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

L. B. Cebik, W4RNL

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]

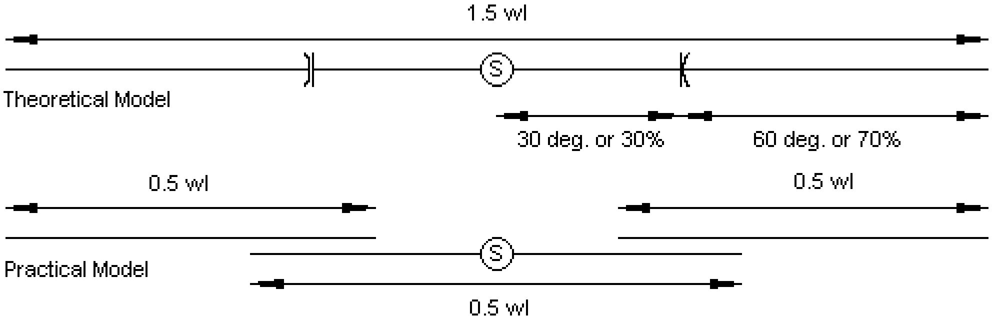
Fortunately, the RSGB materials and Tanner’s patents application give us ample material for examining the basic features of the extended element and its application to LPDA arrays—at least in a preliminary manner. The inventor of the EALPDA also describes a standard optimized LPDA in his application 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.

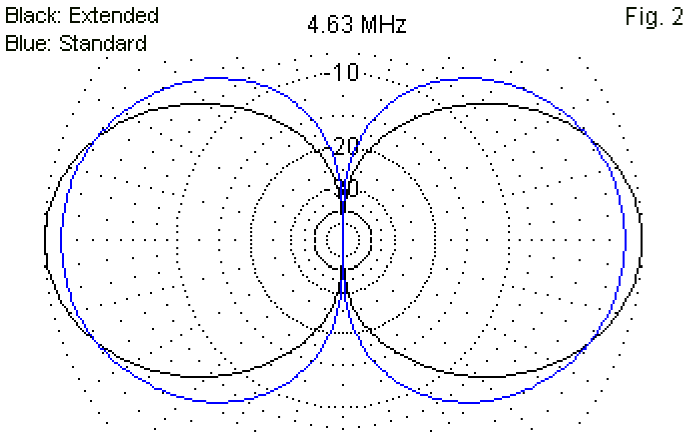


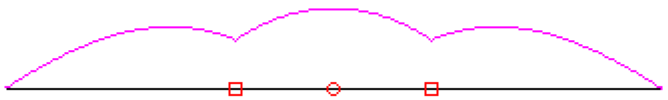
Fig. 2

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

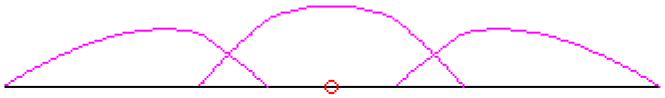
Although the current distribution along the two versions of the extended element is similar—with similar consequences for the radiation pattern—the curves are not identical, as is evident in **Fig. 3**. The overlapping-wire version of the extended element has deeper current minimums, and there are slight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



Capacitor Version

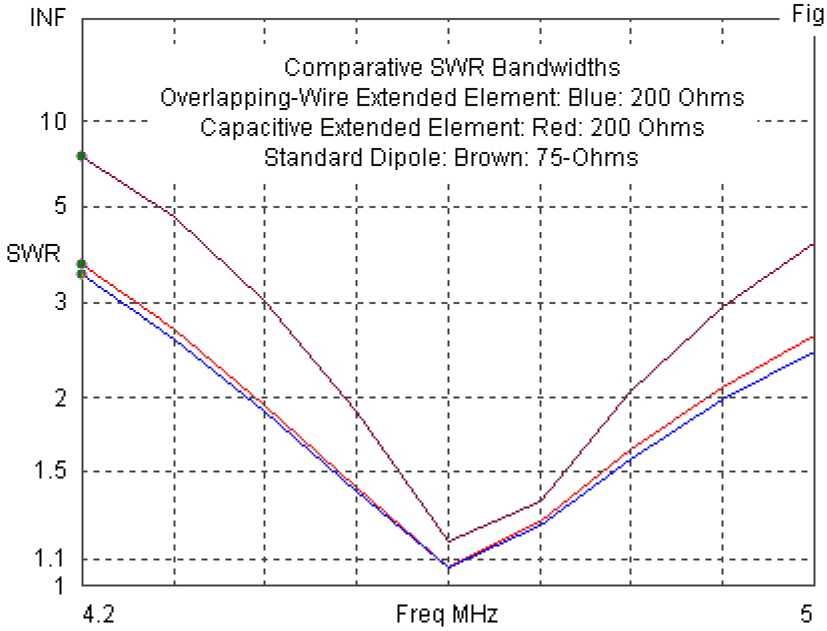


Overlapping-Wire Version

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.

