Set up a versatile sloping-vee antenna for your shortwave receiver of ham rig to improve your transmission and reception at low cost.

SLOPING V ANTENNA

RICHARD A. FORMATO

THE SLOPING-VEE ANTENNA IS ONE of the most versatile broadband antenna designs available to amateur radio enthusiasts and shortwave listeners. It is structurally simple, inexpensive, easy-to-build, and easy to set up in the field if you want to take your rig with you on vacation. The sloping vee can achieve moderate and occasionally even high gain over a frequency span of 5 to 1, 10 to 1, or more. The antenna is functional over the high-frequency (HF) into ultra-high- frequency (UHF)-range from about 3 MHz to about 800 MHz.

The most common configuration for the sloping-vee antenna is shown in Fig. 1. It consists of two sloping, radiating elements (wires) fed by a radio-frequency source at their vertex. The source is located at a height H above the ground, and the elements are terminated by two equal resistors, R, located at or near the Earth's surface. Technically it is an *inverted-vee* sloping antenna.

The *true* sloping-vee antenna has a vertex height, H, that is actually less than the height of its terminations. The radiating elements slope up from the ground, not down as shown in Fig. 1, making this configuration more difficult and expensive to build because two masts are required. However, both forms are called sloping vee's because they resemble a tilted letter "V."

This article presents a systematic design procedure that takes into account the unique characteristics of this antenna. A typical design for an HF/VHF 10- to 60-MHz sloping-vee antenna is discussed in detail, and measured performance data for the actual antenna is given. A frequently overlooked feature of the sloping-vee antenna at HF and a major advantage is that it combines the features of horizontal and vertical antennas, which results in virtual polarization diversity.

In a careful design, the characteristics of the communication links to be supported by the antenna must be considered. For example, the take-off angles at which the antenna must have adequate gain are determined by the transmitter-to-receiver distance and by the virtual ionospheric reflection height.

Another design constraint is the antenna's required bandwidth which is determined by the operating frequencies. For some amateur radio operators, only the HF band (3 to 30 MHz) is of concern; others want to cover the upper HF range and the 6-meter (50 kHz) band as well. High-gain antennas such as Yagis exhibit a bandwidth of a few percent of the center frequency. A well designed sloping vee, by contrast, will cover the entire HF spectrum and even exceed it.

Antenna siting is another important consideration in the design of a sloping vee. From HF well into the VHF range, the Earth's electrical characteristics (ground conductivity and dielectric constant) have a dramatic effect on antenna performance. Ground effects are especially important at low take-off angles (close to the horizon).

Shallow take-off angles are necessary for long-range transmission. For very long distances, the take-off angle could

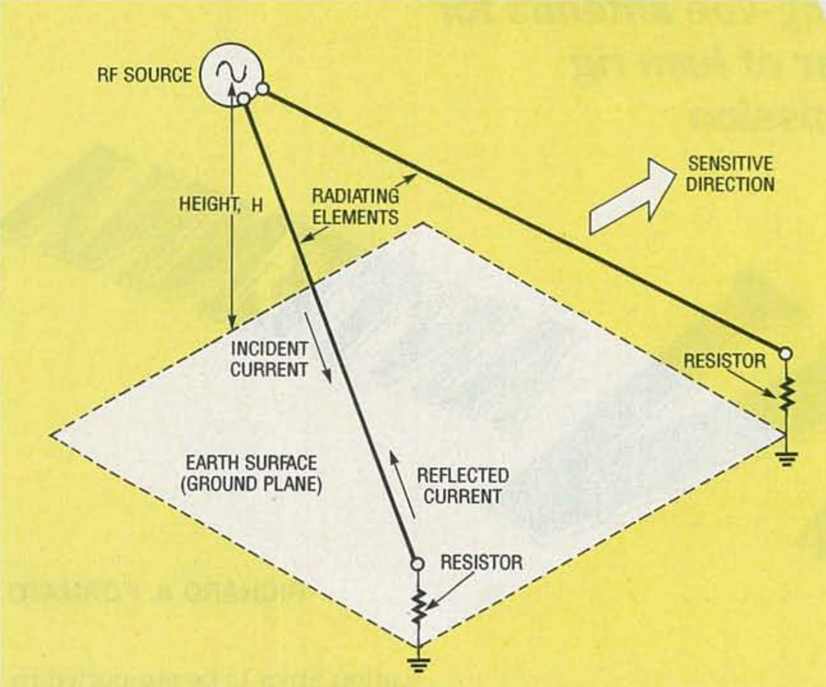


FIG. 1—A SLOPING-VEE ANTENNA is simple, inexpensive to build and erect, and provides excellent broadband performance from HF well into VHF.

be so low that mountains or other terrain features block signal transmission. Those obstructions limit the minimum take-off angle which, in turn, limits the range.

Sloping-vee operation

As shown in Fig. 1, the RF source excites current waves on the vee's radiating elements. The total current consists of two components: an incident wave propagating from the source toward the end of the element, and a reflected wave propagating from the terminating resistor back toward the source. In an ideal vee, the reflected component is zero because the terminating resistor absorbs any incident energy that would otherwise be reflected. In practice, there is a only a slight reflected component. The incident and reflected waves combine point-by-point along the element length to form a weak standing-wave pattern. An unterminated antenna, such as a center-fed, half-wave dipole, propagates a reflected wave with a large amplitude that creates a strong standing-wave pattern.

The half-wave dipole is a resonant, narrow band, standing-wave antenna. By contrast, a properly designed vee is a nonresonant, broadband, traveling-wave antenna. Broadband operation is obtained from the vee antenna by eliminating as much of the reflected current wave as possible. The terminating resistors are capable of absorbing most of the incident energy that is not radiated from the elements. If the terminating resistor is conjugate-matched to the characteristic impedance of the radiating element, there is no reflected signal because all of the power is absorbed.

