Notes on Standard Design HF LPDAs, Pt 1: "Short" Boom Designs

"Short" is a relative term here. These 3 to 30-MHz wide-band antennas have a 167-ft longest element on a 100-ft boom. Definitely a job for computer modeling!

By L. B. Cebik, W4RNL

Hams have heard of 3-30 MHz dream antennas of log-periodic dipole array (LPDA) design since their advent. While wide-band LPDAs are common in governmental and commercial circles, little performance or specification data on the antennas has filtered into amateur publications. LPDAs for 14-20 MHz are much more common. Because modeling software (*NEC-4*) exists to assess the potential for 3.5-octave LPDAs, and because curiosity must ultimately be served, I began a preliminary modeling study, the first two parts of which appear in this series.

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The first part of this preliminary study looks at standard LPDA designs of the order produced by *LPCAD* for three 3-30 MHz antennas:

- 60-ft boom with 20 elements
- 100-ft boom with 20 elements
- 100-ft boom with 26 elements

The 60-foot boom length is not recommended because of difficulties in obtaining an SWR of less than 2:1 across the passband relative to some common impedance and because of very significant pattern anomalies at numerous frequencies.

More feasible is a 100-ft boom using either 20 or 26 elements, if a free-space forward gain of less than 6.0 dBi is acceptable across the passband. Except at the lowest frequencies, the front-to-back ratio is acceptable (more than 18 dB from 9 MHz upward), although rear lobes are broader than would be expected for an LPDA of narrower frequency range. By careful selection of the interelement transmission-line value and the use of an antenna line terminating stub, an SWR of under 2:1 can be obtained for the entire passband with only small (and likely correctable) exceptions.

For some designs—especially the 100-ft boom, 20-element version—element diameter tapering according to the value of Tau shows significant improvements across the passband. However, this technique results in unrealistically large diameters for the tubular elements. A possible wire simulation of the large elements is proposed, along with a simple mechanism for shortening the physical length of the element while preserving its resonant frequency.

Preliminary Design and Modeling Considerations

Flat-plane LPDAs are normally designed in accord with well-published design equations. There are several LPDA design programs employing these equations, of which *LPCAD* by Roger Cox may be the best known and most widely distributed. The 3-30 MHz LPDAs described here were initially designed using *LPCAD*. Since the theory and equations for standard LPDA designs appear in so many publications, they will be only briefly noted here.

Tau is the ratio between element lengths. It is, as Fig 1 shows, also the ratio of element distances from the center of a circle such that the element lengths define an arc having a constant angle. Since the angle, which is twice Alpha, is often difficult to work with, we may also define a spacing constant, Sigma. Sigma can be defined, as shown in the diagram, in terms of Tau and Alpha, but often it is more convenient to calculate it by taking the spacing of any two elements and dividing that distance by twice the length of the longer element.

For dipole arrays, there is an optimal value for Sigma:

$Sigma_{opt} = (0.243\ Tau) - 0.051$ (Eq 1)

Suppose we opt for a Tau value of 0.94. The optimal value of sigma will be 0.1774. Plugging this value back into the equation by which we determine Alpha yields an angle of about 4.833°; this results, in turn, in a very long boom. For a 3-30 MHz LPDA with a longest element of 167.28 ft, the boom length becomes about 989 ft.

For most applications, much shorter lengths are physically required for LPDAs. The immediate consequence is a reduction in gain, along with irregularities in gain across the design passband of the array. When the length becomes too short, pattern shaping also tends to become irregular and often unusable at many frequencies within the passband of the LPDA design. Finally, obtaining a relatively constant source impedance across the passband becomes nigh well impossible.

One of the initial goals of this preliminary study was to determine the approximate shortest length that would be feasible for a 3-30 MHz LPDA. Since antenna gain has not been specified in advance, the criteria for an acceptable length included the ability of the antenna to achieve a 2:1 SWR across the passband relative to some specific impedance value. In addition, free-space azimuth patterns must achieve reasonable shapes for all test frequencies, with no spurious forward or rearward lobes of consequence.

An additional goal of this preliminary study was to look at the effect of element diameter upon antenna performance. Standard (but simplified) tubing diameter progressions would be compared to element diameters increased for each element by the value of Tau used in the element-length schedule. The latter schedule of element diameters would result in a constant length-to-diameter ratio for the entire array.

The designs resulting from *LPCAD* inputs were modeled on *NEC-4* (*EZNEC*) using aluminum elements throughout. The environment selected was free space, so that all values reported would be comparable and not subject to variations due to height above ground. The resulting models were sizable: 836 segments for 20-element versions and 1184 segments for 26-element versions of the LPDA. Even on a 400-MHz computer, the run time for the models—especially for frequency sweeps from 3 to 30 MHz in 1-MHz increments—limited the number of variations possible. Consequently, there are design modification possibilities that have not been explored in these preliminary notes. Moreover, instead of a survey of boom lengths in small increments, only two selected boom lengths could be initially checked: 60 and 100 ft. Whether an intermediate length realizes the improvements found in the 100-ft boom length was not determined.

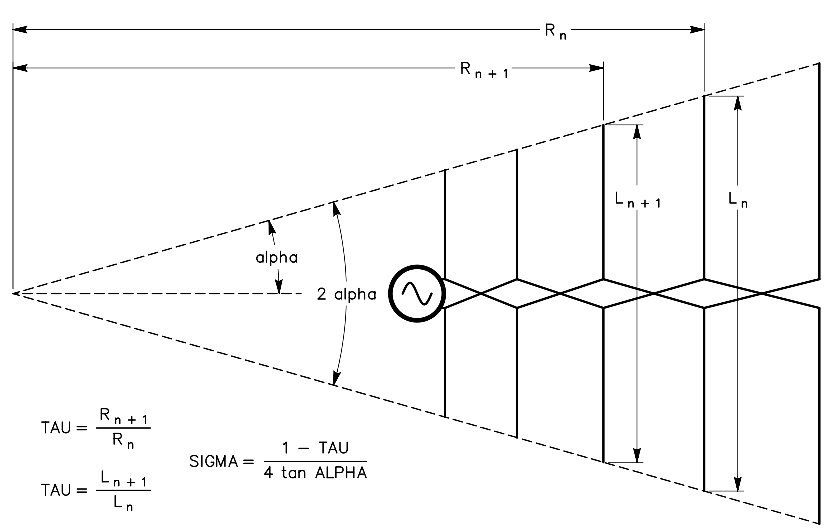

Fig 1—Some of the basic relations used in standard LPDA design [adapted from Richard C. Johnson, Ed., *Antenna Engineering Handbook*, 3rd ed. (New York: McGraw-Hill, 1993), p 14-36.]

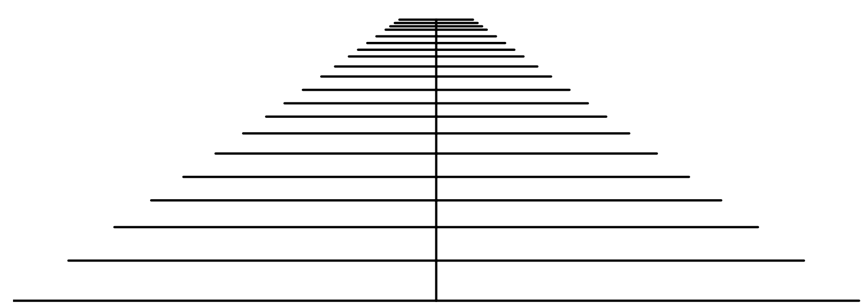

Fig 2—Outline of the 60-ft, 20-element 3-30 MHz LPDA.

The models themselves are further limited by the use of the TL facility in NEC—the mathematical modeling of transmission lines used to interconnect elements. Physical models of LPDAs with transmission lines are not feasible due to certain limitations in NEC, most notably the angular junction of wires of dissimilar diameter. However, mathematical transmission lines do not account for losses in these lines, and therefore, all performance figures may be very slightly off the mark.

Within these limitations, certain trends are notable and reported in the following.

A 60-ft, 20-Element LPDA

The first model developed used a 60-ft boom length with 20 elements ranging from 2.0 inches in diameter at the rear to 0.5 inch in diameter for the shortest element. Based on initial modeling tests for a "best" SWR curve, the interelement transmission line was set at 150 Ω. The *EZNEC* model description is appended at the end of the report to show the facets of design, including the tubing schedule. In general, each diameter divisible by 1/4 inch is used twice, while those divisible only by 1/8 inch are used only once in the element progression.

Fig 2 displays the generalized outline of the 60 ft, 20-element LPDA used in this study. The longest element is 2007 inches (or about 167 ft), while the shortest is 155 inches (or about 13 ft). See Table 1 for a listing of element half-lengths and cumulative spacing for the final model design. For this design, overall length and the number of elements were specified, with the values of Tau (0.87) and Sigma (0.02) becoming the results of the calculations. It is interesting that *LPCAD* initially predicted a free-space forward gain of about 6.5 dBi, with front-to-back ratios ranging from 13 to 19 dB. Only the front-to-back ratios met the prediction. Although a 150-Ω transmission line was finally used, *LPCAD* recommended a 200-Ω line and predicted that the antenna input resistance would be about 85 Ω.

Apparently, the 60-ft boom length is categorically unable to yield a SWR under 2:1 for any particular reference impedance value. Using 1-MHz increments from 3 to 30 MHz, impedance values varied widely. The range of the resistive component was from a 24 Ω low to a 168 Ω high. Reactance varied between –68 Ω and +71 Ω. The SWR curve for the 3-30 MHz passband, shown in Fig 3, reveals only a couple of minor excursions below 2:1 relative to a 75-Ω reference value. Other reference values will yield more values below 2:1, but the peak values of SWR climb proportionately. The result is a design that is unlikely to be matchable to standard feed lines by any straightforward means.

In addition to an unacceptable set of SWR values across the passband, the 60-ft, 20-element design also shows numerous pattern anomalies. Often, an LPDA design will show a small frequency region of unacceptable pattern shape. Such problems are sometimes amenable to input-stub correction. However, the present design shows anomalies at many frequencies.

Table 2 samples performance values at 3-MHz intervals across the passband and reveals the general performance trends for the antenna. The table reveals some strong difficulties at the lower and upper ends of the passband. The gain and front-to-back ratio at 3 MHz is exceptionally low and only slowly improves as the frequency progresses toward 9 MHz. At the upper end of the passband, the source impedance reaches very low values. The gain shows large excursions throughout the 3 to 30 MHz range.

Some selected free-space azimuth patterns for 3, 9, 15 and 30 MHz can

Table 1—Element half-lengths and cumulative spacing of the 60-ft, 20-element 3-30 MHz LPDA model

Element	*Half Length (inches)*	*Cumulative Spacing (inches)*
1	1003.68	0.00
2	876.93	98.50
3	766.19	184.56
4	669.44	259.75
5	584.90	325.45
6	511.04	382.85
7	446.50	433.00
8	390.12	476.82
9	340.85	515.11
10	297.81	546.56
11	260.20	577.79
12	227.34	603.32
13	198.65	625.63
14	173.55	645.13
15	151.63	662.16
16	132.49	677.04
17	115.76	690.04
18	101.14	701.40
19	88.37	711.33
20	77.21	720.00

Table 2 —Performance of the 60-ft, 20-element model LPDA at 3-MHz increments from 3-30 MHz

Frequency (MHz)	*Free-Space Gain (dBi)*	*Front-to-Back Ratio (dB)*	*Source Impedance (R ± jX Ω)*	*SWR (75-Ω)*
3	3.66	3.6	120 –*j*68	2.30
6	5.93	10.2	168 +*j*40	2.39
9	4.88	16.1	108 +*j*63	2.16
12	5.50	16.4	162 +*j*11	2.18
15	6.00	18.7	35 +*j*12	2.24
18	5.36	19.0	86 +*j*60	2.09
21	6.08	18.7	124 +*j*50	2.04
24	6.01	18.7	81 +*j*50	1.89
27	5.18	17.5	25 +*j*27	3.47
30	5.64	18.7	27 –*j*24	3.05

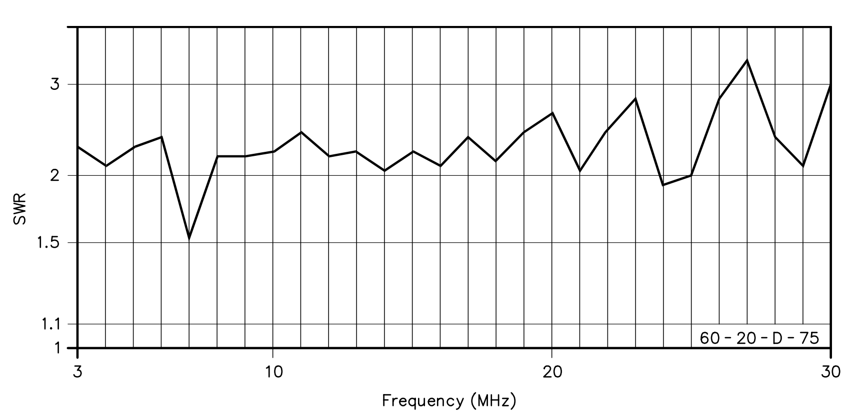

Fig 3—3-30 MHz SWR sweep of the 60-ft, 20-element LPDA model referenced to 75 Ω.

reveal other weaknesses in the design. The 3-MHz pattern in Fig 4 reveals clearly the very weak directional pattern for the design at its lowest frequency. Although gain and front-to-back ratio improve as frequency is increased, the size of the rear lobes at 9 MHz is still very much larger than is desirable for most operation.

The 15-MHz pattern in Fig 4 reveals a double forward lobe, along with added side lobes in both the forward and rearward quadrants. Although this pattern might be corrected to some degree by compensatory loading, the fact that a similar set of problems attach to the 30-MHz pattern largely precludes this course of action. There would still be sets of frequencies with unacceptable azimuth patterns.

The general conclusion to be reached from this exploration is that the standard LPDA design—as produced by *LPCAD*—yields unacceptable results. Moreover, the problematical performance numbers are unlikely to be overcome by compensatory actions on the design. In the end, a 60-ft boom is simply too short for a standard LPDA design to achieve any set of desired goals.

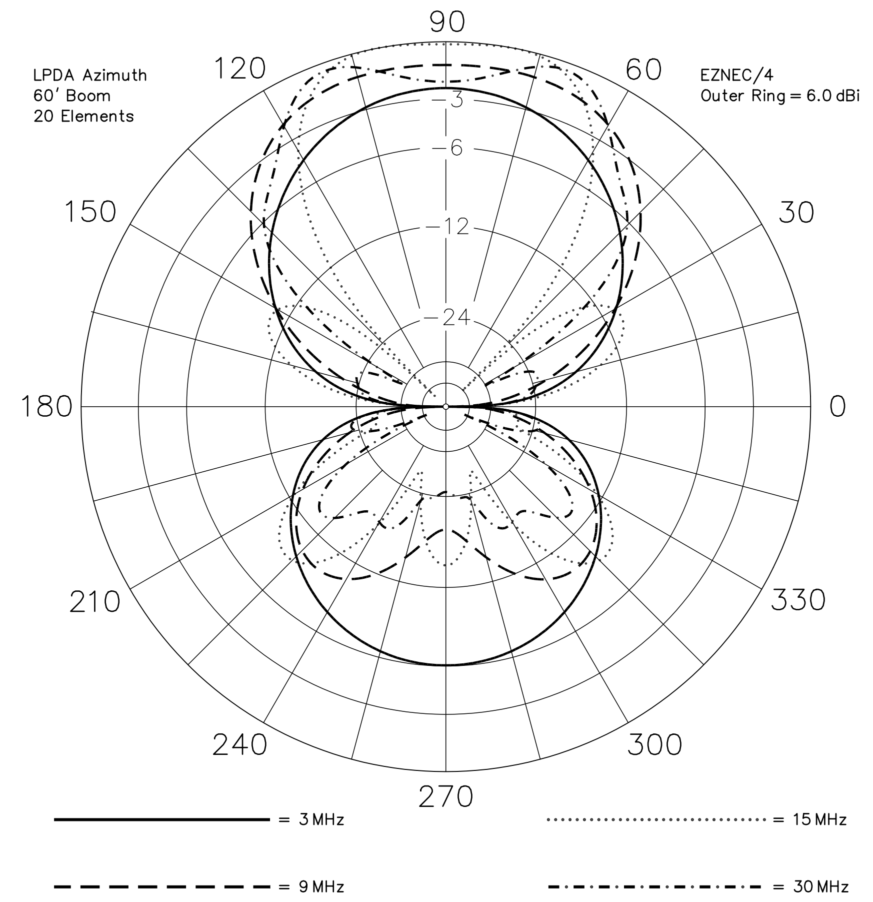

Fig 4—Free-space azimuth pattern of the 60-ft, 20-element LPDA model at 3, 9, 15 and 30 MHz.

100-ft, 20-Element LPDA

Since the model sizes precluded incremental investigation with the goal of finding the shortest acceptable boom, a longer boom was arbitrarily selected for modeling. A 100-ft length was chosen because it seemed sufficiently longer than the 60-ft boom (167%) to offer significantly modified antenna behavior. The parameters were presented to *LPCAD*, which produced a design with the same element lengths as used in the 60-ft design, but with a new spacing schedule. Fig 5 shows the general outline of the longer design, while Table 3 provides element half-lengths and cumulative spacing for the model. Initially, the tubing diameter schedule used in the 60-ft-boom model was

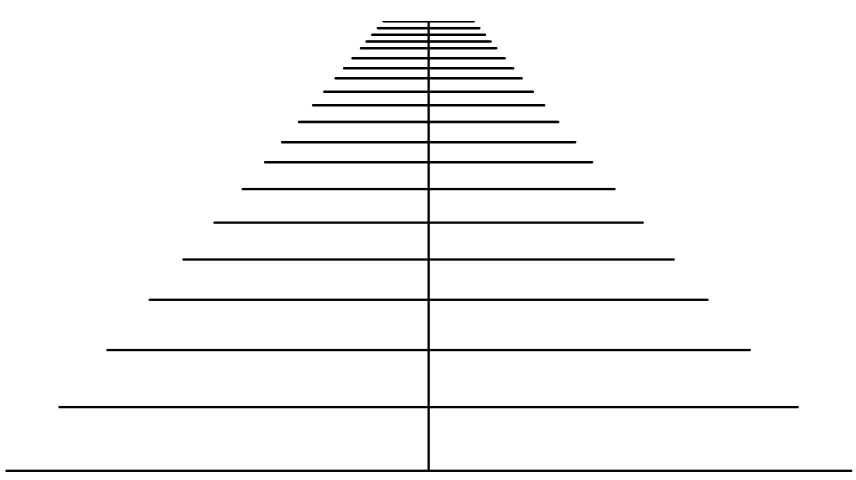

Fig 5—Outline of the 100-ft, 20-element 3-30 MHz LPDA.

Table 3—Element half-lengths and cumulative spacing of the 100-ft, 20-element 3-30 MHz LPDA model

Element	*Half Length (inches)*	*Cumulative Spacing (inches)*
1	1003.68	0.00
2	876.93	164.17
3	766.19	307.60
4	669.44	432.92
5	584.90	542.42
6	511.04	638.09
7	446.50	721.68
8	390.12	794.71
9	340.85	858.52
10	297.81	914.28
11	260.20	962.98
12	227.34	1005.54
13	198.65	1042.72
14	173.55	1075.21
15	151.63	1103.60
16	132.49	1128.40
17	115.76	1150.07
18	101.14	1169.00
19	88.37	1185.55
20	77.21	1200.00

transferred to the new 100-ft version.

