CHAPTER 4

ANTENNA DESIGN AND CHARACTERISTICS

Many factors must be considered before antennas can be correctly chosen to fulfill the communications mission requirements.

The physical and electrical characteristics of an antenna, such as radiation pattern, polarization, impedance, gain, directivity and bandwidth will influence the selection. These characteristics, in turn, must be weighed against land availability and other economic considerations before final selection is made.

The characteristics of those antennas which are most commonly used in point-to-point, ship/shore/ship, ground/air/ground, and broadcast communications are presented in this chapter. The design of HF antennas is accomplished in accordance with NAVELEX standard plans or other specifications provided by NAVELEX. Detailed design procedures for most HF antennas used in Navy communications systems are also included in reference 14.

Most HF antennas are obtained from commercial sources rather than being designed and fabricated by a field activity. Log-periodic, conical monopole, and inverted cone antennas are typical of this group. In some cases, "off-the-shelf" units which meet the communications requirements are available. For other applications, however, antennas are designed and fabricated by a manufacturer to meet NAVELEX specifications which take into account the structural requirements established by NAVFAC.
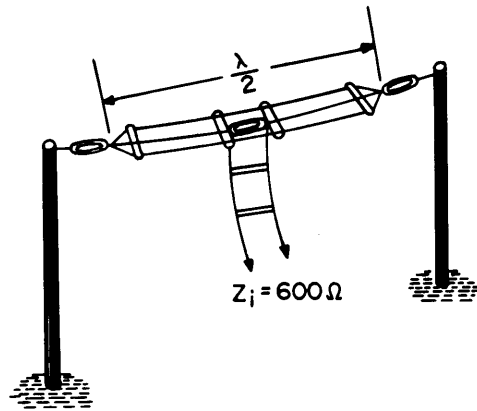
4.1 HALF-WAVE ANTENNA (DIPOLE/DOUBLET)

The basic half-wave resonant antenna called either a dipole or doublet, is one of the simplest and most fundamental of the radiating systems in common use. Geometrically, this antenna is a simple linear element which has an electrical length of one-half wavelength. Normally the radiator is a thin wire, but larger conductors are sometimes used for those antenna applications which require slightly wider bandwidth or lower input impedance than that of a thin wire.

The two-and three-wire folded dipole versions of the half-wave antenna (illustrated in figure 4-1) normally are used for Navy communications service because they provide greater power handling capability and increased bandwidth. NAVSHIPS Drawings RE-F2691939, 2691941, 2691942, 2691950, 2691953, 2691956 and 2691982 (formerly BUSHIPS Drawings RE 66F 2034, 2036, 2037, 2045, 2048, 2051 and 2077, respectively) are standard plans for these antennas

4.1.1 Physical and Electrical Characteristics

The impedance at the center of the basic half-wave thin wire in free space is approximately 73 ohms. For antennas of this type installed over earth of average conductivity, the measured input impedance is likely to lie between 50 and 90 ohms, depending on the

antenna height above ground. In applications where an unbalanced coaxial transmission line is preferred, the basic half-wave antenna can provide a close impedance match to the standard 50-ohm line. At heights above one-quarter wavelength, the input impedance exhibits a cyclic variation with height, and the mean impedance approaches the free-space value at great heights.

3—WIRE FOLDED DIPOLE ANTENNA
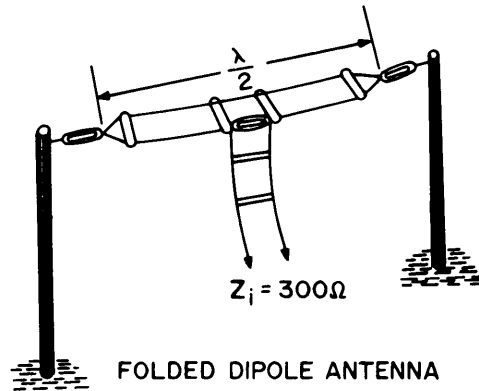
FOLDED DIPOLE ANTENNA
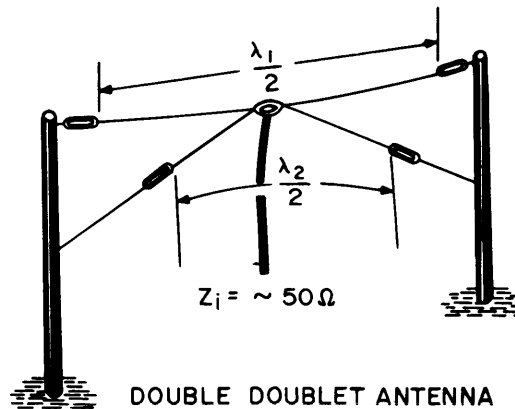
DOUBLE DOUBLET ANTENNA

Figure 4-1. Dipole and Doublet Antennas

When RF voltage is impressed across the center feedpoint of the balanced half-wave antenna, a traveling wave of current moves out toward the end of the driven conductor; at the end of the conductor, the traveling wave is reflected back toward the feedpoint. Since the incident and reflected current waves are in phase at the center of a resonant half-wave antenna, the impedance at the feedpoint is determined by the scalar sum of incident and reflected waves of current. If more than one path is provided for the reflection, the reflected current will divide among the paths so that the total of incident and reflected currents in the branch containing the feedpoint is reduced. The input impedance at resonance of a practical half-wave antenna can, therefore, be increased to several hundred ohms by arranging other conductors of the same length parallel to the driven conductor and connected to the driven conductor only at the ends. Spacing of the individual conductors is held to a very small fraction of a wavelength in order that the additional conductors function only to alter the impedance characteristics rather than the radiation pattern of the antenna.

This variation of the simple half-wave antenna is commonly called a folded dipole. If the basic antenna has only one such additional conductor, the input impedance becomes approximately 200 to 300 ohms; when the configuration consists of a total of three conductors, the input impedance can be increased to approximately 600 ohms. For transmitting applications where an open-wire transmission line is preferred, the three-conductor configuration provides a close impedance match to the common types of open-wire line. The procedures for matching doublet antennas to open-wire lines, and for tuning doublets, are presented in appendix A.

The exact value of input impedance depends upon the spacing between conductors, the length-to-diameter ratios of the individual conductors, the ratios of conductor spacing to the conductor diameters, and the electrical constants of the soil over which the antenna is erected.

Half-wave antennas can be driven at points other than the geometric center, and they are sometimes fed off-center or at one end. The impedance at the ends (points of current null) is quite high, typically 2000 ohms or more. Impedance matching of the transmitter, line, and antenna becomes more difficult and more frequency dependent with end-fed configurations, so the end-fed arrangement is seldom used.

