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Log-Periodic Dipole Arrays

Log Periodic Dipole Array (*LPDA*) is one of a family of frequency-independent antennas. The LPDA forms a directional antenna with relatively constant characteristics across a wide frequency range. It may also be used with parasitic elements to achieve specific characteristics within a narrow frequency range. Common names for such hybrid arrays are the *log-cell Yagi* or the *Log-Yagi*. (Information on the log-cell Yagi is available on this book's CD-ROM.) Designs for log-periodic antennas at HF and VHF-UHF are presented in the **Multiband HF Antennas** and **VHF and UHF Antenna Systems** chapters. This chapter was contributed originally by L. B. Cebik, W4RNL (SK), with additional contributions from John Stanley, K4ERO.

7.1 BASIC LPDA DESIGN

The LPDA is the most popular form of log-periodic systems which also include zigzag, planar, trapezoidal, slot, and V forms. The appeal of the LPDA version of the log periodic antenna owes much to its structural similarity to the Yagi-Uda parasitic array. This permits the construction of directional LPDAs that can be rotated — at least within the upper HF and higher frequency ranges. Nevertheless, the LPDA has special structural as well as design considerations that distinguish it from the Yagi. Different construction techniques for both wire and tubular elements are illustrated later in this chapter.

The LPDA in its present form derives from the pioneering work of D. E. Isbell at the University of Illinois in the late 1950s. Although you may design LPDAs for large frequency ranges — for example, from 3 to 30 MHz or a little over 3 octaves — the most common LPDA designs that radio amateurs use are limited to a one-octave range, usually from 14 to 30 MHz. Amateur designs for this range tend to consist of linear elements. However, experimental designs for lower frequencies have used elements shaped like inverted Vs and some versions use vertically oriented ¼-λ elements over a ground system.

Figure 7.1 shows the parts of a typical LPDA. The structure consists of a number of linear elements, the longest of which is approximately ½ λ long at the lowest design frequency. The shortest element is usually about ½ λ long at a frequency well above the highest operating frequency. The antenna feeder, also informally called the *phase-line*, connects the center points of each element in the series, with a
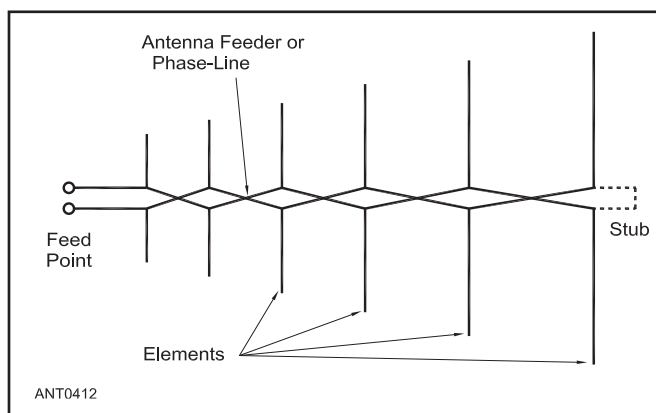
Figure 7.1 — The basic components of a log periodic dipole array (LPDA). The forward direction is to the left in this sketch. Many variations of the basic design are possible.
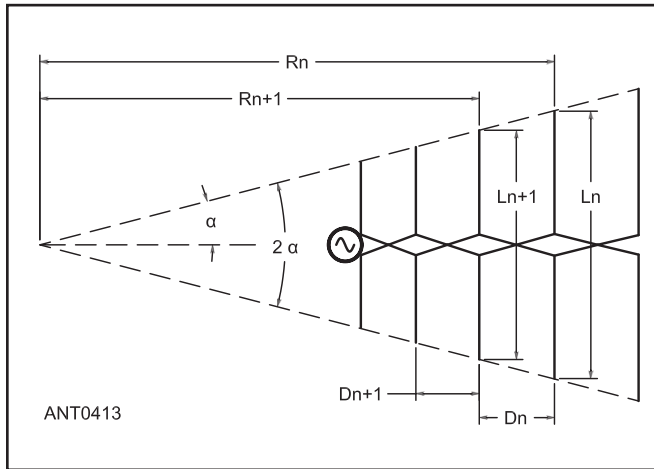
Figure 7.2 — Some fundamental relationships that define an array as an LPDA. See the text for the defining equations.

phase reversal or *crossover* between each element. A stub consisting of a shorted length of parallel-wire feed line is often added at the back of an LPDA.

The arrangement of elements and the method of feed yield an array with relatively constant gain and front-to-back ratio across the designed operating range. In addition, the LPDA exhibits a relatively constant feed point impedance, simplifying matching to a transmission line.

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

Figure 7.2 shows the basic components of an LPDA. The angle α defines the outline of an LPDA and permits every dimension to be treated as a radius or the consequence of a radius (R) of a circle. The most basic structural dimensions are the element lengths (L), the distance (R) of each
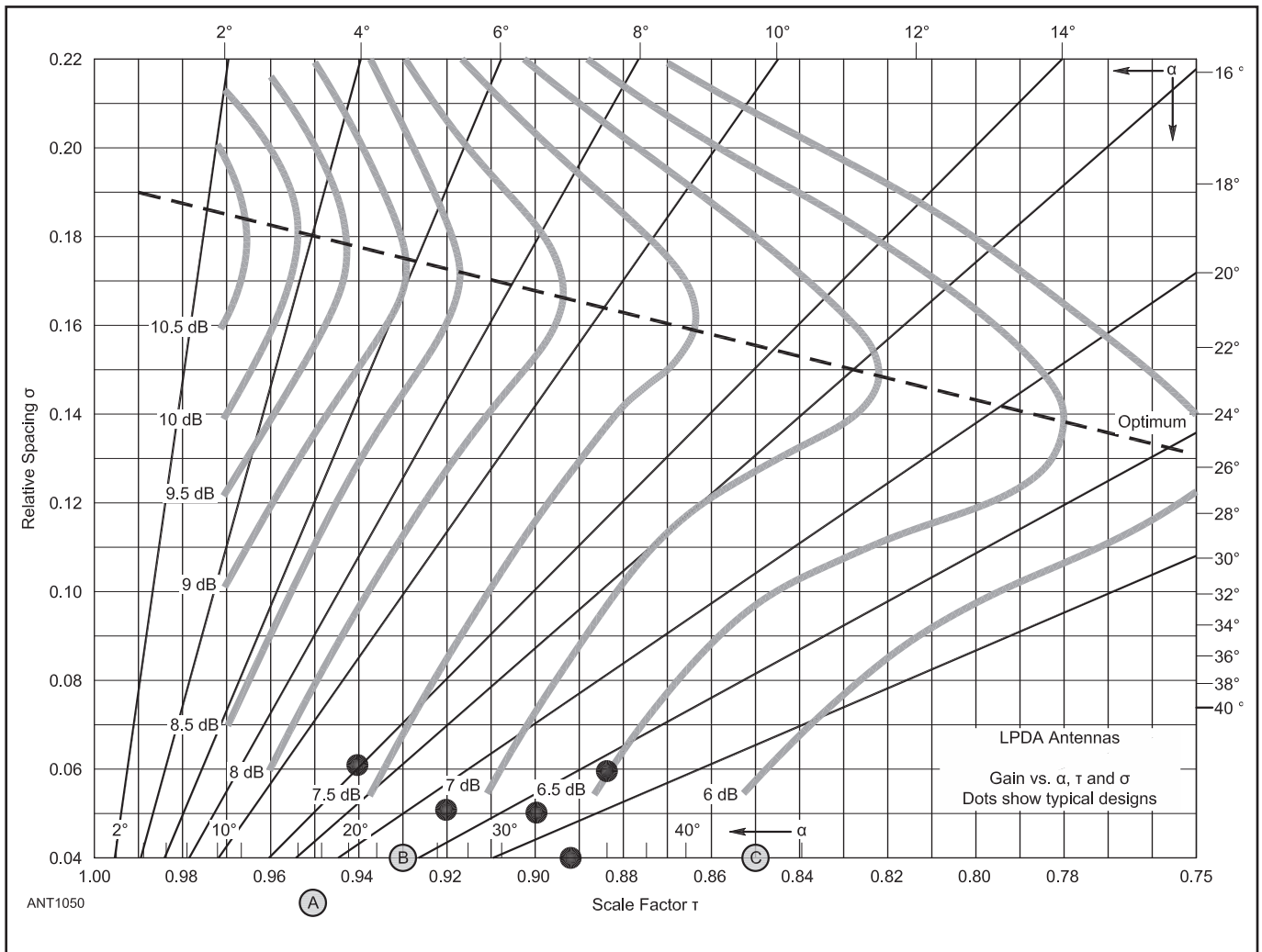
Figure 7.3 — The optimum value for σ lies on the straight line that intersects the constant-gain curves at different values of τ. Using the optimum value of σ to design an LPDA usually results in antenna that is impractically large at HF (see text). Points labeled "A", "B", and "C" represent values of σ and τ are given for the three design examples in this chapter; "9302", "8904", and "8504", respectively. (Graphic after Carrel, et al; see Bibliography.)

