Dream Beams: Part 1
LPDAs and Quads

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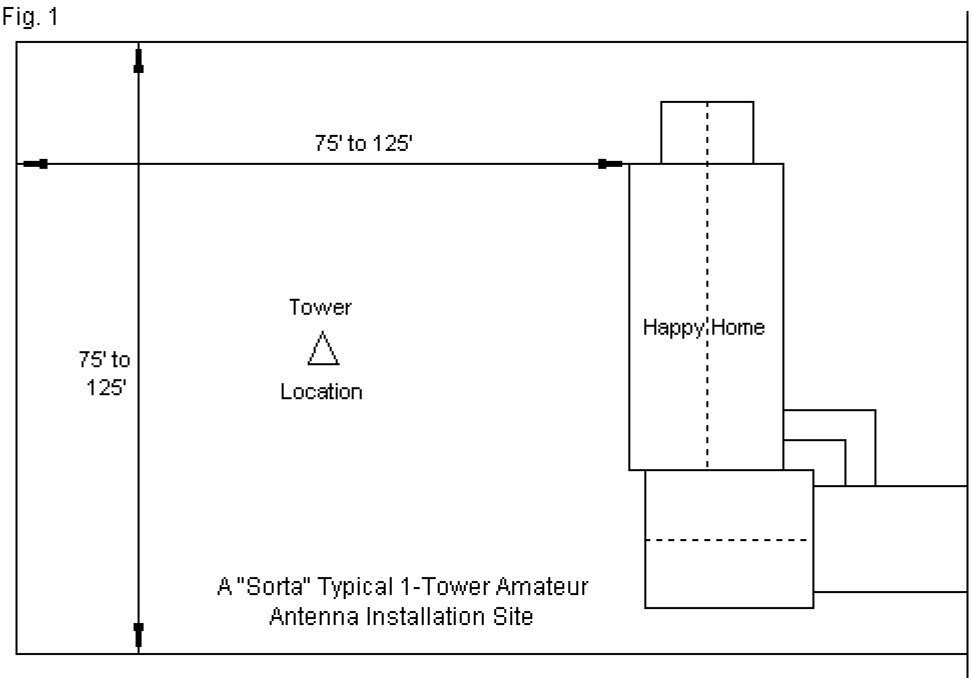
A number of years ago, I did a small presentation called “dream beams.” Since that time, I have had occasion to refine some of the designs, and so I thought that making the notes available to a wider audience might be enjoyable for some—if for no other purpose than to dream on a cold winter’s night.

The premise of the exercise is simple. Suppose that we have room for only one tower in a suburban back yard. The layout might look something like **Fig. 1**. Space is restricted, so only one beam for the upper HF bands (20 through 10 meters) will fit. It must have multi-band capability, since we cannot stack a collection of monoband beams. The exact height does not matter, so we shall not trouble ourselves with ordinances and restrictive covenants. Perhaps a height of about 70’ might be good. Nevertheless, to avoid problems with variable heights above real ground, all of our exercise models will use free space values. For any given height above ground, the comparative performance figures will still hold good.

Fig. 1



Of course, to make the exercise complete, we must assume a number of other matters. First, as in the sketch, we do not have any interfering trees within our own yard. As well, the yard is wide and deep enough so that if anything falls, it lands inside our yard and not in a neighbor’s civil suit. We do not have power or other lines to restrict the position of the tower from dead center in the back yard. Finally, the spouse approves both the presence of the system and its cost. (That is part of the dream.)

Our options for very large upper HF multi-band beams are somewhat restricted by current practice. Essentially, we have three types of beams from which to choose: LPDAs, quads, and Yagis. Of the three, LPDAs are less used by radio amateurs—and therefore less understood.

Therefore, we shall begin with an idealized LPDA that is much too large, but that does encapsulate the maximum performance that we can generate from these designs. Unlike parasitic beams that we can enlarge indefinitely by adding directors, LPDAs answer to different design criteria and have performance limits. After looking at these limits, we shall examine a more practical version that is a mere 57' long, well within our yard limits. Both LPDAs offer continuous coverage of the 14-30-MHz frequency span. The first amateur-band-only array will be a quad using 4 to 6 elements on any one band. The quad—for various structural reasons—is only 30' long, but it has an 18' vertical dimension in contrast to planar LPDAs and Yagis.

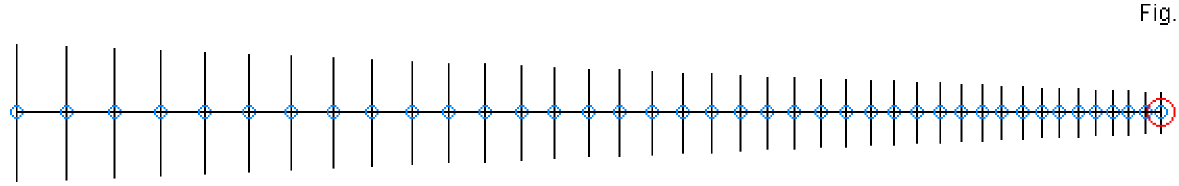
We shall save an array of Yagis for Part 2 of the mini-series. We shall look at a pure forward-stagger design derived from but not identical to a design published a few years back by ON4ANT. The boom length is 63'. The antenna has 5 separate feedpoints, one for each band, of course. More common are large tri-band Yagis with interlaced elements. I shall offer two versions in the 46' to 53' boom-length range. Each one has a distant origin in a commercial design, but the versions shown here are not necessarily like any presently offered commercial antenna. The variety of Yagis in the collection may be instructive relative to the compromises that any designer must accept when trying to perfect a very high-performance array.

My reason for dividing the presentation into two parts rests in the data necessary to understand and appreciate the performance of each array. For each antenna, I shall offer a considerable variety of data in both tabular and graphical form. As we move into the realm of amateur-band-only designs, the information that I shall show represents the sort of data that I wish were commonly made available by commercial beam makers, whatever the size of the beam. Although I cannot change commercial marketing strategies, I can at least make it relatively easy for the reader to make straightforward comparisons among the dream beams in our exercise.

An Ideal (and Impractical) 40-Element LPDA for 14-30 MHz

Let's begin with an antenna that outperforms all of the other antennas in this series: a 40-element LPDA design for a τ of 0.97, along with an optimized σ of 0.18. The outline of the 300' antenna appears in **Fig. 2**.

Fig. 2



General Outline: 40-Element 14-30-MHz LPDA: Length: 300'

To maximize the forward gain of the array, it has some special features. First, the element diameters are τ-tapered. Each element uses a uniform diameter, but the succession of elements changes diameter in accord with the value of τ, which also dictates the change in element length. Hence, the element length-to-diameter ratio remains constant throughout the beam. In addition, the phase line of the array uses a very low value: 55 Ω. The result is incidentally as 50-Ω feedpoint impedance. More significantly, lower phase-line impedances yield higher forward gain values. (As we shall later see, they also carry a danger.) A 55-Ω phase line with a velocity factor of 1.0 is almost (but not quite) impossible to obtain, but then, this beam is an idealization to show the performance limits of LPDAs in general. So for a very brief moment, we may set aide practical concerns of replication. Merely supporting and rotating a beam of this order would require a pair of towers on tracks.

The idealized LPDA displays very constant performance across the defined frequency spread. As well, the front-to-back ratio is superior. **Fig. 3** tracks the gain and two versions of the front-to-back ratio from 14 to 30 MHz in 0.25-MHz increments. The line labeled "front/back ratio" is the 180° ratio, while the line labeled "front/sidelobe ratio" is actually the worst-case front-to-back ratio. Since there is only a single forward lobe throughout the spectrum, the strongest sidelobe happens to be the strongest rearward lobe in all cases. The worst-case values may equal the 180° value or they may be lower, but they can never be higher.

