Some Notes on FM BC Antennas
Part 4: Some LPDA Options

L. B. Cebik, W4RNL (SK)

We have examined both the potentials and the limitations of Yagi antennas for enhancing reception on the 20-MHz-wide FM band. Most Yagi designs of reasonable size and common construction have the ability to cover no more than about 1/4 to 1/3 of the band. The one Yagi that was capable of covering the entire band used very fat elements and a very long boom.

For full band coverage with a single antenna, one popular option is the log periodic dipole array (LPDA). The LPDA is inherently a wide-band antenna and falls in a class sometimes called frequency-independent antennas. We shall examine this option by looking at two different designs: a modest length (7.3') version with good performance and a long-boom version (14') for excellent performance. In both cases, we shall instantly notice from azimuth patterns that the LPDA at any good gain level has a smooth and regular forward lobe with no lumps or side lobes. As well, compared to the wide-band Yagi we explored, the rear lobes of an LPDA are much smaller. In other words, the LPDA exhibits a much better front-to-back ratio for the suppression of signals from the rear.

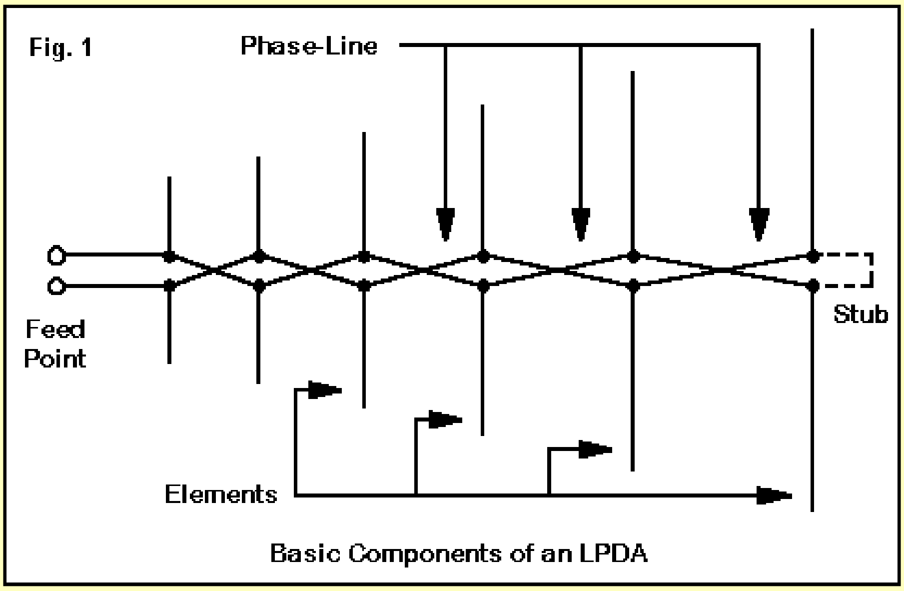
For a given boom length, a well-designed LPDA will require more elements than a comparable Yagi. Our 7' LPDA will have 8 elements, although the narrow-band OWA (actually considered a broadband antenna among Yagis) used only 6 for the same length boom. The wide-band Yagi used 8 elements in 14' of boom, but our LPDA of the same length will use 16.

Commercial LPDAs for FM reception come in many sizes and shapes. Some use a structure that forms a vertical V, although no particular advantage accrues to that shape. Others get by with short booms and/or fewer elements. Some sweep their elements forward, a practice that actually reduces their potential performance level. Unfortunately, marginal design is a hallmark of consumer-grade LPDAs. The two designs that we shall examine might be considered to be over-designed, but they exhibit smooth performance across the entire band, each at its own level.

Before we jump into actual designs, let's pause for a moment to understand somewhat the basic principles and parts of an LPDA.

A Few LPDA Basics

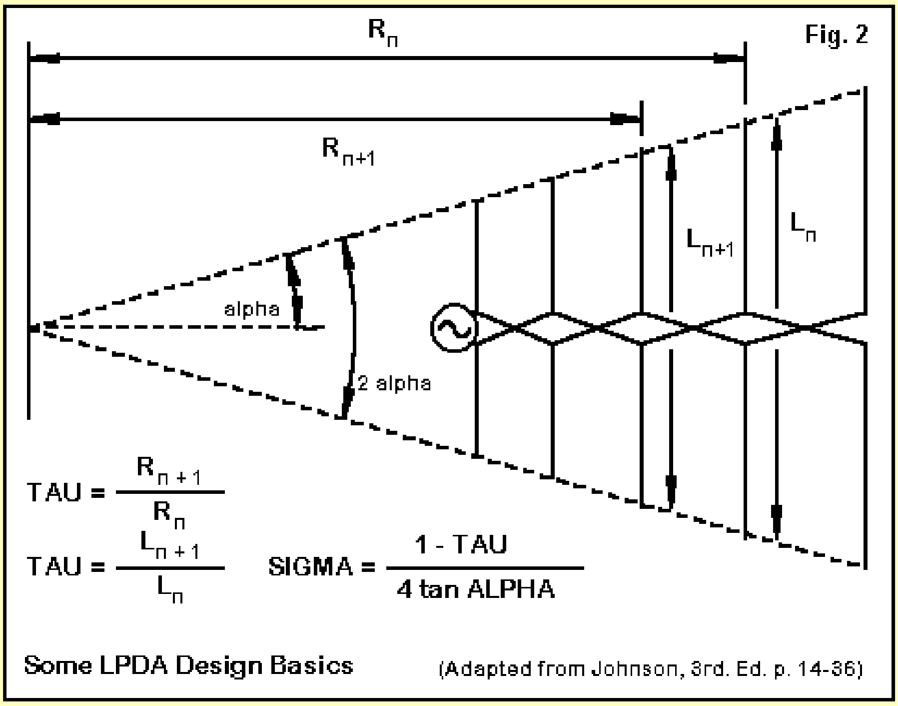
The log periodic dipole array differs from a Yagi in that we feed direct signal to each element. Hence, compared to a Yagi, the antenna has extra parts. See **Fig. 1**.