The maximum power handling capability of the half-wave dipole antenna is limited generally by the capacity of transmission line used and by corona effects at the ends of the antenna elements. The radiation efficiency is substantially 100 percent.

Figure 4-1 illustrates each half-wave configuration discussed. The illustration shows only horizontally oriented antennas since veritcal orientation results in a structure of impractical height for frequencies below 5 MHz.

The basic half-wave antenna is often used as the reference antenna in gain calculations for more complex antennas. However, gain of this antenna itself must be referred to a more fundamental reference, the isotropic radiator. An evaluation of the gain with reference to the field intensity produced at a specific point by an isotropic radiator, must take into account the conductivity and dielectric constant of the reflecting ground, and the height of the antenna in wavelengths above ground.

The bandwidth of the half-wave antenna is normally limited to 5 percent of the center design frequency by the allowable impedance variation rather than by pattern variation.

A variation of the basic half-wave antenna from which increased bandwidth can be realized involves the use of non-parallel multiple conductors joined at each side of the feedpoint, and extended to a maximum separation at the ends. When only one such additional conductor on each side of the feedpoint is utilized, the resulting configuration (illustrated in figure 4-1) is called a double doublet. The additional conductors are generally one-half the length of the original antenna conductors. A properly designed double doublet will operate with a low VSWR over two narrow bands around the resonant frequency of each antenna, thereby yielding some increase in frequency coverage. The two doublets must not be harmonically related since unwanted radiation can result from this relationship.

4.1.2 Summary

Assuming an optimum configuration for a given application, the general group of horizontal half-wave antennas can be considered as medium-power, narrow-band, low-gain, and moderately directive radiators of very simple and inexpensive construction.

4.2 YAGI ANTENNA

The Yagi antenna is an end-fire parasitic array. It is constructed of parallel and co-planar dipole elements arranged along a line perpendicular to the axes of the dipoles as illustrated in figure 4-2. Only one dipole element is driven. The others are parasitic elements that are coupled to the driven element by currents induced by the field of the driven element.

4.2.1 Physical and Electrical Characteristics

To obtain directive gain, the phase of currents induced in each element is controlled by careful adjustment of element spacing and length so that the fields of the driven and the parasitic elements are additive in one direction. For close element spacings, which normally correspond with high directive gain, the effect of mutual impedance is to substantially reduce the antenna input impedance. Typically, the input impedance at resonance might range from 10 to 60 ohms. Impedance transformation through a balun or other matching device is usually required to properly terminate the standard unbalanced 50-ohm transmission line which feeds the antenna. In a parasitic array the effect of mutual impedance is to lower the value of the radiation resistance relative to that of a radiator without parasitic elements. In the long Yagi configurations, radiation resistance is so low that the ohmic losses of the antenna conductors approach a significant fraction of the radiation resistance. Since radiation resistance is an equivalent resistance which accounts for energy radiated, a small ratio of radiation resistance to conductor ohmic resistance indicates an antenna of poor radiation efficiency.

The radiation pattern, gain, lobe alignment, and front-to-back ratio of a Yagi varies with array height above ground and the number, length, spacing, and radius of the elements. A typical Yagi array, designed either for optimum gain or for a particular front-to-back ratio, operates at a power gain which ranges from 6 to 19 dB. Generally, Yagi antennas will develop only one significant horizontal-plane minor lobe, which is the back lobe. Other minor lobes usually can be suppressed more than 20 dB. Suppression of the back lobe by more than 12 dB is extremely difficult when antenna

REFLECTOR

L

DRIVEN
ELEMENT

ℓ_r

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DIRECTOR

ℓ_e

d_d

ℓ_d

H

MAXIMUM
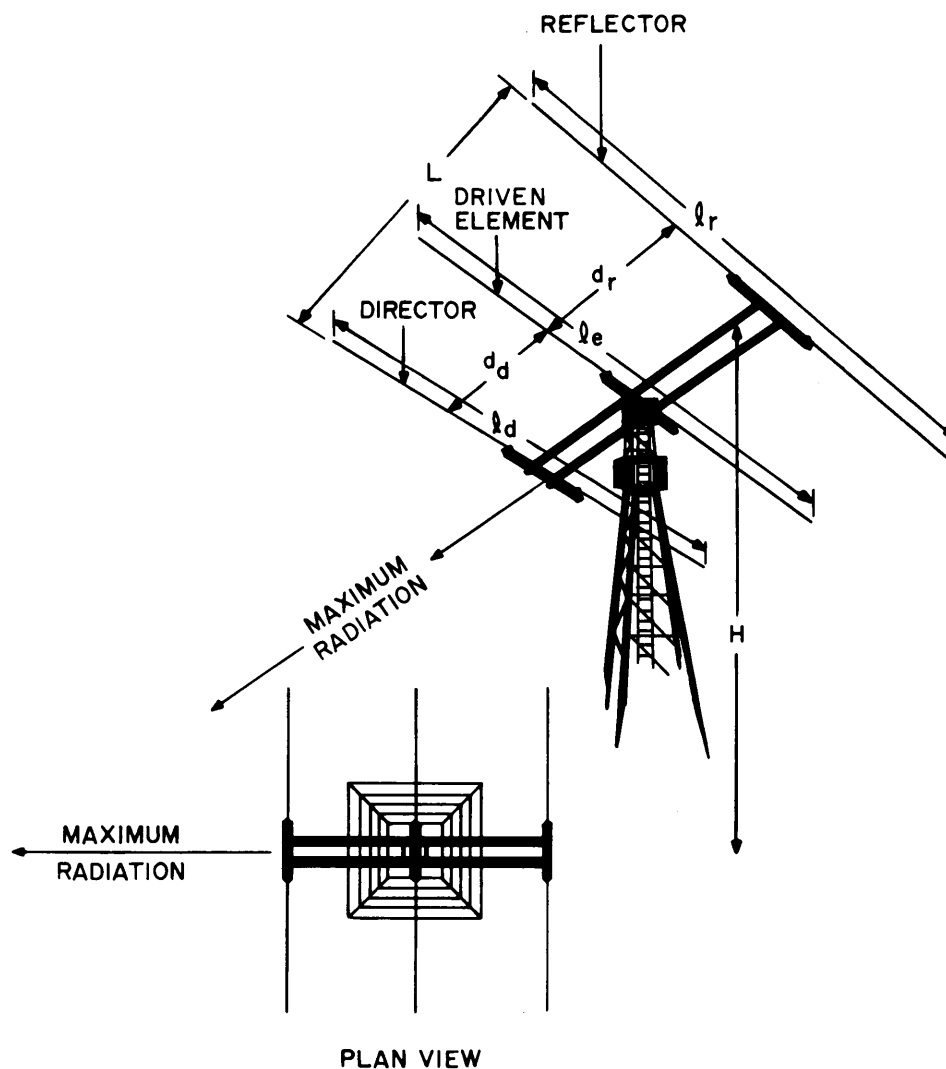RADIATION

MAXIMUM
RADIATION

PLAN VIEW

Figure 4-2. Yagi Antenna

parameters are chosen for maximum forward gain without regard to back lobe suppression. Figure 4-3 illustrates a two-element Yagi radiation pattern (ref. 14).