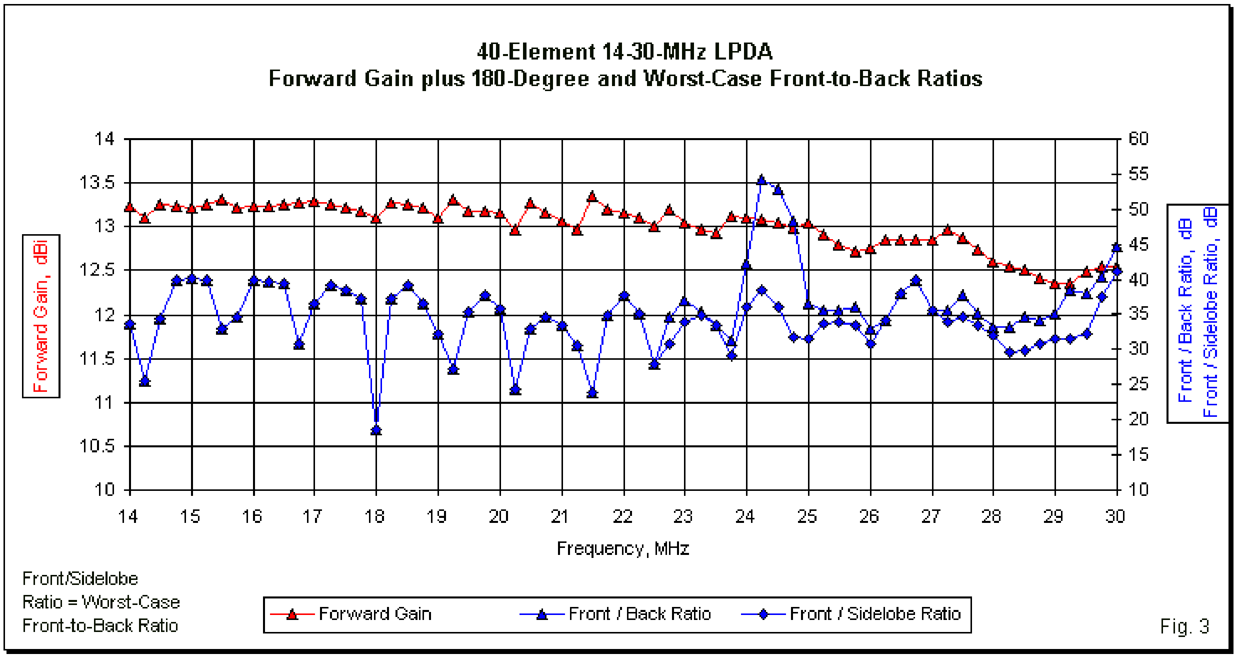


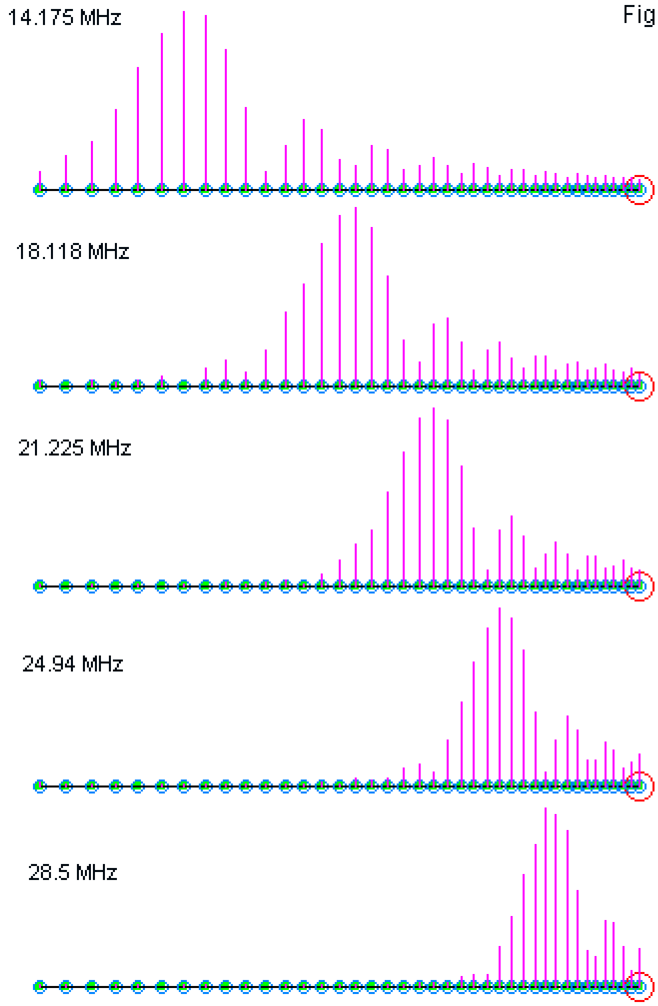
Fig. 3

One of the interesting aspects of LPDA performance curves is their cyclical nature, even if in very high performance versions, the range of values within a cycle is small. Front-to-back values tend to vary more widely within cycles than gain values. As well, they are more prone to sudden peaks and depressions, as the values for 18 MHz and 24.25 MHz suggest. Part of the relatively high consistency in the values for both the gain and the front-to-back ratios emerges from the design process. Rather than setting the self-resonant length of the shortest element at a frequency that is 1.3 times the highest operating frequency, this design uses 1.6 times the highest operating frequency to set the length of the shortest element.

Despite the procedures used to optimize performance, we can see a small but distinct decline in the forward gain from one end of the passband to the other—about 1 dB overall. To appreciate the decline, however small, requires that we understand the LPDA a bit better. We know that it uses a transposed transmission line between each element and therefore directly feeds each element. However, the elements are sufficiently close together to provide considerable mutual coupling. In addition, in an ideal LPDA, all of the elements forward of the most active element for a given operating frequency are active to one or another degree. **Fig. 4** shows the relative peak current distribution along the line of elements for the center of each amateur band. On 20 meters, virtually every element, no matter how short, is active, as the

LPDA becomes the "ultimate forward-stagger" beam design. As we raise the operating frequency, fewer elements are active, and those to the rear of the most active element become virtually inert. In fact, by the time we reach the 17-meter band, almost a third of the LPDA is inactive.

Fig. 4



40-Element 14-30-MHz LPDA
Peak Relative Current Magnitude Distribution

We can count the cycles of peak current ahead of the most active element for each operating frequency. At the low end of the operating spectrum, the most active element, that is, the element with the highest peak current, should occur well within the set of elements so that the current level on the rearmost element is low. At the upper end of the passband, the peak current should occur far enough behind the feedpoint (on the shortest element) so that there are at least two full cycles of current peaks and nulls. Even so, the reduction in the number of full current peak cycles is sufficient to reduce the gain at the upper end of the spectrum slightly. The peak current cycles for the amateur bands shown in **Fig. 4** meet the desired criteria, resulting in relatively even gain across the entire passband, with only a small decrease as the operating frequency approaches 30 MHz. **Table 1** provides modeled free-space data for the idealized LPDA. For the wider amateur bands (20, 15, and 10 meters) the table shows three sets of values. The narrower bands (17 and 12 meters) show single values.

Table 1. Modeled free-space performance of the 40-element 300' idealized LPDA

Band Meters	Frequency MHz	Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ω
20	14.0	13.23	33.75	51.2 – j1.0
	14.175	13.18	29.60	51.2 – j1.3
	14.35	13.13	24.22	51.0 – j0.4
17	18.118	13.31	31.33	51.4 – j0.7
15	21.0	13.06	33.55	49.6 – j2.3
	21.225	12.98	31.18	50.0 – j1.5
	21.45	13.12	21.10	49.9 – j1.1
12	24.94	13.05	37.74	51.0 – j5.2
10	28.0	12.61	33.23	48.3 – j7.9
	28.5	12.51	34.60	44.8 – j3.7
	29.0	12.36	35.03	47.5 + j0.8
Summary		Gain dBi	180° F-B dB	Worst-Case F-B dB
	Minimum	12.36	18.66	18.66
	Maximum	13.34	54.20	41.03
	Average	13.01	35.89	34.04

An LPDA uses enough sweep sampling points to make sense of providing summary data on the gain and on the 180° and worst-case front-to-back ratios. The maximum worst-case value will not equal the maximum 180° value, but the closer together that we find the averages of the two types of front-to-back values, the better behaved are the rear lobes of the patterns.

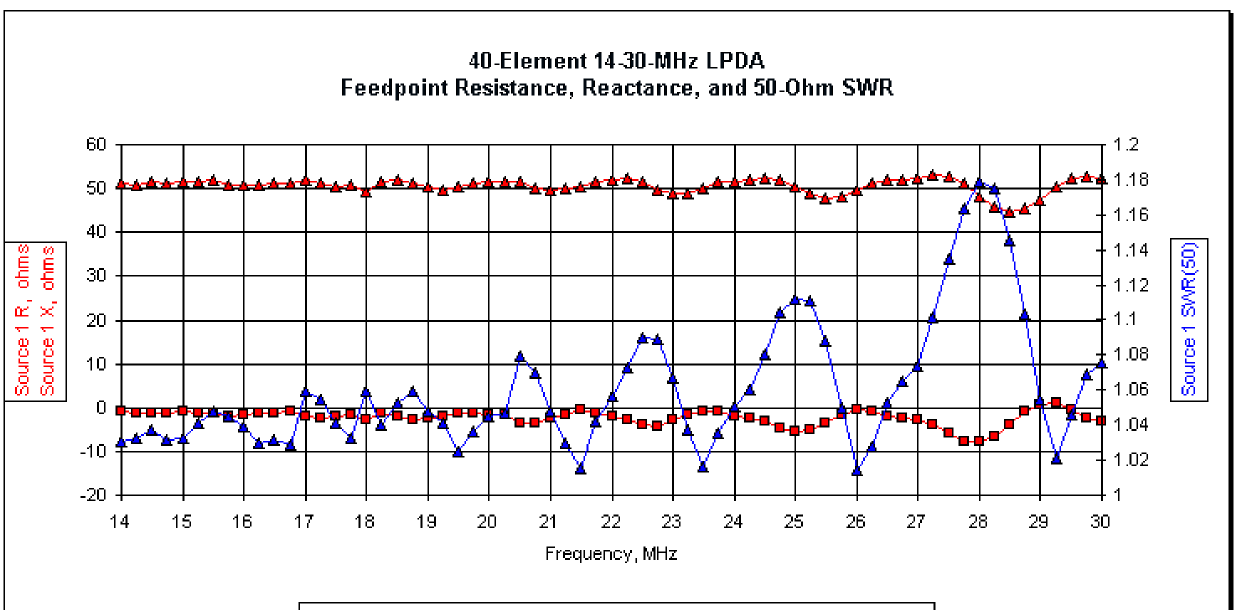


Fig. 5

Fig. 5 shows the sweep of the ideal LPDA resistance, reactance, and 50-Ω SWR values at 0.25-MHz increments. The values tend to track the gain curve in the sense that as we raise the operating frequency, the cycles show a greater range between maximum and minimum values. The cyclical nature of these curves is not eliminable from the behavior of even the very best

LPDA design. For the 40-element design exercise with a 55-Ω phase line, the peak 50-Ω SWR value does not reach 1.2:1.

The numerical data in **Table 1** suggests that the E-plane radiation patterns should be as close to ideal as possible, with strong forward lobes and virtually insignificant rearward lobes. The gallery of free-space patterns in **Fig. 6**, with a sample from the center of each amateur band, confirms the impression left by the numbers.

