# The Half-Rhombic Antenna

## *A Directive System for V.H.F.*

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**• At lower frequencies the half-rhombic antenna is impractical for amateur use because of the required height of the support. However, at v.h.f. it provides a relatively simple means of obtaining high directivity and gain with vertical polarization. This article gives complete design data for constructing an antenna of this type.**

The first practical form of a half-rhombic antenna was the tilt wire or inverted V-type antenna shown in Fig. 1. Gains comparable to a rhombic of the same dimensions are sometimes obtained, but because of variations in ground resistance with changing weather conditions a low-resistance ground generally is not realized. This, of course, detracts noticeably from the gain of the antenna. Consequently the use of this type of antenna has been discouraged unless the ground resistance for a particular locality is extremely low. Many experiments have been conducted using large ground screens under the antenna, and extending a half-wavelength or so beyond the wire in all directions. This provides a low-resistance ground, but the construction entailed is usually impractical. To alleviate this difficulty, the basic design was modified and a solid conductor or counterpoise was stretched under the antenna as shown in Fig. 2. This provides a good electrical ground of low resistance. A counterpoise in combination with an inverted-V-type antenna is called a half-rhombic antenna.

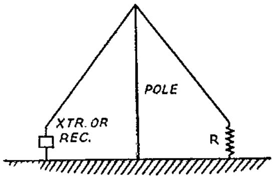

*Fig. 1* — **The tilted-wire or inverted-Vee antenna.**

The triangle of Fig. 3 represents an antenna of the half-rhombic type. The triangular dimensions are mathematically related to the operating frequency and physical height of the antenna support. The height of this support varies inversely with frequency; that is, the lower the operating frequency used, the higher the antenna pole or support must be, while, on the other hand, the higher the frequency, the lower the pole. At frequencies above about 30 megacycles, the required height of the support or antenna pole becomes a practically attainable value so that small poles, masts or trees may be used.

Also, a direct relationship exists between the required length of each leg of the antenna, the height of the upper angle (apex angle) above ground, and the length of the counterpoise. The dotted line represents the height of the triangle. The wire length in wavelengths as indicated on the left leg of the triangle is a measure which may be used for the design of any given half-rhombic. How to convert it to feet will be given later in this article. The tilt angle is of great importance in the design, and must be correct for maximum antenna gain. The counterpoise length is determined by the leg length and the tilt angle.

### *Pointers on Choosing Size*

At any given frequency there are several half-rhombic sizes which may be used. They vary from a minimum at which the beam will work to a size limited only by the height of the antenna pole, the weight of the wire the pole will support, and the amount of wire available. The larger the size for a given frequency, the sharper will be the beam produced, and the greater the gain realized within the beam.

In practice various half-rhombic sizes are identified by referring to the number of full electrical wavelengths in one leg of the antenna at the frequency at which the antenna is being operated. The following formula may be used to convert full wavelengths to feet:

$$\text{Length of } \lambda = \frac{984}{f_{Mc.}} \text{ ft.}$$

Generally the smallest size at which a half-rhombic will perform satisfactorily is one having a single full wavelength on a leg, or side, at the average frequency at which it is to be operated.

Fig. 4 shows a half-rhombic antenna design chart. From this chart the triangular dimensions of any half-rhombic antenna may be quickly determined. The tilt angle is plotted against the wire length for one leg measured in wavelengths. For example, let us determine the dimensions of a half-rhombic antenna having 2 wavelengths per leg for 41 Mc.

$$\text{Length} = \frac{984}{41} = 24 \text{ ft. per } \lambda$$

Each leg of the antenna would then measure

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24 × 2 (for two wavelengths) or 48 feet. From Fig. 4 the tilt angle, $\phi$, for an antenna with two wavelengths per leg is shown as approximately 49 degrees. Since the tilt angle is exactly half the apex angle, the angle formed by the two legs will be 98 degrees. The correct counterpoise length will be that required to complete the base side of the triangle of Fig. 3.

### *Determining Counterpoise Length and Pole Height*

To avoid trigonometric functions, the following Table I keys all dimensions of the antenna triangle to the length of a side. Note that each dimension is expressed in wavelengths at the desired frequency. This is readily converted to linear feet by the formula given previously. Using this method, any size half-rhombic antenna may be designed for any frequency by no more than multiplication.

