Nulling an Unwanted Station: Worse and Better Solutions

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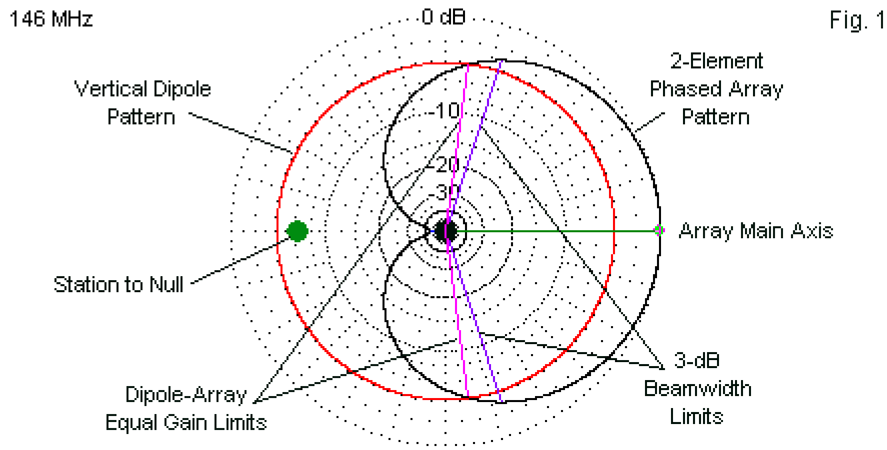
As the number of VHF and UHF stations continues to multiply, seemingly without limit, conflicts arise among services. Sometimes, they involve two stations on the same or adjacent frequencies within the same general service. At other times, there may be conflicts between services in the same general area. When such conflicts arise, solutions may emerge from general mediation or arbitration. In a few cases, one service may have a clear legal or regulatory priority, forcing a solution upon the other station in the lesser service.

Overlapping coverage in a general area represents one significant problem faced by many services and individual stations. **Fig. 1** shows the general problem. In the sketch, an omni-directional antenna includes the station in its coverage. One of the most direct routes to removing the station from the coverage is to place it within the null of an array especially designed to have a deep rearward null. With careful design, nulls deeper than 40 dB, relative to the maximum array gain, are possible, although rarely does the null need to be deeper than about 30 dB. The slightly relaxed requirement is useful because in virtually all arrays with a deep rearward null, the null is highly frequency specific, and only a few kHz of frequency movement will reduce the null depth. The more relaxed the null-depth requirement, the easier it normally is to construct an antenna achieving the goal.



The Challenge of Effectively Nulling Out a Station from Coverage

The sketch also shows some other lines of interest to the station that must change antennas from a vertical dipole, with its omni-directional coverage, to a directional array that is capable of nulling out the second station. Every directional array limits the coverage area to one or another degree. The pattern designated as belonging to a phased array has a certain beamwidth as measured by the half-power points. Because the array gain is greater than 3-dB relative to the dipole, these points do not coincide with the points at which the array pattern crosses the dipole pattern. The latter points are significant because they provide a measure of the new array's ability to provide coverage as consistent as formerly produced by the dipole. Coverage to the rear of the array is not negligible, as it might be with a multi-element Yagi, but the coverage is at lesser strength and goes to virtual zero in the direction of the nulled station.

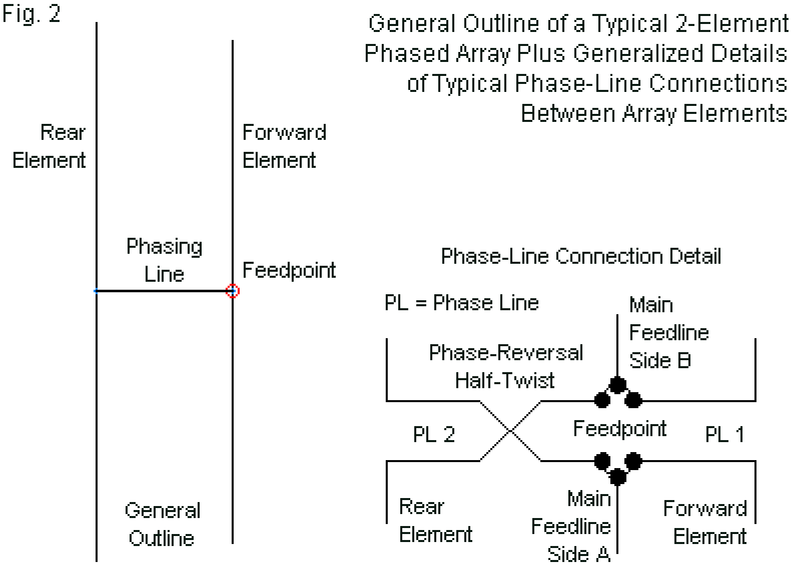
For vertically polarized services, the cardioidal pattern of a phased array is often the pattern of choice among those available. It maximizes the coverage area with only modest forward gain (about the gain of a 2-element Yagi). In circumstances calling for relatively equal coverage across a wide area, the absence of major lobes and nulls in the pattern is usually desirable.

