ANTENNAS FROM THE GROUND UP

42. Diamonds are Forever
or The Terminated Vee-Beam and Rhombic

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The terminated longwire antenna that we explored in the last episode is perhaps the simplest of the large terminated wire arrays, but its is not the best performer. In this follow-up session, we shall look at two other arrays. The long, terminated Vee-beam provides considerably more gain for the same length legs, but does not have the longwire's ease of feeding over a large frequency spread. The rhombic, in contrast, provides gain even over the Vee-beam and allows multi-band coverage. However, it is perhaps the most complex of the terminated arrays.

Designing either type of array for maximum performance is not simply a matter of stringing hundreds of feet of wire. Behind each type of array are a number of design equations that take into account the length of the legs, the angles formed by the wires, and the antenna height (or desired elevation angle of maximum radiation). These notes only survey some of the potential of these wire antennas, but are not sufficient for designing an effective array for your own farm. Our goal is to provide enough information so that you may decide whether further study into the designs is a worthwhile project.

The Vee-Beam: Do not confuse the Vee-Beam with some of the small Vee-shaped antennas whose total wire length is only about 1/2-wavelength. We do not arrive in Vee-beam territory until each leg is several wavelengths long. Like the longwire antenna, the Vee-beam depends upon the fact that as we make a wire longer and longer in wavelengths, the main radiation lobe moves from broadside to the wire to a position nearly in line with the wire.

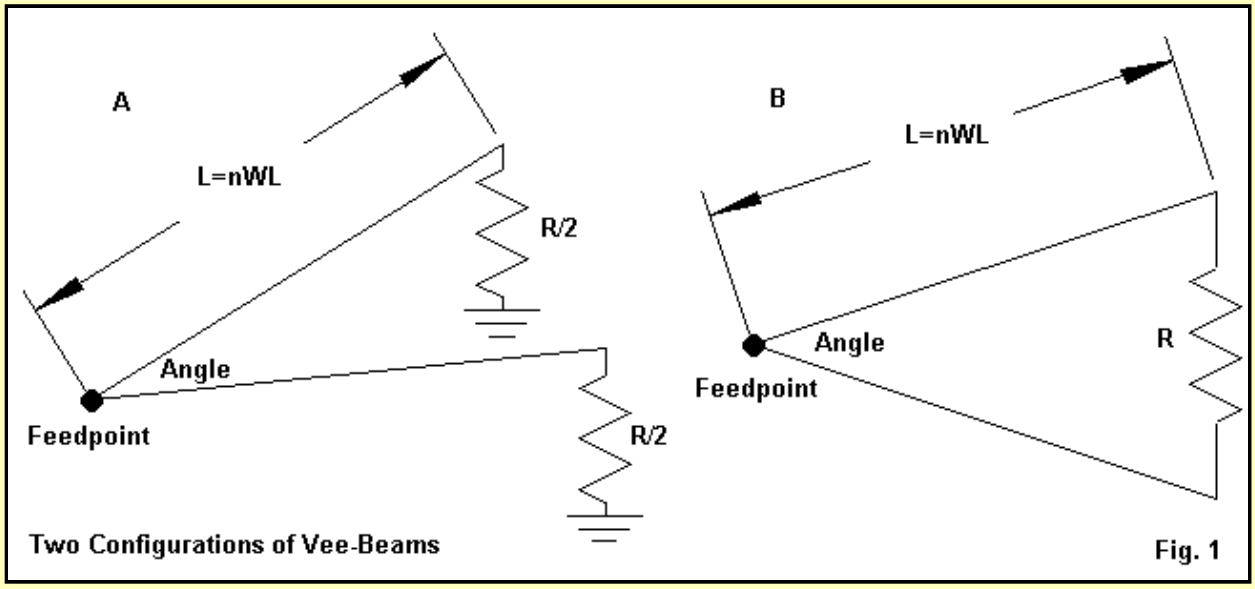
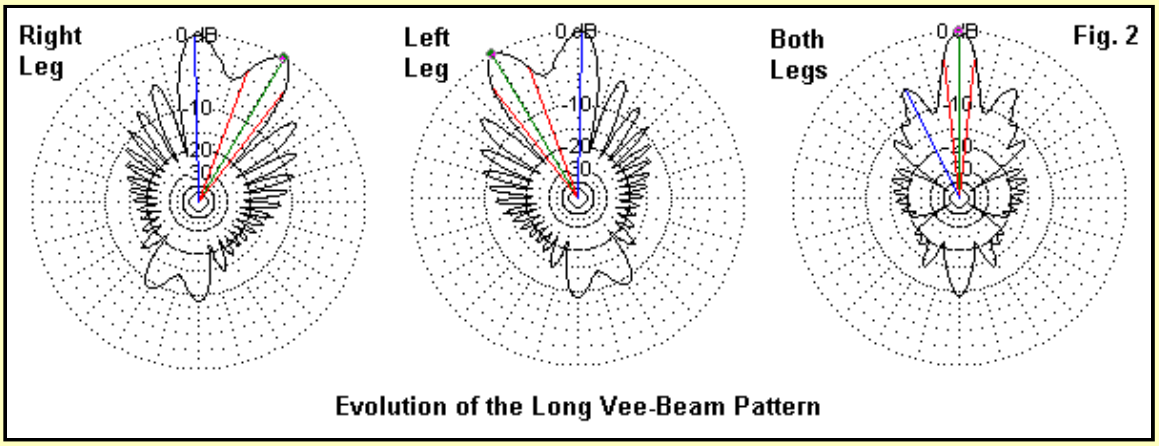