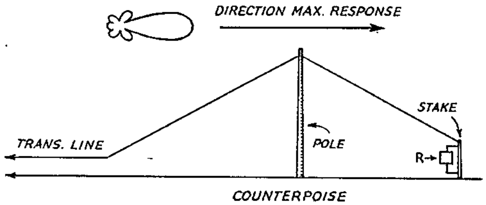


***Fig. 2* — The inverted-rhombic antenna with counterpoise. Directivity is in the direction of the terminated end.**

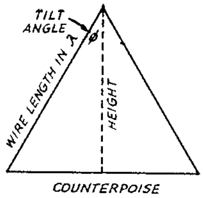
For example, the half-rhombic antenna using 2 wavelengths on a side at 41 Mc. was found to require 48 feet on a leg. Glancing at Table I, it can be seen that an antenna with two wavelengths on a leg has a tilt angle of 49 degrees, the pole height required is 1.3 wavelengths, and the overall counterpoise length 3 wavelengths. Since the length of a wavelength at 41 megacycles is 24 feet, the height of the pole required will be 24 × 1.3 = 31.2 feet, and the counterpoise length 24 × 3 = 72 feet.

Where the size of the antenna will be governed wholly by the height of the supporting pole, tree or mast, quick calculations can be made using the tabular column showing the required pole height so the maximum size antenna (thus the greatest gain) may be designed for the available mast height. For example, a 70-foot tree which appears to offer an excellent half-rhombic antenna support may be available. If the mean operating frequency to be used is 36.4 megacycles, dividing 984 by 36.4 shows a full wavelength to be approximately 27 feet at that frequency. Table I indicates that an antenna having two wavelengths on a leg requires a mast or pole height of 1.3 wavelengths, or 35.1 feet. Since the tree is taller than 35.1 feet, a larger antenna is possible. Therefore the table is re-examined for an antenna having six wavelengths on a leg which, the table indicates, requires a pole height of 2.3 wavelengths or 62.1 feet. Simple multiplication then shows that the antenna will have 162 feet on each leg and 297 feet for its counterpoise. The beam produced by this antenna may be pointed in any direction simply by rotating the antenna around the tree.

**Table I — Half-Rhombic Design Data**

| *λ per leg* | *Tilt Angle ø°* | *Pole Height in λ* | *Counterpoise length in λ* |
|---|---|---|---|
| 1 | 30 | 0.87 | 1 |
| 2 | 49 | 1.3 | 3 |
| 3 | 57 | 1.6 | 5 |
| 4 | 62 | 1.9 | 7 |
| 5 | 65 | 2.1 | 9 |
| 6 | 67 | 2.3 | 11 |
| 7 | 68 | 2.6 | 13 |
| 8 | 70 | 2.7 | 15 |
| 9 | 70.5 | 3.0 | 17 |
| 10 | 71 | 3.3 | 19 |
| 11 | 72 | 3.4 | 21 |
| 12 | 73 | 3.5 | 23 |

***Fig. 3* — Antenna triangle representing the half-rhombic antenna with the important factors labeled.**



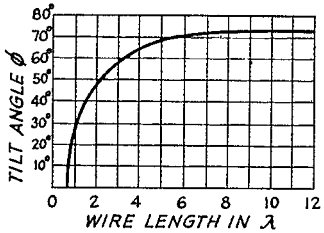


***Fig. 4* — Chart showing the tilt angle, ø, for various leg lengths in wavelengths.**

### *Terminating Resistors*

The terminating resistor plays a dual function in the operation of a half-rhombic antenna. Upon it depends the unidirectivity of the antenna and the absence of any resonant effect. When a half-rhombic antenna is properly terminated it will offer a constant input impedance. This allows it to be operated over a wide band of frequencies without the necessity for readjusting the coupling at the transmitter.

This resistor should be a non-inductive type and it may have a resistance between 400 and 700 ohms without adversely affecting its terminating properties. It must be rated to handle approximately one-half the transmitter input power to the antenna. When using a half-rhombic for reception only, the resistor power rating is not important. The terminating resistor should be mechanically suitable for outdoor installation. Common practice dictates that it should be placed in a weatherproof box for protection from the elements.

