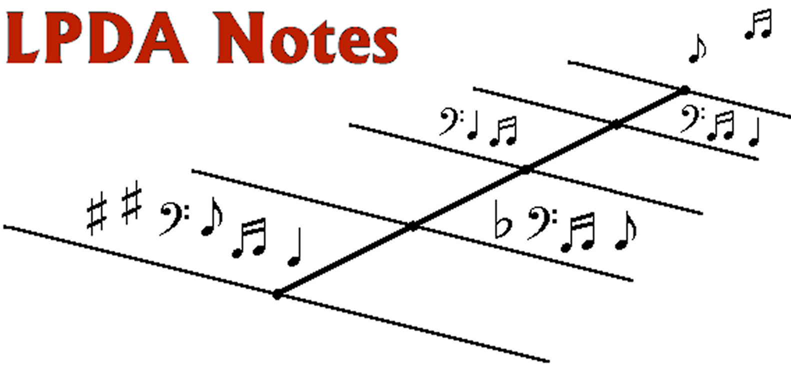
LPDA Notes



Volume 2
Hybrid LPDAs

L. B. Cebik, W4RNL

LPDA Notes

Volume 2
Hybrid LPDAs

L. B. Cebik, W4RNL

Published by
antenneX Online Magazine
http://www.antennex.com/
POB 72022
Corpus Christi, Texas 78472 USA

ISBN: 1-877992-31-3

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

In Volume 1, we explored the principles by which we design LPDAs and then correct them for flaws that occur in performance whenever designs are less than optimum. This latter condition is a way of life for not only amateur LPDAs, but as well for almost any rotatable HF LPDA. Below 30 MHz, it is almost physically impossible to develop an LPDA that employs a very high value of τ along with its associated optimal value of σ. Consequently, for arrays that are not fixed, a considerable portion of the design effort must be devoted to overcoming the shortcomings inherent in using low values of τ and σ.

One of the performance enhancements that we used was the addition of a parasitic director to an HF array in order to increase the gain at the upper end of the operating range without adding a host of further elements to overcome the "truncation" effect. In adding that director, we had already entered the realm of hybrid LPDAs. In this volume, we shall immerse ourselves in hybrid LPDAs for at least half the volume. These arrays go under an alias: the log-cell Yagi. The name we choose will be less important to us than trying to figure out through systematic modeling the place they hold in the collection of monoband directional antennas. As we shall discover, most of the claims originally made for these beams must be reformulated, especially in light of the many advances made in the last two decades in the field of Yagi-Usa design. However, we shall also learn that the amateur practice of trying to compact HF antenna performance onto very short booms may have restricted the development of log-cell Yagis as arrays worthy of consideration today and tomorrow.

The use of log cells for narrow band applications of LPDA principles to special communications needs gives us the occasion to explore the role of pure LPDAs for frequency ranges much smaller than the typical 2:1 range used with the HF LPDA family in Volume 1. Interestingly, bands as well separated as 80 meters and 2 meters form natural homes for small-range LPDAs, although for very different reasons. In the process of dealing with the 80-meter question, we shall have occasion to explore further the potential of wire-element LPDAs.

If LPDA use for narrow-band applications is limited, the potential for very wide-band applications has been a dream of hams (and others) since the advent of frequency-independent theory. The idea of a single antenna to cover the entire HF spectrum has an appeal, but perhaps an outdated one in many ways. We shall explore alternative strategies to the use of a single HF array to arrive at better performance and reliability. If the single array for a 10:1 frequency span has any application at all, perhaps it lies within the VHF/UHF region. We shall investigate some of the necessary design considerations for achieving at least an adequately performing utility antenna for this range.

As our final foray into LPDA design, we shall look at a common practice in commercial LPDA design: the split-range array that uses two independent LPDAs combined on a single phase line. As a forewarning, I shall only note here that, unless one can be satisfied with relatively mediocre performance from a split-band LPDA, the development of a single unified LPDA design for the entire frequency range may offer significant advantages. However, as with all of the notes in this 2-volume set, the conclusion itself may be far less important than what we learn about LPDA behavior along the way.

Throughout, my methods will remain largely based on systematic modeling using NEC-4. For the class of arrays with which we are working, the facilities of NEC in its commercial implementations are quite adequate for reliable projections of the performance potential for virtually any LPDA. If there is a limitation, it is likely to be in the upper UHF range, where the physical size of phase lines may interact with very short elements in ways that the use of mathematical phase lines within NEC cannot fully capture. For LPDAs below UHF, the modeling results can almost always be directly translated into a physical antenna that works as predicted—at least within the constraints of construction precision within the home shop environment.

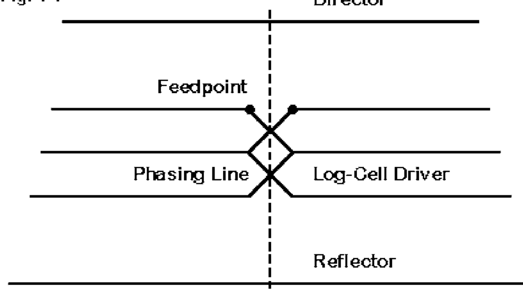
Throughout this 2-volume collection of LPDA notes, my aim has not been to write the exhaustive treatise on this antenna type. Instead, my goal has been far more modest: to make a useful contribution or two to the understanding of amateur band and allied uses of the log periodic dipole array. The LPDA has subtleties that defy encapsulation in any set of notes.

Part 1. Log-Cell Yagis

Chapter 1: Log-Cell Yagi and Some Standards of Comparison

Although the design had been known earlier, the monoband log-cell Yagi array was briefly popular in amateur literature in the late 1970s and early 1980s, largely through the work of Rhodes, K4EWG, Painter, W4BBP, and Zimmer, K4JZB.[1] Versions can be found in Orr and Cowan's *Beam Antenna Handbook*, and in the *ARRL Antenna Book*. In recent times, interest in the design has renewed.

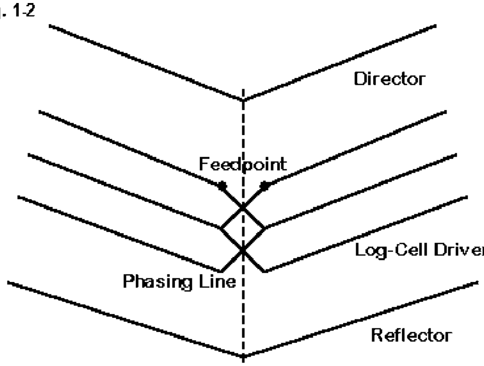
Fig. 1-1



A Typical Monoband Log-Cell Yagi Outline

Fig. 1-1 shows the outline of a typical monoband log-cell Yagi. It consists of a log-cell driver consisting of 2 or more elements driven with a phasing line that reverses as it connects each element. The element set is fed at the forward-most position, much like a log-periodic dipole array (LPDA). To the driver cell are added a reflector (usually) and one or more directors.

Fig. 1-2



A Typical "Vee-ed" Monoband Log-Cell Yagi Outline

In **Fig. 1-2**, we see a common variant of the basic log-cell Yagi. In this case, favored especially by K4JZB, the elements are bent forward by about 40 degrees from linear each side of center.

Since most of the articles on the log-cell Yagi appeared before the advent of computer antenna modeling via MININEC and NEC, the claims for their performance are highly optimistic. One source reports a 6-element log-cell Yagi to have a gain of 16 dB, but it conveniently gives no reference standard. Most sources report gain to be greater than for Yagis of equivalent boom length, but these reports compare the log-cell Yagi with antennas developed before computerized optimization of the Yagi design became commonplace. Perhaps only Rhodes and Painter stress operating bandwidth as a major advantage of the antenna design.

With the renewed interest in the antenna, many potential users read the older claims as if they would stand up to modern scrutiny. However, to date, I have seen no re-evaluation of the log-cell Yagi design. Modern analytical tools, such as computer modeling, offer us a chance to better understand the antenna and to assess its place among monoband antennas used by amateurs.

The purpose of these first chapters is to contribute a little toward the re-evaluation of the log-cell Yagi, using NEC-4 as a means of analyzing various aspects of the design. Throughout, I shall uses 10-meters as a focal point, since this band is the widest of the upper HF amateur bands. In this introduction, I shall look briefly at a superior log-cell Yagi design, and then look at the performance characteristics of some pure Yagi designs that we might use as standards of comparison. In this way, we can begin to see more clearly where the log-cell Yagi fits into the amateur arsenal of antennas.

In Chapter 2, we shall examine some basic principles behind the log cell itself, with especial attention to element phasing. One might also use LPDA principles to show how a log-cell works, but the basics of element phasing can make a number of facets of both Yagi and log-cell Yagi design somewhat clearer.

In Chapter 3, we shall look at several (at least 4) practical 10-meter log-cell Yagi designs. I shall claim no great originality for any of the designs, although each has required considerable effort to optimize all of the operating characteristics, including gain, front-to-back ratio, and SWR bandwidth. All of the antenna designs will feature direct 50-Ohm feedpoint impedances.

In Chapter 4, we shall examine the V-element question. Does bending half-wavelength elements forward contribute anything useful to the performance of the log-cell

Yagi? This question, of course, will involve us in the broader question of V-ing any half-wavelength element.

A Real Log-Cell Yagi of Considerable Potential

Let's begin with an advanced log-cell Yagi design using a 5-element log-cell plus a reflector and director. This 7-element array was extensively revised from a CB design sent to me by Alan Hughes, ZL3KR. The original had a free-space gain of about 9 dBi, but poor front-to-back ratio. In addition, the SWR and operating characteristics remained usable over only a very narrow portion of the spectrum.

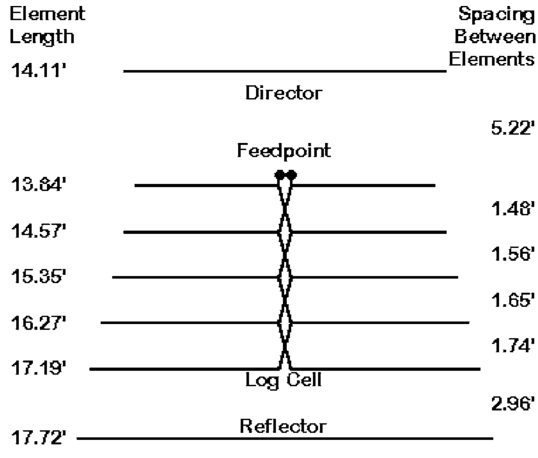


Fig. 1-3 A 7-Element 10-Meter Log-Cell Yagi

The basic dimensions of the refined model appear in **Fig. 1-3**. The material for the model is 1" diameter aluminum, although similar performance can be achieved with elements as small as 0.5" in diameter.

The log-cell is designed as a true LPDA, with elements tapering in length and spacing as one moves forward toward the feedpoint. As one might expect, the reflector is the longest element of the entire set. However, the director is longer than the forward-most element of the log cell. Directors for log-cell Yagis must be cut for the operating frequency, while the forward element of the log cell will be resonant well above the highest operating frequency. The overall length of the antenna is about 14.6' or so, which would fit the antenna easily on a 15' boom.

Fig. 1-4 provides a snapshot of antenna performance across all of 10 meters from 28.0 to 29.7 MHz. The highest free-space gain is at the upper end of the band, with the free-space gain at 28 MHz being just above 8 dBi. The first MHz of the band also shows a very high and stable front-to-back ratio of 30 dB or more, with the figure at 28.5 MHz exceeding 40 dB. The 50-Ohm SWR of this antenna remains well below 2:1 across the entire 10-meter band.

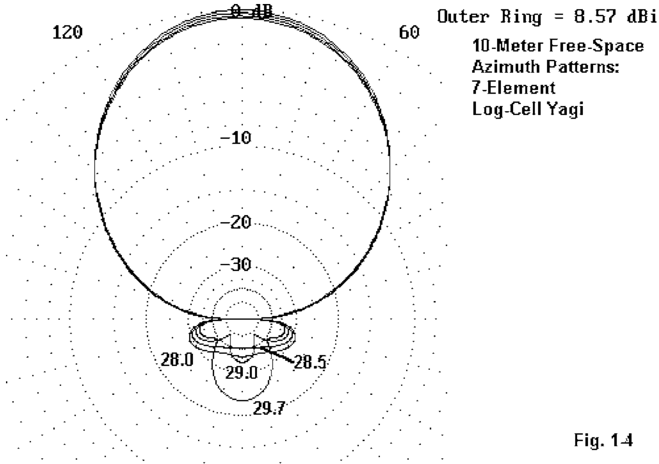


Fig. 1-4

Actually building this antenna would require element length adjustment if an element diameter-tapering schedule is used. However, nothing in the design would require special construction except perhaps the 100-Ω phasing line for the log cell. We shall return to this and other practical designs later in the series. First, let's consider whether the antenna is worth building. For that evaluation, we need some standards of comparison.

Some Standards of Comparison

Since the days in which log-cell Yagis were claimed as higher gain, more compact beam designs than pure Yagis, the understanding of Yagi design has improved considerably. Lawson's *Yagi Antenna Design*[2] has become the basic volume for modern Yagi design. In addition, there are several Yagi optimizing programs whose results correlate well with NEC models, assuring the builder of predictable results. Consequently, monoband Yagi designs as we enter the new century are quite different from those of 15 to 20 years ago.

Because the most common comparator for a log-cell Yagi is a pure monoband Yagi, perhaps it may be useful to examine some of the operating characteristics of several good Yagi designs. Let's begin with designs I refer to as medium-bandwidth arrays, because they hold their operating characteristics from 28 MHz up to 29 MHz—or close to it. We shall look at three designs in particular.

Table 1-1. Medium-Bandwidth 10-Meter Yagi Dimensions

1. 3-8: 3-Element, Short-Boom (< 8') Yagi: 0.5" diameter aluminum elements

Element	Length (“)	Distance from Reflector (“)
Reflector	211.9	———
Driver	193.8	36.0
Director	184.9	90.0

2. 3-12: 3-Element, Long-Boom (<12') Yagi: 0.5" diameter aluminum elements

Element	Length (“)	Distance from Reflector (“)
Reflector	206.3	———
Driver	197.0	62.4
Director	185.3	134.5

3. 4-13: 4-Element, 13'-Boom Yagi: 0.5" diameter aluminum elements

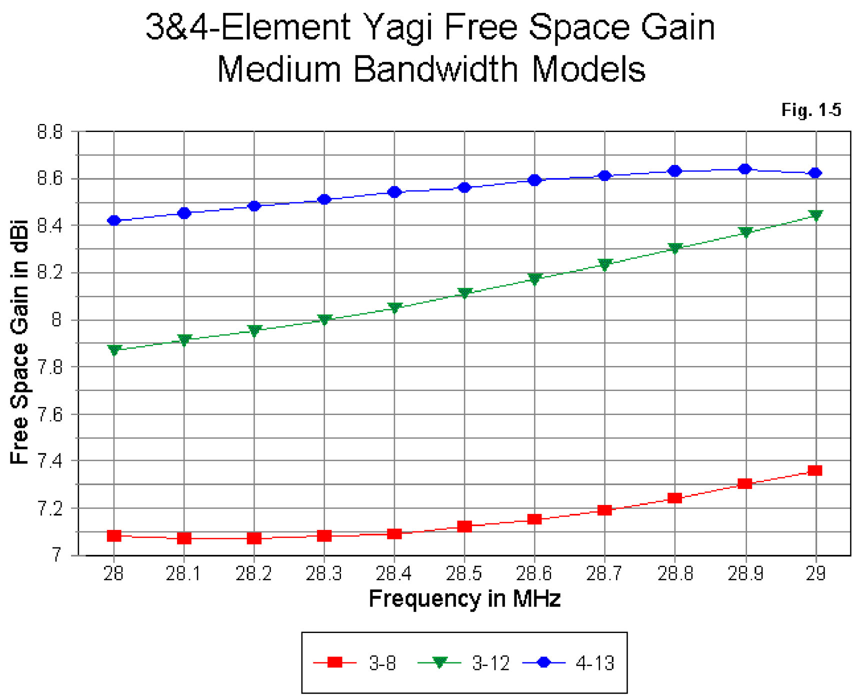
Element	Length (“)	Distance from Reflector (“)
Reflector	207.5	———
Driver	195.9	35.8
Director 1	194.4	65.5
Director 2	182.2	152.2

First is a 3-element Yagi on an 8' boom (3-8). The actual overall length of the antenna is about 7.5'. The design is adapted from one of Dean Straw’s (N6BV) designs in the collection of antennas accompanying the program YA.[3] **Table 1-1** provides the modeled dimensions for this and the other two antennas in the medium bandwidth group.

The second design is adapted from Brian Beezley’s (K6STI) design in the samples accompanying AO.[4] This longer-boom design (3-12) is actually about 11.2' long and fits easily on a 12' boom. The third design (4-13), again adapted from an N6BV design, uses 4 elements in under 12.7' of length for an easy fit on a 13' boom.

For this exercise, all designs use uniform diameter elements. All are modeled on NEC-4 in free space for the purposes of direct comparison.[5] The driven elements of the 3-element beams have been resonated so that SWR figures can be taken relative to the resonant impedance. Because the 4-element beam had a somewhat lower impedance, it has been equipped with a beta match, that is, a shorted transmission-line stub to effect a match compatible with 50-Ω coax. The 3-element beams can be matched with a quarter-wavelength matching section, or their drivers can be shortened for use with a beta match.

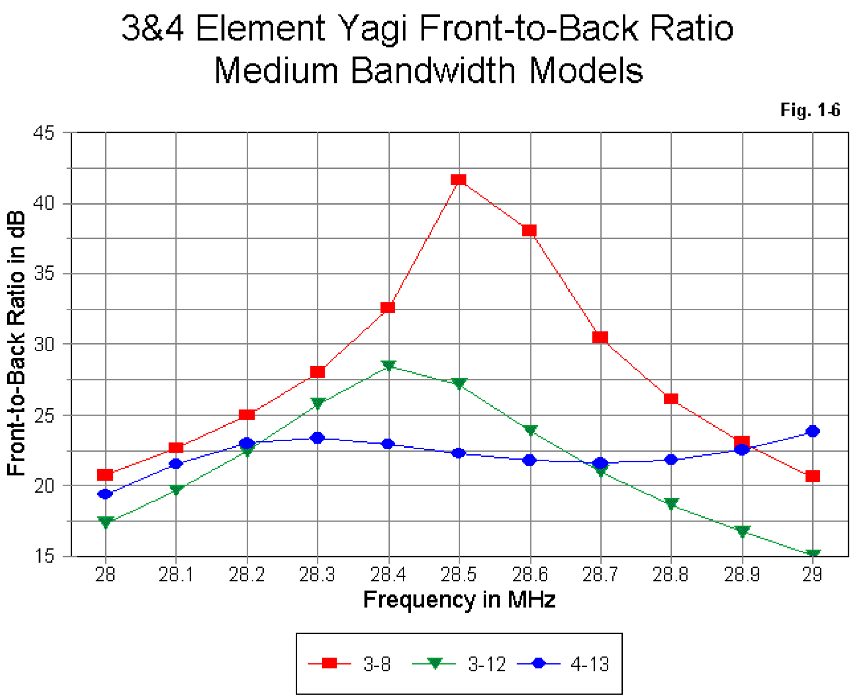
Fig. 1-5 provides a sweep of the free-space gain of each beam design from 28.0 to 29.0 MHz. As one might expect, the 3-element, 8' boom model shows the lowest gain—just above 7 dBi. However, the gain is fairly constant across the selected portion of the band.



The long-boom 3-element Yagi shows considerably higher gain, averaging nearly a full dB above the short-boom model. Because the boom length is close to the limit of stable operation for a considerable bandwidth, the curve shows greater changes with increasing frequency.

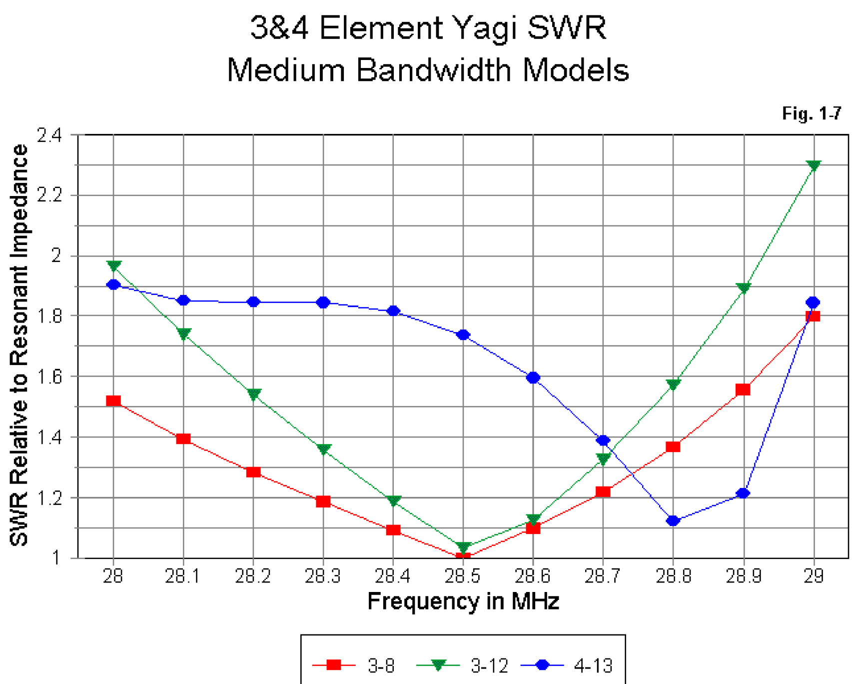
In contrast, the 4-element Yagi shows only slightly higher gain than the 3-element long-boom model. However, the boom length is only about a foot greater than the long-boom 3-element Yagi. What the fourth element provides is more even gain across the selected bandwidth.

In **Fig. 1-6**, we get a picture of the 180-degree front-to-back ratio of the antennas. Interestingly, the short-boom 3-element Yagi shows the highest peak front-to-back ratio and the highest average front-to-back ratio across the band, never falling below 20 dB. Comparatively, the long-boom 3-element Yagi shows a good peak front-to-back ratio, but the value falls below 20 dB between 28.7 and 28.8 MHz. The 4-element Yagi shows a much lower value of peak front-to-back ratio, but the overall curve is smooth and falls below 20 dB only at the lower edge of the band.



From these two parameters alone, we can obtain an impression of the designs. The short-boom 3-element and the 4-element designs are conservative. However, the long-boom 3-element design is pressing the limits of what is possible for that number of elements and boom length. One might obtain even higher gain, but at the expense of an even narrower bandwidth for the operating characteristics.

The impression is further deepened in the SWR curves in **Fig. 1-7**. The long-boom model shows under 2:1 SWR relative to the resonant impedance through 28.9 MHz. The short-boom 3-element Yagi easily achieves a 2:1 SWR bandwidth, relative to the resonant impedance, that is wider than the selected band portion. Despite the slight narrowing of the long-boom SWR bandwidth, the use of a beta match would likely permit a wider operating bandwidth at the 50-Ωmatched value. This is illustrated by the 4-element Yagi 50-Ω bandwidth, which shows under 2:1 SWR across the band. The native bandwidth relative to the antenna's resonant impedance would be about



800 kHz. (However, there may be slight losses associated with operating a beta match well off its optimal values, despite the resulting good impedance match.)

These three antennas are good designs of their types, despite the limitations of each. However, they are not adequate to cover the entirety of 10-meters from 28.0 to 29.7 MHz. In order to achieve that goal, we must turn to wide-band designs. The dimensions of two wide-band Yagi designs appear in **Table 1-2**.

Table 1-2. Wide-Bandwidth 10-Meter Yagi Dimensions

1. 3-Element, Long-Boom (<12') Yagi: 1.0" diameter aluminum elements

Element	Length (“)	Distance from Reflector (“)
Reflector	214.0	———
Driver	195.6	74.5
Director	176.0	134.5

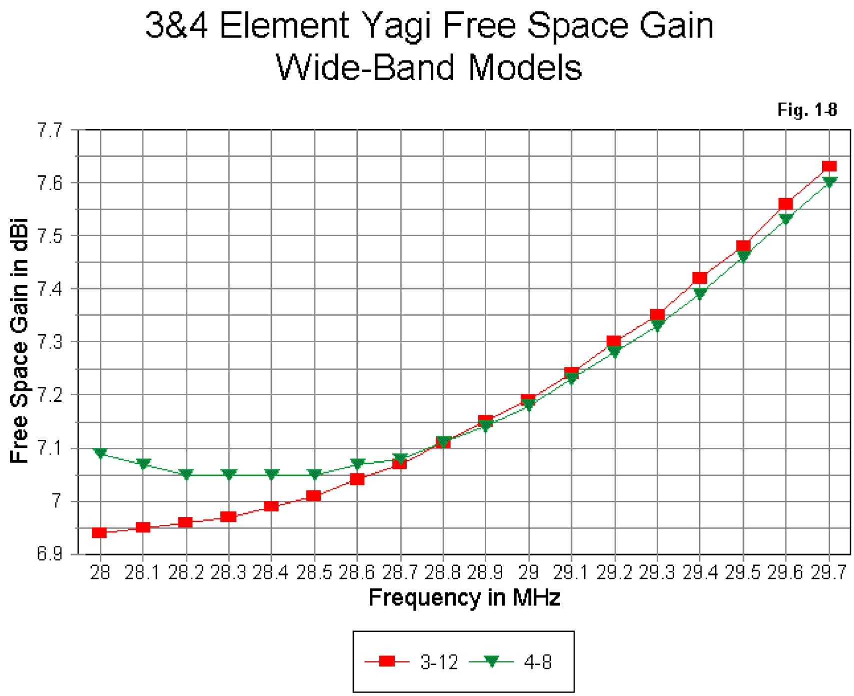
2. 4-Element, Short-Boom (8') Yagi: 0.5" diameter aluminum elements

Element	Length (“)	Distance from Reflector (“)
Reflector	212.0	———
Driver	205.0	40.5
Slaved Driver	189.0	44.0
Director	181.0	96.0

One design is a 3-element Yagi. This version was developed by Joe Reisert, W1JR, and is similar to a design published by Bill Orr, W6SAI, in *Ham Radio* many years ago.[6] The boom would be 12' long to hold an antenna whose inherent length is about 11.2' or so. The other design is my own, which fits on a 8' boom and uses 4 elements. The extra element is a second driver that is open-sleeve coupled to the first driver such that the two drivers together cover all of 10-meters.

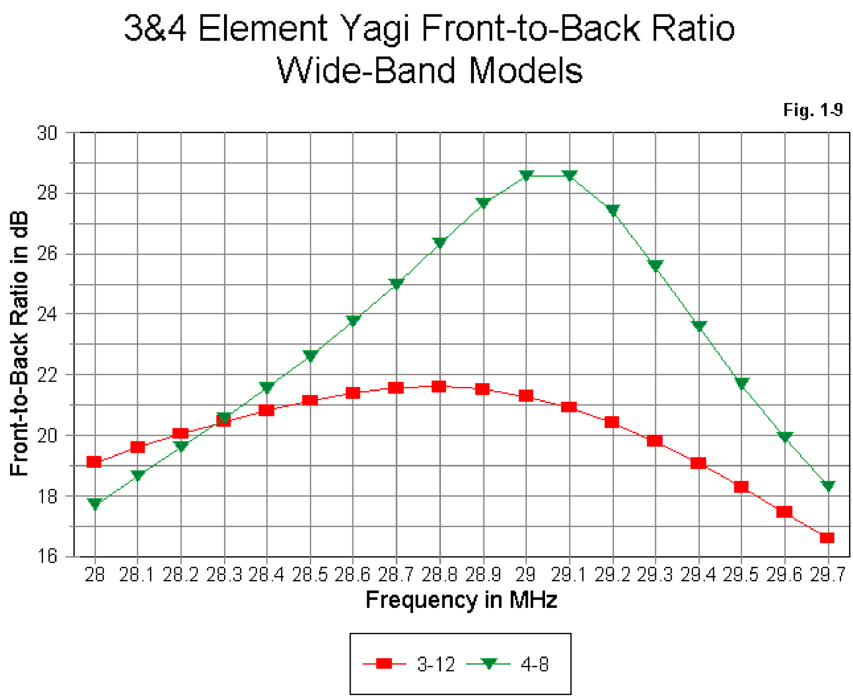
As shown in **Fig. 1-8**, the gain curves of the two antennas are very similar, with the 4-element model having a slight edge at the lower end of the band, a function of the dual driver system. It is notable that in a 3-element design, wide-banding the gain requires a boom length similar to that of the higher-gain medium-bandwidth long-boom model—about 12'.

Obtaining the desired wide-band gain with a significantly shorter boom (8') requires the use of an extra element. It is possible also to create a pure LPDA design using 4 elements and an 8' boom: the performance is nearly identical to that of the 4-element wide-band Yagi. This fact should be kept in mind as we later evaluate the performance of some of the smaller log-cell Yagi designs—which nonetheless use 4 or more elements.



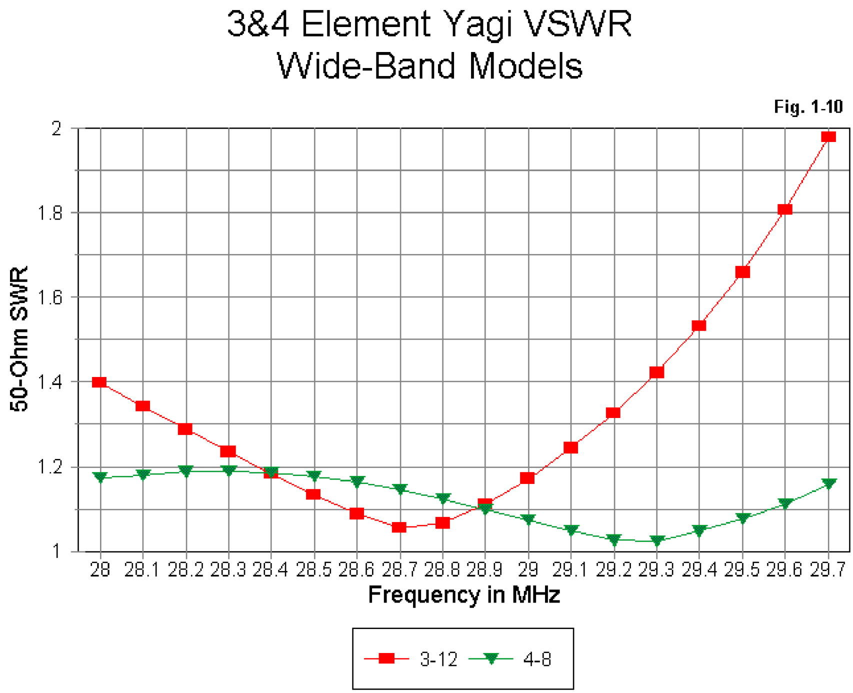
The front-to-back curves in **Fig. 1-9** once more do not give one design a major edge over the other. The dip in value below 20 dB occurs at opposite ends of the band for the two designs—but might be made more coincident with slight redesign of element lengths and spacings.

The 4-element model shows a very high front-to-back ratio peak around 29 MHz, where all 4 elements show the highest activity in terms of current magnitude. However, a better gauge of front-to-back performance is the lowest value within the operating passband. As well, for any design, it is useful to examine the entire rearward performance to obtain an estimate of the average front-to-rear performance. Often, the 180-degree front-to-back ratio can obscure the existence of quartering rear side lobes of considerable strength.



The SWR curves for both wide-band antennas in **Fig. 1-10** are referenced to 50 Ω without need for a matching system. The 3-element antenna easily achieves a 2:1 operating bandwidth that covers the entire band. The open-sleeve coupled drivers of the 4-element model allow superior performance in this department, with an SWR that never rises to 1.2:1 across the entire band.

In the vicinity of 30 MHz, the losses in a coaxial cable feed line begin to become significant. The exact degree of significance depends on two factors: the quality (or loss per 100') of the line used and the length of the line. Consequently, whether one needs to strive toward the SWR performance of the 4-element design or settle comfortably for the 3-element SWR curve depends on the specific properties of the antenna installation.



Relevant Comparisons

The standards of comparison we have just established will be used throughout this series in various ways. To illustrate how we may sensibly use them, we may return to the 7-element log-cell Yagi that we briefly described. The 4-element medium-bandwidth Yagi matches the log-cell Yagi in gain on a boom that is 1-2 feet shorter. However, short-boom pure Yagi is limited to only about 1 MHz of the band, while the log-cell Yagi provides coverage of the entire band. The gain of the log-cell Yagi is from 1 to 1.5 dB greater than either of the 2 wide-band beams discussed.

In front-to-back ratio, the log-cell Yagi is superior to all of the standard designs, with better than 30 dB until well past 29 MHz and better than 22 dB across all of the band. One of the areas in which well-designed log-cell Yagis excel is in front-to-back ratio. The log-cell Yagi also has a 50-Ω SWR well under 2:1 across the entirety of the 10-meter band, matching both wide-band Yagis in that performance category.

For a given boom length, then, a log-cell Yagi does not make its claim to fame in the 21st century in the gain department. Advances in pure monoband Yagi design give the edge to the pure Yagi. What may have been true of 1980 Yagi designs is no longer true today.

However, well-designed log-cell Yagis can achieve very wide operating bandwidths, not only with respect to SWR, but as well with respect to operating characteristics. In particular, the log-cell Yagi has the potential for very smooth front-to-back ratio curves at very high levels across a band as wide as 10 meters.

There is, of course, a cost involved in achieving these goals: extra elements and their associated weight. In addition, the log cell requires careful design with considerable attention to the phasing line that interconnects the phased driven elements. To the subject of element phasing we shall turn in Chapter 2.

Notes

1. For information on various log-cell Yagi designs see the following items on this incomplete literature list:

P. D. Rhodes, K4EWG, and J. R. Painter, W4BBP, "The Log-Yagi Array," *QST*, Dec, 1976. The main elements of this article are reprinted in *The ARRL Antenna Book*, 18th Ed., pp. 10-25 to 10-27.

Robert F. Zimmer, K4JZB, "Development and Construction of 'V' Beam Antennas," *CQ*, Aug., 1983, pp. 28-32; and "Three Experimental Antennas for 15 Meters," *CQ*, Jan., 1983, pp. 44-45.

W. I. Orr, W6SAI, and S. D. Cowan, W2LX, *Beam Antenna Handbook*, pp. 251-253.

John J. Meyer, N5JM, "A Simple Log-Yag Array for 50 MHz," *Antenna Compendium*, Vol. 1, pp 62-63.

Reference to log-cell Yagis is also made by L. A. Moxon, *HF Antennas for All Locations*, 2nd Ed., pp. 199-200, but the design shown in his classic is the Rhodes-Painter version in *The ARRL Antenna Book*.

2. James L. Lawson, W2PV, *Yagi Antenna Design* (ARRL, 1986).

3. YA is a Yagi Analysis program developed by Brian Beezley, K6STI, and accompanies recent editions of *The ARRL Antenna Book*. N6BV has updated and improved the program into a Windows version for the 19th Edition.

4. AO is a MININEC analysis and antenna optimizer program by K6STI that is no longer available.

5. Two commercial implementations of NEC-4 are available: EZNEC Pro by Roy Lewallen, W7EL, P.O. Box 6658, Beaverton, OR 97007 (http://www.eznec.com) and GNEC by Nittany Scientific, 1733 W 12600 S, Suite 420, Riverton, UT 84065-7043 (http://www.nittany-scientific.com). Use of NEC-4 requires licensure from the University of California in addition to the cost of software. Fortunately, most of the analysis in this series can be replicated using more easily obtained versions of NEC-2. EZNEC 3.0 and NEC-Win Plus are two such programs.

6. Joe, Reisert, W1JR, "Yagi/Uda Antenna Design: Part 1: A Different Approach," *Communications Quarterly*, Winter, 1998, pp. 49-59. Orr's version of the antenna appeared in his regular column for *Ham Radio*, May, 1990.

Chapter 2: Element Phasing and Log-Cell Design

Monoband log-cell Yagis have been designed using anywhere from 2 to 5 elements in the log cell itself. They may or may not use a reflector, and the number of directors has ranged from 1 to 3 in the designs that I have encountered. Some log-cell designs have been very casual, while others (such as the Rhodes-Painter array[1]) have adhered to rigorous LPDA design procedures. Since the key to a log-cell Yagi is the log cell itself, it may be useful for us to spend some time exploring some facets of its design.

When the log cell has only 2 elements, one cannot distinguish it from a 2-element phased array. Indeed, one can build a successful beam by adding a director to a 2-element phased array—if the phased elements are properly designed. So let's begin with this simplified case and then proceed to more complex log cells.

The Phasing of 2 Elements

Element phasing refers to the relative current magnitude and phase of each element in an array of elements. The current magnitude and phase are ordinarily read at the center of elements in symmetrical arrays in which each element length is in the vicinity of 1/2 wavelength.

By this accounting, a 2-element Yagi is a phased array, even though only the driven element is fed. The current magnitude and phase on the parasitic reflector is a function of coupled energy from the driver. We alter the current magnitude and phase on the rear element by varying the lengths of the elements and the spacing between them. For a simple 2-element driver-reflector Yagi, we have limited abilities to adjust the rear element relative current magnitude and phasing through modifying the antenna geometry itself. For example, the rear lobe gain of such arrays is rarely more than 12 dB below the main forward lobe.

By some judicious alterations of geometry, we can change the rear element current magnitude and phase to improve the depth of the rear null. One of the most remarkable designs in this regard is the Moxon rectangle. Folding the elements toward each other at the ends results in a rear element current magnitude and phase for the element spacing that yields a very deep rear null—often better than 35 dB below the main forward lobe at the design frequency.

As an alternative to the limitations of geometric means of altering the rear element relative current magnitude and phase, we can directly feed both elements of the array. Let's adopt the convention that the forward element will be set at a relative current value of 1.0 at a phase angle of zero degrees. With this constant, we may then focus on the current magnitude and phase angle of the rear element (always relative to the constant values of the forward element).

The required current magnitude and phase on the rear element will depend upon several variables. First are the lengths of the elements. We may make them equal or unequal. Moreover, we may set the lengths close to resonance or distant from resonance. Each variation will show changes in either or both the magnitude and the phase on the rear element for a desired operating characteristic of the array. For example, if the elements, whether equal in length or unequal, show a feedpoint impedance close to resonance when only the forward element is fed, then the phase angles of equal length and unequal length element sets will be very close in value, although the current magnitudes will vary for a given spacing and operating condition.

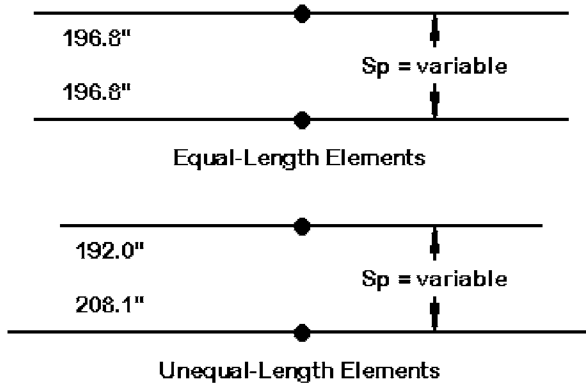
Second, element spacing will have a major affect on the required rear element current magnitude and phase for a desired operating characteristic. However, spacing may not show significant differences in both magnitude and phase angle for arrays with equal and unequal element lengths.

Third, the selection of the desired operating characteristic will also alter the current magnitude and phase for any set element lengths and spacing.

As a little experiment, let's look at what happens when we phase both elements of two different array pairs, shown in **Fig. 2-1**. At a spacing of about 0.125 wavelength, the unequal element pair makes up a very workable 2-element Yagi for 28.5 MHz, when only the forward element is fed. At the same spacing, the equal-length pair is close to resonant, but with a typical dipole pattern.

Now let's set as our operating goal achieving a maximum rear null 180-degrees from the peak of the forward lobe. We can define the null as adequate if it exceeds -

50 dB relative to the forward lobe. This value would exist only over a tiny bandwidth, but for study purposes, it is a goal that modeling programs, such as NEC-4, can easily show. We shall vary the distance between the elements in 0.05 λ increments. For each distance, we shall change the current magnitude and phase on the rear element until the desired null is achieved.



2 Element Sets: A Phasing Experiment Fig. 2-1

Table 2-1 shows the results for both element pairs. As predicted, the current phase for each step is virtually the same for both arrays, but the required current magnitude on the rear element is different according to whether the elements have the same or different lengths. Other element lengths we might have chosen would have resulted in other values.

For each increase in spacing, the current magnitude changes very little with each array, but the required phase angle on the rear element shows a continuous decrease. In short, there is no single ideal spacing for achieving a deep rear null. Instead, for any spacing, there is a current magnitude and phase angle that will achieve the null.

Table 2-1. Phasing 2 Elements for Maximum Rear Null
Equal vs. Unequal Element Lengths

Spacing λ	Spacing inches	Rear Element Current Magnitude (relative)	Phase degrees	Free-Space Gain dBi	Front-to-Back Ratio dB
Designed for Maximum Rear Null:					
Equal-Length Elements (196.8" x2 at 28.5 MHz)					
0.05	20.7	1.035	163	6.55	>50
0.1	41.4	1.07	145	6.46	>50
0.15	62.1	1.09	125.5	6.18	>50

0.2	82.8	1.09	106	5.76	>50
0.25	103.5	1.07	87	5.14	>50
0.3	124.2	1.045	69	4.26	>50
0.35	144.9	1.02	51	2.72	>50
0.4	165.7	1.00	34	0.31	>50
Unequal-Length Elements (192" forward, 208.1" rear at 28.5 MHz)					
0.05	20.7	0.925	163.3	6.57	>50
0.1	41.4	0.945	145	6.45	>50
0.15	62.1	0.955	126.0	6.19	>50
0.2	82.8	0.95	106.7	5.77	>50
0.25	103.5	0.94	88	5.16	>50
0.3	124.2	0.92	69.5	4.21	>50
0.35	144.9	0.90	51.8	2.73	>50
0.4	165.7	0.88	34.5	0.28	>50

Note 1: All forward element currents set at a relative magnitude of 1.0 at 0-degrees phase angle.

Note 2: All values of rear current relative magnitude and phase angle taken when the rear null passed -50 dB relative to the forward lobe.

Note 3: Elements are 1" diameter aluminum.

Table 2-2. Phasing 2 Elements for Maximum Forward Gain
Equal vs. Unequal Element Lengths

		Rear Element Current			
Spacing λ	Spacing inches	Magnitude (relative)	Phase degrees	Free-Space Gain dBi	Front-to-Back Ratio dB
Designed for Maximum Rear Null:					
Equal-Length Elements (196.8" x2 at 28.5 MHz)					
0.05	20.7	1.02	173	7.32	7.64
0.1	41.4	1.03	165	7.35	7.19
0.15	62.1	1.02	158	7.23	6.90
0.2	82.8	1.03	152	7.03	6.00
0.25	103.5	1.03	147	6.76	5.03

Unequal-Length Elements (192" forward, 208.1" rear at 28.5 MHz)					
0.05	20.7	0.91	173	7.33	7.70
0.1	41.4	0.92	166	7.36	7.22
0.15	62.1	0.92	159	7.24	7.03
0.2	82.8	0.92	150	7.04	6.59
0.25	103.5	0.93	147	6.77	5.13

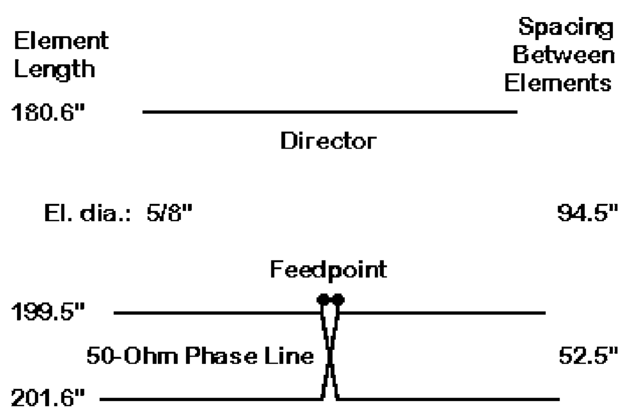
Note 1: All forward element currents set at a relative magnitude of 1.0 at 0-degrees phase angle.

Note 2: All values of rear current relative magnitude and phase angle taken when the forward lobe reached a peak gain, beyond which gain fell off.

Note 3: Elements are 1" diameter aluminum.

Much of antenna element phasing theory is devoted to the achievement of rearward nulls. Little attention has been given to achieving maximum gain from the array. Let's look at **Table 2-2** to see what the effects of changing the element spacing might have on the required rear element relative current magnitude and phase for this goal. For spacing distances from 0.05 through 0.25 wavelengths, the required current magnitude for each array remains relatively constant. However, the required phase angle decreases with increased spacing, but at far less than the rate for achieving a maximum rearward null. Maximum gain does not occur with the closest spacing, but in the vicinity of 0.1 λ. As one might expect, the front-to-back ratio of two elements becomes mediocre (at best) when the goal is maximum gain.

The reason I have presented the table of values for maximum forward gain is simple: when designing an array with a pair of phased elements plus some further element—such as a director—the proper design procedure is to set the phased pair of elements for maximum forward gain. It will be



3-Element Phase-Driven Array Fig. 2-2

the added element (or elements) that shapes the antenna's operating pattern to the desired specifications.

Let's examine a test array consisting of a phased pair of elements plus a director, as shown in **Fig. 2-2**. The phased portion of the array consists of unequal-length elements. In this design, a 50-Ohm phase line about 69.3" (for 0.66 VF line) provides the requisite current magnitude and phase transformation. (Although 50-Ohm parallel line is not possible using round conductors, parallel strips can be used, with the velocity factor adjusted back to 1.0. If the boom is RF transparent, then coaxial cable can also be used.) The design frequency for this test array is 28.5 MHz.

Although the array that we are contemplating is not likely to have practical application on the wide 10-meter band, it may serve well on a WARC band.

Fig. 2-3 shows two things at once. One azimuth pattern shows what happens if we omit the director. The phased pair is set for maximum gain—or very close to it. Adding the director increases gain, but even more significantly, the director increases the front-to-back ratio to a very respectable level. (Even in pure Yagi design, reflectors do not control the front-to-back ratio nearly so much as do the directors.)

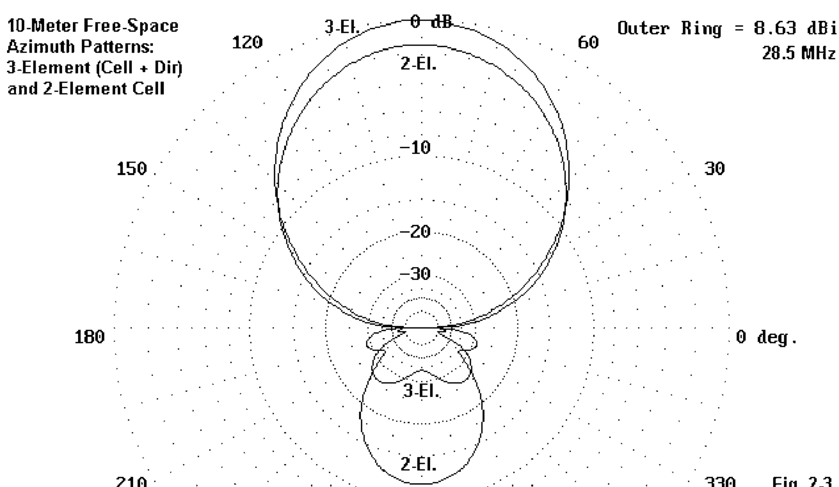
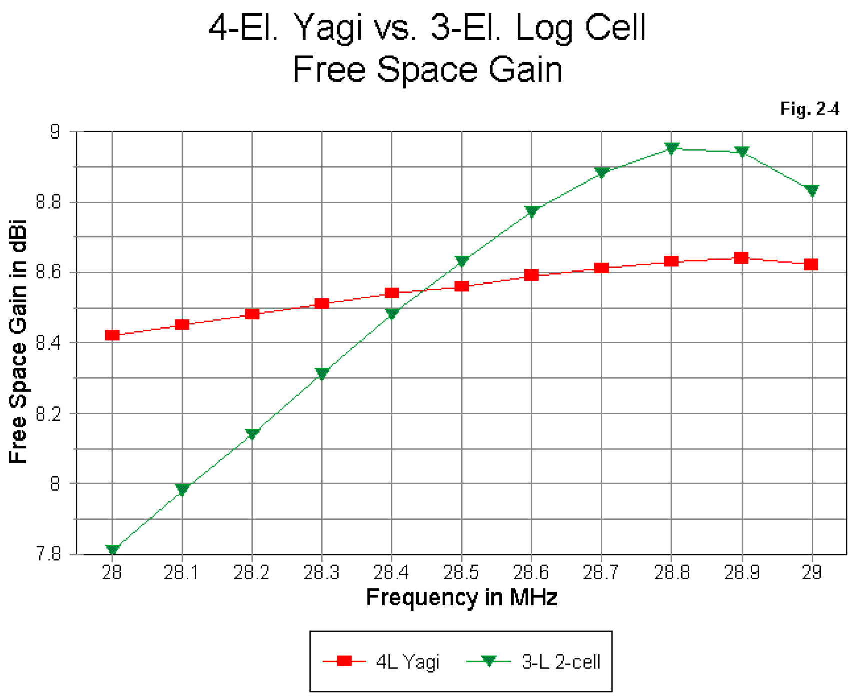


Fig. 2-3

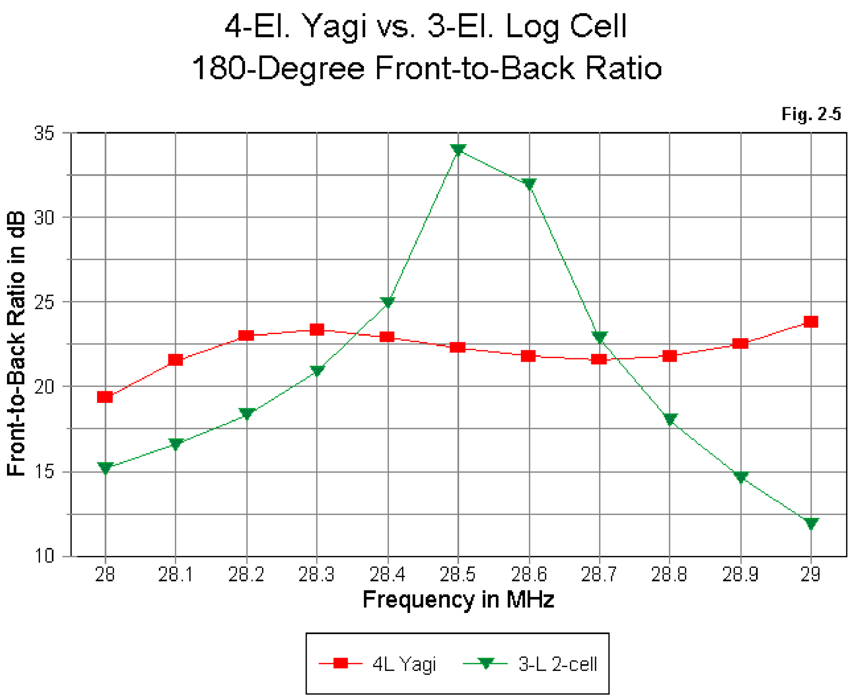
Let's look more closely at the performance of this antenna across the first MHz of 10 meters. **Fig. 2-4** graphs the gain across the band, with the 4-element Yagi presented as a comparator in Part 1 as a standard for comparison. Both antennas are about the same overall length—a bit over 12.5' long. The 3-element array (labeled "3-L 2-cell" on the graphs) shows a very steep gain curve, especially when compared to



the stable 4-element Yagi curve. At the design center frequency (28.5 MHz), the 3-element array actually show slightly better gain.

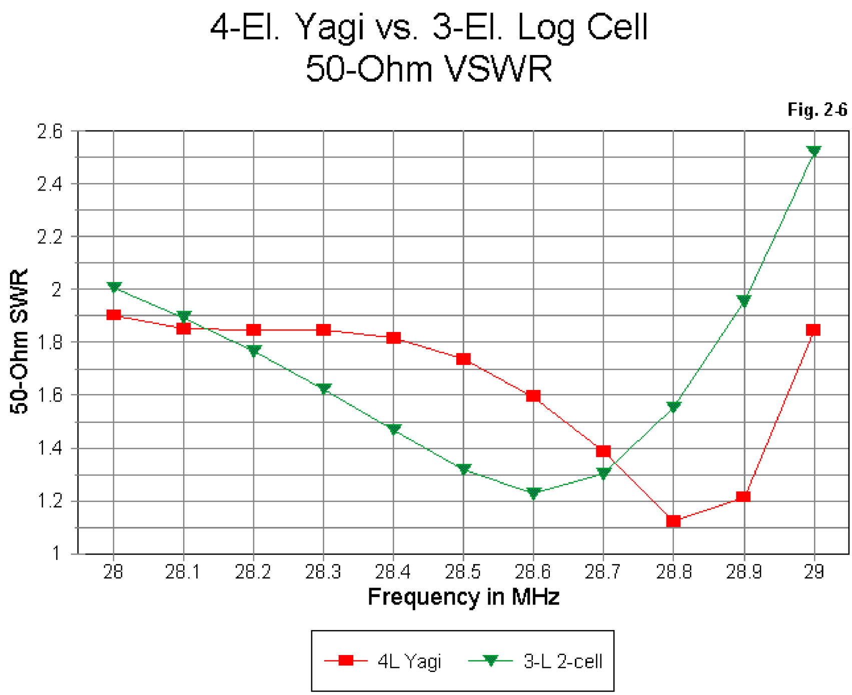
As always, however, spot superiority is true superiority only for an array designed for a single frequency.

