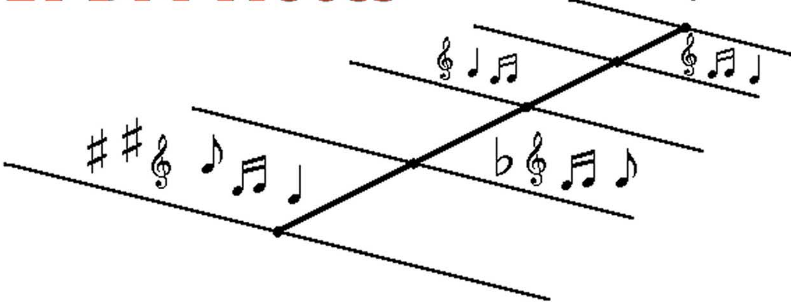
LPDA Notes



Volume 1
Pure LPDAs

L. B. Cebik, W4RNL

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Table of Contents

Dedication

This volume of studies of the log periodic dipole array is dedicated to my wife, my friend, my supporter, and my colleague, all of whom are Jean. Her patience, understanding, and assistance gave me the confidence to retire early from academic life to undertake full-time the continued development of my website (http://www.cebik.com), which is devoted to providing, as best I can, information of use to radio amateurs and others--both beginning and experienced--on various antenna and related topics. This volume is an outgrowth of that work--and hence, of Jean's help at every step.

Preface

The log periodic dipole array or LPDA burst upon the antenna scene in the 1960s as a practical antenna with directional gain and an exceptionally wide (theoretically unlimited) frequency range. Like the Yagi-Uda array, it used linear elements. At the upper HF range and above, the elements might be aluminum tubing or rods. The result would be an antenna that we might rotate in the usual ways that we apply to Yagis. However, we would obtain Yagi performance over frequency spreads of 2:1, 3:1, and higher. Moreover, the entire set of LPDA dimensions could be calculated from a set of engineering equations that assured success due to their precision.

Unfortunately, the amateur versions of the LPDA never lived up to the initial expectations bred by the early literature. The sources of the disappointment are two. First, the initial calculations of gain expectations from the LPDA were faulty, and later revisions seriously lowered the gain estimates for LPDAs of all sizes.

Second, amateur versions of LPDAs tend to be short-boomed and sparsely populated with elements. Although they fit within the minimal recommended values for certain design constants, these antennas had performance problems that the theory underlying these frequency-independent antennas did not predict. Gain and directivity tended to fall off seriously at either the upper or lower end of the design spectrum. Additionally, even in modest LPDAs for a 2:1 frequency range, there emerged mid-range frequencies at which the gain and directivity decreased dramatically, with instances of pattern reversal. As well, the feedpoint impedance would depart radically from the calculated curve. Amateurs also constructed wire versions of LPDAs, only to be disappointed in the gain levels that did not live up to even the modified predictions of LPDA theory.

The advent of accurate computer modeling of LPDAs has allowed us to look systematically at LPDA designs, especially those smaller, shorter, sparser versions likely to be used by radio amateurs. Out of such studies have surfaced two benefits. One advance has been a better understanding of the properties of LPDAs as we transform calculations into wire and tubular arrays. Earlier studies based on experimental physical models were as thorough as such work could be, but were still limited by the need to check the antenna at selected frequencies. Systematic modeling can increase the number of checkpoints across a frequency range nearly without limit, uncovering unsuspected behaviors along the way. Many of the formerly odd behaviors of LPDAs have become customary expectations, especially of smaller versions. Indeed, we may now catalog the potential limitations of small LPDAs.

The second advantage that systematic modeling has brought to the study of LPDAs is the development of some curatives for at least the most problematical limitations of LPDAs. Many of these ameliorative measures we must apply to individual designs in doses that vary from one design to the next. Modeling permits the rapid modification of an LPDA design so that it comes to live up better to expectations--or shows the designer the reason why it needs a replacement.

My accumulated notes on LPDAs include a good number of designs and curatives that may be of use to amateur designers. Indeed, after looking at the limitations of the LPDA design procedure and the process of adequately modeling an LPDA, we shall explore these potentials for elevating the performance of small LPDA designs. In the process, we shall also uncover some myths of LPDA and other array designs, including arranging elements in a forward-looking Vee.

The latter pages of this volume will focus on developing some practical LPDA designs for various purposes. Within the 2:1 frequency range that marks amateur interest in the 14-30 MHz spread, we shall examine some practical designs at various gain levels. We shall even investigate the potential for a wider-band LPDA to cover 10-30 MHz. I wish that I had more room for more practical applications, but we shall find our plates filled with the subjects noted.

This first volume of notes is largely devoted to “pure” or nearly pure versions of the LPDA. In a subsequent volume, I shall turn attention to hybrid LPDA-Yagi designs, often called “log-cell Yagis,” and often designed for single amateur bands. They, too, deserve some new and systematic attention. In addition, a second volume will allow some room to take up additional applications of the LPDA.

Part 1. LPDA Fundamentals

Chapter 1: Introduction

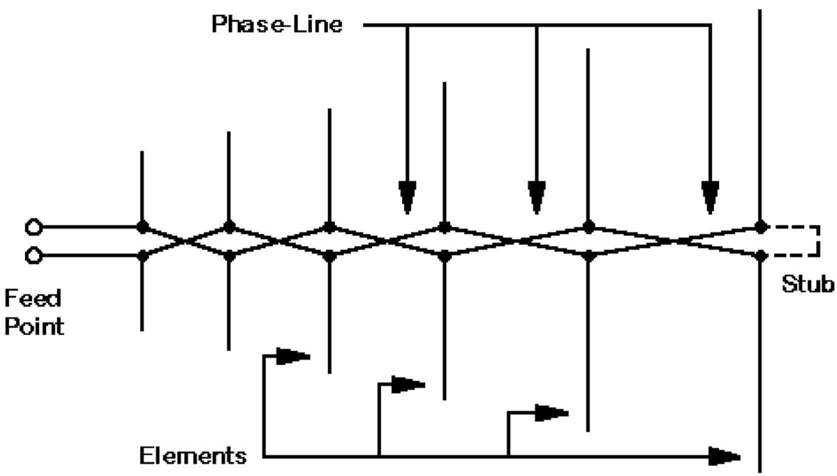
The advent of computer modeling has brought the design of the Log Periodic Dipole Array (LPDA) under systematic scrutiny. In fact, re-examination of the LPDA has perhaps been more intense recently than at any time since the late 1960s, when initial testing of the design concepts, originated by D. E. Isbell at the University of Illinois in the late 1950s, reached it most thorough form. These notes are a small contribution to the renewed interest in and study of the LPDA.

The LPDA is the most popular form of the log periodic systems, which also include zig-zag, planar, trapezoidal, slot, and V forms. It is only one of an entire family of "frequency-independent" antennas. Although the family in theory yields frequency-independent antennas, in actual practice, these antennas are designed for large but finite frequency ranges.

Much of LPDA's popularity among log periodic antennas stems from its structural similarity to the Yagi-Uda parasitic array. For upper HF, VHF, and UHF work, elements are composed usually of aluminum tubing or rod, with a central boom, although the boom may be doubled to perform a second duty by becoming the phase line between elements. Indeed, early treatments of the LPDA tended to think of the array (erroneously) as a continuous sequence of 3-element Yagis. Nevertheless, the LPDA has both structural and design considerations that distinguish it from the Yagi.

Fig. 1-1 presents the common parts of an LPDA. The structure consists of a number of linear elements, the longest of which is approximately 1/2 wavelength long at the lowest design frequency. The shortest element is usually about 1/2 wavelength long at a frequency well above the highest operating frequency. The "phase-line," (also called—with some confusion on the part of those new to the design—the "antenna feeder") connects the center points of each element in the sequence, with a phase reversal between each element. A stub consisting of a shorted length of parallel feed line is often added, although rarely for the purposes envisioned in the initial guides to designing LPDAs.

According to the theory of LPDA operation, the arrangement of elements and the method of feed yields an array with relatively constant gain and front-to-back ratio across the designed operating range. In addition, the array exhibits a relatively constant feedpoint impedance, simplifying the transmission line requirements of the antenna installation. As we shall see, these promising potentials of LPDA design are subject to significant limitations, especially where the number of elements is low for a given frequency spread of operation. In most amateur radio LPDA installations, the element count will in fact be well below optimal levels due to natural limitations of the real estate available for an LPDA. However, as we shall also see, there are some limitations built into the system by which one calculates the working dimensions for an LPDA.



Basic Components of an LPDA

Fig 1-1

Some Basic Design Considerations

For the LPDA designer, the most fundamental aspects of the array revolve around three interrelated design variables: α (alpha), τ (tau), and σ (sigma). Any one of the three variables may be defined by reference to the other two.

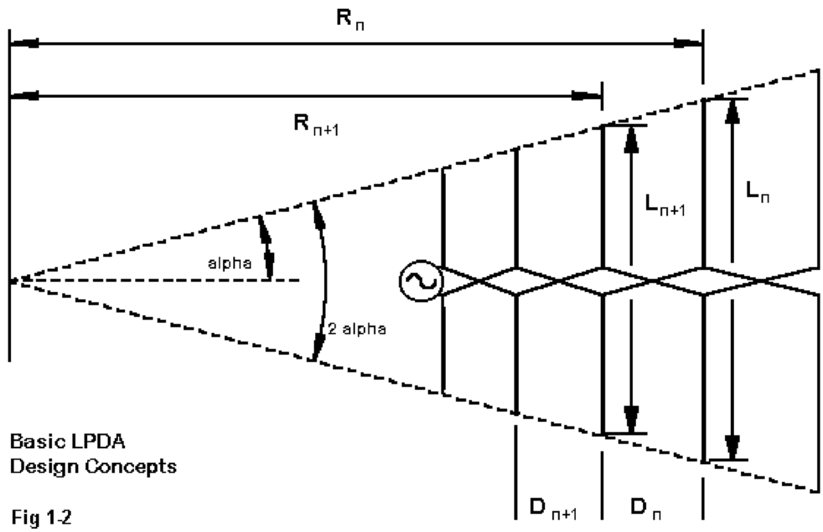


Fig. 1-2 shows the basic components of an LPDA. The angle α defines the outline of an LPDA and permits every dimension to be treated as a radius or as the consequence of a radius (R). The most basic structural dimensions are the element lengths (L), the distance of each element (R) from the apex of angle α, and the distance between elements (D). The distance of an element from the angle apex is considered to be large enough so that the curve for radius approximates the straight line of the element. A single value, τ, can be defined in terms of all of the components in the following manner:

$$\tau = \frac{R_{n+1}}{R_n} = \frac{D_{n+1}}{D_n} = \frac{L_{n+1}}{L_n} \qquad \textbf{(1)}$$

where element n and n+1 are successive elements in the array working toward the apex of angle α. The value of τ is always less than 1.0, although effective LPDA design requires values as close to 1.0 as may be feasible.

τ defines the relationship between successive element spacings, but it does not itself determine the initial spacing between the longest and next longest elements upon which to apply τ successively. The initial spacing also defines the angle α for the array. Hence, we have two ways to determine the value of σ:

$$\sigma = \frac{1 - \tau}{4 \tan \alpha} = \frac{D_n}{2 L_n} \qquad \textbf{(2)}$$

where D_n is the distance between any two elements of the array and L_n is the length of the longer of the two elements. From the first of the two methods of determining the value of σ, we may also find a means of determining α when we know both τ and σ.

For any value of τ, we may determine the optimal value of σ:

$$\sigma_{opt} = 0.243\, \tau - 0.051 \qquad \textbf{(3)}$$

The combination of a value for τ and its corresponding optimal value of σ yields the highest performance of which an LPDA is theoretically capable. For values of τ from 0.80 through 0.98, the value of optimal σ varies from 0.143 to 0.187 in increments of 0.00243 for each 0.01 change in τ. However, in most cases, using the optimal value of σ yields a total array length that is beyond ham construction or support capabilities. Consequently, amateur LPDAs usually employ compromise values of τ and σ that yield lesser but acceptable performance.

Standardized design procedures usually set the length of the rear element for a frequency about 7% lower than the lowest design frequency and use the common dipole formula ($L_{feet} = 468/f_{MHz}$) to determine its length (2% lower than a true half wavelength, where $L_{feet} = 492/f_{MHz}$). The upper frequency limit of the design is ordinarily set at about 1.3 times the highest design frequency. Since τ and σ set the increment between successive element lengths, the number of elements becomes a function of when the shortest element reaches the dipole length for the adjusted highest frequency.

The adjusted upper frequency limit results from the behavior of LPDAs with respect to the number of active elements. **Fig. 1-3** shows an edge view of a 10-element LPDA for 20 through 10 meters. The vertical lines represent the peak relative current magnitude for each element at the specified frequency. At 14 MHz, virtually every element of the array shows a significant current magnitude. However, at 28 MHz, only the forward 5 elements carry significant current. Without extending the design range to nearly 40 MHz, the number of elements with significant current levels would be severely reduced, along with upper frequency performance.

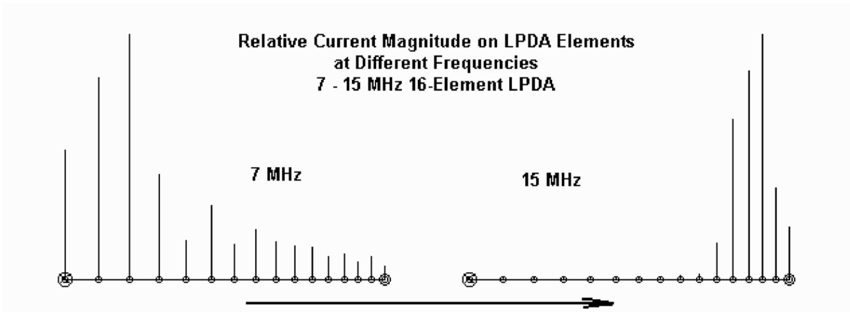


Fig 1-3

Early work on LPDAs assumed that only those elements in the immediate vicinity of the most active element—thought to be the element closest to 1/2-wavelength resonance—were active. Smith's 1966 *Log Periodic Antenna Design Handbook* adheres to this belief, but also recognizes a high frequency "truncation" factor. Showing that the truncation factor in fact results from the relatively high activity of all forward elements had to await the arrival of adequate antenna modeling software such as that used to produce **Fig. 1-3**.

The simple relationships among α, τ, and σ give an air of elegance to LPDA design, so much so, that some inherent limitations of the calculating scheme have been overlooked by many amateur LPDA designers. Therefore, it may prove useful to examine the design equations and to comment where necessary on some of those limitations.

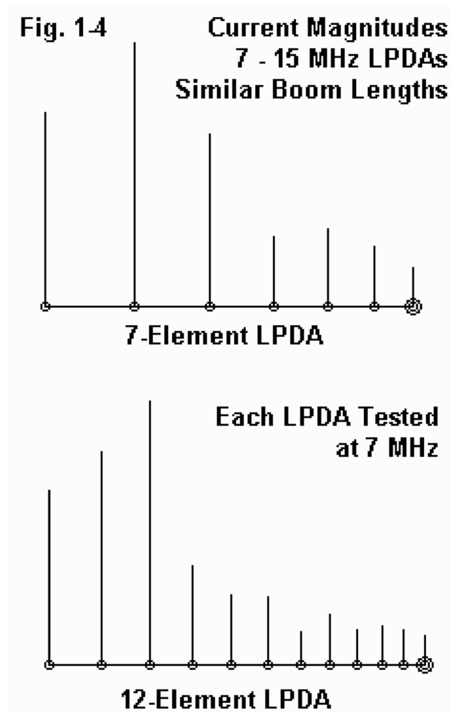
A Procedure to Calculate an LPDA Array

The following notes present one of the systematic step-by-step design procedures for an LPDA array for any desired bandwidth. The steps generally follow the set of equations found in Chapter 10 of *The ARRL Antenna Book* for many past editions. They were developed from original sources by Peter Rhodes, K4EWG, a long-time experimenter with LPDAs. Additional notes have been added here and there, but the treatment remains largely that of Rhodes and his sources. The notation used in the progression of equations may vary slightly from that used earlier in this chapter, but it is internally consistent.

1) Selection of the operating bandwidth, B, between f_1, lowest frequency and f_n, highest frequency:

$$B = \frac{f_n}{f_1} \tag{4}$$

The operating bandwidth for the array design is subject limitations imposed by the selection of τ and σ in the next step. The higher the value of σ, the better the performance at the high end of the specified passband. Hence, for higher values of σ the high end of the operating spectrum need not be chosen as far above the actual limit of the operating frequency as for low values of σ. A high frequency limit of about 1.3 times the upper operating limit tends to work well for higher values of σ, while low values may require a design specification of up to 1.6 times the upper operating frequency limit.



The need to extend the design equations below the lowest proposed operating frequency varies with the value of τ. In **Fig. 1-4**, we can compare the current on the rear elements of two LPDAs. The upper design uses a τ of 0.91 and a σ of 0.04, while the lower design uses a τ of 0.93 and a σ of 0.06. The most significant current bearing element moves forward with increases in τ, reducing (but not wholly eliminating) the need for elements below the lowest operating frequency.

2) Selection of values of τ and σ to give the desired estimated average gain:

$$0.8 \leq \tau \leq 0.98 \qquad and \qquad 0.03 \leq \sigma \leq \sigma_{opt} \tag{5}$$

where σ_{opt} is calculated as noted earlier in this chapter.

Note that we have given no method so far of estimating the average gain, since all such schemes have proven quite inadequate for combinations of τ and σ that are less than optimal for a very long-boom LPDA. For combinations of τ values between 0.85 and 0.95 and of σ values between 0.02 and 0.07, you can obtain a ballpark gain estimate by multiplying the sum of τ and twice σ by 25 and subtracting 18.25. The result will be as reasonable an estimate of the free-space gain of the array in dBi as any other method I know. For combinations of τ and σ that are in either case well below the upper limits, the designer should not expect to find the average gain figure everywhere across the spectrum unless the upper and lower frequency limits have been specified well above and below the actual operating frequencies.

In addition, the gain estimates, whether calculated informally by the estimate shown here or more formally calculated by the original aperture-based methods, apply only to LPDAs using elements of considerable diameter. HF LPDAs using thin wire may have gain levels that peak 2 to 3 dB below those designs using elements whose diameters measure from 0.5" at 30 MHz and larger with decreasing frequency. The performance of a practical LPDA depends as much upon the inter-element or mutual coupling of the elements as it does upon the direct provision of power to each element by virtue of its impedance to accept that power. For a given spacing between elements, the element diameter plays a significant role in establishing coupling that results in a directional pattern of the desired sort. With sparsely populated designs using a low value of τ or too high a value of σ for the selected τ, the performance will become in part a direct function of element diameter.

3) The cotangent of the apex half-angle α:

$$\cot \alpha = \frac{4\,\sigma}{1 - \tau} \tag{6}$$

Although α is not directly used in these calculations, cotα is used often.

4) Determination of the bandwidth of the active region, B_{ar}:

$$B_{ar} = 1.1 + 7.7\,(1 - \tau)^2 \cot\alpha \tag{7}$$

5) Determination of the structure (array) bandwidth, B_s:

$$B_s = B \bullet B_{ar} \tag{8}$$

6) Determination of the boom length L, number of elements N, and longest element length l_1:

$$L_{ft} = \left(1 - \frac{1}{B_s}\right)\cot\alpha \bullet \frac{\lambda_{\max}}{4} \tag{9}$$

$$\lambda_{\max} = \frac{984}{f_1} \tag{10}$$

$$N = 1 + \frac{\log B_s}{\log \frac{1}{\tau}} = 1 + \frac{\ln B_s}{\ln \frac{1}{\tau}} \tag{11}$$

$$l_{1\,ft} = \frac{492}{f_1} \tag{12}$$

Normally, the calculated value for N will not be an integral number of elements. If the fractional value is more than about 0.3, increase the value of N to the next higher integer. Increasing the value of N will also increase the actual value of L over the value obtained from the procedures so far.

7) Determination of the terminating stub Z_t:

$$Z_t = \frac{\lambda_{\max}}{8} \tag{13}$$

Note that for most HF and VHF arrays, you may omit the stub. However, some form of stub may serve two purposes. First, it places both sides of the phase line at the same DC potential, which may be useful for "bleeding" away static charges on the otherwise isolated element side. Second, the judicious design and emplacement of a stub can overcome performance weaknesses within the operating spectrum. We shall examine the "therapeutic" use of stubs in a future chapter.

8) Determination of the remaining element lengths:

$$l_n = \tau \, l_{n-1} \tag{14}$$

9) Determination of the element spacing $d_{1\text{-}2}$:

$$d_{1\text{-}2} = \frac{(l_1 - l_2)\cot\alpha}{2} \tag{15}$$

where l_1 and l_2 are the lengths of the rearmost elements, and $d_{1\text{-}2}$ is the distance between the elements with the lengths l_1 and l_2. The remaining element-to-element spacings emerge from this equation:

$$d_{(n-1)\text{-}n} = \tau \, d_{(n-2)\text{-}(n-1)} \tag{16}$$

10) Selection of R_0, the desired feed-point resistance, to give the lowest SWR for the intended balun ratio and feed-line impedance. R_0, the mean radiation resistance level of the LPDA input impedance, is approximated by

$$R_0 = \frac{Z_0}{\sqrt{1 + \dfrac{Z_0}{4\sigma' Z_{AV}}}} \tag{17}$$

where the component terms are defined and/or calculated as follows. Z_0 is the necessary antenna feeder (phase-line) impedance:

$$Z_O = \frac{R_0^{\,2}}{8\,\sigma'\,Z_{AV}} + R_0\sqrt{\left(\frac{R_0}{8\,\sigma'\,Z_{AV}}\right)^2 + 1} \qquad \textbf{(18)}$$

σ' is the mean spacing factor:

$$\sigma' = \frac{\sigma}{\sqrt{\tau}} \qquad \textbf{(19)}$$

Z_{AV} is the average characteristic impedance of a dipole:

$$Z_{AV} = 120\left[\ \ln\left(\frac{l_n}{diam_n}\right) - 2.25\ \right] \qquad \textbf{(20)}$$

The ratio, $l_n/diam_n$ is the length-to-diameter ratio of the element n.

There are alternative forms of equation (17) above, one of which appears in Lo and Lee, *Antenna Handbook*, Vol. 2 (1993), p. 9-28. My thanks go to Spencer Webb, KW2S for calling this variant to my attention.

The differential between alternative calculations of R_O lies in using either the square root of τ to obtain the result, as in the Rhodes version, or using τ to obtain the value of R_O, as do Lo and Lee. The difference for values of τ above 0.92 will be quite small. For values of τ less than 0.9, the feedpoint resistance—or more correctly, its impedance in terms of R ± jX—will vary considerably, washing out the differential created by the two version of the equation.

Fig. 1-5 provides a frequency sweep from 7 to 15 MHz of the feedpoint resistance and reactance for a very well-behaved 16-element LPDA. The resistance varies by 65 Ohms across the passband, while the reactance varies by 50 Ohms. The greatest swings occur at the lower and, especially, the upper ends of the passband. Note that the reactance remains predominantly capacitive with only occasional excursions into the inductive reactance area. It is common for more sparsely populated LPDAs to show much wider swings of both resistance and reactance. Moreover, R_O will be significantly affected by the interaction of the value of the phase line characteristic impedance, Z_O, and the selected values of τ and σ. Hence, the initial calculation of R_O should be treated as a beginning estimate only.

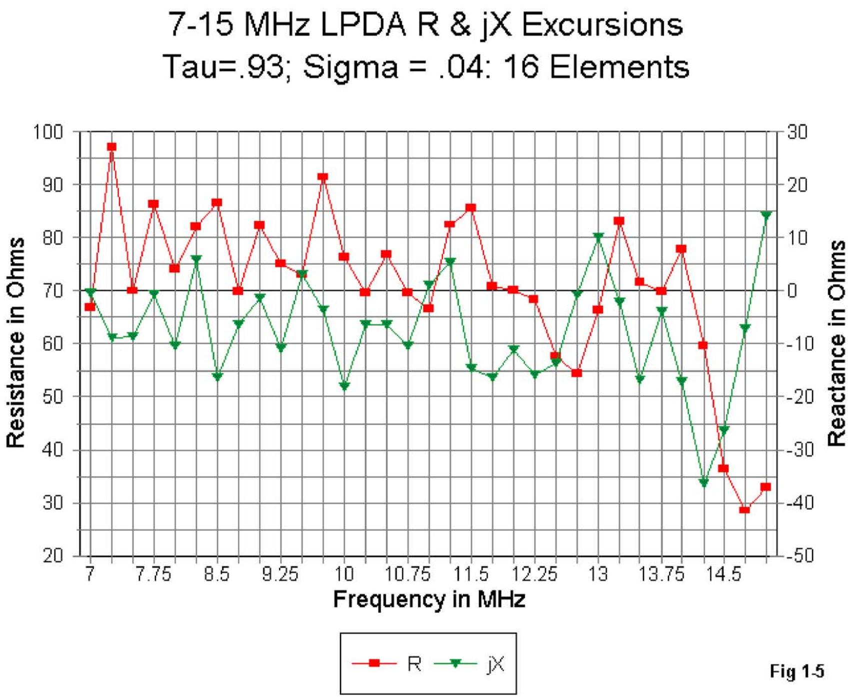
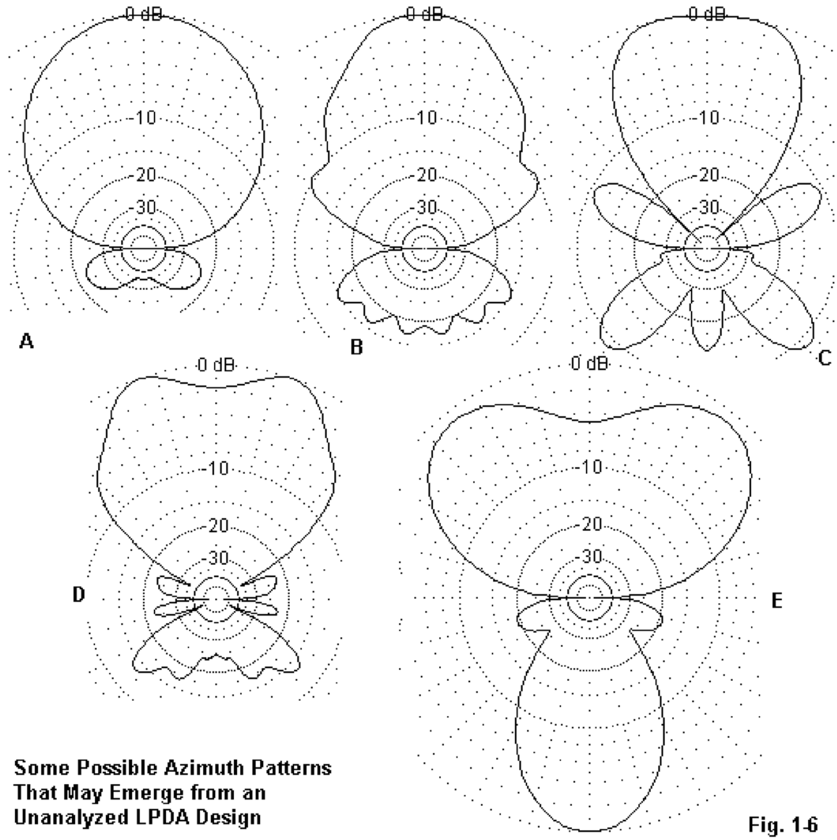


Fig 1-5

In addition to the limitations discussed so far, simple application of the design equations without further analysis can result in designs that yield radiation patterns of less than desired quality. **Fig. 1-6** provides an assortment of patterns taken from various LPDA designs, most of which relied on inadequate values of τ and σ, resulting in either inadequate array length or in too few elements to sustain adequate operation across the spectrum. Pattern A in the figure represents the desired array performance goal: a directional pattern with a single oval forward lobe and a well-confined set of rear lobes. The exact strength of the rear lobes tends to be a relatively direct function of the strength of the forward lobe, although the fluctuations of forward gain and front-to-back ratio tend not to be synchronized across the design passband.



Some Possible Azimuth Patterns That May Emerge from an Unanalyzed LPDA Design

Fig. 1-6

Pattern B shows the development of secondary lobes and increased signal strength in the rear lobes. Pattern C shows the fuller development of those lobes into major aspects of the array pattern. An alternative to Pattern C appears in Pattern D, where the main forward lobe has begun to break into to forward lobes, with additional side lobes fore and aft. All of these patterns are possible from the same array at different frequencies when the design is not adequate and no compensatory measures are applied. The final pattern in the group, E, is a continuation of the sequence. The double lobe in the presumed forward direction has spread wider and the main strength of the array is in the reverse direction.

Practical Design Work

For practical design work using the shorter structures typical of amateur radio LPDAs, the classic design equations are only a starting point. They should be considered rough estimates and a beginning to the design process. In no way should they be considered precise, despite their appearance. In the course of these notes, we shall even discover arrays that necessarily violate one or more of the guidelines contained within the calculations, for example, an array that requires a σ value as low a 0.02.

Since the design calculations are only the first step in the LPDA design process, there is no good reason (except raw curiosity) for anyone to go through the process with a hand calculator. Roger Cox, WB0DGF, has developed a perfectly competent DOS program called LPCAD, now in version 2.8, that will do the calculations and yield a set of element lengths and spacings that fit either of two scenarios for a set of frequency limits: a specification of τ and σ or a specification of the desired boom length and number of elements. The program calculates the longest element for a frequency about 2% below the lowest frequency entered by the user and the shortest element for a frequency about 30% above the highest frequency entered, using a full half wavelength rather than the shortened dipole constant (that is, 492/f instead of 468/f). In addition to dimensions, LPCAD returns a variety of data useful to the array designer. The program is available as a bonus on the CDROM that accompanies the latest (19th) edition of *The ARRL Antenna Book*.

Basic design calculations for an LPDA should always be checked and dimension refined by modeling the first-cut array on a version of NEC. Only in this way can one revise various dimensions and know the results. The process will either show the way to improving the design or demonstrate that improvement up to acceptable standards is not feasible. Because modeling LPDA designs is such an important step in the development of arrays, we shall walk slowly through the process of adequately, accurately, and effectively modeling LPDA arrays.

Chapter 2: Modeling the LPDA

Antenna modeling programs have become an indispensable tool in analyzing and refining the designs of LPDAs. Therefore, it seems fitting that we devote some considerable space at the very beginning to a cluster of questions about modeling log periodic arrays. How should we model LPDAs? What are the limitations of LPDA models? Are there precautions that we can take to ensure adequate LPDA models?

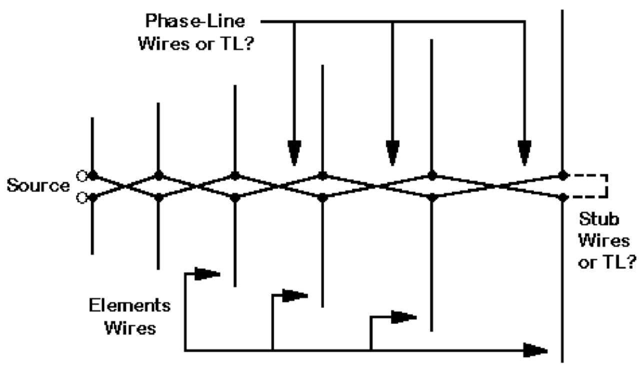


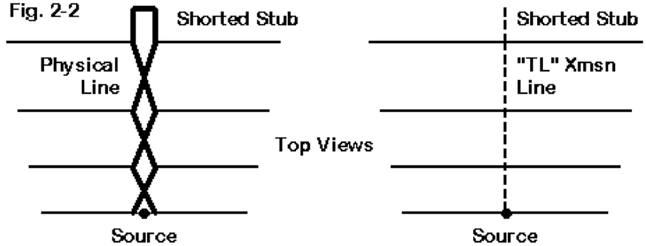
Fig. 2-1 Modeling Components of an LPDA

The answers to these questions might usefully fill a book by themselves, but we shall try to squeeze some essentials into one chapter.

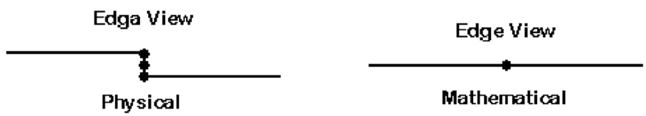
1. How should we model LPDAs?

The log periodic dipole array consists of a series of dipoles whose self-resonant frequencies and lengths are set up in a periodic fashion and whose spacing is equally periodic. The elements are interconnected with a transmission line that reverses connections at each new dipole element, with the feedpoint normally at the junction with the shortest dipole of the array. Many LPDAs also make use of shorted stubs at the rear of the array. In this chapter, we shall not dwell on design considerations, but rather on the task of making an adequate model of an LPDA. **Fig. 2-1** reviews the major components of the array.

Fig. 2-2



Physical vs. Mathematical Modeling of LPDA Phase Lines



Essentially, we have two major modeling choices. We can attempt to model physically all aspects of the antenna array, as shown in the left part of **Fig. 2-2**. Unfortunately, for NEC, this strategy quickly meets with some of the geometry limitations within the program. These limitations are functions of the calculation core and not of any particular implementation of NEC.

Since the elements are rarely of the same diameter as the transmission line wires, we encounter NEC's difficulties with angular junctions of dissimilar diameter wires. Results will rarely be accurate. Of course, every physical implementation of an LPDA has to deal with the crossing transmission line wires. The simplest scheme that works well appears in the left edge view. Let the inter-element transmission line (or phase line for short) be set up vertically. Then the left and right sides of each dipole can intersect alternate upper and lower wires of the phase line. The misalignment of up to a few inches of the two sides of the dipole will create no significant errors in the resulting antenna pattern or performance figures. However, the angular junction problem can only be overcome for a few designs by using a constant diameter for all portions of the antenna.

MININEC (3.13) does not have the same angular junction limitation that troubles NEC, but MININEC does have limitations of its own. Sharp angular junctions require the use of high levels of segmentation or the use of length tapering to ensure that each junction is met with very short segment lengths. The short segment lengths minimize errors created by MININEC's tendency to "cut off" corners. The end result of overcoming the inherent MININEC limitation is a model that will overrun the maximum segment limitation of most versions of the program. Those programs that have extended the number of available segments will run very slowly with very high numbers of wires and segments in the model.

The most promising way to model an LPDA is to follow the lead of the right hand sketch in **Fig. 2-2**, which applies only to NEC (-2 or -4) models. Set up each dipole in its proper position. Use an odd number of segments on each dipole wire. From one dipole to the next, run a TL transmission line of the desired characteristic impedance. Reverse the connection of each transmission line installed. Place the source on the center of the shortest dipole. Many LPDA designs employ a shorted transmission line stub at the center of the longest element, and this can also be put in place in the model using the TL facility.

The following model description illustrates the model construction principles.

```
17-10m Log Per - ARRL Ant Book          Frequency = 28  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          0.000,-163.46,  0.000         0.000,163.460,  0.000 1.25E+00  41
2         39.230,-130.76,  0.000        39.230,130.760,  0.000 1.00E+00  33
3         70.620,-104.62,  0.000        70.620,104.620,  0.000 7.50E-01  25
4         95.720,-83.690,  0.000        95.720, 83.690,  0.000 6.25E-01  21
5        115.810,-66.950,  0.000       115.810, 66.950,  0.000 5.00E-01  17

               -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           9     5 / 50.00   (  5 / 50.00)      1.000       0.000       I
```

```
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1  Wire #/% From End 1    Length    Z0   Vel Rev/
      Actual  (Specified)  Actual  (Specified)             Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  490.1  1.00  R
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  490.1  1.00  R
3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  490.1  1.00  R
4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  490.1  1.00  R
5    1/50.0  (  1/50.0)  Short ckt (Short ck)    6.000 in   490.1  1.00

Ground type is Free Space
```

To save space in future model listings, wherever the transmission line list is standard, I shall list only the first 2 and last 2 lines, plus any stub in the design. Although this particular design is a good illustration of the modeling technique, the model itself does not show exceptional performance.

2. What are the limitations of LPDA models?

Use of the TL facility avoids most of the difficulties of physically modeling the LPDA. However, the use of TL phasing lines has some limitations of its own. Theoretically, the phase line does not enter into the antenna's radiation on any frequency. However, physical placement of the stub can sometimes alter the antenna's performance on certain frequencies. As mathematical entities created by a network placed at a large distance from the antenna model proper, the TL phase line cannot show the potential effects of placement.

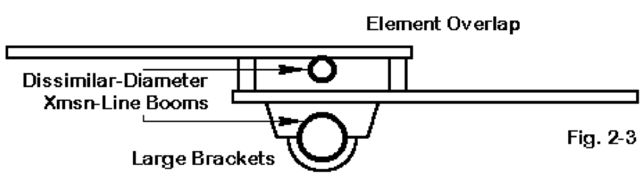


Fig. 2-3

Some Potential Modeling Difficulties with LPDAs

In addition, there are construction variables connected with the assembly of real LPDAs, and some of these cannot be captured by the suggested NEC modeling technique. For example, K4EWG presented a 20-10 meter LPDA in Vol. 3 of the *ARRL Antenna Compendium*. He used a number of interesting construction techniques, sketched in **Fig. 2-3**. His phase line consisted of two tubes having different diameters. Ordinarily, the impedance of the line created by the two should be calculable from the diameter of the smaller tube, but the physical effects of the arrangement would be missing from the suggested modeling technique. In addition, he used muffler clamps to connect the lower element set to the larger boom. Most significant are the overlapping element ends—8" each side of the center line. Overlapping the ends of dipole elements does affect antenna impedance in ways that the simplified model cannot fully capture.

For the most part, none of these construction techniques—and others that might be comparable—affects the antenna pattern with respect to gain, shape, or front-to-back ratio. When trying to model an LPDA using construction methods that have physical significance, it is important to establish ahead of final model construction that these physical elements do not have distorting affects relative to the propose final model. You can do this by modeling individual elements with all physical aspect taken into account and comparing the results with simplified single elements.

Where construction elements of the sort illustrated have their main effect is on the performance of the phase line. Its net effective impedance may not match the design impedance that we calculate from standard equations and simple round wires. The most straightforward way to deal with phase line variables is to survey the antenna performances at each check point using a variety of phase-line characteristic impedances from about 75-80 Ohms at the lower end of the spectrum to about 200-250 Ohms at the upper end.

3. The “Best” Modeling Program for LPDAs

The most common software used to model log periodic dipole arrays (LPDAs) is probably NEC-2. NEC-2 allows us to use the TL facility to construct the phasing line from mathematical lines that suffer no problems with the fact that they must be reversed as they connect with each set of elements. In its most common implementations, NEC-2 is cheaper than NEC-4 but has a higher segment limit than many implementations of MININEC 3.13. (An exception to this general rule is NEC4WIN95VM.)

If the models that we generate have uniform diameters, then we encounter few problems with NEC-2 other than ensuring an adequate number of segments for each element on all the frequencies covered by the LPDA. However, suppose we meet an antenna design with tapered element diameters, that is, with several sizes of tubing use to make up each element. **Fig. 2-4** shows a 7-element LPDA and allows you to distinguish the segment junction dots from the dots indicating a new tubing diameter. The model description for this 14 to 30 MHz LPDA shows the element-diameter tapering complexity.

7-Element LPDA: 14 - 30 MHz

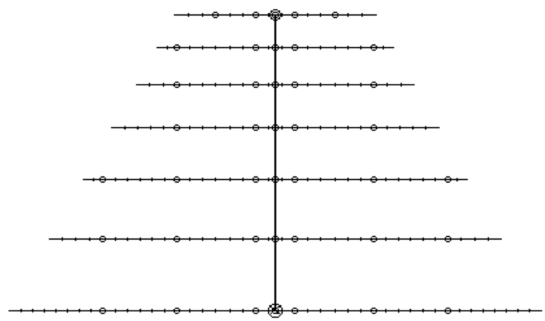


Fig. 2-4

```
7 el lpda 20-10m                      Frequency = 29  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         -216.50,  0.000,  0.000  W2E1 -140.00,  0.000,  0.000 7.50E-01   8
2   W1E2 -140.00,  0.000,  0.000  W3E1 -80.000,  0.000,  0.000 8.75E-01   6
3   W2E2 -80.000,  0.000,  0.000  W4E1 -16.000,  0.000,  0.000 1.00E+00   6
4   W3E2 -16.000,  0.000,  0.000  W5E1  16.000,  0.000,  0.000 1.12E+00   3
5   W4E2  16.000,  0.000,  0.000  W6E1  80.000,  0.000,  0.000 1.00E+00   6
6   W5E2  80.000,  0.000,  0.000  W7E1 140.000,  0.000,  0.000 8.75E-01   6
7   W6E2 140.000,  0.000,  0.000       216.500,  0.000,  0.000 7.50E-01   8
8          -183.88, 57.360, 0.000  W9E1 -140.00, 57.360,  0.000 7.50E-01   4
9   W8E2 -140.00, 57.360,  0.000 W10E1 -80.000, 57.360,  0.000 8.75E-01   6
10  W9E2 -80.000, 57.360,  0.000 W11E1 -16.000, 57.360,  0.000 1.00E+00   6
11 W10E2 -16.000, 57.360,  0.000 W12E1  16.000, 57.360,  0.000 1.12E+00   3
12 W11E2  16.000, 57.360,  0.000 W13E1  80.000, 57.360,  0.000 1.00E+00   6
13 W12E2  80.000, 57.360,  0.000 W14E1 140.000, 57.360,  0.000 8.75E-01   6
14 W13E2 140.000, 57.360,  0.000       183.875, 57.360,  0.000 7.50E-01   4
15        -155.62,106.270,  0.000 W16E1 -140.00,106.270,  0.000 7.50E-01   2
```

```
16 W15E2 -140.00,106.270,  0.000 W17E1 -80.000,106.270,  0.000 8.75E-01   6
17 W16E2 -80.000,106.270,  0.000 W18E1 -16.000,106.270,  0.000 1.00E+00   6
18 W17E2 -16.000,106.270,  0.000 W19E1  16.000,106.270,  0.000 1.12E+00   3
19 W18E2  16.000,106.270,  0.000 W20E1  80.000,106.270,  0.000 1.00E+00   6
20 W19E2  80.000,106.270,  0.000 W21E1 140.000,106.270,  0.000 8.75E-01   6
21 W20E2 140.000,106.270,  0.000       155.625,106.270,  0.000 7.50E-01   2
22       -132.50,147.980,  0.000 W23E1 -80.000,147.980,  0.000 8.75E-01   5
23 W22E2 -80.000,147.980,  0.000 W24E1 -16.000,147.980,  0.000 1.00E+00   6
24 W23E2 -16.000,147.980,  0.000 W25E1  16.000,147.980,  0.000 1.12E+00   3
25 W24E2  16.000,147.980,  0.000 W26E1  80.000,147.980,  0.000 1.00E+00   6
26 W25E2  80.000,147.980,  0.000       132.500,147.980,  0.000 8.75E-01   5
27       -113.06,183.540,  0.000 W28E1 -80.000,183.540,  0.000 8.75E-01   3
28 W27E2 -80.000,183.540,  0.000 W29E1 -16.000,183.540,  0.000 1.00E+00   6
29 W28E2 -16.000,183.540,  0.000 W30E1  16.000,183.540,  0.000 1.12E+00   3
30 W29E2  16.000,183.540,  0.000 W31E1  80.000,183.540,  0.000 1.00E+00   6
31 W30E2  80.000,183.540,  0.000       113.060,183.540,  0.000 8.75E-01   3
32       -95.940,213.870,  0.000 W33E1 -80.000,213.870,  0.000 8.75E-01   2
33 W32E2 -80.000,213.870,  0.000 W34E1 -16.000,213.870,  0.000 1.00E+00   6
34 W33E2 -16.000,213.870,  0.000 W35E1  16.000,213.870,  0.000 1.12E+00   3
35 W34E2  16.000,213.870,  0.000 W36E1  80.000,213.870,  0.000 1.00E+00   6
36 W35E2  80.000,213.870,  0.000        95.940,213.870,  0.000 8.75E-01   2
37       -82.500,239.730,  0.000 W38E1 -48.000,239.730,  0.000 8.75E-01   3
38 W37E2 -48.000,239.730,  0.000 W39E1 -16.000,239.730,  0.000 1.00E+00   3
39 W38E2 -16.000,239.730,  0.000 W40E1  16.000,239.730,  0.000 1.12E+00   3
40 W39E2  16.000,239.730,  0.000 W41E1  48.000,239.730,  0.000 1.00E+00   3
41 W40E2  48.000,239.730,  0.000        82.500,239.730,  0.000 8.75E-01   3

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           2    39 / 50.00   ( 39 / 50.00)      1.000       0.000       I
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    4/50.0  (  4/50.0)   11/50.0  ( 11/50.0)  Actual dist  100.0  1.00  R
2   11/50.0  ( 11/50.0)   18/50.0  ( 18/50.0)  Actual dist  100.0  1.00  R
3   18/50.0  ( 18/50.0)   24/50.0  ( 24/50.0)  Actual dist  100.0  1.00  R
4   24/50.0  ( 24/50.0)   29/50.0  ( 29/50.0)  Actual dist  100.0  1.00  R
5   29/50.0  ( 29/50.0)   34/50.0  ( 34/50.0)  Actual dist  100.0  1.00  R
6   34/50.0  ( 34/50.0)   39/50.0  ( 39/50.0)  Actual dist  100.0  1.00  R
7    4/50.0  (  4/50.0)  Short ckt (Short ck)   90.000 in    75.0  0.66
```

The design is an adaptation of a 20' LPDA designed by K4EWG for *The ARRL Antenna Compendium*, Vol. 3 (pp. 118-123). However, a few things have been changed, such as the length of the stub. Moreover, some of the construction features of the original—such as the overlapping elements and the large brackets—have not been captured in this model.

The model has several interesting features in addition to the tapered element diameter schedules, which parallel the original design. The 90" stub, composed of 75-Ohm, 0.66 velocity factor line moves the depression of feedpoint impedances outside the 14-30 MHz passband of the antenna. The 100-Ohm phasing line was selected for the best modeled performance. Nonetheless, we have a more immediate question: What is the most accurate way to model this LPDA?

As a hint, let me provide you with a series of representative figures taken from different ways of modeling the antenna. See **Table 2-1**. For each of the mid-band frequencies, there are 3 sets of performance numbers: "NEC-4," "NEC-2-C" (NEC-2 with Leeson corrections in operation: Leeson corrections correct the inherent tendency of NEC-2 to give incorrect results for tapered diameter linear elements) and "NEC-2-N" for NEC-2 data without the correction factors activated. Frequency is in MHz, Gain is the free-space value in dBi, F-B is in dB, Feed Z is R +/- jX in Ohms, and the 50/75 Ohms SWR is self-explanatory.

Table 2-1. Performance Reports from 3 NEC Modeling Modes

Freq	Core	Gain	F-B	Feed Z	50/75 Ohm SWR
14.175	NEC-4	5.36	9.53	83.0 + j 8.8	1.69 / 1.16
	NEC-2-C	5.30	9.48	77.9 + j10.8	1.61 / 1.16
	NEC-2-N	5.49	9.73	82.5 + j 5.5	1.66 / 1.13
18.12	NEC-4	6.26	13.61	67.4 - j10.3	1.42 / 1.20
	NEC-2-C	6.24	13.58	69.0 - j 5.8	1.40 / 1.12
	NEC-2-N	5.31	13.59	63.8 - j 9.3	1.34 / 1.24
21.225	NEC-4	6.44	16.70	67.7 - j 1.5	1.36 / 1.11
	NEC-2-C	6.46	16.70	66.8 - j 3.9	1.35 / 1.14
	NEC-2-N	6.55	15.96	66.8 - j 0.3	1.30 / 1.16

24.94	NEC-4	6.34	15.33	71.2 - j33.2	1.91 / 1.57
	NEC-2-C	6.35	15.43	66.5 - j30.2	1.80 / 1.55
	NEC-2-N	6.44	15.11	67.9 - j34.2	1.92 / 1.62
29.0	NEC-4	6.17	19.36	65.5 - j26.5	1.70 / 1.49
	NEC-2-C	6.17	19.69	59.5 - j28.1	1.71 / 1.61
	NEC-2-N	6.20	19.38	61.4 - j28.6	1.73 / 1.59

If all that we wish to receive from the data reports is a general impression of how well the antenna might work within the ham bands covered by the design, then the answer to our question is simple. Any of the modeling techniques is sufficient to provide the general impression. Nothing fatal seems to be reported by any of the techniques, despite some variance among the numbers.

Uncorrected NEC-2, of course, is considered least accurate when modeling elements with a diameter-tapering schedule. We can note that the reports for this option tend to yield slightly higher gains than either of the other two options. NEC-4 is considered to be a very significant improvement on NEC-2 in the handling of tapered-diameter linear elements, and the values that it yields are somewhat closer to the values offered by NEC-2 with the element diameter correction activated.

For precision work, in which numerical progressions might be important (in contrast to the simple operational significance of the data), NEC-4 results do not tally exactly with corrected NEC-2. There is still some variance.

In an LPDA model, the NEC-2 correction factor does not affect every element. It has a limit, being activated for wire groups composed of elements within about 15% of 1/2 wavelength resonance. Hence, the figures for the corrected NEC-2 entries are misleading. On 20, only elements 1 and 2 were corrected. 17, 15, 12, and 10 activated only one wire each: numbers 3, 4, 5, and 6, respectively. Wire 7 was not corrected in length for its taper within any model run. To call the modeling run “corrected” was a misnomer; at best, each run was only partly corrected. Moreover, the corrections changed the length relationships among the elements.

NEC-2 is most accurate when the linear elements of a model have a uniform diameter. Under those conditions, a NEC-2 and a NEC-4 run on the same LPDA model will show virtually indistinguishable results. Hence, for the most accurate modeling results, it is advisable to convert each tapered diameter element into its equivalent uniform diameter element, using Leeson or similar equations. Utility programs are available for this task.

However, NEC-2 software having the correction factor available can do the work for us. Each program allows us to see the corrected uniform diameter element length and diameter. We may have to make several software runs, changing frequency each time, in order to compile a complete list of the equivalent elements, but that process is usually faster than entering all of the tapered diameter element lengths and sizes into a utility program.

