Split or Continuous LPDAs for Personal Communications?

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A split-band LPDA is simply 2 LPDAs for different frequency ranges that have been placed on the same boom and designed for the same phase-line characteristic impedance. Of course, the lower frequency section with its longer elements goes behind the higher frequency, short-element section. A single feedline handles the duties for the pair of frequency ranges covered by the array. **Fig. 1** sketches the general arrangement.

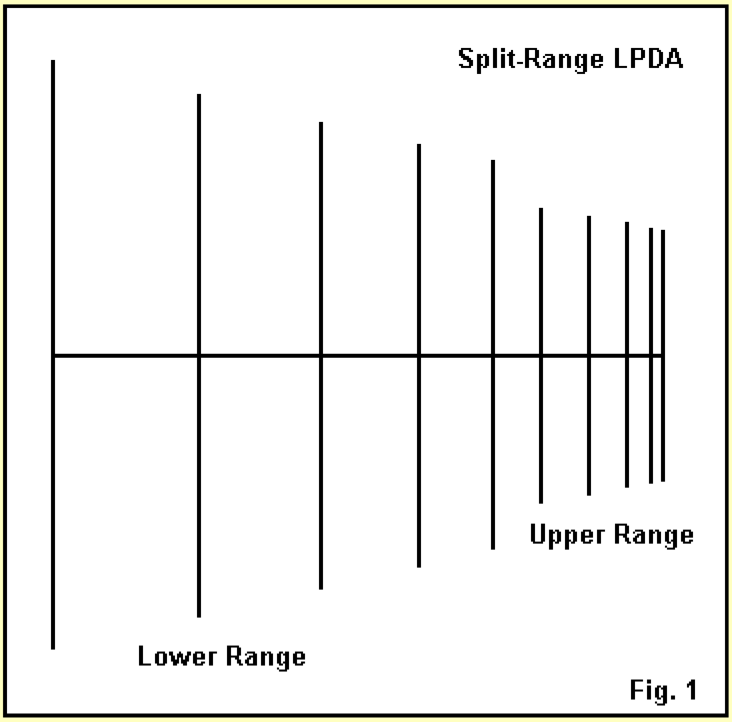


Fig. 1

One of the motivating factors behind the development of such arrays is to save space and possibly money (in commercial antenna construction) by omitting the unnecessary elements. The question that confronts the LPDA designer is at what point a split-frequency LPDA makes good sense relative to one designed for continuous coverage of the desired pair of bands. Older conceptions of LPDA design placed the highest frequency element at about 1.3 times the highest frequency used. However, to avoid significant decreases in performance at the highest operating frequencies, the resonant length of the shortest element turns out to be closer to 1.6 times the highest operating frequency. This value is somewhat variable and depends upon the choices made for tau and sigma in the basic design

The concept of split-frequency LPDAs is most generally applicable to VHF and UHF services other than amateur radio. Amateur bands are generally narrow enough so that for the ranges of free-space gain attained by LPDAs (generally below 11 dBi), wide-band Yagis that cover entire amateur bands are feasible. However, there are a pair of commercial service bands, one in the 800-1000 MHz region, the other in the 1800-2000 MHz region.

To make the investigation significant, we must set some specification for the performance that we expect of the LPDA. Let's set a free-space gain value of 9.5 dBi as the minimum gain for our arrays. This gain assures about 30 dB or better front-to-back ratio. Because it would be anticipated that construction might involve twin U-channel booms, we may use phase-line characteristic impedance values from 75 to 100 Ohms in the designs. With these simple parameters as our design goals, we may begin our work.

The problems posed by the new bands to be covered by an LPDA are multiple. First, for standard construction, the sizes of the materials--for example, the twin boom pieces--begin to interact with the very short element lengths. Consequently, designing for a very precise frequency range may prove self-defeating should the materials shift the frequency range as a whole. Therefore, we shall adopt the procedure of setting the two design bands as 800 to 1000 MHz and 1800 to 2000 MHz.

Second, many antenna types can be developed for each of these bands. For example, wide-band Yagis are possible. As well, corner reflector arrays become quite feasible with respect to both size and performance. The appeal of the LPDA lies in its ability to be designed to cover both bands.

Before beginning detailed design work, let's go through a few basic calculations.

1. The upper limit of the low band is 1000 MHz. The older resonant frequency for the shortest element would be 1300 MHz, while the newer recommendation would yield 1600 MHz as the resonant frequency of the shortest element.

2. The lower limit of the upper band is 1800 MHz, with the longest element resonated about 2.5% lower, or about 1755 MHz.

The two elements of concern are at a border line. They are close enough together to suggest that a continuous frequency LPDA design might be applicable. However, they are far enough apart to make the process of designing separate LPDAs and combining them sensible as a preliminary investigation. In the days before computer antenna modeling, such a process would call for extensive construction and range testing. Today, mathematical simulation shortens the work considerably.