2-element phased arrays come in as many varieties and styles as one might generate from various combinations of element lengths and spacing values. For any two elements close to ½-λ long each and for any spacing up to about ¼-λ or more, there will be a set of conditions that will yield a deep rearward null and a cardioidal forward pattern. The required conditions involve the ratio of relative current magnitude and the difference of the phase angle of the current at the centers of each element. If we designate the elements by the terms forward and rear, we can literally catalog the range of values for the ratio of current magnitude and the phase angle differences that will yield the desired results. (See *2-Element Horizontal Beams*, Volume 1, for graphs and tables on this subject. When turned to a vertical orientation, the maximum front-to-back values yield the desired cardioidal patterns.)

Obtaining the desired current magnitude ratio and phase difference has been the subject of considerable experimenter effort over the second half of the 20th century. It is possible to develop networks that will effect the required set of relationships between element currents, but experimenters have sought for simpler means. Hence, the 1950s saw the advent of the ZL-Special and the HB9CV. The early attempts to develop working phased arrays suffered from two flaws. First, proponents of various designs drastically overstated the potential gain of these arrays, largely due to comparisons with rather poor Yagi designs in the middle of the last century. Second, the experimenters attempted to understand the operation of phased arrays almost wholly in terms of the relative impedance values of the elements.

What the early and later developments in phased array design had in common was an urge toward construction simplicity. Instead of complex networks of lumped components, the experimenters tried to use convenient lengths of transmission line to create the required current ratio and phase difference. **Fig. 2** shows the general outline of a 2-element phased array and some details relating to the phase lines involved. The details call for a bit of background description.

Fig. 2



The most common form of applying phasing lines to a phased array involves two lines, one from the forward element and one from the rear element. In many designs, the length of the forward phase line can go to zero, but in theory, we should always consider it present. For most arrays using spacing values less than 0.25-λ, the rear element current phase angle—relative to the forward element phase angle—will run from perhaps 100° to 150°. With a spacing of 1/8-λ, the value will be close to but rarely exactly 135°. The exact current ratio will tend to fluctuate between 0.95 and 1.15 (rear element to forward element), depending upon the element lengths used. The phasing lines usually will not be impedance matched to the individual elements, although some designs have used supplemental matching networks—such as the gamma match in the HB9CV or the beta match in the N6LF arrays—to effect such a match. However, we cannot assume a match, since the mutual coupling between the elements will result in impedance values quite distant from the values that each element would sow in independent tests.

If the element and the phase line show an impedance match, the voltage, current, and impedance will be constant along the phase line. Otherwise, the phase lines will transform the impedance according to the frequency, the degree of mismatch, and the line's characteristic impedance, length, and velocity factor. The goal of any array using phase lines to establish the desired current conditions on the two elements is to meet properly at the junction with the main feedline. Whether the forward line has real length or is zero length, the junction must show identical voltage magnitude and phase angle values—at least for the system shown, which uses a parallel junction of lines. It is also a design goal for the array to show net voltage and current values that result in a junction impedance that either is directly compatible with the characteristic impedance of the main feedline or that is matchable by a relatively simple method. We must not forget that one goal of the designs is simplicity of structure and assembly, ostensibly to ease building problems and to ensure durability.

The urge toward simplicity also occasions the half twist in the rearward phase line. To effect a change of current phase that is over 90°, we would normally require a line that is also over 90°. (Note that I purposely am avoiding the rhetoric of 135° lines, since this way of talking emerged from impedance considerations that ended up producing as many bad phased arrays as good ones.) The exact line length that we require is a function of the other variables in the design, but we should note that the magnitude and phase angle of the current under mismatches between the element and the line do not change at the same rate as the impedance, nor does either change at the same rate as the voltage. However, to use a line without the half twist would require a phase-line length in excess of ¼-λ when the element spacing will be in the vicinity of 1/8-λ. We may effect a 180° impedance change by putting a half twist into the line, that is, by making reverse connections on the rear element relative to the forward element.

