Notes on the Extended Aperture Log-Periodic Array
Part 1: The Extended Element and the Standard LPDA

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In the *R.S.G.B. Bulletin* for July, 1961, F. J. H. Charman, G6CJ, resurrected a 1938 idea for antenna elements developed by E. C. Cork of E.M.I. Electronics. The elements are variously called loaded or extended wire elements. Charman increased the length of a center-fed wire to 1-λ while still obtaining a bi-directional pattern and a usable feedpoint impedance. He inserted capacitances between the center ½-λ section and the outer sections, thereby changing the current distribution. After a brief flurry of HF and VHF antenna ideas, the technique fell into obscurity, although the basic concept is related to certain collinear designs that use an inductance and a space between sections to obtain the correct phasing. I am indebted to Roger Paskvan, WA0IUJ, for sending me the relevant RSGB materials on the Charman element.

In the 1970s, the element reappeared in a new garb as integral to the 1973 U.S. patent for "Extended Aperture Log-Periodic and Quasi-Log-Periodic Antennas and Arrays" received by Robert L. Tanner, founder and technical director of TCI, Inc. (U.S. patent 3,765,022, Oct. 9, 1973) The ideas found their way into TCI's Model 510 and Model 512 5-30-MHz extended aperture log-periodic dipole arrays (EALPDAs). The arrays may have been in the TCI book since Tanner's filing date (1971) or shortly thereafter, although TCI had previously produced other versions of the log-periodic dipole array (LPDA). Tanner himself authored the first issue of TCI's Technical Notes in 1987 with an incomplete description of the EALPDA. An earlier version of the material must exist, since all of the 1981 RSGB notice for the revived Cork-Charman elements are identical to some of the graphics used in Tanner's technical note. My thanks go to Alois Krischke, DJ0TR, for sending me a copy of the patent.[1]

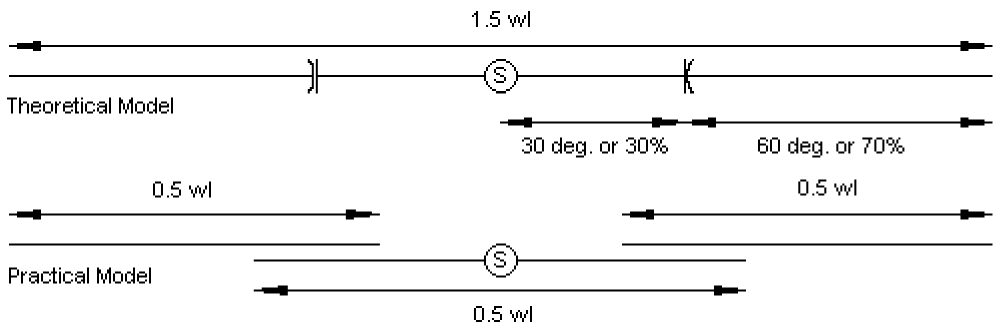
Fortunately, the RSGB materials and Tanner's patents application give us ample material for examining the basic features of the extended element and its application to LPDA arrays—at least in a preliminary manner. The inventor of the EALPDA also describes a standard optimized LPDA in his application to use as a comparator with the EALPDA. As well, he provides a table of sample elements for an EALPDA in enough detail to permit close modeling via NEC-4. So we may proceed in an orderly way to develop the EALPDA from basic elements. Although we shall discover some design and some modeling limitations, we shall be able to determine if the EALPDA has the potential to do the job ultimately assigned to it.

The start of our journey involves understanding some prerequisite information. First, we need to look at the basic concept that underlies the extend element, the heart of the EALPDA. We shall discover that we can build and model the element in at least two different ways with comparable results. Second, we need to examine the performance of a long-boom LPDA of standard design, the array used as comparator in Tanner's patent application. Because so much of our understanding of LPDA operation and performance rests on older information, we shall spend an inordinate amount of time reviewing LPDA performance in various contexts and configurations.

The Basic Extended Element

Charman's account of the extended element structure includes much of what we would now consider controlled current distribution (CCD) antenna. Our interest in the extended element only encompasses the inclusion of a single capacitor between the feedpoint and the element end. Monopoles, of course, require only a single capacitor, while a dipole requires 2. There are various approaches to the calculation of the proper position for the capacitor, but a 30° value most often appears. In fact, a half dipole that is resonant is 90° long, but the TCI implementation of the element, uses a positional value of 30% of the element length each side of the feedpoint. (The TCI patent also shows variations on the extended element within EALPDAs that use 2 capacitors per branch.)

Fig. 1 shows the general outline of two versions of the extended element. The upper version is used for theoretical calculations, while the lower version corresponds to the practical considerations of implementing capacitance along a linear element—also shown in Charman's work. Placing a capacitor at the correct position and with the correct value for the position can be mechanically complex. Therefore, the recommended practice includes the use of overlapping wires, where the spacing between the wire and the length of the overlapping section determine the precise capacitance. For the home builder, pruning the antenna to resonance and pruning the capacitors to value involve wire snipping.



Theory and Practice with the Basic Extended Element

Fig. 1

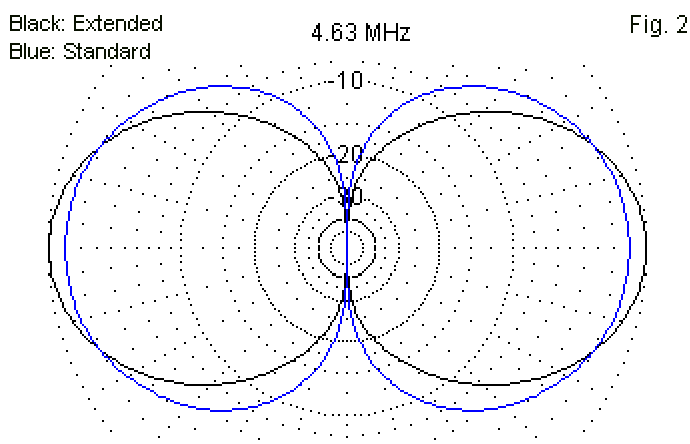
To evaluate the performance of the element, I began with one of the patent application elements listed in its Table 1 in column 8. The wire diameter is 0.16" (and I used perfect or lossless wire in the model). The inner length is 81.0'. Each outer length is 80.5' long. The spacing between the overlapping sections is 4" (0.333'). The overall length is 200', which places the center of each overlapping section exactly 30.0' from the feedpoint (or 30% from the feedpoint to the element's outer tip). Each overlapping section is 21.0' long.

Theoretically, we may replace each overlapping section of the element with a single capacitor, as suggested by the upper portion of the diagram. To find the value, I simply created a 200' single wire and inserted capacitive loads 30% of the distance on each side of the feedpoint (+/- 30'). To find the correct value, I first found the resonant frequency in free space of the 3-wire version: 4.63 MHz, a value that coincides with the TCI use of the wire as the rearmost element in an EALPDA with a lower operational frequency of 5 MHz. The required values of capacitance for the 1-wire version became 35.5 pf (-j968.3 Ω reactance at the resonant frequency). **Table 1** shows the relative performance reports for the two versions of the extended element. The table includes a standard ½-λ dipole for reference. However, the reference dipole has a length of 113.2'. The overall length of the extended elements is 200' in both cases. The calculated length of the extended element is less than the amount calculated by Charman, and the required capacitance is significantly lower. However, his impedance and beamwidth figures are very close to the modeled values (200 Ω and 56°, respectively). The table includes beamwidth values only for the E-plane because the H-plane pattern is simply a circle for a single element, whether a normal dipole or extended.

Table 1. Performance of extended dipole elements with capacitors and with overlapping wires

Version	Max. Gain dBi	E-Plane BW degrees	Impedance R +/- jX Ω
Capacitors	3.24	55.2	209.5 + j2.5
Overlap	3.12	56.0	209.1 + j0.6
½-λ Dipole	2.14	78.2	72.0 – j0.7

The theoretical gain of the extended element over the standard dipole elements is about 1.1 dB. The gain of the overlap version is numerically slightly less, but operationally indistinguishable. **Fig. 2** overlays the free-space E-plane patterns of the standard dipole and the overlapping extended element for comparison. In many ways, the narrower beamwidth may be the more prized of the advantages of using an extended element.

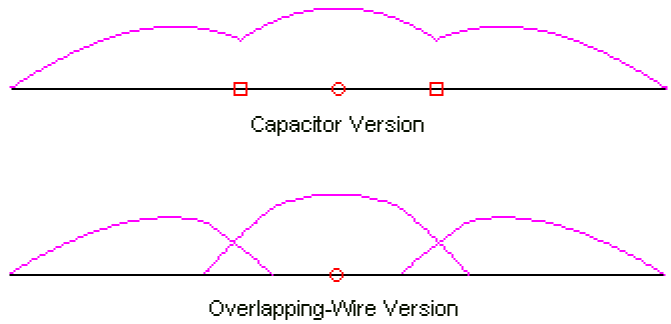


Free-Space E-Plane Patterns of a Standard and an Extended Element

Although the current distribution along the two versions of the extended element is similar—with similar consequences for the radiation pattern—the curves are not identical, as is evident in **Fig. 3**. The overlapping-wire version of the extended element has deeper current minimums, and there are slight differences in the current phase angles between the two versions at various positions along the wire.

The feedpoint impedance shown in **Table 1** applies to the series resonant frequency of the antenna. Unlike a standard center-fed element, which shows a parallel resonance at nearly double the frequency of the series resonance, the extended element's parallel resonance occurs at a much lower frequency ratio to the series resonant frequency: about 1.2 times the series resonant frequency. The overlapping-wire version of the element resonated at just over 5.51 MHz. The note is worth giving, since the parallel resonant impedance is also much lower than the impedance of a resonant 1-λ center-fed wire. The model showed an impedance of between 1000 Ω and 1100 Ω, depending on the version. A casual builder of an array using these elements might easily confuse the two points.

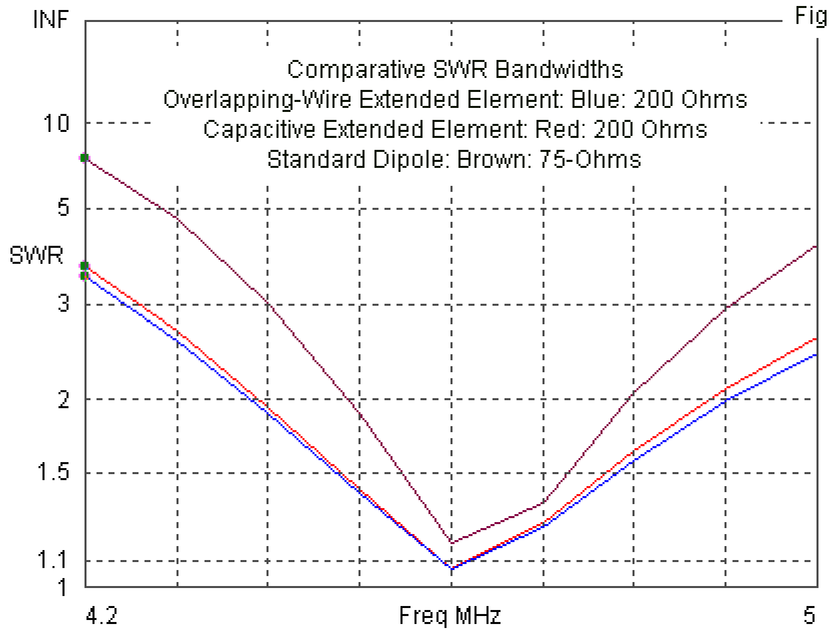
Fig. 3



Relative Current Magnitude Distribution along
Capacitor and Overlapping-Wire Version of the Extended Element

Another prized property of the extended element is its broader SWR curve than one can obtain from a standard dipole. **Fig. 4** shows the modeled SWR curves for a standard dipole (75-Ω reference) and for both versions of the extended element (200-Ω reference). In all cases, the resonant frequency is 4.63 MHz. The nearly identical curves for the extended elements are over 1.5 times wider at the 2:1 level than the curve for the standard ½-λ element.

Fig. 4



The raw SWR bandwidth of the extended element is not the only concern that we should have relative to the use of the extended element in the context of an LPDA. The SWR bandwidth will allow us to use fewer elements and still obtain an impedance match. However, LPDA designers are also interested in the rate of performance change as we change the operating frequency. The parameters of most relevance are the rate of gain change and the rate of beamwidth change over comparable frequency spans. The SWR curves define the range as about 4.4 MHz to 4.88 MHz between 200-Ω 2:1 SWR points. The dipole, normally used in LPDA construction, changes gain by only 0.1 dB and beamwidth by only 2.6° over this range, despite the more rapid change in SWR. In contrast, the extended element changes gain by 0.43 dB and beamwidth by 6.4° over the same frequency spread. Although these figures are harmless to the use of the extended element as an independent antenna, they suggest that an LPDA employing such elements—using a lower value of τ to reduce the element count—may show more variable gain and beamwidth curves than a dipole version of an LPDA using more elements with a higher value of τ.

In many design contexts, you will see the extended element modeled as a monopole over perfect ground. **Fig. 5** shows the overlap and the capacitor versions of this method of exploring the element's basic properties. The figure also contains the elevation plot that we derive from such a model (of either version). Since virtually all modeling programs use an image method of calculating all properties over perfect ground, the current distribution is identical to what we find on one-half of the dipole models of the extended element.

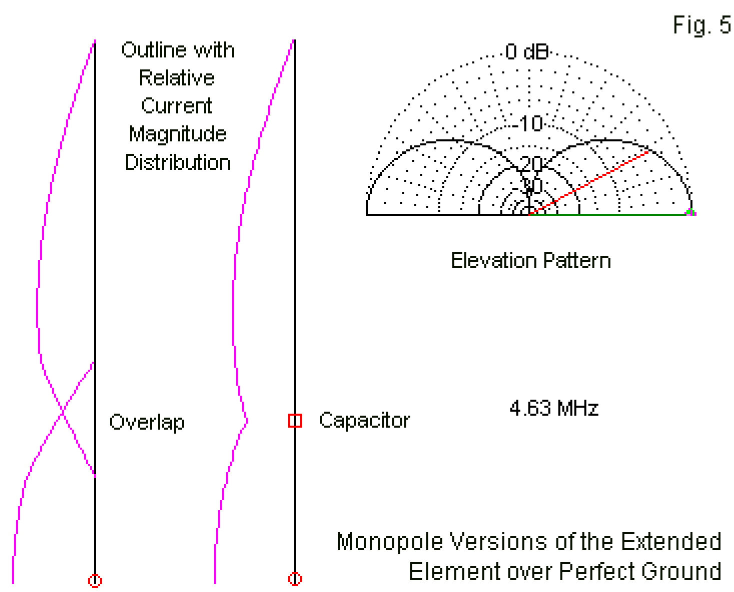


Table 2 lists the essential properties of the extended elements as monopoles, along with information on a reference ¼-λ monopole at the design frequency. Each antenna is exactly half the length of its dipole counterpart. The extended elements are 100' long. The capacitor position is 30' above perfect ground. The overlap extends from 19.5' to 40.5'. The monopole is 51.6' long. All use the standard lossless 0.16"-diameter wire.

