A Tale of Three LPAs: Some Notes on Zig-Zag Log-Periodic Arrays
1. Preliminaries and LPDAs

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In amateur radio literature on log-periodic arrays (LPAs), an interesting situation has arisen. One of the many types of LPAs, the log-periodic dipole array (LPDA), has supplanted all other types. Today, literature generally available to amateurs (with one exception) overlooks other types of wire-based LPAs and provides detailed design information only on the LPDA. That situation naturally aroused my curiosity. How well or poorly did other types of LPAs perform relative to the easily modeled LPDA?

Two configurations of LPAs that were cotemporary with the earliest LPAs used structures that the average builder might reasonably replicate: trapezoidal elements and saw tooth elements in a zig-zag arrangement. Therefore, we obtain a 3-way comparison that gives us our title, a tale of three LPAs. However, the situation is not as simple as this, since we find versions that use a central boom and versions without the boom. Hence, we end up with the 5 varieties shown in **Fig. 1**.

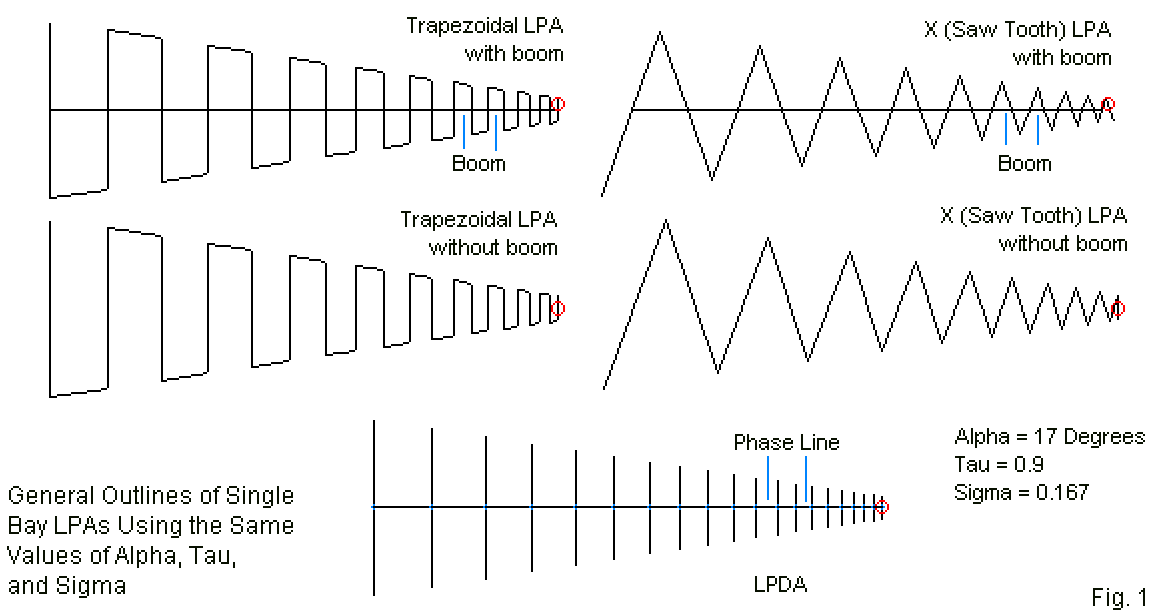
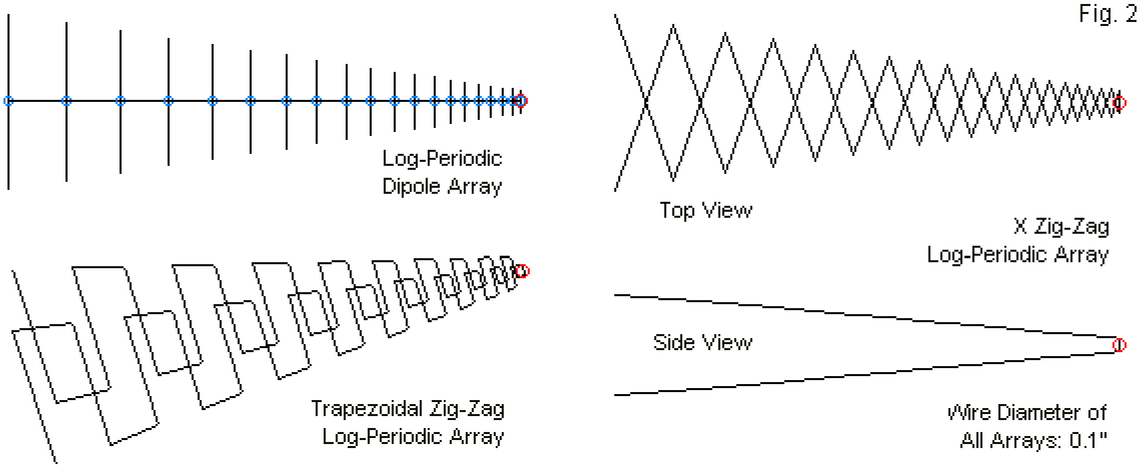


Fig. 1

Next, we add in a second complication. Normally, we find the LPDA, composed of dipole elements with a central 2-wire phase line transposed between each adjacent element, used in single bays. However, to make a directional array from any of the zig-zag forms, we need two bays, since the feedpoint is single-ended for a 1-bay version. In use, the 2-bay zig-zag LPAs show an angle between the bays in the H-plane. Therefore, all of the zig-zag arrays, whether using trapezoidal or saw-tooth elements, have a 3-dimensional structure, as shown in **Fig. 2**. The sample zig-zag arrays show only boomless versions for clarity. We might have as easily, but less clearly, used zig-zag LPAs with booms. The side and top view of the saw-tooth version of the zig-zag array shows us how the array developed the “X” designation.

By comparison, we may consider the single-bay LPDA to be a 2-dimensional structure. Nothing in the theory of LPDA development precludes the use of multiple bays, and some commercial examples do exist. In developing our comparisons, we shall want to examine at least 2-bay LPDAs to improve the scope of our comparisons. One critical variance between 2-bay zig-zag LPAs and 2-bay LPDAs is a difference in how we feed the bays. Zig-zag arrays will require a single series feed between the bays, while 2-bay LPDAs will require parallel in-phase feeding.

Fig. 2



A Family of Log-Periodic Arrays

We also need to find a common set of standards for the design of each array so that all versions used in comparisons are in fact comparable. Setting aside the general tendency to try to obtain the greatest performance from the least wire, we shall use fairly long-boom versions of the arrays. Each array will use 20 elements per bay with design values that yield no anomalous frequencies across a 50-200-MHz passband. To avoid pressing NEC modeling limitations within the passband, all LPAs will use 0.1"-diameter (2.54-mm) lossless wire.

For various reasons that will become clear as we progress, the comparisons will require that we take relatively small and orderly steps. In this part of our journey, we shall look at some basic differences between the ways in which zig-zag and LPDA arrays are designed in classical terms. In addition, since the LPDA is the modern standard LPA for radio amateurs, we shall set up some base-line data for both single-bay and double-bay versions of the antenna. In part 2, we shall survey trapezoidal zig-zag arrays including versions with and without booms. Part 3 will look at the X or saw tooth configuration of the zig-zag LPA, again including versions with and without booms. The exercise has yielded a very large collection of NEC-4 modeling data, far too much for inclusion in the main text of these notes. Therefore, I shall make available a data appendix containing tabular and graphical information derived from each variation of each LPA that we consider. At 45 pages, the data appendix will be almost as long as all three parts of these notes combined.