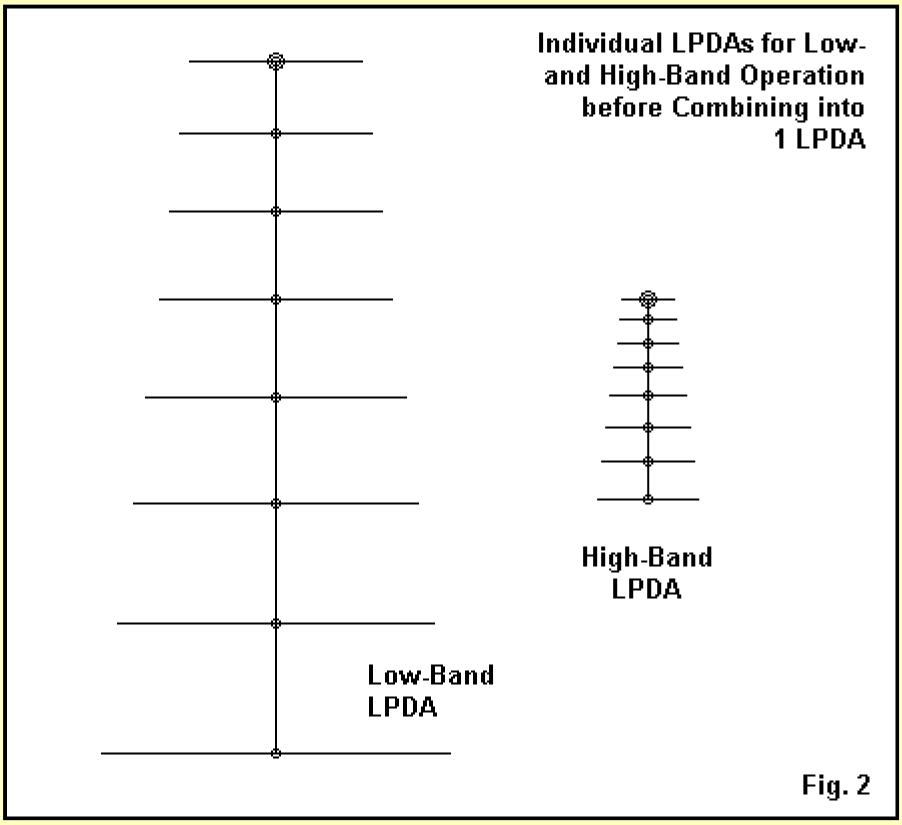


Fig. 2

I used the same values of tau (0.9045) and sigma (0.1879) for the individual LPDAs and for the single design. The low-band and the high-band LPDAs each required 8 elements. **Fig. 2** provides the outlines for the two arrays. **Table 1** supplies the dimensions. The designs used an 80-Ohm phase line and 0.118" (3 mm) elements.

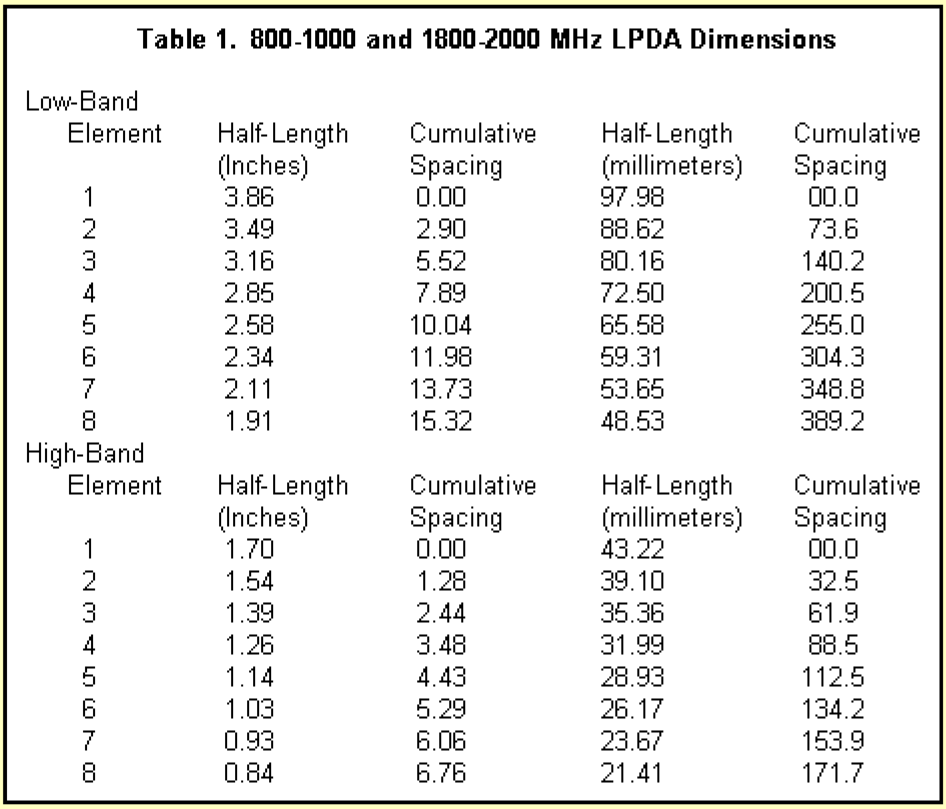


Table 1. 800-1000 and 1800-2000 MHz LPDA Dimensions

Low-Band Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	3.86	0.00	97.98	00.0
2	3.49	2.90	88.62	73.6
3	3.16	5.52	80.16	140.2
4	2.85	7.89	72.50	200.5
5	2.58	10.04	65.58	255.0
6	2.34	11.98	59.31	304.3
7	2.11	13.73	53.65	348.8
8	1.91	15.32	48.53	389.2
High-Band Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	1.70	0.00	43.22	00.0
2	1.54	1.28	39.10	32.5
3	1.39	2.44	35.36	61.9
4	1.26	3.48	31.99	88.5
5	1.14	4.43	28.93	112.5
6	1.03	5.29	26.17	134.2
7	0.93	6.06	23.67	153.9
8	0.84	6.76	21.41	171.7

Each of the two individual LPDAs offers adequate performance relative to the standards with which we began: a minimum free-space gain of 9.5 dBi (with its associated high front-to-back ratio) and a 50-Ohm SWR well under 2:1. **Table 2** provides the modeled performance data at 20 MHz intervals in each of the two bands.