Fig. 1 shows two ways of designing a terminated Vee-beam. One uses terminating resistors that operate like those in the simple longwire. The other uses a cross wire that includes the terminating resistor. Just as in the last episode, the terminating resistor must be a non-inductive element with the ability to dissipate about half of the power supplied to the antenna. Both versions of the Vee-beam use the same principle of operation.

To design a Vee-beam, we must know the planned length of the element legs in wavelengths. Since the length of the leg determines the angle of the main lobes relative to the plane of the leg, the length of the legs also determines the angle that we must use between the two legs for maximum forward gain. The

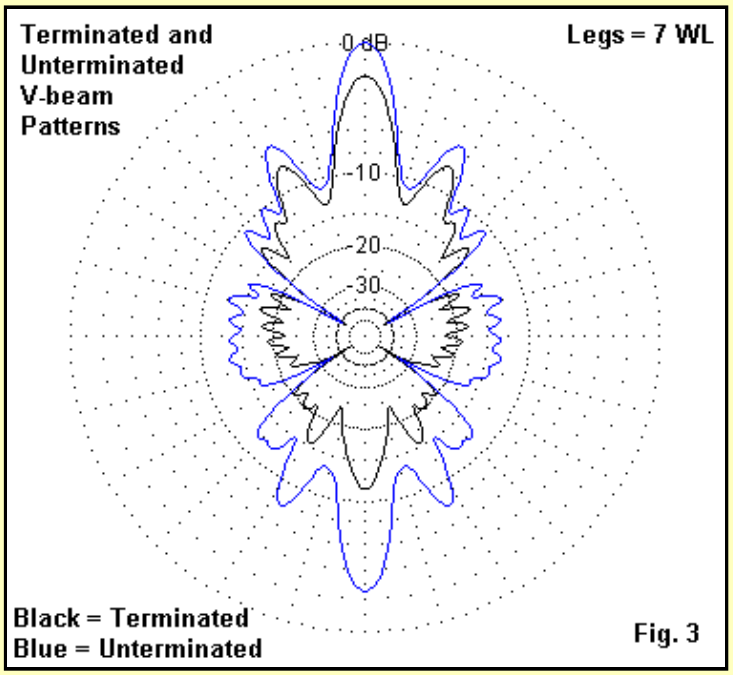
goal is to align the two legs so that a main lobe from each wire combine to form a single large forward lobe. See **Fig. 2**.