Early experimenters with phase-line based arrays thought of the half-twist as producing equal values as a full-length line without the twist, when both lines are shorter than ½-λ. Hence, a 1/8-λ line with a twist equaled a 3/8-λ line without a twist. However, only the impedance repeats its values every half wavelength. Voltage and current cycles require a full wavelength for repetition. The current on the short line still only underwent a transformation that we can expect from the line length, but the starting value will not be xx A @ yy°, but rather xx A @ -yy°.

A parallel junction of phase lines divides the supplied current into forward and rearward components, each of which is transformed by the phase lines to final element values. Had we selected a series connection, the current at the junction would be the same on both lines, with a voltage division. Because most implementations of phased arrays use current division, we shall focus only upon the parallel connections. For most linear element designs, the experimenter has only a limited number of available cables. (In folded-dipole element arrays, the designer can often fabricate custom parallel transmission line characteristic impedance values.) Most of the cables are coaxial constructs and we find only a few select characteristic impedance values from which to choose. Therefore, lines that may show the desired current transformations are often longer than the element spacing (since we have to reject modeled or calculated values that are shorter than the physical spacing). The experimenter must also be prepared to use a non-zero-length forward line or to resort to other mechanisms to arrive at the desired pattern and at a usable feedpoint impedance.

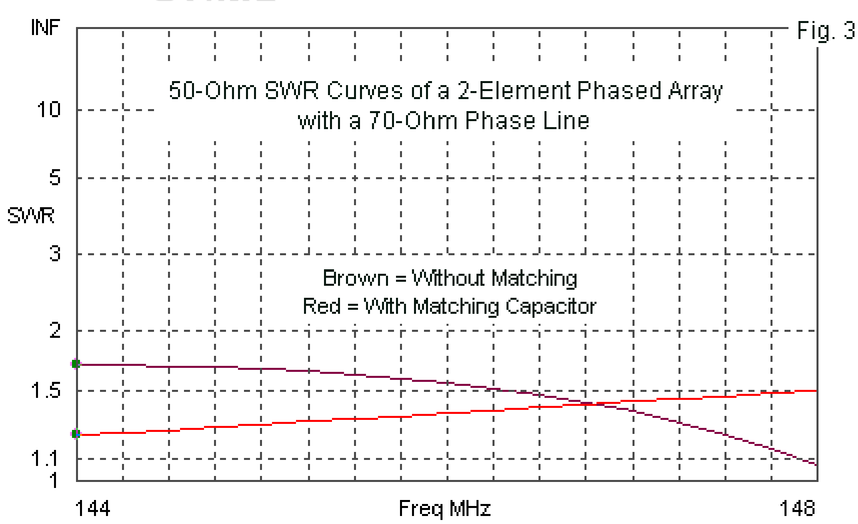
With this background, let's look at a pair of sample 2-meter arrays, both of which arrive at the desired deep null. One will be better than the other, but we may not appreciate the difference initially.

An Appealing But Problematical Array for 146 MHz

All of the antennas that we shall consider use 0.375"-diameter aluminum elements, and all are designed for 146 MHz. The first of the set uses a single 70-Ω (VF = 0.78) phase line with a half twist from the rear element to the forward elements, where the design locates the feedpoint. **Table 1** provides the dimensions in wavelengths and in inches. Without altering the element diameter, one can easily scale the dimensions to any frequency in the 2-meter band to obtain peak performance at any necessary frequency. The appearance is identical to the outline shown earlier.

Table 1. Dimensions of a 2-element phased array using 0.375"-diameter elements and a 70-Ω phase line (VF = 0.78) with maximum nulling at 146 MHz

Dimension	Forward Element Length	Rear Element Length	Spacing	Phase Line Length
Wavelengths	0.468	0.50	0.125	0.259
Inches	37.83	40.42	10.11	20.94