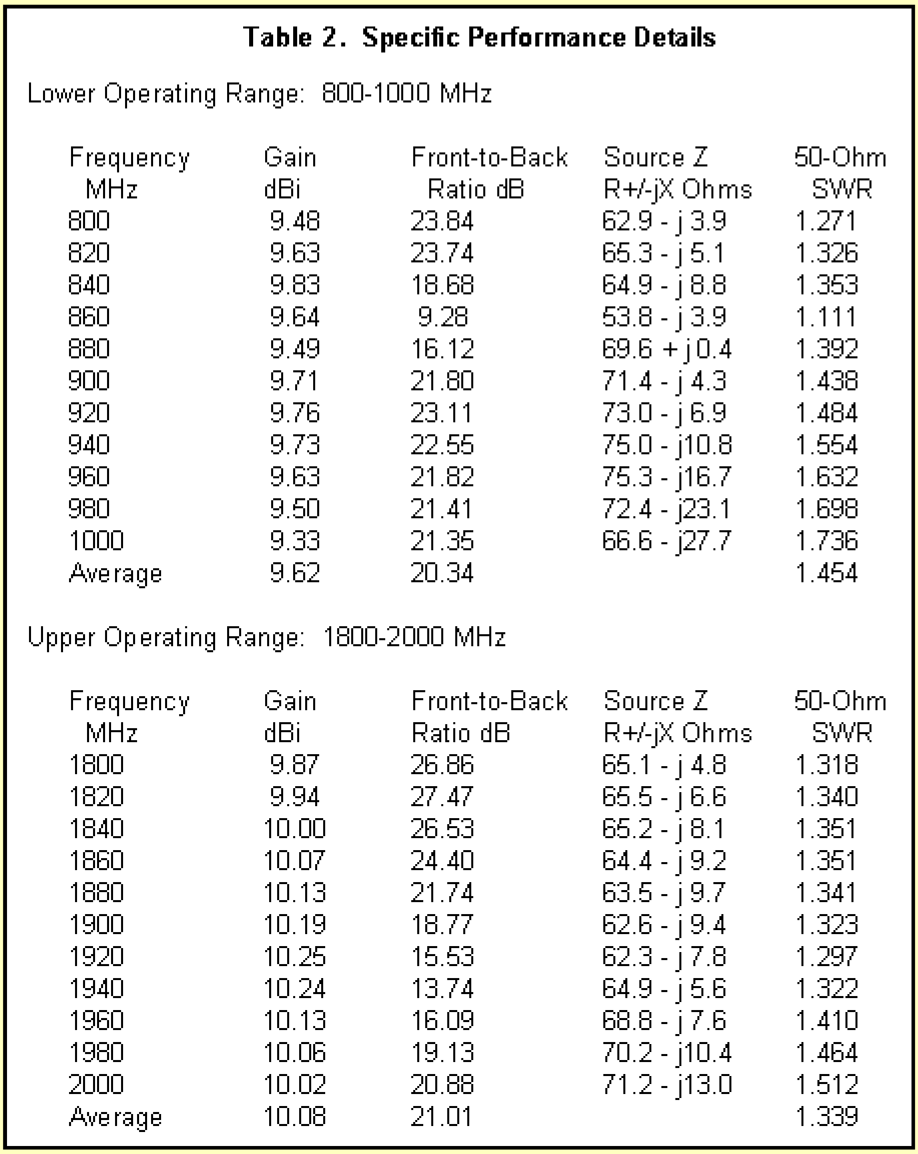


Table 2. Specific Performance Details

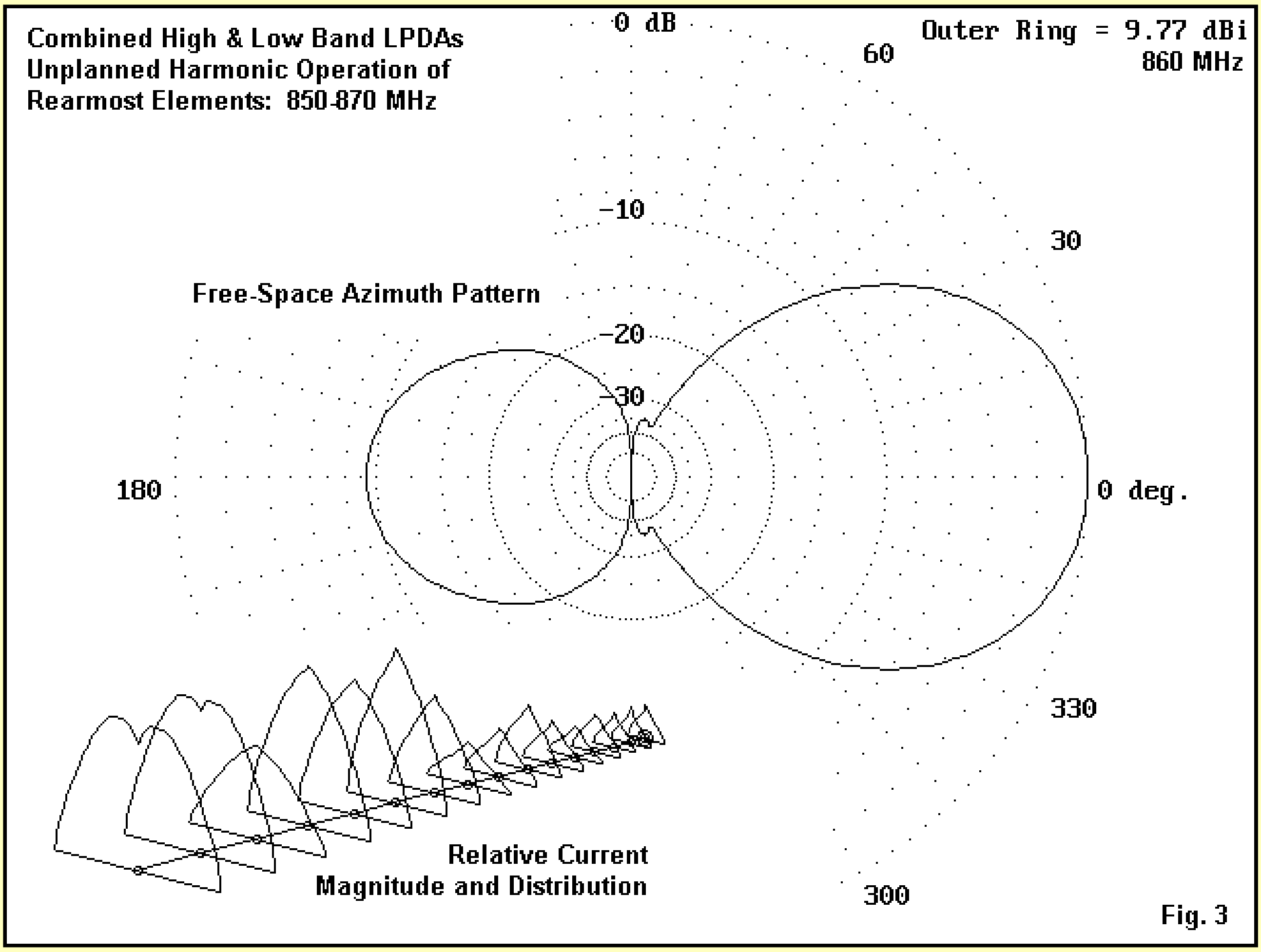
Lower Operating Range: 800-1000 MHz

Frequency MHz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
800	9.48	23.84	62.9 - j 3.9	1.271
820	9.63	23.74	65.3 - j 5.1	1.326
840	9.83	18.68	64.9 - j 8.8	1.353
860	9.64	9.28	53.8 - j 3.9	1.111
880	9.49	16.12	69.6 + j 0.4	1.392
900	9.71	21.80	71.4 - j 4.3	1.438
920	9.76	23.11	73.0 - j 6.9	1.484
940	9.73	22.55	75.0 - j10.8	1.554
960	9.63	21.82	75.3 - j16.7	1.632
980	9.50	21.41	72.4 - j23.1	1.698
1000	9.33	21.35	66.6 - j27.7	1.736
Average	9.62	20.34		1.454

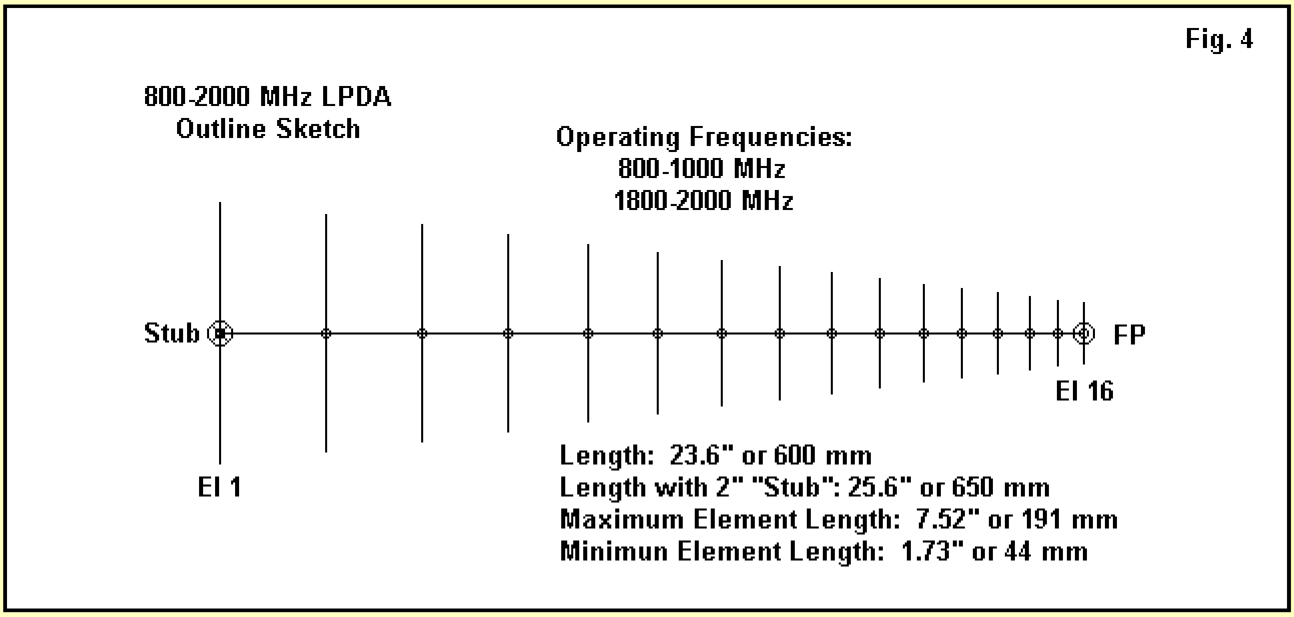
Upper Operating Range: 1800-2000 MHz

Frequency MHz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
1800	9.87	26.86	65.1 - j 4.8	1.318
1820	9.94	27.47	65.5 - j 6.6	1.340
1840	10.00	26.53	65.2 - j 8.1	1.351
1860	10.07	24.40	64.4 - j 9.2	1.351
1880	10.13	21.74	63.5 - j 9.7	1.341
1900	10.19	18.77	62.6 - j 9.4	1.323
1920	10.25	15.53	62.3 - j 7.8	1.297
1940	10.24	13.74	64.9 - j 5.6	1.322
1960	10.13	16.09	68.8 - j 7.6	1.410
1980	10.06	19.13	70.2 - j10.4	1.464
2000	10.02	20.88	71.2 - j13.0	1.512
Average	10.08	21.01		1.339

If we combine the two arrays into a single array, using the same phase line value, we obtain an LPDA that is about 23.5" (597 mm) long. The performance does not vary by much from the values produced by the individual arrays that comprise it. Unfortunately, this performance also includes the weakness at 860 MHz, as shown in **Fig. 3**.



Combining arrays did not remove this weakness, and the addition of a shorted stub manages to move its frequency upward, but not out of the desired operating range of the low band. Indeed, the relatively weak front-to-back performance of the individual and combined arrays results from using a value of sigma that is slightly above the optimum value. The arrays yield more gain, but at the cost of the front-to-back ratio. As well, the element diameters may be somewhat large for the frequency range in use.



We may create a single LPDA using the very same values of tau and sigma. Fig. **4** shows the outline of such an array. Note that the length is a mere 3 mm greater than the combined array. What differs, however, is the fact that the space between elements 8 and 9 adheres to the specifications for the array and is not based on an arbitrary or experimental adjustment. For comparison with the individual arrays, **Table 3** lists the total array dimensions.

