Special Needs Call for Special Antennas: The X-Array

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Consider the following scenarios and **Fig. 1**.

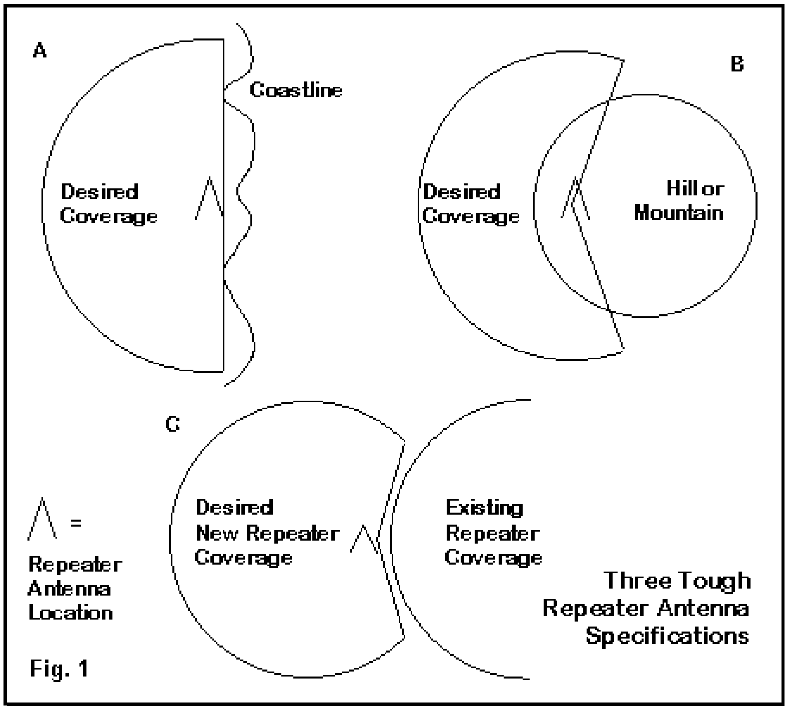

Fig. 1

1. A repeater station is located on the coastline of a given area. The desired coverage area is inland, with no maritime activity.

2. Another repeater station is located near or at the base of a hill or mountain. It suffers from reflected signals returning from the hill surface. The desired coverage area lies in front of the hill and to the sides of the repeater antenna site.

3. A proposed repeater antenna site (and frequency allocation) lies close enough to another repeater's coverage area on the same or a nearby frequency to promise overlapping coverage and mutual interference. The new station desires an area of coverage that lies in the region not covered by the existing repeater.

These samples of special needs have in common a very similar desired region of coverage, but very different reasons for wanting that coverage. We might nearly endlessly create other plausible scenarios to provide other avenues to the same need. In each case, we need at least a semi-circle of coverage, with extensions to the rear. However, we need to diminish the signal to the rear for at least 60 degrees either side of a hypothetical center line.

We can, of course, design a complex array of multiple antennas to create the semi-circle-plus. However, if we can develop a single antenna to do the job, we obtain a maintenance advantage in terms of the mechanical and electrical simplicity of the installation.

Notice that forward gain is not one of the criteria for the antenna installation. Anything close to the gain of a vertical dipole at an equivalent height would suffice. The major specification for this antenna installation--whatever the reasons behind it--is the pattern shape.

The X-Array

Steve Giess, a UK radio astronomer and experimenter in long-range TV reception, introduced me to an interesting commercial antenna from days past. The Antiference "Antex" antenna provided service for British 405-line television, channel 2, with the audio at 48.25 MHz and the video at 51.75 MHz. The antenna is vertically polarized. It is an X-array.

I call it an array to distinguish it from various forms of X-beam that have been used in horizontal service in the amateur bands. Among the many forms are the full X, the Roman X, and the folded X-beam. (See "Modeling and Understanding Small Beams: Part 1. The Folded X-Beam," *Communications Quarterly* (Winter, 1995), pp. 33-50.) All of these design had relatively narrow operating bandwidths and only marginal performance levels to recommend them.

The Antiference X-array stands vertically, with two shorter arms to one side and two longer arms to the other. See **Fig. 2**.

