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.

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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.

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.

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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.

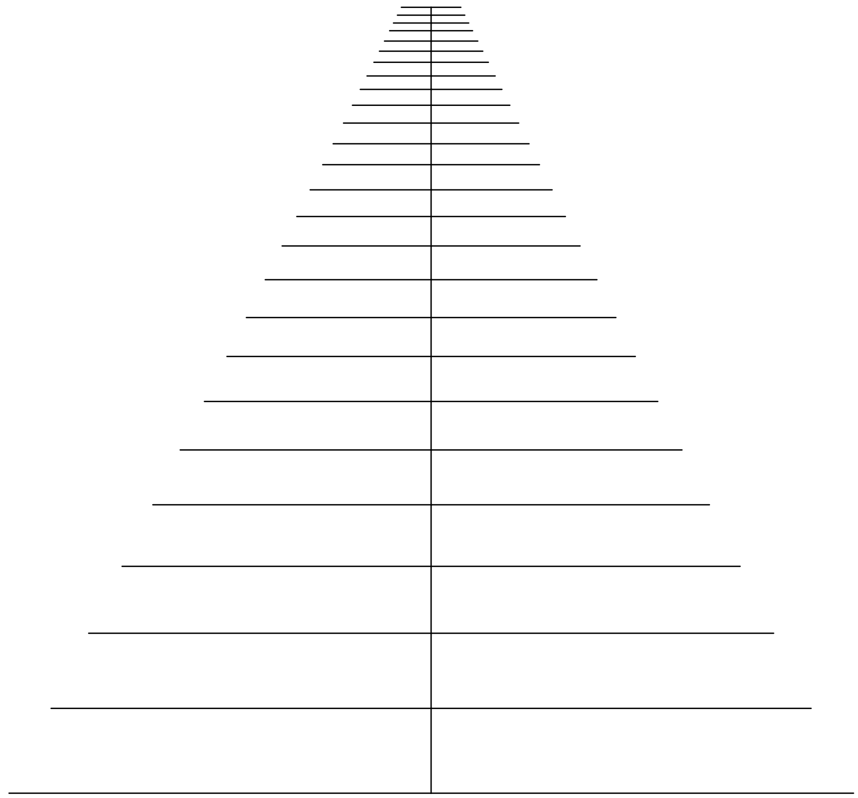

Fig 1—Outline of the 164-foot, 26-element 3-30 MHz LPDA; Tau = 0.90, Sigma = 0.05.