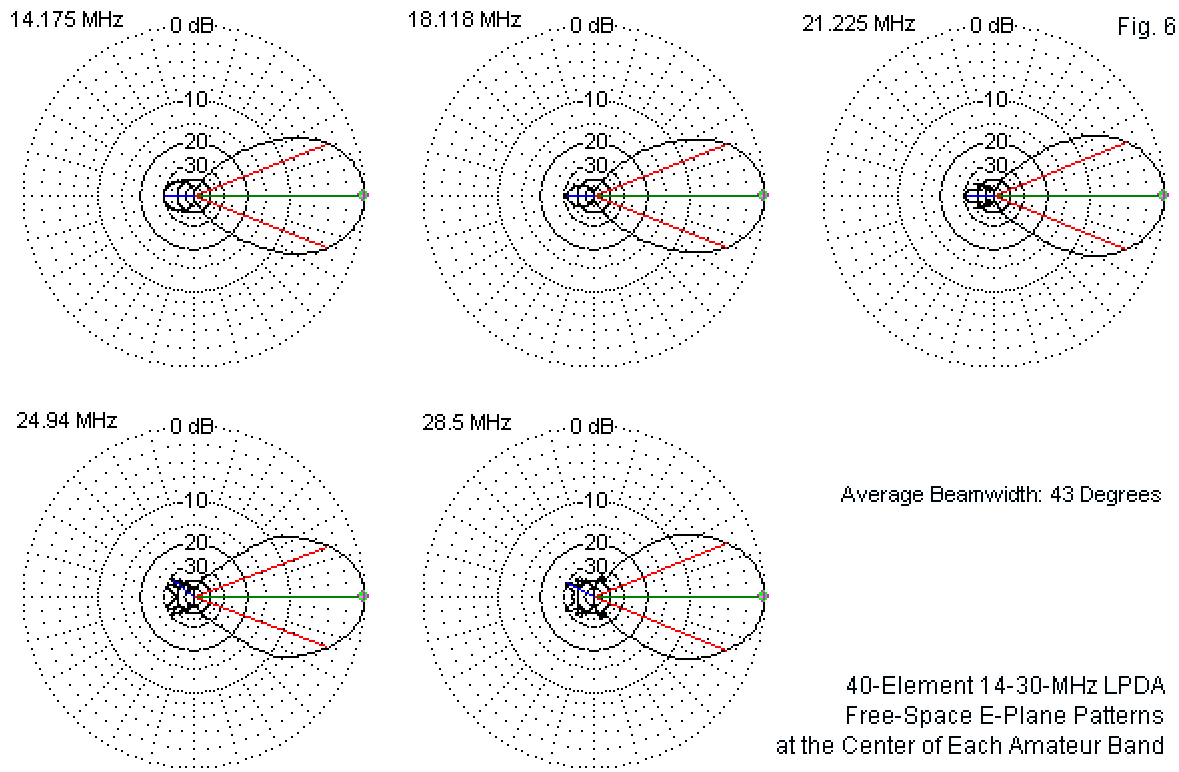


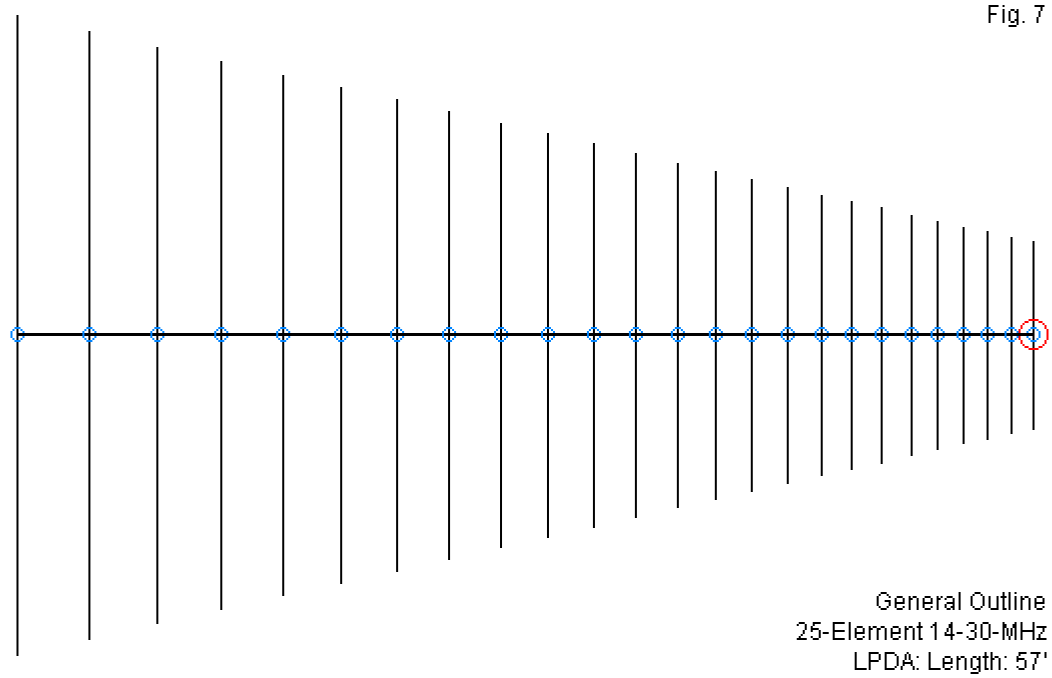
Fig. 6

40-Element 14-30-MHz LPDA
Free-Space E-Plane Patterns
at the Center of Each Amateur Band

Although highly impractical by virtue of the required length and the very low phase-line impedance value, the idealized LPDA is not immune from potential problems that can arise in the implementation of any LPDA. The tabular data showed an oddly low front-to-back value at 21.45 MHz, although the level falls well within usual standard for good performance. At 18 MHz, the front-to-back sweep graph shows another low value—down to 18.66 dB. In the gallery of patterns, the pattern for 24.94 shows a hint of squaring, that is, a tendency toward forming a diamond-shaped pattern rather than a teardrop for the forward lobe. If we could create the LPDA that we have been studying, these features would not be a hindrance to effective use. However, they are notable as hints at what might happen in designing a more practical LPDA with a low phase-line impedance. In fact, we shall see these features in more extreme (but not fatal) form as we turn to an LPDA design that requires only a 57' boom.

A More Practical 25-Element LPDA for 14-30 MHz

Perhaps the longest practical LPDA that we might support from a single tower would have a boom length in the vicinity of 55' to 60' long. The design to which we shall turn is an extension of a similar LPDA that I discussed in both volumes of *LPDA Notes*. The present incarnation uses 25 elements with a τ of 0.95 and a σ of 0.056. The value of σ determines the spacing between the rearmost and the second LPDA element, with all subsequent spacing values decreasing as a function of τ. Even though the value of τ is only 0.02 lower than the value used in the idealized LPDA, the value of σ is less than 1/3 the value in the 40-element design. Hence, we should expect some significant changes in performance. **Fig. 7** shows the outline of perhaps the largest practical (or semi-practical) LPDA for 14 to 30 MHz. When comparing this outline sketch to the one in **Fig. 2**, remember that the longest and the shortest elements are about the same length in each outline. Despite the change in the values of τ and σ, the design uses the same principle of setting the shortest element to be self-resonant at about 1.6 times the highest operating frequency.



Like the larger idealized LPDA, the design uses τ-tapered element diameters from the rear to the front in order to maximize and smooth the gain across the 14- to 30 MHz operating spread. For basic design purposes, each element uses a uniform diameter, although a practical implementation might require stepped-diameter elements having the same effective diameter. As well, it uses a low-impedance phase line (initially) to achieve the same goal. One concession to practicality is the use of a 75-Ω phase line, a value that is readily achievable using flat-face stock for the line. The result will be an imperfect 50-Ω SWR curve relative to the idealized design.

When we expand the angle formed by the elements, shorten the boom, and reduce the element count for a given frequency span, we also decrease the forward gain of which the LPDA is capable. The penalty in this case is a bit over 4 dB relative to the idealized design. **Fig. 8** shows the gain sweep in 0.25-MHz intervals from 14 to 30 MHz. Except for a couple of anomalous frequencies, the gain is almost as steady, if not as high, as for the ideal LPDA. Also similar to the graphs for the long LPDA are the front-to-back curves, with the 180° values showing considerably greater peak values than the steadier worst-case value. However, in tune with the gain curve, the front-to-back curves show the presence of anomalous frequencies at which we find significant decreases in values. Fortunately for the design, neither frequency falls within an amateur band.

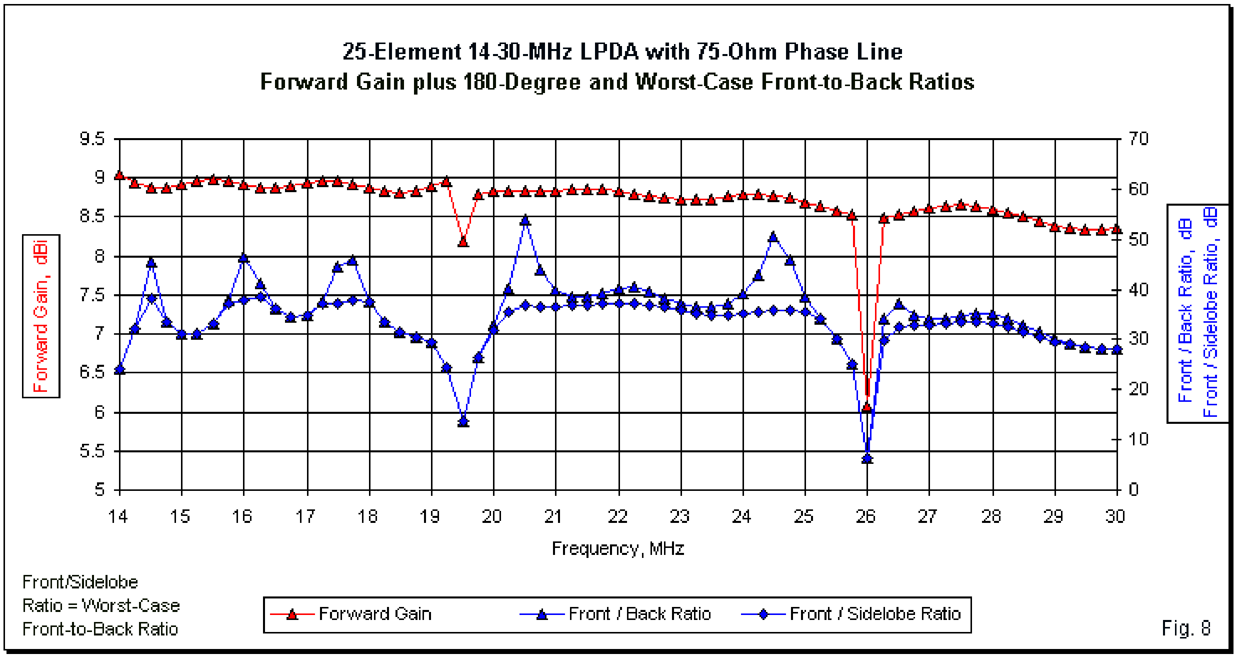
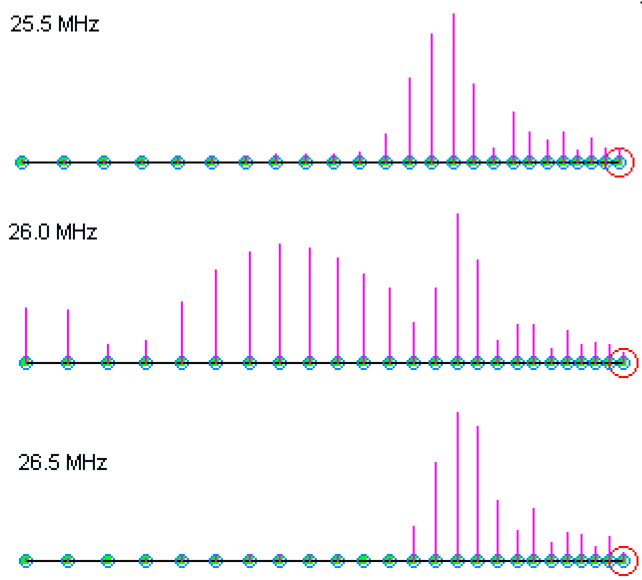