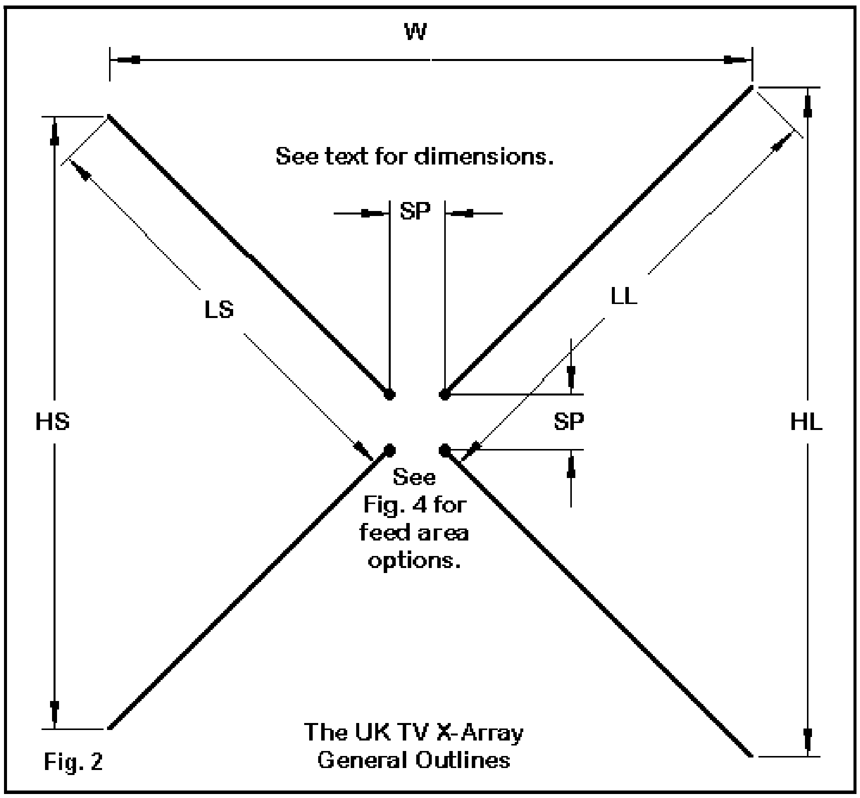

Fig. 2 The UK TV X-Array General Outlines

As shown in the figure, we initially leave the center area of the array open, with no connection among the arms. Of course, in this pre-use condition, we also have no drive, so the antenna simply forms a big mechanical X.

The initial British TV frequencies are close enough to the U.S. 6-meter band to allow for simple scaling. As well, the array may have application on 2 meters, so I adjusted the dimensions for that band as well. In the following table of dimensions--keyed to the designations in **Fig. 2**, the element lengths (LS for the shorter elements and LL for the longer elements) are calculated from the hypothetical crossing point of the elements. For the actual physical element, subtract .70" (18 mm) from each 6-meter element and 0.35" (9 mm) from each 2-meter element.

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Scaled antiference X-array dimensions for 6 and 2 meters

6 Meters: element diameter: 0.5" or 12.7 mm

Dimension	**HS**	**LS**	**HL**	**LL**	**W**	**SP**
Inches	**74.8**	**52.9**	**81.9**	**57.9**	**78.4**	**1.0**
Millimeters	**1900**	**1343.5**	**2080**	**1470.8**	**1990**	**25**

2 Meters: element diameter: 0.25" or 25.4 mm

Dimension	**HS**	**LS**	**HL**	**LL**	**W**	**SP**

Inches	**27.6**	**19.5**	**29.9**	**21.2**	**28.7**	**0.5**
Millimeters	**700**	**495**	**760**	**537.5**	**730**	**13**