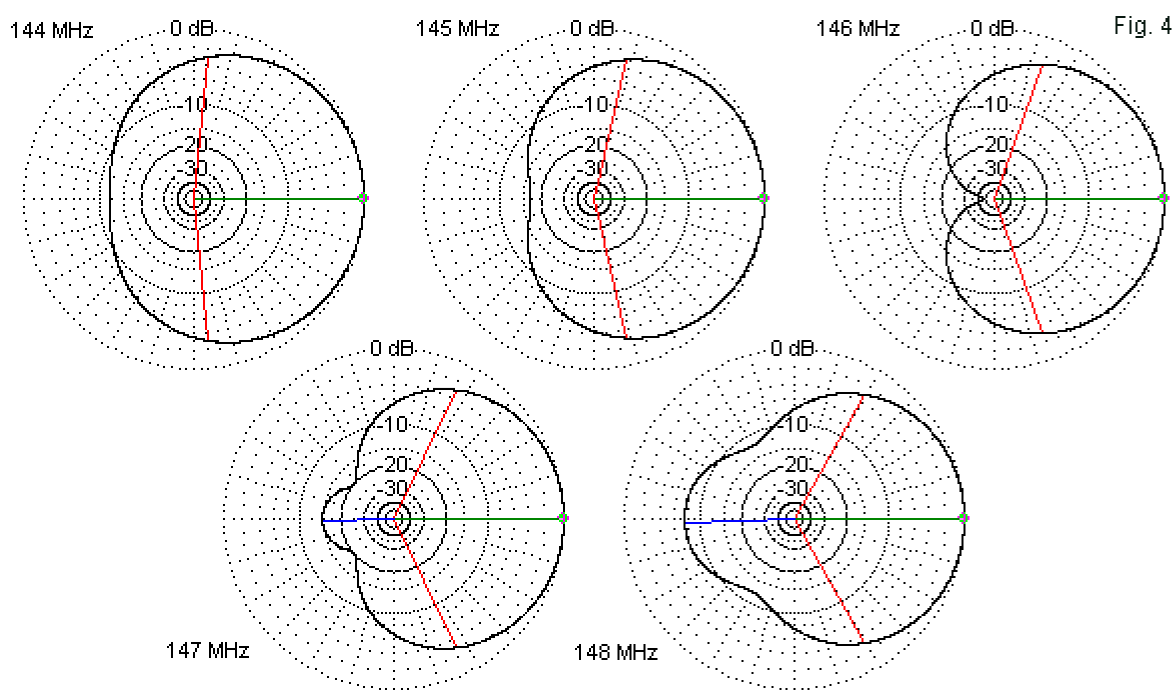
The design has an initial appeal because it employs a common transmission line type for the phase line. Note that the phase line, even though it accounts for the velocity factor of the line, is over twice as long as the distance between the elements. The only drawback of this situation is the need for a method to support the line. A second appeal of the design is the fact that it has an impedance that is compatible with a 50-Ω cable. As shown in the SWR sweeps in **Fig. 3**, we can place a 5-pF capacitor across the feedpoint to lower the SWR somewhat.

At the design frequency, the performance is well suited to the assigned task of nulling a rearward station. The front-to-back ratio at 146 MHz is well over 40 dB, as shown in the sampled data in **Table 2**. The free-space gain in the favored direction is over 4-dB better than the gain of a vertical dipole. Using the single phase line, the current magnitude ratio (rear-to-forward) is 0.991, with a phase difference of 135.7°, very close to ideal for the 1/8-λ element spacing.

Table 2. Modeled performance in free-space of a 2-element phased array using a 70-Ω phase line with maximum nulling at 146 MHz

Category						
Frequency-MHz	144	145	146	147	148	Δ
Gain-dBi	5.31	5.80	6.36	6.82	6.75	1.44
F-B Ratio-dB	12.03	16.91	48.81	14.80	7.49	41.32
Beamwidth-degrees	168.0	154.2	140.8	129.2	121.0	47.0
R +/- jX Ω	42.5 + j23.3	45.7 + j23.9	50.8 + j22.4	56.2 + j15.2	52.7 + j2.1	
50-Ω SWR	1.69	1.65	1.56	1.36	1.07	

Nevertheless, some aspects of the data should give us pause. Before more fully explicating the hesitation, let's also look at a gallery of free-space H-plane plots in **Fig. 4**.



Free-Space H-Plane Patterns of a 2-Element Phased Array with a 70-Ohm Phase Line

Together, the gallery and the numerical data show us that the peak performance with its maximum nulling of the rearward station occurs over a very narrow region of the passband. The very broad SWR curve proved to be no indicator of the front-to-back performance, which falls off very rapidly as we move away from the design frequency. The very narrow passband presents us with construction and adjustment problems. Not only must all dimensions be exact, but as well, the components, such as the phase-line cable, must be precisely as specified. Since the feedpoint impedance and SWR are very flat, they do not guide field adjustment. Rather, one must tune up the antenna in the operating position. The column marked Δ provides a measure of how fast performance changes across the 2-meter band.