For our little sample case, here is the resulting model.

```
7 el lpda 20-10m                            Frequency = 14  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        -212.91,  0.000,  0.000       212.910,  0.000,  0.000 8.93E-01  31
2        -180.94, 57.360,  0.000       180.940, 57.360,  0.000 9.21E-01  27
3        -153.52,106.270,  0.000       153.520,106.270,  0.000 9.49E-01  23
4        -131.05,147.980,  0.000       131.050,147.980,  0.000 9.71E-01  19
5        -111.88,183.540,  0.000       111.880,183.540,  0.000 9.88E-01  15
6        -95.106,213.870,  0.000        95.106,213.870,  0.000 1.00E+00  15
7        -81.342,239.730,  0.000        81.342,239.730,  0.000 9.74E-01  15

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           8     7 / 50.00   (  7 / 50.00)      1.000       0.000       I
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  100.0  1.00  R
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  100.0  1.00  R
3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  100.0  1.00  R
```

```
4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  100.0  1.00  R
5    5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  100.0  1.00  R
6    6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  100.0  1.00  R
7    1/50.0  (  1/50.0)  Short ckt (Short ck)   90.000 in    75.0  0.66
```

The results offered by this equivalent model are as follows.

Table 2-2. Performance Using Equivalent Uniform-Diameter Elements

Freq	Core	Gain	F-B	Feed Z	50/75 Ohm SWR
14.175	NEC-2	5.26	9.27	81.4 + j 9.6	1.66 / 1.16
18.12	NEC-2	6.18	13.40	68.7 - j10.9	1.44 / 1.19
21.225	NEC-2	6.37	16.96	69.0 - j 1.3	1.38 / 1.09
24.94	NEC-2	6.28	15.30	72.7 - j33.4	1.93 / 1.57
29.0	NEC-2	6.12	19.20	66.8 - j25.3	1.68 / 1.44

For casual work, nothing startling emerges from the report. Impedance reports are closest to the NEC-4 reports. The gain reports are lower overall—by about 0.2 dB on the lower bands and by about 0.1 dB on the upper bands. The greater effect on the lower frequencies of the LPDA passband is most likely due to the fact that the element taper schedule used tends to make the longest elements have the smallest equivalent uniform diameter. Normally in LPDAs, we tend to expect the opposite trend.

Had the element tapering schedule been significantly more complex, we would have seen a wider variation among values between the equivalent model and the original. If the original model had included mounting brackets, using substitute short large-diameter segments at the element centers, the differences between the equivalent and original models would likely have been as striking as they can be with many Yagi models. Nonetheless, the amount of difference in the outputs from the various options strongly suggests that it is good modeling practice in NEC-2 always to develop and use the equivalent uniform-diameter element model as the basis for the design and analysis of LPDAs.

4. Some Precautions to Ensure an Adequate Model

There a number of precautions we should take when moving from a page of design calculations, such as those produced by LPCAD, to a NEC model of the antenna design. To ease the transition, many LPDA design programs provide a save function to capture the antenna design in standard NEC format (as well as in other formats). The model description will run on almost any version of NEC-2 and above.

The save function is undoubtedly offered as a convenience to designers. However, the designer who models the antenna in NEC must take responsibility for ensuring that the model meets all of the requirements for being a good NEC model. Let's use an example: a 20-element 100' long 3-30 MHz LPDA of standard design. The value of τ for this example is about 0.8737 and the value of Sigma is about 0.0409. **Fig. 2-5** provides an outline of the general antenna design.

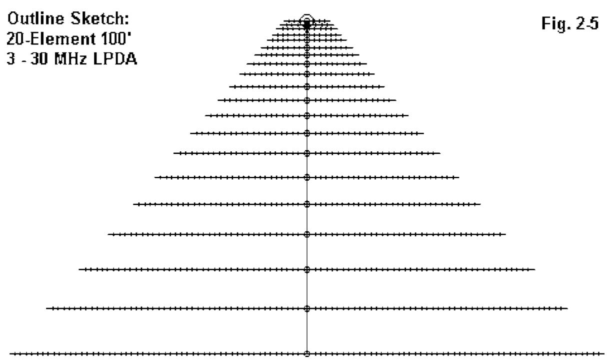


Fig. 2-5

The design software NEC-file may not specify any wire loss, since material specifications are not used in the element calculations. Therefore, the first step for the modeler is to specify the wire material for the elements. Second, the modeler should check the output azimuth plot specification to ensure that the step between reports yields a smooth pattern with enough detail. With just these steps, a description of the resulting file will look like the following listing.

```
20 el 100' 3-30 MHz                     Frequency = 3  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           0.000,-1003.7,  0.000         0.000,1003.68,  0.000 3.50E+00  15
2         164.166,-876.93,  0.000       164.166,876.934,  0.000 3.50E+00  15
3         307.601,-766.19,  0.000       307.601,766.193,  0.000 3.50E+00  15
4         432.923,-669.44,  0.000       432.923,669.437,  0.000 3.50E+00  15
5         542.419,-584.90,  0.000       542.419,584.899,  0.000 3.50E+00  15
6         638.087,-511.04,  0.000       638.087,511.037,  0.000 3.50E+00  15
7         721.675,-446.50,  0.000       721.675,446.503,  0.000 3.50E+00  15
8         794.707,-390.12,  0.000       794.707,390.118,  0.000 3.50E+00  15
9         858.516,-340.85,  0.000       858.516,340.853,  0.000 3.50E+00  15
10        914.267,-297.81,  0.000       914.267,297.810,  0.000 3.50E+00  15
11        962.978,-260.20,  0.000       962.978,260.202,  0.000 3.50E+00  15
12        1005.54,-227.34,  0.000       1005.54,227.343,  0.000 3.50E+00  15
13        1042.72,-198.63,  0.000       1042.72,198.634,  0.000 3.50E+00  15
14        1075.21,-173.55,  0.000       1075.21,173.550,  0.000 3.50E+00  15
15        1103.60,-151.63,  0.000       1103.60,151.634,  0.000 3.50E+00  15
16        1128.40,-132.49,  0.000       1128.40,132.485,  0.000 3.50E+00  15
17        1150.07,-115.75,  0.000       1150.07,115.755,  0.000 3.50E+00  15
18        1169.00,-101.14,  0.000       1169.00,101.137,  0.000 3.50E+00  15
19        1185.55,-88.365,  0.000       1185.55, 88.365,  0.000 3.50E+00  15
20        1200.00,-77.206,  0.000       1200.00, 77.206,  0.000 3.50E+00  15

               -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           8    20 / 50.00   ( 20 / 50.00)      0.707       0.000       V
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
18  18/50.0  ( 18/50.0)   19/50.0  ( 19/50.0)  Actual dist  200.0  1.00  R
19  19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  200.0  1.00  R
```

Many modelers would accept this model at face value as a proper model and proceed to check the performance at frequencies of interest. However, there are two important modifications that one should make to this model before trusting any outputs.

First, the model is uniformly specified with 15 segments per wire throughout the 20 elements. However, every element is a different length. Hence, segmentation should vary from one element to the next. How many segments each element should have is a function of the length of the longest element and the highest frequency at which the antenna will operate. The longest element is a little over 2000" and the highest frequency is 30 MHz. We need conservatively about 10 segments per half wavelength. Because we shall place a transmission line along the exact centerline of the antenna, we need for each element an odd number of segments. The requirement for an odd number of elements will limit the precision of our segmentation.

Since the longest element is a bit over 5 wavelengths long at 30 MHz, let's assign 107 segments to the longest element. For each shorter element, in order, we simply multiply by τ, using the preceding element answer as the basis for the next element. We shall have to round upward or downward to the closest odd number to obtain the segment number for the element in question. For the example in question, the shortest two elements each receive 9 segments, since their 1/2 wavelength resonant frequencies are above 30 MHz.

Second, consider the element diameter. The value in the diameter column is the average element diameter that the user specified as an input to the calculations. However, this value is very often not an accurate reflection of the intended element diameter for the actual antenna. Hence, we should replace the average diameter with values as close to reality as possible.

For the model in question, I specified a range of diameters from 0.5" for the shortest element to 6.5" for the longest. The design required that each element change according to τ in the descent from 6.5" to 0.5". Once more, this is a simply matter of successive multiplication of preceding values by τ to obtain the next smaller diameter. (The design purpose in this case was to have a constant element length-to-diameter ratio for the entire model. In any event, you should use element diameter values as close to reality as the stage of design will allow.)

The modified antenna model then took on this appearance.

```
20 el 100' 3-30 MHz                        Frequency = 3  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          0.000,-1003.7,  0.000         0.000,1003.68,  0.000 6.50E+00 107
2        164.166,-876.93,  0.000       164.166,876.934,  0.000 5.68E+00  93
3        307.601,-766.19,  0.000       307.601,766.193,  0.000 4.96E+00  81
4        432.923,-669.44,  0.000       432.923,669.437,  0.000 4.34E+00  71
5        542.419,-584.90,  0.000       542.419,584.899,  0.000 3.79E+00  63
6        638.087,-511.04,  0.000       638.087,511.037,  0.000 3.31E+00  55
7        721.675,-446.50,  0.000       721.675,446.503,  0.000 2.89E+00  47
8        794.707,-390.12,  0.000       794.707,390.118,  0.000 2.53E+00  41
9        858.516,-340.85,  0.000       858.516,340.853,  0.000 2.21E+00  37
10       914.267,-297.81,  0.000       914.267,297.810,  0.000 1.93E+00  31
11       962.978,-260.20,  0.000       962.978,260.202,  0.000 1.69E+00  27
12       1005.54,-227.34,  0.000       1005.54,227.343,  0.000 1.47E+00  25
13       1042.72,-198.63,  0.000       1042.72,198.634,  0.000 1.29E+00  21
14       1075.21,-173.55,  0.000       1075.21,173.550,  0.000 1.12E+00  19
15       1103.60,-151.63,  0.000       1103.60,151.634,  0.000 9.80E-01  17
16       1128.40,-132.49,  0.000       1128.40,132.485,  0.000 8.60E-01  15
17       1150.07,-115.75,  0.000       1150.07,115.755,  0.000 7.50E-01  13
18       1169.00,-101.14,  0.000       1169.00,101.137,  0.000 6.50E-01  11
19       1185.55,-88.365,  0.000       1185.55, 88.365,  0.000 5.70E-01   9
20       1200.00,-77.206,  0.000       1200.00, 77.206,  0.000 5.00E-01   9

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           5    20 / 50.00   ( 20 / 50.00)      0.707       0.000       V
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
18  18/50.0  ( 18/50.0)   19/50.0  ( 19/50.0)  Actual dist  200.0  1.00  R
```

```
19  19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  200.0  1.00  R
20   1/50.0  (  1/50.0)  Short ckt (Short ck)   90.000 in   200.0  1.00
```

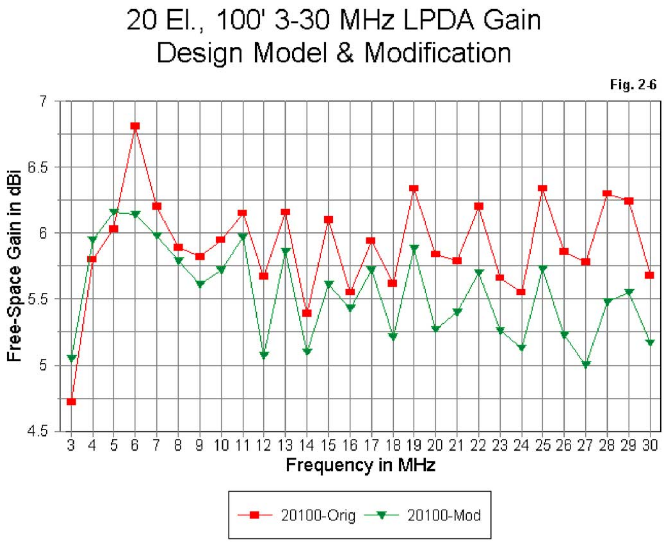
Besides the changes to the element segments and element diameter columns, one other addition to the model is evident. I added a shorted transmission line stub to the phasing line at the rearmost element. Actually, I ran this model with and without the stub to see the difference in performance at selected frequencies. Notice also that the stub has a specific length and is not the oft-used 1/4 wavelength (or the length of 1/2 the longest element). The stub was chosen to improve low frequency performance while having the least effect on upper frequency performance.

The modifications significantly increase the segment count for the entire model. The example above uses 792 segments, which may be beyond the common 500-segment limit of many entry-level NEC programs. However, it is the minimal satisfactory model of the LPDA design in question. In fact, convergence testing should check the model up to at least 1.5 times the segmentation density used here. (See the end of this chapter for the convergence test.)

Is all this modification really necessary? To find out, let's run frequency sweeps of the original model (with the aluminum elements and smaller plot step level in place) and of a modified model with a stub. If the original model formulation is satisfactory, then its curves should track the curves of the modified models except for any stub effects. As a preliminary set of checks, let's plot only the following parameters: free-space gain in dBi and the source resistance in Ohms.

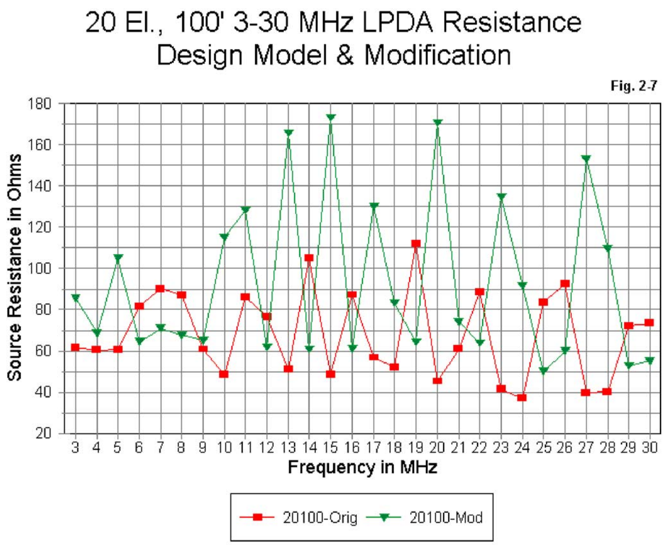
For a real design, we would run detailed frequency sweeps across each intended band of operation. For this general profile, we can use a sweep that checks the values of interest at 1 MHz intervals from 3 through 30 MHz, the design range of the model. **Fig. 2-6** provides graphs of the gain values for the three models. The original model using a constant 15-segments per element erroneously predicts a gain peak at 6 MHz. More significantly, above about 12 MHz, the original model provides significantly over-optimistic values for the gain of the antenna, a typical result of inadequate segmentation. However, note that the values occur in the frequency region in which we might think that the segmentation is adequate. This is a lesson to the effect that all of the elements of an LPDA design play a role at all frequencies.

We may omit front-to-back curves, since they are generally coincident for all three models. The original model is once more a bit over-optimistic at the highest frequencies. The stub-model does take care of equal gain and front-to-back anomalies in the 6 MHz region.



When we turn to the resistance and reactance components of the source impedance, the odd performance of the original model shows itself most vividly. The initial model tends to dip and peak in a rhythm directly opposite that of the more adequately segmented model. The resistance values reported by the 15-segment per element model would have to be accounted wholly unreliable. See **Fig. 2-7**. The graph of reactance values tells a very similar story.

Because the resistance and reactance values were at such odds, it was necessary to track VSWR against different reference values. The initial model used a 75-Ohm standard, suggesting that it might be directly fed with a coaxial cable. However, the larger model is referenced to 95 Ohms, a value taken as close to the mean between the extremes of the resistive components of the source impedance. The importance of the difference in VSWR reference standards lies in the consequences for designing the impedance matching required for connecting a main feedline to the antenna. The initial model's prediction that a 75-Ohm cable would be sufficient is unlikely to be fulfilled. More likely is the potential for using a wide-band 2:1 impedance matching device to connect the antenna to a 50-Ohm cable.



The inadequacies of uncritically adopting the transfer model as a proper NEC model are all too evident from the comparative graphs. This is not a criticism of LPDA design software, since the main function of saving the LPDA design as a NEC model is to release the designer from the tedium of entering every element length, space, and transmission line without omission, slippage, or transposition of numbers. However, it remains the responsibility of the modeler to use sufficient care to ensure that the resulting model meets all applicable NEC standards for being a proper model within the guidelines for the core.

5. A Note on the Convergence of Large Models

It is always useful to perform a convergence test on a model to determine its reliability. The convergence test is a necessary but not sufficient test of reliability: a model that fails to converge should be considered unreliable, but one that does converge might have problems that the convergence test cannot detect.

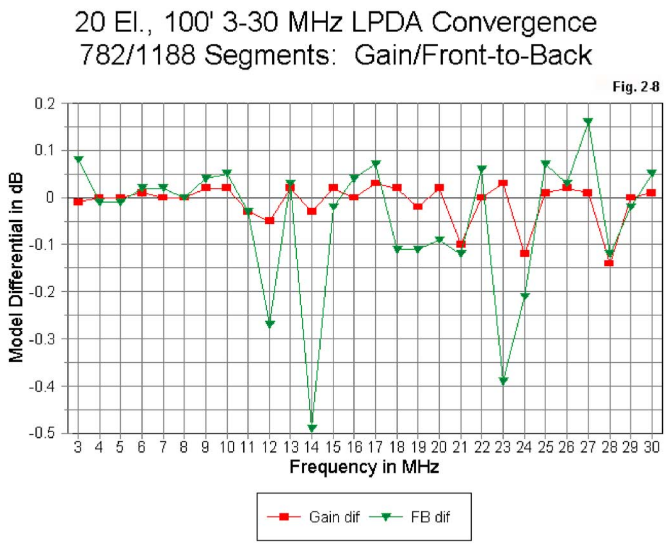
In the present case, we are dealing with relatively large models—relative, that is, to normal amateur radio modeling practices, although these models would be small in the confines of some engineering projects. The modified models—with and without a stub—have 792 segments overall, distributed in 20 elements. A reasonable convergence test might add 50% to that number as a basic convergence check.

However, the segmentation of the model must meet special requirements. The number of segments per element is determined by a rolling τ calculation starting from the longest element. The calculation is then rounded to the nearest odd-number of segments. To avoid double rounding errors, I performed the τ-based calculations, beginning with 161 segments on the rear element, up from 107 on the models considered above. The result appears in the partial model description below:

```
              --------------- WIRES ---------------

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

1          0.000,-1003.7,  0.000        0.000,1003.68,  0.000 6.50E+00 161
2        164.166,-876.93,  0.000      164.166,876.934,  0.000 5.68E+00 141
3        307.601,-766.19,  0.000      307.601,766.193,  0.000 4.96E+00 123
4        432.923,-669.44,  0.000      432.923,669.437,  0.000 4.34E+00 107
5        542.419,-584.90,  0.000      542.419,584.899,  0.000 3.79E+00  93
6        638.087,-511.04,  0.000      638.087,511.037,  0.000 3.31E+00  81
7        721.675,-446.50,  0.000      721.675,446.503,  0.000 2.89E+00  71
8        794.707,-390.12,  0.000      794.707,390.118,  0.000 2.53E+00  63
9        858.516,-340.85,  0.000      858.516,340.853,  0.000 2.21E+00  55
10       914.267,-297.81,  0.000      914.267,297.810,  0.000 1.93E+00  47
11       962.978,-260.20,  0.000      962.978,260.202,  0.000 1.69E+00  41
12       1005.54,-227.34,  0.000      1005.54,227.343,  0.000 1.47E+00  37
13       1042.72,-198.63,  0.000      1042.72,198.634,  0.000 1.29E+00  31
14       1075.21,-173.55,  0.000      1075.21,173.550,  0.000 1.12E+00  27
15       1103.60,-151.63,  0.000      1103.60,151.634,  0.000 9.80E-01  25
16       1128.40,-132.49,  0.000      1128.40,132.485,  0.000 8.60E-01  21
17       1150.07,-115.75,  0.000      1150.07,115.755,  0.000 7.50E-01  19
18       1169.00,-101.14,  0.000      1169.00,101.137,  0.000 6.50E-01  17
19       1185.55,-88.365,  0.000      1185.55, 88.365,  0.000 5.70E-01  15
20       1200.00,-77.206,  0.000      1200.00, 77.206,  0.000 5.00E-01  13
```

I then took a long walk while I frequency swept the enlarged model from 3 to 30 MHz in 1 MHz steps. The results were then entered into a spreadsheet. Differentials between the values for the smaller and the larger model covered gain and front-to-back ratio (in dB), source resistance and reactance (in Ohms), and 95-Ohm VSWR.

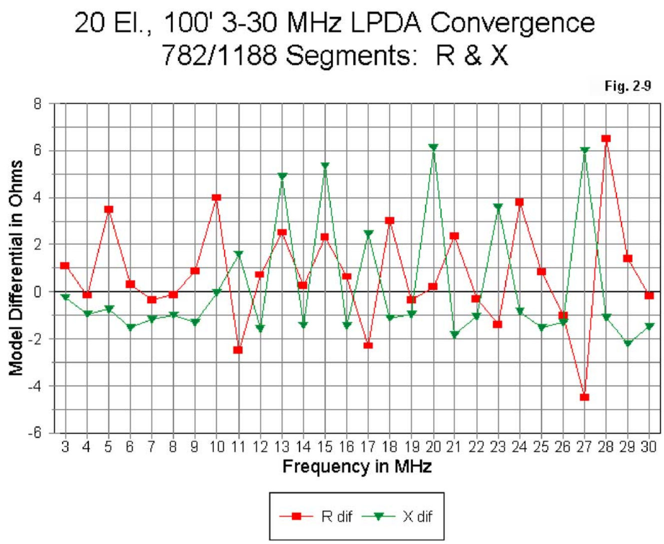
The results form the basis for a judgment of whether the smaller model is sufficiently converged with the larger to be considered reliable. **Fig. 2-8** shows the differentials for gain and front-to-back ratio. The maximum gain difference is under 0.15 dB or less than 3% of the average gain. The maximum front-to-back differential is 0.49 dB, again, less than 3% of the average front-to-back level.



Whether these numbers represent significant differences is a question of judgment related to the purposes for which one is doing the modeling. A gain difference of 0.15 dB is certainly not operationally detectable. Nor is a front-to-back differential of 0.49 dB. Since these maximum figures do not represent a general trend in the curves, they are unlikely to be meaningful for any design work one might do on an antenna of this sort. In fact, the most notable fact about the two curves in Fig. 7 is how closely they coincide, that is, how much of the curves remains within +/-.05 dB of zero.

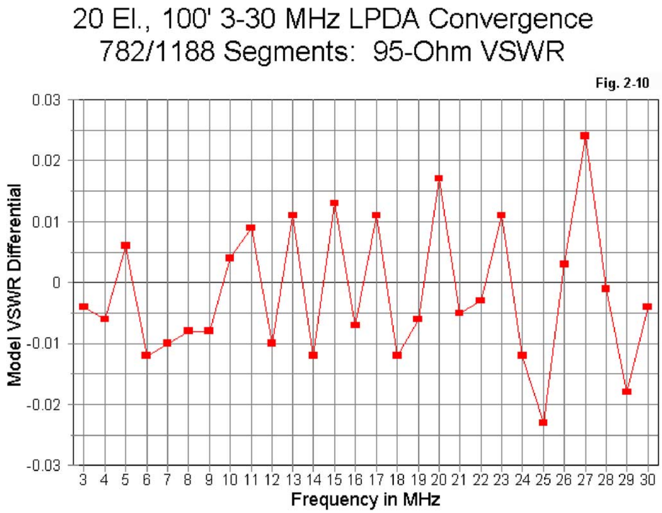
The resistance and reactance curves appear in **Fig. 2-9**. The maximum resistance and reactance deviations are about 6 Ohms each, within 5% of the total range of values for each parameter. What the graph of differences cannot show is that differences are largest where the values compared are large. The resistance ranges from about 49 Ohms to over 170 Ohms. Likewise, reactance ranges from about -55

Ohms to nearly +70 Ohms, and once more, peak differences attach to the highest values. We may have noticed that in the progression of source impedance values for an LPDA, most instances of extreme reactance values occur when the resistance is closest to its mean value. Hence, the resistance and reactance peak values appear at different points on the basic graphs.



The result of the non-coincidence of extreme values of resistance and reactance at the feedpoint is a 95-Ohm VSWR graph of differences (**Fig. 2-10**) that peaks at values less than 0.025. This small range is a truly insignificant differential for any operational antenna consideration with which I am acquainted.

The general conclusion one might reach here is that the smaller model converges well with the larger and may be considered reliable for most purposes, assuming that the model has passed all other tests as well. (Among other relevant tests for models are a set of guideline checks to ensure that the model does not approach or pass known limitations of the modeling core with respect to wire geometry and the average gain test.) The convergence test—and its results—also give us confidence that the graphed results for the modified models are far more reliable than those for the earlier unmodified model that used a standard 15 elements per element.



Nevertheless, the general conclusion represents a "smoothed" judgment. There are still a few values on the difference graphs that call attention to themselves. In such cases, we may usefully do two things: 1. We can keep our eye out in further modeling for significant anomalies that occur at the same frequencies. 2. Should we implement the design used for discussion here, we might make a few special checks at these frequencies during the field testing and adjustment to ensure that operational values do not exceed whatever limits might be specified in the final design.

I have lingered over some of the details of producing adequate NEC models of LPDAs because much of the analysis of various designs rests upon such modeling. Because these arrays cover such a wide band of frequencies and because we must have reasonable confidence in our models before investing in materials for prototype construction, grounding ourselves in good modeling practices is an essential part of the progression toward success. Needless to say, poor models will mislead us into wasted effort and misunderstanding of the performance potential of an LPDA design. However, with proper care, we can construct LPDA models using NEC software that will be fully adequate both as tools of analysis and as guides to construction.

Chapter 3: Some Common LPDA Properties

The standard calculation of LPDA designs tends to leave the impression that a very good design using a very high value of τ and an optimal value of σ has almost uniform performance across the design passband. Even the first time modeler of LPDAs is struck by the variations in performance that occur, even with the most careful adherence to design procedures. Since most of these characteristic variations have been uncovered since 1990 and since LPDA literature aimed at radio amateurs went into slumber long before then, perhaps a review of the general tendencies of LPDAs may be in order.

We shall begin with a high potency design for the upper amateur HF bands: 14-30 MHz. The design would require a 217' boom and employs 27 elements to achieve excellent performance. Then we shall turn our attention to a sample of a design more apt to be used in an amateur installation: a 9-element LPDA on a 20' boom.

What an Optimized LPDA Design Tells Us

Using a τ value of 0.96 approaches the recommended limit for LPDA design. The corresponding optimized σ value is about 0.18. With these figures in hand, we can design an array by setting frequency limits of about 13.6 MHz at the low end to about 30 MHz at the high end of the passband. The intended range of use is 14-29.7 MHz. The resulting array and its 27 elements appears in outline form in **Fig. 3-1**.

General Outline: 14 - 30 MHz 27-Element LPDA
Tau = 0.96; Sigma = 0.18; Boom Length = 217.2'

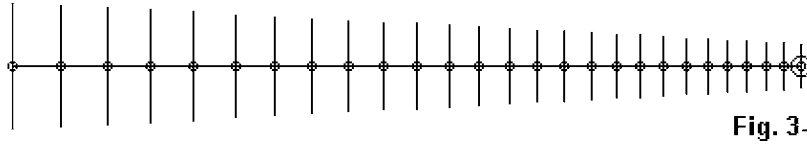


Fig. 3-1

The particular array that we shall explore uses a 200-Ohm phase line. However, the characteristic impedance of the line at the forward or feed end has been tapered from 80 Ohms at the feedpoint to the standard value by the 6th element to the rear of the feedpoint. This technique, to be explained in full in a later chapter, can smooth some "lumps" in the VSWR curve at the high end of the design spectrum. As well, the design uses 0.5" diameter aluminum elements throughout.

Our interest in the design is not its practicality. As the model description demonstrates, few amateurs will be willing to work with a 217' boom.

```
.96/.18 13.6-30 27 el                   Frequency = 28  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             0.000,-221.40,  0.000         0.000,221.400,  0.000 5.00E-01  31
2           159.408,-212.54,  0.000       159.408,212.544,  0.000 5.00E-01  31
3           312.440,-204.04,  0.000       312.440,204.042,  0.000 5.00E-01  29
4           459.350,-195.88,  0.000       459.350,195.881,  0.000 5.00E-01  29
5           600.384,-188.05,  0.000       600.384,188.045,  0.000 5.00E-01  27
6           735.776,-180.52,  0.000       735.776,180.523,  0.000 5.00E-01  25
7           865.754,-173.30,  0.000       865.754,173.303,  0.000 5.00E-01  25
8           990.531,-166.37,  0.000       990.531,166.370,  0.000 5.00E-01  23
9           1110.32,-159.72,  0.000       1110.32,159.716,  0.000 5.00E-01  23
10          1225.31,-153.33,  0.000       1225.31,153.327,  0.000 5.00E-01  23
11          1335.71,-147.19,  0.000       1335.71,147.194,  0.000 5.00E-01  21
12          1441.69,-141.31,  0.000       1441.69,141.306,  0.000 5.00E-01  21
13          1543.43,-135.65,  0.000       1543.43,135.654,  0.000 5.00E-01  19
14          1641.10,-130.23,  0.000       1641.10,130.228,  0.000 5.00E-01  19
15          1734.86,-125.02,  0.000       1734.86,125.019,  0.000 5.00E-01  17
16          1824.88,-120.02,  0.000       1824.88,120.018,  0.000 5.00E-01  17
17          1911.29,-115.22,  0.000       1911.29,115.217,  0.000 5.00E-01  17
18          1994.25,-110.61,  0.000       1994.25,110.608,  0.000 5.00E-01  15
19          2073.88,-106.18,  0.000       2073.88,106.184,  0.000 5.00E-01  15
20          2150.34,-101.94,  0.000       2150.34,101.937,  0.000 5.00E-01  15
21          2223.73,-97.859,  0.000       2223.73, 97.859,  0.000 5.00E-01  15
22          2294.19,-93.945,  0.000       2294.19, 93.945,  0.000 5.00E-01  13
23          2361.83,-90.187,  0.000       2361.83, 90.187,  0.000 5.00E-01  13
24          2426.77,-86.580,  0.000       2426.77, 86.580,  0.000 5.00E-01  13
25          2489.10,-83.116,  0.000       2489.10, 83.116,  0.000 5.00E-01  11
26          2548.95,-79.792,  0.000       2548.95, 79.792,  0.000 5.00E-01  11
27          2606.40,-76.600,  0.000       2606.40, 76.600,  0.000 5.00E-01  11



               -------------- SOURCES --------------
```

```
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    27 / 50.00   ( 27 / 50.00)      0.707       0.000       V
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)               Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
3      3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  200.0  1.00  R
4      4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  200.0  1.00  R
5      5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
6      6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
7      7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  200.0  1.00  R
8      8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  200.0  1.00  R
9      9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  200.0  1.00  R
10    10/50.0  ( 10/50.0)   11/50.0  ( 11/50.0)  Actual dist  200.0  1.00  R
11    11/50.0  ( 11/50.0)   12/50.0  ( 12/50.0)  Actual dist  200.0  1.00  R
12    12/50.0  ( 12/50.0)   13/50.0  ( 13/50.0)  Actual dist  200.0  1.00  R
13    13/50.0  ( 13/50.0)   14/50.0  ( 14/50.0)  Actual dist  200.0  1.00  R
14    14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  200.0  1.00  R
15    15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  200.0  1.00  R
16    16/50.0  ( 16/50.0)   17/50.0  ( 17/50.0)  Actual dist  200.0  1.00  R
17    17/50.0  ( 17/50.0)   18/50.0  ( 18/50.0)  Actual dist  200.0  1.00  R
18    18/50.0  ( 18/50.0)   19/50.0  ( 19/50.0)  Actual dist  200.0  1.00  R
19    19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  200.0  1.00  R
20    20/50.0  ( 20/50.0)   21/50.0  ( 21/50.0)  Actual dist  200.0  1.00  R
21    21/50.0  ( 21/50.0)   22/50.0  ( 22/50.0)  Actual dist  200.0  1.00  R
22    22/50.0  ( 22/50.0)   23/50.0  ( 23/50.0)  Actual dist  175.0  1.00  R
23    23/50.0  ( 23/50.0)   24/50.0  ( 24/50.0)  Actual dist  150.0  1.00  R
24    24/50.0  ( 24/50.0)   25/50.0  ( 25/50.0)  Actual dist  125.0  1.00  R
25    25/50.0  ( 25/50.0)   26/50.0  ( 26/50.0)  Actual dist  100.0  1.00  R
26    26/50.0  ( 26/50.0)   27/50.0  ( 27/50.0)  Actual dist   80.0  1.00  R

Ground type is Free Space
```

The technique by which we garner a handhold on the operating situation of this array is a detailed frequency sweep across the passband. For this exercise, we shall sweep the antenna from 14 through 30 MHz in 0.25 MHz intervals. This interval is small enough to catch any anomalies that might occur. However, the effective interval between steps in terms of a percentage of a wavelength decreases with increasing frequency. Initially, we shall combine the gain sweep with the front-to-back ratio sweep, since a comparison of these two parameters will be of considerable interest.

Fig. 3-2 shows the gain and front-to-back sweeps, with the curve that shows sharp peaks being the front-to-back ratio. Of first note is the fact that each curve is far from level. Instead, each undergoes cyclical variations as we move smoothly from one frequency to the next. As we change frequency, the inter-element coupling changes, altering every other operating parameter and the level of potential gain and front-to-back ratio.

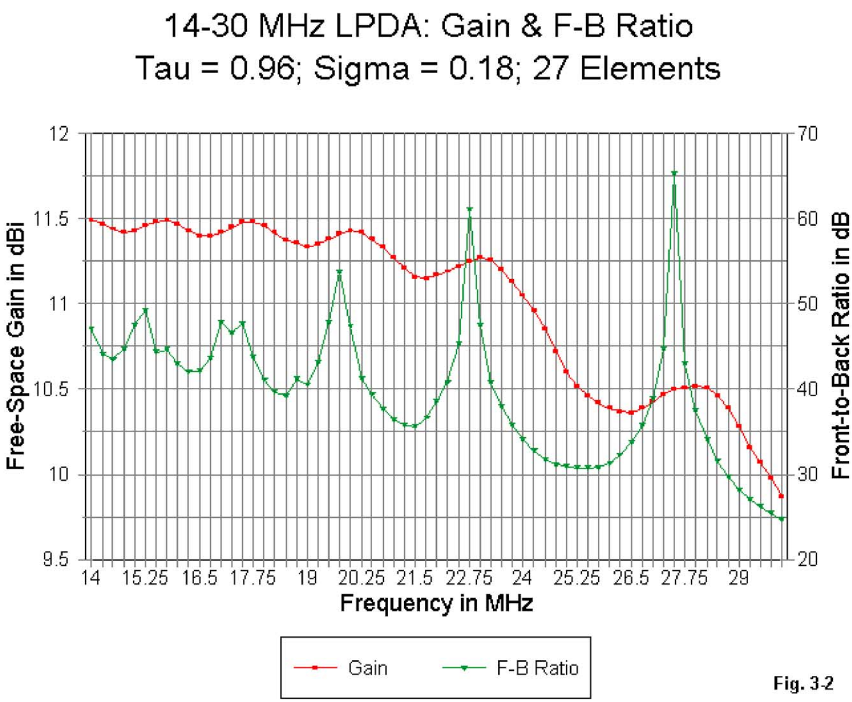


Fig. 3-2

Moreover, the peaks and valleys in the two performance curves do not occur on the same frequencies, but are displaced. As we increase frequency, the peak front-to-back value occurs at a slightly lower frequency than the corresponding gain peak. In addition, for a given design, peak front-to-back values tend to increase with frequency. However, the average front-to-back value tends to decrease across the passband. Of equal note is the fact that there is a considerable drop in average performance as we increase frequency. As we noted in Chapter 1, this phenomena was recorded in the 1960s in the Smith papers. However, as we shall see a bit further on, part of the decrease represents a design limitation of this particular LPDA.

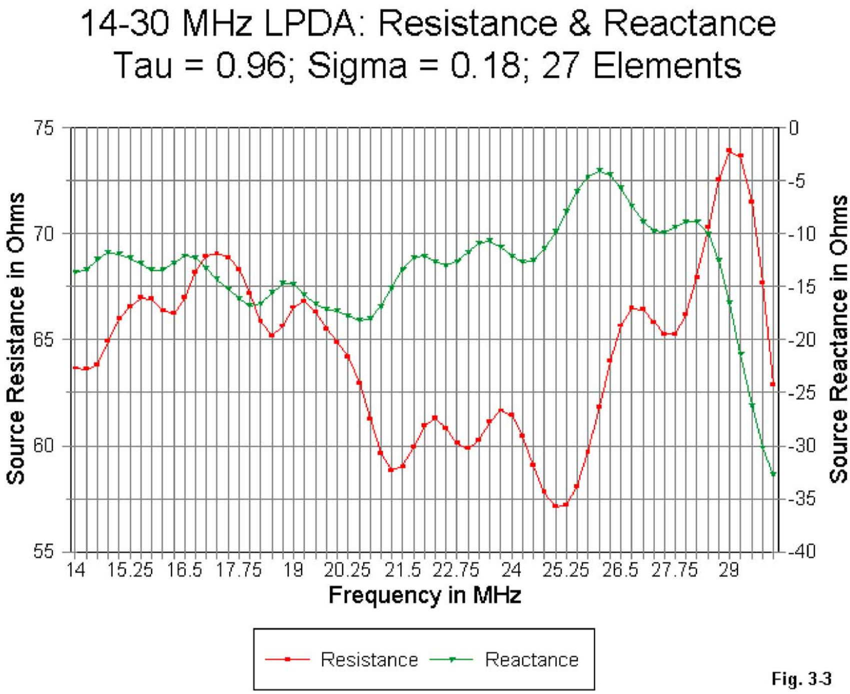


Fig. 3-3

If we turn to plotting the values of the resistive and reactive components of the source impedance across the passband, shown in **Fig. 3-3**, we find equally interesting characteristics to note. Both resistance and reactance show periodic curves, and once more, the two curves are not synchronized, at least not to the unobservant eye. The median resistance is about 63 Ohms across the passband. As the graph clearly shows, it varies somewhat in particular regions within the overall design spectrum. However, if we carefully trace the median value—in general or for a specific region—we discover that the most positive and most negative peaks in reactance tend to occur when the resistance is closest to its median value. When the resistance departs most from its median value, the reactance tends to be closest to its own median value. The net result is an SWR that, when referenced to the median value of resistive impedance, swings over a smaller than expected range of values.

When an LPDA is designed for a high value of τ and a σ that is close to optimal, the reactance at the feedpoint of the array tends be capacitive for every frequency in the operating passband. Since any transmission line shows at least a tiny inductive reactance, some of the capacitive reactance inherent in the array will be offset, but certainly not a majority of it. However, in the present case, except for the very highest frequencies, the reactance is small and no hindrance to an easy match with common coaxial cables.

Fig. 3-4

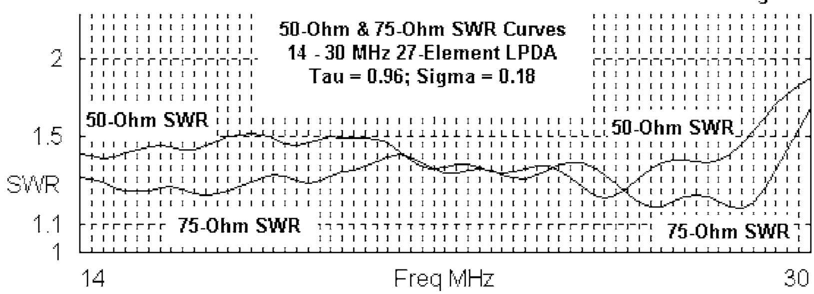


Fig. 3-4 shows the 50-Ohm and 75-Ohm VSWR curves for the array across the operating passband. Either cable value is usable, although the 75-Ohm cable shows a slightly flatter SWR curve. Note that, like all other properties examined so far, the SWR curve has peaks and valleys, and that the maximums and minimums do not occur at the same frequencies for each cable value due to the variations of resistance and reactance. In the end, one reaches the conclusion that for any frequency region within the overall design passband, the relationship among all of the operating parameters involves a complex set of factors revolving around the activity of the elements and their mutual coupling.

Apart from the lack of coincidence of maximums and minimums, the average front-to-back ratio for a well-behaved LPDA tends to be a function of the array gain. The higher the array gain, the better the front-to-back ratio. For well-behaved patterns, this generalization applies not only to the 180-degree ratio, but as well to the average front-to-rear ratio. **Fig. 3-5** shows three representative patterns for the array under study. In none of the patterns can the rear lobes be considered anything but well-controlled. Indeed, part of the short-wave broadcasting appeal of the LPDA is that, when optimally designed, little signal goes anywhere other than in the intended direction.

The free-space azimuth patterns in **Fig. 3-5** also confirm that the higher the gain, then generally, the higher the average front-to-back ratio—with exceptions for those interesting front-to-back peaks in **Fig. 3-2**. The gain for the array shows a decrease as we increase frequency, and the patterns show stronger rear lobes with increasing frequency. Not apparent in this optimized design is the other side of the coin. When LPDAs are designed for lower gain values, the front-to-back ratio tends to shrink with the gain. However, in many cases, reduced front-to-back performance will be the least of the designer's problems.

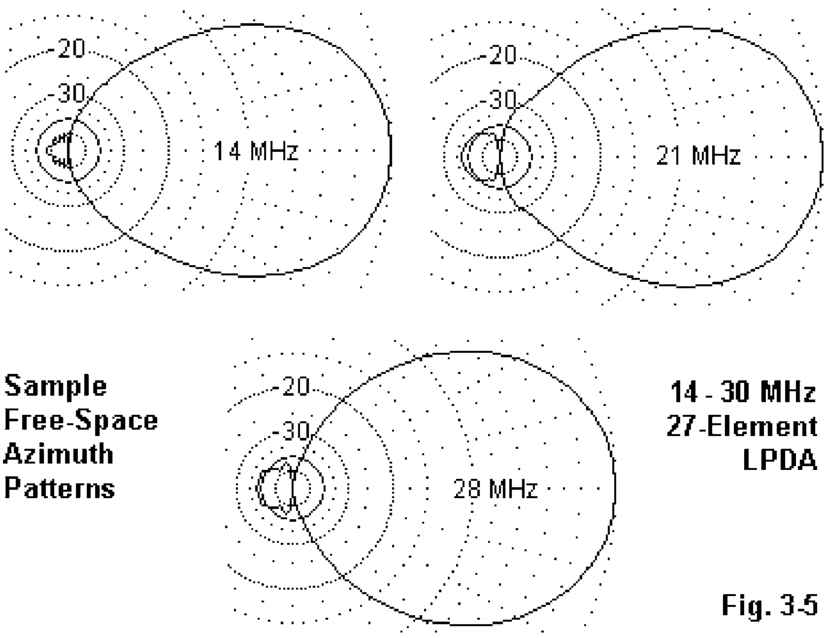


Fig. 3-5

The reduction of gain at the high end of the passband in the present design requires accounting. The design set 13.6 MHz as its lowest operating frequency in order to assure that performance at 14 MHz would be adequate. Normal design equations usually set the longest element about 2% below the resonant length by using the constant 492 in the length-setting equation. However, this procedure does not adequately account for the variability in low-end performance according to the value of τ. For any given lower frequency limit used in the design process, the higher the value of τ, the better the array performance as it approaches that limit. Indeed, the higher the value of τ, the further from the array rear will be the most active element at the lowest frequency used.

Fig. 3-6 shows that the 8th element from the rear is the most active at 14 MHz, which represents a waste of elements if this is the lowest frequency to be used. Not all of the back seven elements can be removed, but perhaps the rear 2 or 3 might go without loss of performance at 14 MHz.

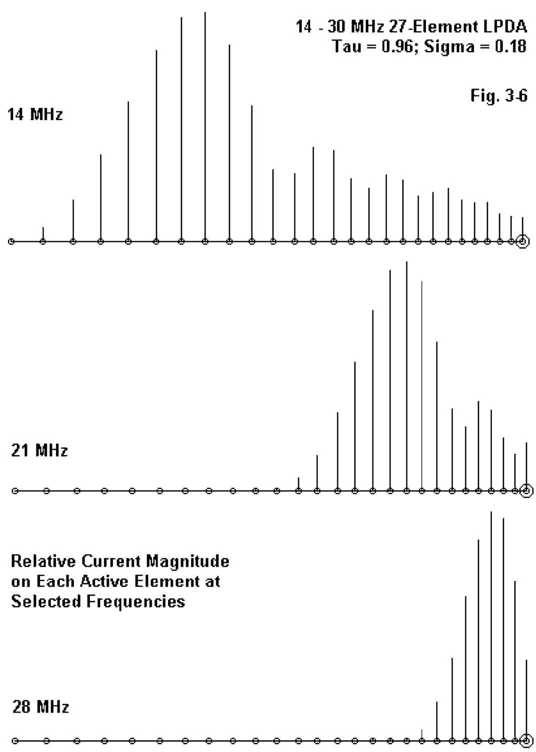


Fig. 3-6 also shows that by 21 MHz, less than half of the array length is active, with 11 elements close to inert. This is simply the price one pays for having access to the lower half of the passband.

At 28 MHz, we find that the number of active elements ahead of the most active element has been seriously reduced—enough to warrant a redesign of the array. Indeed, for the smoothest performance at the high end of the operating passband, the standard design value of 1.3 times the highest used frequency is inadequate. A more usable figure is close to 1.6 times the highest used frequency, but the exact value will more likely require case-by-case design exploration. For the present design, calling the highest used frequency about 33 MHz and letting the calculating software use 1.3 times that value would have improved upper end performance considerably.

So far, we have elicited general characteristics of the LPDA, but have used only a single optimized design as an illustration of them. Gleaning gain values that are much higher than the best for the design would likely prove to be an arduous design task. In order to confirm that the characteristics of the high-performance array are indeed typical of any LPDA, perhaps we should look at a second example, one with considerably less performance potential.

What a Lesser LPDA Design Tells Us

For our second example, let's create an LPDA for the same 14-30 MHz frequency range. However, let's confine ourselves to nine 0.5" diameter elements on a 20' boom. Such an array might well be within the radio amateur's construction abilities (not to mention the need for support and rotation at a working height). For this antenna, the resulting value of τ is 0.8687 (or 0.87) and the σ is 0.0525 (or 0.05). **Fig. 3-7** provides an outline sketch of the array. Immediately evident is the much sharper slope to the outline of the element ends.

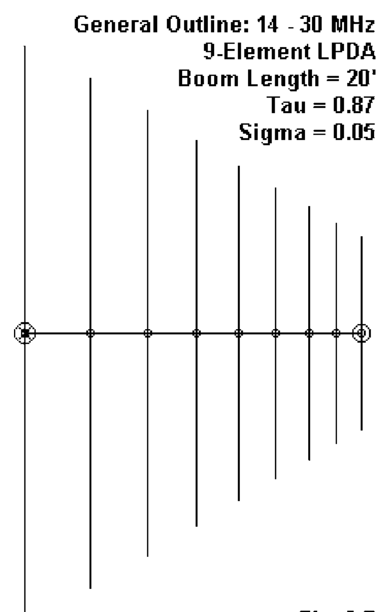


Fig. 3-7

The array will use a 100-Ohm phase line, with a shorted transmission line stub. The function of the stub will be a major subject of inquiry in a later chapter. The use of a lower impedance phase-line—which can be constructed from flat aluminum stock, among other materials—is to provide as good a match as possible across the passband for the usual coaxial cables. Note that as we decrease the values of τ and σ, the phase line characteristic impedance required for a low feedpoint impedance decreases as well.

The wire table below the figure confirms with dimensions the impression created by the outline sketch of the new LPDA design. The length difference between the longest element and the next longest is nearly 4', whereas the corresponding difference for the optimal model was less than 2'. (Note that the dimensions for the first model are in inches, whereas the present model dimensions are given in feet.) We might well anticipate in advance of viewing the modeling data that the short LPDA design will show considerably greater variations across its passband as well as lower values of both gain and front-to-back ratio.

```
14-30 MHz t=.87 s=.05                               Frequency = 29.7  MHz.

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

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

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

1             0.000,-18.100,  0.000         0.000, 18.100,  0.000 5.00E-01  33
2             3.886,-16.148,  0.000         3.886, 16.148,  0.000 5.00E-01  29
3             7.261,-14.029,  0.000         7.261, 14.029,  0.000 5.00E-01  25
4            10.194,-12.188,  0.000        10.194, 12.188,  0.000 5.00E-01  23
5            12.742,-10.588,  0.000        12.742, 10.588,  0.000 5.00E-01  19
6            14.955, -9.199,  0.000        14.955,  9.199,  0.000 5.00E-01  17
7            16.878, -7.992,  0.000        16.878,  7.992,  0.000 5.00E-01  15
8            18.549, -6.943,  0.000        18.549,  6.943,  0.000 5.00E-01  13
9            20.000, -6.032,  0.000        20.000,  6.032,  0.000 5.00E-01  11

              -------------- SOURCES --------------
*
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6     9 / 50.00   (  9 / 50.00)      0.707       0.000       V
                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)               Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  100.0  1.00  R
```

```
2       2/50.0  (   2/50.0)    3/50.0  (   3/50.0)  Actual dist  100.0  1.00  R
3       3/50.0  (   3/50.0)    4/50.0  (   4/50.0)  Actual dist  100.0  1.00  R
4       4/50.0  (   4/50.0)    5/50.0  (   5/50.0)  Actual dist  100.0  1.00  R
5       5/50.0  (   5/50.0)    6/50.0  (   6/50.0)  Actual dist  100.0  1.00  R
6       6/50.0  (   6/50.0)    7/50.0  (   7/50.0)  Actual dist  100.0  1.00  R
7       7/50.0  (   7/50.0)    8/50.0  (   8/50.0)  Actual dist  100.0  1.00  R
8       8/50.0  (   8/50.0)    9/50.0  (   9/50.0)  Actual dist  100.0  1.00  R
9       1/50.0  (   1/50.0)  Short ckt (Short ck)    2.400 ft   450.0  1.00
Ground type is Free Space
```

We shall not be disappointed in our expectations if we read **Fig. 3-8** correctly. The main curves for gain and front-to-back ratio appear to be shallower than those for the optimized array, only because we had to make space for the major anomaly in the progression of values. Allowing for the scale compression, we should readily note the undulating values of gain and front-to-back ratio, as well as the fact that the front-to-back ratio reaches peak values at slightly lower frequencies than corresponding gain peaks.