Some LPA Background and Design Considerations

We may consider the years between the late 1950s and about 1970 as the period of peak development in log periodic frequency-independent antennas. Earlier work exists and later developments have improved the state of the art, but the indicated period was perhaps the most productive. Much of the work emerged from the Antenna Lab at the University of Illinois (Champagne-Urbana) or from the students and faculty after leaving Illinois. Paul Mayes kindly provided me with a copy of his 1982 article, “Frequency-Independent Antennas: Birth and

Growth of an Idea," which appeared in the August issue of the *Antennas and Propagation Society Newsletter* of the IEEE. One may track the contents of this brief history of developments by reading in chronological order the references in Chapter 14 of the third edition of Johnson's *Antenna Engineering Handbook*. Since our interests lie in wire-outline versions of the LPA, we may pass over the fundamental work on conical log-periodic antennas and focus more directly on linear antennas.

We may call our subject LPAs wire-outline arrays because they ultimately derived from solid element versions. For example, we may picture the zig-zag bays in **Fig. 1** as if each "tooth" consisted of a solid surface of conductive material. Early tooth designs assumed many shapes, many with curved structures that remind us that the LPA is based on limited arcs of a circle. The discovery that straight elements did not significantly reduce performance potential led to the substitution of wire outlines for the solid teeth. The counterpart of the boom in these early LPAs also increased in width as one moved from the vertex outward to the longest element. Shrinking the boom to a single wire led J. W. Carr to remove the boom altogether and still obtain a workable LPA. Hence, we have the potential for both boomed and boomless zig-zag LPAs, although in practice, only the X-array received much attention. Around 1970, I built a simple boomless X LPA as an attic television antenna that served well to improve reception in Athens, GA, from the network Atlanta stations about 70 miles distant.

In its most basic form and in terms that precede those we commonly use for LPDAs, the zig-zag LPA requires attention to only 3 terms: τ, α, and ψ. **Fig. 3** gives us a basic orientation to the meanings of these terms.

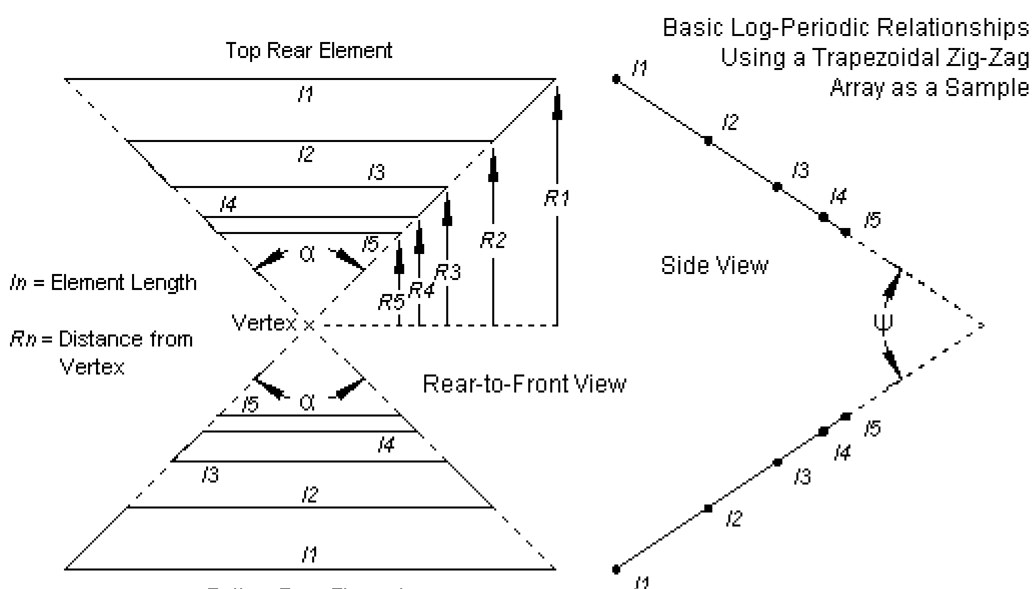


Fig. 3

The series of elements in the sketch have lengths and a distance from the vertex of the angles determined by the value of τ. We may define τ in terms of the element lengths (L), the distances from the vertex (R), or the spacing between elements (D):

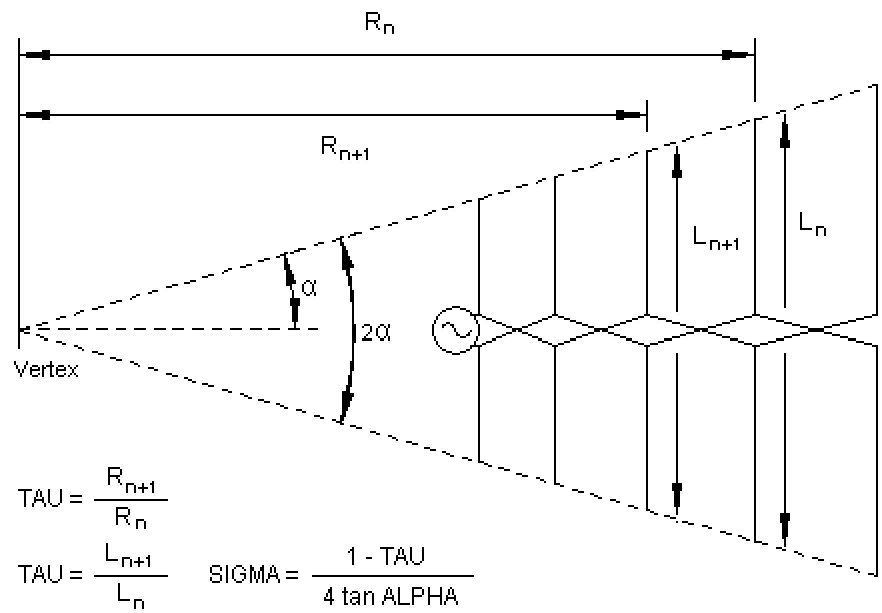
$$\tau = \frac{R_{n+1}}{R_n} = \frac{D_{n+1}}{D_n} = \frac{L_{n+1}}{L_n}$$

We use the designation R for the distance from the vertex because each element is a straight-line distortion of what should in principle be an arc. However, the arc sections are too small to notice the distortion.

The distance from the longest element to the vertex depends upon its length. For this exercise, I have cut the element to be a physical half-wavelength at the lowest operating frequency. In practice, this element might be advisably somewhat longer. However, the slightly deficient longest element will be serviceable to our comparisons, since we may compare the degree of decrease in performance at the low end of the passband within the scans for each LPA. Once we know the length of the longest element, the distance to the vertex, R_V, is a simple tan function:

$$R_V = \frac{0.5\,L_1}{\tan(0.5\alpha)}$$

Note that determining the distance requires that we select the angle α (as designated in **Fig. 3**). At this point we encounter a difference between designations used for zig-zag designs and for LPDAs. For zig-zag designs, α is the total angle from one edge of the array to the other. As shown in **Fig. 4**, LPDAs nowadays define α as the angle from the centerline of the array to either virtual edge line. To avoid confusion in the immediately following notes, I shall re-designate the zig-zag angle as α'.