Table 2. Performance of extended monopole elements with capacitors and with overlapping wires

Version	Max. Gain dBi	E-Plane BW degrees	Impedance R +/- jX Ω
Capacitors	6.25	27.6	104.3 + j0.3
Overlap	6.20	28.0	104.9 + j1.1
¼-λ Dipole	5.15	39.1	36.0 – j0.2

These notes introduce one of the pre-requisites for exploring an LPDA making use of them.

The Standard Optimized Wide-Band LPDA

The Tanner patent and the technical notes on the extended element LPDA refer to a standard-design LPDA, although in somewhat different terms. The patent submission mentions a comparable LPDA with 13-dBi gain that uses up to 53 elements with a total length of 750'. The technical notes mention a 17-dBi standard LPDA that requires 800'. In either case, we shall be interested in the beamwidth as well as the forward gain. However we set up the standard LPDA, it will form the second pre-requisite by providing a standard of reference against which to evaluate the extended-aperture LPDA.

To create a reasonable—but not necessarily perfect—model of the standard LPDA, I employed the latest version of Roger Cox's LPCAD to design a 750' LPDA. The maximum number of elements permitted by the program is 50. This maximum is satisfactory for two reasons. First, as we shall soon discover, standard calculations for LPDAs misrepresent the resonant frequency of the shortest element by calling for a frequency that is about 1.3 times the highest operating frequency. To achieve performance at the highest operating frequency that is comparable to performance at all lower frequencies requires that we use elements up to about 1.6 times the highest frequency (close to 50 MHz in this instance). Therefore, I manually added 6 elements to the computer-generated design. The new elements increased the boom length to about 775'. Second, the literature various refers LPDA length to either its boom or to the distance from the rearmost element to the vertex, the point at which an element length would be zero. For the design values of τ and σ (0.96 and 0.18, respectively), α is about 3.34° yielding a length to the vertex of well over 800'. Therefore, the embellished computerized design represents a reasonable compromise, as well as an informative model of an idealized standard LPDA.

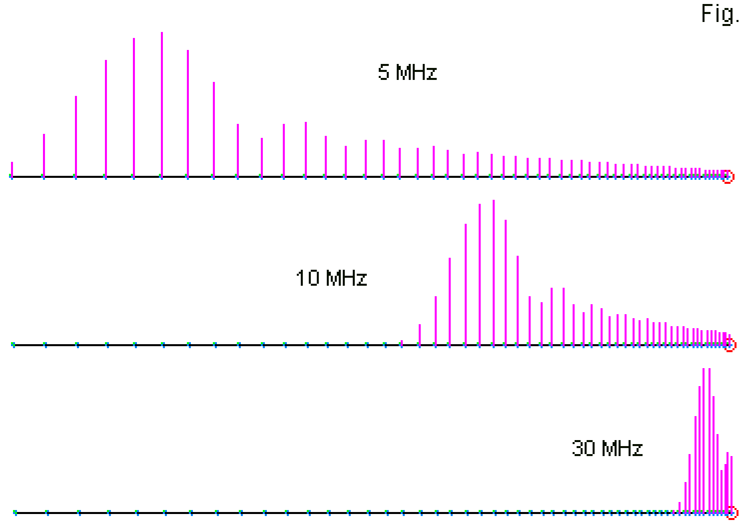
One facet of the LPDA model is less than ideal. The model will use 0.16" diameter wire for the elements. LPDAs show higher gain with fatter elements. Therefore, the model will not achieve all of the gain that the geometry makes possible. Moreover, ideal LPDA design τ-tapers not only the element length and spacing, but the element diameter as well. The use of 0.16"-diameter wire for the longest elements results in an element diameter of about 0.02" for the shortest elements. The element length-to-diameter ratio is about 7500:1. With a constant element diameter—which would be normal construction practice for a practical wire-element LPDA—the ratio will vary continuously, becoming lower as the element grow shorter. The major effect—given the enhancement of the design using added forward elements—will be a small departure from an ideal feedpoint impedance value at the upper end of the operating spectrum.

The calculated design calls for a 237-Ohm phase line—reversed or transposed between each element pair—to obtain a target 200-Ω feedpoint impedance. Higher feedpoint and phase-line impedance values are generally safer with wire elements. However, they also reduce the maximum possible gain relative to phase lines with lower impedance values. Lower impedance lines often result in anomalous frequencies, especially in very wide-band LPDAs. An anomalous frequency is one for which rearward elements operate in a harmonic mode. The result is often a skewed pattern and reduced or reversed gain.

For the first 30 years or so of LPDA designs, array operation fell prey to a misconception that hindered our understanding of anomalies and higher-frequency performance. The operative idea was that only the 2 or 3 elements surrounding the element nearest to resonance were significantly active. The extensive modeling done in preparation for the 2 volumes of *LPDA Notes* definitively established that in an LPDA, all elements forward of the ones nearest resonance are significantly active in terms of having a notable relative current magnitude. **Fig.**

6 shows the relative current magnitudes at the centers of each element in our standard LPDA at 5, 10, and 30 MHz.

Fig. 6



Relative Current Magnitude on Elements of a Standard LPDA

At 5 MHz, the array is active on virtually every element, with current magnitudes that are about 0.1 or more of the peak value. At 10 MHz, the number of active elements is halved. All of the current magnitude curves show a secondary peak forward of the maximum current value. Had we omitted the final six elements, the array would not have shown the secondary peak, with a resulting loss in performance relative to lower frequencies. Although these and subsequent data listings will only spot check this design, an actual design would require frequency sweep information as small intervals to detect rearward element activity. Significant current on one or more rearward elements, especially at lengths near 1-λ at the operating frequency, would normally indicate anomalous array behavior. The sample current distribution curves in **Fig. 6** are remarkably free of rearward current activity.

For reference, **Table 3** lists the dimensions of the standard LPDA model.

Standard LPDA Design			5-30 MHz		Tau = 0.96, Sigma = 0.18						Table 3
Element	Space	1/2 Len	Element	Space	1/2 Len	Element	Space	1/2 Len	Element	Space	1/2 Len
1	0.0	-50.2	15	381.9	-27.9	29	594.3	-15.5	43	712.4	-8.6
2	35.3	-48.1	16	401.6	-26.8	30	605.2	-14.9	44	718.5	-8.3
3	69.2	-46.1	17	420.4	-25.7	31	615.7	-14.3	45	724.3	-7.9
4	101.7	-44.3	18	438.5	-24.6	32	625.7	-13.7	46	729.9	-7.6
5	132.8	-42.4	19	455.8	-23.6	33	635.4	-13.1	47	735.2	-7.3
6	162.7	-40.7	20	472.4	-22.6	34	644.6	-12.6	48	740.4	-7.0
7	191.3	-39.0	21	488.3	-21.7	35	653.5	-12.1	49	745.3	-6.7
8	218.8	-37.4	22	503.6	-20.8	36	661.9	-11.6	50	750.0	-6.4
9	245.1	-35.9	23	518.2	-20.0	37	670.1	-11.1	51	754.5	-6.2
10	270.4	-34.4	24	532.3	-19.1	38	677.9	-10.6	52	758.9	-5.9
11	294.6	-33.0	25	545.7	-18.3	39	685.4	-10.2	53	763.1	-5.7
12	317.8	-31.6	26	558.6	-17.6	40	692.6	-9.8	54	767.1	-5.5
13	340.1	-30.3	27	571.0	-16.9	41	699.4	-9.4	55	770.9	-5.2
14	361.4	-29.1	28	582.9	-16.2	42	706.1	-9.0	56	774.6	-5.0
Notes:	All space and 1/2 Len dimensions in feet. Space counts from the longest element forward. 1/2 Len is the half-length										
	of each element. Double the list length to arrive at the total lement length. All elements are 0.16" in diameter.										

How well does the standard LPDA perform? The numerical answer to this question depends on the exact configuration and where we place the antenna. Let's begin in free-space and compare the 50-element 750' LPDA with the 56-element, 775' version. Both use τ-tapered elements ranging from 0.16" to 0.02" in diameter. **Table 4** shows clearly the improvements in performance above 20 MHz for the longer array, even though the first 50 elements of each array are identical. The beamwidth data is for the E-plane.

Table 4. Performance comparison between 50- and 56-element LPDAs, both using τ-tapered elements. T = 0.96; σ = 0.18. L_{50} = 750'; L_{56} = 774.6'. Element diameters 0.16" – 0.02"

50-Element Version						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	10.59	10.60	10.50	10.46	10.16	9.50
Front-back dB	50.29	49.50	49.86	40.62	33.41	27.36
Beamwidth degrees	53.8	53.8	54.8	54.4	57.4	59.8
Z (R +/- jX) Ω	203 – j4	204 – j7	202 – j12	202 – j17	185 – j46	177 – j100
SWR 200 Ω	1.03	1.04	1.06	1.09	1.29	1.71

56-Element Version						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	10.59	10.58	10.57	10.57	10.38	10.41
Front-back dB	50.56	50.27	48.83	43.50	43.17	41.69
Beamwidth degrees	53.8	54.0	54.2	53.8	55.4	54.4
Z (R +/- jX) Ω	205 – j3	203 – j9	202 – j10	203 – j14	198 – j17	201 – j25
SWR 200 Ω	1.07	1.05	1.06	1.07	1.09	1.13

Since practical implementations of the array are likely to use wires with a uniform diameter, the following listings are for 0.16"-diameter elements only. **Table 5** provides data for the array in free space and horizontally above ground. The height is 100' or close to ½-λ at 5 MHz (and higher as the operating frequency increases. The horizontal array will be over perfect, very good, and very poor ground in order to sample the effects of ground on horizontal array performance. In free-space, note both the slight increase in gain and the more rapid departure of the feedpoint impedance from the calculated value of 200 Ω, relative to the τ-tapered elements in **Table 4**. Above ground, note the variations in the take-off (TO) angle, as well as the changes in gain with operating frequency that result from additional height measured in wavelengths.

100' above perfect ground, we encounter gain values that correspond roughly to the 17-dBi value cited in one TCI document. (We shall look at other LPDA orientations in addition to this one.) The free-space values are about 2-dB lower than the value cited in the Tanner patent. However, the original set of equations for calculating LPDA dimensions and performance were shown in the 1970s to calculate to high a gain value, and revised calculations—after the patent submission) lowered the value closer to the free-space values shown in the table.

The table provides modeled values for the same 100' height over two levels of real ground: very good and very poor. The numbers do not change significantly relative to values over perfect ground. The gain differential between perfect and very good ground averages about 0.2 dB, and the additional gain loss by moving to very poor ground is about 0.5 dB. Although texts make it clear that the effects of ground quality on a horizontally oriented antenna are very small, especially as the antenna height increases as a function of a wavelength at the operating frequency, the sample LPDA demonstrates the point rather vividly.

Table 5. Horizontally oriented 56-element LPDA with a constant element diameter in free space and 100' above grounds of various qualities.

Free Space

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	10.71	10.89	10.96	11.08	11.02	10.96
Front-back dB	50.48	54.05	46.53	44.64	41.72	34.23
Beamwidth degrees	53.2	52.8	52.6	52.2	52.0	53.2
Z (R +/- jX) Ω	196 – j5	193 – j8	191 – j12	191 – j23	192 – j24	193 – j48
SWR 200 Ω	1.03	1.06	1.08	1.13	1.14	1.28

100' above Perfect Ground

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	15.32	16.49	16.79	17.00	19.92	16.89
TO angle degrees	23	14	9	7	6	5
Front-back dB	34.34	51.97	46.57	43.94	41.50	34.28
Beamwidth degrees	50.0	52.2	52.2	51.8	52.0	53.0
Z (R +/- jX) Ω	195 – j4	193 – j9	191 – j12	192 – j23	192 – j24	193 – j48
SWR 200 Ω	1.03	1.06	1.08	1.13	1.14	1.28

100' above Very Good Ground (conductivity = 0.0303 S/m, permittivity = 20)