Basic Components of an LPDA

An LPDA has numerous elements, all of which grow longer in a very regular fashion as we move from front to back. The feedpoint is at the front end of the array. The LPDA uses a transmission line to directly feed power to each elements in the array. The current distribution on any element is thus a combination of the supplied power and the coupled power from adjacent elements. Note in the figure that as we move from one element to the next, we reverse the feedline. There are different ways of achieving the phase reversal, so some designs might not seem to twist a line. Some designs may require the use of a stub at the rear element gap, and others may not.

The foundations of the LPDA go back to the late 1960s, with the identification of 3 critical and interlocking design factors given the names alpha, tau, and sigma. How these factor inter-relate appears in **Fig. 2**.



The LPDA starts with a section of a circle. Since we will use straight elements, we can think of the LPDA as a triangle. If we draw a line down the center of the array, we shall create an angle with a line drawn along the outside tips of the array. We call the angle alpha and measure it in degrees.

Any two adjacent elements in the array will form a ratio between the length of the shorter and the length of the longer. That ratio also describes the spacing between any two elements and the next two elements rearward. We call that ratio tau.

The relationship of the spacing between any two elements and the length of the rearward one is called sigma. As the figure suggests, knowing any two of the three design figures let's us algebraically derive the third one. In fact, most LPDA designs begin with the designer selecting values for tau and sigma and therefore letting alpha become whatever the mathematics dictate.

Most cursory glances at LPDAs tend to stop once we have these numbers. However, LPDA design depends on much more than these factors alone. In any LPDA, at any operating frequency within its range, there will be a most active element, that is, one showing the highest level of current magnitude. Contrary to what designers once thought, all of the elements forward of the most active element will also be active. We knew from the beginning that we needed a rearmost element that was longer than 1/2-wavelength at the lowest operating frequency so that it could be moderately active in order for the LPDA to give full performance at that lowest operating frequency. However, assumptions about how long to make the shortest element were considerably off the mark until recent times. We used to make it resonant at a frequency about 1.3 times the highest operating frequency, but that practice proved to provide too few active elements ahead of the most active one at the upper operating limit. Increasing the resonant frequency of the shortest element to about 1.6 times the upper operating frequency drastically improves high-end performance--but it also adds to the number of necessary elements in an array for a given set of tau and sigma values.

In addition, we have learned that we may modify the lengths and spacings of the elements at the rear and the front of an array to better tailor the set of operating characteristics. We may also vary the characteristic impedance of the phase line feeding the elements to change the performance level. Indeed, as we lower the characteristic impedance, we improve gain, but at a certain point for any design, we destabilize performance. Destabilization occurs when the array--at some frequency within its operating range--shows a reduction in gain and front-to-back ratio, and sometimes shows an actual reversal of pattern. This problem also occurs if we try to cover too wide a frequency range with too few elements.

The most complete up-to-date coverage of LPDA design appears in the 2-volume set of books, *LPDA Notes*, available from *antenneX*. For a succinct technical coverage of LPDA basics, see Chapter 10 of the *ARRL Antenna Book*, 19th or later edition.

These brief notes on LPDA basics tell us that a designer must not only select values of tau and sigma in order to create an LPDA. He must also consider the element population, the phase line characteristic impedance (which will have a strong influence on the impedance at the feedpoint), the employment of modifications, and a possible stub in order to come up with a complete working design. A good design should provide the following performance characteristics:

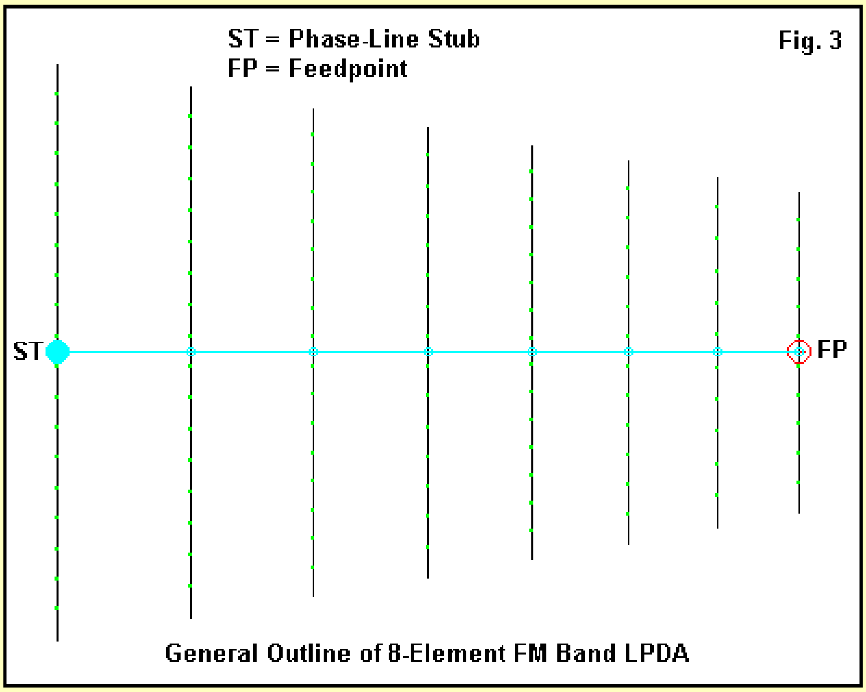
- 1. A smooth gain curve: in the FM band, perhaps no more than 1 dB variation across the entire band;
- 2. A certain minimum front-to-back ratio: that ratio tends to increase as the forward gain increases; and
- 3. A good match to a given feedline selection: under 2:1 SWR within the FM band is normal.

Since every small change in frequency alters the current phasing difference between two adjacent elements, we do not expect a perfect flat curve. In addition, we do not expect that the gain, front-to-back, and SWR curves will coincide in terms of their peaks and valleys. Instead, we speak in terms of falling within good operating limits.

Although these notes are not adequate to let you design your own LPDA from scratch, they may be enough to let you understand each of the two designs that we shall examine in detail.

An 8-Element 7.3'-Long LPDA for Good Performance

Our first example of an LPDA for the FM broadcast band is modest in LPDA circles. It uses 8 elements distributed along a 7.3' boom and has the general proportions outlined in **Fig. 3**.