The front-to-back curves appear in **Fig. 2-5**. The 3-element array shows a very high peak value at the design frequency, but exceeds 20 dB for less than half of the bandwidth in the graph. The stability of the 4-element Yagi front-to-back ratio across the band is self-evident.



Unfortunately, much of the literature and advertising of amateur band arrays tends to neglect the importance of the stability of the antenna operating characteristics across the entire band of interest. If the SWR is 2:1 or less across a band, then stability is presumed by the reader. Much to the contrary, the stability of both gain and the front-to-back ratio—observing both the 180 degrees front-to-back ratio and the worst-case front-to-back ratio—deserves equal if not greater attention when evaluating a design.

The native feedpoint impedance of the 3-element array is about 15 + j23 Ohms. This value is amenable to a beta match using an open stub (instead of the usual shorted stub used when the reactance is capacitive). 2:1 SWR operation across all of the first MHz of 10 meters is not possible.



The narrow-band characteristics of this array illustrate in part what happens when 2-element phased pairs are operated too close to maximum gain. Nevertheless, scaled for any of the WARC bands, this array might provide quite good performance with only 3 elements. Indeed, we have tended to ignore the differences in the requirements for an array between the wide and narrow amateur bands. For minimal boom length on a WARC band, a 2-element driver-director array is often ideal.

More Complex Log Cells

Larger log cells are often designed exactly as one might design a full LPDA, except that the design will be for a single band and also be considerably shorter that

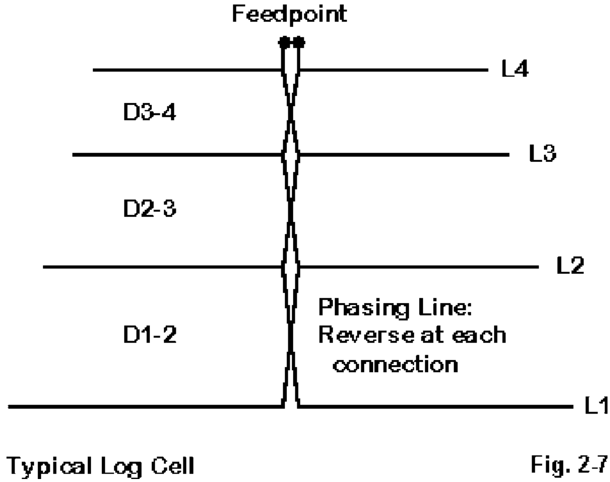


Fig. 2-7

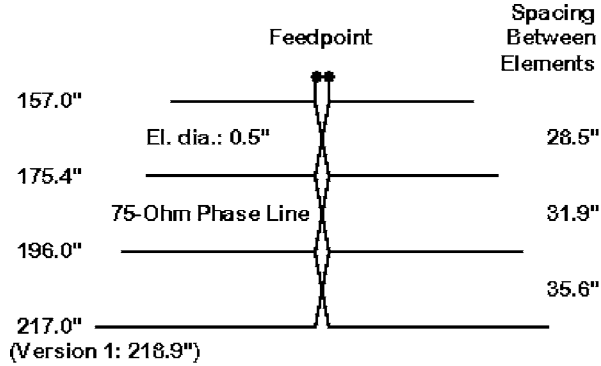
an independent LPDA, as illustrated in **Fig. 2-7**. The design principles for LPDAs are fully described in Chapter 1 of the first volume of these notes, in Chapter 10 of the latest *The ARRL Antenna Book*, and in standard professional antenna compendia, so I shall not review them in detail here.[2] Most of the math can be passed through a computer design program, such as LPCAD by Roger Cox, WB0DGF.[3] To these resources, we shall add only a few practical notes relevant to log-cell Yagi design.

First, many LPDA and log-cell designers select too high a phase-line impedance to achieve maximum gain from the array. My experiences designing a monoband LPDA suggest strongly that the lowest practical phase-line impedance yields the highest gain and overall operating characteristics. This procedure may require careful rethinking of the mechanical aspects of the design, especially implementing a low impedance phase line with double-boom construction or other means.

Second, the fatter the elements, the higher the cell gain and the wider the bandwidth for the desired operating characteristics. For monoband cells and LPDAs at 10 meters, elements should be at least 0.5" in diameter, with diameters up to 1" being even more desirable.

Third, the closer one attends to making the cell in accord with the LPDA principles in which both element lengths and spacings decrease together, the wider the bandwidth of the resulting cell and array. One test of a good log cell—as we shall illustrate in more detail in Chapter 3—is that the feedpoint impedance of the log cell without the added parasitic elements should not radically change from the feedpoint impedance with those elements in place.

Even with these practical notes in mind, a good modeling program is a major aid to log-cell Yagi and LPDA design. Every cell design requires TW^2 (Twisting and Tweaking), that is, final adjustment of element lengths and spacings, along with phase-line impedance value settings, to produce the desired operating characteristics of the antenna.

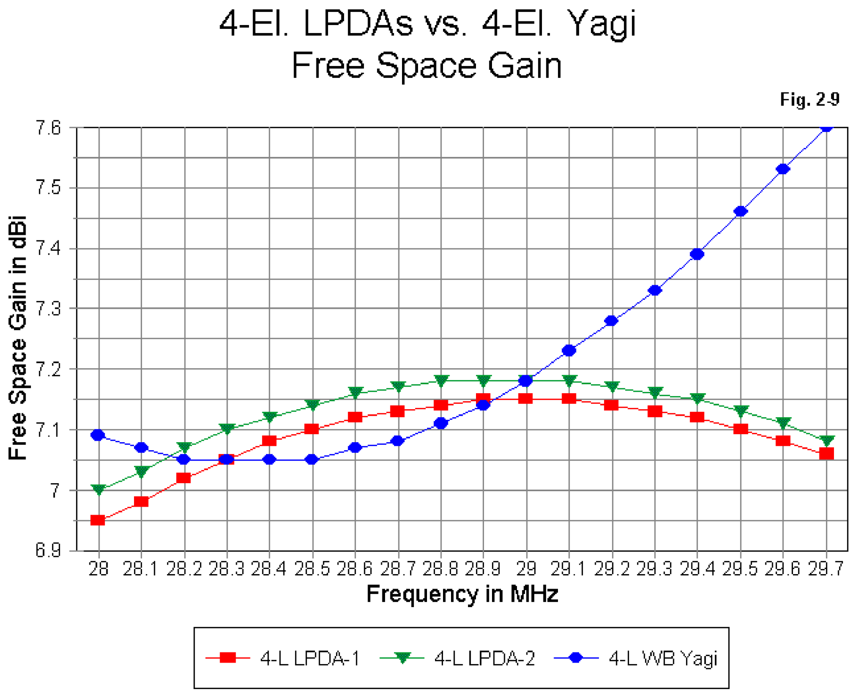


4-Element 10-Meter LPDA: Version 2 Fig. 2-8

To illustrate this point, let's look briefly at an LPDA—a log cell without additional parasitic elements—for 10 meters. **Fig. 2-8** shows the outlines of the antenna, which is given in two versions, one with a 217" rear element, the other with a longer 218.9" element. The 75-Ohm phase line can be achieved with twin square booms or with facing aluminum strips. Although the basic dimensions emerged from LPDA calculations, the final dimensions are the result of considerable tweaking.

Because this antenna sought to combine smooth curves of both acceptable gain and an adequate front-to-back ratio, a ratio of about 0.90 was selected. That is, each element forward of the one to its rear is about 0.90 of its length. Moreover, the element spacing moving forward is also 0.90 of the spacing between the next elements rearward. As we shall see in Chapter 3, practical log-cell design for log-cell Yagis employs a ratio closer to about 0.95.

The gain across the entire span of 10-meters appears in **Fig. 2-9**, with the curve for the 4-element wide-band Yagi from Part 1 added for comparison. The LPDAs and the wide-band 4-element Yagi are both 8' long. Version 2 of the LPDA provides slightly higher gain than version 1. Both curves are more stable across the band than is the Yagi curve. Indeed, the LPDA curves are well centered in the band, but the 4-element Yagi gain increases with frequency above about 28.5 MHz. Whether the Yagi gain is usefully placed is a user judgment.



Although version 1 of the LPDA has slightly less gain than version 2, the first version shows an overall better front-to-back profile across the band, with a very high peak at 28.5 MHz, as shown in **Fig. 2-10**. Both versions of the LPDA exceed the Yagi in average front-to-back ratio across the band. Moreover, both LPDAs show the best front-to-back values in the most active region of the band, where QRM suppression may be most needed. In general terms, we need to evaluate variable antenna characteristics across a band in operating terms.

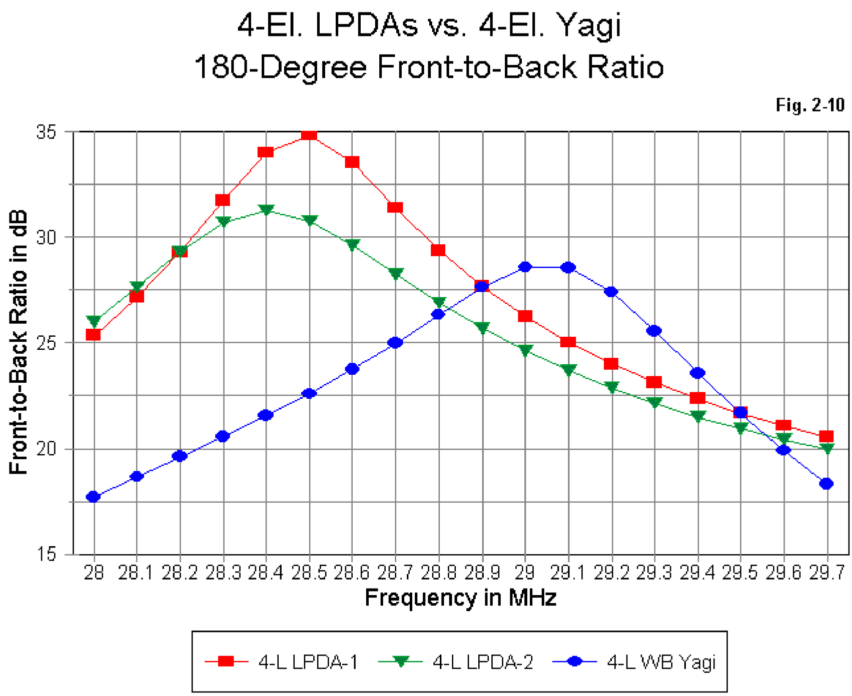


Fig. 2-10

In **Fig. 2-11**, we have the 50-Ohm SWR curves for all three antennas, none of which requires a matching network. With a peak SWR value of 1.35:1, there is little to choose among the antennas in this department.

A 4-element log-cell designed for 10-meters without parasitic elements is capable of better than 7 dBi free-space gain all across the band with excellent front-to-back ratio values and an easy direct coax match—all on an 8' boom. This becomes another standard of comparison for log-cell designs by giving us a new question for our list: what advantages do parasitic elements give us?

A partial answer to that question showed up in the narrow-band, high-gain, high-front-to-back design we discussed earlier. We can add some gain and possibly improve the front-to-back ratio. We shall do that by designing our log cells to enhance gain rather than striving for a balance of operating characteristics. Parasitic elements will finish the job of tailoring the pattern.

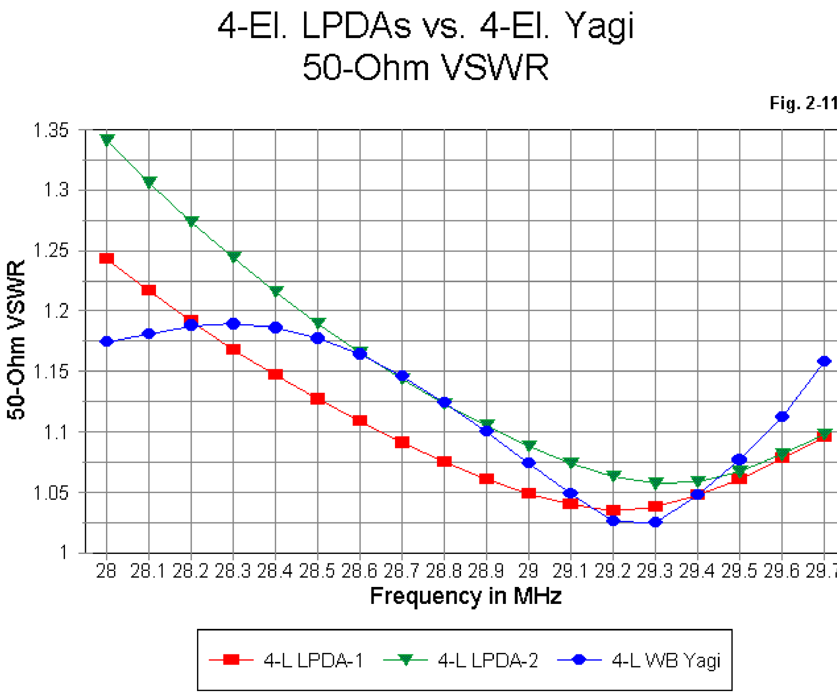


Fig. 2-11

We shall encounter some practical designs that casually design the cell and some that design it very carefully. The results of each practice will show themselves in the resulting antenna performance. But all of that is for Chapter 3.

Notes

1. P. D. Rhodes, K4EWG, and J. R. Painter, W4BBP, "The Log-Yagi Array," *QST*, Dec, 1976. The main elements of this article are reprinted in *The ARRL Antenna Book*, 19th Ed., pp. 10-25 to 10-27.

2. See *The ARRL Antenna Book*, 19th Ed., pp. 10-1 to 10-10, plus such professional references as Johnson and Jasik.

3. LPCAD 2.8 is available on the CDROM that accompanies *The ARRL Antenna Book*, 19th ed.

Chapter 3: Some Practical Log-Cell Yagi Designs

In this part of our visit to the log-cell Yagi, we shall look at some practical designs. The first two versions—using log cells of 2 and 3 elements, respectively—will involve casual designs, typical of those in some of the past literature. Then, we shall examine more complex designs using log cells with 4 and 5 elements, each carefully constructed on LPDA principles. In the process, we shall also look at a test we can perform to estimate the chances for a log cell Yagi performing to its fullest potential.

Each of our design examples will use a reflector and a director in addition to the log-cell driver. Hence, the total element count will be two greater than the number of elements in the cell. As with all of the models in this series, the designs will be for 10 meters. Scaling to 20 meters in one direction and to 6 meters in the other direction are straightforward tasks.

All models will use uniform diameter elements. Actual element lengths will have to be lengthened if a builder chooses a tapered diameter schedule. Additionally, the builder will have to devise a plan for implementing the phase line associated with each log cell. High impedance lines can be fabricated from round wires. Low impedance lines may require the use of flat aluminum strap or of a double square boom to effect a satisfactory phase line.

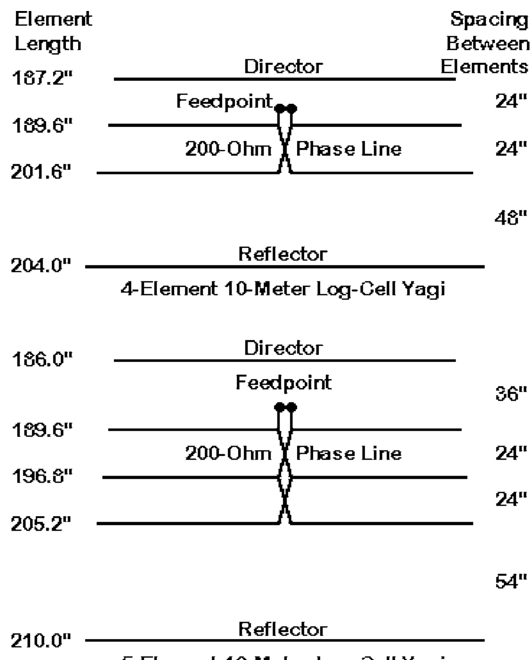
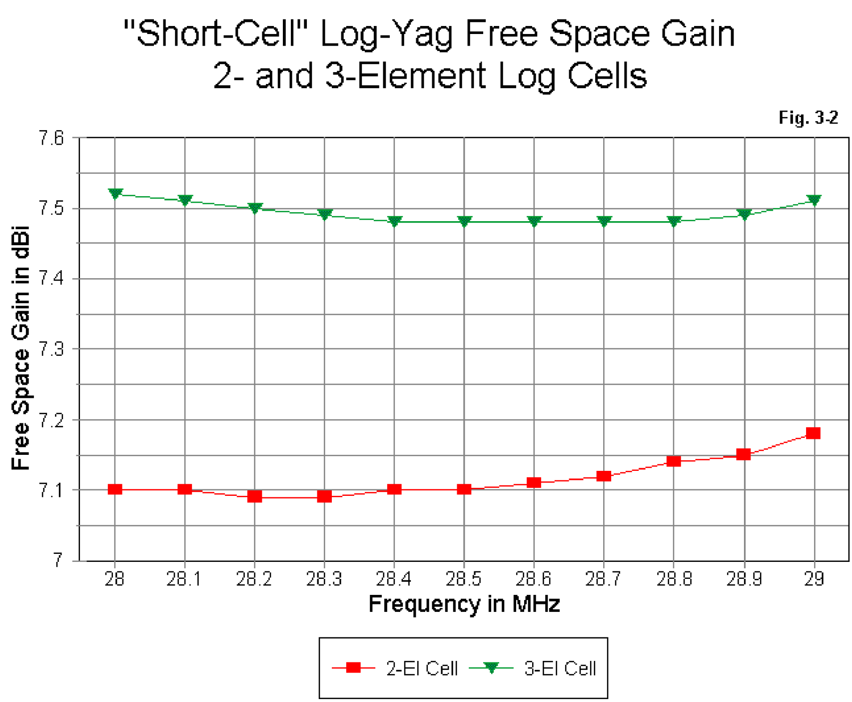


Fig. 3-1

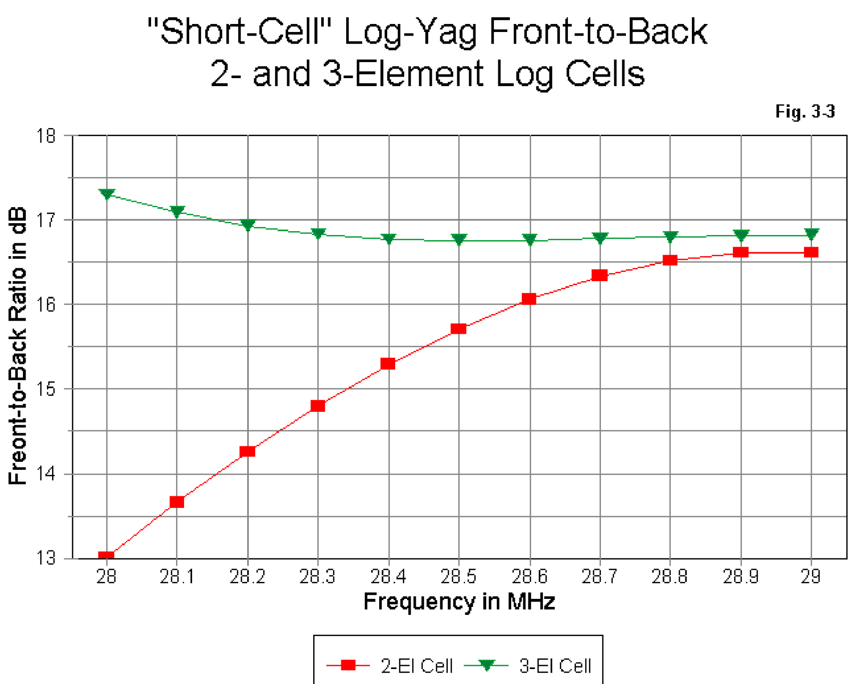
Casual 4- and 5-Element Log-Cell Yagis

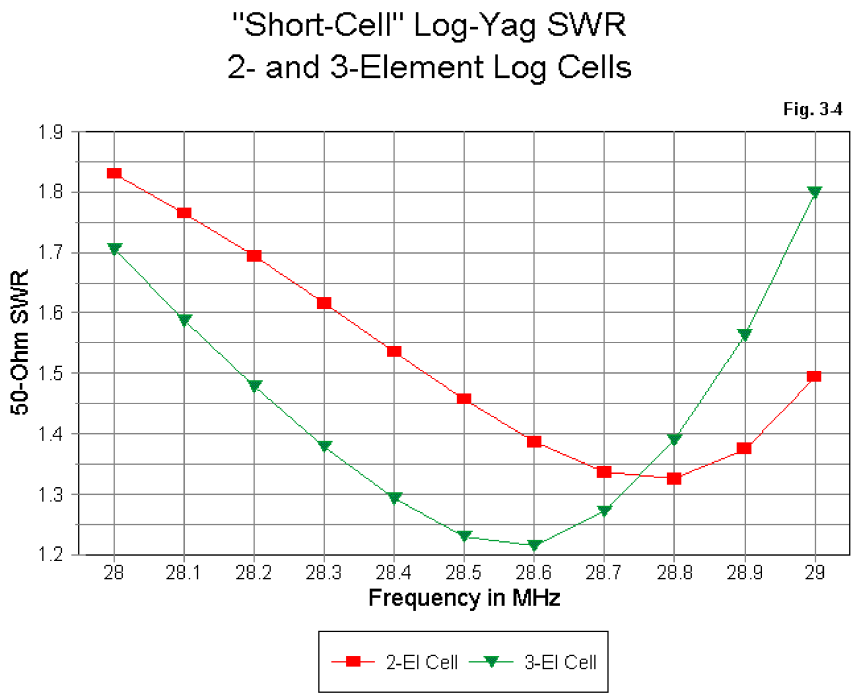
Our initial models employ either 2 or 3 elements in the log cell, as illustrated in **Fig. 3-1**. Both models use 200-Ohm phase lines, with driver elements spaced a standard 2' apart. This spacing accords with a number of articles from the past, although the magic in its selection eludes me. The resulting 4-element log-cell Yagi is 96" (8') long, while the 5-element log-cell Yagi is 138" long (11.5'). Coincidentally, these two lengths coincide closely with the lengths of the medium-bandwidth Yagis introduced in Chapter 1 as comparators for log-cell Yagis. You should keep the graphs for those antennas handy as we examine the 2 new designs. Both of the antennas in **Fig. 3-1** use 1" diameter elements.



Both log-cell Yagis exhibit very smooth gain curves over the first MHz of 10 meters, as demonstrated in the frequency sweep graph in **Fig. 3-2**. The 4-element antenna with only 2 elements in the cell has the lower gain level, as one might expect. It coincides roughly with the gain curve for the 8' 3-element Yagi of Part 1. The 5-element antenna provides only about a half dB of additional gain. In contrast, the 3-element Yagi of the same boom length in Part 1 provides an average free-space gain of about 8 dBi, another half dB greater than the log-cell Yagi with the same boom length.

Fig. 3-3 shows that the two log-cell Yagi designs provide fairly mediocre front-to-back ratios. No where in the specified bandwidth does the front-to-back ratio of either antenna reach 18 dB. (In contrast, both Yagi designs exceed 20 dB front-to-back ratio for most of the first MHz of 10 meters.) Where the log-cell Yagis have an advantage is in the feedpoint impedance. Both designs, as illustrated in **Fig. 3-4**, provide less than 2:1 50-Ohm SWR from 28 to 29 MHz. By way of contrast, the two Yagi designs require a beta match or comparable network to yield similar results.





The two log-cell Yagis, then, require extra elements to provide performance that fails to equal the performance of well-designed 3-element Yagis. One only skirts the issue by saying that the failure results from casual design, since that statement gives no clue of how to distinguish casual from careful design. However, there is a fairly simple modeling test we can perform as a measure of a log-cell Yagi's performance.

If we extract the log-cell driver elements from the overall antenna, we may model them independently. In a well-designed log-cell driver, the array will show fairly high gain and a feedpoint impedance that does not depart radically from the values obtained when the driver is part of the total log-cell Yagi.

Table 3-1. 2- and 3-Element Log Cell Independent Performance

Frequency (MHz)	28.0	28.5	29.0
2-Element Log Cell:			
Free-Space Gain (dBi)	4.58	4.70	4.83
Front-to-Back Ratio (dB)	6.88	7.21	7.48
Feedpoint Impedance (R +/- jX Ohms)	13 + j 0	12 + j 5	11 + j11
3-Element Log Cell:			
Free-Space Gain (dBi)	7.09	6.93	6.74
Front-to-Back Ratio (dB)	11.6	11.9	12.0
Feedpoint Impedance (R +/- jX Ohms)	11 - j22	9 - j 8	8 + j 3

Table 3-1 provides values for the 2- and 3-element log cells extracted from the antennas we have been examining. The checkpoints at 28, 28.5, and 29 MHz for both cells show fairly low gain, with the 2-element cell especially low. (Although registered for reference, the low front-to-back ratios are of no concern in this test.) The feedpoint impedances of the cells are roughly one-fourth the values obtained for the complete antennas. We shall want to keep these figures in mind as we check more complex and more carefully designed log-cell drivers.

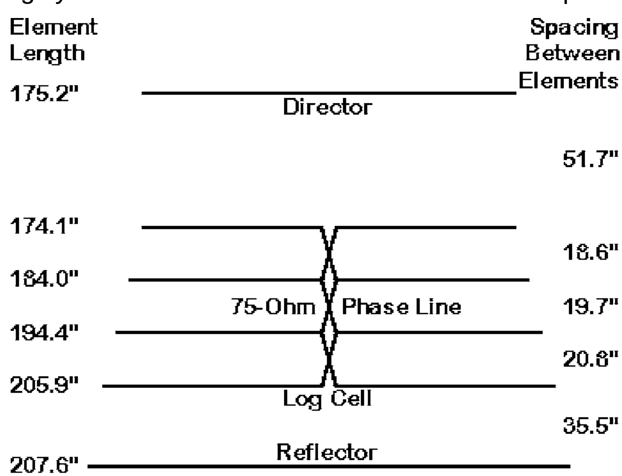


Fig. 3-5

A 6-Element Log-Cell Yagi

The 6-element log-cell Yagi, with a 4-element log cell, shown in **Fig. 3-5**, is adapted and scaled from the Rhodes and Painter log-cell Yagi for 20 meters in *The ARRL Antenna Book*.[1] The log cell has been designed according to LPDA principles, using an element length and spacing ratio of approximately 0.95. This ratio, when applied to a pure LPDA, tends to produce more gain but a lesser front-to-back ratio than lower τ values, for example, the value of 0.90 used in the LPDA design examined in Chapter 2. The higher ratio value also produces a shorter cell for the same number of elements. The entire antenna, including the reflector and director, requires a 12.2' boom, nearly as long as the 4-element medium-bandwidth Yagi presented in Chapter 1 as a potential comparator.

Table 3-2. 4-Element Log Cell Independent Performance

Frequency (MHz)	28.0	28.5	29.0	29.5
Free-Space Gain (dBi)	7.24	7.47	7.47	7.29
Front-to-Back Ratio (dB)	17.7	14.0	12.8	13.1
Feedpoint Impedance (R +/- jX Ohms)	95 - j 2	39 - j11	39 + j12	75 + j 4
50-Ohm SWR	1.90	1.41	1.42	1.51

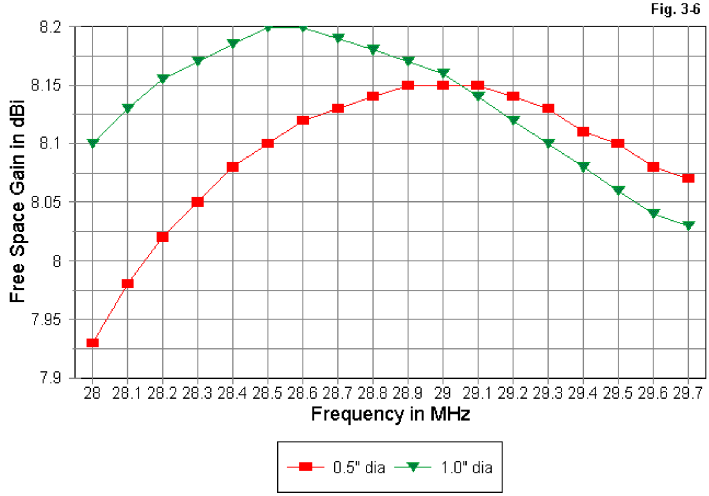
If we extract the log cell from the antenna, we obtain the check-point values recorded in **Table 3-2**. Note the relatively uniform gain across the entirety of 10 meters, as well as the 50-Ohm SWR values. According to our test, this log cell promises to form the basis of a good antenna that may be useful across all of 10 meters.

Before we look at the modeled performance figures, we should note an additional dimension of this antenna. The phase line impedance is low (75 Ohms). In addition, if we use different element diameters, we obtain results that change to a degree that is greater than the changes we might expect in a Yagi using the same two element diameters. The effects of element diameter on log cell drivers (or on LPDAs) are significant. Therefore, the performance graphs for this antenna will record values for both 1/2" and 1" diameter elements.

Free-space gain figures appear in **Fig. 3-6**. The fatter element model not only shows a gain peak that is lower in frequency than the thinner version, but as well its peak gain values are higher. Moreover, the curve is flatter. The gain values rival those of the 3-element medium-bandwidth Yagi on a 12' boom, but do not match the values for the 4-element medium bandwidth Yagi on the 13' boom. Both of the Yagis, of course, only covered the first MHz of 10 meters.

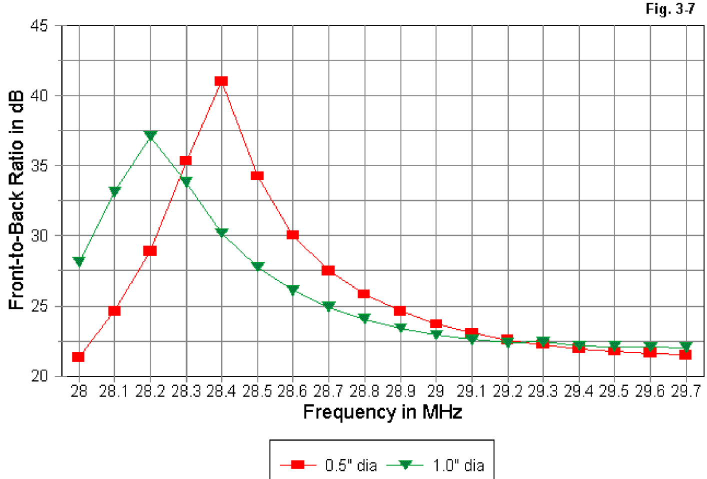
4-Element Log Cell + Dir/Ref
0.5" and 1.0" Diameter Elements

Fig. 3-6



4-Element Log Cell + Dir/Ref
0.5" and 1.0" Diameter Elements

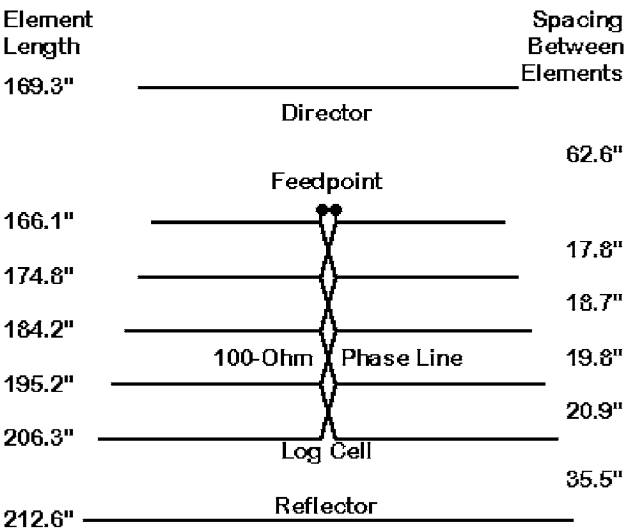
Fig. 3-7



The front-to-back values are less radically different, as illustrated in **Fig. 3-7**. Essentially, the thinner version is capable of a higher peak front-to-back ratio. However, both versions of the antenna exhibit better than 20 dB front-to-back ratio across the 28 to 29.7 MHz span.

Both versions of the antenna exhibit acceptable SWR curves across all of 10-meters, as shown in **Fig. 3-8**.

A 7-Element Log-Cell Yagi



A 7-Element 10-Meter Log-Cell Yagi

Fig. 3-9

The bandwidth of 10 meters presses the 4-element log cell to its limits, although the 6-element log-cell Yagi does manage to cover the band with good gain, good front-to-back values, and a direct 50-Ohm feed system. We can improve upon the design by adding one more element to the log-cell to obtain the design shown in **Fig. 3-9**. The 5-element log cell for this antenna uses the same tapering ratio for elements in the log cell. However, using an additional element allows the longest element to be a bit longer and the shortest element to be a bit shorter. The cost is a longer boom, about 14.6' long in this case. The phase line is 100 Ohms.

Table 3-3 provides a look at the performance of the log cell independently of the entire antenna. Gain is even more uniform across the band than for the 4-element log cell, with acceptable 50-Ohm SWR figures. Once more, the front-to-back figures are unimportant in this context, since the parasitic elements will establish those values in the final antenna. In fact, the log cells used in these antennas are designed for gain rather than for a balance of operating characteristics, just as was the case for the 2-element cell in the 3-element array examined in Chapter 2.)

By now, it should be clear that we should expect the overall antenna to reflect the potentials of the log cell alone. This fact suggests that a so-called log-cell Yagi is actually a modified LPDA.

Table 3-3. 5-Element Log Cell Independent Performance

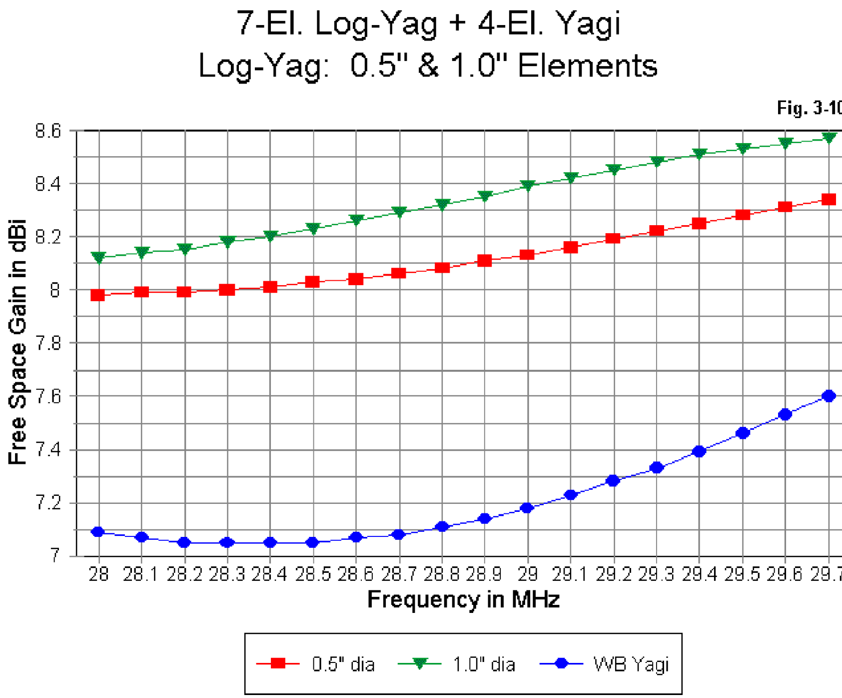
Frequency (MHz)	28.0	28.5	29.0	29.5
Free-Space Gain (dBi)	7.31	7.38	‘7.42	7.43
Front-to-Back Ratio (dB)	12.0	12.4	13.4	15.2
Feedpoint Impedance				
(R +/- jX Ohms)	34 - j 6	46 + j14	80 - j 1	46 - j27
50-Ohm SWR	1.51	1.37	1.60	1.77

Fig. 3-10 shows the free-space gain of two versions of the resulting log-cell Yagi, one using 1/2" diameter elements, the other using 1" diameter elements. For contrast, values are also shown for the 4-element wide-band Yagi, introduced in Chapter 1. We should expect lesser performance from this 8' boom Yagi. If you desire, you may substitute the values for the 8'-boom LPDA.

The differences between the half-inch and 1-inch versions of the log-cell Yagi are even more dramatic than for the preceding model, with nearly 0.25 dB differential in gain in places across the band. Values for the half-inch model are similar to those for the 3-element 12-foot boom medium-bandwidth Yagi, but the log-cell Yagi covers the entire 10-meter band. The one-inch model shows only slightly less gain than the 4-element medium-bandwidth Yagi. For either model, the gain curve is very smooth, illustrating the benefit of the extra element in the log-cell.

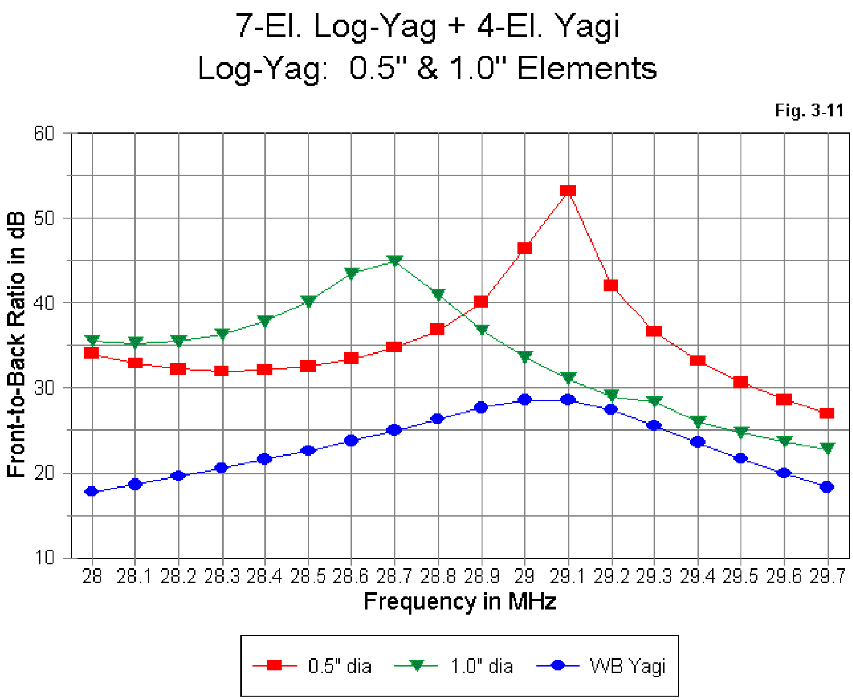
One reason for adding the wide-band 4-element Yagi to the graphs is that it demonstrates the incremental improvement in front-to-back ratio provided by the 7-element log-cell Yagi all across the band, as shown in **Fig. 3-11**. Because no element length adjustments were made when changing element diameters, the half-inch model exhibits the superior curve, with a front-to-back ratio better than 30 dB up to 29.5 MHz.

The 1" model, with a few added adjustments, can replicate the half-inch model curve, but with a slightly lower peak value.



If you refer to the azimuth "snapshot" in Chapter 1 of this volume, you will also learn that the rear quadrants show a very well-behaved rear lobe with no major quartering side lobes to falsify the impression left by the 180-degree front-to-back values.

The 50-Ohm SWR curves, shown in **Fig. 3-12**, demonstrate that the 7-element log-cell Yagi has a smoother curve than its 6-element counterpart. The curve for the version using 1" diameter elements is flatter, but does not dip quite so low as the curve for the half-inch version. However, adjustments to the exact phase-line characteristic impedance would likely permit either curve to bottom at close to 1:1 SWR. The phase-line characteristic impedance selected for the models represent a standard number, but actual construction would permit refinements.



Summing Up So Far

The development of a log-cell Yagi requires careful attention to the design of the log-cell driver to obtain optimal results. Well-designed log-cell Yagis are capable of good gain, but their chief operating characteristics that fall into the range of excellence (when compared to other available designs) are the front-to-back ratio and the operating bandwidth. As the 6- and 7-element log-cell Yagis demonstrate, the antenna type is capable of well over 6% frequency coverage in a monoband design.

Designing a log-cell Yagi for gain as we enter into the 21st century appears to be an exercise in futility. Although Yagi design in the late 1970s and early 1980s had yet to reap the benefits of computerized optimization, current Yagi design can provide as much or more gain for a given boom length than log-cell designs. The Yagis have the additional advantage of mechanical simplicity, since they do not require the precision construction of a phase line to interconnect the elements in the log cell driver.

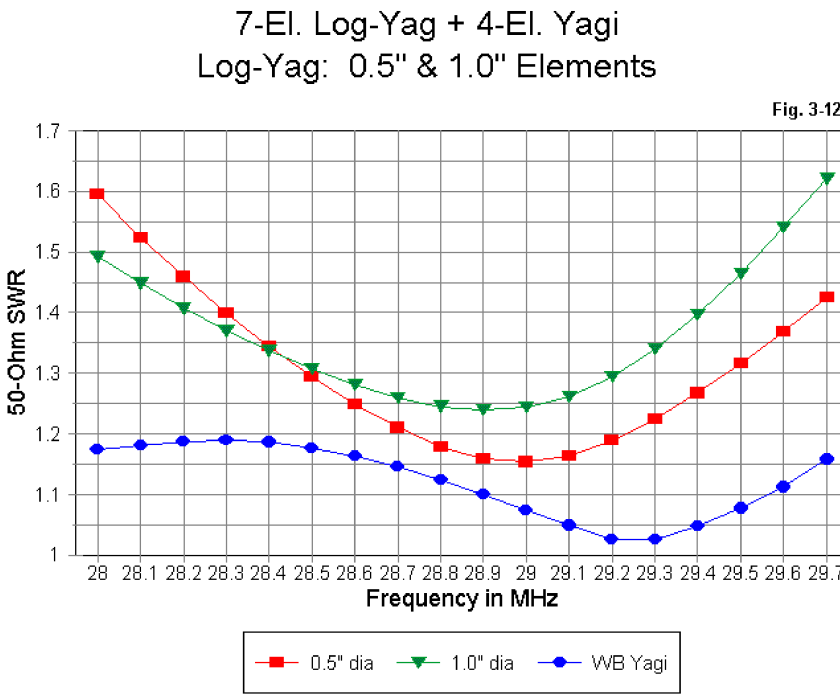


Fig. 3-12

An interesting example of this point can be found by modeling the 5-element log-cell driven Yagi in Orr and Cowan.[2] The antenna uses a 2-element log-cell with a reflector and 2 more directors. This design on a 21' boom is capable of a peak free-space gain of about 9.5 dBi, with a very sharp peak in both the operating characteristics and the SWR curve. The rear lobes are acceptable but the front-to-back ratio exceeds 20 dB for only a narrow bandwidth.

I had occasion to study 5- and 6-element 20-meter Yagis of existing design.[3] The boom lengths ranges from 45 to 55 feet, corresponding to 22- to 27-foot booms on 10 meters. All of the designs were capable of a free space gain of 10 dBi across all of 20 meters, with better than a 20 dB front-to-back ratio. Some, such as the NW3Z/WA3FET

OWA 6-element design, were capable of exceptionally low 50-Ohm SWR values all across the band. In fact, the OWA design can be scaled readily for 10 meters and provide 1 MHz coverage on a 24' boom.[4]

As a gain enhancement, the log-cell driver technique has very limited utility amid current Yagi technology. Its chief merits involve operating bandwidth and front-to-back ratio. However, even here, its utility may be limited when the complexity and weight of the array are factored into antenna design and construction decisions. The medium-bandwidth Yagis described in Chapter 1 as comparators are fully adequate to provide full coverage of all of the upper HF bands except 10 meters. Only if weight is no concern and if extra front-to-back performance is a necessity on 20 or 15 meters would a log-cell Yagi such as the 6- and 7-element designs seem justified.

The natural home of the log-cell Yagi in the new century is at 10 meters and above, where the bandwidths are more than 3% or so of their center frequencies. However, as we increase frequency, the materials we use for antenna elements increase in diameter relative to a wavelength. So even at VHF, the fat elements of Yagis can provide a wider operating bandwidth that often precludes the need for log-cell technology.

These notes are far from exhaustive, and my summary is based only on a few hundred models, the best of which have appeared in these chapters. Since antenna enthusiasts have an endless appetite for experimentation, it would not surprise me to see these analyses supplanted in the future by better and more ingenious log-cell Yagi designs.

One perennial direction of experimentation that we have not examined is the effect of setting the antenna elements into a forward swept Vee. Perhaps we can overstay our welcome for one more chapter devoted to this one topic in order to discover whether “V” means “victory” or only half of a “virtual reality.”

Notes

1. P. D. Rhodes, K4EWG, and J. R. Painter, W4BBP, "The Log-Yagi Array," *QST*, Dec, 1976. The main elements of this article are reprinted in *The ARRL Antenna Book*, 19th Ed., pp. 10-25 to 10-27.

2. W. I. Orr, W6SAI, and S. D. Cowan, W2LX, *Beam Antenna Handbook*, pp. 251-253. For a 6-meter adaptation, see John J. Meyer, N5JM, "A Simple Log-Yag Array for 50 MHz," *Antenna Compendium*, Vol. 1, pp 62-63.

3. See "Modeling 6 Long-Boom Yagis" at my website, http://www.cebik.com.

4. A model of a 10-meter version (as well as 6 and 2 meter versions) of the NW3Z/WA3FET OWA is reported in Cebik, "The OWA for 10, 6, and 2 Meters," *antenneX*, August, 1999.

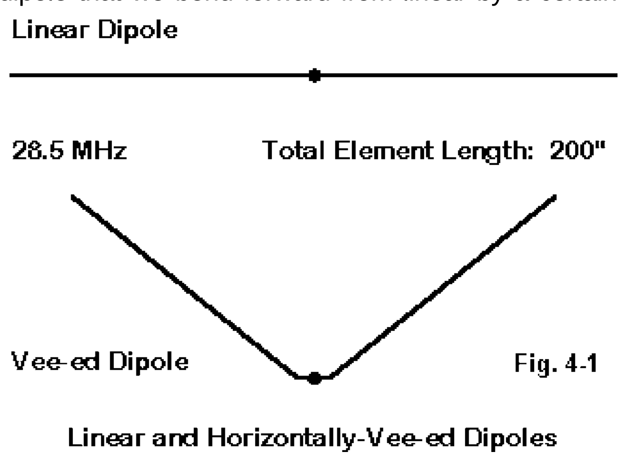
Chapter 4: Vee-ing the Log-Cell Yagi Elements

One perennial design feature of log-cell Yagis has been the use of elements that form a forward Vee. Perhaps the chief proponent of this design features has been Zimmer, K4JZB, in his 1983 *CQ* articles on log-cell Yagis, although the idea reappears from time to time in related contexts.[1] For one 5-element version of the antenna, the text claims a 16 dB gain, although the frame of reference for the gain figure is not given.

All of the designs that we have explored in the first three parts of this series have used linear elements. Given the wide-spread repute of Vee-ed elements to improve gain, directivity, or other aspects of beam performance, it may be useful to explore the matter further. Since Vee-ed elements present no challenges to the limits of NEC, we may use this modeling software to develop some appropriate comparisons between various types of antennas using linear and Vee-ed elements.

The Vee-ed Dipole

In order to understand the performance of Vee-ed beams, we should begin with the Vee-ed dipole, that is, a dipole that we bend forward from linear by a certain number of degrees on each side of center. **Fig. 4-1** shows the general outline of the models used in this exercise. We shall use a standard 200" dipole length throughout, with 1" aluminum tubing as the material. The model uses a short, 3-segment, linear wire at the center of the antenna in order to provide the feedpoint segment with equal length segments on either side.



The degree of Vee-ing refers to the angle made on each side of the antenna relative to a line that would represent a linear element. Hence, 10 degrees of Vee-ing would bend each side of the dipole 10 degrees forward of the linear line. None of the angles used in this test presses any NEC limitation for accuracy.

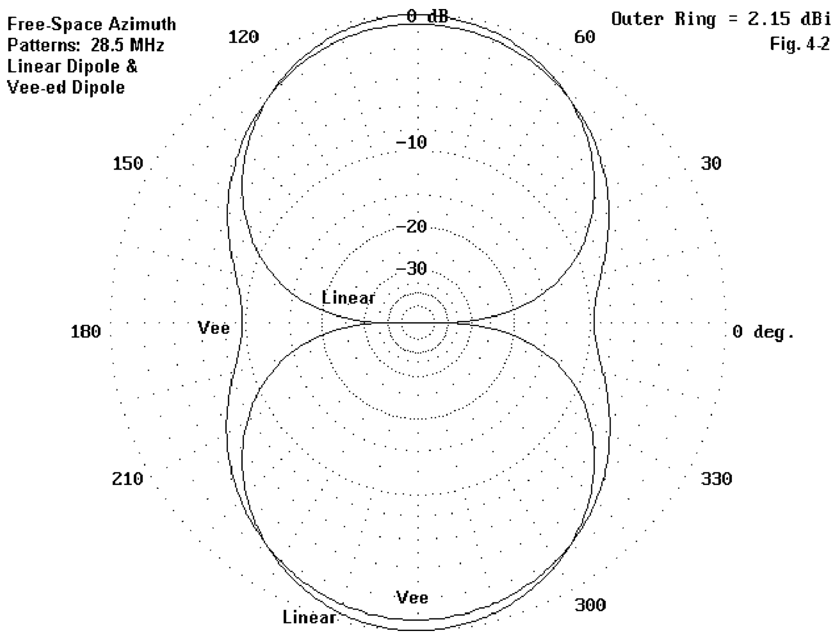
Table 4-1. Gain, Front-to-Side Ratio, and Impedance of Dipoles at Various Degrees of Vee-ing

Forward Angle Relative to a Linear Dipole (Degrees)	Free-Space Gain (dBi)	Front-to-Side Ratio (dB)	Feedpoint Impedance (R +/- jX Ohms)
0 (linear)	2.15	> 30	77 + j18
10	2.12	21	76 + j17
20	2.02	15	70 + j15
30	1.85	12	62 + j10
40	1.62	9	50 + j 2
50	1.37	7	37 - j 8

Note: The total length of the 1" diameter aluminum dipole element is 200" to yield a feedpoint impedance close to resonance at 28.5 MHz when each side is bent forward 40 degrees from linear. See **Fig. 4-1** for the general outline of the test model.

Table 4-1 provides an indication of what occurs when we Vee a dipole element forward. The maximum free-space gain of the antenna decreases for each level of Vee-ing. As well, the feedpoint impedance decreases. Perhaps most significantly, the front-to-side ratio also decreases. **Fig. 4-2** compares the free-space azimuth patterns of a linear and a 40-degree Vee-ed dipole and graphically illustrates the reduction in side rejection for the Vee-ed version.

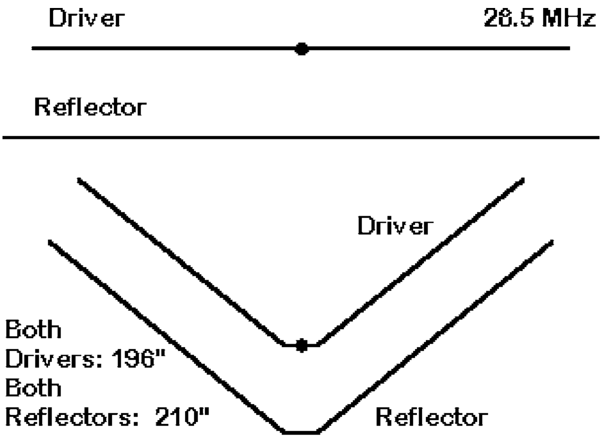
When used as an inverted Vee antenna with the legs angled downward, the reduced side rejection is sometimes listed as an advantage, despite the reduction in broadside gain. However, when the dipole is Vee-ed horizontally, nothing is gained by way of directivity or other effect that might be useful in a multi-element beam antenna. Since all of the designs that we shall consider use the 1/2 λ dipole as their starting point, we should not have any expectations that Vee-ing the elements will yield added performance in any particular area.