The interelement transmission line impedance was set at 200 Ω, in accord with *LPCAD* recommendations. To this and all subsequent models in Part 1 of these notes, I added a 90-inch shorted stub at the end of the line at the longest element to effect a transmission-line termination. In all cases, this stub has the same characteristic impedance as the interelement line. Again, because models are so large, varying the length of this stub might produce small improvements in the projected performance of some of the models. However, it is unlikely that major changes will be created.

As revealed in Fig 6, the 100-ft boom, 20-element LPDA is capable of a quite good SWR curve relative to a reference value of 95 Ω (in contrast to the *LPCAD* predicted input resistance of 103 Ω). Only once (in the 1-MHz increment scan) does the SWR value just barely exceed 2.0. Consequently, the antenna design passes one of the major criteria of acceptability.

LPCAD predicted that the antenna free-space gain would be about 6.5 dBi, with front-to-back ratios ranging from 13 to 19 dB. In some performance categories, the antenna shows a few serious shortcomings, especially with respect to gain. Table 4 presents selected frequency performance figures, which reveal some of the design's weakness. The notation "BFL" records a judgment that the antenna at the given frequency exhibits a *broad forward lobe*. However, even where technically double, the difference between the forward direction and the peak is under 0.5 dB and therefore is more accurately called a broad lobe than a double lobe.

The gain at the lower end of the passband remains low, but slightly better than that of the 60-ft model. Numerous test frequencies show broad frontal lobes, with equally wide rear lobes, although the front-to-back ratio is very consistent from 12 MHz upward. Moreover, the gain figures, while lower on some bands than those of the 60-ft model, are far more consistent from one test frequency to the next. All in all, the 100-ft, 20-element version of the LPDA shows distinct improvements over the 60-ft model.

Although the model uses a set of element diameters that increase as frequency decreases, the rate of increase does not match the inverse of Tau (0.87). Table 5 gives a comparison of the initially modeled and the "Tau-tapered" element diameters, counting from element 20 at the highest frequency downward toward element 1 at the lowest frequency.

The element diameters remain roughly the same for the shortest seven elements. Then the rigorous "Tau-tapering" schedule increases the element diameter much more rapidly, reaching a final value of 6.5 inches for the longest element. Although this element diameter may be impractical in a tubular design, there may be a way of simulating such elements. One possibility will be suggested in the final section of these notes.

To test whether the "Tau-taper" element set would make a difference in the performance predicted by *NEC-4*, the 100-ft model was reset using the new element diameters. For the initial test, I retained the 200-Ω interelement feed line, the 90-inch terminating stub and the SWR reference impedance of 95 Ω. The resulting SWR curve in Fig 7 remains quite good, with only one slight excursion above 2:1.

Table 6 reveals the performance improvements that occur at the lower end of the antenna passband. Relative to the original 100-ft model, the "Tau-tapered" model shows improved front-to-back ratio at every frequency. Gain at 3 MHz is improved so that it never drops below 5 dBi throughout the entire frequency range for the frequencies tested. Only at 18, 27 and 30 MHz is the gain of the new model slightly lower than for its companion. However, the frequencies at which we encounter broad forward lobes (BFL) remain constant between the two models. The

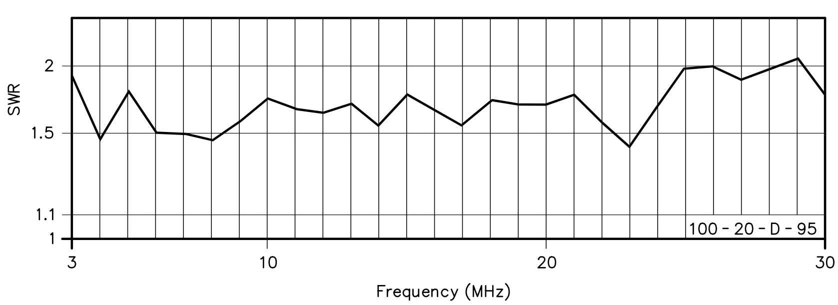

Fig 6—3-30 MHz SWR sweep of the 100-ft, 20-element LPDA model referenced to 95 Ω.

Table 4—Performance of the 100-ft, 20-element model LPDA at 3-MHz increments from 3-30 MHz "BFL" means broad forward lobe (see text).

Frequency (MHz)	*Free-Space Gain (dBi)*	*Front-to-Back Ratio (dB)*	*Source Impedance (R ± jX Ω)*	*SWR (95-Ω)*	
3	4.70	6.9	148 –*j*57	1.91	
6	6.02	15.2	67 –*j*18	1.52	
9	5.60	17.7	71 –*j*29	1.58	
12	4.95	19.1	61 –*j*17	1.64	BFL
15	5.56	21.8	167 –*j*11	1.77	
18	5.32	18.7	80 –*j*46	1.73	BFL
21	5.27	22.0	71 –*j*40	1.75	BFL
24	5.07	22.7	81 –*j*43	1.68	BFL
27	5.21	20.9	166 +*j*37	1.87	BFL
30	5.23	20.9	55 +*j*16	1.78	

Table 5 —Comparison of the element diameters for the initial and "Tau-tapered" versions of the 100-ft, 20-element LPDA model. Diameters are in inches.

Element	*Initial*	*Tau-Taper*
20	0.50	0.50
19	0.50	0.57
18	0.625	0.66
17	0.75	0.75
16	0.75	0.86
15	0.875	0.98
14	1.00	1.12
13	1.00	1.29
12	1.125	1.47
11	1.25	1.69
10	1.25	1.93
9	1.375	2.21
8	1.50	2.53
7	1.50	2.89
6	1.625	3.31
5	1.75	3.79
4	1.75	4.34
3	1.875	4.96
2	2.00	5.68
1	2.00	6.50

improvements at the lowest frequencies alone strongly suggest that the longest elements may benefit from increased diameter.

100-ft, 26-Element LPDA

If 20 elements provide a baseline of performance for the 100-ft long standard LPDA, would more elements yield further improvements? Additional elements would reduce the separation of resonant frequencies from one element to the next.

A 26-element model, outlined in Fig 8, was created using an extension of the original element-diameter scheme so that the longest elements are 2.5 inches in diameter. Despite the increased diameter of the longest element (still 167 ft long), there is considerable disparity of length-to-diameter ratio between it and the shortest element. Table 7 lists the element half-lengths and cumulative spacing for the model. *LPCAD* predicted a gain of 7 dBi, with front-to-back ratios ranging from 17 to 23 dB. The Tau for the model is 0.90, with a Sigma of 0.03. With a recommended 200-Ω interelement feed line, *LPCAD* predicted the feed-point impedance to be 93 Ω.

Modeling of the antenna on *NEC-4* suggested the use of a 150-Ω interelement feed line, with retention of the 90-inch terminating stub. The resulting SWR curve, referenced to 75 Ω as shown in Fig 9, is quite good. Excursions above 2:1 SWR values occur only at the high end of the passband.

Relative to the comparable 20-element model, the 26-element model shows detectable improvements in performance at virtually every test frequency. Gain is up by perhaps 0.25 dB on average, and the front-to-back ratio exceeds 20 dB more consistently. In almost all cases, the 26-element model also shows improvements over the "Tau-tapered" version of the 20-element model.

Nonetheless, as Table 8 demonstrates, the gain of the standard-design LPDA rarely reaches 6 dBi, a figure common to monoband two-element

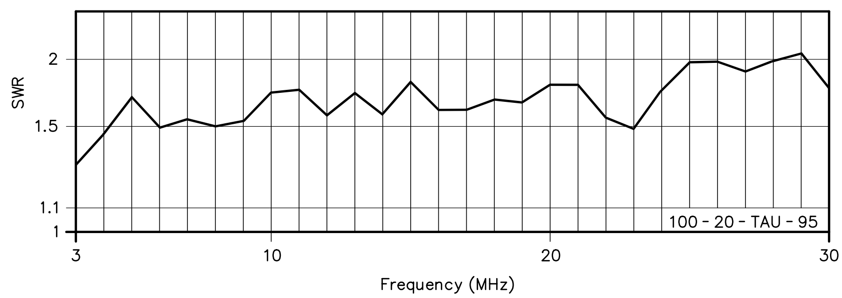

Fig 7—3-30 MHz SWR sweep of the 100-ft, 20-element LPDA model (with "Tau-tapered" element diameters) referenced to 95 Ω.

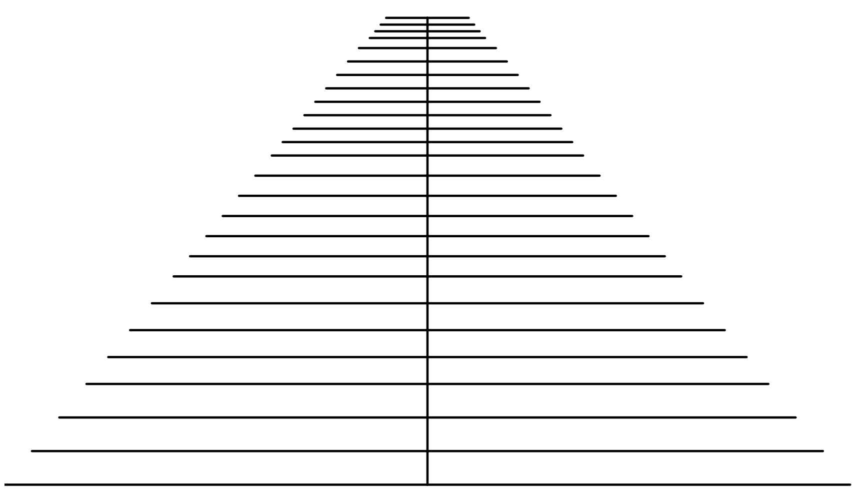

Fig 8—Outline of the 100-ft, 26-element 3-30 MHz LPDA.

Table 6—Performance of the 100-ft, 20-element model LPDA with "Tau-tapered" element diameters at 3-MHz increments from 3-30 MHz "BFL" means broad forward lobe (see text)

Frequency (MHz)	*Free-Space Gain (dBi)*	*Front-to-Back Ratio (dB)*	*Source Impedance (R ±jX Ω)*	*SWR (95-Ω)*	
3	5.05	8.3	85 –*j*22	1.31	
6	6.14	15.9	66 +*j*5	1.50	
9	5.61	18.4	64 –*j*15	1.54	
12	5.06	20.8	61 –*j*9	1.57	BFL
15	5.61	22.8	170 –*j*15	1.81	
18	5.20	19.3	80 –*j*44	1.69	BFL
21	5.41	23.1	71 –*j*42	1.79	BFL
24	5.15	22.8	86 –*j*50	1.74	BFL
27	5.01	21.3	159 +*j*47	1.89	BFL
30	5.18	22.1	55 +*j*12	1.76	

Table 7—Element half-lengths and cumulative spacing of the 100-ft, 26-element 3-30 MHz LPDA model

Element	*Half Length (inches)*	*Cumulative Spacing (inches)*
1	1003.68	0.00
2	905.81	126.76
3	817.49	241.17
4	737.77	344.41
5	655.83	437.59
6	600.91	521.69
7	542.31	597.58
8	489.43	666.07
9	441.71	727.89
10	398.64	783.64
11	359.76	834.02
12	324.68	879.46
13	293.02	920.47
14	264.45	957.47
15	238.66	990.87
16	215.39	1021.01
17	194.39	1048.22
18	175.43	1072.77
19	158.33	1094.93
20	142.89	1114.93
21	128.96	1132.97
22	116.38	1149.26
23	105.03	1163.96
24	94.79	1177.22
25	85.55	1189.20
26	77.21	1200.00

Yagis. The standard design predictions for gain, as reflected in the *LPCAD* implementation, overestimate gain by a full decibel. It likely would require a considerably longer boom to achieve the predicted 7 dBi figure in *NEC-4* models.

Except for diminished performance at the lowest test frequencies, this LPDA shows good consistency for most of the passband. The number of test frequencies at which we encounter broad forward lobes (BFL) is reduced relative to the 20-element model. If the modest forward gain figures are acceptable, this model or a variant would likely meet both the SWR and pattern-shape criteria set forth earlier in this study.

The 26-element model uses 2.5-inch diameter elements for the lowest frequencies—a significant increase over the largest diameter used in the 20-element model. Whether a "Tau-taper" element set might effect any improvements became the next question. With a Tau of 0.903, the requisite element set showed the sizes listed in Table 9, once more set against the element-diameter schedule for the initial 26-element model.

The resulting model uses the same 150 Ω inter-element transmission line as used in the initial 26-element model. The SWR curve is well behaved, with excursions into values above 2:1 occurring only at the upper frequencies. If we set the reference impedance to 65 Ω, the maximum SWR is about 2.17:1 at 28 and 29 MHz, as shown in Fig 10. Use of this reference value results in a rougher curve for other frequencies than it might otherwise be.

If we select 75 Ω as the reference impedance for the SWR curve, as was done for Fig 11, values for frequencies under 20 MHz show a lower SWR, but the peak SWR value at 28 MHz rises to 2.49:1. Of course, the actual source impedances have not changed, but the choice of reference impedance may have a bearing on the selection of means to match the antenna to a specific main feed line for the system.

Except for the lowest frequencies, the gain performance of the "Tau-tapered" version of this model is slightly under that of the initial model. The result owes partially to the greater diameter of the rear elements (2.5 inches) in the initial 26-element model. Table 10 is instructive. SWR values are referenced to 65 Ω. Except perhaps for 3 MHz, there is nothing overall to choose between the two 26-element models. The number of cases of "broad forward

Table 8—Performance of the 100-ft, 26-element model LPDA at 3-MHz increments from 3-30 MHz "BFL" means broad forward lobe (see text)

Frequency (MHz)	*Free-Space Gain (dBi)*	*Front-to-Back Ratio (dB)*	*Source Impedance (R ±jX Ω)*	*SWR (75-Ω)*	
3	5.08	8.5	71 –*j*7	1.12	
6	6.24	16.4	64 –*j*31	1.61	
9	5.97	18.4	92 –*j*34	1.58	
12	5.90	20.5	95 +*j*26	1.62	
15	5.65	19.8	117 +*j*15	1.61	BFL
18	5.95	21.2	51 +*j*21	1.68	
21	5.44	21.8	108 –*j*16	1.50	
24	5.80	22.4	67 –*j*37	1.69	BFL
27	5.66	21.8	49 –*j*30	1.91	BFL
30	5.69	20.6	106 –*j*49	1.89	

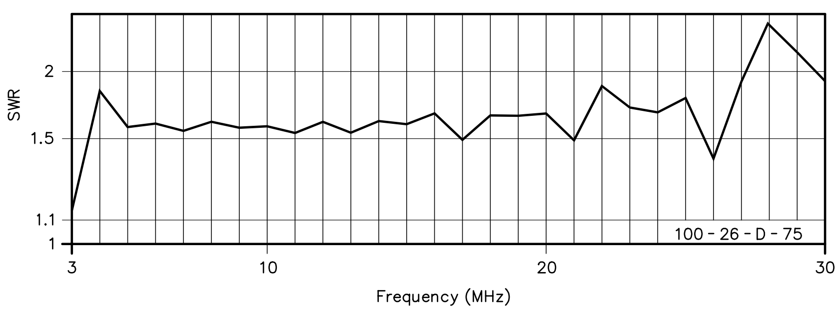

Fig 9—3-30 MHz SWR sweep of the 100-ft, 26-element LPDA model referenced to 75 Ω.

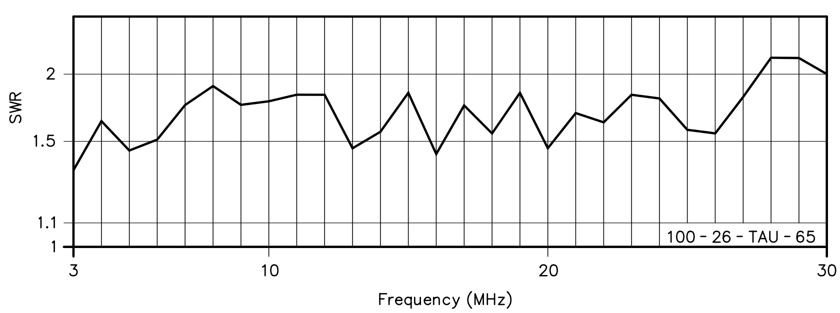

Fig 10—3-30 MHz SWR sweep of the 100-ft, 26-element LPDA model (with "Tau-tapered" element diameters) referenced to 65 Ω.

Table 9—Comparison of the element diameters for the initial and "Tau-tapered" versions of the 100-ft, 26-element LPDA model Diameters are in inches.

Element	*Initial*	*Tau-Taper*
26	0.50	0.50
25	0.50	0.56
24	0.625	0.62
23	0.75	0.69
22	0.75	0.76
21	0.875	0.85
20	1.00	0.94
19	1.00	1.04
18	1.125	1.15
17	1.25	1.27
16	1.25	1.41
15	1.375	1.56
14	1.50	1.73
13	1.50	1.91
12	1.625	2.12
11	1.75	2.34
10	1.75	2.59
9	1.825	2.87
8	2.00	3.18
7	2.00	3.52
6	2.125	3.90
5	2.25	4.32
4	2.25	4.79
3	2.375	5.30
2	2.50	5.87
1	2.50	6.50

lobe" (BFL) continues to diminish with each improved model.

However, the entire progression of models at the 100-ft length has shown significant improvements over the 60-ft model. How much improvement we have made can be judged by the following series of free-space azimuth patterns taken at 3, 9, 15 and 30 MHz. These are the same frequencies used for patterns of the 60-ft model. Directly comparing the patterns in Fig 12 with those in Fig 4 provides a measure of the improvements made by increasing the boom length and number of elements.

The 3-MHz pattern in Fig 12 shows the same circularity of the forward and rear lobes as does the 3 MHz 60-ft model pattern. However, the improved gain and front-to-back ratio are readily apparent. The 9-MHz pattern for the "Tau-tapered" 100-ft, 26-element model shows far better control (relative to the 60-ft model) of the rear lobe, despite its broadness.

The 60-ft model showed a many-lobed pattern at 15 MHz. In Fig 12, the 26-element model shows only forward and rearward lobes at the same frequency. The forward lobe is technically a double lobe, but the center-point is down only a fraction of a decibel, far too little to be detected in operation. Nonetheless, this lobe, like the lobes at many frequencies, continues to be somewhat broader than those associated with monoband Yagi antennas. At 30 MHz, the 26-element "Tau-tapered" model shows a similar pattern, although technically having only a single peak value. The irregularities on the sides of the forward lobe and all around the rear lobe are incipient secondary lobes created by the cumulative effects of the elements behind the shortest elements. Although current magnitudes in the longer elements are low, together they add remnant multiwavelength, multilobe facets to the 30-MHz pattern.