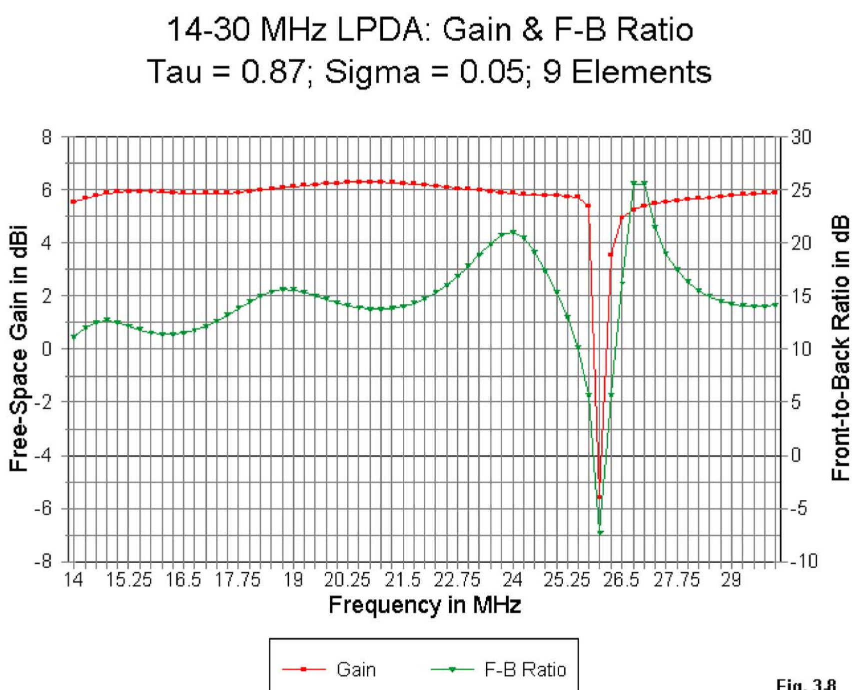


Fig. 3-8

However, typical of most low-τ, short-boom LPDA designs, the curve shows a major anomaly that peaks at 26 MHz in this example. In fact, the pattern reverses at this check frequency and hence, both gain and front-to-back ratio are recorded on the graph as negative values. Although the maximum values of these reversed figures are almost coincident in frequency, the curves approaching and departing from the anomaly are also interesting. As we increase frequency toward 26 MHz, the front-to-back ratio more gradually descends than does the gain value. Indeed, just above the 26 MHz is a flatted portion of the front-to-back curve: between these check points is a very high and sharp peak ratio value. Note also that the gain restores its more normal value more slowly than it lost it between 25.5 and 26 MHz.

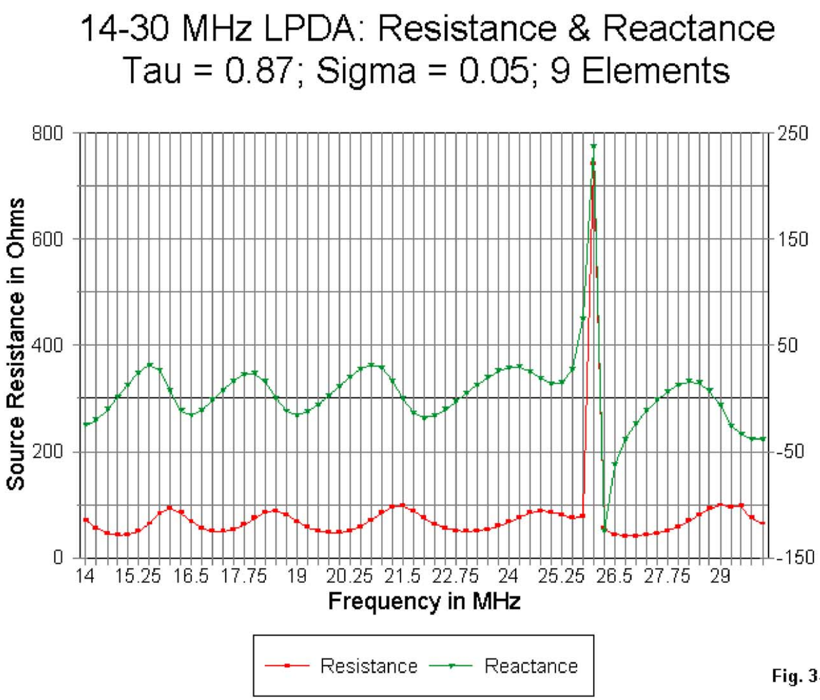
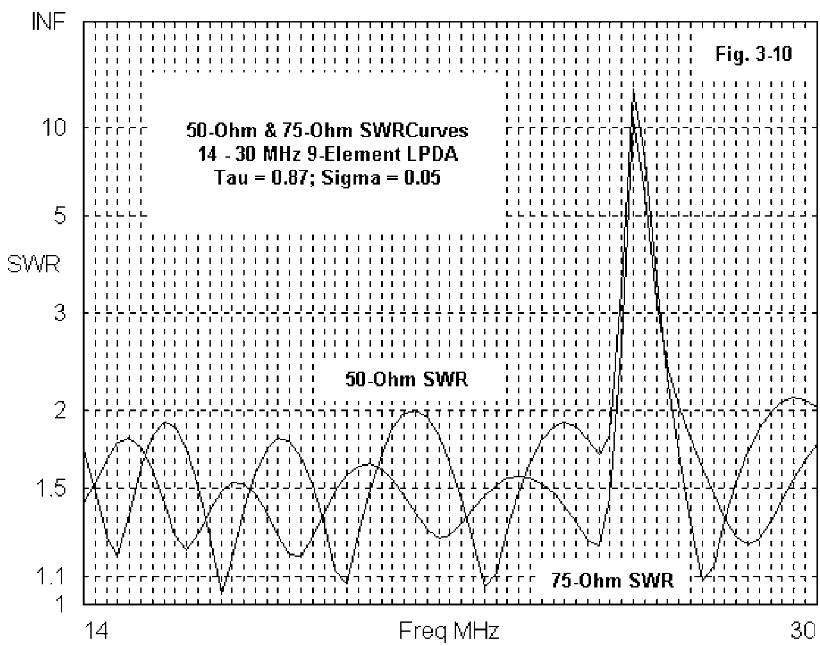


Fig. 3-9

The resistive and reactive components of the source impedance also demonstrate the same anomaly in performance, as illustrated in **Fig. 3-9**. At 26 MHz, both the resistance and reactance reach very high values. Anomalous points on an LPDA curve do not always show themselves with high resistive values—very low values are also common. However, the reactance is especially interesting, since it undergoes a sharp reversal of type, shifting rapidly from a high inductive reactance to a high capacitive reactance. Needless to say, for the region between about 25.5 and 26.25 MHz, the array would be virtually useless. Not only would the pattern be unsuited for transmission or reception, but as well, the array would provide a very large mismatch with whatever cable might be chosen as the main transmission line.

The normal portions of the resistance and reactance curves are also interesting. The median resistance value is close to 65 Ohms, giving a potential match for either 50-Ohm or 75-Ohm cable. The 100-Ohm phase line value was selected to yield just this result. However, the severity of any anomaly increases as we decrease the characteristic impedance of the phase line. Had we selected a phase line impedance closer to 250 Ohms, either the anomaly might be seriously reduced or it might disappear altogether.



Additionally, as with the optimized design, the reactance maximums occur when the resistance value is close to its median value, and the reactance is close to its own median value when the resistance departs most widely from its middle value. However, with the reduction in τ, we find that the reactance is no longer strictly capacitive. Instead, it fluctuates through both inductive and capacitive values across the passband.

The SWR curve, shown if **Fig. 3-10**, also replicates the behavior of the optimized design. The 50-Ohm and 75-Ohm curves do not trace the same peaks and valleys. The 75-Ohm curve shows a lower average value, although both cables would be usable. Of course, the anomaly in the 26-MHz region also appears in the SWR curves. Since the anomaly does not appear within an amateur band, the array might be successfully used on every amateur frequency from 14 through 29.7 MHz. However, before deciding to construct this particular design, carefully review the gain and front-to-back ratio curves to determine if they are adequate to a given set of operating goals. The array provides performance that is not better than that of a series of 2-element reflector-driver Yagi-Uda beams.

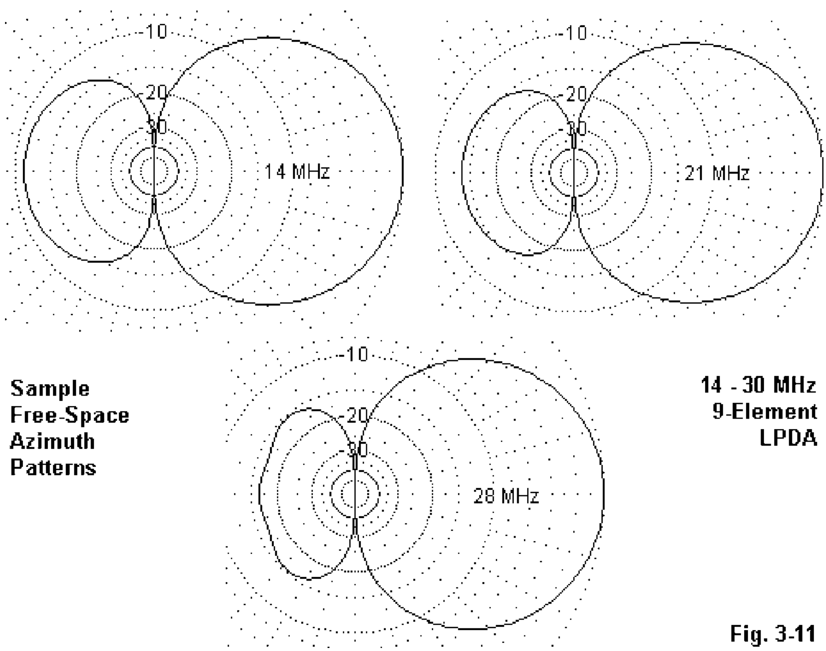


Fig. 3-11

Fig. 3-11 provides selected patterns for the array at the same frequencies sampled for the optimized array. These patterns are similar in forward gain and vary between 11 and 16 dB front-to-back ratio. The upper end of the operating passband holds up somewhat better than with the optimal array because of two factors. First, the lower value of τ tends to favor performance at the high end of the design spectrum. Second, the upper operating frequency was specified as 33 MHz in the design process. However, the lower value of τ also shows itself as a reduction in gain at the lower end of the design passband, with the free-space gain at 14 MHz falling to about 5.5 dBi.

In **Fig. 3-12**, we gain an appreciation for the lower general performance level and the higher degree of variability in performance provided by the smaller LPDA array. The figure provides a record of the relative current magnitude on each element of the array at the designated frequencies.

At 14 MHz, both rear elements are highly active, and the array might well benefit from a further element to the rear to improve the gain at this frequency. Likewise, the gain at 28 MHz is almost as low as at 14 MHz, and the scarceness of elements ahead of the most active element provides sufficient reason for the low level. Only at 21 MHz is there a good balance of active elements behind and ahead of the most active element, and the gain at this frequency is about 0.75 dB greater than at either of the other sampled frequencies.

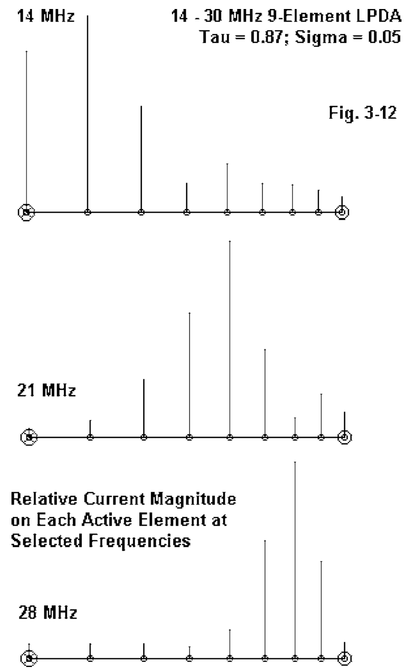


Fig. 3-12

Also notable in the relative magnitude graphics is the fact that elements far to the rear of the most active element remain noticeably active, although at a low level. In the optimal LPDA design, rearward elements tend to have almost no significant current. The presence of current on rearward elements that are considerably longer than the active element tends to indicate harmonic operation. At 26 MHz, the harmonic operation of rear element dominates the array and the pattern reverses. This sort of operation, of curse, is undesirable for an LPDA, and curatives are in order. We shall look at this problem in more detail in the next two chapters.

The aim of this chapter has been to understand some of the normal properties of LPDAs as revealed in detailed frequency sweeps of array models. Although this examination is far from complete, it has identified a number of LPDA characteristics not usually mentioned in literature available to radio amateurs. The periodic nature of almost all of the performance parameters (gain, front-to-back ratio, source resistance, and source reactance) of even the largest LPDAs has been of special note. Anomalies such as the 26 MHz pattern reversal in the smaller antenna, when encountered in very large arrays designed to cover an operating passband several octaves wide, also tend to reappear in periodic fashion.

Equally notable were the differences between large and small LPDA designs intended to cover the same operating passband. The low gain values and front-to-back ratios of the 9-element array suggest that obtaining performance competitive with multi-band Yagis and quads may require sizable LPDA structures. However, the LPDA, if well designed, is capable of providing full performance across each of the bands within its design spectrum, a goal which multi-band Yagis and quads often fail to meet.

With this chapter, we have completed our introduction into the calculation, modeling, and general characteristics of log periodic dipole arrays. Although incomplete in many respects, it forms a necessary background for entering into practical amateur LPDA design work. Those interested in the fundamentals of LPDA design—both theoretic and practical should take at least one of two steps. First, consult the classical literature or basic antenna text chapters on LPDAs, much of which is listed in the bibliography to Chapter 10 of *The ARRL Antenna Book*, 19th Edition. Second, obtain a good antenna modeling program and explore the properties of LPDA designs.

In the next section, we shall explore more typical amateur arrays, the majority of which are relatively short and sparsely populated with elements. Our goal will be to understand the problems of these types of arrays and to see what cures may be possible for under-performing LPDAs.

Part 2. Problems of and Cures for Under-Performing LPDAs

Chapter 4: Exploring LPDA Designs

In this exercise, I want to look at three questions:

1. How precisely does the value of τ affect the performance of an LPDA? There are some graphic curves in the literature, but they apply to a generalized gain value calculated for an entire array. Some judicious modeling in NEC might reveal how the array performance is affected across the entire passband assigned to a design.

2. What precisely is the effect of σ on LPDA performance? Suppose we keep a constant value of τ and then see—with reasonably well-constructed models—what the resulting effect will be on gain, front-to-back ratio, and feedpoint impedance as we vary σ. There are notices in the literature that tell us that the gain will decrease if we reduce σ and that we should not use values below 0.03. But hams do use values down to 0.02. How much do we lose (or gain, if we move in the other direction) for each increment of σ in a typical case?

3. Hams love short-boom antennas, hoping to gain the world with 1-pound antennas. What performance expectations should we have of short-boom LPDAs? How do τ and σ interrelate to yield array sizes that are practical and that we can term "good performers?" Although this exercise will not be an exhaustive study, it will start a process by which some combinations can be recommended as promising and others excluded as excessively deficient.

How shall I proceed? Most hams who use (or discuss) LPDAs work with designs that cover 14 to 30 MHz—or thereabouts. Because of the number of commercial and handbook designs available, working with that frequency range can be distracting. So I chose to work with the range of 7 to 15 MHz and to design independently a collection of models with which to work. In this way, I can focus on the questions of what τ and σ are doing to the array and its performance without worrying about whether I was treading on the toes of another designer or a manufacturer.

Of course, one can always scale the models by a factor of two--including the element diameter--to come up with a 14-30 MHz model that does exactly the same thing in free-space modeling. My outputs for this exercise consist of profiles of performance across the 7-15 MHz range at 0.5 MHz intervals. My object is to look at overall performance. Anyone interested in the models for more serious purposes would have to examine more closely the frequency bands of interest. Nonetheless, the 7 and 7.5 MHz results will give clues to 40-meter operation, while 10 MHz is close to 30 meters. The 14 and 14.5 MHz range gives an overview of probable 20 meter performance. But, again, a design of interest needs a frequency sweep in small intervals across each ham band.

Likewise, anyone contemplating scaling the model can get a usable impression by looking at 7 MHz for 20 meters, 9 MHz for 17, 10.5 MHz for 15, 12.5 MHz for 12, and 14-14.5 MHz for 10 meters. It pays in such cases to look at the values on either side of the target frequency to see trends that may be hopeful or worrisome.

All of the LPDAs in this initial exercise use element diameters of 1" for all elements. This value corresponds roughly to the equivalent uniform diameter that would emerge from common tapered element practice in this frequency range. Moreover, it scales to 0.5" in the next frequency range upward, which is also roughly the uniform element diameter emergent from tapered element schedules used from 20-10 meters. For consistency in this initial exercise, all LPDA designs use a 200-Ohm inter-element phasing line. An appendix at the end of this chapter lists the 11 models (plus one modified extra) used in this very basic study.

I have bypassed picturing each LPDA model, since they are all alike, varying only in the number of elements and the spacing between them. Instead, prepare yourself for some complex graphs, a few having some confusing zigzags.

What Does τ Do for My LPDA?

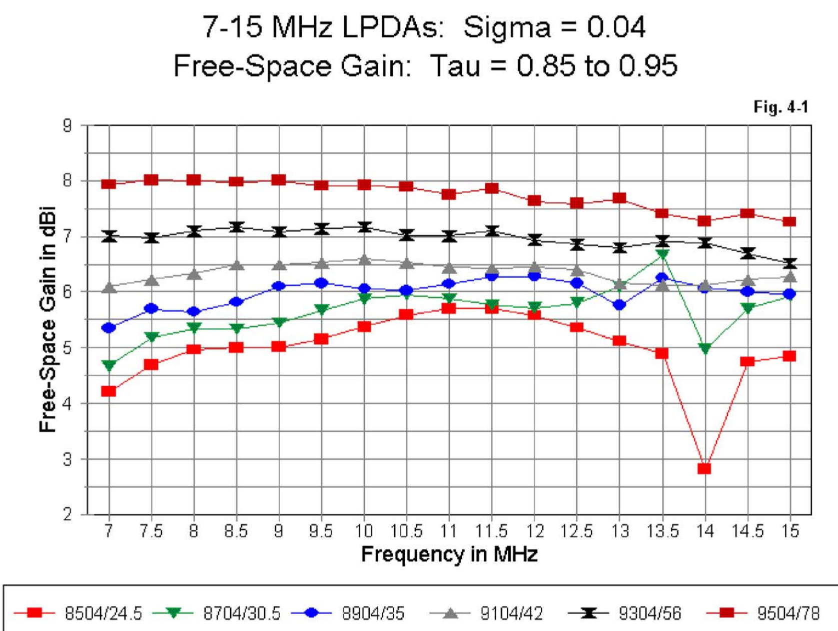
For a given value of σ—which sets the initial spacing between the rear two elements--the array length and number of elements will vary with the value of τ. The recommended values of τ are usually given as extending from 0.80 to 0.96. Suppose we survey values between 0.87 and 0.95 in intervals of 0.02.

A complete survey at fair increments would also develop a cross matrix of values of σ between 0.03 and about 0.05, the most common range for amateur LPDAs. However, in this short exercise, we can only sample a single value. So let’s arbitrarily pick 0.04 as falling in the middle of the range. With these selections of values, we obtain the array of arrays in **Table 4-1**.

Table 4-1. A Set of LPDAs with a Constant σ

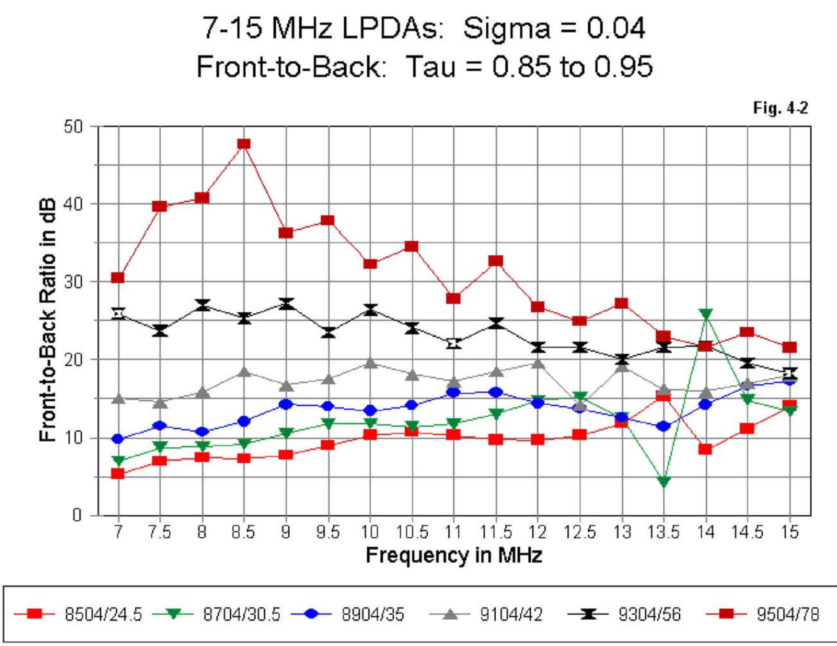
τ	No. of El.	Array length (feet)	Scaled length for 14-30 MHz	Model name
0.85	7	24.52'	12.3'	8504
0.87	9	30.51'	15.3'	8704
0.89	10	34.87'	17.5'	8904
0.91	12	42.35'	21.2'	9104
0.93	16	55.94'	28.0'	9304
0.95	22	77.87'	39.0'	9504

As you can see, there is a code in the model filenames, with the value of τ appearing first, followed by the value of σ. This practice will be followed throughout the exercise for ease of correlating the models in the appendix to the work at hand. Be-



cause calculations must work to an integral number of elements, the taper of the elements and the precise spacing between the first two elements will vary slightly from model to model.

Fig. 4-1 shows the modeled gain values. The first thing to notice is that the higher the value of τ, the higher the average gain of the array. However, some incremental increases appear to have greater affects on gain than others. Once τ is greater than about 0.90, the gain difference per 0.02 change in τ is about the same: about 0.5 dB on average. Moreover, the curves for values of τ above 0.90 are quite well behaved (meaning that they do not show large excursions in the gain value from one check frequency to the next).



Values of τ below 0.90 (for a σ of 0.04) show two significant phenomena. First, the gain values at the lower end of the passband are more significantly lower than the peak value for the curve. Second, values at the upper end of the passband are subject to sudden erratic changes that become worse as the value of τ decreases.

We shall have further notes on both these phenomena at various places along the way in this exercise. For now, let us note that the degree of erratic change at both ends of the gain curve does correlate inversely, although only roughly, to the number of elements in the array.

For all the curves, the gain tends to decrease toward the upper end of the pass-band relative to the peak value along the curve. What these 1-octave curves cannot show--in part because of the large interval between readings--is that the gain and other properties tend to move in waves with peaks and nulls, similar to those in the graphs in Chapter 3. The topmost curves for the highest values of τ tend to indicate this wave-like movement most clearly.

In **Fig. 4-2**, we have the 180-degree front-to-back curves for the 6 arrays. In a general way, the level of front-to-back ratio is a function of the gain at any particular place along the curves. Gain values below 5 dBi (free-space) rarely achieve a 10 dB ratio, while gain values above or close to 8 dBi are capable of front-to-back ratios of 30+ dB. In general, these high front-to-back ratios are not simply dimples in a broader front-to-rear lobe set. Rather, they represent reductions in the entire radiation pattern to the rear quadrants, as shown in **Fig. 4-3**. The rear pattern may be variable in shape as one changes frequency within the operating passband of a given LPDA design. Rarely, however, do we encounter deep nulls with large side lobes less than 20 dB down.

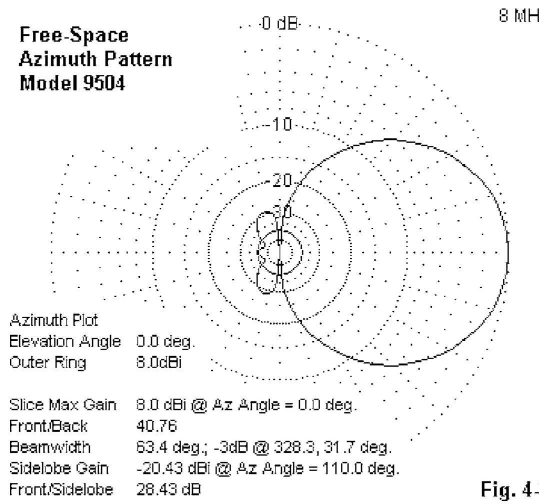
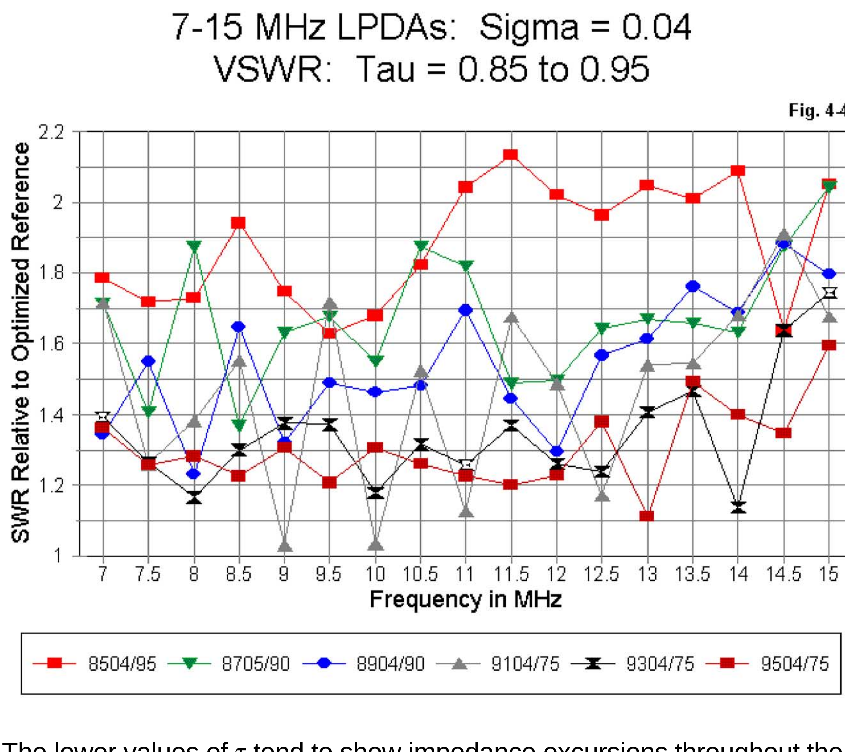


Fig. 4-3

As you progress to the right in **Fig. 4-2**, you will note the same sort of erratic behavior of models with lower values of τ. It is important to distinguish this behavior from the general trend toward reduced value in front-to-back ratios that accompanies similar gain trends for the models with the highest values of τ. We may also note that with a σ of 0.04, we do not achieve a consistent front-to-back ratio in excess of 20 dB until a τ value of .93.

The curves for SWR in **Fig. 4-4** form a confusing medley that requires good patience to sort. With increasing frequency, both the resistive and reactive components of the feedpoint impedance become more erratic, relative to general trends lower in the passband. Both resistance and reactance excursions show much wider limits. Hence, the selection of a reference impedance for taking the curve becomes tricky at best.



The lower values of τ tend to show impedance excursions throughout the passband that require a higher reference impedance in order to derive curves in which the values surpass 2:1 at as few places as possible. In contrast, the higher values of τ tend to yield flatter curves at the 75-Ohm reference level--again, with a 0.04 σ value and a 200-Ohm phase line. These curves are of greatest importance if one is interested in using the entire antenna passband. However, the SWR problem for lower values of τ (or for shorter arrays with fewer elements) can be overcome if one is interested in only selected portions of the passband--as would be the case for purely amateur radio applications. Changing the impedance of the phase line is one technique, while other correctives will appear in the next chapter.

Before we depart these curves for a constant σ and variable τ, let's look once more at the gain curves in **Fig. 4-1**. Why do the band edges tend to show lower gain values (and usually lower front-to-back ratios) than the mid-region of the passband? Part of the answer appears in **Fig. 4-5**. The patterns of current magnitude shown in this figure generally replicate those found in the sample LPDAs in Chapter 3, thus establishing that they are a general phenomenon of LPDAs and not just a feature of certain specific designs.

At 10 MHz for model 9304 (16 elements), there are at least 5 elements with high current levels, with several elements forward of this group having moderate current levels. Elements to the rear have lower and descending values. In essence, every element in an LPDA contributes in one or another way to the pattern formation, and the number of elements with a significant current level is far higher than general LPDA tradition usually allows.

Current Distribution in a 16-Element LPDA for 7-15 MHz at 3 Selected Frequencies. All Curves to Scale.

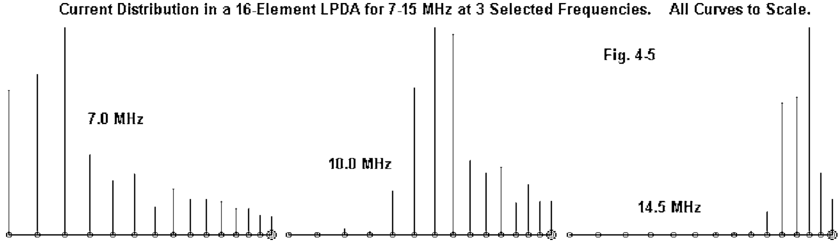


Fig. 4-5

At 7 MHz, there are once more 5 elements with the highest current levels, as well as elements with some current forward of that group. However, there is no element with significant current behind the group of 5. In a large array, such as 9304, the drop of gain at the low end of the passband is small. But, in arrays with only a small number of elements, the problem of low-end gain becomes much greater. The problem of "low-end" gain would be even worse had all of the models in this exercise not been designed with a lower frequency limit of 6.8 MHz, about 3% below the operational lowest frequency. Even though standard LPDA design sets the longest element at a frequency about 2% below the operationally selected low frequency, additional margins are necessary for adequate performance unless the design uses a relatively high number of elements and a correspondingly high value of τ.

At the high end of the passband, normal design procedure calculates the shortest element for a frequency 1.3 times the upper operating frequency. However, even this margin cannot fully compensate for the number of elements with moderate current levels at 10 MHz. The 15 MHz current distribution shows 6 elements with high levels, with elements to the rear having only modest to negligible current levels. Three of the 6 high-current elements have current levels that we might associate with Yagi directors--although the function of the elements of the two antenna types differs. Missing are elements forward of the group that have moderate current levels--gradually reducing the gain at the upper frequencies of the passband.

For each of the problems we have so far noted, there are compensating techniques. However, we shall reserve mention of them for the next chapter.

What Does σ Do for My LPDA?

For a given τ, the array length will vary in direct proportion to the value of σ. An array with a σ of 0.035 will be half as long as one with a σ of 0.07, if the value of τ is the same. However, the array will have the same number of elements.

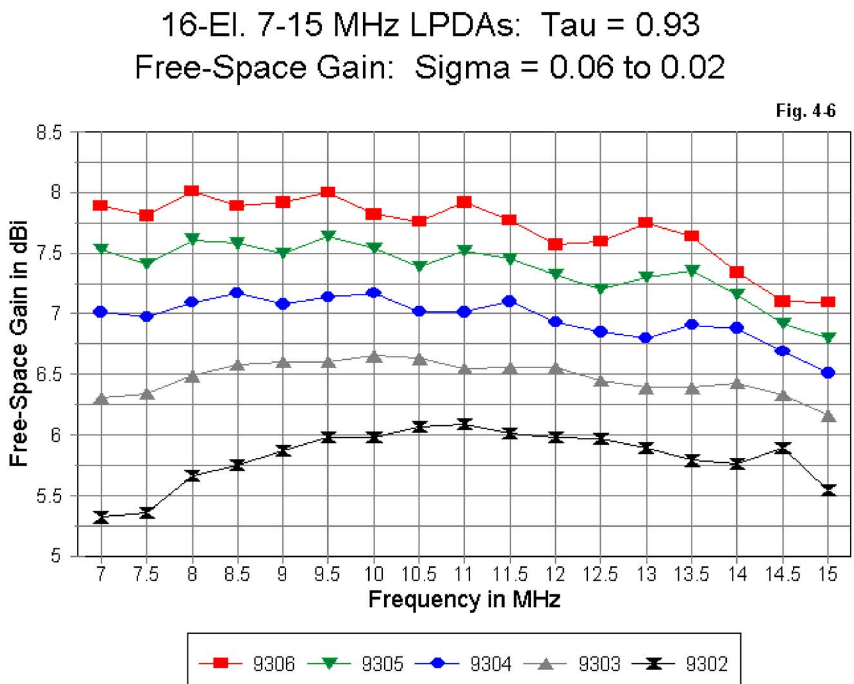
To see what σ values might mean for performance, I chose an arbitrary value of τ: 0.93. Actually, this value is not totally arbitrary. It is in the upper range of values. Hence, the value of σ is likely to have a significant effect on antenna parameters, if it has any effect at all. For the design range of 6.8 to 15 MHz, the resulting LPDAs all have 16 elements.

As noted earlier, I chose to set the lower frequency limit of the array design at 6.8 MHz rather than at the lowest operating frequency of 7.0 MHz. The result is an antenna whose performance comes nearly "up to speed" by the 7 MHz mark--unless the design has an inherently slow rise due to overall design factors. Likewise, the antenna lengths produced by a τ of 0.93 are not wholly outside of construction range, even in the 7-15 MHz range. **Table 4-2** gives the array lengths for LPDA with a τ of 0.93 and values of σ between 0.6 and 0.2.

Table 4-2. A Set of LPDAs with a Constant τ

σ	No. of El.	Array length (feet)	Scaled length for 14-30 MHz	Model name
0.06	16	83.92'	42.0'	9306
0.05	16	69.93'	35.0'	9305
0.04	16	55.94'	28.0'	9304
0.03	16	41.92'	21.0'	9303
0.02	16	27.97'	14.0'	9302

Although 84' is somewhat long for amateur construction, its scaled counterpart for 14-30 MHz is well within ham capabilities.



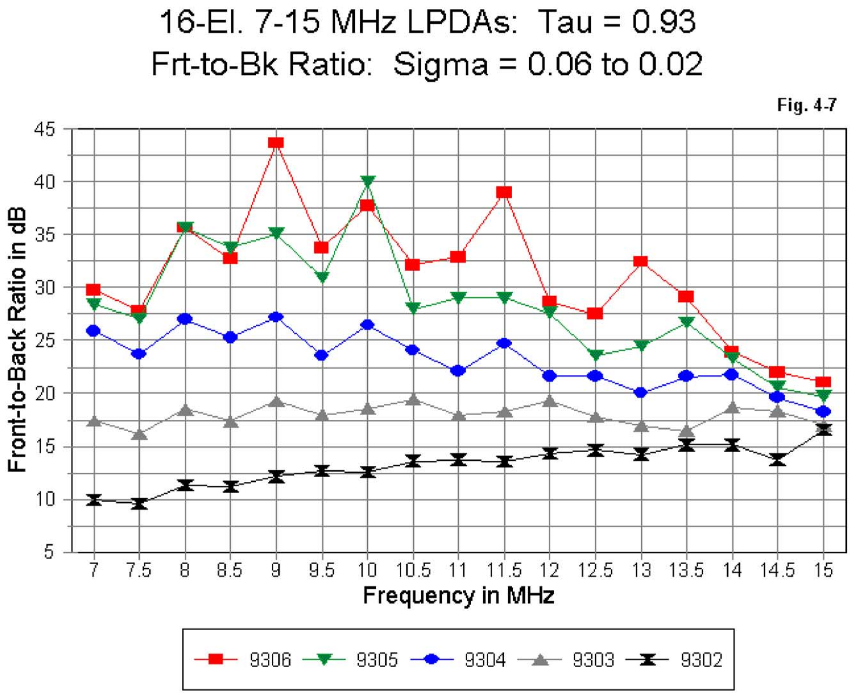
In **Fig. 4-6**, we can clearly see the "wave" motion of free-space gain values across the passband, especially for σ values from 0.04 upward. With a τ as high as 0.93, the curves show much less tendency toward erratic values. Moreover, except for the lowest value of σ, the average gain increase for every σ increase of 0.01 is about 0.5 dB. The relative evenness of the gain increase with increases in the value of σ stands in contrast to the curve in **Fig. 4-1**. There, the gain increase itself appears to become larger as we increase τ arithmetically. Because the curves are functions of complex geometric properties of the antenna structure--including the individual element lengths and spacings—a more precise quantification of the relationship would involve many other variables.

As a point of reference, model 9304 appears in the graphs for both the constant-τ and the constant-σ graphs. Using this reference, we might note that the curve for model 9306 in the constant-τ graph is roughly comparable to the curve for model 9504 in the constant-σ graph. The "2-point" differential in both models relative to 9304 should not go unnoticed. However, 9504 has 22 elements on a 77' boom, while 9304 has 16 elements on an 84' boom. Additional elements can go some ways toward smoothing curves and reducing the rate of higher-frequency gain decrease.

At the other end of the scale, model 9302 is interesting, despite the fact that the σ value falls below recommended levels. This 14' long array shows a relatively smooth gain curve, with little sign of erratic behavior, owing to the relative high value of τ involved. The front-to-back curve in **Fig. 4-7** shows those values to be equally well-behaved. However, 16 elements is normally more than short-boom LPDA designers desire.

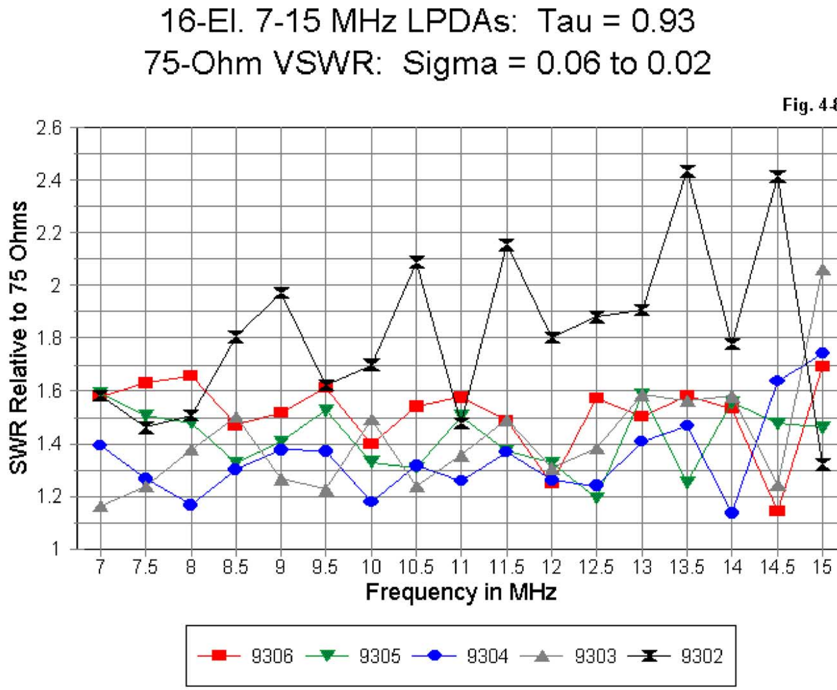
Like the gain curve, the front-to-back curve for the highest performing models in **Fig. 4-7** shows a rapid decrease at the upper end of the passband. Arrays with a σ of 0.04 or higher (for a τ of 0.93) show an average front-to-back ratio of better than 20 dB.

Interestingly, the highest performing antenna models show the most variability in front-to-back ratio. This fact stems from the shapes taken by the rearward lobes as we change frequency and other antenna characteristics. At some frequencies, the rear lobes will look like the "bow-tie" of **Fig. 4-3**. At other frequencies, the lobe will be a small "bell," which decreases the front-to-back ratio without changing the amount of energy radiated rearward. In general, one may mentally smooth all front-to-back ratio curves in excess of 30 dB without significant distortion to actual antenna performance.



Some designers believe that the second element length at the lowest operating frequency should be near resonance. This theory is incomplete, since all of the elements--place for place--in this series of models are the same length. Yet the transition from 7 to 7.5 MHz in the gain curve is upward in 4 models and downward in 2. Much more consistent is the front-to-back pattern, which shows a downward turn in all models from 7 to 7.5 MHz, with a subsequent upward turn. Only the spacing of the elements has changed in this sequence.

The SWR curves in **Fig. 4-8** for the collection of LPDA designs show the usual morass of twists. All are referenced to 75 Ohms in this case for a number of reasons. Most important is the fact that as one increases the value of σ, using a 200-Ohm inter-element phase line, the "natural" reference impedance as we increase the value of τ should be higher--something closer to 100 Ohms. The higher level would reduce the SWR values of these curves and better suit the arrays to the use of a wide-band 2:1 matching device for a 50-Ohm coax main feedline.



Nonetheless, all of the higher-τ curves fall tamely within a 1.8:1 75-Ohm SWR level. Only the lower two values of σ result in values that exceed 2:1, and for model 9303, only at 15 MHz. In contrast is **Fig. 4-4**, the SWR curve for the constant-σ, variable-τ exercise, where a number of models show values in excess of 1.8:1 when referenced to an optimized level. All of those models have τ values of 0.91 or less, suggesting that perhaps higher τ values tend to level SWR excursions.

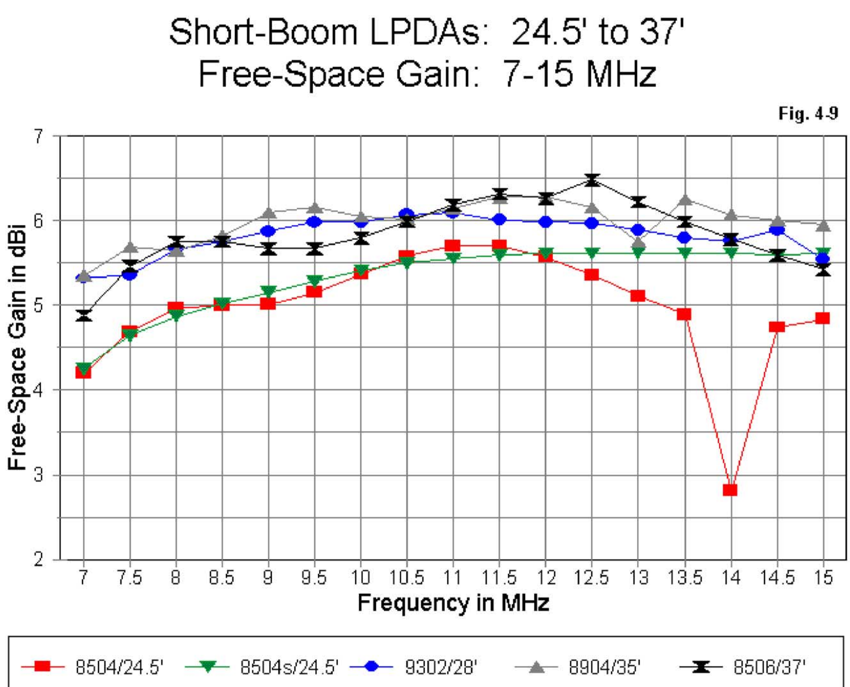
Once more, model 9304, with a boom length of 56' for the 7-15 MHz range, marks a certain breaking point. LPDA arrays with τ values of at least 0.93 AND σ values of at least 0.3 tend to be the most stable in almost all performance categories without any need for compensatory actions to improve the performance of the design. However, 56' (or 28' in the 20-10 meters version) is a fairly sizable array. Many hams are looking for short-booms and high performance.

What Should I Expect From My Short-Boom LPDA?

It is not possible to answer our third question exhaustively, but some sort of suggestive answer may be possible. I have gathered together the models we have so-far explored with lengths of 35' or less. I added to it another "stray design" with a 37' length. (Translated by a factor of 2, the upper HF boom length would be under 20' for all of these models.) Here are the particulars for the short-boom LPDA designs.

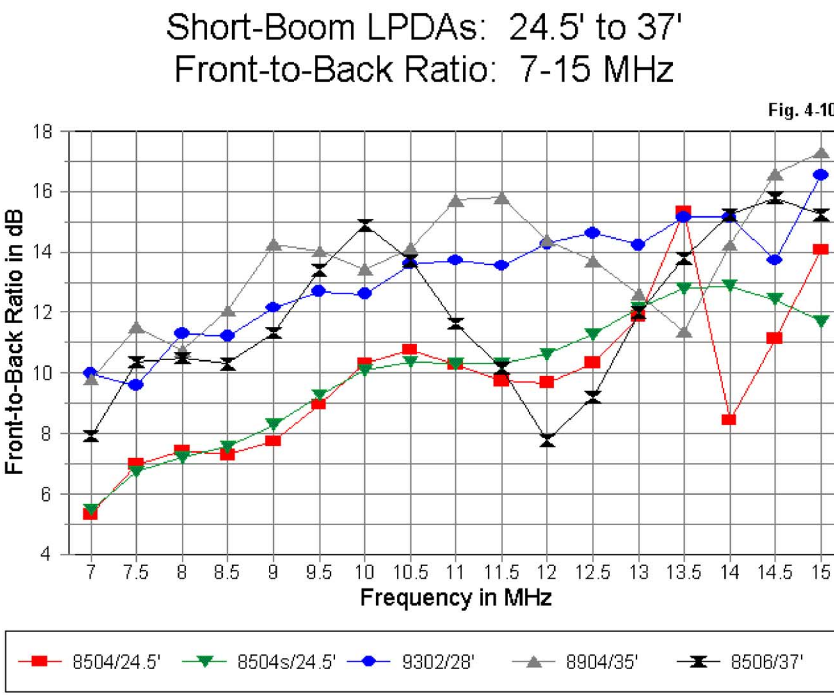
Table 4-3. A Set of Short-Boom LPDAs

Model	Length	No. of El.	τ	σ
8504	24.52'	7	0.85	0.06
9302	27.97'	16	0.93	0.02
8904	34.87'	10	0.89	0.04
8506	36.77'	7	0.89	0.06



In the graphs to follow, there is also a variant of model 8504 that we shall discuss after some more general notes on these models.

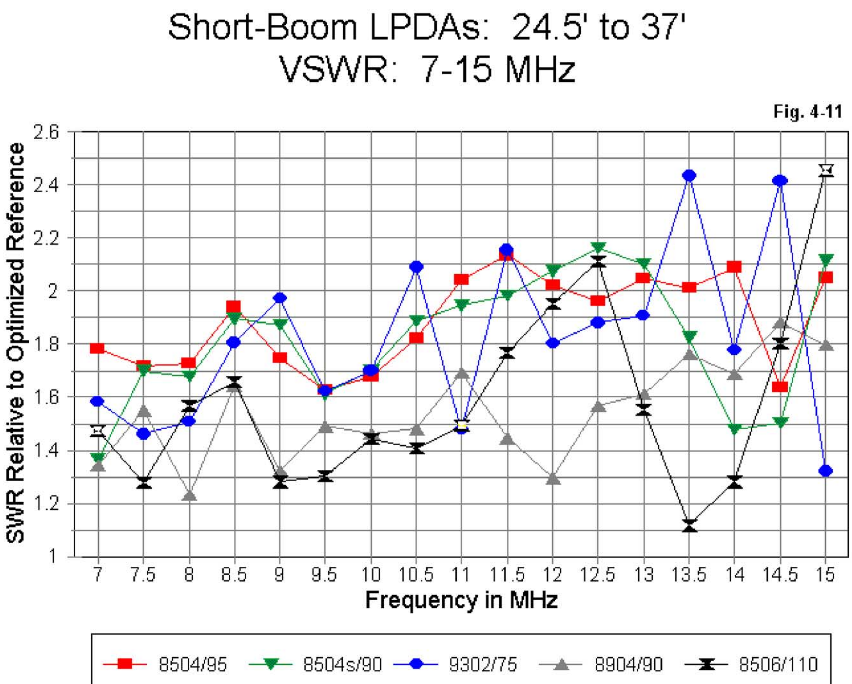
In **Fig. 4-9** are the free-space gain curves for the models in this group. Note that they fall into two general groups. 9302, 8904, and 8506 all have very comparable gain curves, with a maximum variation of about 0.25 dB. Hence, there is little to choose among them. 9302 has the shortest boom of the lot, but also requires a higher number of elements than any other model.



The two versions of model 8504 have lesser gain, although the curves in the main are congruent with those of the higher-gain group. The precipitous drop in gain of the basic 8504 model at 14 MHz is corrected in the model called 8504s. 8504 is noteworthy for having the shortest length of all of the models.

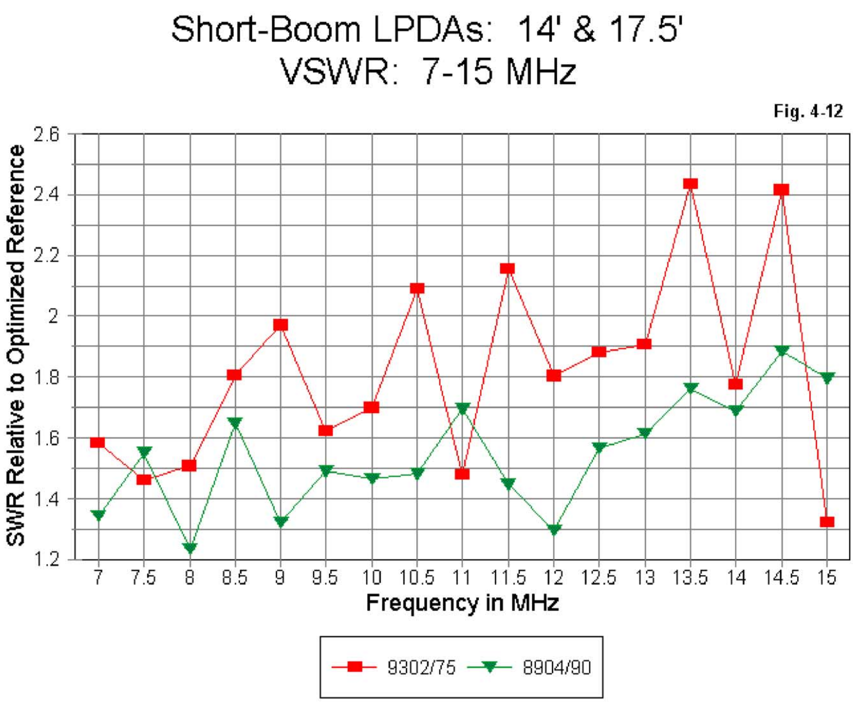
Boom length makes a difference to the front-to-back ratio as well as to gain. In **Fig. 4-10**, we can identify a 14 MHz drop in front-to-back ratio for 8504. Note, however, that the drop is preceded by an erratic rise in front-to-back ratio at 13.5 MHz. This phenomenon is not unusual: erratic performance is often forecast by an unnatural rise in performance at a slightly lower frequency.