Fig. 8

The anomalies occur at 19.5 and at 26.0 MHz. Neither frequency shows a reversal of pattern—common in many scantily populated amateur-band LPDAs—but we might examine the current distribution at and around the more serious depression in gain and front-to-back ratio. **Fig. 9** provides the peak current magnitude distribution for the array at the anomalous frequency and +/-0.5MHz from it. The 25.5- and 26.5-MHz current displays are as clean as those we viewed in **Fig. 4** for the 40-element array.

Fig. 9



25-Element 14-30-MHz LPDA
Peak Relative Current Magnitude Distribution

LPDA anomalous frequencies are those on which the elements behind the most active element become active in an unwanted harmonic mode. The result is significant radiation in both the forward and rearward directions, enough to reduce the forward gain and the front-to-back ratio by amounts greatly in excess of the normal cycles. There are two primary sources for these anomalies. One, which is not present in this design, is the use of values for τ and σ that are too small, normally in an effort to obtain a short boom LPDA with the fewest possible elements. The second source is the use of a phase-line impedance that falls below a certain threshold. The 75-Ω line in this design is such a case.

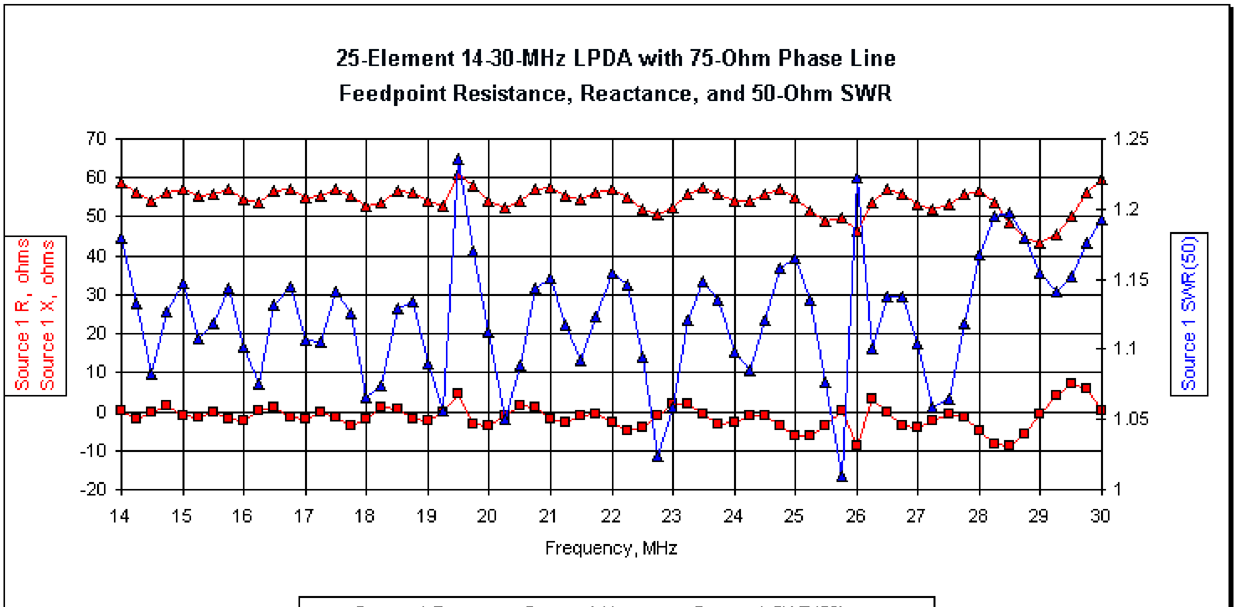


Fig. 10

Table 2. Modeled free-space performance of the 25-element 57' LPDA with a 75-Ω phase line

Band	Frequency	Gain	Front-Back	Feedpoint Impedance
Meters	MHz	dBi	Ratio dB	R +/- jX Ω
20	14.0	9.04	24.06	59.0 + j0.2
	14.175	8.98	29.07	57.4 – j1.4
	14.35	8.92	38.19	55.1 – j1.6
17	18.118	8.85	35.29	52.6 – j0.4
15	21.0	8.83	39.72	57.3 – j1.9
	21.225	8.85	38.46	55.4 – j2.7
	21.45	8.86	38.33	54.4 – j1.5
12	24.94	8.70	39.98	55.7 – j5.8
10	28.0	8.60	35.18	56.5 – j5.1
	28.5	8.50	32.82	48.5 – j8.8
	29.0	8.39	30.12	43.4 – j0.8
Summary		Gain	180° F-B	Worst-Case F-B
		dBi	dB	dB
	Minimum	6.08	6.36	6.36
	Maximum	9.04	53.81	38.45
	Average	8.70	35.13	32.77

As **Fig. 10** shows, neither anomaly in the 25-element design is so bad as to adversely affect the usable SWR curve. We find small rises in both the resistance and the reactance at 19.5 MHz. Decreases in both the resistance and reactance at the feedpoint result in the SWR peak at 26 MHz. As well, the SWR values are not as generally low as was the case for ideal LPDA, since the average impedance value falls close to 55 Ω. Nevertheless, the peak 50-Ω SWR value remains less than 1.25:1.

Within the amateur bands, as revealed by the data in **Table 2**, we find no signs of anomalous behavior. Indeed, the range of gain values between the lowest and the highest does not materially differ from the range that we find in the 40-element LPDA. Despite the two anomalous frequencies within the operating spectrum, the average values of both front-to-back values are comparable for the two designs.

Removing the anomalies requires no change in the array dimensions. The only change that we need to make is to alter the characteristic impedance of the transposed phase line between elements. Designs rarely seek the minimal value that will achieve the goal. Instead, designers usually look for a value that is both high enough to remove the anomalies and positioned to provide a convenient feedpoint impedance. For the present design, a 500-Ω phaseline yields feedpoint impedance values that center around 200 Ω, a value that we may conveniently convert to 50 Ω by the use of a wide-band 4:1 impedance balun. **Fig. 11** shows the consequences of the higher-impedance phase line on the gain and the front-to-back values. The anomalous frequencies are completely absent from both curves, although the peaks in the 180° front-to-back ratio remain as the rear lobes change their formation across the overall passband. The cost of the corrective action, besides the requirement for a 4:1 balun, is about 0.3-dB of forward gain.

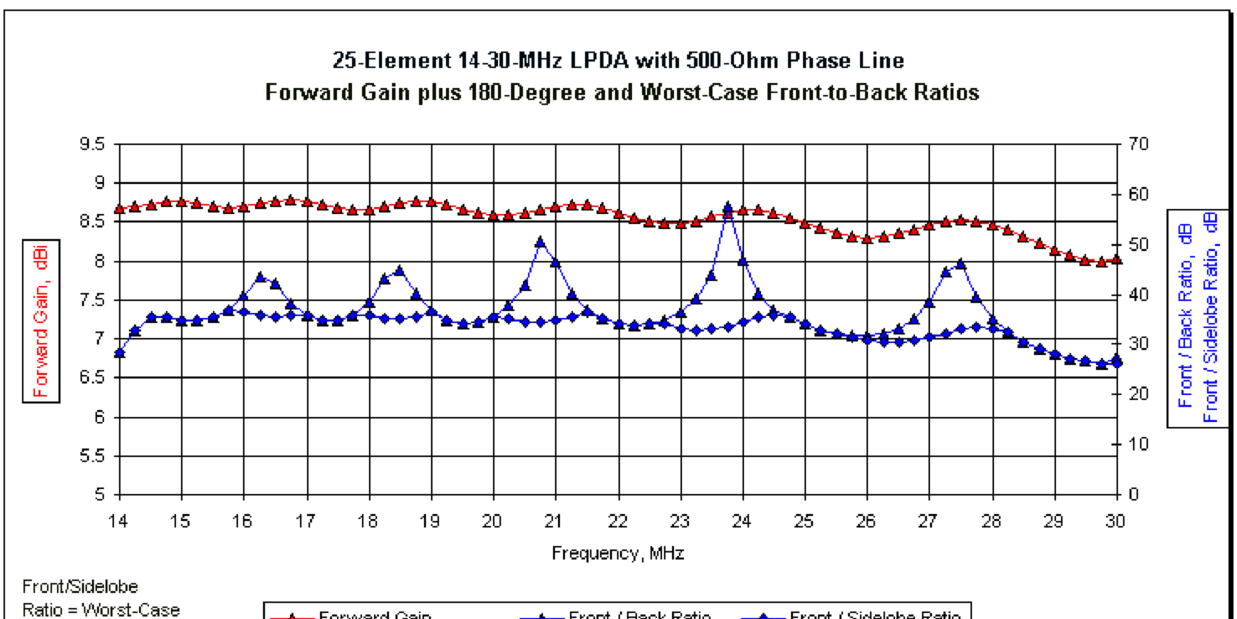


Fig. 11

Table 3 provides the amateur-band modeled performance data with the higher phase-line impedance. Note that the front-to-back values do not significantly change, although the peak values may shift in frequency relative to the low-impedance line. The feedpoint impedance values presume the presence of the balun.