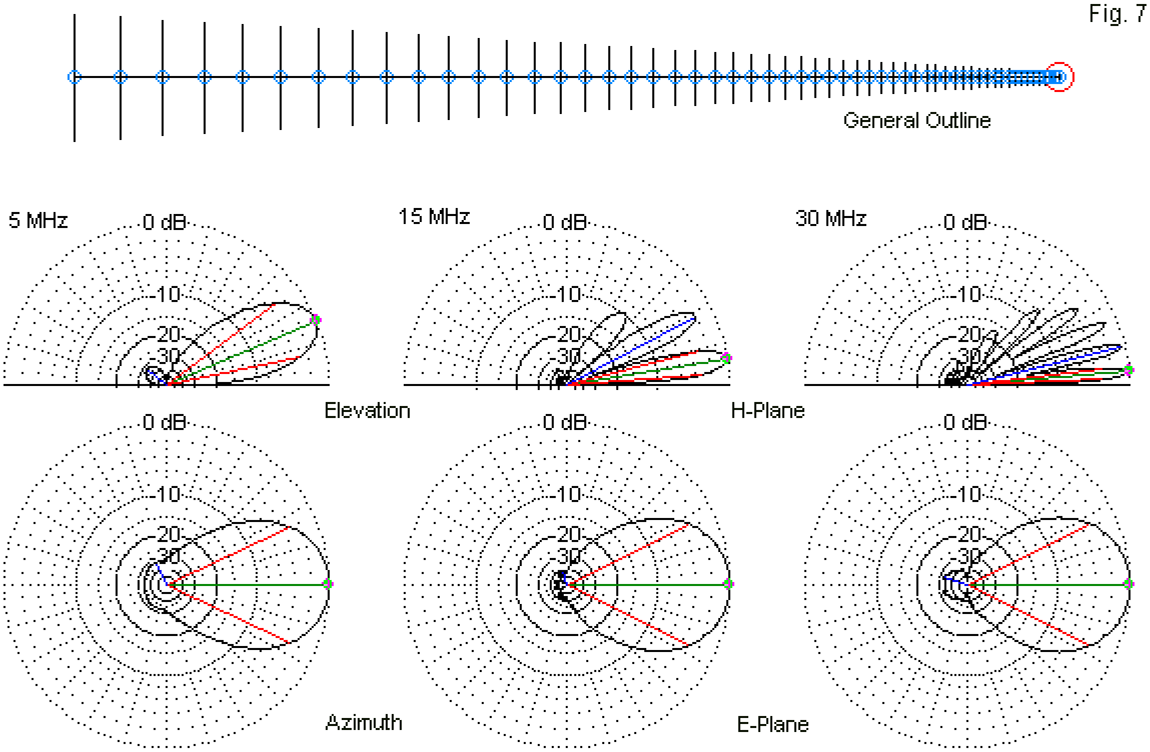
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	15.12	16.29	16.62	16.84	16.76	16.75
TO angle degrees	23	13	9	7	6	5
Front-back dB	35.19	52.35	46.29	44.38	41.49	34.29
Beamwidth degrees	49.8	52.0	52.2	51.8	51.8	53.0
Z (R +/- jX) Ω	195 – j4	193 – j8	191 – j12	192 – j23	192 – j23	193 – j48
SWR 200 Ω	1.03	1.06	1.08	1.13	1.14	1.28

100' above Very Poor Ground (conductivity = 0.001 S/m, permittivity = 5)

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	14.18	15.61	16.17	16.50	16.49	16.52
TO angle degrees	22	13	9	7	5	5
Front-back dB	41.74	53.51	46.44	44.76	41.63	34.30
Beamwidth degrees	50.2	51.8	52.0	51.8	52.0	53.0
Z (R +/- jX) Ω	196 – j4	193 – j8	191 – j12	191 – j23	192 – j24	193 – j48
SWR 200 Ω	1.03	1.06	1.08	1.13	1.14	1.28

Fig. 7 provides an outline sketch of the 56-element LPDA, along with sample elevation and azimuth plots 100' above perfect ground. The azimuth or E-plane patterns are typical of those that appear in all contexts, that is, over real ground and in free space. If one compares the cleanliness of the pattern with patterns for typical rhombic arrays, one can see why the LPDA supplanted the older long-wire technology for many (but not all) applications. The horizontally oriented LPDA provides very clean forward patterns with no sidelobes. As well, the rearward radiation is virtually negligible, even at the highest frequencies of operation. Perhaps the one limitation noted for the LPDA as a wide-band antenna is the E-plane beamwidth: about 50° to 53° regardless of the ground environment. The beamwidth is useful for such applications as shortwave broadcasting and broad regional coverage in the point-to-point communications arena. However, the beamwidth is perhaps 3 times wider than the main lobe of a very long rhombic array, although the older design requires much more acreage and has a more limited operating span when measured in terms of the pattern shape. However, many of the

transoceanic city-to-city links once the province of long terminated HF rhombic arrays are now handled via satellite links. Therefore, rhombics have largely fallen into disuse, as rhombic farms have become subdivisions.



Sample Elevation and Azimuth Patterns of a Horizontal 56-Element LPDA over Perfect Ground

The 56-element LPDA model requires 56 wires and 3066 segments. An alternative method of modeling an LPDA involves setting up half-elements over perfect ground in the form of monopoles. Each half-element, of course, requires only half the number of segments. The final model of this version of the LPDA required only 1557 segments. The source and the transposed transmission lines go on the lowest segment of each element. In the present model, each segment is about 1' long, effectively placing the phase line about 6" above ground. Since we are working with half-elements, we halve the characteristic impedance of the phase line from 237 Ω to 119 Ω. We anticipate that the feedpoint impedance will be half the value shown by the free-space model. We also anticipate that the forward gain of the model will show a 3-dB increase due to calculated ground reflections. Since the elements are vertical, azimuth plots will show H-plane patterns, rather than the E-plane patterns that we have so far viewed. **Table 6** shows a sampling of the data from this alternative basic LPDA model.

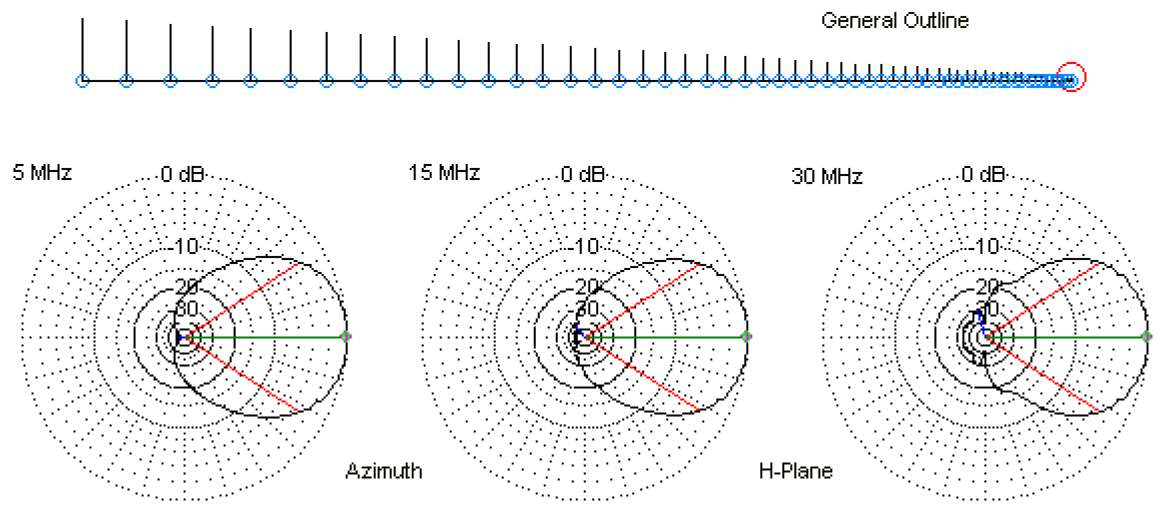
Monopole modeling of the LPDA represents another possible source of the 13-dBi gain figure cited in the Tanner patent for the EALPDA. All other values tally with both the free-space and the perfect ground models of the 56-element standard LPDA, once we have made the proper adjustments.

Table 6. Performance of a 56-element monopole LPDA over perfect ground, with a constant element diameter. T = 0.96; σ = 0.18. L_{50} = 750'; L_{56} = 774.6'. Element diameters 0.16" – 0.02"

56-Element Version						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	13.71	13.90	13.97	14.10	14.02	13.99
Front-back dB	49.98	53.33	46.43	44.79	41.65	34.61
Beamwidth degrees	66.4	65.2	65.0	63.8	64.6	66.0
Z (R +/- jX) Ω	99 – j2	98 – j4	98 – j6	98 – j11	97 – j11	99 – j21
SWR 100 Ω	1.02	1.04	1.07	1.12	1.12	1.25

Perhaps the most interesting and largely overlooked fact about the monopole model lies in the H-plane beamwidth data. The beamwidth values average about 12° larger than the values cited for the E-plane pattern that all of the horizontal models have produced. The number, however, do not tell the full tale. **Fig. 8** shows the outline of the monopole model along with 3 sample azimuth plot H-plane patterns (at 5, 15, and 30 MHz). H-plane patterns do not share all of the properties of E-plane patterns with linear elements. For example, the 5-MHz plot shows a small cardioidal shape to the rear. In addition, as we reduce the number of directors forward of the most active elements, the H-plane pattern shows the development of sidelobes. Compare the 30-MHz pattern with the corresponding pattern for the horizontal version of the antenna over perfect ground.

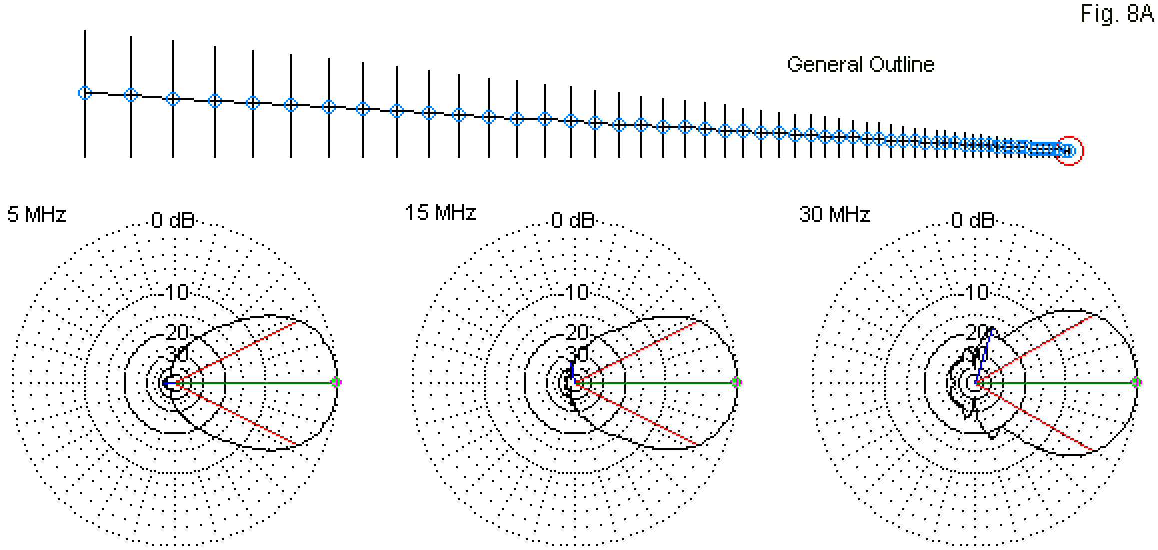
Fig. 8



Sample Azimuth Patterns of a Vertical Monopole 56-Element LPDA over Perfect Ground

Ultimately, we shall be interested in the performance of a full vertical LPDA with a constant base height above ground. Arbitrarily, in the absence of definitive data, I selected 4' as the minimum height. Given the taper of the full elements, the resulting phase line tapers from a height over 50' above ground down to about 10' over the 775' length of the array. **Fig. 8A** shows the outline of the array in this configuration and provides sample patterns at the same frequencies used in previous figures. Note that the H-plane (azimuth) pattern for 30 MHz lacks the "perfection" of the E-plane patterns at all operating frequencies and the H-plane patterns at lower frequencies. Compare the 30-MHz pattern to the comparable pattern in **Fig. 8** for the array in a monopole form. The emergence of sidelobes is not a function of rearward element activity, because there is virtually no such activity. Rather, the imperfection of the pattern—relative to expectations that we may have developed from earlier patterns—results from the short boom length and the relative paucity of forward elements, even though we designed the array for 1.6 times the highest operating frequency and used almost the highest value of τ allowable. The 30-MHz H-plane pattern is a testament to the importance of the activity of the forward elements in forming the LPDA pattern, even if the elements seem far removed from the actual operating frequency.

Fig. 8A



Sample Azimuth Patterns of a Vertically Oriented Sloping 56-element LPDA over Perfect Ground

Table 7 contains the results of the modeling exercise over perfect ground and then over three real ground qualities: very good, average, and very poor. The table shows us the sort of performance changes that a vertical array may undergo with changes in the soil quality beneath the array.

Table 7. Vertically oriented 56-element LPDA with a constant element diameter in 4' above grounds of various qualities.

Perfect Ground						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	15.91	16.11	16.19	16.27	16.28	16.05
Front-back dB	44.89	61.32	50.36	43.00	46.29	35.91
Beamwidth degrees	54.8	54.2	54.5	55.0	56.0	60.4
Z (R +/- jX) Ω	195 – j5	194 – j9	193 – j11	190 – j26	196 – j26	190 – j59
SWR 200 Ω	1.04	1.06	1.07	1.15	1.14	1.36

Very Good Ground (conductivity = 0.0303 S/m, permittivity = 20)						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	10.33	9.01	8.40	8.24	8.12	8.18
TO angle degrees	12	13	13	13	13	13
Front-back dB	44.36	54.63	46.84	39.34	39.32	31.18
Beamwidth degrees	50.8	50.0	51.0	51.8	53.8	57.8
Z (R +/- jX) Ω	195 – j5	194 – j9	193 – j12	188 – j24	194 – j27	186 – j54
SWR 200 Ω	1.04	1.06	1.08	1.14	1.15	1.33

Average Ground (conductivity = 0.005 S/m, permittivity = 13)

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	6.33	6.53	7.09	7.61	7.90	8.25
TO angle degrees	15	15	15	15	15	14
Front-back dB	43.41	52.62	45.49	39.80	38.71	31.33
Beamwidth degrees	50.2	51.6	53.0	53.0	55.2	58.4
Z (R +/- jX) Ω	195 – j5	194 – j9	193 – j13	189 – j23	193 – j27	187 – j52
SWR 200 Ω	1.04	1.06	1.08	1.14	1.15	1.32

Very Poor Ground (conductivity = 0.001 S/m, permittivity = 5)

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	4.14	5.59	6.43	7.09	7.47	7.96
TO angle degrees	16	17	17	16	16	16
Front-back dB	42.54	51.63	44.55	40.86	38.28	31.23
Beamwidth degrees	53.8	54.8	55.6	55.2	57.4	59.2
Z (R +/- jX) Ω	195 – j5	194 – j9	192 – j13	190 – j22	192 – j26	188 – j50
SWR 200 Ω	1.04	1.06	1.08	1.13	1.15	1.30

In the sloping configuration, the performance of the 56-full-element LPDA changes slightly with decreases in the front-to-back ratio above 15 MHz. As well, the 200-Ω SWR is higher at the upper end of the spectrum relative to horizontal arrays, although this deviation decreases as the ground quality becomes poorer. Over perfect ground, the array maintains a forward gain of about 16 dBi across the operating spectrum.

Over real ground, the forward gain diminishes as the ground quality becomes poorer. To say only this much is to miss some interesting features of the interaction of the array at various frequencies with the various levels of ground quality. Therefore, **Table 8** summarizes the array's gain behavior.