Log-Periodic Basics Applied to Dipole Arrays Fig. 4

Unlike design procedures for LPDAs, zig-zag designs normally calculate element (L) and spacing (R) dimensions by reference solely to τ and to α'. The length of element 2 is τ times the length of element 1. The distance from the vertex to the position of element 2 is τ times R_V. When we are done adding elements, the array boom length is simply R_V - R_n, where n is the most forward element. The procedure is simple enough to admit of an equally simple spreadsheet. **Fig. 5** provides a sample, with the dimensional values that we shall eventually employ in NEC-4 models of the three types of LPAs. Note that the worksheet has an entry marked "L*1.6." This is the length of an element with a resonant frequency that is 1.6 times the highest operating frequency. This practice follows general guidelines for effective LPDA design, but it may prove to be a limiting factor for at least some zig-zag designs.

Zig-Zag Log-Periodic Antenna Elements											Fig. 5
Work Sheet		**Bold = User Entry**									
Tau		**0.90**								Sigma	0.167
Alpha'	degrees	**17.00**	degrees	0.297	radians	1/2Alpha'	0.148	tanAlpha	0.1495		0.167
F-low		**50.00**	MHz								
F-high		**200.00**	MHz								
L-long		3.00	meters	9.84	feet	118.11	inches				
Lhigh		0.75	meters	2.46	feet	29.53	inches				
L*1.6		0.47	meters	1.54	feet	18.45	inches				
Rv	Vertex R	10.04	meters	32.93	feet	395.15	inches				
Element	Ln	Ln/2	Rn	Element	Lfeet	Lft/2	Rfeet	Element	Linch	Lin/2	Rinch
1	3.00	1.50	10.04	1	9.84	4.92	32.93	1	118.11	59.06	395.15
2	2.70	1.35	9.03	2	8.86	4.43	29.64	2	106.30	53.15	355.63
3	2.43	1.22	8.13	3	7.97	3.99	26.67	3	95.67	47.83	320.07
4	2.19	1.09	7.32	4	7.18	3.59	24.01	4	86.10	43.05	288.06
5	1.97	0.98	6.59	5	6.46	3.23	21.60	5	77.49	38.75	259.26
6	1.77	0.89	5.93	6	5.81	2.91	19.44	6	69.74	34.87	233.33
7	1.59	0.80	5.33	7	5.23	2.62	17.50	7	62.77	31.38	210.00
8	1.43	0.72	4.80	8	4.71	2.35	15.75	8	56.49	28.25	189.00
9	1.29	0.65	4.32	9	4.24	2.12	14.17	9	50.84	25.42	170.10
10	1.16	0.58	3.89	10	3.81	1.91	12.76	10	45.76	22.88	153.09
11	1.05	0.52	3.50	11	3.43	1.72	11.48	11	41.18	20.59	137.78
12	0.94	0.47	3.15	12	3.09	1.54	10.33	12	37.06	18.53	124.00
13	0.85	0.42	2.83	13	2.78	1.39	9.30	13	33.36	16.68	111.60
14	0.76	0.38	2.55	14	2.50	1.25	8.37	14	30.02	15.01	100.44
15	0.69	0.34	2.30	15	2.25	1.13	7.53	15	27.02	13.51	90.40
16	0.62	0.31	2.07	16	2.03	1.01	6.78	16	24.32	12.16	81.36
17	0.56	0.28	1.86	17	1.82	0.91	6.10	17	21.89	10.94	73.22
18	0.50	0.25	1.67	18	1.64	0.82	5.49	18	19.70	9.85	65.90
19	0.45	0.23	1.51	19	1.48	0.74	4.94	19	17.73	8.86	59.31
20	0.41	0.20	1.36	20	1.33	0.66	4.45	20	15.95	7.98	53.38

Basic zig-zag design procedures do not require the term σ, which LPDAs depend upon for more than one step in the design procedure. We may derive σ from α and τ in LPDA terms:

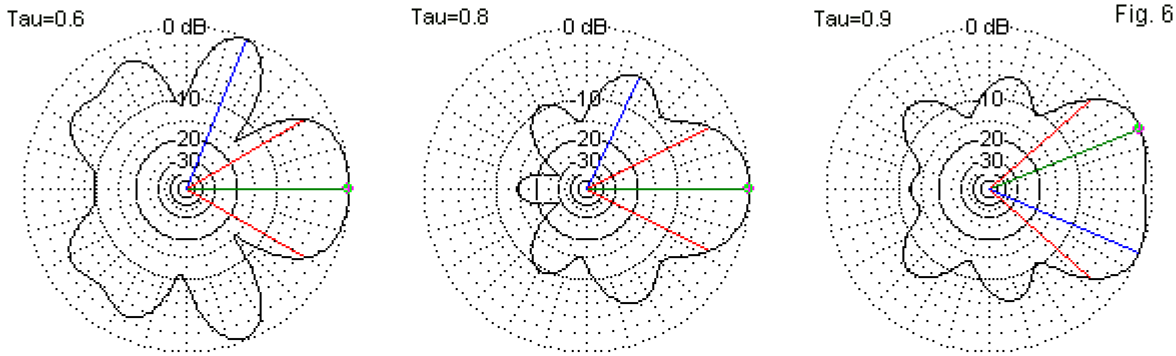
$$\sigma = \frac{1-\tau}{4\tan\alpha} = \frac{D_n}{2L_n}$$

Most LPDA design literature recommends the use of the optimal values for σ:

$$\sigma_{opt} = 0.243\tau - 0.051$$

In fact, many zig-zag designs employ values of what I shall call virtual σ that are close to optimal. Where the literature seems oddest is in the occasional use of very low values of τ. LPDA design recommends the use of values above 0.8—and considerably higher if feasible. However, we may commonly find τ values from 0.6 to 0.7 in some zig-zag designs. The modeled performance of some zig-zag designs using low values of τ eventually led to the use of 0.9 in the three models that we shall compare. See **Fig. 5** for a visual account of why low values of τ produce less than optimal results.

The three patterns all use the same values of α' (60°) and of ψ (35°) for a trapezoidal zig-zag LPA with a 50-200-MHz design range. (We shall examine ψ momentarily.) As we increase the value of τ, the sidelobes diminish. However, as we reach a τ of 0.9, the pattern degrades in a different manner, with a broader main lobe—almost a double lobe to match the enlarged rear quartering lobes. This pattern results from the use of a value of α' much larger than is optimal for the value of τ.



All E-plane patterns are for 150 MHz, with Alpha = 60 degrees and Psi = 35 degrees.

Sample Free-Space E-Plane Patterns of Trapezoidal Zig-Zag LPAs Using Low Values of Tau

By using a selected value of τ, we may calculate the optimal value of σ from LPDA design recommendations. Next, we may back-calculate, using the recommended value of σ_{opt}, the corresponding value of α':

$$\alpha'_{opt} = 2\tan^{-1}\left(\frac{1-\tau}{4\sigma}\right)$$

For a τ of 0.9, the optimal value of σ is about 0.1677. The corresponding value of α' is very close to 17°. The worksheet in **Fig. 5** shows the entries for α' and τ, along with the calculated value of virtual σ as a check.