Perhaps what lies behind the idea that Vee-ing elements may yield added performance is the concept of the Vee-beam, a very old and simple antenna design. However, the Vee-beam is always many wavelengths long and produces many lobes and nulls. When the designer chooses the proper angle between the elements, the main lobes combine to form a single very strong bi-directional lobe set along the line bisecting the angle between wires. There will almost always be lesser lobes and nulls to the sides, that is, roughly broadside to the wires. If one terminates each of the far ends of the Vee with resistors to ground, then the Vee-beam develops a uni-directional pattern.

However, the 1/2 λ dipole develops only a single lobe at right angles to the wire, resulting in a bi-directional pattern. There are no lobes at angles away from broadside that may combine into a single stronger lobe. The dipole lobes can only be distorted from their shape when produced by a linear wire.

2-Element Vee-ed Beams

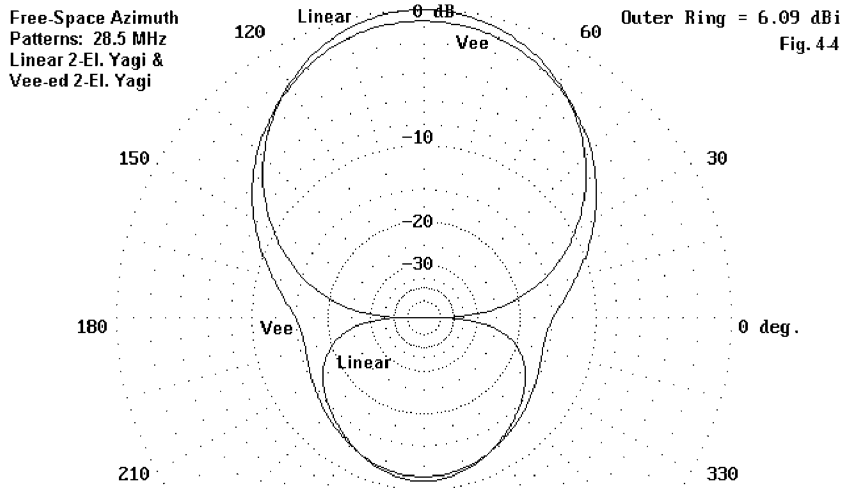


Linear and Vee-ed 2-element Yagis
Fig. 4-3

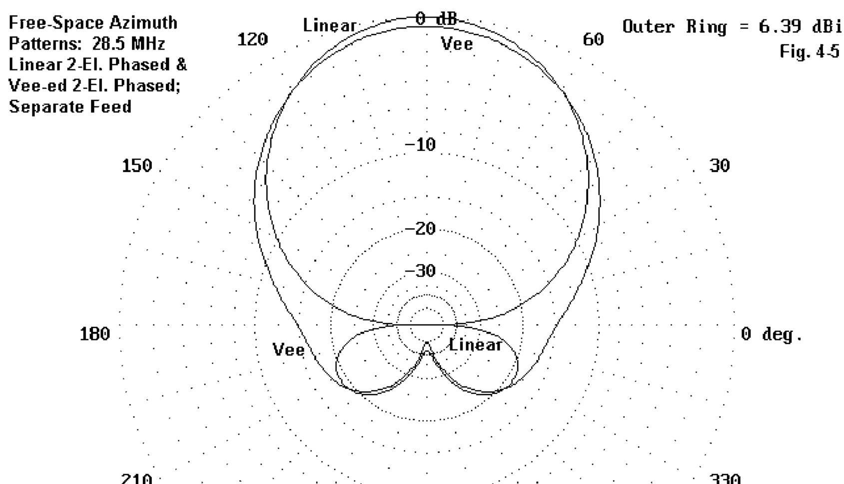
Rather than leave the subject with only the dipole as an indicator of the performance of Vee-ed antenna arrays, let's look at a few beam designs, beginning with 2 elements. Throughout, we shall bend the elements forward 40 degrees as a standard level of Vee-ing. **Fig. 4-3** shows the general outline of linear and Vee Yagis using a driver and reflector in each case. The driver length is 196" for both antennas, and the reflector is 210" long. Element spacing is 48". The Vee-ed version of the antenna shows a feedpoint impedance of 23 + j 4 Ohms at 28.5 MHz, close to resonance. When stretched to linear shape, the impedance rises to 36 + j30 Ohms.

Fig. 4-4 provides comparative free-space azimuth patterns for the two versions of the Yagi. The Vee-ed version has a free-space gain of only 5.45 dBi. compared to the linear version gain of 6.09 dBi. Both antennas have front-to-back ratios of about 10.8 dB, but the Vee shows far less side rejection than the linear antenna. This result is, of course, consistent with the results of our dipole test.

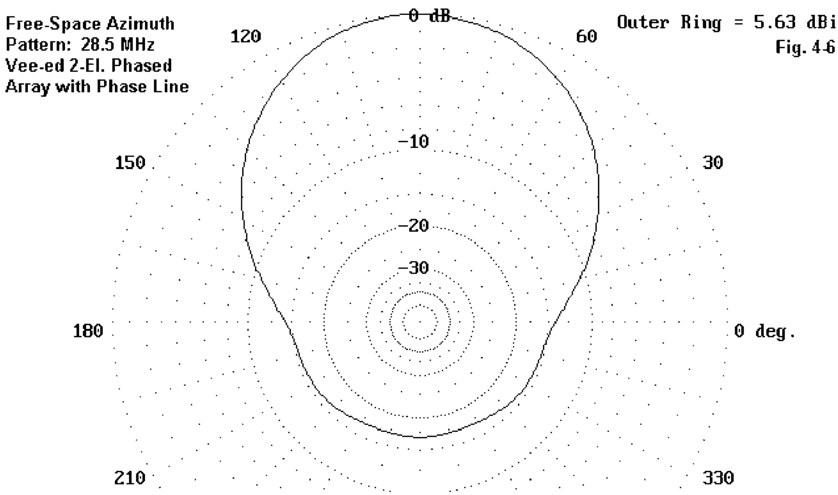
Since our ultimate goal is to evaluate the use of Vee-ed elements log-cell Yagis, we may revise the outline in **Fig. 4-3** to provide each element with a separate feed point. In this manner, we may directly control the relative current magnitude and phasing on each element. Let's try this experiment to see if Vee-elements promise any improved performance when independently phased.



When independently phased for a maximum rear null, the Vee-ed version shows a free-space forward gain just below 5.9 dBi when the rear element is set at a relative current magnitude of 0.94 and a phase of 141 degrees (with the forward element set to a magnitude of 1.0 at a phase angle of zero degrees). For a maximum null to the rear, the comparable linear rear element must be set at a current magnitude of 0.98 with a phase angle of 139 degrees. Under these conditions, the linear phased array



shows a forward gain of nearly 6.4 dBi. **Fig. 4-5** shows free-space azimuth patterns that illustrate the pattern differences. Besides the half-dB gain differential, the low side rejection of the Vee version is clearly evident.



There are no simple means of obtaining the optimal phasing conditions for the Vee-ed phased array. The closest that I have come is the use of a 35-Ohm phasing line from one element to the next. Higher values of phase-line characteristic impedance yield lower performance figures. However, unlike available lines, the modeled line required a velocity factor of 1.0, with lesser values producing poorer results. **Fig. 4-6** shows the resulting free-space azimuth pattern, which has a forward gain of just over 5.6 dBi and a front-to-back ratio of just under 17 dB.

All in all, we must account the results of our attempt to Vee 2-element arrays a disappointment. However, the results should not be surprising, since such arrays depend for their performance directly upon the dipoles that compose them.

The Vee-ed Log-Cell Yagi

The results of our experiments with 2-element parasitic and phased arrays unfortunately do not bode well for the performance of Vee-ed log-cell Yagis. However, with a multi-element cell and additional parasitic elements, we cannot dismiss without suit-able testing the possibility of superior Vee performance. Therefore, I have taken one of Zimmer's designs—a 5-element log-cell Yagi—and developed both linear and Vee-ed models. The general outline of the Vee-ed version appears in **Fig. 4-7**.

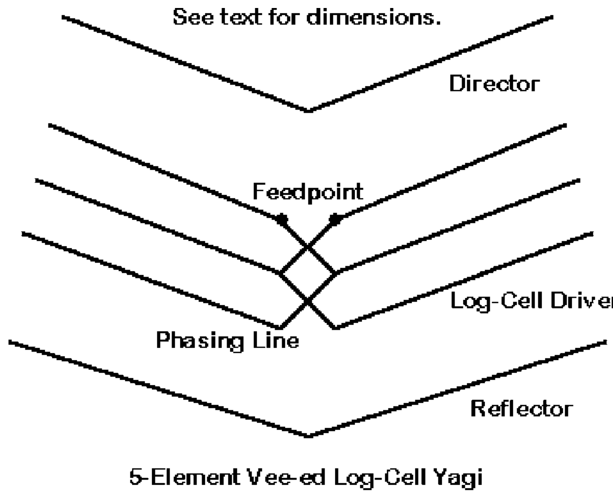


Fig. 4-7

The reflector for each model is 211.5" long and placed 48" behind the 3-element log-cell. Working from the rear forward, the cell elements are 201', 198.8", and 196.6", each spaced 24" from the next. The director is placed 48" forward of the cell and is 187.6" long. The phase-line characteristic impedance producing the most usable results was 200 Ohms.

Fig. 4-8 shows free-space azimuth patterns for the linear and the Vee-ed versions of this antenna. The linear version is virtually identical to the 5-element log-cell

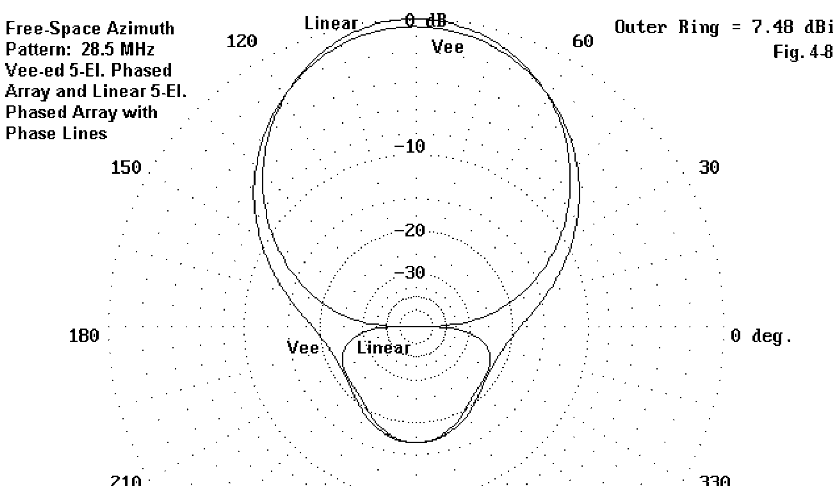
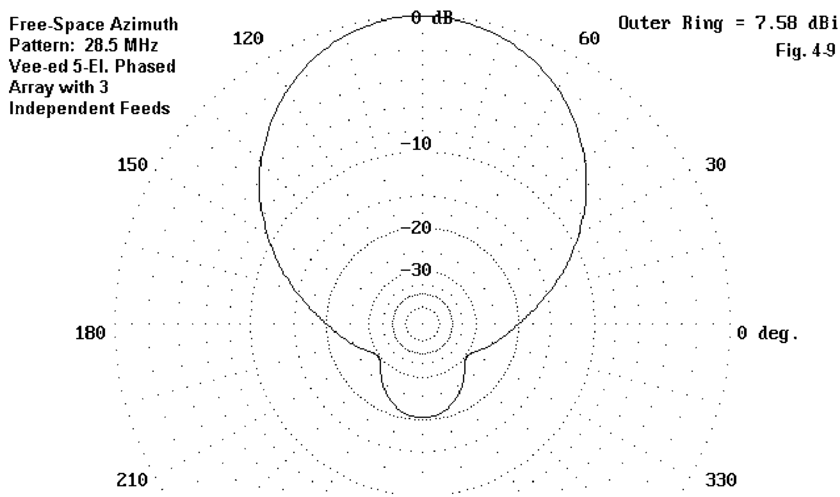


Fig. 4-8

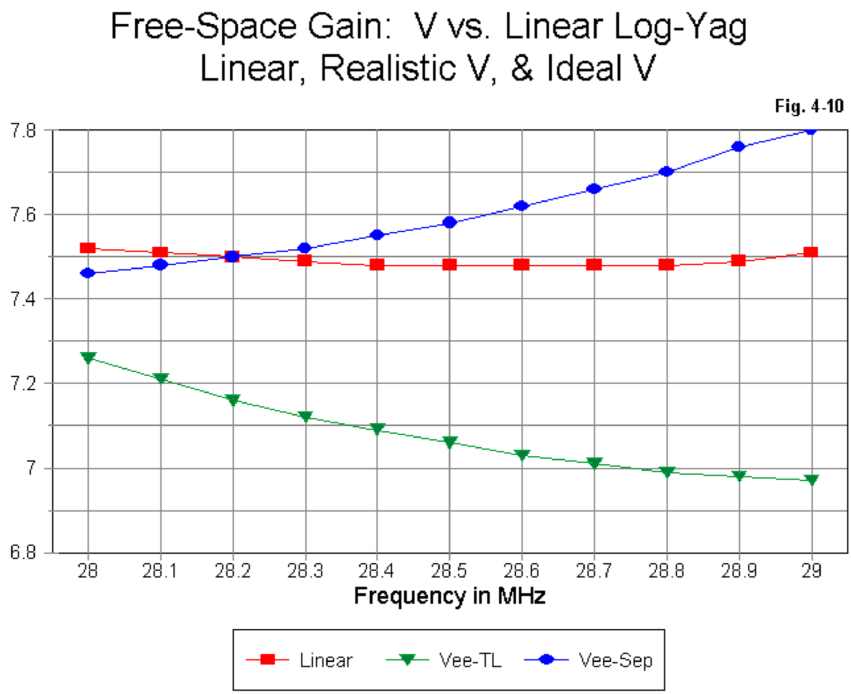
Yagi examined in Chapter 3 of this volume. Once more, the Vee-ed version of the antenna shows lower gain with a reduced front-to-side ratio.

For the Vee-ed log-cell Yagi, the relative current magnitude and phasing on the three driven elements at 28.5 MHz with the 200-Ohm phasing line—from front to rear—was 0.87 at 15.9 degrees, 0.52 at 147.2 degrees, and 0.32 at 171.4 degrees. These values offer us one more experimental possibility. Suppose we separately feed each element of the log cell and optimize the current magnitude and phasing on each element.

For example, if we set the forward element at a magnitude of 0.7 and a phase angle of 20 degrees, the middle element at 0.67 at 145 degrees, and the rear element at 0.4 at 169 degrees, we can increase both the gain and the front-to-back ratio of the array. The resulting free-space azimuth pattern appears in **Fig. 4-9**. The initial improvement holds the promise of an array with at least hypothetical promise of good performance.

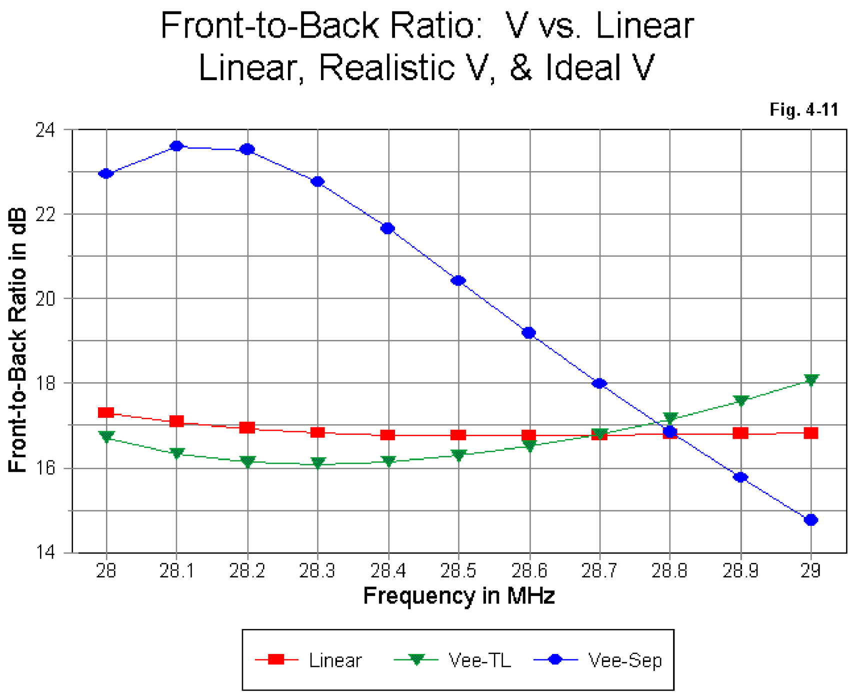


For a further comparison across the first MHz of 10 meters, we can plot the free-space gain values of the linear and 200-Ohm phase-line Vee array against the Vee array with separately fed driver elements. **Fig. 4-10** shows the results. The linear array exceeds the gain of the phase-line-fed Vee array by an average half dB. The hypothetical separately fed array has slightly more gain than the linear array.



In **Fig. 4-11**, we can see the potential front-to-back values for each antenna, with the linear and phase-line-fed Vee-ed array having quite similar values. The hypothetical array using separately fed driver elements is potentially capable of considerably better front-to-back performance.

The difficulty with both the phase-line-fed Vee array and the alternative with separately fed drivers is feeding the system. The Vee-ed array with a phase line shows a tendency toward rapid feedpoint impedance changes, ranging from 50 Ohms at 28 MHz down to about 10 Ohms at 29 MHz. Indeed, experiments that varied the spacing of the reflector and the director failed to come up with a relatively constant feedpoint impedance for the first MHz of 10 meters. The smooth 50-Ohm direct feed obtained by the linear model (which was far from the best of the log-cell Yagis examined in Chapter 3) is wholly absent from the Vee-ed model. Hence, the Vee-ed model with a phasing line would be useful for only a narrow operating bandwidth.



With separate feed for each driver element, the problem becomes insurmountable for the average amateur construction project. I know of no practical way to effect separate feeds for each element short of phasing networks for each element. The builder would also need the ability to measure currents and phase angles to a degree of precision beyond most ham shops.

The Bottom Line

In the entire set of experiments reported here—plus a considerable number of other models—Vee-ing elements of 1/2 λ-based arrays has proven to be an exercise in futility. Throughout, the Vee-ed versions always exhibited lower gain and reduced side rejection relative to comparable arrays using linear elements. The comparative azimuth patterns shown in this final part of the series are truly representative of the total collection of Vee-ed models run.

Since each Vee-ed model shows its heritage in the Vee-ed dipole, we may take the performance of that basic antenna in comparison to a linear dipole as correctly indicative of the performance reduction likely to occur in any vee-ed array when set over and against a comparable array of linear elements. This note, of course, applies only to arrays based upon the 1/2 λ dipole. As we noted at the very beginning, multi-wavelength Vee-beams are another matter entirely.

The myth of the Vee-ed element array of 1/2 λ elements has perhaps persisted too long in amateur circles. I hope these notes help dispel it to some degree. More to the point, if a monoband log-cell Yagi is the design of choice to meet a given set of operating needs, then the best of the linear element log-cell Yagis examined in Chapter 3 will likely always be a better selection than a Vee-ed counterpart.

Notes

1. Robert F. Zimmer, K4JZB, "Development and Construction of 'V' Beam Antennas," *CQ*, Aug., 1983, pp. 28-32; and "Three Experimental Antennas for 15 Meters," *CQ*, Jan., 1983, pp. 44-45.

Part 2: Long-Boom Log-Cell Yagi Design

Chapter 5: The Fundamentals of Long-Boom Log-Cell Yagi Design

Monoband log-cell Yagi designs currently come in two varieties: a. Short-boom designs with 2 to 5 elements in the log cell, and b. Long-boom designs using 2 elements in the cell and numerous parasitic elements. Since the advent of computer-aided antenna design, both log-cell Yagi types have shown shortcomings based on misunderstandings of what is possible with the log-cell Yagi. Short-boom log-cell Yagis employ up to twice as many elements as competing Yagi designs for comparable performance. Long-boom designs with small log cells tend to show no advantages at all over modern Yagi designs of similar boom length.

In Chapters 1-4, I developed a number of emergent properties of short-boom log-cell Yagis. Among them were the following:

1. Moderate gain for a given boom length, with the ability to provide relatively smooth gain over a considerable bandwidth.

2. Superior front-to-back ratios, again with the ability to provide relatively smooth front-to-back ratios across a considerable bandwidth.

3. Superior front-to-rear ratios, defined as the averaged value of power from -90 degrees off the main lobe maximum in one direction around the rear of the azimuth pattern to the corresponding azimuth point that is -90 degrees from the main lobe on the other side of the azimuth pattern, subtracted from the maximum forward power of the main lobe, and given in dB.

4. Superior flat VSWR curves for a considerable bandwidth.

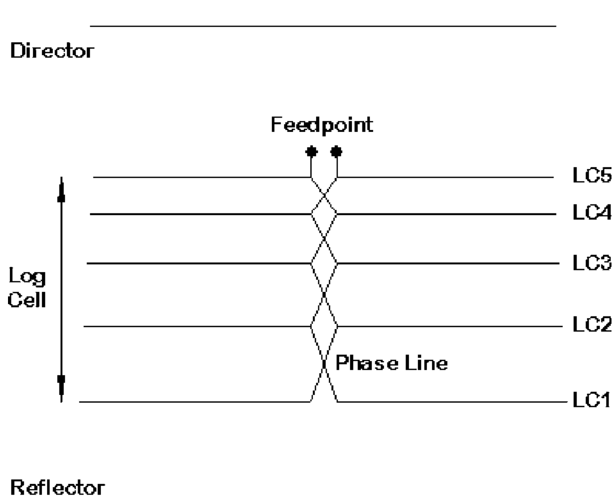
The unanswered question left by these studies is whether these properties can be developed in a long-boom, higher-gain log-cell Yagi. This basic question led to others, including perhaps the most fundamental of all: what is involved in the design of a long-boom log-cell Yagi.

In the following notes, I shall try to develop the major parameters of long-boom log-cell Yagi design. Following a brief review of basic log-cell principles, I shall try to sort out and track the significant design variables that influence log-cell Yagi performance. The results will be a series of preliminary designs of various boom lengths. To assess the potential of long-boom log-cell Yagis, we shall close with a brief comparison between a selected design and a roughly comparable pure Yagi design of similar boom length and operating bandwidth.

Background

The log-cell Yagi is a hybrid array composed of a log-periodic dipole array (LPDA) used as the driver "cell," along with one or more parasitic elements. **Fig. 5-1** provides an outline of a typical log-cell Yagi, along with some designations that we shall use later in this study. Although the sketch shows one reflector and one director, other designs have omitted the reflector and some have added further directors.

Fig. 5-1 Components of a Monoband Log-Cell Yagi



The log-cell historically has been either casually or rigorously designed. Small cells (usually 2 elements) have employed phased element techniques such as those found in the ZL-Special. More complex cells have used standard LPDA design techniques, following the lead of P. D. Rhodes, K4EWG, in his article, "The Log-Periodic Dipole Array," (*QST*, Nov 1973, pp 16-22). The most fundamental aspects of LPDA revolve around three interrelated design variables: α

(alpha), τ (tau), and σ (sigma). We may define any one of the three variables by reference to the other two.

Fig. 5-2 reviews the basic components of an LPDA, as explored in Volume 1. The angle α defines the outline of an LPDA and permits every dimension to be treated as a radius or the consequence of a radius (R). The most basic structural dimensions are the element lengths (L), the distance of each element from the apex of angle α (R), and the distance between elements (D). A single value, t, defines all of these relationships in the following manner:

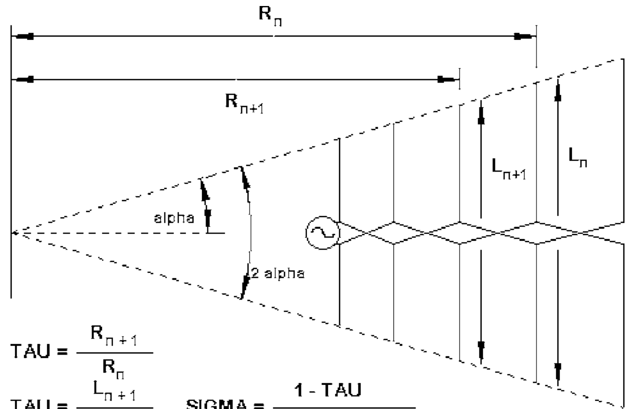


Fig. 5-2

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

where elements *n* and *n+1* are successive elements in the array working toward the apex of angle α.

For the log-cell of a hybrid design, one usually selects values of τ and of τ to create an LPDA for a relatively narrow frequency range. Rhodes recommended a τ of 0.95, which is close to the maximum recommend value for any LPDA design. He selected a σ of 0.05 to produce what he apparently considered to be a reasonably short cell length. Interestingly, I have encountered no questions in the literature concerning these values.

The original Rhodes array is still featured in *The ARRL Antenna Book* (Chapter 10). It uses a 4-element cell for 20 meters. Because 20 meters is a fairly narrow band (about 2.47% of the band center frequency), it does not provide a test of log-cell Yagi bandwidth potential. Therefore, as in preceding chapters, I shall adopt the entire 10-

meter band from 28.0 to 29.7 MHz as a more appropriate test ground for log-cell Yagi design (about 5.89% of the band center frequency of 28.85 MHz).

Moreover, I shall also adopt a 5-element log cell design in preference to the 4-element cell used by Rhodes. In preliminary design work that used a slight modification of the Rhodes design, scaled to 10 meters (model 412), and a corresponding 5-element cell—plus reflector and director—(model 514), I developed the arrays whose dimensions appear in **Table 5-1**.

In NEC-4 models of these arrays, I encountered a collection of general property differences that make the 5-element log-cell superior to the smaller version. Complete details of the differences have been explored in the preceding chapters, but a graphical review of the differences may be a useful preliminary to our attempts to expand and improve the performance the log-cell Yagis.

Ultimately, our goal shall be to see if we are able to design a log-cell Yagi that is competitive with a Yagi of similar boom-length and a similar number of elements. Otherwise, from the combined perspectives of performance and construction, we would have little reason to turn to the log-cell Yagi design at all. Standard Yagis offer feed systems that we may implement more simply when moving from lines on a drawing or wires in a NEC model to assemblies of aluminum tubing. Hence, we must have a good reason for wanting to build a log-cell Yagi of any length.

Table 5-1. Dimensions of Preliminary 10-Meter Log-Cell Yagis

4-Element Log-Cell (6-Element Array): Model 412

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.65	0.255	—	—
LC1	8.58	0.252	2.96	0.087
LC2	8.10	0.238	4.70	0.138
LC3	7.66	0.225	6.34	0.186
LC4	7.25	0.213	7.87	0.231
Director	7.20	0.211	12.40	0.364

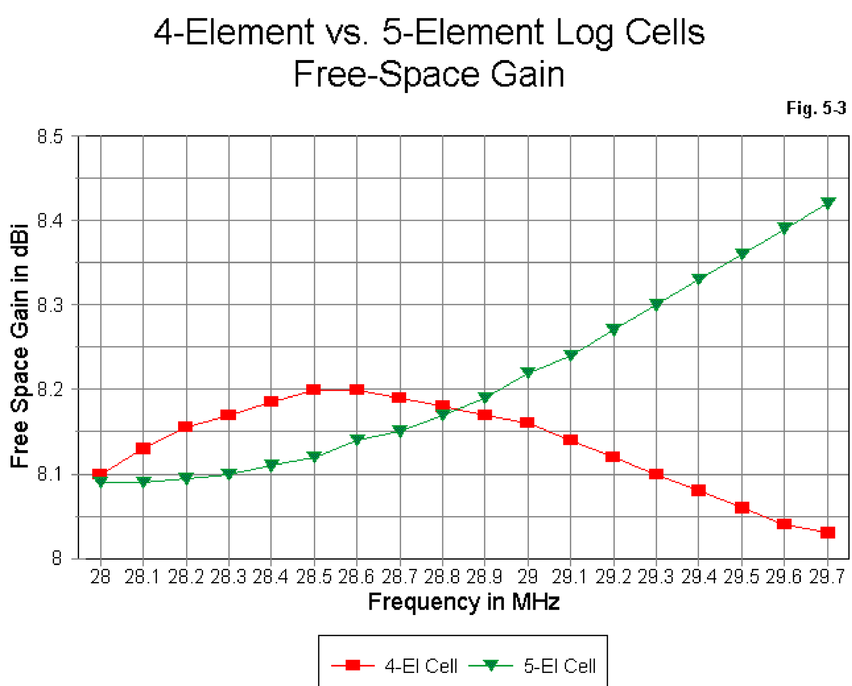
$\tau = 0.95$ $\sigma = 0.05$ Element Diameter = 1.0" Phase Line Zo = 75 Ohms

5-Element Log-Cell (7-Element Array): Model 514

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.76	0.260	—	—
LC1	8.50	0.249	2.93	0.086
LC2	8.05	0.236	4.65	0.136
LC3	7.59	0.223	6.28	0.184
LC4	7.20	0.211	7.82	0.230
LC5	6.85	0.201	9.29	0.272
Director	6.98	0.205	14.45	0.424

$\tau = 0.95$ $\sigma = 0.05$ Element Diameter = 0.875" Phase Line Zo = 80 Ohms

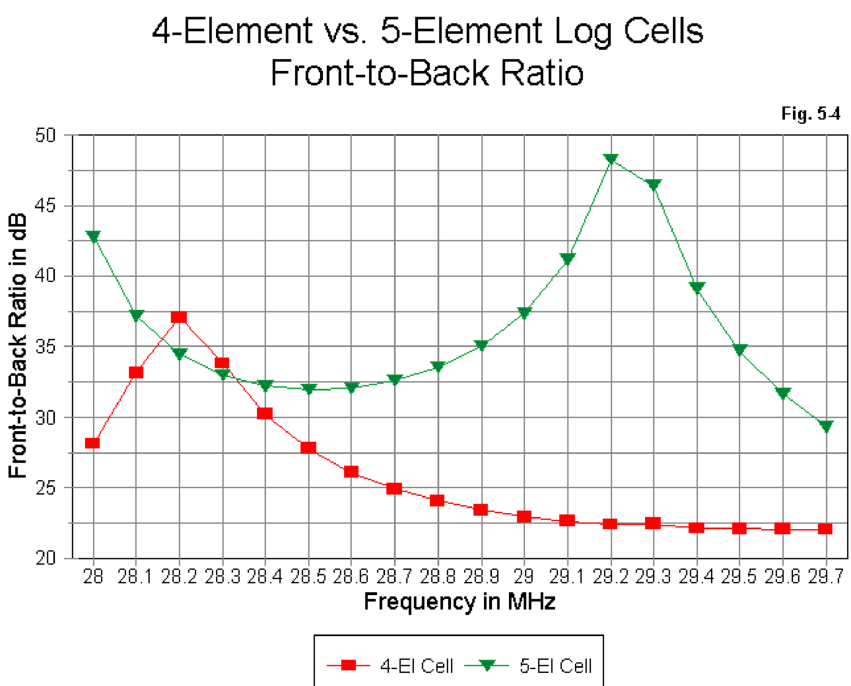
Note: Wavelength dimensions taken at 28.85 Mhz.



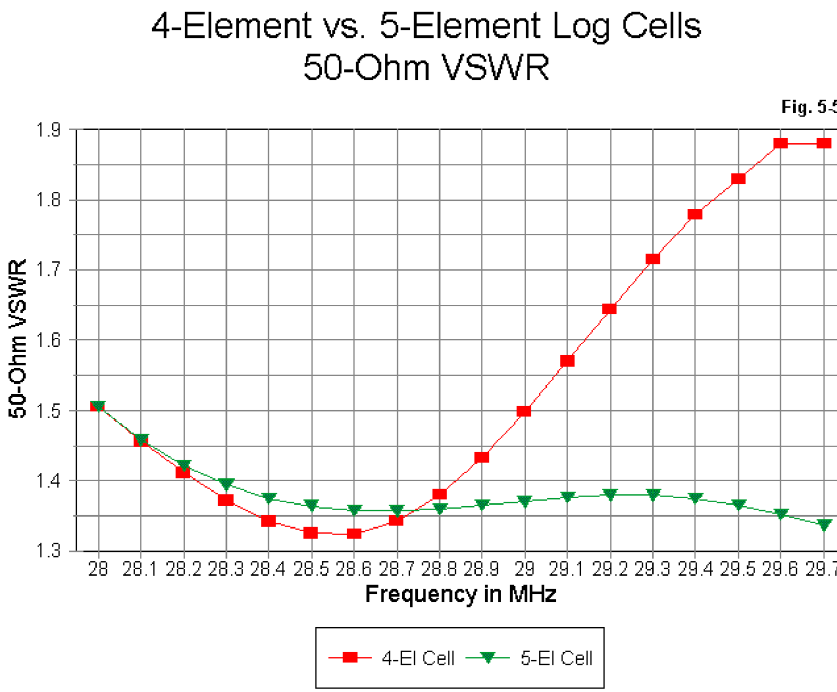
The 5-element log-cell allows the use of a longer rear element and a shorter forward element than those found in the 4-element cell. As we have seen, the larger cell permits improvements in the operating bandwidth of several performance categories.

As shown in **Fig. 5-3**, the gain curves for the two antennas differ in form—a factor which will become one of the design questions to be explored in long-boom arrays. The initial values of the 5-element cell array are lower than those of the 4-element cell array, although the larger array shows a steady increase in gain across 10 meters. We shall explore ways of centering the gain peak on all log-cell Yagis.

Fig. 5-4 clearly demonstrates an improvement in 180-degree front-to-back ratio by adding one more element to the log cell. However, both curves show radical peaks. Perhaps we may find a way to smooth the front-to-back performance across the band.



The flatter 50-Ohm VSWR curve is apparent in **Fig. 5-5**. It is possible to refine the two models to level some of the differences between them. However, the 5-element cell remains superior in its performance across a band as wide as 10 meters.



In fact, the 5-element cell shows a classic feature of most very wide-band Yagis: the double dip in the SWR curve. In a standard Yagi, the second dip coincides with the rise of the first director current magnitude to a level in excess of the current magnitude on the driver. In such Yagis, the first director becomes a secondary or parasitic array driver, sometimes called a slaved driver.

As is evident from the curves for the two preliminary log-cell Yagi designs, the studies of design elements will be undertaken using NEC-4. Elements will be of uniform diameter, although they may vary from one model to another. Thus, the modeling work may also be undertaken in NEC-2 with equal ease and accuracy.

Each element will have 21 segments, since this value assures convergence of results without excessive segmentation. We create phasing lines by using the TL facility of NEC. The velocity factor is set at 1.0 for all models. Some models may use phase line characteristic impedances that may be very difficult to fabricate. In general, values as low as 75 and 80 Ohms require facing flat face stock, since these characteristic impedance values are not feasible with air dielectric lines using round conductors. Methods of physically constructing the arrays modeled lie beyond the scope of this study, but may be found in recent editions of *The ARRL Antenna Book* and other sources.

The Fundamentals of Long-Boom Design

Historically, log-cell Yagi design appears to be confined to relatively short boom lengths if the log-cell is complex. Long-boom designs have largely been confined to log-cells with only two elements. It remains unclear why long-boom log-cell Yagis with complex cells have not appeared in the amateur literature. One might speculate that Rhodes' note setting σ at 0.05 may have been taken as a limiting value.

However, we may extend the length of any LPDA at least up the its optimum value for σ, which is calculated as follows:

$$\sigma_{opt} = 0.243\,\tau - 0.051 \qquad \textbf{(2)}$$

For a τ of 0.95, the optimum value of σ is about 0.18. Between the Rhodes limit of 0.05 and the optimum σ of 0.18, we have considerable room for experimentally lengthening the log cell by increasing the value of σ to achieve almost any reasonable boom length.

Some of the rhetoric surrounding LPDA design also leaves a misimpression for those who have not calculated actual designs. We tend to most closely associate array gain with the value of τ such that, the higher the value, the greater the array gain for any value of σ. What we may not clearly realize is that for any value of τ, the array gain also increases with increasing values of σ. As an initial move, we may increase a log-cell Yagi's gain by simply increasing the value of σ and expanding the log-cell dimensions length-wise.

One consequence of taking this design route is that the number of elements in the array does not increase with the boom length. Given the earlier decision to work with 7-element arrays only, the number of elements becomes more sensible with longer boom lengths. Although 7 elements may seem to be excessive for a 14' beam, they become more natural with 26' and 28' booms. (Here, "natural" means simply more in line with common experience with pure Yagi designs.)

To test the initial potential for long-boom log-cell Yagis with longer log cells, I created a number of models to compare with Model 514. **Table 5-2** provides the dimensions of Models 520, 526, and 528. Although 526 and 528 reflect boom lengths of about 26' and 28', respectively, the boom length of Model 520 varies from 19 to nearly 20 feet, depending upon some variations to be created later.

Table 5-2. Dimensions of 4 7-Element Log-Cell Yagis

5-Element Log-Cell (7-Element Array): Model 514 (See **Table 5-1**.)

5-Element Log-Cell (7-Element Array): Model 520

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.80	0.258	—	—
LC1	8.38	0.246	2.89	0.085
LC2	7.93	0.233	5.81	0.171
LC3	7.49	0.220	8.59	0.252
LC4	7.10	0.208	11.23	0.330
LC5	6.75	0.198	13.74	0.403
Director	6.65	0.195	19.00	0.557

$\tau = 0.95$ $\sigma = 0.0873$ Element Diameter = 0.5" Phase Line Zo = 80 Ohms

5-Element Log-Cell (7-Element Array): Model 526

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	9.00	0.264	—	—
LC1	8.36	0.245	4.12	0.121
LC2	7.91	0.232	8.19	0.240
LC3	7.47	0.219	12.06	0.354
LC4	7.09	0.208	15.73	0.461

LC5	6.73	0.198	19.21	0.563
Director	6.30	0.185	25.80	0.757

τ = 0.95 σ = 0.121 Element Diameter = 0.75" Phase Line Zo = 65 Ohms

5-Element Log-Cell (7-Element Array): Model 528

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.70	0.255	—	—
LC1	8.11	0.238	4.00	0.118
LC2	7.68	0.225	8.55	0.251
LC3	7.25	0.213	12.88	0.378
LC4	6.88	0.202	17.01	0.499
LC5	6.53	0.192	21.10	0.619
Director	6.00	0.176	28.10	0.824

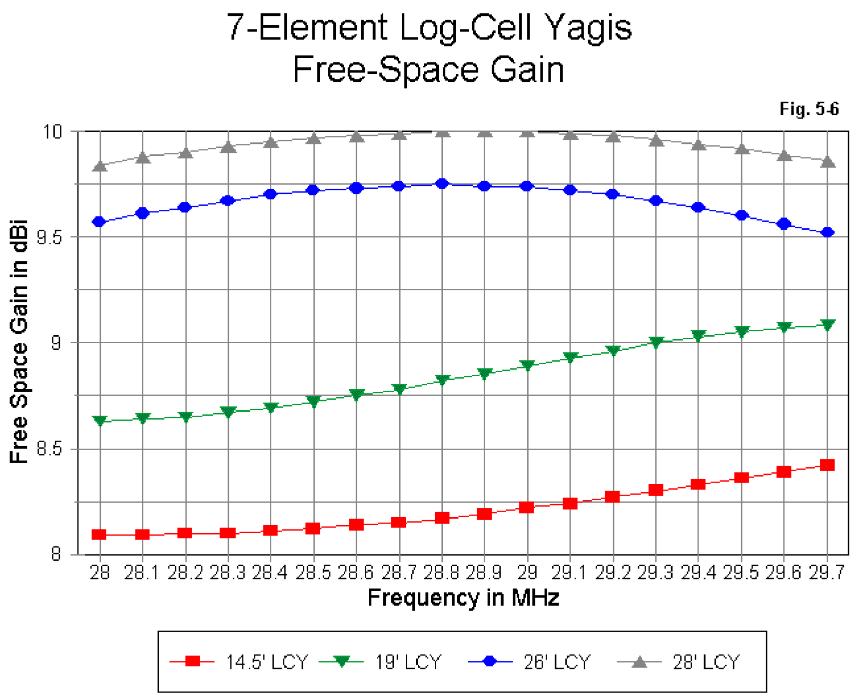
τ = 0.95 σ = 0.141 Element Diameter = 0. 75" Phase Line Zo = 70 Ohms

Note: Wavelength dimensions taken at 28.85 MHz.

The technique for creating these designs was initially simple (and simplistic): increase the value of σ, recalculate element spacing using a τ of 0.95, and then adjust the reflector and director length and spacing to develop a usable design. "Usable design" meant one that—across 10 meters—had a reasonably stable gain, a stable front-to-back ratio, and a 50-Ohm SWR below 1.5:1. To achieve these goals in the shortest possible time, I varied other factors, including the characteristic impedance of the phase line and the element diameter.

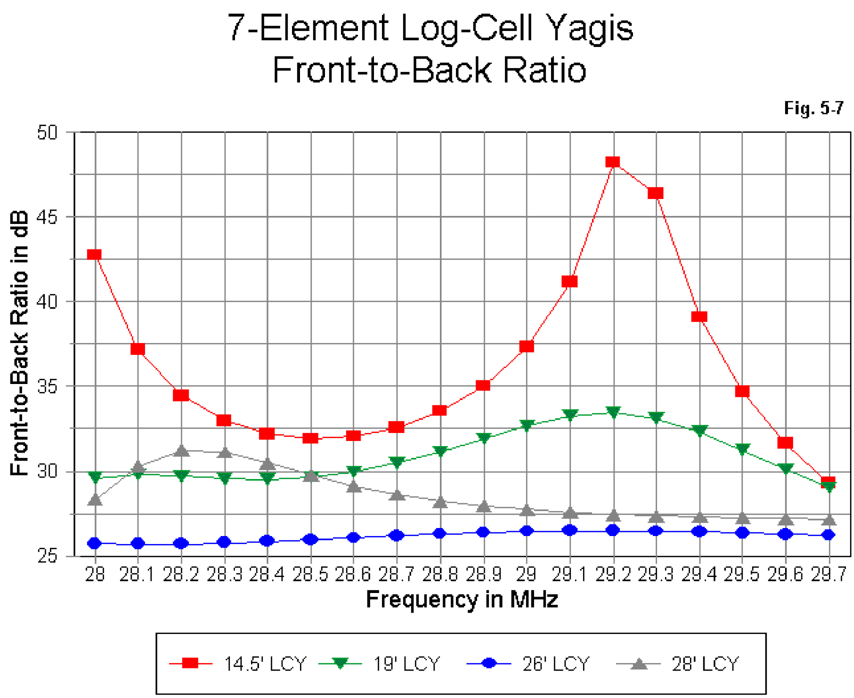
Most immediately apparent from **Table 5-2** is that fact that increasing σ required a resizing of the log-cell relative to its initial calculation. A simple increase in σ using the same initial rear element length should theoretically have produced performance curves similar to those of model 514. However, with each increase of σ, the log cells required a downward adjustment in element length to achieve acceptable performance. Only models 526 and 528 use elements similar in length, but there are significant differences in the performance of these two arrays that go beyond gain differences. The table also shows the final values of σ for each design: 0.051, 0.087, 0.121, and 0.1412, respectively, for the designs in order of increasing length.

Fig. 5-6 shows the free-space gain curves for models 514 through 528. On the wide-range gain scale, the upward progression of gain in 514 is put into somewhat better perspective to display the 0.33 dB total gain change across the band. Model 520 is about 4.5' longer overall and displays a similar gain curve. However, the upper end of the curve is reaching its peak value as the rate of increase approaches zero.



Model 526 is about 6.5' longer than 520, and the amount of increase in gain over 520 is proportional to the boom-length increase. However, this curve peaks almost exactly at the mid-band point. The overall change in gain across the band is only 0.23 dB. The longest model, 528, shows the expected further increase in gain over 526. The 10.0 dBi gain figure extends from 28.8 to 29.0 MHz so that the band edge gain values are only 0.02 dB apart for a total gain change of only 0.26 dB across the band. We shall shortly explore the reasons for the two distinctly different types of gain curves within the overall set.

In **Fig. 5-7**, we find an even greater diversity of curve types. The very high front-to-back ratios of the shortest design, 514, also show the greatest variation in level, with nearly 19 dB separating the peaks from the “nulls” (if we may call a minimum front-to-back value of 27.2 dB a “null”). Models 520 and 528 show an overall change of just above 4 dB in the 180-degree front-to-back ratio across the band. The shorter of the two models exhibits the higher intrinsic values, and the peaks for the two antennas fall toward opposite ends of the band.



Model 526 shows the least variation in front-to-back ratio—a mere 0.79 dB over the 1.7 MHz of 10 meters. However, the average front-to-back ratio is 26.1 dB, which is considerably lower than the value for any other of the designs. Of importance to the design is the increased spacing for both the reflector and director, relative to the smaller models, as well as the lengths of these elements. Also significant is the lower characteristic impedance of the phase line.

Virtually all of the designs share one trait in common: a well-controlled rear lobe structure. **Fig. 5-8** illustrates this point by displaying expanded azimuth patterns of the rear lobes of model 520 at the band edges and at the mid-band point. The three rear patterns reflect 180-degree front-to-back patterns between 27 and 28 dB. In all three cases, an averaged front-to-rear value for the array would exceed the 180-degree front-to-back value.

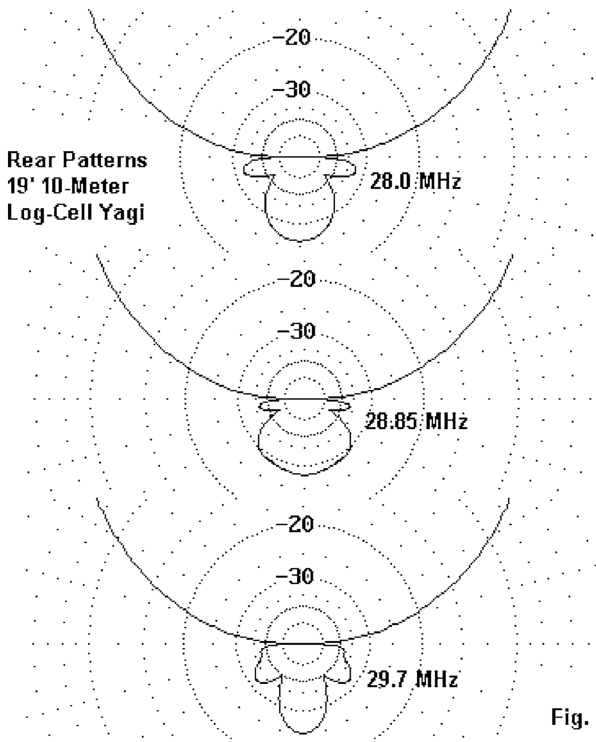
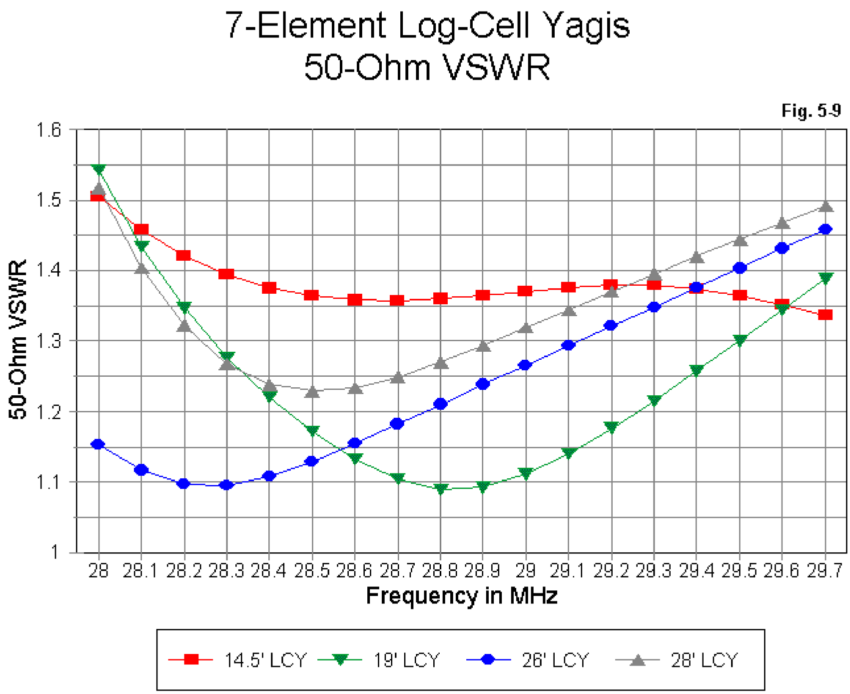


Fig. 5-8

Fig. 5-9 shows another aspect of model 526: its 50-Ohm SWR never climbs as high as 1.5:1. The other curves show much the same variety as the front-to-back curves, with only the curve for model 520 showing the anticipated mid-band minimum value.



We began the exercise with a question: can we enlarge the 7-element log-cell Yagi by increasing the value of σ and making other small adjustments to obtain good wide-band gain, front-to-back ratio, and 50-Ohm SWR curves? The modeled performance curves we have just examined provide an affirmative answer. However, these same curves raise a larger number of questions still to be answered. Perhaps we can formulate a summary question to cover the unexamined territory: what are the variables in log-cell Yagi design and how does each affect the performance curves?

In the next chapter, we shall attempt to provide a preliminary and provisional answer to our general question. In addition, we shall optimize a "semi-final" log-cell Yagi design and compare it to a comparable wide-band Yagi.

Chapter 6: Design Variables and Relevant Comparisons

Thus far, we have isolated only one definitive variable in the design of log-cell Yagis. As we increase σ, we must decrease the initial log-cell element length (for element LC1) before applying the prescribed value of τ to obtain the lengths and spacings of the other log-cell elements. However, this design guideline is incomplete, since it does not give us an indication of how much to shorten the element length or how to know when we have it where we want it.

Performance Variables in Log-Cell Yagi Design

The following notes contribute to, but in no way complete, an enumeration of the performance variables involved in long-boom log-cell Yagi design.

1. Log-Cell Element Length: To examine the effects of log-cell element length on the performance curves of a given design, I took model 520 and ran it through some variations in element length. I varied only the log-cell element lengths and then adjusted only the position (but not the length) of the parasitic director to yield acceptable front-to-back and SWR curves. **Table 6-1** lists the dimensions of three representative models.