Table 8. Sloping LPDA over perfect and real ground: forward gain patterns. Δ refers to the difference between the listed gain for the ground quality and the gain over perfect ground.

	Forward Gain (dBi) over Ground						
Frequency	Perfect	Very Good	Δ	Average	Δ	Very Poor	Δ
5 MHz	15.91	10.33	5.58	6.33	9.58	4.14	11.77
10	16.11	9.01	7.10	6.53	9.58	5.59	10.52
15	16.19	8.40	7.79	7.09	9.10	6.43	9.76
20	16.27	8.24	8.03	7.63	8.64	7.09	9.18
25	16.28	8.18	8.10	7.90	8.38	7.47	8.81
30	16.05	8.12	7.93	8.25	7.80	7.96	8.09

The rate of change in the gain deficit over real ground relative to perfect ground varies with both the ground quality and the frequency. Over very good ground, the deficit decreases with rising frequency, at least until about 25 MHz. Over average or very poor ground, the deficit increases with rising frequency. Therefore, at the low end of the operating spectrum, the difference in gain deficit is over 6 dB, but at 30 MHz, the difference is only about 0.3 dB, as we move from very good to very poor soil.

We have viewed the performance of the standard optimized LPDA from as many perspectives as possible for two reasons. One purpose has been to understand the behavior of the LPDA in both horizontal and vertical orientations over various ground types. The other goal has been to ready ourselves to understand the behavior of the extended aperture LPDA. This prerequisite to handling the EALPDA combines with our initial examination of the extended element to set the stage for the full array. All of Part 2 of these notes is devoted to the EALPDA. We shall discover that even a rudimentary examination of the EALPDA is not simply a matter of combining the prerequisite information into a composite. Along the way, we shall have to tackle both design and modeling issues. Hence, the results will be somewhat tentative, but perhaps usable as a general overview of extended aperture LPDA design.

Note

1. Alois Krischke, DJ0TR, who edits the current edition of *Rothammels Antennebuch*, published by DARC, graciously provided me with a collection of patents related to the extended element and its CCD kin, establishing the Cork may have been perhaps only the immediate predecessor of Charman's work. The following list of patents are related to the concept and its eventual use in the extended aperture LPDA:

"The inventor of capacitively loaded antennas was not Cork, as Charman (G6CJ) said in the RSGB Bulletin 1961. It was Franklin from Marconi. In the original specification of the British patent 4514 of 1913 (GB191304514) there is no drawing! But I have here the German patent of it, DE 334 655 and there is a drawing of a rectangle with several distributed condensers. In the year 1920, H.H. Beverage filed a patent US 1,381,089 and followed by a patent of G.G. v. Arco et al US 1,839,426 dated 1924 DE (Germany). Many samples of capacitively loaded antennas are shown by E.F.W. Alexanderson in US 1,790,646 dated 1925. Also P.S. Carter in his patent US 2,166,750 dated 1936 has the capacitors in the Figures 1, 2, and 3.

"But now came the UK patent GB 490,414 priority 1937 from E.C. Cork, M. Bowman-Manifold and J.L. Pawsey of EMI. After that follows GB 493,758, also dated 1937, and from the same three EMI individuals. In patent US 2,217,911 of N.E. Lindenblad dated 1938 also capacitors can be seen in Fig. 3. Also from E.C. Cork is a patent GB 628,986 dated 1946/1947; the corresponding patent in USA is US 2,715,184. There are 2 more patents about reflection-free antennas from Sweden (SE 133 888 and SE 137 026), corresponding to US 2,712,602 dated 1950/1951 SE (Sweden) by E.G. Hallen from Ericson. Next comes the patent US 2,887,682 dated 1954 GB from F.J.H. Charman (G6CJ) and E.C. Cork of EMI. It is interesting that in the original British patent GB 773,996, 3 names are listed. The 3rd one there is A.W.H. Carter. Also a patent with this principle is US 3,337,873 dated 1963 SE from K.E. Cassel of Allgon in Sweden. The patent of H.A. Mills et al US 3,564,551 dated 1970 does not use capacitors but rather tuned ferrite sleeves. H.A. Mills (W4FD) is together with G. Brizendine (W4ATE) author of an early article about CCD in 73, October 1978. Then comes US 3,765,022 of R.L. Tanner of TCI dated 1971. The last known patent is from United Kingdom GB 1 542 210 dated 1975 of G.T. Newington from Marconi; the corresponding patent in USA is US 4,092,646."

Notes on the Extended Aperture Log-Periodic Array
Part 2: The Extended Aperture LPDA

L. B. Cebik, W4RNL

In Part 1 of this exploration, we examined the extended element, which lies at the heart of the extended aperture LPDA (EALPDA). A center-fed element about twice as long as a normal resonant dipole with a capacitance equi-spaced about 30% of the distance from the feedpoint outward along each half element will show about 1.1 dB additional gain and a narrower E-plane beamwidth than the dipole. The resonant impedance of the extended element is about 200 Ω or roughly 3 times the impedance of a resonant dipole. We may construct such elements as monopoles or as extended dipoles. Longer elements with additional capacitances and higher gain values are possible, but the simplest extended element is all that we need for the basic EALPDA.

We also took a long look at optimized wide-band standard-design LPDAs for the 5-30 MHz range, the frequency span covered by the basic EALPDA shown in the Tanner 1973 patent submission. To replicate the somewhat vague reference to a long-boom LPDA, I modeled a 56-element LPDA using a τ of 0.96 and a σ of 0.18. Because LPDAs are subject to somewhat dated understandings based on literature from the 1960s and 1970s, we explored the antenna's performance in several modeling contexts. We looked at the antenna in free space and as a horizontal array 100' over perfect ground and over various grades of real ground. We rotated the antenna 90° to examine its properties in monopole form over perfect ground. Finally, we created a sloping LPDA with each element terminated 4' above perfect ground and above several qualities of real ground. The exercise familiarized us with the types of performance values that we see in each orientation so that we can apply the correct set for comparison with the EALPDA in its many possible configurations.

With these prerequisite, we are in a position to examine—within the limits of the available design information and the ability of modeling software to capture the design—the extended aperture log-periodic dipole array.

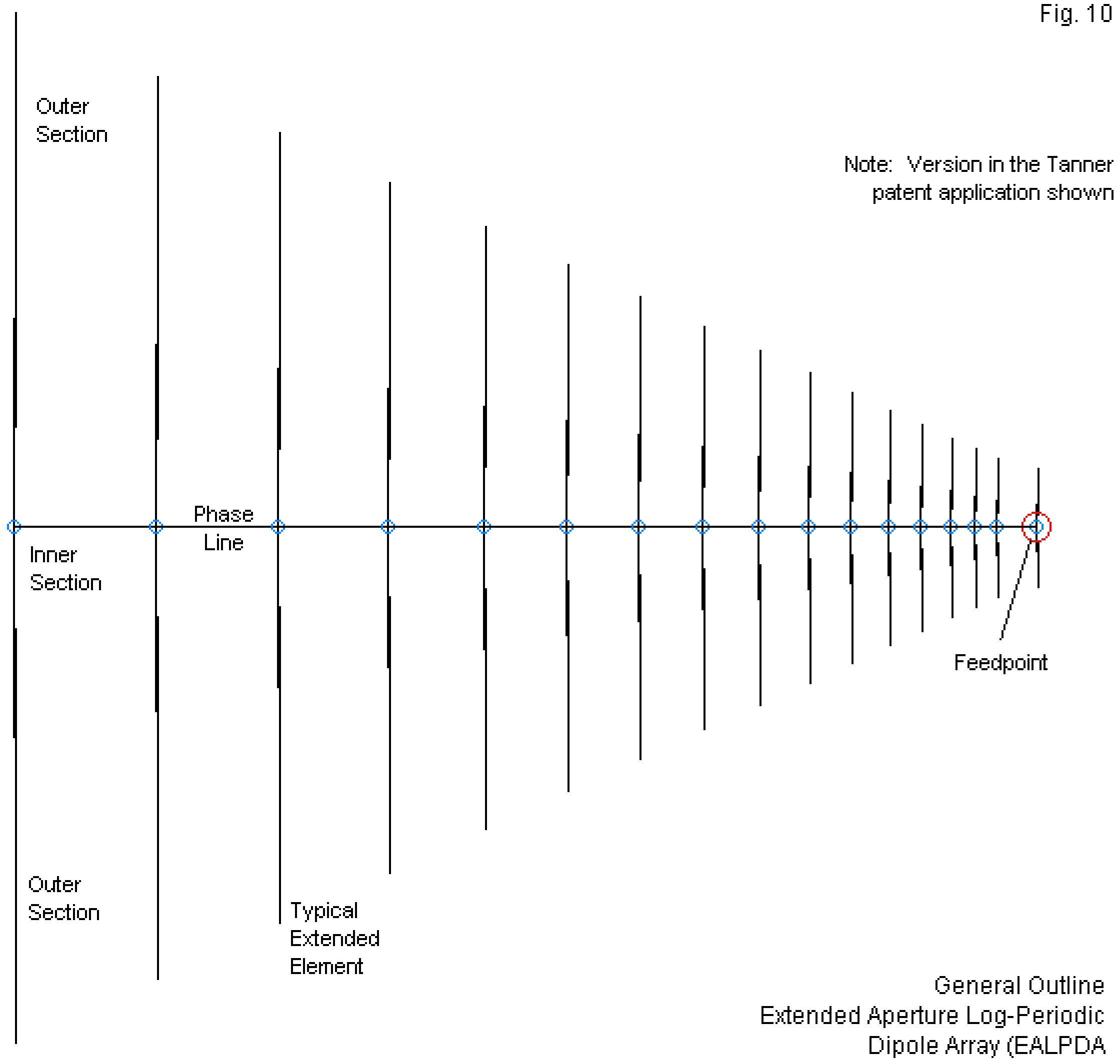
The Extended Aperture Log-Periodic Dipole Array (EALPDA)

A patent submission is not a technical document. Instead, it is a legal document and subject to numerous technical shortcomings. The Tanner patent for the EALPDA is also dated in its understanding of standard LPDA operation. For example, the document notes in column 1 that "in a prior art log-periodic antenna, the elements have high Q's so that few elements tend to be active at any frequency within the antenna's frequency range." The author repeats this claim in other places (for example, column 6). As we have seen (in **Fig. 6**), this 1960s-1970s claim has given way in this decade to a better understanding of element activity.

The EALPDA rests on 2 general properties of the extended element: its higher gain and its broader bandwidth relative to a standard dipole element. On the basis of these properties, Tanner's EALPDA uses extended elements to arrive at an LPDA that requires perhaps ¼ the boom length of a standard LPDA for the same performance level. Since it requires extended elements, the total height of a vertical sloping version of the EALPDA is twice as high as the height of a standard vertical sloping LPDA. However, the array uses only about 1/3 the number of elements ostensibly for the same performance. The lower Q or broader bandwidth of each extended element "causes more elements to be active at any one frequency, thereby lengthening the active region of the antenna" at any operating frequency (column 3). We may pass over this problematical reference to active regions and simply note that the broader bandwidth of each element allows the inventor to use fewer elements, along with a much smaller value of τ in the design of an EALPDA.

The patent material provides the dimensions for a sample EALPDA in Table 1 in column 8. However, the text and the table are not in full agreement. For example, the text specifies 18 elements (items 51 to 68 in patent figure 3), but the table itself lists only 17 elements (51 to 67). 16 of the elements meet general requirements for τ-tapering of lengths and spacing between elements. However, the final element in the table has a specified position that is out of line. Therefore, it is initially unclear whether the table's information is technically correct for a viable design. The only way to find out is to model the array of wires specified in the patent and to see what we obtain. **Fig. 10** shows the array outline in an expanded sketch that shows the division of each element into 3 overlapping sections making up Charman-Cork extended elements.

Fig. 10



The applicable value of τ for the EALPDA is 0.875, well below the 0.96 value of τ necessary to achieve the performance of the standard LPDA. For a τ of 0.875, the standard equation gives an optimal σ value of 0.161, but the patent design has a σ of about 0.170. In addition, the patent design information does not specify a characteristic impedance for the phase line (or transposed transmission line). Hence, this parameter will be subject to trial and error. With these reservations, **Table 9** lists the dimensions of the modeled EALPDA. Each element entry has two components: a center section and an outer section. As a result, we also find an "overlap" entry for the distance occupied by both the center and the out sections. The space between the inner and the outer sections is a constant 4", and the wire diameter is 0.16". The center section lists its half-length, presuming a standard modeling practice of extending the element equally on each side of a selected axis line. The outer-1 and outer-2 entries indicate the coordinates for the start and end of each outer section relative to the selected axis.

