**Notes on 2-Band (2-M, 70-CM) LPDAs**
**Part 1. Narrow-Band LPDAs**

L. B. Cebik, W4RNL

The amateur 2-meter and 70-centimeter bands have an approximate 3:1 frequency ratio. On both bands, FM repeaters use the upper portion of the bands, so the ratio is more exact. For example, the 3rd harmonic of 146.7 MHz is about 440 MHz. FM repeater services use vertically polarized antennas on both bands. Therefore, the idea of a single antenna to cover the FM repeater portions of both bands naturally arises.

It is possible to use a ½-λ dipole element in the 3/2-λ mode to provide dual band coverage. The advantage of this strategy is that the impedance on both frequencies will be relatively low. However, as we increase the mode of use, the self-resonant impedance does increase. As well, because a 3/2-λ center-fed element has only two ends—and hence, only two end-effect regions—the ratio of self-resonant frequencies tends to be slightly higher than 3:1.

One way to overcome these potential limitations is to use one or another form of wide-band technology. The most common form is to create a log-periodic dipole array (LPDA) for the lower frequency region and then to operate the array on the upper band as well. These notes examine the practice as commonly implemented and then with improvements. In this part, we shall look at a minimalist design intended to cover only the amateur band at 2 meters and the FM portion of the 70-cm band. Then we shall see if we can make some improvements in performance, where performance includes not only forward gain, but pattern shape as well. In the second part of the notes, we shall take as a premise that amateur activities in the present setting of emergency services include not only the FM portion of assigned amateur allocations, but as well the monitoring of land, aeronautical, and maritime frequencies. Therefore, we shall try to expand the frequency coverage on both the upper and lower bands of service. The antennas under consideration will range from 24" to 60" long, so they do not fall within the long-boom class. However, some will use a considerable number of elements as dictated by basic LPDA theory. (See *LPDA Notes*, volumes 1 to 3, for information on the basics of LPDA design.)

*A 5-Element 2-Band LPDA*

The simplest practical LPDA to cover the amateur 2-meter band from 144 to 148 MHz will use about 5 elements and require a 24" boom. Although commercial designs exist in this class, I do not have access to one. Therefore, I designed a standard LPDA using 3/16" (0.1875") diameter elements. I used a τ of 0.93 and a σ of 0.08. For ease of matching the standard 50-Ω cable, I set the phase-line characteristic impedance at 75-Ω, which we can achieve using one or another of the standard techniques of twin-boom construction. **Table 1** supplies the dimensional details. The boom length is about 23" plus end-cap allowance.

Table 1. Dimensions for a 5-element 2-band LPDA with straight elements

Element diameter = 0.1875", τ = 0.93, σ = 0.08, phase-line = 75 Ω

| El. No. | Total Length | Space from rear |
|---|---|---|
| 1 | 39.83" | 0" |
| 2 | 37.05 | 6.35 |
| 3 | 34.46 | 12.26 |
| 4 | 32.05 | 17.75 |
| 5 | 29.81 | 22.86 |

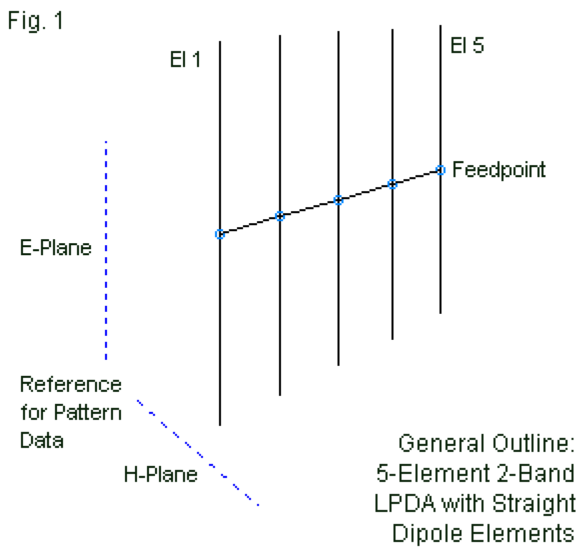



**Fig. 1** provides a view of the antenna. Unlike most examinations of LPDAs, the antenna orientation for vertical polarization above ground dictates that we change our expectations of the pattern shape. The azimuth patterns over ground will record the H-plane pattern shape. Since the H-plane has no element end geometry to confine the beamwidth, we shall expect to find greater azimuth or H-plane beamwidths than if we had oriented the antenna horizontally, where the E-plane would dictate the azimuth beamwidth. The E-plane beamwidth and pattern shape, however, will have consequences for the elevation patterns that we obtain from the antenna.

With a 75-Ω phase line, we may obtain from our sample small LPDA acceptable SWR curves on both the lower and upper ranges. **Fig. 2** provides the modeled 50-Ω and 75-Ω curves for both bands, where we have confined the 70-cm band to just the upper 10 MHz of repeater activity. The models employ a 20' length of RG-213 cable (with a loss factor of 2.1 dB at 100 MHz) to provide results that might occur in a typical amateur installation. SWR values do not change significantly if we substitute a low loss cable such as LMR500 or model with no cable at all.

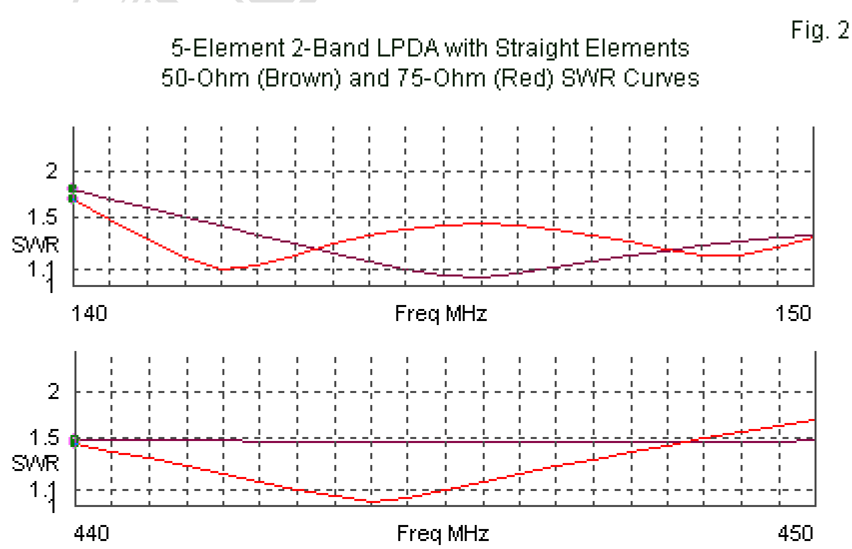


Table 2. Performance of the 5-element, 2-band LPDA in free space and 20' above average ground