This situation is the same as the maximum power transfer condition for a transmission line feeding a load. The load absorbs maximum power when its internal impedance is equal to the complex conjugate of the transmission line's characteristic impedance Z_0. Because Z_0 for well-designed transmission lines is nearly a pure resistance, the matched load is a resistance of equal value. The most common coaxial cable impedance is 50 ohms, and the corresponding matched load is a resistive 50 ohms. The load could be a 50-ohm dummy (essentially a resistor), or it could be an antenna with an input impedance of $50 + j0$ ohms.

The frequencies at which the vee exhibits near traveling-wave behavior determine its useful bandwidth. The precise definition of *impedance bandwidth* is the range of frequencies at which antenna input voltage standing-wave ratio (VSWR) is less than or equal to some threshold value, typically 2 to 2.5:1 for transmitters and up to 5:1 for receivers. There are different thresholds because transmitter circuits cannot tolerate high VSWR without reducing output power or shutting down; by contrast, a receiver is not limited by VSWR.

For receive-only operation, increased antenna VSWR causes higher mismatch loss into the receiver front-end, which reduces the available signal level. There is a point at which the mismatch loss is so high that receiver sensitivity (minimum detectable signal) becomes unacceptable low. Figure 2 is a plot of mismatch loss as a function of VSWR with one end of the transmission line matched . At a VSWR of 5:1, receiver sensitivity is reduced by only 2.5 dB; but at 21:1, the reduction approaches 8 dB.

An objective for the design of a vee antenna is to maximize the range of frequencies in which VSWR is less than 2.5:1 for transmission and less than 5:1 for reception. An antenna meeting the transmission criterion between 3.5 and 30 MHz, for example, could be loaded directly on all bands from 80 to 10 meters without a tuner or matching network! The same antenna could receive over an even wider bandwidth.

Design procedure

The design of a good vee involves three steps. The first is to evaluate the kinds of communication links for which the antenna is intended. The designer must answer the following questions: What are the distances and operating frequencies involved, and what is the propagation mode? The second step calls for the selection of the vee's apex angle based upon the intended operating frequency and antenna size. The third

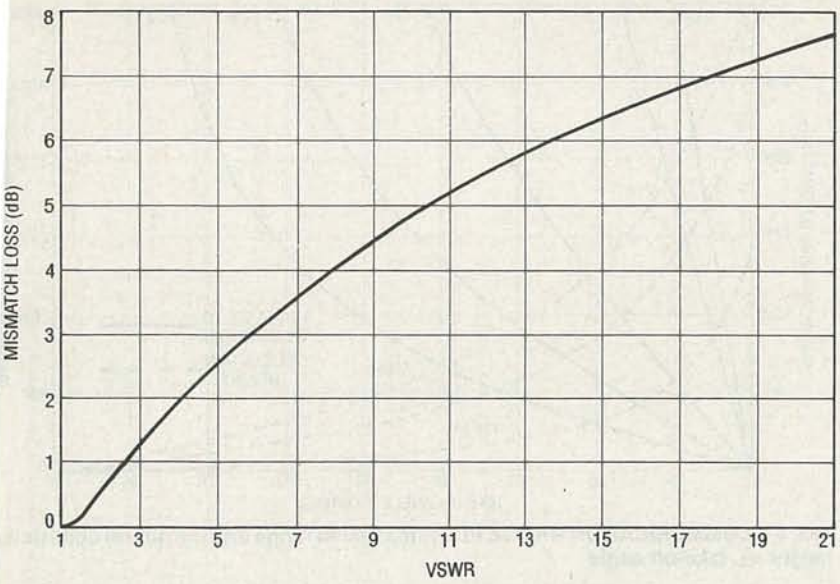


FIG. 2—PLOT OF MISMATCH LOSS in decibels vs. VSWR with one end of the transmission-line matched.

step is the computation of the antenna radiation patterns for the desired distances.

The assumed specifications for the design of a vee antenna are:

- Frequency range—15 to 50 MHz (continuous)
- Propagation mode—meteor trails at 100 kilometers
- Link distances—400 to 1200 kilometers (250 to 750 miles
- Antenna siting—limited to an area 100 × 100 feet and a height 25 feet
- Main lobe gain—0 dBi, minimum value

Step 1—Link evaluation

Three transmission-path factors influence vee design: distance between transmitter and receiver (determines antenna take-off angles); operating frequencies (determines required bandwidth); and propagation mode (determines take-off angles). Each of those factors must be known or estimated to design an antenna matched to the path.

Signals propagating between points on the Earth's surface are bent by the ionosphere or other scattering mechanism such as a meteor reflection. The most common (but not the only) propagation mode at HF is the skywave. The transmitted signal is bent back toward the Earth's surface by the ionosphere's changing refractive index. This process is equivalent to a specular reflection from a virtual reflection point. The simplest model of HF skywave propagation is a straight-line signal ray from the transmitter to a location near the reflection point where it is bent back as another straight line ray from the reflection point to the receiver as shown in Fig. 3.

The attainable distance in a communication path depends, in part, on the reflection height, with higher reflections providing greater distances. HF skywave propagation is caused by reflections from the ionosphere's layers: D layer (about 50 kilometers high), E layer (about 120 kilometer high) and F layer (200 to 500 kilometers high). Meteor-trail reflections are of growing interest because of the increased availability of high-speed packet data equipment. Those reflections occur at altitudes of about 100 kilometers.