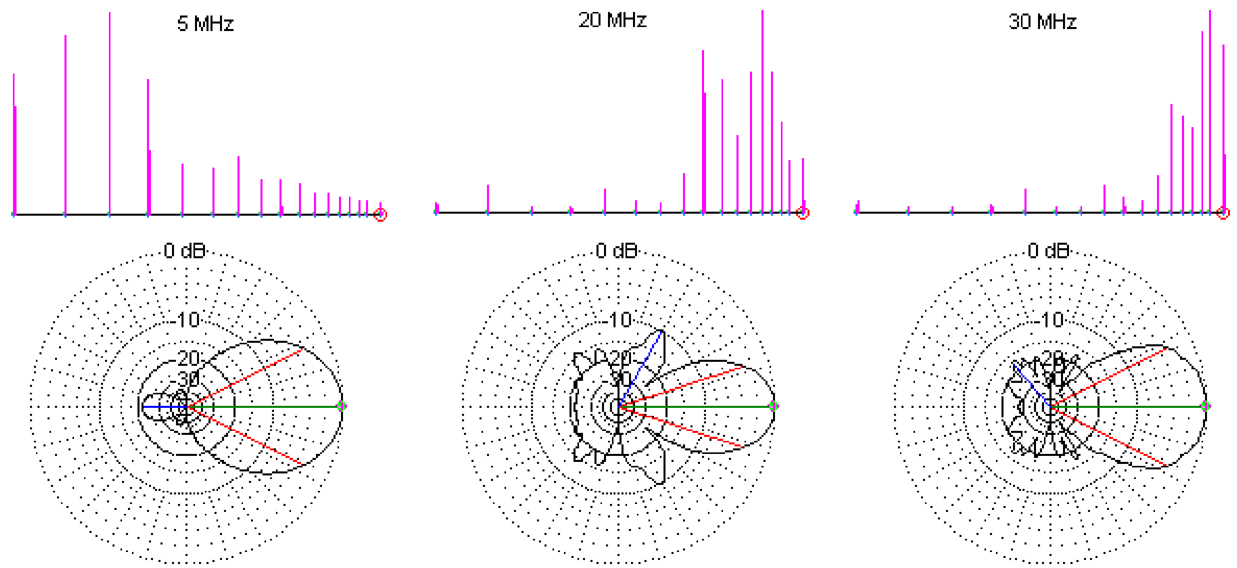
EALPDA Design	5-30 MHz				Table 9	
Tau = 0.875, Sigma = 0.17						
Element	Space	1/2 Ctr	Outer-1	Outer-2	Overlap	Ttl Len
1	0.0	40.5	19.5	100.0	21.0	200.0
2	27.5	35.5	17.1	87.5	18.4	175.0
3	51.5	31.1	15.0	76.6	16.1	153.2
4	72.5	27.2	13.1	67.0	14.1	134.0
5	91.0	23.8	11.5	58.6	12.3	117.2
6	107.0	20.8	10.0	51.3	10.8	102.6
7	121.0	18.2	8.8	44.9	9.4	89.8
8	133.4	15.9	7.7	39.3	8.2	78.6
9	144.2	14.0	6.8	34.4	7.2	68.8
10	153.7	12.2	5.9	30.1	6.3	60.2
11	162.0	10.7	5.2	26.3	5.5	52.6
12	169.2	9.4	4.5	23.0	4.9	46.0
13	175.6	8.3	4.0	20.2	4.3	40.4
14	181.2	7.2	3.5	17.6	3.7	35.2
15	186.0	6.3	3.1	15.4	3.2	30.8
16	190.2	5.6	2.7	13.5	2.9	27.0
17	198.0	4.8	2.3	11.8	2.5	23.6

Note the position in the Spacing column of element 17. A perfect progression of τ would place it at about 194' from the rear element. For the initial model, the longest element used 99 segments per section (297 segments overall for the element). The segmentation decreases by the antennas τ factor as the elements grow shorter. Both of these factors—the departure from the τ-progression relative to spacing and the level of segmentation—will become model and modeling issues shortly. However, to gain some insight into the potential performance of the array in free space, we may examine the spot data in **Table 10** and the sampling of patterns and current distribution in **Fig. 11**. (Compare **Table 10** with the free-space values for the standard array in **Table 5**.)

Several trials yielded a 250-Ω phase line as the best fit for a 200-Ω target feedpoint impedance, corresponding with the same impedance target for the standard array. Indeed, although the impedance of an individual element is about 3 times higher than for a standard dipole element (200 Ω vs. 70 Ω), the use of extended elements in an EALPDA does not appear to change the relationship between the phase-line characteristic impedance and the array feedpoint impedance.

Table 10. Horizontally oriented 17-element EALPDA with a constant element diameter in free space.

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	8.82	9.52	9.40	9.58	10.35	8.46
Front-back dB	21.53	20.02	22.74	21.41	28.05	26.62
Beamwidth degrees	52.4	39.4	38.6	36.0	39.8	53.6
Z (R +/- jX) Ω	214 + j22	185 + j16	216 + j20	207 + j2	253 – j95	267 – j86
SWR 200 Ω	1.13	1.13	1.13	1.03	1.62	1.60



Sample E-Plane Patterns and Current Distributions: Tanner Patent EALPDA

Fig. 11

Compared to the free-space values of the 56-element standard LPDA, the gain of the initial EALPDA model is about a full dB low. As well, the front-to-back values are modest. More striking are the E-plane patterns in **Fig. 11**, which shows various levels of less than ideal shapes above the lowest operating frequency. The current distribution curves show one reason why: the rearward elements show selective activity of significant proportions for all but the lowest frequency of operation.

The initial design, taken directly from the patent document raises two questions. The absence of an 18th element in the table along with the odd placement of the most forward element suggests that the design may not be as complete an array as it seems. The sudden drop in gain along with the rising SWR values at 25 and 30 MHz abet the doubt about the design. In addition, the pattern shapes suggest the possibility that the segmentation—adequate by reference to the standard LPDA design—may not be able to allow accurate calculations of the capacitance in the element-wire overlap regions, especially with shorter elements. Therefore, I reset element 17, added a new 18th element, and increased the element segmentation. The rearmost element now uses 137 segments per section, with the number of segment tapered by the τ-factor as the elements grow shorter. The revised version of the array approaches 3000 segments. However, average gain test (AGT) values for the array range from 0.993 to 1.005, suggesting a maximum gain error of only 0.03 dB. **Table 11** provides the dimensions of the modified EALPDA model using overlapping wires.

The overlapping-wire model is subject to the precision of the wire overlaps in establishing the correct capacitance between element sections. As shown in the first portion of these notes, it is possible to construct the elements from a single wire, placing a capacitor (or a modeled capacitive load) 30% of the distance from the center of the element outward. Therefore, I constructed a second model using this technique. I used sufficient segments in each element to place the required capacitive loads within 0.5% of the ideal position. The right 2 columns of **Table 11** provide the total element length and the values of each of the two required capacitors. The element spacing and the total element length are identical for the two models.

Modified 18-Element EALPDA Design				5-30 MHz	Tau = 0.875, Sigma = 0.17		
		Overlapping-Wire Model				Cap-Loaded Model	
Element	Space	1/2 Ctr	Outer-1	Outer-2	Overlap	Ttl Len	Cap pF
1	0.0	40.5	19.5	100.0	21.0	200.0	35.5
2	27.5	35.5	17.1	87.5	18.4	175.0	31.1
3	51.5	31.1	15.0	76.6	16.1	153.2	27.2
4	72.5	27.2	13.1	67.0	14.1	134.0	23.8
5	91.0	23.8	11.5	58.6	12.3	117.2	20.8
6	107.0	20.8	10.0	51.3	10.8	102.6	18.2
7	121.0	18.2	8.8	44.9	9.4	89.8	15.9
8	133.4	15.9	7.7	39.3	8.2	78.6	13.9
9	144.2	14.0	6.8	34.4	7.2	68.8	12.2
10	153.7	12.2	5.9	30.1	6.3	60.2	10.7
11	162.0	10.7	5.2	26.3	5.5	52.6	9.3
12	169.2	9.4	4.5	23.0	4.9	46.0	8.2
13	175.6	8.3	4.0	20.2	4.3	40.4	7.2
14	181.2	7.2	3.5	17.6	3.7	35.2	6.3
15	186.0	6.3	3.1	15.4	3.2	30.8	5.5
16	190.2	5.6	2.7	13.5	2.9	27.0	4.8
17	193.9	4.8	2.3	11.8	2.5	23.6	4.2
18	197.1	4.2	2.0	10.3	2.2	20.6	3.7
Note: Spacing and total length are the same for both models.							Table 11

Table 12. Horizontally oriented 18-element modified EALPDA with a constant element diameter in free space.

Overlapping-Wire Model

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	8.63	9.74	9.93	9.82	9.98	9.52
Front-back dB	20.46	19.82	22.57	22.25	25.90	24.09
Beamwidth degrees	52.2	38.8	38.6	37.8	41.0	42.0
Z (R +/- jX) Ω	176 + j8	170 + j5	179 - j28	178 – j31	166 – j4	230 – j26
SWR 200 Ω	1.14	1.19	1.20	1.22	1.21	1.21

Capacitor-Loaded Model

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	8.56	9.71	9.97	9.95	9.99	9.68
Front-back dB	18.82	24.81	24.81	34.58	27.87	33.77
Beamwidth degrees	51.8	38.2	36.2	38.2	39.0	41.0
Z (R +/- jX) Ω	170 + j3	191 – j23	218 – j26	225 – j6	188 – j52	163 – j27
SWR 200 Ω	1.18	1.13	1.16	1.13	1.32	1.29

Reference data for a 56-element standard design LPDA in free space

Frequency MHz	5	10	15	20	25	30
Max. gain dBi	10.71	10.89	10.96	11.08	11.02	10.96
Front-back dB	50.48	54.05	46.53	44.64	41.72	34.23
Beamwidth degrees	53.2	52.8	52.6	52.2	52.0	53.2
Z (R +/- jX) Ω	196 – j5	193 – j8	191 – j12	191 – j23	192 – j24	193 – j48
SWR 200 Ω	1.03	1.06	1.08	1.13	1.14	1.28

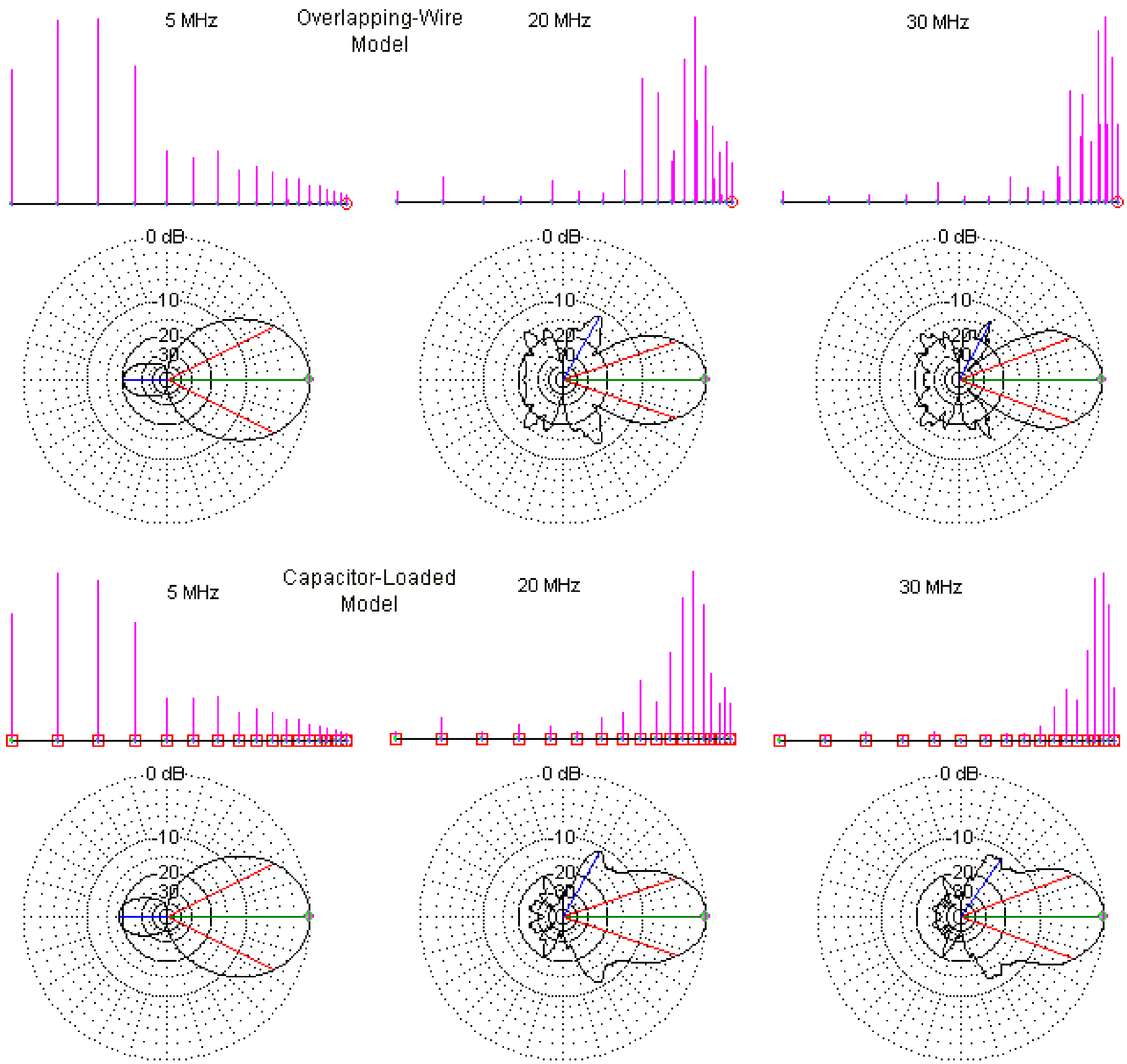
The sample data in **Table 12** show no major changes in either the gain or the beamwidth number between the two versions of the 18-element modified EALPDA. However, the capacitor-loaded version shows significantly higher 180° front-to-back ratios above the lowest operating frequency. In addition, we find significant differences in the feedpoint resistance and reactance values between the models, although neither set results in an unacceptable 200-Ω SWR value.

Fig. 12 compares the current distribution along each version of the array and E-plane patterns at 5, 20, and 30 MHz. Above 5 MHz, the capacitor-loaded model results in cleaner pattern shapes as well as somewhat lower levels of rear-element activity. It is quite likely that the capacitor-loaded model comes closer to the theoretically possible performance of the EALPDA, while the overlapping-wire model might show what the user can expect in practice from the subject array.

The performance improvement that emerges from moving to 18-elements is apparent at the upper end of the operating spectrum. The gain at 30 MHz is on a par with other values within the spectrum. The high-end SWR values are also down. Perhaps more significant than individual values is the shift in the reactive feedpoint components from inductive to capacitive, generally a sign of reasonably good array control. It is likely that the addition of further elements might lead to additional impedance control, since the τ of the array is low at 0.875.

In one arena, the modifications appear not to have effected improvements. The patterns in **Fig. 12** show similar shapes to those in **Fig. 11**. Moreover, we continue to find activity on rearward elements as we increase the operating frequency. The presence of significant forward and rearward sidelobes also raises the possibility of anomalous frequencies at which the pattern shows serious degradation or even reversal. The only sure way to determine—prior to construction and field testing—whether anomalous frequencies do exist is to subject the models to a series of frequency sweeps in which each sweep covers a relatively small range and uses sampling increments as small as 0.1 MHz. Although we shall perform some frequency sweeps for our models, we shall limit the increments to 0.5 MHz. Our goal is to obtain an overview of the potential performance, not to perform engineering design analysis.

