 m
8	19.82	33.17	1.00	
9	19.09	40.50	1.00	12 m
10	17.59	43.37	0.88	
11	17.30	46.70	0.88	10 m
12	16.18	48.33	0.88	
13	15.70	54.76	0.88	
14	15.30	62.90	0.88	
Notes:	1. Length and spacing dimensions in feet;			
	diameter dimensions in inches			
	2. Spacing is from the rear element			
	(Element 1)			

23-Element, 53' Interlaced Yagi				
Element	Length	Spacing	Diameter	Drivers
1	35.70	0.00	0.67	
2	24.00	7.33	0.65	
3	17.08	10.67	0.60	
4	22.48	14.92	0.65	
5	33.30	15.35	0.67	20, 15 m
6	16.67	17.25	0.60	10 m
7	16.04	19.00	0.60	
8	21.17	21.50	0.65	
9	15.67	23.17	0.60	
10	15.75	26.75	0.60	
11	15.50	27.75	0.60	
12	31.50	28.17	0.67	
13	15.92	31.00	0.60	
14	21.17	32.67	0.65	
15	15.08	36.42	0.60	
16	14.33	39.08	0.60	
17	15.42	43.33	0.60	
18	20.83	44.00	0.65	
19	16.00	47.42	0.60	
20	15.00	49.25	0.60	
21	30.30	49.58	0.67	
22	20.50	51.58	0.65	
23	15.75	53.17	0.60	
Notes:	1. Length and spacing dimensions in feet;			
	diameter dimensions in inches			
	2. Spacing is from the rear element			
	(Element 1)			

20-Element, 46' Interlaced Yagi				
Element	Length	Spacing	Diameter	Drivers
1	34.68	0.00	0.70	
2	17.29	1.64	0.54	
3	23.25	3.28	0.62	
4	16.77	6.89	0.55	
5	33.99	8.86	0.71	20/15/10
6	22.16	10.83	0.63	
7	15.73	12.47	0.55	
8	15.73	14.44	0.55	
9	32.17	16.40	0.72	
10	15.99	18.04	0.55	
11	21.27	20.01	0.64	
12	15.47	21.98	0.56	
13	15.66	27.89	0.55	
14	31.17	29.53	0.73	
15	21.58	31.17	0.64	
16	15.73	32.81	0.55	
17	15.66	41.01	0.55	
18	28.22	42.65	0.73	
19	21.00	44.29	0.64	
20	15.73	45.93	0.55	
Notes:	1. Length and spacing dimensions in feet;			
	diameter dimensions in inches			
	2. Spacing is from the rear element			
	(Element 1)			