Fuller Frequency Sweeps

There are dangers associated with performing only spot performance checks at 3-MHz intervals. Therefore, I ran some 0.5-MHz-increment frequency sweeps of the tubing and the "Tau-tapered" element versions of the 100-ft, 26-element design. The purpose was to determine whether there were any hidden oddities of performance in either design. Although superior to checks at 3-MHz intervals,

Table 10—Performance of the 100-ft, 26-element model LPDA with "Tau-tapered" element diameters at 3-MHz increments from 3-30 MHz "BFL" means broad forward lobe (see text)

Frequency (MHz)	*Free-Space Gain (dBi)*	*Front-to-Back Ratio (dB)*	*Source Impedance (R ±jX Ω)*	*SWR (65 Ω)*	
3	5.38	9.9	71 +j17	1.30	
6	6.29	16.6	55 –j24	1.54	
9	5.80	18.5	85 –j38	1.75	
12	5.85	21.0	100 +j36	1.83	
15	5.56	19.5	117 +j20	1.87	BFL
18	5.80	21.1	48 +j17	1.56	
21	5.44	21.8	110 –j10	1.70	
24	5.76	22.6	72 –j41	1.81	BFL
27	5.57	22.4	51 –j32	1.83	
30	5.47	21.2	101 –j45	1.99	

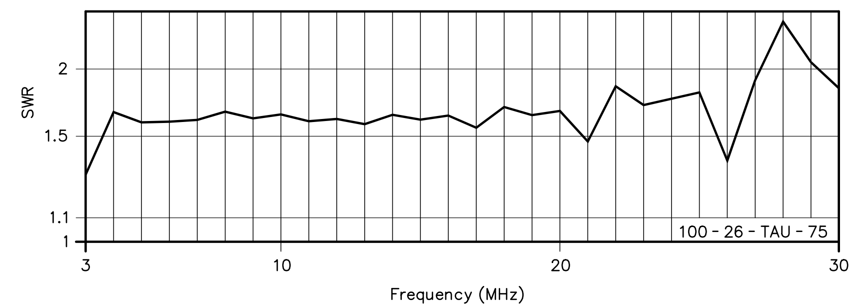

Fig 11—3-30 MHz SWR sweep of the 100-ft, 26-element LPDA model (with "Tau-tapered" element diameters) referenced to 75 Ω.

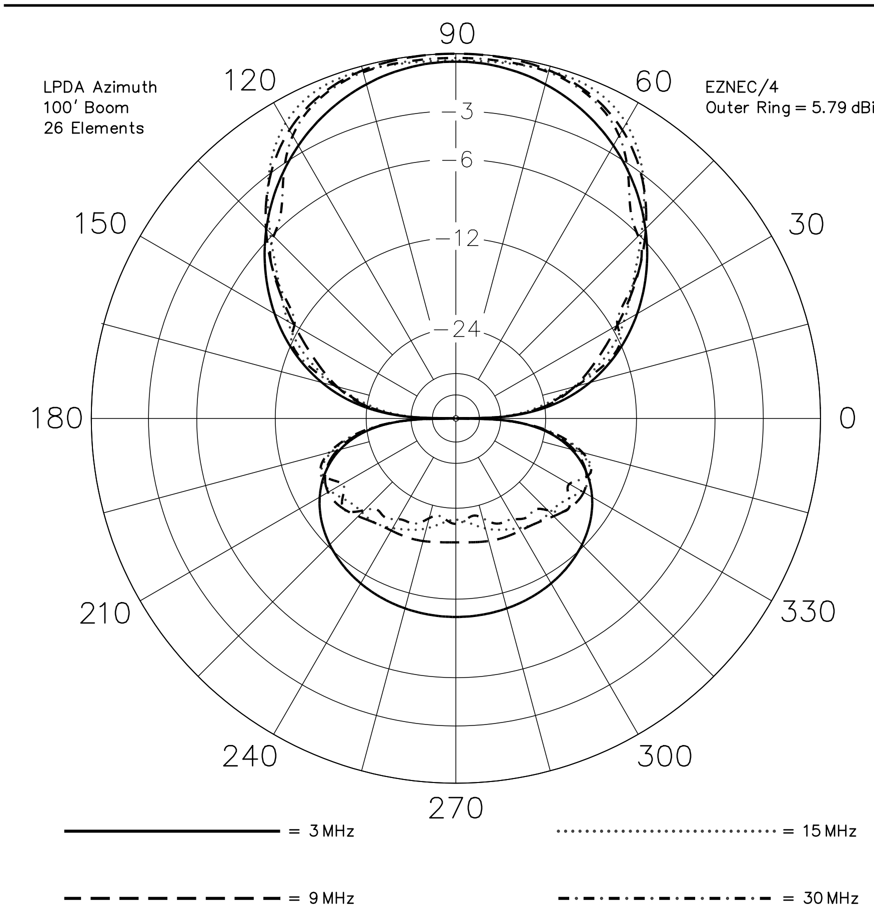

Fig 12—Free-space azimuth pattern of the 100-ft, 26-element LPDA model at 3, 9, 15 and 30 MHz.

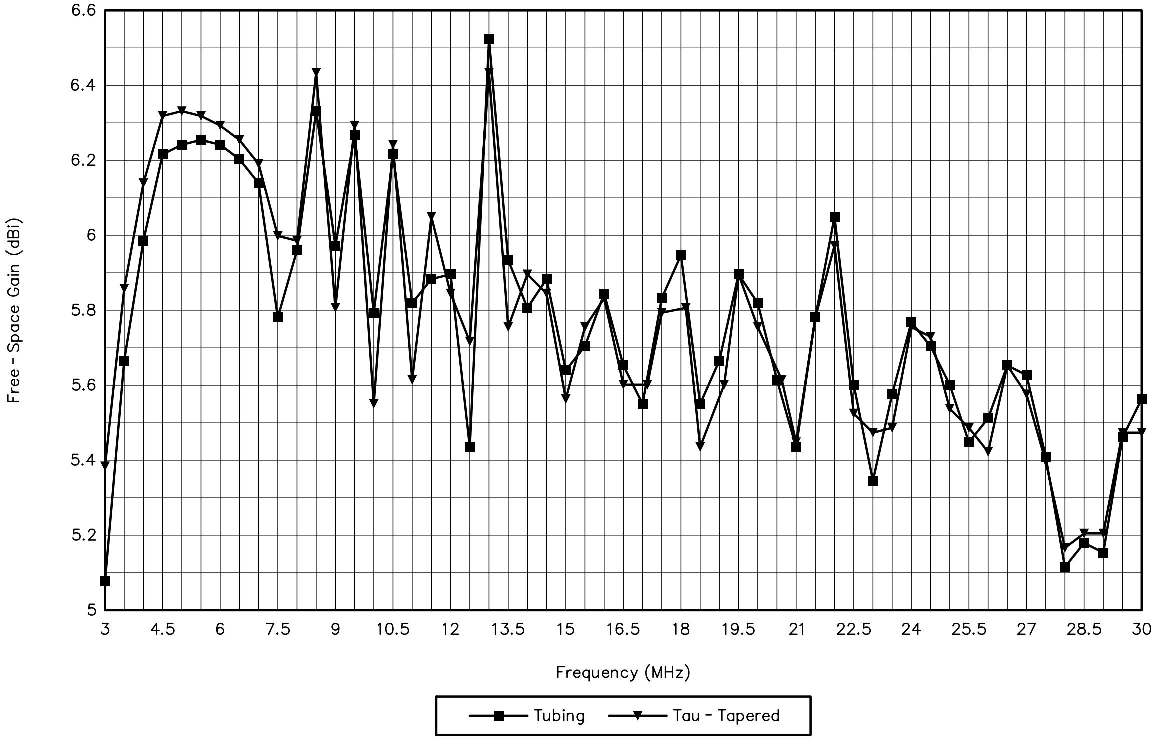

Fig 13—Frequency sweep at 0.5 MHz intervals of free-space gain (dBi) for both versions of the 100-ft, 26-element LPDA model.

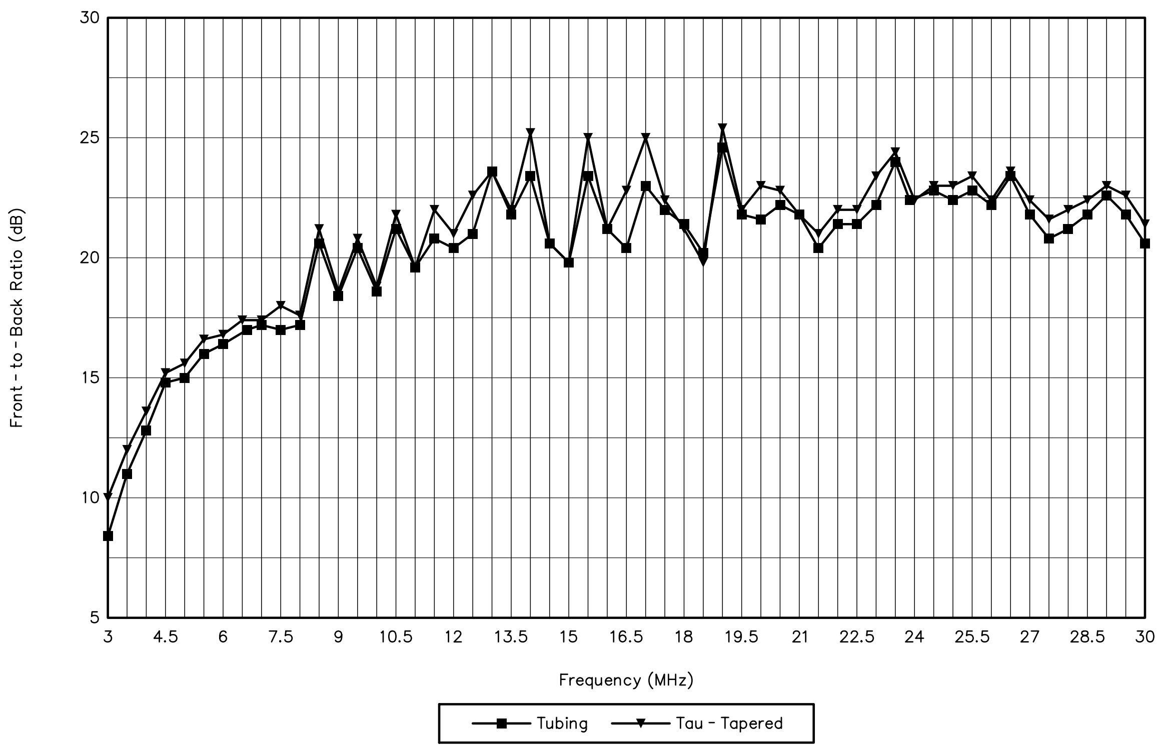

Fig 14—Frequency sweep at 0.5 MHz intervals of the front-to-back ratio (in dB) for both versions of the 100-ft, 26-element LPDA model.

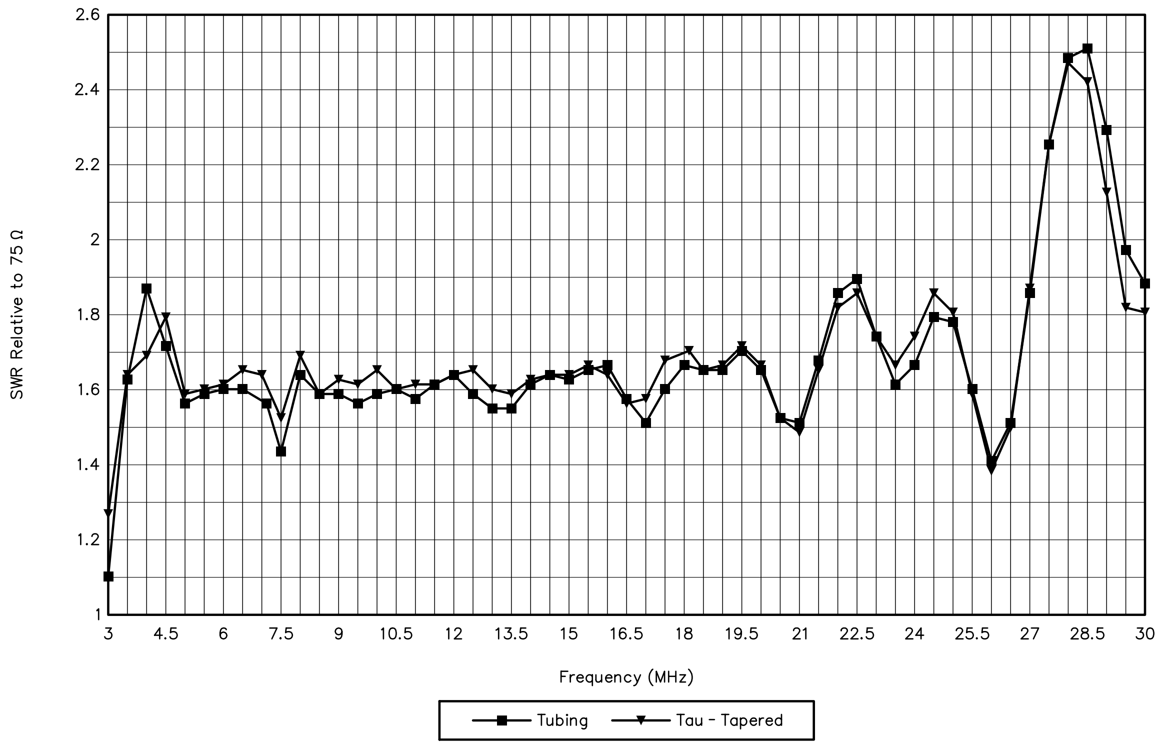

Fig 15—Frequency sweep at 0.5 MHz intervals of the 75-Ω SWR for both versions of the 100-ft, 26-element LPDA model.

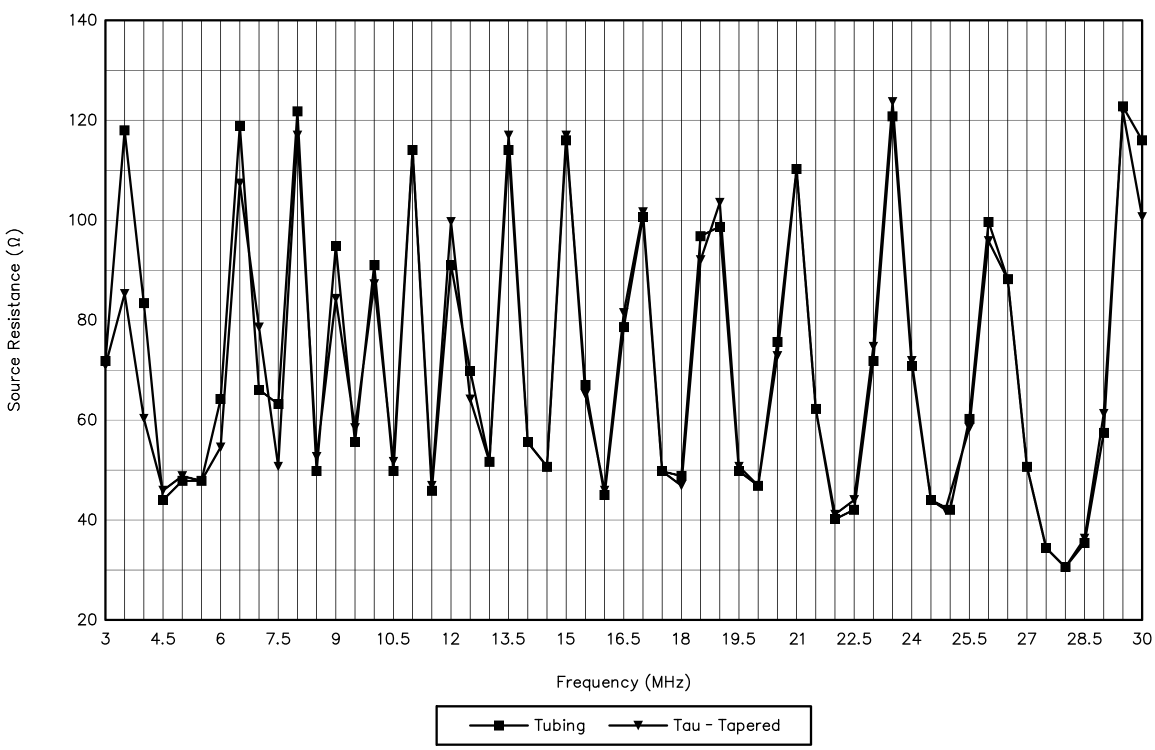

Fig 16—Frequency sweep at 0.5-MHz intervals of the feedpoint resistance (Ω) for both versions of the 100-ft, 26-element LPDA model.

even 0.5-MHz increments can miss some properties. Therefore, every LPDA design of interest should be swept at smaller intervals across every portion of the spectrum at which operation is contemplated.

The free-space gain graph in Fig 13 shows relatively good coincidence between the two design variants. However, in the lower third of the passband, the tubing version, which is limited to a maximum element diameter of 2.5 inches, shows greater excursions of free-space gain, including significantly lower values at 3 and 12.5 MHz.

The 180° front-to-back curves in Fig 14 are remarkably coincident across the entire passband. The 90-inch 150-Ω shorted stub used on both models smoothes the curve below 8.5 MHz, above which frequency the familiar sawtooth LPDA progression of values re-emerges.

The three final graphs should be read in this order: 75-Ω SWR (Fig 15), Source Resistance (Fig 16) and Source Reactance (Fig 17). The SWR curve in Fig 15 is quite smooth through at least 20 MHz, average a little over 1.6:1 relative to a 75-Ω standard. The illusion created by this curve is that the source impedance has a fairly constant value across this range. As the following Source Resistance graph (Fig 16) shows, the actual resistive impedance varies over a range greater than 4:1. What holds the SWR values to a narrow range is the reactance associated with each resistance value, which appears in Fig 17. Resistance values near the impedance standard of 75 Ω are accompanied by high inductive or capacitive reactance values. Resistive values more distant from the standard have associated reactance values that are much lower. The exception is in the 27.5 to 29 MHz range, where low resistance values are accompanied by high reactance values.

Indeed, the fuller frequency sweeps did uncover some interesting properties of the 100-ft, 26-element LPDAs that the wider-interval checks left obscure. Initially, the curves were developed to compare the tubing and the "Tau-tapered" element designs, but the interesting properties that emerged applied equally to both models.

Tentative Conclusions

Of the models evaluated in this part of the preliminary study, the 100-ft, 26-element versions provide the best overall performance. Additional elements within the 100-ft length are unlikely to add significantly to performance. Only additional boom length—to provide a more satisfactory value of Sigma—would show increases in gain. However, the gain advantage may be offset by a reduction in lower-frequency performance if the element density is not maintained. With the element density set to at least 20 elements per 100 ft of boom and up to 26 elements per 100 ft, obtaining a satisfactory SWR curve and well-controlled pattern shapes for the array should pose no major problem.