It is difficult to achieve very low vertical radiation angles at the low end of the HF band because the antenna height required becomes prohibitive. For a vertical radiation angle of 5 degrees the array height must be 2.75 wavelengths. Because of this height requirement, the designer should first consider other antenna types for vertical radiation angles in the 5 to 10 degree range when the operating frequency is lower than 15 MHz.
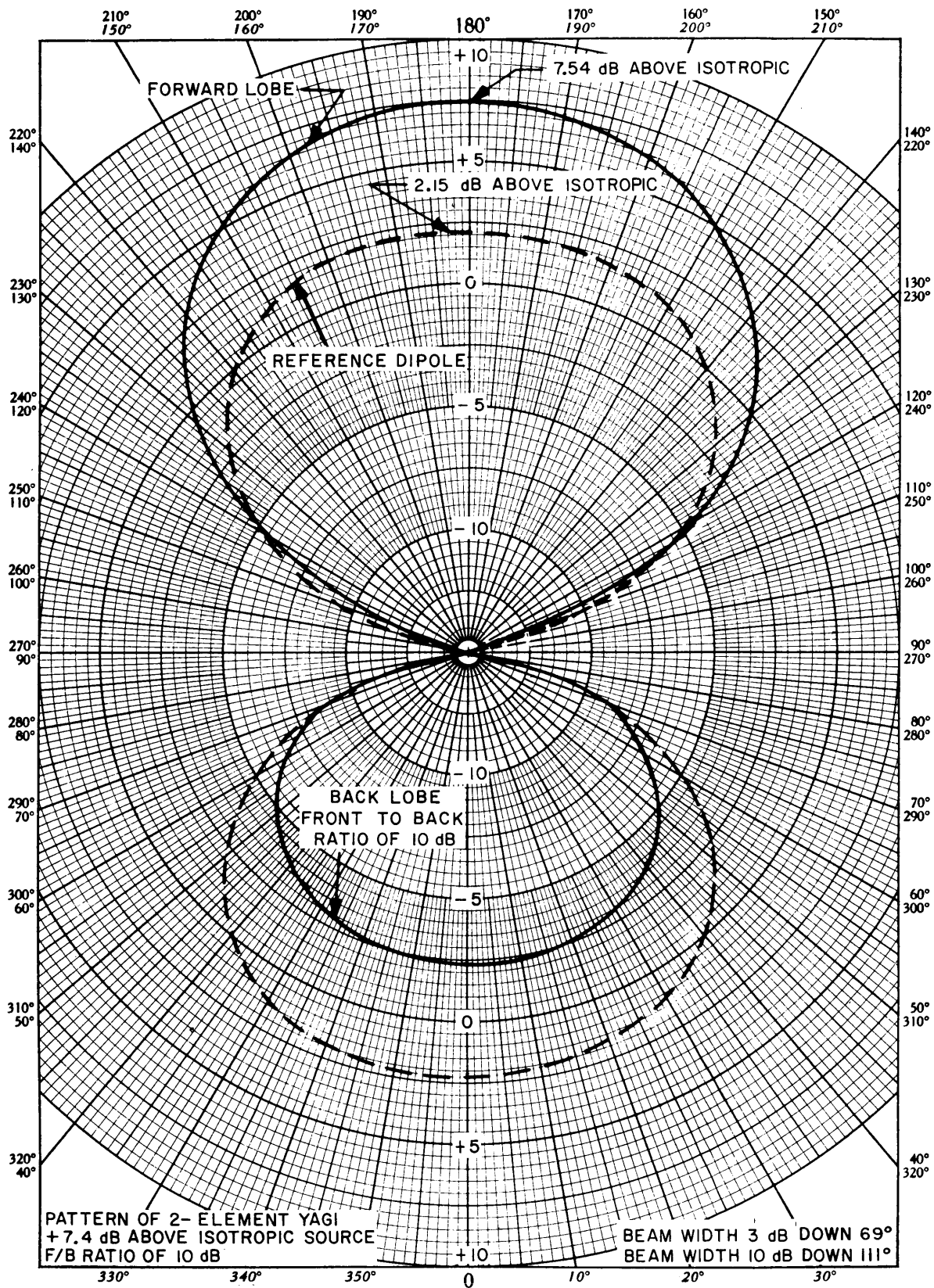
Figure 4-3. Horizontal Two-Element Yagi Antenna
Radiation Pattern

The most limiting characteristic of the Yagi antenna is its extremely narrow bandwidth. Three percent of the center frequency is considered acceptable bandwidth ratio for a Yagi antenna.

The width of a Yagi array is determined by the lengths of the elements of which it is composed; the element length is approximately one-half wavelength, the exact length depending on the desired action (driver, reflector or director) of the element. The required length of the array depends upon the desired gain and directivity. Typically, the length of an array might range from 0.3 wavelength for three-element arrays, to 3 wavelengths for arrays consisting of numerous elements. For HF applications, the maximum practical array length of the Yagi is generally considered to be 2 wavelengths. Since the vertical radiation angle depends primarily upon the array height above ground, required array height ranges between 0.25 and 2.5 wavelengths. At a frequency of 16 MHz and a vertical radiation angle of 25 degrees, an array height of approximately 40 feet would be required and a three-element array would be approximately 19 feet long and 32 feet wide. The dipole elements are normally constructed of tubing rather than wire since the smaller length-to-diameter ratio of the tubing provides an array of better gain and bandwidth characteristics. The use of tubing for the dipole elements also provides sufficient mechanical rigidity for self-support; consequently the array is often used in applications which require a rotatable antenna. Yagi arrays of four elements or less are not structurally complicated. Longer arrays, and arrays for the lower frequencies, where the width of the array exceeds 40 feet, require elaborate booms and supporting structures.

4.2.2 Summary

The Yagi antenna can be characterized as a narrow-band, medium-power, high-gain, highly directive radiator of medium-to-high radiation angle, compact size, and low cost. A typical Yagi array designed either for optimum gain or for a particular front-to-back ratio presents to the transmission line an impedance ranging from 10 to 60 ohms, and operates at a power gain which ranges from 6 to 19 dB, depending on the array characteristics. Power handling capability is limited by the feedline, insulators, capacity of impedance matching device, and corona at the ends of the elements.