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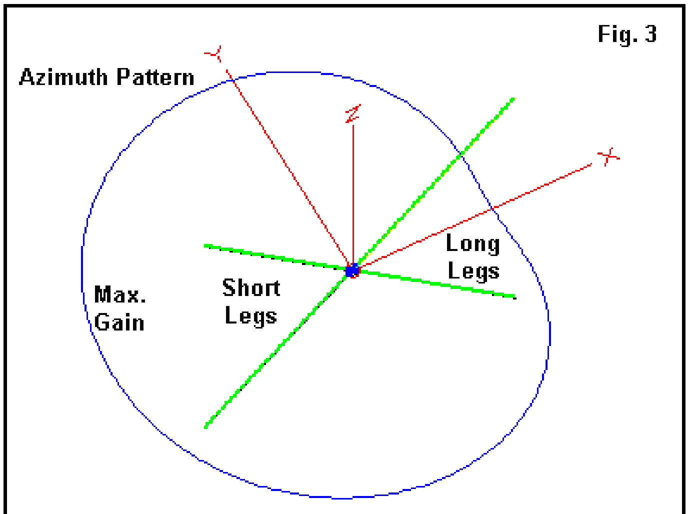
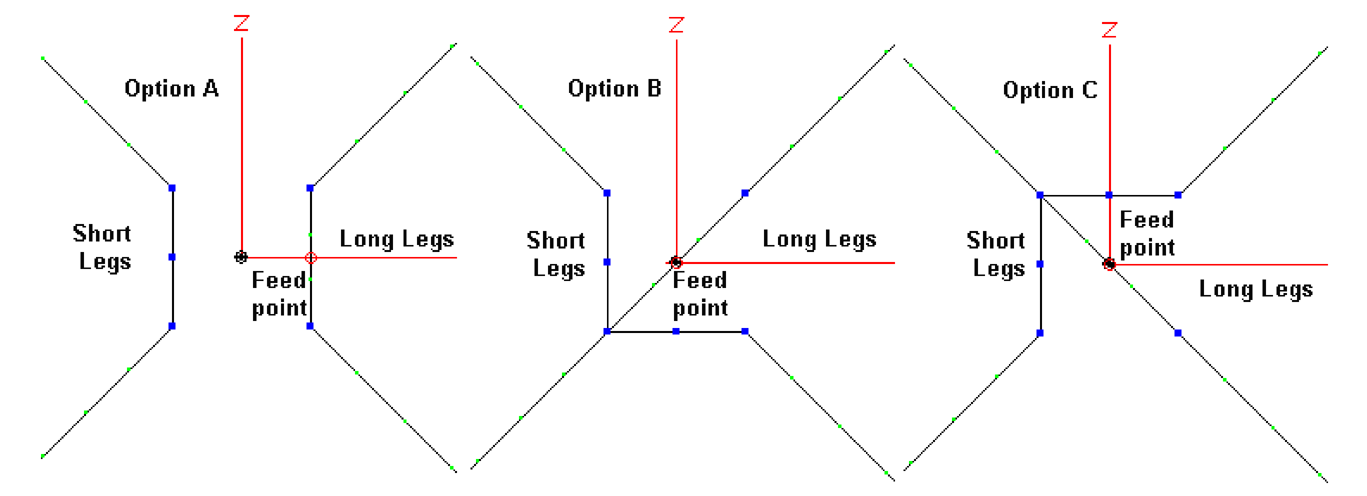
Each beam is shorter than a vertical dipole for the frequency, but much wider, of course.



Azimuth Pattern Orientation Relative to Antenna Shape

The azimuth pattern for the array is oriented with the main axis in line with the X frame, with the weakest signal--the rear--on the long element side. **Fig. 3** shows the general orientation of the pattern. Note that the pattern is very wide. In some options for interconnecting elements and feeding the array, the maximum gain is not in perfect alignment with the frame axis, but off set symmetrically to each side. However, the broad forward lobe is generally equal to or within 0.5 dB of maximum strength along the main aiming axis.

What we derive from the X-array depends upon how we feed the antenna and how we interconnect the element centers. **Fig. 4** shows us several options of interest, although the maker countenanced only the first two.



Feeding Options for the X-Array

Fig. 4

In option A, the array forms a relatively standard driver-director array. The other two versions are free-space mirror images of each other. Whatever the selected option, the antennas cover the two amateur bands with under 1.5:1 50-Ohm SWR. To achieve the best patterns across the FM portions of the 6- and 2-meter bands, I used design frequencies of 52.5 and 146.5 MHz.

In options B and C, shorting bars link three out of the 4 elements. A feedpoint link or wire connects the free element and the junction of the other two links. This ingenious scheme has some interesting consequences, as we shall see.

The most ordinary configuration--the parasitic driver-director array--produces easily anticipated free-space patterns. The plots appear in **Fig. 5**.