Some modification of low-frequency performance can be obtained by adjustments to the terminating stub. In all cases, the final length should be obtained by experiment on the physical antenna in order to make all due allowance for interelement transmission-line losses, which the *NEC-4* models cannot take into account. As well, the shortest elements active in the formation of the 27 to 30 MHz patterns should be experimentally adjusted to obtain the best patterns and the most satisfactory impedance values. However, such empirical adjustments may also throw off the feedpoint impedance,

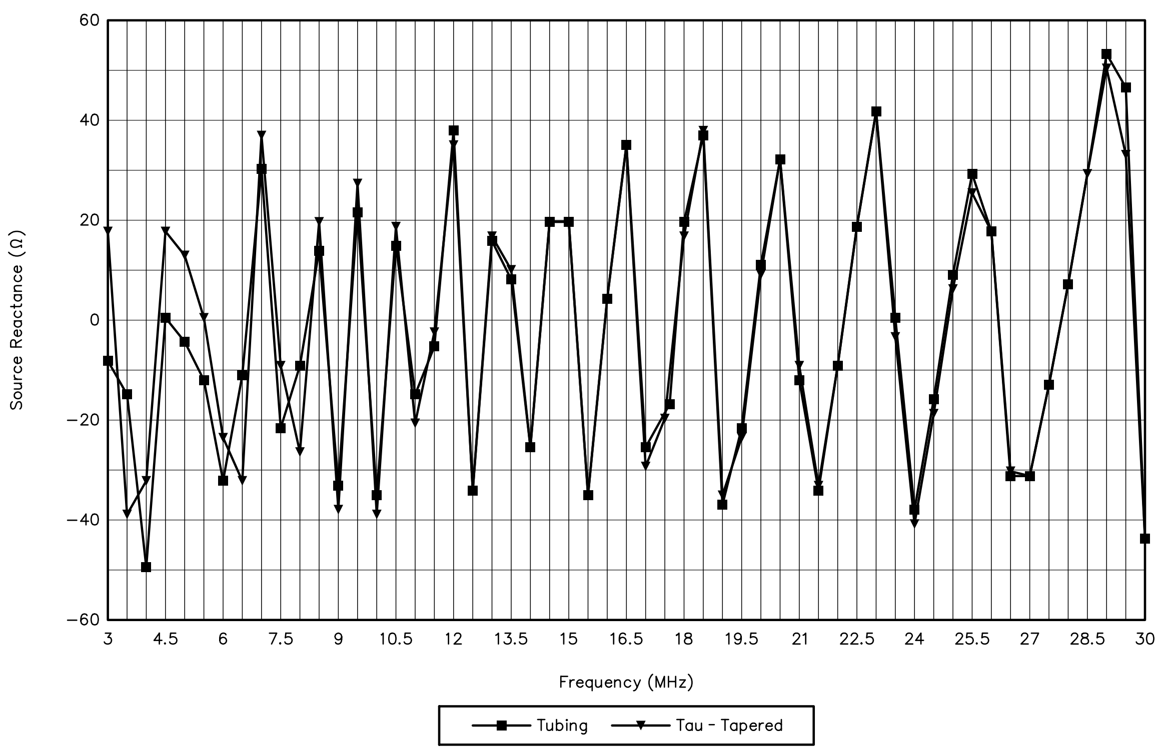

Fig 17—Frequency sweep at 0.5-MHz intervals of the feedpoint reactance (Ω) for both versions of the 100-ft, 26-element LPDA model.

even at frequencies distant from the ones for which element lengths and spacings are changed.

All of the models examined in these preliminary notes are of standard LPDA design. No attempt to use periodic element length techniques or other suggested enhancements has been attempted. Moreover, there are apparently some proprietary alternative algorithms said to provide improved performance across the 3-30 MHz spectrum. These algorithms are not accessible to me at present and therefore the designs that might result from them cannot be evaluated. Nonetheless, the general trends of standard LPDA designs have proven instructive in themselves.

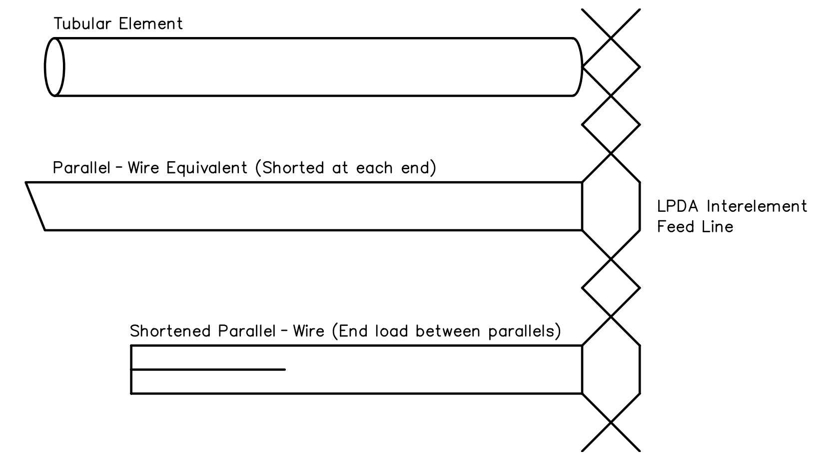

Fig 18—Evolution from tubular elements to equivalent wire elements to possible shortened-wire elements.

Tau-Tapered Element Design

True "Tau-tapered" elements result in impractical element diameters. However, an alternative construction method might use wire instead of tubing.

For a given element with an assigned tubular diameter, there will be a self-resonant frequency. One may construct the same element in skeleton form from wire. The length can be made equal to the original element and the spacing between wires adjusted until the wire element is resonant on the same frequency as the original tubular element. The principle is illustrated in Fig 18.

As a practical—although still hypothetical—example, let us take the longest element of the 100-ft, 20-element "Tau-tapered" array. This element in tubular form is 6.5 inches in diameter. The element is 2007.36 inches (167.28 ft) long. Isolated, it is resonant at 2.796 MHz, with a source impedance of 72.00 $-j0.02$ Ω. An equivalent #10-aluminum-wire element of the same length requires that the pair of wires be shorted at both their outer ends and at the feed point. Under these conditions, a spacing of 14 inches yields a resonant element at 2.796 MHz with an impedance of 70.53 + $j0.08$ Ω. There is a 0.02-dB deficit in gain owing to the slightly higher loss of the wire element.

Now let us shorten the wire element to 1680 inches (140 ft) or 840 inches each side of center. If we run a wire from the center of the outer end shorting wire toward the feed point to a position 67.4 inches away from the feed point, we again achieve resonance at 2.796 MHz. The loading effect reduces the element impedance to 46.50 + $j0.88$ Ω, and the gain is further decreased 0.25 dB. The seven-inch spacing between wires is sufficient to prevent arcing between wires for any power level.

Whether the shortened element would yield acceptable performance at the lower end of the 3-30 MHz passband has not been determined with models. However, the technique represents one of the simplest methods of shortening elements and preserving much of the current distribution on the element's center in an all-wire LPDA design.

A Final Question: Gain

The low gain of the LPDA models we have so far examined likely has two causes. First is the short boom length used, which results in borderline values for Sigma, in the 0.03 region. Ideal values for Sigma result in wider-spaced elements on much longer booms.

A second cause for the low gain, especially as it tapers off below 9 MHz, lies in the use of thin elements. Programs like *LPCAD* calculate element lengths based on a length-to-diameter ratio of 125, whereas even in the "Tau-tapered" models, the ratio is about 300:1. In general, as frequency increases, there is no gain problem, since the effective region of activity can simply move rearward for any frequency relative to what the active region would be for an idealized design. For the lowest frequencies, the longest element sets the limit of how far back the active region can move.

However, gain at the lowest design frequency is not solely a function of the longest element. It is also a function of the number and arrangement of elements forward of the longest element. Whichever way one wishes to achieve more gain, there is no escaping the need for a longer boom. We shall examine some longer designs in Part 2.

Antenna Model Descriptions

You can download this package from the ARRL Web site http://www.arrl.org/files/*qex*/. Look for LPDAPT1.ZIP.

60' 20-Element 3-30 MHz LPDA   Frequency = 3 MHz.

Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000,	0.000	1003.68, 0.000, 0.000	2.00E+00	105
2		876.93, 98.500,	0.000	876.930, 98.500, 0.000	2.00E+00	87
3		766.19,184.560,	0.000	766.190,184.560, 0.000	1.87E+00	75
4		669.44,259.750,	0.000	669.440,259.750, 0.000	1.75E+00	69
5		584.90,325.450,	0.000	584.900,325.450, 0.000	1.75E+00	57
6		511.04,382.850,	0.000	511.040,382.850, 0.000	1.62E+00	49
7		446.50,433.000,	0.000	446.500,433.000, 0.000	1.50E+00	43
8		390.12,476.820,	0.000	390.120,476.820, 0.000	1.50E+00	39
9		340.85,515.110,	0.000	340.850,515.110, 0.000	1.38E+00	37
10		297.81,546.560,	0.000	297.810,548.560, 0.000	1.25E+00	35
11		260.20,577.790,	0.000	260.200,577.790, 0.000	1.25E+00	33
12		227.34,603.320,	0.000	227.340,603.320, 0.000	1.12E+00	31
13		198.65,625.630,	0.000	198.650,625.630, 0.000	1.00E+00	29
14		173.55,645.130,	0.000	173.550,645.130, 0.000	1.00E+00	27
15		151.63,662.160,	0.000	151.630,662.160, 0.000	8.75E01	25
16		132.49,677.040,	0.000	132.490,677.040, 0.000	7.50E01	23
17		115.76,690.040,	0.000	115.760,690.040, 0.000	7.50E01	21
18		101.14,701.400,	0.000	101.140,701.400, 0.000	7.50E01	19
19		88.370,711.330,	0.000	88.370,711.330, 0.000	6.25E01	17
20		77.210,720.000,	0.000	77.210,720.000, 0.000	5.00E01	15

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	8	20 / 50.00	(20 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	150.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	150.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	150.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	150.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	150.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	150.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	150.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	150.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	150.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	150.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	150.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	150.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	150.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	150.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	150.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	150.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	150.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	150.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	150.0	1.00	R

Ground type is Free Space

100' 20-Element 3-30 MHz LPDA   Frequency = 10 MHz.

Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000,	0.000	1003.68, 0.000, 0.000	2.00E+00	105
2		876.93,164.170,	0.000	876.930,164.170, 0.000	2.00E+00	87
3		766.19,307.600,	0.000	766.190,307.600, 0.000	1.87E+00	75
4		669.44,432.920,	0.000	669.440,432.920, 0.000	1.75E+00	69
5		584.90,542.420,	0.000	584.900,542.420, 0.000	1.75E+00	57
6		511.04,638.090,	0.000	511.040,638.090, 0.000	1.62E+00	49
7		446.50,721.680,	0.000	446.500,721.680, 0.000	1.50E+00	43
8		390.12,794.710,	0.000	390.120,794.710, 0.000	1.50E+00	39
9		340.85,858.520,	0.000	340.850,858.520, 0.000	1.38E+00	37
10		297.81,914.280,	0.000	297.810,914.280, 0.000	1.25E+00	35
11		260.20,962.980,	0.000	260.200,962.980, 0.000	1.25E+00	33
12		227.34,1005.54,	0.000	227.340,1005.54, 0.000	1.12E+00	31
13		198.65,1042.72,	0.000	198.650,1042.72, 0.000	1.00E+00	29
14		173.55,1075.21,	0.000	173.550,1075.21, 0.000	1.00E+00	27
15		151.63,1103.60,	0.000	151.630,1103.60, 0.000	8.75E01	25
16		132.49,1128.40,	0.000	132.490,1128.40, 0.000	7.50E01	23
17		115.76,1150.07,	0.000	115.760,1150.07, 0.000	7.50E01	21
18		101.14,1169.00,	0.000	101.140,1169.00, 0.000	7.50E01	19
19		88.370,1185.55,	0.000	88.370,1185.55, 0.000	6.25E01	17
20		77.210,1200.00,	0.000	77.210,1200.00, 0.000	5.00E01	15

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	8	20 / 50.00	(20 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	200.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	200.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	200.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	200.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	200.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	200.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	200.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	200.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	200.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	200.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	200.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	200.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	200.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	200.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	200.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	200.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	200.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	200.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	200.0	1.00	R
20	1/50.0	(1/50.0)	Short ckt	(Short ck)	90.000 in	200.0	1.00	

Ground type is Free Space

100' 20-Element 3-30 MHz LPDA, "Tau-tapered" elements   Frequency = 10 MHz.

Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000,	0.000	1003.68, 0.000, 0.000	6.50E+00	105
2		876.93,164.170,	0.000	876.930,164.170, 0.000	5.68E+00	87
3		766.19,307.600,	0.000	766.190,307.600, 0.000	4.96E+00	75
4		669.44,432.920,	0.000	669.440,432.920, 0.000	4.33E+00	69
5		584.90,542.420,	0.000	584.900,542.420, 0.000	3.79E+00	57
6		511.04,638.090,	0.000	511.040,638.090, 0.000	3.31E+00	49
7		446.50,721.680,	0.000	446.500,721.680, 0.000	2.89E+00	43
8		390.12,794.710,	0.000	390.120,794.710, 0.000	2.53E+00	39
9		340.85,858.520,	0.000	340.850,858.520, 0.000	2.20E+00	37
10		297.81,914.280,	0.000	297.810,914.280, 0.000	1.93E+00	35
11		260.20,962.980,	0.000	260.200,962.980, 0.000	1.69E+00	33
12		227.34,1005.54,	0.000	227.340,1005.54, 0.000	1.47E+00	31
13		198.65,1042.72,	0.000	198.650,1042.72, 0.000	1.29E+00	29
14		173.55,1075.21,	0.000	173.550,1075.21, 0.000	1.12E+00	27
15		151.63,1103.60,	0.000	151.630,1103.60, 0.000	9.80E01	25
16		132.49,1128.40,	0.000	132.490,1128.40, 0.000	8.60E01	23
17		115.76,1150.07,	0.000	115.760,1150.07, 0.000	7.50E01	21
18		101.14,1169.00,	0.000	101.140,1169.00, 0.000	6.60E01	19
19		88.370,1185.55,	0.000	88.370,1185.55, 0.000	5.70E01	17
20		77.210,1200.00,	0.000	77.210,1200.00, 0.000	5.00E01	15

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	8	20 / 50.00	(20 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	200.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	200.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	200.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	200.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	200.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	200.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	200.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	200.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	200.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	200.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	200.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	200.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	200.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	200.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	200.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	200.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	200.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	200.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	200.0	1.00	R
20	1/50.0	(1/50.0)	Short ckt	(Short ck)	90.000 in	200.0	1.00	

Ground type is Free Space

100' 26-Element 3-30 MHz LPDA Frequency = 10 MHz.

Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000, 0.000		1003.68, 0.000, 0.000	2.50E+00	107
2		905.81,126.760, 0.000		905.810,126.760, 0.000	2.50E+00	97
3		817.49,241.170, 0.000		817.490,241.170, 0.000	2.38E+00	87
4		737.77,344.410, 0.000		737.770,344.410, 0.000	2.25E+00	79
5		655.83,437.590, 0.000		655.830,437.590, 0.000	2.25E+00	71
6		600.91,521.690, 0.000		600.910,521.690, 0.000	2.12E+00	65
7		542.31,597.580, 0.000		542.310,597.580, 0.000	2.00E+00	57
8		489.43,666.070, 0.000		489.430,666.070, 0.000	2.00E+00	53
9		441.71,727.890, 0.000		441.710,727.890, 0.000	1.87E+00	47
10		398.64,783.640, 0.000		398.640,783.640, 0.000	1.75E+00	43
11		359.76,834.020, 0.000		359.760,834.020, 0.000	1.75E+00	39
12		324.68,879.460, 0.000		324.680,879.460, 0.000	1.62E+00	35
13		293.02,920.470, 0.000		293.020,920.470, 0.000	1.50E+00	31
14		264.45,957.470, 0.000		264.450,957.470, 0.000	1.50E+00	29
15		238.66,990.870, 0.000		238.660,990.870, 0.000	1.38E+00	25
16		215.39,1021.01, 0.000		215.390,1021.01, 0.000	1.25E+00	23
17		194.39,1048.22, 0.000		194.390,1048.22, 0.000	1.25E+00	21
18		175.43,1072.77, 0.000		175.430,1072.77, 0.000	1.12E+00	19
19		158.33,1094.93, 0.000		158.330,1094.93, 0.000	1.00E+00	17
20		142.89,1114.93, 0.000		142.890,1114.93, 0.000	1.00E+00	15
21		128.96,1132.97, 0.000		128.960,1132.97, 0.000	8.75E01	15
22		116.38,1149.26, 0.000		116.380,1149.26, 0.000	7.50E01	13
23		105.03,1163.96, 0.000		105.030,1163.96, 0.000	7.50E01	11
24		94.790,1177.22, 0.000		94.790,1177.22, 0.000	6.25E01	11
25		85.550,1189.20, 0.000		85.550,1189.20, 0.000	5.00E01	9
26		77.210,1200.00, 0.000		77.210,1200.00, 0.000	5.00E01	9

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	5	26 / 50.00	(26 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	150.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	150.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	150.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	150.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	150.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	150.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	150.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	150.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	150.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	150.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	150.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	150.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	150.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	150.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	150.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	150.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	150.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	150.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	150.0	1.00	R
20	20/50.0	(20/50.0)	21/50.0	(21/50.0)	Actual dist	150.0	1.00	R
21	21/50.0	(21/50.0)	22/50.0	(22/50.0)	Actual dist	150.0	1.00	R
22	22/50.0	(22/50.0)	23/50.0	(23/50.0)	Actual dist	150.0	1.00	R
23	23/50.0	(23/50.0)	24/50.0	(24/50.0)	Actual dist	150.0	1.00	R
24	24/50.0	(24/50.0)	25/50.0	(25/50.0)	Actual dist	150.0	1.00	R
25	25/50.0	(25/50.0)	26/50.0	(26/50.0)	Actual dist	150.0	1.00	R
26	1/50.0	(1/50.0)	Short ckt	(Short ck)	90.000 in	150.0	1.00	

Ground type is Free Space

100' 26-Element 3-30 MHz LPDA, "Tau-tapered" elements   Frequency = 10 MHz.

Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000,	0.000	1003.68, 0.000, 0.000	6.50E+00	107
2		905.81,126.760,	0.000	905.810,126.760, 0.000	5.87E+00	97
3		817.49,241.170,	0.000	817.490,241.170, 0.000	5.30E+00	87
4		737.77,344.410,	0.000	737.770,344.410, 0.000	4.79E+00	79
5		655.83,437.590,	0.000	655.830,437.590, 0.000	4.32E+00	71
6		600.91,521.690,	0.000	600.910,521.690, 0.000	3.90E+00	65
7		542.31,597.580,	0.000	542.310,597.580, 0.000	3.52E+00	57
8		489.43,666.070,	0.000	489.430,666.070, 0.000	3.18E+00	53
9		441.71,727.890,	0.000	441.710,727.890, 0.000	2.87E+00	47
10		398.64,783.640,	0.000	398.640,783.640, 0.000	2.59E+00	43
11		359.76,834.020,	0.000	359.760,834.020, 0.000	2.34E+00	39
12		324.68,879.460,	0.000	324.680,879.460, 0.000	2.12E+00	35
13		293.02,920.470,	0.000	293.020,920.470, 0.000	1.91E+00	31
14		264.45,957.470,	0.000	264.450,957.470, 0.000	1.73E+00	29
15		238.66,990.870,	0.000	238.660,990.870, 0.000	1.56E+00	25
16		215.39,1021.01,	0.000	215.390,1021.01, 0.000	1.41E+00	23
17		194.39,1048.22,	0.000	194.390,1048.22, 0.000	1.27E+00	21
18		175.43,1072.77,	0.000	175.430,1072.77, 0.000	1.15E+00	19
19		158.33,1094.93,	0.000	158.330,1094.93, 0.000	1.04E+00	17
20		142.89,1114.93,	0.000	142.890,1114.93, 0.000	9.40E01	15
21		128.96,1132.97,	0.000	128.960,1132.97, 0.000	8.40E01	15
22		116.38,1149.26,	0.000	116.380,1149.26, 0.000	7.60E01	13
23		105.03,1163.96,	0.000	105.030,1163.96, 0.000	6.90E01	11
24		94.790,1177.22,	0.000	94.790,1177.22, 0.000	6.20E01	11
25		85.550,1189.20,	0.000	85.550,1189.20, 0.000	5.60E01	9
26		77.210,1200.00,	0.000	77.210,1200.00, 0.000	5.00E01	9

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	5	26 / 50.00	(26 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 Ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	150.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	150.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	150.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	150.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	150.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	150.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	150.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	150.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	150.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	150.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	150.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	150.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	150.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	150.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	150.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	150.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	150.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	150.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	150.0	1.00	R
20	20/50.0	(20/50.0)	21/50.0	(21/50.0)	Actual dist	150.0	1.00	R
21	21/50.0	(21/50.0)	22/50.0	(22/50.0)	Actual dist	150.0	1.00	R
22	22/50.0	(22/50.0)	23/50.0	(23/50.0)	Actual dist	150.0	1.00	R
23	23/50.0	(23/50.0)	24/50.0	(24/50.0)	Actual dist	150.0	1.00	R
24	24/50.0	(24/50.0)	25/50.0	(25/50.0)	Actual dist	150.0	1.00	R
25	25/50.0	(25/50.0)	26/50.0	(26/50.0)	Actual dist	150.0	1.00	R
26	1/50.0	(1/50.0)	Short ckt	(Short ck)	90.000 in	150.0	1.00	

Ground type is Free Space

Notes on Standard Design LPDAs for 3-30 MHz Pt 2: 164-Foot Boom Designs

Let's analyze two longer designs in search of maximum HF gain, summarize what we've learned and consider avenues for further exploration.