The same generic type of forecast is offered to model 8506 by the drop in front-to-back ratio at 12 MHz, followed by a notable, but only slightly better value at 12.5 MHz. The anomaly in the performance of model 8506 is at 12.5 MHz with the sudden peak in gain--not a very large peak, but noticeable in relationship to the general trend in the curve. A similar glitch in the smooth curves occurs with model 8904 with a front-to-back warning at 13 MHz and further drop at 13.5 MHz: watch the gain curve for this model from 12.5 to 13.5 MHz.



These exceptions to smooth curves are common for short-boom LPDAs. Otherwise, the curves for front-to-back ratios again divide themselves between those for 8504 and for the longer-boom designs.

The SWR curves, set out in **Fig. 4-11**, will also show some of the same anomalies, even though they are each matched to an optimized reference impedance. With a 200-Ohm inter-element phase line, it is almost impossible to achieve a curve with values under 2:1 at the antenna feedpoint for the entirety of the passband--without using some compensatory measures or using only selected portions of the passband.



One of the models in the group is a "sleeper." That is, it has a reasonable 90-Ohm SWR curve with no value higher than 1.9. The SWR curve for model 8904 appears in **Fig. 4-12** with the curve for 9302 as a contrast. These two antennas exhibit the best gain and front-to-back curves of the group, but 9302--with its very low value for σ and its 16 elements--would still be a more difficult antenna to match to a coaxial cable. It is more likely that 8904 would work well into 50-Ohm coax with an intervening 2:1 broadband impedance matching device.

However, let's not give up on the shortest boom model, 8504, before trying to fix the anomalies in all of its curves. The critical frequency for this antenna is 14 MHz.

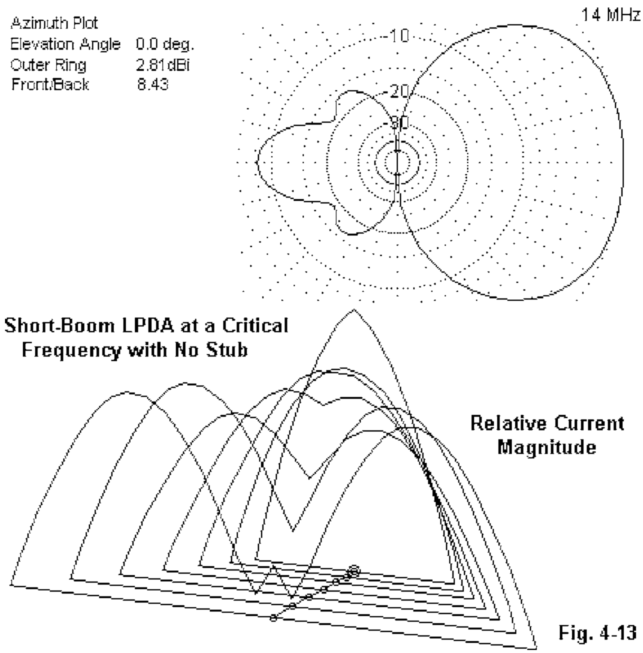


Fig. 4-13

In **Fig. 4-13**, we can see the problematical azimuth pattern, as well as its source. In every other well-behaved current distribution curve, we saw only one current peak per wire, whatever the frequency within the passband and whatever the wire length. However, with 8504, the rearmost wires are operating in a true harmonic mode, with double peaks of current. These double peaks radiate both forward and rearward, widening the forward lobe and producing very significant rearward radiation. In this short-boom design with only 7 elements, the inter-element phase line is not terminated properly to prevent this mode of operation. Note also that forward-most element carries the highest current level.

The solution to the problem, known almost as long as LPDAs have been designed, is to change the termination of the rear-most element by adding a shorted stub. In model 8504s, a 36", 600-Ohm stub has been added to the rear of the model. The exact value is not critical, and further tweaking is certainly possible. The results of adding this stub are visible in all of the short-boom graphs and in **Fig. 4-14**.

The array's gain and front-to-back ratio have been returned to normal, relative to curves for LPDAs with τ and σ values in the ballpark of those for model 8504. Why this happens appears in the current distribution curve. The stub prevents the rear-most elements from operating in a harmonic mode by changing the element source impedances. In fact, the SWR for the array goes down between 13.5 and 14.5 MHz, relative to the uncorrected version. Moreover, the second most forward element now shows the highest current level, just where the peak should be for an array of this size. The array has been saved for valuable use--if operating needs call for an LPDA of this small size and for the modest gain and front-to-back characteristics it offers.

More?

The use of a stub to change the operating characteristics of an LPDA over part of its frequency range is but one of a number of ways in which LPDA designers find higher performance than the levels offered by the basic models. Among other techniques we might try are the following:

1. Changing some of the design criteria.

2. Changing the inter-element phase line impedance.

3. Varying τ and/or σ along the array length.

4. Changing the element diameters.

Some of these measures are easy to implement, but others require a good bit of fundamental redesign. Since this chapter is already too long, we shall likely have to work up another to cover them--as soon as I finish the complete cross-matrix of models with τ values from 0.85 to 0.95 (interval 0.02) and σ values from 0.02 to 0.06 (interval 0.01). Remember that we have only sampled the field, and hence, any conclusions can only be very tentative so far.

Incidentally, there is a model LPDA for the 7-15 MHz range with a gain at 7 MHz of 11.5 dBi and a gain at 14.5 of 10.3 dBi, all with a feedpoint impedance across the range that will match either 50 or 75 Ohms with smoothness and ease. Unfortunately, the antenna's 27 elements require 434 feet.

Appendix: Some LPDA Model Descriptions

As in previous chapters, wherever the TL phase-line entries are perfectly standard, only the first and last 2 entries are shown, along with any stub that may be part of the model.

9504:

```
6.8-15 MHz .95/.04                  Frequency = 7  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             0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  33
2            70.848,-420.66,  0.000        70.848,420.660,  0.000 1.00E+00  31
3           138.154,-399.63,  0.000       138.154,399.627,  0.000 1.00E+00  29
4           202.094,-379.65,  0.000       202.094,379.646,  0.000 1.00E+00  27
5           262.837,-360.66,  0.000       262.837,360.663,  0.000 1.00E+00  27
6           320.543,-342.63,  0.000       320.543,342.630,  0.000 1.00E+00  25
7           375.364,-325.50,  0.000       375.364,325.499,  0.000 1.00E+00  23
8           427.444,-309.22,  0.000       427.444,309.224,  0.000 1.00E+00  23
9           476.920,-293.76,  0.000       476.920,293.763,  0.000 1.00E+00  21
10          523.922,-279.07,  0.000       523.922,279.074,  0.000 1.00E+00  21
11          568.574,-265.12,  0.000       568.574,265.121,  0.000 1.00E+00  19
12          610.993,-251.86,  0.000       610.993,251.865,  0.000 1.00E+00  19
13          651.291,-239.27,  0.000       651.291,239.271,  0.000 1.00E+00  17
14          689.575,-227.31,  0.000       689.575,227.308,  0.000 1.00E+00  17
15          725.944,-215.94,  0.000       725.944,215.942,  0.000 1.00E+00  15
16          760.495,-205.15,  0.000       760.495,205.145,  0.000 1.00E+00  15
17          793.318,-194.89,  0.000       793.318,194.888,  0.000 1.00E+00  15
18          824.500,-185.14,  0.000       824.500,185.144,  0.000 1.00E+00  13
19          854.123,-175.89,  0.000       854.123,175.887,  0.000 1.00E+00  13
20          882.265,-167.09,  0.000       882.265,167.092,  0.000 1.00E+00  13
21          909.000,-158.74,  0.000       909.000,158.738,  0.000 1.00E+00  11
22          934.398,-150.80,  0.000       934.398,150.801,  0.000 1.00E+00  11
```

```
                  -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    22 / 50.00   ( 22 / 50.00)      0.707       0.000       V

                  -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
20    20/50.0  ( 20/50.0)   21/50.0  ( 21/50.0)  Actual dist  200.0  1.00  R
21    21/50.0  ( 21/50.0)   22/50.0  ( 22/50.0)  Actual dist  200.0  1.00  R
```

9104:

```
6.8-15 MHz .91/.04                      Frequency = 7  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            0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  31
2           70.848,-402.95,  0.000        70.848,402.948,  0.000 1.00E+00  29
3          135.320,-366.68,  0.000       135.320,366.683,  0.000 1.00E+00  25
4          193.989,-333.68,  0.000       193.989,333.681,  0.000 1.00E+00  23
5          247.378,-303.65,  0.000       247.378,303.650,  0.000 1.00E+00  21
6          295.962,-276.32,  0.000       295.962,276.321,  0.000 1.00E+00  19
7          340.173,-251.45,  0.000       340.173,251.452,  0.000 1.00E+00  17
8          380.406,-228.82,  0.000       380.406,228.822,  0.000 1.00E+00  17
9          417.017,-208.23,  0.000       417.017,208.228,  0.000 1.00E+00  15
10         450.334,-189.49,  0.000       450.334,189.487,  0.000 1.00E+00  13
11         480.652,-172.43,  0.000       480.652,172.434,  0.000 1.00E+00  13
12         508.241,-156.91,  0.000       508.241,156.915,  0.000 1.00E+00  11

                  -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    12 / 50.00   ( 12 / 50.00)      0.707       0.000       V
```

```
                 -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1       1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2       2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
10     10/50.0  ( 10/50.0)   11/50.0  ( 11/50.0)  Actual dist  200.0  1.00  R
11     11/50.0  ( 11/50.0)   12/50.0  ( 12/50.0)  Actual dist  200.0  1.00  R
```

8704

```
6.8-15 .87/.04                          Frequency = 7  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            0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  33
2           70.848,-385.24,  0.000        70.848,385.236,  0.000 1.00E+00  29
3          132.486,-335.16,  0.000       132.486,335.155,  0.000 1.00E+00  25
4          186.111,-291.59,  0.000       186.111,291.585,  0.000 1.00E+00  23
5          232.764,-253.68,  0.000       232.764,253.679,  0.000 1.00E+00  19
6          273.353,-220.70,  0.000       273.353,220.701,  0.000 1.00E+00  17
7          308.665,-192.01,  0.000       308.665,192.010,  0.000 1.00E+00  15
8          339.387,-167.05,  0.000       339.387,167.048,  0.000 1.00E+00  13
9          366.114,-145.33,  0.000       366.114,145.332,  0.000 1.00E+00  11

                 -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6     9 / 50.00   (  9 / 50.00)      0.707       0.000       V

                 -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1       1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2       2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
7       7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  200.0  1.00  R
8       8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  200.0  1.00  R
```

9306

```
6.8-15 MHz 16 el .93/.06                Frequency = 7  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            0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  27
2          106.272,-411.80,  0.000       106.272,411.804,  0.000 1.00E+00  27
3          205.105,-382.98,  0.000       205.105,382.978,  0.000 1.00E+00  25
4          297.020,-356.17,  0.000       297.020,356.169,  0.000 1.00E+00  23
5          382.500,-331.24,  0.000       382.500,331.237,  0.000 1.00E+00  21
6          461.997,-308.05,  0.000       461.997,308.051,  0.000 1.00E+00  21
7          535.929,-286.49,  0.000       535.929,286.487,  0.000 1.00E+00  19
8          604.686,-266.43,  0.000       604.686,266.433,  0.000 1.00E+00  19
9          668.630,-247.78,  0.000       668.630,247.783,  0.000 1.00E+00  17
10         728.098,-230.44,  0.000       728.098,230.438,  0.000 1.00E+00  15
11         783.403,-214.31,  0.000       783.403,214.307,  0.000 1.00E+00  15
12         834.837,-199.31,  0.000       834.837,199.306,  0.000 1.00E+00  15
13         882.670,-185.35,  0.000       882.670,185.354,  0.000 1.00E+00  13
14         927.156,-172.38,  0.000       927.156,172.380,  0.000 1.00E+00  13
15         968.527,-160.31,  0.000       968.527,160.313,  0.000 1.00E+00  11
16         1007.00,-149.09,  0.000       1007.00,149.091,  0.000 1.00E+00  11

                     -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    16 / 50.00   ( 16 / 50.00)      0.707       0.000       V

                     -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
14    14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  200.0  1.00  R
15    15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  200.0  1.00  R
```

9305

```
6.8-15 MHz 16 el .93/.05              Frequency = 7  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            0.000,-442.80,  0.000          0.000,442.800,  0.000 1.00E+00  27
2           88.560,-411.80,  0.000         88.560,411.804,  0.000 1.00E+00  27
3          170.921,-382.98,  0.000        170.921,382.978,  0.000 1.00E+00  25
4          247.516,-356.17,  0.000        247.516,356.169,  0.000 1.00E+00  23
5          318.750,-331.24,  0.000        318.750,331.237,  0.000 1.00E+00  21
6          384.998,-308.05,  0.000        384.998,308.051,  0.000 1.00E+00  21
7          446.608,-286.49,  0.000        446.608,286.487,  0.000 1.00E+00  19
8          503.905,-266.43,  0.000        503.905,266.433,  0.000 1.00E+00  19
9          557.192,-247.78,  0.000        557.192,247.783,  0.000 1.00E+00  17
10         606.748,-230.44,  0.000        606.748,230.438,  0.000 1.00E+00  15
11         652.836,-214.31,  0.000        652.836,214.307,  0.000 1.00E+00  15
12         695.698,-199.31,  0.000        695.698,199.306,  0.000 1.00E+00  15
13         735.559,-185.35,  0.000        735.559,185.354,  0.000 1.00E+00  13
14         772.630,-172.38,  0.000        772.630,172.380,  0.000 1.00E+00  13
15         807.106,-160.31,  0.000        807.106,160.313,  0.000 1.00E+00  11
16         839.168,-149.09,  0.000        839.168,149.091,  0.000 1.00E+00  11

                   -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    16 / 50.00   ( 16 / 50.00)      0.707       0.000       V

                   -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
14    14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  200.0  1.00  R
15    15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  200.0  1.00  R
```

9304

```
.93/.04 6.88-15 MHz                  Frequency = 7  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           0.000,-442.80,  0.000        0.000,442.800,  0.000 1.00E+00  27
2          70.848,-411.80,  0.000       70.848,411.804,  0.000 1.00E+00  27
3         136.737,-382.98,  0.000      136.737,382.978,  0.000 1.00E+00  25
4         198.013,-356.17,  0.000      198.013,356.169,  0.000 1.00E+00  23
5         255.000,-331.24,  0.000      255.000,331.237,  0.000 1.00E+00  21
6         307.998,-308.05,  0.000      307.998,308.051,  0.000 1.00E+00  21
7         357.286,-286.49,  0.000      357.286,286.487,  0.000 1.00E+00  19
8         403.124,-266.43,  0.000      403.124,266.433,  0.000 1.00E+00  19
9         445.754,-247.78,  0.000      445.754,247.783,  0.000 1.00E+00  17
10        485.399,-230.44,  0.000      485.399,230.438,  0.000 1.00E+00  15
11        522.269,-214.31,  0.000      522.269,214.307,  0.000 1.00E+00  15
12        556.558,-199.31,  0.000      556.558,199.306,  0.000 1.00E+00  15
13        588.447,-185.35,  0.000      588.447,185.354,  0.000 1.00E+00  13
14        618.104,-172.38,  0.000      618.104,172.380,  0.000 1.00E+00  13
15        645.684,-160.31,  0.000      645.684,160.313,  0.000 1.00E+00  11
16        671.334,-149.09,  0.000      671.334,149.091,  0.000 1.00E+00  11

                     -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    16 / 50.00   ( 16 / 50.00)      0.707       0.000       V

                     -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
14    14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  200.0  1.00  R
15    15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  200.0  1.00  R
```

9303

.98/.03 6.8-15 MHz Frequency = 7 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		0.000,-442.80, 0.000		0.000,442.800, 0.000	1.00E+00	27
2		53.136,-411.80, 0.000		53.136,411.804, 0.000	1.00E+00	27
3		102.552,-382.98, 0.000		102.552,382.978, 0.000	1.00E+00	25
4		148.510,-356.17, 0.000		148.510,356.169, 0.000	1.00E+00	23
5		191.250,-331.24, 0.000		191.250,331.237, 0.000	1.00E+00	21
6		230.999,-308.05, 0.000		230.999,308.051, 0.000	1.00E+00	21
7		267.965,-286.49, 0.000		267.965,286.487, 0.000	1.00E+00	19
8		302.343,-266.43, 0.000		302.343,266.433, 0.000	1.00E+00	19
9		334.315,-247.78, 0.000		334.315,247.783, 0.000	1.00E+00	17
10		364.049,-230.44, 0.000		364.049,230.438, 0.000	1.00E+00	15
11		391.702,-214.31, 0.000		391.702,214.307, 0.000	1.00E+00	15
12		417.418,-199.31, 0.000		417.418,199.306, 0.000	1.00E+00	15
13		441.335,-185.35, 0.000		441.335,185.354, 0.000	1.00E+00	13
14		463.578,-172.38, 0.000		463.578,172.380, 0.000	1.00E+00	13
15		484.263,-160.31, 0.000		484.263,160.313, 0.000	1.00E+00	11
16		503.501,-149.09, 0.000		503.501,149.091, 0.000	1.00E+00	11

-------------- SOURCES --------------

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	6	16 / 50.00	(16 / 50.00)	0.707	0.000	V

-------- TRANSMISSION LINES ---------

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	200.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	200.0	1.00	R
. . .								
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	200.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	200.0	1.00	R

9302

```
.93/.02 6.88-15 MHz                    Frequency = 7  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            0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  27
2           35.424,-411.80,  0.000        35.424,411.804,  0.000 1.00E+00  27
3           68.369,-382.98,  0.000        68.369,382.978,  0.000 1.00E+00  25
4           99.007,-356.17,  0.000        99.007,356.169,  0.000 1.00E+00  23
5          127.500,-331.24,  0.000       127.500,331.237,  0.000 1.00E+00  21
6          153.999,-308.05,  0.000       153.999,308.051,  0.000 1.00E+00  21
7          178.643,-286.49,  0.000       178.643,286.487,  0.000 1.00E+00  19
8          201.562,-266.43,  0.000       201.562,266.433,  0.000 1.00E+00  19
9          222.877,-247.78,  0.000       222.877,247.783,  0.000 1.00E+00  17
10         242.700,-230.44,  0.000       242.700,230.438,  0.000 1.00E+00  15
11         261.135,-214.31,  0.000       261.135,214.307,  0.000 1.00E+00  15
12         278.279,-199.31,  0.000       278.279,199.306,  0.000 1.00E+00  15
13         294.224,-185.35,  0.000       294.224,185.354,  0.000 1.00E+00  13
14         309.052,-172.38,  0.000       309.052,172.380,  0.000 1.00E+00  13
15         322.842,-160.31,  0.000       322.842,160.313,  0.000 1.00E+00  11
16         335.668,-149.09,  0.000       335.668,149.091,  0.000 1.00E+00  11

                  -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    16 / 50.00   ( 16 / 50.00)      0.707       0.000       V

                  -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1       1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2       2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
14    14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  200.0  1.00  R
15    15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  200.0  1.00  R
```

8506

```
6.8-15 MHz .85/.06                     Frequency = 7  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            0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  29
2          106.272,-376.38,  0.000       106.272,376.380,  0.000 1.00E+00  25
3          196.603,-319.92,  0.000       196.603,319.923,  0.000 1.00E+00  21
4          273.385,-271.93,  0.000       273.385,271.935,  0.000 1.00E+00  17
5          338.649,-231.14,  0.000       338.649,231.144,  0.000 1.00E+00  15
6          394.124,-196.47,  0.000       394.124,196.473,  0.000 1.00E+00  13
7          441.277,-167.00,  0.000       441.277,167.002,  0.000 1.00E+00  11

                   -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6     7 / 50.00   (  7 / 50.00)      0.707       0.000       V

                   -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
5      5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
6      6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
```

8904

```
6.8-15 MHz .89/.04                  Frequency = 7  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            0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  31
2           70.848,-394.09,  0.000        70.848,394.092,  0.000 1.00E+00  27
3          133.903,-350.74,  0.000       133.903,350.742,  0.000 1.00E+00  25
4          190.021,-312.16,  0.000       190.021,312.160,  0.000 1.00E+00  23
```

```
5          239.967,-277.82,  0.000      239.967,277.823,  0.000 1.00E+00  19
6          284.419,-247.26,  0.000      284.419,247.262,  0.000 1.00E+00  17
7          323.981,-220.06,  0.000      323.981,220.063,  0.000 1.00E+00  15
8          359.191,-195.86,  0.000      359.191,195.856,  0.000 1.00E+00  13
9          390.528,-174.31,  0.000      390.528,174.312,  0.000 1.00E+00  13
10         418.418,-155.14,  0.000      418.418,155.138,  0.000 1.00E+00  11

                  -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    10 / 50.00   ( 10 / 50.00)      0.707       0.000       V

                  -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)               Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
8      8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  200.0  1.00  R
9      9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  200.0  1.00  R
```

8504S (Stub)

```
6.8-15 .85/.04                         Frequency = 7  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            0.000,-442.80,  0.000        0.000,442.800,  0.000 1.00E+00  29
2           70.848,-376.38,  0.000       70.848,376.380,  0.000 1.00E+00  25
3          131.069,-319.92,  0.000      131.069,319.923,  0.000 1.00E+00  21
4          182.257,-271.93,  0.000      182.257,271.935,  0.000 1.00E+00  17
5          225.766,-231.14,  0.000      225.766,231.144,  0.000 1.00E+00  15
6          262.749,-196.47,  0.000      262.749,196.473,  0.000 1.00E+00  13
7          294.185,-167.00,  0.000      294.185,167.002,  0.000 1.00E+00  11

                  -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6     7 / 50.00   (  7 / 50.00)      0.707       0.000       V
```

```
                    -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1       1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2       2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
5       5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
6       6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
7       1/50.0  (  1/50.0)  Short ckt (Short ck)   36.000 in   600.0  1.00
```

8504 (No Stub)

```
6.8-15 .85/.04                             Frequency = 7  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            0.000,-442.80,  0.000          0.000,442.800,  0.000 1.00E+00  29
2           70.848,-376.38,  0.000         70.848,376.380,  0.000 1.00E+00  25
3          131.069,-319.92,  0.000        131.069,319.923,  0.000 1.00E+00  21
4          182.257,-271.93,  0.000        182.257,271.935,  0.000 1.00E+00  17
5          225.766,-231.14,  0.000        225.766,231.144,  0.000 1.00E+00  15
6          262.749,-196.47,  0.000        262.749,196.473,  0.000 1.00E+00  13
7          294.185,-167.00,  0.000        294.185,167.002,  0.000 1.00E+00  11

                    -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6     7 / 50.00   (  7 / 50.00)      0.707       0.000       V

                    -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1       1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2       2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
.  .  .
5       5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
6       6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
```

Chapter 5: Strategies for Improving Basic Designs

In Chapter 4, we looked at the effects of varying τ and σ (over a limited range of samples) and at some short-boom LPDAs. All of the designs used standard calculation techniques. In addition, each was assigned a 200-Ohm inter-element phasing line, according to general recommendations. Since our frequency range for the exercise is 7 to 15 MHz, we selected a standard 1" uniform diameter for every element of every design. The only concession we made to improvement was to decrease the lower design frequency from the 7 MHz operational limit to 6.8 MHz to ensure a reasonable gain at the low end of the passband.

In this part of the exercise, let's explore some of the means that might be used to improve the performance of a basic LPDA design. We shall explore each technique individually, rather than try from the start to develop an optimized design. Our goal will be to understand the likely amount and type of improvement that each technique offers. In practice, optimizing an LPDA design with all of the factors involves many iterations, each making a small adjustment in one or more of the possible improvement factors until one reaches a peak performance level or ends the process in exhaustion.

We should make each effort comparable, so that we can distinguish major advances from minor ones. One step in this direction is to select from the models in Chapter 4 a single design that might benefit from the efforts. My choice is model 8904, a 10-element LPDA that is 34.87' long with a τ of 0.89 and a σ of 0.04. **Fig. 5-1** provides the general outline.

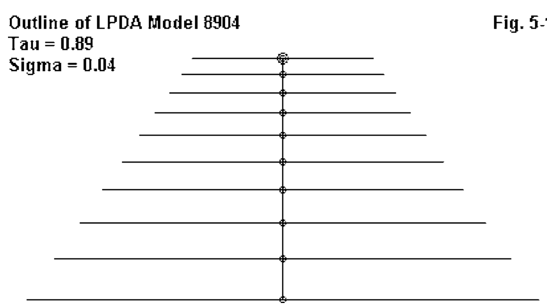


Fig. 5-1

For most of the efforts, the dimensions of this design will not change. It will retain throughout the same element lengths with the same element spacing (with one or two clearly announced exceptions). Hence, the following description will suffice for almost all of our work.

```
8904C

6.8-15 MHz .89/.04                          Frequency = 7  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          0.000,-442.80,  0.000         0.000,442.800,  0.000 2.85E+00  31
2         70.848,-394.09,  0.000        70.848,394.092,  0.000 2.54E+00  27
3        133.903,-350.74,  0.000       133.903,350.742,  0.000 2.26E+00  25
4        190.021,-312.16,  0.000       190.021,312.160,  0.000 2.01E+00  23
5        239.967,-277.82,  0.000       239.967,277.823,  0.000 1.79E+00  19
6        284.419,-247.26,  0.000       284.419,247.262,  0.000 1.59E+00  17
7        323.981,-220.06,  0.000       323.981,220.063,  0.000 1.42E+00  15
8        359.191,-195.86,  0.000       359.191,195.856,  0.000 1.26E+00  13
9        390.528,-174.31,  0.000       390.528,174.312,  0.000 1.12E+00  13
10       418.418,-155.14,  0.000       418.418,155.138,  0.000 1.00E+00  11

              -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1   Ampl.(V, A)  Phase(Deg.)  Type
           Seg.     Actual      (Specified)

1           6    10 / 50.00   ( 10 / 50.00)     0.707       0.000       V

                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  200.0  1.00  R
4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  200.0  1.00  R
5    5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
6    6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
7    7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  200.0  1.00  R
8    8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  200.0  1.00  R
9    9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  200.0  1.00  R
```

You may note that the element diameters are not uniform. That will be one of our exercises. However, it is easy enough to substitute any desired element diameter for any element in the set (including our standard 1" diameter) All models use aluminum elements.

Element Diameter

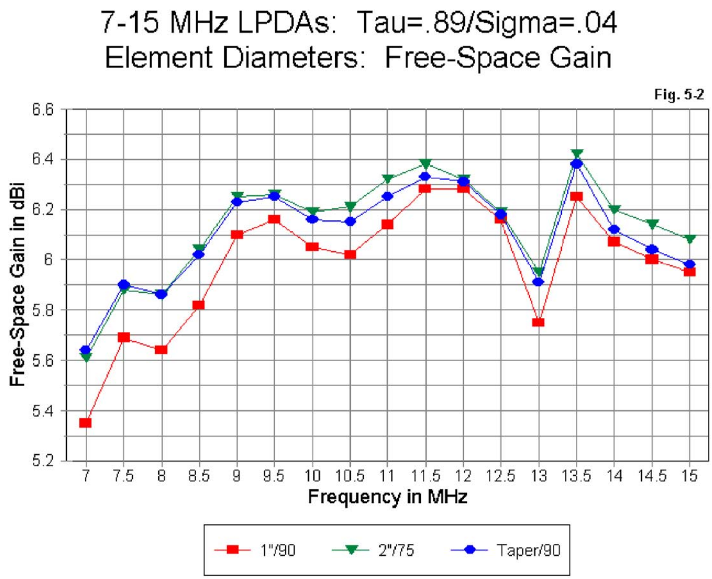
Since standard LPDA design uses a very low element length-to-diameter ratio as an assumption underlying the calculation of elements lengths, increasing the diameter of the elements should effect some improvement in performance. And it does.

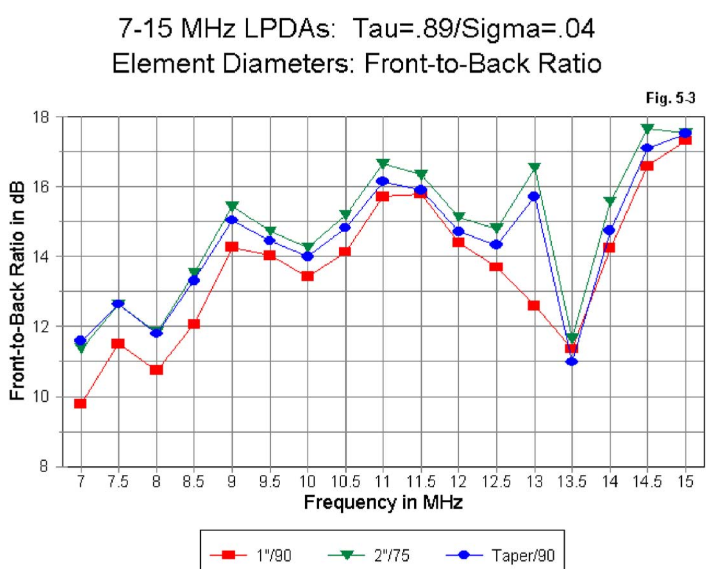
One strategy for increasing element diameter is simply to increase all element diameters by the same amount. Since our original designs specified 1" diameter elements, we might check performance with 2" diameter elements. We are here more interested in the degree of improvement we might obtain than with the question of how easily we might implement the change. Elements with an average diameter of 2" at 7 MHz are heavy under any design, and they present stress loads to the central boom of the design.

A second strategy we might try is to taper the element diameters. Although we could start with an arbitrary scheme, one effective way to ensure that elements have the same length-to-diameter ratio throughout the design is to use the value of τ. If we set a diameter for the shortest elements, we may simply increase the diameter of each longer element by the inverse of τ (sometimes called κ). The inverse of 0.89 is 1.1235955. . .. If we limit the precision to 2 decimal places, the tapered elements have the diameters shown in the model description above. The length-to-diameter ratio is a little over 310:1.

These are enough changes to make at one time, so let's explore the results.

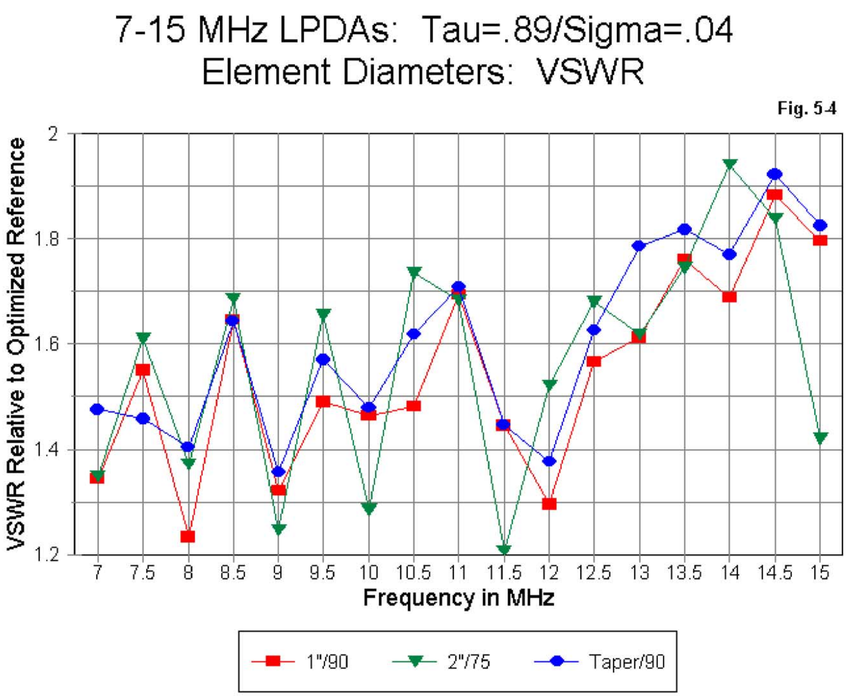
Fig. 5-2 shows the free-space gain in dBi of the three models with 1", 2", and tapered-diameter elements, respectively. Note that the curves generally track each other, coming together in the 12-12.5 MHz region of the passband. In general, the fatter elements add between 0.25 and 0.5 dB gain to the array, especially at the lower portion of the passband. Except for the top two MHz of the passband, the tapered-element design general tracks the constant 2" design in gain performance.


7-15 MHz LPDAs: Tau=.89/Sigma=.04
Element Diameters: Free-Space Gain
Fig. 5-2
Free-Space Gain in dBi
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
Frequency in MHz
1"/90
2"/75
Taper/90


7-15 MHz LPDAs: Tau=.89/Sigma=.04
Element Diameters: Front-to-Back Ratio
Fig. 5-3
Front-to-Back Ratio in dB
18
16
14
12
10
8
7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
Frequency in MHz
1"/90
2"/75
Taper/90

One interpretation of this result is that the element diameter at the upper portion of the passband had already been satisfactory for maximum inter-element coupling.

The front-to-back performance of the three models appears in **Fig. 5-3**. Once more, the 3 curves track each other with one major exception. In the 12 to 13.5 MHz range, the 1" diameter model shows a continuous decrease in front-to-back ratio, while the two designs with larger elements show a single sharp dip. Both of the larger-diameter models add about 1.5 dB to the front-to-back ratio at the low end of the passband, where it is naturally the lowest, due to the lower gain in that region.



The VSWR curves in **Fig. 5-4** tell us that each of these designs is capable of achieving an SWR level of below 2:1 throughout the passband of the antenna. The 2" diameter model uses a 75-Ohm reference, while the 1" and tapered diameter models use a 90-Ohm reference. Hence, among the designs, there may be differences in the way in which we match the arrays to 50-Ohm feedlines, for example, in the ratio of a wide-band balun. Otherwise, in this performance category, there is nothing to choose among the arrays.

One of the reasons for selecting model 8904 as our subject was the existence of the gain and front-to-back ratio dip. The dip is not fatal to array operation, as the SWR curves remain within limits in the 13-14 MHz region of the passband. Moreover, the decrease in value does not extend below the lowest values for the entire passband. But it is still a problem if one of the design goals is the most even performance we can attain across the entire passband.

Once More, The Stub

We have briefly noted in several preceding chapters that a transmission line stub connected to the center of the longest element in the array can often eliminate performance aberrations in some 1-octave LPDA designs. Let's explore this concept a little further. However, first, we must select a single design from the three we have so far examined, lest our graphs become excessively cluttered. My choice is the tapered-element diameter model matching the description given earlier. I could make up a set of reasons, but since we have no specific operational goals (other than smooth performance across the passband at the highest levels we can achieve), none of them would be superior to reasons we might use to select one of the other models. At this stage of design improvement, it is simply as good as either of the other models.

All three models are subject to harmonic operation of the rear-most elements within a critical frequency region of the passband. Where that mode of operation occurs most drastically is indicated by the frequency difference between the lowest gain and the lowest front-to-back ratio. We should look in the vicinity of about 13.25 MHz.

Fig. 5-5 shows the current distribution (and relative magnitudes) for the stubless tapered-diameter array at 13.25 MHz. Note that only the forward 5 elements show a single gain peak. The rear 5 elements all show the double hump of harmonic operation. (If the words were not so long, we could label the difference as that between dromedary and bactrian operation.) In LPDA operation, suppression of harmonic operation of elements is normally desired as a means to smooth the performance across the passband. So let's suppress it.

For the 1-octave LPDA, a simple shorted transmission line stub is sufficient to alter the impedances of the longest elements in the critical frequency region so that harmonic operation of the element does not occur. With a stub, element currents remain too low for the pattern of the array to be altered from its norm at the critical frequency region. Almost any stub length of moderate proportions will do the job. Generally, higher impedance stubs are preferred to lower impedance stubs, since they can be shorter for the same reactance level. However, some lengths are better than others.

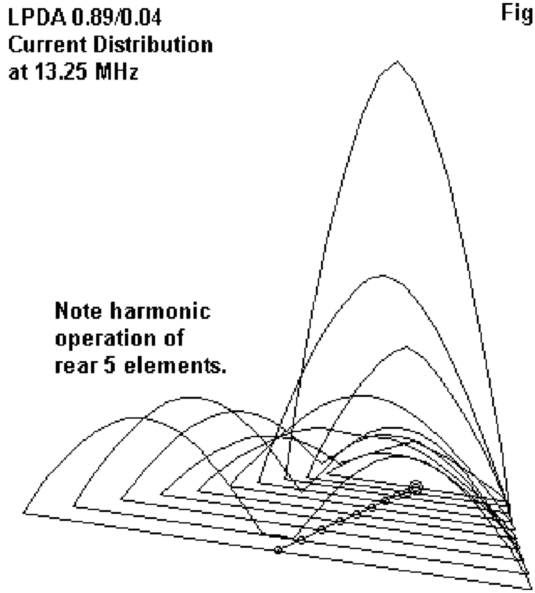


Fig. 5-5

To find the right stub length in a model simply means trying various lengths and watching the performance figures over the critical region of the passband. In my trials for 8904 with the tapered diameter elements, I examined lengths ranging from 36" down to 3" while checking performance at half-MHz intervals from 12.5 to 15 MHz. Here, in **Table 5-1**, is a portion of the survey. The figures shown are free-space gain in dBi and the front-to-back ratio in dB.

Table 5-1. Comparative Stub Performance for LPDA 8904

Freq	8904C Stub length in inches		
(MHz)	36"	18"	6"
12.5	6.09 / 15.54	6.08 / 15.65	6.08 / 15.75
13.0	5.99 / 15.44	6.00 / 15.35	6.00 / 15.27
13.5	5.95 / 15.53	5.97 / 15.35	5.99 / 15.11
14.0	5.97 / 15.57	6.00 / 15.45	6.01 / 15.11
14.5	6.01 / 15.16	6.03 / 15.75	6.03 / 15.95
15.0	6.02 / 13.63	6.01 / 15.89	6.00 / 16.33

There is nothing dramatic in the differences among stub lengths, although the shortest stub length shown does, on average, promise to outperform longer lengths. Nevertheless, field trimming the stub, however it might be implemented, is far from a tedious job, since any approximation would be indistinguishable in operation from any other.

The dramatic changes in performance come from comparing the same model, both with and without the stub.

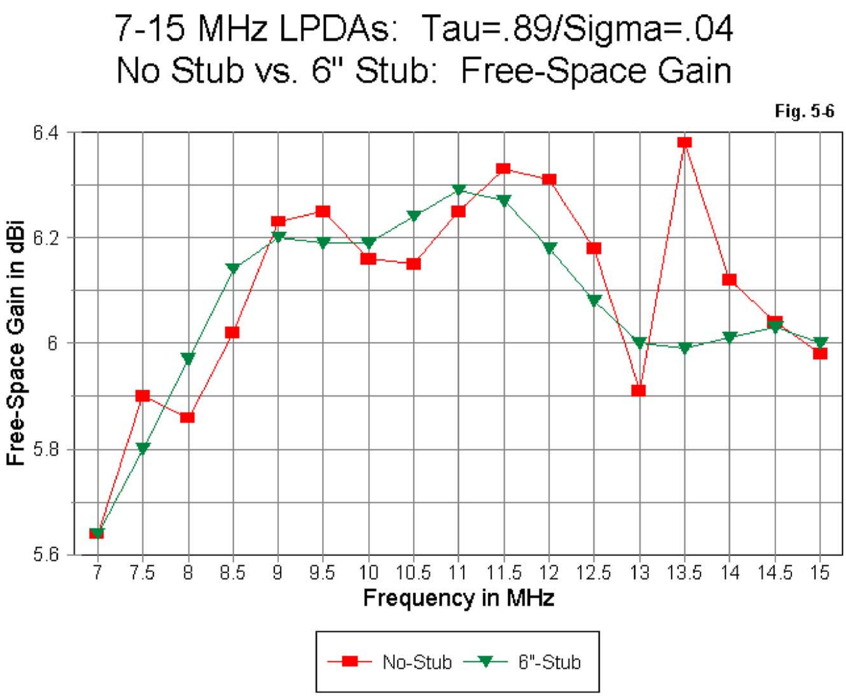
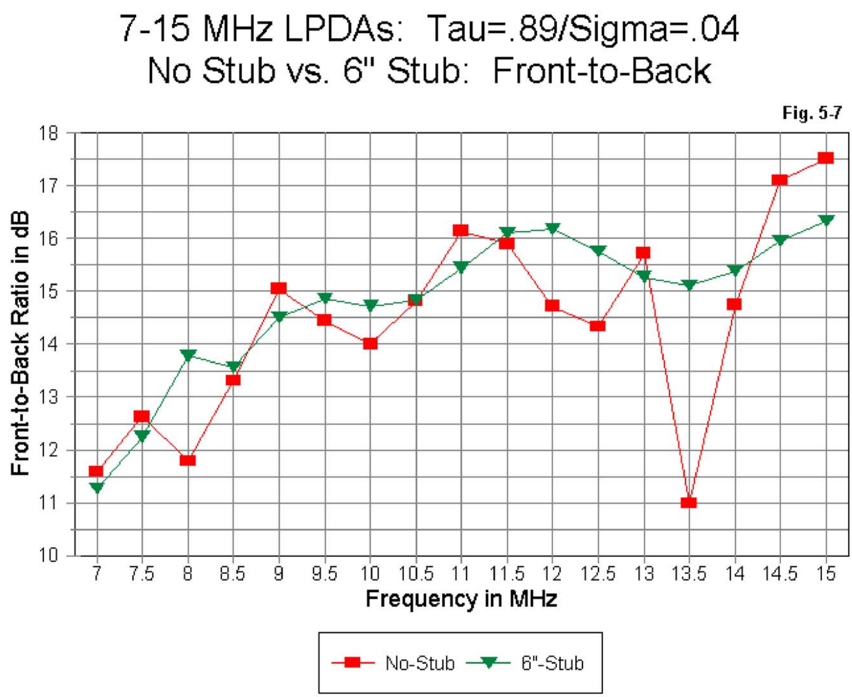


Fig. 5-6 provides the free-space gain curves for the stubless and stubbed models of 8904. If we say that the gain from 13 to 15 MHz now makes a smooth curve, we have only begun to notice significant differences in the curves. The addition of the stub has also altered the number and frequency placement of gain peaks across the passband. With the stub, we find peaks at 9, 11, and 14.5 MHz. Without the stub, we noticed peaks at 7.5, 9.5, 11.5, and 13.5 MHz. The 2 MHz interval between peaks in

the stubless model has been replaced with peaks showing far less of an obvious pattern.

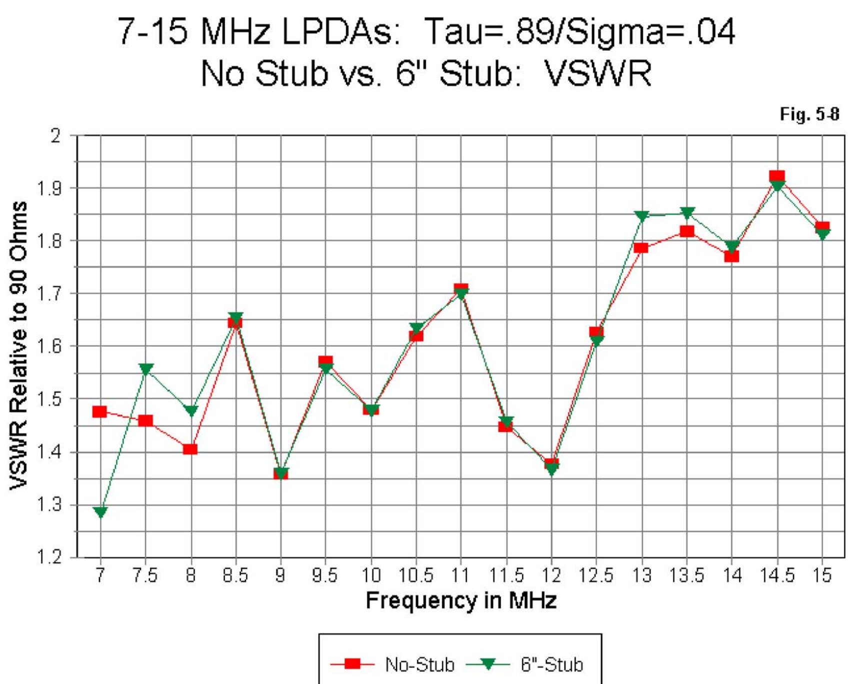
In exchange for the smoothness of the curve, we lost some interesting gain peaks. In a 1/2-scale version of the antenna, gain would be less at both 21 and 28 MHz. Nevertheless, given the variables of construction, we might find that the gain nulls might just move from the modeled positions to less desirable ones. Hence, a smooth curve is a major goal wherever it can be achieved.

The front-to-back ratio curves in **Fig. 5-7** also show the same curve displacement that we saw in the gain curves. However, note that gain and front-to-back ratio do not peak for most designs at the same frequencies. When we spot unnaturally large peaks on the same or adjacent check frequencies, we should examine the design for harmonic operation of some elements.



The stubbed model has peaks at 8, 9.5, and 12 MHz, with a possible peak at 15 MHz. The placement is about a half MHz higher than the corresponding gain peaks. In the unstubbed model, peaks occur at 7.5, 9, 11, 13, and 15 MHz, in almost all cases, about a half-MHz below the gain-peak frequencies. There are further refinements to the development of these curves that the profile intervals cannot display, but this much should suffice to show the power of a stub to move performance peaks and valleys around, while smoothing the curve overall. I suppose we should note in passing that the deep front-to-back dip at 13.5 MHz is missing from the stubbed curve.

The SWR curves, shown in **Fig. 5-8**, provide evidence that an optimized stub for an LPDA array has minimal effect on the overall SWR performance of the antenna. As we might expect, the stub does alter the source resistance and reactance at the lowest frequencies, where peak current magnitudes involve the longest elements--where the stub is attached. A second region of source impedance change is in the critical



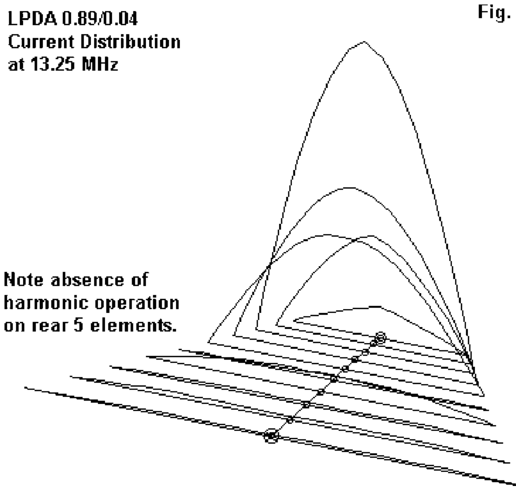
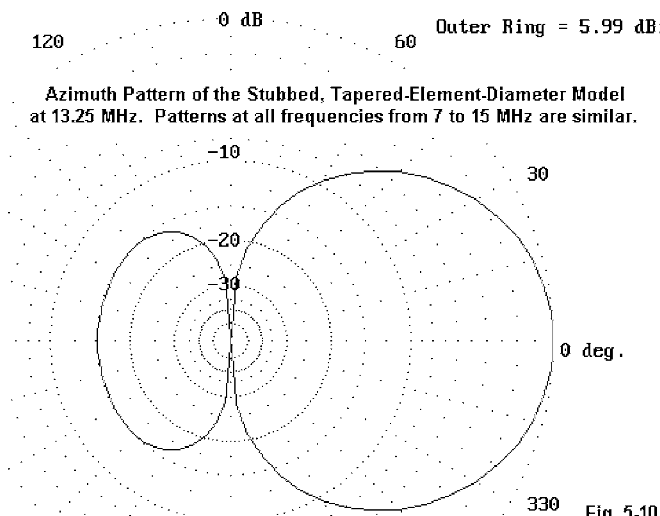


Fig. 5-9

frequency region. Outside of these two regions, the SWR curves for the stubbed and unstubbed models track each other closely.

We might record what is now happening at 13.25 MHz, the frequency at which we examined the current distribution and magnitude on the elements of the 8904C LPDA array. As **Fig. 5-9** shows, the addition of the 6" stub brings the rear 5 elements into relative quiescence so that the forward 5 elements take almost complete control of the antenna pattern.

While we are completing the record for the adjustments that we have so far made to model 8904, we can add a free-space azimuth pattern. **Fig. 5-10** shows the azimuth pattern of the stubbed array at 13.25 MHz. The pattern is perfectly ordinary for an array of this size. All of the patterns at all of the frequencies within the model's operating passband look almost identical. That is why we added the stub: to ensure that the weakness in coverage or the anomalous behavior (according to how one might wish to label the property that the stub overcomes) was eliminated—or, at least, it moved outside a frequency region of interest to the array user.



Azimuth Pattern of the Stubbed, Tapered-Element-Diameter Model at 13.25 MHz. Patterns at all frequencies from 7 to 15 MHz are similar.

Fig. 5-10

The Inter-Element Phasing Line Characteristic Impedance

Another way in which designers improve the performance of standard LPDA designs is to reduce the inter-element phase line characteristic impedance. The recommended standard design value is 200 Ohms. This high value tends to reduce the erratic behavior occasioned by the harmonic operation of rearward elements, although in shorter-boom designs it does not always succeed--as we just saw with our stub exercise.

Many LPDA designs--for example, those intended for use on the amateur band only--do not care about having smooth performance curves across a given pass band. Instead, they wish to optimize performance within specific passband segments. Since we can control wayward performance in critical frequency regions with a stub, we can often obtain good ham band performance, but at the expense of performance outside those primary frequencies.

Lowering the inter-element phaseline characteristic impedance can increase the harmonic operation of the rearward elements. Therefore, there is a certain “danger” in designing with a lower phaseline impedance. Nonetheless, the appeal of more gain and possibly a higher front-to-back ratio make this strategy attractive to designers.

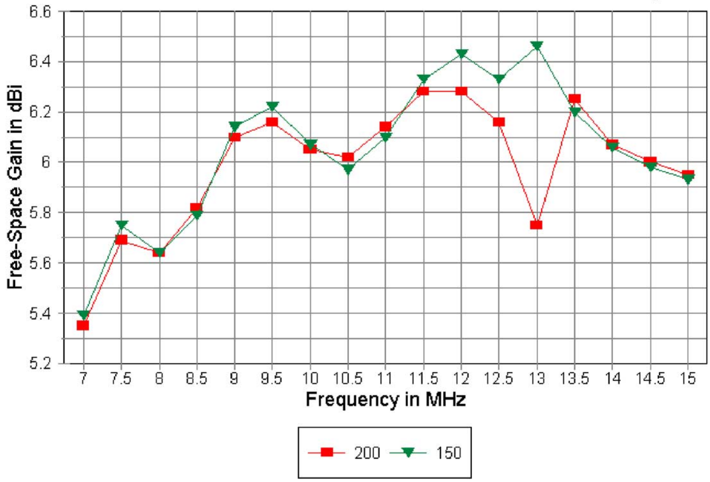
Our prime model, 8904, is actually not a good candidate for this use. The performance increase, while notable on a graph, will not be very operationally significant. LPDAs with higher values of τ tend to show better results. Nonetheless, rather than confuse matters by introducing wholly new designs, let’s see what happens with old 8904.