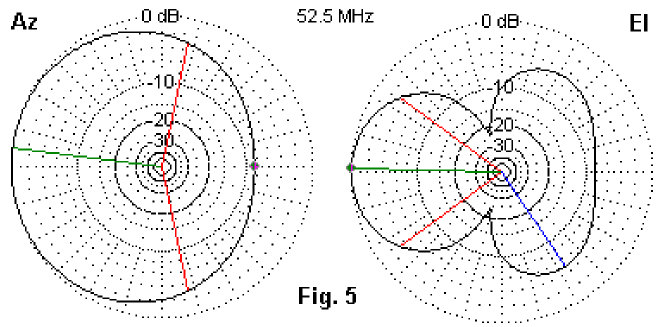


Fig. 5

X-Array Free-Space Patterns: Option A

One of the disadvantages of the X-beam in horizontal service is the fact that the rear lobes are very large. This feature shows clearly in the "elevation" plot--actually the E-plane pattern for the array. However, this feature is no particular impediment to vertical service for the array over ground. **Fig. 6** shows the azimuth and elevation patterns of the option-A version of the antenna at a center height of 2 wavelengths above average ground (37.5' or 11.42 m). The following table provides both the free-space and the over-ground performance of the array at the design frequency.

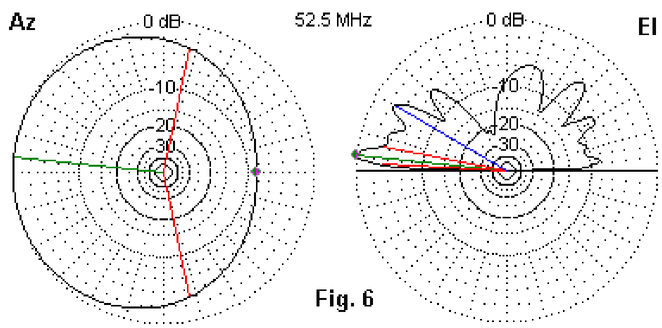


Fig. 6

X-Array 2-WL Height Patterns: Option A

6-Meter Performance of the X-Array: 52.5 MHz

Option A Feed

Parameter	Gain	TO Angle	Horiz BW	F-B Ratio	Feedpoint Z
	dBi	degrees	degrees	dB	R+/-jX Ohms
Free Space	4.5	---	204	8.4	65 + j 6
2-WL Above Ground	7.3	6	204	8.2	65 + j 6

Options B and C, when modeled in free space, provide a lesson in modeling: do not always judge the performance of an antenna by its free space model unless you plan to use it in free space. Instead, verify its performance at the proposed height above real ground. **Fig. 7** provides the free-space elevation or E-plane patterns for the X-array when connected as shown in options B and C in **Fig. 4**.

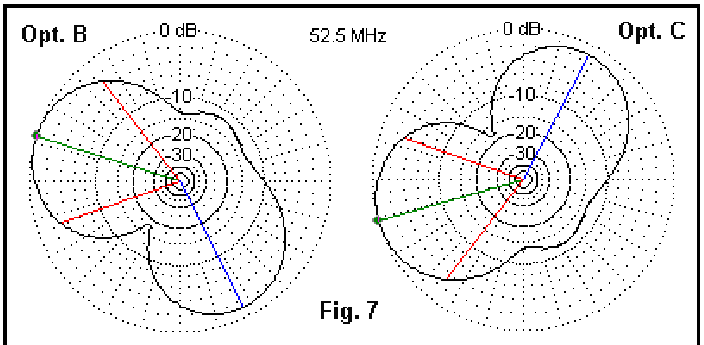


Fig. 7

X-Array Free-Space Elevation Plots: Options B and C

We shall initially promise better performance over real ground than appears to be the case from the free-space patterns. However, the two patterns, although mirror images in free space, do not produce identical patterns over ground. Option B connects the lower long leg to the forward elements and yields a rearward free-space lobe that is--by graphical convention downward. Option C does the opposite, connecting the upper long leg to the forward elements and yielding a rear upward lobe. Over real ground, the rear lobes interact with the ground differently, producing differing amounts of rearward energy. As shown in **Fig. 8**, option C wastes considerable energy in high-angle rearward lobes, while the rearward portions of the option-B pattern are much better behaved. There is little wonder why the antenna makers countenanced option B but not option C.