Table 6-1. Dimensions of 3 Versions of Model 520

Original Model 520

Element	Half-Length Feet	Half-Length Wavelengths	Spacing from Reflector Feet	Spacing from Reflector Wavelengths
Reflector	8.80	0.258	—	—
LC1	8.38	0.246	2.89	0.085
LC2	7.93	0.233	5.81	0.171
LC3	7.49	0.220	8.59	0.252
LC4	7.10	0.208	11.23	0.330
LC5	6.75	0.198	13.74	0.403
Director	6.65	0.195	19.00	0.557

τ = 0.95 σ = 0.0873 Element Diameter = 0.5" Phase Line Zo = 80 Ohms

Revision 1 to Model 520

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.80	0.258	—	—
LC1	8.50	0.249	2.89	0.085
LC2	8.08	0.237	5.81	0.171
LC3	7.67	0.225	8.59	0.252
LC4	7.29	0.214	11.23	0.330
LC5	6.92	0.203	13.74	0.403
Director	6.65	0.195	19.40	0.569

$\tau = 0.95$ $\sigma = 0.0860$ Element Diameter = 0.5" Phase Line Zo = 80 Ohms

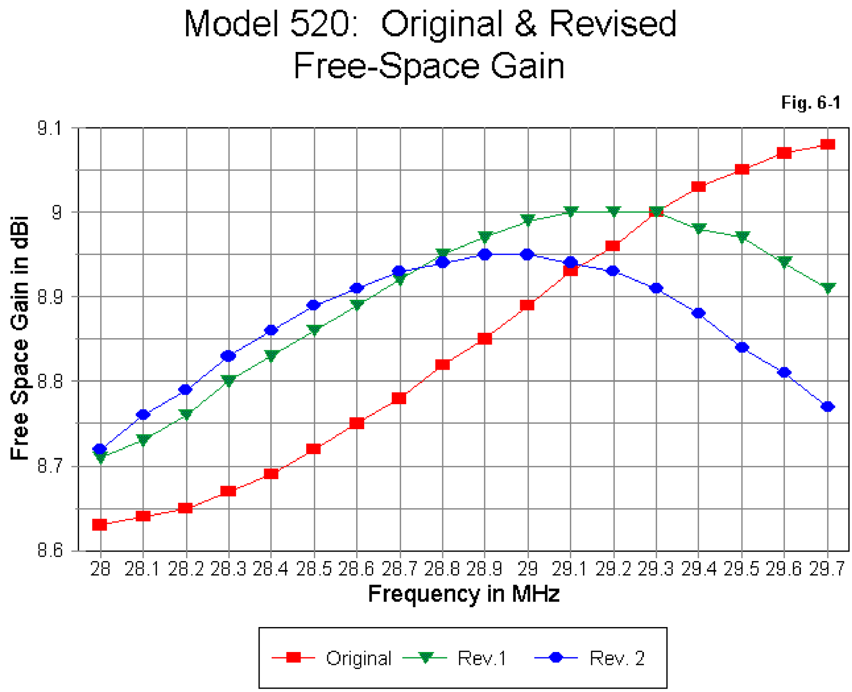
Revision 2 to Model 520

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.80	0.258	—	—
LC1	8.58	0.252	2.89	0.085
LC2	8.15	0.239	5.81	0.171
LC3	7.75	0.227	8.59	0.252
LC4	7.36	0.216	11.23	0.330
LC5	6.99	0.205	13.74	0.403
Director	6.65	0.195	19.70	0.578

$\tau = 0.95$ $\sigma = 0.0852$ Element Diameter = 0.5" Phase Line Zo = 80 Ohms

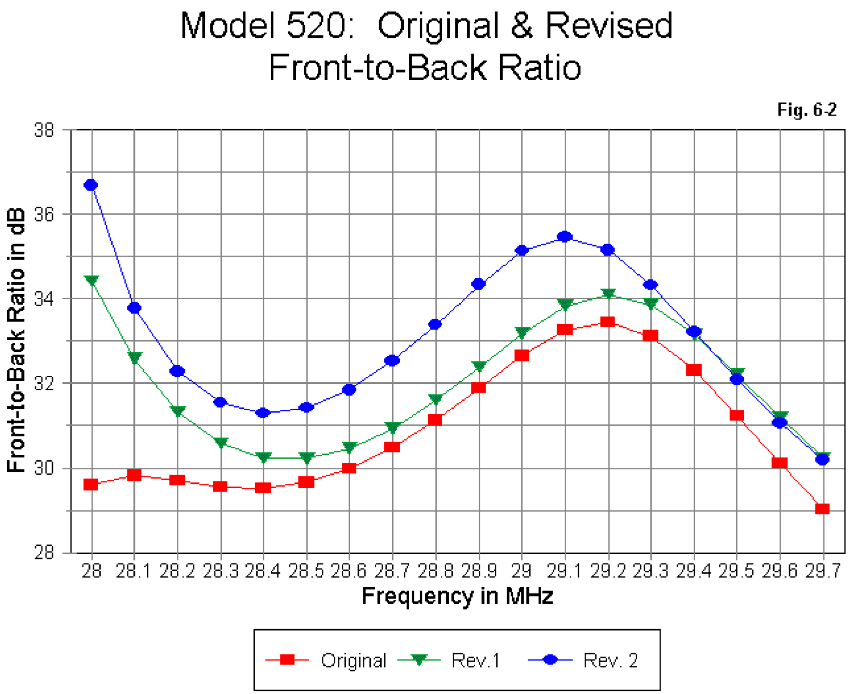
Changing the element length obviously changes the value of σ. Since the revisions to the original model increased the element lengths in the log cell (without changing the value of τ), the value of σ decreases slightly with each step in the maneuver. In addition, the overall length of the array increases, since the director must be displaced forward to return reasonable front-to-back ratio and SWR curves. As the table shows, the length of the director stayed constant, while only its position changed. Moreover, the reflector length and position, as well as the phase line Zo and the element diameter, remained constant throughout the exercise. Obviously, we might have varied any of the constants to achieve further performance improvements.

Fig. 6-1 shows the effects of the changes on the array gain. Lengthening the log-cell elements gradually centers the gain peak well within the operating passband of the beam. One consequence of lengthening the log cell is that the gain at the lower end of the band increases. However, as the peak gain approaches the mid-band frequency, the magnitude of the peak gain decreases.



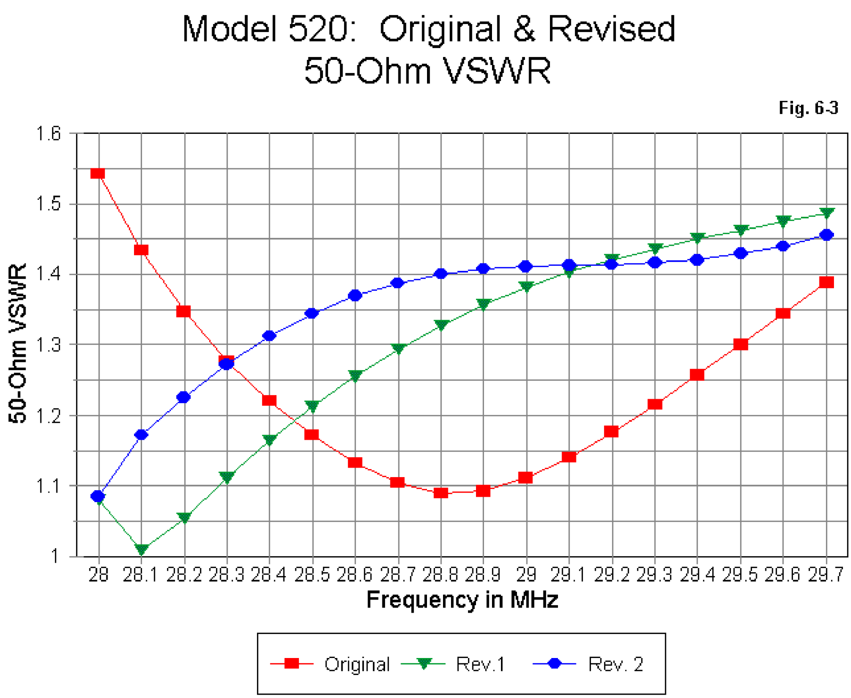
The designer, therefore, has a choice. For the most even gain across the band, longer log-cell elements are desirable, but at the cost of peak gain. If peak gain is desired, then the gain at the low end of the band will suffer accordingly. Which sort of gain curve within any operating passband is more desirable will depend upon the operating specifications that the designer brings to the enterprise.

Higher peak gain also results in a somewhat lower front-to-back value across the band, as revealed in **Fig. 6-2**. Changing the log-cell element length to smooth out the gain actually produces greater variations in the front-to-back ratio across the band. One conclusion we may reach from these curves is that the smooth front-to-back curve in model 526 does not result alone from centering the gain curve by lengthening log-cell elements.



Lengthening the log-cell elements, relative to the original version of model 520 also changes the SWR curve when the phase-line Zo remains constant. See **Fig. 6-3**. The shallow dip at the band center for the original model becomes a sharp dip at 28.1 MHz for the first revision. For the second revision, the dip moves below the end of the band. Had we lengthened the elements further, the curve would have flattened further.

The gain-centering effect of modifying the lengths of the log-cell elements can be examined by modeling the log cell alone, without the parasitic elements. Because the director and reflector are dimensioned to smooth log-cell Yagi performance across the operating bandwidth, the log cell alone will show more variation in gain across the band. However, the frequency at which we find gain peaks will closely coincide with peak gain frequency for the entire beam. The gain of the log-cell alone may only be down by about 0.6 dB relative to the peak gain of the final array. However, at band edges, the gain difference may well exceed a full dB. As the length of a log-cell Yagi increases (by lengthening the log cell itself), the role of the parasitic elements changes from increasing gain to smoothing performance across the pass band.



2. Element Diameter: As one would expect, increasing the diameter of the elements in a log-cell Yagi has the consequence of lowering the center frequency of the curves in all of the categories that we have been using to express array performance: gain, front-to-back ratio, and 50-Ohm VSWR. As a demonstration of the phenomenon, I used the original model 520, the dimensions of which appear at the top of **Table 6-1**, as the basis for a number of variations. I increased the initial 0.5" diameter elements first to 0.75" and then to 1.0" without changing any other physical or electrical property of the beam.

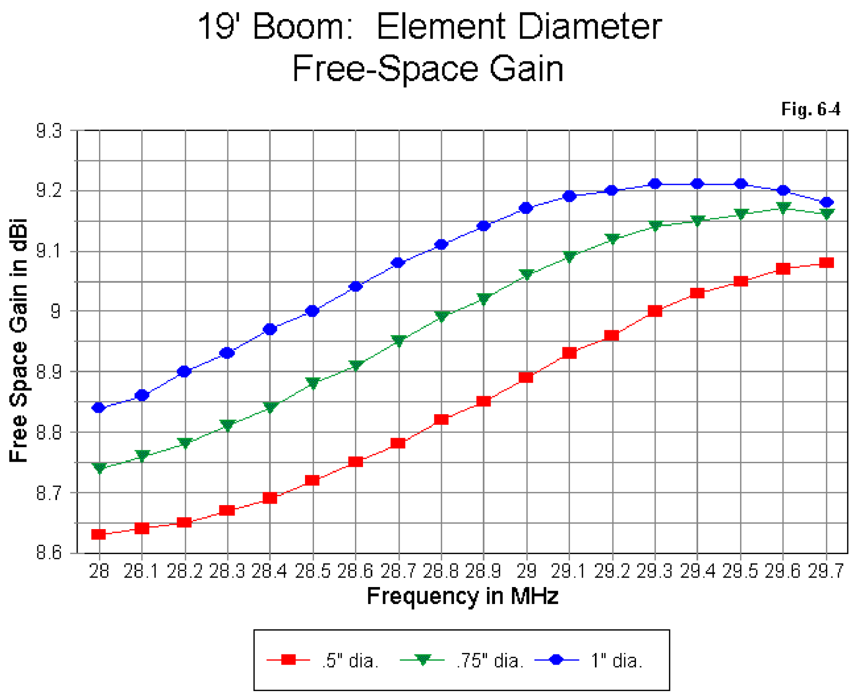
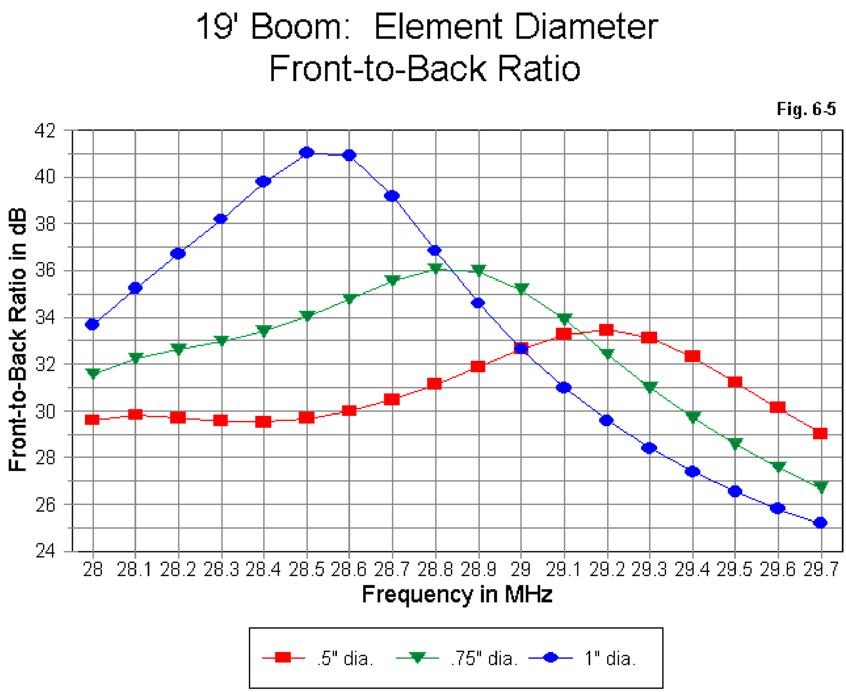
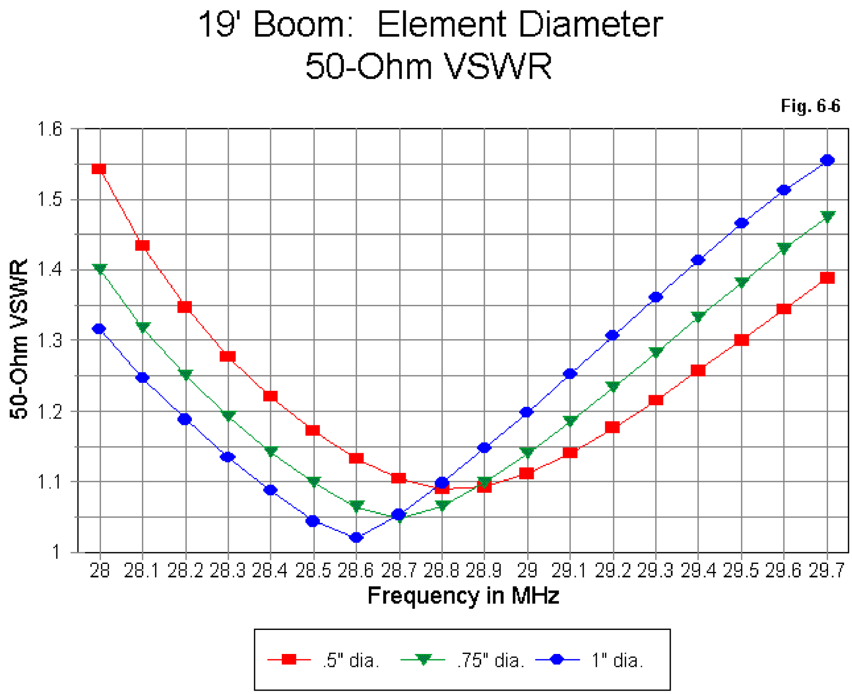


Fig. 6-4 shows the effects of the increases upon the free-space gain of the array. Although the peak gain of the 0.5" design occurs above the 10-meter band, the larger diameter models reveal peak gain vales within the band, with an approximate 0.25 MHz decrease in frequency per 0.25" increase in diameter. Moreover, increasing the element diameter increases the intrinsic peak gain value by an amount that is slightly more than one expects with a single driver, such as in a pure Yagi. The effect is a function of the total driver cell and is consistent with results for pure LPDA arrays using low-impedance phasing lines.

More dramatic are the curve shifts in the 180-degree front-to-back ratio as we increase element diameter alone. In **Fig. 6-5**, we note a larger shift down the band as we move from 0.5" to 1.0" elements. As well, the maximum front-to-back peak for the 1.0" element model is much higher than for the smaller elements. However, the range of front-to-back values also increases. To smooth the curve for the front-to-back element for the larger diameter elements would require other modifications to the design, including readjustments to the parasitic elements.

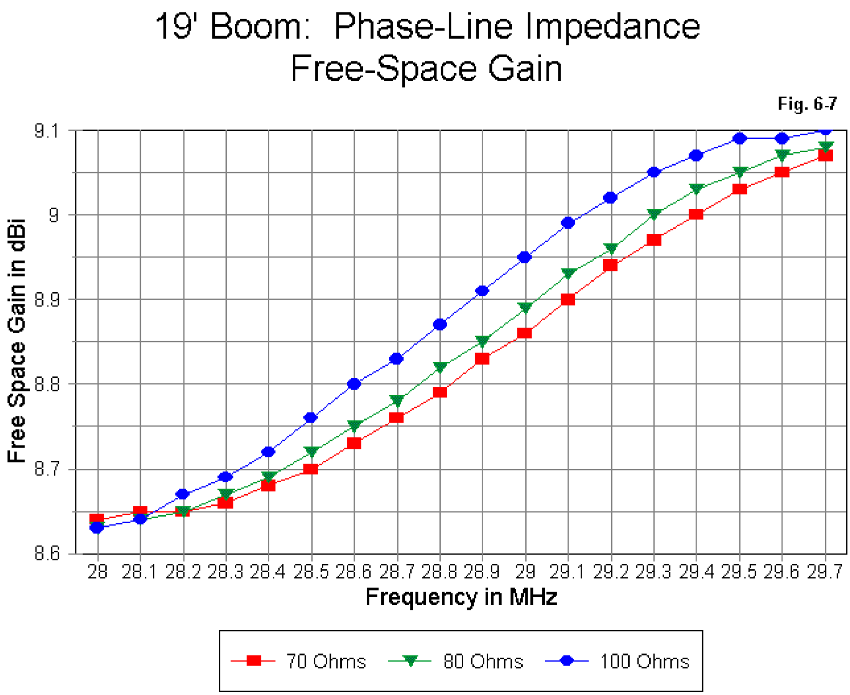


As shown in **Fig. 6-6**, the 50-Ohm VSWR curves are nearly congruent, with the larger element models achieving the lowest SWR minimum. As the element diameter increases, the resistive component of the impedance decreases, but only marginally. Across the band, for a design given, the resistive component increases steadily from near 40 Ohms at the 28.0 MHz to about 65 Ohms at 29.7 MHz. The reactance curve, however, shifts more radically. In model 520 for all element diameters, the reactance never reaches a positive (inductive) value of 1 Ohm anywhere in the pass band. Instead it remains capacitive, with the zero or near zero point moving lower in the band as the element diameter increases. Since the zero-reactance point coincides with a lower resistive component when the diameter is largest, the net VSWR minimum is lower.



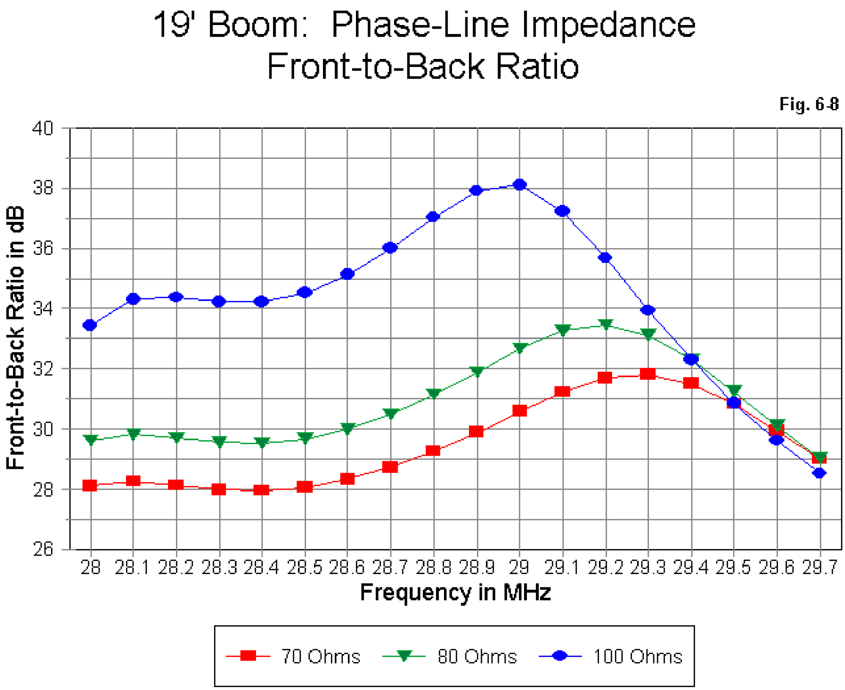
In every respect, the effects of increasing the element diameter in a log-cell Yagi can be classified as normal to the LPDA behavior of the log cell.

3. Phase-Line Characteristic Impedance: Whereas changing the element diameter has rather large consequences for the gain curve of a log-cell Yagi, changing the characteristic impedance of the log-cell phase line has minimal effect. Using the same design—the original model 520 at the top of **Table 6-1**—I changed the characteristic impedance of the phase line, using a low value of 70 Ohms and a high value of 100 Ohms. The small pull on the gain curve toward a lower frequency and very slightly higher peak value shows up on **Fig. 6-7**.



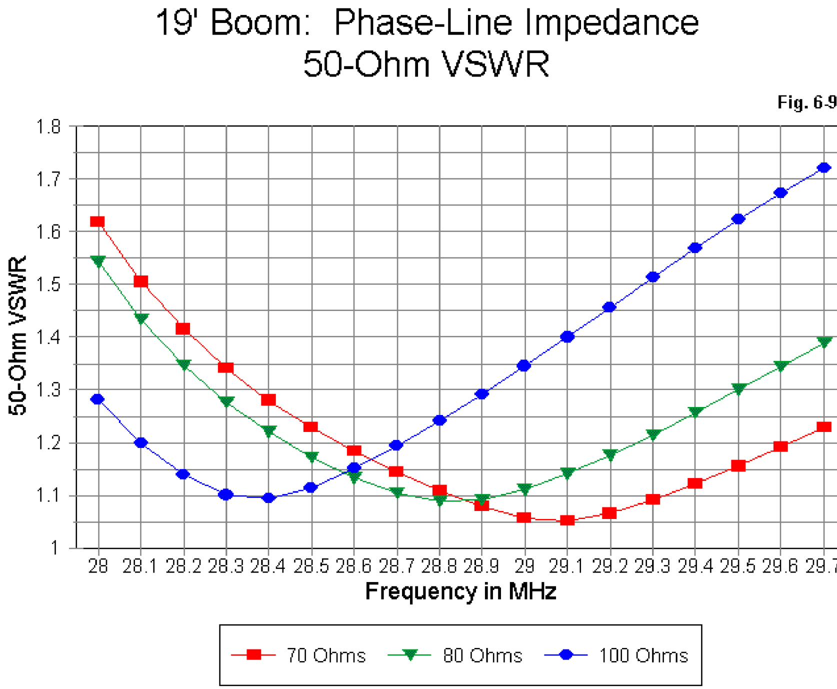
Much more profound is the effect of the phase-line impedance on the 180-degree front-to-back curve in **Fig. 6-8**. As the phase-line impedance increases, so too does the peak front-to-back ratio and the rate of change in value from one frequency to the next. In general, the smoothest front-to-back curves for long-boom log-cell Yagis occur with the lowest obtainable phase-line characteristic impedance.

The characteristic impedance of the phase line is directly related to the resistive component of the cell feedpoint impedance. The higher the line Zo, the higher the resistive part of the impedance. At the mid-band frequency (28.85 Mhz), the feedpoint impedance is 50 - j4 Ohms for the 70-Ohm design, 53 - j3 Ohms for the 80-Ohm model, and 63 + j1 Ohms for the 100-Ohm version of model 520. Moreover, the lowest feasible characteristic impedance for the log-cell also tends to yield the smoothest SWR curve. See **Fig. 6-9**.



Although element diameter and phase-line Zo produce relatively small changes in the performance curves compared to changing the length of the log-cell elements, these facets of log-cell Yagi design provide a measure of array design control. In effect, by varying one or both of these parameters, the designer can tailor the performance curves more closely to a desired profile.

4. The Parasitic Elements: From the analyses so far given, we can begin to redesign some of the original log-cell Yagis that we initially sampled. Models 514 and 520 would both benefit from lengthening the log-cell elements to center the gain curve within the 10-meter pass band. As well, reducing the phase-line Zo to about 70 Ohms would reduce the front-to-back excursions in 514. Obviously, we would need to adjust the director length and/or spacing to bring all three performance curves into a maximally centered position, if one or more of the curves was not smooth enough to suit standards applied to the design.



Two of the designs appear to achieve the smoothest performance across the band. Model 528 achieves the smoothest gain curve and an acceptably high front-to-back ratio, despite a small "bump" in the curve near 28.2 MHz. The model's impedance ranges from about 38 to 65 Ohms resistance and from -13 to + 20 Ohms reactance. Hence, its VSWR curve will not match that of model 526.

526 manages the smoothest composite set of performances curves of any of the initial models. The gain varies by under 0.25 dB across the band, while the front-to-back ratio varies by under 0.8 dB. The 50-Ohm SWR is under 1.5:1 across the band. In exchange for the smooth performance, the front-to-back ratio never exceeds 26.5 dB, a somewhat low figure for log-cell Yagi designs in general.

For the moment, our question is simple: how can we obtain this performance (other than simply by replicating the design in hand)? The answer emerges from the way in which we size and place the parasitic elements. The initial guidelines provided by Rhodes for placing the director and reflector call for spacings from the nearest log-cell element of 0.15 and 0.085 wavelengths, respectively. In general, the use of these spacing values will net a working log-cell Yagi, with two provisos: a. The lengths of these element will change as the value of σ increases, and b. The spacing—especially of the director—will increase with increases in the value of σ.

Close spacing of the director and reflector tends to yield the highest values of front-to-back ratio. The front-to-back ratio will be somewhat erratic with close spacing of the parasitic elements, and gain will not be maximum. Smoothing the front-to-back ratio across a wide operating passband requires increased spacing between the log cell and the two parasitic elements. Model 526 shows the degree of increase necessary. The reflector is spaced about 0.12 wavelengths from the rear element of the log cell, while the reflector is about 0.19 wavelengths ahead of the cell.

To test and illustrate the principles of parasitic element placement, I returned once more to model 520. The first revision of this model in **Table 6-1** has a log cell that is almost perfectly proportional to the one used in the longer model 526. I then used reflector and director spacings similar to those in the longer model to smooth the performance of the shorter version of the array. To further match the models, I decreased the phase-line Zo to 65 Ohms and increased the element diameter to 0.75". **Table 6-2** reviews the dimensions of model 526, along with the subsequent revisions to model 520 that attempt to achieve similar performance curves (at, of course, a lower gain level).

Table 6-2. Dimensions of Wide-Band Log-Cell Yagis

5-Element Log-Cell (7-Element Array): Model 526

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	9.00	0.264	—	—
LC1	8.36	0.245	4.12	0.121
LC2	7.91	0.232	8.19	0.240
LC3	7.47	0.219	12.06	0.354
LC4	7.09	0.208	15.73	0.461
LC5	6.73	0.198	19.21	0.563
Director	6.30	0.185	25.80	0.757

τ = 0.95 σ = 0.121 Element Diameter = 0.75" Phase Line Zo = 65 Ohms

Revision 1 to Model 520

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	8.80	0.258	—	—
LC1	8.50	0.249	2.89	0.085
LC2	8.08	0.237	5.81	0.171
LC3	7.67	0.225	8.59	0.252
LC4	7.29	0.214	11.23	0.330
LC5	6.92	0.203	13.74	0.403
Director	6.65	0.195	19.40	0.569

τ = 0.95 σ = 0.0860 Element Diameter = 0.5" Phase Line Zo = 80 Ohms

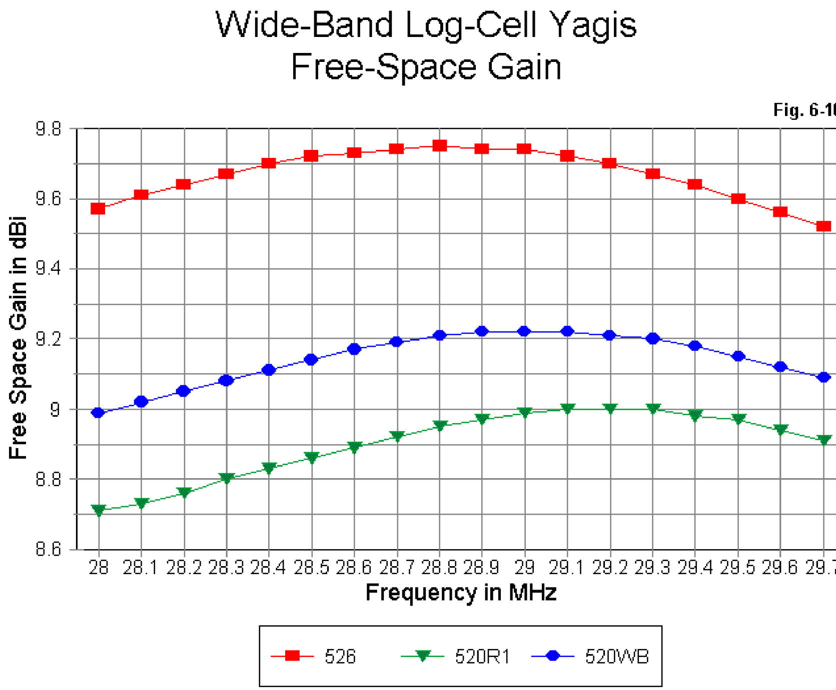
Wide-Band Version of Model 520

Element	Half-Length		Spacing from Reflector	
	Feet	Wavelengths	Feet	Wavelengths
Reflector	9.00	0.264	—	—
LC1	8.50	0.249	4.10	0.120
LC2	8.08	0.237	7.02	0.206
LC3	7.67	0.225	9.80	0.287
LC4	7.29	0.214	12.44	0.365
LC5	6.92	0.203	14.95	0.438
Director	6.80	0.200	21.21	0.622

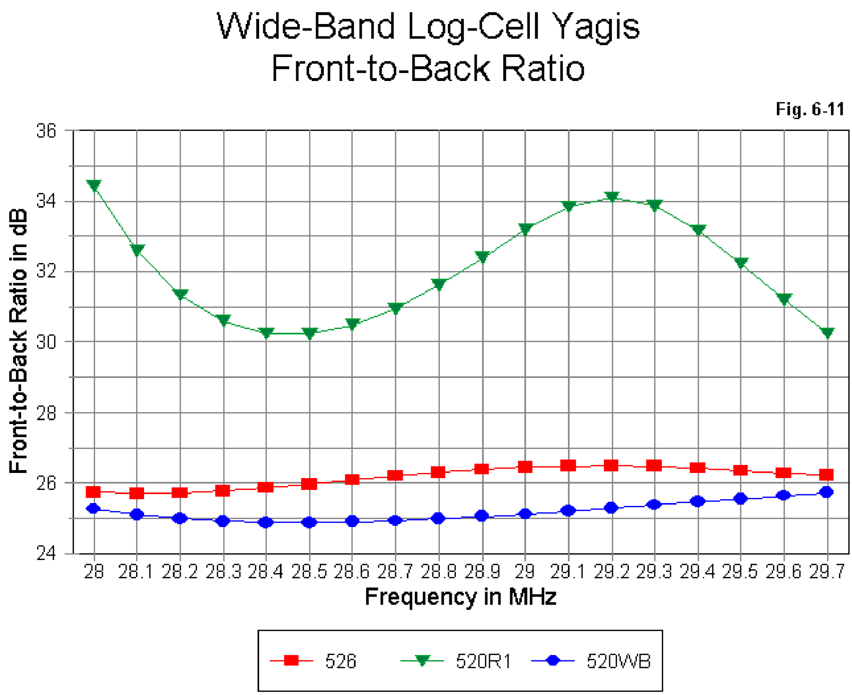
τ = 0.95 σ = 0.0860 Element Diameter = 0.75" Phase Line Zo = 65 Ohms

Of course, in the process of increasing the parasitic element spacing, the total model length for 520 grew to about 21.1'. **Table 6-2** summarizes the results by giving the dimensions for model 526, for the first revision of 520, and for the wide-band version of 520. The long reflector of the wide-band version of 520 is identical to that use in 526 and also is about 0.12 wavelength behind the log cell. The required director for 520 is longer but less widely spaced than the one used in 526. Smaller spacing calls for longer director elements in most parasitic designs.

Fig. 6-10 compares the gain of the three models on which we are focused. 526 has the highest and best-centered gain curve. However, the wide-band version of 520 shows increased gain and better curve centering relative to the design version on which it is based. Part of the centering derives from the decrease in phase-line Zo, while part of the gain increase stems from the use of larger diameter elements. However, some of the increase can also be ascribed to the overall lengthening of the array. The gain differential across the 10-meter band for 520 has fallen to 0.23 dB.

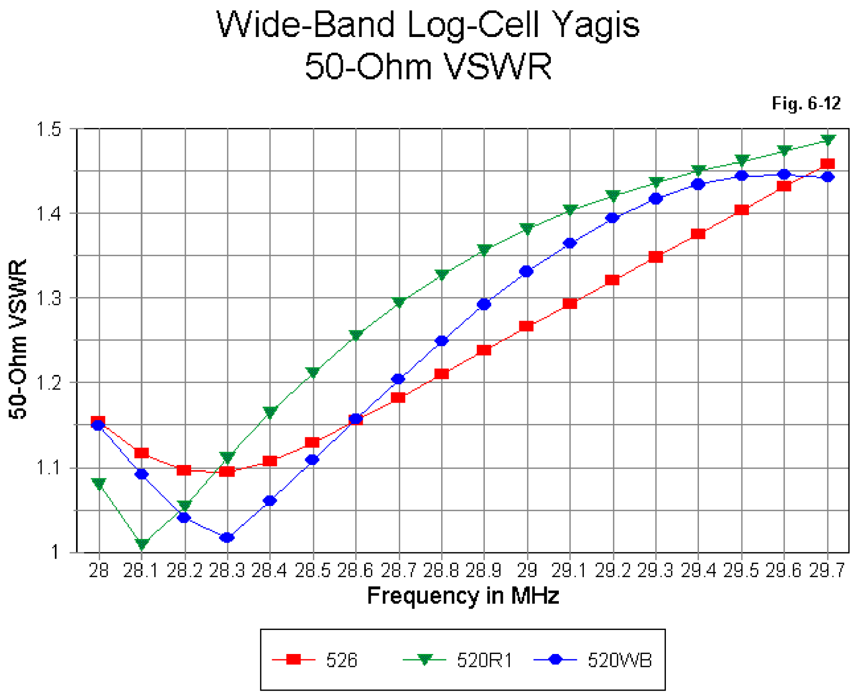


The front-to-back ratio of the wide-band version of 520 exhibits a similar levelness, as shown in **Fig. 6-11**. The differential is less than 0.85 dB across the band, which is far smoother than provided by the base-line model, whose front-to-back curve is also traced in the graphic. The cost of such even performance is, of course, a lowering of the intrinsic front-to-back values by an average of 7 dB, down to the 25 dB level. Note also that the front-to-back ratio of the wide-band version of 520 is about a half dB lower than for model 526.



Because model 520 was not optimized to center its gain curve prior to working with the parasitic elements, the 50-Ohm VSWR curve in **Fig. 6-12** has a slightly different shape than the corresponding curve for model 526. However, the SWR never rises above 1.45:1 across 10 meters and the curves for 526 and 520-wide-band reach their minimum values at the same frequency. A log-cell Yagi with the smoothest pass-band performance, then, will not usually have the double-dip SWR curve of a very wide-band Yagi.

The exercise establishes that achieving flatter performance curves, especially for gain and front-to-back ratio, is possible for virtually any boom length that is feasible with a 5-element log cell. Spreading the reflector and director elements provides added gain but decreased front-to-back ratio in the process of smoothing the performance curves. In contrast, closer spacing of the reflector and director yield higher but more erratic front-to-back values, as well as a bit less gain.



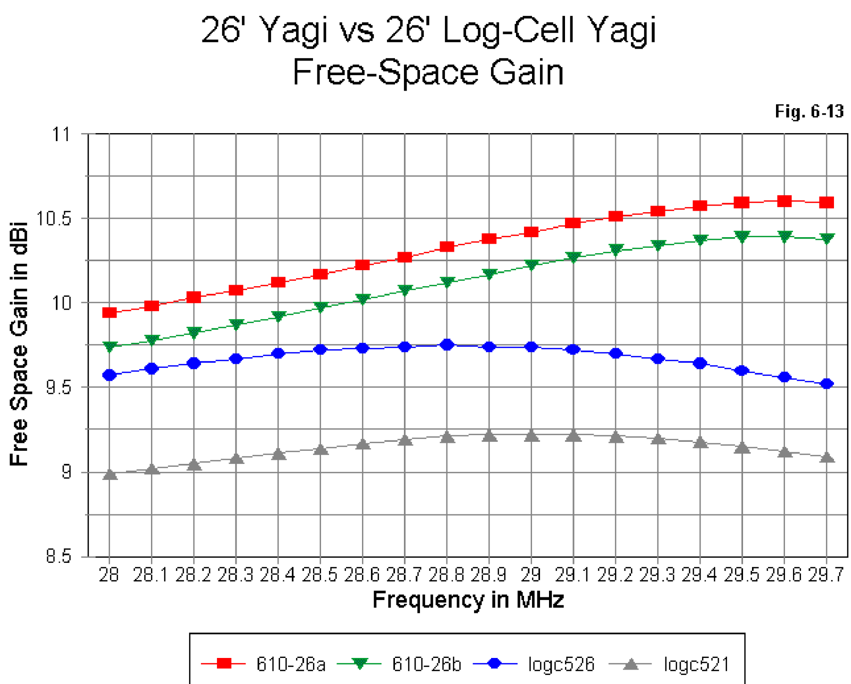
A Comparison with Wide-Band Yagis

The analyses of the parameters affecting the performance of log-cell Yagis has aimed at producing a better understanding of how each design variable contributes to the final design. In the process of developing the analysis, we have encountered some models that have interesting properties, not the least of which are the wide-band models with relatively constant performance over the spread of the 10-meter band. Although the main purpose of these notes is not either to promote or denigrate the log-cell Yagi, some comparisons may be inevitable. So far, we have developed performance numbers, but placing those numbers into some sort of usable perspective remains undone.

All of the log-cell Yagis we have examined use a total of seven elements. At the 26' boom length, it is possible to develop a wide-band 6-element Yagi. One preliminary design of promise has emerged from the work of Dean Straw, N6BV. The dimensions appear in **Table 6-3**. The design should be considered provisional and subject to further optimization. In the graphs that follow, performance values are given for this array and an earlier version of it, along with values for models 520 and 526.

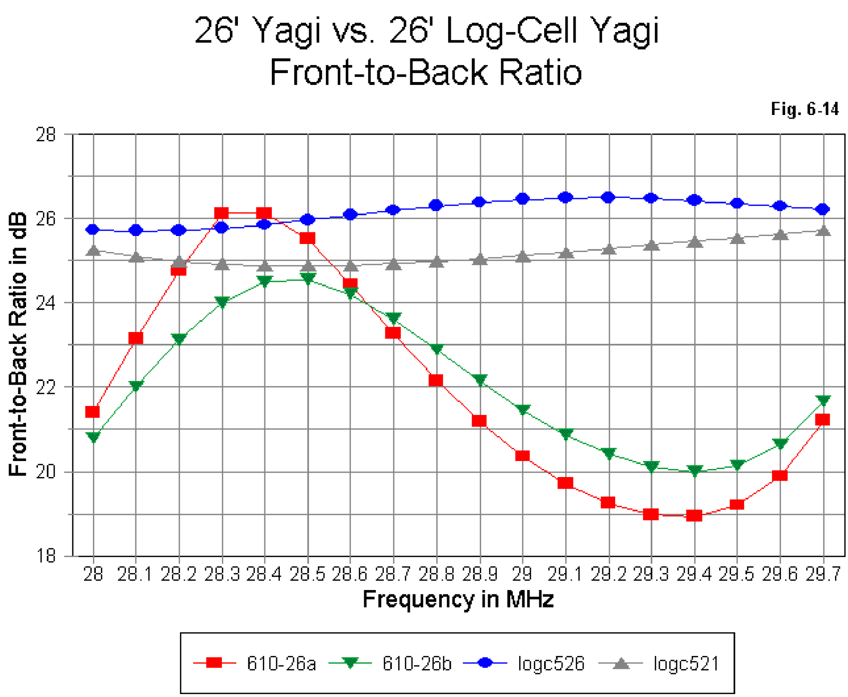
Table 6-3. Dimension of a Wide-Band 6-Element 10-Meter Yagi

Element	Half-Length Feet	Spacing from Reflector Feet
Reflector	8.75	——
Driver	8.21	3.95
Dir. 1	7.75	6.19
Dir. 2	7.59	11.35
Dir. 3	7.67	17.95
Dir. 4	7.32	26.00



As shown in **Fig. 6-13**, the Yagi shows superior gain to the log-cell Yagi, despite the equivalency of boom length. The average gain of the better Yagi is about 10.3 dBi, for an advantage over the log-cell Yagi (model 526) of about 0.6 to 0.7 dB. Typical of Yagis with directors, the gain increases with frequency and does not peak until 29.6 MHz. The total variation in gain across the band is about 0.65 dB. In contrast, the 26' log-cell Yagi varies by less than 0.25 dB across the band.

The front-to-back ratio of the log-cell Yagi is the same across 10 meters, varying by less than 0.8 dB. As is evident in **Fig. 6-14**, the Yagi front-to-back ratio varies by more than 7 dB. The early version of the array reaches the level of the log-cell Yagi for only a small portion of the pass band, near the lower end of the band. The perfected Yagi (610-26b) settles for a slightly lower peak front-to-back value, but less variation in that value across the band.



The graphed figures are, as usual, for the 180-degree front-to-back ratio. There is an additional advantage that accrues to the log-cell Yagi with respect to its rear lobes.

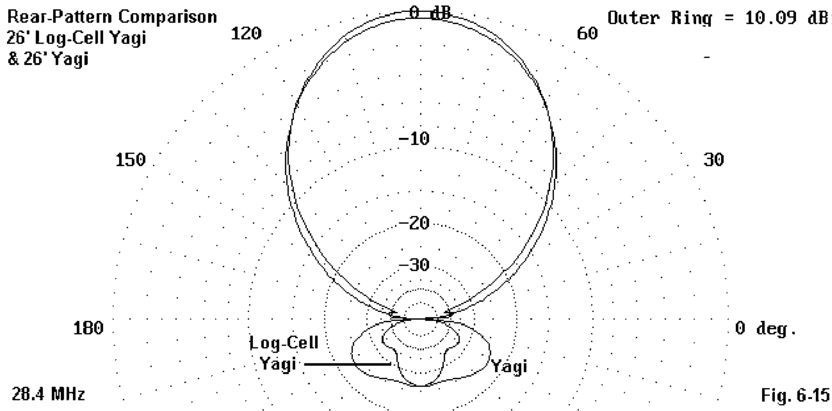
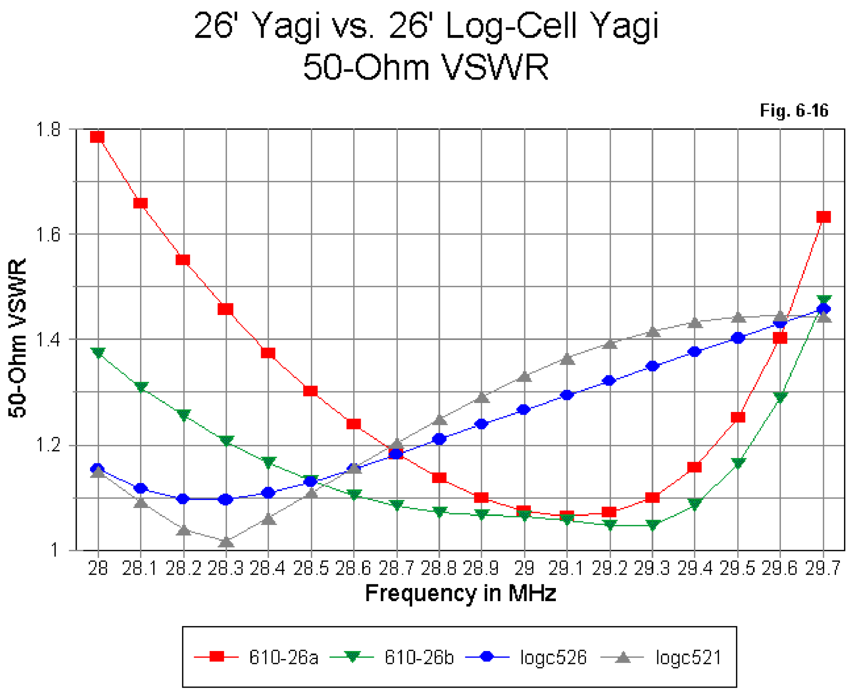


Fig. 6-15

Fig. 6-15 overlays azimuth patterns at 28.4 MHz for the two antennas near the Yagi peak front-to-back peak value. As we noted with respect to **Fig. 5-8** in the last chapter, the rear lobes of the log-cell Yagi tend to have a 180-degree front-to-back ratio which is also the worst case front-to-back ratio. Hence, an average front-to-rear ratio for the log-cell design would show a higher value. However, the Yagi rear pattern shows stronger radiation in quartering directions. Hence, the averaged front-to-rear ratio would show a lower value than the 180-degree front-to-back ratio. The patterns in the figure are not only typical of those at every frequency across the band for these designs, they are also typical of the general classes of long-boom, wide-band Yagi and of long-boom log-cell Yagi designs.

In **Fig. 6-16**, we find the 50-Ohm VSWR curves for the two 26' arrays. The Yagi SWR curve, which peaks at about 1.8:1, can be refined into a double dip curve with a lower peak value. However, the log-cell Yagi curve, with a peak value just above 1.45:1, would remain slightly superior.

The comparison of the long-boom Yagi to the long-boom log-cell Yagi is designed solely to place a few specifications in perspective. Consistent with the results for short-boom log-cell Yagis, long-boom log-cell Yagis do not yield as much forward gain as comparably long pure Yagi designs. However, the log-cell Yagi can be tailored to yield either very high front-to-back values or to have roughly equal gain and front-to-back values across a band as wide as 10 meters.



In the end, the type of array that a builder chooses will be a function of the specifications brought to the selection process. I hope these notes contribute to an understanding of what log-call Yagis can produce by way of long-boom performance and the ways in which the many design variables contribute to the achievement of that performance.

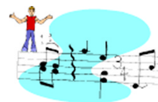
References

The ARRL Antenna Book, 19th Edition (Newington, 1997), Chapter 10.
W. I. Orr, and S. D. Cowan, *Beam Antenna Handbook*, pp. 251-253.

P. D. Rhodes and J. R. Painter, ?The Log-Yag Array,? *QST*, Dec 1976, pp 18-21.

R. F. Zimmer, “Three Experimental Antennas for 15 Meters,” *CQ*, Jan 1983, pp 44-45.

R. F. Zimmer, “Development and Construction of ‘V’ Beam Antennas,” *CQ*, Aug 1983, pp 28-32.



Part 3 Practical LPDA Design Considerations

Chapter 7: Ham-Band vs. Ham-Band-Plus LPDAs

The primary use—and perhaps the only feasible use—of a log-cell Yagi, whatever its length, is as a monoband directional array. The addition of the parasitic elements front and rear restricts frequency coverage, even if the development of an adequate log-cell broadens and smoothes the response across the passband. This restriction stands in contrast to the simple high-end enhancing addition of a director, which we explored in Volume 1. The single director elevates performance at the upper end of the passband without restricting low-end performance.

In this chapter, I wish to explore in a preliminary way the feasibility of using a pure LPDA to cover a wide amateur band. Certainly we can design such an antenna. However, the key question is whether such designs offer any advantages over other designs with which the LPDA might compete. The most used antenna for the amateur bands is the Yagi-Uda parasitic array, and this antenna type will form the key comparator for our small investigation.

We shall proceed in two steps. First, we shall look at some special designs for the 10-meter band, that is, for the entirety of the 10-meter band from 28.0 to 29.7 MHz. Then we shall look at some 2-meter possibilities.

10-Meter Wide-Band Yagis and LPDAs

As a matter of curiosity more than practicality, I examined the possibility of developing a directional array for 10 meters that would cover the entire band. Antennas for the first MHz of the band abound, but the thought of having a wide-band antenna for all of 10 meters was intriguing. Wide-band 3-element Yagis, developed by Orr and others, do exist, but they require a 12' boom to achieve the gain of a 1 MHz, 8'-boom 3-element Yagi. To make the challenge somewhat more interesting, I restricted myself to a total element spacing of 8' (96"). The desired minimum free-space gain across the band was 7 dBi and the desired minimum 180 degrees front-to-back ratio was 20 dB.

From these exercises, there emerged both a Yagi and an LPDA design that met the basic criteria for the challenge. In the course of looking at log-cell Yagis, we had occasion to use both of these designs as comparators for various log-cell configurations. However, perhaps it may be useful to place the final construction versions of these antennas side-by-side in order to assess their merits.

4-Element 28-29.7 MHz Yagi Outline

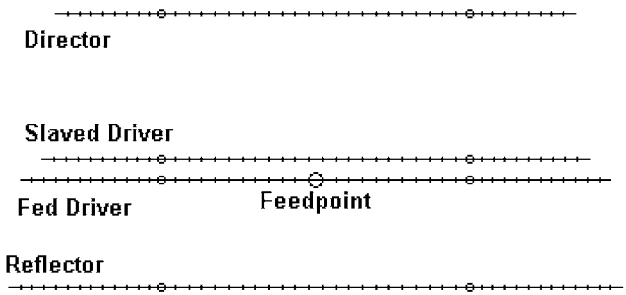


Fig. 7-1

Fig. 7-1 provides an outline sketch of the wide-band Yagi. The design requires 4 elements. Essentially (but not absolutely purely), the design can be viewed as a 3-element Yagi with an extra driver that is open-sleeve coupled to the fed driver. The circles on each element indicate that the inner portions of the elements—54" each side of the centerline—consist of 5/8" tubing, while the outer ends are 1/2" diameter tubing. The following model description provides all of the key dimensions.

```
4-el WB Yagi                                    Frequency = 28.85  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,-107.75,  0.000  W2E1   0.000,-54.000,  0.000 5.00E-01  13
2      W1E2   0.000,-54.000,  0.000  W3E1   0.000, 54.000,  0.000 6.25E-01  23
3      W2E2   0.000, 54.000,  0.000         0.000,107.750,  0.000 5.00E-01  13
4            37.500,-103.60,  0.000  W5E1  37.500,-54.000,  0.000 5.00E-01  12
5      W4E2  37.500,-54.000,  0.000  W6E1  37.500, 54.000,  0.000 6.25E-01  23
6      W5E2  37.500, 54.000,  0.000        37.500,103.600,  0.000 5.00E-01  12
7            45.000,-95.900,  0.000  W8E1  45.000,-54.000,  0.000 5.00E-01  10
```

```
8     W7E2  45.000,-54.000,  0.000  W9E1  45.000, 54.000,  0.000 6.35E-01  23
9     W8E2  45.000, 54.000,  0.000        45.000, 95.900,  0.000 5.00E-01  10
10          96.000,-91.300,  0.000 W11E1  96.000,-54.000,  0.000 5.00E-01  9
11   W10E2  96.000,-54.000,  0.000 W12E1  96.000, 54.000,  0.000 6.25E-01  23
12   W11E2  96.000, 54.000,  0.000        96.000, 91.300,  0.000 5.00E-01  9

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

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

1          12     5 / 50.00   (  5 / 50.00)      1.000       0.000       I
```

4-Element 28-29.7 MHz LPDA Outline

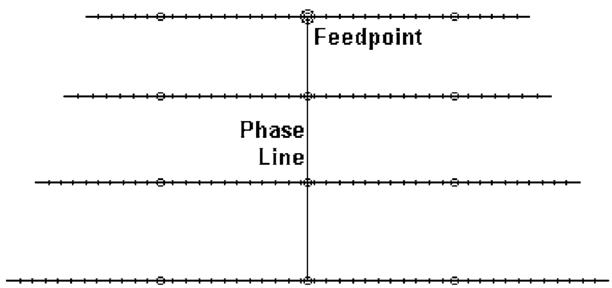


Fig. 7-2

In physical contrast to the wide-band Yagi is the 4-element LPDA that I designed to achieve the same goals **Fig 7-2**. The overall length is the same as the Yagi, and the elements use the same inner and out section tubing diameters. However, the LPDA uses a 75-Ohm phase-line with the feedpoint located at the forward end of the array. The model description will reveal some other interesting differences between the two array types.