General Outline of 8-Element FM Band LPDA

The following table lists the dimensions of the LPDA, element-by-element. Each element will require a center gap, and the length dimension gives the tip-to-tip length including the gap. The overall length is the element boom length. As always, you will need a support boom slightly longer to allow for element mounting hardware.

. . . .

An 8-Element FM Band LPDA: Dimensions

All dimensions in inches. Element spacing is listed as the cumulative distance from the rearmost element. All elements 0.25" diameter.

El. #	Length	Space from Rear
1	68.43	----
2	63.06	15.85
3	58.11	30.46
4	53.54	43.93
5	49.34	56.33
6	45.46	67.76
7	41.89	78.29
8	38.00	88.00

. . . .

The array uses an initial tau of about 0.92 and a sigma of about 0.12. The antenna is designed for a phase line using standard 300-Ohm good-quality TV twinlead with a velocity factor of 0.8. The feedpoint impedance will be close enough to 200 Ohms to permit the use of a 4:1 transformer at the feedpoint and preferably a 50-Ohm coaxial cable from that point to the receiver. The array also employs a 3" shorted stub of 300-Ohm twinlead across the rear element gap. A builder can leave the stub unsupported so long as it does not touch the support boom. As we shall see in a bit, the array is designed for a support boom and an independent phase line.

We can sample the performance of the array across the FM band from the following table of values.

. . . .

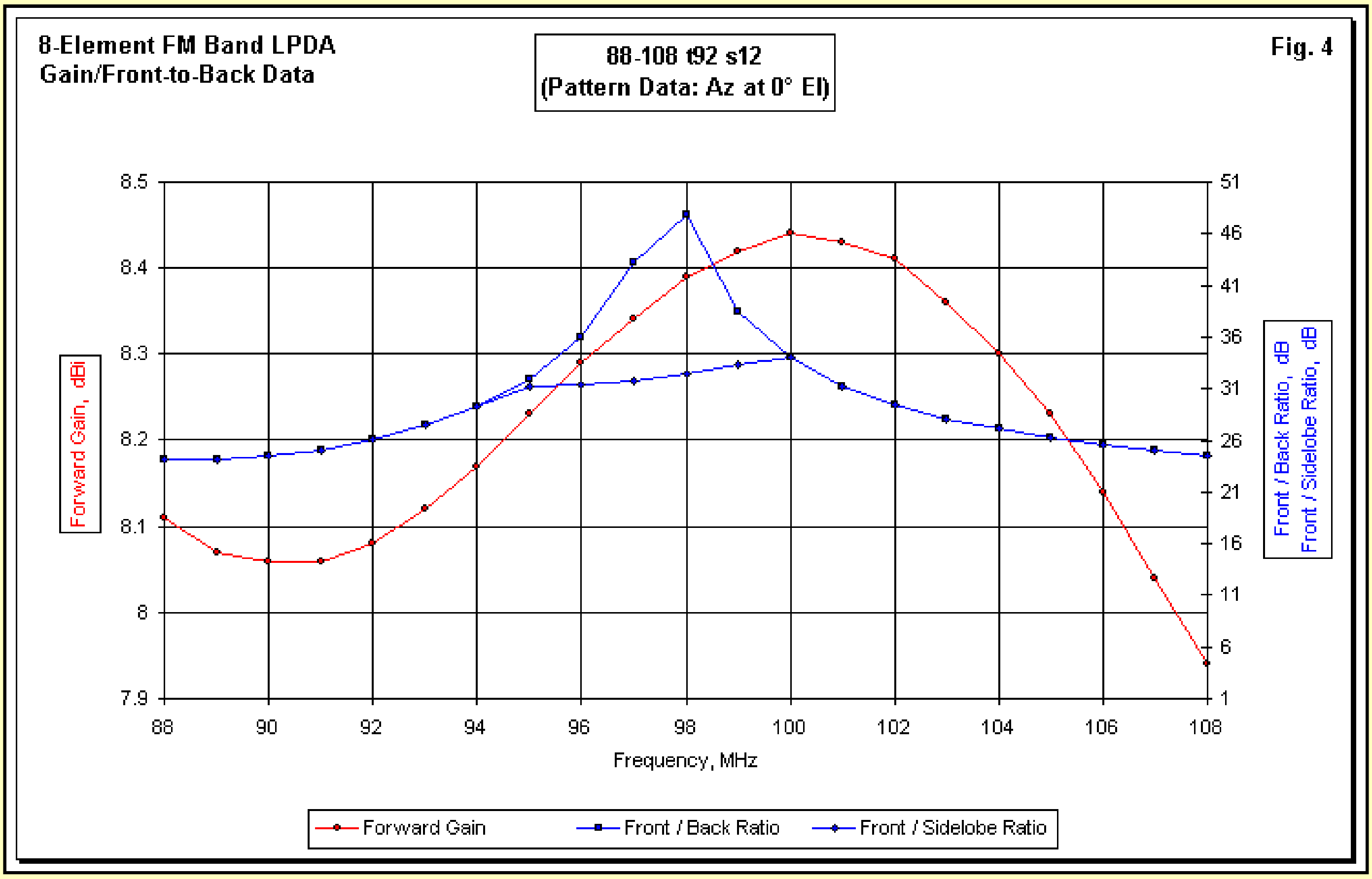
8-Element FM Band LPDA Performance

Gain = Free-space gain in dBi **Frequency in MHz**
Front-Back = 180-degree front-to-back ratio in dB