| Freq. MHz | Gain dBi | F-B Ratio dB | H-plane BW deg | E-Plane BW deg | Impedance R +/- jX Ω | 50-Ω SWR |
|---|---|---|---|---|---|---|
| Free Space | | | | | | |
| 144 | 6.87 | 10.75 | 113 | 66 | 56.3 – j4.1 | 1.15 |
| 146 | 7.02 | 11.51 | 111 | 65 | 52.8 + j2.1 | 1.07 |
| 148 | 7.15 | 12.48 | 108 | 65 | 61.0 + j1.9 | 1.22 |
| | | | | | | |
| 440 | 6.37 | 15.63 | 122 | 25* | 59.7 + j19.4 | 1.48 |
| 445 | 6.37 | 20.53 | 126 | 25* | 71.9 – j6.2 | 1.46 |
| 450 | 5.89 | 29.11 | 130 | 29* | 50.0 – j19.3 | 1.47 |
| 20' above Average Ground (conductivity 0.005 S/m, permittivity 13) | | | | | | |
| 144 | 10.53 | 10.78 | 113 | -- | 56.3 – j4.1 | 1.15 |
| 146 | 10.71 | 11.55 | 111 | -- | 52.8 + j2.1 | 1.07 |
| 148 | 10.86 | 12.51 | 108 | -- | 61.0 + j1.9 | 1.22 |
| | | | | | | |
| 440 | 11.50 | 15.62 | 122 | -- | 59.7 + j19.4 | 1.48 |
| 445 | 11.21 | 20.47 | 126 | -- | 71.9 – j6.2 | 1.46 |
| 450 | 10.78 | 29.42 | 130 | -- | 50.0 – j19.3 | 1.47 |

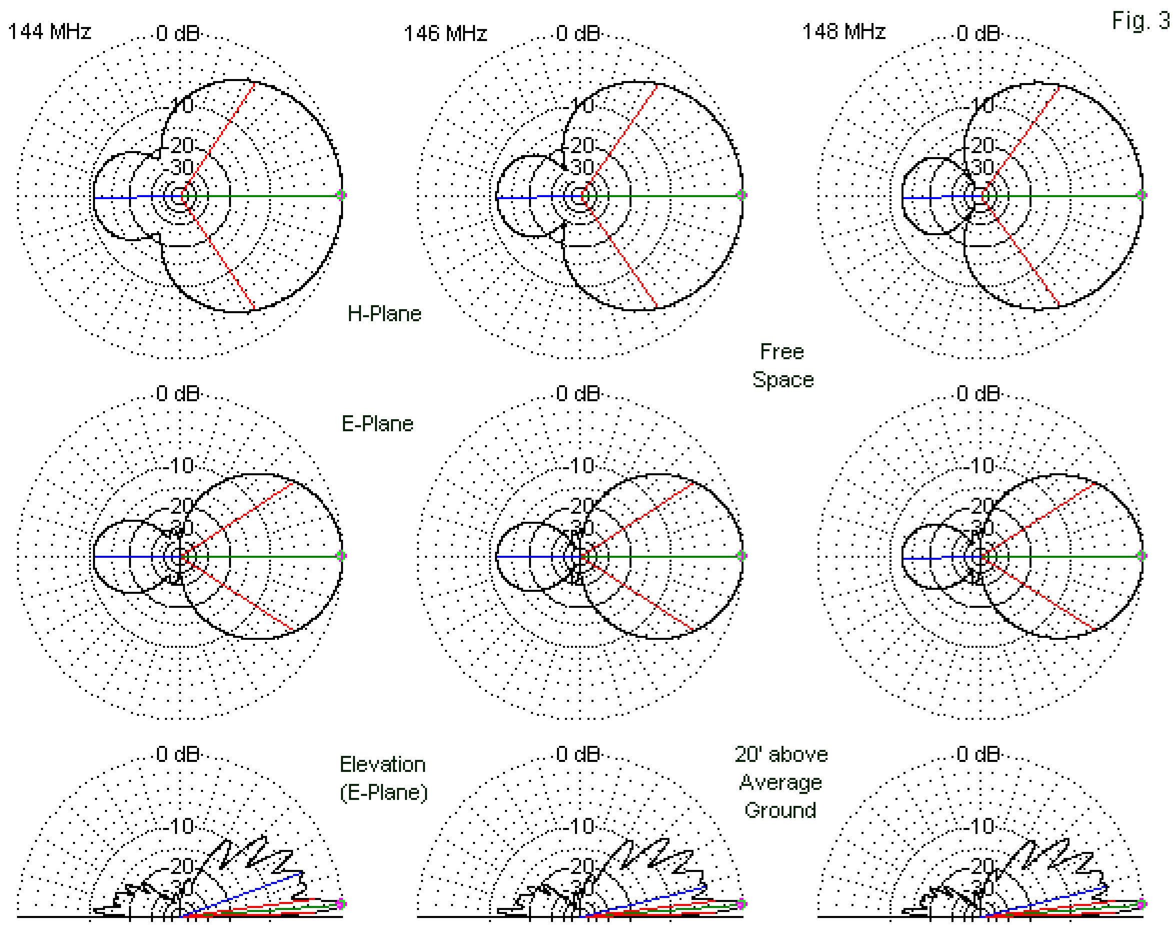
Note: * indicates that the beamwidth is for one lobe of a 3-lobe pattern.

**Table 2** provides sample numerical performance data for both 2 meters and the upper portion of the 70-cm band. Note that the impedances do not change as we move the array from a free-space environment to a position 20' above average ground (conductivity 0.005 S/m, permittivity 13). 20' is nearly 3 λ, and by that height, ground effects on the array impedance are negligible. In addition, the H-plane (azimuth) beamwidth is also constant as we change the model's environment. We shall reserve comment on the E-plane beamwidth for the moment.

Almost as constant with the environmental shift is the front-to-back ratio. With a minimalist design of only 5 straight elements, the 2-meter front-to-back ratio is modest—about the level of a 2-element driver-reflector Yagi. The gain level is consistent for both bands in both environments. Whether the equality of gain is good or not depends upon the importance that we place upon path losses in each of the operational frequency ranges.

In **Fig. 3**, we find a gallery of both free-space and over-ground patterns for the LPDA at 2 meters. Only the free-space H-plane (azimuth) patterns appear, since the over-ground versions are identical in shape. Vertically oriented directional arrays sacrifice some forward gain for the increased beamwidth.