The path geometry (reflection height and transmitter-to-re-

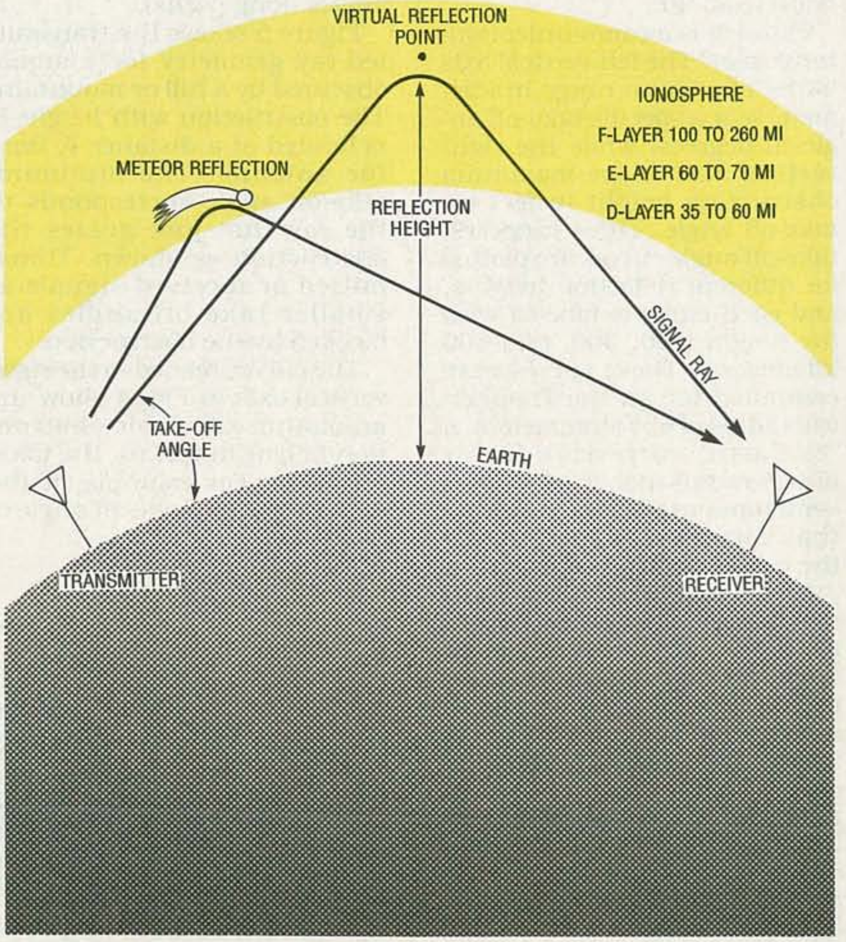


FIG. 3—DIAGRAM SHOWING RELATIONS between take-off angle, virtual reflection point, and signal range.

veiver distance) determines the range of required take-off angles for the antenna. Signal rays transmitted at too high an angle fall short of the receiver, while those transmitted at too shallow an angle can overshoot the receiver.

Figure 3 shows two important angles in vee design. The take-off (or elevation) angle is measured upward from the earth's surface to the ray direction. The polar (or zenith) angle is measured down from the vertical to the ray direction. Both angles are important because path requirements are usually described in terms of the take-off angle, but antenna performance is usually referred to a coordinate system based on the polar angle. The sum of the polar angle and the take-off angle is 90°, so the polar angle can always be determined by subtracting the take-off angle from 90° and the take off-angle can be found by subtracting the polar angle from 90°.

Figure 4 is a communication-range plot. The left vertical axis is the maximum range in kilometers for a specific take-off angle in degrees, while the right vertical axis is the maximum obstruction height in feet vs. take-off angle. Three range vs. take-off angle curves are plotted for different reflection heights, and each curve is labeled with the height (100, 300, and 500 kilometers). These curves were computed for an Earth spherical radius of 6371 kilometers. A "4/3-Earth" correction factor (Earth radius increased by 1/3) is sometimes used at HF. Applying that correction would modify the curves shown somewhat.

Either the maximum path distance for a given take-off angle or the appropriate take-off angle for a specified distance can be determined from Fig. 5. At a take-off angle of 20°, for example, the maximum range is about 2100 kilometers (1300 miles) for 500-kilometer reflections in the F2 region. The range increases to 4000 kilometers (2500 miles) at about a 5° take-off angle.

If the path length were 3200 kilometers, the appropriate take-off angle for 500-kilometer reflections is about 10°, and it's about 3° for 300-kilometer reflections. Also plotted in Fig. 5 is a family of five obstruction height curves. They are important in antenna siting, especially for very shallow take-off angles (long paths).

Figure 5 shows the transmitted-ray geometry for a signal obscured by a hill or mountain. The obstruction with height H is located at a distance R from the antenna. The minimum take-off angle corresponds to the ray that just grazes the obstruction as shown. Transmitted or received signals at smaller take-off angles are blocked by the obstruction.

The curves related to the right vertical axis in Fig. 4 show the maximum allowable obstruction height in feet vs. the take-off angle. For example, if the path requires a take-off angle of 20°, a land-mass or structural obstruction 1/4 mile away must be less than 500 feet high if the ray is to pass without being blocked. A 500-foot hill 1/4 mile away would obscure all signals with take-off angles below 20°. Higher obstructions can be tolerated if they are further away. At a distance of 1/2 mile, for example, the obstruction could be as high as 1000 feet before obscuring a ray with a 20° take-off angle.

The curves in Fig. 4 also show maximum range in kilometers vs. take-off angles in degrees for the vee. For 100-kilometer reflections, the most effective angles are between about 8° and 25°. The objective in designing a vee antenna is the placement of this lobe in this angular range. The the 8° minimum take-off angle requires that the antenna be carefully sited to avoid lobe blockage by a nearby