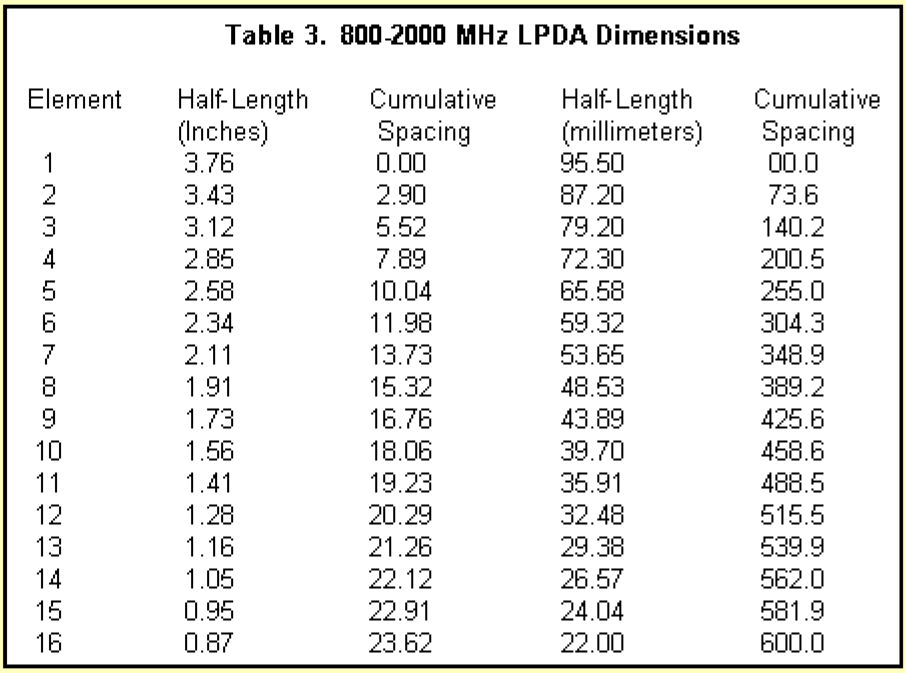


Table 3. 800-2000 MHz LPDA Dimensions

Element	Half-Length (Inches)	Cumulative Spacing	Half-Length (millimeters)	Cumulative Spacing
1	3.76	0.00	95.50	00.0
2	3.43	2.90	87.20	73.6
3	3.12	5.52	79.20	140.2
4	2.85	7.89	72.30	200.5
5	2.58	10.04	65.58	255.0
6	2.34	11.98	59.32	304.3
7	2.11	13.73	53.65	348.9
8	1.91	15.32	48.53	389.2
9	1.73	16.76	43.89	425.6
10	1.56	18.06	39.70	458.6
11	1.41	19.23	35.91	488.5
12	1.28	20.29	32.48	515.5
13	1.16	21.26	29.38	539.9
14	1.05	22.12	26.57	562.0
15	0.95	22.91	24.04	581.9
16	0.87	23.62	22.00	600.0

From some of the rounded numbers in the millimeters column for element lengths, it should be clear that the four rear-most and the last forward elements have been modified to improve performance. Moreover, the phase-line has a continuously variable characteristic impedance ranging from 78 Ohms at the feedpoint to 120 Ohms at the array rear. In addition, a 2" (50 mm) 120-Ohm stub has been added to the rear of the array. This combination of ingredients removes weakness from the coverage and smoothes the SWR values across the passband. The benefit includes a modicum of gain, but an even greater improvement in the front-to-back ratio. **Table 4** provides the modeled performance values.