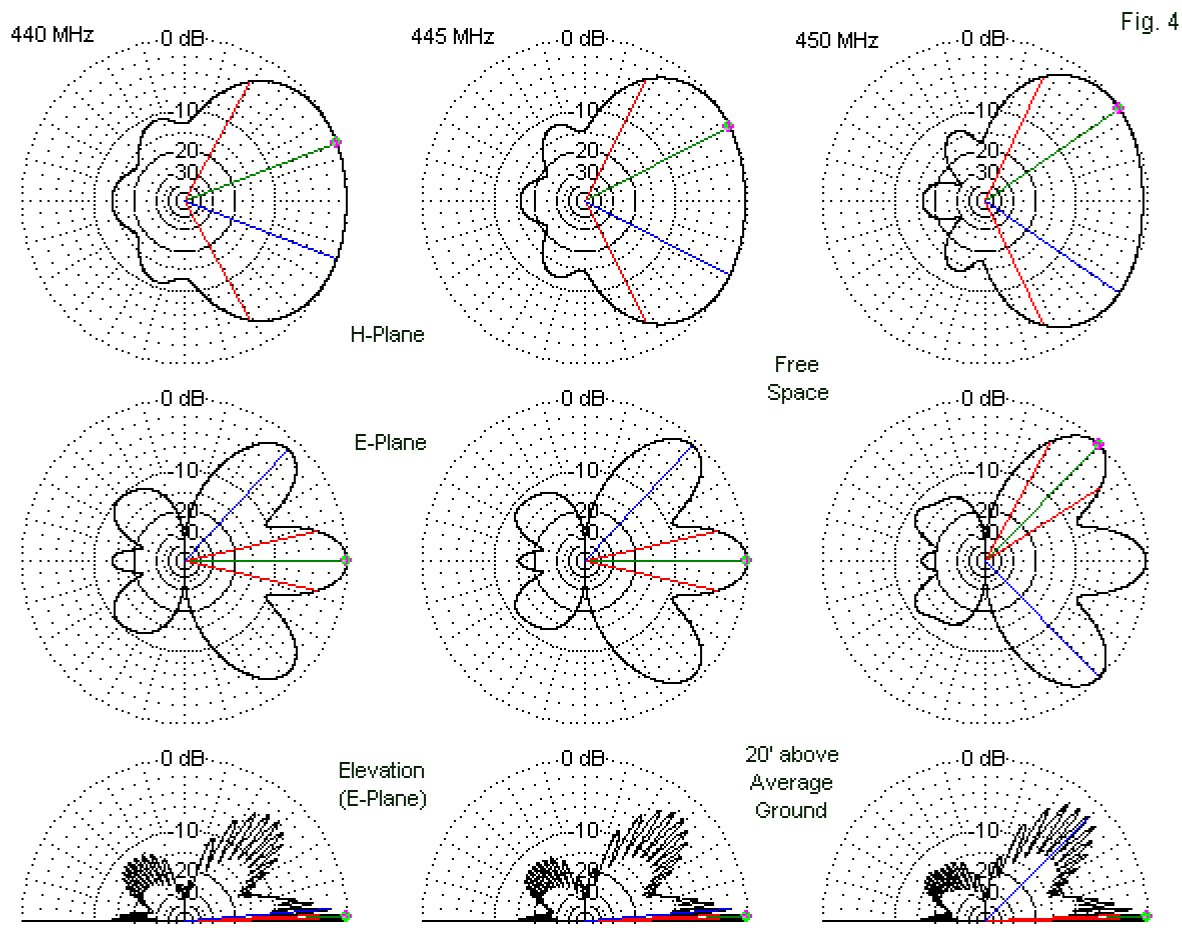
The figure provides separate views of the free-space and over-ground E-plane patterns, which are normal in every respect. If we were to overlay the two sets of E-plane patterns so that the outer ring equaled maximum forward gain in both cases, the free-space outline would fully enclose the over-ground view. Over perfect ground, the lobe peaks for the over-ground pattern would just touch the outline of the free-space plot. With ground losses, the over-ground high-angle peaks do not quite reach the free-space outline.




Gallery of 2-Meter Patterns: 5-Element 2-Band LPDA

Operating an LPDA with straight (dipole) elements in its 3/2-λ mode changes the patterns that we obtain in the upper frequency range. **Fig. 4** gives us a gallery of free-space and over-ground patterns to show what happens. As in the 2-m band, the H-plane (azimuth) patterns show no shape change as we move from free space to 20’ above average ground. Note that the maximum forward gain lines on these plots do not occur directly forward of the array element line, but are at an angle in each direction away from that line. The difference between maximum gain and the gain in line with the array is not operationally significant, but is numerically noticeable. One consequence of the off-axis gain maximums is to widen the half-power beamwidth in the 440-MHz region. The upper-range beamwidth is 10° to 15° wider than the 2-meter beamwidth.

The most noticeable difference between operating the LPDA in the ½-λ and the 3/2-λ modes appears in both the free-space and over-ground E-plane patterns. With straight elements, the E-plane pattern has three distinct lobes, just as would occur when using a simple 3/2-λ doublet on any frequency. At 2 meters, we might flip the LPDA to a horizontal position and obtain similar performance to what we obtain with the antenna vertical. However, 440-MHz operation of the antenna is largely restricted to the vertical position for single forward-lobe directional service. (Before we conclude, we shall overcome this limitation of straight-element 2-band LPDAs.)




Gallery of 70-Centimeter Patterns: 5-Element 2-Band LPDA

Like the 2-meter E-plane patterns, the over-ground versions would fit inside the outline formed by the free-space versions if the outer plot ring recorded the maximum gain in each environment. As a result, the elevation patterns at a 20' height show high-angle forward and rearward lobes of considerable proportions. At 450 MHz, only ground losses prevent the forward high-angle energy from equally or exceeding the maximum array gain. Relative to line-of-sight FM repeater service, the array is wasting considerable energy and may be sensitive to high-angle noise sources, especially in urban environments.

Despite the energy waste in the upper operating range, the minimalist LPDA does provide moderate performance on both bands. However, we should inquire as to whether we can do better. The first strategy that we shall examine is using more elements in a design that better optimizes the τ and σ for 2-band operation.

*A 13-Element 2-Band LPDA*

We may judiciously redesign the 5-element LPDA for perhaps 13 elements on a boom that is about 36" long. The mere 50% increase in boom length suggests correctly that the design uses a higher value for τ: 0.956. As well, the value of σ is lower (0.0446) so that at the upper range, the value is closer to the optimal sigma—about 3 times the basic value. **Fig. 5** shows the outline of the resulting array—again vertically oriented for FM service.