By L. B. Cebik, W4RNL

Part 2 of these preliminary design notes adds the criterion of gain to those used in Part 1 (*QEX/Communications Quarterly*, May/June 2000): a usable SWR curve and good pattern control. The present exercise looks at a pair of designs based on increasing the array length again. One design expands the 26-element design to fill the 164-foot boom length, which results in a Tau of 0.9 and a Sigma of 0.05. The other design maintains the segment density of the 100-foot model by selecting a Tau of 0.94, with a resulting Sigma of 0.032. The number of elements in the larger array is 42. Both arrays were designed using "Tau-tapered" element diameters between 0.5 and 6.5 inches.

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Both designs are capable of a free-space gain of about 7 dBi over much of the 3-30 MHz design passband, but not over all of it. The 26-element design falls short at the lower end of the spectrum, while the 42-element array shows reduced gain above 24 MHz. The front-to-back ratios of both designs are quite satisfactory for most operating circumstances, and obtaining usable SWR curves across the entire passband is no longer a problem.

The notes will also briefly explore the temptation to spot-modify LPDAs to enhance performance at one or more frequencies. The results often produce unpleasant surprises at other frequen-cies with no obvious harmonic relationship to the optimized frequency. Finally, we shall see the utility of making more detailed frequency sweeps across the intended passband of a given design.

Preliminary Design and Modeling Considerations

Because of time constraints, the sampling of different models had necessary limits. The models all require at least 1000 segments to meet minimal segmentation density requirements across the range from 3 to 30 MHz. The larger model approaches 1700 segments in 42 wires. Even on a 400-MHz computer, 1-MHz-increment frequency sweeps across the passband required from 30 to 60 minutes.

Consequently, model construction

required considerable selectivity. A boom length of 164 feet resulted from considering various preliminary designs. The length is nearly the same percentage increment above the 100-foot designs as those were above the initial 60-foot design.

The models presented in this part of the notes represent two different design philosophies, despite the use of a constant 164-foot boom length. The 26-element model sought to increase Sigma to a better value by expanding the spacing between elements relative to the 100-foot design of Part 1. The design goal was to achieve a higher gain throughout the passband, whatever might be the results for source impedance, front-to-back ratio and pattern shape.

The 42-element design resulted from trying to sustain an element density similar to that used in the 100-foot 26-element design. The goal was to maintain the high front-to-back ratio and smooth SWR curve across the passband—with special emphasis on the lower frequencies—and to let the gain and pattern shape be whatever might emerge.

Although the 100-foot designs required terminating stubs for the inter-element transmission lines, neither of the two 164-foot designs seemed to benefit significantly from the terminations. Therefore, as a further move toward simplification, the stubs were omitted from the present design models.

164-foot, 26-Element LPDA

By increasing the boom length of the 26-element LPDA to 164 feet, the value of Sigma increases to about 0.05. This value is closer to optimal for highest gain from the array, since the spacing between elements is increased significantly (as the outline in Fig 1 shows). Selection of the precise length was made, in fact, by the second of our two models, which was designed by selecting both Tau and Sigma and allowing the length to be what it would. However, the 164-foot length proved useful, since it increased the array length over the 100-foot models by nearly two-thirds, the same ratio as between the 100 and 60-foot models. Therefore, to equalize lengths between the two designs used here, the 164-foot length was retained for both.

Table 1 provides a listing of element half-lengths and cumulative element spacing for the 164-foot, 26-element model. To maintain a relatively constant length-to-diameter ratio, "Tau-

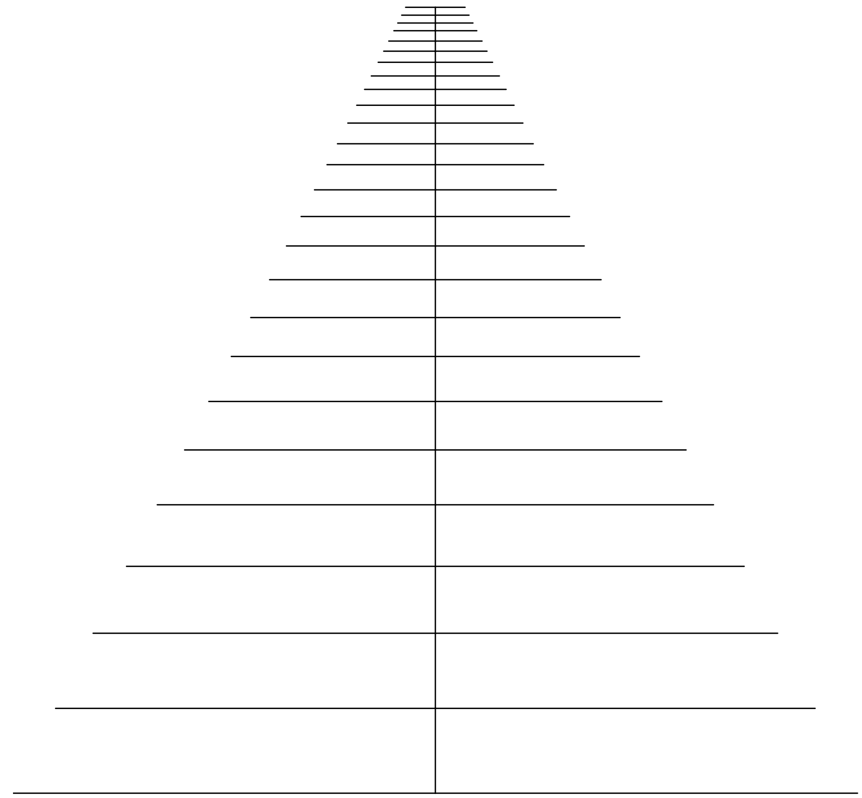

Fig 1—Outline of the 164-foot, 26-element 3-30 MHz LPDA; Tau = 0.90, Sigma = 0.05.

Table 1—Element half-lengths and cumulative spacing of the 164-foot, 26-element 3-30 MHz LPDA model.

Element No.	*Half Length (inches)*	*Cumulative Spacing (inches)*
1	1003.68	0.00
2	905.81	208.31
3	817.49	396.32
4	737.77	565.99
5	655.83	719.11
6	600.91	857.30
7	542.31	982.02
8	489.43	1094.58
9	441.71	1196.16
10	398.64	1287.84
11	359.76	1370.57
12	324.68	1445.24
13	293.02	1512.63
14	264.45	1573.45
15	238.66	1628.34
16	215.39	1677.87
17	194.39	1722.58
18	175.43	1762.92
19	158.33	1799.33
20	142.89	1832.19
21	128.96	1861.85
22	116.38	1888.62
23	105.03	1912.77
24	94.79	1934.57
25	85.55	1954.24
26	77.21	1972.00

tapering" was used for element diameters as well as lengths. Although noted in Part 1, the list of diameters is repeated in Table 2 for reference. As in past diameter tables, the progression is from the smallest to the largest element.

The omission of the terminating stub left open a question: What characteristic impedance would be best for the interelement transmission line? Therefore, the model was examined at 3-MHz intervals for its primary characteristics (free-space gain, front-to-back ratio and source impedance) to see if there was an advantage to one value over another. Characteristic impedances of 100, 150, 200 and 250 Ω were used at each check frequency. The results are recorded in Table 3. "Gain" is free-space gain in dBi; "Front-to-Back" is the 180° front-to-back ratio in decibels; and "Impedance" is the feedpoint or source impedance recorded as resistance ± reactance in ohms. The highest gain and front-to-back values for each frequency are marked with an asterisk.

Certain trends are immediately apparent. First, the highest gain figures occur at the lowest interelement transmission-line characteristic impedance. Second, as the frequency increases, the gain values tend to fall off more rapidly with increasing values of transmission-line impedance. Consequently, it would appear that the use of 100-Ω line would be automatic. At that value, all frequencies except 3 MHz would show a free-space gain of at least 7.0 dBi.

Before we select a line value, let's examine some of the free-space azimuth patterns yielded by the model. The 150-Ω, 3-MHz pattern shown in Fig 2, for example, is perfectly normal relative to expectations of pattern shape that we developed from looking at smaller models. To this point, we have come to expect the gain and front-to-back ratio of the array at 3 MHz to be lower than at every other frequency.

At 30 MHz, the 150-Ω pattern exhibits irregularities, as shown in Fig 2, indicating incipient side lobes. The spade-shaped forward lobe is also unusual. The irregularities grow more prominent with further reductions in transmission-line impedance. At 21 and 24 MHz, detectable side lobes appear in both the forward and rearward quadrants with a line impedance of 100 Ω, although they shrink to small irregularities with line values of 150 Ω.

Perhaps the worst case occurs at 18 MHz. The overlaid patterns in Fig 3 are for line values of 100 and 150 Ω. The triple rear lobes and side lobes on the forward lobe are clear for the lower line value. To a large measure, they diminish by increasing the line value to 150 Ω, although a smooth pattern is not obtained until the line value reaches 200 Ω. There are stub techniques for overcoming some pattern disturbances when using lower line-impedance values, but for the present exercise, they were not used.

In addition to pattern irregularities with low values of line impedance, the use of a 100-Ω line also produces a high source-impedance value (>100 Ω) at 3 MHz. This high impedance value shows up clearly when the SWR for the

Table 2—"Tau-tapered" element diameters for the 164-foot, 26-element 3-30 MHz LPDA.

Element No.	*Diameter (Inches)*	*Element No.*	*Diameter (Inches)*
26	0.50	13	1.91
25	0.56	12	2.12
24	0.62	11	2.34
23	0.69	10	2.59
22	0.76	9	2.87
21	0.85	8	3.18
20	0.94	7	3.52
19	1.04	6	3.90
18	1.15	5	4.32
17	1.27	4	4.79
16	1.41	3	5.30
15	1.56	2	5.87
14	1.73	1	6.50

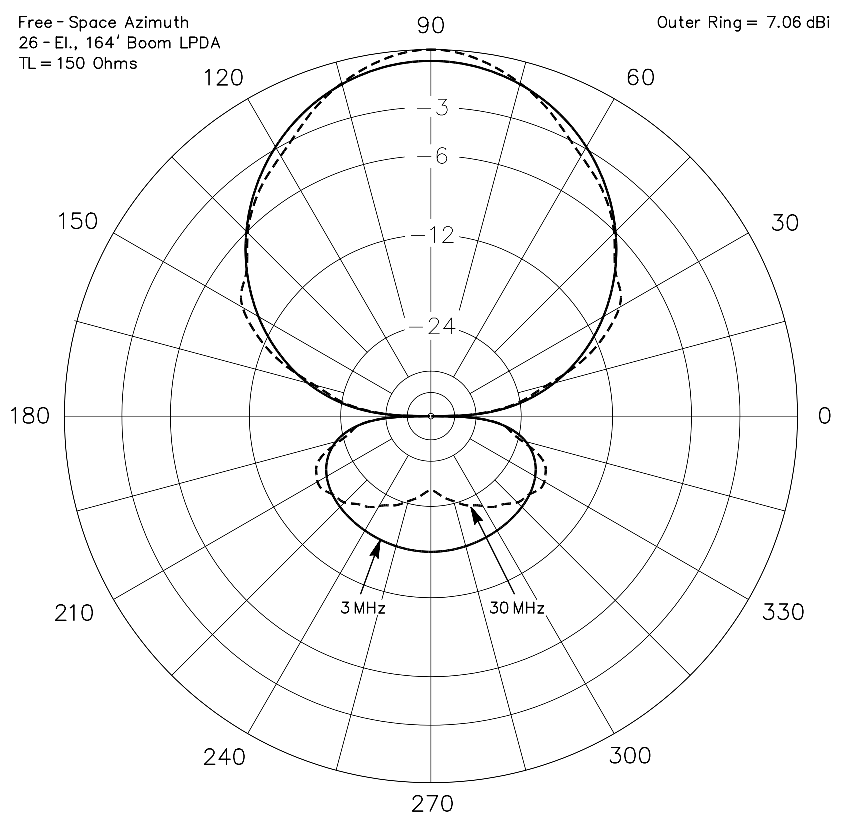

Fig 2—Free-space azimuth patterns of the 164-foot, 26-element LPDA model at 3 and 30 MHz.

Table 3—Performance of the 164-foot, 26-element model LPDA at 3-MHz increments from 3 to 30 MHz with different phase-line characteristic impedances.

Frequency	*Inter-Element Transmission Line Impedance (Ω)*			
	100	*150*	*200*	*250*
3 MHz				
Gain	6.57*	6.52	6.47	6.42
Front-to-Back	17.1*	16.5	16.1	15.7
Impedance	104. –*j*1	84. –*j*32	82. +*j*0	120. +*j*36
6 MHz				
Gain	7.00*	6.99	6.97	6.95
Front-to-Back	22.4	22.8	23.0	23.1*
Impedance	59. +*j*6	104. –*j*14	134. –*j*14	126. –*j*30
9 MHz				
Gain	7.81*	7.51	7.33	7.22
Front-to-Back	27.3*	26.2	25.6	25.3
Impedance	57. –*j*4	83. +*j*12	125. +*j*14	153. –*j*13
12 MHz				
Gain	7.85*	7.49	7.26	7.12
Front-to-Back	27.0	27.3	27.5	27.6*
Impedance	75. –*j*12	80. –*j*14	90. +*j*1	114. +*j*18
15 MHz				
Gain	7.99*	7.59	7.34	7.19
Front-to-Back	31.9*	29.8	29.2	29.0
Impedance	70. –*j*12	78. –*j*11	92. +*j*2	118. +*j*16
18 MHz				
Gain	7.54*	7.38	7.22	7.11
Front-to-Back	21.3	26.1	28.6	29.8*
Impedance	80. +*j*4	104. –*j*16	106. –*j*27	106. –*j*23
21 MHz				
Gain	7.26*	7.06	6.90	6.82
Front-to-Back	35.3*	29.2	28.0	27.5
Impedance	58. –*j*10	70. –*j*3	87. +*j*9	114. +*j*21
24 MHz				
Gain	7.54*	7.12	6.83	6.63
Front-to-Back	31.4*	30.0	29.7	29.3
Impedance	53. –*j*5	73. +*j*2	99. +*j*5	125. –*j*3
27 MHz				
Gain	7.49*	7.01	6.72	6.58
Front-to-Back	24.9	26.1	26.4	26.6*
Impedance	41. +*j*1	55. +*j*14	77. +*j*29	110. +*j*40
30 MHz				
Gain	7.49*	7.06	6.81	6.67
Front-to-Back	27.4	27.4	27.6	27.6*
Impedance	47. –*j*17	56. –*j*12	69. –*j*3	89. +*j*3

100-Ω-line model is plotted from 3 to 30 MHz in 1-MHz steps, as the graph in Fig 4 demonstrates. The highest value of 50-Ω SWR other than at 3 MHz occurs at 29 MHz: only 1.84:1. The use of a shorted terminating stub (90 inches of 100-Ω line) reduces the 3-MHz impedance to 62 –*j*19 Ω, well within the 2:1 SWR range desired; however, there are alternatives to the use of a terminating stub.

If the SWR curve is referenced to 65 Ω, as it is in Fig 5, no value of SWR rises above 1.6:1. As noted in Part 1, none of the impedance values have changed, but the reference impedance for the smoothest curve may help determine the best way to match the antenna to the main feed line for the array.

The SWR curve for a 150-Ω line is interesting when the reference value is 75 Ω. See Fig 6. The highest value of SWR is 1.6:1, and the SWR exceeds 1.5:1 at only three of the frequencies checked in the 1-MHz-increment sweep. Consequently, direct feed of the system with a 75-Ω main feed line is feasible.

The SWR curve for a 200-Ω line when referenced to 95 Ω is even smoother, as shown in Fig 7. This curve suggests the use of a 2:1 balun at the feed point with a 50-Ω main feed line. A reminder is due here. Although checks at 1-MHz intervals indicate a smooth curve, they do not guarantee that every intermediate frequency will be as well behaved. Were one to seriously consider implementing one or more of these study designs, a more thorough sweep would be in order.

Perhaps the best compromise among the criteria of gain, pattern smoothness and SWR is achieved by the version with a 150-Ω interelement transmission line. It provides about 7 dBi of free-space gain from 6 MHz upward, with only the low end of the band exhibiting lesser performance. However, should such a design be used with "Tau-tapered" wire elements according to the suggestion made in Part 1, one might expect at least a 0.1 to 0.2 dB reduction in gain, since the effects of the small gain deficit for the wire equivalents are cumulative for all active elements at any particular frequency.

164-foot, 42-Element LPDA

Although the 26-element LPDA might fulfill about 90% of the demands for such an array, it still suffers reduced gain and front-to-back ratio below 6 MHz. Therefore, it seemed appropriate to see whether an alternative design might show improvements in this regard. It would be obvious to try a design having about the same element density as the 100-foot 26-element design of Part 1. The result is a 42-element model with a Tau of 0.94 and a Sigma of 0.032. The outline of the design appears in Fig 8. Table 4 lists the element half-lengths and cumulative spacing for this model.

Standard LPDA design theory, as implemented in *LPCAD*, predicts a free-space gain of about 7.5 dBi and a front-to-back range of 22 to 28 dB. For the most part, the actual antenna as modeled in *NEC-4* will show less gain and superior front-to-back ratios.

In accord with the 26-element model, the 42-element model used "Tau-tapered" element diameters. Because of the greater number of elements, the tapering schedule differs, as Table 5 shows.

When checked across a set of line-impedance values and at 3-MHz intervals across the passband, the element-dense LPDA exhibits some interesting properties, some of which are at odds with the 26-element model. For example, the most favored interelement transmission-line characteristic impedance will be higher, rather than lower. Likewise, the best performance occurs at the lower end of the 3-30 MHz passband. The results are summarized in Table 6, which is a corresponds to Table 3 for the preceding model.