As shown in **Fig. 3**, zig-zag LPAs require two bays separated by an angle designated ψ. Early designs favored relatively wide angles or high values of ψ. As we increase the value of ψ, the gain increases but the front-to-back ratio decreases. As a consequence, designers settled on a value for ψ experimentally, arriving at a compromise that best fit the research or communications application at hand. Since the rates of change of gain and of the front-to-back ratio are not constant at all frequencies within the operating range, there is no clear mathematical relationship between the values of α' and ψ. However, in a broad sense, we may note in advance that the two angles are related so that decreases in the value of α' result in decreased values for ψ. To establish that fact for both trapezoidal and X versions of zig-zag LPAs, we shall have to explore samples in Part 2 and 3 of these notes.

The exploration will employ NEC-4 models in free space using 0.1"-diameter lossless or perfect wire. Modeling the elements for any type of LPA is routine with one exception. If we multiply each value for R by –1, we obtain an X-coordinate for the element's position. This procedure offsets the array from the coordinate system center in accord with the calculated value of R_V, the distance of the element to the vertex of the array. Then we may rotate the bay on the Y-axis using either an interface facility in the program (such as EZNEC Pro/4) or via the GM command. As well, we need model only a single bay, since we may replicate that bay and rotate the replica 180° on the X-axis. I have used a simple feedpoint system of running a wire from the free ends of the two most forward elements. Experiments that extended wires to the vertex produced no significant changes in the basic array performance, so I settled on the simpler feedpoint modeling procedure.

Segmenting NEC models of an LPA with a significant frequency range (in this case, 4:1) generally require a compromise between adequate segmentation and model size. Ideally, the segment length should be about 0.05-λ at the highest frequency used. Maintained this segmentation density requires inverse τ-tapering of the number of segments per element as we proceed from the vertex toward the longest element. Of course, the number of segments is an integer, with consequential rounding. In an LPDA, the segment count must also be an odd number to place the modeled phase line (a transmission line using NEC's TL facility) at the element center. Since the models are committed to a uniform wire diameter throughout (rather than using τ-tapered element diameters), there is a limit to the level of segmentation, since that is determined by the wavelength at a frequency about 1.6 times the highest frequency in the passband. It is fairly easy to exceed recommended ratios between the wire radius and the segment length for the most accurate results. The most common occurrence of the difficulty lies in some of the sharp angles at wire junctions, where wires may penetrate the adjacent segment center region and create current calculation errors without triggering a warning.

In all cases, the serious modeler must keep an eye on the average gain test (AGT) score to hold it as close as feasible to the ideal value of 1.000. Since our goal is a comparison of general properties and not an exercise that will result in a prototype, we may use values between 0.995 and 1.005 as acceptable AGT scores.

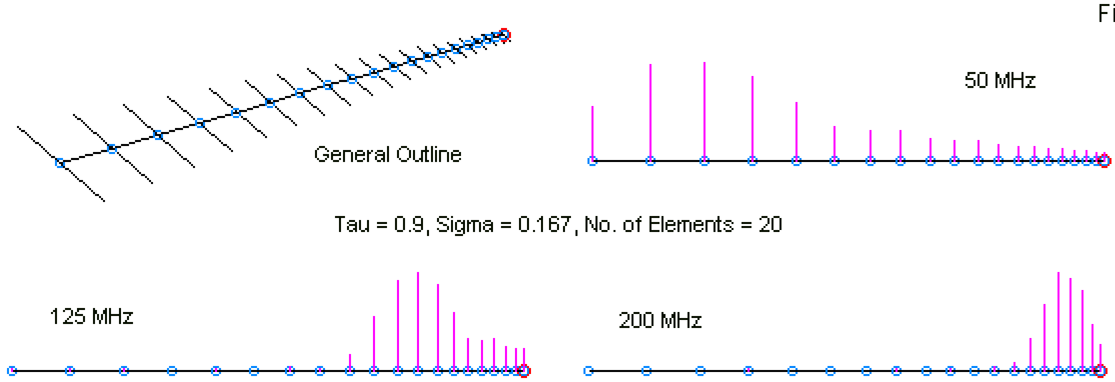
The Single-Bay LPDA "Standard"

Isbell and Carrel's work on the LPDA in the very early 1960s became encoded in many forms, and the design procedures applicable to LPDAs appear in many sources. One often-used progression appears in Chapter 1 of *LPDA Notes* and in Chapter 10 of *The ARRL Antenna Book*, following the Rhodes' *QST* article of November, 1973 ("The Log-Periodic Dipole Array," pp. 16-22). An additional version appeared in "Log-Periodic Antenna Design," *Ham Radio*, December, 1979, pp. 34-39. Examples of further design procedures appear in Lo and Lee, *Antenna Handbook* (1993), Vol. 2, pp. 9-28, and in Balanis, *Antenna Theory: Analysis and Design*, 2nd Ed. (1997), pp. 561-563. There are computer programs devoted to LPDA design, such as LPCAD 3.2, by Roger Cox, WB0DGF. We need not here track the progression of small corrections that have improved the procedures over the years. The design that we shall use as our sample derives simply from the dimensions in **Fig. 5**.

We may model a 20-element planar LPDA using a τ of 0.9 and a σ of 0.167 to arrive at an array with a total angle across the virtual outline of the elements of about 17°. Although this array has half the total elements of the 2-bay models that we shall explore in zig-zag models, basic log-periodic theory takes it to be the equivalent of these arrays that require an optimized value of ψ. Like the other models, our LPDA will use lossless 0.1"-diameter wire throughout in order to equalize any comparisons. In ideal LPDA designs, the element diameter should have a constant length-to-diameter ratio, which would therefore vary the element diameter by the value of τ. In addition, practical versions of the array would use elements having a larger diameter (usually aluminum tubing). The model also uses a 254-Ω phase-line to obtain a feedpoint impedance centered on 200-Ω. A combination of larger elements, τ-tapered elements, and a lower phase-line impedance might yield up to 1 dB additional gain over the version of the array used in this exercise.

Fig. 7 shows the general outline of the LPDA, along with current magnitude distribution graphs for 50, 125, and 200 MHz. The significant current magnitude on the rear elements at 50 MHz suggests that the array might benefit from a slightly longer rear element. As well, the 200-MHz current graphic fails to show a second peak, suggesting that a few more forward elements might also be useful to overall performance. The LPDA shows peak current on the element (or elements) closest to self-resonance at the operating frequency.

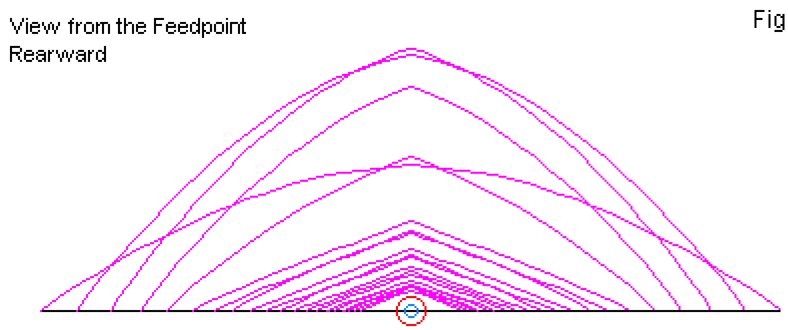
Fig. 7



General Outline and Current Magnitude Distribution Along an LPDA at 3 Frequencies within the Operating Range

In **Fig. 8** we have a different perspective on the relative current magnitude distribution among the LPDA elements. Because each element has two open or free ends, the current distribution on each is perfectly symmetrical. At the lowest frequency within the operating passband (50 MHz), the current on the forward-most element is about 7% of the peak current on the most active element. No element is wholly inert.