element from the apex of angle α, and the distance between elements (D). A single design constant, τ, defines all of these relationships in the following manner:

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

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

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

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

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

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

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

The combination of a value for τ and its corresponding optimal value of σ yields the highest performance of which an LPDA is capable. For values of τ from 0.80 through 0.98, the value of optimal σ varies from 0.143 to 0.187, in increments of 0.00243 for each 0.01 change in τ. This is illustrated by the graph in **Figure 7.3**, originally published by Carrel and updated by Butson and Thompson (see the Bibliography).

Practically however, using the optimal value of σ usually yields a total array length that is beyond amateur construction or tower/mast support capabilities. A design procedure more likely to result in a useful design at HF is to reduce σ until maximum gain begins to fall significantly. Consequently, amateur LPDAs usually employ compromise values of τ and σ that yield lesser but acceptable performance. The sidebar "Determining LPDA Design Parameters Quickly" shows how to arrive at acceptable values of τ and σ for use in *LPCAD* and similar software.

For a given frequency range, increasing the value of τ increases both the gain and the number of required elements. Increasing the value of σ increases both the gain and the overall boom length. A τ of 0.96 — which approaches the upper maximum recommended value for τ — yields an optimal σ of about 0.18, and the resulting array grows to over 100 feet long for the 14 to 30 MHz range. The maximum free space gain is about 11 dBi, with a front-to-back ratio that approaches 40 dB. Normal amateur practice, however, uses values of τ from about 0.88 to 0.95 and values of σ from about 0.03 to 0.06.
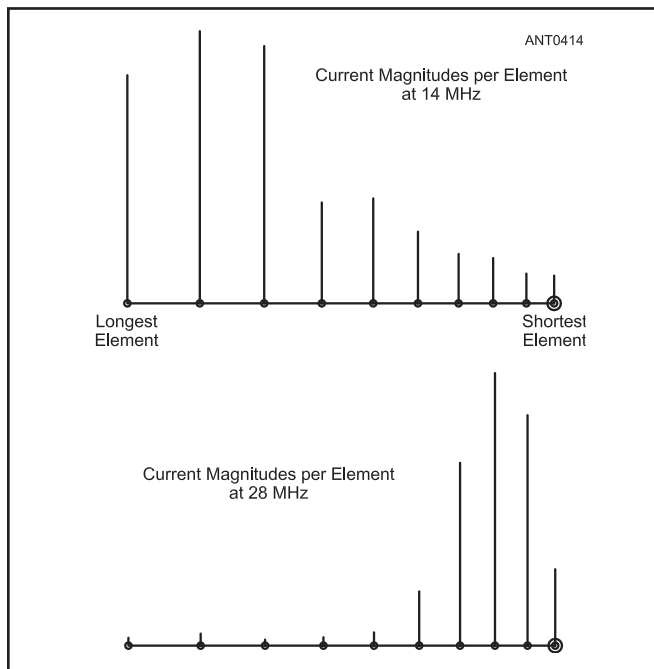
Figure 7.4 — The relative current magnitude on the elements of an LPDA at the lowest and highest operating frequencies for a given design. Compare the number of "active" elements, that is, those with current levels at least ¹⁄₁₀ of the highest level.
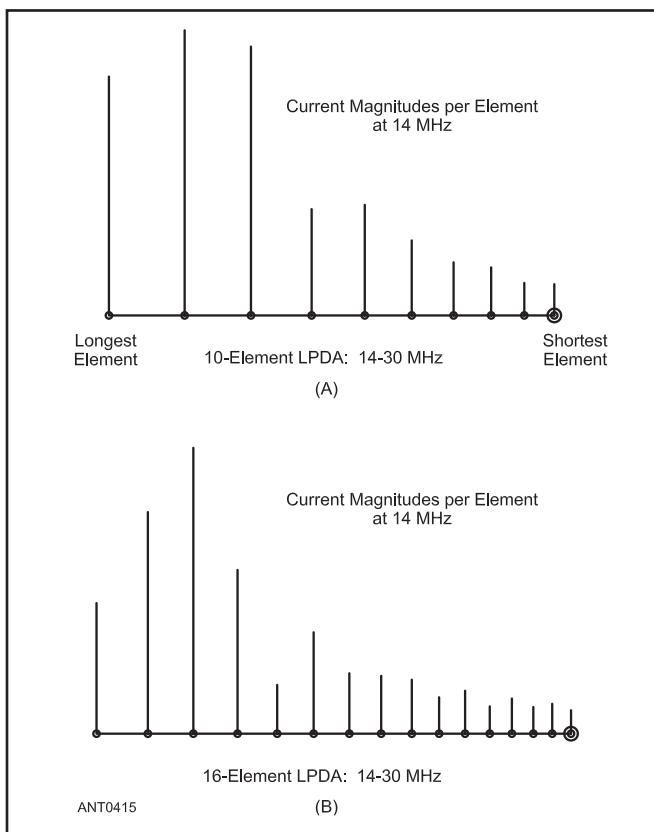
Figure 7.5 — Patterns of current magnitude at the lowest operating frequency of two different LPDA designs: a 10-element low-τ design and a 16-element higher-τ design.

Standard design procedures usually assign to the rear element a resonant frequency about 7% lower than the lowest design frequency with a physical length 5% lower than a free-space half wavelength. The upper frequency limit of the design is ordinarily set at about 1.3 times the highest design frequency. Since τ and σ set the increment between successive element lengths, the number of elements becomes a function of when the shortest element reaches the dipole length for the adjusted upper frequency.