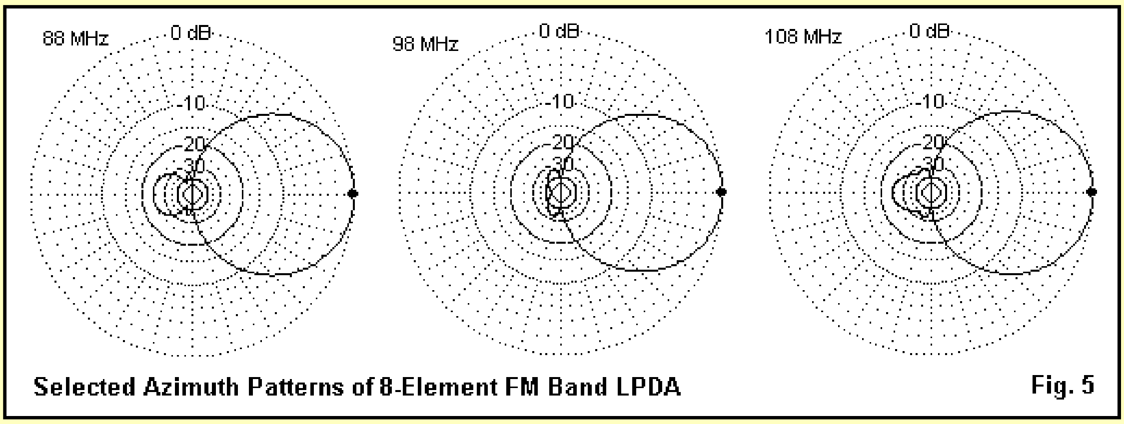
Frequency	88	98	108
Gain	8.1	8.4	7.9
Front-Back	24	48	25

. . . .

Compared to the wide-band Yagi, explored in part 2, the LPDA has a little over 2 dB less gain. However, the front-to-back performance is much superior throughout the band. We can gain a better appreciation of these sample numbers be looking at some graphs of both the gain and front-to-back performance.



From **Fig. 4**, we seem to see a gain level (red line) that has a major fluctuation. However, examine the left axis values and you will discover that the gain changes by only 0.5 dB across the entire band. In terms of equal sensitivity to signals across the entire FM band, this performance is far superior to what we could obtain from the wide-band Yagi. As well, the front-to-back performance of the LPDA is also superior to that of the wide-band Yagi at any frequency of operation. The minimum value is about 24 dB. An interesting side note is a comparison of the 180-degree ratio with the worst-case ratio, indicated by the line labeled front-to-sidelobe ratio. Although the exact rearward gain shows a deep dimple, the overall front-to-back ratio in worst case terms tends to remain stable across the entire band.



We can get a better view of the difference between the two ways of listing front-to-back performance by examining the azimuth patterns in **Fig. 5**. The 98-MHz pattern has the deep dimple directly to the rear, but rearward angling lobes that are a bit stronger. However, even the minimum value of 24 dB assures very high rejection of signals from the rear quadrants of the antenna.

Equally apparent in the azimuth patterns of **Fig. 5** is the clean shape at all frequencies of the forward lobe. There is virtually no change in the shape of this forward lobe at any frequency across the FM band.

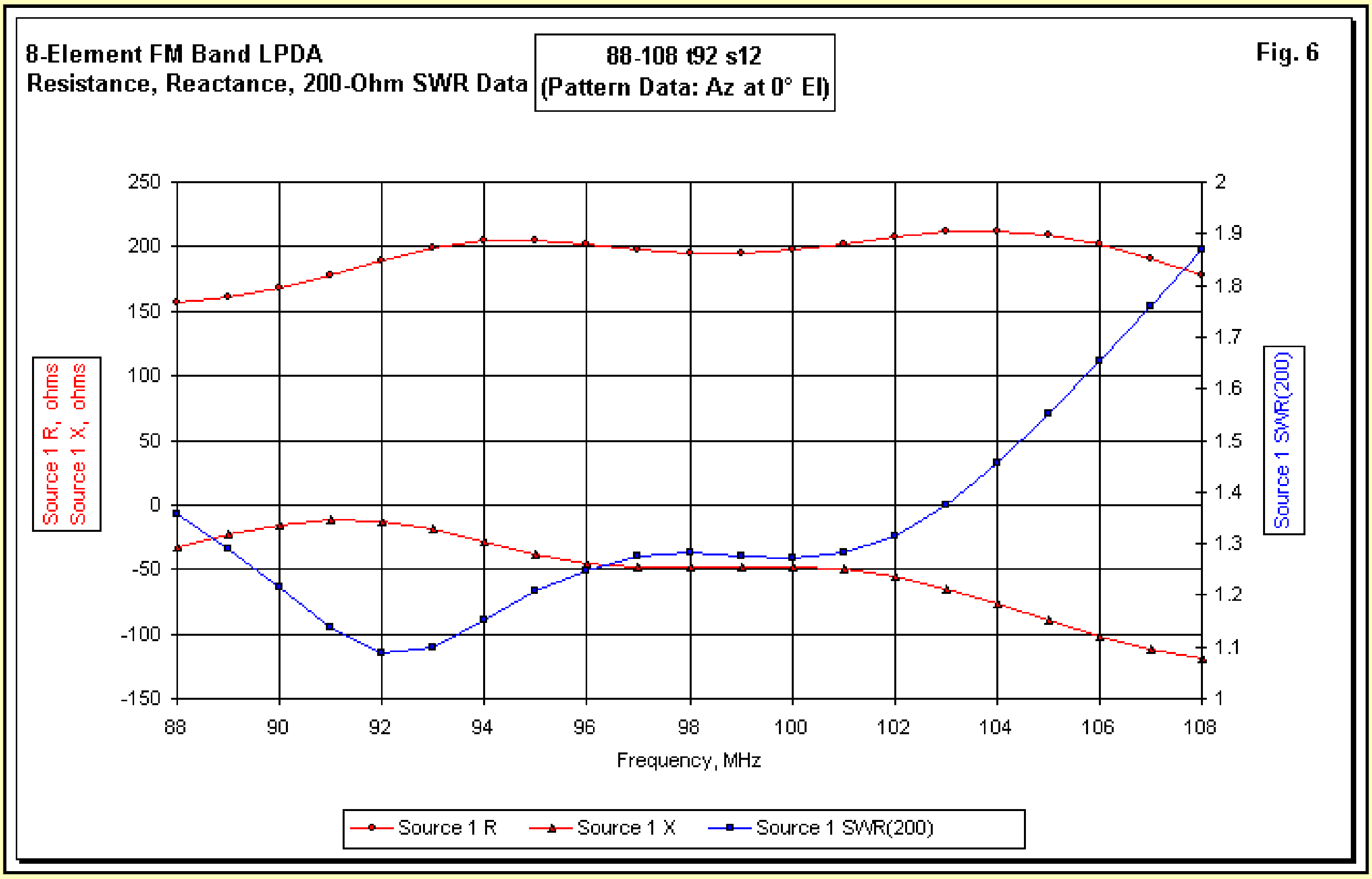


Fig. 6 shows us the changes in feedpoint resistance, reactance, and 200-Ohm SWR as we move along the FM band. By choosing the reference value of 200 Ohms for the SWR curve, we obtain the anticipated SWR values relative to 50 Ohms after we insert a 4:1 transformer at the feedpoint. The highest SWR is about 1.9:1 at the upper end of the band, a product of the design procedure that reduced the top frequency of design from the ideal 1.6 times 108 MHz in order to obtain more gain within the band from the 8 elements on the 88" boom.