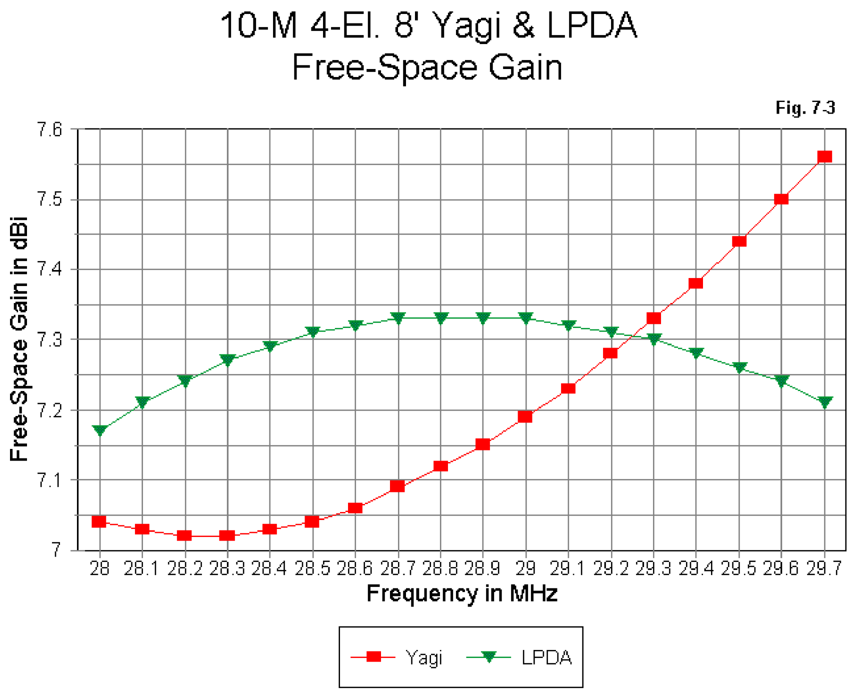
```
lpda 10m                                      Frequency = 28.85  MHz.

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,-110.00,  0.000  W2E1   0.000,-54.000,  0.000 5.00E-01  12
2     W1E2   0.000,-54.000,  0.000  W3E1   0.000, 54.000,  0.000 6.25E-01  23
3     W2E2   0.000, 54.000,  0.000         0.000,110.000,  0.000 5.00E-01  12
```

```
4             35.605,-99.400,  0.000  W5E1  35.605,-54.000,  0.000 5.00E-01  10
5      W4E2  35.605,-54.000,  0.000  W6E1  35.605, 54.000,  0.000 6.25E-01  23
6      W5E2  35.605, 54.000,  0.000        35.605, 99.400,  0.000 5.00E-01  10
7             67.475,-88.850,  0.000  W8E1  67.475,-54.000,  0.000 5.00E-01  7
8      W7E2  67.475,-54.000,  0.000  W9E1  67.475, 54.000,  0.000 6.25E-01  23
9      W8E2  67.475, 54.000,  0.000        67.475, 88.850,  0.000 5.00E-01  7
10            96.000,-81.000,  0.000 W11E1  96.000,-54.000,  0.000 5.00E-01  6
11    W10E2  96.000,-54.000,  0.000 W12E1  96.000, 54.000,  0.000 6.25E-01  23
12    W11E2  96.000, 54.000,  0.000        96.000, 81.000,  0.000 5.00E-01  6

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

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

1          12    11 / 50.00   ( 11 / 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   75.0  1.00  R
2      5/50.0  (  5/50.0)    8/50.0  (  8/50.0)  Actual dist   75.0  1.00  R
3      8/50.0  (  8/50.0)   11/50.0  ( 11/50.0)  Actual dist   75.0  1.00  R
```

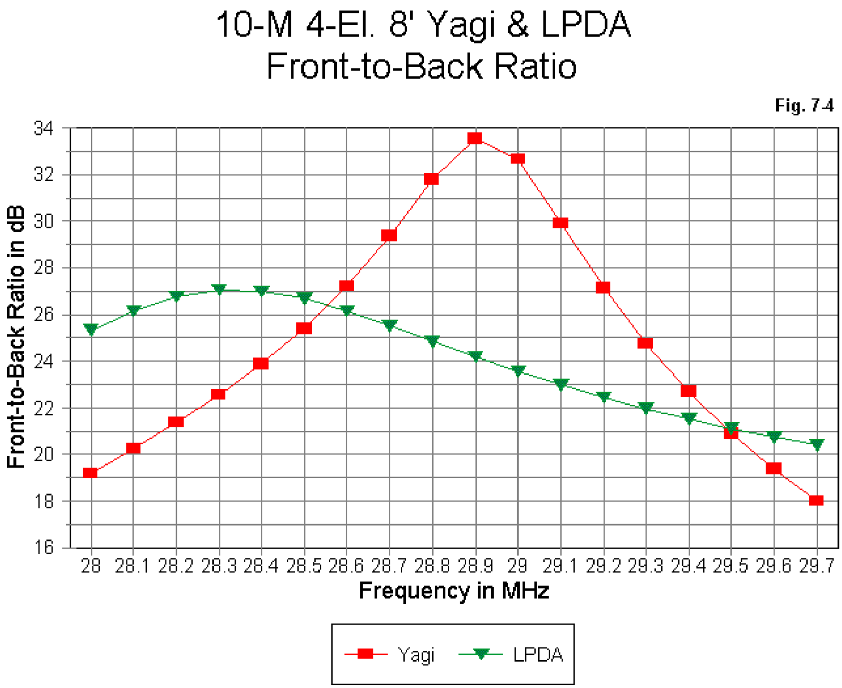
First, the element spacing is quite different, since the array is a true 4-element LPDA and not a double-driver 3-element beam. However, the LPDA uses variable values of τ and σ between elements, the result of individualized element adjustments in the hunt for smooth performance across the 1.7 MHz of the 10-meter band. Second, the taper of element lengths is much higher than with the Yagi. Although the rear elements are comparable, with the LPDA slightly longer, the forward element of the Yagi is a full 10" longer than the forward element of the LPDA. As we have seen, the upper frequency “cut” for the forward element must be for a frequency considerably higher than the intended highest operating frequency. Even a monoband LPDA is no exception to this guiding principle.

There is probably no physical advantage to either design. The LPDA requires a phase line, which I built from 1/2" L-stock. This system allowed me to use the same basic boom and element materials for both versions of the test antennas. The added construction time for the LPDA was offset virtually completely by the time it took to adjust the two drivers of the wide-band Yagi for performance curves that reflected the modeled version of the array.

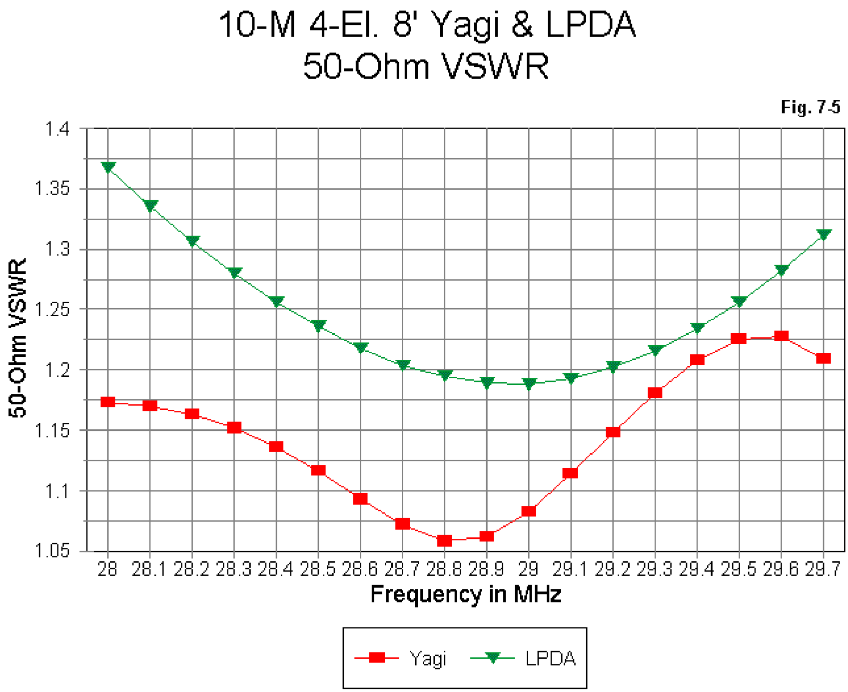
In the end, performance of the two arrays was as indistinguishable as the time of construction and adjustment. **Fig. 7-3** shows the modeled free-space gain pattern for the two antennas. The LPDA achieves a very smooth curve with only about 0.16 dB differential between the maximum and minimum values. The Yagi shows the typical 3-element rise in gain across the band. However, the Yagi average gain about matches that of the LPDA, and the differences are not operationally significant.



The average front-to-back values (**Fig. 7-4)** for the arrays are also about the same, although the LPDA exhibits the smoother curve with under 7 dB total difference between the low and high values. The Yagi curve has a very high peak, but the band-edge front-to-back ratio falls off on both ends of the passband to values below 20 dB. However, since 180-degrees front-to-back ratios to not tell the entire story about rearward performance and since increments in front-to-back ratio less than 3 dB are not especially operationally significant when the average value is 20 dB or more, the Yagi pattern proved to be entirely acceptable.



The 50-Ohm SWR (**Fig. 7-5)** curves for the two arrays also show no significant operational differences. The Yagi curve is an outstanding one, with no value in excess of 1.23:1. However, the highest value for the LPDA is about 1.37:1, which is not a concern at 10 meters under almost any set of circumstances. With some redesign of the flat-face phase-line, the curve can be brought lower, since the narrow operating bandwidth of the array presents no potential for the weaknesses that appear in wide-band LPDAs with low-impedance phase lines. However, for the present exercise, such redesign was superfluous, since the design goals gave more importance to the gain and front-to-back performance curves.



Between the two design, each of which I believe to "milk" as much from an 8' boom as possible within the design specifications, there is not much, if anything, to choose. Both types of antennas achieve the gain goal, and the average again is above the minimum desired value. Except for the band-edges, the Yagi achieves the front-to-back goal, and the average front-to-back value for both arrays is quite similar and well above the values usually seen, even in arrays for only the first MHz of 10 meters. The Yagi has a numerically superior potential for edge-to-edge SWR, but both arrays would have to be accounted superior in this category of concern. In the end, if one had to choose among the arrays, the decision would come down to one's preference for simplicity of structure—a Yagi advantage—or simplicity of initial adjustment—which favors the LPDA.

The equality of the arrays also shows itself in the radiation patterns. **Fig. 7-6** overlays the free-space azimuth patterns for the 2 antennas, with the outer ring representing the maximum gain of each array at the sampled frequency. There is no difference in horizontal beamwidth, as evidenced by the fact that one cannot distinguish one forward pattern line from the other. The rearward lobes have different structures, but the overall power in each is roughly the same.

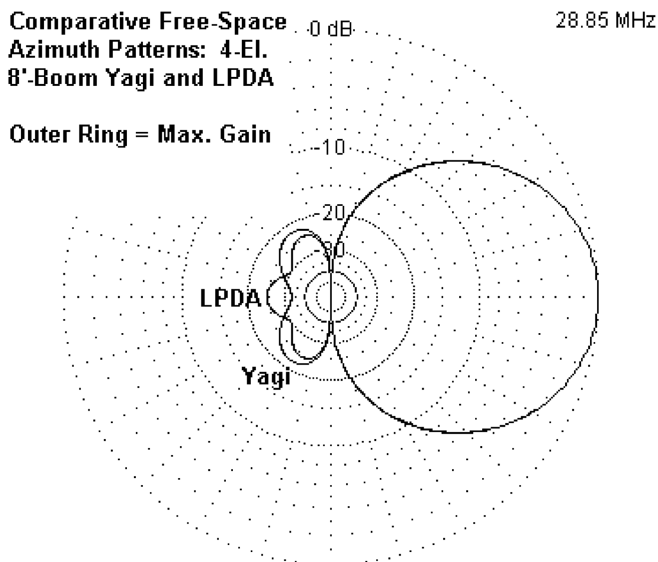


Fig. 7-6

Our initial question wondered if there is any advantage to using LPDA arrays for monoband purposes. In the case of our special wide-band 10-meter project, we could find none. But then, we also could not find a reason not to use an LPDA for the specified design goals.

2-Meter Wide-Band Yagis and LPDAs

Except for the 80/75-meter band, 10 meters is the widest of the HF amateur bands, with a 5.9% bandwidth relative the center frequency of the band. Above 10 meters, the 6-meter band is wider at 7.7% and, depending on how one figures it, the 432 MHz band can be count for a bandwidth up to 6.7%. Other VHF bands may be wider in the available frequency space, but are lesser in terms of bandwidth. For example, 2 meters is only 2.8% wide.

It is possible to use LPDAs for essentially monoband purposes on 2 meters, but the circumstances that give good sense to that use will change. Consider the 6-element LPDA design sketched in **Fig. 7-7**. It is 54" long by design and uses a τ of 0.924 with a σ of 0.146. The antenna was designed for peak performance within the 2-meter band, at least peak performance that is commensurate with smooth gain and front-to-back ratio curves. To maximize performance within normal building parameters for 2-meter antennas, the LPDA uses 3/16" diameter elements. 1/8" diameter elements might be used with either some readjustment of dimensions or a slight decrease in performance. 0.25" diameter elements are also possible for this array. The particulars of the design show up in the model description.

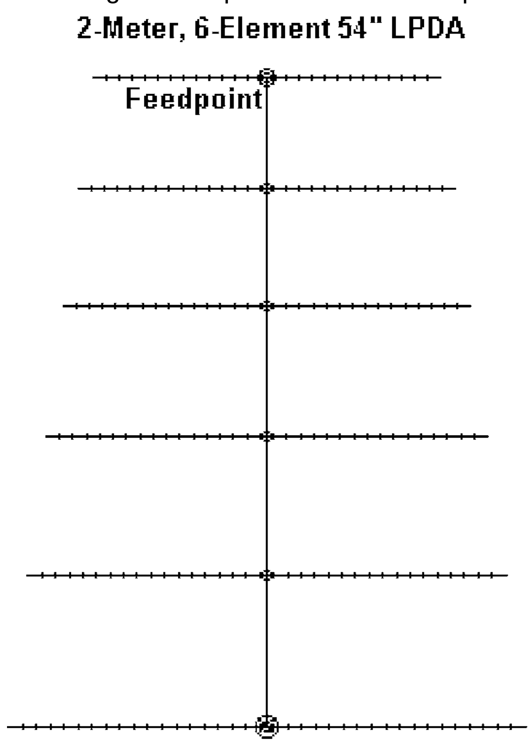


Fig. 7-7

```
2-meter LPDA .92/.15                                Frequency = 146  MHz.

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


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

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

1             0.000,-21.507,  0.000         0.000, 21.507,  0.000 1.88E-01  37
2            12.574,-19.870,  0.000        12.574, 19.870,  0.000 1.88E-01  35
3            24.191,-18.358,  0.000        24.191, 18.358,  0.000 1.88E-01  33
4            34.924,-16.960,  0.000        34.924, 16.960,  0.000 1.88E-01  31
5            44.839,-15.669,  0.000        44.839, 15.669,  0.000 1.88E-01  29
6            54.000,-14.476,  0.000        54.000, 14.476,  0.000 1.88E-01  27

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

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

1          14     6 / 50.00   (  6 / 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   75.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist   75.0  1.00  R
3      3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist   75.0  1.00  R
4      4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist   75.0  1.00  R
5      5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist   75.0  1.00  R
6      1/50.0  (  1/50.0)  Short ckt (Short ck)    4.000 in    75.0  1.00
```

The design uses a 75-Ohm phase line composed of two pieces of U-channel stock with the rear flat sides facing each other at a spacing of about 0.32". This method of twin-boom construction is common in the VHF and UHF ranges. It permits the elements to be press-fit into hole pairs at each location. Alternatively, for home construction, one can tap the side-face holes and screw the elements in place, using nuts within the U-channel to lock the elements in place.

The LPDA design shown here uses a 4" 75-Ohm shorted stub, the physical length of which is adjusted for the velocity factor of the coaxial line used to form the stub. The 75-Ohm phase line permits the use of 50-Ohm cable for a direct feed system.

Before we examine the potential operating potential of this LPDA, let examine another 54" boom design, this time a 6-element Yagi designed to OWA principles.

Fig. 7-8 sketches the outline of the antenna. The design is for elements that are insulated from the boom. The feedpoint impedance has been set close to 50 Ohms for a direct 50-Ohm coax feed system.

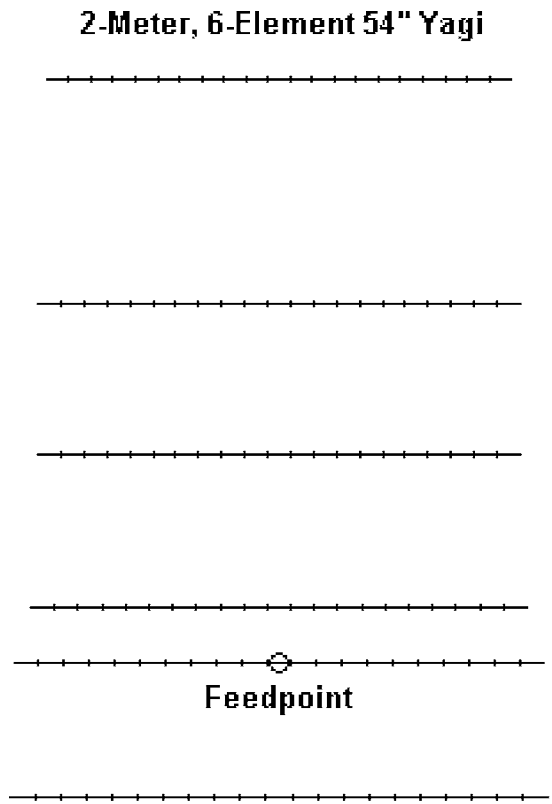


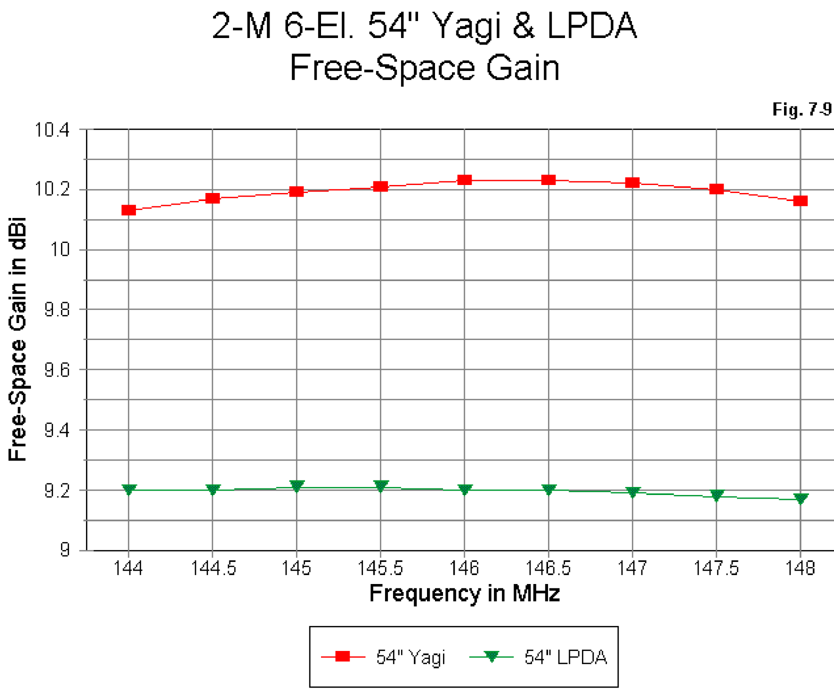
Fig. 7-8

The first director of the array is closer than one might usually expect for such an array. Its function is mainly to work in conjunction with the reflector spacing to set the feedpoint impedance and to sustain that impedance over a wide range of frequencies—here 144 to 148 MHz. The overall gain potential is thus about equivalent to that of a standard 5-element Yagi design of the same boom length. For reference, the following model description provides full dimensional details.

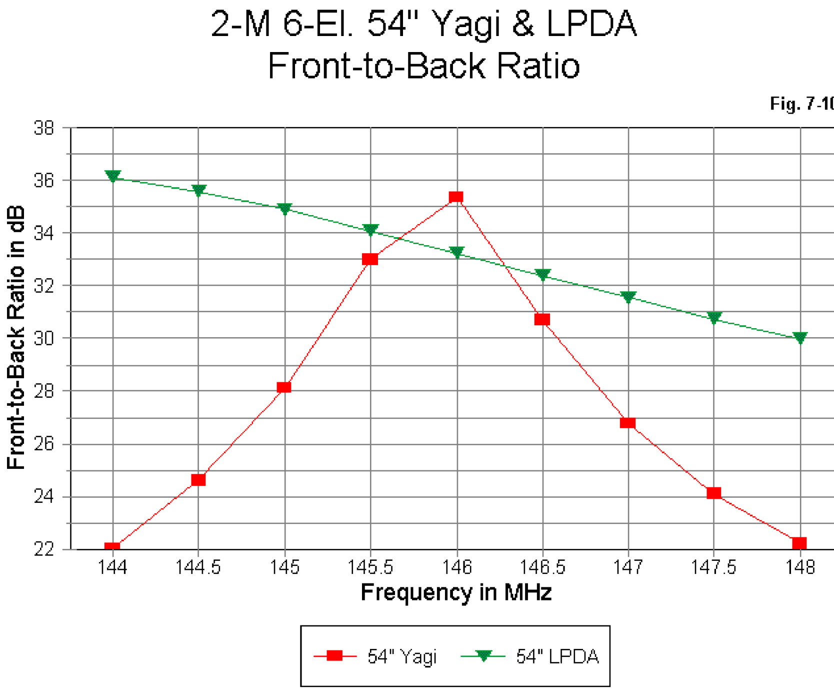
```
6-el 2M Yagi                                    Frequency = 146  MHz.

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

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

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

1            0.000,-20.260,  0.000         0.000, 20.260,  0.000 1.88E-01  21
2           10.130,-19.981,  0.000        10.130, 19.981,  0.000 1.88E-01  21
3           14.322,-18.688,  0.000        14.322, 18.688,  0.000 1.88E-01  21
4           25.926,-18.155,  0.000        25.926, 18.155,  0.000 1.88E-01  21
5           37.282,-18.155,  0.000        37.282, 18.155,  0.000 1.88E-01  21
6           54.218,-17.480,  0.000        54.218, 17.480,  0.000 1.88E-01  21

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

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

1          11     2 / 50.00   (  2 / 50.00)     1.000       0.000       I
```

Like the LPDA, the array uses 3/16" diameter elements. 4-mm elements would be a close substitute and require no adjustment of the elements. However, moving down to 1/8" diameter elements or up to 1/4" diameter elements would likely require some tweaking of the design. Like the LPDA, the design presumes elements that are insulated from the boom, in addition to the required insulation of the driver from the boom for a direct feed system. Of course, a builder might wish to construct this antenna using a fiberglass or polycarbonate boom.

Since the two antennas are within about 0.22" of boom length from each other, it makes sense to compare performance within the 2-meter band. **Fig. 7-9** provides the free-space gain curves from 144 to 148 MHz, and both curves are both flat and smooth. However, the Yagi manages on the same boom length about a full dB of extra gain. This gain level is not a fluke, but is common to 5-element standard and 6-element OWA Yagis at virtually any frequency when the boom length, element lengths, and element diameters are properly scaled. We shall require adjustments in element lengths and spacings wherever the scaled element size proves to be impractical at the new frequency or wherever the builder uses a schedule of element diameter tapering. Nonetheless, the OWA Yagi has a clear superiority over the LPDA in the gain category.



At first appearances from **Fig. 7-10**, the LPDA seems to enjoy a clear superiority of front-to-back ratio. The Yagi front-to-back ratio seems to exceed the LPDA for only about 1 MHz of the 4-MHz band. Clearly, the LPDA shows a very high front-to-back ratio, with about a 6 dB variation across the band. In contrast, the Yagi front-to-back ratio shows its typical peak—designed for mid-band placement in this array. There is a reason for placing the peak at the middle of 2 meters: by doing so, one can achieve roughly equal front-to-back values at the band edges. Perhaps the key factor to note is that the minimum front-to-back ratio for the Yagi is about 22 dB, which is normally considered a superior figure in Yagi performance and an operationally satisfactory ratio for almost any type of amateur operation. In the end, one might well need to operationally justify the need for additional front-to-back differential before opting for the LPDA.



Unlike the 10-meter situation, where the Yagi and LPDA designs had virtually interchangeable free-space azimuth patterns, the 2-meter patterns for the 54" arrays shows some important differences. **Fig. 7-11** overlays the two patterns at mid-band. The outer ring of the pattern represents the maximum gain of the antenna at 146 MHz in order to show more clearly the structural variations between the patterns. Two facets of the patterns are notable.

First, the Yagi exhibits a narrower beamwidth than the LPDA. Part of the beamwidth narrowing results from the higher gain. However, part is also a function of the arrangement of elements and their lengths. As one develops equivalently high gain

Yagis and LPDAs, the LPDAs tend to show smoother forward lobe outlines than do the Yagis.

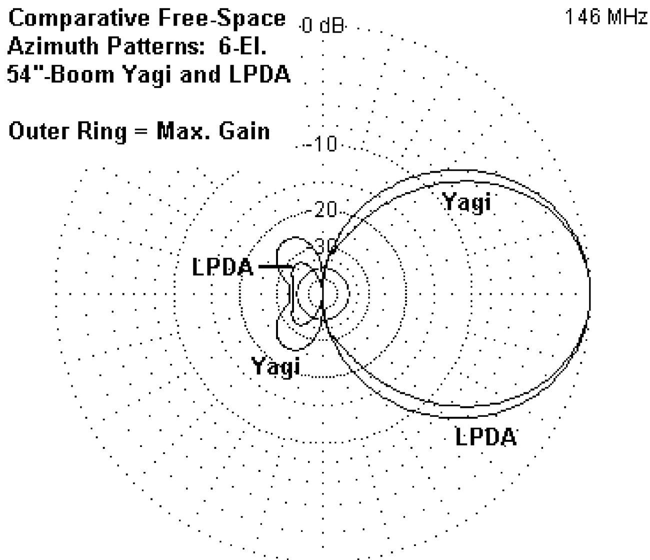
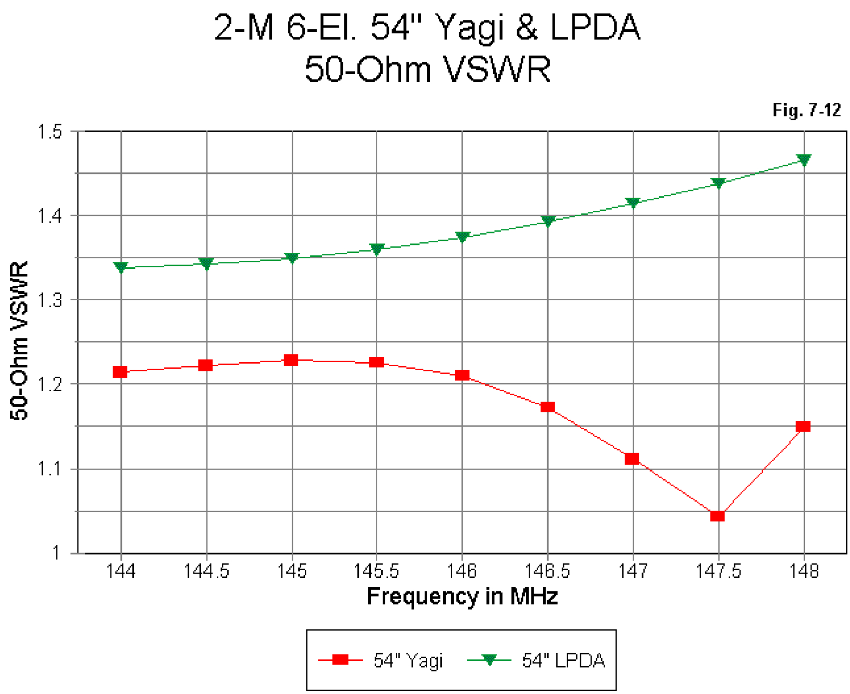


Fig. 7-11

The second aspect of the pattern to notice is the rear lobes for each type of array. Despite its lower gain, the LPDA shows a higher front-to-rear ratio by any standard one might wish to apply. Since the front-to-back ratio of an LPDA is directly proportional to its gain—with allowances to be made for the non-synchronized peaks and valleys of the two curves—higher gain LPDAs (above 8 dBi free-space gain) will normally show superior rearward behavior relative to most Yagis. In some cases, the LPDA's added suppression of rearward radiation may be useful or essential; in other cases, it may be superfluous.

The OWA Yagi, however, exhibits by design a superior 50-Ohm SWR curve to that yielded by the LPDA. As shown in **Fig. 7-12**, the 50-Ohm SWR for the Yagi remains below 1.25:1 throughout the 2-meter band. By judicious selection of the reflector and first director lengths and spacings from the driven element, the designer can achieve most reasonable values of low impedance so that direct drive via a common coaxial cable is possible. As well, lower impedances are possible so that one might step up the impedance to coaxial cable values and convert from a balanced antenna input to an unbalanced cable at the same time. Indeed, OWA design possibilities have yet to be fully explored.



The LPDA uses a 75-Ohm phase line, which results in an average feedpoint impedance of about 60 Ohms. Thus, the LPDA can be fed with either 50-Ohm or 75-Ohm cable. Further reduction of the average feedpoint impedance is possible by bringing the U-channel twin booms closer together. However, spacing grows more critical with reduction in the phase-line characteristic impedance, which may create construction challenges.

In the end, if the LPDA were specified for operation only within the 144 to 148 MHz range, the OWA Yagi with the same boom length and the same number of elements would be preferable. It has superior gain and a flatter SWR curve, with sufficient front-to-back ratio for virtually any operational situation.

The LPDA, on the other hand, offers a bonus in terms of its ability to provide reasonable gain and well-behaved patterns for a much larger bandwidth. The region below 2-meter—from about 130 to 144 MH—is populated largely by aeronautical mobile services, while the frequencies above 2 meters—up to about 170 MHz—serves both land and maritime communications. If monitoring either of these frequency ranges is part of a necessary or desired operation, then the LPDA may well be the antenna of choice.

Fig. 7-13 shows both the free-space gain and the front-to-back characteristics of the LPDA from 130 to 170 MHz in 5 MHz intervals. Although the gain falls off more rapidly above than below the 2-meter band, it remains above 7 dBi to the upper limit of

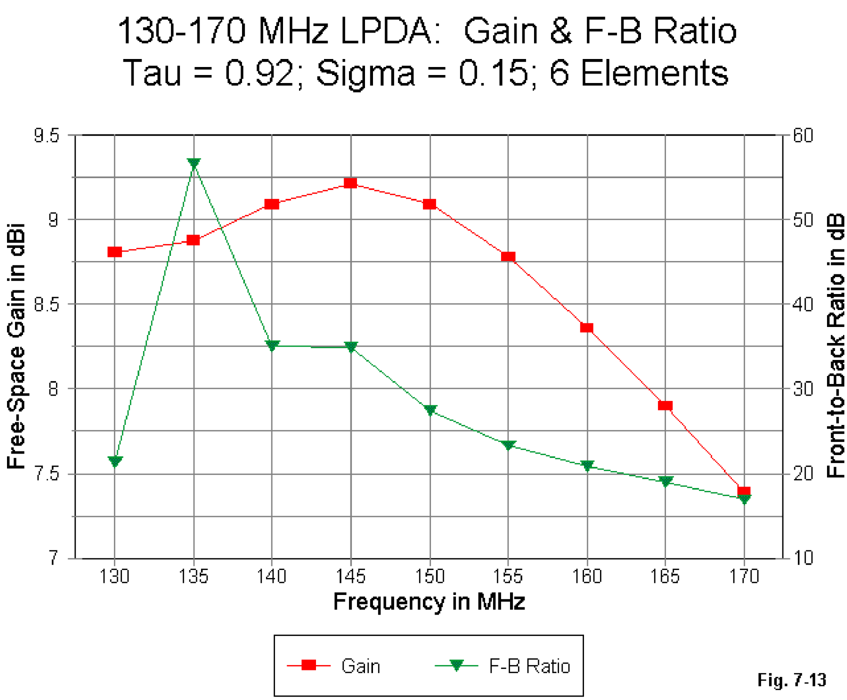


Fig. 7-13

the operating range. The front-to-back ratio is above 17 dB across the entire range, with values above 20 dB up though 160 MHz.

In **Fig. 7-14**, we find the variations in feedpoint resistance and reactance for the expanded operating range of the LPDA. The resistive component varies from a low of about 30 Ohms to a high of about 75 Ohms. Thus, in expanded service, the LPDA is better suited to a 50-Ohm cable than to a 75-Ohm cable. The reactance—as is typical of LPDAs designed to high values of both τ and σ—is everywhere in the spectrum capacitive. The magnitude ranges from -7 to -33 Ohms. In general, low values of the resistive component comprise the limiting factors for feeding the antenna with an SWR under 2:1.

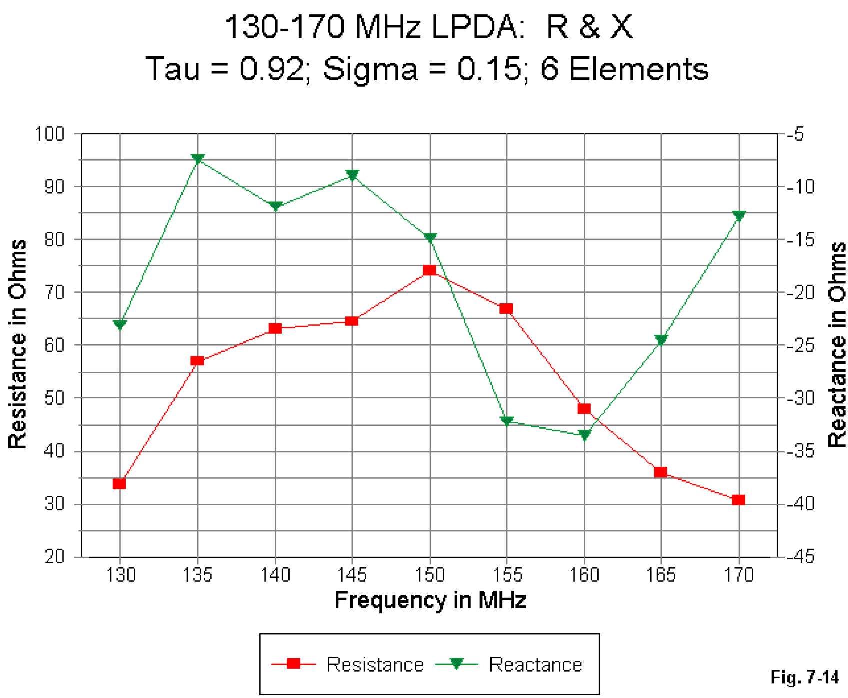


Fig. 7-14

The SWR curves, shown in **Fig. 7-15**, confirm the story told by the feedpoint resistance and reactance curves. The 2:1 SWR range of the array is limit to 130 to

160 MHz with a 75-Ohm cable feedline, although within much of that range, the SWR is lower than can be achieved with a 50-Ohm cable. However, with a 50-Ohm cable, using the 2:1 SWR standard and not including cable losses and their effect on SWR as measured closer to the equipment, the entire frequency range designed into the LPDA is available for use. In fact, the 50-Ohm SWR continues to decrease for a small frequency range above 170 MHz, but the fall off in gain, shown in **Fig. 7-13**, becomes the limiting factor at that point.

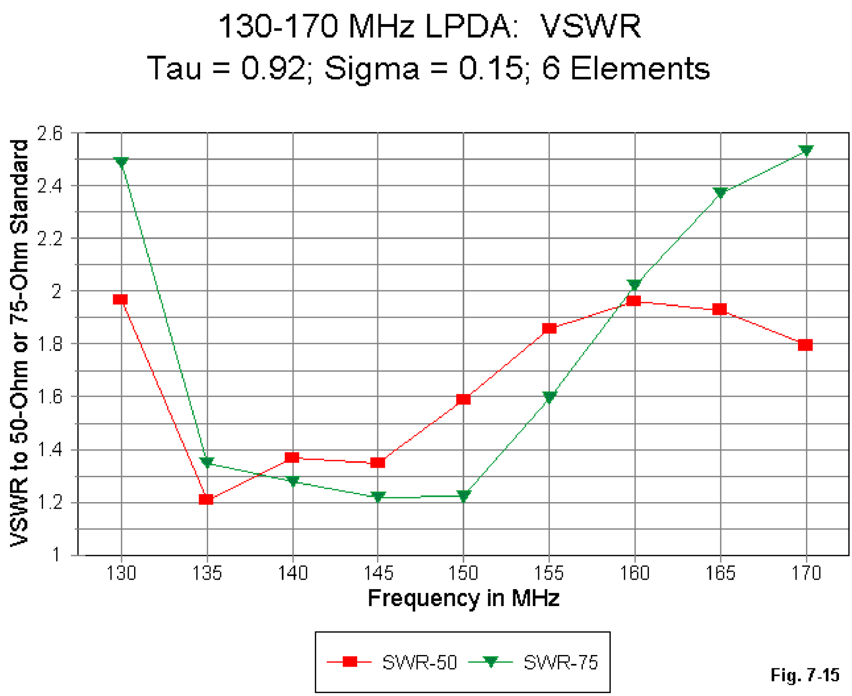


Fig. 7-15

The purpose of the comparison between Yagis and LPDAs has been to determine in broad outline when it makes the most sense to turn to a narrow-band LPDA and when it makes more sense to employ an optimized Yagi design (or some other type of array). For very wide amateur bands, such as the entirety of 10 meters, the LPDA or a log-cell Yagi can under certain circumstances be quite competitive with standard Yagi design. However, when the operating bandwidth is narrower, the Yagi is normally capable of higher gain for a given boom length and number of elements.

The LPDA comes into its own, even when the operating bandwidth is well under 1 octave, where expanded coverage is necessary or desirable, as was the case with the 2-meter LPDA (at least in terms of the hypothetical example). Although OWA techniques have expanded the SWR curves of Yagis to a considerable bandwidth, a 5% to 6% operating bandwidth is a normal limit if we are to preserve the full array full gain. In contrast, the LPDA offers the builder a choice of operating bandwidth within the design and design-evaluation process. At a small sacrifice in gain, one can design LPDAs for extended frequency coverage as needed.

Chapter 8: Wire LPDAs for 80 Meter

Among the potential narrow-band uses of LPDAs, one amateur allocation holds a special place: the 80/75 meter band that extends from 3.5 to 4.0 MHz. Relative to the center frequency, the bandwidth is over 13%. Many techniques have been used to expand the coverage of common antennas to cover the entire band, including the use of open-sleeve coupling with dipoles. However, when applied to wire Yagi designs, the result has been simply to make available two individual regions within the band. Hence, the LPDA becomes a relevant candidate to cover the entire 80/75-meter band—if we design it adequately.

For many years, *The ARRL Antenna Book* has contained an LPDA for 80 meters that uses 4 elements and is arranged as both a forward-sloping Vee and an inverted Vee, with its ends close to the ground. It was carefully designed from basic LPDA design equations with a τ of 0.845 and a σ of 0.06, resulting in a #14 copper wire array close to 50' from front to rear (ignoring the forward Vee extension).

Unfortunately, this array has a number of properties that reduce its potential performance:

1. The elements are Vee'd forward, reducing gain and decreasing the front-to-side ratio.

2. The elements are modified inverted Vees, again reducing gain and decreasing the front-to-side ratio.

3. The array uses thin wire, reducing gain relative to elements of an optimal diameter.

4. The combination of τ (0.845) and σ (0.06) limit the maximum free-space gain potential to well under 6 dBi.

The combination of performance-degrading factors in this array strongly suggests that a redesign is in order. In these notes, I shall explore more adequate arrays for 80 meters. However, each will presume standard linear elements at right angles to the main array axis. In Volume 1 and again, with respect to log-cell Yagis, we explored the performance deficits of using Vee'd elements in arrays of all sorts.

In the course of these notes, we shall look at the question of optimal element size and how to simulate it with a wire array. We shall also examine some limits (and the reasons for those limits) of improving thin wire lower HF arrays with simulated fatter elements.

An Improved 6-Element Wire LPDA for 80 Meters

Fig. 8-1 shows the outline of an LPDA using 6 elements, with a τ of 0.8918 and a σ of 0.0702. The τ and σ values are the initial values of the design. However, the element lengths have been optimized for the best performance across the 80-meter band (3.5-4.0 MHz) using standard circularized-τ techniques. The final design—which might still be improved further with judicious experimentation—retains the original spacing, but 4 of the 6 elements have modified lengths.

Key to array performance is the element diameter, specified in the original design as 2". The elements are modeled as copper, although there is less than 0.02 dB difference between copper and aluminum when the elements are as fat as specified here.

The following table provides the wire specifications in the form of a NEC wire table. The phase line has a characteristic impedance of 100 Ohms.

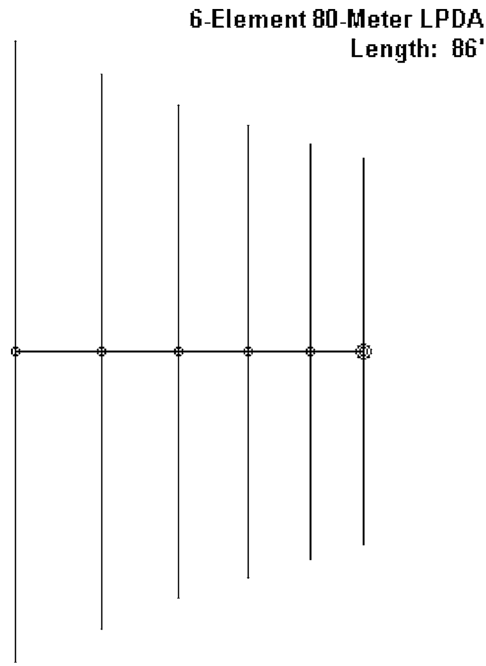


Fig. 8-1

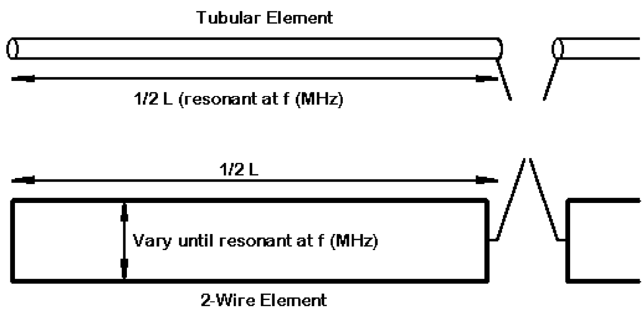
```
3.3-4.5 MHz t=.89 s=.07                 Frequency = 4  MHz.

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,-76.000,  0.000        0.000, 76.000,  0.000 2.00E+00  91
2           21.346,-67.800,  0.000       21.346, 67.800,  0.000 2.00E+00  81
3           40.382,-60.500,  0.000       40.382, 60.500,  0.000 2.00E+00  73
4           57.358,-55.500,  0.000       57.358, 55.500,  0.000 2.00E+00  65
5           72.498,-51.000,  0.000       72.498, 51.000,  0.000 2.00E+00  59
6           86.000,-47.500,  0.000       86.000, 47.500,  0.000 2.00E+00  53

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

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

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

The performance of this array is quite good for an 86' long LPDA on 80 meters, with an average free-space gain of about 6.9 dBi across the band. Whether the performance can be maintained in practice depends, of course, on the ability of the builder to raise the antenna to a height where horizontally polarized antennas perform well over desired propagation paths. The front-to-back ratio is above 20 dB across the band.

The use of 2" diameter elements on 80 meters is exceptionally rare, given the need for elements that are, at their longest, 152'. As an experiment, I took the same array and tested it in model form using #12 AWG wire (0.0808" diameter). Interestingly, the average free-space gain dropped to about 5.9 dBi with an average front-to-back ratio of about 13.5 dB. The loss of a full dB of gain in the move from 2" to 0.0808" element diameter seemed less than desirable.

Therefore, I reconstructed the elements from 2 parallel wires in accord with the sketch in **Fig. 8-2**.

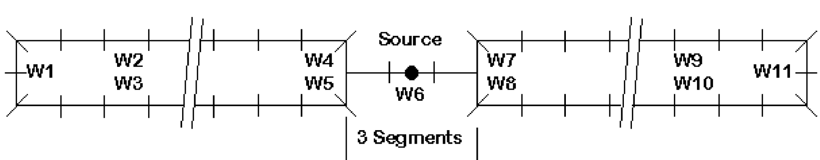
The principle, as I have elsewhere noted, consists of testing a representative element in the array for its self-resonant frequency. Then, I constructed a model of a two-wire element of the same length and varied the spacing between the wires until it was resonant at the same frequency. In the present exercise, a spacing of between 10 and 12 inches proved to be close to precise, with a remnant reactance of under 10 Ohms at the widest spacing used.



Development of a Thin-Wire "Near" Equivalent
to a "Fat" Wire LPDA Element

Fig. 8-2

For modeling simplicity, I used the 12" spacing, which translates into 1 foot (or a shortest segment length of 0.5'). **Fig. 8-3** shows the single element model. The center portion is (for this model) 1.5' long and consists of 3 segments to ensure that the source segment is equal in length to the segments adjacent to it. The single wire is also necessary within the LPDA array, since the phase-line must meet a single wire segment at each element in the array. On each side of center, single segment wires, each 0.5' long, connect the center wire to the parallel wires that constitute the bulk of the elements. These wires, which have the same number of segments to sustain parallel segment junctions throughout, are connected together at the outer ends with 2-segment wires. The 11-wire element constitutes a reasonably fair model of the 2-wire element.



Modeling a Double-Wire Substitute LPDA Element

Fig. 8-3

The attention to segment lengths at the center-most part of the element allowed me to reduced the number of segments in the long wires. Ideally, the segment length should be 0.5' throughout the model, which would have resulted in about 150 segments per long wire in the longest element. However, reducing the number to about 50 yielded a change of reactance in the test element of under 5 Ohms. So reduced segmentation—but still with parallel segment junctions—was used in the final array model. For reference, the following partial table shows just 2 elements of the modified array.

```
lpda 80, t=.89 s=.07                              Frequency = 3.5  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	W2E1	0.000,-76.000, -0.500	W3E1	0.000,-76.000, 0.500	# 12	2
2	W1E1	0.000,-76.000, -0.500	W4E1	0.000, -0.750, -0.500	# 12	51
3	W1E2	0.000,-76.000, 0.500	W5E1	0.000, -0.750, 0.500	# 12	51
4	W2E2	0.000, -0.750, -0.500	W5E2	0.000, -0.750, 0.000	# 12	1
5	W3E2	0.000, -0.750, 0.500	W6E1	0.000, -0.750, 0.000	# 12	1
6	W4E2	0.000, -0.750, 0.000	W7E1	0.000, 0.750, 0.000	# 12	3
7	W8E1	0.000, 0.750, 0.000	W9E1	0.000, 0.750, -0.500	# 12	1
8	W6E2	0.000, 0.750, 0.000	W10E1	0.000, 0.750, 0.500	# 12	1
9	W7E2	0.000, 0.750, -0.500	W11E1	0.000, 76.000, -0.500	# 12	51
10	W8E2	0.000, 0.750, 0.500	W11E2	0.000, 76.000, 0.500	# 12	51
11	W9E2	0.000, 76.000, -0.500	W10E2	0.000, 76.000, 0.500	# 12	2
12	W13E1	21.346,-67.800, -0.500	W14E1	21.346,-67.800, 0.500	# 12	2
13	W12E1	21.346,-67.800, -0.500	W15E1	21.346, -0.750, -0.500	# 12	46
14	W12E2	21.346,-67.800, 0.500	W16E1	21.346, -0.750, 0.500	# 12	46
15	W13E2	21.346, -0.750, -0.500	W16E2	21.346, -0.750, 0.000	# 12	1
16	W14E2	21.346, -0.750, 0.500	W17E1	21.346, -0.750, 0.000	# 12	1
17	W15E2	21.346, -0.750, 0.000	W18E1	21.346, 0.750, 0.000	# 12	3
18	W19E1	21.346, 0.750, 0.000	W20E1	21.346, 0.750, -0.500	# 12	1
19	W17E2	21.346, 0.750, 0.000	W21E1	21.346, 0.750, 0.500	# 12	1
20	W18E2	21.346, 0.750, -0.500	W22E1	21.346, 67.800, -0.500	# 12	46
21	W19E2	21.346, 0.750, 0.500	W22E2	21.346, 67.800, 0.500	# 12	46
22	W20E2	21.346, 67.800, -0.500	W21E2	21.346, 67.800, 0.500	# 12	2

The use of the twin-wire (#12 AWG) elements restored much of the performance to the array—on average about 80% of the performance lost in going from a 2" element to a #12 single wire element. The average free-space gain rose to over 6.6 dBi, with an average front-to-back ratio of over 20 dB.

However, a better measure of appreciating how well the double-wire elements simulate the tubular elements can be gleaned from some graphs.

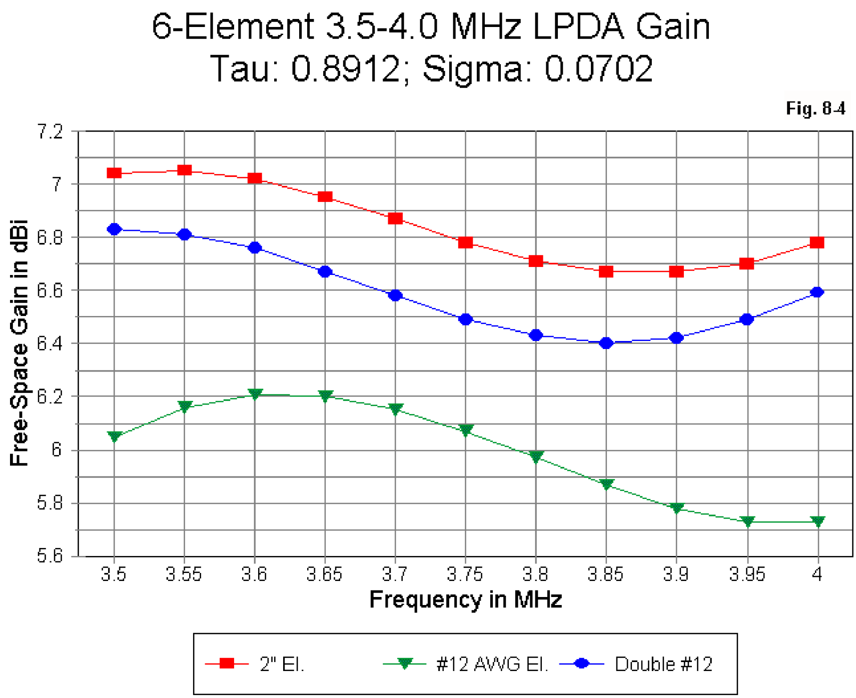
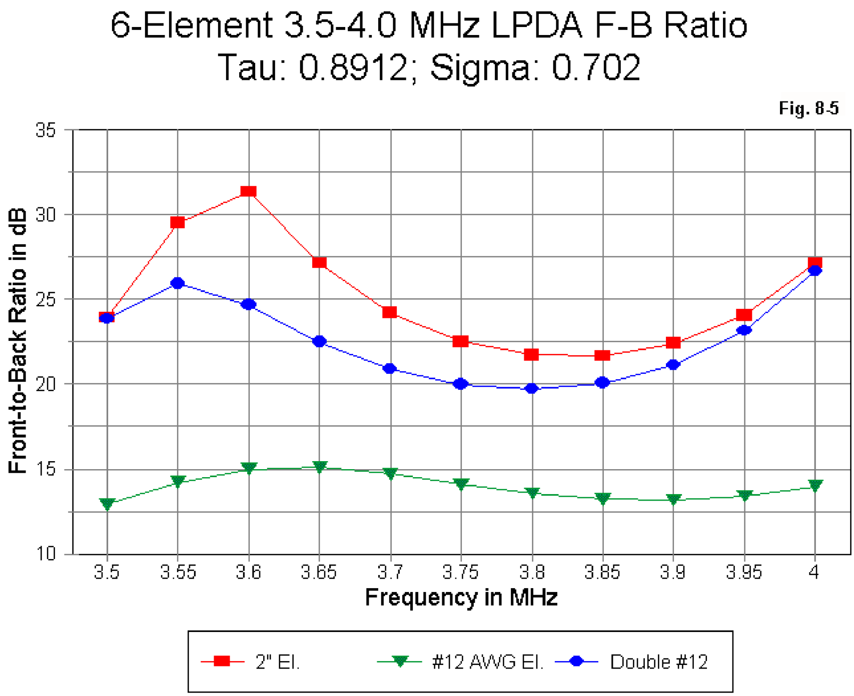


Fig. 8-4 shows the free-space gain across 80 meters at 0.05 MHz intervals. Not only is the double wire curve much higher on average than the single wire curve; as well, it parallels the 2" element curve very closely. The single-wire curve peaks at a quite different frequency from the peak for the upper two curves.

In **Fig. 8-5**, for the front-to-back ratio, we find a similar pattern, with the 2" element and the double-wire curves not only higher, but also more parallel than the curve for the single thin-wire version of the antenna.

Perhaps the least significant set of differences can be found in the 50-Ohm VSWR curve for the three versions of the array, shown in **Fig. 8-6**. All would be acceptable

80-meter SWR curves. I shall note in passing that these curves are easy to obtain by experimentally changing the phase-line characteristic impedance. However, the original design equations called for a phase-line impedance of closer to 200 Ohms, with the illusion of needing a matching device to use a coaxial feedline with the array.



The ability of a simple 2-wire element to restore most of the performance to the array arises from the fact that an LPDA—like any multi-element array—derives its performance not only from the driving of the elements, but as well from the mutual coupling between elements. The simulated fat elements, composed of wide-spaced wires, indeed has close to the same mutual coupling between array elements as the fat-wire model.

What differs between the 2-wire model and the fatter single-element version is the overall efficiency of the antenna. With 2" elements, the array is about 99.7%

efficient, with losses due to material resistance that are a small fraction of 1%. The single #12 wire version is about 95.9% efficient, with over 4% material losses. The double-wire version reaches an efficiency of about 97.1%, which is only about a third of the way above the efficiency of the single-wire version toward the fat-element version. In short, the double-wire version of the antenna cannot restore all of the performance of the fat-wire version because it cannot decrease wire losses to the level of a single fat element. However, it can restore a large portion of the mutual coupling lost by using a single thin wire for each element.