The adjusted upper frequency limit results from the behavior of LPDAs with respect to the number of active elements. See **Figure 7.4**, which shows an edge view of a 10-element LPDA for 20 through 10 meters. The vertical lines represent the peak relative current magnitude for each element at the specified frequency. At 14 MHz, virtually every element of the array shows a significant current magnitude. However, at 28 MHz, only the forward 5 elements carry significant current. Without the extended design range to nearly 40 MHz, the number of elements with significant current levels would be severely reduced, along with upper frequency performance.

The need to extend the design equations below the lowest proposed operating frequency varies with the value of τ. In **Figure 7.5**, we can compare the current on the rear elements of two LPDAs, both with a σ value of 0.04. The upper design uses a τ of 0.89, while the lower design uses a value of 0.93. The most significant current-bearing element moves forward with increases in τ, reducing (but not wholly eliminating) the need for elements whose lengths are longer than a dipole for the lowest operating frequency.

7.1.1 LPDA DESIGN AND COMPUTERS

Originally, LPDA design proceeded through a series of design equations intended to yield the complete specifications for an array. More recent techniques available to radio amateurs include basic LPDA design software and antenna modeling software. One good example of LPDA design software is *LPCAD* by Roger Cox, WBØDGF, available for downloading from **wb0dgf.com/LPCAD.htm**. The user begins by specifying the lowest and highest frequencies in the design. The user then selects values for τ and σ or choices for the number of elements and the total length of the array. With this and other input data, the program provides a table of element lengths and spacings, using the adjusted upper and lower frequency limits described earlier. (A spreadsheet to assist with performing the calculations in this chapter was contributed by Dennis Miller, KM9O, and is available for downloading from **www.arrl.org/antenna-book**.)

The program also requests the diameters of the longest and shortest elements in the array, as well as the diameter of average element. From this data, the program calculates a recommended value for the characteristic impedance of the phase-line connecting the elements and the approximate resistive value of the input impedance. Among the additional data that *LPCAD* makes available is the spacing of conductors to achieve the desired characteristic impedance of the phase-line. These conductors may be round — as we would

Determining LPDA Design Parameters Quickly

LPCAD provides a very efficient method of arriving at a preliminary design for an LPDA. When using the program, it is much faster to use the boom length and number of elements input method rather than the τ and σ data entry method. Those parameters will be calculated along with all dimensions. For those wishing to better understand the trade-offs or who wish to use the formulas in this chapter to calculate all dimensions, the following procedure will help you to arrive at starting values of τ and σ that will make your progress towards a final design much more rapid.

The first consideration is the frequency range to be covered. Many ham LPDA designs cover about a 2:1 frequency range, for example, 14 to 29 MHz. Extending the high end of the frequency range adds little to the size and cost and can smooth out operation at the higher frequencies of interest. An LPDA with an 8:1 range will be only 1.8 times longer than an antenna with a 2:1 range, while the frequency range is 4 times more. However, use of a very wide-band LPDA only at its high frequency end means most of the size and weight of the antenna is wasted since the largest parts of the antenna are inactive. Covering only the desired frequencies reduces boom length. **Figure 7.A** illustrates the different sizes of arrays having the same gain but different frequency coverage.

The lowest frequency determines the longest element length, which will be somewhat more than ½ wavelength at that frequency. An approximate length in feet can be gotten by dividing 500 by the frequency in MHz. This dimension is pretty much fixed, although in some large designs it is reduced somewhat by inductive or capacitive loading of the lowest frequency elements.

The boom length is the next logical parameter to be determined and will be based on what you can afford to build, raise, support and rotate versus the performance to be expected for various boom options. For a given frequency ratio — the longer the boom, the higher the gain. **Figure 7.B** will give

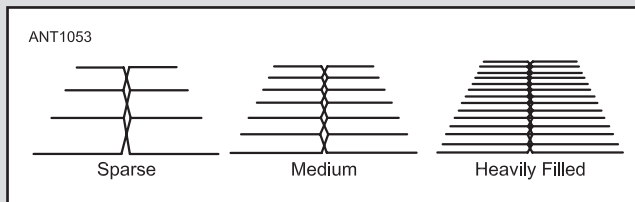Frequency range vs. boom length for constant gain LPDA antennas
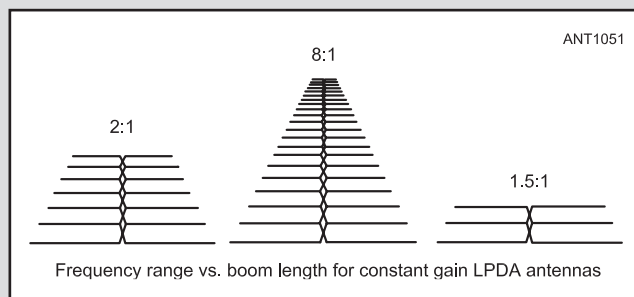
Figure 7.A — Comparison of boom length for several LPDA designs with the same gain but different ratios of maximum to minimum frequency coverage.
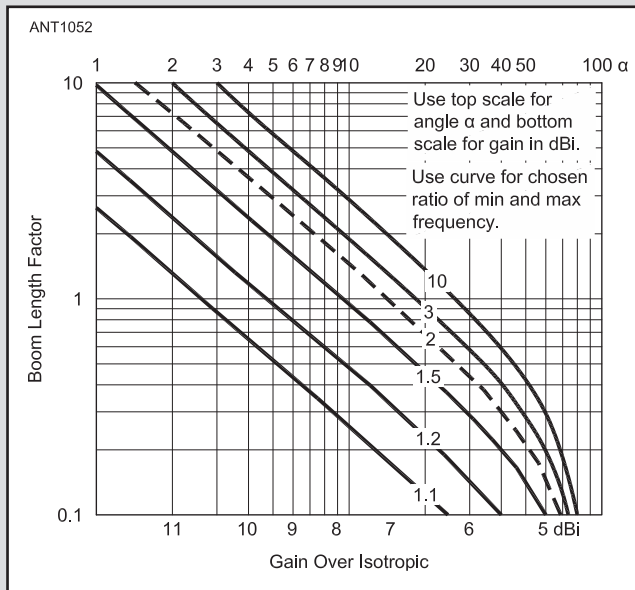
Figure 7.B — A chart relating gain, boom length factor, and α.

Figure 7.C — Illustration of sparse to heavily filled arrays.

some guidance as to the gain to be expected for a given boom length. The boom length factor (BLF) represents the boom length compared to the length of the longest element. As a rough rule of thumb, each doubling of the boom length will add about 1 dB of gain. Beyond a certain point, doubling the boom length to add 1 dB will be uneconomical. Keeping the boom to a reasonable length means accepting either a reduced frequency range or a lower gain.

Once a boom length is chosen, based on a trade-off between mechanical limits and the desired gain value and frequency range ratio, we can also read off the angle using this same graph, since gain is closely associated with α.

Once α is determined along with the frequency coverage, the shape and size of the antenna is defined. We must now decide how to fill up this outlined shape with elements. In other words, determine the number, length and spacing of the elements. The chart of Figure 7.3 is useful in this. This chart plots gain as a function of τ, σ and α. The α values are represented by the slanted lines between the marked degree values on the chart. Since we have determined the desired value of α, we can use that value to choose values of τ and σ.