The design promises very good performance across the entire band with 1 antenna, if we can only build it. Although I shall not provide complete construction details, here are some ideas.

First, you will need a boom. 1" to 1.25" diameter aluminum tubing is ideal, although obtaining an 8' length from which to cut the boom down to size may be difficult if you use mail order sources. You can use 6' lengths in the following way. Whatever the outer diameter you choose, cut a 6' and a 3' section. Then obtain the next size smaller that just fits inside the outer tube. Cut a 6' and a 3' section. However, when joining the tubes, let the outer 3' length and half the outer 6' length slip over a 6' length of the inner tube. Then slide the inner 3' length inside the remaining part of the 6' outer tube. Secure the tube sections with sheet metal screws. Before you nest the tubes, you will have some cleaning work to ensure that there are no burrs or other impediments that will leave you with two partially nested tubes that will not either nest in their final position or unnest for further preparation.

Once you have a boom, prepare a set of element mounting plates. I prefer UV-protected polycarbonate (trade name Lexan), but other materials will also work. The plate dimensions are not critical. Make each one wide enough to support each half element with two mounting brackets or very small u-bolts. Some folks like to scribe a groove into the plate just deep enough so that the element rides in it, but no so deep as to weaken the plate. The plate dimension along the boom should be large enough so that the u-bolts that go around the boom are at least an inch or so from the element going the other direction on the plate.

Once we have cut, mounted and positioned each element, it is time to consider the phase line. The gap at the center of each element can be narrow, since the space between the wires of good-quality TV twinlead is only about 3/8". Find or create solderable lugs at least an inch or so long--to separate the phase line from the boom. You can mount the lugs to the element by drilling and tapping a #6 or #8 threaded hole in the inner end of each half elements. Use a stainless steel bolt and lock-washer to fix the lug in place. Then open the vinyl insulation on the line just enough top permit soldering to the lug.

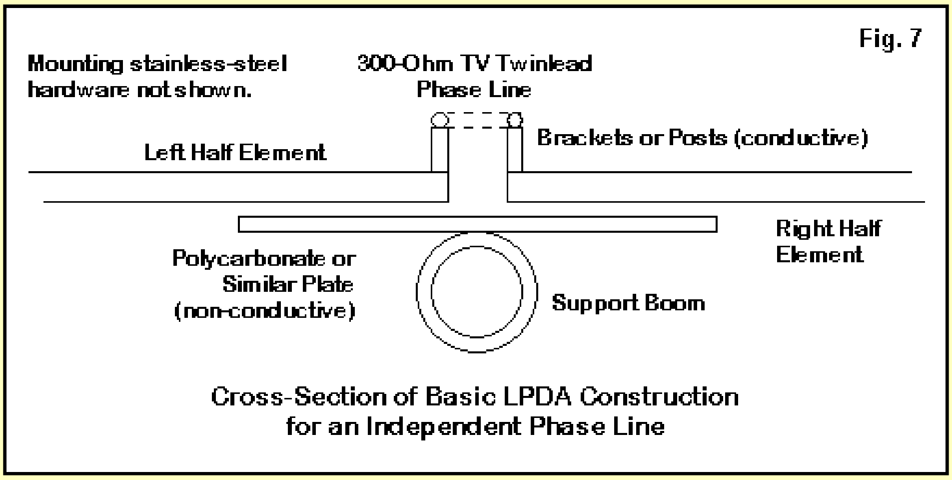


Fig. 7 is provided mostly as a reminder for these notes, but not as a detailed drawing of all of the details.

Note: be certain to give the line a half twist and only a half twist between each element.

Note: Be sure to stretch the line firmly enough so that it does no sag downward to touch the boom. If necessary, add an insulator at the midpoint between elements to support the line. A piece of plastic rod drilled at each end to accept cable ties will allow fastening to both the boom and the line.

At the rearmost element, let the line extend 3" (not very critical) beyond the last element. Solder the two line wires together to short the stub. At the front end (just in front of the shortest element), add a small plate and the kind of connector that will mate with your 4:1 transformer. If the transformer has leads instead of a connector on the high-impedance side, shorten the leads until you have just enough lead length to solder them to the short-element lugs.

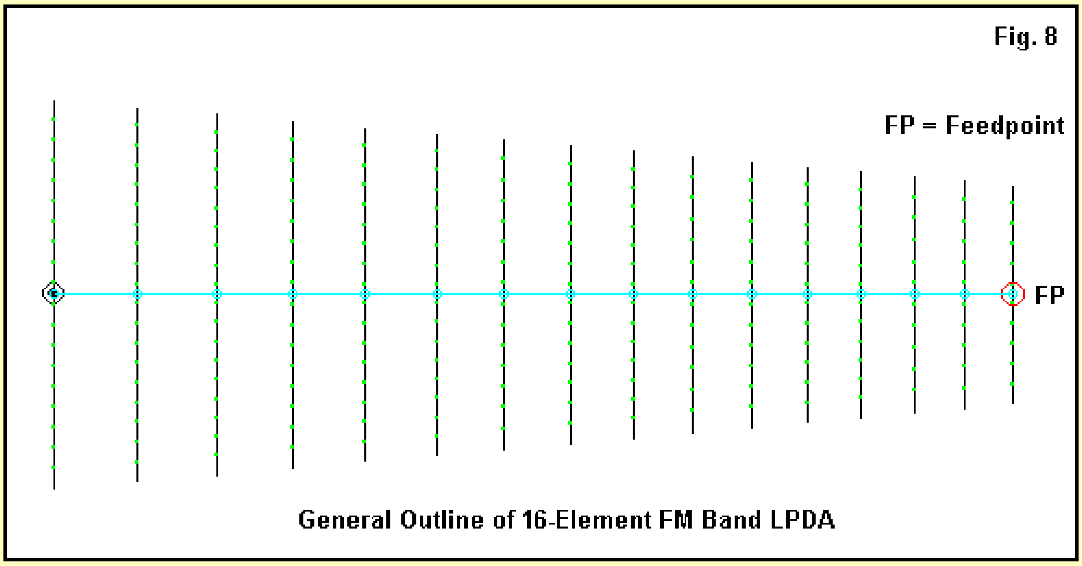
Of course, add whatever further support is needed for the transformer and the coaxial cable. Be certain--after testing--to coat all of the connections with something like Plasti-Dip or Brushable Electrical Tape to seal these connections from the weather.