Fig. 8

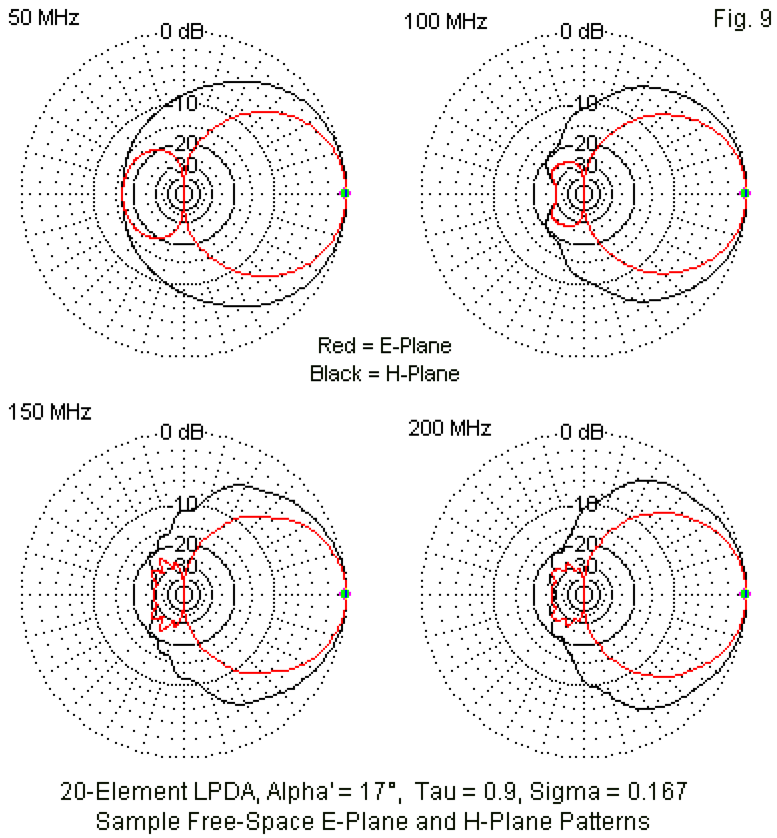


Relative Current Magnitude Distribution on the Elements of a Single-Bay LPDA at it Lowest Operating Frequency

Table 1 provides sample performance values at 50, 100, 150, and 200 MHz. Since the planar LPDA is not subject to ψ as a variable, both tables are considerably shorter than their zig-zag LPA counterparts. **Fig. 9** follows with a gallery of E-plane and H-plane free-space patterns at the sample frequencies. The performance data and the free-space plots confirm that the LPDA has a slight deficiency in gain and in the front-to-back ratio at the lowest frequency. Therefore, a slightly lower self-resonant frequency for the longest element might well increase the low-end front-to-back ratio and decrease the range of value change—but without significantly changing the average front-to-back value shown in the sweep summary. In addition, one might add one or more dipoles at the forward end, if not to improve gain, then perhaps to enhance pattern control at the upper end of the band. The LPDA shows an increasing beamwidth in the H-plane as we increase the operating frequency, even though the E-plane beamwidth varies by less than 6° across the operating passband.

Table 1. Sample performance values: single-bay LPDA: 20 elements, α' = 17°, τ = 0.9, σ = 0.167

Frequency MHz	Max. Gain dBi	Front-Back Ratio dB	E BW degrees	H BW degrees	Impedance R +/- jX Ω	200-Ω SWR
50	7.33	16.71	67.0	107.8	209 - j 5	1.05
100	8.19	30.77	63.0	94.6	196 - j 30	1.16
150	8.30	29.16	62.6	93.2	180 - j 19	1.16
200	7.88	28.38	63.7	109.4	182 - j 11	1.29



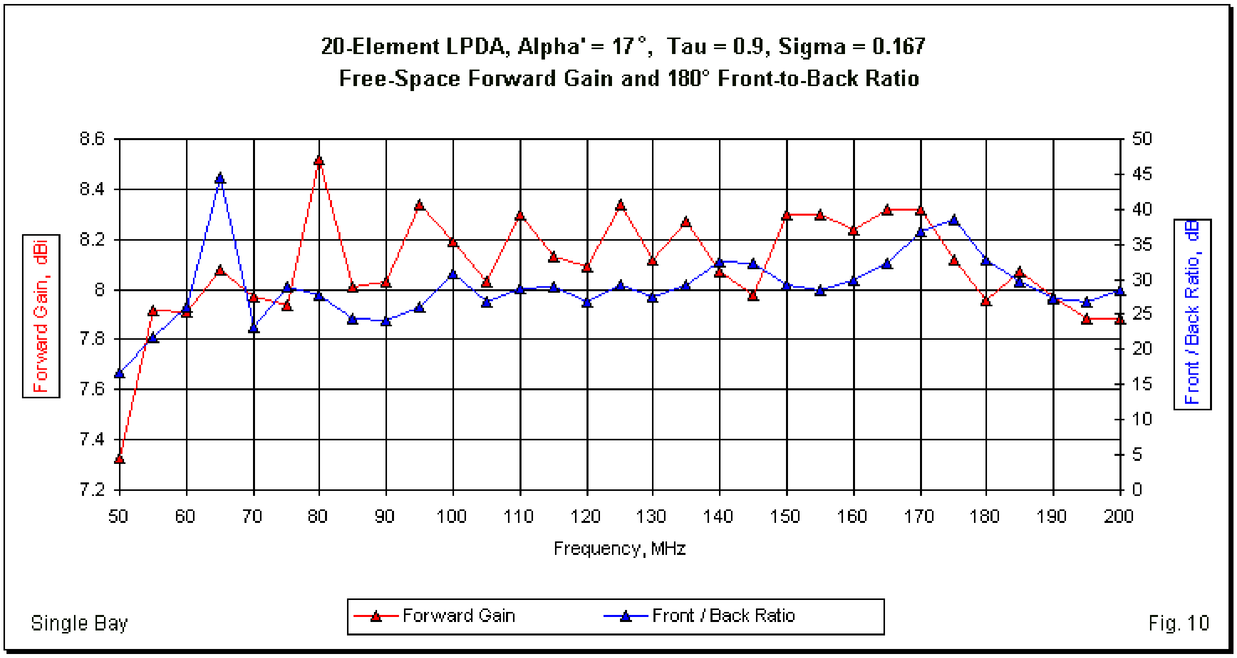
In **Table 2** are the summery values derived from a frequency sweep across the entire operating passband in 5-MHz increments.