Table 3. Modeled free-space performance of the 25-element 57' LPDA with a 500-Ω phase line

Band Meters	Frequency MHz	Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ω
20	14.0	8.69	28.51	48.5 – j2.8
	14.175	8.69	31.62	50.6 – j2.0
	14.35	8.71	34.24	51.9 – j3.8
17	18.118	8.68	40.42	51.1 – j4.9
15	21.0	8.71	46.50	48.1 – j6.4
	21.225	8.73	40.52	48.9 – j6.2
	21.45	8.72	37.38	49.7 – j7.7
12	24.94	8.51	34.42	42.8 – j12.6
10	28.0	8.47	35.27	46.7 – j13.1
	28.5	8.32	30.63	40.4 – j16.4
	29.0	8.14	28.11	33.9 – j11.8
Summary		Gain dBi	180° F-B dB	Worst-Case F-B dB
	Minimum	8.01	26.18	26.18
	Maximum	8.79	57.47	36.94
	Average	8.56	36.61	33.49

The use of a higher impedance for the phase line removes the anomalies, but yields a somewhat less stable feedpoint impedance. The variations increase with frequency. As shown in the resistance, reactance, and 50-Ω SWR curves in **Fig. 12**, the SWR values peaks at about 1.8:1 at 29 MHz. Different phase-line impedance values often yield slight differences in the cycles of the curves as we raise the frequency. The periodic nature of the curves was not clearly visible in the sweep for the low-impedance line due to the presence of the anomalous frequencies. However, the 2-strep cycles of the three parameters become much more noticeable in **Fig. 12**. They result from the fact that the resistance and the reactance do not reach their peak and null values at the same frequencies within the operating spectrum.

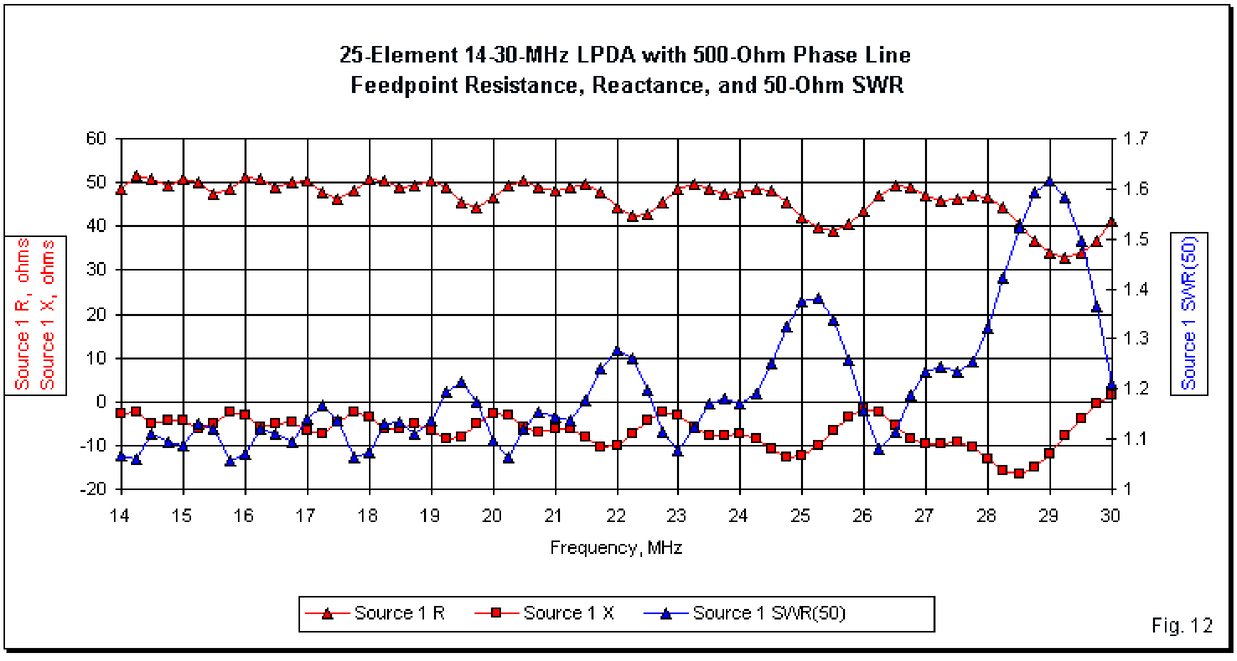


Fig. 12

With either value of impedance for the phase line, the free-space E-plane patterns within the amateur bands are equally clean and well behaved, as shown in the sample gallery on **Fig. 13**. The most noticeable difference between these patterns and the one in **Fig. 6** is a function of the reduced forward gain. The beamwidth for the 25-element array is about 18° wider than the beamwidth of the 40-element LPDA. In both cases, the beamwidth remains nearly constant (+/- 0.5°) across the operating passband.

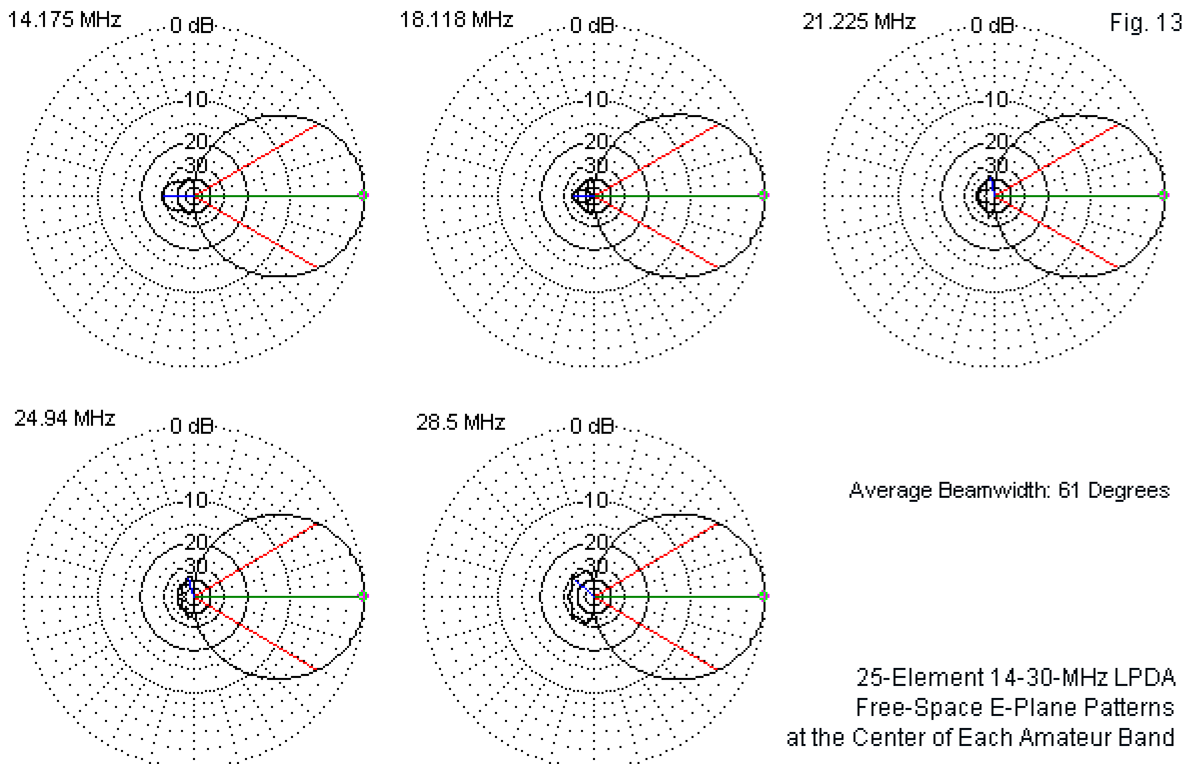


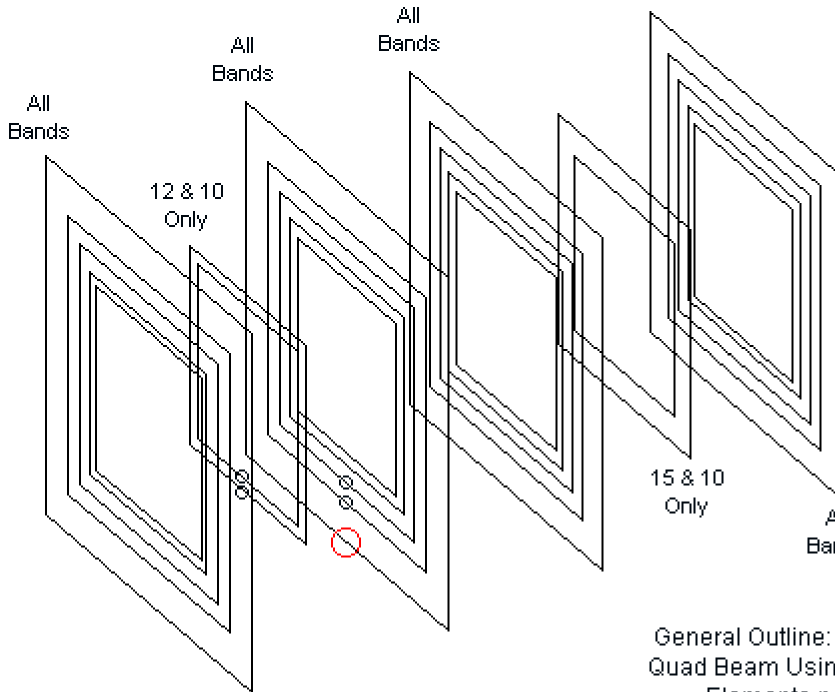
Fig. 13

The 25-element LPDA represents perhaps the largest semi-practical dream beam in terms of element count. The pattern control is outstanding on the ham bands in both versions, while the use of a high-impedance phase line eliminates anomalies within the passband. The forward gain of the LPDA is approximately equivalent to a monoband 4-element Yagi. Unlike the narrow-band Yagi, the LPDA provides continuous coverage of the entire operating spectrum from 14 to 30 MHz—with something to spare at both ends of the passband. At a boom length of 57', the LPDA is not the longest dream beam that we shall encounter, although it presents enough construction challenges to engage the best beam builders around. The materials needed to support and rotate such an array will likely exceed the cost of the array itself. Still, the prospect of instant band switching with a reliable pattern and virtually no QRM from the rear quadrants is a highly attractive thought.