It should be noted that the terminating resistor affects neither the strength of the signal nor the field distribution in the forward direction. Its primary function is to decrease the radiation and reception from the back or reverse direction when it is connected. This power is wasted only in the sense that it is not radiated in the reverse direction, because it would not be radiated in the forward direction with or without a terminating resistor. In other words, the terminating resistor is the factor responsible for making a half-rhombic a unidirectional antenna. In cases where interference is negligible it is possible to remove or short out the terminating resistor and make the antenna bi-directional. Fig. 5 illustrates the principle of the terminating resistor.

### *Transmission Line*

The characteristic impedance of a half-rhombic looking into the sending or input end when properly terminated in a resistance at the far end is of the order of 400 to 500 ohms. The resonance curve of a half-rhombic antenna is quite broad. If the broad frequency characteristic is to be properly utilized, the feeder system used with it must also be broad. The transmission-line impedance should equal the characteristic impedance of the antenna which is 400 to 500 ohms. The proper spacing for a transmission line of this impedance is rather awkward because of the mechanical difficulties involved in construction. Table II shows wire size and spacing for 400-, 500- and 600-ohm lines.

**Table II — Transmission-Line Dimensions for Two-Wire Lines**

| *Wire Size* | *Spacing in Inches* | | |
|---|---|---|---|
| | *400 ohms* | *500 ohms* | *600 ohms* |
| 6 | 2¼ | 5⅛ | 11⅞ |
| 8 | | 4⅛ | 9⅜ |
| 10 | | 3¼ | 7⅜ |
| 12 | | 2½ | 6 |

Standard matching stubs can be used to provide an impedance transformation to a more desirable line impedance. Of course this limits the frequency characteristic of the line to that for which the stub is adjusted. If the standard 600-ohm line is used, the small mismatch encountered should not adversely effect the over-all efficiency of the antenna, because the standing-wave ratio is quite low. The primary disadvantage of mismatching any transmission line is the necessity for readjusting the transmitter coupling to the line at certain frequencies to maintain a constant input.

### *Selecting a V.H.F. Site*

Maximum effective range and signal strength are obtained at v.h.f. when two sites are selected between which there is an unobstructed transmission path. At these frequencies radio waves tend to travel in straight lines, thus line-of-sight transmission paths are of major importance because the signal strength attenuates rapidly over paths which have obstructions between the transmitter and receiver. Although the radio waves bend slightly around these obstructions, reliable communication generally is obtained only over line-of-sight paths. This condition is obtained when the transmitter antenna is theoretically within optical range of the receiver antenna.

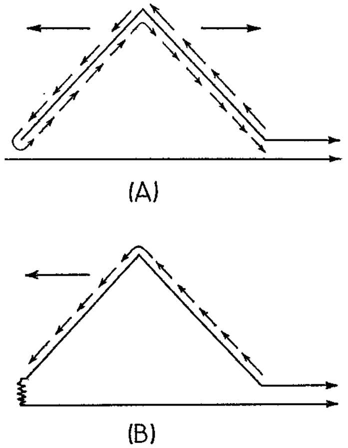


*Fig. 5* — Sketch showing the current path and directivity of (A) an unterminated half-rhombic and (B) one which is terminated.

The curvature of the earth limits the distance over which a line-of-sight path is possible. For example, with both transmitting and receiving antennas located 40 feet above sea level, the maximum distance which can be spanned before the line-of-sight is intercepted by the curvature of the earth is approximately 18 miles. This assumes the altitude of the intervening terrain also to be at sea level. To determine the maximum distance between two radio stations with intervening terrain at sea level, the following formula is used:

$D = H_T + H_R$,
where $D$ = distance in miles,
$H_T$ = height in feet of transmitting antenna,
$H_R$ = height in feet of receiving antenna.