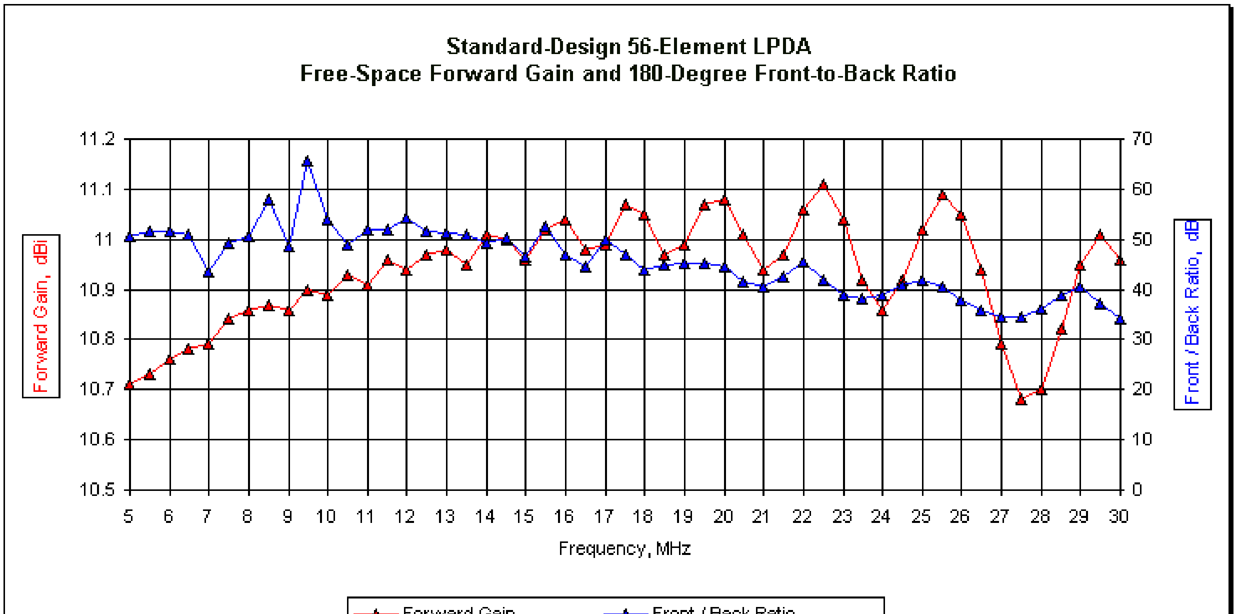
(A further intriguing but unexplored question involves the assigned length of the array in the patent. It records a boom length from rear element to vertex of 220', resulting in a 200' length between the longest and shortest elements. One might add within the assigned value of τ one or more additional forward elements to determine the effects on the 30 MHz performance. Alternatively, one might re-design the array for τ values that increase the array length to perhaps 250' or even 300'. As well, one might experiment with slightly lower values of σ. Such experimental designs might not prove to be suitable for physical implementation, since longer booms involve increased catenary effects on the element support lines. However, the performance trends, including the current distribution on the elements sections, would prove quite interesting.)



Sample E-Plane Patterns and Current Distributions: Modified 18-Element EALPDA

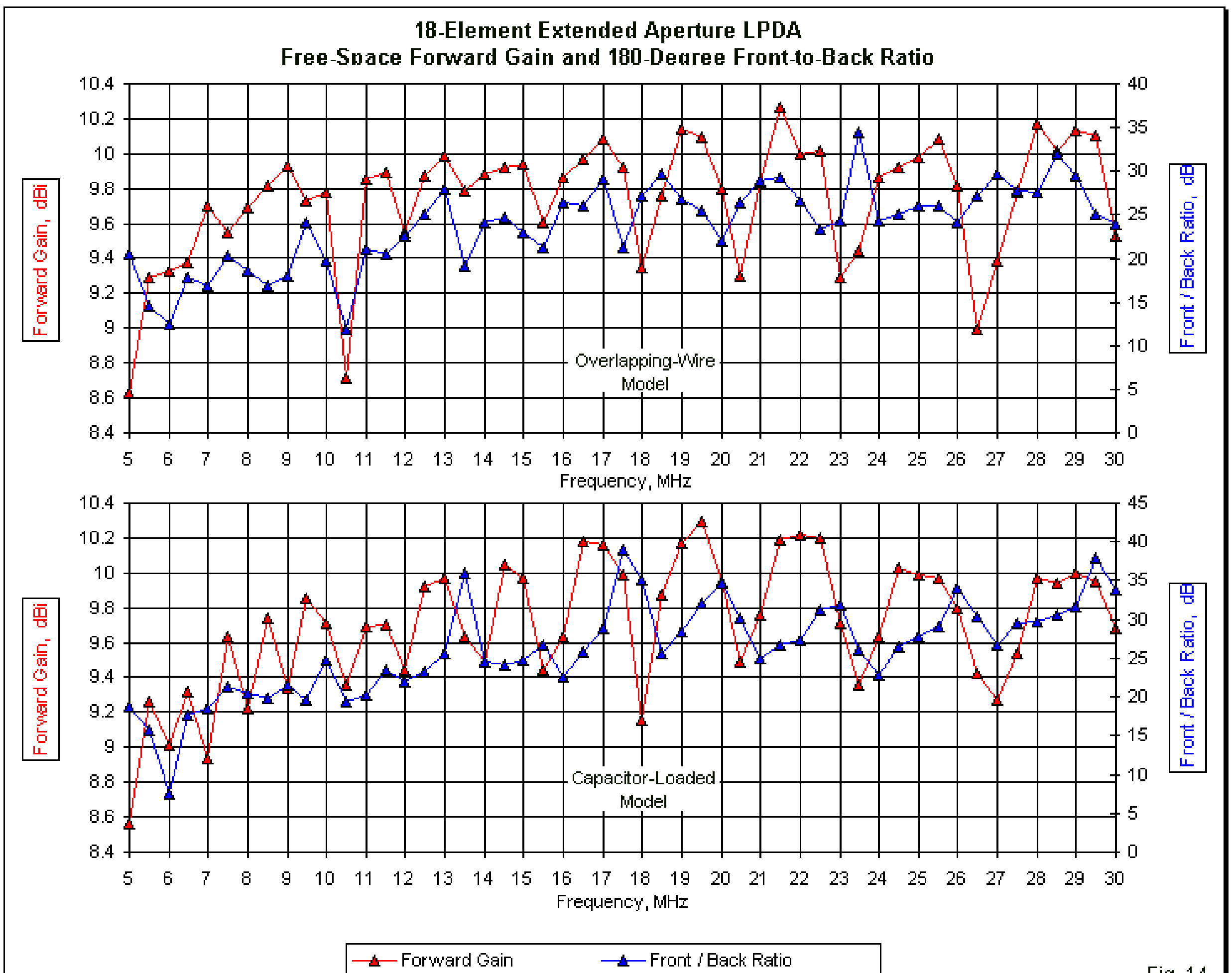
Fig. 12

To test this possibility, I ran frequency sweeps of two free-space LPDAs in 0.5-MHz increments from 5 to 30 MHz. One subject was the free-space version of the 56-element standard LPDA. The other was the modified 18-element EALPDA. We may compare the performance patterns of the two arrays while checking for the possibility of anomalous frequencies. Both models use constant-diameter elements with a 0.16" diameter. **Fig. 13** sweeps the free-space forward gain and the 180° front-to-back ratio of the standard LPDA. Both curves show that performance undulates with changing frequency, although over a very small region for both parameters. Typically, the performance peaks for no two parameters exactly coincide in frequency, since element activity is a joint function of the energy from the phase line and mutual coupling among elements.



Standard-Design 56-Element LPDA
Free-Space Forward Gain and 180-Degree Front-to-Back Ratio
Forward Gain, dBi
Front / Back Ratio, dB
Frequency, MHz
Forward Gain
Front / Back Ratio

Fig. 13



18-Element Extended Aperture LPDA
Free-Space Forward Gain and 180-Degree Front-to-Back Ratio
Forward Gain, dBi
Front / Back Ratio, dB
Overlapping-Wire Model
Frequency, MHz
Capacitor-Loaded Model
Forward Gain
Front / Back Ratio

Fig. 14

The comparable sweep curves for the modified EALPDA design appear in **Fig. 14**. The apparently natural variation in performance levels for both the gain and the front-to-back ratio are much higher, partly as a function of the low value of τ used in the design. However, one goal of the EALPDA was to obtain high performance with a much shorter boom length, a goal that necessitated the use of a lower value for τ. Perhaps the most striking fact to emerge from the sweep is that fact that none of the excursions in gain or front-to-back ratio indicate the presence of an anomalous frequency, although the front-to-back ratio at 6 MHz in the capacitor-loaded model is suspiciously low.

The general notes on **Fig. 14** apply to both models of the array. Between the two versions of the EALPDA, we find some minor and some major differences. The gain curve for the overlapping-wire version shows larger gain excursions in the natural undulation of the forward gain value across the spectrum. Nevertheless, the overall maximum and minimum gain values are very similar. Averaging over the complete sweep spectrum, the capacitor-loaded model exhibits a higher front-to-back value. The table lists the 180° value, but the sample patterns also suggest less overall rearward radiation from the model that uses capacitor loading instead of overlapping wires. The one suspect frequency in the sweep occurs only on this model and appears as a very low front-to-back value at 6 MHz. However, before we register the frequency as anomalous (in this particular model), we must examine some other performance data.

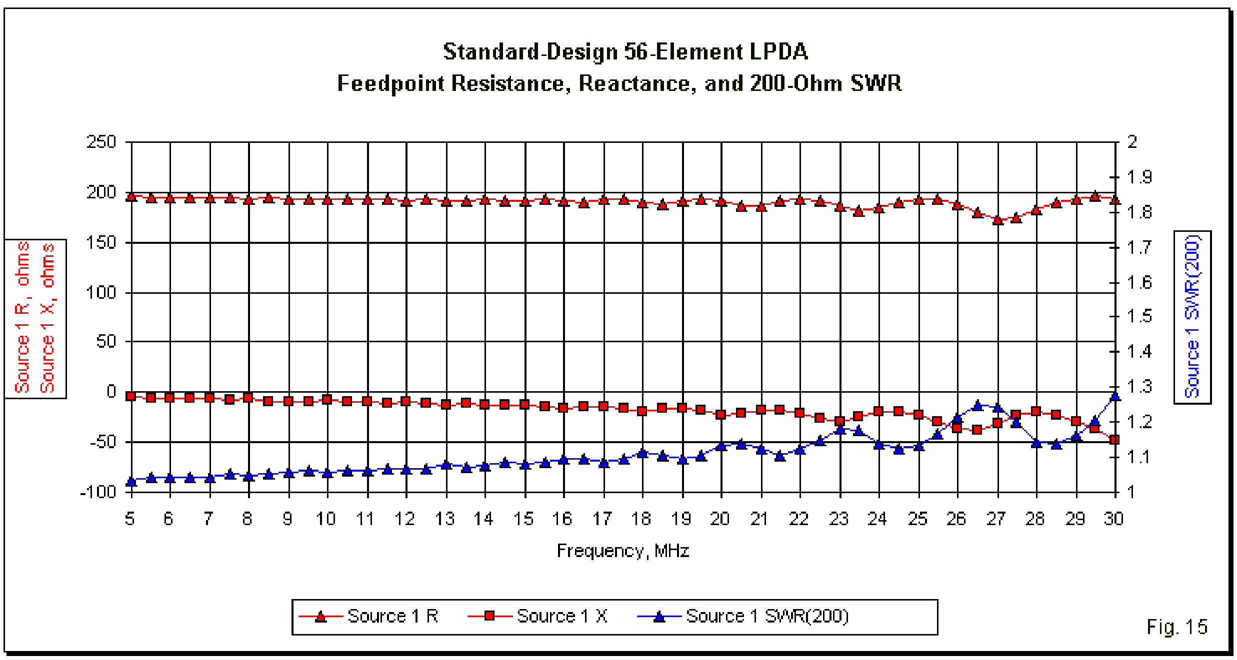


Fig. 15

The standard 56-element LPDA shows equal control of the feedpoint properties across the operating range in **Fig. 15**. As the frequency increases and the number of forward elements become less numerous, the curves show an increasing level of undulation. However, the 200-Ω SWR does not reach 1.3:1 by 30 MHz.

In contrast, we find much less smoothness in the resistance, reactance, and 200-Ω SWR curves for the modified EALPDA, as revealed in **Fig. 16**. However, the SWR value for the overlapping-wire model only exceeds 1.5:1 in the vicinity of 6 MHz and remains below 1.35:1 across the remainder of the operating spectrum. In the capacitor-loaded model, we find an SWR value that exceeds 2:1 by a wide margin, owing mostly to sudden spike in the feedpoint resistance relative to the desired 200-Ω value. The anomaly occurs therefore in both versions of the array, offset by a small frequency difference that makes it apparent on one graph but easy to miss on the other. The existence of the anomaly points to the importance of sweeping designs of wide-band LPDAs using very small frequency increments. However, for the terms of this exercise, we shall simply presume that good engineering can easily smooth out the graphs.

The general absence of sudden changes in the feedpoint resistance and reactance are further good indications that the EALPDA is not subject to any further anomalies. Indeed, the EALPDA has achieved one of its goals, namely, relatively high performance with no significant anomalous frequencies from 5 to 30 MHz with a value of τ that allows a short boom length for the array compared to standard designs. Whether the 20-dB front-to-back ratios in the overlapping-wire version, the 1-dB gain deficit shown by the models relative to the 56-element standard design, and the side-lobe structures are hindrances to the array's use falls outside the realm of this exploration.