Fig. 5

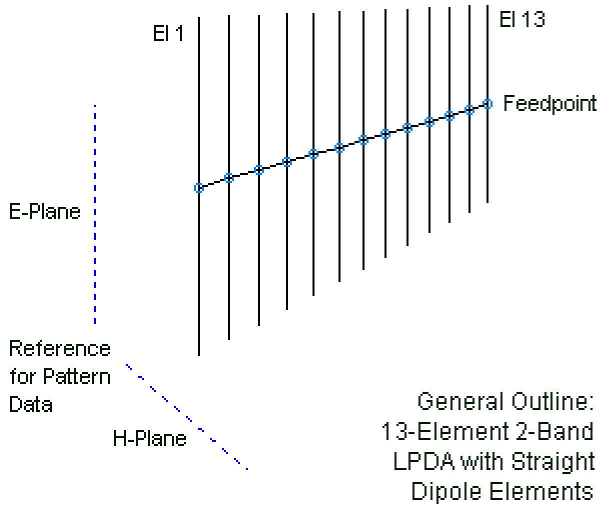



Table 3. . Dimensions for a 13-element 2-band LPDA with straight elements

Element diameter = 0.125”, τ = 0.956, σ = 0.0446, phase-line = 80 Ω

| El. No. | Total Length | Space from rear |
|---|---|---|
| 1 | 42.14” | 0” |
| 2 | 40.26 | 3.76 |
| 3 | 38.50 | 7.36 |
| 4 | 36.00 | 10.80 |
| 5 | 35.18 | 14.08 |
| 6 | 33.63 | 17.22 |
| 7 | 32.15 | 20.22 |
| 8 | 30.74 | 23.10 |
| 9 | 29.38 | 25.84 |
| 10 | 28.10 | 28.47 |
| 11 | 26.86 | 30.98 |
| 12 | 25.68 | 33.37 |
| 13 | 24.54 | 35.67 |

**Table 3** provides the dimensional detail for the array model, which uses 1/8” (0.125”) elements. The design phase-line has a characteristic impedance of 80 Ω. Note that the longest element is longer than the corresponding element on the 5-element LPDA to ensure more adequate performance on the low range. As well, the shortest element is self-resonant in the low range at a frequency about 1.6 times higher than the upper end of 2 meters. In common with the smaller array, the 13-element LPDA uses straight dipole elements.

The use of an 80-Ω phase line provides adequate SWR results on both ranges of operations, as shown in **Fig. 6**. With a 50-Ω main feedline, the curves are quite similar to those obtained with the small array—and flatter on 2 meters. However, both arrays would prove satisfactory if the main feedline happened to be surplus 75-Ω hard-line for minimal losses. If there are significant performance differences between the small and the large LPDAs, they do not lie in the consideration of their SWR characteristics.