The difficulty of this design, simple and appealing though it be, stems from the use of a relatively high characteristic impedance for the phase line. The impedance (70 Ω) may seem to match the dipole lengths, but with mutual coupling between elements, the individual element impedance values are closer to 30 Ω. Even though the use of a higher phase-line impedance value may result in an attractive feedpoint impedance, the very narrow passband relative to the critical performance feature—the front-to-back ratio—may create more difficulties than other schemes.

A Better 2-Element Phased Array for 146 MHz

With a bit of judicious re-design, we can broaden the response of the array. Let's alter the driver length a bit and widen the spacing somewhat. We can still obtain the desired deep null at 146 MHz, but the dimensions in **Table 3** may serve us better in other ways.

Table 3. Dimensions of a 2-element phased array using 0.375"-diameter elements, a 50-Ω phase line (VF = 0.78), and a 35-Ω matching section (VF = 0.78) with maximum nulling at 146 MHz

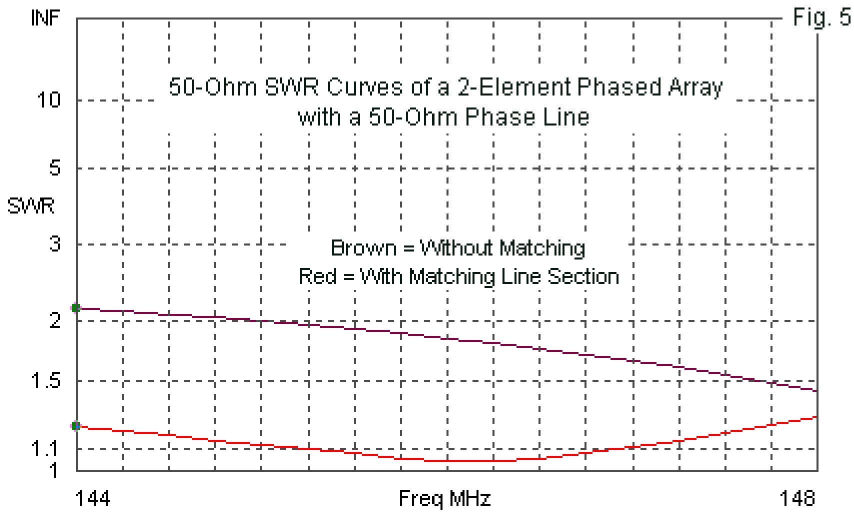
Dimension	Forward Element Length	Rear Element Length	Spacing	Phase Line Length	Match Line Length
Wavelengths	0.454	0.50	0.140	0.195	0.115
Inches	36.70	40.42	11.32	15.76	9.30

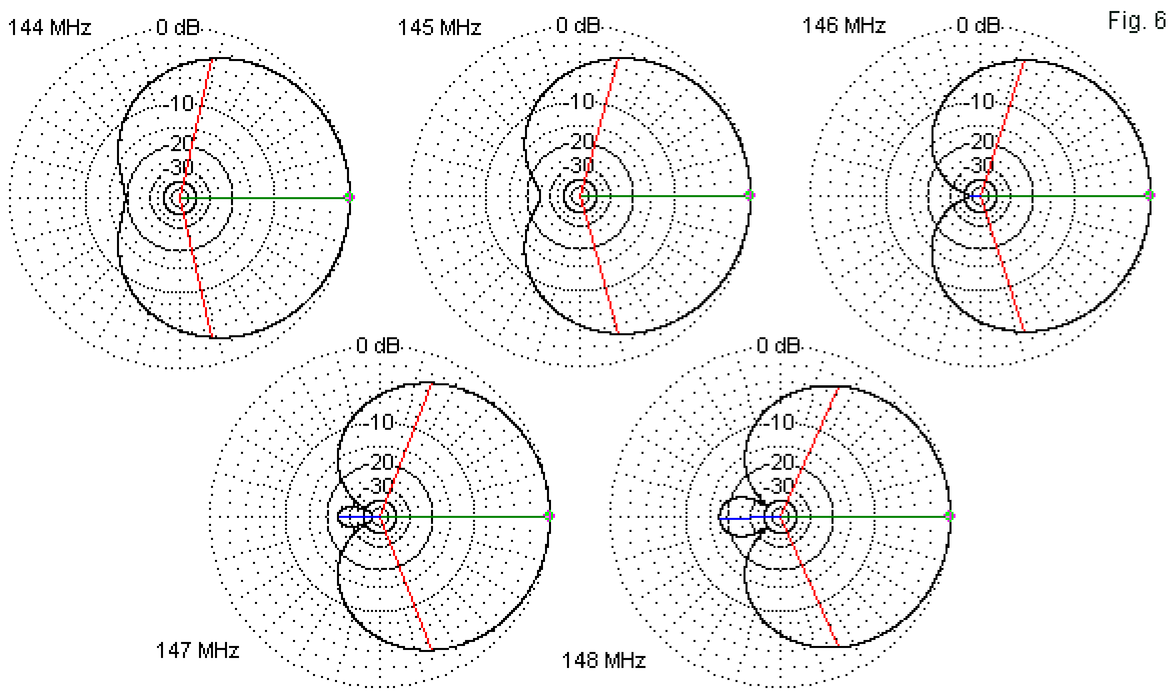
With the new values and a 50-Ω phase line, we obtain the performance numbers that appear in **Table 4**. The adequacy of the performance at the design frequency is clear from the numbers. The rear-to-forward current magnitude ratio is 0.954, with a phase difference of 130.3°, again, close to ideal for the wider element spacing.