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-

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

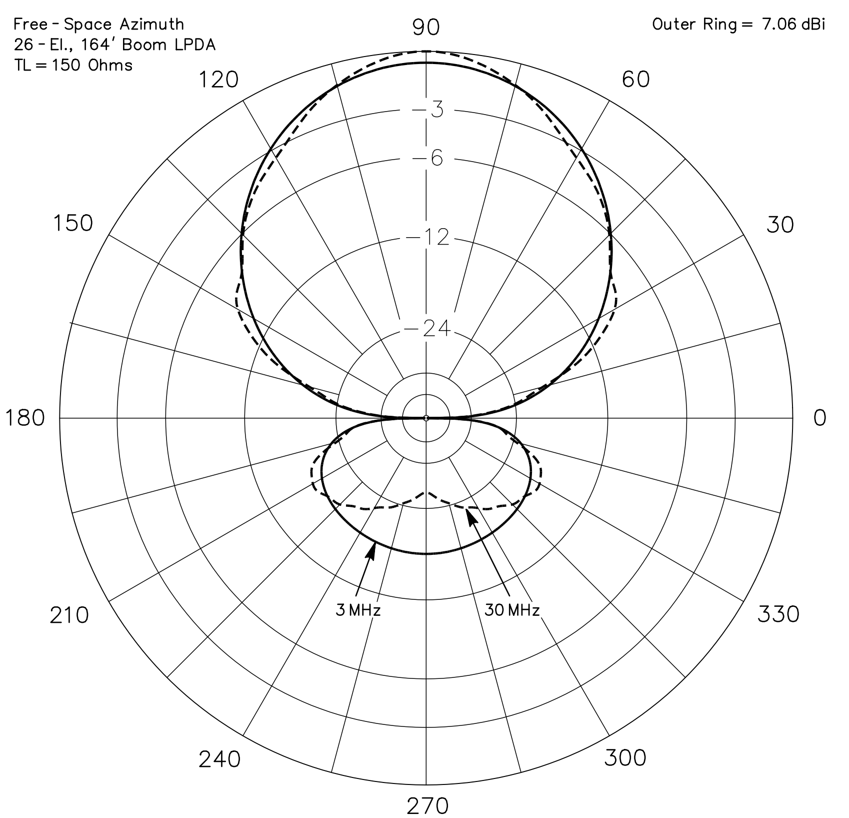

Fig 2—Free-space azimuth patterns of the 164-foot, 26-element LPDA model at 3 and 30 MHz.

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.

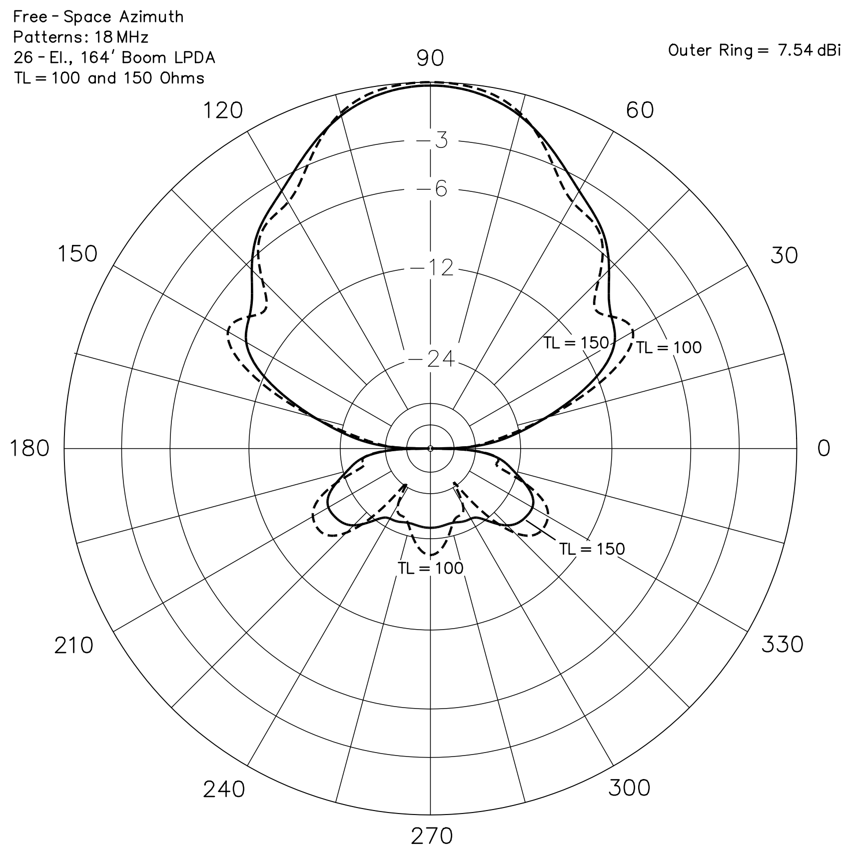

Fig 3—Free-space azimuth pattern of the 164-foot, 26-element LPDA model at 18 MHz with 100 Ω and 150 Ω transmission lines.

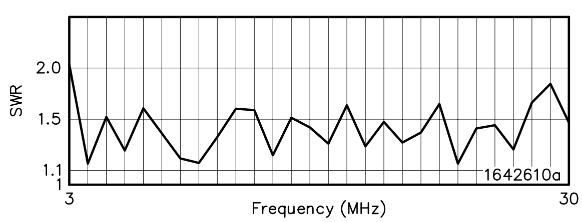

Fig 4—3-30 MHz SWR sweep of the 164-foot, 26-element LPDA model referenced to 50 Ω with a 100-Ω phase line.