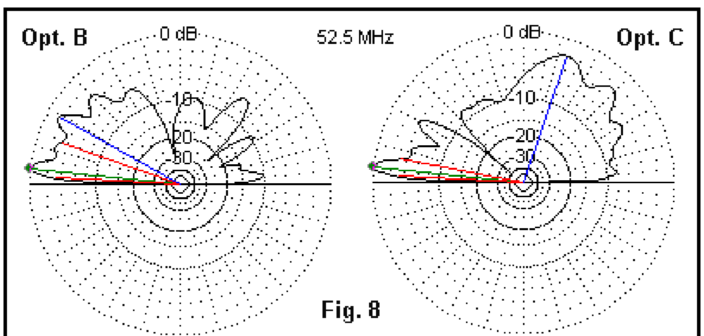


Fig. 8

X-Array 2-WL Height Elevation Plots: Options B and C

With respect to the forward lobes, there is little on the surface to choose between the azimuth patterns of either option. **Fig. 9** provides the two patterns for comparison.

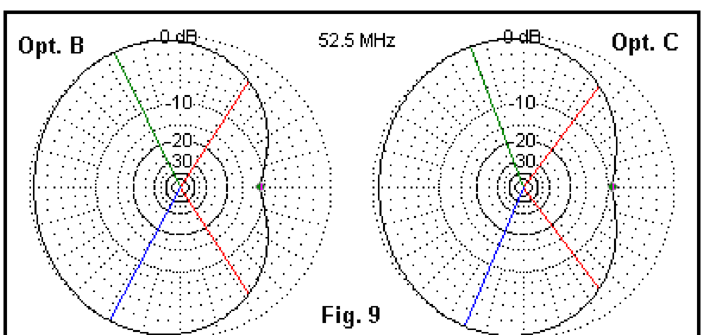


Fig. 9

X-Array 2-WL Height Azimuth Patterns: Options B and C

However, there are--besides the matter of upward rear-lobe energy--some significant differences in the performance of the two arrays. The following table present both free-space and 2-wavelength height performance numbers for both options B and C.

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6-Meter Performance of the X-Array: 52.5 MHz

Option B Feed

Parameter	Gain dBi	TO Angle degrees	Horiz BW degrees	F-B Ratio dB	Feedpoint Z R+/-jX Ohms
Free Space	**2.7**	**---**	**236**	**9.3**	**55 + j 9**
2-WL Above Ground	**5.7**	**6**	**246**	**10.2**	**53 + j 8**

Option C Feed

Parameter	Gain dBi	TO Angle degrees	Horiz BW degrees	F-B Ratio dB	Feedpoint Z R+/-jX Ohms
Free Space	**2.7**	**---**	**236**	**9.3**	**55 + j 9**
2-WL Above Ground	**5.2**	**6**	**253**	**8.2**	**55 + j 8**

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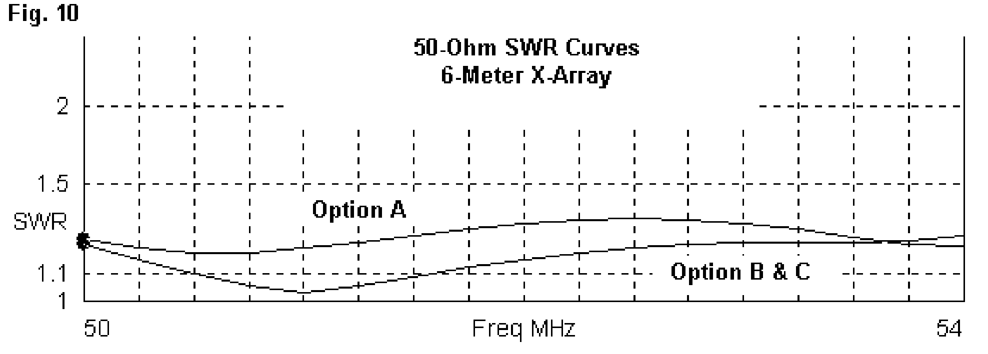
The free-space reports are the same in both cases. However, option B provides about a half-dB more gain along the axis of the array than option C. In both cases--as indicated by the blue and green line in the patterns of **Fig. 9**--maximum gain does not occur along the axis. In option C, there is a 0.8 dB difference between gain along the axis and maximum gain. That differential is under 0.5 dB for option B.