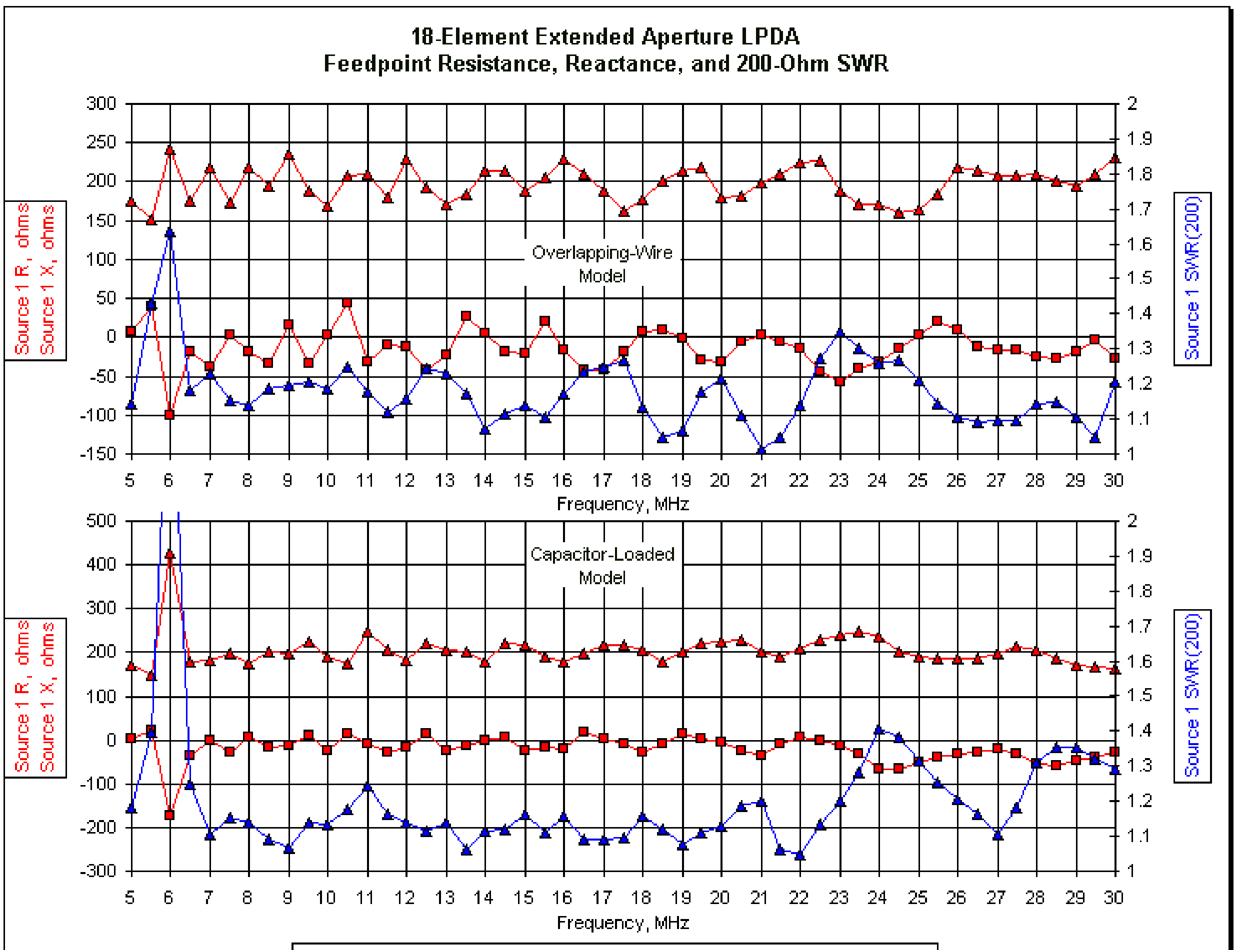


Fig. 16

One further patent claim is worth our immediate attention, namely that the EALPDA design results in narrower pattern beamwidth values than we may obtain from standard LPDA designs. **Fig. 17** combines sweeps from both arrays to provide a fulsome sampling. The 56-element standard design produces a very smooth beamwidth curve, with undulations only appearing in the upper third of the spectrum (counting linearly). The average value is about 53°. Over the sampling, the beamwidth varies by no more than 3.2°.

The modified EALPDA overlapping-wire model shows a range of beamwidth values from 35.2° to 52.2° for an average value of 41.4°. However, the range would be considerably reduced without the presence of the values for 5.0 and 5.5 MHz. Above these frequencies, the capacitor-loaded model tends to show a narrower range of variation than the overlapping-wire model. (The initial EALPDA design using the listings in the patent also showed a 50° beamwidth at 30 MHz, providing a further justification for the modifications.) If we use a figure of about 40° as the average beamwidth, the EALPDA—as modeled in these notes—shows a full 25% reduction in the beamwidth. This reduction does not quite meet the claims in the patent, but the reduction is real and may be of interest to numerous LPDA applications. The primary application envisioned by the patent for the basic EALPDA involves the use of the array in a vertical orientation. Therefore, we shall have to examine the H-plane beamwidths over ground before we can reach any conclusions.

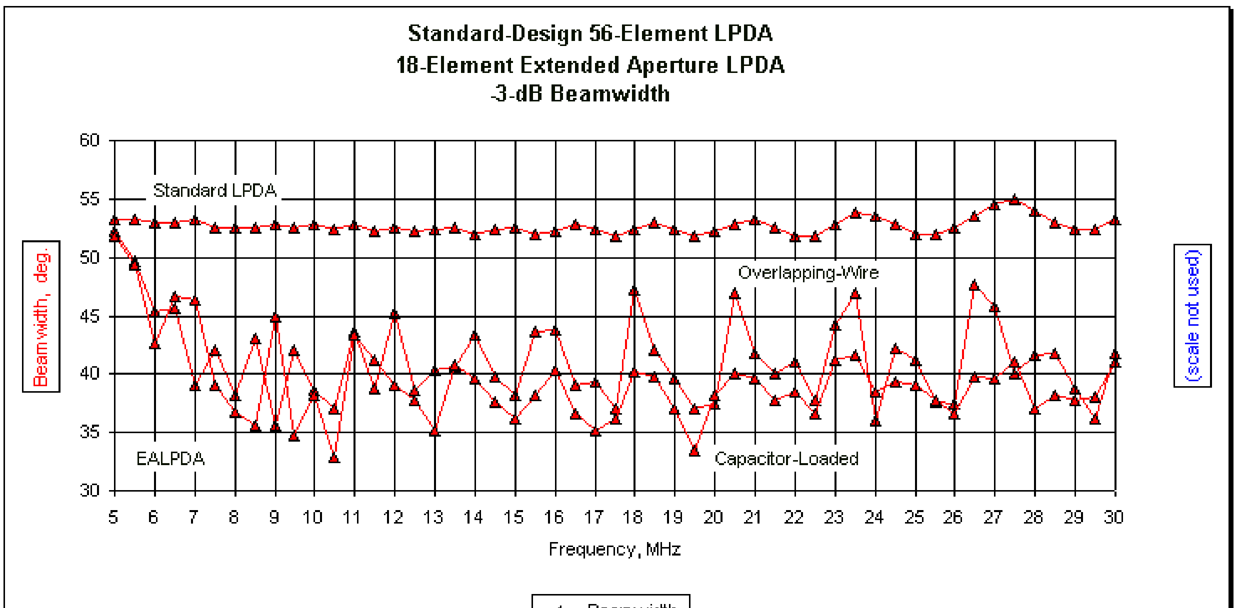
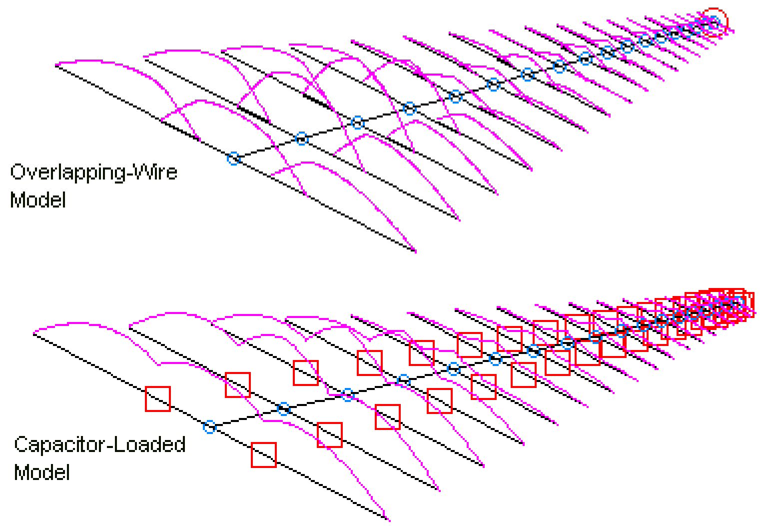


Fig. 17

Before we turn to vertical versions of the EALPDA, let's consider the undulations in the sweeps of the array a bit further. We have noted that the antenna design under examination meets the basic claims of the patent, even if it does not reflect the smooth performance of a standard very long LPDA using a 0.96 value for τ. We have attributed part of the undulation to the low EALPDA τ (0.875) and part to the activity of rearward elements. Still another part emerges from the unequal illumination of forward elements (relative to the most active array region). **Fig. 18** shows the current distribution along the elements at 5 MHz. Note that the center section of the forward elements remains significantly active, while the outer sections become relatively inert as we move forward of the first few elements. The pattern is quite similar whether we separate the inner and outer sections with overlapping wires (and overlapping current distribution curves) or whether we use a capacitor to divide the inner and outer sections. The pattern of activity varies with the operating frequency. However, the net result is that the outer element sections of the very forward elements do not contribute to stability of the curves as much as do the inner sections. Whether this phenomenon is endemic to the general design direction or is peculiar to the present embodiment lies outside the sphere of these notes.

Fig. 18



5-MHz Current Distribution: Modified EALPDA

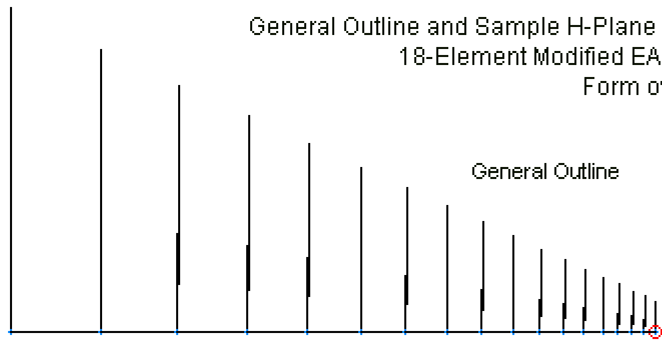
When we examined the standard 56-element LPDA, we created a monopole version for two purposes: the see what sorts of performance numbers emerged for comparison to the free-space performance data and to take an initial look at the H-plane beamwidth values. The resulting values for the standard LPDA appear in **Table 6**. We may perform a similar task for the EALPDA, although we must examine 2 models. Like the free-space models, we may create extended element monopoles over perfect ground using either overlapping wires of capacitive loads to separate inner from outer section. The dimensions shown in **Table 11** provide adequate guidance, since the models simply rotate the free-space models along the boom, prune ½ of each total element, and then set the array on perfect ground. In NEC models, we must review the transmission lines and the source positions. In addition, we reduce the characteristic impedance of the phase line by half, and reference the resulting source impedance values to 100 Ω (instead of the 200-Ω value used with the free-space or other full-element models).

Fig. 19 and **Fig. 20** supply general outlines of the two new monopole EALPDA models and provide sample H-plane patterns. We shall need to comment on both the common features and the unique properties that emerge from the models, following the data in **Table 13**. In view of patent claims for a narrower beamwidth for the EALPDA, the general appearance of the patterns (especially when compared to those in **Fig. 8**) immediately raises questions. The 56-element long-boom standard LPDA showed no H-plane sidelobes to either the forward or the rearward main lobe until we reached the very high end of the operating spectrum. At 30 MHz, the H-plane pattern for both the monopole and the sloping, full-element versions of the array showed relatively small forward and rearward sidelobe structures. We attributed those structures to the electrical shortening of the total boom length at the highest frequencies of operation, even in view of the fact that the standard array contained elements up through 50 MHz.

Fig. 19

General Outline and Sample H-Plane (Azimuth) Patterns
18-Element Modified EALPDA in Monopole
Form over Perfect Ground

Note: Detail of multiple element sections missing due to reduction in size of sketch.



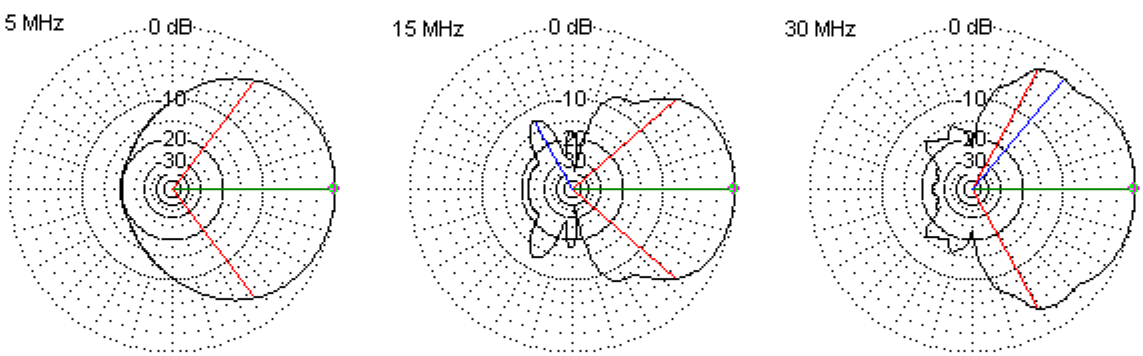
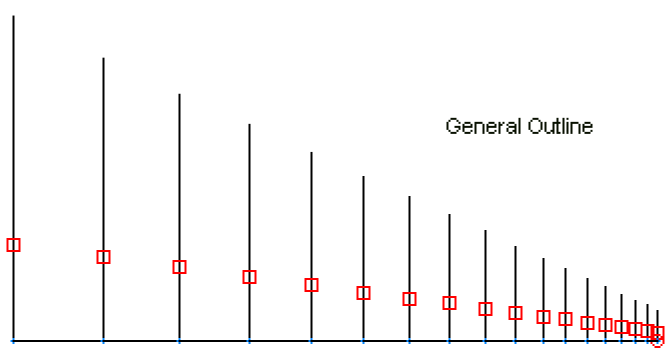


Fig. 20

General Outline and Sample
H-Plane (Azimuth) Patterns
18-Element Modified EALPDA
in Monopole Form over
Perfect Ground