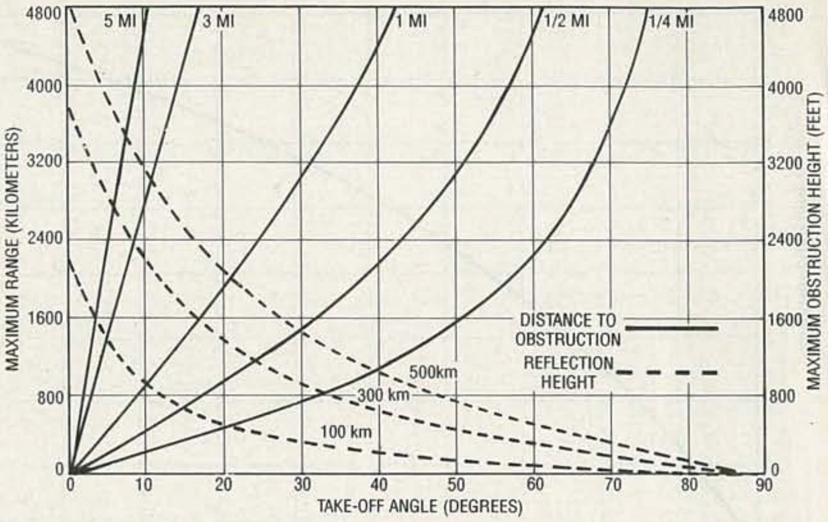


FIG. 4—COMMUNICATION RANGE PLOT: maximum range and maximum obstruction height vs. take-off angle

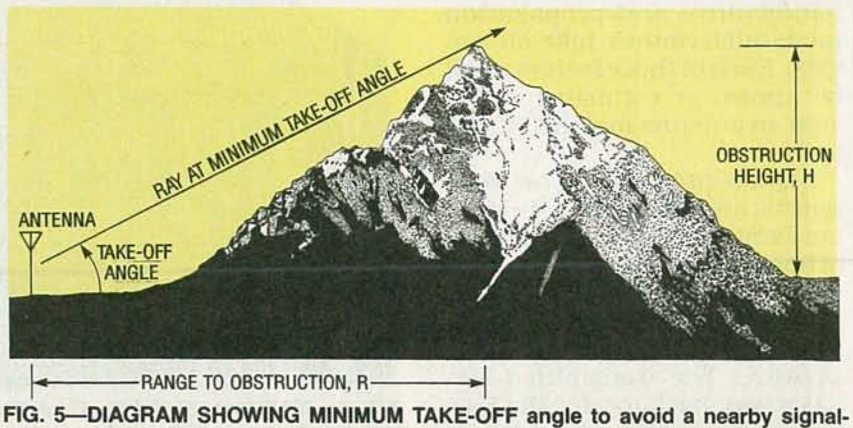


FIG. 5—DIAGRAM SHOWING MINIMUM TAKE-OFF angle to avoid a nearby signal-blocking obstruction.

ill or structure. The maximum eight of that obstruction can e only about 200 feet if the anenna is to be located ¼ mile way. This requirement might asily be exceeded in hilly terain or near tall buildings.

itep 2—The apex angle

Figures 6 and 7 plot the opimum vee apex angle in degrees is it changes with frequency ind antenna element (radiator) ength. The apex angle is inversely related to both frequency and element length. Thus, short elements at low frequencies must have wide apex angles while long elements at high frequencis can have small angles. The curves in Fig. 6 are for frequencies of 10, 30, and 50 MHz with respect to element lengths in meters, while those in Fig. 7 are for element lengths of 20, 40 and 60 meters with respect to frequency. Our example vee must operate over a wide frequency range (15 to 50 MHz).

It turns out that a given apex angle is optimum at only one frequency, not over a range of frequencies. Therefore, the selection of an *optimum* apex angle calls for both judgment and compromise. The objective is to select an angle that provides good performance at all frequencies over the stated range.

The design example calls for a vee antenna that will fit in a 100 × 100 foot square plot. Therefore, 40- or 60-meter elements are too long; only the 20-meter length will fit. By referring to both Figs. 6 and 7, it can be seen that for a 20-meter element the optimum apex angle at 10 MHz is 116°, but at 50 MHz it is 54°. It can also be seen that a good compromise for apex angle with a 20-meter element over the 15- to 50-MHz band can be reached by finding the apex angle for 30 MHz—69°. That angle will now become the trial value, and it will be retained unless the gain or pattern fails to meet the design objectives. In that case, the selection process must be repeated with another choice for the apex angle.

Now look at the vee input resistance at the design apex angle. Figure 8 is a plot of input resistance in ohms (R_{in}) vs. frequency for apex angles of 40°, 70°, and 100°. The input resistance value for a 70° apex angle at 30 MHz is about 690 ohms. (The vee is generally considered to be a 600-ohm antenna, so this is close to a match). The value of input resistance increases to 780 ohms at 15 MHz but drops to 630 ohms at 50 MHz. For design purposes, 690 ohms can be selected as a representative average value of R_{in} over the 15- to 50-MHz band.

The value of R_{in} is needed to specify the vee input balun. Because the vee is a balanced radiating system, feeding it with an unbalanced coaxial cable requires a balun (a *bal*anced to *un*balanced transformer). Matching a 50-ohm transmitter to 690 ohms requires a 14:1 balun, which can be made by winding magnet wire on a ferrite core or purchasing the component complete.

A value for R_{in} is also needed in the specification of each terminating resistor. Those values are $R_{in}/2$ (345 ohms for the design example). Select the standard value closest to 345 ohms. That value is not critical because R_{in} changes with frequency.

The tentative geometry for the

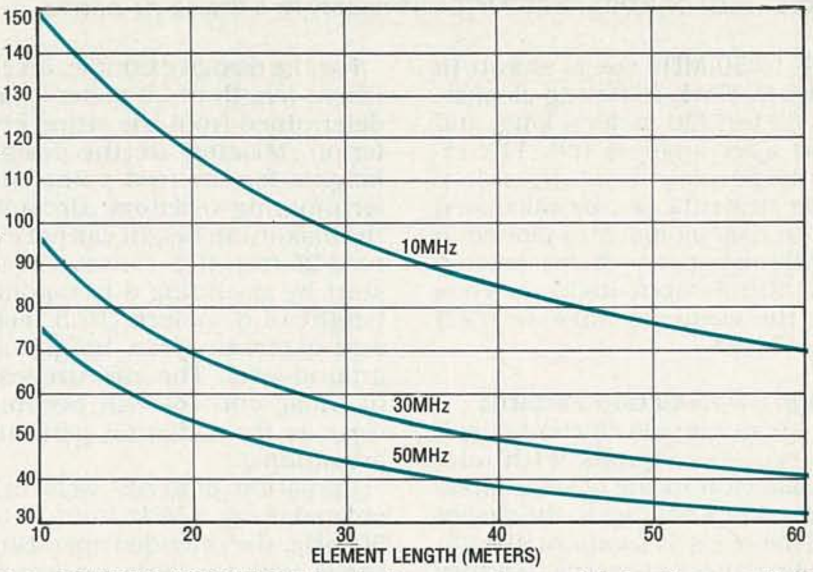


FIG. 6—OPTIMUM APEX ANGLE for sloping-vee antenna: plot of optimum angle vs. element length at three different frequencies.