In both cases, the forward gain over ground is less than for the option-A simple parasitic array. However, the horizontal beamwidth of both B and C is significantly wider, providing much smoother signal strength or reception sensitivity for a greater arc.

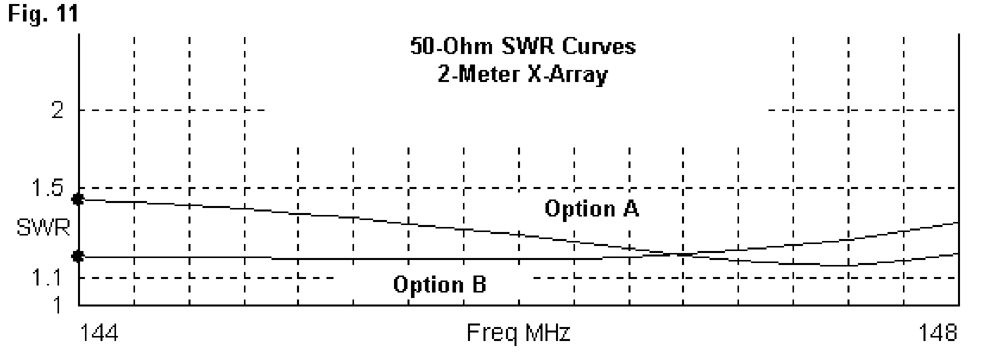
Nevertheless, either option A or option B will provide quite good service is meeting the needs specified at the beginning of these notes. The rearward signal is down about 10 dB relative to a very broad forward signal area. As well, both will provide very good 50-Ohm SWR curves across the band, as shown in **Fig. 10**.

Fig. 10



Equally good are curves for the 2-meter version of the array. The 50-Ohm SWR curves appear in **Fig. 11**.

Fig. 11



However, in the process of optimizing the 2-meter design, I encountered a temptation that the designer should overcome. The change in relative element diameter to something fatter as a fraction of a wavelength required some adjustment of element lengths from their originally scaled values. The aim was to replicate as closely as possible the design frequency feedpoint impedances for both feedpoint options A and B. In the process, I obtained the following free-space performance values.

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2-Meter Performance of the X-Array: 146.5 MHz

Free-space Parameter	Gain dBi	TO Angle degrees	Horiz BW degrees	F-B Ratio dB	Feedpoint Z R+/-jX Ohms
Option A Feed	4.7	---	160	20.1	61 + j 2
Option B Feed	3.8	---	186	19.5	50 + j 8

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The front-to-back ratios in both cases are superior to those of the 6-meter model. However, the horizontal beamwidth values are well down from the 6-meter values. In short, there is a price to pay for the added peak front-to-back values.

From Single Frequency Design to Frequency Sweeps

Since the ratio of gain and front-to-back ratio to the horizontal beamwidth of the array can make a difference to our design decision--given the initial premises for these notes--let's examine what happens to these parameters somewhat more systematically. We might begin by adjusting the dimensions of the 52.5-MHz array in its option-A, free-space version. The following table provides some steps in the evolution of the design working toward maximum front-to-back ratio at the design frequency.

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6-Meter Performance of the X-Array: 52.5 MHz

Free-space Element Lengths LL / LS	Gain dBi	Horiz BW degrees	F-B Ratio dB	Feedpoint Z R+/-jX Ohms
1471 / 1344 mm 57.9 / 52.9 in	4.5	204	8.4	65 + j 6
1471 / 1358 mm 57.9 / 53.5 in	4.8	189	10.5	62 - j 1
1478 / 1372 mm 58.2 / 54.0 in	5.2	173	14.0	56 - j 4
1492 / 1379 mm 58.7 / 54.3 in	5.4	165	17.1	54 + j 1
1499 / 1386 mm 59.0 / 54.6 in	5.6	157	21.8	49 + j 2

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Certain trends become obvious in the design process. Lengthening the director increases the gain and front-to-back ratio. In the process, the feedpoint resistance decreases, and so does the reactance. It is necessary to lengthen the driver to restore the near-resonant condition of the array. Small driver adjustments do not affect gain, but do slightly increase the front-to-back ratio.