Fig. 6

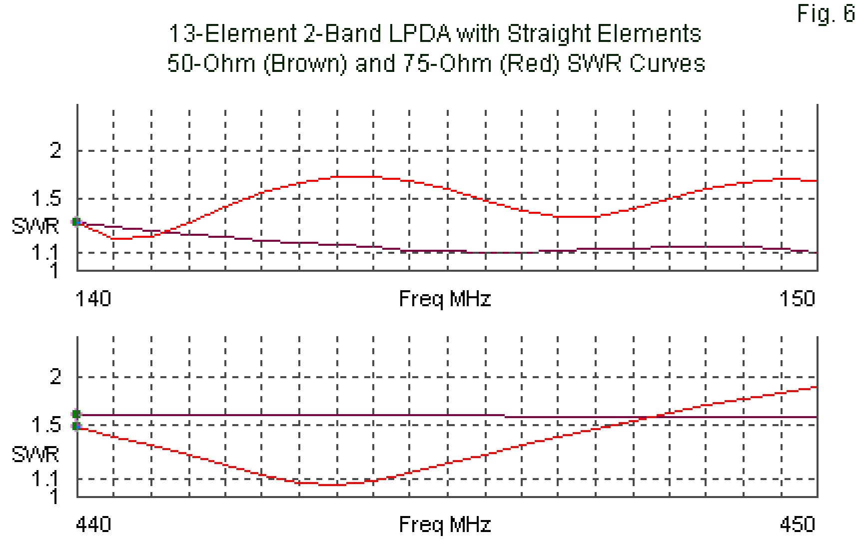


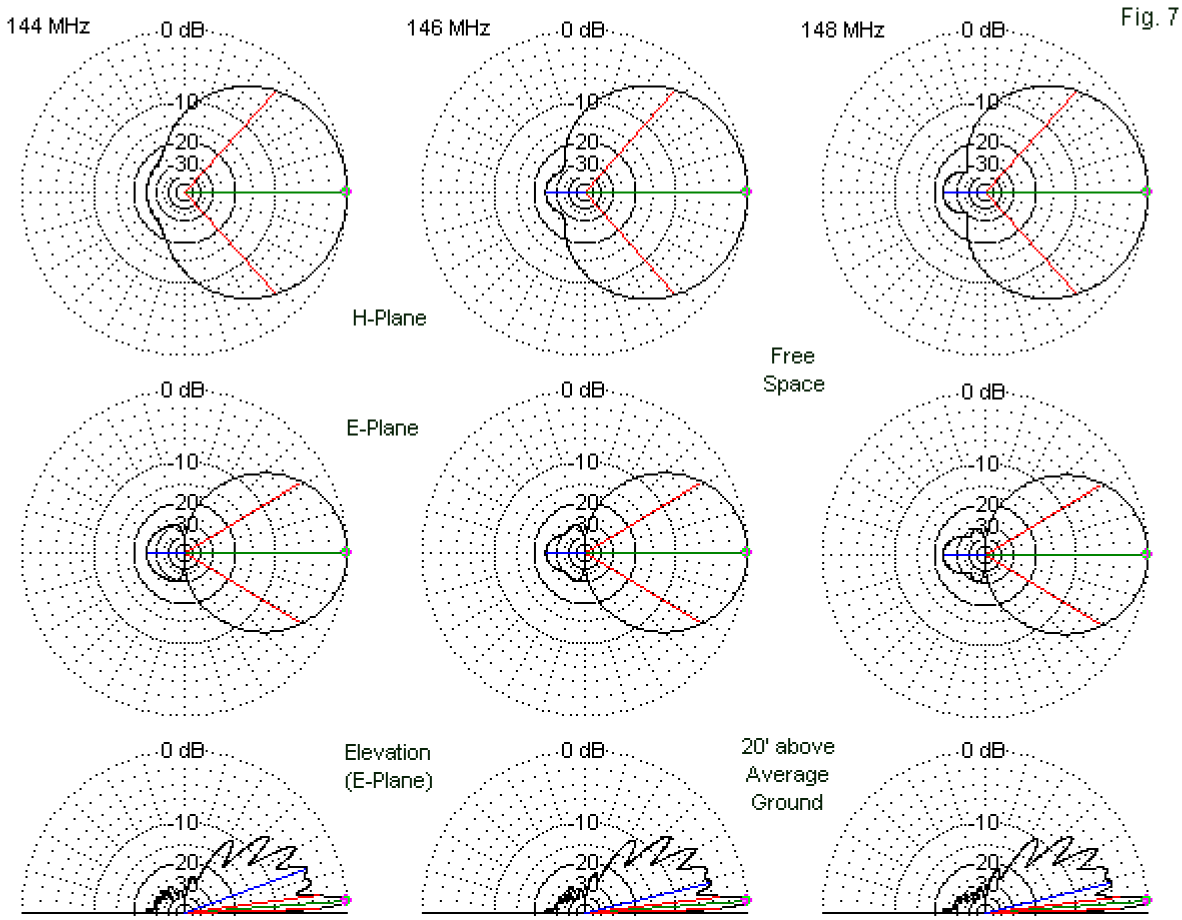

Table 4. Performance of the 13-element, 2-band LPDA in free space and 20' above average ground

| Freq. MHz | Gain dBi | F-B Ratio dB | H-plane BW deg | E-Plane BW deg | Impedance R +/- jX Ω | 50-Ω SWR |
|---|---|---|---|---|---|---|
| Free Space | | | | | | |
| 144 | 7.80 | 25.00 | 96 | 62 | 43.9 – j0.1 | 1.14 |
| 146 | 7.76 | 24.42 | 97 | 62 | 53.9 + j3.8 | 1.11 |
| 148 | 7.79 | 23.22 | 96 | 62 | 50.4 – j6.7 | 1.14 |
| 440 | 6.89 | 28.93 | 137 | 26* | 61.5 + j23.6 | 1.60 |
| 445 | 7.25 | 27.36 | 132 | 26* | 74.8 – j14.1 | 1.59 |
| 450 | 7.64 | 26.27 | 116 | 20* | 44.1 – j20.6 | 1.57 |
| 20' above Average Ground (conductivity 0.005 S/m, permittivity 13) | | | | | | |
| 144 | 11.45 | 25.00 | 96 | -- | 43.9 – j0.1 | 1.14 |
| 146 | 11.44 | 24.47 | 97 | -- | 53.9 + j3.8 | 1.11 |
| 148 | 11.50 | 23.26 | 97 | -- | 50.4 – j6.6 | 1.14 |
| 440 | 11.99 | 28.92 | 137 | -- | 61.5 + j23.6 | 1.60 |
| 445 | 12.37 | 27.37 | 132 | -- | 74.8 – j14.1 | 1.59 |
| 450 | 12.77 | 26.29 | 116 | -- | 44.1 – j20.6 | 1.57 |

Note: * indicates that the beamwidth is for one lobe of a 3-lobe pattern.

The free-space and over-ground performance data in **Table 4** provides a clearer portrait of the improvements that we may obtain from using more elements in a generally better design—as measured by LPDA theory. The average gain increase is a full dB or more. In the low range, the increased forward gain results in a 15° reduction in the H-plane (azimuth) beamwidth.

More significant is the front-to-back ratio and what it indicates about rearward energy. In the low range, the front-to-back ratio is about 15-dB better than for the small array. In the upper range, the improvement is nearly 10 dB.  The importance of these figures lies not only in the ability to not interfere with repeaters to the rear of the station, but as well in the reduction of wasted rearward high-angle energy.

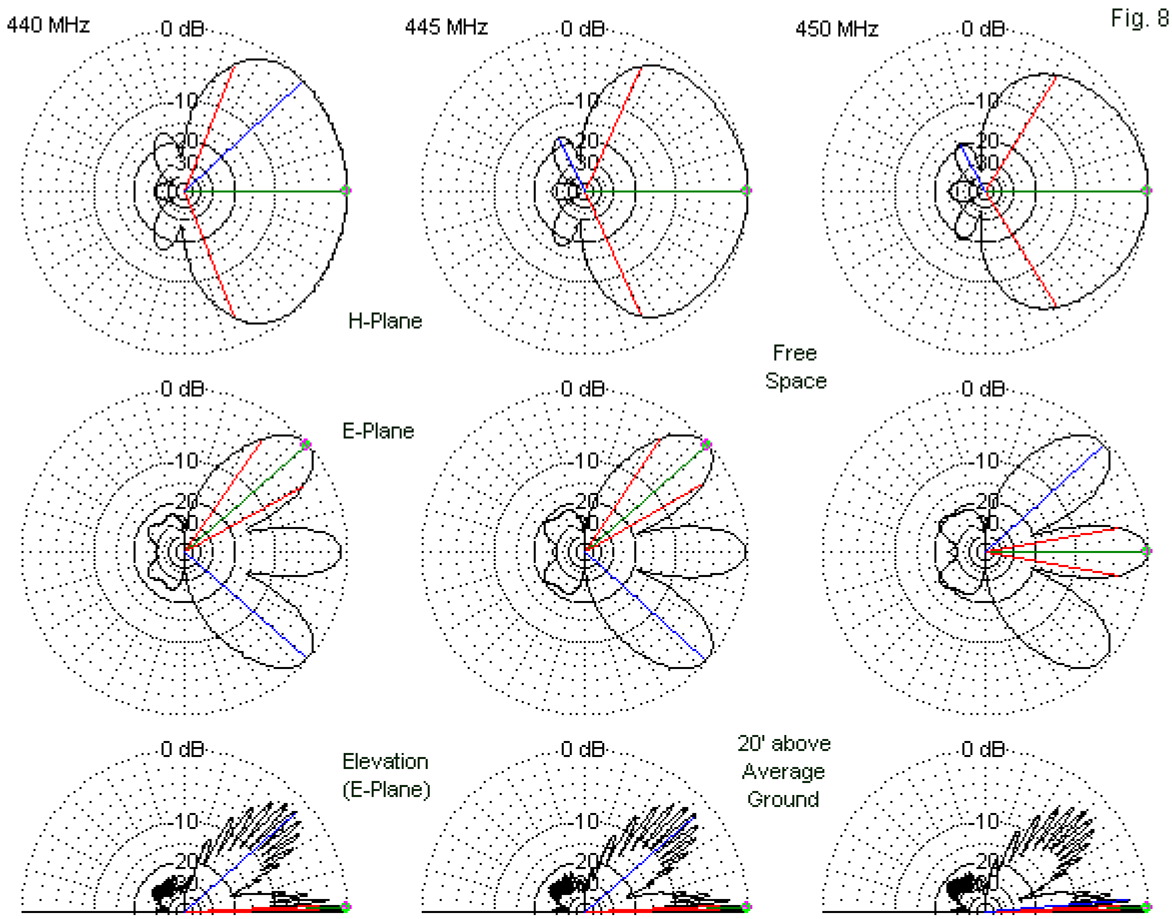



Gallery of 2-Meter Patterns: 13-Element 2-Band LPDA

**Fig. 7** provides a gallery of free-space and over-ground patterns for the lower range of operation.  Both the E-plane and the H-plane free-space patterns show the improved control of rearward radiation on 2 meters.  The result for the over-ground E-plane (elevation) patterns is a significant reduction in rearward radiation (and receiving sensitivity) at any elevation angle.