Fig. 5

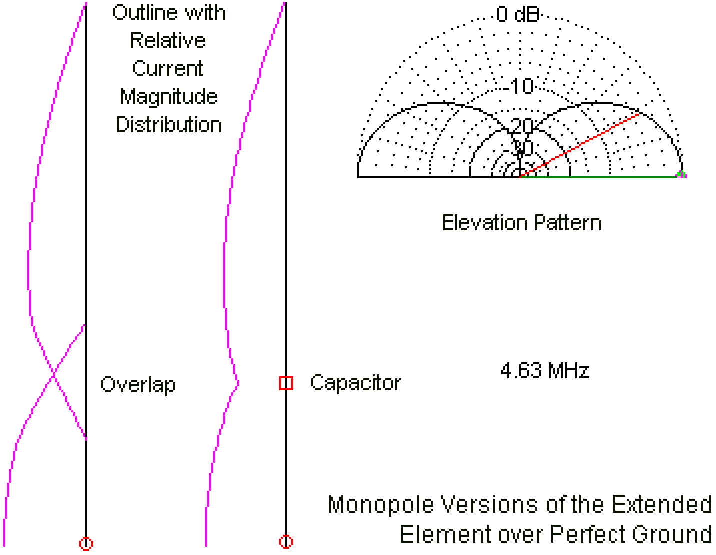


Table 2 lists the essential properties of the extended elements as monopoles, along with information on a reference ¼-λ monopole at the design frequency. Each antenna is exactly half the length of its dipole counterpart. The extended elements are 100' long. The capacitor position is 30' above perfect 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.

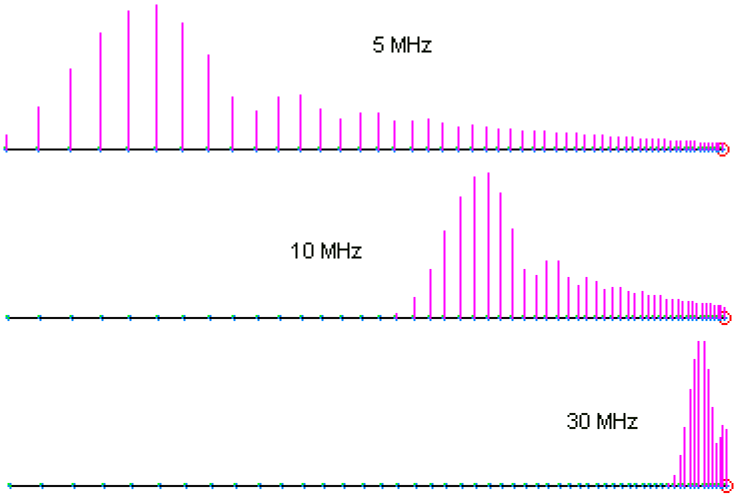
One facet of the LPDA model is less than ideal. The model will use 0.16” diameter wire for the elements. LPDAs show higher gain with fatter elements. Therefore, the model will not achieve all of the gain that the geometry makes possible. Moreover, ideal LPDA design τ-tapers not only the element length 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

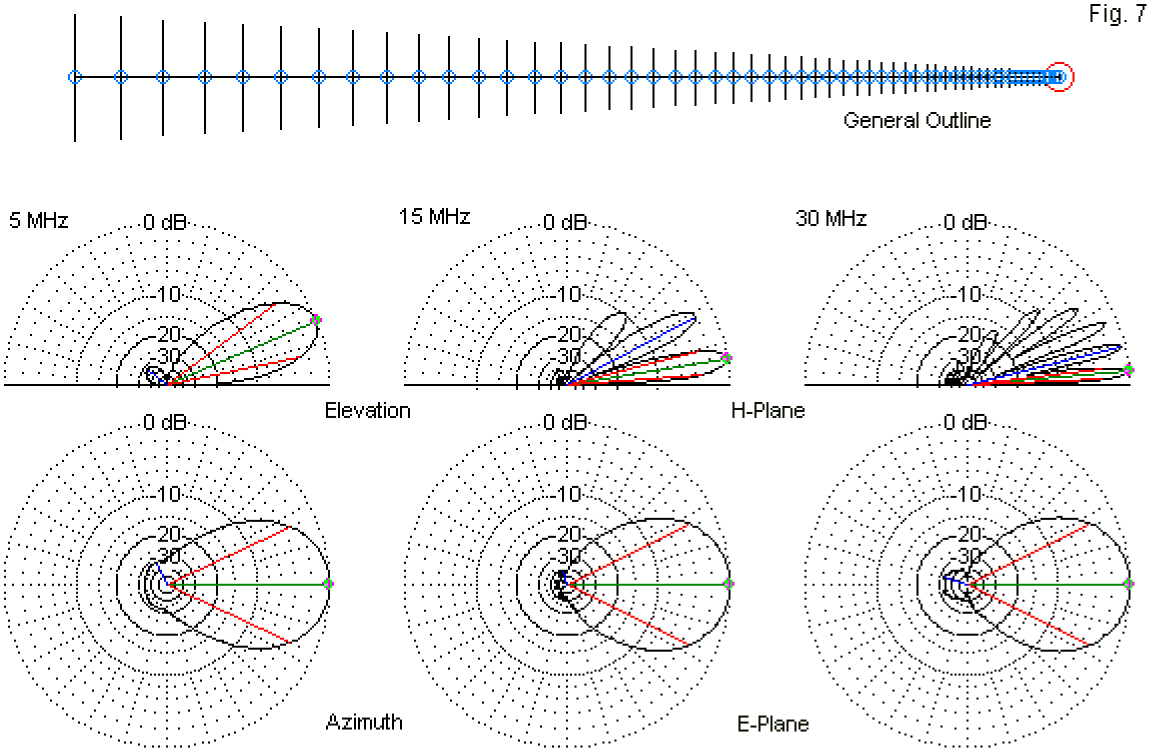
100’ above Very Poor Ground (conductivity = 0.001 S/m, permittivity = 5)