If we focus on the gain and front-to-back ratio alone, then the last set of dimensions in the sequence appears to be the best. However, that judgment is premature, given that one crucial parameter in the exercise is the -3-dB horizontal beamwidth of the array. As we raise the gain and the front-to-back ratio, the beamwidth diminishes--by 50 degrees over the span of the adjustments in the chart.

For a given spot frequency (or repeater frequency pair, since the performance of the array does not vary significantly over a relatively small frequency span), we must reach a decision regarding the optimal combination of gain, front-to-back ratio, and horizontal beamwidth. That decision, of course, will rest upon factors outside the exercise itself.

We may explore the array properties in another manner: by taking selected performance readings at frequencies within the overall amateur band to which we might apply the array. Let's look at the first and the last steps in the design evolution and take modeled performance readings at each MHz marker in the 6-meter band.

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Free-Space 6-Meter Performance of 2 Versions of the X-Array

Original Version: LL = 1471 mm/57.9"; LS = 1344 mm/52.9"; Option A

Parameter	50	51	52	53	54
Gain (dBi)	3.5	3.8	4.2	4.8	5.5
Hor. B/W degrees	280	247	218	189	161
Front-Back dB	3.9	5.1	7.0	10.4	19.7
Feed R+/-jX Ohms	54-j10	60-j1	65+j4	64+j6	53+j9

Optimized Version: LL = 1499 mm/59.0"; LS = 1386 mm/54.6"; Option A

Parameter	50	51	52	53	54
Gain (dBi)	4.0	4.5	5.2	6.0	6.2
Hor. B/W degrees	231	202	172	143	118
Front-Back dB	5.9	8.6	14.4	21.3	7.6
Feed R+/-jX Ohms	61-j6	63-j2	57-j1	40+j9	26+j33

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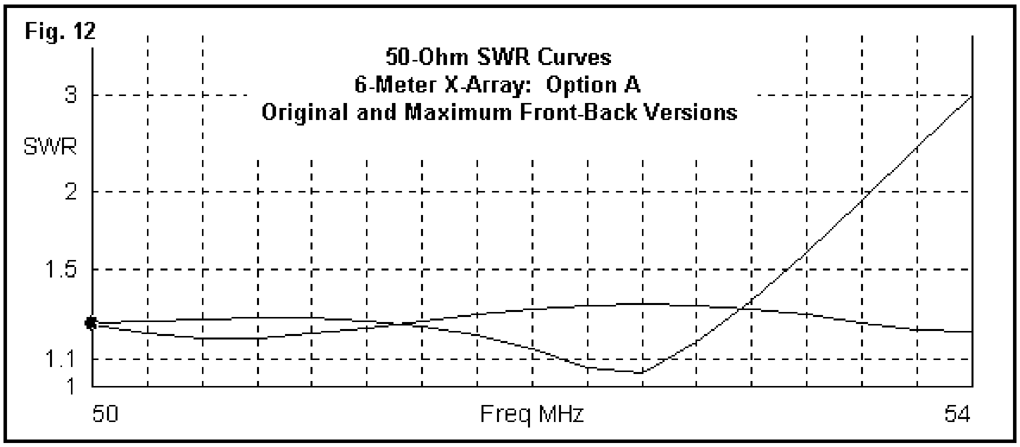
In the process of optimizing the gain and front-to-back performance of the 6-meter X-array, we managed to radically alter the SWR curve for the array across the band. **Fig. 12** gives us a dramatic comparison of the 50-Ohm SWR curves for both the original and optimized versions of the array. Apart from any other parameter that we might question, the optimized version of the array is clearly usable only at spot frequencies, since the bandwidth for matching a 50-Ohm cable and obtaining the higher performance is considerably narrowed. Above the design frequency, the 50-Ohm SWR rises steeply. Below the design frequency, performance falls off rapidly.

Fig. 12



Apart from the question of 50-Ohm SWR, the chart re-confirms that as we increase the gain and front-to-back ratio of the array, the optimized version loses 40-50 degrees of beamwidth. For a spot frequency, we may press optimization to the limit of whatever balance we have struck in terms of our need for both gain and beamwidth. However, if we need an array for full band coverage, we must accept a more modest set of performance figures with fewer radical changes across the operating passband.