### 4.3 LOGARITHMICALLY PERIODIC ANTENNAS

An antenna arranged so that the electrical length and spacing between successive elements causes the input impedance and pattern characteristics to be repeated periodically with the logarithm of the driving frequency is called a log-periodic antenna (LPA). Both fixed-azimuth and rotatable LPA's are widely used in naval communications.

### 4.3.1 Physical and Electrical Characteristics

Three fixed-azimuth antenna configurations which meet the physical conditions required for frequency independence are shown in figure 4-4. The family of antennas which exhibit a periodic variation of electrical properties with the logarithm of frequency includes the dipole array, the trapezoidal outline array, and the vertical monopole array.
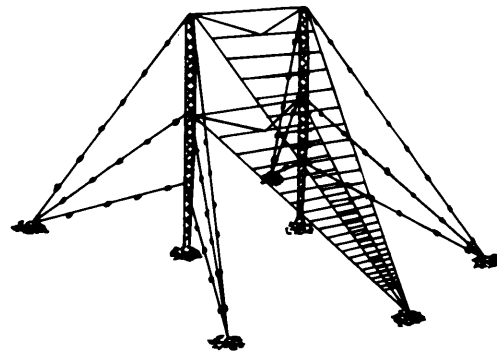
TRAPEZOIDAL LOG-PERIODIC ANTENNA
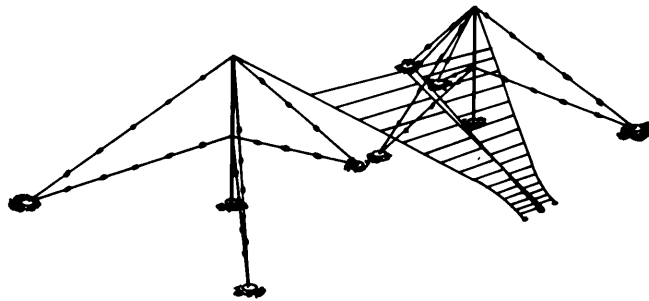
HORIZONTAL DIPOLE LOG-PERIODIC ANTENNA

(GROUND SYSTEM
NOT SHOWN)
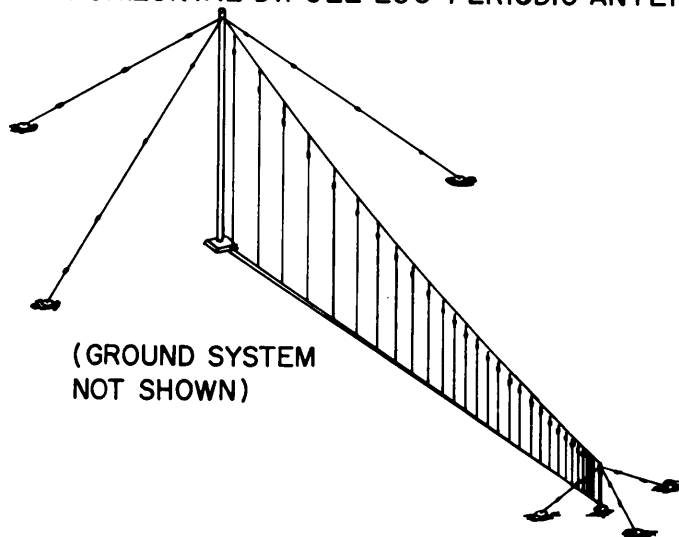
LOG-PERIODIC VERTICAL MONOPOLE ANTENNA

Figure 4-4. Log-Periodic Antennas

The log-periodic horizontal dipole antenna consists of several parallel and linear dipole elements arranged side-by-side in a plane and energized so as to generate a unidirectional beam in the direction of the shorter elements. This antenna is fed with a balanced two-wire line entering at the apex and running through the center of the structure, transposed between adjacent elements so that all adjacent elements are fed 180 ° out of phase. Feeding from an unbalanced line requires the use of a balun, which can be included as part of the antenna structure.

The log-periodic vertical monopole configuration is similar to the dipole arrangement except that the plane containing the radiating elements is vertical, and the longest element is approximately one-quarter wavelength at the lower cutoff frequency. Geometrically, the monopole arrangement is one-half of the dipole system, but in the monopole arrangement a ground system provides the "image" equivalent of the other other half-dipoles. A single vertical LPA requires only one tower, and is easier to install than a horizontal LPA. To reduce earth current losses, however, an artificial ground system normally is required for almost all vertical-monopole systems. The AS-2224/FRC is typical of the vertical monopoles in naval service.

Another LPA configuration commonly used is the horizontally polarized trapezoidal outline. In this configuration, the radiating system consists of two planes of parallel elements, with the elements in each plane arranged in a repeating trapezoid. One end of the longest element is connected to the end of the shorter element adjacent to it; the other end of this adjacent element is connected to the end of the next shorter adjacent element, and so on down to the apex. This configuration is similar to the horizontal dipole antenna. For horizontal polarization, the two planes containing the elements are arranged so that they join near ground level and extend outward and upward in two bays, one under the other.

The input impedance of the LPA typically ranges from 100 to 300 ohms (balanced). LPA's generally are suitable for moderate-to-high power levels, the maximum power handling capability normally being limited by transmission lines, baluns and coupling devices. Typical log-periodic systems operate at power levels ranging from 10 to 50 kW average power.

Radiation efficiency for LPA's is substantially 100 percent except for the vertical monopole configuration which normally is installed over a ground system. The efficiency of the vertical monopole configuration is limited by the ground losses.

The performance of an LPA is very dependent upon the proper choice of physical characteristics for each application. The most fundamental physical characteristic, upon which all others depend, is the geometric scaling factor, sometimes termed the "design ratio." For any particular set of performance limits, the scaling factor determines the other physical parameters; element length, element spacing, and number of elements. As is usually the case for antennas operating under the influence of ground reflection, the height of the array, in wavelengths above ground determines the vertical radiation angle.

The ground system for the vertical monopole LPA requires from 3 to 5 acres of land in the immediate vicinity of the antenna. A typical vertical monopole designed to cover a frequency range of 2 to 30 MHz requires one tower approximately 140 feet high and an antenna length of approximately 500 feet. The space requirement for a LPA dipole configuration is large if the antenna is to operate near the low end of the HF spectrum.

A typical dipole LPA for 2.5 to 30 MHz can require from 3 to 5 acres of land when space for guys is included. Typical tower heights range from 100 to 140 feet.

A typical trapezoidal configuration for a frequency range of 4 to 40 MHz requires two towers approximately 230 feet in height, and a total land area of approximately 5 acres.