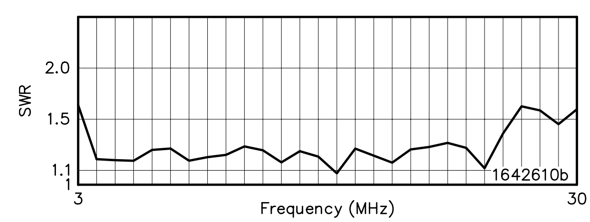

Fig 5—3-30 MHz SWR sweep of the 164-foot 26-element LPDA model referenced to 65 Ω with a 100-Ω phase line.

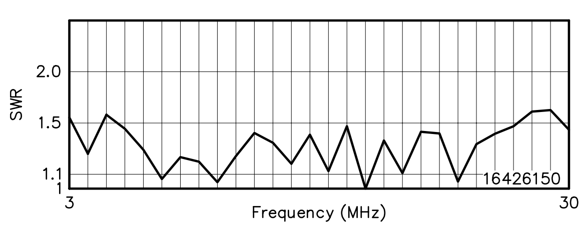

Fig 6—3-30 MHz SWR sweep of the 164-foot 26-element LPDA model referenced to 75 Ω with a 150-Ω phase line.

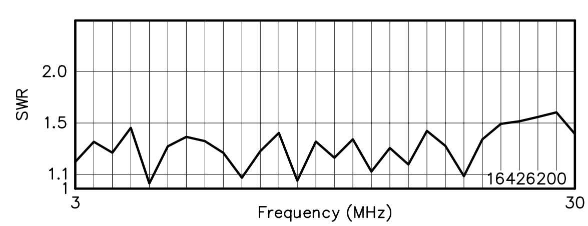

Fig 7—3-30 MHz SWR sweep of the 164-foot 26-element LPDA model referenced to 95 Ω with a 200-Ω phase line.

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

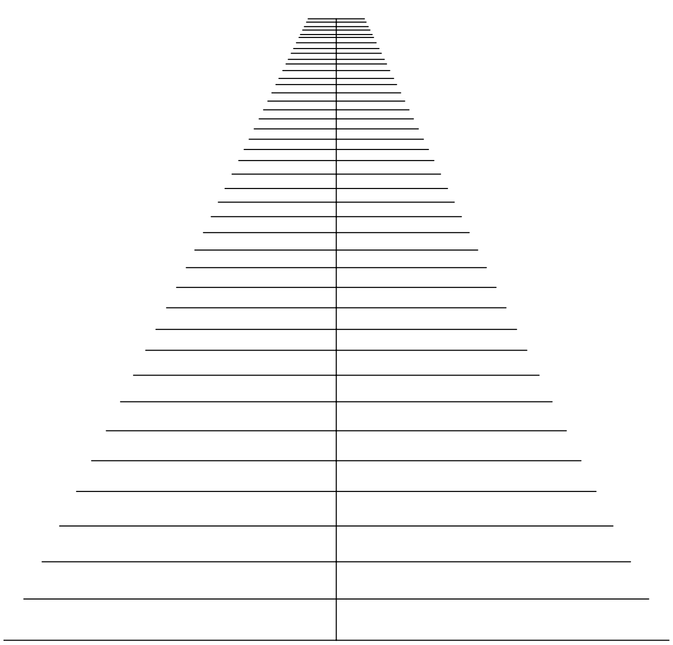

Fig 8—Outline of the 164-foot, 42-element 3-30 MHz LPDA; Tau = 0.94, Sigma = 0.032.