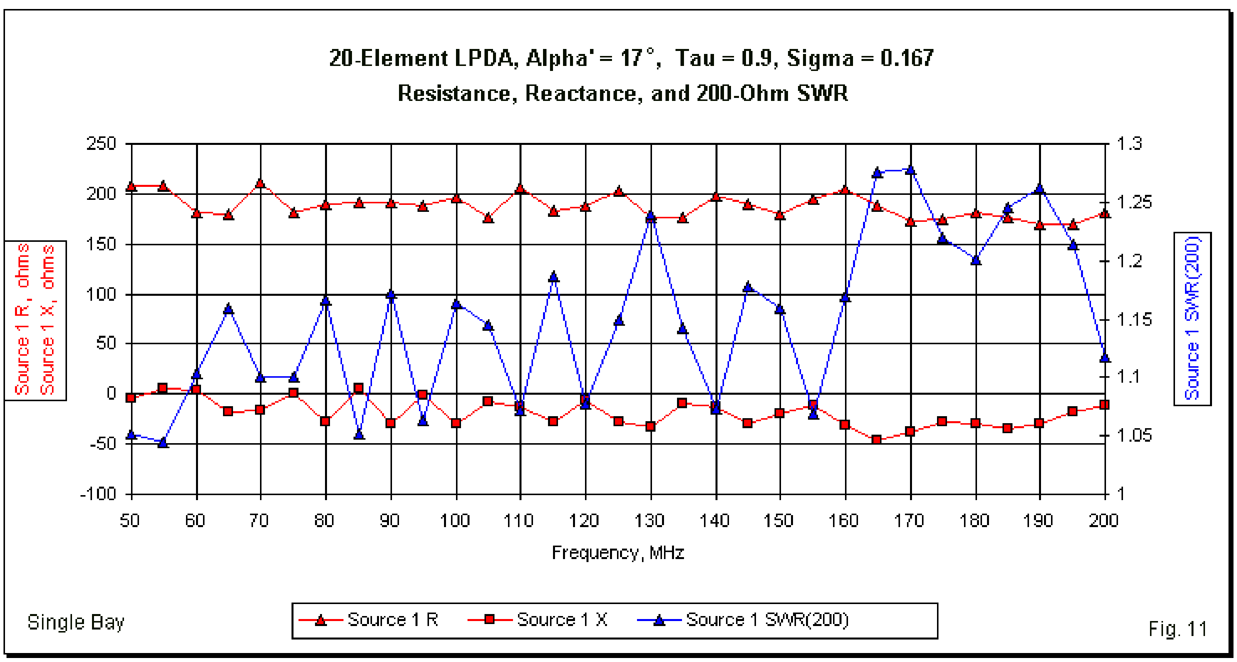
Table 2. Sweep data summary, 50-200 MHz in 5-MHz increments: single-bay LPDA: 20 elements, α' = 17°, τ = 0.9, σ = 0.167

Category	Minimum	Maximum	Δ	Average
Gain dBi	7.33	8.52	1.19	8.09
Front-Back dB	16.71	44.56	27.85	28.93
E Beamwidth °	60.8	66.4	5.6	63.7
H Beamwidth °	83.8	109.4	25.6	99.8

Fig. 10 and **Fig. 11** graph the data gathered from the frequency sweeps in terms of forward gain, 180° front-to-back ration, feedpoint resistance and reactance, and the 200-Ω SWR. The

gain and front-to-back graphs shows the decrease in values below about 60 MHz. However, it is useful to note that even with this seeming deficiency, the range of gain variation across the operating passband is less than 1.2 dB. Equally notable is the 200-Ω SWR curve, which never reaches a value of 1.3:1 across the band.



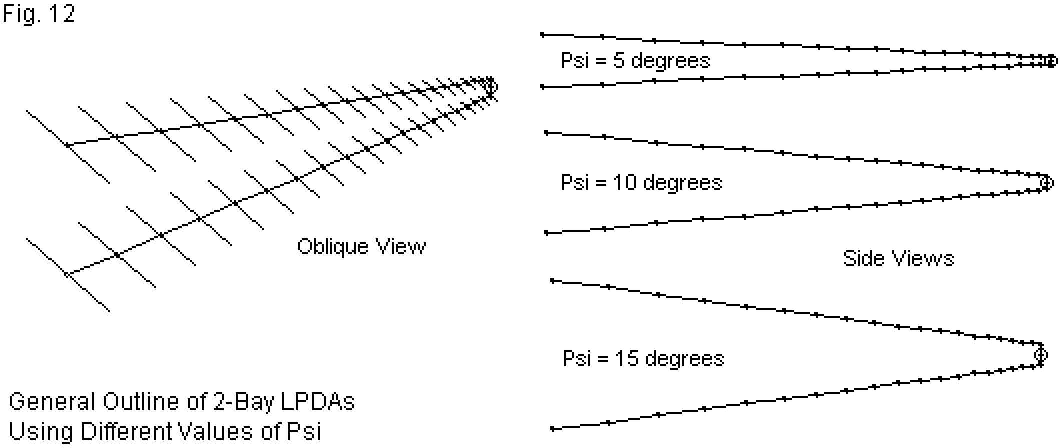


The LPDA is a single-bay array. Therefore, like any directional antenna composed of dipole elements, the H-plane beamwidth is naturally wider than the E-plane beamwidth. The average beamwidth values are similar to those that we associate with a long-boom (>0.32 λ) 3-element Yagi (normally using larger-diameter elements), and the average LPDA forward gain is slightly higher when we consider the element diameter used in the model (0.1"). (In comparison, a 3-element Yagi with a short boom of less than 0.23 λ would show about a dB less gain and somewhat larger beamwidth values.)

2-Bay LPDAs

Although I know of only a few commercial examples of wire LPDAs that use two bays, we should examine the possibility to form one more comparator with the zig-zag LPAs that must use two bays. Unlike early zig-zag LPAs that combined low values of τ with high values of ψ, a successful 2-bay LPDA stack requires much narrower angles. In addition, the two LPDA bays must be fed in phase. Nevertheless, the use of a constant angle between the bays provides a constant distance between them as measured in wavelengths for any operating frequency. To sample the performance trends for such arrangements, I created 2-bay models using ψ-angles of 5°, 10°, and 15°. **Fig. 12** shows the general outline of the models with side views of each array angle.

Fig. 12



General Outline of 2-Bay LPDAs
Using Different Values of Psi

For comparison with the single-bay data in **Table 1**, I extracted free-space information on each model at 50, 100, 150, and 200 MHz. The additional data appear in **Table 3**. Compared to the single-bay version, the parallel feed for the 20bay models yields a reference impedance of 100 Ω for tabulating SWR values. Although a small matter, the highest SWR value is less than 1.2:1, compared to the single-bay maximum value of nearly 1.3:1. At any of the sampled values of ψ, the 2-bay LPDA is a very stable array with respect to the source impedance.