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.

Fig. 7



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.

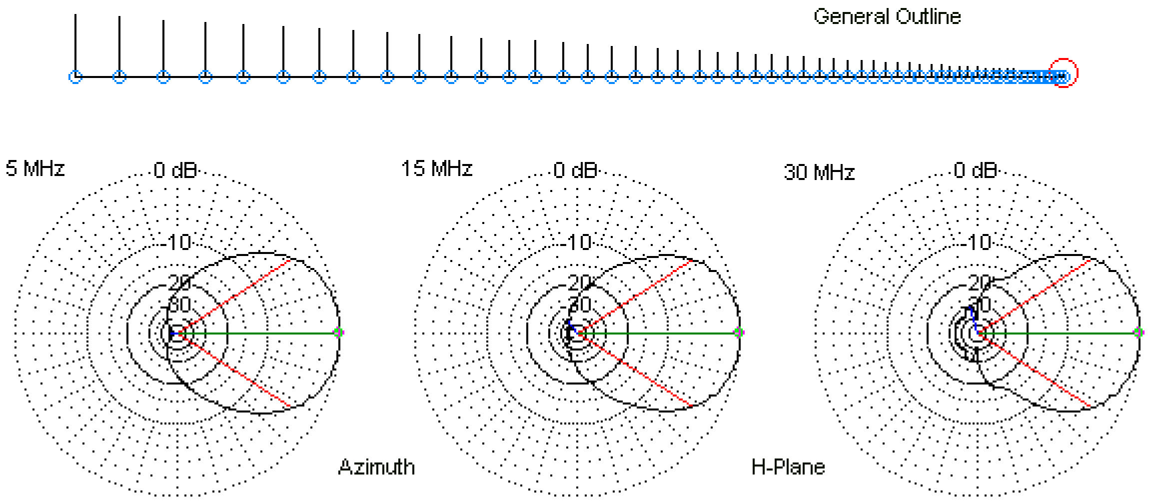
Table 6. Performance of a 56-element monopole LPDA over perfect ground, with a constant element diameter. T = 0.96; σ = 0.18. L_{50} = 750'; L_{56} = 774.6'. Element diameters 0.16" – 0.02"

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.

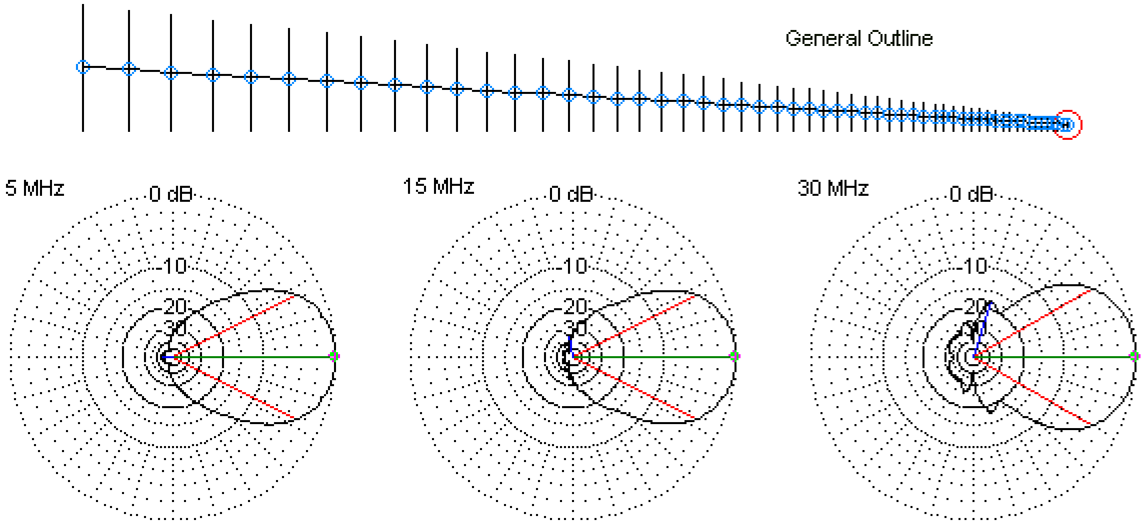
Fig. 8



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."