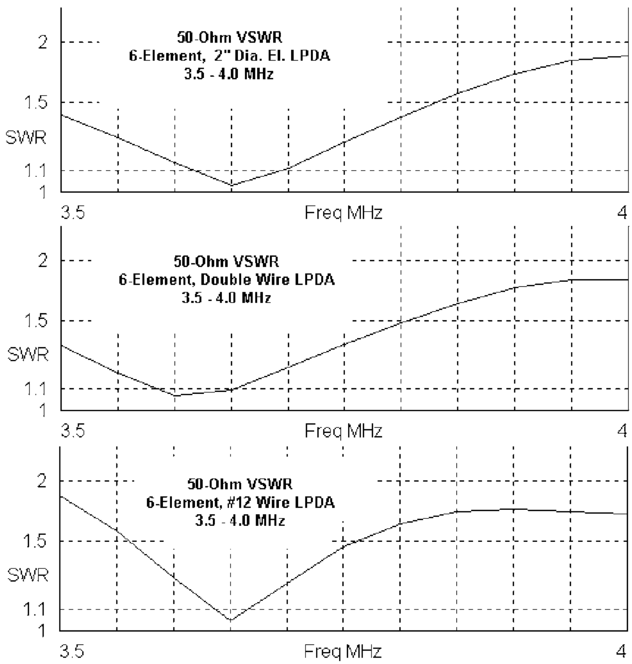


Fig. 8-6

The process of restoring performance has a limit, and another LPDA design can illustrate this limit.

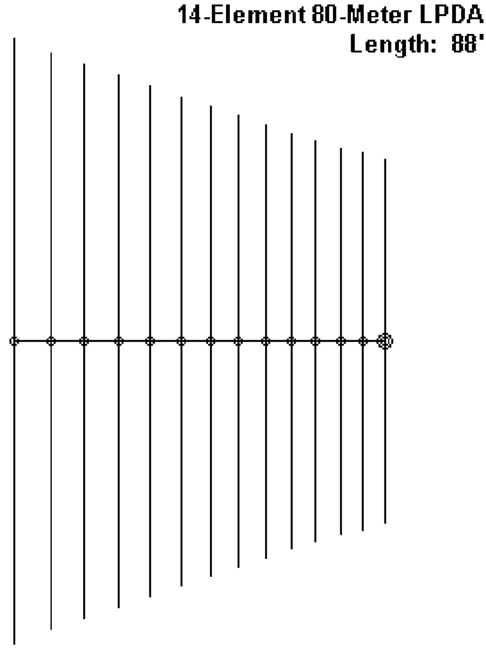


Fig. 8-7

A 14-Element Wire LPDA for 80 Meters

By judiciously changing the values of τ and σ, it is possible to arrive at an LPDA design with even better performance than we have so far attained. **Fig. 8-7** shows the outline of a 14-element 88.5' long array, again, initially using 2" elements in order to establish relatively peak performance.

The new array uses a τ of 0.96 and a σ of 0.03 to pack the large number of elements into the prescribed space. Again, the phase-line characteristic impedance is 100 Ohms to arrive at a 50-Ohm feedpoint impedance. The following table of modeling values shows the dimensions of the revised array.

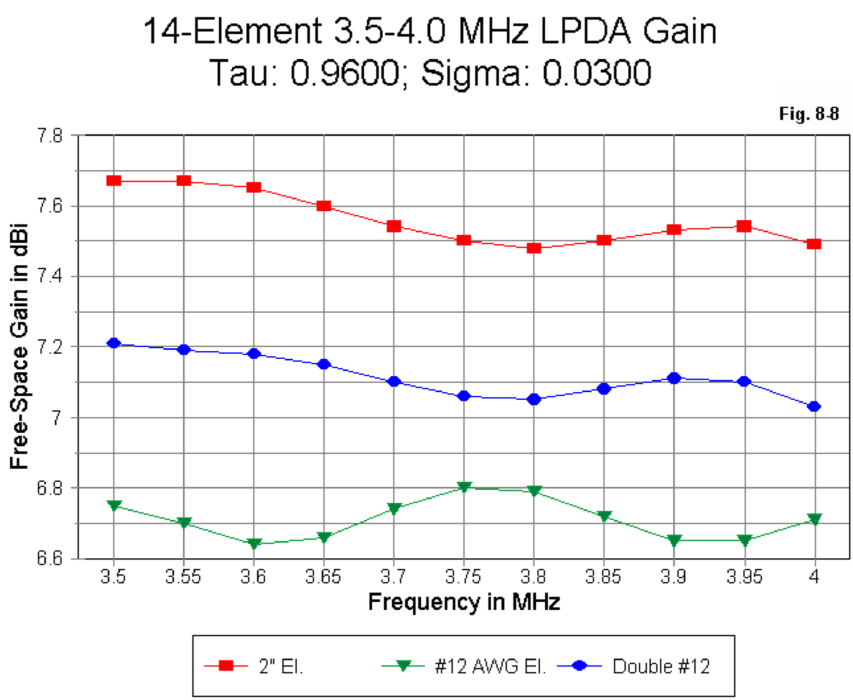
```
80m t=.96 s=.03                                   Frequency = 4  MHz.

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,-72.500,  0.000          0.000, 72.500,  0.000 2.00E+00  25
2            8.603,-69.000,  0.000          8.603, 69.000,  0.000 2.00E+00  25
3           16.862,-66.071,  0.000         16.862, 66.071,  0.000 2.00E+00  23
4           24.790,-63.428,  0.000         24.790, 63.428,  0.000 2.00E+00  23
5           32.402,-60.891,  0.000         32.402, 60.891,  0.000 2.00E+00  21
6           39.709,-58.455,  0.000         39.709, 58.455,  0.000 2.00E+00  21
7           46.723,-56.117,  0.000         46.723, 56.117,  0.000 2.00E+00  19
8           53.457,-53.872,  0.000         53.457, 53.872,  0.000 2.00E+00  19
9           59.922,-51.717,  0.000         59.922, 51.717,  0.000 2.00E+00  19
10          66.128,-49.649,  0.000         66.128, 49.649,  0.000 2.00E+00  17
11          72.086,-47.663,  0.000         72.086, 47.663,  0.000 2.00E+00  17
12          77.805,-46.000,  0.000         77.805, 46.000,  0.000 2.00E+00  17
13          83.296,-45.000,  0.000         83.296, 45.000,  0.000 2.00E+00  15
14          88.567,-43.500,  0.000         88.567, 43.500,  0.000 2.00E+00  15

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

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

1           8    14 / 50.00   ( 14 / 50.00)      0.707       0.000       V
```

Like the smaller array, this design employs a measure of circularized τ to obtain better performance than provided by the initial design taken from LPDA equations. The rear-most 2 and the forwardmost 3 elements have been modified, and further refinement may be possible.

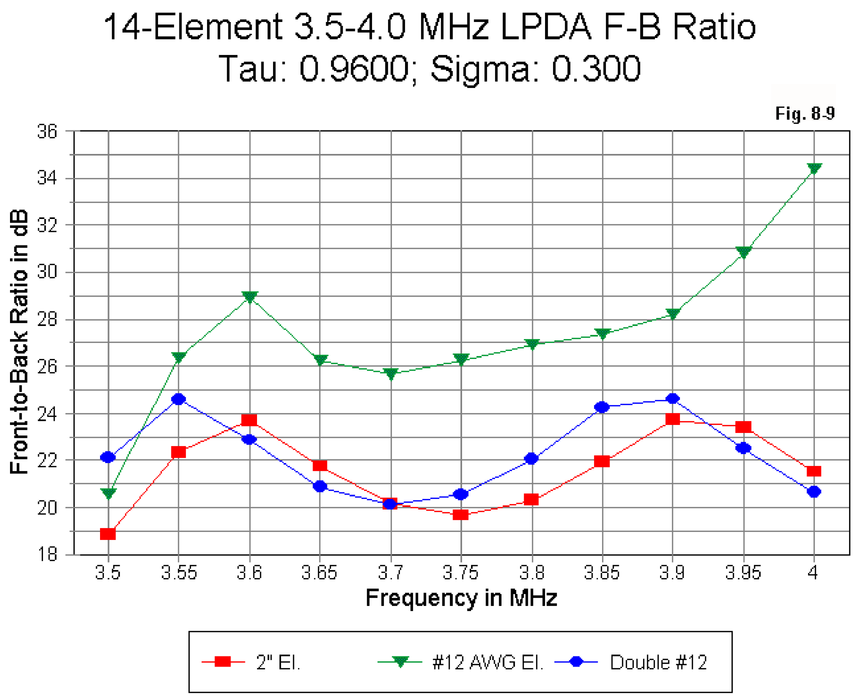
With 2" elements, the array has an average free-space gain across 80 meters of nearly 7.6 dBi, with an average front-to-back ratio of about 20 dB. A single #12 wire version of the antenna achieves an average free-space gain of about 6.75 dBi, about 0.8 dB lower than the fat-element version. Interestingly, the single-wire version of the antenna has an average front-to-back ratio of about 25 dB, about 5 dB higher than that of the fat-element version.

The same techniques used with the smaller array were applied to the 14-element LPDA to produce a double wire version. The resulting array model had over 2300 segments, even using the reduced levels of segmentation in the long parallel sections of each double-wire element. The resulting array showed an average free-space gain of about 7.1 dBi, less than half way toward the fat-element version from the single-wire model. The average front-to-back ratio was about 21 dB, close to the value of the fat-element version.

Fig. 8-8 shows the gain curves for the three models. The double-wire and fat-wire versions are very synchronous, while the single-wire model curve shows divergent frequencies for its peaks and valleys. Of course, the single "fat-wire" version of the modeled array shows the highest gain of the three versions.



In **Fig. 8-9**, we see similar results. The fat-wire and double-wire curves are closely matched with respect to the peaks and valleys of the curves, while the single-wire takes a direction of its own—and at a higher average level of front-to-back ratio. It has long been known that the use of higher resistance reflectors in Yagi-Uda arrays—either by the use of thinner and hence lossier wire or through the use of spot loading of the element—will often yield higher front-to-back ratios. However, to this point, the phenomenon has not been noted with narrow-band LPDAs. It remains uncertain whether the higher front-to-back ratios of the single-wire LPDA are wholly due to the use of a lossier set of wire elements or also partially due to the displacement of the performance curves.



In keeping with the front-to-back curves, **Fig. 8-10** shows 50-Ohm VSWR curves that are very similar for the fat-wire and double wire models. In contrast, although still a very flat curve, the single-wire SWR curve shows a progression of its own.

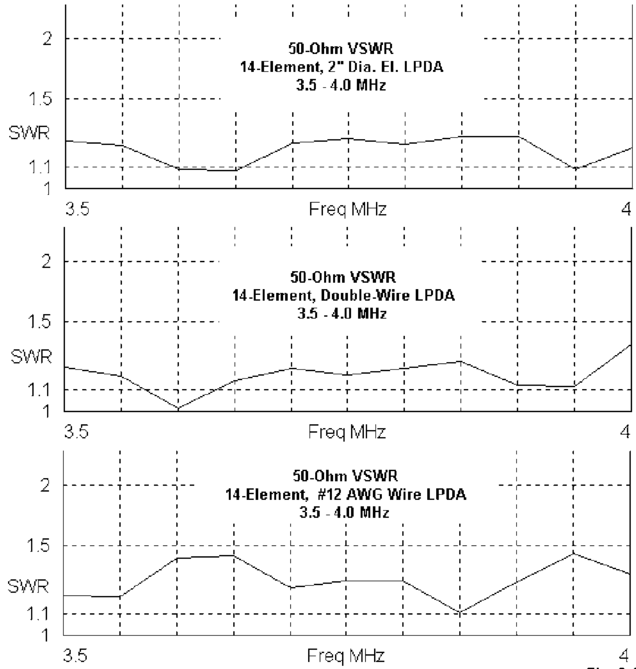


Fig. 8-10

Initially, one might have expected a relatively uniform performance upgrade relative to that shown for the 6-element LPDA. However, 2 factors count against that expectation.

First, the efficiency of the larger array is inherently lower than that of the small LPDA. The fat-element version has an efficiency of about 99.2%, against a single #12 wire version efficiency of 88.5%. Doubling the wires for each element only raises the efficiency to 90.8%, a gain of 2.3% but still 8.4% shy of the fat wire model. From an efficiency perspective alone, the ability of the double-wire version to restore most of the performance of the fat-wire version is limited.

However, we should have also noted the fact that the LPDA front-to-back ratio decreased as we moved from the thin-wire to the fat-wire model. This fact suggests that the closely spaced elements of the 14-element array are already over-coupled when using fat elements. Gain increases with wire size are largely functions of increased efficiency rather than better mutual coupling between elements. The following table provides the key performance reports of NEC for the same 14-element array using a variety of element diameters ranging from the single-wire #12 AWG version up to and including the 2" element version. The progression may prove interesting for data taken at 3.75 Hz.

Table 8-1. Performance Potential of a 14-Element 80-Meter LPDA

El. Dia. inches	Gain dBi	F-B Ratio dB	Feed Impedance R+/-jX Ohms	50-Ohm VSWR
0.0808	6.80	26.25	62.9 - j 4.4	1.28
0.25	7.24	23.57	60.2 - j 6.9	1.25
0.5	7.37	21.91	55.0 - j 9.2	1.22
1.0	7.45	20.65	46.8 + j 8.2	1.20
1.5	7.48	20.03	42.3 - j 4.9	1.22
2.0	7.50	19.68	40.1 - j 1.5	1.25

The largest increment of gain occurs with the first move that increases the element diameter by a factor of 3. As well, the front-to-back ratio also shows its steepest decrease. Above that level, performance stabilizes within a quite narrow range.

The result for this particular model is a set of alternative building strategies. One might go to the trouble of constructing 14 sets of double-wire elements. However, one can get as much performance improvement of the single-thin-wire model by simply using 0.25" wire, either copper or aluminum—the latter being lighter.

An Alternative Method of Modeling 2-Wire LPDA Elements

The method used in these notes to model the 2-wire substitute elements for an LPDA results in a very large model. The model of the 14-element array used 154 wires and 2334 segments. Even the smaller 6-element LPDA required 66 wires and 1010 segments for the 2-wire substitute.

There is a technique that results in smaller models with respect to the number of wires and segments, although the number of TL-transmission lines does increase. An increase in TL entries does not materially increase the run time of a model. Nor does it press any program limitations for the number of allowable segments. Consequently, the alternative method does have some advantages for the LPDA modeler. Therefore, consider **Fig. 8-11**.

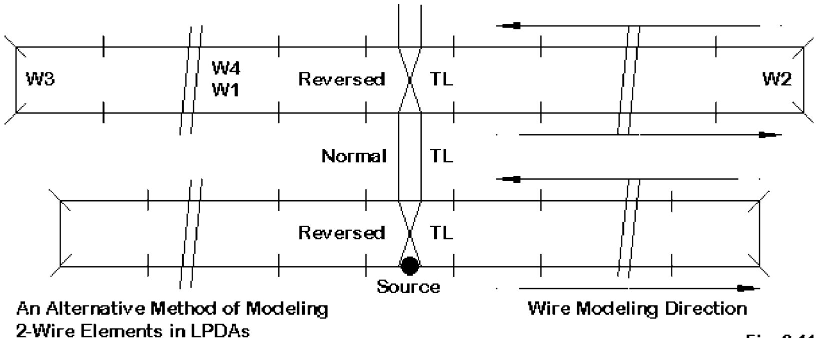


Fig. 8-11

The sketch shows the modeling structure--reduced to the forward 2 elements of a full array. The sketch presumes that the modeler creates a single 4-wire loop for each element, proceeding in a counter-clockwise direction as he adds wires to make the loop. With only 4 wires, the modeler has already saved 7 wires per element in the process. Moreover, each wire can use longer segment lengths, thus reducing the number of segments per element by as much as half to two-thirds.

The presumption that the element loop was created by going "around the horn" with wires creates an interesting situation with respect to the TL (transmission line) entries for the phase line. With a single wire assembly per element (or the single-wire central sections to the earlier technique for creating double-wire elements), each TL entry would be set to "Reverse" rather than to "Normal" in order to simulate the phase reversal between elements. In the new technique, using the presumed method of forming elements, we want to have both wires of each element connected in parallel, with a phase reversal between elements.

To achieve this goal, we must remember that our method of forming elements has reversed the direction of current. Therefore, to simulate a direct parallel connection between the two closely spaced wires, we must use a reverse connection of the tiny TL line between them. We can make the line that creates the parallel connection as short as we wish, since the line is mathematical only--and the physical distance between wires makes no difference. A TL entry for a length as short as 0.001 foot (since the model is in feet) will do fine (although such an entry for a physical wire would likely yield an error).

Between elements, we wish to have a phase reversal. However, the current directions of the two wires we connect are already opposite in phase. Therefore, we use a “Normal” TL line entry for the “actual” distance between wires. The following extracts from an LPDA model using this technique will demonstrate the process further.

```
3.3-4.5 MHz t=.89 s=.07                              Frequency = 4  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     W4E2   0.000,-72.500,  0.000  W2E1   0.000, 72.500,  0.000    # 12   57
2     W1E2   0.000, 72.500,  0.000  W3E1   0.000, 72.500,  1.000    # 12   1
3     W2E2   0.000, 72.500,  1.000  W4E1   0.000,-72.500,  1.000    # 12   57
4     W3E2   0.000,-72.500,  1.000  W1E1   0.000,-72.500,  0.000    # 12   1
5     W8E2   8.603,-69.000,  0.000  W6E1   8.603, 69.000,  0.000    # 12   53
6     W5E2   8.603, 69.000,  0.000  W7E1   8.603, 69.000,  1.000    # 12   1
7     W6E2   8.603, 69.000,  1.000  W8E1   8.603,-69.000,  1.000    # 12   53
8     W7E2   8.603,-69.000,  1.000  W5E1   8.603,-69.000,  0.000    # 12   1
9    W12E2  16.862,-66.071,  0.000 W10E1  16.862, 66.071,  0.000    # 12   51
10    W9E2  16.862, 66.071,  0.000 W11E1  16.862, 66.071,  1.000    # 12   1
11   W10E2  16.862, 66.071,  1.000 W12E1  16.862,-66.071,  1.000    # 12   51
12   W11E2  16.862,-66.071,  1.000  W9E1  16.862,-66.071,  0.000    # 12   1
. . .
              -------------- SOURCES --------------

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

1          17    55 / 50.00   ( 55 / 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)    3/50.0  (  3/50.0)    0.001 ft   100.0  1.00  R
2       3/50.0  (  3/50.0)    5/50.0  (  5/50.0)  Actual dist  100.0  1.00  N
3       5/50.0  (  5/50.0)    7/50.0  (  7/50.0)    0.001 ft   100.0  1.00  R
4       7/50.0  (  7/50.0)    9/50.0  (  9/50.0)  Actual dist  100.0  1.00  N
5       9/50.0  (  9/50.0)   11/50.0  ( 11/50.0)    0.001 ft   100.0  1.00  R
```

The "wires" portion of the table shows the rear 3 elements of an LPDA composed of 2-wire elements. The 4 "Transmission Line" entries show the portions of the phase line connecting these elements. TLs 1, 3, and 5 are clearly the connections within each element, while lines 2 and 4 interconnect elements.

Some modelers run all long wires either left-to-right or right-to-left. Had we used this convention, the short TL within an element would require a "Normal" connection and the inter-element phase lines would require a "Reverse" connection. Either system will yield accurate results in terms of antenna performance, but mixed systems will result in bewildering (and wholly useless) outputs. Hence, a modeler should select a single convention and stick with it.

The alternative modeling system for LPDA double-wire elements may in fact produce more accurate results. At least the results are a bit more coincident with those for the single fat elements that the double-wire versions replace. **Table 8-2** summarize for each of the two different LPDA designs the key parameters for 3.5, 3.75, and 4 MHz.

Within the table are clues to the modeling adequacy of using the alternative method. Key to an evaluation are not only the individual numbers for each sampled frequency, but as well the progression of those numbers across the entire 80/75-meter band.

Table 8-2. 6-Element and 14-Element LPDA Model Performance

6-element LPDA Model Performance

Frequency MHz	Gain dBi	Front-to Back Ratio	Feedpoint Impedance R +/- jX Ohms	50-Ohm VSWR
2" Elements				
3.5	7.04	23.91	59.9 - j 16.5	1.418
3.75	6.78	22.51	52.8 + j 11.1	1.248
4.0	6.78	27.13	92.2 + j 10.3	1.875
Double-Wire Model: Initial Method				
3.5	6.83	23.84	58.3 - j 13.3	1.336
3.75	6.49	19.99	55.8 + j 14.6	1.346
4.0	6.59	26.65	90.8 + j 4.6	1.822

Double-Wire Model: Revised Method				
3.5	6.87	23.18	60.4 - j 15.5	1.402
3.75	6.58	20.82	54.7 + j 12.6	1.291
4.0	6.57	25.46	90.8 + j 12.4	1.864

14-element LPDA Model Performance

Frequency MHz	Gain dBi	Front-to Back Ratio	Feedpoint Impedance R +/- jX Ohms	50-Ohm VSWR
2" Elements				
3.5	7.67	18.84	61.5 + j 3.1	1.239
3.75	7.50	19.68	40.1 - j 1.5	1.250
4.0	7.49	21.52	58.4 - j 5.3	1.202
Double-Wire Model: Initial Method				
3.5	7.21	22.11	60.3 - j 3.8	1.220
3.75	7.06	20.54	44.3 + j 5.2	1.178
4.0	7.03	20.64	50.3 - j 15.2	1.352
Double-Wire Model: Revised Method				
3.5	7.27	20.33	60.7 + j 2.7	1.221
3.75	7.10	20.02	42.9 - j 0.0	1.165
4.0	7.10	21.33	58.7 - j 9.0	1.259

Operationally, the differences between the two double-wire substitutes for 2" tubular elements are insignificant. However, in terms of finding the most adequate model of the 2-wire substitute, both alternatively modeled 2-wire arrays show a slightly greater coincidence with the fat-wire model in terms of parallel value changes. Note, for example, the dip in the gain curve of the original substitute element model, compared to the way in which the new model changes values. As well, the impedance values--in terms both of values and of the type of reactance—of the new method more closely match those of the basic model.

In short, the alternate method of modeling double-wire LPDAs may result in both smaller and slightly more accurate models.

Alternative Designs

Between 6 and 14 elements, there is a great design space for the individual who wishes to eventually build an LPDA for 80 meters. To save some initial effort in evaluating what different designs might do within the space allocated for the array, I have calculated and then modified for relatively (but not perfectly) optimized performance a collection of LPDA designs ranging from 6 to 14 elements. All except the 14-element version are limited to 86' in length, with the longest one being about 88.5' in total length. All use 100-Ohm phase lines. Other values can be used but would require an impedance matching network or device at the array feedpoint. As well, higher phase line values may slightly alter the performance curves—in places showing slight gain reductions.

As we have seen from the graphs presented earlier, every LPDA exhibits peaks and valleys of gain, front-to-back ratio, feedpoint impedance, and SWR. However, for an initial evaluation of the collection of models in **Table 8-3**, we can use average values, since the gain changes across the 80/75-meter band are under 0.3 dB in the worst case. Only the longest LPDA in the collection shows front-to-back values under 20 dB. The average value of the 50-Ohm SWR is a reasonably good indicator of the impedance swing range. The "Model" label indicates the approximate values of τ and σ, as well as the number of elements. All models use 2" copper elements, and further on, we shall note the potential of these models for conversion to double-wire substitutes.

Table 8-3. Performance of 80-Meter LPDAs by Element Populations

Model	Gain dBi	F-B dB	50-Ohm SWR
8907-6	6.86	24.33	1.517
9205-8	7.10	26.74	1.420
9404-10	7.18	25.91	1.378
9503-12	7.26	25.40	1.186
9603-14	7.55	19.95	1.230

As we would expect, the gain increases steadily as we increase the number of elements. However, the front-to-back ratio peaks with the 8-element design. This peak is a rough indication that, with respect to the front-to-back ratio, optimal inter-element coupling occurs with the spacings of this array. We may also note that the average SWR decreases steadily until at the 1.25:1 region, differences no longer make a difference. As well, impedance swings decrease in step with the average SWR.

Selecting an array to replicate is always a composite judgment based on many factors. The more elements, the higher the gain, but not necessarily a higher the front-to-back ratio. If we translate the designs into double wire elements, then we must also consider the fact that as we increase the number of elements, the lower the return rate to full 2"-element performance due to a decreasing efficiency as we add more double-wire elements.

In broadest terms, perhaps the 8- and 10-element arrays show the most promise. They provide a useful increment of gain above the 6-element LPDA and provide peak front-to-back performance. Using double-wire elements will allow the wire array to more closely approximate the performance of the fat-element model. The prospective builder can interpolate from the 6-element and the 14-element figures the likely performance figures for double-wire versions of these arrays. The overall array weight of the 8- and 10-element LPDAs is also likely to be more manageable than the weight of larger models.

For reference, the following wire-tables of the models will provide enough guidance to replicate as models or in wire any of the designs discussed.

```
8907-6 elements
Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in)

1            0.000,-76.000,  0.000         0.000, 76.000,  0.000 2.00E+00
2           21.346,-67.800,  0.000        21.346, 67.800,  0.000 2.00E+00
3           40.382,-60.500,  0.000        40.382, 60.500,  0.000 2.00E+00
4           57.358,-55.500,  0.000        57.358, 55.500,  0.000 2.00E+00
5           72.498,-51.000,  0.000        72.498, 51.000,  0.000 2.00E+00
6           86.000,-47.500,  0.000        86.000, 47.500,  0.000 2.00E+00
```

```
9205-8 elements
Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in)

1            0.000,-75.500,  0.000         0.000, 75.500,  0.000 2.00E+00
2           15.494,-69.500,  0.000        15.494, 69.500,  0.000 2.00E+00
3           29.771,-64.563,  0.000        29.771, 64.563,  0.000 2.00E+00
4           42.928,-60.000,  0.000        42.928, 60.000,  0.000 2.00E+00
5           55.050,-55.500,  0.000        55.050, 55.500,  0.000 2.00E+00
6           66.221,-51.500,  0.000        66.221, 51.500,  0.000 2.00E+00
7           76.515,-48.000,  0.000        76.515, 48.000,  0.000 2.00E+00
8           86.000,-44.500,  0.000        86.000, 44.500,  0.000 2.00E+00
```

```
9404-10 elements
Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in)

1             0.000,-75.500,  0.000         0.000, 75.500,  0.000 2.00E+00
2            12.160,-71.000,  0.000        12.160, 71.000,  0.000 2.00E+00
3            23.570,-66.953,  0.000        23.570, 66.953,  0.000 2.00E+00
4            34.277,-62.826,  0.000        34.277, 62.826,  0.000 2.00E+00
5            44.324,-58.700,  0.000        44.324, 58.700,  0.000 2.00E+00
6            53.752,-55.800,  0.000        53.752, 55.800,  0.000 2.00E+00
7            62.599,-53.000,  0.000        62.599, 53.000,  0.000 2.00E+00
8            70.900,-49.500,  0.000        70.900, 49.500,  0.000 2.00E+00
9            78.690,-47.500,  0.000        78.690, 47.500,  0.000 2.00E+00
10           86.000,-45.000,  0.000        86.000, 45.000,  0.000 2.00E+00
```

```
9503-12 elements
Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in)

1             0.000,-75.500,  0.000         0.000, 75.500,  0.000 2.00E+00
2            10.006,-71.800,  0.000        10.006, 71.800,  0.000 2.00E+00
3            19.504,-68.519,  0.000        19.504, 68.519,  0.000 2.00E+00
4            28.521,-65.044,  0.000        28.521, 65.044,  0.000 2.00E+00
5            37.081,-61.746,  0.000        37.081, 61.746,  0.000 2.00E+00
6            45.206,-58.614,  0.000        45.206, 58.614,  0.000 2.00E+00
7            52.919,-55.641,  0.000        52.919, 55.641,  0.000 2.00E+00
8            60.241,-53.000,  0.000        60.241, 53.000,  0.000 2.00E+00
9            67.192,-52.000,  0.000        67.192, 52.000,  0.000 2.00E+00
10           73.790,-48.500,  0.000        73.790, 48.500,  0.000 2.00E+00
11           80.054,-46.500,  0.000        80.054, 46.500,  0.000 2.00E+00
12           86.000,-44.500,  0.000        86.000, 44.500,  0.000 2.00E+00
```

```
9603-14 elements
Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in)

1             0.000,-72.500,  0.000         0.000, 72.500,  0.000 2.00E+00
2             8.603,-69.000,  0.000         8.603, 69.000,  0.000 2.00E+00
3            16.862,-66.071,  0.000        16.862, 66.071,  0.000 2.00E+00
4            24.790,-63.428,  0.000        24.790, 63.428,  0.000 2.00E+00
5            32.402,-60.891,  0.000        32.402, 60.891,  0.000 2.00E+00
6            39.709,-58.455,  0.000        39.709, 58.455,  0.000 2.00E+00
7            46.723,-56.117,  0.000        46.723, 56.117,  0.000 2.00E+00
8            53.457,-53.872,  0.000        53.457, 53.872,  0.000 2.00E+00
9            59.922,-51.717,  0.000        59.922, 51.717,  0.000 2.00E+00
10           66.128,-49.649,  0.000        66.128, 49.649,  0.000 2.00E+00
11           72.086,-47.663,  0.000        72.086, 47.663,  0.000 2.00E+00
```

```
    12          77.805,-46.000,  0.000        77.805, 46.000,  0.000 2.00E+00
    13          83.296,-45.000,  0.000        83.296, 45.000,  0.000 2.00E+00
    14          88.567,-43.500,  0.000        88.567, 43.500,  0.000 2.00E+00
```

Conclusion—So Far

80-meter wire LPDAs can be effective horizontally polarized antennas for the entire band if we designed them better than past versions. Minimally, I would recommend the 6-element or 8-element 86' long models as arrays whose effort at construction and mounting would be rewarded by decent performance. The double-wire version is apt for fixed installations, while—for certain builders with abilities matching the mass of the array—the use of large tubular elements might well permit rotation of the antenna.

Further increments of performance will require larger arrays, up to and including the 14-element 88' LPDA that we explored in the design exercise. However, because the elements have already reached the limits of their inter-element coupling, the double-wire version may require more work than the effort will return in improved performance over a single-wire version. The use of a larger wire size—0.25" or greater—may be the best way to improve performance above the level one can obtain from a single #12 wire. If copper wire becomes too heavy for a proposed installation, then the use of aluminum wire should be considered. The object would be to increase the wire diameter by a sufficiently large increment over the original, common #12 AWG size to offset the slightly higher losses of aluminum as an element material. Unless the element diameter increases dramatically, the wire size used will likely yield somewhat lesser performance than the single "fat-wire" models.

Along the way, we have seen that the double-wire simulation of fat elements has a limit. The more elements to the array, the less the double-wire element can effectively restore performance lost when using single thin wires. Mutual coupling depends upon several variables, including element spacing, element diameter, and frequency. The peaks and valleys evident in both gain and front-to-back curves for LPDAs arise largely because the mutual coupling among the most active elements does vary with frequency—variations in which also yield changes in the current magnitude on each element in the array. The peaks and valleys in the performance curves are not coincident for both gain and the front-to-back ratio, suggesting that the optimum mutual coupling conditions for one parameter are not necessarily optimum for the other. However, since many elements are simultaneously active to a significant—

if not controlling—degree, exacting formulations of the relationships lie beyond the realm of modeling. Nevertheless, in revealing the coincidence and displacement of curves as we vary the element diameter of the elements, modeling can show the effects of changes in coupling among elements.

We have also seen that for a given τ and σ, it is possible to reach an element diameter that may be "too large." I place quotation marks around the expression "too large" because there is no simple way to determine the dividing line. A decrease in front-to-back ratio may occur while the gain continues to increase. In part, the phenomenon may be due to the natural lack of synchronization of the gain and front-to-back curves of LPDAs. In part, the phenomenon may indicate that one has passed the element diameter that yields optimal inter-element coupling. The same factors that obscure the breaking point between the use or non-use of double wire elements also can obscure the point at which further increases in element diameter are no longer productive.

The upshot of these exercises is more advisory than theoretically conclusive: it pays to explore a given design using many different kinds of models that cover many variables before deciding on the best method of construction. In addition—and equally important—one should use these modeling exercises to develop a clear set of realistic electrical and physical specifications for the proposed LPDA design. At that point, one may be in a position to decide upon the best design for the operating need.

Chapter 9: Wide-Band vs. Narrow-Band LPDA Strategies for HF

Government, military, and some commercial enterprises have employed wide-range LPDAs for coverage of the HF region from about 4 to 30 MHz. The appeal of using a single antenna for the entire frequency range is multi-faceted. A single antenna permits frequency scanning and rapid changes of frequency without the need for antenna retuning or switching. The directional pattern of the LPDA offers gain in the desired direction at all frequencies, as well as QRM and QRN reduction from other directions.

A Review of single LPDA Design Potential

However, the single LPDA designed to cover the entire HF spectrum from about 4 to 30 MHz suffers some serious limitations. In a pair of articles in *QEX* ("Notes on Standard Design HF LPDAs," May-August, 2000), I explored some of the problems and pitfalls of designing LPDAs with a wide passband—something of the order of a 10:1 frequency range. It may be useful to review some of the outcomes of the study.

Fig. 9-1 provides outlines of three different LPDAs, each the best of its boom length used in the earlier study. **Table 9-1** provides some of the basic data about each antenna model.

Table 1. Basic dimensions of 4-30 MHz LPDAs

Model	Boom Length feet	No. of Elements	Phase Line Impedance	Stub?	Element Treatment
1.	65'	20	200	No	τ-tapered diameter
2.	100'	23	200	Yes	τ-tapered diameter
3.	164'	26	150	Yes	τ-tapered diameter

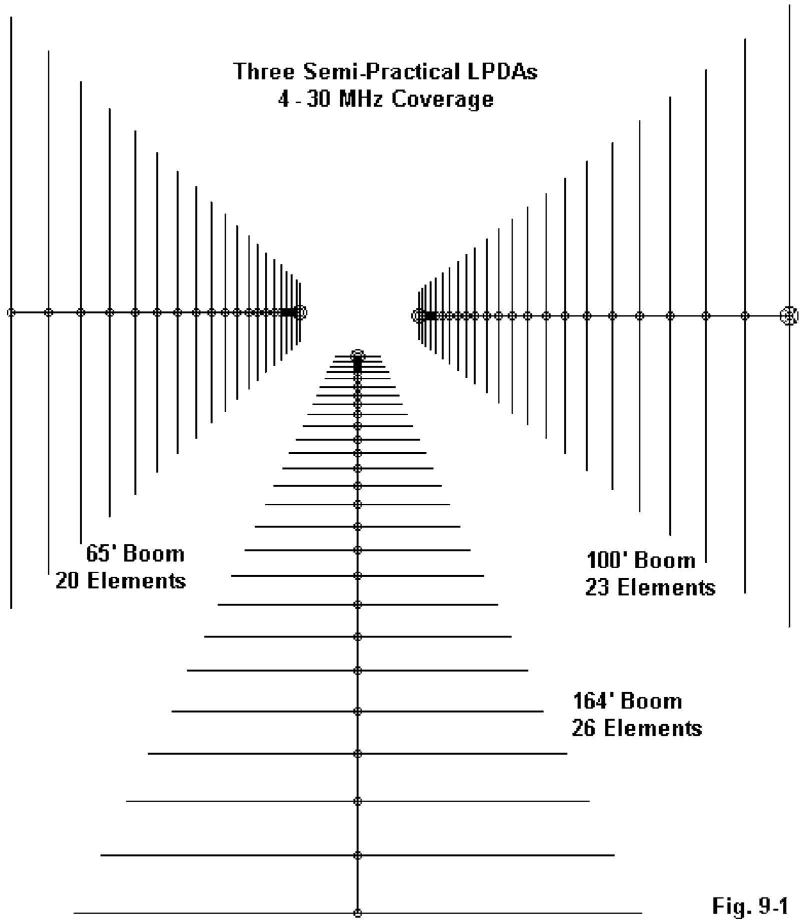


Fig. 9-1

The reference to τ-tapering of the element diameter refers to increasing the diameter of each element—referenced to the most forward elements—by the inverse of the value of τ used to establish the basic design. In general, element diameters ranged from 0.5" for the forward element to about 6.5" for the rear-most element. This practice maintains a relatively constant length-to-diameter ratio for the design.

The shortest LPDA in the lot was specifically designed for 4-30 MHz and has a 132.1' rear (longest) element. The longer boom designs set the low frequency cut-off at 3 MHz and have a 167.3' rear element.

The following graphs explore the performance potential of the resulting LPDAs in 0.25 MHz increments. To make the graphs readable, I have divided each parameter into 2 charts, one covering 3.5-17 MHz, the other covering 17.25-30 MHz. Vertical axis scales are matched so that the two graphs for each parameter will join seamlessly.

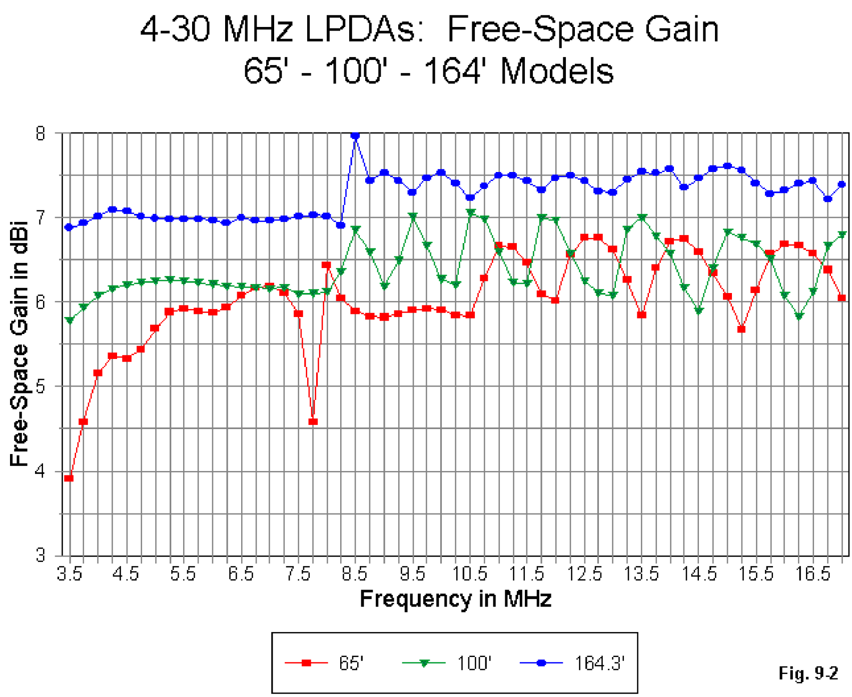


Fig. 9-2

Fig. 9-2 and **Fig. 9-3** provide the gain potential of the LPDA designs. The shortest-boom model is obviously gain deficient until it reaches 5 MHz or higher. As well, it exhibits an obvious weakness at about 7.75 MHz. Above 10 MHz, the average free-space gain fluctuates around the 6 dBi mark.

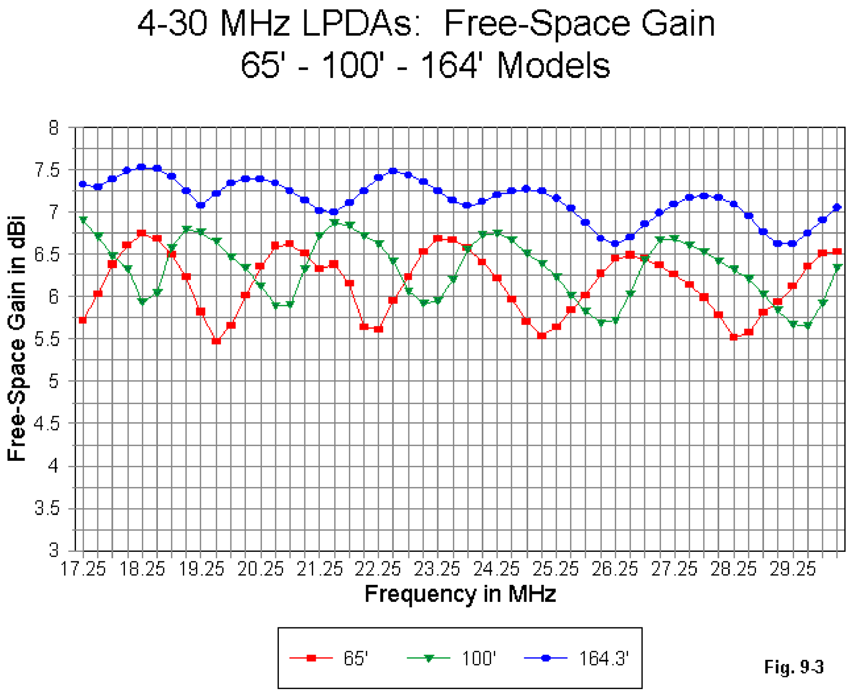


Fig. 9-3

The 100' boom model has no obvious weaknesses in gain across the spectrum, but the added 35' of boom and 3 additional elements raises the average gain only to about 6.3 dBi (free-space). However, the 100' boom length is already a major mechanical challenge for support and rotation.

The longest model averages just above 7 dBi free-space gain, with one odd peak at 8.5 MHz. To achieve this gain, we need at least 26 elements and a boom-length of nearly 165'.

Fig. 9-4 and **Fig. 9-5** present the potential 180-degree front-to-back ratio performance potential of the big LPDAs. Only the longest LPDA model sustains a front-to-back ratio of better than 20 dB. The mid-size model achieves that level of performance above about 8 MHz, while the shortest model slowly approaches the 20 dB level in the 12-14 MHz range. Below 5 MHz, the front-to-back ratio of the 65' model drops below 10 dB.

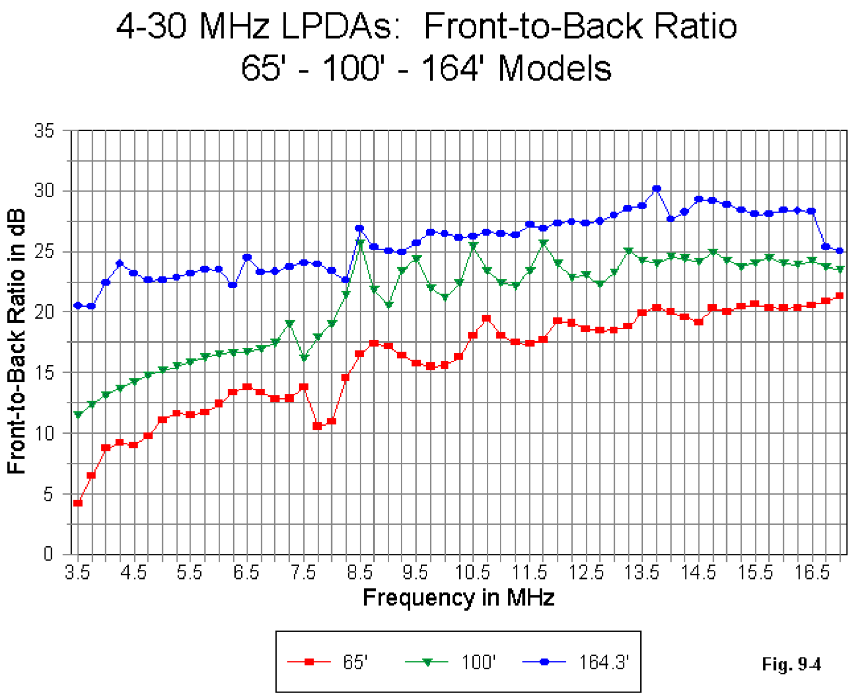


Fig. 9-4

The VSWR curves of **Fig. 9-6** and **Fig. 9-7** use different reference impedances. Each was chosen to provide the flattest possible SWR curve. Of the three wide-range LPDA models, only the longest maintains an SWR of less than 2:1 across the design range (with a 75-Ohm reference). The mid-size model, using a 95-Ohm reference, shows significant peaks above 2:1 in the upper frequency region—where SWR in the HF region becomes a more important factor in terms of line losses. The shortest model, using an 85-Ohm reference, shows similar upper HF peaks as well as some narrow peaks at the low end of the spectrum.

Not evident in these graphs is the very high variability in the behavior of the antenna patterns. The shorter the boom length, the wider the frequency range over which we encounter pattern distortion. The forward lobe may take on a shape like a garden spade or even develop a minor double lobe. Rear patterns tend to broaden so that the 180-degree front-to-back ratio is no longer a reasonable guide to rear lobe behavior. Rear side lobes down by only 15 dB are common. These expanded rear lobes are marks of incipient harmonic activity in elements to the rear of those most active at a given frequency. Hence, the problems tend to increase with frequency.

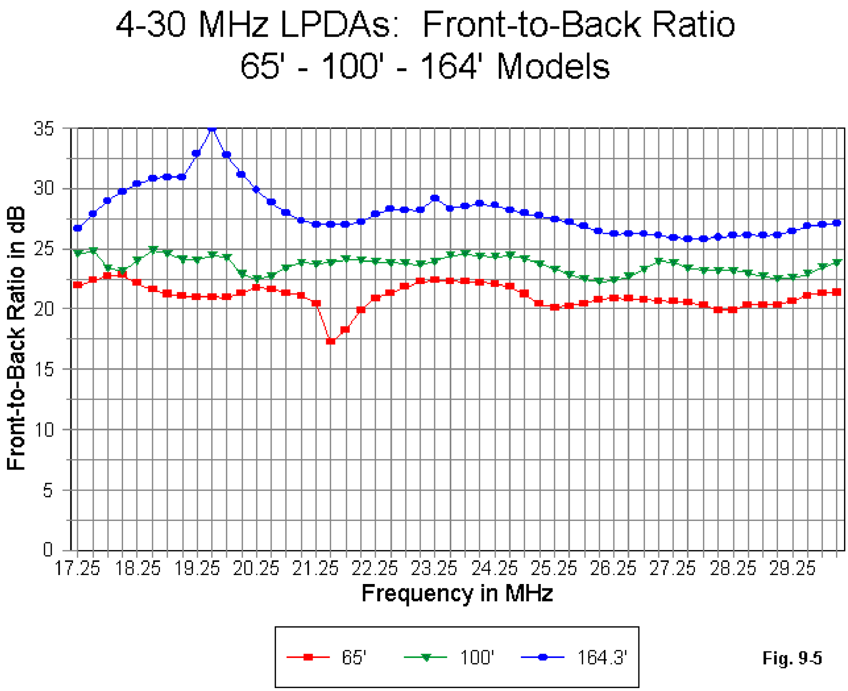


Fig. 9-5

If we take these models as typical of LPDA performance for the boom lengths indicated—and well-engineered exceptions certainly are possible—we are faced with a dilemma. The shortest boom is most easily maintained at its operating height but has marginal performance at best. However, to attain performance roughly on a par with a 2-element quad—but across the wide passband—we need boom lengths that present very major mechanical challenges. The challenges do not merely include erecting the array, but also involve wind, snow, and ice load factors.

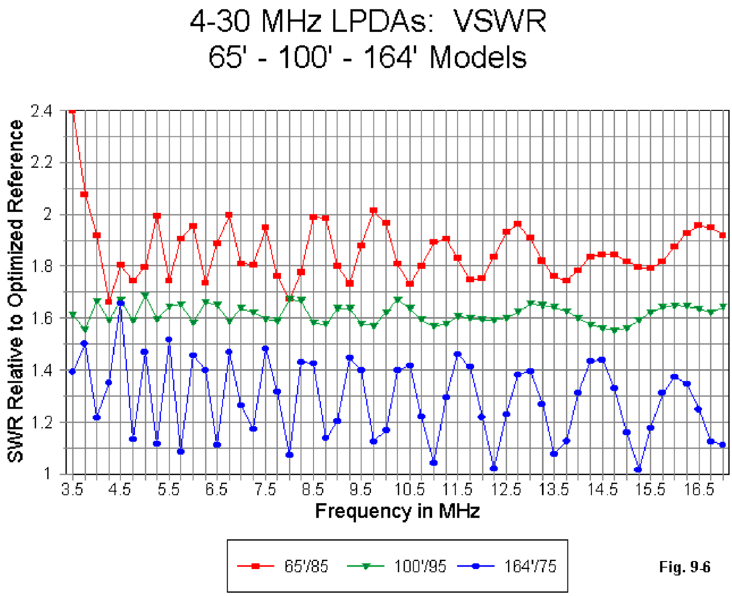

4-30 MHz LPDAs: VSWR
65' - 100' - 164' Models
SWR Relative to Optimized Reference
2.4
2.2
2
1.8
1.6
1.4
1.2
1
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
16.5
Frequency in MHz
65'/85
100'/95
164'/75

Fig. 9-6

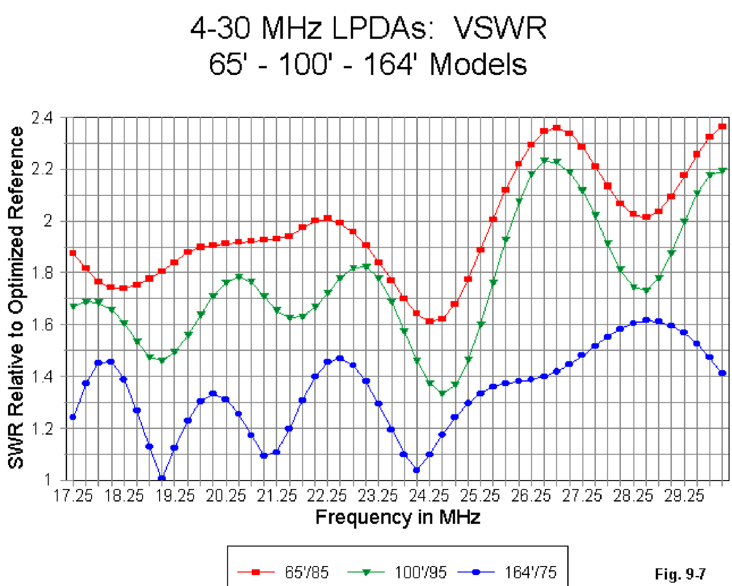

4-30 MHz LPDAs: VSWR
65' - 100' - 164' Models
SWR Relative to Optimized Reference
2.4
2.2
2
1.8
1.6
1.4
1.2
1
17.25
18.25
19.25
20.25
21.25
22.25
23.25
24.25
25.25
26.25
27.25
28.25
29.25
Frequency in MHz
65'/85
100'/95
164'/75

Fig. 9-7

The single LPDA for the entire HF range concept arose over 30 years ago. At that time, the basic idea was a single antenna for a single receiver or transceiver, with a single feedline coming to the equipment's single antenna connection. In the intervening years, a number of technical advances have appeared that seem not yet to have affect HF LPDA use for complete spectrum coverage. Perhaps it is time to rethink the LPDA for 4-30 MHz.

Not 1 LPDA, But 3

In the intervening years, a number of techniques for antenna selection or "polling" have appeared, and the technology is widely applied to cell and related services wherever higher gain and narrower beamwidth antennas are required. Such techniques might easily be applied to wide-range HF service as well.

In addition, for most applications requiring the coverage or scanning of the entire HF range, neither resources nor real estate are a major problem. Hence, one might well erect multiple towers, each one holding an LPDA optimized to the degree possible for a portion of the total frequency range. The feedlines can be brought to a central location for polling and then routed to the equipment.

The entire 4-30 MHz range is nearly 3 octaves in bandwidth. We may easily subdivide the design problem into 3 roughly 2:1 frequency-range models. 2:1 bandwidth LPDAs are significantly easier to design than a single antenna with nearly a 10:1 frequency range. To make the design challenge more difficult but the mechanical and maintenance problem less daunting, let's set a 50-56 foot limit to the boom in each case.

It might be tempting to suggest placing all three antennas on a single rotating tower. Such a system might well be made to work in some cases. However, it presents another dilemma. Mechanically, the antenna for the lowest portion of the range wants to rest at the lowest of the 3 levels, where mechanical support is greatest. However, electronically, it needs to be at the highest level for transmitting and receiving effectiveness in terms of lower elevation angles of radiation.

For the moment, we can set aside the problem of support systems and look in a more focused way at the electrical design of the individual LPDAs. For convenience, we shall divide the spectrum into 3 sections. The Low Range will run from 4 to 7 MHz.

The Middle Range will cover 7 to 14 MHz. The High Range will complete the picture with 14 to 30 MHz coverage. The ratio of highest to lowest frequencies for each antenna increases with frequency, since we have limited the boom length. It is easier to reach beyond the 2:1 target ratio at the upper HF region than it is even to reach that ratio at the low end of the spectrum.

As well, the system of LPDAs in this design exercise has considerable overlap, as shown in **Table 9-2**.

Table 9-2. 3 LPDAs for 3 Octaves

Range	Boundary Frequency	Low Freq. Limit for <2:1 VSWR	High Freq. Limit for <2:1 VSWR	Overlap as a Percentage of Boundary Frequency
Low	7	3.75 MHz	7.70 MHz	12%
Middle	14	6.85	15.4	16%
High	—	13.1	30+	

The overlapping coverage of the arrays points to a further advantage of a triple LPDA antenna farm for covering the HF spectrum: if one antenna suffers damage, the other two remain in operation. As well, some of the coverage gap may be covered by them.