A 5-Band Quad Beam Using 4, 5, or 6 Elements per Band

If the 25-element quad is not the longest beam of our collection, neither is it the shortest. That honor goes to the first of our beams that does not provide continuous upper HF coverage, but does provide service on all 5 amateur bands between 14 and 30 MHz. The array is a 5-band quad beam, built on the square, as shown in **Fig. 14**. The antenna design itself has a curious history. It began life as a Cubex 4-element quad that ON7NQ modified to provide improved service. The modifications more than the original beam attracted my efforts that gradually evolved into the design shown here. The red circle represents the 20-meter feedpoint. Small black circles show the positions of the feedpoints for the other bands. 17 and 15 meters use that same set of concentric loops as 20 meters. However, the intermediate set of two loops contains the driver pair for 12 and 10 meters. Essentially, these are the modifications originated by ON7NQ.

Fig. 14



General Outline: 5-Band Quad Beam Using 4 to 6 Elements per Band

My own modifications involved mostly the forward end of the array. I extended the forward set of directors to create the 30' boom length, with large loop sets spaced at 10' intervals. The added drivers are equidistant from the reflectors and the next large loop group. So, too, are the added directors behind the forward most set of loops. Note that this new intermediate set of elements serves only 15 and 10 meters. Since 12 meters is so narrow, performance is adequate without an extra director. However, on 15 and 10 meters, the added directors are necessary to increase the operating bandwidth. Despite my best efforts, 10-meter coverage remains limited to 28 to 28.8 MHz. The full set of design notes for the evolution of this beam appeared in *QEX* ("Notes on Designing Large 5-Band Quads," Nov-Dec, 2003, pp. 12-24).

Monoband quads can select whatever element spacing yields the best performance (as defined by the designer). In contrast, multi-band quads carry an important structural restriction. For reasons of weight and complexity, a 5-band quad cannot employ separate support spreaders for each loop on each band. Therefore, relatively standard practice for quad beams with more than 2 elements per band is to group elements at standard intervals and then to adjust the loop sizes to achieve the best possible performance. For the lower bands in the upper HF collection, a spacing of 10' between elements has proven relatively successful. However, as the outline for the present design attests, additional higher-band elements at 5' intervals can be useful. The spacing also allows the design to arrive at 50-Ohm feedpoints—separate, of course.

The design process becomes somewhat fussy, since the elements in each concentric group interact with each other. In addition, one must use care that the parasitic elements, which are closed loops, do not turn off-band directors into reflectors or turn off-band reflectors into directors—in both cases in the wrong direction. A tri-band quad (for 20, 15, and 10 meters) is easier to design in this respect, since the greater frequency distance between bands generally guards against this unwanted situation. In contrast, it is relatively easy for a 12-meter director to function as a 10-meter reflector.

A quad beam has a further inherent characteristic that limits the performance we may obtain from the array. Due to the loop structure, the operating bandwidth for forward gain normally exceeds the bandwidth possible for either the front-to-back ratio or for the feedpoint SWR. Although the peak 180° front-to-back ratio may exceed 20 dB—the usual amateur standard of good performance—the value declines rapidly away from the frequency at which the peak value occurs. At the band edges, the front-to-back ratio may drop to well under 15 dB. The 20-meter performance sweep in **Fig. 15** is a case in point. The gain level holds relatively steady across the band within about 0.6 dB, but the front-to-back ratio drops to just greater than 10 dB at the upper end of the band. One consequence of the narrow-band front-to-back performance is that aficionados of quad beams generally do not hold a beam's front-to-back ratio in as high regard as do proponents of Yagi and other parasitic beams.

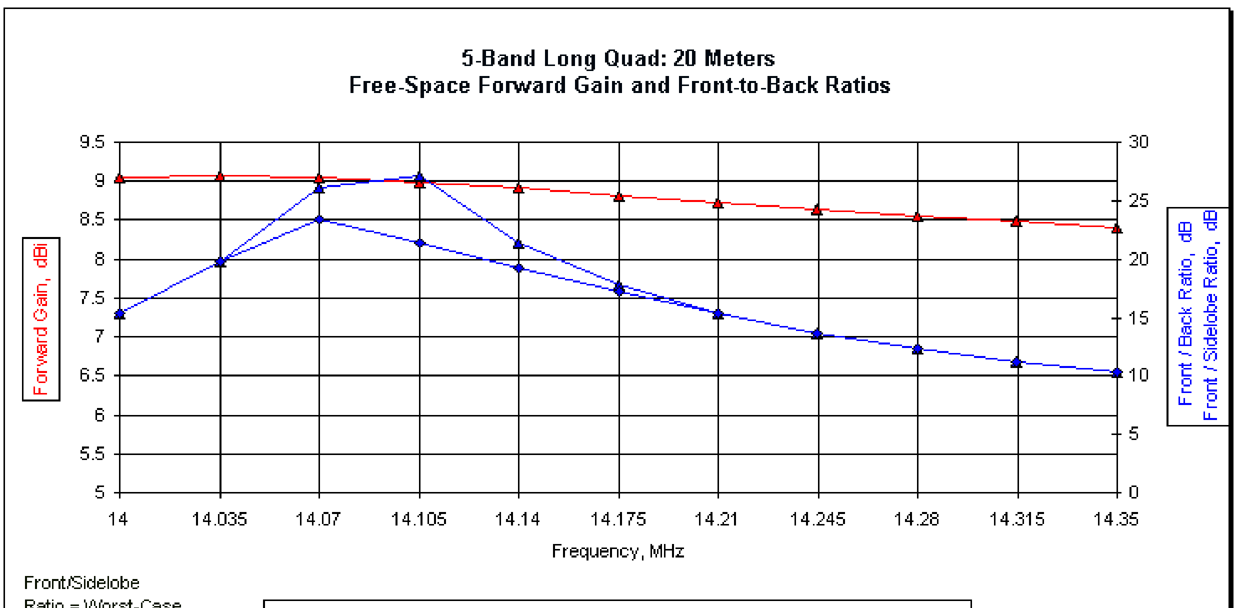


Fig. 15

We may omit frequency sweeps for 17 and 12 meters, since each of these bands is only 100 kHz wide. The next wide amateur band is 15 meters, shown in **Fig. 16**. The 20-meter front-to-back ratio had shown a high peak between 14.07 and 14.1 MHz. The corresponding 15-meter curves show a relative shallow front-to-back curve with no evident peak. Instead, the curve just barely exceeds 20 dB at the center of the band. The band-edge values are closer to 15 dB. In fact, the worst-case front-to-back values are almost constant at that level across the entire band. Likewise, the forward gain curve is almost a flat line from one end of the band to the other.

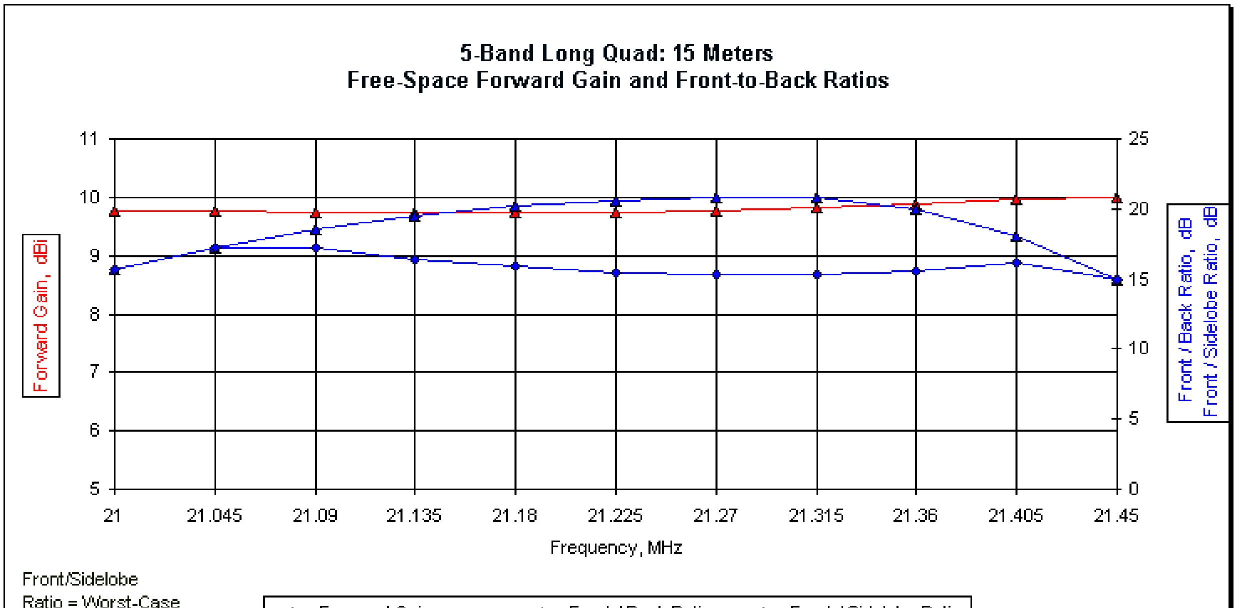


Fig. 16

The 10-meter gain and front-to-back sweep in **Fig. 17** shows a similar parallel between the gain curve and the worst-case front-to-back ratio. Once more, the 180° front-to-back ratio shows a set of high values in the upper half of the (restricted) passband, but the worst-case values show much more modest numbers in this region of the band. Even more modest are the front-to-back values at the band edges, despite the relatively high forward gain across the band.