When mounting the antenna, you will use some sort of plate or other fixture to attach the rough center of the boom (away from elements) to the mast. You may have to tip a phase-line support between elements away from the mast to assure good spacing that does not disrupt the balance of the line along its length.

Vary the construction as fits your own special skills and available suitable materials, but only after you think through what combined electrical and mechanical functions each recommended construction detail fulfills.

A 16-Element, 14'-Long FM Band LPDA for Excellent Performance

Not only did the wide-band Yagi use a 14' boom, but as well, I have seen more than one FM narrow-band Yagi use a boom approaching this length. So I wondered what we might achieve with an LPDA designed for a 14' boom. The design required 16 elements, but like the short LPDA, performance promises to be outstanding. **Fig. 8** shows the general outline.



The outline reveals that we will not need a stub with this design, although, as in every LPDA, we need a feedpoint. The array is designed to a tau of about 0.96 and a sigma of 0.11. The following table lists the dimensions using the same conventions that we applied to the short LPDA.

. . . .

A 16-Element FM Band LPDA: Dimensions

All dimensions in inches. Element spacing is listed as the cumulative distance from the rearmost element. All elements 0.25" diameter.

El. #	Length	Space from Rear
1	68.43	----
2	65.87	14.43
3	63.40	28.33
4	61.03	41.70
5	58.74	54.57
6	56.54	66.96
7	54.43	78.89
8	52.39	90.36
9	50.43	101.41
10	48.54	112.05
11	46.72	122.29
12	44.97	132.14
13	43.29	141.62
14	41.67	150.75
15	40.10	159.54
16	38.60	168.00

. . . .

What we gain for our effort reveals itself in the following table of sampled performance results anticipated from the design.

. . . .

16-Element FM Band LPDA Performance

Gain = Free-space gain in dBi **Frequency in MHz**
Front-Back = 180-degree front-to-back ratio in dB

Frequency	88	98	108
Gain	11.0	10.7	10.3
Front-Back	32	29	30

. . . .

The overall gain performance is better than that of the wide-band Yagi (but at a cost of more but thinner elements). Moreover, we also obtain further improvement in the front-to-back ratio, with an average value of 29 dB. As with the shorter LPDA, we can better appreciate the performance by examining graphs of these performance values.

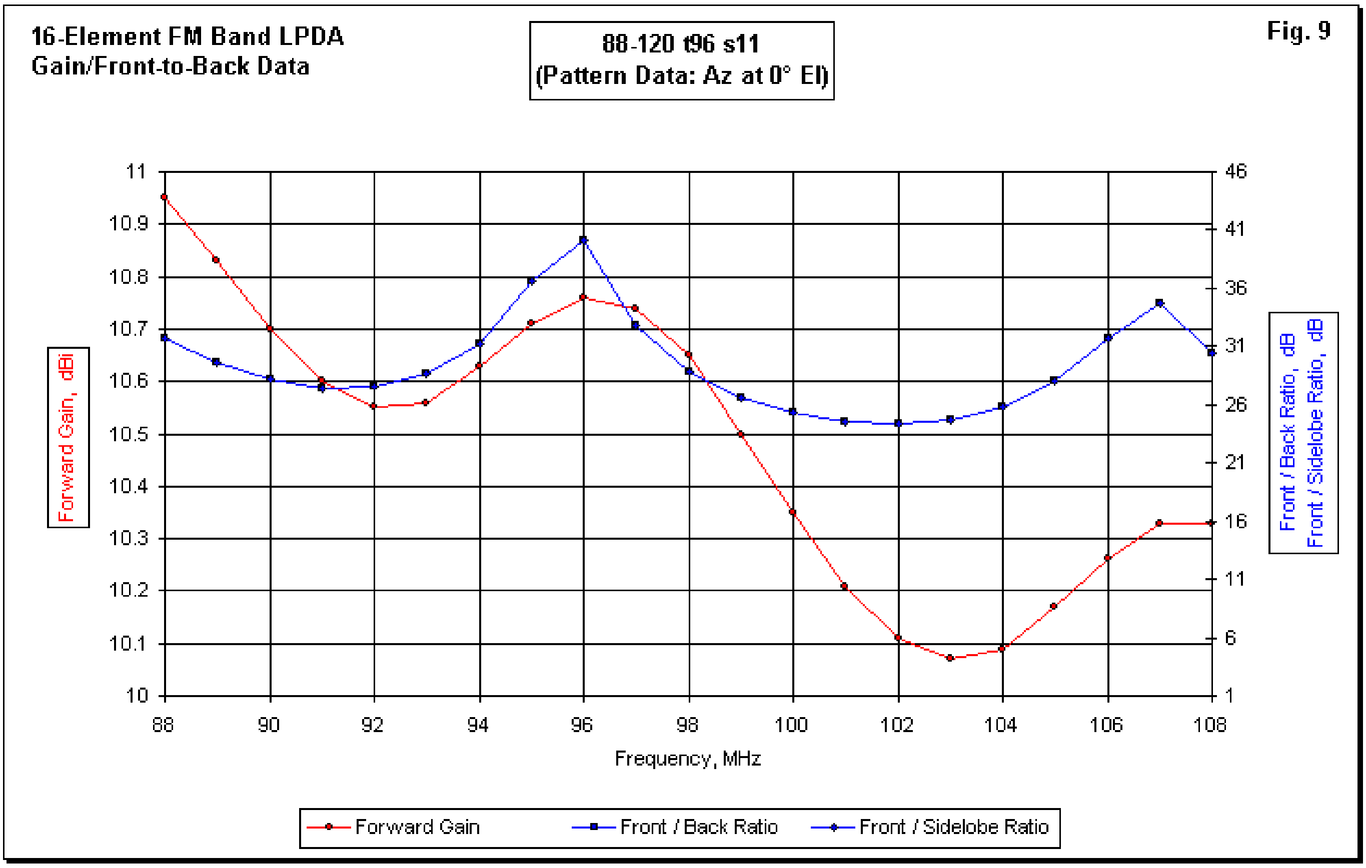
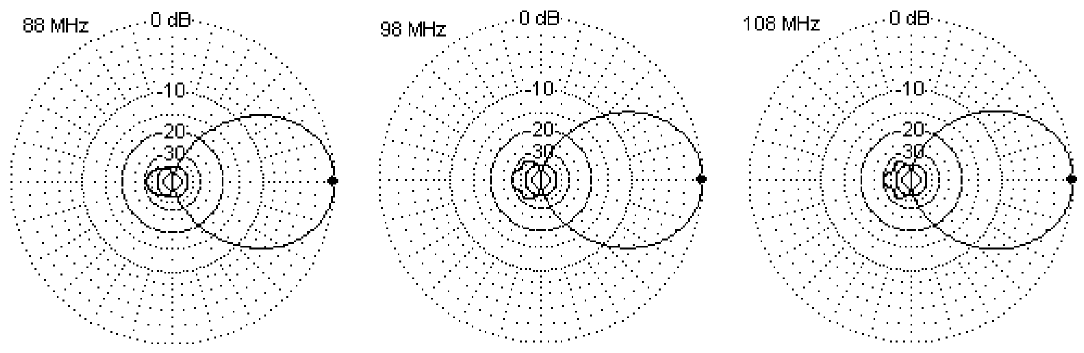