We shall begin with the initial model that used 1" elements throughout.

See **Fig. 5-11**. If we reduce the phaseline impedance to 150 Ohms, the 1" model acquires a little free-space gain at most frequencies, along with a gain peak at 13 MHz, rather than the original dip. There are a few places in the spectrum where the original 200-Ohm model surpasses the 150-Ohm model in gain, such as 8.5, 10.5, and above 13.5 MHz. In fact, for all of the comparisons in this section, we shall discover that with standard design element lengths and spacings, the lower the phaseline impedance, the lower the upper-end gain.

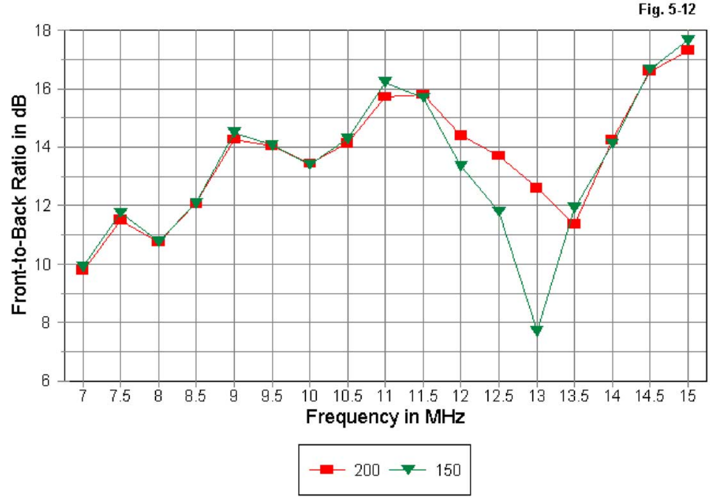
7-15 MHz LPDA 8904: No Stub
200 & 150 Ohm Lines: Free-Space Gain

Fig. 5-11



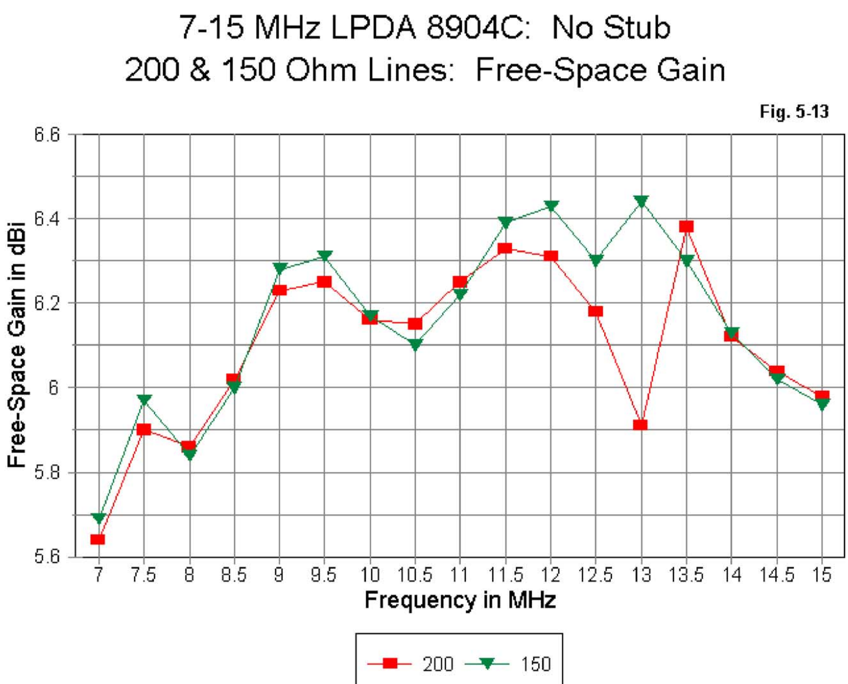
7-15 MHz LPDA 8904: No Stub
200 & 150 Ohm Lines: Front-to-Back

Fig. 5-12



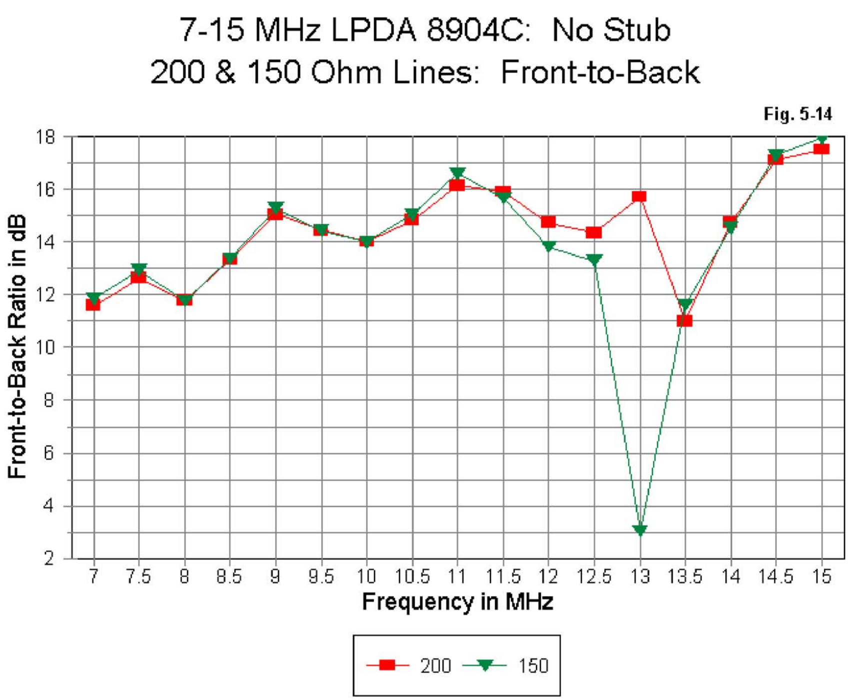
Before we cheer too loudly over the gain peaks in **Fig. 5-11**, we should examine **Fig. 5-12**, the graph of front-to-back ratios for the 200-Ohm and 150-Ohm versions of 8904. Although we can see some peak values for the 150-Ohm version marginally above those for the 200-Ohm version, we can hardly miss the deep depression in the front-to-back ratio from 12 to 14 MHz. Not only is the reduction of the ratio much deeper with our lower impedance line, it is also displaced to a lower frequency. The situation illustrates graphically the possibility in LPDA design of exacerbating undesirable conditions by lowering the phaseline impedance.

Other measures that we take to improve performance may also contribute to problems in obtaining smooth performance across the passband when we add in the reduction in phase line impedance. Let's look at what happens when we taper the element diameters, as we did in version C of 8904.



The free-space gain curves of **Fig. 5-13** compare 200-Ohm and 150-Ohm versions of the tapered-element-diameter version of our basic LPDA design. What we find in these graphs is--at the gain levels appropriate to the design change--essentially the same as with the basic 8904 model. Higher gain peaks are accompanied by deeper valleys. Moreover, pay especial attention to the frequency region between 12.5 and 13 MHz. One might get the impression that only a mild dip in gain occurs at 12.5 MHz, followed by a rise on the way to 13 MHz. In fact, as a detailed (0.1 MHz) sweep might show, the dip goes much deeper before it starts back upward toward the mark it reaches at 13 MHz.

The front-to-back curves in **Fig. 5-14** tend to replicate the results we obtained earlier. 13 MHz in this profile is a disaster of harmonic operation of the rearward elements. For the remainder of the curve, the lower impedance phaseline does yield on average a slightly higher front-to-back ratio.



These notes are, of course, predicated on the design goal of the exercise to obtain smooth performance of the highest attainable levels across the passband. Therefore, the gain and front-to-back ratio problems in the critical frequency region for this design have great weight. If one only wished to operate on 40, 30, and 20 meters, performance in the critical frequency region would likely be of little or no concern.

In this section we are bypassing concern for the VSWR curves, basically because for each model, there is a reference impedance that will yield values under 2:1 throughout to pass band. For 8904-200, the reference value is 90 Ohms, while for 8904-150, the value is 65 Ohms. For 8904C-200, the reference value is 90 Ohms, while for 8904C-150, the value is 75 Ohms. The trend is obvious: as we lower the phaseline impedance, the reference source impedance decreases.

What we have not shown--basically because graphing the phenomenon clearly is difficult--is the relative behavior of resistance and reactance as they compose the impedance. For the most part within the design passband, when the resistance reaches either its uppermost value or lowermost value, the reactance tends to be very low. At the median value of resistance, the reactance tends to be the highest. Hence, for a given reference impedance taken at about the median resistance value, the SWR level tends to be stable.

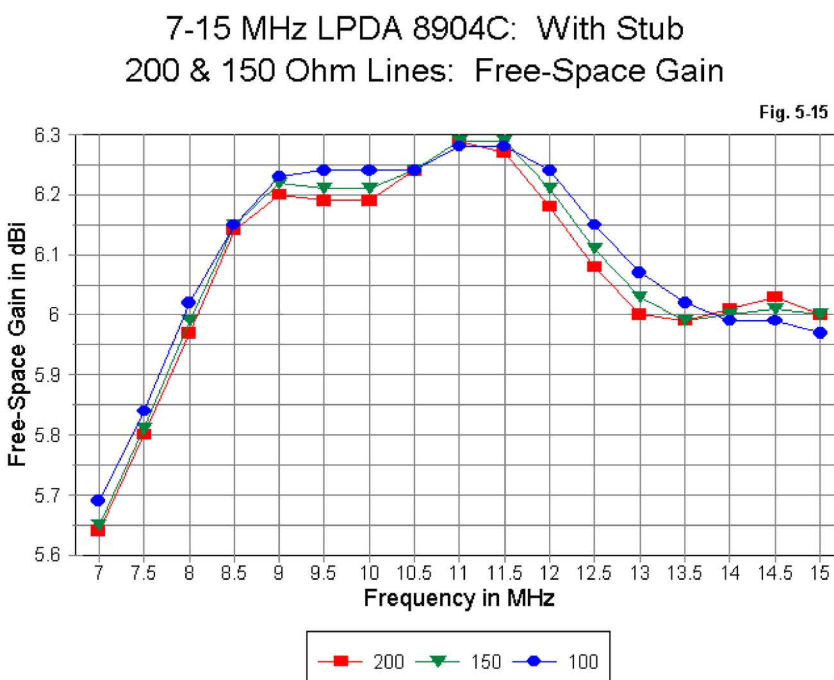
With very high values of τ and optimum σ, the resistance value may change only by a few Ohms across the best operating range of the array. Likewise, the reactance will also vary little, yielding a very low SWR, relative to a reference impedance. But even the longest LPDAs are not immune to changes in impedance, especially at the upper end of the passband.

Short-boom LPDAs tend to show the widest variation in both resistance and reactance. For example, the basic 8904 model with 1" diameter elements showed a resistance as high as 149 Ohms and as low as 51 Ohms. These are not the absolute peak values, but only the high and low that appeared within the boundaries of our limited profiles. In fact, the two values appeared at 14 and 15 MHz, with highs and lows hitting 120 and 60 Ohms, respectively, at lower frequencies in the passband.

The reactance range for 8904, as recorded in the profile, was +36 Ohms inductive and -52 Ohms capacitive. Capacitive reactance entries outnumbered inductive reactance entries, suggesting that this particular design has a median value that is inherently capacitively reactive.

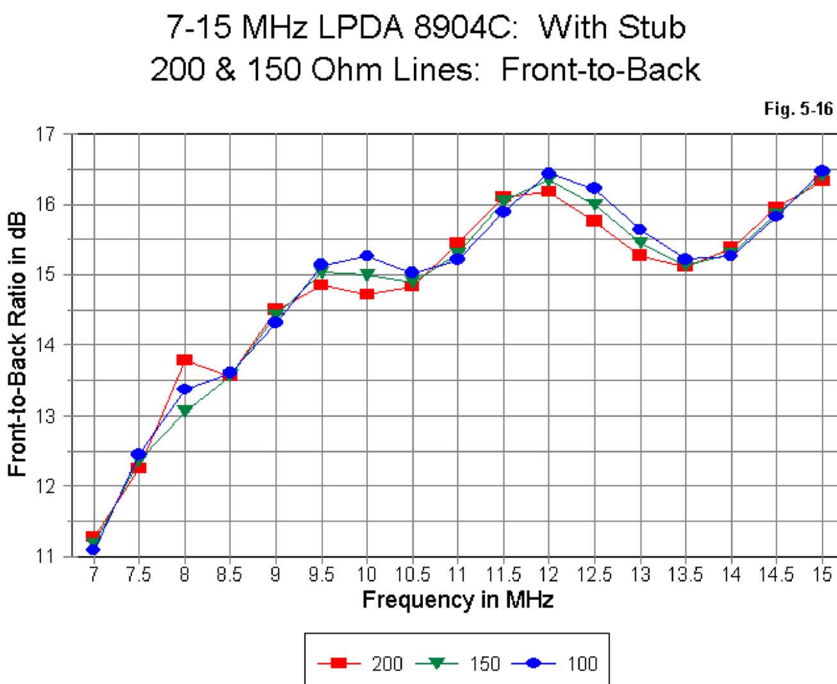
To serve as a contrast, let me note once more the 434' LPDA design that covers 7 to 15 MHz with a τ of .96 and a σ of 0.18 (optimal by calculation). The resistance rises above 69 Ohms only once, at 14.5 MHz, where it reaches 74 Ohms. The lowest profiled value is 57 Ohms, for a maximum range of 17 Ohms. If we exclude the 15 MHz reactance value of -33 Ohms, then the range of values across the rest of the passband runs from a low of j-4 Ohms to a high of j-17 Ohms, a mere 13 Ohms. And the reactance was capacitive throughout the profiled range. Such performance is largely unavailable to the short-boom LPDA designer.

Before we depart the strategy of reducing phaseline impedance to improve performance of a design with a set value of τ and σ, let's look briefly at the model 8904C with a stub. This time, we shall compare three phaseline impedances: 200, 150, and



100 Ohms. As with the other exercises in reducing phaseline impedance, the reference impedance for the 2:1 SWR curve also goes down. The 200-Ohm model uses a reference impedance of 90 Ohms. The 150-Ohm version uses 75 Ohms, while the 100-Ohm model uses 55 Ohms (but might have used 50 Ohms as well).

Fig. 5-15 presents the free-space gain curves of the three variant models. The 100-Ohm model has the highest average gain of the group, although its gain falls at the upper end of the passband. The front-to-back ratio curves in **Fig. 5-16** also show the general, but slight, superiority of the 100-Ohm model.



The general equality of values from an operational standpoint raises the question of why one would move to the 100-Ohm phase line value. There is more than one reason. First, the 100-Ohm model can be fed directly with 50-Ohm feedline, without a matching device. Second, phase lines in the vicinity of 100 Ohms can be fabricated from square metal stock, thus allowing the phaseline also to serve as the boom to support the antenna elements. From a structural perspective, then, there are good reasons for lowering the phaseline impedance even when the performance improvements are marginal or non-existent.

However, a lower phaseline value requires a shorter stub than a higher phaseline value if we are to control the critical frequency region of the passband. The 200-Ohm model used a 6" stub, while the 150-Ohm version used a 3" stub, both 600-Ohm lines. The 100-Ohm model used a 1" stub, essentially a short circuit jumper at the rear of the double boom phaseline. Despite tailoring the stub length to the phaseline impedance value, the stub proved less effective in reducing harmonic operation of the rear elements as the phaseline impedance decreased. **Fig. 5-17** shows the remnant harmonic current distribution and magnitude for the 100-Ohm model at 13.25 MHz.

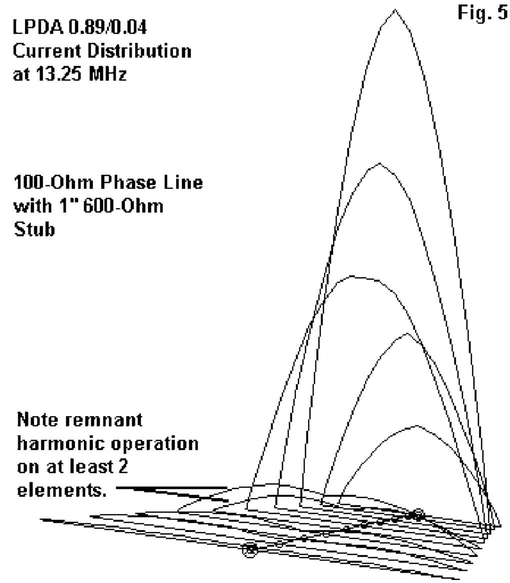


Fig. 5-17

The design goal with lower impedance phaselines is rarely to wholly eliminate harmonic operation of the rear elements. Rather, the aim is to reduce such currents to levels that permit relatively normal performance levels relative to the overall curves, as well as azimuth patterns that can be called "well-behaved." The current distribution and magnitude on the rear elements of **Fig. 5-17**, while higher than for the 200-Ohm model at the same frequency, still do not significantly distort the main pattern.

Nevertheless, the overall gain pattern of **Fig. 5-15** might be considered a bit distressing from the design perspective. The gain falls off at both ends of the passband, with the lower end of the band a special concern. Is there a way to elevate the gain at the band edges without losing significant amounts of gain in the mid-passband region?

Extending the Curves: Circular τ

One seemingly obvious route toward extending the gain and front-to-back curves for better performance at the passband edges is simply to redesign the LPDA. We may choose the same τ and σ values (in our examples, 0.89 and 0.04), and then select lower and higher frequency limits. The graphic curves we have seen so far might suggest that 6.4 and 17 MHz might make better limiting frequencies.

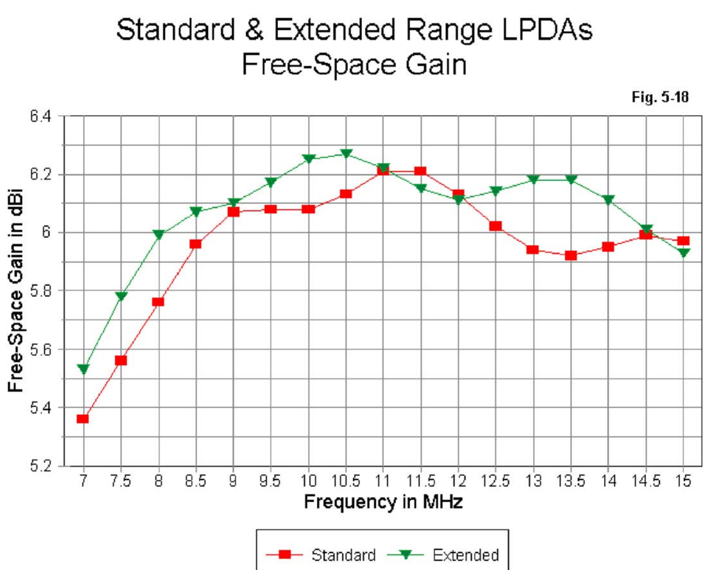
The resulting LPDA appears in the following description.

```
8904EX.EZ

6.4-17 MHz .89/.04                        Frequency = 14  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          0.000,-470.47,  0.000         0.000,470.475,  0.000 1.00E+00  39
2         75.276,-418.72,  0.000        75.276,418.723,  0.000 1.00E+00  35
3        142.272,-372.66,  0.000       142.272,372.663,  0.000 1.00E+00  31
4        201.898,-331.67,  0.000       201.898,331.670,  0.000 1.00E+00  27
5        254.965,-295.19,  0.000       254.965,295.187,  0.000 1.00E+00  25
6        302.195,-262.72,  0.000       302.195,262.716,  0.000 1.00E+00  23
7        344.229,-233.82,  0.000       344.229,233.817,  0.000 1.00E+00  19
8        381.640,-208.10,  0.000       381.640,208.097,  0.000 1.00E+00  17
9        414.936,-185.21,  0.000       414.936,185.207,  0.000 1.00E+00  15
10       444.569,-164.83,  0.000       444.569,164.834,  0.000 1.00E+00  13
11       470.942,-146.70,  0.000       470.942,146.702,  0.000 1.00E+00  13
12       494.415,-130.56,  0.000       494.415,130.565,  0.000 1.00E+00  11

              -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
           Seg.     Actual      (Specified)

1            6    12 / 50.00   ( 12 / 50.00)      0.707       0.000        V
```

-------- TRANSMISSION LINES ---------

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	200.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	200.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	200.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	200.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	200.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	200.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	200.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	200.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	200.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	200.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	200.0	1.00	R
12	1/50.0	(1/50.0)	Short ckt	(Short ck)	6.000 in	600.0	1.00	

Immediately apparent is the fact that the new LPDA design with which we hope to achieve performance extensions is about 6.3' longer than our standard model (41.2' vs. 34.9'), and it has two more elements. It is in every way a larger antenna. Now we can ask what we gain for our trouble.



To set the comparison on fair ground, both model will use our original 1" diameter elements and the standard 200-Ohm inter-element phaseline. Hence, the standard of comparison will be the antenna described at the beginning of this part. To smooth the curves, a 6" 600-Ohm stub has been installed at the center of the longest element of each antenna. Since we have established that virtually all of the models with which we are dealing have decent SWR profiles across the 7 to 15 MHz passband, we shall omit these curves. The original 10-element model is referenced to 90 Ohms, while the new extended model is referenced to 100 Ohms. With this in mind, we can look at the free-space gain and front-to-back curves in search on improvements.

Fig. 5-18 shows us what we gained in the battle for gain: only a little. The extended LPDA improves the low-end gain by under 0.2 dB. There are higher gain peaks along the curve, especially in the 12.5 to 14 MHz region, but the gain is actually lower than that of the original model at the upper passband limit.

Our most consistent gain is in front-to-back ratio, as shown in **Fig. 5-19**. Except for the significant improvement in the 13 to 14.5 MHz region, the increase tends to average about 1 dB. It is dubious whether this improvement would be operationally significant--and whether it would justify the added complexity of the resulting design.

If we recall that our goal was to improve performance at the passband edges rather than seeking an overall improvement, we have gained very little from the first effort to improve performance. We need a different strategy.

One commercial strategy appears to be varying the τ used for element lengths while preserving a constant τ for element spacing. There are proprietary algorithms used for such designs that may go under the name of "circular" design. I have also seen an interesting spot application of the principle by Eric Gustafson, N7CL. The general principle is sound, and might even be applied also to element spacing, although I have not tried it there.

I have redesigned the original 8904 model (with stub) according to the circular-τ principle, so let's examine the new element lengths as a basis for explaining the procedure and discovering why it might be called circular.

```
8906CIR.EZ

6.8-15 MHz .89/.04                          Frequency = 7  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          0.000,-424.00,  0.000        0.000,424.000,  0.000 1.00E+00  31
2         70.848,-386.30,  0.000       70.848,386.300,  0.000 1.00E+00  27
3        133.903,-349.00,  0.000      133.903,349.000,  0.000 1.00E+00  25
4        190.021,-312.16,  0.000      190.021,312.160,  0.000 1.00E+00  23
5        239.967,-277.82,  0.000      239.967,277.823,  0.000 1.00E+00  19
6        284.419,-247.26,  0.000      284.419,247.262,  0.000 1.00E+00  17
7        323.981,-221.00,  0.000      323.981,221.000,  0.000 1.00E+00  15
8        359.191,-198.00,  0.000      359.191,198.000,  0.000 1.00E+00  13
9        390.528,-181.00,  0.000      390.528,181.000,  0.000 1.00E+00  13
10       418.418,-170.00,  0.000      418.418,170.000,  0.000 1.00E+00  11
```

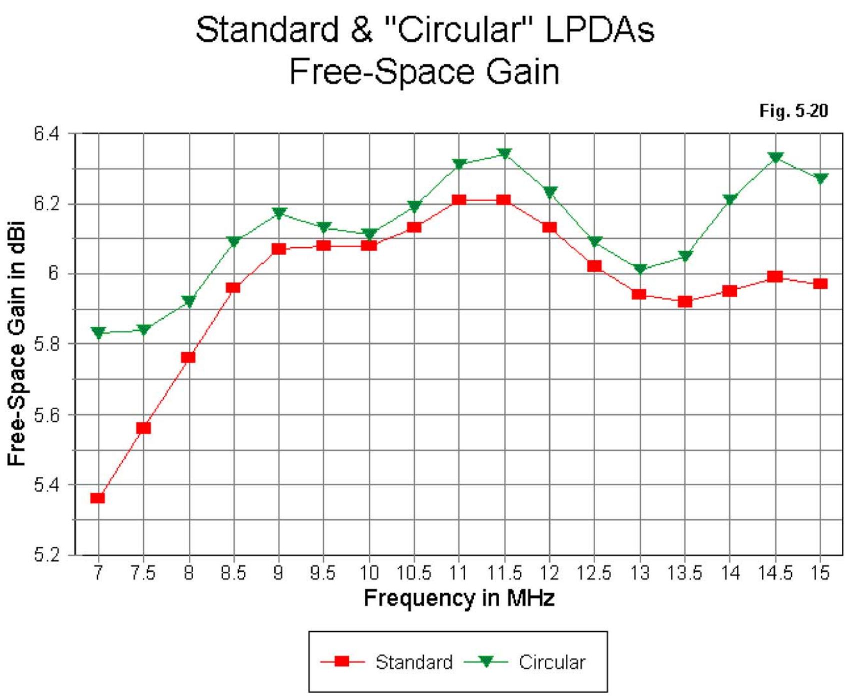
```
                  -------------- SOURCES --------------

    Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
Seg.     Actual      (Specified)

    1           6    10 / 50.00   ( 10 / 50.00)      0.707       0.000       V

                    -------- TRANSMISSION LINES ---------

    Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
          Actual  (Specified)   Actual  (Specified)             Ohms Fact Norm

    1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
    2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
    3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  200.0  1.00  R
    4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  200.0  1.00  R
    5    5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
    6    6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
    7    7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  200.0  1.00  R
    8    8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  200.0  1.00  R
    9    9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  200.0  1.00  R
    10   1/50.0  (  1/50.0)  Short ckt (Short ck)    6.000 in   600.0  1.00
```

In this sample application, I chose to preserve the lengths of elements 4, 5, and 6. These element lengths are related by a τ of 0.89. The rear three elements and forward 4 elements use a variable τ that might roughly approximate a curve described by a circle.

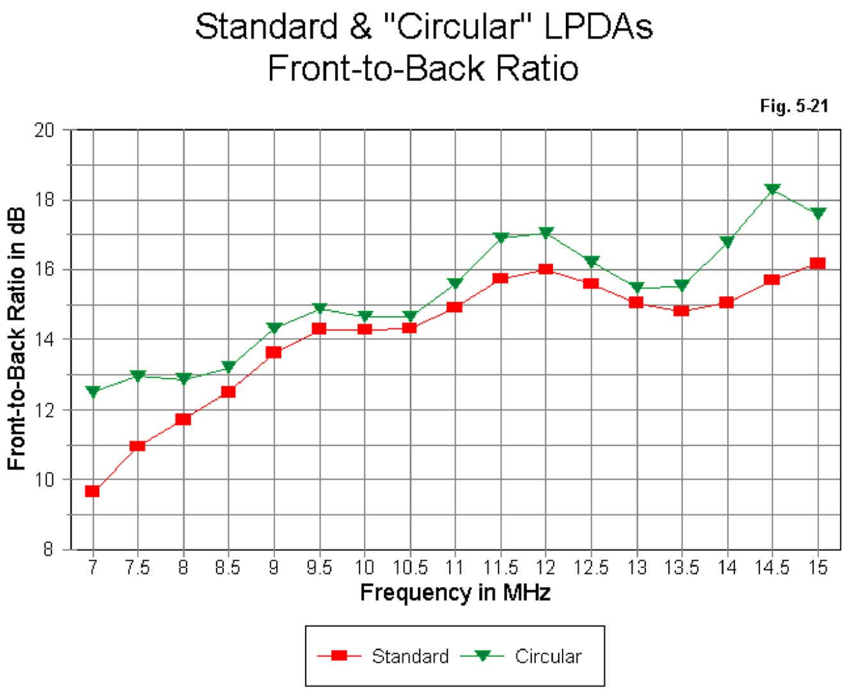
Elements 3 and 7 increase the value of τ by about 0.05% (multiply 0.89 by 1.005). The 7th element length is thus about 0.894 times the 6th element length. For the rearward elements, we use the inverse of τ, or about 1.118 to obtain the new length of element 3 from element 4. Then, we increase τ once more, this time by a slightly greater amount, say 1%. Hence, we take our new value of τ and multiply by 1.01 to get about 0.903. The 8th element length is about 0.903 the length of the new 7th element, while the 2nd element is about 1.107 times the length of the new 3rd element. The next τ value can be about 1.5% or so the values just established, or about 0.917, and so on until we run out of elements in either direction, or until we reach about 0.96 for τ.

The elements shown use rounded lengths for our experiment, since we are only testing the principle of circular τ. Moreover, the shortening of the rearmost element was halted just at the point where the SWR curve (referenced to 95 Ohms) remained within the 2:1 limit without changing the 6" stub. This called for a longer than ideal length for the rear element. You may experiment with changing the stub to effect further improvements while retaining a usable SWR profile. In fact, you may also wish to apply any of the other strategies we have so far discussed to our circular τ model. Remember that we are illustrating techniques only. We are not striving for a final design to build.

However, circularizing τ brings us dramatically toward that goal, as witnessed by **Fig. 5-20**. The gain at both passband edges shows a dramatic upturn: about 0.5 dB at the low end and 0.3 dB at the upper end. The overall curve is slightly stronger than that of the original model, but the chief improvement is more consistent gain across the entire spectrum.



The improved front-to-back curve, shown in **Fig. 5-21**, would also be a marginal improvement were it not for passband edge improvements. At 7 MHz, the improvement is nearly 3 dB, an amount that approaches operational notice. Unlike the extended range LPDA design, these improvements add nothing to the length of the array, the number of elements, or the weight. Hence, pursuit of this strategy--perhaps in conjunction with larger element diameters, stub refinements, and a lower inter-element phaseline characteristic impedance to obtain a direct 50-Ohm match across the passband--might be a useful exercise for anyone wishing to perfect old 8904.



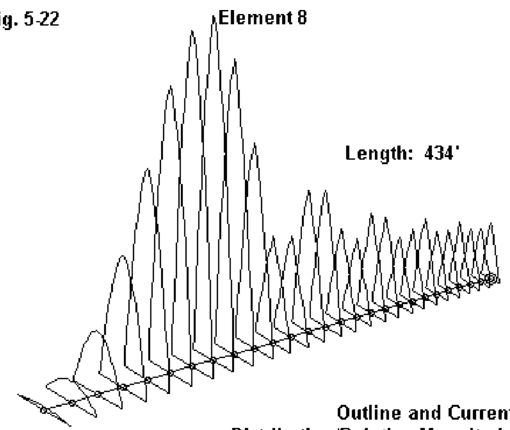
The Variable Impedance Phaseline

One of the phenomena attached to standard LPDA design is the drift in source resistance as we approach the upper frequency limit of the array. The profiles do not all show this phenomenon clearly because we are taking spot checks at 0.5 MHz points. Hence, the 15 MHz source impedance may or may not fall nicely within the general curves. Nonetheless, the gradual skewing of source impedance is a general tendency.

There is a technique that will overcome this tendency. Let's specify that the design will use the standard 200-Ohm inter-element phaseline as a basic factor. This impedance may not offer the highest gain at every point in the passband, but it helps to suppress any instabilities in pattern shape occasioned by harmonic operation of longer elements.

Instead of bringing the 200-Ohm line all the way to the shortest element, let's taper the characteristic impedance until it reaches a lower value at the feedline junction. The exact lower limit of the tapered Zo will depend on the natural reference impedance for the antenna, but something between 80 and 150 Ohms will do for most designs. We need not taper the impedance for the entire length of the LPDA, but only for about the forward-most 15% of the elements. Since this value amounts to about 1.5 elements for our standard demonstration model, it is inconvenient to demonstrate the technique on a small LPDA without introducing some modeling techniques that would obscure the point.

Fig. 5-22



Outline and Current
Distribution/Relative Magnitude
27-Element LPDA: Tau = 0.96; Sigma = 0.18; Freq. = 7.0 MHz

However, I have mentioned, in this part and the last, a long LPDA (434') that uses 27 elements with a τ of 0.96 (maximum recommended value) and a σ of 0.18 (optimum value). This is a convenient model to use for the demonstration for several reasons. First, it has many elements, and the tapered phaseline can be implemented in small steps that simulate the taper. Second, the design, created by standard calculations, has some other features of interest.

Fig. 5-22 shows the outline of the antenna. Remember that the elements are within the same length range used by those of the short LPDA we have been studying. Thus, the scaled sketch gives a true picture of the antenna's overall length.

Of great interest is the current distribution and relative magnitude shown in the graphic. Of first note is the element showing the highest current in this 7 MHz view. As we increase τ, we increase the number of elements and, with it, the inter-element coupling. Hence, we should for any high-τ design also see the low-frequency high-current element move forward in the array. In this array, we might remove the rear-most element with little ill effect.

Of second note is the number of very active elements that affect the pattern formation of the array at even the lowest frequency. For all but one element, the current levels are non-negligible. We should expect from this array a good gain, but more especially, an astounding front-to-back ratio, regardless of whether we are concerned with 180-degree, worst-case, or front-to-rear ratios.

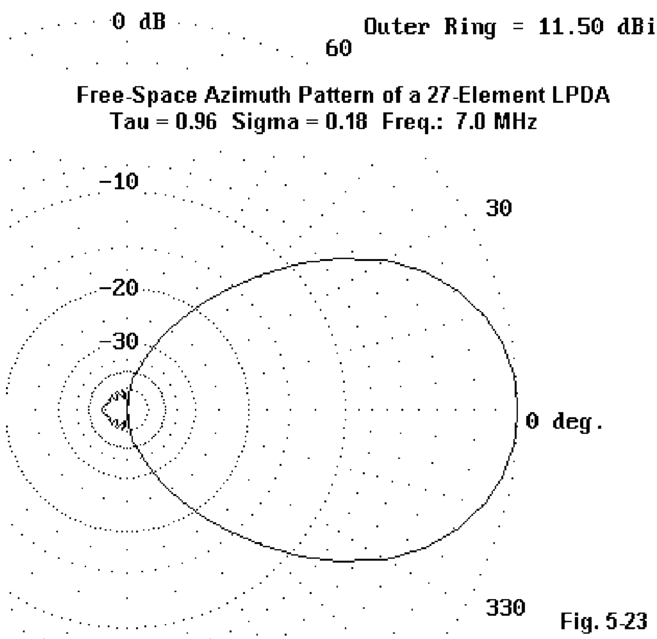


Fig. 5-23

Fig. 5-23 confirms our suspicions. More dramatic than the 11.5 dBi free-space gain of the array is the truly insignificant radiation to the rear. It should be no mystery why many commercial and government shortwave stations have gone to sizable LPDA arrays and given up many of the older wire arrays that once covered hillsides.

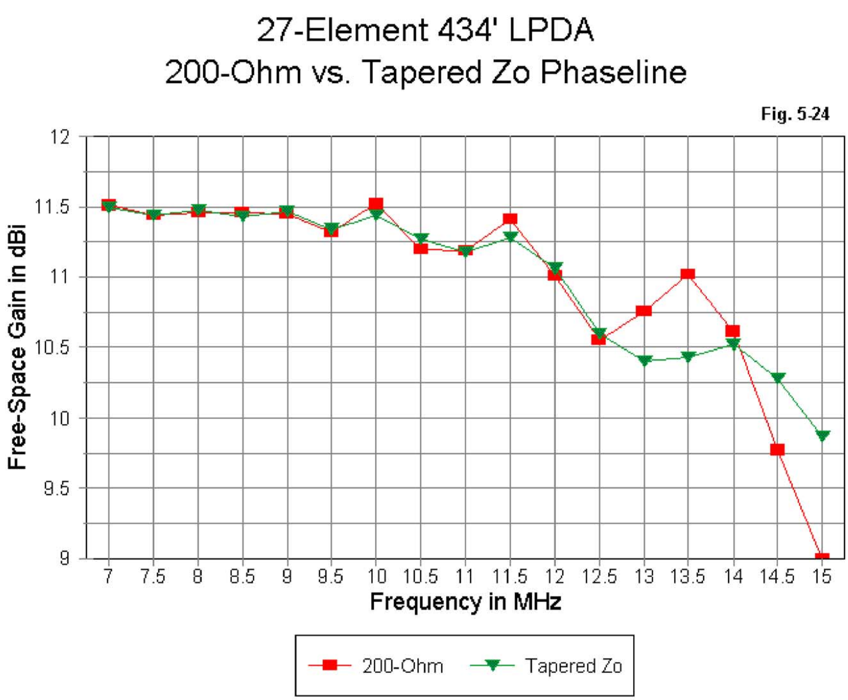
In case you wish to operate a (duly-licensed) multi-frequency shortwave station between 7 and 15 MHz, here is the model description, using 1" diameter elements and requiring no stub.

```
9618.EZ

.96/.18 6.8-15 MHz 27 el                       Frequency = 7  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          0.000,-442.80,  0.000         0.000,442.800,  0.000 1.00E+00  31
2        318.816,-425.09,  0.000       318.816,425.088,  0.000 1.00E+00  31
3        624.879,-408.08,  0.000       624.879,408.084,  0.000 1.00E+00  29
4        918.700,-391.76,  0.000       918.700,391.761,  0.000 1.00E+00  29
5        1200.77,-376.09,  0.000       1200.77,376.091,  0.000 1.00E+00  27
6        1471.55,-361.05,  0.000       1471.55,361.047,  0.000 1.00E+00  25
7        1731.51,-346.61,  0.000       1731.51,346.605,  0.000 1.00E+00  25
8        1981.06,-332.74,  0.000       1981.06,332.741,  0.000 1.00E+00  23
9        2220.64,-319.43,  0.000       2220.64,319.431,  0.000 1.00E+00  23
10       2450.63,-306.65,  0.000       2450.63,306.654,  0.000 1.00E+00  23
11       2671.42,-294.39,  0.000       2671.42,294.388,  0.000 1.00E+00  21
12       2883.38,-282.61,  0.000       2883.38,282.612,  0.000 1.00E+00  21
13       3086.86,-271.31,  0.000       3086.86,271.308,  0.000 1.00E+00  19
14       3282.20,-260.46,  0.000       3282.20,260.456,  0.000 1.00E+00  19
15       3469.73,-250.04,  0.000       3469.73,250.037,  0.000 1.00E+00  17
16       3649.75,-240.04,  0.000       3649.75,240.036,  0.000 1.00E+00  17
17       3822.58,-230.43,  0.000       3822.58,230.434,  0.000 1.00E+00  17
18       3988.49,-221.22,  0.000       3988.49,221.217,  0.000 1.00E+00  15
19       4147.77,-212.37,  0.000       4147.77,212.368,  0.000 1.00E+00  15
20       4300.67,-203.87,  0.000       4300.67,203.874,  0.000 1.00E+00  15
21       4447.46,-195.72,  0.000       4447.46,195.719,  0.000 1.00E+00  15
22       4588.38,-187.89,  0.000       4588.38,187.890,  0.000 1.00E+00  13
23       4723.66,-180.37,  0.000       4723.66,180.374,  0.000 1.00E+00  13
24       4853.53,-173.16,  0.000       4853.53,173.159,  0.000 1.00E+00  13
25       4978.21,-166.23,  0.000       4978.21,166.233,  0.000 1.00E+00  11
```

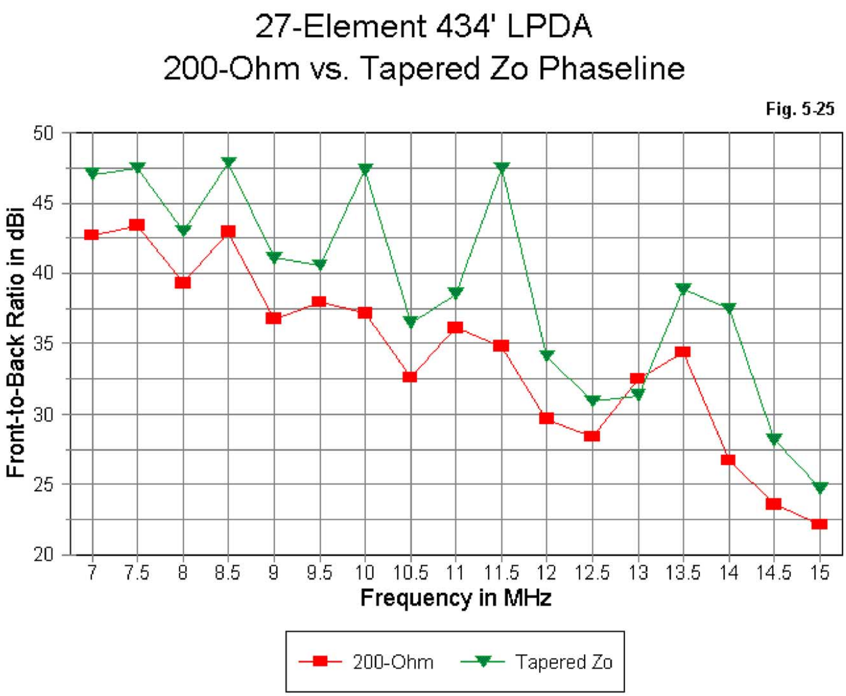
```
    26      5097.89,-159.58,  0.000      5097.89,159.584,  0.000 1.00E+00  11
    27      5212.79,-153.20,  0.000      5212.79,153.200,  0.000 1.00E+00  11

                  -------------- SOURCES --------------

    Source    Wire      Wire #/Pct From End 1   Ampl.(V, A)  Phase(Deg.)  Type
               Seg.     Actual      (Specified)

    1           6    27 / 50.00   ( 27 / 50.00)      0.707       0.000       V

                    -------- TRANSMISSION LINES ---------

    Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
         Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

    1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  200.0  1.00  R
    2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  200.0  1.00  R
    3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  200.0  1.00  R
    4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  200.0  1.00  R
    5    5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  200.0  1.00  R
    6    6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  200.0  1.00  R
    7    7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  200.0  1.00  R
    8    8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  200.0  1.00  R
    9    9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  200.0  1.00  R
    10  10/50.0  ( 10/50.0)   11/50.0  ( 11/50.0)  Actual dist  200.0  1.00  R
    11  11/50.0  ( 11/50.0)   12/50.0  ( 12/50.0)  Actual dist  200.0  1.00  R
    12  12/50.0  ( 12/50.0)   13/50.0  ( 13/50.0)  Actual dist  200.0  1.00  R
    13  13/50.0  ( 13/50.0)   14/50.0  ( 14/50.0)  Actual dist  200.0  1.00  R
    14  14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  200.0  1.00  R
    15  15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  200.0  1.00  R
    16  16/50.0  ( 16/50.0)   17/50.0  ( 17/50.0)  Actual dist  200.0  1.00  R
    17  17/50.0  ( 17/50.0)   18/50.0  ( 18/50.0)  Actual dist  200.0  1.00  R
    18  18/50.0  ( 18/50.0)   19/50.0  ( 19/50.0)  Actual dist  200.0  1.00  R
    19  19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  200.0  1.00  R
    20  20/50.0  ( 20/50.0)   21/50.0  ( 21/50.0)  Actual dist  200.0  1.00  R
    21  21/50.0  ( 21/50.0)   22/50.0  ( 22/50.0)  Actual dist  200.0  1.00  R
    22  22/50.0  ( 22/50.0)   23/50.0  ( 23/50.0)  Actual dist  175.0  1.00  R
    23  23/50.0  ( 23/50.0)   24/50.0  ( 24/50.0)  Actual dist  150.0  1.00  R
    24  24/50.0  ( 24/50.0)   25/50.0  ( 25/50.0)  Actual dist  125.0  1.00  R
    25  25/50.0  ( 25/50.0)   26/50.0  ( 26/50.0)  Actual dist  100.0  1.00  R
    26  26/50.0  ( 26/50.0)   27/50.0  ( 27/50.0)  Actual dist   80.0  1.00  R
```

The model description actually shows the modifications in transmission lines 22-26 for the tapered impedance technique. Returning all of the lines to 200 Ohms would show the basic model. Note that the impedance increases in 20-25 Ohm steps from a feedpoint junction value of 80 Ohms up to the standard value for the remainder of the line. The impedance-tapering technique does have some useful effects on the performance of the array at the upper end of the passband.

In **Fig. 5-24**, we can see the smoothing of the gain curve above 12.5 MHz. What we lose in the 13.5 MHz peak of the original we more than make up in the improved gain at 14.5 and 15 MHz. The front-to-back curve in **Fig. 5-25** shows improvements for the tapered-impedance line model, although there are sharper peaks. Only at 13 MHz does the original model show a higher front-to-back ratio, but I suspect that adding a stub to the original might smooth its curve in this region. However, I did not add a 6" stub to the 434' array. Nor did I apply a circular τ correction to the forward elements, although such a trial might show whether the value of τ can be usefully raised above 0.96 to improve upper frequency performance. Implementing this last possible strategy might have obscured the effects of the tapered-impedance phaseline.

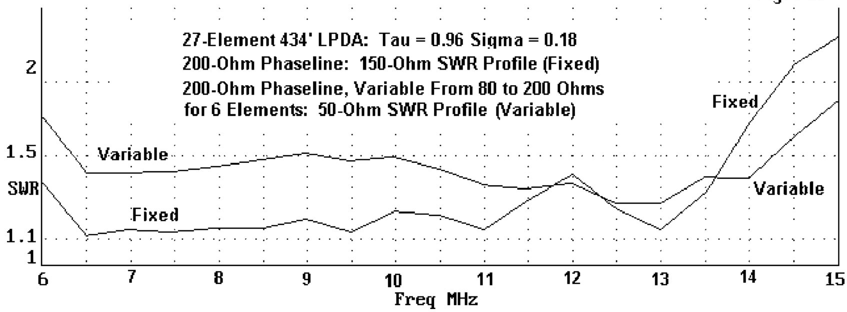


We noted earlier that this high-τ array has extended low-frequency capability. In fact, the array performance does not decrease significantly until below 6.5 MHz, and it is still usable at 6 MHz, where the gain is above 10 dBi and the front-to-back ratio above 20 dB. Therefore, the following SWR curves encompass the range of 6 to 16 MHz.



The portion of **Fig. 5-26** marked “fixed” shows the 150-Ohm SWR curve for the model with a uniform 200-Ohm phase line. For a very large portion of the passband, the 150-Ohm reference is clearly the natural impedance of the antenna. However, at the upper end of the spectrum, the resistive component of the impedance descends toward 80 Ohms, while the reactance climbs to exceed 100 Ohms at the passband limit.

Fig. 5-26



The curve marked “variable” uses a 50-Ohm reference. The entire curve is well below the 2:1 limit we set somewhat arbitrarily as the goal. By the use of the tapered-impedance phase line, we electrically simplify the array by eliminating the need for a wide-band matching device at the feedpoint, should we choose to feed the array with standard 50-Ohm coaxial cable.

The 7-15 MHz “ideal” LPDA that we have been exploring should not strike you as something new. If you look back at Chapter 3, where we examined some of the basic properties of LPDAs, we used a 14-30 MHz 27-element LPDA that also used a τ of 0.96 and a σ of 0.18. Moreover, it has 0.5" diameter elements with a 217' boom. Even the phase line was stepped upward in characteristic impedance from the feedpoint to the 6th element. Obviously, our present 434' LPDA is simply a frequency-scaled version of the earlier design (or vice versa). So long as the element diameters make sense and the passband has the same width in terms of octaves, scaling LPDA designs from one frequency range to another can save a great deal of design time.

Conclusion--For Now

We have surveyed 5 different strategies for improving LPDA performance. These may not be all of the ways, but they are the main ones. Remember that our goals in this exercise were not directly ham-band related. We did not strive to achieve peak performance at specific frequencies. Instead, we strove for the smoothest performance across the passband at the highest levels we could obtain. In that task, we came a considerable distance—a fact that you can confirm by comparing the “raw” performance of 8904 against the best of the refinements that we managed.

Nonetheless, in this chapter, we have only demonstrated the techniques. We did not seek to arrive at a final design that we might build. The techniques can be combined to yield a final design, but just which combination and to what degree each technique might be used would form a set of design decisions based on having a clear set of operational goals. Without such goals, but only our general guideline, any claim that one of the design results within the demonstration was "best" would be foolish.

Moreover, we chose as a basic model for illustrating the techniques a design that clearly could stand improvement. Old 8904 is a modest LPDA design, not necessarily the best, even for its boom length. Other combinations of τ and σ that yield the same boom length might prove initially superior--or more amenable to some of the improvement techniques. 8904 was simply handy because it permitted all but one of the techniques to be demonstrated.

Likewise, the frequency range used for the exercise was semi-arbitrary, since it avoided any possible controversy that might surround comparing LPDAs that have been built for the upper HF region. Nevertheless, the models used are easily scaled by a factor of 2 (including element diameter) for the 14 to 30 MHz range—as the long-boom design clearly illustrated. Only the losses of the aluminum elements will shift any of the modeled results--and any shift will be slight.

With all of these qualifications, I still hope that sorting out the various techniques available to improve the performance of basic LPDA designs is useful. The exercise may go some distance toward improving our understanding of LPDAs in all their major variations. At the very least, it should convince us that the design of an LPDA is not a simple "go/no-go" affair. LPDA designs require patient work to refine the performance curves and to eliminate weakness in the coverage. Computer modeling greatly simplifies the task, although it remains a somewhat time-consuming operation. However, everything good does take some time to perfect.

Chapter 6: Wire and Vee-Element LPDAs

Considerable interest persists in the Telerana, a very light-weight wire LPDA with elements bent forward into Vees. The original design emerged from work by George Smith, W4AEO, and Ansyl Eckols, YV5DLT. The design first appeared in *QST* for July, 1981, and has been in most editions of *The ARRL Antenna Book* since that time (pp. 10-13 to 10-16 in the 18th Edition). A modified hybrid, consisting of the basic Telerana with parasitic reflectors, by Markus Hansen, VE7CA, appeared on Vol. 4 of *The ARRL Antenna Compendium* (pp. 112-117).