The maximum gain of a log-periodic vertical monopole antenna varies from 6 to 8 dB. Slightly more gain can be obtained with the dipole configuration which yields typical maximum values ranging between 8 and 13 dB. The trapezoidal outline configuration has the highest gain of the group with maximum values up to 16 dB. Figure 4-5 illustrates that horizontal beamwidths at the minus 3-dB points range from a typical value of 100° for the vertical monopole configuration, down to 60° for the trapezoidal outline configuration (ref. 14).

The vertical plane beamwidth for ground-mounted LPA's ranges from 40° for the vertical monopole to 25° for the trapezoidal outline antennas. Radiation patterns for the types of LPA's discussed are illustrated in figure 4-5 (ref. 14). Since the vertical angle along which earth-reflected field reinforcement occurs depends upon the electrical height of the radiatior above earth, it is necessary to slope the log-periodic configuration in such a manner that the height of the effective aperture (phase center) is constant when measured in wavelengths. The free-space E- and H- plane patterns of LPA's are inherently frequency independent. When the practical antenna is sloped with respect to ground, the horizontal pattern is unaffected, essentially, by earth reflection.

True frequency independence is an LPA can be achieved only under the theoretical conditions of an infinite progression going from elements of infinitesimal length out to elements of infinite length. In practical circumstances, however, the log-periodic configuration is substantially frequency-independent between upper and lower design-cutoff frequencies.

The high-frequency cutoff is determined largely by the precision to which antenna geometry can be maintained. In the case of the dipole configuration, which must be fed at the apex, high-frequency cutoff is also limited by practical feedline dimensions. The low frequency cutoff is determined by the feedline dimensions and by the maximum practical size of the overall configuration since low-frequency cutoff occurs when the longest element is slightly more than one-quarter wavelength long; that is, one or two longer elements must remain active behind the element which is one-quarter wavelength long. Frequency-independent operation above the low-frequency cutoff is possible because antenna currents decrease rapidly with distance from the apex; thus, a smaller portion of the antenna is utilized as frequency is increased. Bandwidth is limited by the physical limits to which the antenna is constructed. For antennas of practical physical dimensions, VSWR can be held below 2:1 for bandwidth ratios of 15:1 or more.

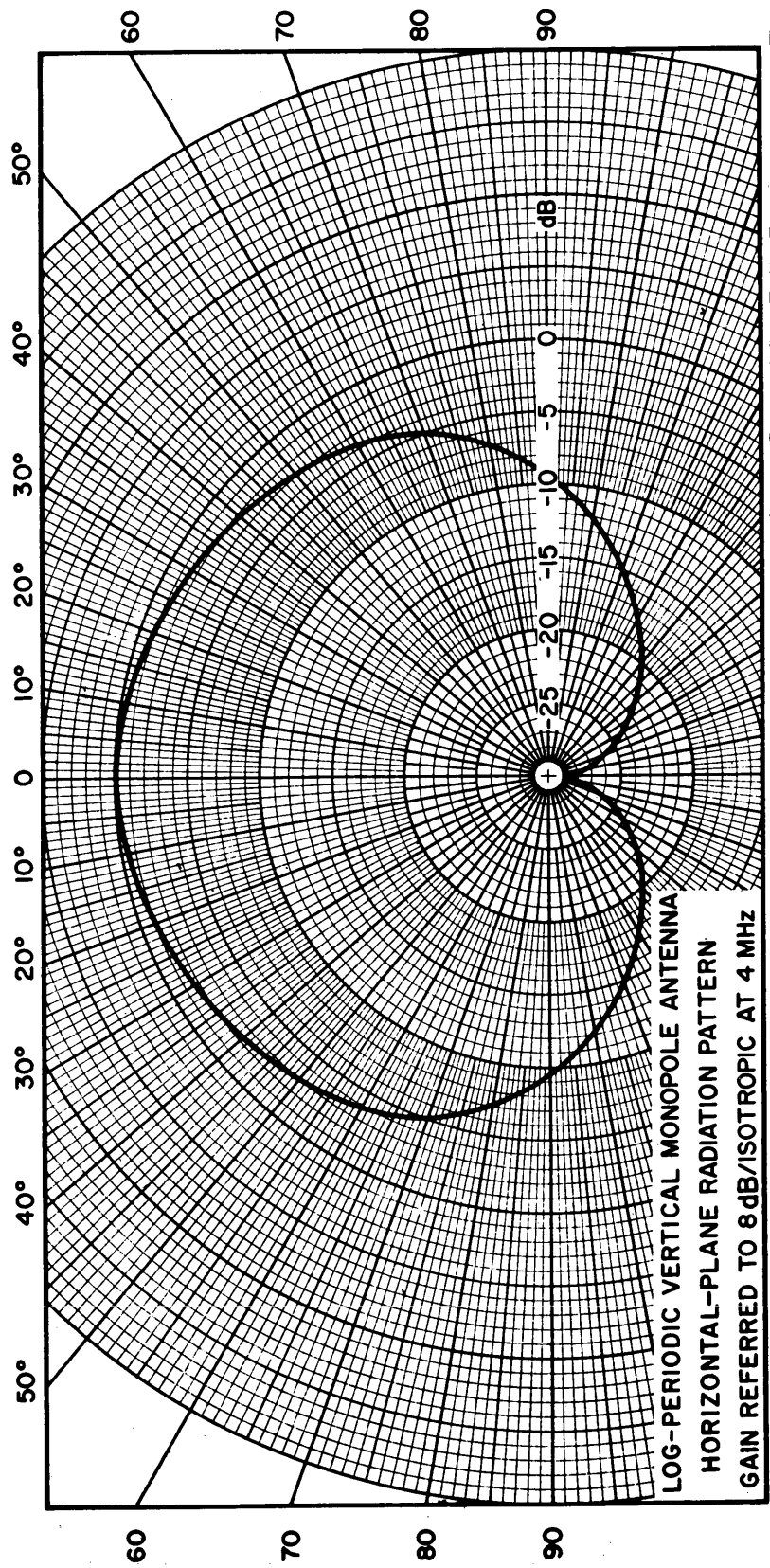In addition to the basic LPA configurations some more sophisticated variations are in use in naval communications.