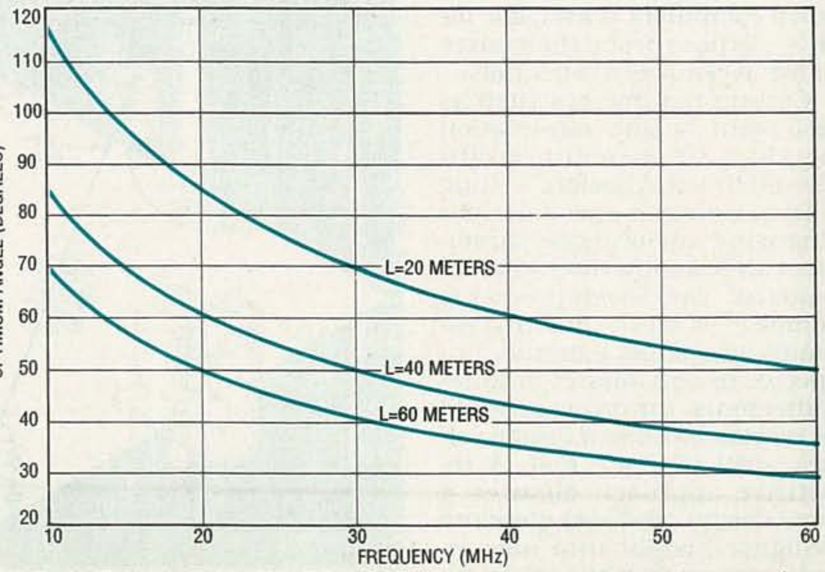


FIG. 7—OPTIMUM APEX ANGLE for sloping-vee antenna: plot of optimum angle vs. frequency for three different element lengths.

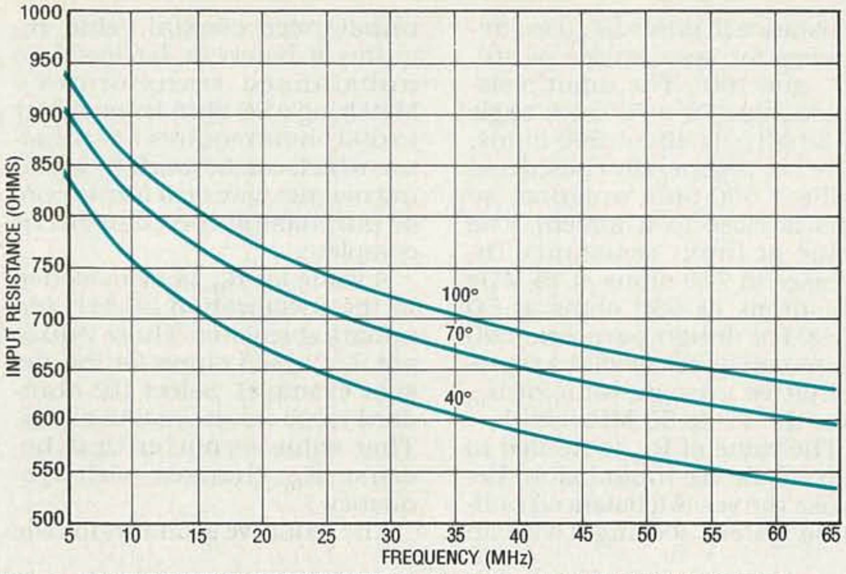


FIG. 8—PLOT OF INPUT RESISTANCE vs. frequency for a sloping-vee antenna.

15- to 50-MHz vee is shown in Fig. 9. Each radiating element is 62 feet (20 meters) long, and the apex angle is 69°. The required separation at the ends of the elements can be calculated with trigomometry or plotted to scale on paper with a protractor. For the 69°-apex angle, the ends of the elements must be 72.5 feet apart.

Step 3—Radiation Patterns

An antenna is efficient only if it radiates signals with adequate gain in the desired direction. The final step in the design of the vee is to compute its radiation patterns to verify that they meet the gain requirements. Software compatible with personal computers is available for this purpose from the source listed in Sources of Materials.

Certain parameters such as feed-point height, termination height, and element length should be varied before writing a final antenna specification. Changing any of those parameters will modify the radiation patterns. The design process is complete when the antenna radiates acceptable patterns. If a specific design doesn't meet requirements, the process should be repeated with new design values until they are met. A repetitive approach ensures a good design, and also gives the designer insight into how an antenna's performance changes with parameter differences.

For the design example, an element length of 20 meters was determined from the siting criterion. Missing are the design heights for the feed point and terminating resistors. Because the maximum height cannot exceed 25 feet, it is convenient to start by assuming a feed-point height of 6 meters (19.5 feet) and a termination height at ground level. The effectiveness of those choices will become clear as the radiation patterns are studied.

Radiation patterns were calculated every 5 MHz from 15 to 50 MHz, the intended operating range, with the tentative design values and element lengths of 20, 40 and 60 meters. Although only the 20-meter element meets the 100 × 100 foot site limit, it's instructive to see how the pattern changes with longer elements. Figures 11, 12, and 13 show the patterns at 15, 30, and 50 MHz. Those frequencies mark the endpoints and mid portion of the desired band. In all three figures the mast height is 6 meters, the apex angle is 69°, the diameter of the element is ⅛ inch and the termination is 689 ohms.