Another factor detrimental to line-of-sight transmission is intervening hills. Intervening hills in a transmission path will reduce the signal strength when they obstruct the line of sight. Radio waves bend over these obstructions slightly, but bending is accompanied by a loss in signal strength; the greater the bending, the greater the loss. Certain combinations of communication sites and intervening hills may provide satisfactory signals because of reflections, but this condition is realized only by luck, or by calculation with detailed terrain maps.

As a general procedure, the distance between two stations should be calculated on the basis of a path with no obstacles intervening. Then, within the limit of this distance, the two stations should be sited with a view to obtaining the smallest angle of diffraction over any intervening obstacle. When the sites have been determined, and the equipment set up, a test receiving antenna should be moved to different positions, usually within a radius of a hundred feet or so, until the strongest signal is received. This indicates that a point has been found where the dominant multipath rays are nearest in phase. This point will provide the greatest signal strength and maximum operating efficiency.

If it becomes necessary to operate in an area which is densely wooded, the best location for a site is in a clearing with a radius in the order of ten or twelve wavelengths. When using a half-rhombic antenna it should be placed as close as possible to a point in the clearing farthest from the transmitter or receiving building, and as equidistant as possible from the sides of the clearing. A knowledge of the field pattern of a given half-rhombic is helpful in determining the proper placement.

If a half-rhombic antenna is installed in keeping with the pointers listed above, it is one of the most effective types of beam antennas for the transmission and reception of high-frequency, vertically-polarized signals. The use of this type of antenna will increase the signal strength many times over and above that provided by a simple vertical half-wave dipole at the same average height above ground. Gains as high as 15 db. can be obtained.

### *Beam Width*

The widths of the beams produced by half-rhombic antennas of various sizes are shown in Fig. 6. They represent an average over varying terrain and soil conditions. They are drawn to half power; in other words, signals sent at any angle within the spread indicated will be more than half the beam's maximum power.

Fig. 7 illustrates the directions of the main lobes for each wire for legs two wavelengths long when the tilt angle, $\phi$, is adjusted for alignment of the lobes.

Several tests using a modified or compromise half-rhombic antenna were conducted with a transceiver rated at 2-watts output, operating in a frequency band of 27 to 38.9 megacycles. This antenna had approximately 46 ft. in each leg, the pole height was 24 ft., the counterpoise 88 ft. and the tilt angle approximately 30 degrees.

The primary reason for conducting these tests was to determine the effects of decreasing the physical height of the antenna. It is possible to operate a compromise half-rhombic antenna and achieve fairly suitable results.

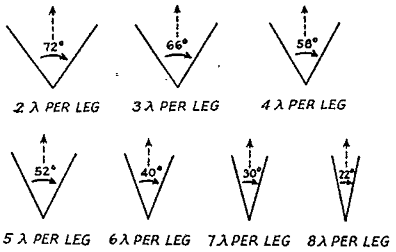


*Fig. 6*—Approximate beam widths to the half-power point for half-rhombic antenna of various sizes.

Field-intensity measurements were taken at approximately every 30 degrees; these measurements showed that the beam width of the pattern exceeded 40 degrees in all cases. If successful point-to-point communication is to be maintained relatively free from adjacent sideband and "brute-force" interference within range, the beam width of the antenna must be corrected to within 20 degrees of the operating direction. Under some conditions it is feasible to have a beam width as great as 90 degrees.

It follows that maximum antenna gain will not be realized in a compromise antenna but, on the other hand, the modified half-rhombic continues to retain the ability to accept power on any frequency for which the legs will be resonant and radiate this power in a fairly predictable pattern. It is better to compromise on the height of a half-rhombic rather than the length of its legs. Height has a much smaller effect upon the gain of a half-rhombic antenna than length. Thus, in the design of a modified or compromise half-rhombic antenna the length of each leg should be at least two wavelengths at the lowest operating frequency.

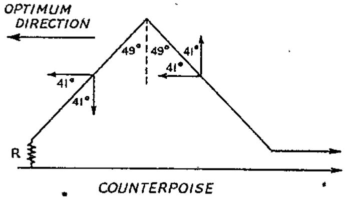


*Fig. 7*—Sketch showing the angles of radiation from each leg of the half-rhombic which combine to give the resultant pattern.

The gain realized with a compromise design is in the vicinity of 10 db.