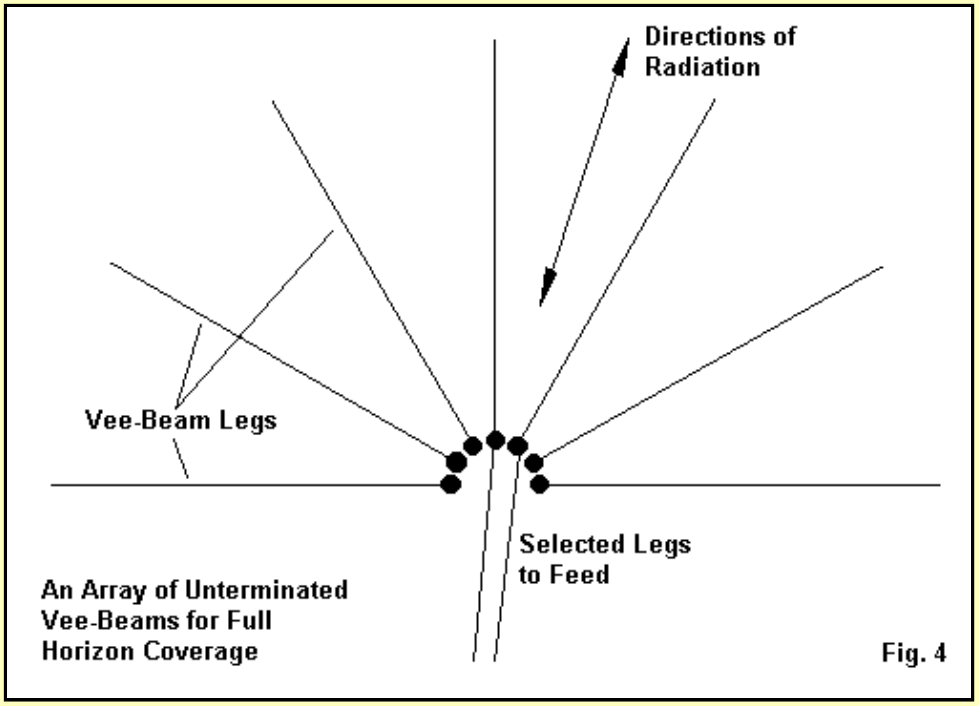
The plots show the patterns for the left and right legs of a planned Vee-beam with 7-wavelength legs. The height of the array is 1 wavelength above average ground. When we combine the two legs, we obtain the pattern at the right. For the leg-lengths that we chose, the main lobes are about 15 degrees off the plane of the wire. By making a Vee with a 30-degree total apex angle, we approach the maximum gain of which the antenna is capable. Obviously, had we selected longer legs, we would have used a narrower apex angle, while shorter legs would have called for a wider angle. If we do not match the angles and the length of the legs, we shall obtain inferior performance.

With 7-wavelength legs, the Vee-beam yields a maximum forward gain over average ground of about 13.5 dBi. This value is considerably higher (by about 5 dB) than the simple longwire antenna. However, the Vee-beam is not capable of achiving the high front-to-back ratio that the terminated longware gave us. If you examine the two left patterns in **Fig. 2**, you will see that each has a rearward lobe that is less than 10 dB down from the favored lobe. In the Vee configuration, these lobes also add, giving the Vee-beam a significant rearward lobe that remains only about 10 dB down from the forward lobe. Like all all arrays composed of wires that are several wavelengths long, the patterns will be filled with sidelobes.

Like the longwire antenna, the Vee-beam is capable of good use with or without its terminating resistors. **Fig. 3** gives us comparative patterns for the two versions, using the same legs. Only the presence or absence of the terminating resistors marks the pattern differences. Note that the unterminated Vee-beam has (like the unterminated longwire) about 2 dB more gain. However, it is more truly bi-directional (than the longwire), since the rearward radiation is down by only about 2.5 dB.