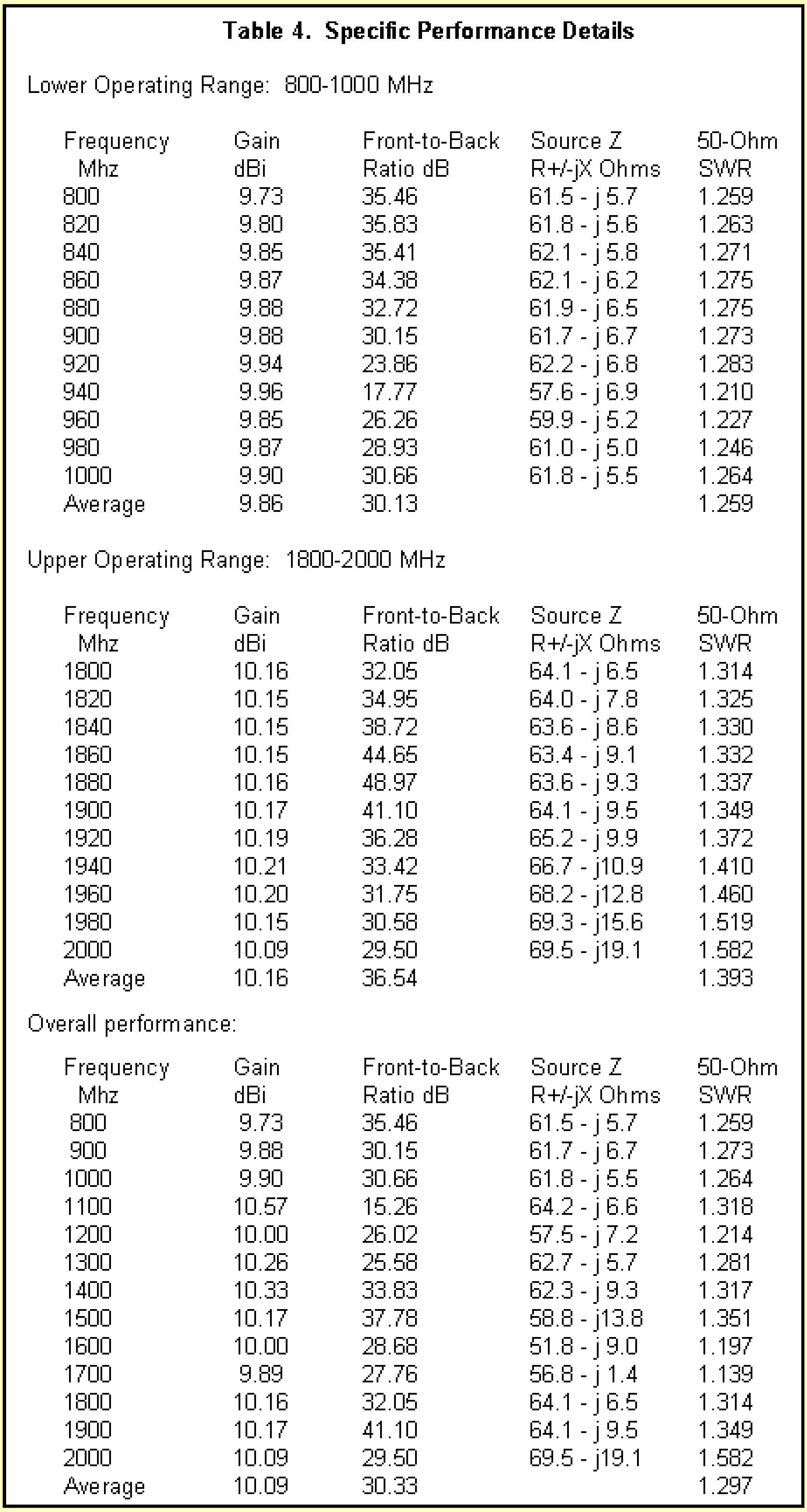


Table 4. Specific Performance Details

Lower Operating Range: 800-1000 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
800	9.73	35.46	61.5 - j 5.7	1.259
820	9.80	35.83	61.8 - j 5.6	1.263
840	9.85	35.41	62.1 - j 5.8	1.271
860	9.87	34.38	62.1 - j 6.2	1.275
880	9.88	32.72	61.9 - j 6.5	1.275
900	9.88	30.15	61.7 - j 6.7	1.273
920	9.94	23.86	62.2 - j 6.8	1.283
940	9.96	17.77	57.6 - j 6.9	1.210
960	9.85	26.26	59.9 - j 5.2	1.227
980	9.87	28.93	61.0 - j 5.0	1.246
1000	9.90	30.66	61.8 - j 5.5	1.264
Average	9.86	30.13		1.259

Upper Operating Range: 1800-2000 MHz

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
1800	10.16	32.05	64.1 - j 6.5	1.314
1820	10.15	34.95	64.0 - j 7.8	1.325
1840	10.15	38.72	63.6 - j 8.6	1.330
1860	10.15	44.65	63.4 - j 9.1	1.332
1880	10.16	48.97	63.6 - j 9.3	1.337
1900	10.17	41.10	64.1 - j 9.5	1.349
1920	10.19	36.28	65.2 - j 9.9	1.372
1940	10.21	33.42	66.7 - j10.9	1.410
1960	10.20	31.75	68.2 - j12.8	1.460
1980	10.15	30.58	69.3 - j15.6	1.519
2000	10.09	29.50	69.5 - j19.1	1.582
Average	10.16	36.54		1.393

Overall performance:

Frequency Mhz	Gain dBi	Front-to-Back Ratio dB	Source Z R+/-jX Ohms	50-Ohm SWR
800	9.73	35.46	61.5 - j 5.7	1.259
900	9.88	30.15	61.7 - j 6.7	1.273
1000	9.90	30.66	61.8 - j 5.5	1.264
1100	10.57	15.26	64.2 - j 6.6	1.318
1200	10.00	26.02	57.5 - j 7.2	1.214
1300	10.26	25.58	62.7 - j 5.7	1.281
1400	10.33	33.83	62.3 - j 9.3	1.317
1500	10.17	37.78	58.8 - j13.8	1.351
1600	10.00	28.68	51.8 - j 9.0	1.197
1700	9.89	27.76	56.8 - j 1.4	1.139
1800	10.16	32.05	64.1 - j 6.5	1.314
1900	10.17	41.10	64.1 - j 9.5	1.349
2000	10.09	29.50	69.5 - j19.1	1.582
Average	10.09	30.33		1.297

All three parts of the table are useful. The specific performance potentials within the two operating regions show about a 0.3 dB differential, which indicates a good match. As well, the single array shows a very high improvement in the front-to-back ratio over the separate or combined separate arrays. As well, within each operating range, there are no signs of any weaknesses in terms of tendencies toward pattern reversals created by harmonic operation of rearward elements.