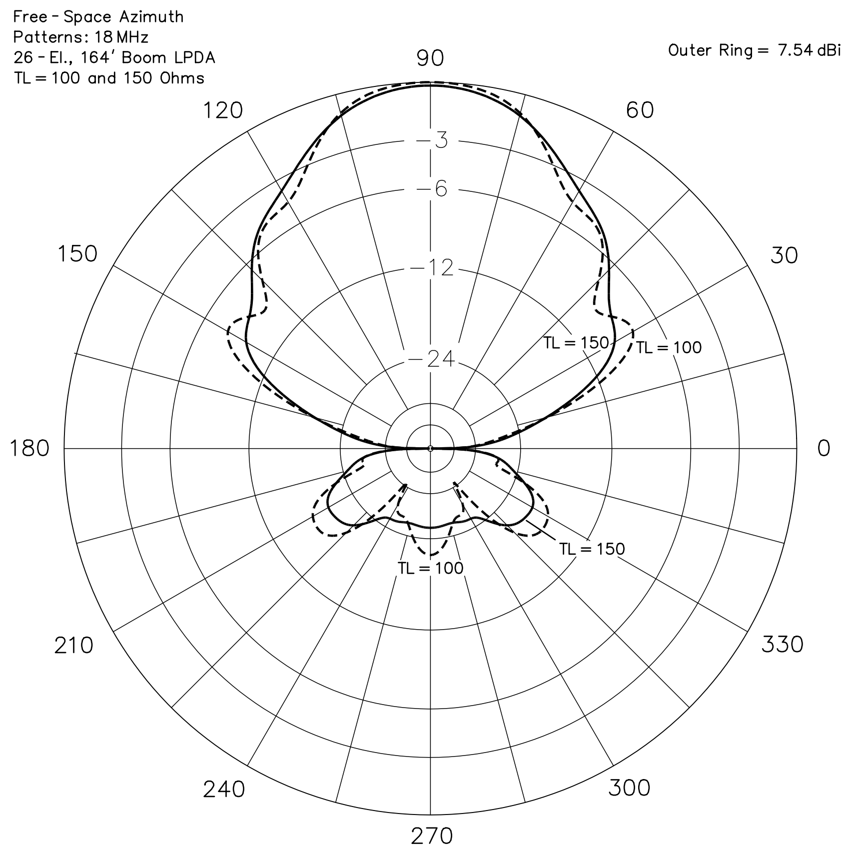

Fig 3—Free-space azimuth pattern of the 164-foot, 26-element LPDA model at 18 MHz with 100 Ω and 150 Ω transmission lines.

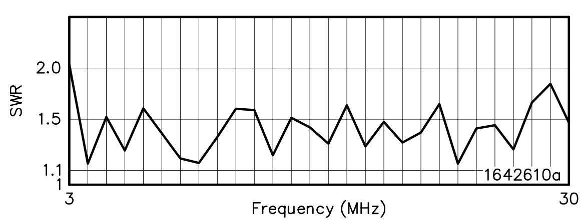

Fig 4—3-30 MHz SWR sweep of the 164-foot, 26-element LPDA model referenced to 50 Ω with a 100-Ω phase line.

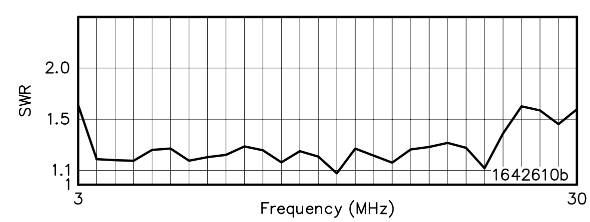

Fig 5—3-30 MHz SWR sweep of the 164-foot 26-element LPDA model referenced to 65 Ω with a 100-Ω phase line.

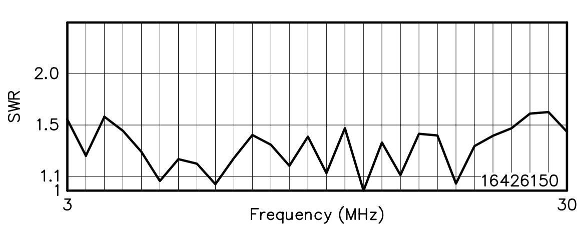

Fig 6—3-30 MHz SWR sweep of the 164-foot 26-element LPDA model referenced to 75 Ω with a 150-Ω phase line.

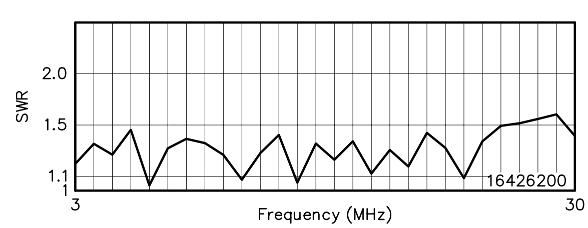

Fig 7—3-30 MHz SWR sweep of the 164-foot 26-element LPDA model referenced to 95 Ω with a 200-Ω phase line.

Perhaps the most notable trend is that the greatest number of peak values of gain and front-to-back ratio occur when using a 250-Ω transmission line (9 of 20 possible values). Indeed, 4 of the 10 gain peaks occur with the highest transmission-line impedance. Although the highest gain value for 3 MHz occurs with a 100-Ω line, its free-space gain is still well above 7.0 dBi with a very satisfactory front-to-back ratio when the array uses a 250-Ω line. Therefore, we may focus our attention on this version of the array in further comments on performance.

Unlike all other models of 3-30 MHz LPDAs that we have examined, the free-space azimuth pattern for 3 MHz (using the 250-Ω line) is a model of Yagi-like behavior. (See Fig 9.) The worst-case front-to-back ratio is above 22 dB at the peak of the rear lobes. Up to about 9 to 10 MHz, this particular design shows performance superior to the 26-element design.

Nonetheless, it is perhaps unreasonable to expect a 3.5-octave LPDA of standard design to show such characteristics throughout its entire passband. We may sample another pattern or two to see the array return to behavior more normal for LPDAs.

The free-space azimuth pattern for 15 MHz in Fig 9 is quite well behaved. However, the rear lobes show the beginning of irregularity relative to standard Yagi-based expectations of smoothly curved lobes. The rear lobes in this case are a bit blocky, but perhaps less so than some of the models we explored in Part 1. Incidentally, 15 MHz is about the frequency beyond which the large array ceases to show superior performance relative to the 26-element model we examined earlier. As Table 6 reveals, free-space gain from 15 through 30 MHz rarely equals that obtainable from the 26-element model with its more optimal Sigma value.

The free-space azimuth pattern for 27 MHz in Fig 9 shows evidence of the "blockiness" and irregularities that we tend to expect from standard-design LPDAs that do not use compensating stubs or other corrections. Although the pattern might be perfectly acceptable for virtually every application, a certain "squaring" of both the forward and rear lobes is evident. The blocking of the pattern would be even more evident if we had a comparable monoband Yagi pattern to place over this LPDA pattern.

Nonetheless, the 42-element, 164-foot-long LPDA design shows greater pattern control than the 26-element model of the same length. There are no instances of spade-shaped forward lobes and no tendencies toward detectable side lobes. Irregularities are minor, compared to the pattern outlines of the 26-element model at upper frequencies in the passband at the most favored line impedances. Despite the array's lower gain at upper HF frequencies, the 42-element array provides very good pattern control throughout its range.

The consequences of lower performance at upper HF frequencies extend to the SWR curve, as we can see in Fig 10. When using a 75-Ω standard, we can reduce the peak SWR value at 29 MHz to 2.10:1; however, the remainder of the curve shows irregularities that are absent if we select 100 Ω as the reference impedance.

The 100-Ω curve in Fig 10 shows exceptionally good values up to about 24 MHz. Only at 23 MHz does the SWR exceed 1.4:1. Most of the values above 24 MHz are greater than 1.4:1, with

Table 4—Element half-lengths and cumulative spacing of the 164-foot, 42–element 3–30 MHz LPDA model.

Element No.	*Half Length (inches)*	*Cumulative Spacing (inches)*
1	1003.68	0.00
2	943.46	128.47
3	888.35	249.23
4	833.64	362.75
5	783.62	469.46
6	736.60	569.76
7	692.41	664.05
8	650.86	752.67
9	611.81	835.99
10	575.10	914.30
11	540.60	987.91
12	508.16	1057.11
13	477.67	1122.15
14	449.01	1183.29
15	422.07	1240.77
16	396.75	1294.79
17	372.94	1345.58
18	350.57	1393.31
19	329.53	1438.18
20	309.76	1480.36
21	291.17	1520.01
22	273.70	1557.28
23	257.20	1592.32
24	241.84	1625.25
25	227.33	1656.21
26	213.69	1685.30
27	200.87	1712.66
28	188.82	1738.37
29	177.49	1762.54
30	166.84	1785.26
31	156.83	1806.61
32	147.42	1826.69
33	138.58	1845.56
34	130.26	1863.29
35	122.45	1879.97
36	115.10	1895.64
37	108.19	1910.37
38	101.70	1924.22
39	95.60	1937.24
40	89.86	1949.48
41	84.47	1960.98
42	79.40	1971.79

29 MHz showing a value of 2.8:1 relative to the 100-Ω standard—a function of the low resistive value of the impedance at that frequency. One must begin to suspect that the element density at the higher end of the HF range for this design is not optimal for either gain or source impedance.

We may graph the gain values for the two models and derive a bit more data, as evidenced by Fig 11. The graph uses the 250-Ω version of the 42-element array and the 150-Ω version of the 26-element array as perhaps the best of each design. Except for frequencies below about 7 MHz, the 26-element design shows considerably higher gain at most frequencies. The gain of the 42-element model remains consistent until just past 21 MHz, after which it decreases rapidly. The 26-element design shows peak gain between 9 and 19 MHz, but drops below 7 dBi only at 3 and 6 MHz.

With respect to 180° front-to-back ratio (shown in Fig 12), the 42-element array shows the more consistent curve. The advantage of the 42-element model is especially clear below 6 MHz. Above that frequency, both antennas show values of front-to-back ratio that would satisfy the most stringent operating specifications: values in excess of 25 dB across most of the passband.

Because the graphs employ the most favored version of each array, they cannot display certain design weaknesses. For example, the 42-element LPDA design shows periodic depressions in its gain. These depressions show themselves most clearly through the tabular performance listings for a 100-Ω interelement transmission line. Gain values drop well below 7 dBi at 9, 18 and 27 MHz and at 15 and 30 MHz.

Table 5—"Tau-tapered" element diameters for the 164-foot, 42-element 3-30 MHz LPDA.

Element	*Diameter (Inches)*	*Element*	*Diameter (Inches)*	*Element*	*Diameter (Inches)*
42	0.50	28	1.22	14	2.91
41	0.55	27	1.30	13	3.09
40	0.58	26	1.38	12	3.29
39	0.62	25	1.47	11	3.50
38	0.66	24	1.57	10	3.72
37	0.70	23	1.67	9	3.96
36	0.75	22	1.77	8	4.22
35	0.79	21	1.89	7	4.48
34	0.84	20	2.00	6	4.77
33	0.90	19	2.13	5	5.07
32	0.95	18	2.27	4	5.40
31	1.02	17	2.42	3	5.74
30	1.08	16	2.57	2	6.11
29	1.15	15	2.73	1	6.50

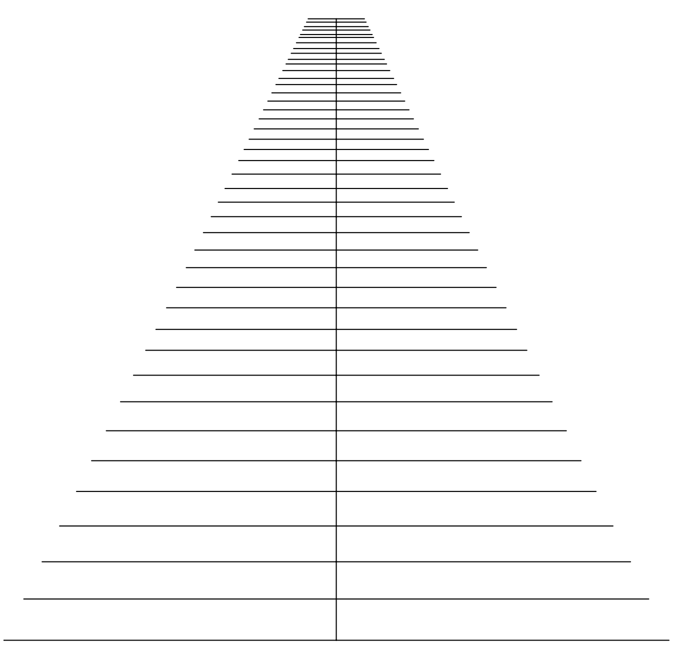

Fig 8—Outline of the 164-foot, 42-element 3-30 MHz LPDA; Tau = 0.94, Sigma = 0.032.

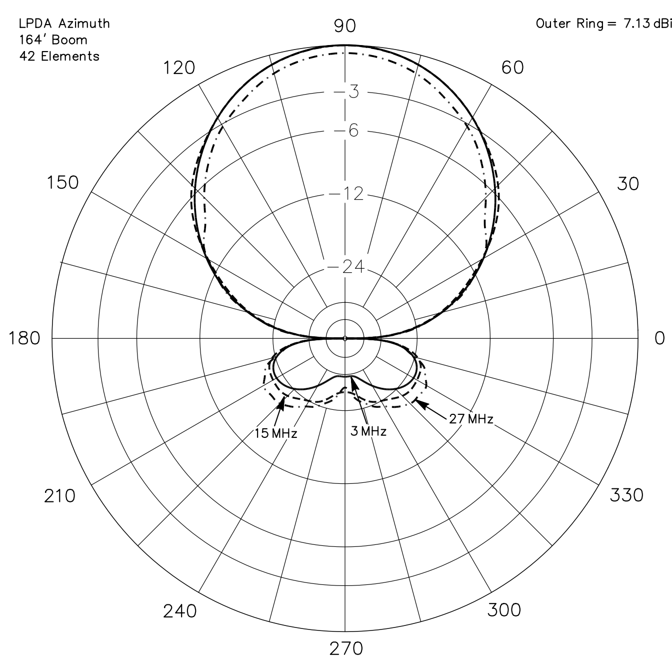

Fig 9—Free-space azimuth pattern of the 164-foot, 42-element LPDA model at 3, 15 and 27 MHz.

Both sets of lower gain values are harmonically related. To what degree harmonically related phenomena are endemic to long LPDA designs with higher element densities would be found through the examination of many more very large models.

Given our limited choice of two designs, the wider-spaced 26-element model shows fewer weaknesses than the larger design, despite the superior performance of the 42-element model at frequencies below 9 MHz. With a 150-Ω interelement transmission line, the 26-element model with "Tau-tapered" element diameters might well meet many sets of operational specifications.

Optimizing an LPDA

Before closing the book on the 164-foot, 26-element design, it may be interesting to flirt with the temptation to manually optimize the lower-frequency performance of the array. With the calculated lengths, the two longest elements are resonant at roughly 2.8 and 3.1 MHz. The high length-to-diameter ratio might suggest that we lengthen the rear element, but, in fact, precisely the opposite tack is required to improve performance at 3 MHz.

How far one should carry an optimizing process—especially when performed manually—is a matter of judgment. At 3 MHz, the original design showed a free-space gain of 6.52 dBi when using the 150-Ω transmission line. The front-to-back ratio was 16.5 dB. For the present exercise, the goal was a front-to-back ratio of at least 20 dB, with whatever gain increase the process might yield. The goal was achieved with a resultant gain of 6.75 dBi.

The final changes involved only the rear two elements. The rearmost element began at 2007 inches. It was shortened to 1960 inches and moved rearward 24 inches (thus increasing the antenna length by 2 feet). The second-longest element was increased from 1811.6 to 1814 inches. No other changes were necessary to produce the reported gain and front-to-back ratio. Source impedance was 75 –*j*39 Ω, an easily manageable value when referenced to 75 Ω in accord with the original model. See Table 7 for a listing of element half-lengths and cumulative spacing.

Spot optimization of LPDAs is a somewhat dangerous process, though, unless a thorough frequency sweep is performed for both the original and final products. Table 8 lists perform-

Table 6—Performance of the 164-foot, 42-element model LPDA at 3-MHz increments from 3 to 30 MHz with different phase-line characteristic impedances.

Frequency	***Inter-Element Transmission Line Impedance (ohms)***			
	100	*150*	*200*	*250*
3 MHz				
Gain	7.26*	7.21	7.17	7.13
Front-to-Back	32.6	36.0	36.9*	35.0
Impedance	61. +*j*8	79. –*j*15	72. +*j*6	119. +*j*27
6 MHz				
Gain	7.22	7.22	7.22	7.22
Front-to-Back	24.5*	24.5	24.4	24.4*
Impedance	67. +*j*8	75. –*j*14	77. +*j*5	115. +*j*16
9 MHz				
Gain	6.77	6.99	7.06	7.10*
Front-to-Back	25.2	25.4	25.5	25.6*
Impedance	55. –*j*10	67. +*j*8	107. +*j*8	110. –*j*22
12 MHz				
Gain	7.03*	7.25	7.29*	7.25
Front-to-Back	27.8	27.9	28.1	28.2*
Impedance	59. +*j*10	87. –*j*11	78. –*j*14	87. +*j*5
15 MHz				
Gain	6.71	6.90	7.02	7.12*
Front-to-Back	29.2*	29.1	29.0	29.1
Impedance	56. –*j*10	61. +*j*2	90. +*j*14	121. –*j*6
18 MHz				
Gain	6.56	6.80	6.90	6.96*
Front-to-Back	30.5	30.5	30.8	30.8*
Impedance	68. –*j*3	67. –*j*15	71. –*j*3	93. +*j*7
21 MHz				
Gain	7.02	7.11*	7.08	7.00
Front-to-Back	31.2*	31.2	30.9	30.4
Impedance	46. –*j*9	70. +*j*4	87. +*j*5	105. –*j*14
24 MHz				
Gain	6.72	6.81*	6.76	6.64
Front-to-Back	30.5*	30.3	30.1	29.7
Impedance	43. –*j*11	54. +*j*2	80. +*j*8	104. –*j*9
27 MHz				
Gain	6.56	6.69	6.71*	6.66
Front-to-Back	29.6	29.8	30.1	30.1*
Impedance	74. –*j*11	59. –*j*27	54. –*j*16	63. –*j*2
30 MHz				
Gain	5.91	6.02	6.11	6.20*
Front-to-Back	26.5	26.9	27.0	27.3*
Impedance	20. +*j*4	59. –*j*27	53. +*j*41	101. +*j*53

ance figures for the original and the modified 26-element designs using a 150-Ω line. As an additional reference, performance values are also listed for the 42-element design. The checkpoints for this table are in 1-MHz increments between 3 and 9 MHz. The remaining values from 10 to 30 MHz for the 26-element design change by less than 0.03 dB in gain and 0.2 dB in front-to-back ratio. These changes are operationally insignificant.

The third column in Table 8 is simply a convenient way to confirm the consistent performance of the 42-element array in the lower third of the spectrum for which the antenna is designed. The chief purpose of the table, however, is to demonstrate a performance anomaly created by manual-optimizing activity. Although 3-MHz performance has been improved by about 0.25 dB in gain and by 3.5 dB in front-to-back ratio, the modification of the two rearmost elements has seriously disturbed 5 MHz performance. Despite the fact that neither element seems relevant to 5-MHz performance (since their resonances are at least 2 MHz lower), the 5-MHz front-to-back ratio has dropped below 10 dB: a 5.5 dB decrease.

One of the enduring myths about LPDA designs is that only the two elements closest to the one nearest resonance are truly active. An intermediate frequency might bring four elements into play. Actually, all elements are active all the time at all frequencies. At least two to three elements on each side of a nearly resonant element carry significant current and are very influential on performance. Resonance and pure harmonic relationships do not appear to be requisites for a distant element to affect the performance of the array on various frequencies.