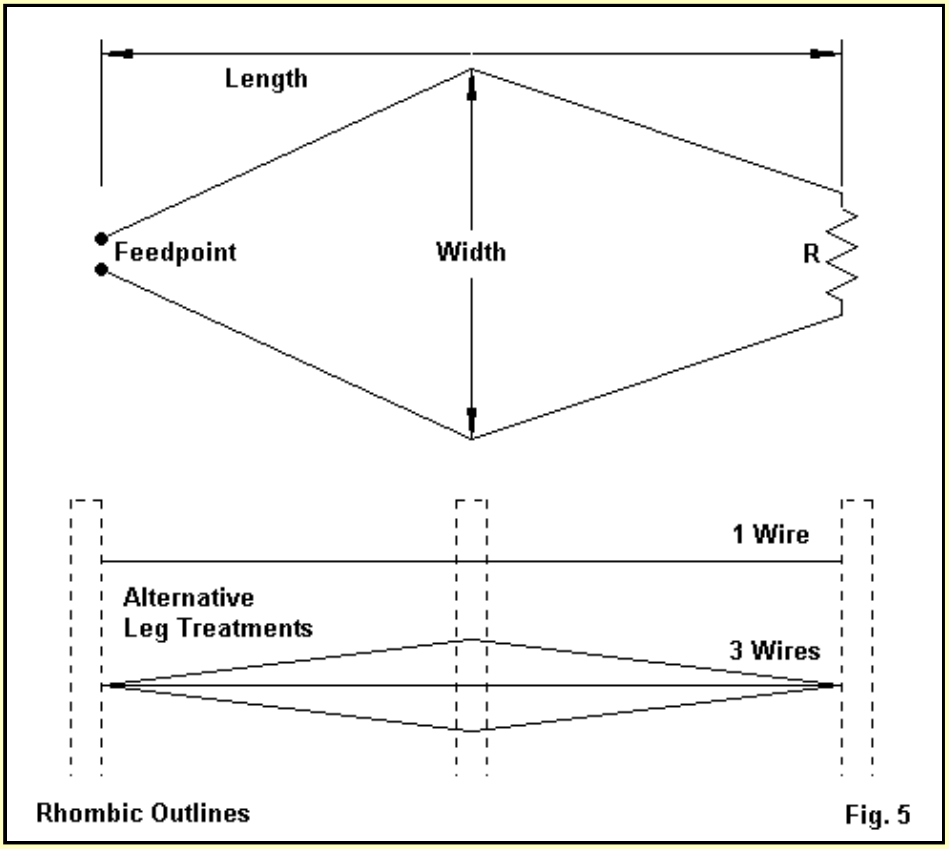
The unterminated Vee-beam is also a useful antenna. It does not require that we obtain suitable terminating resistors (400 Ohms each in the sample antenna). Therefore, only land, wire, and supports stand between us and an array of Vee-beams that can cover the horizon. **Fig. 4** shows the required number of Vee-beam legs needed, if we use the 7-wavelength legs and a 30-degree apex angle between legs.



We need outer-end (and perhaps intermediate) wire supports for each leg. However, we need only a single inner-end support for all of the legs. By a suitable means of switching--either at the antenna or near the shack, to which we bring a circular array of feedline wires--we select the adjoining pair of legs that gives us radiation in the two directions that we want.

The Vee-beam has some limitations. It is essentially a 1-band antenna, although we can press it into service on other bands. However, as we move away from the design frequency, the legs change their length as measured in terms of a wavelength. That change moves the angle of the main lobe on each leg relative to the plane of the wire. Hence, on these distant frequencies, the lobes will not match to form as strong a main lobe. To sustain the higher gain and re-acquire the broadband characteristics, we need to use a different shape.