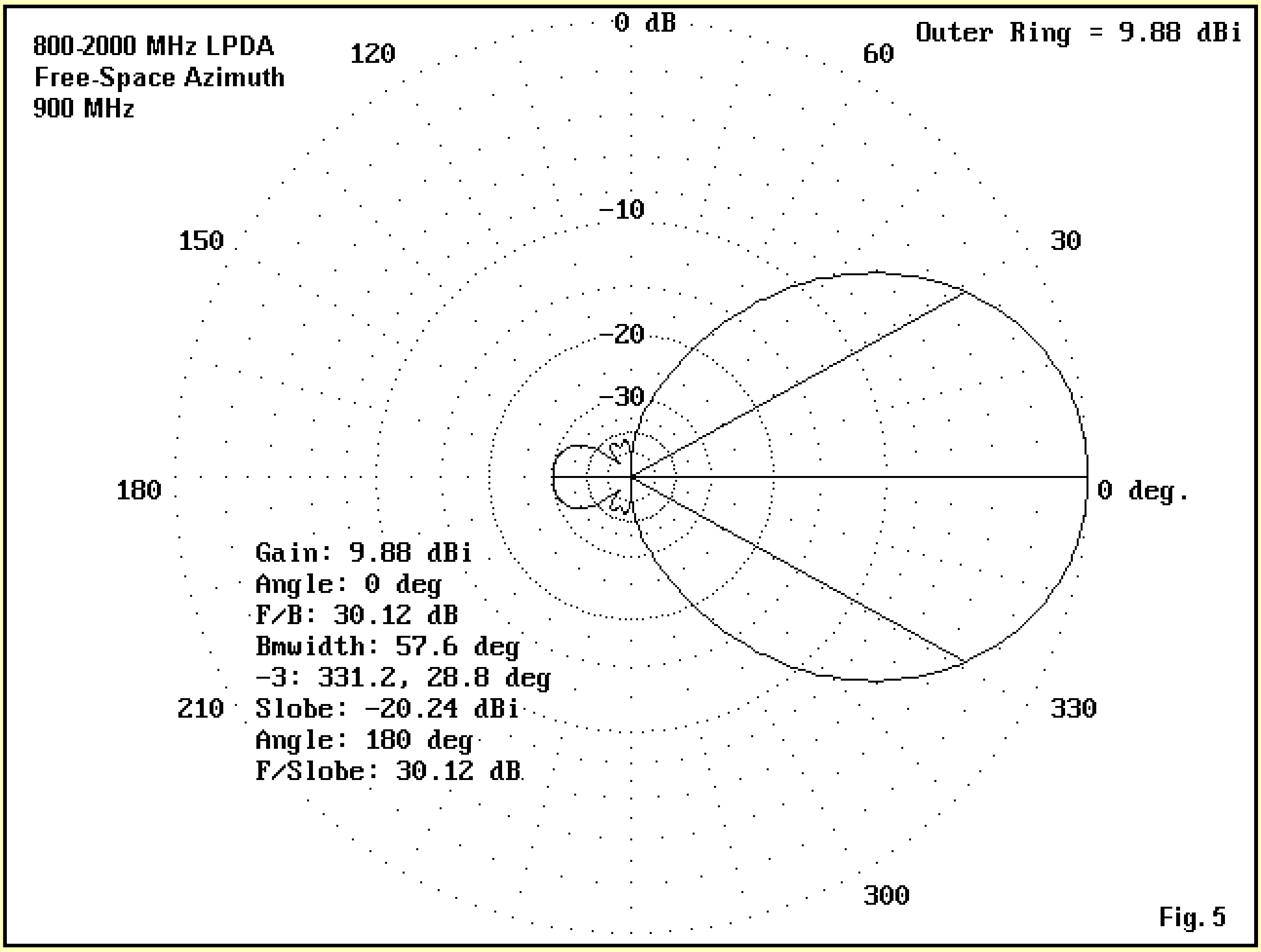


Fig. 5 shows a mid-range (900 MHz) free-space azimuth patterns for the single array. Although the basic numbers for gain and front-to-back ratio, as well as the overall shape of the pattern, appear to be excellent, the rear lobes show a small amount of excess lobing. The extra lobes are operationally insignificant by any standard, but should be noted.

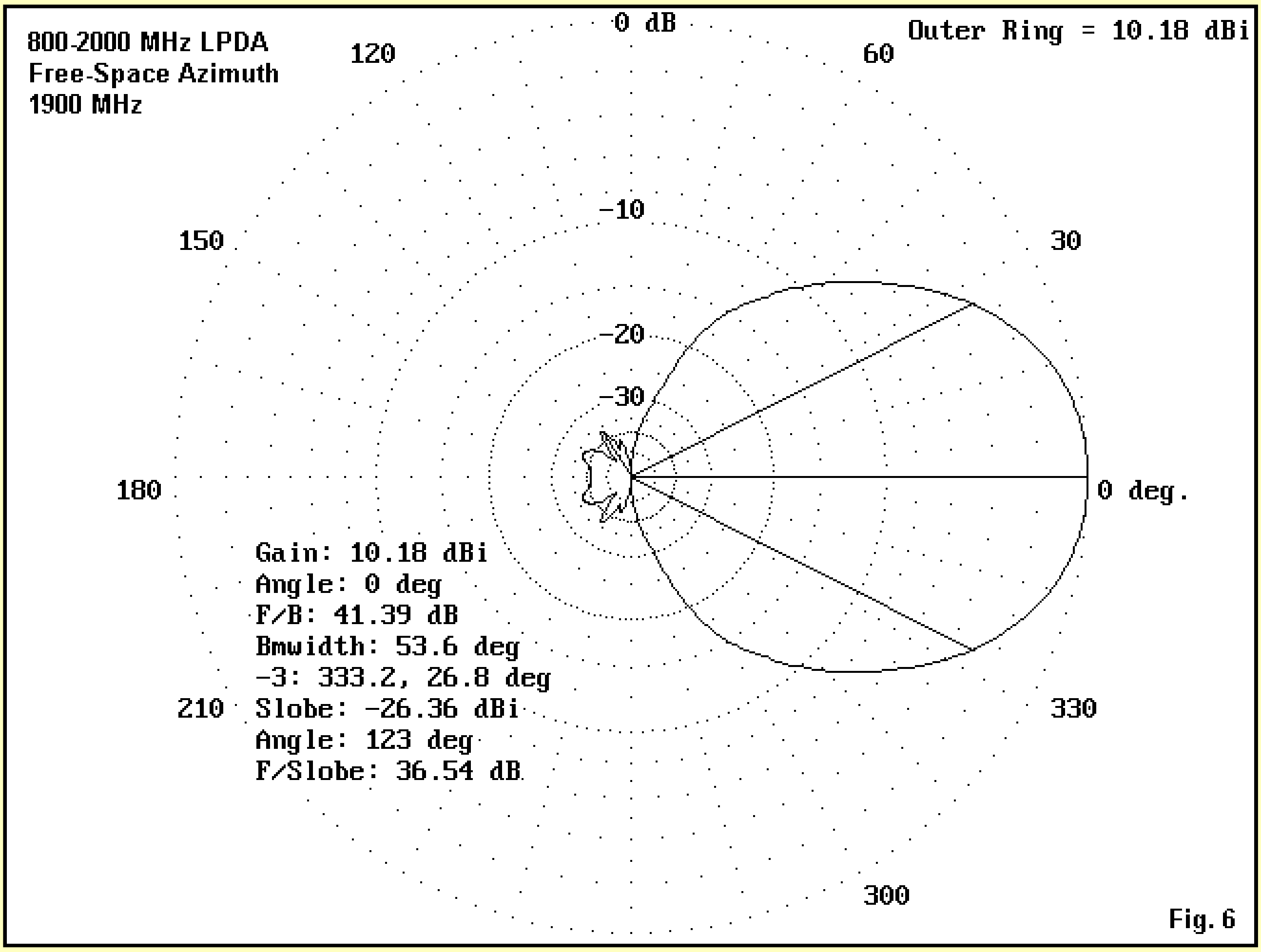
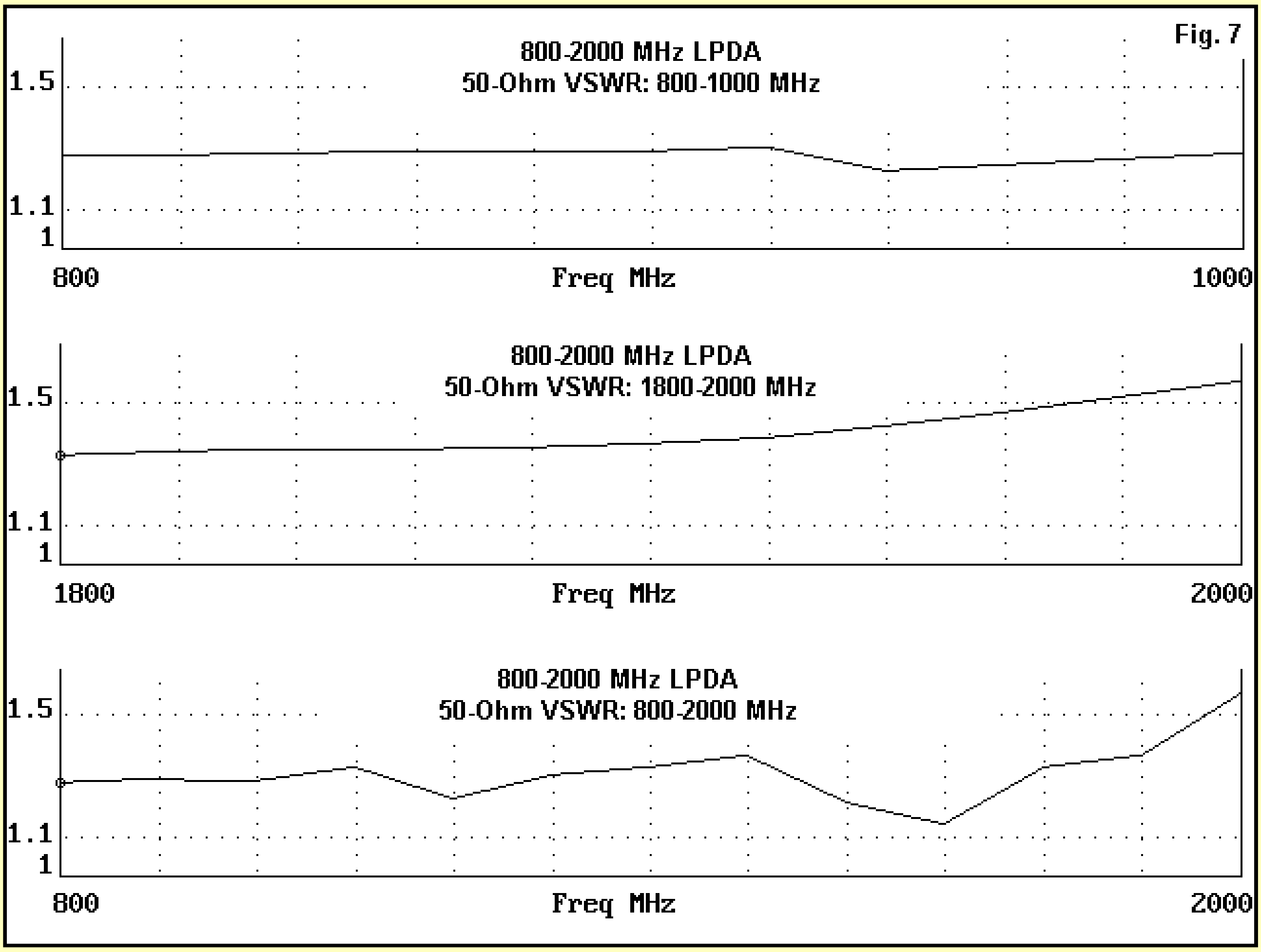