The improvements for upper-range operation require closer inspection and comparison between **Fig. 8** and **Fig. 4**.  The 440-MHz H-plane (azimuth) patterns show that the maximum forward gain is in line with the array.  Nevertheless, the azimuth beamwidth is in fact wider than for the smaller array by 8° to 10° on average.

The E-plane patterns in free-space show reduced rearward radiation compared to the smaller array.  However, the straight elements yield 3-lobe E-plane patterns that would disable the array from effective horizontal service over ground.  The picture of forward radiation over ground continues to show very high-angle regions of radiation—largely wasted.  The waste at the upper frequencies shows most clearly in the near equality of the 2-meter and 70-cm forward gain figures in the performance table.



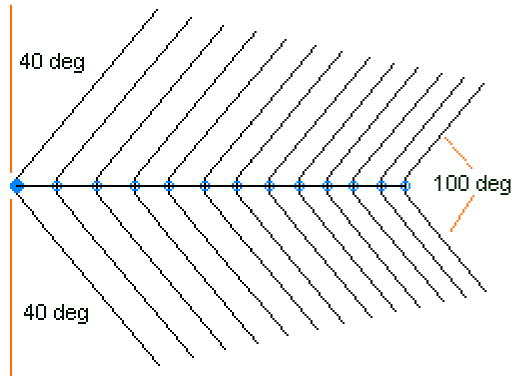

Gallery of 70-Centimeter Patterns: 13-Element 2-Band LPDA

The 13-element straight-element array does provide significant improvements over the minimal 5-element array. Besides adding forward gain, the LPDA redesign has improved the rearward radiation picture and smoothed the upper range azimuth patterns. Further upper range improvements might consist of controlling the high-angle radiation. In free-space pattern terms, the improvement would somehow fold the 3 lobes into as close to a single lobe as we can obtain. There is a way to obtain these results, but it will come at a cost.

*A 13-Element 2-Band LPDA with V-Dipole Elements*

Let's retain the 13-element LPDA design. However, instead of using straight elements, let's bend each element forward by 40° on each side of the centerline. Each element will have an included angle of 100° (instead of the 180° angle for straight elements). **Fig. 9** provides an outline of the resulting array. All of the dimensions in **Table 3** apply to the second redesign of the array. For example, the boom length remains just under 36". However, the array's total length will be slightly longer (43") due to the element bending. As well, the center of mass will move slightly forward of its former position. The outline sketch also indicates the modeling technique involve. A short center element wire with 3 segments is necessary for phase-line connections, so the element bends begin about 0.8" away from the centerline. To keep segments lengths as equal as possible throughout the array, the 1/8"-diameter elements use many segments—857 for the entire array model.

Fig. 9

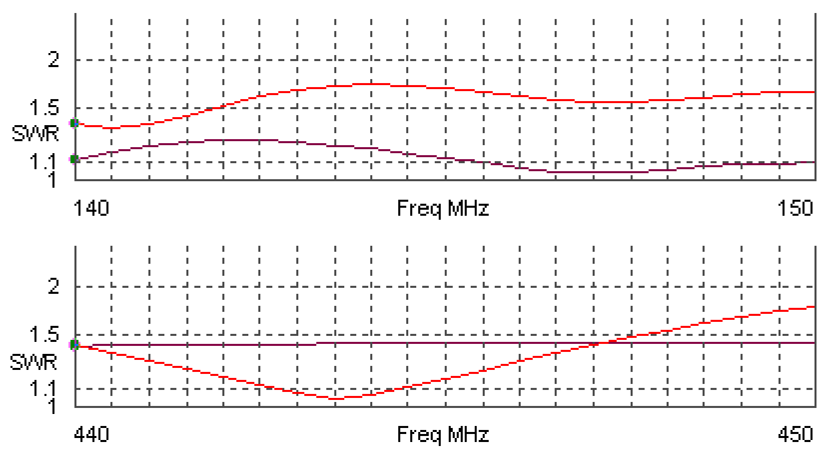



General Outline: 13-Element 2-Band LPDA
with V-Dipole Elements

Using V elements alters the impedance values only slightly. **Fig. 10** provides the SWR picture for both 50-Ω and 75-Ω main feedlines. With the V-configuration, 75-Ω line becomes increasingly attractive, although the 50-Ω values in the lower range remain acceptable.

Fig. 10

13-Element 2-Band LPDA with V-Dipole Elements
50-Ohm (Brown) and 75-Ohm (Red) SWR Curves




The V-angle might have been anywhere between 30° and 40°. I selected the more radical angle to reduce upper sidelobe strength as much as possible. However, every increase in the V-angle relative to a straight element reduces the gain on the lower range. The 40° angle used here represents the maximum low-range gain reduction that I was willing to accept. **Table 5** provides the performance story in numerical terms. Compare the values with those that appear in **Table 4** for the straight-element version of essentially the same antenna.

The low-range gain has dropped to the level of the 5-element LPDA. However, the front-to-back ratio remains well above 20 dB across the lower band. A concomitant effect of using V-elements is an increase in the low band beamwidth in both planes—about 10° in the E-plane and 15° in the H-plane in this case. The differences between straight-element and V-element low-range performance appear both in free-space and over-ground environments.