For a given α value (slanted lines), follow the corresponding line diagonally along and you will see the lower part of the line lies more or less parallel to a constant gain curve. The portion of a constant-α line on the bottom left represents a heavily filled array (more elements, closely spaced) while upper right portion of the constant, a line represents a sparsely filled array (fewer elements). (**see Figure 7.C**)

Notice that as the number of elements decreases (moving right and upwards on the constant-α gain may fluctuate a bit but will reach a point where it quickly falls off as you cross the "optimum σ" line. Values above this line represents a design that has too few elements to realize good performance. The interpretation of this "optimum σ" value is not obvious and perhaps its name was poorly chosen. It may be intended to give the value of σ for maximum gain for a given value of τ. However, this approach disregards the boom length factor. Designs that first choose τ and then use the optimum σ will be outrageously long — of course they will have high gain!

For a given antenna outline (length vs. width or constant-α) "optimum σ" is optimum only in that it indicates the point where further reduction in the number of elements will cause the gain to drop off. Thus, it gives a design with the least number of elements for a given gain. However, this design will not have the smoothest gain and SWR vs. frequency and the F/B ratio may be inadequate. For this reason, very few practical designs fall near the "optimum σ" line. All of the designs in this chapter fall well below the "optimum σ" as shown by the dots on the chart.

For designs with a higher α value, the gain should increase a bit with the more heavily filled arrays. Very narrow (long boom) arrays may have less gain if too heavily filled. It is not wise to approach the "optimum σ" line too closely in an attempt to reduce the element number. On the other hand, designs too far down the sloping a curve will be more expensive to build and will have greater wind load due to having more elements than necessary.

Having selected from the chart some τ and σ combinations that give us the design we want, we can now use software such as *LPCAD* to generate a detailed design using those values of τ and σ. This should result in a boom length fairly close to that desired. A second pass through the program may use the exact boom length desired and the number of elements calculated in the first pass, plus or minus one element. The program will then give us all of the mechanical dimensions, and also generate files for *NEC* analysis. Alternatively, we can proceed with the manual method given elsewhere in this chapter. If using that method we should come out close to the desired design on the first try and avoid multiple guesses as to where to start.

Several different designs that are close to that desired should be prepared as *NEC* files and an analysis done using *NEC*. This may show that a sparsely filled array may have excessive variation of gain and SWR vs. frequency or an inadequate F/B ratio or have other problems such as a weakness on an important frequency.
— *John Stanley, K4ERO*

use for a wire phase-line — or square — as we might use for double-boom construction.

An additional vital output from *LPCAD* is the conversion of the design into antenna modeling input files of several formats, including versions for *AO* and *NEC4WIN* (both *MININEC*-based programs), and a version in the standard *.NEC format usable by many implementations of *NEC-2* and *NEC-4*, including *NECWin Plus*, *GNEC*, and *EZNEC Pro*. Every proposed LPDA design should be verified and optimized by means of antenna modeling, since basic design calculations rarely provide arrays that require no further work before construction. Moreover, some of the design equations are based upon approximations and do not completely predict LPDA behavior. Despite these limitations, most of the sample LPDA designs shown later in this chapter are based directly upon the fundamental calculations.

Modeling LPDA designs is most easily done on a version of *NEC*. The transmission line (TL) facility built into *NEC-2* and *NEC-4* alleviates the problem of modeling the phase-line as a set of physical wires, each section of which has a set of constraints in *MININEC* at the right-angle junctions with the elements. Although the *NEC* TL facility does not account for losses in the lines, the losses are ordinarily low enough to neglect.

NEC models do require some careful construction to obtain the most accurate results. Foremost among the cautions is the need for careful segmentation, since each element has a different length. The shortest element should have about 9 or 11 segments, so that it has sufficient segments at the highest modeling frequency for the design. Each element behind the shortest one should have a greater number of segments than the preceding element by the inverse of the value of τ. However, there is a further limitation. Since the transmission line is at the center of each element, *NEC* elements should have an odd number of segments to hold the phase-line centered. Hence, each segmentation value calculated from the inverse of τ must be rounded up to the nearest odd integer.

Initial modeling of LPDAs in *NEC-2* should be done with uniform-diameter elements, with any provision for stepped-diameter element correction turned off. Since these correction factors apply only to elements within about 15% of dipole resonance at the test frequency, models with stepped-diameter elements will correct for only a few elements at any test frequency. The resulting combination of corrected and uncorrected elements will not yield a model with assured reliability.

Once one has achieved a satisfactory model with uniform-diameter elements, the modeling program can be used to calculate stepped-diameter substitutes. Each uniform-diameter element, when extracted from the larger array, will have a resonant frequency. Once this frequency is determined, the stepped-diameter element to be used in final construction can be resonated to the same frequency. Although *NEC-4* handles stepped diameter elements with much greater accuracy than *NEC-2*, the process just described is also applicable to *NEC-4* models for the greatest precision.

7.1.2 LPDA BEHAVIOR

Although LPDA behavior is remarkably uniform over a wide frequency range compared to narrow-band designs, such as the Yagi-Uda array, it nevertheless exhibits very significant variations within the design range. **Figure 7.6** shows several facets of these behaviors. Figure 7.6 shows the free-space gain for three LPDA designs using 0.5-inch diameter aluminum elements. The designations for each model list the values of τ (0.93, 0.89, and 0.85) and of σ (0.02, 0.04, and 0.06) used to design each array. The resultant array lengths are listed with each designator. The total number of elements varies from 16 for "9302" to 10 for "8904" to 7 for "8504."

First, the gain is never uniform across the entire frequency span. The gain tapers off at both the low and high ends of the design spectrum. Moreover, the amount of gain undulates across the spectrum, with the number of peaks dependent upon the selected value of τ and the resultant number of elements. The front-to-back ratio tends to follow the gain level. In general, it ranges from less than 10 dB when the free-space gain is below 5 dBi to over 20 dB as the gain approaches 7 dBi. The front-to-back ratio may reach the high 30 dBs when the free-space array gain exceeds 8.5 dBi. Well-designed arrays, especially those with high values of τ and σ, tended to have well-controlled rear patterns that result in only small differences between the 180° front-to-back ratio and the averaged front-to-rear ratio.

Since array gain is a mutual function of both τ and σ, average gain becomes a function of array length for any given frequency range. Although the gain curves in Figure 7.6 interweave, there is little to choose among them in terms of average gain for the 14 to 18-foot range of array lengths. Well-designed 20 to 10 meter arrays in the 30-foot array length region are capable of about 7 dBi free-space gain, while 40-foot arrays for the same frequency range can achieve about 8 dBi free-space gain.