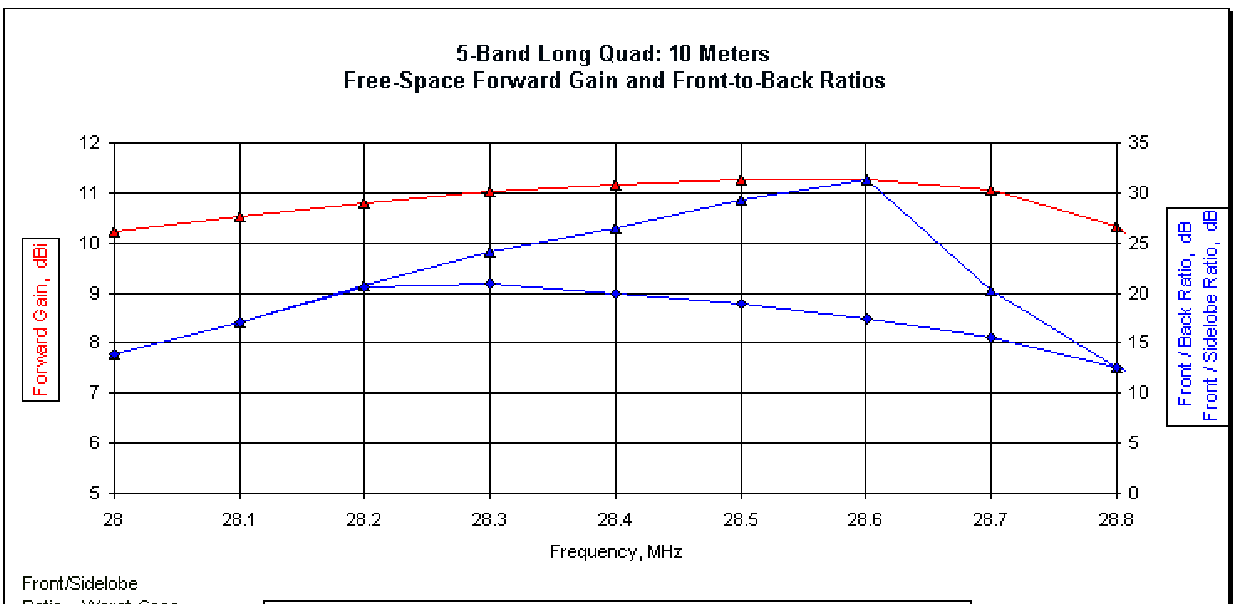


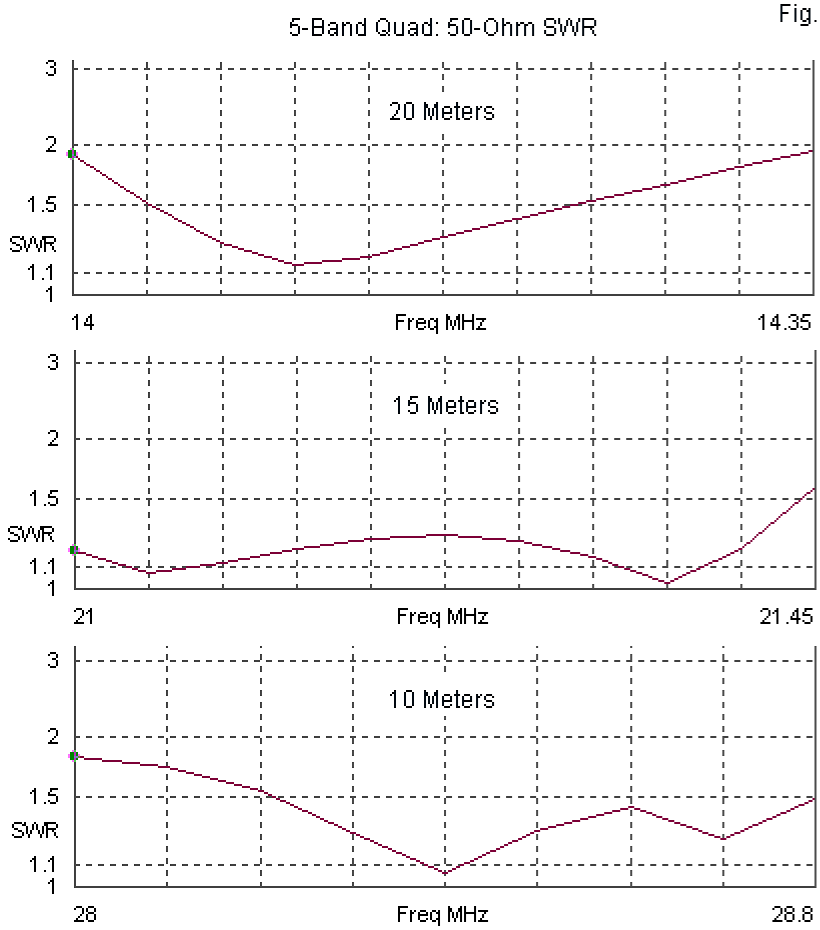
Fig. 17

We may gain some further insights into the 5-band quad's performance potential by examining the tabular data for each band. Following the format used for the LPDAs, the narrow amateur bands contain a single entry, whereas the wider bands have entries for the band edges and center. See **Table 4**.

Table 4. Modeled free-space performance of the 5-band 30' quad beam

Band Meters	Frequency MHz	Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ω
20	14.0	9.04	15.41	31.8 – j18.3
	14.175	8.82	17.79	51.0 + j12.9
	14.35	8.41	10.36	56.6 + j35.3
17	18.118	9.39	21.34	47.9 + j6.4
15	21.0	9.77	15.70	47.0 – j7.6
	21.225	9.74	20.57	63.4 + j1.0
	21.45	10.00	14.99	34.9 + j12.0
12	24.94	10.37	21.02	37.2 + j7.8
10	28.0	10.21	13.87	59.0 – j31.2
	28.5	11.26	29.63	51.6 + j12.4
	28.8	10.32	12.63	33.8 + j1.9

Fig. 18



The impedance information in the table suggests that the quad beam may not have the stability at the feedpoint that we found with the LPDA. This impression is correct. The 50-Ω SWR graphs for the three wide bands appear in **Fig. 18**. The beam uses no matching systems;

instead, each driver shows a natural feedpoint impedance close to 50 Ω. However, a scan of the impedance data shows that both the resistance and the reactance can vary widely across the band. As well, some bands do not achieve a close 50-Ω impedance: the 12 meter feedpoint shows a value under 40 Ω, which is acceptable but less than ideal.

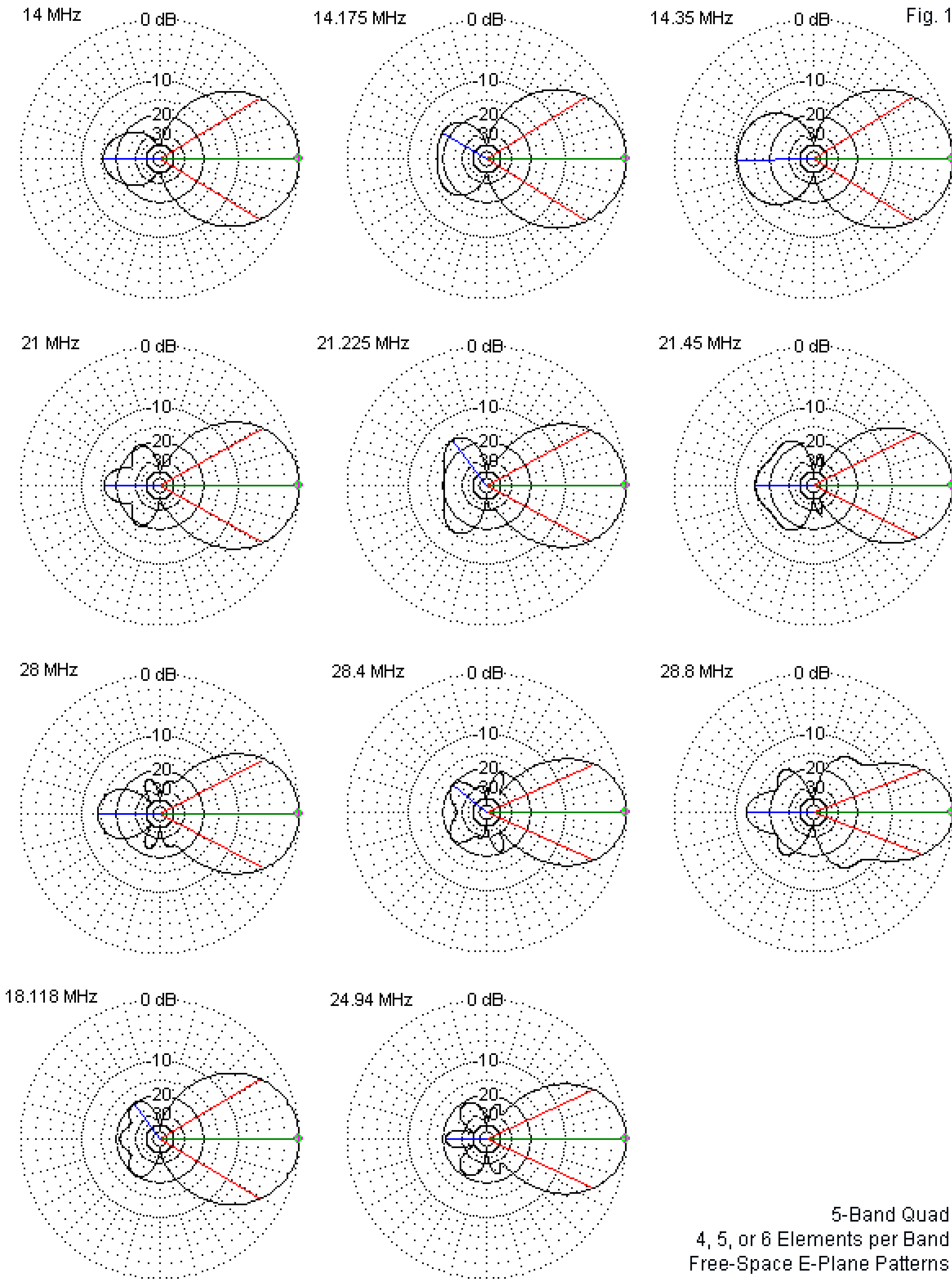
On 20 meters, where interactions among loops are lowest, the curve shows a single minimum value, with higher values away from that frequency. The two higher bands display SWR curves with two minimum values near opposite ends of the band. The general source of dual minimums is the interaction between the driver and the first director. As we move upward in the band, the first director actually becomes a secondary driver that dominates performance in the upper range of the passband. Due to the close coupling between the driver and the first director, we may find at least one of two situations: either the resistance peaks near mid-band and decreases toward the band edges, or the reactance shows a peak inductive value near mid-band and decreases or becomes capacitive near the band edges. This array shows both trends, one on 15 meters, the other on 10.