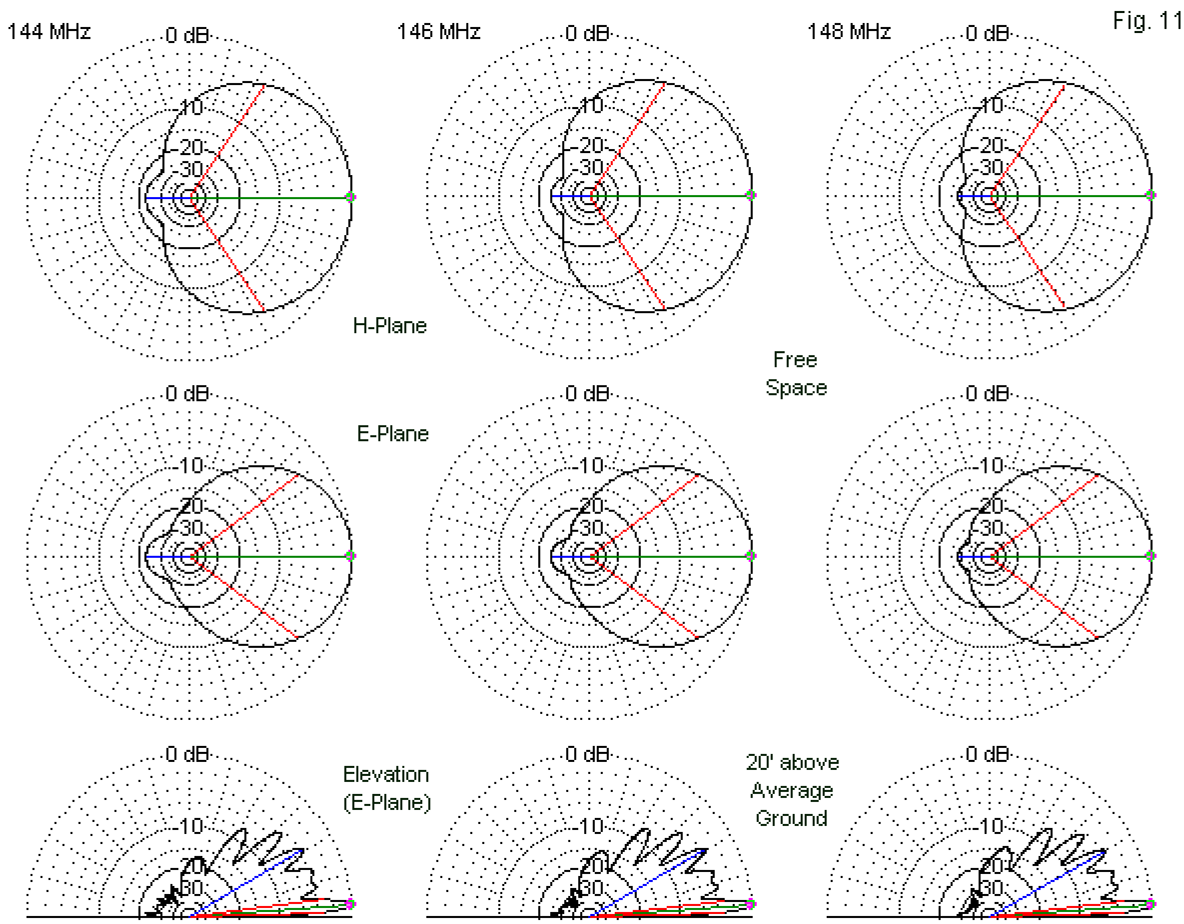
Table 5. Performance of the 13-element, 2-band LPDA with V-dipole elements in free space and 20’ above average ground

| Freq. MHz | Gain dBi | F-B Ratio dB | H-plane BW deg | E-Plane BW deg | Impedance R +/- jX Ω | 50-Ω SWR |
|---|---|---|---|---|---|---|
| Free Space | | | | | | |
| 144 | 6.76 | 22.64 | 112 | 73 | 43.8 – j5.3 | 1.19 |
| 146 | 6.74 | 24.85 | 112 | 73 | 46.7 – j0.1 | 1.07 |
| 148 | 6.76 | 27.97 | 111 | 73 | 47.8 – j2.0 | 1.06 |
| | | | | | | |
| 440 | 9.36 | 29.11 | 95 | 32 | 58.8 + j16.4 | 1.41 |
| 445 | 9.24 | 32.54 | 98 | 31 | 68.9 – j9.51 | 1.43 |
| 450 | 9.22 | 39.67 | 98 | 30 | 45.0 – j16.3 | 1.43 |
| 20’ above Average Ground (conductivity 0.005 S/m, permittivity 13) | | | | | | |
| 144 | 10.44 | 22.74 | 112 | -- | 43.7 – j5.3 | 1.19 |
| 146 | 10.44 | 25.06 | 112 | -- | 46.7 – j0.1 | 1.07 |
| 148 | 10.48 | 28.29 | 111 | -- | 47.8 – j2.1 | 1.06 |
| | | | | | | |
| 440 | 14.49 | 29.08 | 95 | -- | 58.8 + j16.4 | 1.41 |
| 445 | 14.39 | 32.60 | 98 | -- | 68.9 – j9.5 | 1.43 |
| 450 | 14.38 | 39.73 | 98 | -- | 45.0 – j16.3 | 1.43 |

The performance numbers of the upper range tell only a part of the story of whether the 2-meter gain reductions and beamwidth increases are acceptable. The forward gain values in the 70-cm band with V-elements are 2 to 2.5 dB higher than values for the other dual-band arrays. Although still wide, the H-plane (azimuth) beamwidth is about 30° narrower than for the other LPDAs that we have sampled. At the same time, the upper-range front-to-back ratio averages about 30 dB. Whether the improved performance in the upper operating range is sufficient to outweigh the gain loss on 2 meters is a user judgment based upon the operating specifications set for a station.

The remainder of the story appears in the pattern galleries for the V-element LPDA. **Fig. 11** shows the patterns for 2 meters, again using both free-space and over-ground plots. The patterns are not significantly different in shape relative to the straight-element version of the LPDA. However, we must keep in mind that such patterns are normalized such that the maximum gain is co-terminal with the outer ring of the polar plot. Hence, the patterns do not show the difference in gain between the two versions of the 13-element beam.