The three antennas forming the array for this exercise have the basic properties in **Table 9-3**.

Table 9-3. Basic Properties of 3 LPDAs

Range	No. El., Boom Len.	Element Size/Type	τ	σ	Phase Line Zo	Stub?
Low	13 53.0'	τ-taper 2.5-6.4"	0.9245	0.0250	200 Ohms	Yes
Middle	16 56.17'	1.0" alum.	0.9300	0.0400	150	Yes
High	22 55.83'	0.5" alum.	0.9500	0.056	100	No

In all three designs, the value of ô was kept high to maintain a relatively high element density for better low-end performance. As well, the highest frequency of use was set well above the highest frequency to be used to sustain gain at the upper spectrum end. However, each antenna in the set presented unique design challenges, so each deserves an individual examination.

The Low-Range LPDA

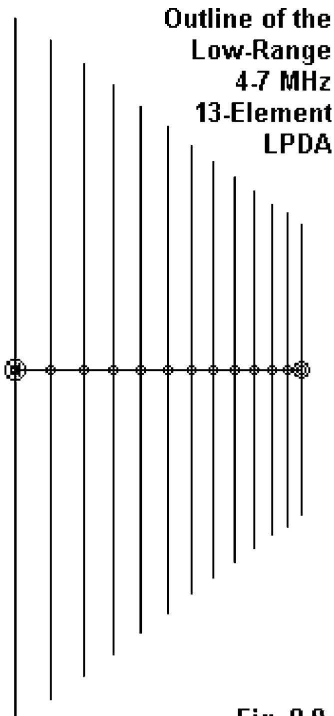


Fig. 9-8

Fig. 9-8 provides an outline of the 13-element low-range antenna designed to cover 4 to 7 MHz. Clearly apparent is the relatively close spacing of the elements that results from the selection of a low σ value. Indeed, the value of σ is below that recommended in design calculations. Hence, the design was developed by a good bit of trial-and-error modeling. The values of τ and σ, suited to the design length of the boom, also dictated the narrower frequency coverage for this array (1.75:1).

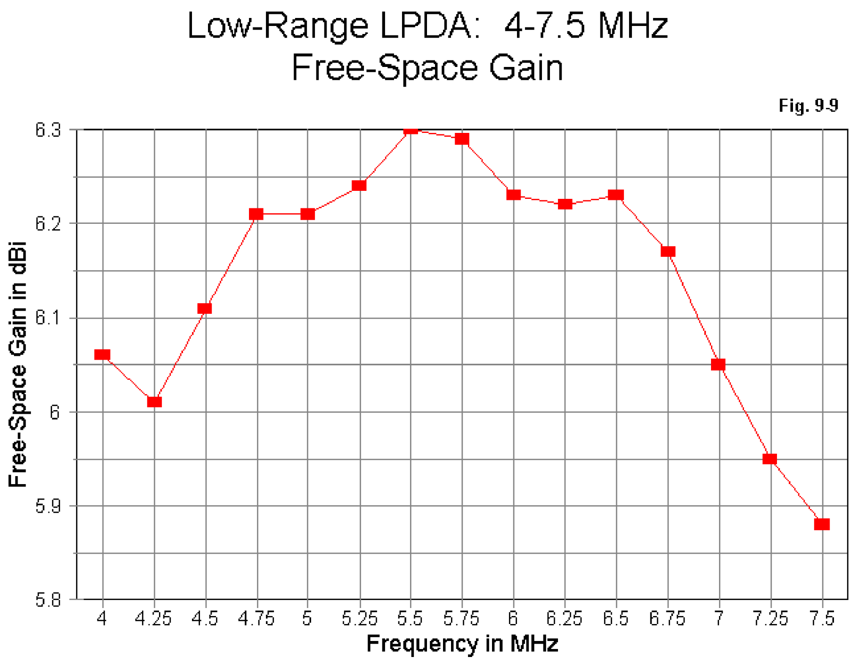
The low-range model has some interesting features. First, it is the only model of the set to require τ-tapered elements to achieve the design goals. The remaining LPDAs in the set use constant-diameter elements. The elements of the low-spectrum array range from 2.5 to 6.4 inches in diameter. Equivalent-diameter elements of lesser weight than the modeled single-wire elements are, of course, possible. However, the mass of this low-frequency array should not be underestimated. The full set of dimensions are shown in the following partial model table. Data for the 200-Ohm phase line has been omitted, since it should be obvious.

```
13 el 53' 3.8-7.5 MHz               Frequency = 4.35  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,-64.729,  0.000         0.000, 64.729,  0.000 6.41E+00  29
2             6.559,-60.750,  0.000         6.559, 60.750,  0.000 5.93E+00  27
3            12.622,-56.435,  0.000        12.622, 56.435,  0.000 5.48E+00  25
4            18.228,-52.173,  0.000        18.228, 52.173,  0.000 5.07E+00  23
5            23.410,-48.233,  0.000        23.410, 48.233,  0.000 4.69E+00  21
6            28.201,-44.591,  0.000        28.201, 44.591,  0.000 4.33E+00  19
7            32.630,-41.223,  0.000        32.630, 41.223,  0.000 4.00E+00  17
8            36.724,-38.110,  0.000        36.724, 38.110,  0.000 3.70E+00  17
9            40.509,-35.417,  0.000        40.509, 35.417,  0.000 3.42E+00  15
10           44.009,-32.667,  0.000        44.009, 32.667,  0.000 3.16E+00  13
11           47.244,-30.167,  0.000        47.244, 30.167,  0.000 2.93E+00  13
12           50.235,-28.750,  0.000        50.235, 28.750,  0.000 2.70E+00  11
13           53.000,-26.583,  0.000        53.000, 26.583,  0.000 2.50E+00  11
```

The stub used in the model is 1.5' of 600-Ohm shorted line.

The free-space gain of the array from 4 to 7.5 MHz appears in **Fig. 9-9**. As with all of the low-frequency range graphs, the sampling increment is 0.25 MHz. Only above 7 MHz does the gain drop below 6 dBi. The gain in this frequency region is similar to that of the 100' wide-range model, but with half the boom length. (However, the lengths of the longest elements of these arrays will be the same—about 2.5 times the boom length of the low-range model.) For the remainder of the frequency span, the gain of the low-region LPDA will be higher than that of any of the 3.5-octave LPDA models. Indeed, part of the design goal was to limit lower gain performance to the smallest possible portion of the entire passband.

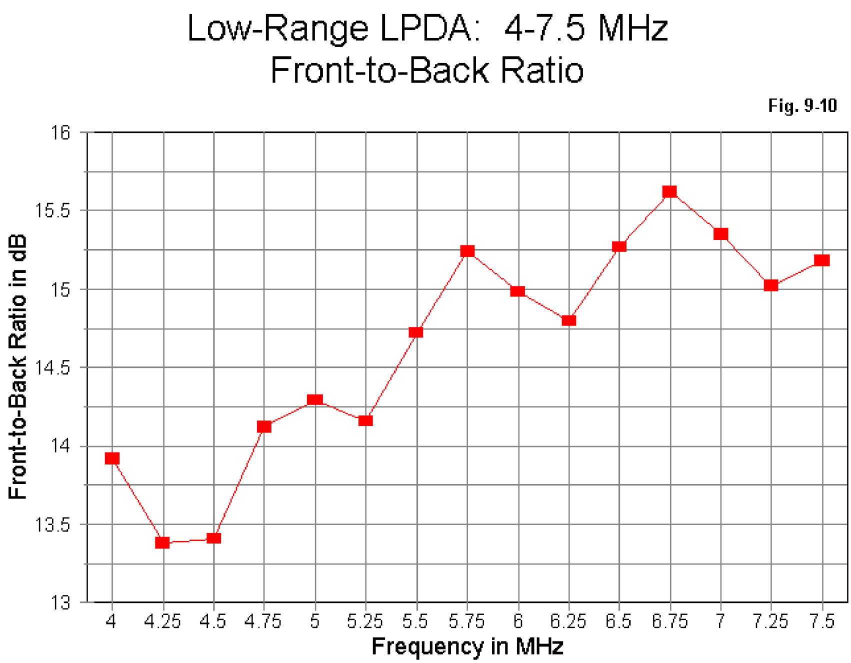
Despite the low gain, the array is the equal of any rotatable wide-range LPDA in use in the low end of the HF range. No other combination of τ and σ within the general limit of the boom length has so far (in my modeling efforts) approached these gain figures for the entire 4-7 MHz range. The design difficulty emerges from the fact that this array is, relatively speaking, a stubby LPDA. Scaled to a high-frequency limit of 30 MHz, the boom would be only about 7.5' long.



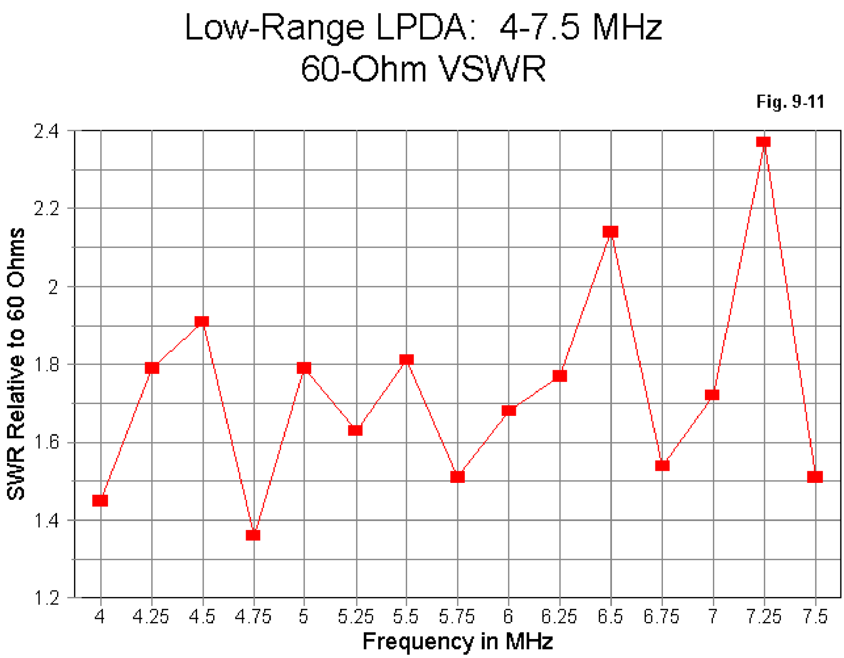
The 180-degree front-to-back ratio shows, in **Fig. 9-10**, generally increasing values as the frequency increases. Although low by upper HF standards, the values are in keeping with the general gain levels shown in **Fig. 9-9**.

Fig. 9-11 provides a 60-Ohm referenced VSWR curve for the array. It surpasses 2:1 at to points: at 6.5 and 7.25 MHz. In general, VSWR values above 2:1 but below 2.5:1 may be considered acceptable in the lowest portion of the spectrum where even coaxial cable losses are close to negligible at these frequencies. If equipment is sensitive to the reflected voltage taken from a line sample, one might well add one of the newer automatic antenna tuners to the line to ensure full power output. Since line losses are low, in "indoor" tuner will serve well without concern for the effects of weather.

Short-boom LPDAs for the lower HF range press LPDA design not only up to its limits, but beyond. However, by judicious experimental modeling, it is possible to design an acceptable LPDA for the lowest frequency range without limiting the remainder of the HF spectrum to the same level of performance. Even a 53' boom length will present mechanical challenges, since the elements will be very long. The longest element is nearly 130'. The design element diameter can be approximated either through the use of open-frame triangular structures or by multiple strands of wire widely spaced. If further reductions in performance can be accepted, element-shortening techniques might well be applied to this array to bring its side-to-side dimension into between alignment with the boom length. However, all efforts to reduce the element lengths would require considerable experimental work. At some point, one might have to compare the results to those obtained from a rotatable doublet and antenna tuner.



In the search for directivity within the lower regions of the HF spectrum, whether via narrow-band beams or wider-band LPDAs, there comes a point where the cost of directivity exceeds the benefits. A rotatable doublet with perhaps an automatic antenna tuner at the feedpoint provides a bi-directional pattern with strong rejection of signals from the sides—assuming that the mounting height is at least a half wavelength up. An array with a very low gain and/or a mediocre front-to-back ratio may not in the end warrant the additional difficulties of erecting and maintaining a complex array with many long elements on a boom of significant length. At what point the gain and directivity become too low to justify the mechanical challenges above and beyond those of a rotatable doublet is a task-driven calculation and judgment with no abstract solution for guidance. Nonetheless, my limited experience suggests that it is a calculation that is too seldom made.



The Mid-Range LPDA

As shown in **Fig. 9-12**, the mid-range LPDA in the set is quite standard in appearance. The 16-element design using 1.0" diameter aluminum elements requires a 56.17' boom and a 150-Ohm phase-line. The basic design constants are a τ-value of 0.93 and a σ-value of 0.04. However, consider optimizing work has gone into this particular design.

In many ways, the array is similar to some of those used in the early chapters of Volume 1 to illustrate more general points about the limitations of and corrections for under-performing LPDAs. The following wire table provides element details.

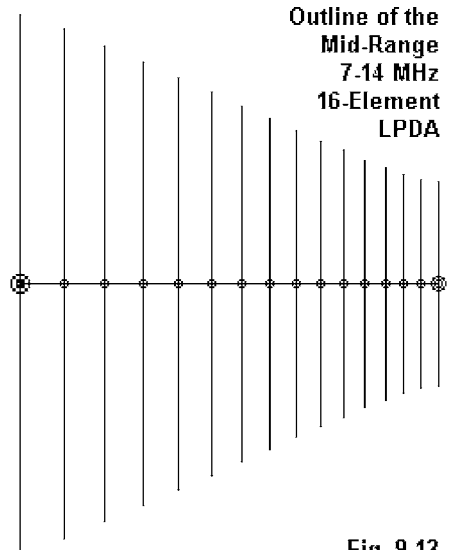


Fig. 9-12

```
.93/.04 6.88-15 MHz                        Frequency = 13  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,-36.200,  0.000         0.000, 36.200,  0.000 1.00E+00  27
2            5.904,-34.150,  0.000         5.904, 34.150,  0.000 1.00E+00  27
3           11.395,-31.915,  0.000        11.395, 31.915,  0.000 1.00E+00  25
4           16.501,-29.681,  0.000        16.501, 29.681,  0.000 1.00E+00  23
5           21.250,-27.603,  0.000        21.250, 27.603,  0.000 1.00E+00  21
6           25.667,-25.671,  0.000        25.667, 25.671,  0.000 1.00E+00  21
7           29.774,-23.874,  0.000        29.774, 23.874,  0.000 1.00E+00  19
8           33.594,-22.203,  0.000        33.594, 22.203,  0.000 1.00E+00  19
9           37.146,-20.649,  0.000        37.146, 20.649,  0.000 1.00E+00  17
10          40.450,-19.203,  0.000        40.450, 19.203,  0.000 1.00E+00  15
11          43.522,-17.859,  0.000        43.522, 17.859,  0.000 1.00E+00  15
12          46.380,-16.609,  0.000        46.380, 16.609,  0.000 1.00E+00  15
13          49.037,-15.525,  0.000        49.037, 15.525,  0.000 1.00E+00  13
14          51.520,-14.654,  0.000        51.520, 14.654,  0.000 1.00E+00  13
```

15	53.892,-14.042, 0.000	53.892, 14.042,	0.000	1.00E+00	11
16	56.167,-13.692, 0.000	56.167, 13.692,	0.000	1.00E+00	11

The 72.4' longest element will likely require an equivalent diameter considerably in excess of 1 inch, while the 27' shortest element might well have an equivalent uniform diameter closer to a half inch. τ-tapering the elements in this array had no significant effect upon the performance. However, a shorted stub consisting of 2' of 600-Ohm line proved useful.

Although the bulk of the elements adhere to the 0.93 τ and 0.04 σ values, the rear-most and forward-most elements were subjected to τ-circularization to optimize performance. A close look at **Fig. 9-12** will reveal that the element tips do not form a straight line, but a small ogee curve. The process was limited by its tendency to adversely affect the impedance values of the array at one or both ends of the spectrum.

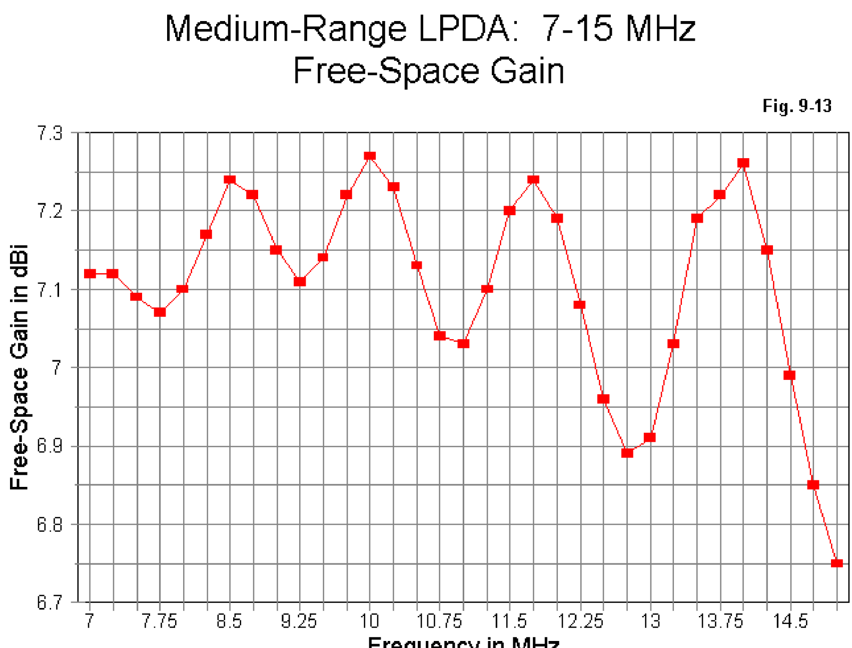


Fig. 9-13

As shown in **Fig. 9-13**, the average free-space gain of the array is between 7.1 and 7.15 dB, about the same as the gain of a 2-element quad. Note that this performance was achieved only by the 164' full-spectrum LPDA model—about 3 times longer than our mid-range LPDA. Because the boom length has been limited, resulting in a fairly low value of σ, the upper end of the spectrum shows increasing fluctuations, for a total gain variance of about 0.35 dB from 7 to 14 MHz. The gain drops below 6.9 dBi only within the overlap region with the high-range LPDA. To some degree, the fluctuations in gain at the high end of the operating passband can be overcome by adding elements to the array, that is, by extending the high-end of the design spectrum to about 17 MHz. The additional elements would provide both more gain and a smoother gain curve between 12.5 and 15 MHz. However, the added elements would have required a boom length several feet longer.

The design compromise involved in the mid-range array results from the fact that the upper-range array performs well below 14 MHz. As well, its has considerably more gain in the overlap region than this array.

Medium-Range LPDA: 7-15 MHz
Front-to-Back Ratio

Fig. 9-14

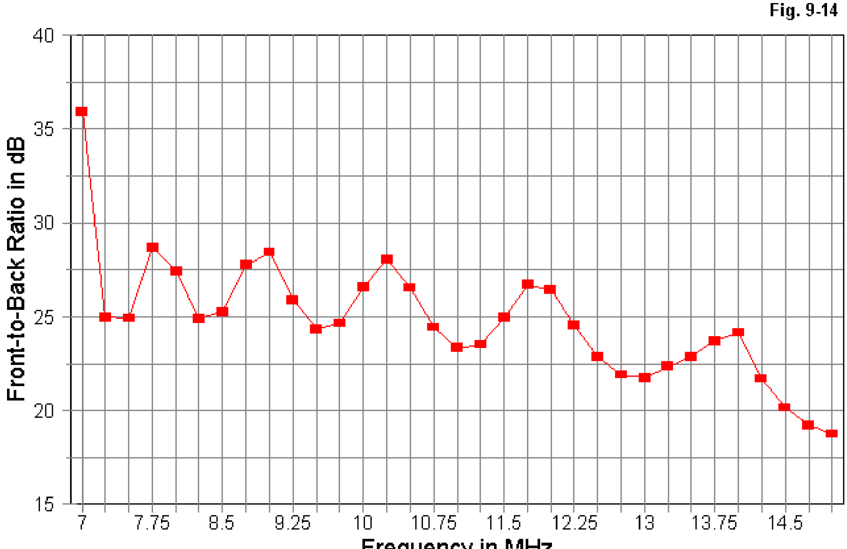
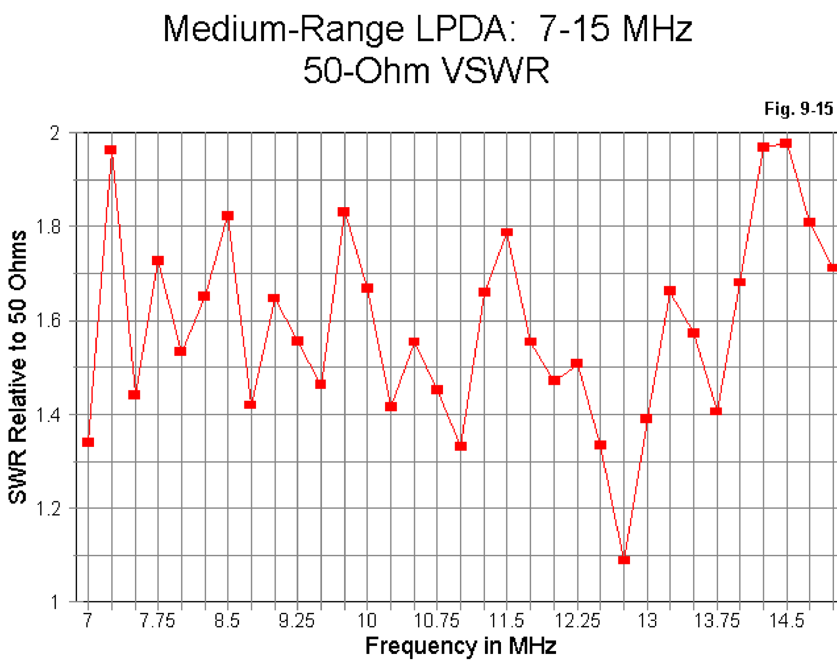


Fig. 9-14 shows the 180-degree front-to-back ratio across the passband. The ratio remains above 20 dB, with well-controlled rear lobes, up to 14 MHz.

For any LPDA, it is useful to closely examine both the gain and front-to-back curves for signs of weaknesses in coverage. One or the other—or both—will tend to show sudden and unexpected peaks or valleys in the vicinity of a weakness where the rear elements display more than minimal harmonic operation. In such cases, it is always useful to perform a frequency sweep using closely spaced frequency markers to determine whether or not such a weakness exists. For this particular design, no such indications are present. Nonetheless, should there be critical frequency regions for which the highest performance is mandatory, such sweeps are recommended as a matter of course.



The 50-Ohm SWR curve in **Fig. 9-15** shows the mid-range LPDA to maintain under 2:1 across the pass band. The curve would be slightly better using a reference impedance of 55 Ohms. Nonetheless, the losses of a feedline within this frequency range are manageable for SWR values below 2:1. Therefore, a standard 50-Ohm coaxial feed system would likely be the line of choice.

The SWR curve will normally show a greater number of sharp peaks and rapid changes when graphed in a manner that spreads the SWR value out, such as in **Fig. 9-15**. The curve responds to changes in both the resistive and reactive components of the feedpoint impedance. Although the reactance tends to change such that its extremes occur in the vicinity of frequencies where the resistance is about at its median value, the curves are not always coincident, especially when the array has undergone corrective modifications.

The mid-range LPDA is in every way conventional, including the circularized τ factor used to modify the original design that emerged from initial calculations. It provides good performance for the boom length and number of elements. But it does not carry with it any delusions of perfection.

For the collection of arrays developed here to illustrate the principle of subdividing the HF spectrum for better communications performance and reliability, the mid-range array shown is quite satisfactory. The design should not be considered to be optimized beyond improvement. Almost any array can be further optimized for special purposes, and the mid-range LPDA is no exception. However, the design might be amenable even to a few general improvements. For anyone involved in antenna design and analysis, there seems to be a guiding precept: “I never met an antenna that could not be improved.”

The High-Range LPDA

The high-range LPDA requires only scant comment, since it has appeared before in these volumes.

As the outline in **Fig. 9-16** reveals, the design is the same 14-30 MHz design on a 55.83' boom developed in detail in Volume 1. The design uses a parasitic director to enhance upper range performance more than circularizing τ alone can do. The following wire table will review the dimensions.

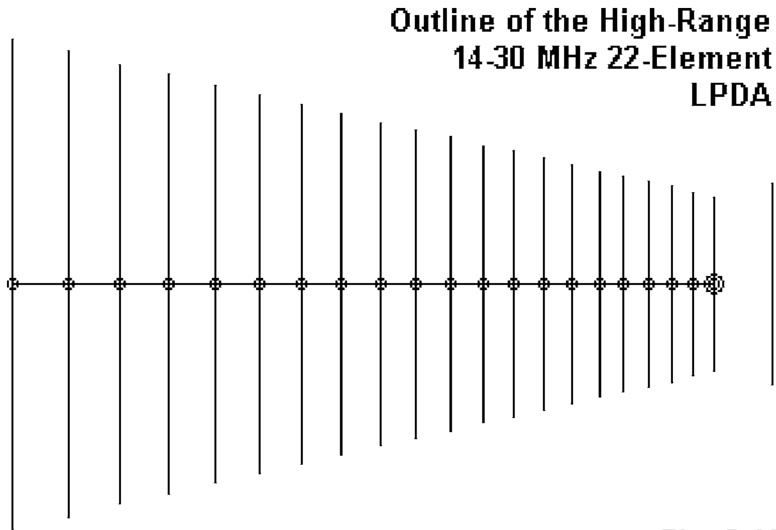


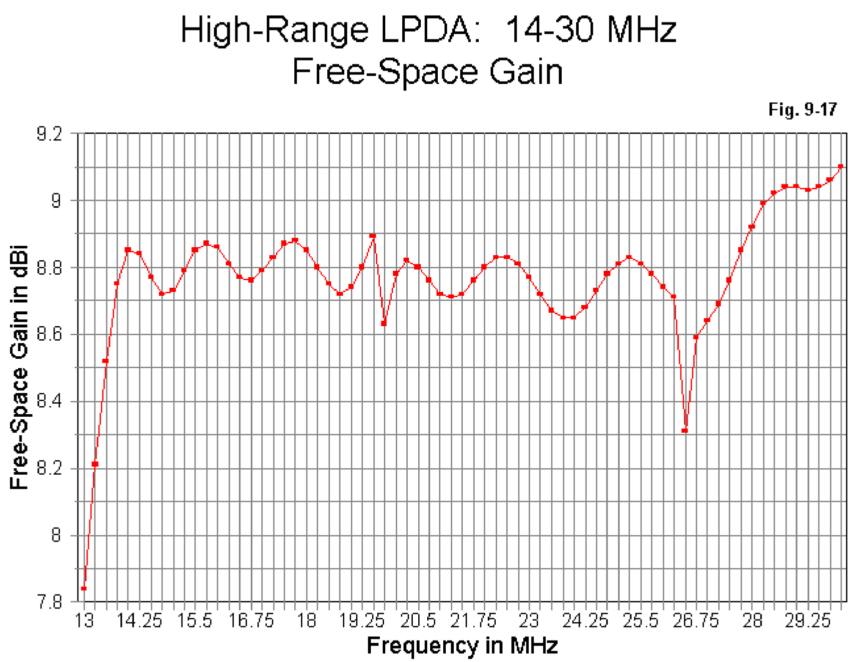
Fig. 9-16

```
14-30 MHz .95/.056 21+dir 55.8           Frequency = 28  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,-18.025,  0.000         0.000, 18.025,  0.000 5.00E-01  25
2             4.015,-17.083,  0.000         4.015, 17.083,  0.000 5.00E-01  23
3             7.829,-16.167,  0.000         7.829, 16.167,  0.000 5.00E-01  23
4            11.452,-15.367,  0.000        11.452, 15.367,  0.000 5.00E-01  21
5            14.894,-14.598,  0.000        14.894, 14.598,  0.000 5.00E-01  21
6            18.164,-13.868,  0.000        18.164, 13.868,  0.000 5.00E-01  19
7            21.271,-13.175,  0.000        21.271, 13.175,  0.000 5.00E-01  19
8            24.222,-12.516,  0.000        24.222, 12.516,  0.000 5.00E-01  17
9            27.025,-11.890,  0.000        27.025, 11.890,  0.000 5.00E-01  17
10           29.689,-11.296,  0.000        29.689, 11.296,  0.000 5.00E-01  15
11           32.219,-10.731,  0.000        32.219, 10.731,  0.000 5.00E-01  15
12           34.623,-10.195,  0.000        34.623, 10.195,  0.000 5.00E-01  15
13           36.907, -9.685,  0.000        36.907,  9.685,  0.000 5.00E-01  13
14           39.076, -9.201,  0.000        39.076,  9.201,  0.000 5.00E-01  13
15           41.137, -8.741,  0.000        41.137,  8.741,  0.000 5.00E-01  13
16           43.095, -8.304,  0.000        43.095,  8.304,  0.000 5.00E-01  11
```

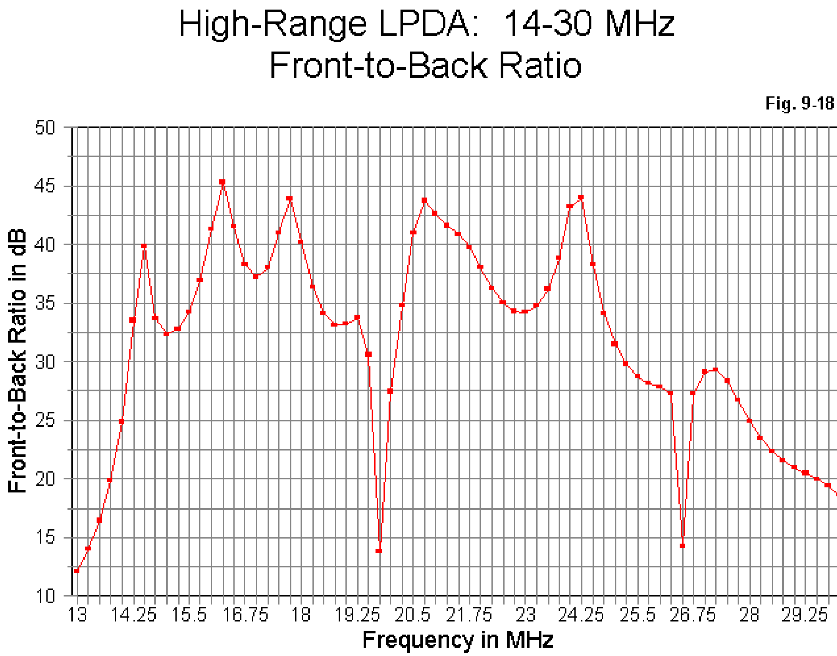
```
17        44.955, -7.888,  0.000      44.955,  7.888,  0.000 5.00E-01  11
18        46.722, -7.494,  0.000      46.722,  7.494,  0.000 5.00E-01  11
19        48.400, -7.119,  0.000      48.400,  7.119,  0.000 5.00E-01  9
20        49.995, -6.763,  0.000      49.995,  6.763,  0.000 5.00E-01  9
21        51.510, -6.425,  0.000      51.510,  6.425,  0.000 5.00E-01  9
22        55.833, -7.392,  0.000      55.833,  7.392,  0.000 5.00E-01  11
```

The feedpoint is on wire 21, and the phase line for this model is 100 Ohms. (The 250-Ohm phase line model uses a 14.2' element for wire 22.) The following graphs are presented to show performance below 14 MHz.

Fig. 9-17 shows the gain curve at 0.25 MHz intervals. Note that this close spacing of check point reveals two relatively weak region: at 19.75 and 26.5 MHz. One or both of these regions can be virtually eliminated by adding a shorted stub to the rear of the assembly. Neither is so serious as to reverse the antenna pattern, but both show that even with relatively high values of τ and σ, harmonic operation of elements to the rear of the most active element may still occur.

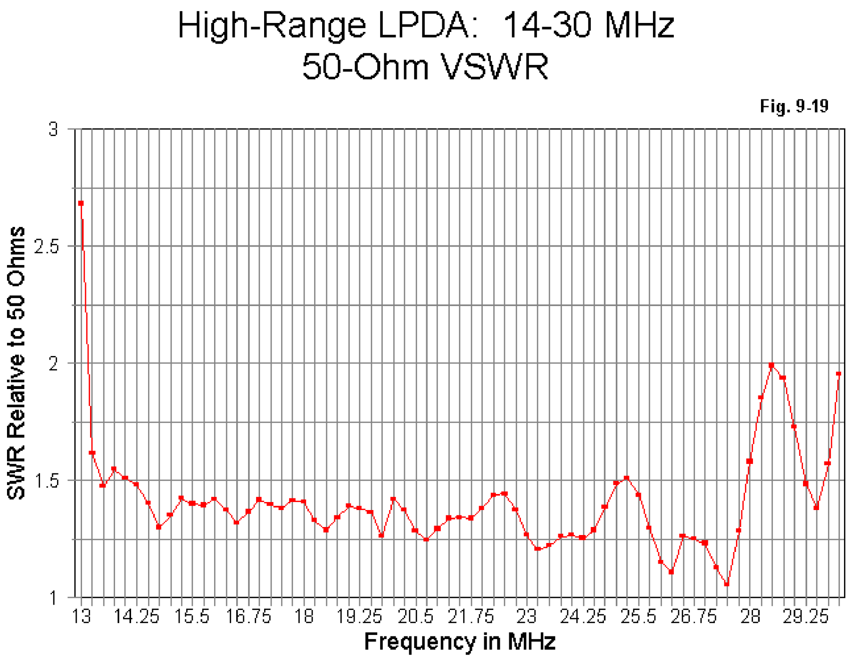


The free-space gain drops off rapidly below 14 MHz, but remains above 8.2 dBi at 13.25 MHz. The parasitic director permits a free-space gain above 9.0 dBi at 28.25 MHz and higher.



The 180-degree front-to-back ratio (**Fig. 9-18**) reaches 20 dB by 13.75 MHz and remains above that value until 29.5 MHz. The exceptions are the two weak regions previously noted. The weaknesses can be removed by using a 250-Ohm phase line. Using this line will lower the gain slightly across the passband and result in a feedpoint impedance best reference to about 110 Ohms. A 2:1 wide-band transmission-line transformer balun would provide a satisfactory match to a 50-Ohm cable.

Fig. 9-19 provides the VSWR curve relative to a directly fed 50-Ohm feedline. The SWR drops to under 2:1 by 13.1 MHz. Only in the upper region of the pass-band—largely as a result of adding the parasitic director—does the SWR approach 2:1.



With high-range LPDA performance that is superior to the mid-range LPDA down to 13.1 MHz, the crossover point between the mid-range and the high-range LPDAs is a matter of choice at installation. The overall free-space gain of the high-range array averages about 8.8 dBi, with a superior front-to-back ratio.

Conclusion

Three 55' boom just about equals the total boom length of the 164' wide-range LPDA. However, each of the individual LPDAs with an approximate 2:1 frequency span manages patterns that are better behaved. The use of three separate arrays confines lesser performance to the frequency region where it may be necessary, with increasingly better performance as we move up in the frequency regions. As well, the use of separate arrays and electronic selection and/or polling offers at least partial system operation should one antenna be down for maintenance.

The triple LPDA array is an expensive proposition, best fit for military, governmental, or commercial applications calling for relatively complete coverage of the HF spectrum. The present design exercise has attempted to see if there might be an alternative to the use of single arrays with somewhat marginal performance in such applications. Using 3 LPDAs, each optimized to a portion of the spectrum, provides increasingly better performance within the 55' boom limitation.

It is possible, in principle, to build an unconditionally stable LPDA to cover the range from 3 to 30 MHz. The free-space gain will range from a low of 10.25 dBi to a high of about 11.35 dBi, using a τ of 0.955 and a σ of 0.18. Unfortunately, this 60-element antenna will be just short of 1250' long.

Perhaps three relatively short LPDAs are not so bad after all as a substitute.

Chapter 10: A 3.5-Octave VHF-UHF LPDA

In the exploration of some of the problems and pitfalls of designing LPDAs with a wide passband—something of the order of a 10:1 frequency range—the notes focused on antennas for the 3-30 MHz range that ran from 60 to 164 feet long with 20 to 43 elements. Essentially, the bottom line was that if the boom length is too short and if τ or σ—the design constants for an LPDA—are too low, the resulting LPDA will exhibit one or more of the following flaws:

1. The overall gain will be too low to be significantly useful.

2. The gain will be uneven across the passband, with serious drops in gain at either the low or high end of the passband.

3. With increasing frequency, the azimuth patterns will become misshapen relative to the normal or "well-behaved" pattern due to harmonic activity on elements behind the most active element.

4. The chance of weakness—frequency regions in which the forward gain deteriorates and even reverses direction due to excessive harmonic activity of elements behind the most active element—increases, especially if the phase line impedance becomes too low in an effort to increase overall gain.

5. The feedpoint impedance will become erratic, with wide excursions of both the resistive and reactive components, so that it may not be possible to achieve an SWR under 2:1 for any center impedance value.

Although impractical for amateur installations, the 164' 26-element model of a standard design LPDA—with slight modifications to even out performance—proved to be among the most promising designs. It used the minimum number of elements necessary to suppress nearly all of the difficulties and still yield an average gain of about 7 dBi—about that of a 2-element quad, but spread over a 3+ octave span. Although not perfectly tamed in all respects, the design was deemed at least acceptable.

Interestingly, utility LPDAs are routinely designed for a 10:1 frequency span at VHF-UHF frequencies. Among the common designs are those for 100-1000 MHz. However, in most cases they are short (30-60 inches boom length) and have a low element population (10-14). Such antennas are about half the size—when rightly scaled—of the HF arrays examined.

I have modeled a number of possibilities in this frequency region, varying the number of elements and the overall boom length. Without exception, all are equally poor performers. 12-element 30" boom-length LPDAs for the frequency span rarely achieved more than 5 dBi free-space gain—a full dB less than a 2-element Yagi—with ragged and irregularly shaped patterns that emerged at less than half way up the passband.

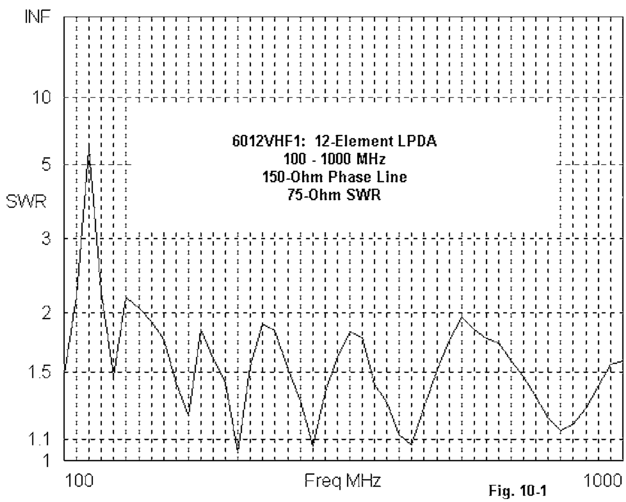
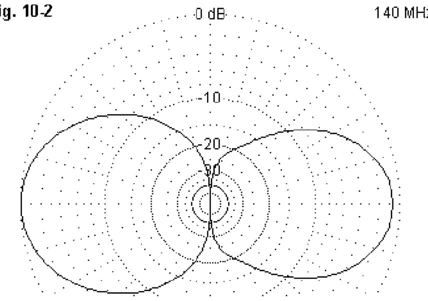


Fig. 10-1

For example, the LPDA whose 75-Ohm SWR curve appears in **Fig. 10-1** is designed with a τ of 0.77 and a σ of 0.11 to place 12 elements within a 60" boom. Once more, irregular pattern shapes emerge very quickly with increasing frequency. Note the spike in the SWR curve. It indicates a potential weakness, that is a pattern that may even reverse direction.

Fig. 10-2 shows the pattern at 140 MHz. Indeed, it is pointing in the wrong direction due to harmonic activity on elements well to the rear of those which are normally active at the working frequency. The antenna required redesign in an effort to remove the offending anomaly in performance.

Fig. 10-2



6012VHF1: 12-Element LPDA
Design Weakness at 140 MHz
150-Ohm Phase Line
75-Ohm SWR

In **Fig. 10-3**, we have the 75-Ohm SWR curve for one variation on the 60" 12-element LPDA for 100-1000 MHz. The SWR spike appears to be reduced relative to the one in **Fig. 10-1**. However, the spike in the SWR curve is just as great as the one in the previous SWR graphic. It has only moved away from the marker frequencies used by the SWR curve (every 20 MHz). The peak SWR anomaly for the second design occurs at about 135 MHz, as shown in the free-space azimuth pattern in **Fig. 10-4**. Once more, the effective beam direction has reversed and the source impedance has reached unusable values.

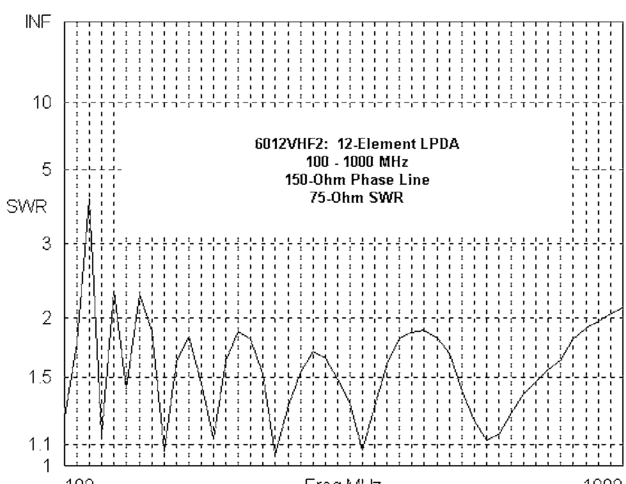
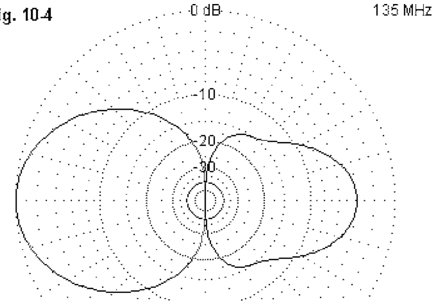


Fig. 10-3

Fig. 10-4



6012VHF2: 12-Element LPDA
Design Weakness at 135 MHz
150-Ohm Phase Line
75-Ohm SWR

One must use considerable caution in frequency sweeping and attend to the different purposes for which sweeps are made. In these chapters, the sweeps are used to present general trends, and wide checkpoint marks may be used to ensure some degree of readability. For design work, sweeps must be made with the checkpoints sufficiently close together to detect any and all weaknesses in the coverage of a given design.

Obtaining satisfactory—if not completely perfect—performance across the 100-1000 MHz region is more easily achieved if we use more elements, a better choice of τ and σ values, and a sufficiently high phase line impedance. The 164' 26-element 3-30 MHz HF array used a τ of 0.9024 and a σ of 0.0519. Certain element lengths and spacings—especially at the low end of the spectrum had been modified for improved low-end performance while retaining good gain at the upper end of the passband.

Fig. 10-5 shows the outline of the resulting array. It also shows the outline of the array scaled for use in the 100-1000 MHz range. The most significant changes required in the scaling process were a stepping of the element diameters, with 0.25" elements used at the low end of the spectrum. The diameter stepped downward in 0.0625" increments until the most forward and shortest elements used 0.0626" (about #14 AWG) diameter elements. The overall scaled length is just about 60". The following table shows the wire setup for the model.

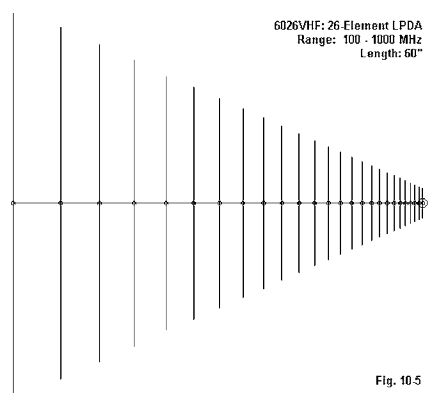


Fig. 10-5

```
60", 26-el 100-1000 MHz LPDA        Frequency = 1000  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          -29.400,  0.000,  0.000        29.400,  0.000,  0.000 2.50E-01 107
2          -27.210,  6.969,  0.000        27.210,  6.969,  0.000 2.50E-01  97
3          -24.525, 12.610,  0.000        24.525, 12.610,  0.000 2.50E-01  87
4          -22.133, 17.700,  0.000        22.133, 17.700,  0.000 2.50E-01  79
5          -19.675, 22.293,  0.000        19.675, 22.293,  0.000 2.50E-01  71
6          -18.027, 26.439,  0.000        18.027, 26.439,  0.000 2.50E-01  65
7          -16.269, 30.181,  0.000        16.269, 30.181,  0.000 2.50E-01  57
8          -14.683, 33.557,  0.000        14.683, 33.557,  0.000 2.50E-01  53
9          -13.251, 36.605,  0.000        13.251, 36.605,  0.000 1.88E-01  47
10         -11.959, 39.355,  0.000        11.959, 39.355,  0.000 1.88E-01  43
11         -10.793, 41.837,  0.000        10.793, 41.837,  0.000 1.88E-01  39
12          -9.740, 44.077,  0.000         9.740, 44.077,  0.000 1.88E-01  35
13          -8.791, 46.099,  0.000         8.791, 46.099,  0.000 1.88E-01  31
14          -7.933, 47.924,  0.000         7.933, 47.924,  0.000 1.88E-01  29
15          -7.160, 49.570,  0.000         7.160, 49.570,  0.000 1.88E-01  25
16          -6.462, 51.056,  0.000         6.462, 51.056,  0.000 1.25E-01  23
17          -5.832, 52.397,  0.000         5.832, 52.397,  0.000 1.25E-01  21
18          -5.263, 53.608,  0.000         5.263, 53.608,  0.000 1.25E-01  19
19          -4.750, 54.700,  0.000         4.750, 54.700,  0.000 1.25E-01  17
20          -4.287, 55.686,  0.000         4.287, 55.686,  0.000 1.25E-01  15
21          -3.869, 56.576,  0.000         3.869, 56.576,  0.000 6.25E-02  15
22          -3.491, 57.379,  0.000         3.491, 57.379,  0.000 6.25E-02  13
23          -3.151, 58.103,  0.000         3.151, 58.103,  0.000 6.25E-02  11
24          -2.844, 58.757,  0.000         2.844, 58.757,  0.000 6.25E-02  11
25          -2.566, 59.347,  0.000         2.566, 59.347,  0.000 6.25E-02  9
26          -2.316, 59.880,  0.000         2.316, 59.880,  0.000 6.25E-02  9

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

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

1           5    26 / 50.00   ( 26 / 50.00)      1.000       0.000       V
```

The actual element lengths are double those shown in the X-column. The element size steps are shown in the second column from the right side of the table. The initial model used a 150-Ohm phase line characteristic impedance throughout. Therefore, that portion of the model table can be omitted in the interests of space.

As shown in **Fig. 10-6**, the resulting array yields a quite acceptable 75-Ohm SWR curve for the entire passband. The 20-MHz check points on which the curve is based may hide a few weaknesses. Therefore, suspect regions were checked at closer intervals. For example, the flat peak in the 600 MHz region might hide a high peak between check points. However, it turned out to yield a smooth line when checked at intervals less than 1 MHz apart.

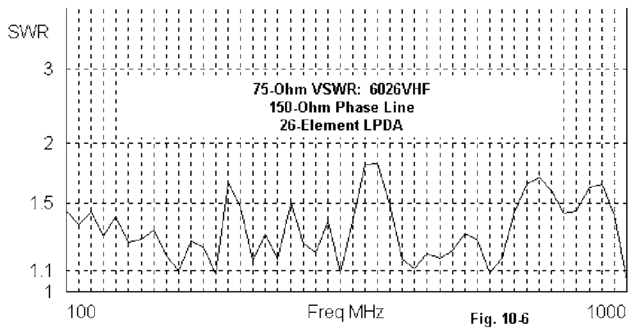


Fig. 10-6

The average free-space gain for the array is just over 7 dBi, with values lower than that at the low end of the pass band and also in the 700 MHz region. The range of gain variation for the array is just over 1 dB. The overlaid free-space azimuth patterns at 100-MHz intervals in **Fig. 10-7** demonstrate how consistent the performance is.

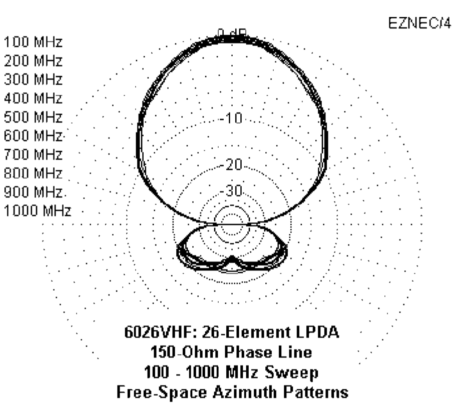


Fig. 10-7

Slight pattern irregularities begin to emerge at about 900 MHz, with a slight "spade" shape to the forward lobe and ripples in the rear lobes. However, by maintaining a 150-Ohm phase line, these affects are minimized while sustaining the highest gain obtainable from the given design.

For some applications, the builder may desire to effect a direct 50-Ohm match for the array. The standard procedure for achieving this goal is to reduce the phase line impedance to 100 Ohms or less. Unfortunately, if the impedance is lowered consistently to this value, weaknesses appear and some patterns display considerable irregularities.

A more modest approach is to use a tapered characteristic impedance for the phase line. If we were to construct the array using 3/4" U-channel (2 pieces) for the element supports and phase line, forward channel separation can be closer than the rear separation. A range of separations of the 3/4" channel phase lines ranging from about 0.3" (8 mm) to 0.9" (23 mm) along the 60" line length will provide an impedance range of about 75 to 150 Ohms.

The following table shows the simulation of the continuously changing phase line impedance within the model.

-------- 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	152.5	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	148.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	143.7	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	139.5	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	135.5	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	131.5	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	127.7	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	124.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	120.4	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	116.8	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	113.4	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	110.1	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	106.9	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	103.8	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	100.8	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	97.9	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	95.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	92.2	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	89.6	1.00	R
20	20/50.0	(20/50.0)	21/50.0	(21/50.0)	Actual dist	86.9	1.00	R
21	21/50.0	(21/50.0)	22/50.0	(22/50.0)	Actual dist	84.4	1.00	R
22	22/50.0	(22/50.0)	23/50.0	(23/50.0)	Actual dist	82.0	1.00	R
23	23/50.0	(23/50.0)	24/50.0	(24/50.0)	Actual dist	79.6	1.00	R
24	24/50.0	(24/50.0)	25/50.0	(25/50.0)	Actual dist	77.3	1.00	R
25	25/50.0	(25/50.0)	26/50.0	(26/50.0)	Actual dist	75.0	1.00	R

Fig. 10-8 shows the resulting 50-Ohm SWR curve for the modified array. So far, no peaks in SWR above 2:1 have been found in searches between the 20-MHz check points used to form the graph. However, the development of a 50-Ohm match is not without some cost.

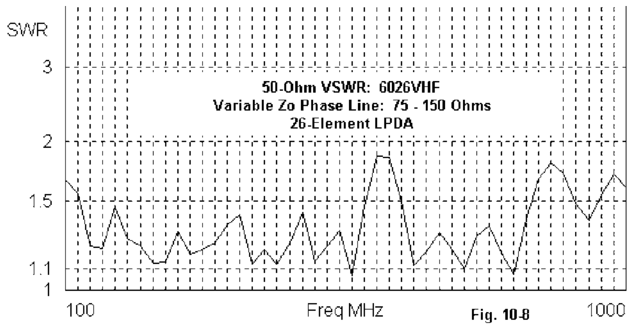


Fig. 10-8

Fig. 10-9 shows the overlaid patterns for the 100-MHz check points in the frequency sweep of the array. Note that a greater number of the patterns show the development of minor side lobes. As well, more of the rear patterns show a widening that reduces the worst-case front-to-back ratio for the upper frequencies to below 20 dB, despite a consistent 23-28 dB 180-degree front-to-back ratio.