Results at intermediate frequencies are not included here. The patterns were computed with the sloping-vee antenna located on rocky ground with a conductivity of 0.001 siemens/meter and a dielectric constant of 4. The patterns change if different ground constants are assumed, so sensitivity to ground constants was also examined, although those results are not included here.

Figure 10 shows the pattern at 15 MHz. The left vertical axis is the antenna power gain in dBi (decibels relative to an isotropic radiator, an antenna that radiates in all directions). The horizontal axis is the polar angle in degrees. Note that the polar angle, not the take-off angle, is used on the horizontal scale. A polar angle of zero is a vertical with respect to the Earth

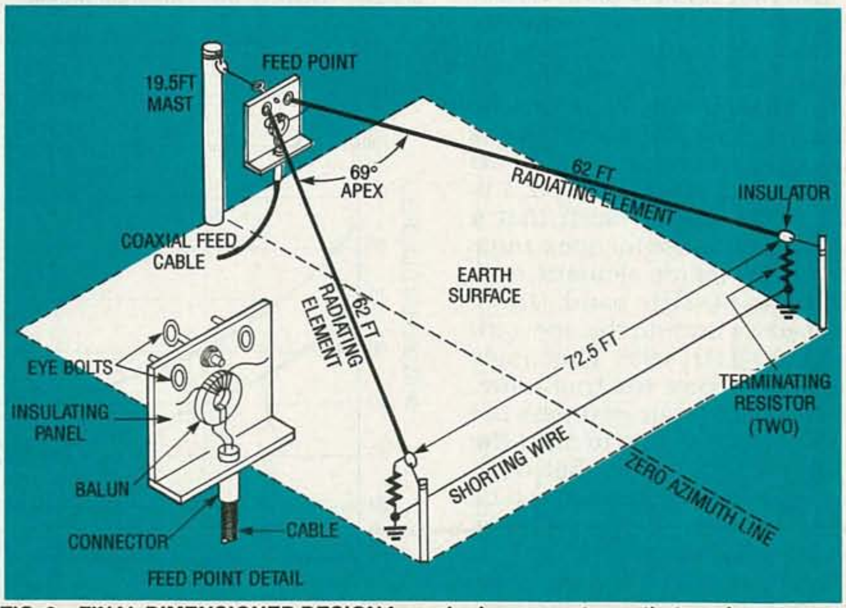
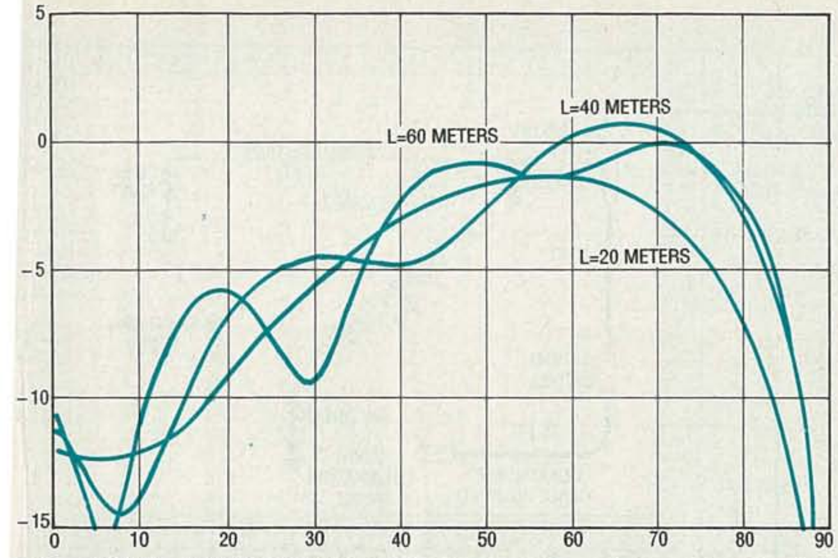


FIG. 9—FINAL DIMENSIONED DESIGN for a sloping-vee antenna that can be set up on a 100 × 100 foot plot.



G. 10—GAIN VS. POLAR ANGLE for a sloping-vee antenna above rocky ground at a equency of 15 MHz for various element lengths.

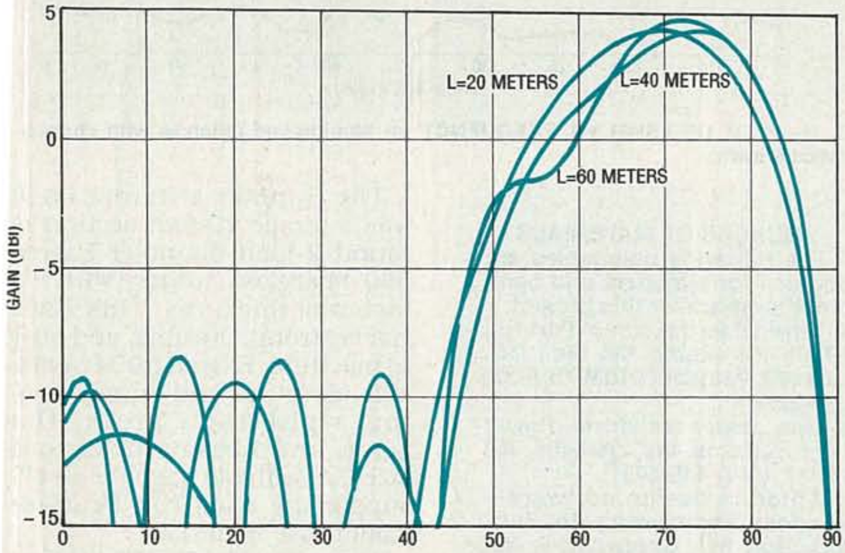


FIG. 11—GAIN VS. POLAR ANGLE for sloping-vee antenna above rocky ground at a frequency of 30 MHz for various element lengths.