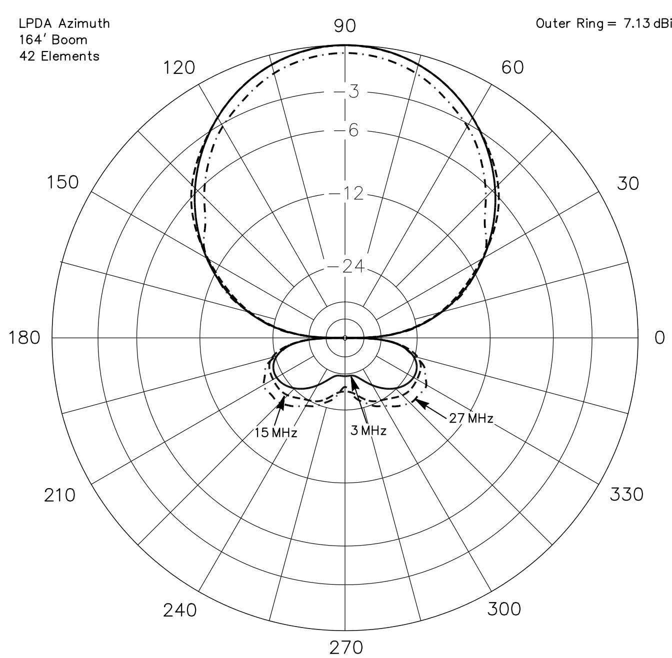

Fig 9—Free-space azimuth pattern of the 164-foot, 42-element LPDA model at 3, 15 and 27 MHz.

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

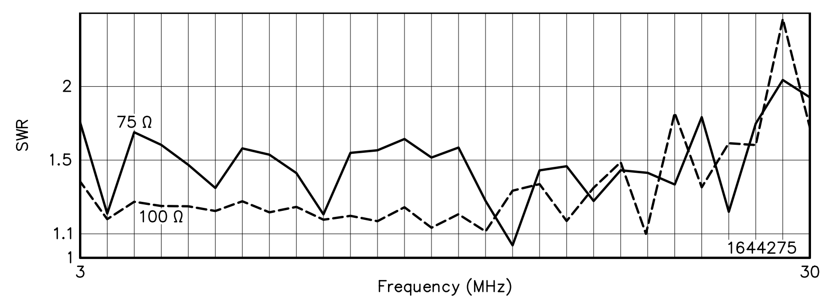

Fig 10—3-30 MHz SWR sweep of the 164-foot, 42-element LPDA model referenced to 75 Ω (solid line) and 100 Ω (dashed) with a 250-Ω phase line.

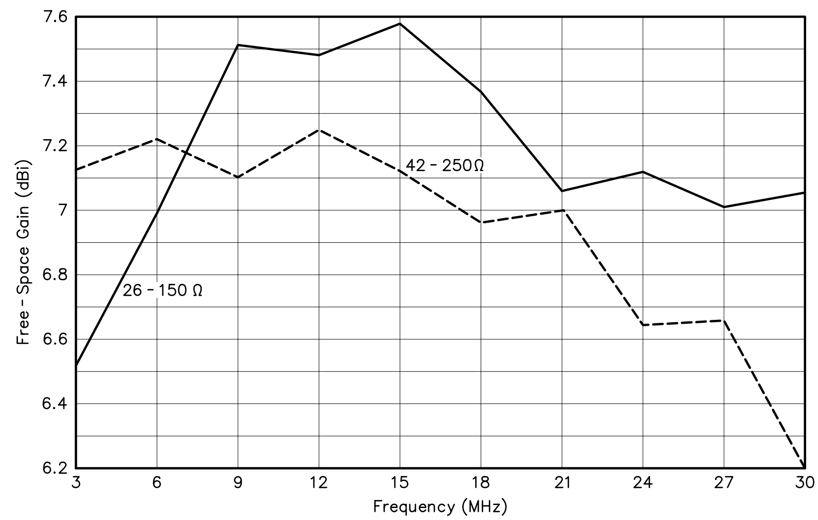

Fig 11—Comparison of the free-space gain of the 26-element (solid) and the 42-element (dashed), 164-foot LPDA models at 3 MHz intervals from 3 to 30 MHz.