Table 4. Modeled performance in free-space of a 2-element phased array using a 50-Ω phase line with maximum nulling at 146 MHz: matching section = 0.115λ (9.3") of 35-Ω, VF 0.78 line

Category						
Frequency-MHz	144	145	146	147	148	Δ
Gain-dBi	5.83	6.04	6.27	6.51	6.74	0.91
F-B Ratio-dB	19.46	25.16	44.39	23.86	17.53	26.86
Beamwidth-degrees	154.4	149.0	143.6	137.8	132.4	22.0
R +/- jX Ω	24.9 + j10.8	26.9 + j11.3	29.5 + j11.7	33.1 + j11.4	37.8 + j9.8	
Post-Match						
R +/- jX Ω	55.1 + j8.8	54.3 + j4.3	52.1 – j0.5	48.0 – j4.8	42.4 – j7.9	
50-Ω SWR	1.21	1.12	1.04	1.11	1.27	

One unappealing aspect to the design is the feedpoint impedance values. However, we may add a 35-Ω matching section (composed of parallel sections of 70-Ω cable) to obtain a wholly satisfactory SWR curve, as shown in **Fig. 5**. The flat SWR curve coincides with the improved passband that shows far lower Δ-values than did **Table 2**. The 50-Ω phase line itself is shorter than the 70-Ω version, calling for less support. However, it is still 4" longer than the distance between elements.





Free-Space H-Plane Patterns of a 2-Element Phased Array with a 50-Ohm Phase Line

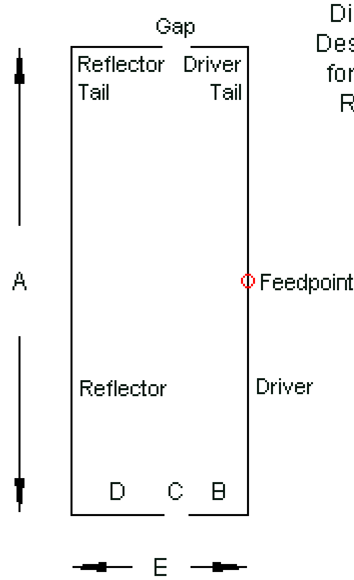
The gallery of H-plane free-space patterns confirms the broader passband of the phased array with a lower phase-line impedance. One might be a few hundred kHz off of peak performance and still obtain at least 30 dB front-to-back ratio for effectively nulling the rearward station.

The use of a phase line that is better matched to the elements allows us the small luxury of avoiding impractical construction exactitude within a home shop. However, the advantage comes at a small price: the need to add a matching section to the feedpoint of the array in order to match the usual 50-Ω coaxial feedline in common use by amateur stations.

A Parasitic Array with a Cardioidal Pattern for 146 MHz

In terms of simple, durable construction, all phased array designs carry a burden: the use of a phase line (or a set of lines) between the two elements. With linear elements in a parasitic arrangement, we cannot obtain the desired deep rear null without resorting to phase lines. Geometry alone will not provide the element current magnitude ratio and phase angle difference necessary to obtain the desired pattern. However, there is a modified parasitic design that does supply the required pattern without the need for a phase line: the Moxon rectangle.