In our initial evaluation of the design, we noticed that option B regularly produced a wider beamwidth than option A, despite option-A's ability to provide higher gain. It is worthwhile to see how those design frequency values work out in a full sweep of the 6-meter band. This time we shall use values taken at 2-wavelengths above average ground at a TO angle of 6 degrees.

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6-Meter Performance of 2 Versions of the X-Array

Option A; Original Version

Parameter	50	51	52	53	54
Gain (dBi)	6.1	6.5	7.0	7.6	8.3
Hor. B/W degrees	281	248	218	190	161
Front-Back dB	3.8	5.0	6.8	10.2	19.1
Feed R+/-jX Ohms	54-j10	60-j1	64+j5	64+j7	53+j10

Option B; Original Version

Parameter	50	51	52	53	54
Gain (dBi)	5.7	5.9	6.1	6.4	7.3
Hor. B/W degrees	270	262	252	236	199
Front-Back dB	5.1	6.5	8.6	12.3	19.6
Feed R+/-jX Ohms	44-j8	49+j0	52+j6	53+j10	48+j12

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Only at the lowest frequency of the band--below the region where vertical antennas are the norm--does the beamwidth of option A exceed that of option B. As well, the option-B rate of decline in beamwidth across the band is less than that of option A. The differential in gain favoring option A increases with frequency, a fact that tells us that the option-B gain is more stable across the band.

The consequences of the comparison are suggestive. For spot frequency use, a partially or fully optimized version A of the X-array may be most apt. However, for general coverage that includes a desire to sustain the pattern shape as well as possible, option B feeding offers the best choice.

These recommendations might hold for any band to which we might scale the X-array if the practicalities of antenna construction and durability allowed us also to scale the element diameter in a true fashion. However, for durability, 2-meter elements must generally be fatter than the true scale diameter. Therefore, for the 2-meter version of the X-array, we chose 0.25" (6.35 mm) diameter elements. Let's performance a sweep of the 2-meter amateur band to see what results we obtain for option A and option B with the array in free space.

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2-Meter Performance of 2 Versions of the X-Array

Option A; Original Version

Parameter	144	145	146	147	148
Gain (dBi)	4.1	4.3	4.6	4.9	5.1
Hor. B/W degrees	186	176	166	155	146
Front-Back dB	11.0	13.4	17.1	24.8	26.3
Feed R+/-jX Ohms	72-j3	69-j2	64+j0	57+j3	51+j8

Option B; Original Version

Parameter	144	145	146	147	148
Gain (dBi)	2.8	3.1	3.5	4.0	4.4
Hor. B/W degrees	224	210	194	178	162
Front-Back dB	11.5	13.8	17.1	22.3	22.7
Feed R+/-jX Ohms	55-j7	55+j7	52+j8	48+j9	44+j12

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The 2-meter design, as presented, shows little difference between the two methods of feeding the array. The standard parasitic feed system in option A yields a little more gain, and the price of gain is a reduction in the beamwidth. For a spot frequency design, the selection between the two designs is a matter of the need for gain vs. the need for horizontal beamwidth.

More generally, the conclusion that emerges is that if beamwidth needs in excess of 200 degrees form a major criterion for the array, then the designer will have to reset the element lengths to decrease the array gain and store the wider beamwidth. The fastest route to this result is a reduction in the length of the shorter elements, with adjustments as needed to the driver to set the 50-Ohm SWR curve at an acceptable level across the operating passband.

Conclusion

The vertically oriented X-array, although not widely used in any service in the US, should not be forgotten. It offers a simple solution to special needs that may arise in repeater operations in the VHF range where beamwidth may sometimes be a major consideration. Perfecting the design to provide an acceptable level of gain, front-to-back ratio, and beamwidth is straightforward. The ingenuity of the Antiference designers in developing the alternative feed system that we have labeled option B provides further flexibility to the array and to the potential user. Etched into a substrate in miniature form, the array may even have applications above 500 MHz for a variety of situations calling for control of the beamwidth and smooth gain values across that beamwidth. The X-array is not for everyday use, but should not be forgotten when the special needs arise for which the antenna is well suited.