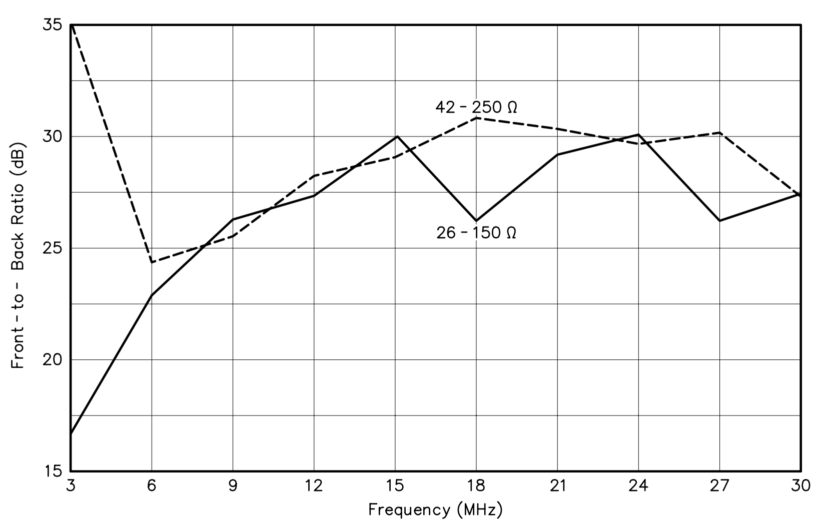

Fig 12—Comparison of the front-to-back ratio of the 26-element (solid) and the 42-element (dashed), 164-foot LPDA models at 3 MHz intervals from 3 to 30 MHz.

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

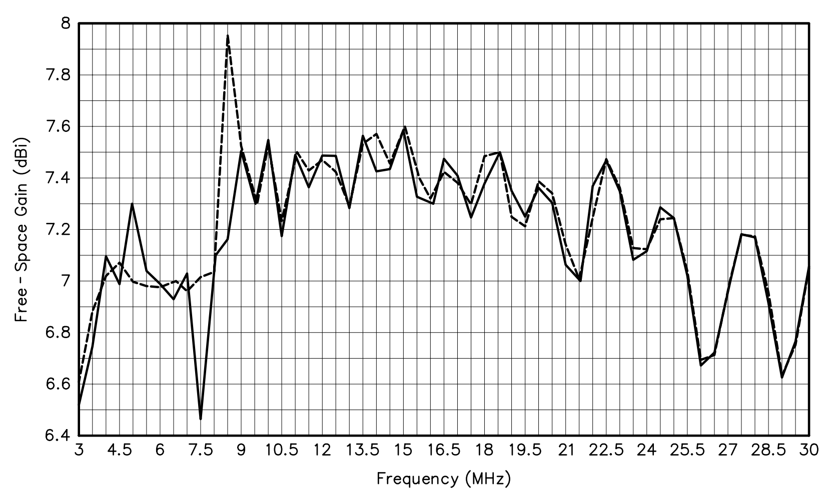

Fig 13—Free-space gain of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

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

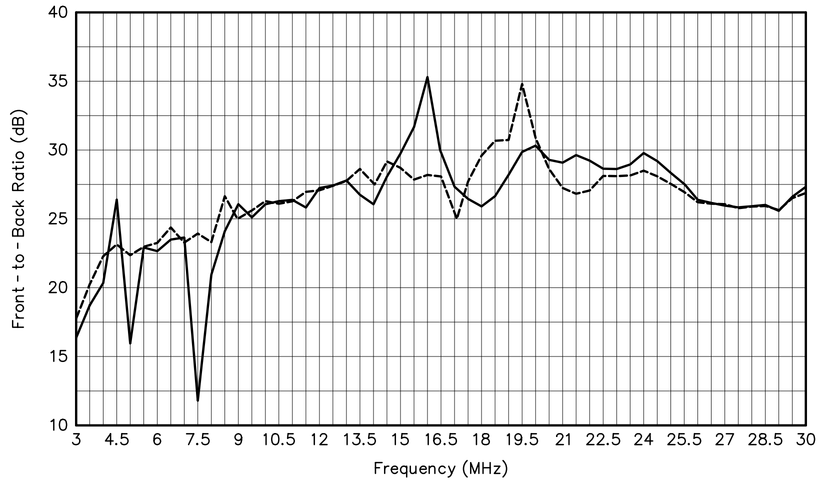

Fig 14—Front-to-back (180°) ratio of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