Short-Boom LPDAs: 14' to 18.5'
Free-Space Gain: 14 to 30 MHz

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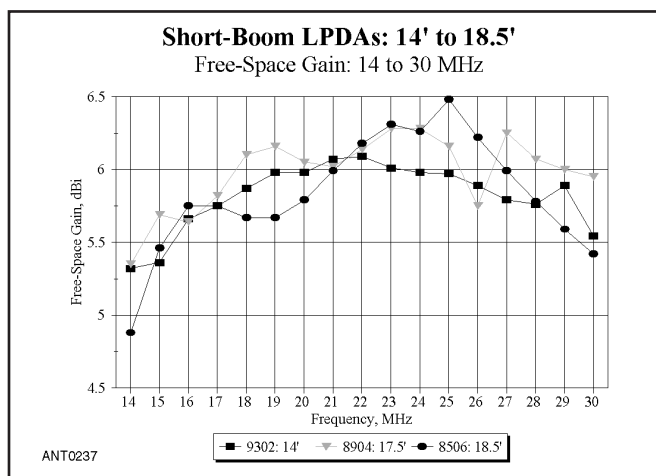
Figure 7.6 — The modeled free-space gain of three relatively small LPDAs of different design. Note the relationship of the values of τ and of σ for these arrays with quite similar performance across the 14-30 MHz span.

Exceeding an average gain of 8.5 dBi requires at least a 50-foot array length for this frequency range. Long arrays with high values of τ and σ also tend to show smaller excursions of gain and of front-to-back ratio in the overall curves. In addition, high-τ designs tend to show higher gain at the low frequency end of the design spectrum.

The frequency sweeps shown in Figure 7.6 are widely spaced at 1 MHz intervals. The evaluation of a specific design for the 14 to 30-MHz range should decrease the interval between check points to no greater than 0.25 MHz in order to detect frequencies at which the array may show a *performance weakness*. Weaknesses are frequency regions in the overall design spectrum at which the array shows unexpectedly lower values of gain and front-to-back ratio. In Figure 7.6 note the unexpected decrease in gain of model "8904" at 26 MHz. The other designs also have weak points, but they fall between the frequencies sampled.

In large arrays, these regions may be quite small and may occur in more than one frequency region. The weakness results from the harmonic operation of longer elements to the rear of those expected to have high current levels. Consider a 7-element LPDA with a boom about 12.25-feet long for 14 to 30 MHz using 0.5-inch aluminum elements. At 28 MHz, the rear elements operate in a harmonic mode as shown by the high relative current magnitude curves in **Figure 7.7**. The result is a radical decrease in gain, as shown in the "No Stub" curve of **Figure 7.8**. The front-to-back ratio also drops as a result of strong radiation from the long elements to the rear of the array.

Early designs of LPDAs called for terminating transmission-line stubs as standard practice to help eliminate such weak spots in frequency coverage. In contemporary designs, their use tends to be more specific for eliminating or moving frequencies that show gain and front-to-back weakness. (Stubs have the added function of keeping both sides of each element at the same dc level of static charge or discharge.) The model dubbed "8504" was fitted (by trial and error) with an 18-inch shorted stub of 600-Ω transmission line. As Figure 7.7B shows, the harmonic operation of the rear elements is attenuated. The "stub" curve of Figure 7.8 shows the smoothing of the gain curve for the array throughout the upper half of its design spectrum. In some arrays showing multiple weaknesses, a single stub may not eliminate all of them. However, it may move the weaknesses to unused frequency regions. Where full-spectrum operation of an LPDA is necessary, additional stubs located at specific elements may be needed.

Most LPDA designs benefit (with respect to gain and front-to-back ratio) from the use of larger-diameter elements. Elements with an average diameter of at least 0.5-inch are desirable in the 14 to 30 MHz range. However, standard designs usually presume a constant element length-to-diameter ratio. In the case of *LPCAD*, this ratio is about 125:1, which
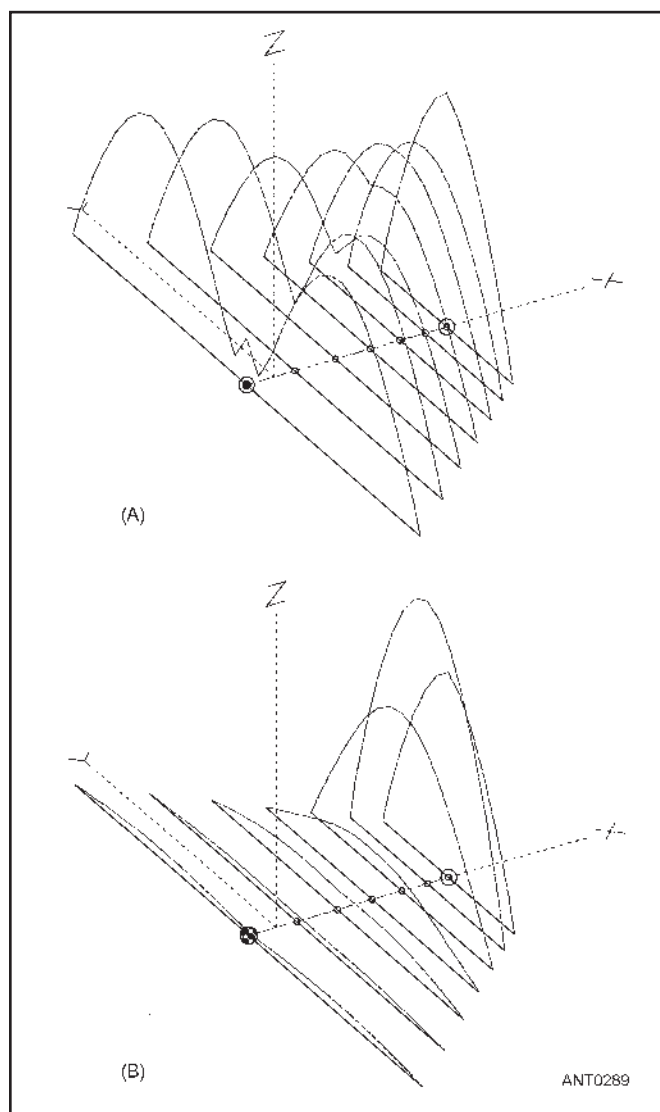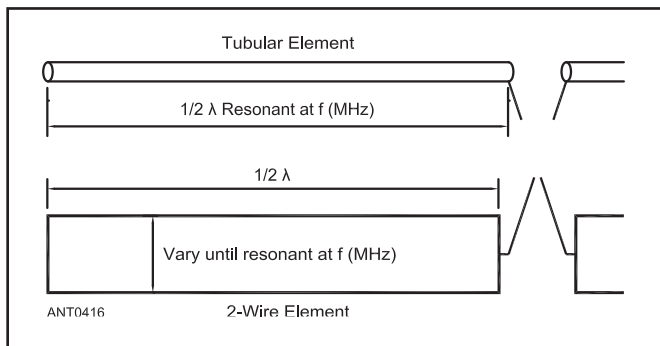

Figure 7.7 — The relative current magnitude on the elements of model "8504" at 28 MHz without and with a stub. Note the harmonic operation of the rear elements before a stub is added to suppress such operation.
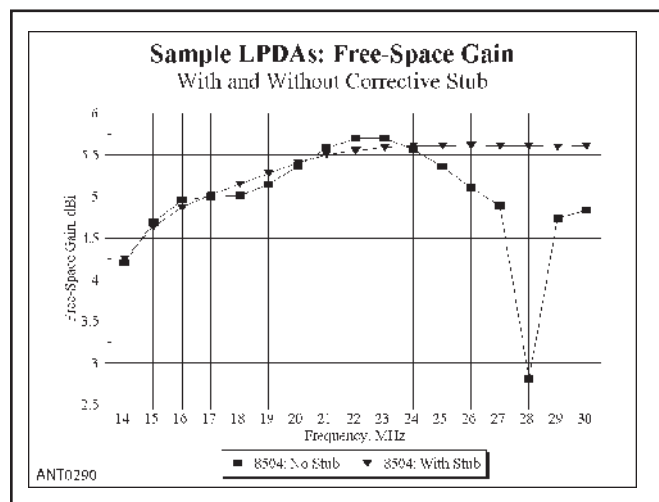
Figure 7.8 — A graph of the gain of model "8504" showing the frequency region in which a "weakness" occurs and its absence once a suitable stub is added to the array.