Fig. 7



Outline and Dimension Designators for a Moxon Rectangle Parasitic Array

Fig. 7 provides the required outline and letter designations for the parts of the array. The dimensions for a 146-MHz version with 3/8"-diameter elements appear in **Table 5**. Each dimension corresponds to the lettered items in the outline sketch.

Table 5. Modeled performance in free-space of a 2-element Moxon rectangle using 0.375"-diameter elements with maximum nulling at 146 MHz

Dimension	A	B	C	D	E
Wavelengths	0.3562	0.0439	0.0199	0.0693	0.1331
Inches	28.80	3.55	1.61	5.60	10.76

The folded-in elements provide the means for improving the element current values so that we obtain the desired pattern on the design frequency. Essentially, the Moxon rectangle provides normal parasitic coupling between the parallel long portions of the elements. The tails and the prescribed gap supply element end coupling that contributes to the overall pattern. A side benefit of the folding process is that the overall length of the array is only about 70% of the length of either phased array that we have examined. The spacing from the driver to the reflector (appropriate terms, since we are now working with a wholly parasitic array) falls between the spacing values used in the two phased arrays. We can easily lock the gap after initial tune-up by using a ¼"-diameter rod or tube inserted into the element tails and epoxied or screwed in place.

Table 6. Modeled performance in free-space of a 2-element Moxon rectangle with maximum nulling at 146 MHz

Category						
Frequency-MHz	144	145	146	147	148	Δ
Gain-dBi	6.27	6.13	5.98	5.84	5.71	0.56
F-B Ratio-dB	19.97	26.59	41.81	26.81	21.51	21.84
Beamwidth-degrees	133.8	138.4	142.8	147.0	150.8	17.0
R +/- jX Ω	41.3 - j10.7	46.8 – j5.8	52.0 - j1.6	56.8 + j2.0	61.3 + j5.2	
50-Ω SWR	1.35	1.15	1.05	1.14	1.25	

The performance data in **Table 6** shows that the rectangle has slightly less gain at the design frequency than the phased arrays, but the front-to-back ratio at the design frequency is well over 40 dB. Even without a phase line, the rectangle achieves a rear-to-front current magnitude ratio of 0.961, with a phase difference of 127.8°, very close to what we might find with a single-phase-line array using the same element spacing. Moreover, the rectangle requires no matching section to provide a very low SWR across the 2-meter band, as confirmed by **Fig. 8**.