LOG-PERIODIC VERTICAL MONOPOLE ANTENNA
HORIZONTAL-PLANE RADIATION PATTERN
GAIN REFERRED TO 8dB/ISOTROPIC AT 4 MHz

Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 1 of 6)

LOG–PERIODIC HORIZONTAL DIPOLE ANTENNA

HORIZONTAL–PLANE RADIATION PATTERN

H=0.4 λ

GAIN REFERRED TO 11 dB/ISOTROPIC AT 6.5 MHz

Figure 4–5. Log–Periodic Antenna Radiation Patterns (Sheet 2 of 6)

LOG-PERIODIC HORIZONTALLY POLARIZED
TRAPEZOIDAL OUTLINE ANTENNA
HORIZONTAL-PLANE RADIATION PATTERN
H=0.6λ
GAIN REFERRED TO 13.5 dB/ISOTROPIC AT 6.5 MHz

Figure 4-5.   Log-Periodic Antenna Radiation Patterns (Sheet 3 of 6)

LOG-PERIODIC VERTICAL MONOPOLE ANTENNA
VERTICAL-PLANE RADIATION PATTERN
GAIN REFERRED TO 8 dB/ ISOTROPIC AT 4 MHz

Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 4 of 6)

LOG-PERIODIC HORIZONTAL DIPOLE ANTENNA
VERTICAL-PLANE RADIATION PATTERN
H=0.4λ
GAIN REFERRED TO 11 dB/ ISOTROPIC AT 6.5 MHz

Figure 4-5.   Log-Periodic Antenna Radiation Patterns (Sheet 5 of 6)

LOG-PERIODIC HORIZONTALLY POLARIZED TRAPEZOIDAL OUTLINE ANTENNA
VERTICAL-PLANE RADIATION PATTERN
H=0.6λ
GAIN REFERRED TO 13.5 dB/ISOTROPIC AT 6.5 MHz

Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 6 of 6)

4.3.2 Sector Log-Periodic Array

This version of a vertically polarized fixed-azimuth LPA consists of four separate antenna curtains supported by a common central tower as shown in figure 4-6. Each of the four curtains operates independently, providing antennas for a minimum of four transmit or receive systems, and a choice of sector coverage. The four curtains are also capable of radiating a rosette pattern of overlapping sectors for full coverage in azimuth, as shown by the radiation pattern in figure 4-6. The central supporting tower is constructed of steel, and may range in height to approximately 250 feet. The length of each curtain can be up to approximately 250 feet (according to the frequency range).

Land requirements for the antenna including its ground plane (not used in all sector LPA's) will usually be approximately 4 to 6 acres for a sector LPA covering the full HF spectrum.

The power handling capability of this type of LPA can be as high as 20 kW average power with a VSWR no greater than 2:1. A gain greater than 11 dB with respect to isotropic is possible.
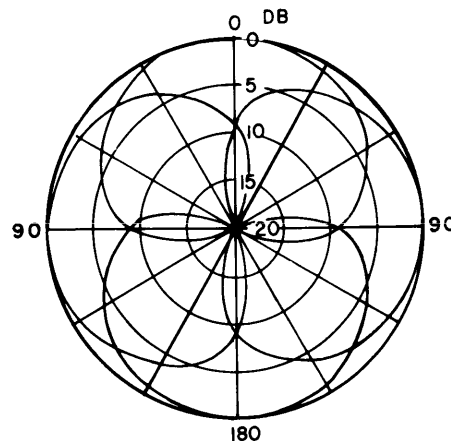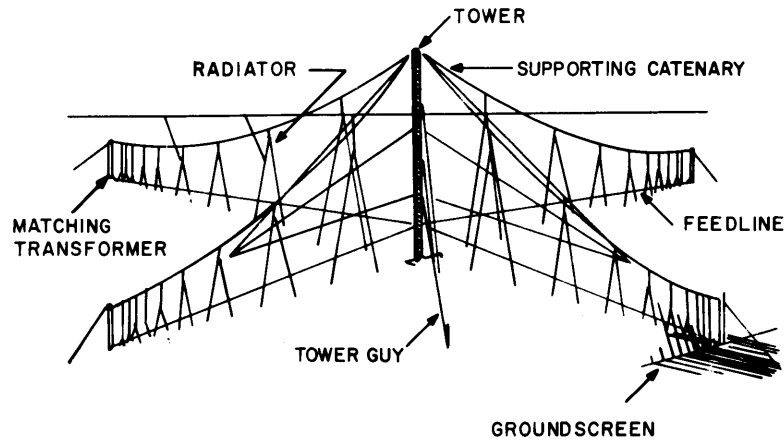

Figure 4-6. Sector LPA and Horizontal Radiation Pattern

4.3.3 Rotatable Log-Periodic Antenna

The rotatable LPA (RLPA) possesses essentially the same characteristics as the fixed LPA, but has a different physical form.

RLPA's commonly are used in ship/shore/ship and in point-to-point communications. The ability to rotate the array 360 degrees is a distinct advantage when the relative merits of the fixed and rotatable versions of the LPA are compared.

Widely divergent construction methods are found in RLPA's. Some are constructed using tubular antenna elements; others utilize wire elements. Figure 4-7 illustrates the AS-2187/FRC, one type of RLPA in naval communications use. This antenna has wire elements strung on three aluminum booms of equal length which are spaced equally and arranged radially about a central hub on top of a tower. The tower is steel, and is approximately 100 feet high. The frequency range of this RLPA is approximately 6 to 32 MHz, the gain is 12 dB with respect to isotropic, power handling capability is 20 kW average and VSWR is 2:1 over the frequency range. NAVELEX Drawings RW 66B 450 through 456 provide engineering-installation details for the AS-2187/FRC.
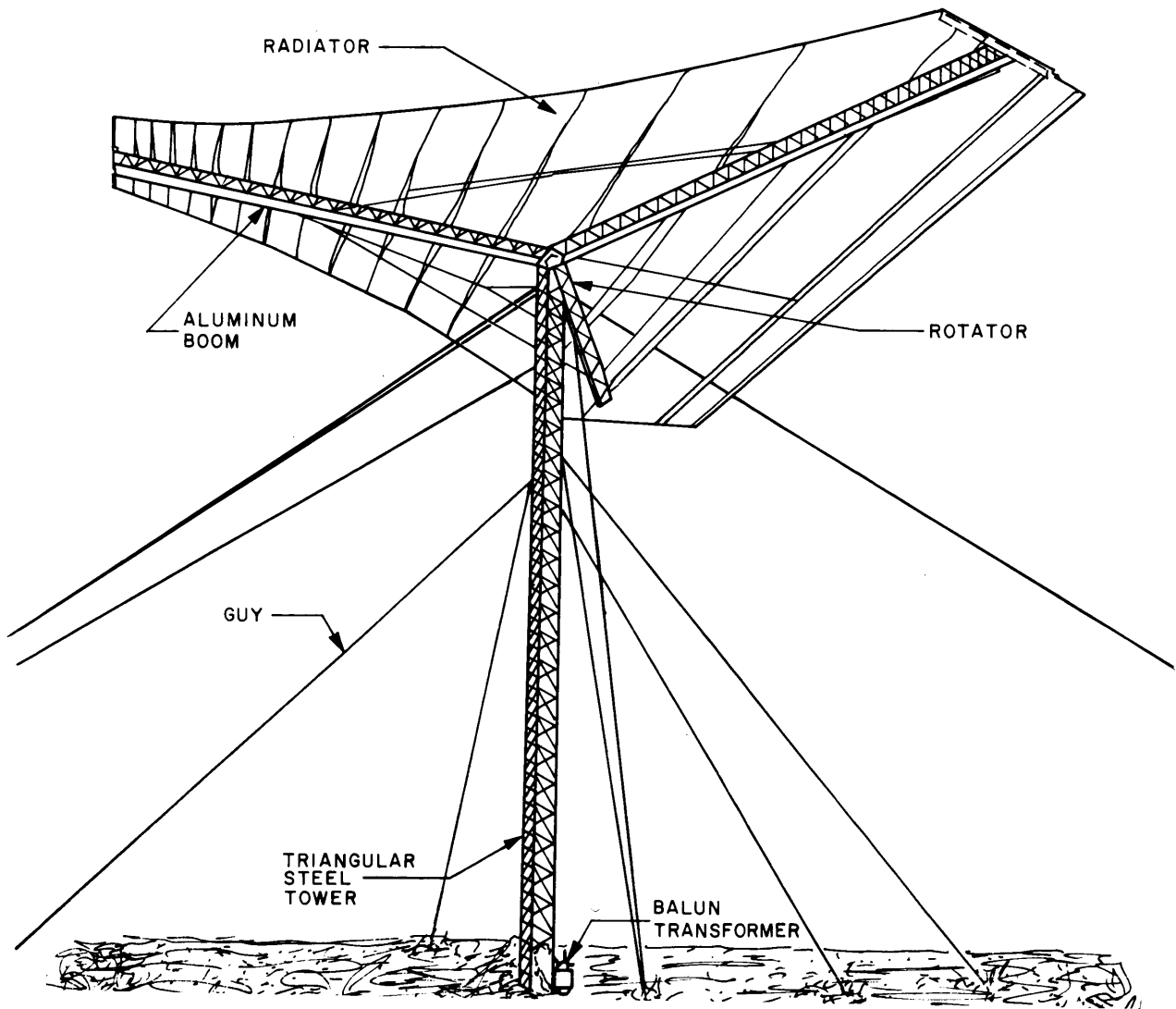