Table 3. Sample performance values: 2-bay LPDAs: 20 elements, α' = 17°, τ = 0.9, σ = 0.167

Ψ = 5°

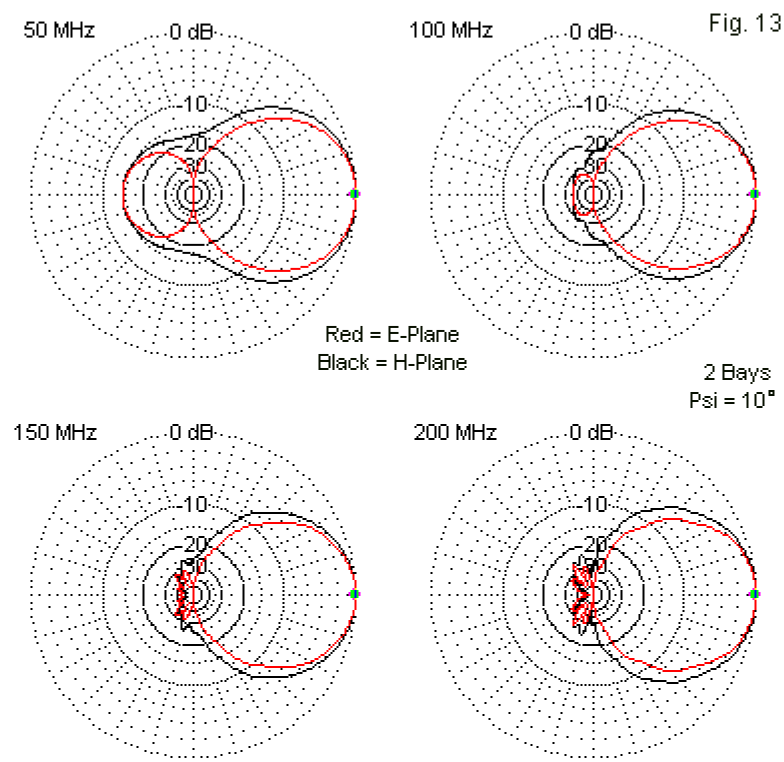
Frequency MHz	Max. Gain dBi	Front-Back Ratio dB	E BW degrees	H BW degrees	Impedance R +/- jX Ω	200-Ω SWR
50	9.09	18.10	61.4	83.2	94 - j 7	1.10
100	9.82	39.75	57.0	74.4	94 - j 9	1.12
150	9.88	47.35	57.0	74.2	97 - j 11	1.12
200	9.55	39.30	57.5	75.2	100 - j 11	1.11

Ψ = 10°

Frequency MHz	Max. Gain dBi	Front-Back Ratio dB	E BW degrees	H BW degrees	Impedance R +/- jX Ω	200-Ω SWR
50	9.35	14.28	61.0	73.2	89 - j 2	1.13
100	10.17	36.27	57.8	68.4	93 - j 8	1.11
150	10.31	42.41	57.4	66.4	98 - j 12	1.14
200	9.85	48.23	57.8	69.2	99 - j 12	1.13

Ψ = 15°

Frequency MHz	Max. Gain dBi	Front-Back Ratio dB	E BW degrees	H BW degrees	Impedance R +/- jX Ω	200-Ω SWR
50	9.70	11.19	61.6	61.7	88 + j 9	1.18
100	10.40	26.23	57.2	59.0	96 - j 2	1.04
150	10.20	29.51	60.6	62.0	101 - j 17	1.19
200	10.34	33.26	61.0	60.0	96 - j 17	1.19



20-Element LPDA, Alpha' = 17°, Tau = 0.9, Sigma = 0.167
Sample Free-Space E-Plane and H-Plane Patterns

To go with the data on the E-plane and H-plane beamwidths, **Fig. 13** presents combined free-space patterns for the version using a ψ-angle of 10°. As we increase the value of ψ, the H-plane beamwidth decreases with almost no effect upon the E-plane beamwidth. At an angle of 15°, the two beamwidth values are virtually equal.

Selecting the 2-bay model with ψ=10° as the graphic representative of all three 2-bay models emerges most clearly if we tabulate some of the summary data from frequency sweeps made for all of the models. **Table 4** presents information that we may directly compare with the information in **Table 2** for the single-bay LPDA.

Table 4. Sweep data summary, 50-200 MHz in 5-MHz increments: 2-bay LPDAs: 20 elements, α' = 17°, τ = 0.9, σ = 0.167

Ψ=5°

Category	Minimum	Maximum	Δ	Average
Gain dBi	9.09	10.00	0.91	9.72
Front-Back dB	18.10	54.74	36.64	36.02
E Beamwidth °	55.4	61.4	6.0	57.6

Ψ=10°

Category	Minimum	Maximum	Δ	Average
Gain dBi	9.35	10.79	1.18	10.00
Front-Back dB	14.28	63.75	49.47	35.93
E Beamwidth °	54.0	61.0	7.0	57.8

Ψ=15°

Category	Minimum	Maximum	Δ	Average
Gain dBi	9.70	10.79	1.09	10.39
Front-Back dB	11.19	42.10	30.91	28.27
E Beamwidth °	54.4	62.8	8.4	58.8

Early on, investigators recognized that as we increase the ψ-angle of an LPA, the gain increases while the front-to-back ratio decreases. Ordinarily, the front-to-back ratio becomes too small for effective directional array use before the gain ceases to rise. Those trends also apply to 2-bay LPDAs, as the table indicates. The phenomenon shows up most clearly at the lowest operating frequency, where gain is minimum due to the inadequate length of the rear element in the model. However, the same situation also appears in the columns for maximum and average values.

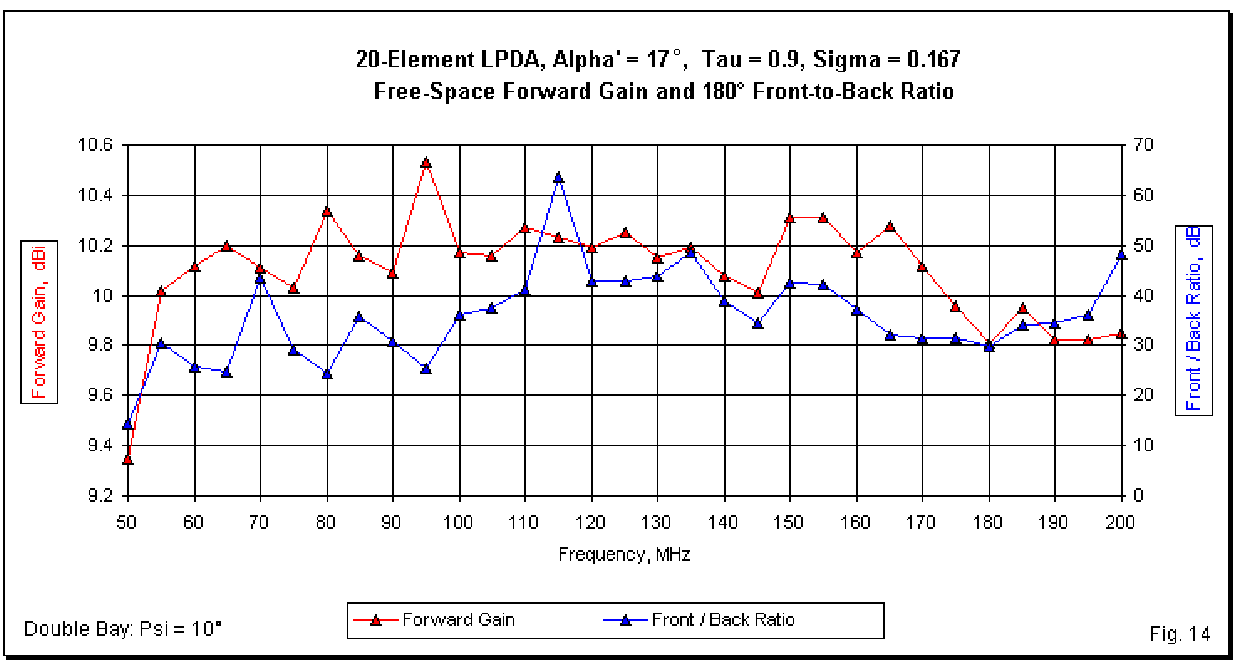


Fig. 14

Fig. 14 provides sweep graphs of free-space forward gain and the 180° front-to-back ratio of the models using a ψ-angle of 10°. The performance weakness below 55 MHz shows itself very clearly. Note also the smaller but evident decrease in gain performance at the high end of the passband. 2-bay LPDAs tend to reflect whatever large or small weaknesses that we design into the root single-bay version of the antenna. The front-to-back data, however, requires some caution. Although the values are very high, compare the sample E-plane patterns in **Fig. 13** with the corresponding single-bay patterns in **Fig. 9**. The 180° value of the front-to-back ratio is not always a sufficient indicator of rearward performance. Examining the strongest rearward lobes is always good practice in evaluating array performance.