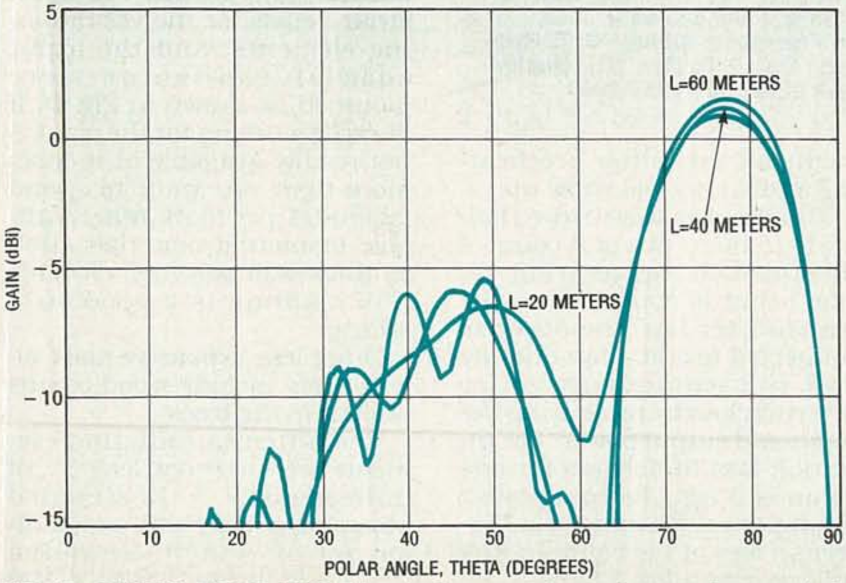


FIG. 12—GAIN VS. POLAR ANGLE for sloping-vee antenna above rocky ground at a frequency of 50 MHz for various element lengths.

(zenith), while 90° is parallel to the Earth's surface (horizon). Take-off angles of interest, 8° to 25°, correspond to polar angles of 82° to 65° in the figure. The design objective is to obtain at least 0 dBi gain in a main lobe propagating generally between polar angles of 65° to 82°.

The main lobe maximum gain at 15 MHz is -1.5 dBi at 57° for the 20-meter element. The lobe is broad, and the gain rolls off slowly on either side of the maximum. The -3 dB points are at about 32° and 74°. The highest gain, 1.5 dBi, is obtained with the 40-meter element in a broad main lobe that shows minor scalloping (sidelobing) near 40°. The pattern for the 60-meter element shows signs of breaking up —a significant secondary lobe is forming near 18°.

The 30-MHz pattern (Fig. 11) is interesting because all three elements produce a maximum gain of about 4 dBi, and their main lobe structures are very similar. The lobes are broad and smooth between 40° and 88° and the -3 dB points are near 55° and 82°. The 40- and 60-meter elements show considerable pattern scalloping between 0° and 40°, but the 20-meter element is electrically too short to develop a highly structured pattern.

Scalloping is due to constructive and destructive interference between direct rays from the antenna and rays reflected from the Earth's surface. Electrically long antennas (measured in wavelengths) are more susceptible to scalloping than shorter ones. Sidelobes waste energy by radiating it in undesired directions. Good antenna designs, therefore, minimize sidelobes as much as possible.

The 50-MHz vee pattern is shown in Fig. 12. The main lobe is again similar for the three element lengths. Maximum gain is about 6.5 dBi near 77° (13° take-off), and the -3 dB points are at approximately 70° and 83°. The main lobes are smooth and narrower than they are at the lower frequencies. The 20-meter element is beginning to show some scalloping. It has a peak sidelobe gain of -2 dBi at 50°).

However, the 40- and 60-meter antenna elements show more scalloping and even higher side-lobe gains.

An assessment of the patterns supports the conclusion that a vee antenna with 20-meter elements fed at a 6-meter height with a 69° apex and ground-level terminating resistors meets the objectives. Gain could be improved at the low end of the band with a longer radiating element, but that could violate the site limit.

The actual dimensions selected for the vee antenna are those of Fig. 9. A shorting wire connects the terminating resistors (which might or might not be connected to actual Earth ground). That wire, a current path between the resistors, is very important. In an ideal vee, the resistors are connected to a perfect ground plane that provides the current path. Omitting the shorting wire in a vee mounted on poorly conducting ground degrades performance significantly.

Antenna Construction and Measured VSWR

The antenna shown in Fig. 9 was built and tested on rocky ground in New England. It was fed through a 14:1 balun wound with 18 AWG magnet wire on a 2-inch outside diameter toroidal ferrite core. The turns ratio is the square root of the impedance ratio (in this case 3.75:1). The balun was wound with 2 turns in its primary and 7.5 turns in its secondary. If the sloping-vee is to transmit, the balun should be tested for power handling by operating at full power for several hours. Any problems that might develop such as transmitter overheating and arcing will show up.

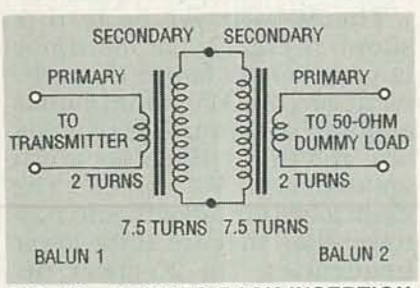


FIG. 13—BACK-TO-BACK INSERTION LOSS TEST of baluns for sloping-vee antenna.