The Telerana begins as a standard-design 13-element LPDA with a τ of 0.9 and a σ of 0.05. It presents us with the opportunity to analyze two facets of LPDA design: 1. the advantages or disadvantages of using Vee-shape elements and 2. the advantages or disadvantages of using small diameter wire in contrast to large tubular elements. We shall look only at the original design in what follows, since the topic of LPDA-parasitic hybrids is a subject all its own. By sticking to the pure LPDA design, the results will be comparable to those drawn out of models in Chapters 4 and 5.

Straight vs. Vee-Element Models

Modeling the Telerana design, with its Vee elements, presents some challenges. I began with a straight element model using the element lengths and spacings provided by the designers. The overall length of the straight-line model is just over 29 feet and uses #14 AWG copper wire for modeling purposes--about 0.064" in diameter. The outline of this model appears in **Fig. 6-1**.

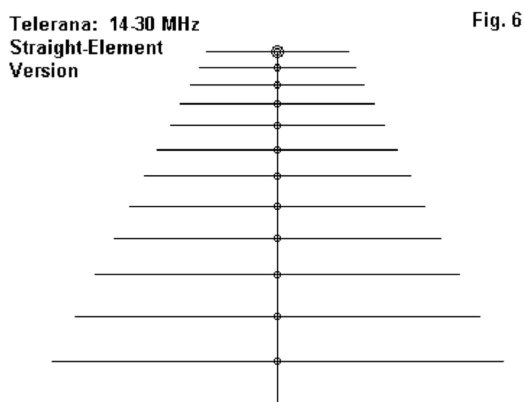


Fig. 6-1

The design specifies a 400-Ohm inter-element phasing line, with a 200-Ohm design feedpoint impedance. In the model, each element is assigned an odd number of segments so that the TL-facility transmission line will be centered on each element. Segment numbers were assigned by giving the shortest element 11 segments and increasing that number for longer elements by the inverse of τ (1.11) and rounding to the nearest odd number. This technique ensures that the longest element will have a sufficient number of segments at the highest frequency (30 MHz) used by the antenna.

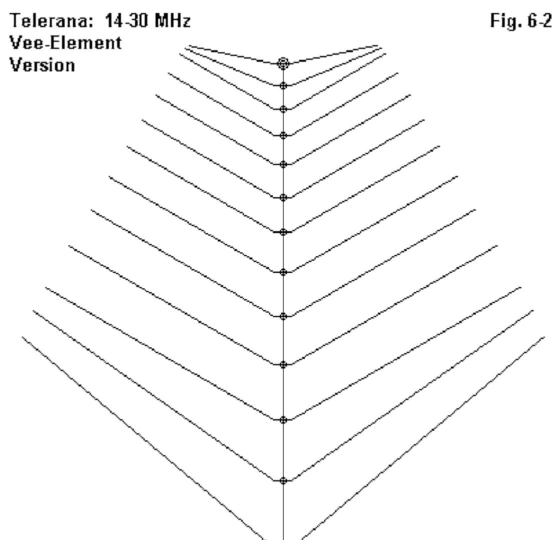
For reference, here is the antenna model description.

```
Telerana-Ant Bk 10-13: Straight Elements          Frequency = 14  MHz.

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

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

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

1          0.000,-20.330,  0.000        0.000, 20.330,  0.000    # 14   39
2          4.060,-18.300,  0.000        4.060, 18.300,  0.000    # 14   35
3          7.710,-16.460,  0.000        7.710, 16.460,  0.000    # 14   31
4         11.020,-14.820,  0.000       11.020, 14.820,  0.000    # 14   29
5         13.970,-13.310,  0.000       13.970, 13.310,  0.000    # 14   25
6         16.630,-12.000,  0.000       16.630, 12.000,  0.000    # 14   23
7         19.050,-10.790,  0.000       19.050, 10.790,  0.000    # 14   21
8         21.140, -9.710,  0.000       21.140,  9.710,  0.000    # 14   19
9         23.150, -8.720,  0.000       23.150,  8.720,  0.000    # 14   17
10        24.890, -7.870,  0.000       24.890,  7.870,  0.000    # 14   15
11        26.470, -7.080,  0.000       26.460,  7.080,  0.000    # 14   13
12        27.890, -6.360,  0.000       27.890,  6.360,  0.000    # 14   13
13        29.160, -5.740,  0.000       29.160,  5.740,  0.000    # 14   11

              -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1   Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           6    13 / 50.00   ( 13 / 50.00)      1.000       0.000       V

               -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
     Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  400.0  1.00  R
```

```
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  400.0  1.00  R
3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  400.0  1.00  R
4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  400.0  1.00  R
5    5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  400.0  1.00  R
6    6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  400.0  1.00  R
7    7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  400.0  1.00  R
8    8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  400.0  1.00  R
9    9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  400.0  1.00  R
10  10/50.0  ( 10/50.0)   11/50.0  ( 11/50.0)  Actual dist  400.0  1.00  R
11  11/50.0  ( 11/50.0)   12/50.0  ( 12/50.0)  Actual dist  400.0  1.00  R
12  12/50.0  ( 12/50.0)   13/50.0  ( 13/50.0)  Actual dist  400.0  1.00  R
```

Note that no stub is used with this design, and none of the compensation techniques noted in Chapter 5 of this sequence has been applied. No stub is needed because the high characteristic impedance of the phasing line tends to suppress harmonic operation of rear elements on the upper frequencies. The absence of compensation techniques was a design choice by the originators of the Telerana.

Transforming the antenna into one with elements that form forward Vees requires considerable care. The outline of the model appears in **Fig. 6-2**.



The segmentation of the straight-element model yielded a segment length of just about 1 foot. To ensure that the TL transmission line in NEC would be centered on each element, I created a 1-segment, 1-foot wire at each element position. The outer portions of each element were segmented in approximate 1-foot lengths and then bent forward at the appropriate angle. Let's count elements from the longest (#1) to the shortest (#13).

Elements #2 through #11 are bent forward about 30 degrees on each side, relative to an equivalent straight element. Element #1 is bent forward by about 45 degrees, while elements #12 and #13 are bent forward about 22 degrees and 12 degrees, respectively. The angle change for these elements is a function of fitting the elements within the framework specifically design for the antenna. The resulting antenna is longer (30.3') but narrower than the straight-element model.

For reference, here is the model description.

```
Telerana-Ant Bk 10-13: Vee                  Frequency = 14  MHz.

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

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

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

1          12.746,-15.691,  0.000  W2E1   0.000, -0.500,  0.000    # 14   20
2   W1E2    0.000, -0.500,  0.000  W3E1   0.000,  0.500,  0.000    # 14    1
3   W2E2    0.000,  0.500,  0.000        12.746, 15.691,  0.000    # 14   20
4          14.270,-15.081,  0.000  W5E1   4.060, -0.500,  0.000    # 14   17
5   W4E2    4.060, -0.500,  0.000  W6E1   4.060,  0.500,  0.000    # 14    1
6   W5E2    4.060,  0.500,  0.000        14.270, 15.081,  0.000    # 14   17
7          15.690,-14.322,  0.000  W8E1   7.710, -0.500,  0.000    # 14   15
8   W7E2    7.710, -0.500,  0.000  W9E1   7.710,  0.500,  0.000    # 14    1
9   W8E2    7.710,  0.500,  0.000        15.690, 14.322,  0.000    # 14   15
10         18.180,-12.901,  0.000 W11E1  11.020, -0.500,  0.000    # 14   14
11 W10E2   11.020, -0.500,  0.000 W12E1  11.020,  0.500,  0.000    # 14    1
12 W11E2   11.020,  0.500,  0.000        18.180, 12.901,  0.000    # 14   14
13         20.375,-11.594,  0.000 W14E1  13.970, -0.500,  0.000    # 14   12
14 W13E2   13.970, -0.500,  0.000 W15E1  13.970,  0.500,  0.000    # 14    1
15 W14E2   13.970,  0.500,  0.000        20.375, 11.594,  0.000    # 14   12
16         22.380,-10.459,  0.000 W17E1  16.630, -0.500,  0.000    # 14   11
17 W16E2   16.630, -0.500,  0.000 W18E1  16.630,  0.500,  0.000    # 14    1
18 W17E2   16.630,  0.500,  0.000        22.380, 10.459,  0.000    # 14   11
19         24.195, -9.411,  0.000 W20E1  19.050, -0.500,  0.000    # 14   10
20 W19E2   19.050, -0.500,  0.000 W21E1  19.050,  0.500,  0.000    # 14    1
21 W20E2   19.050,  0.500,  0.000        24.195,  9.411,  0.000    # 14   10
22         25.745, -8.476,  0.000 W23E1  21.140, -0.500,  0.000    # 14    9
23 W22E2   21.140, -0.500,  0.000 W24E1  21.140,  0.500,  0.000    # 14    1
24 W23E2   21.140,  0.500,  0.000        25.745,  8.476,  0.000    # 14    9
25         27.260, -7.619,  0.000 W26E1  23.150, -0.500,  0.000    # 14    8
26 W25E2   23.150, -0.500,  0.000 W27E1  23.150,  0.500,  0.000    # 14    1
27 W26E2   23.150,  0.500,  0.000        27.260,  7.619,  0.000    # 14    8
28         28.575, -6.883,  0.000 W29E1  24.890, -0.500,  0.000    # 14    7
```

```
29 W28E2  24.890, -0.500,  0.000 W30E1  24.890,  0.500,  0.000    # 14    1
30 W29E2  24.890,  0.500,  0.000        28.575,  6.883,  0.000    # 14    7
31        29.760, -6.198,  0.000 W32E1  26.470, -0.500,  0.000    # 14    6
32 W31E2  26.470, -0.500,  0.000 W33E1  26.470,  0.500,  0.000    # 14    1
33 W32E2  26.470,  0.500,  0.000        29.751,  6.203,  0.000    # 14    6
34        30.085, -5.933,  0.000 W35E1  27.890, -0.500,  0.000    # 14    6
35 W34E2  27.890, -0.500,  0.000 W36E1  27.890,  0.500,  0.000    # 14    1
36 W35E2  27.890,  0.500,  0.000        30.085,  5.933,  0.000    # 14    6
37        30.249, -5.625,  0.000 W38E1  29.160, -0.500,  0.000    # 14    5
38 W37E2  29.160, -0.500,  0.000 W39E1  29.160,  0.500,  0.000    # 14    1
39 W38E2  29.160,  0.500,  0.000        30.249,  5.625,  0.000    # 14    5

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
           Seg.     Actual      (Specified)

1           1    38 / 50.00   ( 38 / 50.00)      1.000       0.000       V

                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    2/50.0  (  2/50.0)    5/50.0  (  5/50.0)  Actual dist  400.0  1.00  R
2    5/50.0  (  5/50.0)    8/50.0  (  8/50.0)  Actual dist  400.0  1.00  R
3    8/50.0  (  8/50.0)   11/50.0  ( 11/50.0)  Actual dist  400.0  1.00  R
4   11/50.0  ( 11/50.0)   14/50.0  ( 14/50.0)  Actual dist  400.0  1.00  R
5   14/50.0  ( 14/50.0)   17/50.0  ( 17/50.0)  Actual dist  400.0  1.00  R
6   17/50.0  ( 17/50.0)   20/50.0  ( 20/50.0)  Actual dist  400.0  1.00  R
7   20/50.0  ( 20/50.0)   23/50.0  ( 23/50.0)  Actual dist  400.0  1.00  R
8   23/50.0  ( 23/50.0)   26/50.0  ( 26/50.0)  Actual dist  400.0  1.00  R
9   26/50.0  ( 26/50.0)   29/50.0  ( 29/50.0)  Actual dist  400.0  1.00  R
10  29/50.0  ( 29/50.0)   32/50.0  ( 32/50.0)  Actual dist  400.0  1.00  R
11  32/50.0  ( 32/50.0)   35/50.0  ( 35/50.0)  Actual dist  400.0  1.00  R
12  35/50.0  ( 35/50.0)   38/50.0  ( 38/50.0)  Actual dist  400.0  1.00  R
```

The number of wires increases, but the total number of segments remains about the same as with the straight-line model. The phasing line remains the same as in the other model.

Both models were checked within each of the 5 ham bands between the 14 to 30 MHz, the design passband for the antenna. Modeling was done on NEC-4, but NEC-2 would be entirely satisfactory, since neither model presses any limitation in either program. The only limitation applies to both programs and both models: the mathematical phasing line does not show wire losses, although these would be minimal. By intention, the velocity factor of the phasing line has been set at 1.0.

Both antennas have feedpoint impedances that fall generally within the design figures for a 2:1 SWR relative to 200 Ohms. The simplest way to show the relative performance between the Vee and straight element models is a simple table of gain and front-to-back ratios (**Table 6-1)**. A single frequency was used for 17 and 12 meters, but on 20 and 15 meters, band-edge and band-center values are shown. For 10 meters, the values cover 0.5 MHz intervals from 28 to 30 MHz.

Table 6-1. Comparative Performance of Straight and Vee'd Teleranas

Frequency	Free-Space Gain (dBi)		Front-to-Back Ratio (dB)	
MHz	Straight	Vee	Straight	Vee
14.0	5.71	4.50	11.63	7.53
14.175	5.71	4.54	11.69	7.73
14.35	5.72	4.58	11.79	7.92
18.12	6.08	5.21	15.85	11.16
21.0	6.26	5.40	16.70	12.17
21.225	6.24	5.38	16.70	12.16
21.45	6.21	5.36	16.92	12.13
24.95	6.13	5.18	18.16	12.75
28.0	5.93	5.14	18.23	13.06
28.5	5.86	5.11	17.77	12.74
29.0	5.81	5.08	17.31	12.39
29.5	5.79	5.05	16.87	12.04
30.0	5.80	5.03	16.48	11.75

If we select the center-point of each band and average the gain values and the front-to-back values, we obtain 5.99 dBi and 15.94 dB for the straight-element model and 5.08 dBi and 11.24 dB for the true Telerana with Vee elements. The straight-line model is almost a full dB higher in gain and over 3.5 dB better in front-to-back ratio.

These values are not unusual for arrays using elements near 1/2 wavelength long, whether LPDA or parasitic in design.

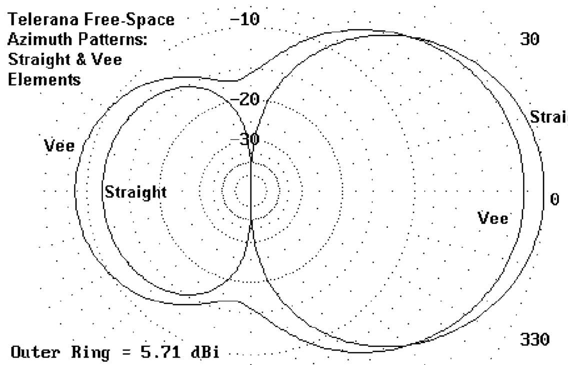


Fig. 6-3

Fig. 6-3 overlays the free-space azimuth patterns for the straight-element and the Vee model at 14 MHz. The figure demonstrates some of the reasons why Vee-ed elements have a lower forward gain. Not only does the Vee-model radiate more strongly to the rear, it also radiates to the sides, reducing the front-to-side ratio that some designers count on to reduce QRM levels in unidirectional arrays. Unless one wishes stronger radiation from the sides and rear, the Vee-model is inferior.

Fig. 6-4 shows the same two free-space azimuth patterns at 21 MHz, with essentially the same results. Front and side radiation from the Vee is stronger than from the

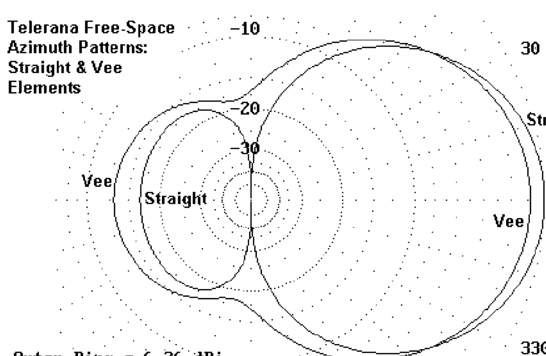


Fig. 6-4

straight-element model. These same phenomena reappear at 28 MHz, as shown in the free-space azimuth plot **Fig. 6-5**.

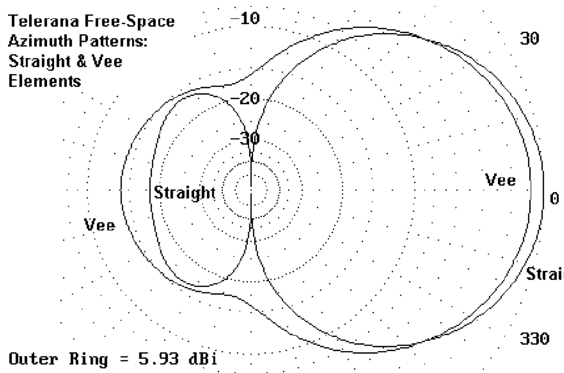


Fig. 6-5

I have shown several comparative azimuth patterns to establish that the pattern shapes for each antenna are not isolated or frequency-specific phenomena. The once-prevalent notion that Vee-ing elements increased gain has proven to have no foundation in any modeling that I have done with arrays based on 1/2 wavelength elements. In all cases, Vee-ing elements reduces gain, front-to-back ratio, and front-to-side ratio. Anyone who desires to examine the basis for these reductions should begin first by comparing a 1/2 wavelength dipole with a Vee of the same element length. What happens to the pattern for a single element simply accumulates for arrays of similar elements.

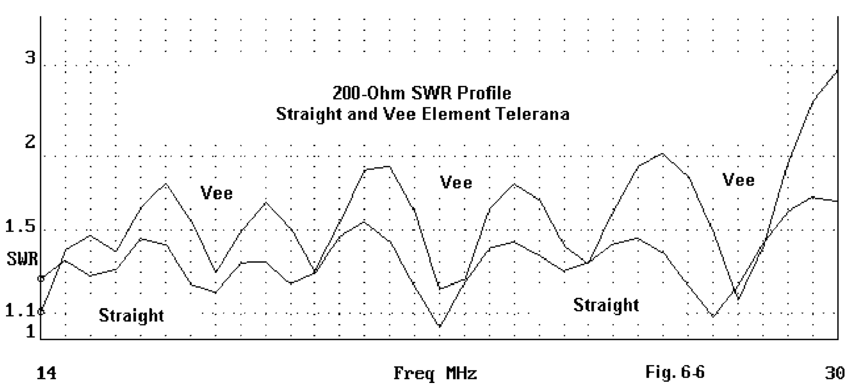


Fig. 6-6

Although Vee-ing the elements in the Telerana yields an acceptable 200-Ohm SWR profile across the passband of the antenna, the equivalent profile for the straight-element design is somewhat superior, with smaller excursions in both the resistive and reactive components of the feedpoint impedance. **Fig. 6-6** shows the two profiles for comparison. The Vee model would show an acceptable feedpoint impedance only up to about 29 MHz, but at the end of a 4:1 balun-plus-coaxial feedline, the SWR might appear to be somewhat lower.

Lest the Vee model be open to question, I performed a convergence test on it. To ensure that there were equal segments lengths on either side of the source/phaseline segment at the element centers, I increased the number of segments to 3. This required an increase by a factor of 3 for the number of segments on each wire making up the outer sections of the elements. For comparison, **Table 6-2** presents some values for the smaller and larger models of the Vee-d Telerana.

Table 6-2. Convergence Test of Telerana Models

	Freq. MHz	F-S Gain dBi	Front-Back dB	Feedpoint Impedance (R +/- jX Ohms)
	14.0			
Smaller		4.50	7.53	195.0 - j 19.5
Larger		4.48	7.53	190.6 - j 19.9
	18.12			
Smaller		5.21	11.16	213.6 - j 91.5
Larger		5.17	11.15	203.7 - j 92.2
	21.0			
Smaller		5.21	12.17	195.0 - j 19.5
Larger		5.36	12.14	190.6 - j 19.9
	24.95			
Smaller		5.18	12.75	256.7 + j 22.5
Larger		5.14	12.76	258.7 + j 12.3
	28.0			
Smaller		5.14	13.06	173.8 - j 3.5
Larger		5.06	13.04	172.9 - j 7.1

Nothing in the differences in the values returned by NEC-4 suggests that anything is amiss in the general accuracy of the analysis.

Element Diameter

Whether one chooses the Telerana as originally designed for its light-weight structure or selects the straight-element version for its higher performance is a design decision that goes beyond the present analysis. We are here only concerned with the electrical performance of the antenna design, and structural matters would add a dimension to the analysis to which modeling cannot contribute.

A similar set of considerations applies to the decision on whether to use wire or tubular elements. Wire is lighter than tubing. However, tubing may be obtained in much larger diameters than wire. The only question to which modeling can contribute an answer is whether larger diameter tubing offers any advantages in antenna performance over the same design in wire.

To answer this question, I changed diameter of the elements in the straight-element model from #14 AWG to 0.5". The increase factor is nearly 8. Since the elements in the model are of uniform diameter, the choice of 0.5" as the new diameter reflects the effective diameter of heavily stepped diameter elements that might begin with diameters of nearly 1" and descend to about 3/8" at the element tips. Therefore, as a modeling exercise, the comparison might well be representative of building practice.

For reference, here is the revised straight-element model description.

```
Telerana-Ant Bk 10-13: Straight: 0.5" elements     Frequency = 14  MHz.

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

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

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

1          0.000,-20.330,  0.000        0.000, 20.330,  0.000 5.00E-01  39
2          4.060,-18.300,  0.000        4.060, 18.300,  0.000 5.00E-01  35
3          7.710,-16.460,  0.000        7.710, 16.460,  0.000 5.00E-01  31
4         11.020,-14.820,  0.000       11.020, 14.820,  0.000 5.00E-01  29
5         13.970,-13.310,  0.000       13.970, 13.310,  0.000 5.00E-01  25
6         16.630,-12.000,  0.000       16.630, 12.000,  0.000 5.00E-01  23
7         19.050,-10.790,  0.000       19.050, 10.790,  0.000 5.00E-01  21
8         21.140, -9.710,  0.000       21.140,  9.710,  0.000 5.00E-01  19
9         23.150, -8.720,  0.000       23.150,  8.720,  0.000 5.00E-01  17
10        24.890, -7.870,  0.000       24.890,  7.870,  0.000 5.00E-01  15
```

11	26.470, -7.080, 0.000	26.460, 7.080, 0.000	5.00E-01	13
12	27.890, -6.360, 0.000	27.890, 6.360, 0.000	5.00E-01	13
13	29.160, -5.740, 0.000	29.160, 5.740, 0.000	5.00E-01	11

-------------- SOURCES --------------

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	6	13 / 50.00	(13 / 50.00)	1.000	0.000	V

-------- TRANSMISSION LINES ---------

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	200.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	200.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	200.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	200.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	200.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	200.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	200.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	200.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	200.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	200.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	200.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	200.0	1.00	R

The other change occasioned by the altered element diameter was the choice of the optimal inter-element phasing line characteristic impedance. Although higher gain levels are possible with lower phase line impedances, evidences of harmonic operation of longer wires shows up especially in the 15-meter band. These would have required compensating treatment, such as the addition of a stub. The result would have altered overall performance enough to cast doubt on the fairness of the comparison. Therefore, I selected a 200-Ohm line with no further "doctoring" of the design.

I also left the material as copper: The difference in performance values by using aluminum will be 0.01 dB of gain and 0.01 dB of front-to-back ratio. Once the diameter of an element reaches a certain level, changes of conductivity in the range between copper and aluminum no longer make a significant difference in the radiation efficiency of otherwise equivalent elements. In the upper HF region, that diameter is about a half inch.

However, diameter differences between #14 wire and 0.5" tubing can make a significant difference in performance. This difference shows up not only in LPDA designs, but as well in other arrays. One reason that multi-element quads fail to achieve their theoretically possible improvement over Yagis with an equal number of elements is not a function of basic design. Instead, it involves the habitual use of small-diameter wire in quad elements. Increasing the element diameters to a half-inch or more shows a much higher potential for quad designs, whatever the mechanical difficulties of implementing such designs.

Table 6-3. Effects of Element Diameter on LPDA Performance

Frequency	Free-Space Gain (dBi)		Front-to-Back Ratio (dB)	
MHz	#14	0.5"	#14	0.5"
14.0	5.71	6.39	11.63	15.59
14.175	5.71	6.37	11.69	15.63
14.35	5.72	6.36	11.79	15.81
18.12	6.08	6.59	15.85	21.01
21.0	6.26	6.90	16.70	17.90
21.225	6.24	6.92	16.70	17.72
21.45	6.21	6.99	16.92	16.49
24.95	6.13	6.66	18.16	21.31
28.0	5.93	6.45	18.23	20.79
28.5	5.86	6.39	17.77	20.30
29.0	5.81	6.36	17.31	19.65
29.5	5.79	6.35	16.87	18.89
30.0	5.80	6.38	16.48	18.09

As **Table 6-3** shows, at the 21.45 MHz marker, one can see evidence of the onset of harmonic operation with the peak gain that opposes the curve for the wire model. The lowering of the front-to-back ratio below expected norms is also a clue to this phenomenon. Reducing the phase line impedance to 100 or 150 Ohms allows the harmonic operation to become graphic. Indeed, even for the 200-Ohm phase-line model, I would recommend stub treatment to suppress this phenomenon or to move it well outside the ham bands. There is some literature that suggests the operation of LPDAs in harmonic mode for added gain. However, combined fundamental and harmonic operation of elements is generally to be avoided in LPDAs operating over an octave or more range. Smooth performance figures over the frequency bands of interest become more difficult to obtain where both fundamental and harmonic operations are combined.

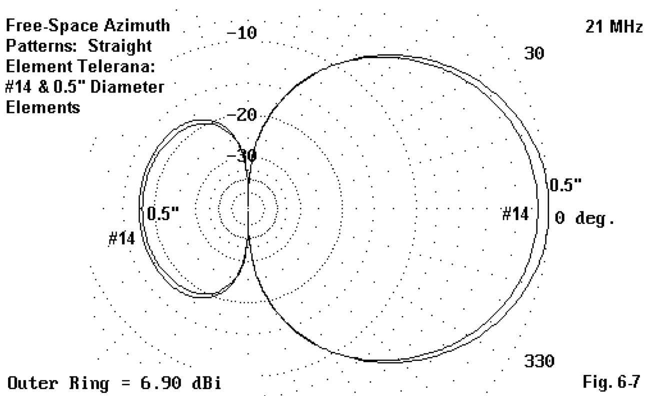


Fig. 6-7

The average gain for the wire model is 5.99 dBi and the front-to-back ratio average to 15.94 dB. The 0.5" model shows 6.58 dBi and 19.06 dB as the comparable averages. Although the gain figure is only about 0.6 dB more, the 3 dB advantage in front-to-back ratio may well be worthy. **Fig. 6-7** shows one representative comparison: the overlaid free-space azimuth patterns of the wire and tube models at 21 MHz.

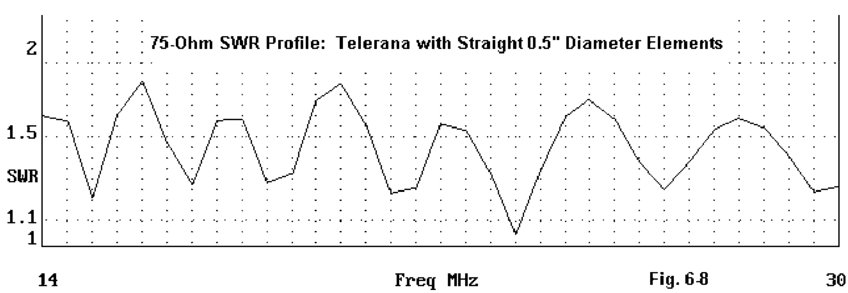


Fig. 6-8

The lower phase-line characteristic impedance yields a lower design feedpoint impedance. Although it might well be refined further, 75 Ohms provides a reasonable reference for an SWR profile. As **Fig. 6-8** shows, the 0.5" model has a well-behaved SWR curves relative to the reference.

Additional design refinements are certainly possible. We have already noted the utility of adding a stub to this model. The elements might also be increased in size, working from the shortest element and increasing the diameter by the inverse of τ. Likewise, circularization of τ, especially at the lower end of the spectrum, would tend to equalize the gain and front-to-back ratio across the passband at the highest level obtained near mid-band.

I shall not try to implement such revisions in this exercise. The goal of this study has been to compare straight-wire LPDA design to designs using Vee-ed elements and to compare thin-wire and fat-wire elements within the same design. Having done that much, it is time to set the Telerana at rest.

Nothing in this analysis has tried to be critical of the Telerana design. It is a mechanical marvel of stressed fiberglass supporting of a complex wire assembly. This analysis has looked at some electrical properties of LPDAs without regard for the ease or difficulty of implementation. Only the Telerana electrical design has been brought to the modeling table. The mechanical aspect of the Telerana remains a classic in amateur antenna design.

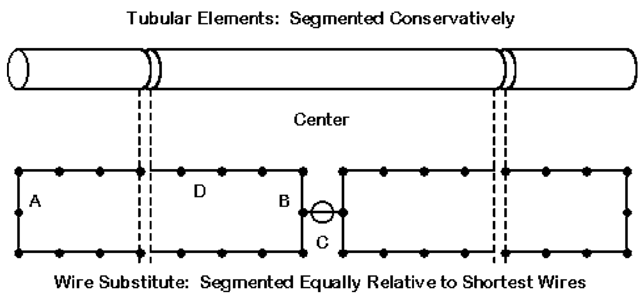
Wire Substitutes for Tubular Elements

It is possible to obtain the performance of a “fat” tubular element with a wire substitute. Two parallel wires can be shorted at their far ends and shorted again on each side of the feedpoint or phaseline connection point in the center. If the wires are properly spaced apart, they will simulate very closely the behavior of a single fat wire.

In this space, we cannot develop a complete database of wire equivalents to tubes. First of all, too many tube sizes are used to make this feasible. Second, the wire spacing will depend on the wire size used, and that multiplies the number of possibilities. However, we can make a small demonstration and show the modeling procedures one might use to develop a specific substitution.

Let's begin with the longest element of the Telerana in its 0.5" implementation. If we separate that element from the LPDA of which it is a part, we can find its resonant frequency. The 487.92" (40.66') element resonates at 11.63 MHz with a source impedance of 72.0 - j 0.1 Ohms. I generally set a reactance of +/-j1 Ohm as the criterion of resonance for most investigations--a figure somewhat more precise than we would need for an operational situation.

Now let's take 2 #14 AWG wires and make them parallel. Now we must figure out how to feed the wires without creating a folded dipole. **Fig. 6-9** shows the general technique.



Modeling a Wire Equivalent to a "Fat" Element Fig. 6-9

We create a short single center section of 1 segment (C). Then, we create short wires from the center section to each long wire of the pairs (B). This action will make 2 wires, which we recreate with a single 2-segment wire at the far ends of the assembly (A). Each horizontal wire (D) is appropriately segmented.

The ideal situation would require that all wire segments be of approximately equal length. Hence, the lengths, of segments in A, B, C, and D would be the same. Equalizing the segment (wire) lengths of B and C is especially important. The far-end wires (A) can be of 1 or 2 segments: the difference makes little difference to the result. The segments of the parallel wires (D) should be no more than about 1.5 to 2.0 times the length of B or C. Working outside these dimensions generally yields poor results from the wire model.

A parallel-wire (#14 AWG) model of the 0.5" element yielded resonance at 11.60 MHz when the wires were 2" apart. With 120 segments each side of center along wire

D, the feedpoint impedance was 72.81 + j0.3 Ohms, which was satisfactorily close to the value for the 0.5" tube. One might have nudged the spacing more precisely to place the resonance at 11.63 MHz, but the convenient 2" spacing number would have been lost.

So far, we have created a single element out of wire, one that has the same length as the original tube. One reason we wanted to preserve the length is to also preserve the current distribution along the length of the element. This function is just as important to LPDA operation as the phase line, since mutual coupling works together with phased element feed to yield the LPDA performance.

Will these substitution elements produce the same performance as the tubular original elements in an LPDA design? To create a little demonstration, let's look at a simpler design than the one with which we have been working. The reasons for this will become self-evident in a bit. The design we shall use is one that appears in *The ARRL Antenna Book* as a little exercise. It is not an especially good LPDA, but its merit is that it is small and designed for 17-10 meters. The model description of the test version follows.

```
17-10m Log Per - ARRL Ant Book              Frequency = 18.12  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          0.000,-163.46,  0.000         0.000,163.460,  0.000 5.00E-01  37
2         39.230,-130.76,  0.000        39.230,130.760,  0.000 5.00E-01  29
3         70.620,-104.62,  0.000        70.620,104.620,  0.000 5.00E-01  23
4         95.720,-83.690,  0.000        95.720, 83.690,  0.000 5.00E-01  19
5        115.810,-66.950,  0.000       115.810, 66.950,  0.000 5.00E-01  15

              -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1   Ampl.(V, A)  Phase(Deg.)  Type
           Seg.     Actual      (Specified)

1           8     5 / 50.00   (  5 / 50.00)     1.000       0.000       I
```

```
                 -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  490.1  1.00  R
2    2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  490.1  1.00  R
3    3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  490.1  1.00  R
4    4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  490.1  1.00  R
5    1/50.0  (  1/50.0)  Short ckt (Short ck)   6.000 in   490.1  1.00
```

Now let's present the substitute wire-element model.

```
17-10m Log Per Ant Bk Wire Sub              Frequency = 18.12  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   W3E1 -163.46, -1.000,  0.000  W2E1  -1.000, -1.000,  0.000    # 14   60
2   W1E2  -1.000, -1.000,  0.000  W5E2  -1.000,  0.000,  0.000    # 14    1
3   W1E1 -163.46, -1.000,  0.000  W4E1 -163.46,  1.000,  0.000    # 14    2
4   W3E2 -163.46,  1.000,  0.000  W5E1  -1.000,  1.000,  0.000    # 14   60
5   W4E2  -1.000,  1.000,  0.000  W6E1  -1.000,  0.000,  0.000    # 14    1
6   W2E2  -1.000,  0.000,  0.000  W7E1   1.000,  0.000,  0.000    # 14    1
7  W10E1   1.000,  0.000,  0.000  W8E1   1.000,  1.000,  0.000    # 14    1
8   W7E2   1.000,  1.000,  0.000  W9E1 163.460,  1.000,  0.000    # 14   60
9   W8E2 163.460,  1.000,  0.000 W11E2 163.460, -1.000,  0.000    # 14    2
10  W6E2   1.000,  0.000,  0.000 W11E1   1.000, -1.000,  0.000    # 14    1
11 W10E2   1.000, -1.000,  0.000  W9E2 163.460, -1.000,  0.000    # 14   60
12 W14E1 -130.76, 38.230,  0.000 W13E1  -1.000, 38.230,  0.000    # 14   50
13 W12E2  -1.000, 38.230,  0.000 W16E2  -1.000, 39.230,  0.000    # 14    1
14 W12E1 -130.76, 38.230,  0.000 W15E1 -130.76, 40.230,  0.000    # 14    2
15 W14E2 -130.76, 40.230,  0.000 W16E1  -1.000, 40.230,  0.000    # 14   50
16 W15E2  -1.000, 40.230,  0.000 W17E1  -1.000, 39.230,  0.000    # 14    1
17 W13E2  -1.000, 39.230,  0.000 W18E1   1.000, 39.230,  0.000    # 14    1
18 W21E1   1.000, 39.230,  0.000 W19E1   1.000, 40.230,  0.000    # 14    1
19 W18E2   1.000, 40.230,  0.000 W20E1 130.760, 40.230,  0.000    # 14   50
20 W19E2 130.760, 40.230,  0.000 W22E2 130.760, 38.230,  0.000    # 14    2
21 W17E2   1.000, 39.230,  0.000 W22E1   1.000, 38.230,  0.000    # 14    1
22 W21E2   1.000, 38.230,  0.000 W20E2 130.760, 38.230,  0.000    # 14   50
23 W25E1 -104.62, 69.620,  0.000 W24E1  -1.000, 69.620,  0.000    # 14   40
24 W23E2  -1.000, 69.620,  0.000 W27E2  -1.000, 70.620,  0.000    # 14    1
25 W23E1 -104.62, 69.620,  0.000 W26E1 -104.62, 71.620,  0.000    # 14    2
```

```
26 W25E2 -104.62, 71.620,  0.000 W27E1  -1.000, 71.620,  0.000   # 14   40
27 W26E2  -1.000, 71.620,  0.000 W28E1  -1.000, 70.620,  0.000   # 14    1
28 W24E2  -1.000, 70.620,  0.000 W29E1   1.000, 70.620,  0.000   # 14    1
29 W32E1   1.000, 70.620,  0.000 W30E1   1.000, 71.620,  0.000   # 14    1
30 W29E2   1.000, 71.620,  0.000 W31E1 104.620, 71.620,  0.000   # 14   40
31 W30E2 104.620, 71.620,  0.000 W33E2 104.620, 69.620,  0.000   # 14    2
32 W28E2   1.000, 70.620,  0.000 W33E1   1.000, 69.620,  0.000   # 14    1
33 W32E2   1.000, 69.620,  0.000 W31E2 104.620, 69.620,  0.000   # 14   40
34 W36E1 -83.690, 94.720,  0.000 W35E1  -1.000, 94.720,  0.000   # 14   30
35 W34E2  -1.000, 94.720,  0.000 W38E2  -1.000, 95.720,  0.000   # 14    1
36 W34E1 -83.690, 94.720,  0.000 W37E1 -83.690, 96.720,  0.000   # 14    2
37 W36E2 -83.690, 96.720,  0.000 W38E1  -1.000, 96.720,  0.000   # 14   30
38 W37E2  -1.000, 96.720,  0.000 W39E1  -1.000, 95.720,  0.000   # 14    1
39 W35E2  -1.000, 95.720,  0.000 W40E1   1.000, 95.720,  0.000   # 14    1
40 W43E1   1.000, 95.720,  0.000 W41E1   1.000, 96.720,  0.000   # 14    1
41 W40E2   1.000, 96.720,  0.000 W42E1  83.690, 96.720,  0.000   # 14   30
42 W41E2  83.690, 96.720,  0.000 W44E2  83.690, 94.720,  0.000   # 14    2
43 W39E2   1.000, 95.720,  0.000 W44E1   1.000, 94.720,  0.000   # 14    1
44 W43E2   1.000, 94.720,  0.000 W42E2  83.690, 94.720,  0.000   # 14   30
45 W47E1 -66.950,114.810,  0.000 W46E1  -1.000,114.810,  0.000   # 14   25
46 W45E2  -1.000,114.810,  0.000 W49E2  -1.000,115.810,  0.000   # 14    1
47 W45E1 -66.950,114.810,  0.000 W48E1 -66.950,116.810,  0.000   # 14    2
48 W47E2 -66.950,116.810,  0.000 W49E1  -1.000,116.810,  0.000   # 14   25
49 W48E2  -1.000,116.810,  0.000 W50E1  -1.000,115.810,  0.000   # 14    1
50 W46E2  -1.000,115.810,  0.000 W51E1   1.000,115.810,  0.000   # 14    1
51 W54E1   1.000,115.810,  0.000 W52E1   1.000,116.810,  0.000   # 14    1
52 W51E2   1.000,116.810,  0.000 W53E1  66.950,116.810,  0.000   # 14   25
53 W52E2  66.950,116.810,  0.000 W55E2  66.950,114.810,  0.000   # 14    2
54 W50E2   1.000,115.810,  0.000 W55E1   1.000,114.810,  0.000   # 14    1
55 W54E2   1.000,114.810,  0.000 W53E2  66.950,114.810,  0.000   # 14   25

                -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1   Ampl.(V, A)  Phase(Deg.)  Type
           Seg.     Actual      (Specified)

1           1    50 / 50.00   ( 50 / 50.00)     1.000       0.000       V

                  -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length     Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1    6/50.0  (  6/50.0)   17/50.0  ( 17/50.0)  Actual dist  490.1  1.00  R
2   17/50.0  ( 17/50.0)   28/50.0  ( 28/50.0)  Actual dist  490.1  1.00  R
3   28/50.0  ( 28/50.0)   39/50.0  ( 39/50.0)  Actual dist  490.1  1.00  R
```

```
4   39/50.0  ( 39/50.0)   50/50.0  ( 50/50.0)  Actual dist  490.1  1.00  R
5    6/50.0  (  6/50.0)  Short ckt (Short ck)   6.000 in   490.1  1.00
```

This 55-wire, 865-segment model is sizable and slow running. However, it is considerably shorter and faster than had we presented the wire substitute for the Telerana with its 13 elements replaced by 143 wires and well over double the total number of segments as the small model. The smaller model is also a good test of the substitution, since it does not have especially good performance. If the substitute were a poor one, we could expect results that significantly diverge from the original.

The following table shows how the original and the substitute fared in modeling tests at sample frequencies.

Table 6-4. Comparison of 2-Wire and Tubular Element LPDAs

Frequency MHz	Free-Space Gain dBi	Front-Back Ratio dB	Feed Impedance R +/- jX Ohms
18.12			
Original	4.44	6.42	60.2 + j 95.8
Substitute	4.35	6.29	72.3 + j112.5
21.0			
Original	4.47	6.15	142.9 - j 87.0
Substitute	4.43	6.10	127.6 - j 70.5
24.95			
Original	5.09	7.94	382.8 - j 82.3
Substitute	5.07	8.02	330.0 - j141.6
28.0			
Original	5.36	9.81	105.3 - j 54.8
Substitute	5.32	9.81	102.7 - j 36.9

The maximum gain differential is 0.09 dB and the maximum front-to-back differential is 0.13 dB. The very small gain degradation stems in part from the smaller area available on the two wire surfaces compared to the surface of the larger tube. The original tube from which we derived the substitute 2-wire spacing had a dipole gain of 2.13 dBi, while the substitute had a gain of 2.07 dBi in free space.

Although the impedance differences are greater, they are in part attributable to the slight difference we selected for resonant frequencies for the elements in order to preserve round numbers for with wire spacing. However, the impedance differences are not great enough to disturb the general trends of an SWR profile.

The demonstration shows that it is possible to develop 2-wire equivalents of larger elements. The technique used to develop the #14 wire substitute for 0.5" elements can be replicated to make substitutes out of almost any size wire for any size original element. The demonstration also shows that the performance of the 2-wire substitute can be effectively modeled with due attention to the constraints of NEC segmentation--and if one is willing to work with larger models that require considerable run time.

Whether the 2-wire substitute element would be satisfactory in an actual LPDA antenna involves mechanical considerations beyond the scope of this modeling exercise. Nonetheless, it is an option that the LPDA designer-builder should not overlook in the quest for an adequate LPDA.

Needless to say, the 5-element demonstration model would be hardly worth the effort of building. There are far better designs with which to work. We shall examine a few in the upcoming chapters.

Part 3: Practical 1-Octave HF LPDAs

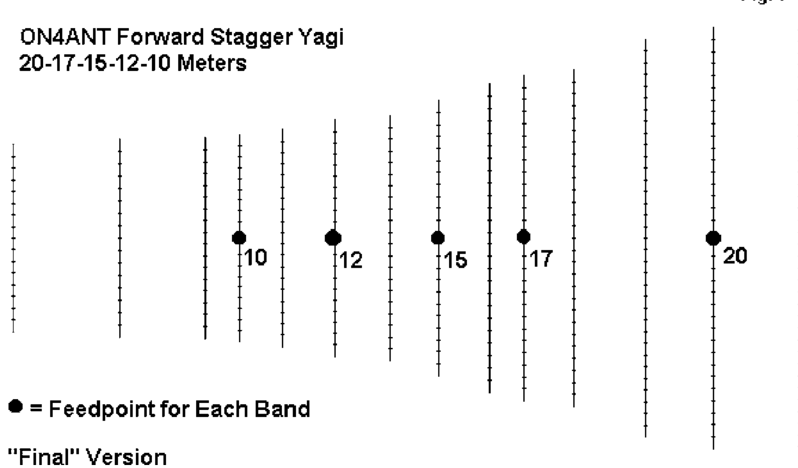
Chapter 7: A High-Performance, Long-Boom 14-30 MHz LPDA

In this chapter, I want to discuss a pair of long-boom LPDA designs to cover all of the amateur bands from 20 through 10 meters. "Long-boom" means (for our purposes) anything over 45' or so. We know that 5-6 element monoband Yagis can achieve a little over 10.1 dBi free-space gain with better than 20 dB front-to-back ratios across 20 meters with boom lengths between 45 and 53 feet. The question before us is this: what can we achieve using a similar boom length in a multi-band antenna?

Standards of Comparison

Our comparators will be arrays using linear elements. In the triband category, Force 12 has a 49-foot model with excellent performance on 20, 15, and 10 meters. However, the standard for comparison for an LPDA would need to cover all 5 upper HF bands.

Fig. 7-1



The only single-boom design with high performance on all 5 amateur bands is the ON4ANT forward-stagger design, which has recently appeared in journals and also appears at my website. **Fig. 7-1** shows the general outline of the "final" 14-element, 60'-boom model designed by Johan Van de Velde.

For each band below 10 meters, the director also serves as the reflector for the next higher band. As well, for all bands above 20 meters, the director serves as the reflector for the next higher band. Additional directors have been added to improve 10-meter performance.

For reference, the following model description will provide the dimensions (in meters):

```
ON4ANT 5-band Yagi:  14-28 Final            Frequency = 14.175  MHz.

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

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

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

1           -5.450,  0.000,  0.000         5.450,  0.000,  0.000 3.20E+01  37
2           -5.200,  2.000,  0.000         5.200,  2.000,  0.000 3.20E+01  35
3           -4.900,  3.600,  0.000         4.900,  3.600,  0.000 3.20E+01  34
4           -4.150,  5.250,  0.000         4.150,  5.250,  0.000 2.50E+01  28
5           -4.020,  6.400,  0.000         4.020,  6.400,  0.000 2.50E+01  27
6           -3.800,  7.200,  0.000         3.800,  7.200,  0.000 2.50E+01  25
7           -3.395,  8.400,  0.000         3.395,  8.400,  0.000 2.50E+01  23
8           -3.020,  9.500,  0.000         3.020,  9.500,  0.000 2.50E+01  21
9           -2.910, 10.800,  0.000         2.910, 10.800,  0.000 2.50E+01  21
10          -2.680, 12.000,  0.000         2.680, 12.000,  0.000 2.30E+01  19
11          -2.550, 13.014,  0.000         2.550, 13.014,  0.000 2.30E+01  19
12          -2.470, 13.816,  0.000         2.470, 13.816,  0.000 2.30E+01  17
13          -2.440, 15.775,  0.000         2.440, 15.775,  0.000 2.30E+01  16
14          -2.310, 18.250,  0.000         2.310, 18.250,  0.000 2.30E+01  16

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1          18     2 / 50.00   (  2 / 50.00)      1.000       0.000       I
```

More important is the performance potential, which **Table 7-1** reveals.

Table 7-1. 5-Band Yagi Performance Potential

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms
20				
	14.0	8.30	36.74	28.8 - j 0.4
	14.175	8.41	27.35	24.7 + j 7.9
	14.35	8.55	20.57	19.0 + j18.8
17				
	18.118	8.35	23.06	31.7 - j 4.9
15				
	21.0	8.73	23.12	34.1 + j 2.0
	21.225	8.86	23.15	35.9 + j10.3
	21.45	8.99	23.04	37.4 + j18.6
12				
	24.94	9.70	37.50	23.4 + j14.6
10				
	28.0	9.92	26.58	30.0 - j 8.8
	28.35	9.99	39.15	33.5 - j 4.7
	28.7	9.69	34.30	20.3 - j12.2

Because elements must do double duty, performance improves with frequency. Even the 20-meter performance improves as one moves up the band, since the 20-meter director must be cut and positioned also to serve as the 17-meter reflector. 15 meters shows a similar pattern. The 180-degree front-to-back value exceeds 20 dB throughout the passband.

No SWR figures appear since the antenna's 5 feedpoints (one for each band) are designed for use with a gamma match. The significant limitation (from the perspective of broadband design, but not from the perspective of some kinds of operating interests) is the "cut-off" of 10-meter coverage somewhere between 28.7 and 28.8 MHz, as gain continues to decrease and the feedpoint resistive component of the impedances also continues to decrease.

The ON4ANT design makes a good standard against which to compare a high-performance LPDA.

Version 1: Circular-τ-Modified Standard LPDA Design

The initial version of the LPDA uses a τ of 0.95 and a σ of 0.056. Ideally, one should use a τ of 0.96 and an optimized σ somewhat higher than 0.18. However, the boom length for such an antenna becomes well over 3 times the length of the present design. With the τ and σ values given, the boom length is about 51.5' with 21 elements, all of which are uniformly 0.5" in diameter. **Fig. 7-2** shows the general outline of the array.