In the present case, the modifications have adverse consequences on 5-MHz performance. Had the frequency region of reduced front-to-back ratio not appeared on one of the spot-check frequencies, it might well have been missed. As a result, spot modifications must be undertaken with great care, and a subsequent frequency sweep of the final design at all frequencies of interest is recommended.

The 164-foot, 26 Element LPDA: More thorough Sweeping

Because of the suggestion above, I undertook a performance sweep of the 164-foot, 26-element model. Among the models evaluated, this model appeared to be the most promising with respect

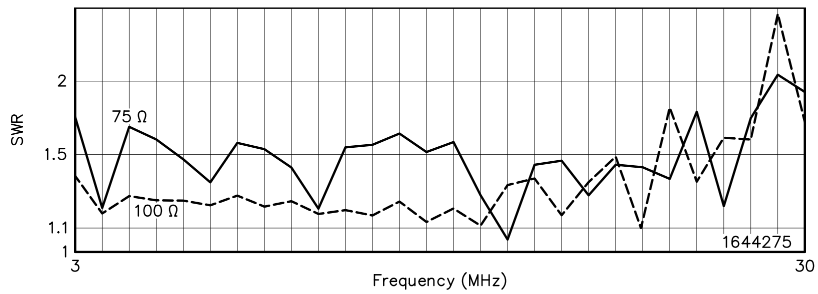

Fig 10—3-30 MHz SWR sweep of the 164-foot, 42-element LPDA model referenced to 75 Ω (solid line) and 100 Ω (dashed) with a 250-Ω phase line.

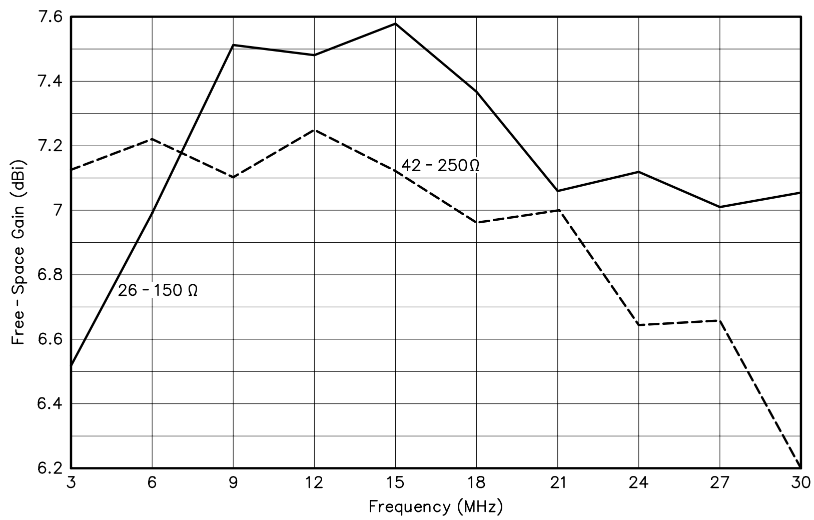

Fig 11—Comparison of the free-space gain of the 26-element (solid) and the 42-element (dashed), 164-foot LPDA models at 3 MHz intervals from 3 to 30 MHz.

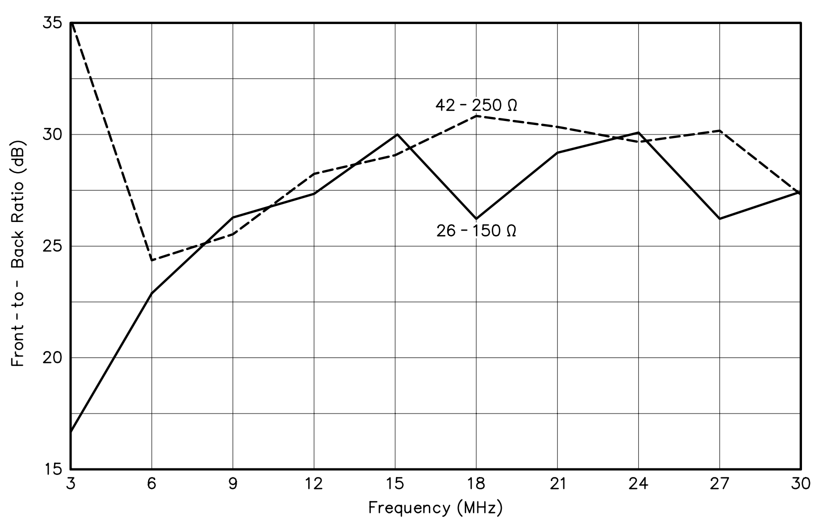

Fig 12—Comparison of the front-to-back ratio of the 26-element (solid) and the 42-element (dashed), 164-foot LPDA models at 3 MHz intervals from 3 to 30 MHz.

to gain, front-to-back ratio, SWR curve and pattern control, especially if used with a 150-Ω interelement transmission line.

For the frequency sweeps, I used the basic model with no terminating stub. I also modified the model by adding a 40-inch shorted stub of 150-Ω transmission line to the center of the longest element. The stub length was experimentally determined in the model to yield slightly improved performance at 3 MHz. The goal was to see whether the stub had any significant effects on antenna performance at frequencies distant from 3 MHz.

For the sweep, I chose frequency intervals of 0.5 MHz from 3 to 30 MHz. Although these frequencies are farther apart than one might wish for truly detailed analysis within a band of interest, smaller increments would not have produced readable graphs.

The graph of free-space gain across the antenna's passband is a case in point and appears in Fig 13. Even with 0.5-MHz increments, one must use great care in tracing the curves. Most notably, the graph reveals some significant gain deviations compared with the 3-MHz increments of earlier performance checks. The version with no stub shows low gain (well below 7 dBi) at 7 MHz, and both versions show lower gain in the 26 to 26.5 MHz region and again in the 28.5 to 29.5 MHz region. These deficits, of course, did not appear in the earlier checks. Also notable is the unusually high gain (7.96 dBi) at 8.5 MHz in the version of the antenna with the stub attached.

Otherwise, the two plots overlay each other quite closely. Above 10 MHz, a few spot values differ by as much as 0.15 dB, but most differences are below 0.05 dB. Neither level of difference is operationally significant.

The graph of 180° front-to-back ratio in Fig 14 shows the consistently high front-to-back ratio of the design. The stub-less model shows noticeably lower values at 5, 7.5 and 8 MHz, with a surprisingly higher value at 4.5 MHz. A shorted stub can smooth the front-to-back performance of the antenna below 10 MHz, suggesting that adding the stub to the system has merit.

Each model shows a frequency region where the front-to-back ratio reaches a peak at about 35 dB. Interestingly, the model with the stub raises the frequency of this peak by about 4 MHz without creating significant changes in the antenna gain. Since the typical rear-quadrant pattern shows lobes to each side of the maximum front-to-back ratio, the peaks are of numeric rather than operational significance. Even with the exceptions noted for the stub-less model and the decreased values at the lowest frequency of use, the model shows a front-to-rear ratio that is consistently 20 dB or better.

The graphs of resistance (Fig 15) and reactance (Fig 16) at the feed point of the antenna require less examination. From 9 MHz upward, they so closely overlap that a single line suffices for both models. Below 9 MHz, the feed point resistance plots very closely

Table 7—Element half-lengths and cumulative spacing of the modified 164-foot, 26-element 3-30 MHz LPDA model.

Element	*Half Length (inches)*	*Cumulative Spacing (inches)*
1	980.00	–24.00
2	907.00	208.31
3	817.49	396.32
4	737.77	565.99
5	655.83	719.11
6	600.91	857.30
7	542.31	982.02
8	489.43	1094.58
9	441.71	1196.16
10	398.64	1287.84
11	359.76	1370.57
12	324.68	1445.24
13	293.02	1512.63
14	264.45	1573.45
15	238.66	1628.34
16	215.39	1677.87
17	194.39	1722.58
18	175.43	1762.92
19	158.33	1799.33
20	142.89	1832.19
21	128.96	1861.85
22	116.38	1888.62
23	105.03	1912.77
24	94.79	1934.57
25	85.55	1954.24
26	77.21	1972.00

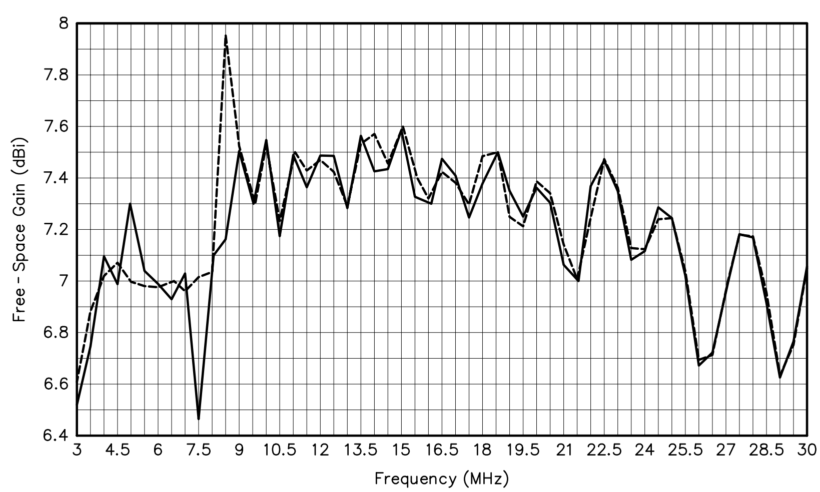

Fig 13—Free-space gain of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

coincide, with the stub-model tending to reduce the resistance slightly from the values for the stub-less model.

The stub makes a greater difference in the value of reactance at the feed point below 9 MHz. The reactance yielded by each model shows the greatest divergence at 3, 5 and 7.5 MHz; however, in no case does the reactance value exceed the maximum values found on the main plot—either inductively or capacitively. Consequently, we should expect that SWR curves for either version will overlap considerably, regardless of the reference impedance value we choose for the plot.

The rough coincidence of resistance and reactance values between models with and without a stub would show no differences worth noting in a pair of SWR curves set to the same reference impedance value. Therefore, I set the reference impedance value for the stub-less model to 100 Ω and the value for the model with the stub to 75 Ω. A 100-Ω value is useful to designers because one may introduce a wide-band 2:1 matching device at the feed point and feed the array with 50-Ω coaxial cable. The 75-Ω standard tends to imply direct feed with 75-Ω cable or a 1.4:1 wide-band matching device.

Fig 17 shows the resulting SWR plots. The 100-Ω curve shows peak values of SWR above 1.8:1 at 26.5, 27 and 30 MHz, with all other values below 1.5:1. In contrast, the 75-Ω curve shows more variance among values at all frequencies, but it displays peaks above 1.6:1 only at 4.5 and 28.5 MHz. For most purposes, either approach—and the matching techniques implied by it—would prove satisfactory for the antenna.

Conclusion

Bringing "preliminary notes" to a conclusion is nearly a contradiction in terms. The purpose of this exercise has been to see what light is shed by method-of-moments modeling on standard, 3.5-octave HF LPDA design. The notes have surveyed array lengths from 60 to 164 feet with 20 to 42 elements. However, limitations imposed by the size of the models preclude anything close to sufficient coverage of array sizes between those selected for modeling. Likewise, run time for the large models limited the frequencies at which performance checks were made.

Nonetheless, the collection of models has demonstrated both the potential and some weaknesses of conventional LPDA designs that are limited in array length. Strong low-end performers

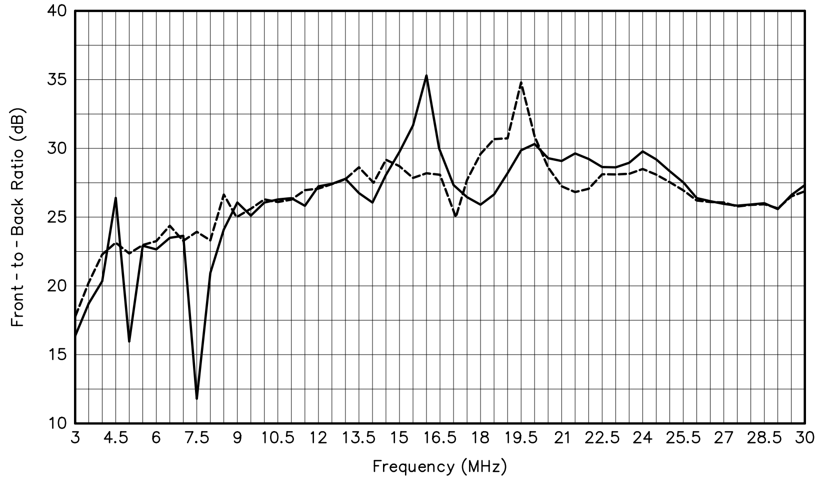

Fig 14—Front-to-back (180°) ratio of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

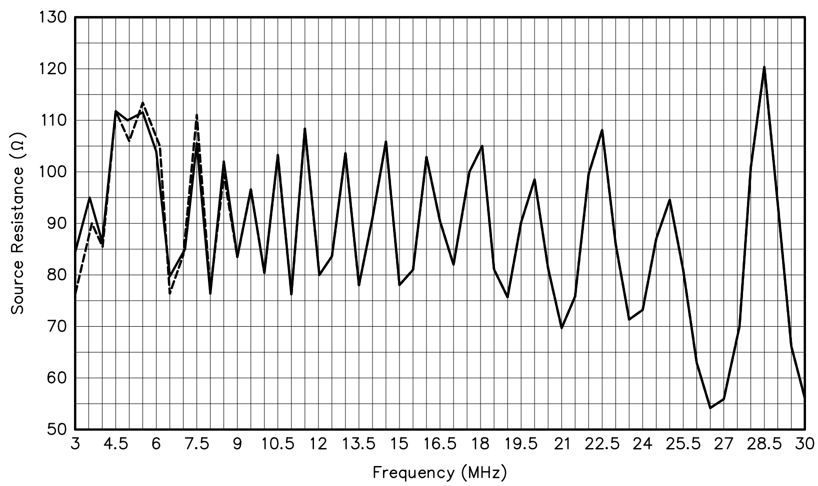

Fig 15—Source resistance of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

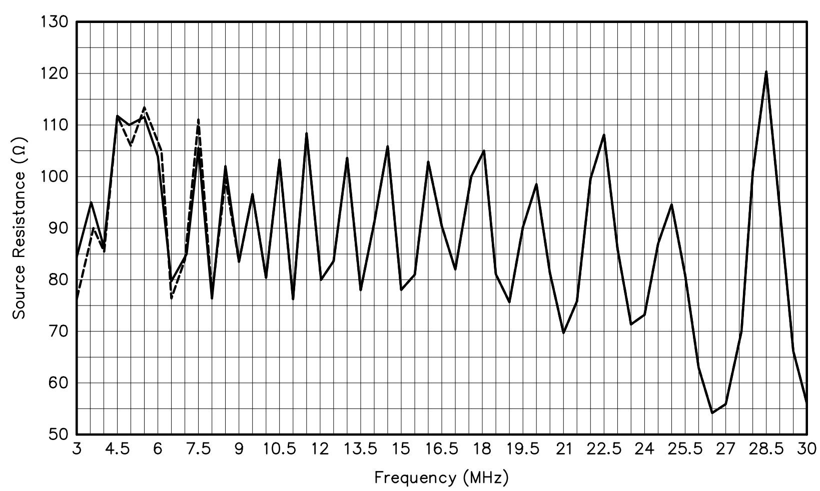

Fig 16—Source reactance of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

showed weaknesses at higher frequencies, while designs that performed strongly at the upper end of the passband were weaker performers at the lowest frequencies. Of the models surveyed, perhaps the original 164-foot 26-element design with "Tau-tapered" elements deserves the most attention. Undoubtedly, careful redesign can tweak its performance even further.

In addition, numerous alternative design techniques exist that have not been covered in these preliminary notes. Hybrid designs and designs using tapered Tau and Sigma values have yet to be explored. The results of these explorations may well be alternative design algorithms that may yield smoother gain performance across the 3-30 MHz spectrum. Other directions still to be examined involve setting the value of Tau to be referenced to frequencies of interest and altering the linear nature of the elements themselves. A short bibliography of both basic and innovative design ideas appears at the end of this article.

One question has been intentionally bypassed: Are any of the better designs mechanically workable? Although a 164-foot rotatable boom is not easily made feasible, its construction may be possible. At a lesser gain, the 100-foot, 26-element model may also be practical under certain circumstances. With wire elements, even the longest design might serve as a fixed-position beam.

This has been a design study attempting to bring *NEC-4* to bear on standard LPDA designs for antennas having a wide frequency range. It cannot be complete, but perhaps it may serve as a beginning for better understanding of standard LPDA performance throughout the HF range.

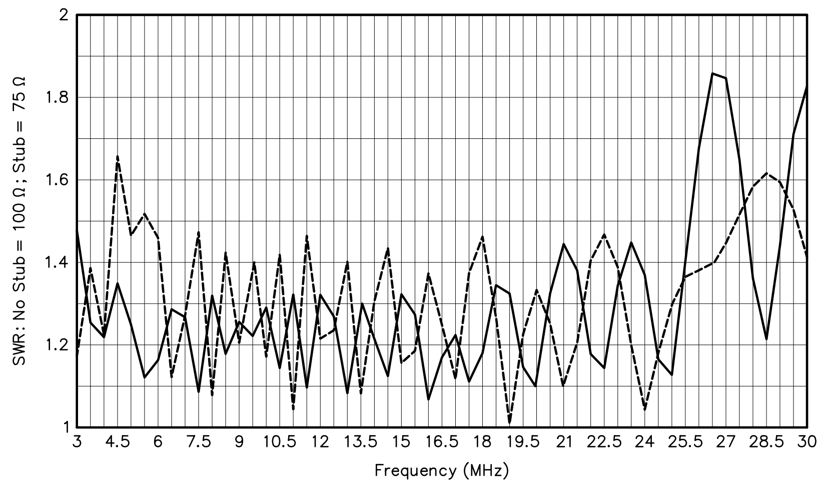

Fig 17—SWR curves of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions. The "no-stub" model is referenced to 100 Ω; the "with-stub" model is referenced to 75 Ω.

Table 8—Spot performance checks at 1-MHz intervals from 3 to 9 MHz for the initial and modified 26-element LPDA models and for the 42-element LPDA model.

	Antenna Design		
	Original 26	*Modified 26*	*42*
3 (MHz)			
Gain	6.52	6.75	7.13
Front-to-Back	16.5	20.0	35.0
Impedance	83. –*j*32	75. –*j*39	119. –*j*27
4 (MHz)			
Gain	7.10	7.11	7.24
Front-to-Back	20.5	20.2	23.6
Impedance	86. +*j*12	86. +*j*12	88. –*j*6
5 (MHz)			
Gain	7.30	7.19	7.22
Front-to-Back	15.7	9.4	23.8
Impedance	110. –*j*21	104. –*j*31	125. +*j*3
6 (MHz)			
Gain	6.99	6.99	7.22
Front-to-Back	22.8	22.7	24.4
Impedance	104. –*j*14	104. –*j*14	115. +*j*16
7 (MHz)			
Gain	7.03	7.02	7.23
Front-to-Back	23.8	23.5	24.5
Impedance	85. –*j*16	85. –*j*16	101. –*j*21
8 (MHz)			
Gain	7.11	7.08	7.23
Front-to-Back	21.0	21.0	24.8
Impedance	76. +*j*4	76. +*j*4	92. –*j*16
9 (MHz)			
Gain	7.51	7.57	7.10
Front-to-Back	26.2	28.3	25.6
Impedance	83. +*j*12	83. +*j*12	110. –*j*22

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15. J. D. Kraus, *Antennas*, 2nd Ed. (New York: McGraw-Hill, 1988), Chapter 15.
16. V. H. Rumsey, *Frequency Independent Antennas* (New York: Academic Press, 1966).
17. R. Dean Straw, Ed., *The ARRL Antenna Book*, 18th Ed. (Newington: ARRL, 1997), Chapter 10. ARRL Order #6133, $30.