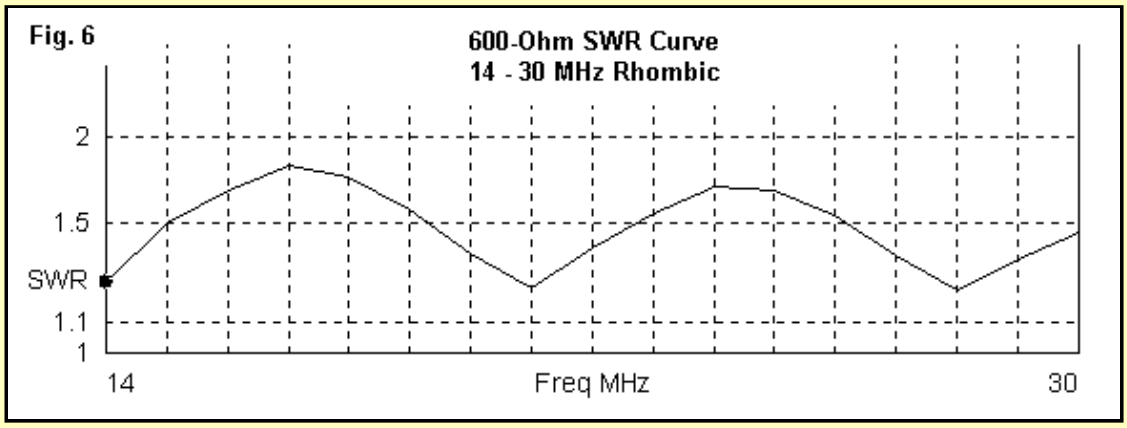
The Rhombic: The terminated Rhombic antenna employs two sets of Vee-beams joined at the outer ends so that the second one forms a distant apex angle at which we install a terminating resistor. **Fig. 5** shows the general outlines of a rhombic. Each leg has a pair of main lobes, and the combination of the 4 legs produces a very strong forward lobe.



The figure also shows in the lower half two ways of building a rhombic using either single-wire legs or tripple-wire legs. Builders have reported improved performance with the three wires, although the 1-wire version is satisfactory for most amateur installations.

The rhombic is a venerable directional array for which design equations had been developed in the 1930s. The design equations take into account the elevation angle of radiation, as well as the proper combination of angles and leg lengths to produce a strong forward lobe and a good front-to-back ratio. Indeed, there are alternative equations for developing various compromise designs that combine antenna height, leg length, and angles in various ways. See John Kraus, *Antennas*, 2nd Ed., pp. 503-508, if you are truly interested in designing a rhombic that will fit your yard.

For many year, *The ARRL Antenna Book* has featured an interesting rhombic design suitable for use on the amateur bands from 20 through 10 meters. It employs a 600-Ohm terminating resistor and is a good match for a 600-Ohm transmission line. Hence, all matching can be done at the shack with a system of impedance-matching transformers or baluns or with an antenna tuner. **Fig. 6** provides a 600-Ohm SWR curve across the operating span to show the relatively good match between the terminating resistor and the feedpoint impedance.



The rhombic is 377.5' long and 184' wide, with a 52-degree angle at both the feedpoint and the termination end. Of course, we shall require longer wire, since each side of the array requires about

420' of wire. If we set the rhombic at 70' above average ground--1 wavelength at 20 meters--we can anticipate the following performance figures.

Sample Rhombic Modeled Performance

Freq. MHz	Length WL	Height WL	Gain dBi	TO Angle degrees	Front-Back Ratio dB	B/W degrees	Feed Z R+/-jX Ohms	600-Ohm SWR
14.2	5.5	1	16.2	14	17.1	17	810 + j 60	1.4
18.12	7	1.25	17.8	10	15.3	13	1010 - j200	1.8
21.2	8.1	1.5	18.4	9	19.2	11	830 + j 60	1.4
24.95	9.5	1.75	18.3	7	15.2	9	990 - j 80	1.7
28.3	11	2	17.2	6	20.2	7	900 + j 40	1.5

Note that the array is optimized for 15 meters, where it shows the highest gain. However, performance is high on all of the bands. However, the array is not without some important limitations.