Fig. 6 shows a mid-range (1900 MHz) free-space pattern for the same array. At this higher frequency, the rearward lobes are considerably more fragmented, even though the magnitude remain below operational significance. As well, careful examination of the forward lobe reveals that it is on the verge of slight deformation. Essentially, this array is close to the limit for using an excessive value of sigma for the value of tau chosen in the design phase. The selected tau has an optimum sigma of 0.1688, whereas the value used in the array is 0.1879, over 10% high. A smaller value of sigma would have increased the element count.



The SWR curves, shown in **Fig. 7**, show no significant problems, either within the operating ranges or overall. In fact, they do not show the indications of any weakness, although the data table tells a different story. The combination of correctives applied to this LPDA design has moved the weakness in the individual arrays outside the operating range. In fact, the SWR curve is accurate in the sense that there is no SWR value above about 1.34:1 in the frequency region of the low value of front-to-back ratio. In addition, the value shown in the overall chart of performance is close to the minimum value encountered in more specific sweeps of the frequency area (15.13 dB at 1102 MHz). Hence, unless the reduction of front-to-back ratio at about 1100 MHz is a problem for some other use of this array, the correctives can be viewed as having eliminated weaknesses in a standard design.

Application of correctives is most usually done with greatest ease and without unexpected surprises when the subject antenna is a single array of unified design. The breach in the normal progression of elements created by combining two independently designed arrays often gives the designer more problems when the goal is multi-faceted, as in the case of this split-range array. In this case, we sought to provide relatively equal gain across each range and to match the gain levels of the two ranges. As well, we wished to have a usable 50-Ohm SWR across each operating range, with no weaknesses in coverage anywhere within them. The use of a unified single design considerably shortened the necessary design process in reaching these goals--at least in models.

As an aside, the element lengths for this array strongly suggest its adaptation to circuit-board fabrication rather than construction using standard twin-boom U-channel methods. When elements are under 1" each side of the centerline, even 1/2" U-channel stock may prove troublesome as a phase line.

Whatever the method of construction, the test case with which we have been working strongly suggests that unified single LPDA design has significant advantages over combining independent designs for split-range operation. If initial array calculation was all that we needed to do in order to create a satisfactory array, then combined independently designed arrays might be useful. However, so long as LPDA designs depart from the use of optimal values for tau and sigma, it is likely that correctives will be needed to reach satisfactory performance. A unified single array facilitates experimenting successfully with these modifications.

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