Fig. 9

Because we are working with more elements, we see that the gain and the front-to-back curves have two peaks apiece in **Fig. 9**. The 180-degree and worst-case front-to-back curves overlie each other, with a minimum value of about 25 dB. The gain curve looks more extreme, but once more the range is narrow--from 10.1 to 11.0 dB. These gain values approximate the best values obtained from the wide-band Yagi.

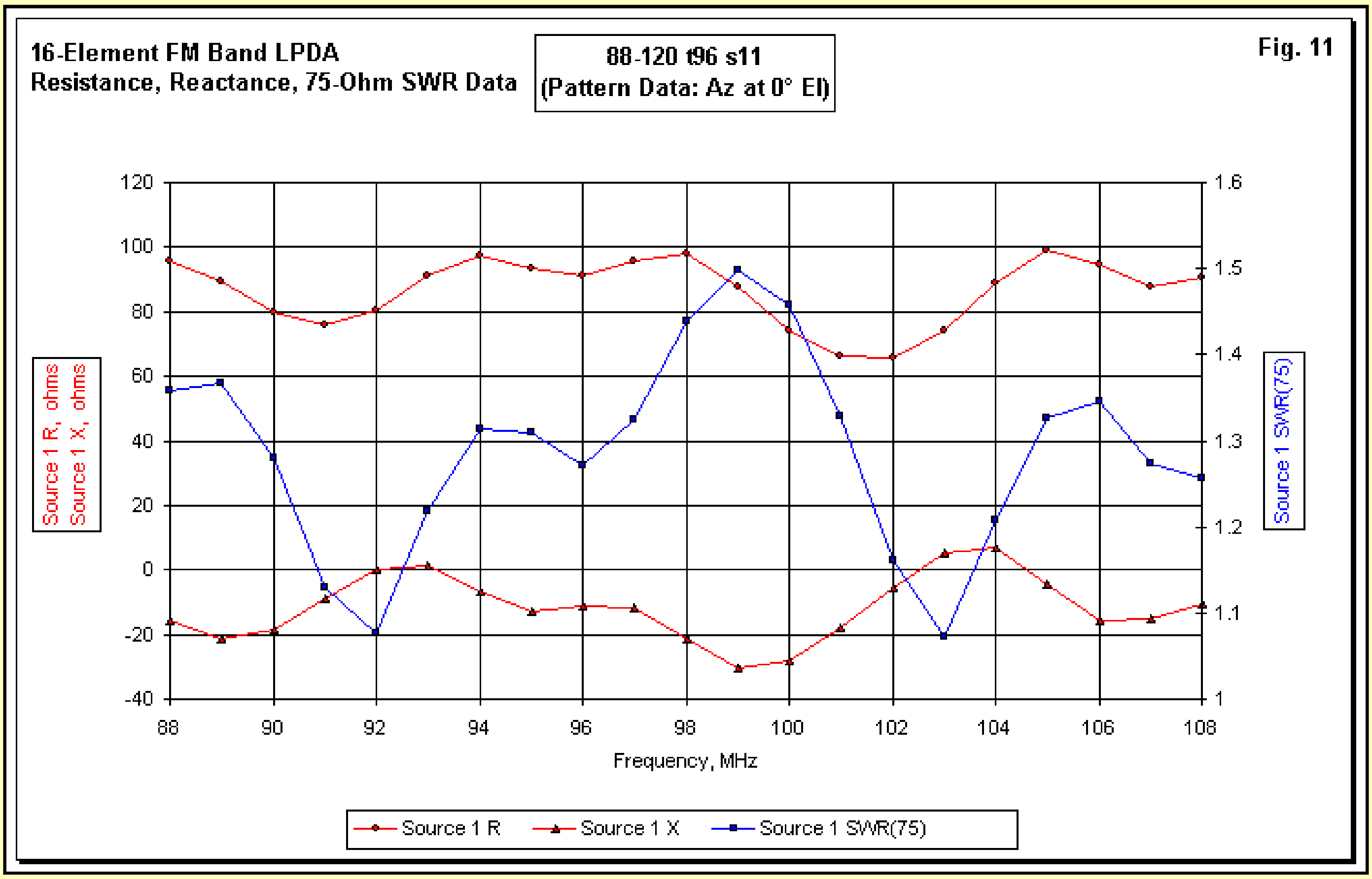


Selected Azimuth Patterns of 16-Element FM Band LPDA

Fig. 10

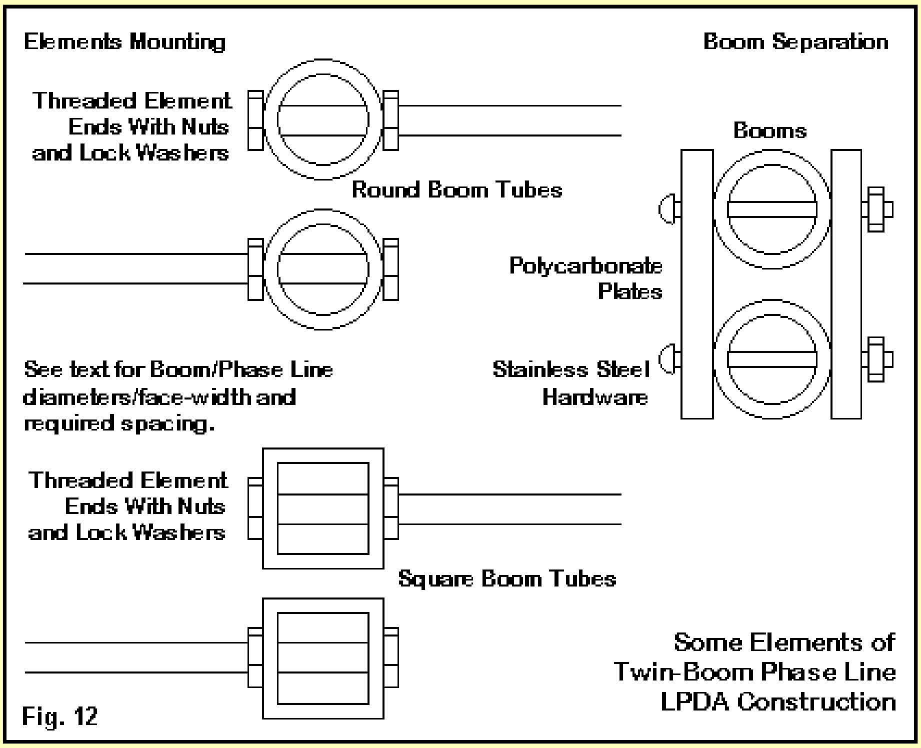
Unlike the wide-band Yagi, we obtain the gain values with azimuth patterns that are well shaped at all frequencies, as sampled by the patterns on **Fig. 10**. The very diminutive rear lobes promise excellent attenuation of strong rearward signals.

The 16-element LPDA design uses a 125-Ohm phase line so that it will yield a feedpoint impedance close to 75-Ohms for use with standard cable TV coaxial cable. See **Fig. 11** for some details of the results.



Although the resistance and reactance curves appear to be simply wiggly lines, the importance of these red curves is to reveal variations that occur within quite narrow limits. Hence, the SWR never reaches 1.5:1 for a 75-Ohm reference.

One reason for developing the design along the indicated lines is to illustrate a different method of LPDA construction. Instead of using a support boom and an independent phase line, we shall let the boom do double duty, serving as the element support and the phase line. **Fig. 12** illustrates the general principles of this method of construction.



First, we need two 14' lengths of boom, here presuming 1" diameter round tubing or 1" face square tubing. We shall have to join shorter lengths of tubing with the next smaller size as inserts. In general, it is best if the junctions do not occur at exactly the same place long the total boom length. Binding the two tubes together into a single assembly requires that we add some plates periodically along the boom. 1/4" polycarbonate will generally do the job, with bolts through the plate and the tubes. Do not use bolts in the vertical direction, since they would short out the phase line.