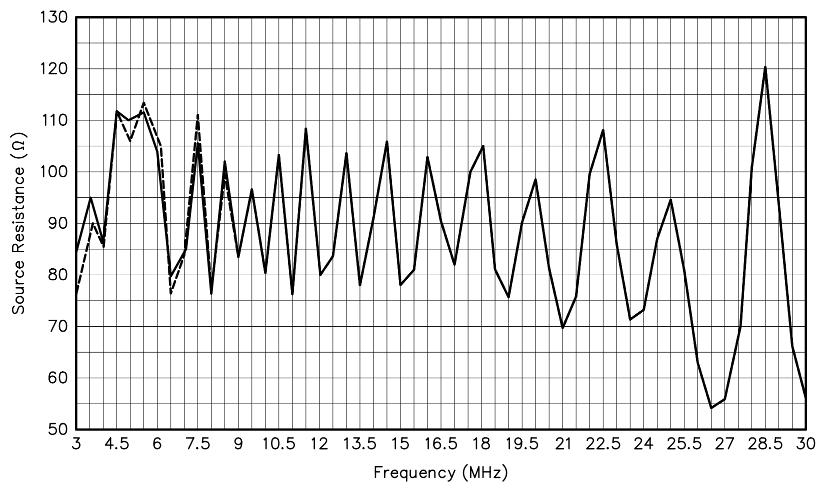

Fig 15—Source resistance of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

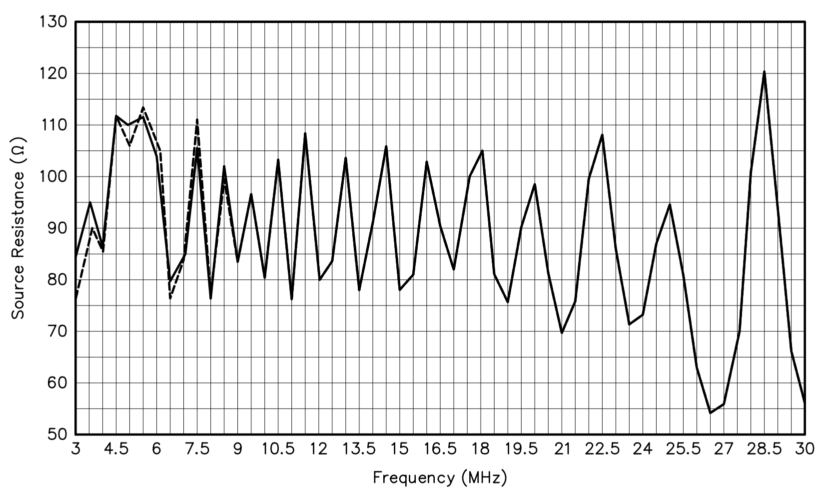

Fig 16—Source reactance of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions.

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.

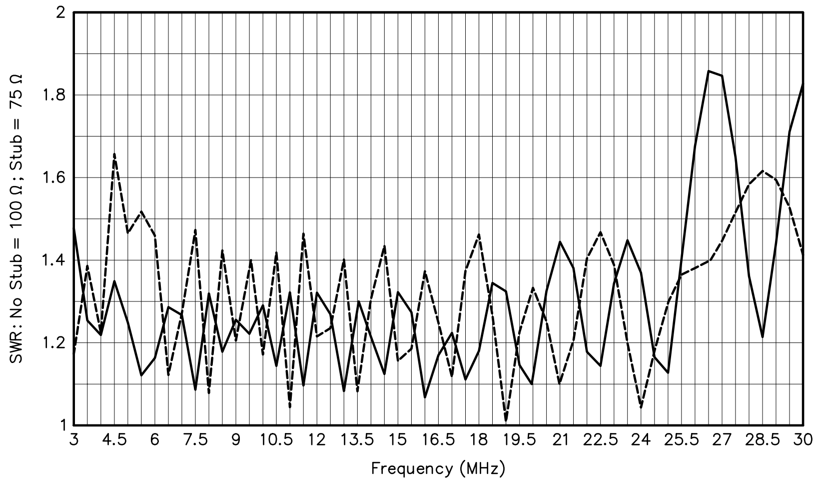

Fig 17—SWR curves of the 26-element, 164-foot LPDA model without (solid) and with (dashed) a shorted stub at 0.5 MHz intervals. See text for stub dimensions. The "no-stub" model is referenced to 100 Ω; the "with-stub" model is referenced to 75 Ω.

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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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.

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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      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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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

Line	Wire #/% From End 1 Actual	(Specified)	Wire #/% From End 1 Actual	(Specified)	Length	Z0 ohms	Vel Fact	Rev/ 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

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 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