Figure 7.9 — A substitute for a large-diameter tubular element composed of two wires shorted at both the outer ends and at the center junction with the phase-line.

assumes an even larger diameter. To achieve a relatively constant length-to-diameter ratio in the computer models, you can set the diameter of the shortest element in a given array design and then increase the element diameter by the inverse of τ for each succeeding longer element. This procedure is often likely to result in unreasonably large element diameters for the longest elements, relative to standard amateur construction practices.

Since most amateur designs using aluminum tubing for elements employ stepped-diameter (tapered) elements, roughly uniform element diameters will result unless the LPDA mechanical design tries to lighten the elements at the forward end of the array. This practice may not be advisable, however. Larger elements at the high end of the design spectrum often counteract (at least partially) the natural decrease in high-frequency gain and show improved performance compared to smaller diameter elements.

An alternative construction method for LPDAs uses wire throughout. At every frequency, single-wire elements reduce gain relative to larger-diameter tubular elements. An alternative to tubular elements appears in **Figure 7.9**. For each element of a tubular design, there is a roughly equivalent 2-wire element that may be substituted. The spacing between the wires is determined by taking one of the modeled tubular elements and finding its resonant frequency. A two-wire element of the same length is then constructed with shorts at the far ends and at the junctions with the phase-line. The separation of the two wires is adjusted until the wire element is resonant at the same frequency as the original tubular element. The required separation will vary with the wire chosen for the element. Models used to develop these substitutes must pay close attention to segmentation rules for *NEC* due to the short length of segments in the end and center shorts, and to the need to keep segment junctions as exactly parallel as possible with close-spaced wires.

7.1.3 FEEDING AND CONSTRUCTING THE LPDA

Original design procedures for LPDAs used a single, ordinarily fairly high, characteristic impedance for the phase-line (antenna feeder). Over time, designers realized that other values of impedance for the phase-line offered both mechanical and performance advantages for LPDA performance. Consequently, for the contemporary designer, phase-line choice and construction techniques are almost inseparable considerations.

High-impedance phase-lines (roughly 200 Ω and higher) are amenable to wire construction similar to that used with ordinary parallel-wire transmission lines. They require careful placement relative to a metal boom used to support individual elements (which themselves must be insulated
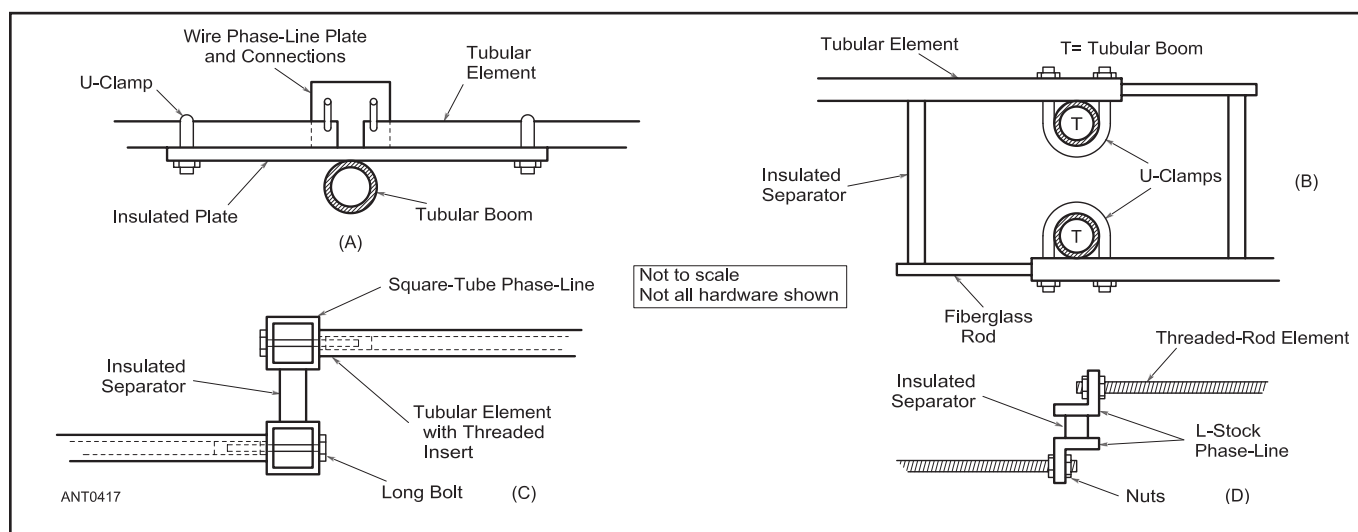
Figure 7.10 — Four (of many) possible construction techniques, shown from the array end. In A, an insulated plate supports and separates the wires of the phase-line, suitable with wire or tubular elements. A dual circular boom phase-line also supports the elements, which are cross-supported for boom stability. Square tubing is used in C, with the elements joined to the boom/phase-line with through-bolts and an insert in each half element. The L-stock shown in D is useful for lighter VHF and UHF arrays.

from the support boom). Connections also require care. If the phase-line is given a half-twist between each element, the construction of the line must ensure constant spacing and relative isolation from metal supports to maintain a constant impedance and to prevent shorts.

Along with the standard parallel-wire line, shown in **Figure 7.10A**, there are a number of possible LPDA structures using booms to support the elements and to create relatively low-impedance (under 200 Ω) phase-lines. Figure 7.10B shows the basics of a twin circular tubing boom with the elements cross-supported by insulated rods. Figure 7.10C shows the use of square tubing with the elements attached directly to each tube by through-bolts. Figure 7.10D illustrates the use of L-stock, which may be practical at VHF frequencies. Each of these sketches is incomplete, however, since it omits the necessary stress analyses that determine the mechanical feasibility of a structure for a given LPDA project.

The use of square boom material requires some adjustment when calculating the characteristic impedance of the phase-line. For conductors with a circular cross-section,

$$Z_0 = 120 \cosh^{-1} \frac{D}{d} \tag{4}$$

where D is the center-to-center spacing of the conductors and d is the outside diameter of each conductor, both expressed in the same units of measurement. Since we are dealing with closely spaced conductors, relative to their diameters, the use of this version of the equation for calculating the characteristic impedance (Z_0) is recommended. For a square conductor,

$$d \approx 1.18\,w \tag{5}$$

where d is the approximate equivalent diameter of the square tubing and w is the width of the tubing across one side. Thus, for a given spacing, a square tube permits you to achieve a lower characteristic impedance than round conductors. However, square tubing requires special attention to matters of strength, relative to comparable round tubing.

Electrically, the characteristic impedance of the LPDA phase-line tends to influence other performance parameters of the array. Decreasing the phase-line Z_0 also decreases the feed point impedance of the array. For small designs with few elements, the decrease is not fully matched by a decrease in the excursions of reactance. Consequently, using a low impedance phase-line may make it more difficult to achieve a 2:1 or less SWR for the entire frequency range. However, higher-impedance phase-lines may result in a feed point impedance that requires the use of an impedance-matching balun.