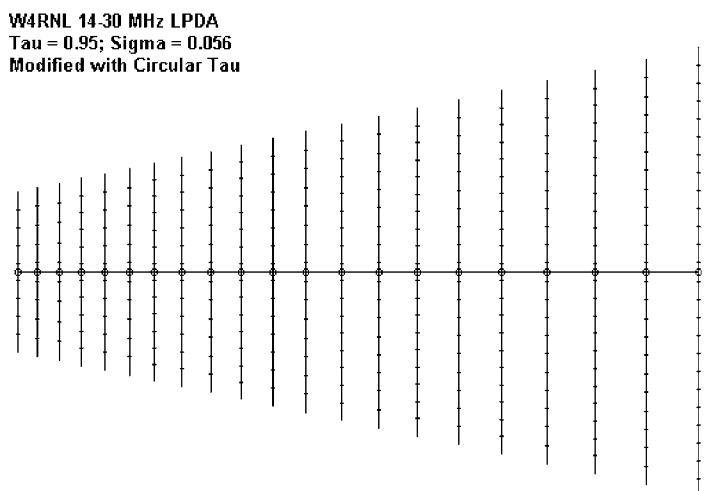


Fig. 7-2

For reference and element dimensions (in inches), the model description follows:

```
14-30 MHz .95/.056 21 el 51.5'            Frequency = 14  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             0.000,-216.30,  0.000         0.000,216.300,  0.000 5.00E-01  25
2            48.177,-205.00,  0.000        48.177,205.000,  0.000 5.00E-01  23
3            93.944,-194.00,  0.000        93.944,194.000,  0.000 5.00E-01  23
4           137.424,-184.40,  0.000       137.424,184.399,  0.000 5.00E-01  21
5           178.729,-175.18,  0.000       178.729,175.179,  0.000 5.00E-01  21
6           217.969,-166.42,  0.000       217.969,166.420,  0.000 5.00E-01  19
7           255.248,-158.10,  0.000       255.248,158.099,  0.000 5.00E-01  19
8           290.662,-150.19,  0.000       290.662,150.194,  0.000 5.00E-01  17
9           324.306,-142.68,  0.000       324.306,142.685,  0.000 5.00E-01  17
10          356.267,-135.55,  0.000       356.267,135.550,  0.000 5.00E-01  15
11          386.630,-128.77,  0.000       386.630,128.773,  0.000 5.00E-01  15
12          415.475,-122.33,  0.000       415.475,122.334,  0.000 5.00E-01  15
13          442.878,-116.22,  0.000       442.878,116.217,  0.000 5.00E-01  13
14          468.911,-110.41,  0.000       468.911,110.407,  0.000 5.00E-01  13
15          493.642,-104.89,  0.000       493.642,104.886,  0.000 5.00E-01  13
16          517.136,-99.642,  0.000       517.136, 99.642,  0.000 5.00E-01  11
17          539.456,-94.660,  0.000       539.456, 94.660,  0.000 5.00E-01  11
18          560.660,-89.927,  0.000       560.660, 89.927,  0.000 5.00E-01  11
19          580.804,-85.431,  0.000       580.804, 85.431,  0.000 5.00E-01  9
20          599.940,-81.159,  0.000       599.940, 81.159,  0.000 5.00E-01  9
21          618.120,-77.101,  0.000       618.120, 77.101,  0.000 5.00E-01  9

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           5    21 / 50.00   ( 21 / 50.00)      0.707       0.000       V

                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  100.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  100.0  1.00  R
.  .  .
19    19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  100.0  1.00  R
20    20/50.0  ( 20/50.0)   21/50.0  ( 21/50.0)  Actual dist  100.0  1.00  R
```

As one decreases the characteristic impedance of the phasing line from 200 Ohms downward, the array draws closer to having an acceptable 50-Ohm or 75-Ohm SWR throughout its passband (14-30 MHz). However, these same reductions often reveal frequencies at which an LPDA will show a weakness. A weakness means that the elements to the rear of the element with the highest current magnitude begin to operate in a harmonic mode. The result is a reduction in forward gain and a very significant reduction in front-to-back ratio. In short, rearward radiation becomes quite large at frequencies of weakness. The design uses a 100-Ohm phase line, which is physically practical for either double boom construction or for a separate phase line structure. The array shows potential weaknesses at about 19.75 MHz and again at 26.5 MHz. Since these frequencies lie between amateur bands, no compensatory treatments were applied.

To enhance performance in the upper HF region, the forward elements were subjected to circularization, a process described in some detail in Chapter 5. Essentially, we increase the value of τ with respect to be element length and spacing for the affected elements. The result was a small increase in upper HF gain, but a more useful improvement in the feedpoint SWR curve.

Table 7-2 provides the potential performance figures for the NEC-4 model.

As the frequency approaches 30 MHz, the 75-Ohm VSWR exceed 2:1 by a small amount, although the 50-Ohm SWR remains at about 1.8:1. The feedpoint resistance begins to sink rapidly above 29.5 MHz.

Below 15 meters, the gain performance of the LPDA exceeds the ON4ANT forward-stagger Yagi. More generally, the LPDA front-to-back ratio is more stable, as it tracks the gain of the antenna at each frequency. 10-meter performance is down considerably relative to the Yagi. This phenomenon is quite normal for an LPDA where the upper design frequency is less than 1.6 times the highest frequency used. Adding further elements (to a self-resonant frequency of about 50 MHz) would have significantly lengthened the boom. At least 5 further elements would have been required.

Table 7-2. LPDA Performance Potential

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
20						
	14.0	8.82	25.45	75.0 + j 0.1	1.50	1.00
	14.175	8.82	31.25	73.9 - j 2.9	1.48	1.04
	14.35	8.78	42.54	72.5 - j 6.3	1.47	1.10
17						
	18.118	8.74	40.48	69.1 - j 7.6	1.42	1.14
15						
	21.0	8.52	34.31	60.6 + j 1.3	1.21	1.24
	21.225	8.50	34.54	65.9 + j 4.2	1.33	1.15
	21.45	8.50	34.73	71.3 + j 1.4	1.43	1.06
12						
	24.94	8.39	32.03	61.7 - j 8.9	1.28	1.25
10						
	28.0	8.00	25.31	66.6 - j16.8	1.50	1.30
	28.5	8.05	26.38	54.1 - j 3.3	1.11	1.39
	29.0	7.97	25.35	73.6 - j 0.8	1.47	1.02
	29.5	7.79	23.27	63.6 - j30.7	1.80	1.60

The reduction in gain (and front-to-back ratio) at higher frequencies stems in large measure from the fact that in a wide-band LPDA array, all of the elements forward of the one with the highest current magnitude at a given frequency are active, essentially adding many "directors" to the array. As we increase frequency, the element with the highest current magnitude moves forward, leaving fewer elements to serve as "directors." Circularizing the value of τ for the forward-most elements can improve the upper-end gain, but it cannot fully compensate for all of the reduction.

As a consequence of the gain fall-off in the upper portion of the operating passband, further design work was undertaken. The result was an array with remarkably even gain across the entire passband.

Version 2: Circular-τ-Modified LPDA Design With a Parasitic Director

I added a director to the array, as shown in **Fig. 7-3**. The director adds only 4.3' to the boom length, but equalizes performance at both ends of the passband.

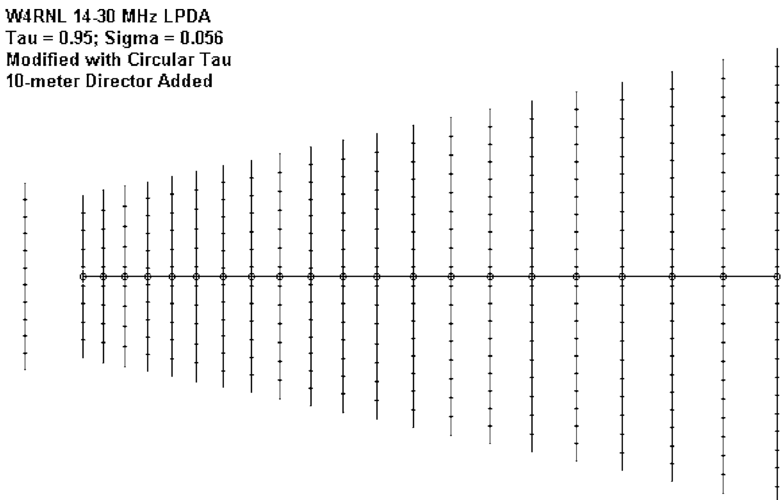


Fig. 7-3

The resulting array can be described in the following terms:

```
14-30 MHz .95/.056 21+dir 55.8'            Frequency = 14  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             0.000,-216.30,  0.000         0.000,216.300,  0.000 5.00E-01  25
2            48.177,-205.00,  0.000        48.177,205.000,  0.000 5.00E-01  23
3            93.944,-194.00,  0.000        93.944,194.000,  0.000 5.00E-01  23
4           137.424,-184.40,  0.000       137.424,184.399,  0.000 5.00E-01  21
5           178.729,-175.18,  0.000       178.729,175.179,  0.000 5.00E-01  21
6           217.969,-166.42,  0.000       217.969,166.420,  0.000 5.00E-01  19
7           255.248,-158.10,  0.000       255.248,158.099,  0.000 5.00E-01  19
8           290.662,-150.19,  0.000       290.662,150.194,  0.000 5.00E-01  17
9           324.306,-142.68,  0.000       324.306,142.685,  0.000 5.00E-01  17
10          356.267,-135.55,  0.000       356.267,135.550,  0.000 5.00E-01  15
```

```
    11          386.630,-128.77,  0.000       386.630,128.773,  0.000 5.00E-01  15
    12          415.475,-122.33,  0.000       415.475,122.334,  0.000 5.00E-01  15
    13          442.878,-116.22,  0.000       442.878,116.217,  0.000 5.00E-01  13
    14          468.911,-110.41,  0.000       468.911,110.407,  0.000 5.00E-01  13
    15          493.642,-104.89,  0.000       493.642,104.886,  0.000 5.00E-01  13
    16          517.136,-99.642,  0.000       517.136, 99.642,  0.000 5.00E-01  11
    17          539.456,-94.660,  0.000       539.456, 94.660,  0.000 5.00E-01  11
    18          560.660,-89.927,  0.000       560.660, 89.927,  0.000 5.00E-01  11
    19          580.804,-85.431,  0.000       580.804, 85.431,  0.000 5.00E-01  9
    20          599.940,-81.159,  0.000       599.940, 81.159,  0.000 5.00E-01  9
    21          618.120,-77.101,  0.000       618.120, 77.101,  0.000 5.00E-01  9
    22          670.000,-88.700,  0.000       670.000, 88.700,  0.000 5.00E-01  11

                 -------------- SOURCES --------------

    Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
              Seg.     Actual      (Specified)

    1           5    21 / 50.00   ( 21 / 50.00)      0.707       0.000       V

                   -------- TRANSMISSION LINES ---------

    Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
          Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm

    1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  100.0  1.00  R
    2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  100.0  1.00  R
    .  .  .
    19    19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  100.0  1.00  R
    20    20/50.0  ( 20/50.0)   21/50.0  ( 21/50.0)  Actual dist  100.0  1.00  R
```

The parasitic director length and position represent a design compromise. Further gain is achievable, but at the cost of unacceptable 10-meter SWR values. In essence, the placement of a forward director is a juggling act to balance gain against the feedpoint impedance. A parasitic element also tends to decrease the front-to-back ratio at upper frequencies of the passband. The design goals included a front-to-back ratio at 29.5 MHz of at least 20 dB plus a 50-Ohm SWR no higher than 2:1 across 10 meters. The following performance numbers (**Table 7-3)** reveal that both objectives were met.

Table 7-3. Modified LPDA Performance Potential

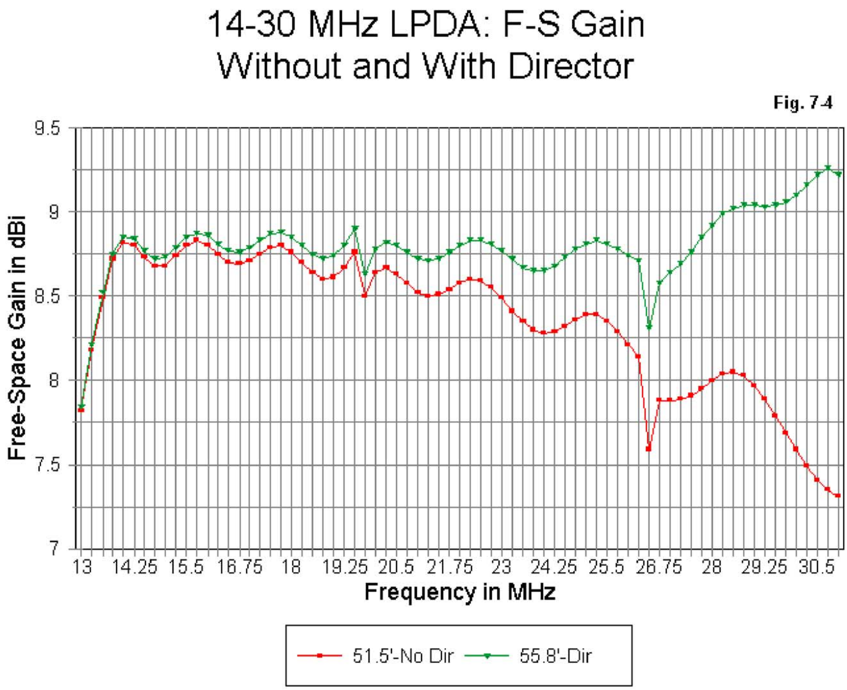
Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
20						
	14.0	8.85	24.83	75.6 + j 0.2	1.51	1.01
	14.175	8.85	30.27	74.2 - j 3.5	1.49	1.05
	14.35	8.81	38.97	71.9 - j 6.5	1.46	1.10
17						
	18.118	8.83	38.07	67.2 - j 6.9	1.38	1.16
15						
	21.0	8.72	42.38	64.8 + j 0.1	1.30	1.16
	21.225	8.71	41.41	66.9 - j 0.6	1.34	1.12
	21.45	8.72	40.76	67.1 - j 1.8	1.34	1.12
12						
	24.94	8.81	32.04	73.6 - j 2.4	1.48	1.04
10						
	28.0	8.92	24.94	72.3 + j16.5	1.58	1.26
	28.5	9.02	22.35	82.3 - j31.3	1.99	1.50
	29.0	9.04	20.97	39.6 - j22.4	1.73	2.12
	29.5	9.04	20.03	38.7 + j 8.8	1.38	1.97

Although the LPDA does not achieve all of the upper-end gain of the ON4ANT Yagi, it does achieve a remarkably smooth free-space gain curve with only about 0.3 dB variation across the entire passband of the array. The costs of these increases in gain are a reduction in the front-to-back ratio and an increase in standard SWR values in the 10-meter band.

Some Comparisons

In order to assess the full potential of the LPDA arrays, I performed frequency sweeps of them in 0.25 MHz increments from 13 through 31 MHz. The following graphics are very nearly self-explanatory. Except where values on the tables above coincide with frequency markers in the graphs below, expect to find very slight differences in values, since all properties of an LPDA undulate across the passband.

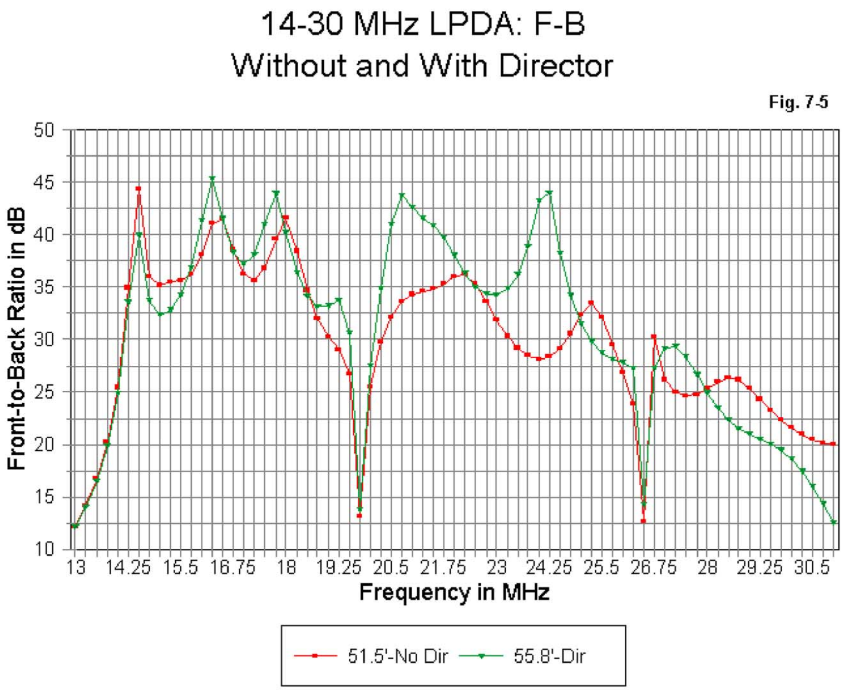
Fig. 7-4 shows the free-space gain curve of the arrays in dBi. Note the frequencies (19.75 MHz and 26.5 MHz) at which the gain shows an abnormal decrease. If one wishes to eliminate these dips, then the weakness can be suppressed with a single stub on the lower frequency element that shows the highest harmonic mode operation.



The graph also shows performance deterioration at both upper and lower ends of the band, except for the gain on the version with the director. However, that increasing high frequency gain will be offset by decreases in the front-to-back ratio.

The most significant feature of the gain curve is a revelation of the effects of the parasitic director. The director improves gain (although insignificantly so) even at the lowest design frequency of the array. Given the current magnitude on it, the director must be considered an active element throughout the design spectrum.

The 180-degree front-to-back curve, shown in **Fig. 7-5**, shows far more variation than the gain curve relative to the two array designs. However, the "unnatural" dips in the front-to-back ratio reach their lowest values at same frequencies as the gain dip minima: 19.75 MHz and 26.5 MHz. In actuality, the minima occur at very slightly different frequencies. The peaks and nulls in the undulating gain and front-to-back curves do not exactly coincide.

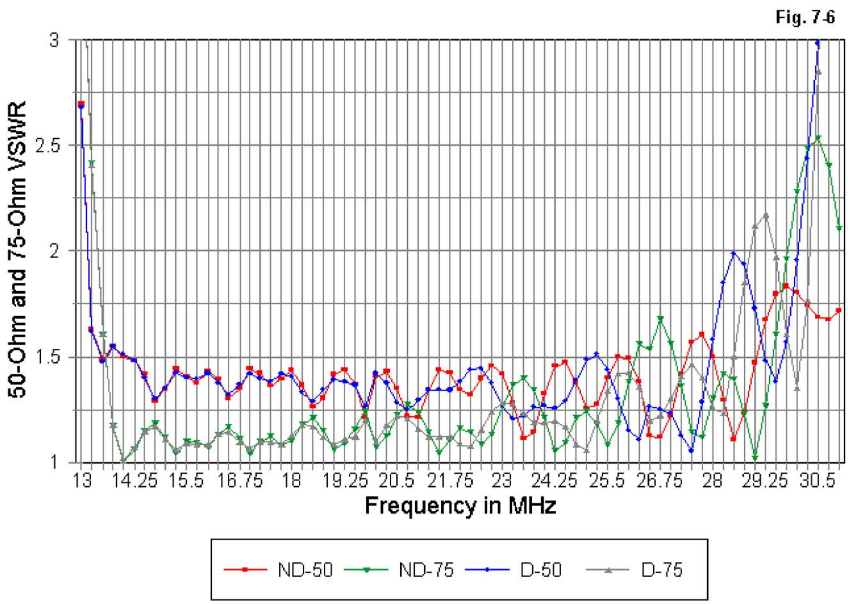


Above 20 MHz, the presence of the director most significantly alters the front-to-back performance of the array, shifting the overall curve so that the peaks are lower in frequency relative to the version without the director. As well, above 28 MHz, the array with the director shows a much more rapid drop in front-to-back ratio. The overall front-to-back curve can be altered further with changes in director length and spacing. However, balancing multiple goals (gain, front-to-back ratio, feedpoint impedance, and overall boom length) requires a design compromise. The closer the

spacing of the director to the forward LPDA element, the more radical its effect upon performance at the upper end of the passband.

Fig. 7-6 shows 2 pairs of SWR curves, with 50-Ohm curves and 75-Ohm curves shown for each version of the array. To distinguish the designs, in the legend, “ND” means “no director,” and “D” means “director.” Despite the fact the impedance values seem to track a 75-Ohm impedance center across most of the passband, a 50-Ohm feedline appears to be the better choice at the passband edges. Both versions of the LPDA show a 50-Ohm 2:1 SWR or better from 14 through 29.7 MHz.

14-30 MHz LPDA: VSWR
Without and With Director



Conclusion

The director-LPDA offers somewhat better low-end performance but slightly inferior high-end performance relative to the ON4ANT Yagi. However, the LPDA 10-meter performance extends across the entire band and slightly above it. The LPDA also has the advantage of requiring only a single feedline, in contrast to the 5 feedpoints and matching networks required by the forward-stagger Yagi. However, the LPDA does require the construction of a phasing line and element-to-boom insulating plates for all elements, thus offsetting a mechanical advantage with a mechanical complexity. Of course, the LPDA is usable at all frequencies between 14 and 30 MHz (with a corrective for the weaknesses noted). To complete our list of comparisons, even with a director, the LPDA is 4' shorter than the “final” forward-stagger Yagi.

Although the design employs a value for τ (0.95) close to the maximum recommended value for LPDAs, the array does not achieve all of its potential gain, even for the number of elements employed. With the use of an optimized value for σ (rather than the 0.056 value actually used in the design), free-space gain would increase to a maximum close to 11.5 dBi, with some front-to-back (and averaged front-to-rear) figures exceeding 50 dB. As noted initially, however, such an array would require 3 to 4 times the boom length. For reference, see the design with a τ of 0.96 and a σ of 0.18 which we explored in both 7-15 MHz and 14-30 MHz versions in earlier chapters.

The LPDA with no director is not so inferior to the director array that it should be ignored. At a height of 70' or so, the gain of the array across the entire passband is remarkable equal. The improved smoothness of performance is a function of the lowering of the take-off angle with increasing frequency and a resulting small increase in maximum gain in the lowest lobe. There is under 0.4 dB difference in maximum among 14, 21, and 28 MHz values. Of course, differences of mounting height will change the relative gain and the spread of differential from band to band, although the general tendency will appear at virtually any mounting height.

One of my motivations in designing this long-boom LPDA has been to overcome an impression left by the usual amateur radio LPDA designs. With their uncorrected element lengths, their short booms, and their sparse population of elements, most of these designs scarcely achieve 2-element monoband Yagi performance across their passbands. Since most of these designs were never swept through an adequate antenna modeling program before construction, weaknesses in performance in various portions of the operating spectrum were not detected until after fabrication.

The advantages of applying adequate modeling techniques to the present designs should be abundantly clear. First, the sweeps provided an overall picture of the basic performance potential of the array, a picture that led both to the circularization of τ and the addition of the parasitic director. Second, the sweeps, when carried out in sufficiently small frequency increments, uncovered the weaknesses that persisted even in the final design. These weakness, although outside the amateur bands, nonetheless reveal a limitation of the use of very low characteristic impedances for the array phase line. With only a small loss in gain, the weaknesses can be eliminated through the use of a higher characteristic impedance phase line.

At present, these LPDA arrays are design exercises, since I lack the facilities to construct them, not to mention the robust tower and rotator to support a long-boom LPDA. Therefore, I shall not include in these notes potential mechanical design considerations beyond those briefly mentioned in the comparison with the forward-stagger Yagi design. Both types of multi-band antennas share the difficulty of supporting and rotating a very heavy antenna that is considerably longer than it is wide. However, the arrays that we have explored are samples of what an LPDA can do within the limitations of what amateurs consider to be long-boom antennas. Although the long-boom LPDA presents mechanical challenges, it achieves performance competitive with stacks of 2 ordinary multi-band Yagis without the extended mast. In short, it is one more option within the amateur arsenal of high performance multi-band arrays.

Chapter 8: A Family of LPDAs for 14-30 MHz

In Chapter 7, I described the basic design of an idealized log-periodic dipole array (LPDA) for the 20-10 meter range. It had a free-space gain range of 8.7 to 9.0 dBi, with correspondingly high front-to-back figures. The 56' boom was not considered a hindrance for this "dream beam." The array used a τ of 0.9500 and a σ of 0.0560 along with 22 elements to achieve its performance.

The design had some interesting features, designed to overcome some of the weaknesses of finite-length LPDAs. First, the value of τ was circularized in the elements at each end of the array, resulting in a shortening of the very longest elements and a lengthening of the shortest elements. The result is an LPDA whose element ends describe a slight ogee curve. The "τ-circularizing" technique tends to equalize gain at the passband ends relative to midband performance. However, it must be used with care so as not to unduly disturb the feedpoint impedance across the pass band.

Since the circularizing technique is most effective at the lower end of the passband, gain still tends to fall off at the upper end of the passband unless the shortest element is calculated as if the highest operating frequency was about 1.6 times its actual value. Such a high upper-end frequency limit adds a number of elements to the design, along with considerable boom length. Interestingly, early work on LPDAs in the 1960s recognized a "high frequency truncation coefficient," but failed to associate the idea with a clear notion of which elements in an LPDA are active. Early thinking led to the misconception that only the immediately adjacent elements to the one nearest resonance were active. In fact, virtually all elements forward of the most active element are themselves active and contribute to the pattern formation for a given frequency.

To effect the desired performance gain with fewer elements, the forward-most element was made parasitic and lengthened to form a director for the highest band (10 meters). The length and spacing for this element were selected to achieve the desired gain with least effect on the feedpoint impedance of the array at all other frequencies. The further away from the closest LPDA element, the higher the gain, but the lower the front-to-back ratio and the greater the disturbance to feedpoint impedance values.

These same design techniques can be applied to shorter-boom LPDAs with relatively equal success—subject only to limitations imposed by using fewer elements on a shorter boom. In this chapter, in addition to a quick review of the ideal LPDA for 20-10 meters, we shall examine designs using 16, 12, and 9 elements on 42, 32, and 21 foot booms respectively. The ideal design replicates 4-element monoband Yagi performance assuming a moderately long boom. The 16-element design provides close to long-boom 3-element monoband Yagi performance across the pass band—about 8 dBi free-space gain. The 12-element model gives us about 2-element quad or short-boom 3-element monoband Yagi performance—about 7 dBi across the passband. Finally, the shortest member of the family approaches 2-element monoband reflector-driver Yagi performance—something close to 6 dBi free-space gain. When comparing the performance numbers to those of other types of arrays, remember that the LPDA provides performance both within and between the ham bands.

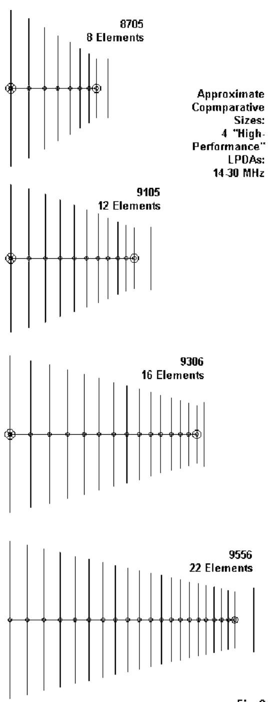
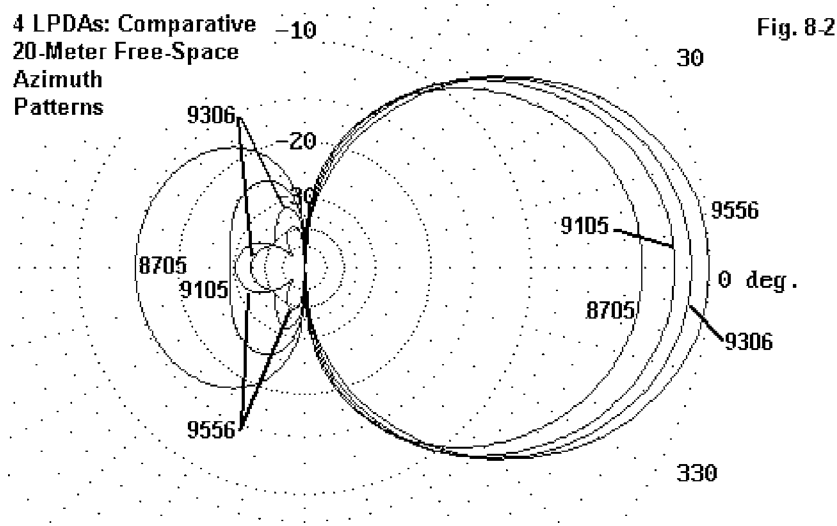


Fig. 8-1

Fig. 8-1 provides some comparative outline sketches of the 4 members of this LPDA family. There is little difference in the longest and shortest elements for each set, but considerable difference in total boom length, total weight, and performance. Note also that the position of the parasitic director has been selected by hand to optimize each design within the overall objectives for each.

In **Fig. 8-2**, we have the free-space azimuth patterns for the family members for the middle of the 20-meter band (14.175 MHz). The stepped gain differential is clearly apparent. The larger step downward in gain for the smallest LPDA is a function of the fact that the shorter the LPDA, the lower both τ and σ go, mutually reducing gain potential for the array.

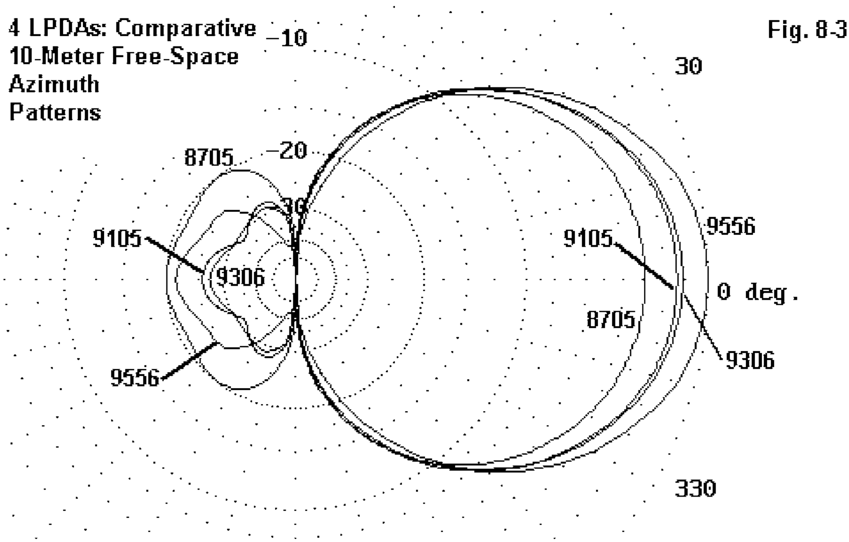
The rear lobes of an LPDA pattern in a very general way are the reciprocal of the forward lobes. The higher the forward gain, the higher the 180-degree front-to-back ratio.



Once that ratio pass about 30 dB, we find variations in the rear pattern, even in the best controlled arrays. The rear may look like a single lobe, a three-lobe patter with either the central or side lobes emphasized, or a small ripply blob. Although gain and front-to-rear performance are closely correlated, the natural variations in each over the full passband do not directly coincide.

Fig. 8-3 shows the corresponding free-space azimuth patterns for 28.85 MHz. Here, we do not see the even stair-stepping of forward gain due to the variable treatment of the parasitic director. The highest gain model (9556) has a widely spaced director which reduces the front-to-back ratio to barely 20 dB. In contrast, the 16-element model (9306) shows considerably better rearward performance, but less relative forward gain—due to the close spacing of the director (see **Fig. 8-1**). The smallest two LPDAs in the collection (9105 and 8705) have relatively wide-spaced directors, although 9105 manages a higher gain than perhaps it needed for balance across the entire passband. However, as we shall see, it also shows the widest gain range across 10 meters.

In designing the members of this LPDA family, I set as a goal the equalization of high-end gain with mid-band gain (about 21 MHz) with acceptable feedpoint impedances and a 180-degree front-to-back ratio of 20 dB. Only in a couple of instances does the front-to-back ratio dip slightly below the target value.



The feedpoint impedance was selected to match either a 50-Ohm or a 75-Ohm system. In some designs, the use of 75-Ohm coaxial cable or a 75-to-50 Ohm balun transformer may yield lower SWR values than a direct 50-Ohm feed. The practical concern is not so much line losses, but the sensitivity of some equipment to SWR values above 1.5:1: some gear tends to reduce power or shut down at SWR values well below the traditional limit of 2:1. In all cases, for the low impedance feed system, the phase lines were set at a characteristic impedance (Zo) of 100 Ohms.

The designs were also tested—and modified, if necessary—for a phase line Zo of 250 Ohms. As we shall see, the higher phase-line impedance reduces gain performance slightly (0.1 to 0.15 dB on average), but results in an unconditionally stable array across the passband. The median feedpoint impedance ranges from 100 to 120 Ohms, and the arrays may be fed using a 2:1 broad-band transmission line transformer, such as one of those designed by W2FMI, Jerry Sevick, and available from Amidon. In general, the higher phase-line Zo results in a smoother SWR curve across the passband and a total absence of "spikes."

All of the family members use an idealized element diameter of 0.5". In general, the dimensions shown for each family member are satisfactory for all but the longest and shortest elements (including the parasitic director) in the arrays. Elements whose lengths have been adjusted for a parasitic function or in the course of circularizing τ should be remodeled using the exact element diameter taper to be used the version constructed. In practical terms, this means remodeling the entire array with each element using its diameter taper. However, this necessary procedure may limit those who model LPDAs in NEC-2. The Leeson-correction system for linear elements using a tapered diameter schedule will only function on elements that are within about 15% of resonant length for the frequency being tested. Elements outside that range will not be corrected, and subtle errors in the modeled performance may result. Hence, NEC-4 would be the software of choice for final design modeling for the LPDAs in our family.

A Review of 9556

Table 8-1. 9556 Dimensions

Element #	Length (feet)	Spacing from Reflector (feet)
1	36.05	——
2	34.17	4.02
3	32.33	7.83
4	30.73	11.45
5	29.20	14.89
6	27.74	18.16
7	26.35	21.27
8	25.03	24.22
9	23.78	27.03
10	22.59	29.69
11	21.46	32.22
12	20.39	34.62
13	19.37	36.91
14	18.40	39.08
15	17.48	41.14
16	16.61	43.10

17	15.78	44.96	
18	14.99	46.72	
19	14.24	48.40	
20	13.53	50.00	
21	12.85	51.51	
22	14.78/14.60	55.83	Director: See text.

9556 is the ideal 56' long LPDA which we have examined in the past. **Table 8-1** gives the overall element length and cumulative spacing for the design.

The two lengths listed for the director apply to the different values of phase-line Zo: the longer director applies to the 100-Ohm line, while the shorter applies to the 250-Ohm line. The change in length was needed to optimize—so far as possible—the gain and SWR curves on 10 meters.

Fig. 8-4 shows the SWR curves for the entire passband, taken at 0.25 MHz intervals. The interval is sufficiently small to show signs of performance instability, and none appear with either choice of phase line Zo. In fact, the design does not require the use of a shorted transmission line stub behind the longest element, although one may be added to set all of the elements at the same DC value. Something of about 450-600 Ohms characteristic impedance and a length of about a foot should do the job with minimal disturbance to the performance curves. When both τ and σ together reach a certain level—obtained in this design—a stub is not necessary to control or remove impedance and performance spikes.

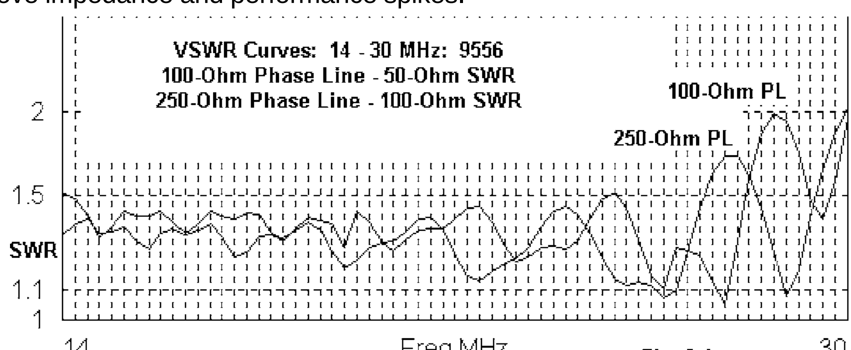


Fig. 8-4

The anticipated performance of the array for each value of phase line Zo is listed in **Table 8-2**.

Table 8-2. 9556 Performance with 100 and 250 Ohm Phase Lines

9556143X: 22 elements (21 LPDA + 1 par): 55.83' boom: 0.5" dia.
τ = 0.9500; σ = 0.0560: ogee'd: TL = 100 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
20						
	14.0	8.85	24.84	75.6 + j 0.2	1.51	1.01
	14.175	8.85	30.28	74.2 - j 3.5	1.49	1.05
	14.35	8.81	39.01	71.9 - j 6.5	1.46	1.10
17						
	18.118	8.83	38.18	67.2 - j 7.0	1.38	1.16
15						
	21.0	8.72	42.61	64.7 + j 0.1	1.29	1.16
	21.225	8.71	41.67	66.9 - j 0.5	1.34	1.12
	21.45	8.72	41.04	67.2 - j 1.8	1.35	1.12
12						
	24.94	8.81	32.04	73.2 - j 2.2	1.47	1.04
10						
	28.0	8.92	24.94	72.3 + j16.5	1.58	1.26
	28.85	9.04	21.29	47.3 - j30.7	1.87	1.98
	29.7	9.05	19.57	50.2 + j20.9	1.51	1.69

Δ Gain: 0.34 dB

9556143Y: 22 elements (21 LPDA + 1 par): 55.83' boom: 0.5" dia.
τ = 0.9500; σ = 0.0560: ogee'd: TL = 250 Ohms
(Parasitic length revised for 250-Ohm TL: from +/-7.392 to +/-7.3)

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	100-Ohm VSWR
20					
	14.0	8.68	26.48	131.1 - j 5.5	1.32

	14.175	8.68	30.95	134.1 - j 3.9	1.34
	14.35	8.69	34.01	137.6 - j 8.2	1.39
17					
	18.118	8.71	47.27	130.3 - j 9.4	1.32
15					
	21.0	8.79	36.30	130.3 - j11.9	1.33
	21.225	8.81	34.27	132.2 - j18.4	1.38
	21.45	8.80	33.29	127.4 - j26.1	1.40
12					
	24.94	8.63	32.78	98.7 - j21.6	1.24
10					
	28.0	8.76	25.63	82.1 - j39.7	1.61
	28.85	8.66	25.92	102.0 - j 7.5	1.08
	29.7	8.83	22.34	70.1 - j40.9	1.82

Δ Gain: 0.20 dB

Since both models are stable across the entire passband, the choice of phase line Zo value is optional with the builder. Note that the average gain of the model with the higher Zo is about 0.15 dB lower than for the model using a 100-Ohm line. However, the 250-Ohm line model shows a lower variation in gain across the pass band.

9306: 16 Elements on a 42' Boom

If 9556 is unrealistic for all but a handful of builders, 9306 might appeal to perhaps a double handful of antenna constructors. The 42' boom is somewhat less daunting, but should not be underestimated for its support complexity. As well, the 16 elements carry considerable raw weight and wind load. Nonetheless, the array comes close to providing full 3-element monoband performance from 14 to 30 MHz.

Table 8-3 provides the dimensions for this smaller LPDA. Be sure to compare the various dimensions with those of the "ideal" or "dream" array (9556).

Table 8-3. 9306 Dimensions

Element #	Length (feet)	Spacing from Reflector (feet)
1	35.80	——
2	33.80	4.43
3	31.70	8.55
4	29.60	12.38
5	27.60	15.94
6	25.67	19.25
7	23.87	22.33
8	22.20	25.20
9	20.65	27.86
10	19.20	30.34
11	17.86	32.64
12	16.61	34.79
13	15.45	36.78
14	14.36	38.63
15	13.36	40.36
16	14.70/14.20	41.96 Director: See text.

Regardless of the choice of phase line Zo, the design uses a 0.5' long shorted stub with a 600-Ohm characteristic impedance. **Fig. 8-5**, which shows the SWR curves for two versions of the LPDA, will reveal why the stub—optional on the big brother of this LPDA—is necessary here. The 100-Ohm phase line curve uses the 75-Ohm SWR because it shows smaller excursions than the corresponding 50-Ohm line. However, either feedline would be quite usable.

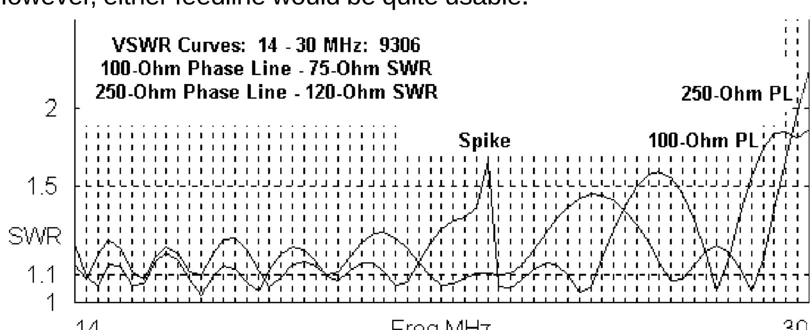


Fig. 8-5

The 250-Ohm phase line model is completely stable. However, the 100-Ohm line model shows a spike at about 23 MHz. The impedance spike actually peaks narrowly at 22.95 MHz with an SWR that is greater than 4:1 and a reduction in gain to under 6 dBi. The front-to-back ratio is less than 10 dB. Such a narrow spike, well outside of the amateur bands, may be acceptable for some builders, but not for others, depending upon the operational goals that one sets for the array.

Within the ham bands, the performance of the array in both versions can be summarized in **Table 8-4**.

Table 8-4. 9306 Performance with 100 and 250 Ohm Phase Lines

9306Q16: 16 elements (15 LPDA + 1 par): 41.96' boom: 0.5" dia.
τ = 0.9300; σ = 0.0600: ogee'd: TL = 100 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
20						
	14.0	8.08	28.78	61.5 + j 3.3	1.24	1.23
	14.175	8.07	33.97	67.2 + j 5.1	1.36	1.14
	14.35	8.05	39.35	72.3 + j 1.4	1.45	1.04
17						
	18.118	8.06	33.96	74.0 - j 5.2	1.49	1.07
15						
	21.0	8.02	37.06	70.9 - j 1.0	1.42	1.06
	21.225	8.03	36.56	72.8 - j 4.3	1.47	1.07
	21.45	8.03	36.38	71.8 - j 8.6	1.47	1.13
12						
	24.94	8.00	40.49	71.5 + j 1.3	1.43	1.05
10						
	28.0	7.77	27.28	72.1 + j 0.4	1.44	1.04
	28.85	7.93	25.88	47.7 - j11.1	1.26	1.63
	29.7	8.15	20.55	56.0 + j33.3	1.88	1.79

Δ Gain: 0.38 dB

9306P16: 16 elements (15 LPDA + 1 par): 41.96' boom: 0.5" dia.
τ = 0.9300; σ = 0.0600: ogee'd: TL = 250 Ohms
(Parasitic length revised for 250-Ohm TL: from +/-7.35 to +/-7.1)

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	120-Ohm VSWR
20					
	14.0	7.95	31.96	126.2 - j15.3	1.14
	14.175	7.97	34.68	126.4 - j 7.5	1.08
	14.35	7.99	38.02	133.4 - j 2.5	1.11
17					
	18.118	7.90	33.98	119.7 - j 9.1	1.08
15					
	21.0	7.91	38.50	116.2 - j26.3	1.25
	21.225	7.86	39.66	112.2 - j20.9	1.21
	21.45	7.82	40.10	111.6 - j14.8	1.16
12					
	24.94	7.83	32.41	112.4 - j41.0	1.43
10					
	28.0	7.70	31.41	104.5 - j15.5	1.22
	28.85	7.85	27.78	126.6 + j 5.1	1.07
	29.7	7.81	23.33	137.3 - j82.3	1.90

Δ Gain: 0.29 dB

The 250-Ohm phase line version of the 16-element LPDA shows a gain deficit of about 0.15 dB on average relative to the 100-Ohm phase line version. In exchange for the reduced gain, the builder obtains a completely stable array, with no weaknesses. In general, the lower the phase-line Zo, the greater the tendency to have one or more weaknesses in the overall performance curve, and these are generally signaled by a spike in the SWR curve. The SWR spike maximum and the greatest disturbance to performance (gain and front-to-back ratio) may not occur at precisely the same frequency. However, they will be overlapping phenomena within 100 kHz or so of each other.

The higher the values of both τ and σ—resulting in a higher number of elements and a longer boom—the narrower that a spike will be. The use of the stub can reduce either the number or severity of a spike, as well as control its frequency. In this case, the spike was moved to a frequency that is generally harmless in terms of amateur operations. As the values of τ and/or σ are reduced, the chief protection from spikes becomes a higher phase line Zo.

9105: 12 Elements on a 32' Boom

The next step down the ladder in our family of LPDAs is a 12-element model on a 32' boom. The dimensions of the array appear in **Table 8-5**.

Table 8-5. 9105 Dimensions

Element #	Length (feet)	Spacing from Reflector (feet)
1	36.00	——
2	34.00	4.15
3	31.30	7.93
4	28.47	11.36
5	25.90	14.48
6	23.55	17.33
7	21.42	19.93
8	19.47	22.28
9	17.70	24.43
10	16.10	26.38
11	14.63	28.15
12	15.17	32.00 Director: See text.

For this design, it was unnecessary to alter the length of the director to obtain acceptable results with both the 100-Ohm and 250-Ohm phase lines. The design does use a 1' 450-Ohm Zo shorted stub on the rear of the boom. However, as we shall see, this stub can reduce and/or move weaknesses that appear in the 100-Ohm phase line model, but it cannot eliminate “spikes” altogether.

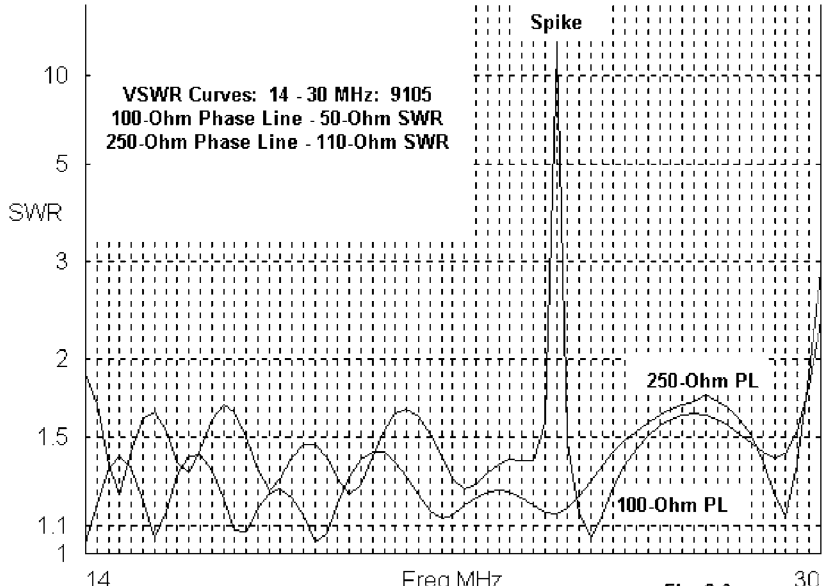


Fig. 8-6

Fig. 8-6 shows the 50-Ohm SWR with the 100-Ohm phase line and the 110-Ohm SWR with the 250-Ohm phase line. As we reduce the number of elements and boom length—with a correspondingly reduced value of τ—we should note larger excursions of SWR, regardless of the phase line value. The excursions are interesting, if we also track the changes of resistance and reactance along the way. Maximum values of capacitive and inductive reactance tend to occur when the resistance value is near its mean, while reactance tends to go to zero when the resistive component of the feedpoint impedance is at a high or low. Excursions of reac-

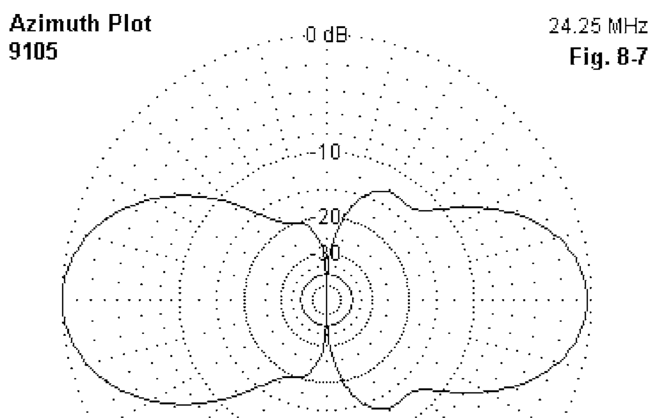


Fig. 8-7

Consequences of a Major Weakness in an LPDA tance are smaller with higher values of τ and σ (together); hence, the SWR changes are also smaller. As we shorten the boom and reduce τ, the reactance undergoes a wider range of values.

The spike in the 50-Ohm curve in **Fig. 8-6** is also more extreme than the one in **Fig. 8-5**. It is both higher—exceeding an SWR of 10:1—and wider, covering nearly a half MHz. **Fig. 8-7** shows the worst-case azimuth pattern, in which the pattern technically reverses direction.

Fig. 8-8 shows why. Virtually all of the elements to the rear of the active one are also active, but in a harmonic mode, as indicated by the "double-hump" curves that register the current magnitude. This example is especially interesting, since in most cases, not all of the rear elements will be so active.

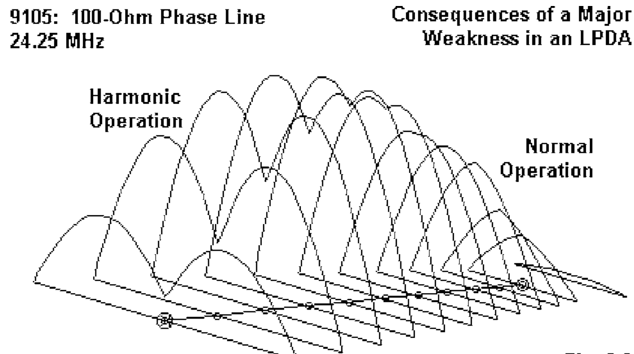


Fig. 8-8

Table 8-6 provides the anticipated performance of the 12-element array.

Table 8-6. 9105 Performance with 100 and 250 Ohm Phase Lines

91051431: 12 elements (11 LPDA + 1 par): 32.000' boom: 0.5" dia.
τ = 0.9099; σ = 0.0550: ogee'd: TL = 100 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
20						
	14.0	7.33	32.93	94.6 - j 1.8	1.89	1.26
	14.175	7.30	27.52	84.5 + j 5.7	1.78	1.26
	14.35	7.25	24.91	71.0 - j16.0	1.55	1.25
17						
	18.118	7.19	26.48	62.7 - j 0.2	1.25	1.20
15						

	21.0	7.24	24.86	82.5 - j 5.4	1.66	1.12
	21.225	7.26	25.85	78.2 - j11.9	1.62	1.17
	21.45	7.28	27.19	71.8 - j14.3	1.54	1.22
12						
	24.94	7.19	24.57	47.7 + j 1.1	1.05	1.57
10						
	28.0	7.57	27.68	41.4 - j18.6	1.56	1.97
	28.85	7.69	24.26	35.6 + j 1.6	1.41	2.11
	29.7	8.01	19.95	70.6 + j25.9	1.73	1.43

Δ Gain: 0.82 dB

91051431: 12 elements (11 LPDA + 1 par): 32.000' boom: 0.5" dia.
τ = 0.9099; σ = 0.0550: ogee'd: TL = 250 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	110-Ohm VSWR
20					
	14.0	7.12	26.83	106.2 - j 0.8	1.04
	14.175	7.07	25.63	117.2 + j11.7	1.13
	14.35	7.03	24.90	134.2 + j14.2	1.26
17					
	18.118	7.02	25.95	131.3 - j15.8	1.25
15					
	21.0	7.20	27.91	107.7 - j28.8	1.30
	21.225	7.18	28.71	105.2 - j21.9	1.23
	21.45	7.15	29.10	106.2 - j16.4	1.17
12					
	24.94	7.20	27.34	138.9 + j 6.0	1.26
10					
	28.0	7.38	28.70	70.4 - j22.4	1.66
	28.85	7.52	26.51	84.3 - j 6.0	1.31
	29.7	7.89	20.33	113.4 - j63.3	1.75

Δ Gain: 0.88 dB

Performance of the 250-Ohm phase line model is down about 0.14 dB from the 100-Ohm phase line model. However, the 250-Ohm version is stable across the entire passband.