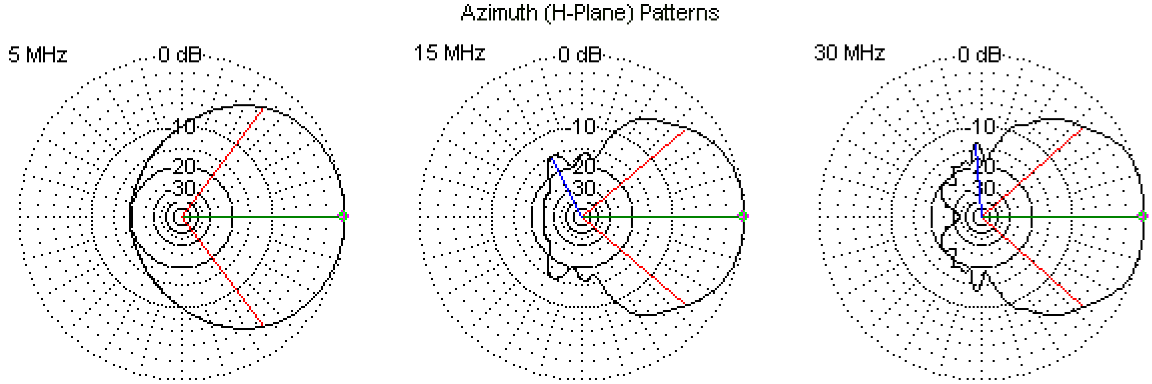


Table 13. Performance of overlapping-wire and capacitor-loaded monopole EALPDAs over perfect ground

Overlapping-Wire Model						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	11.65	12.71	12.92	12.88	13.03	12.59
Front-back dB	19.63	19.26	22.65	22.17	25.91	23.76
Beamwidth degrees	105.6	85.2	82.0	107.2	92.2	122.6
Z (R +/- jX) Ω	88 + j4	85 + j1	90 – j15	91 – j17	83 + j1	118 – j11
SWR 100 Ω	1.15	1.18	1.21	1.22	1.20	1.21
Capacitor-Loaded Model						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	11.59	12.67	12.91	12.96	13.01	12.81
Front-back dB	19.41	25.35	24.95	36.07	26.16	33.95
Beamwidth degrees	106.8	86.2	80.8	76.4	89.2	82.4
Z (R +/- jX) Ω	87 + j2	96 – j10	108 – j14	110 – j6	86 – j16	91 – j16
SWR 100 Ω	1.16	1.12	1.17	1.12	1.26	1.21
Reference values for the 56-element standard LPDA						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	13.71	13.90	13.97	14.10	14.02	13.99
Front-back dB	49.98	53.33	46.43	44.79	41.65	34.61
Beamwidth degrees	66.4	65.2	65.0	63.8	64.6	66.0
Z (R +/- jX) Ω	99 – j2	98 – j4	98 – j6	98 – j11	97 – j11	99 – j21
SWR 100 Ω	1.02	1.04	1.07	1.12	1.12	1.25

Between the two EALPDA models, we do not find significant differences in the forward gain. However, both models—like the free-space model—show values about 1-dB less than the 56-element standard LPDA model. The capacitor-loaded EALPDA shows systematically higher 180° front-to-back values than the overlapping-wire version above 5 MHz, although neither version reaches the values displayed by the standard long-boom LPDA. Moreover, the rear lobe structure above 5 MHz is considerably more complex in the EALPDAs, largely due to the use of the low value of τ (0.875). Still, the capacitor-loaded model shows a slightly cleaner rear-lobe structure than the overlapping-wire model, although the general shapes of the samples shown have a clear kinship.

Perhaps the most striking set of numbers involve the H-plane beamwidth of the EALPDA models. The overlapping-wire model shows two higher-frequency patterns with beamwidth values in excess of 100°. This phenomenon first called my attention to the need for capacitor-loaded models. In those models, the upper frequency patterns show consistent beamwidth values between 76° and 90°. In both models, the 5-MHz pattern shows a 106° beamwidth.

Apart from internal differences between EALPDA models, the relationship between the H-plane and the E-plane beamwidths stands in stark contrast to the comparable relationship in standard LPDA design. The 56-element LPDA shows a 1.2:1 ratio between the H-plane and the E-plane beamwidth values (65° vs. 53°, to use relatively average figures). Above 5 MHz, the capacitively loaded EALPDAs show an average E-plane beamwidth of about 38°. The average H-plane value is about 85°, a 2.2:1 ratio. At 5 MHz, the EALPDA H-plane beamwidth exceeds 100°, while the E-plane value is similar to the value for the standard LDA, about 52°. It is not clear why the lowest operating frequency exhibits this uncharacteristic behavior, but the activity of the forward elements—as shown in **Fig. 18**—may well play a role.

The differences in the modeled performance of the two versions of the EALPDA are not so different as to void the general beamwidth behavior of the Tanner design. The claim for a narrower beamwidth applies only to the E-plane patterns and not to the H-plane patterns. We shall encounter this situation again as we examine the sloping version of the array with a base height of 4' above perfect ground. The data for the comparable standard LPDA appear in **Table 7**, although I have included some of the information in **Table 13** for ready reference.

The sloping versions of the two models of the EALPDA both place the element 4' above perfect ground, with full elements extending upward. *Radio Communications*, the RSGB publication for October, 1981, on p. 926, portrays a single bay sloping TCI EALPDA with 18 elements (labeled as Model 510). The later 1987 issue of TCI's Technical Notes (#1) shows a double version of the array forming a horizontal V, ostensibly for slewing the array's primary direction. The V-angle is not determinate from the sketch, so we shall restrict ourselves to the 18-element modification of the version of the EALPDA in the patent application. However, we shall examine both overlapping-wire and capacitor-loaded versions of the single bay. The modeled data appear in **Table 14**.

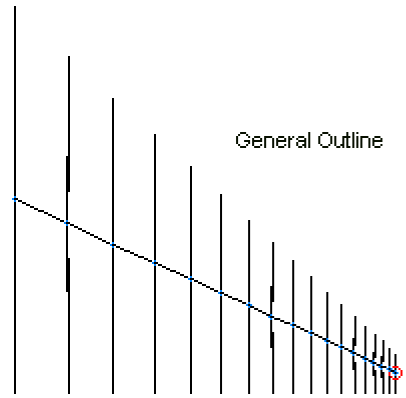
Table 14. Vertically oriented 18-element modified EALPDA with a constant element diameter in 4' above perfect ground.

Overlapping-Wire Model						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	14.14	15.06	15.58	14.74	15.62	14.74
Front-back dB	19.54	18.12	21.74	24.22	23.51	24.89
Beamwidth degrees	100.8	88.2	87.4	91.0	84.6	97.2
Z (R +/- jX) Ω	207 + j25	221 + j29	205 – j5	192 – j9	198 + j7	232 – j43
SWR 200 Ω	1.14	1.19	1.04	1.06	1.04	1.28
Capacitor-Loaded Model						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	14.09	15.19	15.37	15.41	15.54	15.55
Front-back dB	18.10	26.92	25.89	25.59	26.10	25.94
Beamwidth degrees	102.2	81.4	81.8	81.8	88.6	84.8
Z (R +/- jX) Ω	198 + j3	197 + j8	205 – j30	220 – j34	183 – j16	185 – j16
SWR 200 Ω	1.17	1.04	1.16	1.20	1.13	1.12
Reference data for 56-element standard LPDA						
Frequency MHz	5	10	15	20	25	30
Max. gain dBi	15.91	16.11	16.19	16.27	16.28	16.05
Front-back dB	44.89	61.32	50.36	43.00	46.29	35.91
Beamwidth degrees	54.8	54.2	54.5	55.0	56.0	60.4
Z (R +/- jX) Ω	195 – j5	194 – j9	193 – j11	190 – j26	196 – j26	190 – j59
SWR 200 Ω	1.04	1.06	1.07	1.15	1.14	1.36

The table includes reference data on the 56-element 775' long standard LPDA. Clearly, the EALPDA in this form shows the same 1-dB deficit in forward gain shown by the free-space and the monopole versions. As well, we find the same differentials among the values for the 180° front-to-back ratio that we saw in the monopole comparisons. Perhaps more interesting is the fact that the cases in which the overlapping-wire version of the array drop below a 15-dBi forward gain are also cases in which the H-plane beamwidth exceeds 90°. Compare these values with the corresponding values for the capacitor-loaded model. Equally interesting are the sample patterns for 5, 15, and 30 MHz, shown in **Fig. 21** and in **Fig. 22**.

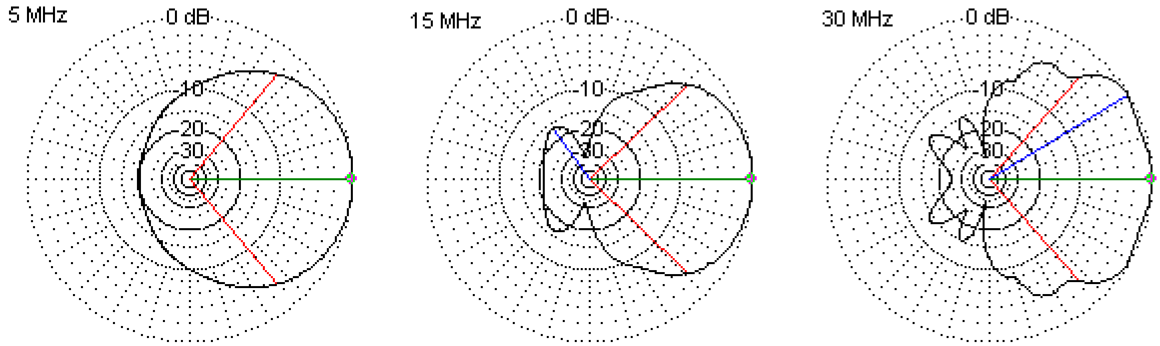
General Outline and Sample
H-Plane (Azimuth) Patterns:
18-Element Modified Sloping
EALPDA 4' over Perfect Ground

Fig. 21



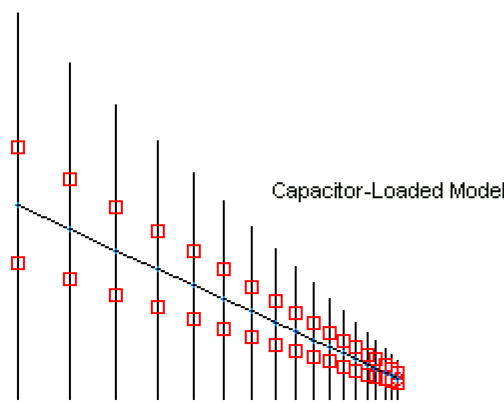
Note: Detail of multiple element sections missing due to reduction in size of sketch.

Sample H-Plane (Azimuth) Patterns

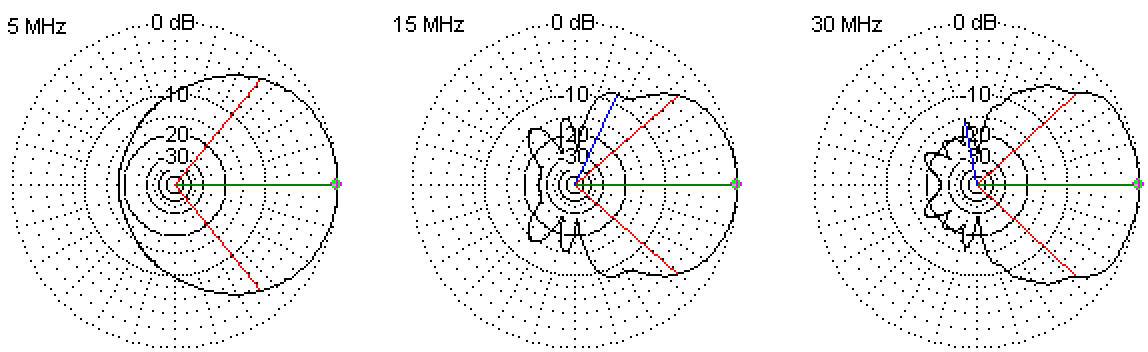


General Outline and Sample
H-Plane (Azimuth) Patterns:
18-Element Modified Sloping
EALPDA 4' over Perfect Ground

Fig. 22



Sample H-Plane (Azimuth) Patterns



The 15-MHz patterns differ both in beamwidth and in the rearward lobe structure. The 30-MHz pattern for the capacitor-loaded model shows signs of approaching the wider pattern of the overlapping-wire version, but the main forward lobe reveals only minor indents in regions where the overlapping-wire version shows almost enough reduction to classify the side bulges as distinct lobes. Even though the modeled data for the two versions of the single-bay EALPDA show a very clear kinship, the results differ enough to set limits on the level of confidence that one may have in either model.

Conclusion

We have explored the basic parameters of EALPDA design and modeling. Although multiple design and modeling issues preclude hard and fast conclusions, we may at least note that the Tanner patent makes a very reasonable case for a long-element, short-boom LPDA design that is able to cover 5 through 30 MHz with high performance—even if that performance does not quite meet the standards established by the very long-boom 56-element LPDA shown in Part 1. In all configurations, we find a gain deficit of about 1 dB, with further deficits in the category of front-to-back ratio. These deficits result largely from the use of a lower value of τ (0.875) so that the boom length is less than 200' (compared to 775' for the 56-element sample standard LPDA). A standard LPDA using the same lower value for τ would not be able to cover the frequency span without much greater fluctuations in performance, along with anomalous frequencies at multiple points in the operating spectrum. The use of the extended element and its wider operating bandwidth allow fewer long elements to do the work of a greater number of shorter elements in terms of providing full frequency coverage without objectionable swings in performance.

Perhaps the major surprise in our survey has been the relatively wide H-plane beamwidth of the monopole and sloping vertical versions of the EALPDA design. The standard LPDA showed a reasonable coincidence between E-plane and H-plane beamwidth values—about the difference that we might expect of a Yagi beam with the same forward gain level. In contrast, the EALPDA shows a ratio of H-plane to E-plane beamwidth of over 2:1. The culprit is most likely the short boom length relative to the operating frequency, a direct function of the selected value of τ. The use of long or extended elements may confine the E-plane beamwidth, but such elements are no better than ½-λ elements in terms of confining the H-plane beamwidth. H-plane beamwidth values appear to be largely a function of boom length. (Note: the term "boom length" refers to the active boom length at any given operating frequency within the operating range of the antenna.)

Despite the one surprise, not hinted at in any of the literature on extended elements of extended aperture LPDAs, the overall EALPDA design is capable of wide-band LPDA performance on its 200' boom length.