Decreasing the phase-line Z_0 also tends to increase LPDA gain and front-to-back ratio. There is a price to be paid for this performance improvement — weaknesses at specific frequency regions become much more pronounced with reductions in the phase-line Z_0. For a specific array you must weigh carefully the gains and losses, while employing one or more transmission line stubs to get around performance weaknesses at specific frequencies.

Depending upon the specific values of τ and σ selected for a design, you can sometimes select a phase-line Z_0 that provides either a 50-Ω or a 75-Ω feed point impedance, holding the SWR under 2:1 for the entire design range of the LPDA. The higher the values of τ and σ for the design, the lower the reactance and resistance excursions around a central value. Designs using optimal values of σ with high values of τ show a very slight capacitive reactance throughout the frequency range. Lower design values obscure this phenomenon due to the wide range of values taken by both resistance and reactance as the frequency is changed.

At the upper end of the frequency range, the source resistance value decreases more rapidly than elsewhere in the design spectrum. In larger arrays, this can be overcome by using a variable Z_0 phase-line for approximately the first 20% of the array length. This technique is, however, difficult to implement with anything other than wire phase-lines. Begin with a line impedance about half of the final value and increase the wire spacing evenly until it reaches its final and fixed spacing. This technique can sometimes produce smoother impedance performance across the entire frequency span and improved high-frequency SWR performance.

Designing an LPDA requires as much attention to designing the phase-line as to element design. It is always useful to run models of the proposed design through several iterations of possible phase-line Z_0 values before freezing the structure for construction.

7.1.4 SPECIAL DESIGN CORRECTIONS

The curve for the sample 8504 LPDA in Figure 7.8 revealed several deficiencies in standard LPDA designs. The weakness in the overall curve was corrected by the use of a stub to eliminate or move the frequency at which rearward elements operated in a harmonic mode. In the course of
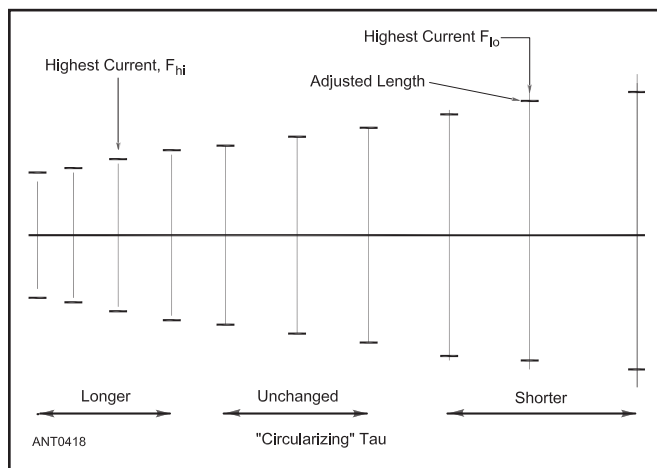
Figure 7.11 — A before and after sketch of an LPDA, showing the original lengths of the elements and their adjustments from diminishing the value of τ at both ends of the array. See the text for the amount of change applicable to each element.

describing the characteristics of the array, we have noted several other means to improve performance. Fattening elements (either uniformly or by increasing their diameter in step with τ) and reducing the characteristic impedance of the phase-line are capable of small improvements in performance. However, they cannot wholly correct the tendency of the array gain and front-to-back ratio to fall off at the upper and lower limits of the LPDA frequency range.

One technique sometimes used to improve performances near the frequency limits is to design the LPDA for upper and lower frequency limits much higher and lower than the frequencies of use. This technique unnecessarily increases the overall size of the array and does not eliminate the downward performance curves. Increasing the values of τ and σ will usually improve performance at no greater cost in size than extending the frequency range. Increasing the value of τ is especially effective in improving the low frequency performance of an LPDA.

Working within the overall size limits of a standard design, one may employ a technique of *circularizing* the value of τ for the rear-most and forward-most elements. See **Figure 7.11**, which is not to-scale relative to overall array length and width. Locate (using an antenna-modeling program) the element with the highest current at the lowest operating frequency, and the element with the highest current at the highest operating frequency. The adjustments to element lengths may begin with these elements or — at most — one element further toward the array center. For the first element (counting from the center) to be modified, reduce the value of τ by about 0.5%. For a rearward element, use the inverse of the adjusted value of τ to calculate the new length of the element relative to the unchanged element just forward of the change. For a forward element, use the new value of τ to calculate the new length of the element relative to the unchanged element immediately to the rear of it.

For succeeding elements outward, calculate new values of τ from the adjusted values, increasing the increment of decrease with each step. Second adjusted elements may use values of τ about 0.75% to 1.0% lower than the values just calculated. Third adjusted elements may use an increment of 1.0% to 1.5% relative to the preceding value.

Not all designs require extensive treatment. As the values of τ and σ increase, fewer elements may require adjustment to obtain the highest possible gain at the frequency limits, and these will always be the most outward elements in the array. A second caution is to check the feed point impedance of the array after each change to ensure that it remains within design limits.

Figure 7.12 shows the free-space gain curves from 14 to 30 MHz for a 10-element LPDA with an initial τ of 0.89 and a σ of 0.04. The design uses a 200-Ω phase-line, 0.5-inch aluminum elements, and a 3-inch 600-Ω stub. The lowest curve shows the modeled performance across the design frequency range with only the stub. Performance at the frequency limits is visibly lower than within the peak performance region. The middle curve shows the effects of circularizing τ. Average
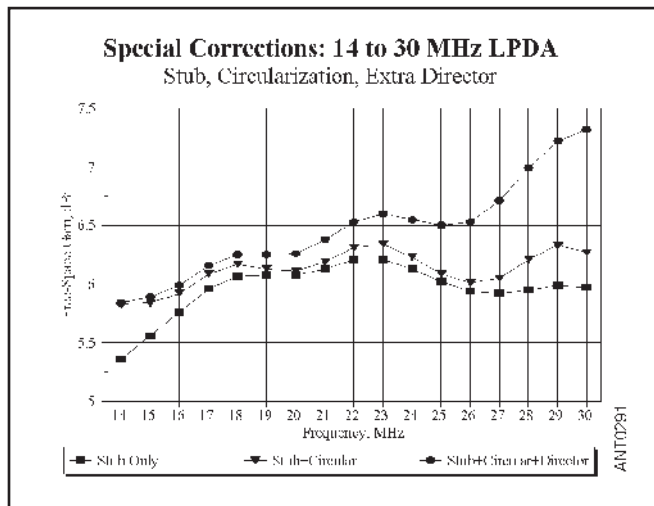
Figure 7.12 — The modeled free space gain from 14 to 30 MHz of an LPDA with τ of 0.89 and σ of 0.04. Squares: just a stub to eliminate a weakness; Triangles: with a stub and circularized elements, and Circles: with a stub, circularized elements and a parasitic director.
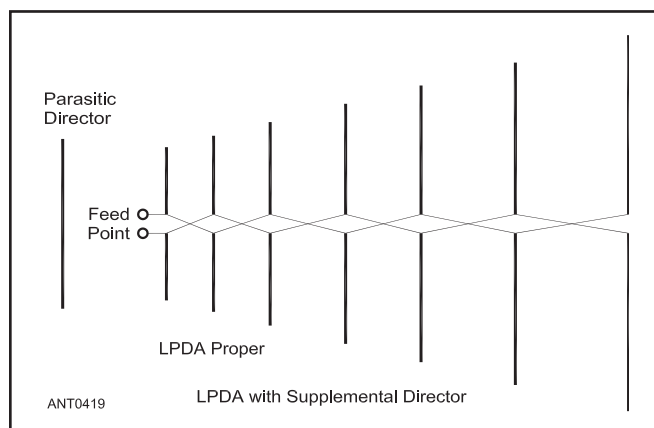
Figure 7.13 — A generalized sketch of an LPDA with the addition of a parasitic director to improve performance at the higher frequencies within the design range.

performance levels have improved noticeably at both ends of the spectrum.