The spacing between the tubes needed for a 125-Ohm assembly differs according to the geometry of the tube. For the 1" round tubes, a center-to-center spacing of 1.59" or a gap of 0.59" gives us a fat transmission line with a characteristic impedance of 125 Ohms. Because square tubes present more surface area to each other, they require a center-to-center space of 1.86" or a gap of 0.86" for the same characteristic impedance.

You will mount a half-element to each of the two tubes. To do this, use a die to thread the 0.25" rods to accept standard stainless steel nuts (and lock-washers). You will have to add a little over 1/2" to each half element to allow for the part that goes through the second half of the tube and outward to receive the nut. Tighten each element securely, but do not deform the phase line/boom tubes or strip the aluminum threads. (I always start at the rear with the longest element so that if I do strip some threads, I can use the rod for a shorter element.)

Be certain to alternate the element halves as you move along the array. Designate one side as left. If you start with the left half element on the top boom, then the second left element goes on the bottom, the third on top, etc.

You can mount a plate on either of the booms at the front and mount on it your coaxial cable connector. Run a lead from the connector center pin to the other boom tube.

Mounting the array to a mast requires care, since the mast needs to be insulated from and separated from a metal mast. You can top a metal mast with a short section of non-conductive mast--such as PVC--and use a standard polycarbonate mounting plate. Alternatively, you can use thicker (3/8") polycarbonate with a longer vertical dimension so that the metal mast mounts well below the booms of the antenna. Whatever mounting system that you use, do not short out the two boom tubes.

Test the antenna at ground level, not only for electrical performance, but also to see if you will need any truss work to keep the vertical stresses on the twin boom to a safe minimum.

Within the gain classes of their respective designs, each of these LPDAs should provide excellent full-band coverage for the FM listener seeking distant stations. With respect to the 14' LPDA, some prospective builders may be hesitant to place so much mass so far from the supporting mast. So in our final installment of these notes, we shall examine an alternative antenna design, one that places most of the mass up and down on the mast. We call the antenna the batwing.

Go to Main Index