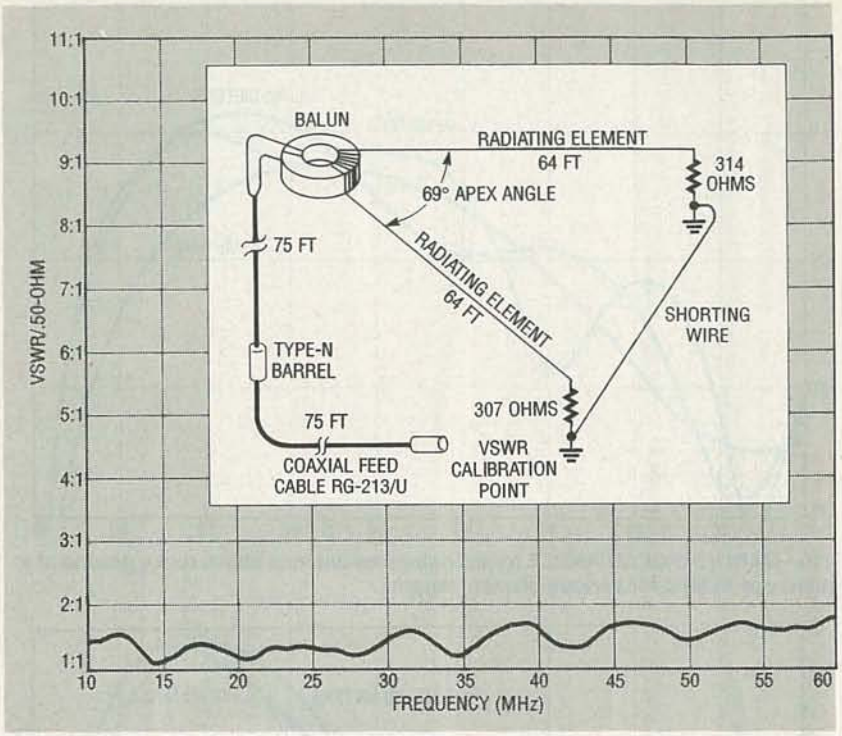


FIG. 14—PLOT OF VSWR VS. FREQUENCY for sloping-vee antenna with characteristics shown.

> **SOURCES OF MATERIALS**
>
> **The following companies are sources for materials and computer software for this project:**
>
> **• Toroidal ferrite cores (Part No. FT240-43)—Radio Kit, Inc., P.O. Box 973, Pelham, NH 03076, (603) 635-2235**
>
> **• Film power resistors—Power Film Systems, Inc., Yellville, AR 72687, (501) 449-4091**
>
> **• Antenna design software—Phadean Engineering Co., Inc., P.O. Box 611, Shrewsbury, MA 01545, (508) 869-6077**
>
> **• Phosphor-bronze wire—Astro Industries, Inc., Dayton, OH 43432, (800) 543-5810**
>
> **• Fiberglass tubing—J. T. Ryerson Co., P. O. Box 1111, Boston, MA 02103, (617) 782-6900**

The simplest way to test a balun is to build two and connect them back-to-back as in Fig. 13. One balun is connected to the transmitter and the other is connected to a 50-ohm dummy load. This setup can also test for insertion loss by measuring the input and output power. The insertion loss in decibels for one balun is 5 $\log_{10}$ (output power/input power). The measured insertion loss of the balun in this this vee was a low 1.5 dB.

The 6-meter antenna mast was a single 20-foot section of round 2-inch diameter Extren 500 fiberglass tubing with ¼-inch wall thickness. This material is strong, durable, and easy to machine. Extren 500 is available as round and square tubing, right-angle stock, flat stock, and I-beams in various sizes. A suitable base for a self-supporting mast can be made from those materials.

Alternatively, the fiberglass mast can be guyed at several points. The balun, eye-hook strain reliefs for the vee radiating elements, and the input coaxial connector were mounted as shown in Fig. 9. If fiberglass tubing for the mast is not readily available or it costs more than you want to spend (about $4 per foot), other suitable insulating materials such as thick-wall polyvinyl chloride (PVC) tubing is a good substitute.

Other less expensive mast alternatives include wood beams or even living trees.

The antenna radiating elements were 62-foot lengths of uninsulated 7 × 19 stranded phosphor-bronze wire with a diameter of ⅛-inch. Stranded

continued on page 100

SLOPING VEE ANTENNA

continued from page 78

phosphor-bronze wire is preferred over stranded copper or aluminum wire because its spring qualities avoid kinks. It is almost impossible to tangle this kind of wire, especially important if you want a field-transportable antenna system. Nevertheless, if phosphor-bronze wire wire is too expensive (about $2 per foot) or difficult for you to obtain stranded copper or aluminum wire can be substituted. The shorting wire was 16 AWG bare, stranded-copper wire.

Solder all connections if the antenna installation is permanent. But if you plan to set up and take down the antenna frequently, be sure that there are clean metal-to metal mechanical connections between all conductive components.

The terminating resistors must be capable of handling a significant amount of power if the antenna is to be used for transmission. Non-inductive carbon-film power resistors, rated for 300 ohms ±10%, were specified for the test antenna, They had measured DC resistances of 307 and 314 ohms. As a general rule, the resistor power dissipation rating should be 10 to 20% of the maximum transmitter output power. Check the termination resistors for overheating.

For receiver-only applications, almost any low-power dissipating resistor with the correct resistance value will be satisfactory. The test sloping-vee antenna showed good VSWR performance and reception with 300-ohm, ¼- watt carbon resistors.

The measured impedance bandwidth of the 15 to 50 MHz vee is shown in Fig. 14. A network analyzer measured the input VSWR of about 150 feet of RG-213/U coaxial cable and was below 2:1 at all frequenci between 10 and 60 MHz; it w particularly good between and 30 MHz. The undulatio in the VSWR curve shown Fig. 14 were caused by tl transmission line's frequenc dependent transformer actio acting on the sloping vee-inp impedance.

VSWR measured directly the antenna input is slight higher because cable loss lowe VSWR. This measurement w made, and the VSWR was ju over 2:1 in the following band 38 to 40 MHz; 44 to 47 MHz; ar 52 to 57 MHz. At all frequenci below 58 MHz, the sloping ve input VSWR was less tha 2.5:1. The test antenna easi exceeded the bandwidth desig objective, and it provides ve good broadband performanc In field tests the slope vee pe formed well as a transmitter a tenna down to frequencies about 4 MHz. R