If we combine the gain and front-to-back sweep graphs with the tabular data and SWR curves, we get the impression that the patterns produced by the quad beam do not have the same regular form displayed by all of the LPDA patterns. Indeed, it pays to study sample patterns across the wider bands for virtually any beam—monoband or multi-band—to reach a judgment as to whether they are satisfactory for a given set of performance goals. Since we shall not impose a set of goal, we can only examine a set of sample patterns and note certain features. **Fig. 19** provides a gallery of free-space E-plane patterns.

At the bottom of the gallery are single patterns for the 12- and 17-meter bands. Over the 100-kHz width of these bands, the pattern shape will not change. The rearward lobes of both patterns appear "normal," that is, typical of almost any parasitic array. The 17-meter forward lobe is also normal. However, in the 5-element 12-meter forward pattern, we find the beginning of secondary lobes. At this point, we may review two design factors. First, as we increase the operating frequency with a fixed physical boom length, the boom length becomes longer as a function of a wavelength. On 17 meters, the boom is just about a half-wavelength long with 4 elements. At this length, the forward lobe typically has no sidelobes. At 12 meters, the boom is approaching 1 λ. At this point, we begin to see the emergence of forward sidelobes. Secondary forward lobes need not appear in a monoband beam if the designer places the directors optimally. However, in a multi-band quad where the only adjustments are the loop sizes, the combination on non-optimal element spacing and interactions among loops for adjacent bands can hasten the development of secondary forward lobes.

On 20 meters, where we find the fewest loop interactions (since there are no larger concentric loops), the patterns develop normally. The single forward lobe is a function of the short boom length and the use of only 4 elements. The gain values reflect these conditions. In addition, the rearward pattern region shows a single lobe that changes its shape gradually with changes in the operating frequency. If we consult the 20-meter sweep graph in **Fig. 15**, we find that the band region near 14.1 MHz shows the greatest difference between the 180° and the worst-case front-to-back values. In this region, we would expect to see the rearward pattern divide into two lobes, one on each side of the pattern centerline. We may also note the decline in the front-to-back ratio, especially in the upper half of the band. The correlation of data from all sources, if available, allows us to correctly infer information about performance factors. However, as suggested by the data collection developed for the 5-band quad, we must have enough data about performance across each band to reach useful conclusions. Unfortunately, such complete data is often missing from the specification sheets of commercial beam offerings.

Fig. 19



5-Band Quad
4, 5, or 6 Elements per Band
Free-Space E-Plane Patterns

The patterns for 15 meters (where 5 elements are primarily active) reveal the beginnings of secondary lobe development about mid-band. The secondary forward lobes are essentially harmless to performance, but suggest a limit to the control that a designer may exert over the pattern shapes using fixed spacing between elements. The limitations become more evident in the rearward lobe structures. The combination of fixed element spacing and loop interactions yield significant rearward radiation at all frequencies. Even though we find a mid-band 180° front-to-back ratio that exceeds 20 dB, the worst-case value across the band is closer to 15 dB. The variability of the rear pattern shape is endemic to multi-band quads in the higher bands.

We find a similar variability on 10 meters, although the use of 6 elements on this band provides a mid-band worst-case ratio of about 20 dB. The forward pattern also shows a typical development of secondary lobes at boom lengths of about 1 λ. The diminutive lobes present at 28 MHz become more evident at mid-band, even though still at a harmless level. At the upper end of the passband—28.8 MHz in this example—the lobes have developed to a significant size. They have the appearance of pattern "bulges" since we do not find a deep null between the sidelobe and the main lobe. Nevertheless, the side bulges represent increased sensitivity to off-axis signals or interference.

We have examined the aberrations in the quad patterns relative to the near-perfect patterns produced by the LPDAs to develop an understanding of some of the limitations of interlaced-element parasitic beams. Despite these limitations, the 5-band quad shows excellent gain performance. The average gain level per band increases as we increase the operating frequency. Except for 20 meters, the quad exceeds the 25-element LPDA gain, although it cannot compete with the LPDA front-to-back figures. Which set of values should take prominence depends on the users operating goals. As well, every dreamer of such beams must consider both the construction and the maintenance facets of each candidate for implementation. Since neither the 25-element LPDA nor the 30' 5-band quad is available either as a commercial offering or as a detailed construction project, we may bypass these considerations and return to our dreaming.

Conclusion to Part 1

We began our dream journey with a nearly perfect 40-element LPDA to show what we might ideally accomplish by way of continuous performance in the upper HF range from 14 to 30 MHz. We then became a bit more realistic in terms of our yard premises by examining a 57' 25-element LPDA. Finally, we entered the realm of beams that cover only the amateur bands with a 5-band quad that uses 4 to 6 elements, depending on the band. Although we did not provide anything close to a complete account of each design, we remained alert both to the potentials and to the limitations of each design. We also passed over a number of design details, such as practical element structures and feedpoint treatments. For example, the LPDAs require a single feedpoint for all frequencies, while the quad requires 5 separate feedlines with a switching system either at the top of the tower or at the operating position.

However, our collection of dream beams is missing an entire genre of multi-band beams: long-boom multi-element Yagis. In Part 2, we shall fill in the gap, at least partially, with three designs: a 63' pure forward stagger Yagi and two different designs that use interlaced elements. At the risk of turning dreams into nightmarish data overload, we shall find these beams to be highly competitive with the designs that we have so far surveyed.

Dimensions of Beams Discussed

40-Element "Ideal" LPDA							
Element	Length	Spacing	Diameter	Element	Length	Spacing	Diameter
1	35.85	0.00	2.00	*21*	19.49	196.24	1.09
2	34.77	12.90	1.94	*22*	18.91	203.25	1.05
3	33.73	25.42	1.88	*23*	18.34	210.06	1.02
4	32.72	37.56	1.83	*24*	17.79	216.66	0.99
5	31.73	49.34	1.77	*25*	17.26	223.07	0.96
6	30.78	60.77	1.72	*26*	16.74	229.28	0.93
7	29.86	71.85	1.67	*27*	16.24	235.31	0.91
8	28.96	82.60	1.62	*28*	15.75	241.15	0.88
9	28.09	93.02	1.57	*29*	15.28	246.82	0.85
10	27.25	103.14	1.52	*30*	14.82	252.32	0.83
11	26.43	112.95	1.47	*31*	14.37	257.66	0.80
12	25.64	122.46	1.43	*32*	13.94	262.83	0.78
13	24.87	131.69	1.39	*33*	13.52	267.85	0.75
14	24.13	140.65	1.35	*34*	13.12	272.72	0.73
15	23.40	149.33	1.31	*35*	12.73	277.44	0.71
16	22.70	157.76	1.27	*36*	12.34	282.02	0.69
17	22.02	165.93	1.23	*37*	11.97	286.47	0.67
18	21.36	173.86	1.19	*38*	11.61	290.78	0.65
19	20.72	181.54	1.16	*39*	11.27	294.96	0.63
20	20.10	189.00	1.12	*40*	10.93	299.02	0.61
Notes:	1. Length and spacing dimensions in feet; diameter dimensions in inches						
	2. Spacing is from the rear element (Element 1)						
	3. Transposed phasing line has a characteristic impedance of 55 Ohms						

25-Element "Practical" LPDA							
Element	Length	Spacing	Diameter	Element	Length	Spacing	Diameter
1	430.15	0.00	1.50	*14*	220.81	468.91	0.77
2	408.64	48.18	1.43	*15*	209.77	493.64	0.73
3	388.21	93.94	1.35	*16*	199.28	517.14	0.69
4	368.80	137.42	1.29	*17*	189.32	539.46	0.66
5	350.36	178.73	1.22	*18*	179.85	560.66	0.63
6	332.84	217.97	1.16	*19*	170.86	580.80	0.60
7	316.20	255.25	1.10	*20*	162.32	599.94	0.57
8	300.39	290.66	1.05	*21*	154.20	618.12	0.54
9	285.37	324.31	1.00	*22*	146.49	635.39	0.51
10	271.10	356.27	0.95	*23*	139.17	651.80	0.49
11	257.55	386.63	0.90	*24*	132.21	667.38	0.46
12	244.67	415.48	0.85	*25*	125.60	682.19	0.44
13	232.43	442.88	0.81				
Notes:	1. All dimensions in inches						
	2. Spacing is from the rear element (Element 1)						
	3. Transposed phasing line has a characteristic impedance of either						
	75 Ohms or 500 Ohms, (see text)						

5-Band Quad: 24 Total Elements					
Element	Function	Band	Side Len	Circum	Spacing
1	Reflector	20	217.0	868.0	0
2	Reflector	17	168.5	674.0	0
3	Reflector	15	145.8	583.2	0
4	Reflector	12	121.8	487.2	0
5	Reflector	10	110.6	442.4	0
6	Driver	12	120.2	480.8	60
7	Driver	10	105.7	422.8	60
8	Driver	20	213.0	852.0	120
9	Driver	17	165.6	662.4	120
10	Driver	15	141.4	565.6	120
11	Director 1	12	119.4	477.6	120
12	Director 1	10	104.4	417.6	120
13	Director 1	20	201.2	804.8	216
14	Director 1	17	160.2	640.8	216
15	Director 1	15	139.0	556.0	216
16	Director 2	12	120.2	480.8	216
17	Director 2	10	104.8	419.2	216
18	Director 3	15	138.8	555.2	288
19	Director 3	10	104.8	419.2	288
20	Director 2	20	194.8	779.2	360
21	Director 2	17	159.6	638.4	360
22	Director 4	15	138.4	553.6	360
23	Director 3	12	117.4	469.6	360
24	Director 4	10	104.2	416.8	360
Notes:	1. All dimensions in inches				
	2. Spacing is from the rear element (Element 1)				
	3. All elements are AWG #13 (0.0808" diameter)				
	4. Side Len = length of a loop side				
	5. Circum = length of loop circumference				