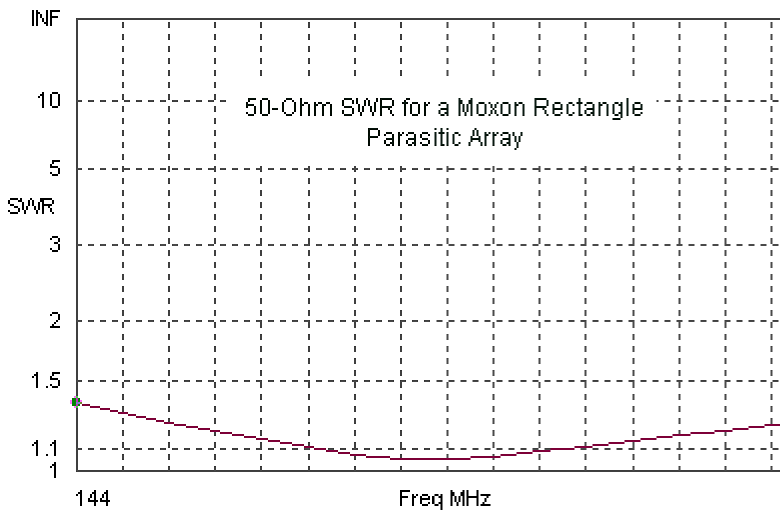


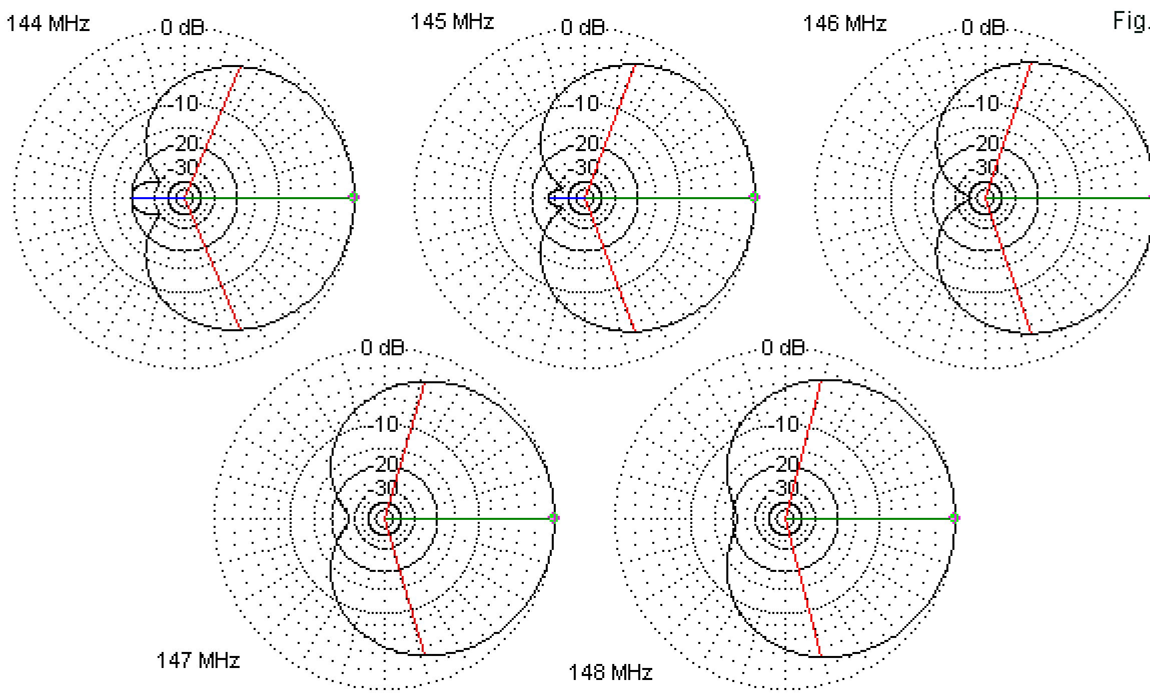
Fig. 8

In addition to these advantages, the Moxon rectangle shows the lowest values of Δ for all categories in the table. Hence, it exhibits precisely the broad banded characteristics that are advantageous to home shop construction. One might be off target by up to +/-0.5 MHz relative to the design frequency and still obtain 30 dB of rearward nulling. **Fig. 9** provides the gallery of free-space H-plane patterns that show the very slow growth of the rearward sector.

Compared to the phased arrays, the rectangle seems to have an anomaly. The phased systems showed an increasing gain with an increase in frequency, while the rectangle shows precisely the opposite trend. In fact, both trends are perfectly appropriate to antennas of the two types. The impedance progression with rising frequency is also natural for 2-element parasitic driver-reflector arrays. With phased arrays, the interrelationship of the phase line with the parasitic coupling between elements makes the impedance variation with frequency somewhat more variable.

At the design frequency, the rectangle shows about a quarter-dB lower gain than the phased arrays, largely due to the reduced overall size. Within the scope of the present challenge—to null out a rearward station—the antenna serves just as well as the other candidates. The rectangle's wholly parasitic operation simplifies construction and adjustment, and it requires no matching components to obtain a perfectly acceptable 50-Ω SWR. The only critical operations in building the antenna are fixing the gap correctly and bending the element corners in a small radius. However, locking the two elements together with the gap rod may yield a structure that is more durable than one composed of linear elements.

Fig. 9



Free-Space H-Plane Patterns of a Moxon Rectangle Parasitic Array

Conclusion

All three arrays perform almost identically at the design frequency. The phased array with the higher characteristic impedance phase line exhibits narrow-band performance characteristics that may complicate construction and adjustment. The wider-band array with the lower characteristic impedance phase line lessens the requirement for ultra-precise construction, but does require a matching section to match a 50-Ω main feedline. The Moxon rectangle requires no phaseline and is a direct match for a 50-Ω line. As well, its length is only 70% of the arrays that use linear elements. However, it does require that the builder bend some tubing.

Although there may be no perfect array for the task of nulling deeply a station to the rear, there are multiple routes to an adequate solution. With more than one way to resolve the issue, which one to choose becomes a judgment by the builder that may depend on local materials and skills more than upon the electrical potential of the possible arrays.