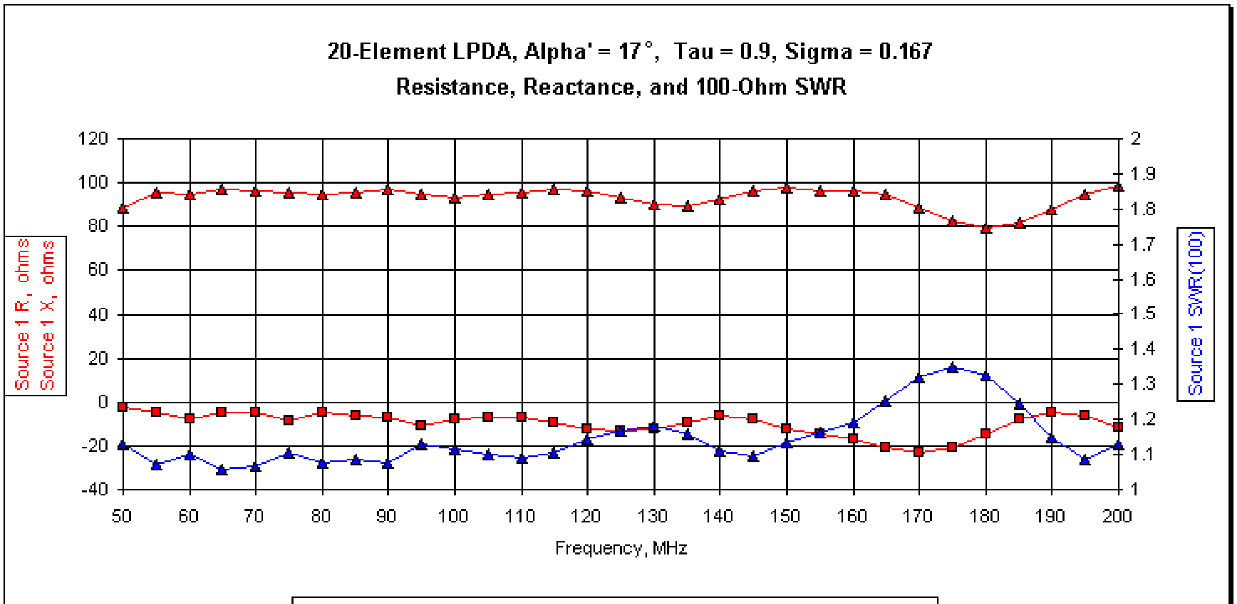


Fig. 15

Fig. 15 provides a graph of the feedpoint performance in terms of the source resistance and reactance, as well as the 100-Ω SWR across the operating passband. Because the SWR values use a different Y-axis maximum value relative to the values shown for the single-bay model in **Fig. 11**, we may legitimately wonder if the smoothness of the curves in the present graph is real or illusory. A comparison between the resistance and reactance curves in the two graphs will establish that the double-bay array shows smoother impedance performance across the operating range.

Table 5. LPDA sweep data summary, 50-200 MHz in 5-MHz increments: 20 elements, α' = 17°, τ = 0.9, σ = 0.167

Single-bay

Category	Minimum	Maximum	Δ	Average
Gain dBi	7.33	8.52	1.19	8.09
Front-Back dB	16.71	44.56	27.85	28.93
E Beamwidth °	60.8	66.4	5.6	63.7
H Beamwidth °	83.8	109.4	25.6	99.8

Double-bay, Ψ=10°

Category	Minimum	Maximum	Δ	Average
Gain dBi	9.35	10.79	1.18	10.00
Front-Back dB	14.28	63.75	49.47	35.93
E Beamwidth °	54.0	61.0	7.0	57.8

To determine whether the 2-bay LPDA provides a significant advantage over its single-bay root antenna, let's compare the summary sweep data for each, using the ψ=10° version of the larger array. **Table 5** allows some ready conclusions. For example, even though the arrays are not optimally spaced relative to our experience with narrow-band antennas such as Yagi-Uda arrays, we obtain a consistent 2-dB gain advantage from the double-bay LPDA. Although the front-to-back ratio for the 2-bay antenna appears to be higher, the advantage may be illusory, since the values at the lowest operating frequency show a reverse trend. Except for the lowest operating frequencies, the front-to-back ratios of both versions of the LPDA are well above 20 dB, largely making comparisons academic.

One advantage of the 2-bay LPDA cannot be shown with free-space models. A single-bay LPDA will normally be installed over ground at a constant physical height. For HF versions of such arrays, the take-off angle will vary with the frequency of operation. We may angle a 2-bay array in such a manner that the take-off angle is virtually constant across a wide frequency range. TCI has long marketed an LPA with just such properties.

It is obvious that the text of these initial notes cannot contain all of the data gathered on all of the LPDA models. Therefore, I have gathered the data collection for the LPDAs and the zig-zag LPAs into a special appendix for leisurely viewing.

Conclusion to Part 1

In these initial notes, we have surveyed—perhaps too rapidly—some of the background and design considerations that go into LPAs of all sorts. In addition, we have set up the now-standard LPDA version of the antenna as a standard against which we may compare the performance of both trapezoidal and X (saw tooth) LPAs in the next two parts of our sojourn in the land of linear-element log-periodic arrays. Although 2-bay LPDAs are rare, I have included models for them, since all of the ensuing zig-zag arrays must use a 2-bay structure to obtain significant directional gain.

Where these notes differ most radically from older practice lies in the basic design parameters. I have selected values of τ, σ, and α (or α') that are optimally related. The choice of τ=0.9 produces reliable good results with no anomalous frequencies in the sweep range, even though it does not yield the maximum gain obtainable from an LPDA. Rather, it achieves good performance while allowing NEC-4 models having a manageable size. Likewise, the element diameter (0.1") allows the models to avoid pressing any NEC-4 limitations, even though fatter elements may produce higher gain values.

Values of ψ emerge from experimental modeling exercises, and the ultimate selection of a ψ-angle may rest on performance objectives and construction limitations that fall outside the scope of this exercise. My selection of a representative example for 2-bay LPAs will rest on the simple appearance of best overall performance or other equally quasi-arbitrary criteria. However, the data appendix will provide identical data for all models within the survey. Perhaps the only partially emergent conclusion that we can draw so far regarding the optimal ψ-angle is that as we increase the value of τ and reduce the value of α, the optimal value of ψ will also decrease. The sampled ψ-angles for 2-bay LPDAs are significantly smaller than those we encounter in older designs for trapezoidal and X LPAs.

In Part 2, we shall examine trapezoidal LPAs, both with and without booms. We may compare the performance of the two zig-zag types and also compare both with LPDA performance, since we shall use the same set of design parameters. As a bonus, we shall examine a trapezoidal zig-zag array of older design.