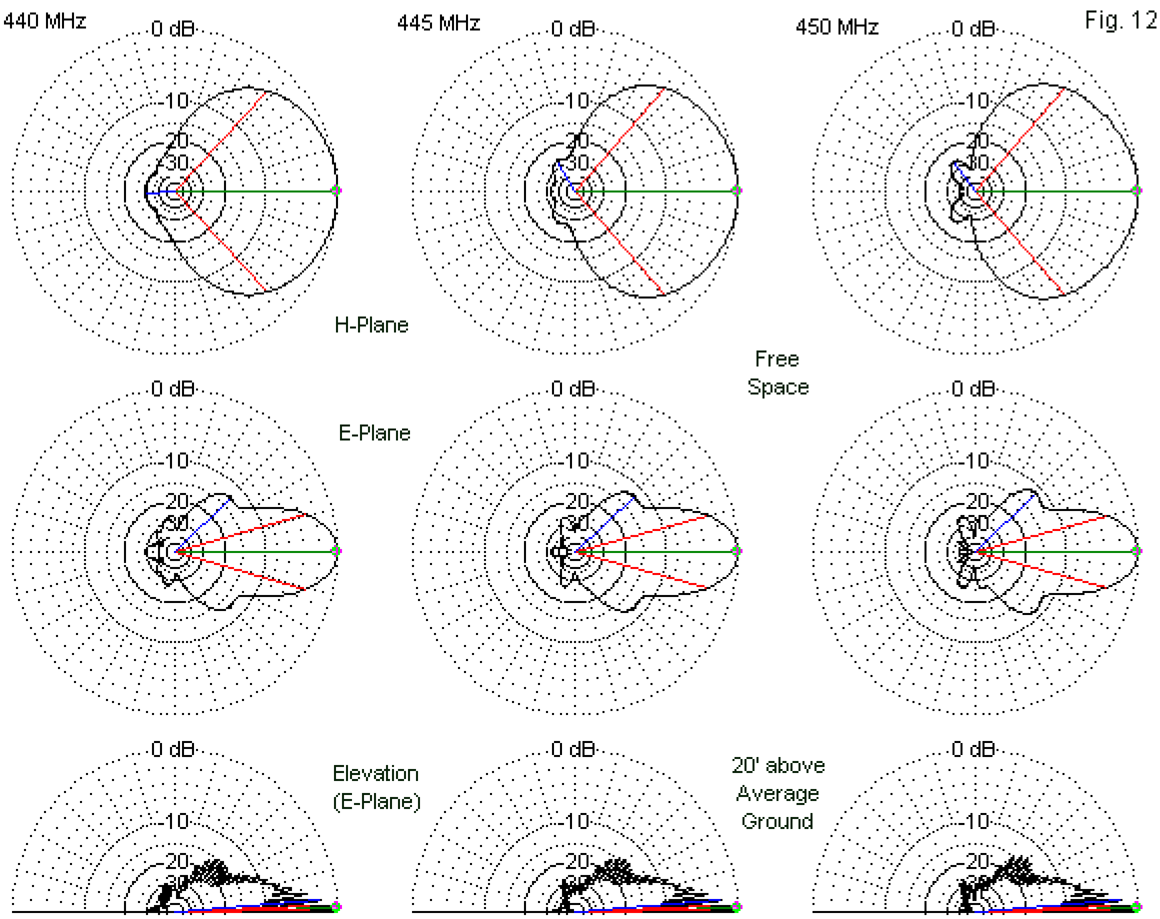
The maximum gain may only equal that of the initial 5-element LPDA with which we began our exploration, but the rear quadrants show why the V-element larger LPDA is superior. Compare the patterns with those in **Fig. 3**. The difference in the amount of energy radiated rearward with respect to the beam’s primary direction is relatively vivid.




Gallery of 2-Meter Patterns: 13-Element 2-Band LPDA with V-Dipole Elements

The counterpart patterns for the upper operating range appear in **Fig. 12**. The H-plane (azimuth) patterns show significantly higher gain with a very high front-to-back ratio. In addition, the beamwidth applicable over ground is about 30° narrower than for either of the straight-element LPDA designs. On the 70-cm band, the V-element design will show noticeably greater directivity than the other designs, but not so directive as to make the precise heading critical.

The E-plane (elevation) patterns show the major reason for employing V-elements when operating an LPDA in the 3/2-λ mode. The use of the V-element draws the outer lobes, so evident in **Fig. 8**, toward the main axis of the beam. They do not fully merge with the main lobe, as evidenced by the sidelobes in the free-space patterns. Lesser angles for the V-elements would yield slightly better 2-meter performance, because the more severe the angle, the greater will be the reduction in the low-range gain and the smaller the increase in low-range beamwidth in the H-plane. However, these lesser angles, such as a 30° V shape, would yield stronger sidelobes. 40° is a good compromise between sidelobe strength and the angle at which the array begins to lose forward gain in the higher operating range. From 440 to 450 MHz, the sidelobe strength varies from about –9.5 to –11 dB relative to the main forward lobe. The over-ground elevation patterns show the consequences of the sidelobe strength reduction. The forward patterns show the sidelobe angles, but the amount of energy radiated at high elevation angles has dropped by at least 10 dB across the upper band. The rearward radiation is relatively insignificant.




Gallery of 70-Centimeter Patterns: 13-Element 2-Band LPDA with V-Dipole Elements

If the improvement in upper range performance outweighs the small reduction in 2-meter gain, then the V-element design is overall the best of the designs that we have surveyed in this sampling. However, the tradeoff between the two ranges is an inevitable part of turning to V-element designs. One of the older myths about using V-elements was that the gain improvement applied to any element whatsoever. However, when we change a straight element into a V-element and operate the antenna as an ordinary dipole, we reduce the maximum gain (whether we are talking of the bi-directional gain of a dipole or the directional gain of an array) and increase the beamwidth in the favored direction or directions. Only when the element operates in the 3/2-λ mode does the gain increase and the beamwidth decrease as a function of merging—however incompletely—the 3-lobe pattern that forms on either side of the center-fed element. The 13-element V-dipole LPDA takes advantage of these facts to yield its performance figures and patterns.

*Conclusion to Part 1*

We have progressed in a somewhat orderly way through three steps in the attempt to produce superior 2-band performance from a vertically oriented LPDA designed for the 2-meter and the 70-centimeter amateur allocations. Beginning with a somewhat minimalist array of 5 elements, we first increased the element count and changed the τ and σ values to yield better performance on both bands, but we retained the straight elements. This step allowed us to see the improvements provided by an increase in the front-to-back ratio, especially in terms of reducing the wasted energy radiate rearward at high elevation angles.

The final step involved changing the element shape to a V-configuration of 40° in order to merge the straight-element's 3-lobes into a stronger central lobe with manageable sidelobes on the upper band. This sizable improvement in high-range performance carried the cost of a modest loss in low-range gain. Nevertheless, for many applications, the net performance remains the best of the series of designs.

One of the difficulties with all of the designs applies to the range of coverage. Although the 5-element beam has a very restricted operating range, the 13-element V-configuration version is capable of covering 420 to 500 MHz with at least 9.25 dBi of free-space gain and less than 2:1 50-Ω SWR with very good pattern control. The limiting factor in the lower operating range is the deterioration of performance below 140 MHz. Although the SWR remains useable, the forward gain rapidly drops. The cure for this condition is the addition of longer elements—properly sized and spaced, of course, to allow at least monitoring coverage down to perhaps 125 MHz. Since short elements with closer spacing at the feedpoint end of the array do not add significant length to the array, we might add a few there to improve the array in both operating regions.

The design of such an array is the focus of Part 2 of these notes.