In lieu of, or in addition to, the adjustment of element lengths, you may also add a parasitic director to an LPDA, as shown in **Figure 7.13**. The director is cut roughly for the highest operating frequency. It may be spaced between 0.1 λ and 0.15 λ from the forward-most element of the LPDA. The exact length and spacing should be determined experimentally (or from models) with two factors in mind. First, the element should not adversely affect the feed point impedance at the highest operating frequencies. Close spacing of the director has the greatest effect on this impedance. Second, the exact spacing and element length should be set to have the most desired effect on the overall performance curve of the array. The mechanical impact of adding a

director is to increase overall array length by the spacing selected for the element.

The upper curve in Figure 7.12 shows the effect of adding a director to the circularized array already equipped with a stub. The effect of the director is cumulative, increasing the upper range gain still further. Note that the added parasitic director is not just effective at the highest frequencies within the LPDA design range. It has a perceptible effect almost all the way across the frequency span of the array, although the effect is smallest at the low-frequency end of the range.

The addition of a director can be used to enhance upper frequency performance of an LPDA, as in the illustration, or simply to equalize upper frequency performance with mid-range performance. High-τ designs, with good low-frequency performance, may need only a director to compensate for high-frequency gain decrease. One potential challenge to adding a director to an LPDA is sustaining a high front-to-back ratio at the upper frequency range. (See this book's CD-ROM for more information on such log-Yagi arrays.)

Throughout the discussion of LPDAs, the performance curves of sample designs have been treated at all frequencies alike, seeking maximum performance across the entire design frequency span. Special compensations are also possible for ham-band-only LPDA designs. They include the insertion of parasitic elements within the array as well as outside the initial design boundaries. In addition, stubs may be employed not so much to eliminate weaknesses, but only to move them to frequencies outside the range of amateur interests.

7.2 DESIGNING AN LPDA

The following presents a systematic step-by-step design procedure for an LPDA with any desired bandwidth. The procedure requires some mathematical calculations, but a common calculator with square-root, logarithmic, and trigonometric functions is completely adequate. The notation used in this section may vary slightly from that used earlier in this chapter.

1) Decide on an operating bandwidth B between f_1, lowest frequency and f_n, highest frequency:

$$B = \frac{f_n}{f_1} \tag{6}$$

2) Choose τ and σ to give the desired estimated average gain.

$$0.8 \le \tau \le 0.98 \text{ and } 0.03 \le \sigma \le \sigma_{opt} \tag{7}$$

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

3) Determine the value for the cotangent of the apex half-angle α from

$$\cot \alpha = \frac{4\sigma}{1 - \tau} \tag{8}$$

Although α is not directly used in the calculations, $\cot \alpha$ is used extensively.

4) Determine the bandwidth of the active region B_{ar} from

$$B_{ar} = 1.1 + 7.7 (1 - \tau)^2 \cot \alpha \tag{9}$$

5) Determine the structure (array) bandwidth B_s from

$$B_S = B \times B_{ar} \tag{10}$$

6) Determine the boom length L, number of elements N, and longest element length ℓ_1.

$$L_n = \left(1 - \frac{1}{B_S}\right) \cot \alpha \times \frac{\lambda_{max}}{4} \tag{11}$$

$$\lambda_{max} = \frac{984}{f_1} \tag{12}$$

$$N = 1 + \frac{\log B_S}{\log \frac{1}{\tau}} = 1 + \frac{\ln B_S}{\ln \frac{1}{\tau}} \tag{13}$$

$$\ell_{1ft} = \frac{492}{f_1} \tag{14}$$

Usually the calculated value for N will not be an integral number of elements. If the fractional value is more than about 0.3, increase the value of N to the next higher integer. Increasing the value of N will also increase the actual value of L over that obtained from the sequence of calculations just performed.

Examine L, N and ℓ_1. to determine whether or not the array size is acceptable for your needs. If the array is too large, increase f_1 or decrease σ or τ and repeat steps 2 through 6. Increasing f_1 will decrease all dimensions. Decreasing σ will decrease the boom length. Decreasing τ will decrease both the boom length and the number of elements.

7) Determine the terminating stub Z_t. (Note: For many HF arrays, you may omit the stub, short out the longest element with a 6-inch jumper, or design a stub to overcome a specific performance weakness.) For VHF and UHF arrays calculate the stub length from

$$Z_t = \frac{\lambda_{max}}{8} \tag{15}$$

8) Solve for the remaining element lengths from

$$\ell_n = \tau \, \ell_{n-1} \tag{16}$$

9) Determine the element spacing d_{1-2} from

$$d_{1-2} = \frac{(\ell_1 - \ell_2) \cot \alpha}{2} \tag{17}$$

where ℓ_1 and ℓ_2 are the lengths of the rearmost elements, and d_{1-2} is the distance between the elements with the lengths ℓ_1 and ℓ_2. Determine the remaining element-to-element spacings from

$$d_{(n-1)-n} = \tau\, d_{(n-2)-(n-1)} \tag{18}$$

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

$$R_0 = \frac{Z_0}{\sqrt{1 + \dfrac{Z_0}{4\sigma' Z_{AV}}}} \tag{19}$$

where the component terms are defined and/or calculated in the following way.

From the following equations, determine the necessary antenna feeder (phase-line) impedance, Z_0:

$$Z_0 = \frac{R_0{}^2}{8\,\sigma' Z_{AV}} + R_0 \sqrt{\left(\frac{R_0}{8\,\sigma' Z_{AV}}\right)^2 + 1} \tag{20}$$

σ' is the mean spacing factor and is given by

$$\sigma' = \frac{\sigma}{\sqrt{\tau}} \tag{21}$$

Z_{AV} is the average characteristic impedance of a dipole and is given by

$$Z_{AV} = 120\left[\ln\left(\frac{\ell_n}{diam_n}\right) - 2.25\right] \tag{22}$$

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

11) Once Z_0 has been determined, select a combination of conductor size and spacing to achieve that impedance, using the appropriate equation for the shape of the conductors. If an impractical spacing results for the antenna feeder, select a different conductor diameter and repeat step 11. In severe cases it may be necessary to select a different R_0 and repeat steps 10 and 11. Once a satisfactory feeder arrangement is found, the LPDA design is complete.

The resultant design should be subjected to extensive modeling tests to determine whether there are performance deficiencies or weaknesses that require modification of the design before actual construction.

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