8705: 9 Elements on a 21' Boom

The final member of the LPDA family is the shortest—only 21' in boom length (plus a little excess for element mounting fixtures). As well it has the least number of elements—9—and the lowest value of τ—0.8688. Indeed, these values are about the least that I would recommend for satisfactory performance, if we define that term as being close to the performance of a 2-element reflector-driver monoband Yagi. Even so, we shall discover that the low values used in the design of the LPDA yield the highest fluctuations in performance.

The dimensions for the 9-element array are in **Table 8-7**.

Table 8-7. 8705 Dimensions

Element #	Length (feet)	Spacing from Reflector (feet)
1	36.00	——
2	32.30	3.89
3	28.06	7.26
4	24.38	10.19
5	21.18	12.74
6	18.40	14.96
7	15.98	16.88
8	13.89	18.55
9	13.60	21.00 Director: See text.

Both designs employ a stub. In both cases, a 1.9' shorted length of 450-Ohm transmission line or its equivalent is sufficient to tame the design.

As with the 12-element model, the 9-element design requires no change in the length of the director as we move from a 100-Ohm phase line to a 250-Ohm version. However, the spike that we might anticipate in the 100-Ohm phase line model shows itself vividly in **Fig. 8-9**, the SWR curves for both phase lines across the entire passband. The spike is higher and wider (with respect to frequency) than any other so far encountered. SWR values higher than 2:1 extend from about 26.25 to 27.5 MHz.

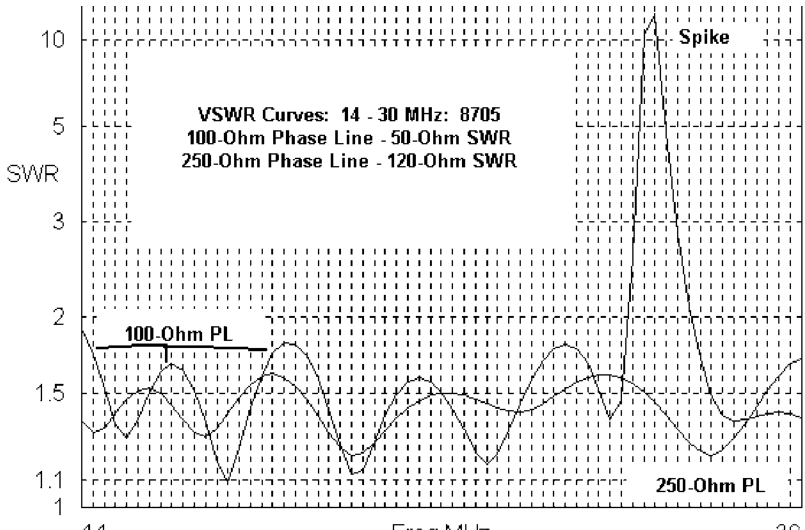


Fig. 8-9

Although the spike in the 100-Ohm phase line model is located well outside the amateur bands, it does interfere with operation of the array on the Citizen's Band. In contrast, the 250-Ohm phase line model permits operation throughout the passband.

Amateur band performance of both models appears in **Table 8-8**.

Table 8-6. 9105 Performance with 100 and 250 Ohm Phase Lines

8705B: 9 elements (8 LPDA + 1 par): 21.000' boom: 0.5" dia.
τ = 0.8688; σ = 0.0523: ogee'd: TL = 100 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
20						
	14.0	5.63	11.20	82.3 - j27.4	1.91	1.43

	14.175	5.74	11.88	67.4 - j29.4	1.79	1.53
	14.35	5.83	12.43	55.4 - j26.0	1.65	1.65
17						
	18.118	6.03	14.13	66.3 + j25.1	1.67	1.46
15						
	21.0	6.33	15.06	61.5 + j19.2	1.49	1.41
	21.225	6.30	15.10	69.5 + j17.6	1.56	1.29
	21.45	6.26	15.18	76.1 + j11.8	1.58	1.17
12						
	24.94	6.13	18.10	67.2 + j29.5	1.79	1.53
10						
	28.0	6.03	18.21	61.4 - j19.0	1.49	1.41
	28.85	6.17	17.05	64.6 - j10.4	1.37	1.23
	29.7	6.24	17.36	61.1 - j14.7	1.39	1.35

Δ Gain: 0.70 dB

8705C: 9 elements (8 LPDA + 1 par): 21.000' boom: 0.5" dia.
τ = 0.8688; σ = 0.0523: ogee'd: TL = 250 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	120-Ohm VSWR
20					
	14.0	5.55	10.69	93.6 - j18.8	1.36
	14.175	5.61	11.07	91.7 - j 3.0	1.31
	14.35	5.66	11.38	94.6 + j12.5	1.30
17					
	18.118	6.09	13.58	168.3 - j48.3	1.61
15					
	21.0	6.14	15.48	150.5 - j29.6	1.37
	21.225	6.13	15.46	136.8 - j41.6	1.42
	21.45	6.12	15.44	120.8 - j45.3	1.45
12					
	24.94	6.26	17.22	159.2 - j47.0	1.55
10					
	28.0	6.27	19.07	104.5 - j13.6	1.20
	28.85	6.27	19.74	100.4 - j29.4	1.38

29.7	6.39	22.64	80.6 - j31.2	1.66

Δ Gain: 0.84 dB

The average gain of the two arrays across the entire passband is about the same. However, the 250-Ohm phase line version begins with lower gain on 20 meters and ends with higher gain on 10 meters. As well, relative to longer members of the array family, the 20-meter gain is in both cases below the array average—a result of decreasing the value of τ below about 0.9. Most LPDAs with τ values below about 0.9 and with σ values in the 0.04 to 0.06 range tend to show decreasing gain at the low end of the spectrum.

Nonetheless, the array provides serviceable performance across the design passband—about as good as a 20' long LPDA can do with elements that average 0.5" in diameter. Increasing the average element diameter can improve gain somewhat, with the most needed increase on 20 meters. A well-designed physical implementation of this array might easily have equivalent element diameters larger than 0.5" for the longest elements, we can expect some natural improvement to 20 meter performance as a matter of course.

Conclusion

The goal of this design exercise was to produce a family of LPDAs with relatively smooth performance across the entire design passband from 14 to 30 MHz. By the judicious use of standard LPDA modification techniques, the goal has been achieved. Nevertheless, before construction can begin, the designs would need to be customized to the element diameter taper schedule actually used in the physical version of the antenna.

This family of LPDA designs departs from customary amateur-band LPDA design by using a somewhat denser population of elements for a given boom length—that is, a higher value of τ. The benefits of this design strategy do not necessarily show up in the mid-range performance of each array. However, the higher τ-value does tend to improve low-end performance considerably. As the smallest design in the sequence reveals, even with the circularization of τ, there is a limit even to this strategy in terms of obtaining a low-end gain that is the equal of the mid-range gain without over-populating the boom with elements.

The parasitic element, in combination with circularization of τ, tends to improve performance mainly at the high end of the operating passband. Nevertheless, the influence of these modifications often shows up—at least in small increases of the modeling numbers—well down the passband. The final reminder for us to note is this caution: one of the limits upon the use of modification strategies is that they tend to throw variations into the feedpoint impedance values in the affected frequency regions. When the feedpoint impedance (whether the resistive or reactive component—or both) exceeds a permissible level, as developed in the design specifications, the modification has reached its limits of improvement.

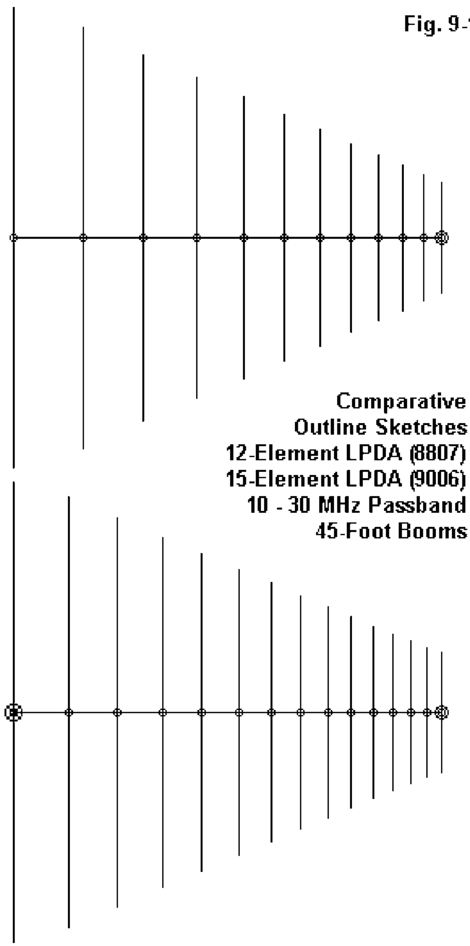
Since small changes of construction may move the spike frequencies that occur on the smaller members of the family, the use of the 250-Ohm phase line or something similar may be the surest route to a successful building project. The average loss of 0.15 dB forward gain is unlikely to be noticed in operation. Because low-loss wide-band 2:1 transmission line transformer baluns are available, the higher feedpoint impedance natural to the high impedance phase line should present no problems. In fact, with the smaller versions of the array, the higher natural feedpoint impedance may reduce SWR excursions.

Since this is a basic design study, I shall forego construction details altogether. The object has been to show what is possible. The 4 LPDA family members do that well enough to encourage those interested to perfect the designs for particular building circumstances.

Chapter 9: Stretching the Octave Limit to 1.5

On several occasions, I have noted that amateur LPDAs tend to be underpopulated with respect to the number of elements for the boom lengths chosen. This problem becomes more acute as we try to extend the 1-octave (2:1 frequency) range of an LPDA to some large value. Even a 1.5 octave antenna (3:1 frequency range) begins to display the symptoms of inadequate design.

Fig. 9-1



In order to gain a better appreciation of the question of element population, let's look at two 1.5-octave designs for the frequency range of 10 to 30 MHz. To equalize matters, we shall use a 45' boom length in both cases. Our subject designs will use 12 and 15 elements respectively, as sketched in **Fig. 9-1**. In both cases, the NEC-4 models will use aluminum 0.5" diameter elements throughout.

The 45' boom length falls roughly between extensions of the shorter members of the 14-30 MHz family of LPDAs examined in Chapter 8. The shortest had a τ of 0.87 and a σ of about 0.7. Using the simplified calculation of average gain developed in Chapter 1, the array should have had an average free-space gain of about 6.0 dBi, and in fact, the model showed a gain range from 5.63 to 6.33 dBi.

As we shall discover, the simple gain estimator will fall apart when we exceed a frequency range of about 2:1. The 12-element model that we shall examine has a τ of 0.876 and a σ of 0.0728, for an average gain estimate of about 7.29 dBi. In contrast, the more populous version uses a τ of 0.9032 and a σ of 0.0571, for an estimated gain of 7.19 dBi. From the estimates, we should expect similar performance—if the estimator holds good for larger frequency spans. It does not. One array will definitively outperform the other.

Each design began as a standard calculation set. Each was subjected to those modifications showing the most promise of improving performance from the collection of treatments in Chapter 5. The use of a stub proved mandatory for both arrays. As well, the forward and rear elements were "circularized" to the degree feasible. With this background, we are ready to examine each of the candidates for 30 through 10 meter service.

The 12-Element Version: 8807

The 12-element version of the 45' array answers to the following modeling description.

```
8807                                 Frequency = 30  MHz.

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

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

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

1            0.000,-24.200,  0.000         0.000, 24.200,  0.000 5.00E-01  47
2            7.276,-22.200,  0.000         7.276, 22.200,  0.000 5.00E-01  41
3           13.650,-19.255,  0.000        13.650, 19.255,  0.000 5.00E-01  37
4           19.233,-16.867,  0.000        19.233, 16.867,  0.000 5.00E-01  31
5           24.125,-14.776,  0.000        24.125, 14.776,  0.000 5.00E-01  27
6           28.409,-12.944,  0.000        28.409, 12.944,  0.000 5.00E-01  25
7           32.162,-11.339,  0.000        32.162, 11.339,  0.000 5.00E-01  21
8           35.450, -9.933,  0.000        35.450,  9.933,  0.000 5.00E-01  19
9           38.331, -8.701,  0.000        38.331,  8.701,  0.000 5.00E-01  17
10          40.854, -7.622,  0.000        40.854,  7.622,  0.000 5.00E-01  15
11          43.064, -6.677,  0.000        43.064,  6.677,  0.000 5.00E-01  13
12          45.000, -5.849,  0.000        45.000,  5.849,  0.000 5.00E-01  11
```

-------------- SOURCES --------------

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	6	12 / 50.00	(12 / 50.00)	0.707	0.000	V

-------- TRANSMISSION LINES ---------

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	250.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	250.0	1.00	R
. . .								
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	250.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	250.0	1.00	R

The array provides excellent patterns from the 15-meter band downward. **Fig. 9-2** provides a sample of the better-behaved patterns. However, even with a 250-Ohm phase line, patterns become less well-behaved on both 12 and 10 meters. The specified 250-Ohm line was the lowest value yielding reasonable patterns at all frequencies, and 100-Ohm phase line versions of the model were rejected as too unstable for most applications.

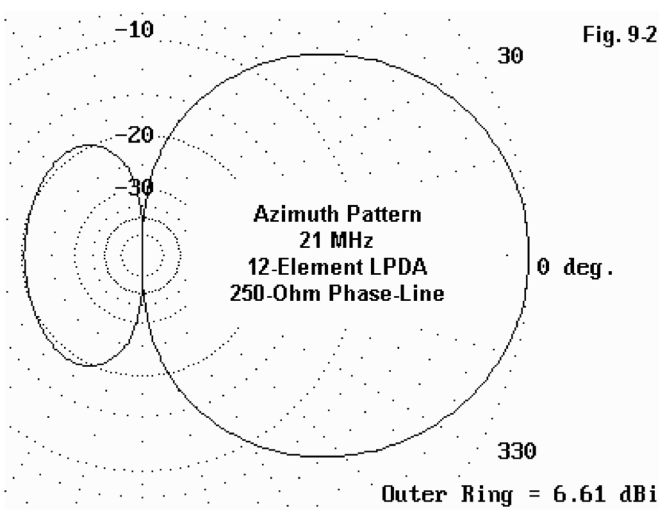
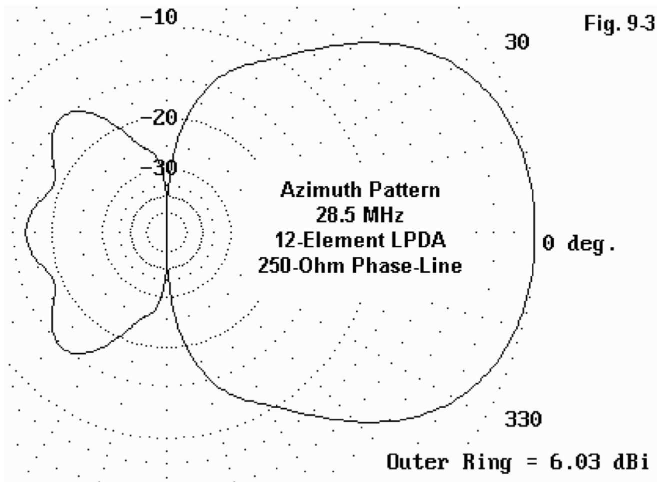


Fig. 9-2

As shown in **Fig. 9-3**, the patterns become somewhat irregular in both the forward and rearward directions at the upper end of the passband, despite the use of a high-value phase-line characteristic impedance. With decreases in the phase-line impedance, the incipient forward and rearward side lobes make a true appearance, and the forward lobe flattens to yield double azimuth bearings of maximum gain.



The use of a 250-Ohm phase line results in a median feedpoint impedance of about 150-Ohms. This value is well within the range for which a wide-band balun may be constructed for feeding the system with a 50-Ohm coaxial cable. In the performance table (**Table 9-1**), the 150-Ohm value is used as the reference standard for SWR values. The table, as usual, lists the free-space gain, 180E front-to-back ratio, feedpoint impedance, and 150-Ohm SWR at selected points throughout the covered ham bands. The wider bands use band-edge and mid-band check points, while the non-harmonic or WARC bands use a single frequency at the band center. In addition, performance figures are given for the extreme ends of the design passband: 10 MHz and 30 MHz.

Table 9-1. 12-Element LPDA Performance

12 Element LPDA: 10 - 30 MHz: 45' Boom: Elements: 0.5" dia.
Tau = 0.8760; Sigma = 0.0725: ogee'd: TL = 250 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	150-Ohm VSWR
30					
	10.0	5.82	11.12	246 + j 7	1.64
	10.125	5.94	12.14	240 - j 18	1.61
20					
	14.0	6.62	19.64	164 - j 34	1.27
	14.175	6.65	19.03	147 - j 37	1.28
	14.35	6.69	18.39	133 - j 31	1.28
17					
	18.118	6.58	24.48	167 - j 4	1.11
15					
	21.0	6.61	20.36	176 - j 15	1.21
	21.225	6.61	20.84	173 - j 31	1.27
	21.45	6.62	21.48	163 - j 42	1.32
12					
	24.94	6.06	26.42	136 - j 26	1.23
10					
	28.0	6.19	16.79	168 + j 5	1.13
	28.5	6.03	16.49	175 - j 24	1.23
	29.0	5.96	17.39	161 - j 47	1.36
	29.5	6.25	19.83	139 - j 54	1.46
	30.0	6.36	21.21	123 - j 48	1.50

Immediately apparent is the performance peak between about 14 and 22 MHz. However, the overall performance is only about that which one might obtain from a series of monoband 2-element Yagis of reflector-driver design. This comparison does not limit the utility of the LPDA, since it covers most of the spectrum from 10 to 30 MHz with similar performance, thus suiting it to use as an SWL as well as an amateur transmitting and receiving antenna.

The performance of the 12-element LPDA is limited by the sparseness of its element population—another way of saying that the value of τ is too low. If we increase the value of τ without increasing the boom length, then the value of σ must decrease. In general or “macro” LPDA design, the operative rule is to increase the 2 values together for improved performance. However, in the refinement of LPDA designs (or “micro” design), where one or more parameters is fixed for any good reason, there is room to violate the general cannon. Instead, the designer must seek the combination of τ and σ that will yield the best performance. In this case, without adding a wholly insupportable amount of weight to the structure, we can improve performance significantly.

The 15-Element Version: 9006

By selecting a τ of about 0.903 and a σ of about 0.57, we can fit 15 elements on the same 45' boom. The array will fit the following model description.

```
10-32 MHz t=.91 s=.05                          Frequency = 10.125  MHz.

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

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

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

1             0.000,-24.300,  0.000         0.000, 24.300,  0.000 5.00E-01  49
2             5.735,-22.663,  0.000         5.735, 22.663,  0.000 5.00E-01  43
3            10.915,-20.469,  0.000        10.915, 20.469,  0.000 5.00E-01  39
4            15.593,-18.487,  0.000        15.593, 18.487,  0.000 5.00E-01  35
5            19.819,-16.698,  0.000        19.819, 16.698,  0.000 5.00E-01  31
6            23.635,-15.081,  0.000        23.635, 15.081,  0.000 5.00E-01  29
7            27.082,-13.621,  0.000        27.082, 13.621,  0.000 5.00E-01  25
8            30.195,-12.302,  0.000        30.195, 12.302,  0.000 5.00E-01  23
9            33.007,-11.111,  0.000        33.007, 11.111,  0.000 5.00E-01  21
10           35.547,-10.036,  0.000        35.547, 10.036,  0.000 5.00E-01  19
11           37.841, -9.064,  0.000        37.841,  9.064,  0.000 5.00E-01  17
12           39.912, -8.187,  0.000        39.912,  8.187,  0.000 5.00E-01  15
13           41.784, -7.500,  0.000        41.784,  7.500,  0.000 5.00E-01  13
14           43.474, -6.900,  0.000        43.474,  6.900,  0.000 5.00E-01  13
15           45.000, -6.400,  0.000        45.000,  6.400,  0.000 5.00E-01  11
```

-------------- SOURCES --------------

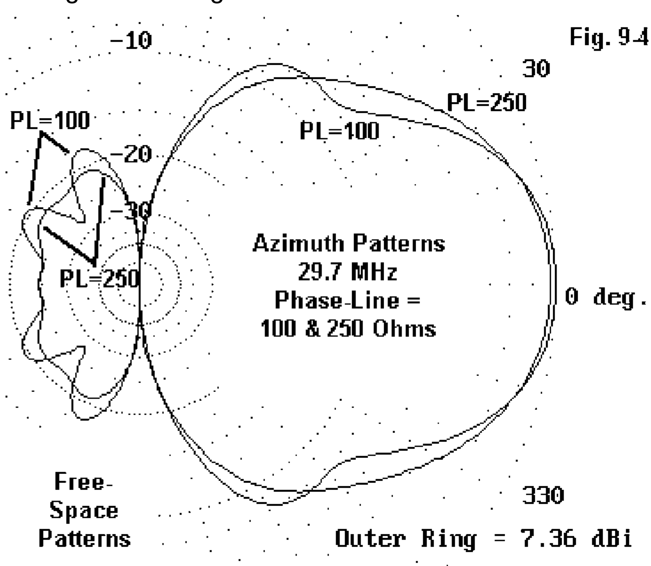
Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	6	15 / 50.00	(15 / 50.00)	0.707	0.000	V

-------- TRANSMISSION LINES ---------

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	Short ckt	(Short ck)	1.000 ft	450.0	1.00	
2	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	250.0	1.00	R
3	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	250.0	1.00	R
. . .								
14	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	250.0	1.00	R
15	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	250.0	1.00	R

The array, like the 12-element version, was subjected to circularization of τ in order to improve performance at the upper and lower limits of the passband. The affected elements are those in the model description whose lengths are carried out to a single decimal place. Although, in practice, one would round all dimensions to the simple limits of construction precision available, I have left the untouched elements at their calculated lengths to distinguish them from the modified elements.

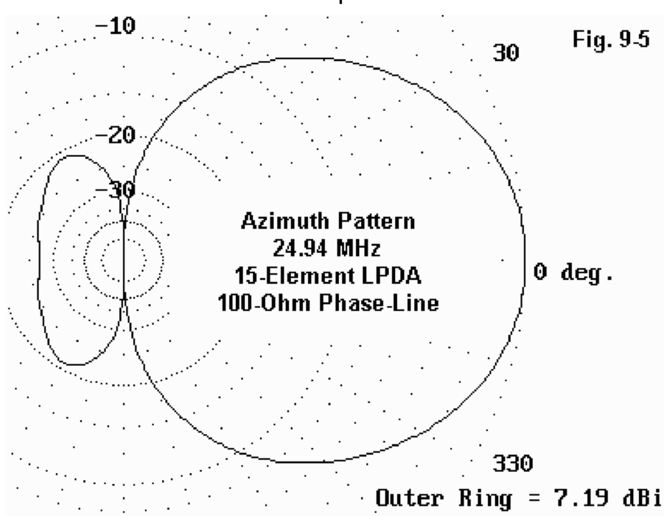
Fig. 9-4



The model shown uses a 250-Ohm phase line to yield a median feedpoint impedance of about 120 Ohms. However, with some limitations, the array can be set up for a 100-Ohm phase line. The lower characteristic impedance of the phase line permits a direct match to 50- or 75-Ohm coaxial cable.

The limitations of using a 100-Ohm phase line have to do with the degree to which patterns at the upper frequencies of the passband are well-behaved. As **Fig. 9-4** shows, the use of a low phase-line characteristic impedance results in patterns with considerable distortion relative to the same array and frequency with a high phase-line impedance. At 29.7 MHz, the sampled frequency, the pattern shows considerable secondary lobe development both forward and to the rear. In contrast, the pattern using a 250-Ohm line, although not perfect, shows considerable improvement, despite a very slight reduction in gain. The rear lobes are small enough so that the worst-case front-to-back ratio is still greater than 20 dB, compared to the 17-dB worst-case front-to-back ratio of the 100-Ohm version of the array. The 100-Ohm high-end patterns are still quite usable, but simply less well-controlled.

The reduction in gain with increasing phase-line impedance is typical of LPDA design in general. The design process must seek out some compromise value that yields the highest consistent gain across the passband while ensuring stable operation. We shall look more closely at the two versions of the LPDA across the entire operational passband before we close the book on the pair.



As shown in **Fig. 9-5**, the 15-element array does improve performance over the 12-element version, even using a 100-Ohm phase line. With a high-impedance line, the smaller version of the array showed pattern distortion above the 15-meter band. However, by adding 3 elements, we obtain—with a low-impedance phase line—good pattern control up though the 12-meter band. With the 100-Ohm line, only 10 meters shows the pattern distortion that appears in **Fig. 9-4**.

We can summarize the performance potential of the larger array. See **Table 9-2**. Both versions use a 450-Ohm, 1' shorted stub at the rear and differ only in the characteristic impedance of the phase line.

Table 9-2. 12-Element LPDA Performance

A. 15-Element LPDA: 10 - 30 MHz: 45' Boom: Elements: 0.5" dia.
Tau = 0.9032; Sigma = 0.0571: ogee'd: TL = 100 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR	75-Ohm VSWR
30						
	10.125	6.86	21.81	70.6 + j 13.8	1.513	1.220
20						
	14.0	7.02	23.55	73.1 + j 2.5	1.465	1.044
	14.175	7.00	24.10	79.2 - j 1.5	1.585	1.059
	14.35	6.99	24.58	80.3 - j 9.0	1.638	1.143
17						
	18.118	6.96	23.63	54.3 - j 21.6	1.521	1.591
15						
	21.0	7.05	27.60	62.7 - j 3.3	1.263	1.204
	21.225	7.01	28.48	64.3 - j 0.5	1.286	1.167
	21.45	6.98	29.00	66.9 + j 0.5	1.338	1.121
12						
	24.94	7.19	27.01	76.4 - j 17.4	1.658	1.258
10						
	28.0	6.94	24.08	42.0 - j 2.4	1.200	1.789
	28.85	7.25	21.43	46.7 + j 15.8	1.393	1.717
	29.7	7.36	24.23	77.8 + j 17.5	1.682	1.260

B. 15-Element LPDA: 10 - 30 MHz: 45' Boom: Elements: 0.5" dia.
Tau = 0.9032; Sigma = 0.0571: ogee'd: TL = 250 Ohms

Band	Freq. MHz	Gain dBi	F-B dB	Feed Impedance R +/- jX Ohms	120-Ohm VSWR
30					
	10.125	6.82	20.86	141.5 - j47.5	1.488
20					
	14.0	6.92	23.04	124.6 - j25.5	1.236
	14.175	6.94	22.92	116.9 - j16.3	1.150
	14.35	6.96	22.76	116.9 - j 4.7	1.049
17					
	18.118	6.94	23.59	126.0 + j 4.0	1.061
15					
	21.0	6.89	28.45	124.9 - j17.3	1.158
	21.225	6.84	26.54	121.7 - j20.4	1.185
	21.45	6.81	25.45	116.5 - j21.1	1.197
12					
	24.94	7.01	28.07	102.4 - j28.3	1.349
10					
	28.0	6.59	20.80	102.1 + j20.7	1.280
	28.85	6.88	21.01	147.9 - j 5.6	1.238
	29.7	7.13	24.16	109.0 - j45.4	1.500

Within the amateur bands, the average free-space gain for version A is 7.04 dBi, while for version B, the average gain is 6.91 dBi. Hence, the average gain deficit for using the higher value of phase line impedance is about 0.13 dB. Both versions of the array show a gain differential of about 0.5 dB when comparing the highest and lowest values listed. The smaller array showed a gain differential of over 3/4 dB.

The average gain of the sampled frequencies for the 12-element array was about 6.34 dBi, about 2/3 dB less than the 15-element version. Near the operating pass-band edges, the improvement approaches a full dB, with the larger array showing smoother performance throughout its range. Indeed, the 15-element LPDA exhibits performance comparable to that of a 5-band 2-element quad, but with operating band-width characteristics (including gain, front-to-back ratio, and SWR) that a quad could not come close to matching. (On the other hand, the LPDA's 45' boom presents a much larger mechanical challenge than the average 8' front-to-back dimension of a 5-

band quad. A 6-band quad to include 30 meters, of course, would present considerable volumetric challenges.)

The 100-Ohm phase line version of the array is not without some weaknesses. **Fig. 9-6** shows the 50- and 75-Ohm SWR sweeps of low-impedance phase-line array across the entire spectrum. Within the amateur bands, either line value would provide adequate performance. However, notice the high values of SWR at about 10.5, 18.5, and 26 MHz. These SWR values are indicators of weaknesses in the coverage of the antenna. Associated with these high SWR values are pattern anomalies due to harmonic operation of elements to the rear of the most active elements for each frequency. Since the graphs use spot frequencies, the displayed SWR values do not necessarily indicate the degree of the pattern problem, since pattern distortion may reach a maximum between checkpoint frequencies. This fact is confirmed by the broad peak in the 25.75-26.0 MHz region.

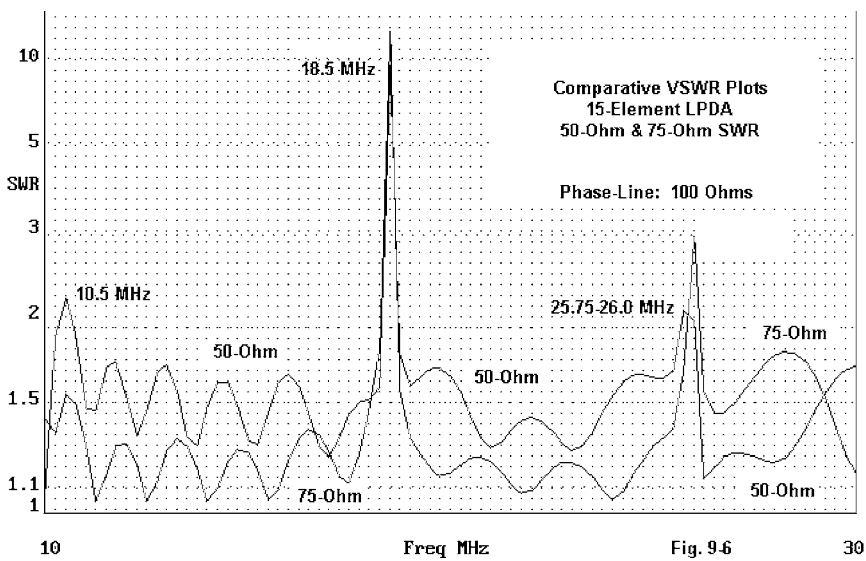


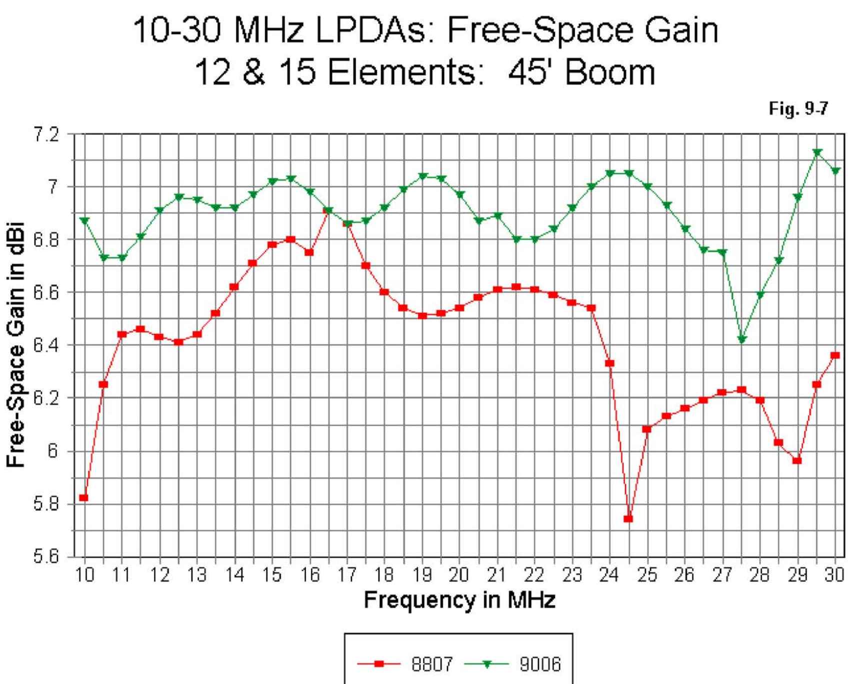
Fig. 9-6

As we shall see, these weaknesses do not appear in sweeps of the 250-Ohm version of the 15-element LPDA design—another benefit of using a higher characteristic impedance phase line.

A More Sweeping Comparison

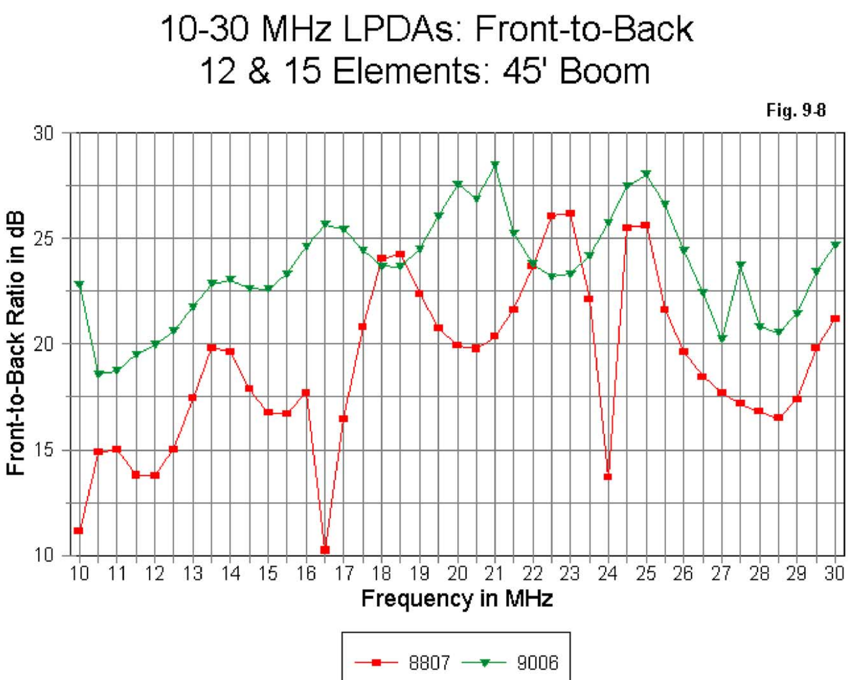
It may be useful to survey the performance of the two array designs more systematically than the ham-band checkpoint method permits. Therefore, let's examine some sweeps of the 12- and 15-element LPDAs across the entire spread from 10 to 30 MHz. To make the graphs as readable as possible, I have used 0.5 MHz checkpoints. This spacing between readings is sufficient for displaying general trends, but may not catch every possible weakness in the overall performance of the arrays.

Fig. 9-7 presents the free-space gain performance of the two arrays. Except for a gain peak in the 16.5 to 17.0 MHz area, the 15-element array shows higher gain everywhere within the passband. Note, however, that the differential in τ and the difference in the number of elements between the two arrays results in a difference in the pattern of peaks and valleys in the general curves of gain performance. This result is to be expected from every pair of arrays with different values of τ.



The smaller array shows a clearly evident weakness at 24.5 MHz. Less evident on this graph is a weakness in the 16.5 MHz region, precisely the area in which the smaller array gain reaches levels attained by the larger LPDA design. Very often, at frequencies just higher than the frequency of a pattern reversal, the forward gain will show such peaks. Therefore, we should be alert in other sweep graphs for signals that would more definitely differentiate a mere gain peak from a sign of a weakness. The upper graph shows a drop in gain for the 15-element array at about 27.5 MHz. However, as we shall see, this turns out to be a simple dip in gain, with no other signals of pattern distortion or reversal from any other indicator.

Fig. 9-8 provides us with the 180-degree front-to-back sweep of the two arrays. The front-to-back peak values tend to occur at frequencies that do not coincide with the gain peaks for these arrays. Immediately apparent is the smoother curve for the larger array. Indeed, the front-to-back curve for the 15-element LPDA dips below 20 dB only twice across the entire 20 MHz passband. In contrast, the front-to-back curve



of the smaller array spends most of its time well below the 20 dB level. Nevertheless, the front-to-back ratio of the 12-element LPDA is considerably superior to that which one can attain from the 2-element reflector-driver Yagi, which we have used as a gain comparator. The question facing the potential LPDA builder is whether the added weight of the 3 extra elements is justified by the improvements in both gain and front-to-back performance of the larger version of the array.

The front-to-back curve for the 12-element LPDA confirms the weaknesses that we detected in the gain curve. The drop in front-to-back ratio at 24 MHz precedes the drop in gain at 24.5 MHz, a normal pattern for signalling a weakness. Should these frequencies be of user interest, a more detailed frequency sweep of the frequency region would be in order. Although the front-to-back ratio returns to its normal values quickly with increasing frequency, the gain climbs more slowly toward a peak at 27.5 MHz. The sudden drop in front-to-back ratio in the 16.5 MHz region confirms our notation of the gain peak in this same region as a possible signal of a weakness.

Although the 15-element LPDA with a 250-Ohm phase line shows no definite weaknesses, we might identify what might be called incipient weaknesses, that is, areas where the gain and front-to-back ratio show irregular increases of decreases. 27.5 MHz is an area ripe for a more refined sweep, since the gain dips and the front-to-back ratio spikes at this frequency. A similar but much smaller case of this phenomenon occurs in the 20.5 to 21.0 MHz region. Such irregularities are common in short-boom LPDAs, and bear investigation in detail, although very often nothing occurs that represents an unacceptable level of performance in the indicated frequency regions.

The SWR graph in **Fig. 9-9** presents us with a small lesson in illusions. The graph combines the curves for the 250-Ohm phase line version of each array, with each curve using the feedpoint impedance standard that most closely approximates the median feedpoint impedance. The curves are very well-behaved across the entire passband, indicating relatively smooth performance.

However, we have seen in the gain and front-to-back graphs indications of performance weaknesses. Very often, the feedpoint impedance goes awry for a very much shorter frequency span than does the antenna pattern, as indicated by gain and front-to-back figures. Since the maximum distortion of gain does not usually occur at the same frequency as the maximum distortion of the front-to-back ratio, the feedpoint impedance will fall within anticipated boundaries except in the narrow frequency region where both performance indicators coincide in their departure from normal curves.

We have used the examination of 1.5-octave LPDA designs for more than a comparison of their relative merits. Every LPDA design exercise is a lesson in how the properties of LPDAs operate, especially when dealing—as amateurs usually must—with designs using either a low τ or a low σ, or both. On the question of which design to choose, assuming that the choice is a live one, we cannot answer in the absence of a list of specifications and limitations.

A Note on Phase-Line Construction

I have generally deferred construction details for LPDAs because the design process used has fallen short of the level necessary for construction. Although useful for illustration of LPDA principles and practices, the designs have generally used uniform diameter elements. Before one can get into construction detail, any candidate HF designs would require refinement in terms of the actual element diameter taper schedule proposed for use in the antenna.

However, it may be useful to add a note on the fabrication of phase lines for LPDAs. Many LPDAs that we have examined require or may optionally use low-impedance phase lines. For high-impedance lines, parallel wires represent an easy and standard calculation. (I shall pass over the past tendency to use crossing wires for phase lines. Such lines present a continuously variable impedance whose limits are reach at two points. One point is where the lines cross and usually yields the lower limit of the variable impedance. The other point is where the lines are furthest apart—normally at the element junction—and usually yields the highest impedance. For casual design using high-impedance lines throughout, the variability may not occasion any readily apparent anomalies relative to rough expectations. However, the practice does tend to mock the precision formerly thought to inhabit the basic design equations.)

Fig. 9-10 sketches the 4 most common basic LPDA structures for lower-impedance phase lines. On the left are two versions of twin-boom structures, one using round stock, the other using square stock. Of course, the distance between the combination boom-phase-lines is held constant by the use of periodic insulated spacers.

The details of various ways of connecting elements to the booms can be found in Chapter 10 of *The ARRL Antenna Book*, 19th Edition.

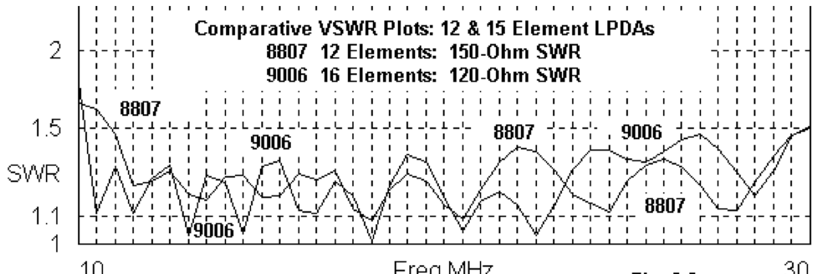


Fig. 9-9

The right side of **Fig. 9-10** shows the use of a single support boom, with the elements insulated by plates or fixtures from the boom. The phase lines can be constructed from a variety of round materials, mostly wire or small-diameter copper tubing. To maintain spacing for a given characteristic impedance, a series of spacers may be used to supplement the periodic support and spacing provided by the element-to-phase-line insulators. In many installations, the components might well be inverted, with the elements and phase line hanging below the boom.

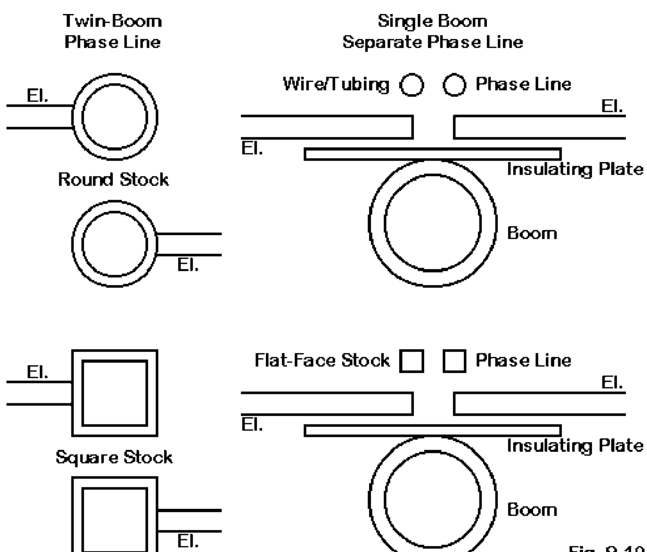


Fig. 9-10

Flat-face stock has both advantages and disadvantages when used for the phase line in either system. In general, round stock tends to be stronger in boom duty. Copper wire and soft-drawn tubing are flexible and stretchable when used as independent phase lines. This latter property can be important. Even with support lines, a boom will sag. Absolute rigidity in the phase line assembly will likely result in the fracture of the phase line components. If the assembly is inverted from the position shown in **Fig. 9-10**, then compression of the lines may result in warpage that can change the line impedance in the affected areas. In large HF arrays, lines that run no further than from one element to the next are likely to be more durable than lines that are continuous from one to the other end of the LPDA assembly.

These precautions are perhaps even more important with the use of flat-faced stock. **Fig. 9-11** sketches the three main candidates for flat-faced phase lines. Square stock may be the strongest, but L-stock is likely the easiest to use. It may be cut into element-to-element sections, with an overlap of the portion used for mounting to the insulators. The line-to-insulator junction is also a good place to mount connecting straps—perhaps of aluminum flashing or other thin sheet. The connectors are short where the line connects to the element section adjacent to the line. For alternate elements, a crossing connector is necessary. At HF, a connecting strap that goes to the rear for one connection and to the front for the other will create no significant impedance bump.

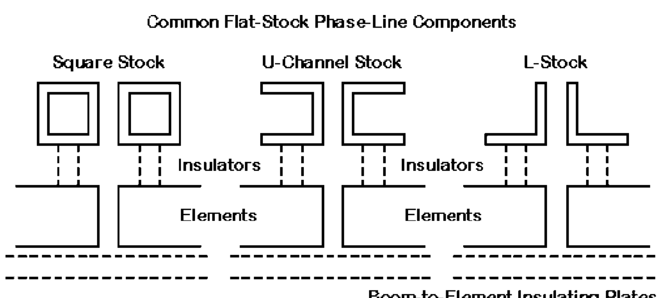


Fig. 9-11

The major advantage of flat-faced stock lies in its ability to achieve lower impedances than round stock whose diameter is equal to the face-width of the stock. The use of flat-faced stock requires some adjustment when calculating the characteristic impedance of the phase-line. For conductors with a circular cross-section,

$$Z_O = 120 \cosh^{-1} \frac{D}{d} \qquad \textbf{(1)}$$

where D is the center-to-center spacing of the conductors and d is the outside diameter of each conductor, and D and d are in the same units. Since we are dealing with closely spaced conductors, relative to their diameters, the use of this version of the equation for calculating the characteristic impedance (Z_O) is more accurate than the version using common logarithms.

For a square conductor,

$$d \approx 1.18\ w \qquad \textbf{(2)}$$

where d is the approximate equivalent diameter of the square tubing and w is the width of the tubing across one side. This simple approximation is subject to refinement, most needed for very low impedance lines that require exceptionally close spacing. Thus, for a given spacing, a square tube permits one to achieve a lower characteristic impedance than with a round conductor. L-stock may not play quite as true to the approximated correction factor as true square stock of U-channel with its “bottom” used as the facing side. However, the deviation in most instances will not create a significant difference in array performance.

Easily used transmission line design programs are available on the HAMCALC suite available from VE3ERP. The programs include calculation of impedance and the physical properties of both round-stock and square-stock lines.

In general, for higher impedance phase lines, round stock, such as wire and tubing offer the greatest convenience. For low impedance lines at HF, the exceptionally close spacing required by round conductors may make flat-faced stock a more attractive option, since for the same impedance, flat-face stock will use a greater separation. Indeed, bare round-conductor parallel transmission line with an impedance less than 80 Ohms is generally not feasible, since the wire surface would penetrate each other.

Table 9-3. 100-Ω Round and Flat Transmission Line

Round			Flat-Faced (Square)	
Wire Size	C-C Space	Gap	Face Width	Gap
12 AWG	0.093"	0.012"	0.25"	0.154"
10 AWG	0.117"	0.015"	0.5"	0.307"
0.25"	0.288"	0.038"	0.75"	0.461"
0.5"	0.576"	0.076"	1"	0.614"

Table 9-3 provides representative figures for 100-Ohm line using common values for both round and flat-face conductors. The numbers of 0.25" and 0.5" materials are directly comparable. For these sizes, the flat-face stock requires a gap about 4 times larger than the round stock, a spacing that is both easier to construct and more likely to be durable once the antenna is in place. In all cases, it is wise to make up a section of line and to measure its characteristic impedance before installation on the LPDA assembly. The casual estimate used in the calculation plus variables in the materials used can sometimes make a significant difference in the outcome.

This brief look at some of the options available for constructing phase lines should ease at least a bit of the planning process for building an LPDA. Even the shortest-boom 20-10-meter model examined in the last chapter is a major structural undertaking as well as a fascinating design challenge. Careful planning of every stage of the work is essential to an array that works as predicted.

Chapter 10: Unfinished Business

Let me be clear about a central point: my notes on LPDAs do not represent anything like a definitive study of this type of antenna. At most, these notes amount to small contributions to amateur practice in the design of log periodic arrays. Even so, we have only scratched the surface of the general field of LPDAs and have far to go before my small stock of notes is exhausted. In short, we have unfinished business.

For example, we have only looked at pure LPDAs, modified only to the extent necessary to optimize their performance over the HF amateur bands. Except for the minor addition of a parasitic director—a technique known since at least the 1970s—we have not touched what might be called hybrid LPDAs, combinations of LPDA and parasitic techniques. Most of the antennas employing the combination are monoband arrays designed to enhance performance on a single amateur band. They are normally called "log-cell Yagis," although we might have easily called them "parasitically-enhanced LPDAs." The difference in name is simply a difference in where one begins the design process. History had ruled on the name, but we need not be so ruled. If we begin with the LPDA portion, we just might uncover some unrealized potentials for this class of array.

In order to find the untapped potential for log-cell Yagis, we shall first have to survey the potential of existing designs. The log-cell Yagi appeared with the claim to achieve better-than-Yagi performance and bandwidth. Although that claim might have been true in about 1980, Yagi design has come a long way since then, and we must re-examine the claim for the current millennium.

Equally unfinished is our survey of practical LPDA designs. We have limited ourselves in this volume to 1-octave and 1.5-octave HF arrays, since the 20-meter to 10-meter span is the frequency region that has attracted the most amateur attention over the years. However, the LPDA has many more practical potentials than just this region of the spectrum.

We can move in 2 pairs of directions. With respect to frequency, we can move both above and below the upper HF region. The LPDA has been used at the low end of the HF spectrum in an attempt to overcome the width of the 80/75-meter band. If we look at this challenge, we shall undoubtedly involve ourselves in wire construction, since 2" diameter and larger tubing is impractical for amateur installations, however desirable it may be as an 80-meter LPDA element.

We can also move upward in frequency, since LPDAs for VHF, UHF, and higher become compact antennas relative to their mountainous HF cousins. The need for broad operating frequency limits also becomes significant to many kinds of operation, both amateur and commercial. The LPDA then becomes a primary candidate in the design process.

The second pair of optional directions in which we can move has to do with the operating bandwidth that we choose for an LPDA design. Monoband log-cell Yagis come close to the ultimate confinement of the LPDA with respect to frequency. At HF, both 80/75 meters and 10 meters represent very wide bands for which some adaptation of the LPDA may be relevant—assuming that one wishes to cover the entire band with roughly equal performance everywhere. We need not think solely of the HF spectrum. At VHF and UHF frequencies, Yagis can be designed to cover almost any of the amateur allocations. However, one might on occasion need a specialized antenna with under a 1-octave performance range, perhaps to monitor 130-170 MHz, with transmission only on the 2-meter, CAP, and/or allied frequencies.

At the other extreme are the very wide-range LPDAs covering more than 3 octaves. We may wish to rethink some of the HF potentials of such antennas. However, at VHF and UHF, LPDAs with operating ranges up to 3.5 octaves might serve many useful purposes.

Since I cannot look at all of these potentials in this volume, I suspect that a second volume on hybrid LPDAs and allied applications will be needed.

Other Publications

We hope you've enjoyed this Volume 1 of the **LPDA Notes.** Be sure to watch for the companion Volume 2 to follow. You'll find it and many other very fine books and publicartions by the author L.B. Cebik, W4RNL in the ***antenneX Online Magazine BookShelf*** at the web site shown below.

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