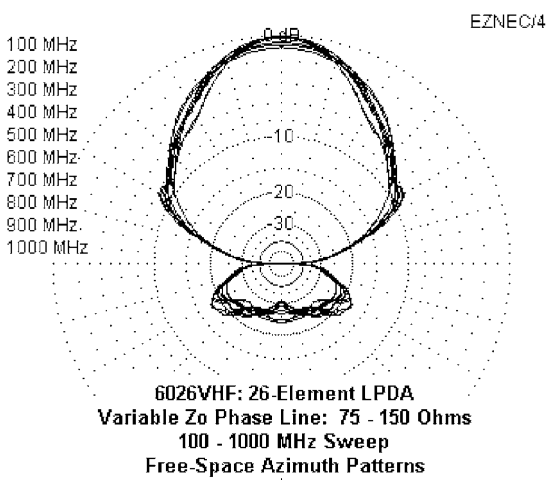
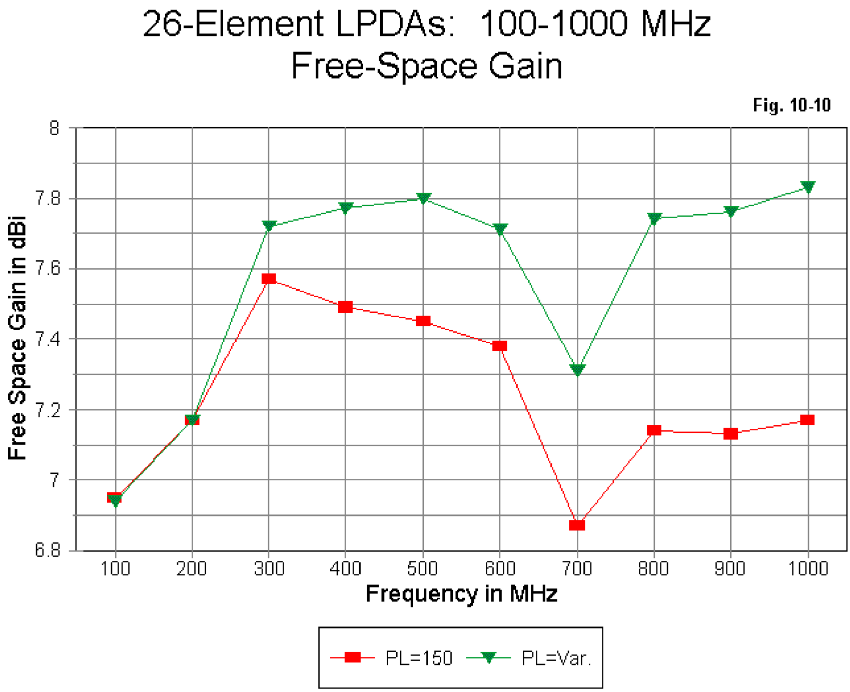
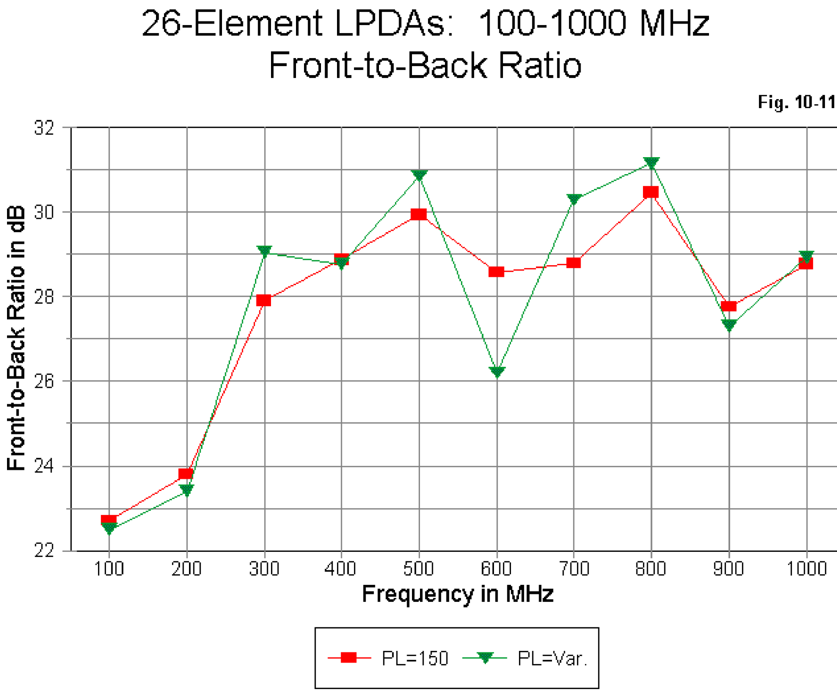


Fig. 10-9



Tapering the phase-line characteristic impedance has one beneficial effect. It raises the array gain above 200 MHz by an average of 0.5 dB. The curves in **Fig. 10-10** compare the gain of the array designs. The general shape of the curve is preserved by the tapered phase line version, including the drop in the 700 MHz region. However, the overall level is higher except for the lowest frequencies in the span.

As seen in **Fig. 10-11**, the 180-degree front-to-back ratio is not harmed or enhanced by the phase line impedance tapering technique. The gain and front-to-back ratios, when examined in greater detail than used in the graphics shown here, exhibit periodic peaks and valleys. However, the gain and front-to-back for any given design do not show coincident peaks and valleys, and the exact frequencies of maximums and minimums will shift with minor design changes. Hence, the exact values in **Fig. 10-11** should not be interpreted as giving one version of the array a significant advantage over the other.



The higher gain of the tapered phase line impedance version of the array and its cost in terms of pattern behavior deserves a further note. A well-behaved azimuth pattern for an LPDA design has the appearance of a standard directional array pattern, for example, as might be produced by a Yagi. **Fig. 10-12** shows the free-space azimuth pattern at 200 MHz for the untapered version of the array, as a simple demonstration of a well-behaved pattern. Observe the element with the highest relative current magnitude. Forward of that element, virtually all the elements are active. Behind the most active element, only two are very active (or have a significant current magnitude), and

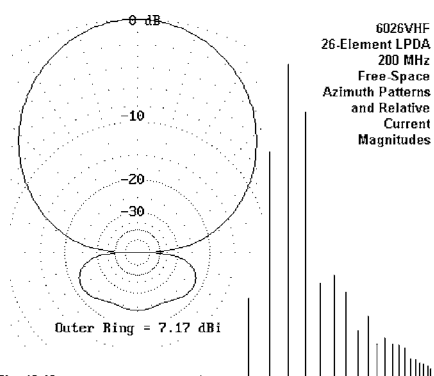


Fig. 10-12

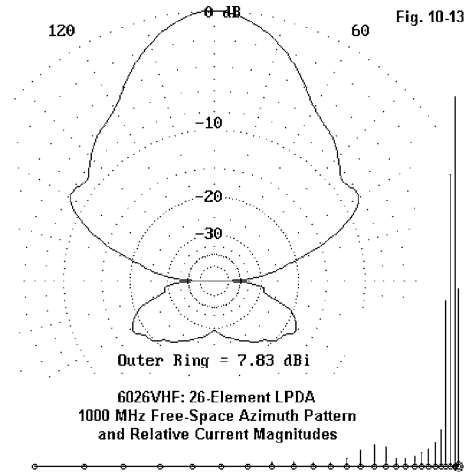
behind them, activity virtually disappears. These are the conditions for a very well-behaved pattern, such as the one in **Fig. 10-12**.

Fig. 10-13 shows the free-space azimuth pattern at 1000 MHz of the tapered phase line version of the model in order to demonstrate how far from well-behaved the patterns might go. To a lesser degree, the patterns at 900 and 1000 MHz of the constant impedance phase line model show some elements of the pattern distortion. However, in the tapered phase line model, the distortions appear at much lower frequencies. The degree of distortion is proportional in the main to the rising frequency.

The forward lobe shows the development of small side lobes. As well, the main portion of the forward lobe has lost its smooth oval and has taken on the appearance of a common garden trowel. The rear lobes have spread so that they are down from the main lobe by only about 17.5 dB at their peaks. Additionally, they show considerable ripple in their outline.

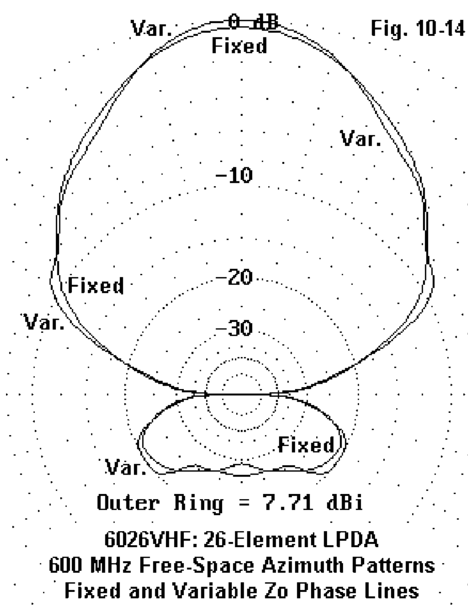
The graph of the relative current magnitude on the elements provides the reason why the pattern has grown distorted. Behind the most active element, there is considerable activity on a number of elements, although the current level decreases smoothly. However, there is also a region of increased current magnitude, indicating harmonic activity of the affected elements. In the main, it is this activity that yields the pattern distortion.

Fig. 10-13



6026VHF: 26-Element LPDA
1000 MHz Free-Space Azimuth Pattern
and Relative Current Magnitudes

Fig. 10-14



6026VHF: 26-Element LPDA
600 MHz Free-Space Azimuth Patterns
Fixed and Variable Zo Phase Lines

Fig. 10-14 compares the free-space azimuth patterns of the two versions of the LPDA at 600 MHz. In this mid-passband region, the fixed impedance model shows greater pattern control, even though there are hints of potential irregularities compared to the well-behaved pattern of **Fig. 10-12**. The tapered impedance model shows incipient secondary forward lobes and a greater ripple to the rear lobes than the fixed impedance version.

Carried to high levels of current, relative to the most active element, active elements behind the most active element would yield a potential weakness that might go so far as to produce a pattern reversal and an unusable feedpoint impedance. However, in the present designs, these consequences have been avoided. Still, an important user question remains.

Just how much pattern distortion is acceptable for an LPDA design? There is no simple answer to this question, since it necessarily involves goals and specifications brought to the antenna design by the user. For general utility purposes, the pattern distortion shown in **Fig. 10-13** might well be considered to be well within needs. For other purposes, the most well-behaved pattern achievable might be required. For utility purposes, either version of the 26-element LPDA shown here would be serviceable, with the final selection perhaps dictated by the desired feedpoint impedance.

There is a considerable difference between the 12-element sample models that were rejected and the 26-element models that proved to be reasonably successful—a 14 element difference to be precise. How many fewer elements than 26 might one use on the 60" boom and obtain the necessary performance in terms of gain, an absence of weaknesses, and an acceptable SWR curve across the passband? There is, once more, no simple answer to the question. Each trial design may alter the value of τ and σ, the total boom length, and the low and high frequencies used in the design exercise. For lower values of τ, a lower minimum frequency should be used to ensure adequate gain near 100 MHz. As well, altering the length and spacing of the longest elements in accord with circularizing techniques may be useful in increasing low-end gain. If high end gain tapers off too badly, the design may use a higher maximum frequency or also employ circularizing techniques to adjust the most forward elements with respect to length and spacing. As a general guide, it may be more useful to begin with the 60" 26-element array and work backwards until performance passes below the task-defined performance standard than to try to work upward from a dozen elements on a 30" boom.

If modeling at the HF range is any guide—and with proper scaling, it can be—then much fewer than 26 elements may not result in a truly satisfactory array, especially at the higher end of the spectrum. The sparser the element population in a 3.5-octave array, the lower the frequency at which pattern distortion becomes significant and the greater the distortion at the highest frequencies of operation. In addition, fewer elements bring with them a higher number of periodic weaknesses, and no single shorted stub or other simple corrective can overcome all of them. However, we have classified the 100-1000 MHz antenna as a utility array. Consequently, it is not possible to say—in the absence of detailed task specifications—just how much pattern distortion and how many areas of weakness are tolerable in light of the intended use.

When we combine the variables of both basic design and useful modifications, a general answer to the question of how few elements we may use and still achieve a desired level of performance becomes impossible. The examples of LPDA design given here represent but two of many possibilities. However, they do illustrate well the general guidance of using a long enough boom and using enough elements to ensure that we get the job done.

Chapter 11: Split-Band LPDAs

A split-band LPDA is simply 2 LPDAs for different frequency ranges that have been placed on the same boom and designed for the same phase-line characteristic impedance. Of course, the lower frequency section with its longer elements goes behind the higher frequency, short-element section. A single feedline handles the duties for the pair of frequency ranges covered by the array. **Fig. 11-1** sketches the general arrangement.

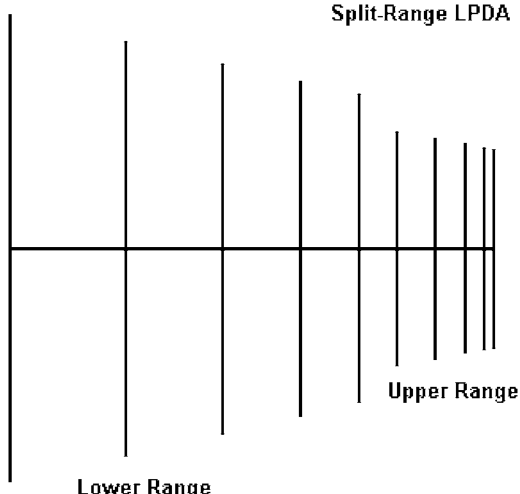


Fig. 11-1

One of the motivating factors behind the development of such arrays is to save space and possibly money (in commercial antenna construction) by omitting the unnecessary elements. The question that confronts the LPDA designer is at what point a split-frequency LPDA makes good sense relative to one designed for continuous coverage of the desired pair of bands. Older conceptions of LPDA design placed the highest frequency element at about 1.3 times the highest frequency used. However, to avoid significant decreases in performance at the highest operating frequencies, the resonant length of the shortest element turns out to be closer to 1.6 times the highest operating frequency. This value is somewhat variable and depends upon the choices made for τ and σ in the basic design.

The concept of split-frequency LPDAs is most generally applicable to VHF and UHF services other than amateur radio. Amateur bands are generally narrow enough so that for the ranges of free-space gain attained by LPDAs (generally below 11 dBi), wide-band Yagis that cover entire amateur bands are feasible. However, there is a commercial split band that runs roughly between 250 and 385 MHz, with each subband covering only about 8 MHz. Again, there is a pair of related commercial service bands, one in the 800-1000 MHz region, the other in the 1800-2000 MHz region. The difference in separation between these two band sets may prove useful in trying to determine at what point it makes sense to use a split LPDA in lieu of a continuous frequency design.

To make the investigation significant, we must set some specification for the performance that we expect of the LPDA. Let's set a free-space gain value of 9.5 dBi as the minimum gain for our arrays. This gain assures about 30 dB or better front-to-back ratio. Because it would be anticipated that construction might involve twin U-channel booms, we may use phase-line characteristic impedance values from 75 to 100 Ohms in the designs. With these simple parameters as our design goals, we may begin with the lower frequency unit.

250-382 MHz

The 250-382 MHz band pair actually uses two sub-ranges: 250-258 MHz and 375-382 MHz. Each range might be served by a Yagi, but since the ranges are used as a pair, a single antenna is most applicable to covering then. Hence, the LPDA becomes a viable candidate, despite the small size of each subrange. However, the two subranges are widely separate by frequencies of no relevance to the service. Consequently, the idea of a split-range LPDA comes to mind.

The decision as to whether we should use a split-frequency LPDA or a continuous coverage LPDA boils down to simple arithmetic. Consider the two bands separately.

1. The upper band has a lower limit of 375 MHz. The longest element in an array designed with no allowance for low-end performance variables would still be resonant

about 2.5% lower in frequency than the operating limit, or about 9.4 MHz below the band end. Hence, the longest element would be resonant at about 365.6 MHz.

2. The upper end of the lower range is 258 MHz. By standard design, the shortest element of this section would be resonant at about 1.3 times the limit or 335.4 MHz. This element is already approaching the resonant frequency of the longest element of the higher range. If we compensate for gain fall-off at the upper end of most LPDA designs, then we would increase the resonant frequency of the longest element. The longest upper region element is resonant at only 1.4 times the highest frequency used in the lower range, well below the suggested value of 1.6 times that highest operating frequency in the lower range.

The consequence of this small exercise is a simple conclusion. Virtually any sound design will result in overlapping designs for the two regions. Hence, a split-range LPDA is not a useful candidate. Instead, a continuous coverage LPDA is required.

The actual design procedure for a continuous coverage LPDA for the dual range operation is subject to some constraints. Ideally, the two ranges should have about the same performance level—perhaps within 0.2 dB of each other in gain. To ensure this result, the upper limit for the design will be specified at 1.6 times the upper operating frequency or about 600 MHz. Although this value may seem unnecessarily high, we shall await the outcome of the design procedure before passing judgment. With a design goal of 9.5 dBi free-space gain across the entire passband, the upper-end frequency limit may not be as excessive as it seems.

The test design restricted itself to a 47.5" boom length for the elements, which permits the use of 4' pieces of boom material for the elements. Within this length, we may select endless pairs of τ and σ values. If we limit ourselves to 21 elements in the boom length, then we end up with a τ of about 0.9447 and a σ of 0.0802. **Fig. 11-2** sketches the outline of the resulting array, with some of the dimensions given in millimeters as well as inches. See **Table 11-1** for the complete dimension set. The initial elements are 3/16" (0.1875") in diameter, although we shall check the array performance using smaller 1/8" (0.125") elements as well. The characteristic impedance of the phase line is 80 Ohms.

Fig. 11-2

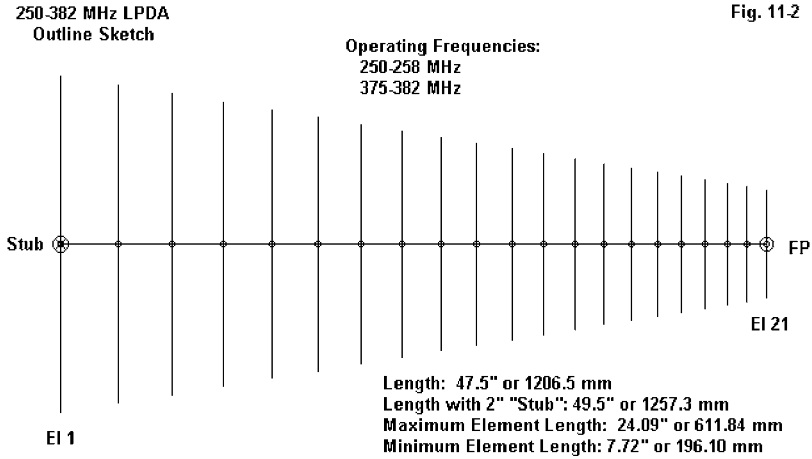


Table 11-1. 250-385 MHz LPDA Dimensions

Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	12.04	0.00	305.9	00.0
2	11.38	3.87	289.0	98.2
3	10.75	7.52	273.0	191.0
4	10.54	10.97	257.9	278.6
5	9.59	14.23	243.7	361.4
6	9.06	17.31	230.2	439.6
7	8.56	20.22	217.5	513.5
8	8.09	22.96	205.4	583.3
9	7.64	25.56	194.1	649.2
10	7.22	28.01	183.3	711.5
11	6.82	30.33	173.2	770.4
12	6.44	32.52	163.6	826.0
13	6.09	34.59	154.6	878.5
14	5.75	36.54	146.0	928.1
15	5.43	38.38	137.9	975.0
16	5.13	40.13	130.3	1019.2
17	4.85	41.77	123.1	1061.1
18	4.58	43.33	116.3	1100.6

19	4.33	44.80	109.9	1137.9
20	4.09	46.19	103.8	1173.2
21	3.86	47.50	98.1	1206.5
Total length with a 2" stub:		49.50"	with a 50.8 mm stub:	1257.3

Before we judge this array to be over-designed, let's look at the performance figures. First, we can examine the overall performance by using 25-MHz checkpoints in **Table 11-2**.

Table 11-2. Overall Performance of the LPDA

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
250	9.68	34.40	57.9 - j 1.6	1.162
275	9.63	36.47	53.3 - j 2.2	1.079
300	9.70	39.23	56.3 - j 4.6	1.159
325	9.60	37.24	56.9 - j 3.1	1.151
350	9.53	32.14	50.6 - j 7.6	1.164
375	9.53	36.88	54.8 - j 5.2	1.145
400	9.37	29.88	47.9 - j10.6	1.247
Average	9.58	35.18		1.158

Except for the last checkpoint at 400 MHz, which falls outside the design range of the array, the free-space gain meets and exceeds the design goal of 9.5 dBi. The front-to-back ratio is commensurately high. The feedpoint impedance is mildly capacitively reactive, as is normal for a high-τ, high-σ LPDA, with very little variation in the resistive component. Of special note is the fact that the figures begin to fall off at the 400-MHz checkpoint, suggesting that the choice of a 600-MHz frequency as the design limit was not unwise—if equalized performance is desired across the entire passband.

More specifically, **Table 11-3** provides performance figures within each of the two prime operating regions for the antenna design.

Table 11-3. Specific Performance Details

Lower Operating Range: 250-258 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
250	9.68	34.40	57.9 - j 1.6	1.162
251	9.69	35.58	57.9 - j 2.1	1.163
252	9.69	36.76	57.7 - j 2.5	1.162
253	9.69	37.95	57.5 - j 2.8	1.160
254	9.70	39.14	57.2 - j 3.0	1.156
255	9.70	40.28	56.9 - j 3.1	1.152
256	9.71	41.35	56.6 - j 3.2	1.148
257	9.71	42.26	56.4 - j 3.1	1.144
258	9.72	42.92	56.3 - j 3.1	1.141
Average	9.70	38.96		1.154

Upper Operating Range: 375-382 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
375	9.53	36.88	54.8 - j 5.2	1.145
376	9.54	37.54	54.3 - j 5.1	1.137
377	9.55	38.18	53.9 - j 4.9	1.129
378	9.55	38.71	53.7 - j 4.6	1.120
379	9.56	39.12	53.6 - j 4.2	1.113
380	9.56	39.29	53.6 - j 3.9	1.107
381	9.57	39.23	53.8 - j 3.5	1.105
382	9.57	38.91	54.1 - j 3.2	1.106
Average	9.55	38.48		1.120

Between the two operating ranges, the gain varies by only 0.15 dB, with a 0.5 dB difference in the average front-to-back ratio.

The patterns of the array are very well-behaved throughout the operating spectrum. There are no detected weaknesses in the coverage. **Fig. 11-3** provides a representative low-range free-space azimuth pattern. **Fig. 11-4** shows a free-space azimuth pattern in the upper operating range. Coverage, including beamwidth, is well matched.

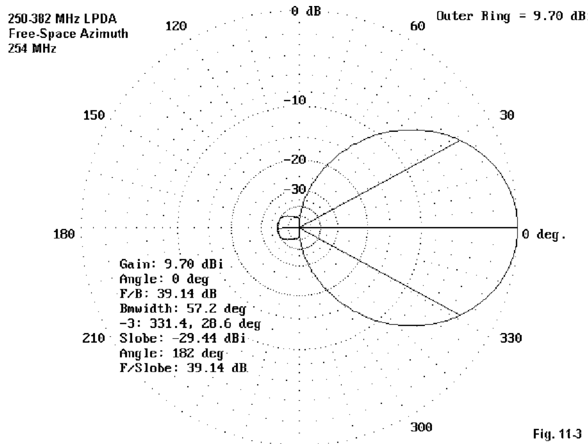


Fig. 11-3

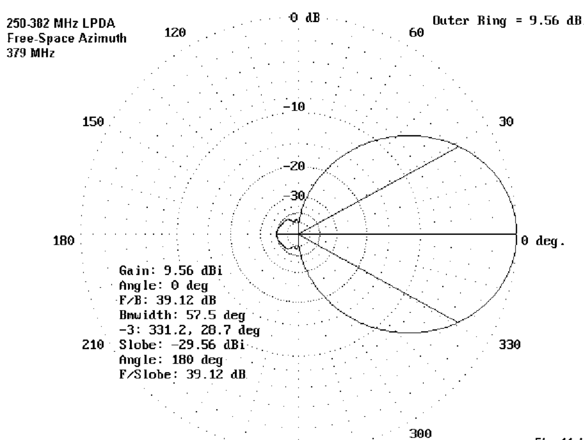


Fig. 11-4

The 50-Ohm VSWR figures in the tables are confirmed by more detailed sweeps, both within each of the prime operating ranges and for the overall performance of the array. The SWR exceeds 1.2:1 only above the highest frequency of use for the array. **Fig. 11-5** provides comprehensive graphs of the 50-Ohm SWR that emerges from the use of the 80-Ohm phase line.

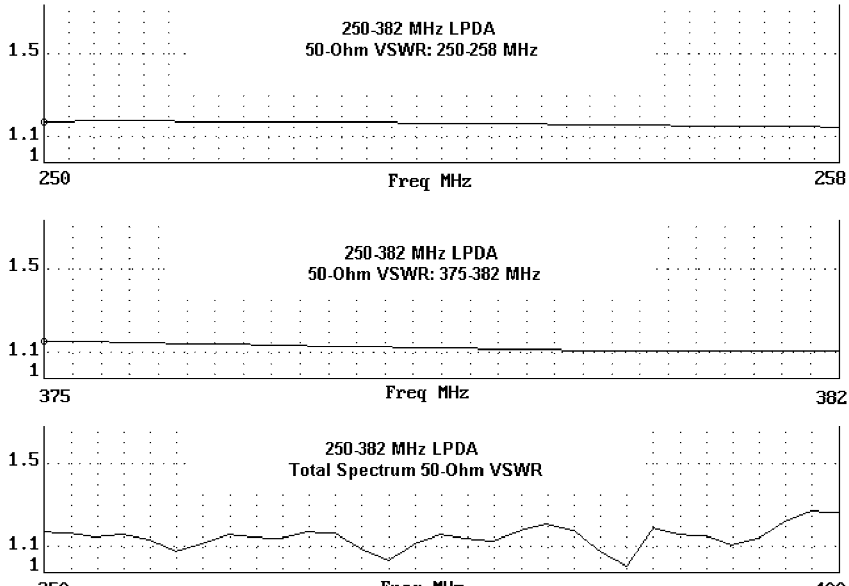


Fig. 11-5

The modeled performance figures for the 21-element array result from the use of 3/16" diameter elements. Many antenna constructors might insist that 3/16" elements are excessively large for the frequency range and represent unnecessary additional weight for the array. To test this general hypothesis, the array was modeled with 1/8" elements, with the results presented in **Table 11-4**. There is a drop in performance due to the lower level of inter-element coupling. Although in some ways, the 0.2 dB decrease in gain might still be acceptable, the level in the upper range falls below the 9.5 dBi target. With the smaller elements, the feedpoint impedance shows some inductive reactance in the lower range of use. However, there is a positive side to the story. Should one wish to use the array above 400 MHz, the element size is better suited to the high end of the passband, with a slower rise in capacitive reactance at the passband edge. τ-tapered elements were not used with the design.

Table 11-4. Performance with 1/8" Elements

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
Overall performance:				
250	9.58	32.09	58.9 + j 0.7	1.179
275	9.58	37.97	56.5 - j 3.6	1.150
300	9.63	44.97	58.3 - j 2.9	1.176
325	9.50	34.99	58.0 - j 0.1	1.160
350	9.53	34.33	58.3 - j 6.9	1.221
375	9.40	33.98	59.5 - j 2.1	1.194
400	9.42	32.24	58.4 - j 9.7	1.267
Average	9.52	35.80		1.192
Lower Operating Range: 250-258 MHz				
250	9.58	32.09	58.9 + j 0.7	1.179
251	9.58	33.00	59.2 + j 0.4	1.184
252	9.58	33.88	59.4 + j 0.1	1.188
253	9.58	34.71	59.6 - j 0.3	1.191
254	9.59	35.50	59.6 - j 0.7	1.193
255	9.59	36.25	59.6 - j 1.2	1.194
256	9.59	36.96	59.5 - j 1.5	1.193
257	9.60	37.65	59.4 - j 1.8	1.191
258	9.60	38.31	59.2 - j 2.1	1.189
Average	9.59	35.37		1.189
Upper Operating Range: 375-382 MHz				
375	9.40	33.98	59.5 - j 2.1	1.194
376	9.41	34.42	59.5 - j 2.9	1.199
377	9.42	34.91	59.3 - j 3.6	1.200
378	9.43	35.46	58.9 - j 4.2	1.199
379	9.44	36.06	58.5 - j 4.6	1.195
380	9.45	36.71	58.0 - j 4.9	1.189
381	9.46	37.39	57.5 - j 5.0	1.182
382	9.47	38.10	57.0 - j 4.9	1.174
Average	9.44	35.62		1.192

Fig. 11-6 shows one possible method of construction for an array of this order, using U-channel twin-booms. The sketch presumes that the array will be suspended

from the rear, allowing for either vertical or horizontal orientation. The 2" shorted stub is built into the twin-boom structure so that it performs not only its electrical function, but as well provides mechanical bracing. Additional details will be a function of the materials chosen and the overall application specifications. Hence, only a concept sketch is shown here.

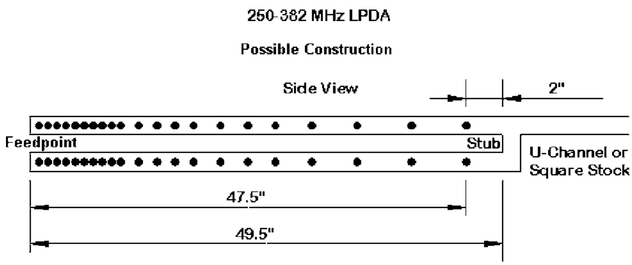


Fig. 11-6

The modeled performance figures of the complete design tend to justify the choice of using a single continuous LPDA design for the split frequency ranges in question here. However, the alternative problem we posed of covering 800-100 and 1800-2000 MHz provides a more radically separated set of operating ranges. Perhaps a split LPDA might be of more relevance for those bands,

800-2000 MHz

The problems posed by the new bands to be covered by an LPDA are multiple. First, for standard construction, the sizes of the materials—for example, the twin boom pieces—begin to interact with the very short element lengths. Consequently, designing for a very precise frequency range may prove self-defeating should the materials shift the frequency range as a whole. Therefore, we shall adopt the procedure of setting the two design bands as 800 to 1000 MHz and 1800 to 2000 MHz.

Second, many antenna types can be developed for each of these bands. For example, wide-band Yagis are possible. As well, flat-plane and corner reflector arrays become quite feasible with respect to both size and performance. The appeal of the LPDA lies in its ability to be designed to cover both bands.

Before beginning detailed design work, let's first replicate the calculations that we performed on the lower-frequency challenge.

1. The upper limit of the low band is 1000 MHz. The older resonant frequency for the shortest element would be 1300 MHz, while the newer recommendation would yield 1600 MHz as the resonant frequency of the shortest element.

2. The lower limit of the upper band is 1800 MHz, with the longest element resonated about 2.5% lower, or about 1755 MHz.

The two elements of concern are at a border line. They are close enough together to suggest that a continuous frequency LPDA design might be applicable. However, they are far enough apart to make the process of designing separate LPDAs and combining them sensible as a preliminary investigation. In the days before computer antenna modeling, such a process would call for extensive construction and range testing. Today, mathematical simulation shortens the work considerably.

I used the same values of τ (0.9045) and σ (0.1879) for the individual LPDAs as I did for the single design. The low-band and the high-band LPDAs each required 8 elements. **Fig. 11-7** provides the outlines for the two arrays. **Table 11-5** supplies the dimensions. The designs used an 80-Ohm phase line and 0.118" (3 mm) elements

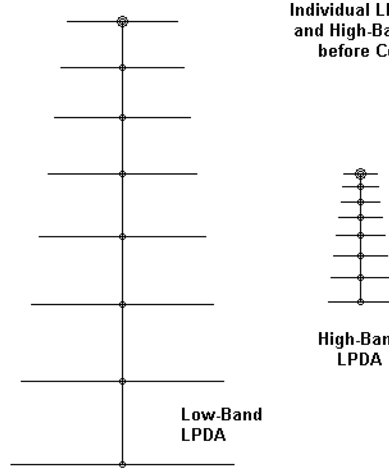


Fig. 11-7

Table 11-5. 800-1000 and 1800-2000 MHz LPDA Dimensions

Low-Band

Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	3.86	0.00	97.98	00.0

2	3.49	2.90	88.62	73.6
3	3.16	5.52	80.16	140.2
4	2.85	7.89	72.50	200.5
5	2.58	10.04	65.58	255.0
6	2.34	11.98	59.31	304.3
7	2.11	13.73	53.65	348.8
8	1.91	15.32	48.53	389.2

High-Band

Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	1.70	0.00	43.22	00.0
2	1.54	1.28	39.10	32.5
3	1.39	2.44	35.36	61.9
4	1.26	3.48	31.99	88.5
5	1.14	4.43	28.93	112.5
6	1.03	5.29	26.17	134.2
7	0.93	6.06	23.67	153.9
8	0.84	6.76	21.41	171.7

Each of the two individual LPDAs offers adequate performance relative to the standards with which we began: a minimum free-space gain of 9.5 dBi (with its associated high front-to-back ratio) and a 50-Ohm SWR well under 2:1. **Table 11-6** provides the modeled performance data at 20 MHz intervals in each of the two bands.

Table 11-6. Specific Performance Details

Lower Operating Range: 800-1000 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
800	9.48	23.84	62.9 - j 3.9	1.271
820	9.63	23.74	65.3 - j 5.1	1.326
840	9.83	18.68	64.9 - j 8.8	1.353
860	9.64	9.28	53.8 - j 3.9	1.111
880	9.49	16.12	69.6 + j 0.4	1.392
900	9.71	21.80	71.4 - j 4.3	1.438
920	9.76	23.11	73.0 - j 6.9	1.484

940	9.73	22.55	75.0 - j10.8	1.554
960	9.63	21.82	75.3 - j16.7	1.632
980	9.50	21.41	72.4 - j23.1	1.698
1000	9.33	21.35	66.6 - j27.7	1.736
Average	9.62	20.34		1.454

Upper Operating Range: 1800-2000 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
1800	9.87	26.86	65.1 - j 4.8	1.318
1820	9.94	27.47	65.5 - j 6.6	1.340
1840	10.00	26.53	65.2 - j 8.1	1.351
1860	10.07	24.40	64.4 - j 9.2	1.351
1880	10.13	21.74	63.5 - j 9.7	1.341
1900	10.19	18.77	62.6 - j 9.4	1.323
1920	10.25	15.53	62.3 - j 7.8	1.297
1940	10.24	13.74	64.9 - j 5.6	1.322
1960	10.13	16.09	68.8 - j 7.6	1.410
1980	10.06	19.13	70.2 - j10.4	1.464
2000	10.02	20.88	71.2 - j13.0	1.512
Average	10.08	21.01		1.339

If we combine the two arrays into a single array, using the same phase line value, we obtain an LPDA that is about 23.5" (597 mm) long. The performance does not vary by much from the values produced by the individual arrays that comprise it. Unfortunately, this performance also includes the weakness at 860 MHz, as shown in **Fig. 11-8**.

Combining arrays did not remove this weakness, and the addition of a shorted stub manages to move its frequency upward, but not out of the desired operating range of the low band. Indeed, the relatively weak front-to-back performance of the individual and combined arrays results from using a value of σ that is slightly above the optimum value. The arrays yields more gain, but at the cost of the front-to-back ratio. As well, the element diameters may be somewhat large for the frequency range in use.

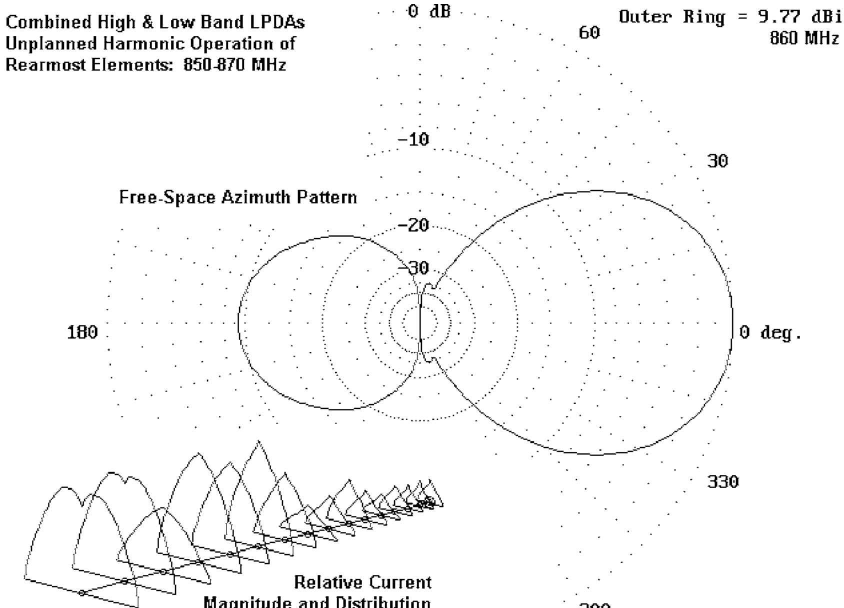


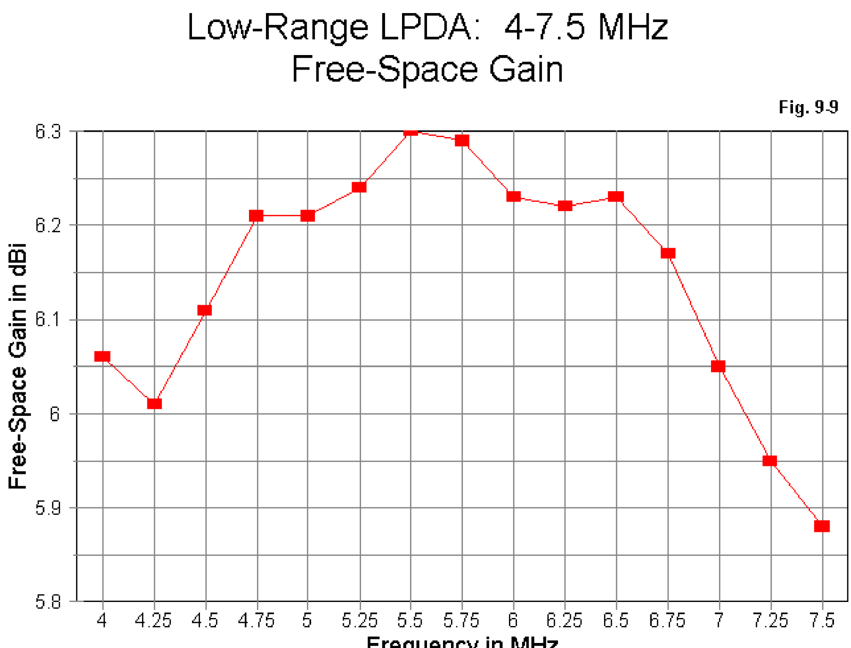
Fig. 11-8

We may create a single LPDA using the very same values of τ and σ. **Fig. 11-9** shows the outline of such an array. Note that the length is a mere 3 mm greater than the combined array. What differs, however, is the fact that the space between elements 8 and 9 adheres to the specifications for the array and is not based on an arbitrary or experimental adjustment. For comparison with the individual arrays, **Table 11-7** lists the total array dimensions.

Table 11-7. 800-2000 MHz LPDA Dimensions

Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	3.76	0.00	95.50	00.0
2	3.43	2.90	87.20	73.6
3	3.12	5.52	79.20	140.2
4	2.85	7.89	72.30	200.5
5	2.58	10.04	65.58	255.0
6	2.34	11.98	59.32	304.3

7	2.11	13.73	53.65	348.9
8	1.91	15.32	48.53	389.2
9	1.73	16.76	43.89	425.6
10	1.56	18.06	39.70	458.6
11	1.41	19.23	35.91	488.5
12	1.28	20.29	32.48	515.5
13	1.16	21.26	29.38	539.9
14	1.05	22.12	26.57	562.0
15	0.95	22.91	24.04	581.9
16	0.87	23.62	22.00	600.0



From some of the rounded numbers in the millimeters column for element lengths, it should be clear that the four rear-most and the last forward elements have been modified to improve performance. In addition, the phase-line has a continuously variable characteristic impedance ranging from 78 Ohms at the feedpoint to 120 Ohms at the array rear. In addition, a 2" (50 mm) 120-Ohm stub has been added to the rear of the array. This combination of ingredients removes weakness from the coverage and smoothes the SWR values across the passband. The benefit includes a modicum of gain, but an even greater improvement in the front-to-back ratio. **Table 11-8** provides the modeled performance values.

Table 11-8. Specific Performance Details

Lower Operating Range: 800-1000 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
800	9.73	35.46	61.5 - j 5.7	1.259
820	9.80	35.83	61.8 - j 5.6	1.263
840	9.85	35.41	62.1 - j 5.8	1.271
860	9.87	34.38	62.1 - j 6.2	1.275
880	9.88	32.72	61.9 - j 6.5	1.275
900	9.88	30.15	61.7 - j 6.7	1.273
920	9.94	23.86	62.2 - j 6.8	1.283
940	9.96	17.77	57.6 - j 6.9	1.210
960	9.85	26.26	59.9 - j 5.2	1.227
980	9.87	28.93	61.0 - j 5.0	1.246
1000	9.90	30.66	61.8 - j 5.5	1.264
Average	9.86	30.13		1.259

Upper Operating Range: 1800-2000 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
1800	10.16	32.05	64.1 - j 6.5	1.314
1820	10.15	34.95	64.0 - j 7.8	1.325
1840	10.15	38.72	63.6 - j 8.6	1.330
1860	10.15	44.65	63.4 - j 9.1	1.332
1880	10.16	48.97	63.6 - j 9.3	1.337
1900	10.17	41.10	64.1 - j 9.5	1.349
1920	10.19	36.28	65.2 - j 9.9	1.372
1940	10.21	33.42	66.7 - j10.9	1.410
1960	10.20	31.75	68.2 - j12.8	1.460
1980	10.15	30.58	69.3 - j15.6	1.519
2000	10.09	29.50	69.5 - j19.1	1.582
Average	10.16	36.54		1.393

Overall performance:

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
800	9.73	35.46	61.5 - j 5.7	1.259
900	9.88	30.15	61.7 - j 6.7	1.273
1000	9.90	30.66	61.8 - j 5.5	1.264
1100	10.57	15.26	64.2 - j 6.6	1.318
1200	10.00	26.02	57.5 - j 7.2	1.214
1300	10.26	25.58	62.7 - j 5.7	1.281
1400	10.33	33.83	62.3 - j 9.3	1.317
1500	10.17	37.78	58.8 - j13.8	1.351
1600	10.00	28.68	51.8 - j 9.0	1.197
1700	9.89	27.76	56.8 - j 1.4	1.139
1800	10.16	32.05	64.1 - j 6.5	1.314
1900	10.17	41.10	64.1 - j 9.5	1.349
2000	10.09	29.50	69.5 - j19.1	1.582
Average	10.09	30.33		1.297

All three parts of the table are useful. The specific performance potentials within the two operating regions show about a 0.3 dB differential, which indicates a good match. As well, the single array shows a very high improvement in the front-to-back ratio over the separate or combined separate arrays. As well, within each operating range, there are no signs of any weaknesses in terms of tendencies toward pattern reversals created by harmonic operation of rearward elements.

Fig. 11-10 shows a mid-range (900 MHz) free-space azimuth pattern for the single array. Although the basic numbers for gain and front-to-back ratio, as well as the overall shape of the pattern, appear to be excellent, the rear lobes show a small amount of excess lobing. The extra lobes are operationally insignificant by any standard, but should be noted.

Fig. 11-11 shows a mid-range (1900 MHz) free-space pattern for the same array. At this higher frequency, the rearward lobes are considerably more fragmented, even though the magnitude remain below operational significance. As well, careful examination of the forward lobe reveals that it is on the verge of slight deformation. Essentially, this array is close to the limit for using an excessive value of σ for the value of τ chosen in the design phase. A τ of 0.9045 has an optimum σ of 0.1688, whereas the value used in the array is 0.1879, over 10% high. A smaller value of σ would have increased the element count.

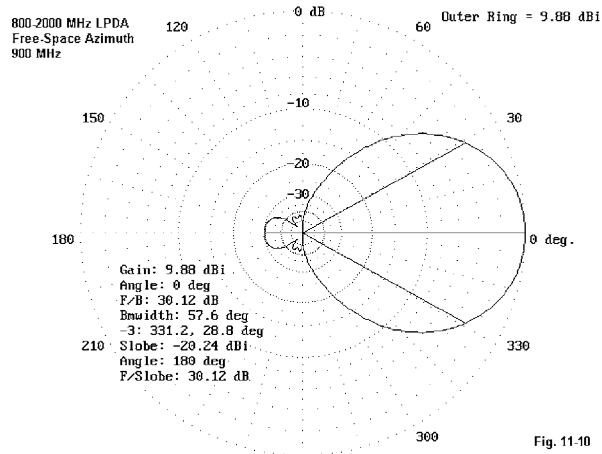


Fig. 11-10

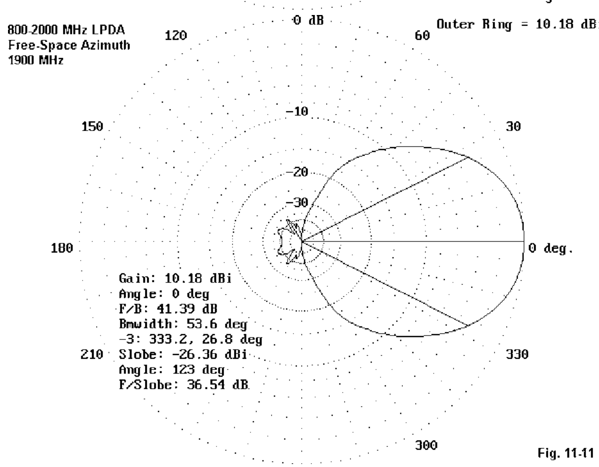


Fig. 11-11

The SWR curves, shown in **Fig. 11-12**, show no significant problems, either within the operating ranges or overall. In fact, they do not show the indications of any weakness, although the data table tells a different story. The combination of correctives applied to this LPDA design has moved the weakness in the individual arrays outside the operating range. Still, the SWR curve is accurate in the sense that there is no SWR value above about 1.34:1 in the frequency region of the low value of front-to-back ratio. In addition, the value shown in the overall chart of performance is close to the minimum value encountered in more specific sweeps of the frequency area (15.13 dB at 1102 MHz). Hence, unless the reduction of front-to-back ratio at about 1100 MHz is a problem for some other use of this array, the correctives can be viewed as having eliminated weaknesses in a standard design.

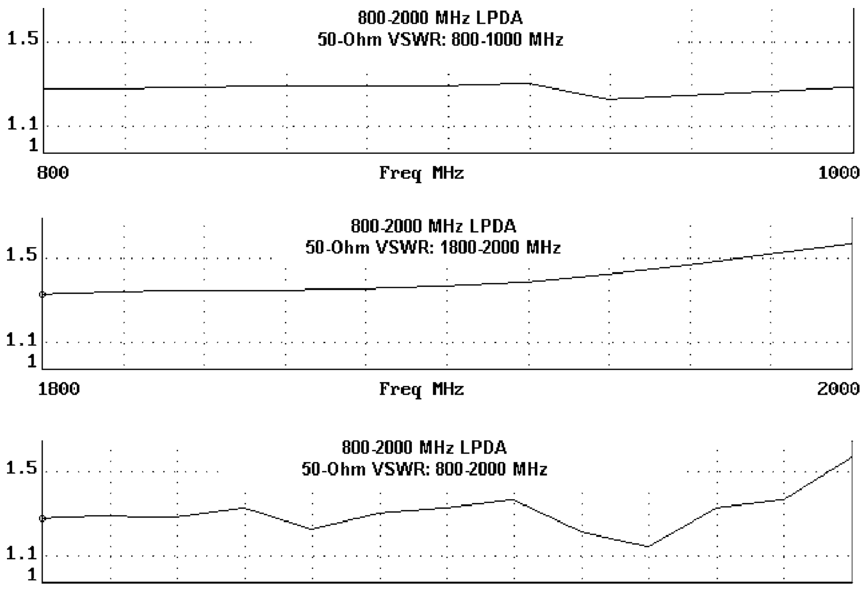
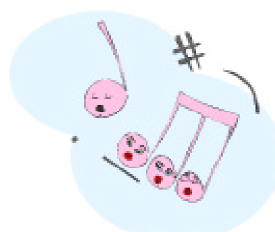


Fig. 11-12

Application of correctives is most usually done with greatest ease and without unexpected surprises when the subject antenna is a single array of unified design. The breach in the normal progression of elements created by combining two independently designed arrays often gives the designer more problems when the goal is multi-faceted, as in the case of this split-range array. In this design, we sought to provide relatively equal gain across each range and to match the gain levels of the two ranges. As well, we wished to have a usable 50-Ohm SWR across each operating range, with no weaknesses in coverage anywhere within them. The use of a unified single design considerably shortened the necessary design process in reaching these goals—at least in models.

As an aside, the element lengths for this array strongly suggest its adaptation to circuit-board fabrication rather than construction using standard twin-boom U-channel methods. When elements are under 1" each side of the centerline, even 1/2" U-channel stock may prove troublesome as a phase line.

Whatever the method of construction, the test case with which we have been working strongly suggests that unified single LPDA designs have significant advantages over combining independent designs for split-range operation. If initial array calculation was all that we needed to do in order to create a satisfactory array, then combined independently designed arrays might be useful. However, so long as LPDA designs depart from the use of optimal values for τ and σ, it is likely that correctives will be needed to reach satisfactory performance. A unified single array facilitates experimenting successfully with these modifications.



Chapter 12: Epi-Log

Although we are at the end of my collection of notes on LPDA design, we certainly are not at the end of the LPDA story. We have surveyed some of the results that I have read out of systematically modeling a wide variety of log periodic dipole arrays. However, one must always exercise caution lest there be some misreadings in the collection.

Systematic modeling using the most adequate methods developed to this point in time has revealed a wide variety of facts about LPDAs and derivatives from them. Most of the facts have not been well appreciated by amateur band designers. If these volumes have framed these facts in a way that enhances LPDA design a small amount, then these two volumes will have done their job.

Yet, much remains to be uncovered—or at least made known to the community of those interested in LPDA design—regarding the theoretic underpinnings of LPDA behavior when the basic designs are less then optimal. Indeed, less-than-optimal design is a fact of life with amateur band arrays, since there are almost always physical limitations within which amateur antennas must fit. Hence, the future offers the theoreticians a wide field of endeavor in developing better the underpinnings of LPDA design so that weaknesses in coverage and other anomalous behaviors become predictable before modeling activities begin.

Moreover, the collection of correctives that we have surveyed and applied to many practical designs may well be incomplete. The techniques that we examined in Volume 1 and applied to LPDAs in both volumes have shown their merits in case after case. However, the horizon may hold additional—and perhaps better—ways of inching small LPDAs toward improved performance.

We departed from the consideration of pure LPDAs in order to integrate into the overall examination a number of variations. The monoband log-cell Yagi, when the log-cell portion is more optimally designed than in past efforts, becomes part of the line of hybrid LPDAs that also includes LPDAs modified by the addition of a single parasitic director. However, even our work on long-boom log-cell Yagis is limited by confining the design to a single amateur band. For that purpose, a pure Yagi may do as well. Where we did not yet go was into the wider-band territory that exceeds the limits of a pure Yagi. Only in this territory do the LPDA and its hybrids gain a performance advantage. How far we can carry the expansion of the bandwidth of LPDAs with parasitic reflectors and directors remains among the work to be done.

Throughout, we should also keep in mind that the log periodic dipole array is but one of many forms of frequency-independent antennas. It linear elements make it perhaps the most easily fabricated type of frequency-independent antenna for the HF region and the home workshop. However, many other varieties of these antennas exist, including spiral and conical versions. Circuit-board construction may give these other types an advantage at UHF and above, especially in conjunction with reflectors that yield high gain with relative insensitivity to frequency. Perhaps the corner reflector with a bow-tie dipole—a fine performer in its day—will give way to the parabolic dish with a spiraling conical driver in a form that anyone might construction in the basement.

In other words, at least for higher frequency ranges, the LPDA may have limited durability as the antenna of choice for wide frequency coverage. However, for HF and VHF work, the array is likely to be used for decades to come—and perfected even further beyond the possibilities that we have surveyed in these pages.

Nevertheless, I hope these 2 volumes of notes have made a small contribution to the amateur community in improving our understanding of how LPDAs work, why they sometimes do not work, and what it takes to make them work. If the notes have done this much, they have been worth creating and compiling.

Other Publications

We hope you've enjoyed this Volume 2 of the **LPDA Notes.** If you did not see Volume 1, be sure to look for this companion to Volume 2. 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.

A Publication by
antenneX Online Magazine
http://www.antennex.com/
POB 72022
Corpus Christi, Texas 78472 USA

ISBN: 1-877992-31-3