Most standard college texts on basic antenna theory and practice have a chapter devoted to the fundamentals of LPDA design.

Appendix

You can download this package from the ARRL Web site: **http://www.arrl.org/files/*qex*/**. Look for LPDASPT2.ZIP.

Antenna Model Descriptions

164' 26-Element 3-30 MHz LPDA Frequency = 3 MHz.

Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000, 0.000		1003.68, 0.000, 0.000	6.50E+00	107
2		905.81,208.310, 0.000		905.810,208.310, 0.000	5.87E+00	97
3		817.49,396.320, 0.000		817.490,396.320, 0.000	5.30E+00	87
4		737.77,565.990, 0.000		737.770,565.990, 0.000	4.79E+00	79
5		655.83,719.110, 0.000		655.830,719.110, 0.000	4.32E+00	71
6		600.91,857.300, 0.000		600.910,857.300, 0.000	3.90E+00	65
7		542.31,982.020, 0.000		542.310,982.020, 0.000	3.52E+00	57
8		489.43,1094.58, 0.000		489.430,1094.58, 0.000	3.18E+00	53
9		441.71,1196.16, 0.000		441.710,1196.16, 0.000	2.87E+00	47
10		398.64,1287.84, 0.000		398.640,1287.84, 0.000	2.59E+00	43
11		359.76,1370.57, 0.000		359.760,1370.57, 0.000	2.34E+00	39
12		324.68,1445.24, 0.000		324.680,1445.24, 0.000	2.12E+00	35
13		293.02,1512.63, 0.000		293.020,1512.63, 0.000	1.91E+00	31
14		264.45,1573.45, 0.000		264.450,1573.45, 0.000	1.73E+00	29
15		238.66,1628.34, 0.000		238.660,1628.34, 0.000	1.56E+00	25
16		215.39,1677.87, 0.000		215.390,1677.87, 0.000	1.41E+00	23
17		194.39,1722.58, 0.000		194.390,1722.58, 0.000	1.27E+00	21
18		175.43,1762.92, 0.000		175.430,1762.92, 0.000	1.15E+00	19
19		158.33,1799.33, 0.000		158.330,1799.33, 0.000	1.04E+00	17
20		142.89,1832.19, 0.000		142.890,1832.19, 0.000	1.15E+00	15
21		128.96,1861.85, 0.000		128.960,1861.85, 0.000	1.04E+00	15
22		116.38,1888.62, 0.000		116.380,1888.62, 0.000	9.40E01	13
23		105.03,1912.77, 0.000		105.030,1912.77, 0.000	8.40E01	11
24		94.790,1934.57, 0.000		94.790,1934.57, 0.000	7.60E01	11
25		85.550,1954.24, 0.000		85.550,1954.24, 0.000	6.90E01	9
26		77.210,1972.00, 0.000		77.210,1972.00, 0.000	5.00E01	9

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	5	26 / 50.00	(26 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	150.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	150.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	150.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	150.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	150.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	150.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	150.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	150.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	150.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	150.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	150.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	150.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	150.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	150.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	150.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	150.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	150.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	150.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	150.0	1.00	R
20	20/50.0	(20/50.0)	21/50.0	(21/50.0)	Actual dist	150.0	1.00	R
21	21/50.0	(21/50.0)	22/50.0	(22/50.0)	Actual dist	150.0	1.00	R
22	22/50.0	(22/50.0)	23/50.0	(23/50.0)	Actual dist	150.0	1.00	R
23	23/50.0	(23/50.0)	24/50.0	(24/50.0)	Actual dist	150.0	1.00	R
24	24/50.0	(24/50.0)	25/50.0	(25/50.0)	Actual dist	150.0	1.00	R
25	25/50.0	(25/50.0)	26/50.0	(26/50.0)	Actual dist	150.0	1.00	R

Ground type is Free Space

164' 42-Element 3-30 MHz LPDA Frequency = 3 MHz.
Wire Loss: Aluminum Resistivity = 4E08 ohmm, Rel. Perm. = 1

WIRES

Wire	Conn.	End 1 (x,y,z : in)	Conn.	End 2 (x,y,z : in)	Dia(in)	Segs
1		1003.7, 0.000, 0.000		1003.68, 0.000, 0.000	6.50E+00	107
2		943.46,128.470, 0.000		943.460,128.470, 0.000	6.11E+00	101
3		888.35,249.230, 0.000		888.350,249.230, 0.000	5.74E+00	95
4		833.64,362.750, 0.000		833.640,362.750, 0.000	5.40E+00	89
5		783.62,469.460, 0.000		783.620,469.460, 0.000	5.07E+00	83
6		736.60,569.760, 0.000		736.600,569.760, 0.000	4.77E+00	79
7		692.41,664.050, 0.000		692.410,664.050, 0.000	4.48E+00	73
8		650.86,752.670, 0.000		650.860,752.670, 0.000	4.22E+00	69
9		611.81,835.990, 0.000		611.810,835.990, 0.000	3.96E+00	65
10		575.10,914.300, 0.000		575.100,914.300, 0.000	3.72E+00	61
11		540.60,987.910, 0.000		540.600,987.910, 0.000	3.50E+00	57
12		508.16,1057.11, 0.000		508.160,1057.11, 0.000	3.29E+00	55
13		477.67,1122.15, 0.000		477.670,1122.15, 0.000	3.09E+00	51
14		449.01,1183.29, 0.000		449.010,1183.29, 0.000	2.91E+00	47
15		422.07,1240.77, 0.000		422.070,1240.77, 0.000	2.73E+00	45
16		396.75,1294.79, 0.000		396.750,1294.79, 0.000	2.57E+00	43
17		372.94,1345.58, 0.000		372.940,1345.58, 0.000	2.42E+00	39
18		350.57,1393.31, 0.000		350.570,1393.31, 0.000	2.27E+00	37
19		329.53,1438.18, 0.000		329.530,1438.18, 0.000	2.13E+00	35
20		309.76,1480.36, 0.000		309.760,1480.36, 0.000	2.00E+00	33
21		291.17,1520.01, 0.000		291.170,1520.01, 0.000	1.89E+00	31
22		273.70,1557.28, 0.000		273.700,1557.28, 0.000	1.77E+00	29
23		257.20,1592.32, 0.000		257.200,1592.32, 0.000	1.67E+00	27
24		241.84,1625.25, 0.000		241.840,1625.25, 0.000	1.57E+00	25
25		227.33,1656.21, 0.000		227.330,1656.21, 0.000	1.47E+00	25
26		213.69,1685.30, 0.000		213.690,1685.30, 0.000	1.38E+00	23
27		200.87,1712.66, 0.000		200.870,1712.66, 0.000	1.30E+00	21
28		188.82,1738.37, 0.000		188.820,1738.37, 0.000	1.22E+00	21
29		177.49,1762.54, 0.000		177.490,1762.54, 0.000	1.15E+00	19
30		166.84,1785.26, 0.000		166.840,1785.26, 0.000	1.08E+00	17
31		156.83,1806.61, 0.000		156.830,1806.61, 0.000	1.02E+00	17
32		147.42,1826.69, 0.000		147.420,1826.69, 0.000	9.50E01	15
33		138.58,1845.56, 0.000		138.580,1845.56, 0.000	9.00E01	15
34		130.26,1863.29, 0.000		130.260,1863.29, 0.000	8.40E01	15
35		122.45,1879.97, 0.000		122.450,1879.97, 0.000	7.90E01	13
36		115.10,1895.64, 0.000		115.100,1895.64, 0.000	7.50E01	13
37		108.19,1910.37, 0.000		108.190,1910.37, 0.000	7.00E01	11
38		101.70,1924.22, 0.000		101.700,1924.22, 0.000	6.60E01	11
39		95.600,1937.24, 0.000		95.600,1937.24, 0.000	6.20E01	11
40		89.860,1949.48, 0.000		89.860,1949.48, 0.000	5.80E01	11
41		84.470,1960.98, 0.000		84.470,1960.98, 0.000	5.50E01	11
42		79.400,1971.79, 0.000		79.400,1971.79, 0.000	5.00E01	11

SOURCES

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	6	42 / 50.00	(42 / 50.00)	1.000	0.000	V

TRANSMISSION LINES

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 ohms	Vel Fact	Rev/ Norm
1	1/50.0	(1/50.0)	2/50.0	(2/50.0)	Actual dist	250.0	1.00	R
2	2/50.0	(2/50.0)	3/50.0	(3/50.0)	Actual dist	250.0	1.00	R
3	3/50.0	(3/50.0)	4/50.0	(4/50.0)	Actual dist	250.0	1.00	R
4	4/50.0	(4/50.0)	5/50.0	(5/50.0)	Actual dist	250.0	1.00	R
5	5/50.0	(5/50.0)	6/50.0	(6/50.0)	Actual dist	250.0	1.00	R
6	6/50.0	(6/50.0)	7/50.0	(7/50.0)	Actual dist	250.0	1.00	R
7	7/50.0	(7/50.0)	8/50.0	(8/50.0)	Actual dist	250.0	1.00	R
8	8/50.0	(8/50.0)	9/50.0	(9/50.0)	Actual dist	250.0	1.00	R
9	9/50.0	(9/50.0)	10/50.0	(10/50.0)	Actual dist	250.0	1.00	R
10	10/50.0	(10/50.0)	11/50.0	(11/50.0)	Actual dist	250.0	1.00	R
11	11/50.0	(11/50.0)	12/50.0	(12/50.0)	Actual dist	250.0	1.00	R
12	12/50.0	(12/50.0)	13/50.0	(13/50.0)	Actual dist	250.0	1.00	R
13	13/50.0	(13/50.0)	14/50.0	(14/50.0)	Actual dist	250.0	1.00	R
14	14/50.0	(14/50.0)	15/50.0	(15/50.0)	Actual dist	250.0	1.00	R
15	15/50.0	(15/50.0)	16/50.0	(16/50.0)	Actual dist	250.0	1.00	R
16	16/50.0	(16/50.0)	17/50.0	(17/50.0)	Actual dist	250.0	1.00	R
17	17/50.0	(17/50.0)	18/50.0	(18/50.0)	Actual dist	250.0	1.00	R
18	18/50.0	(18/50.0)	19/50.0	(19/50.0)	Actual dist	250.0	1.00	R
19	19/50.0	(19/50.0)	20/50.0	(20/50.0)	Actual dist	250.0	1.00	R
20	20/50.0	(20/50.0)	21/50.0	(21/50.0)	Actual dist	250.0	1.00	R
21	21/50.0	(21/50.0)	22/50.0	(22/50.0)	Actual dist	250.0	1.00	R
22	22/50.0	(22/50.0)	23/50.0	(23/50.0)	Actual dist	250.0	1.00	R
23	23/50.0	(23/50.0)	24/50.0	(24/50.0)	Actual dist	250.0	1.00	R
24	24/50.0	(24/50.0)	25/50.0	(25/50.0)	Actual dist	250.0	1.00	R
25	25/50.0	(25/50.0)	26/50.0	(26/50.0)	Actual dist	250.0	1.00	R
26	26/50.0	(26/50.0)	27/50.0	(27/50.0)	Actual dist	250.0	1.00	R
27	27/50.0	(27/50.0)	28/50.0	(28/50.0)	Actual dist	250.0	1.00	R
28	28/50.0	(28/50.0)	29/50.0	(29/50.0)	Actual dist	250.0	1.00	R
29	29/50.0	(29/50.0)	30/50.0	(30/50.0)	Actual dist	250.0	1.00	R
30	30/50.0	(30/50.0)	31/50.0	(31/50.0)	Actual dist	250.0	1.00	R
31	31/50.0	(31/50.0)	32/50.0	(32/50.0)	Actual dist	250.0	1.00	R
32	32/50.0	(32/50.0)	33/50.0	(33/50.0)	Actual dist	250.0	1.00	R
33	33/50.0	(33/50.0)	34/50.0	(34/50.0)	Actual dist	250.0	1.00	R
34	34/50.0	(34/50.0)	35/50.0	(35/50.0)	Actual dist	250.0	1.00	R
35	35/50.0	(35/50.0)	36/50.0	(36/50.0)	Actual dist	250.0	1.00	R
36	36/50.0	(36/50.0)	37/50.0	(37/50.0)	Actual dist	250.0	1.00	R
37	37/50.0	(37/50.0)	38/50.0	(38/50.0)	Actual dist	250.0	1.00	R
38	38/50.0	(38/50.0)	39/50.0	(39/50.0)	Actual dist	250.0	1.00	R

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Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              ohms Fact Norm
39    39/50.0   ( 39/50.0)   40/50.0   ( 40/50.0)  Actual dist  250.0  1.00  R
40    40/50.0   ( 40/50.0)   41/50.0   ( 41/50.0)  Actual dist  250.0  1.00  R
41    41/50.0   ( 41/50.0)   42/50.0   ( 42/50.0)  Actual dist  250.0  1.00  R

Ground type is Free Space
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164' 26-Element 3-30 MHz LPDA, modified                       Frequency = 3  MHz.

Wire Loss: Aluminum  Resistivity = 4E08 ohmm, Rel. Perm. = 1

               WIRES
Wire Conn.  End 1 (x,y,z : in)  Conn.  End 2 (x,y,z : in)   Dia(in) Segs
1          980.00,24.000,  0.000       980.000,24.000,  0.000 6.50E+00 107
2          907.00,208.310,  0.000       907.000,208.310,  0.000 5.87E+00  97
3          817.49,396.320,  0.000       817.490,396.320,  0.000 5.30E+00  87
4          737.77,565.990,  0.000       737.770,565.990,  0.000 4.79E+00  79
5          655.83,719.110,  0.000       655.830,719.110,  0.000 4.32E+00  71
6          600.91,857.300,  0.000       600.910,857.300,  0.000 3.90E+00  65
7          542.31,982.020,  0.000       542.310,982.020,  0.000 3.52E+00  57
8          489.43,1094.58,  0.000       489.430,1094.58,  0.000 3.18E+00  53
9          441.71,1196.16,  0.000       441.710,1196.16,  0.000 2.87E+00  47
10         398.64,1287.84,  0.000       398.640,1287.84,  0.000 2.59E+00  43
11         359.76,1370.57,  0.000       359.760,1370.57,  0.000 2.34E+00  39
12         324.68,1445.24,  0.000       324.680,1445.24,  0.000 2.12E+00  35
13         293.02,1512.63,  0.000       293.020,1512.63,  0.000 1.91E+00  31
14         264.45,1573.45,  0.000       264.450,1573.45,  0.000 1.73E+00  29
15         238.66,1628.34,  0.000       238.660,1628.34,  0.000 1.56E+00  25
16         215.39,1677.87,  0.000       215.390,1677.87,  0.000 1.41E+00  23
17         194.39,1722.58,  0.000       194.390,1722.58,  0.000 1.27E+00  21
18         175.43,1762.92,  0.000       175.430,1762.92,  0.000 1.15E+00  19
19         158.33,1799.33,  0.000       158.330,1799.33,  0.000 1.04E+00  17
20         142.89,1832.19,  0.000       142.890,1832.19,  0.000 1.15E+00  15
21         128.96,1861.85,  0.000       128.960,1861.85,  0.000 1.04E+00  15
22         116.38,1888.62,  0.000       116.380,1888.62,  0.000 9.40E01  13
23         105.03,1912.77,  0.000       105.030,1912.77,  0.000 8.40E01  11
24         94.790,1934.57,  0.000        94.790,1934.57,  0.000 7.60E01  11
25         85.550,1954.24,  0.000        85.550,1954.24,  0.000 6.90E01   9
26         77.210,1972.00,  0.000        77.210,1972.00,  0.000 5.00E01   9

               SOURCES
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1           5    26 / 50.00    ( 26 / 50.00)      1.000       0.000       V

                 TRANSMISSION LINES
Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              ohms Fact Norm
1      1/50.0  (  1/50.0)    2/50.0  (  2/50.0)  Actual dist  150.0  1.00  R
2      2/50.0  (  2/50.0)    3/50.0  (  3/50.0)  Actual dist  150.0  1.00  R
3      3/50.0  (  3/50.0)    4/50.0  (  4/50.0)  Actual dist  150.0  1.00  R
4      4/50.0  (  4/50.0)    5/50.0  (  5/50.0)  Actual dist  150.0  1.00  R
5      5/50.0  (  5/50.0)    6/50.0  (  6/50.0)  Actual dist  150.0  1.00  R
6      6/50.0  (  6/50.0)    7/50.0  (  7/50.0)  Actual dist  150.0  1.00  R
7      7/50.0  (  7/50.0)    8/50.0  (  8/50.0)  Actual dist  150.0  1.00  R
8      8/50.0  (  8/50.0)    9/50.0  (  9/50.0)  Actual dist  150.0  1.00  R
9      9/50.0  (  9/50.0)   10/50.0  ( 10/50.0)  Actual dist  150.0  1.00  R
10    10/50.0  ( 10/50.0)   11/50.0  ( 11/50.0)  Actual dist  150.0  1.00  R
11    11/50.0  ( 11/50.0)   12/50.0  ( 12/50.0)  Actual dist  150.0  1.00  R
12    12/50.0  ( 12/50.0)   13/50.0  ( 13/50.0)  Actual dist  150.0  1.00  R
13    13/50.0  ( 13/50.0)   14/50.0  ( 14/50.0)  Actual dist  150.0  1.00  R
14    14/50.0  ( 14/50.0)   15/50.0  ( 15/50.0)  Actual dist  150.0  1.00  R
15    15/50.0  ( 15/50.0)   16/50.0  ( 16/50.0)  Actual dist  150.0  1.00  R
16    16/50.0  ( 16/50.0)   17/50.0  ( 17/50.0)  Actual dist  150.0  1.00  R
17    17/50.0  ( 17/50.0)   18/50.0  ( 18/50.0)  Actual dist  150.0  1.00  R
18    18/50.0  ( 18/50.0)   19/50.0  ( 19/50.0)  Actual dist  150.0  1.00  R
19    19/50.0  ( 19/50.0)   20/50.0  ( 20/50.0)  Actual dist  150.0  1.00  R
20    20/50.0  ( 20/50.0)   21/50.0  ( 21/50.0)  Actual dist  150.0  1.00  R
21    21/50.0  ( 21/50.0)   22/50.0  ( 22/50.0)  Actual dist  150.0  1.00  R
22    22/50.0  ( 22/50.0)   23/50.0  ( 23/50.0)  Actual dist  150.0  1.00  R
23    23/50.0  ( 23/50.0)   24/50.0  ( 24/50.0)  Actual dist  150.0  1.00  R
24    24/50.0  ( 24/50.0)   25/50.0  ( 25/50.0)  Actual dist  150.0  1.00  R
25    25/50.0  ( 25/50.0)   26/50.0  ( 26/50.0)  Actual dist  150.0  1.00  R
Ground type is Free Space
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