Figure 4-7. Rotatable Log-Periodic Antenna

4.3.4 Summary

The LPA, in general can be characterized as a medium-power, high-gain, moderately directive radiating antenna of extremely broad bandwidth. Bandwidths up to 15:1 are possible with up to 15 dB power gain. The vertical radiation angle remains relatively constant over the antenna bandwidth on the fixed azimuth LPA's.

LPA's are rather complex antenna systems and are relatively expensive. The installation of LPA's is normally more difficult than for other HF antennas because of the tower heights and the complexity of suspension of radiating elements and feedlines from the towers.

4.4 HF WHIP ANTENNAS

HF whip antennas are vertically polarized omnidirectional monopoles which are electrically characteristic of the general class of vertical radiators. They are used in short-range ship/shore/ship communications, in transportable communications systems, and in laboratory and shop installations.

4.4.1 Physical and Electrical Characteristics

Whip antennas used in HF communications are made of tubular metal or fiberglass-covered metal. They are usually 35 feet in length; however, some models are adjustable from a length of 12 feet to a maximum length of 35 feet.

Whips are the least efficient of all the commonly used vertically polarized antennas. Their wide application in Navy HF communications is due primarily to their low cost and simplicity of installation. Even though it is generally assumed that HF whips are designed for efficient operation throughout the 2 to 30 MHz range, actual radiation efficiency is largely dependent upon their operation with associated tuning devices (normally used with transmitters) and a ground plane. Without an antenna tuning system, whips will generally have a narrow bandwidth and will also be limited in power-radiating capability.

Power ratings of most HF whips range from 1 to 5 kW (PEP) but in some cases stainless steel models are used in power applications above 5 kW.

Whips do not present unusual siting or installation problems since they may be readily located on poles or platforms, on the tops or sides of buildings, or similarly located on transportable units. Installation instructions provided with the antennas do not always take into consideration proper antenna location or ground plane requirements. A ground plane of radial wires one-quarter wavelength long at the antennas lowest design frequency is usually required.

Two models commonly used in HF shore applications are the AT-1022/SR and the NT 66047. Both antennas meet Navy requirements and are available through normal procurement channels.

4.4.2 Summary

Although whips are not considered highly efficient antennas, and are unsuitable for many applications, they provide a compromise choice for receiving and low-to-medium power transmitting installations. Because whips are inexpensive and are easily installed their use is particularly advantageous where time, cost, and space are critical factors. The spacing required between tuned whips is not critical if they are operated at sufficiently different frequencies.

4.5 SLEEVE ANTENNA

The HF sleeve antenna is used primarily as a receiving antenna in Navy Communications. In its basic configuration, the sleeve is broadbanded vertically polarized and omnidirectional. Consequently, its primary applications are in broadcast, ship/shore/ship, and ground/air/ground service rather than point-to-point communications. BUSHIPS Drawing RE 66F 2073, Rev. K., and 2075, Rev. G. are the standard plans for transmitting and receiving sleeves, respectively.

4.5.1 Physical and Electrical Characteristics

The sleeve antenna illustrated in figure 4-8 consists of two sections: a grounded lower base section and an upper, ungrounded section. The upper section is of greater length and smaller diameter than the lower section. The upper section is constructed of multiple vertical wires supported by a wood pole. The wires are joined at the lower and upper ends, and spaced to a maximum width at the center. The spacing of the upper-section conductors is varied in a manner which reduces antenna capacitance at the feedpoint. The lower section is a wooden structure with ten parallel wires distributed from top to bottom on each side. The transmission line is connected through a transformer to the junction of the base and upper section. The nominal impedance of the sleeve antenna is 50 ohms. Maximum transmitter power-handling capability generally is limited to 10 kW (PEP) because of limiting factors imposed by the impedance matching device.

The basic omnidirectional sleeve antenna provides a gain of approximately 2 dB over a frequency range of 3:1, and presents a VSWR of 3:1, or less , over the frequency range.

The sleeve antenna is installed above a ground radial system consisting of 120 wires spaced 3° apart and at least one-quarter wavelength long at the lowest design frequency.

The radial wires are connected to the lower grounded section and are electrically common with the lower section. Due to the requirement for a ground plane, a sleeve antenna will occupy from 2 to 4 acres of land.

Several variations of the basic omnidirectional sleeve antenna are used in Navy HF communications.