First, the array is fixed in position. We cannot re-aim it easily, if at all. We may combine this restriction with the second limiting factor: the beamwidth of the rhombic is very narrow compared to most wire arrays. The horizontal beamwidth, as measured to the half-power or -3-dB point is narrower than almost any other array. **Fig. 7** provides a band-by-band view of the azimuth patterns of the array to provide a sense of how narrow the beamwidth really is.

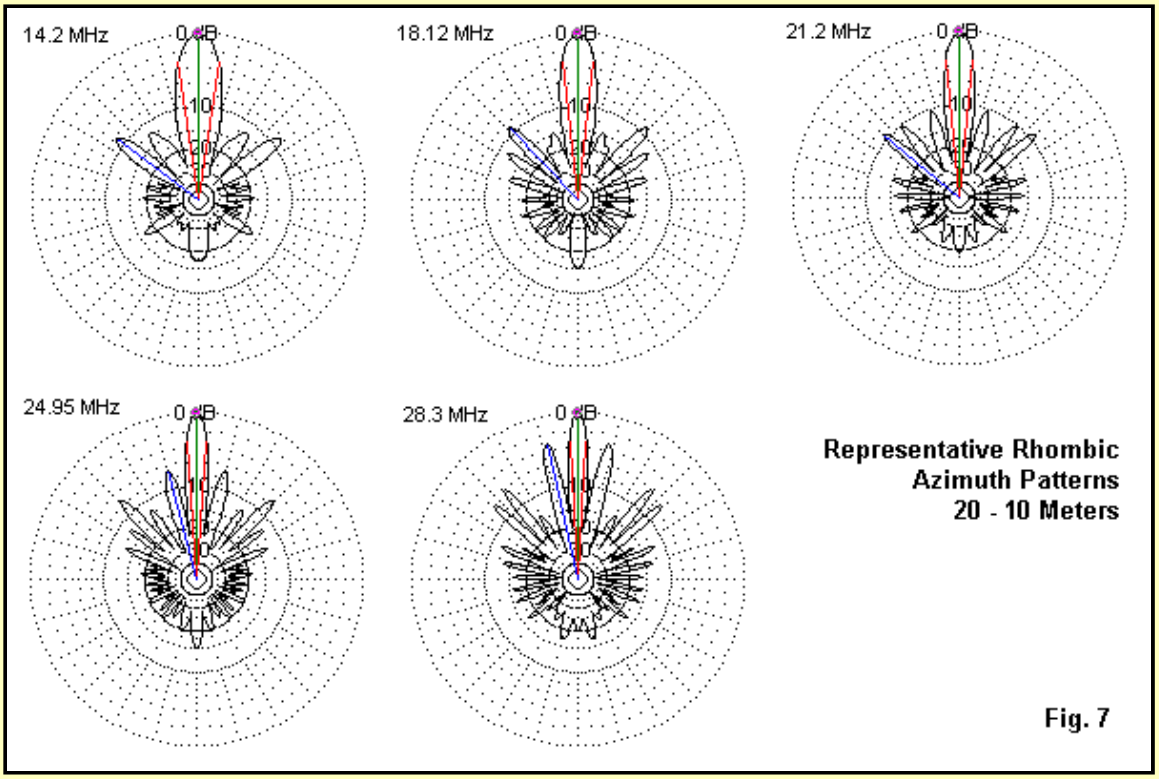


Fig. 7

The earliest uses of the rhombic involved point-to-point communications circuits and well-defined broadcast target areas. Contemporary use of the array should have some of these elements as part of the communications goals before deciding to erect a rhombic.

Rhombics have also seen use in the VHF range as outdoor television receiving antennas. More recent improvements in design techniques have produce double-loop versions that further suppress the side lobes that naturally occur with multi-wavelength element legs. Some amateurs have used these principles on bands as high as 1296 MHz.

The rhombic represents perhaps the pinnacle of refinement of large wire arrays. More recent developments in steerable arrays have largely supplanted the rhombic. However, the design still has adherents and users. It is likely to survive as an antenna option for generations to come.

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