4.5.2 180° Sector Sleeve

This variation of the basic sleeve is illustrated in figure 4-9. The upper and lower sections in the 180° sector sleeve are the same as in the basic antenna. The addition of a director and a reflector provide the directive characteristics. This type of sleeve operates effectively over a frequency range of 3:1 with a VSWR of 3:1, and provides a gain
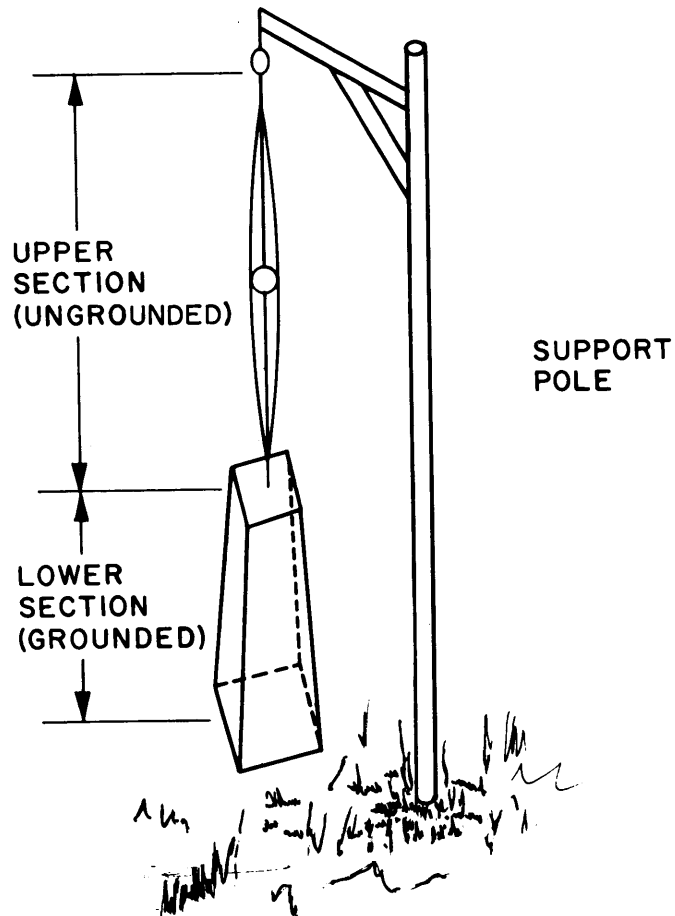
Figure 4-8. Sleeve Antenna

that is approximately 3 dB higher that that of the omnidirectional version. Typical frequency ranges for the 180° sector sleeve are 4 to 12 MHz, and 9 to 27 MHz. BUSHIPS Drawings RE 66F 2115, Rev. A, and 2116, Rev. A are the standard plans for the 180° transmitting and receiving sleeves, respectively.

The primary purpose of the director is to prevent the beam from becoming too broad and splitting at the high end of the frequency range. The director is usually constructed in the form of a cylinder consisting of 6 wires of the type and size of the antenna element.

The reflector consists of 20 vertical wires, 0.1 inch or larger in diameter, connected to the ground plane.

The ground plane required for the 180° sector sleeve is similar to that for the basic sleeve antenna except the radial wires distributed in the direction of the reflector do not extend beyond the reflector. They are terminated at the lower end of the reflector and made electrically common with the reflector wires.
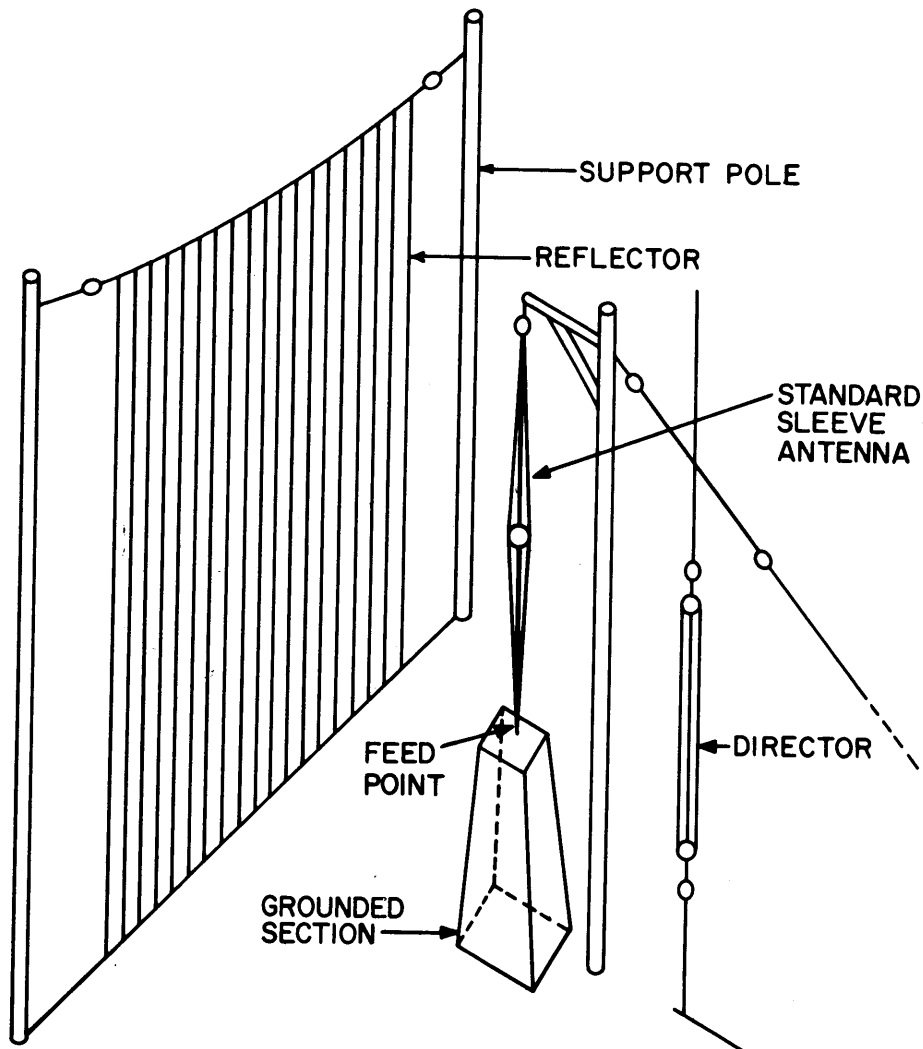
Figure 4-9. 180° Sector Sleeve Antenna

4.5.3 90° Corner Reflector

The corner reflector variation of the basic sleeve antenna is illustrated in figure 4-10. Physical differences of this sleeve antenna and the basic omnidirectional and 180° sector sleeve are readily apparent when figures 4-8, 4-9, and 4-10 are compared.

The 90° corner reflector configuration provides a gain of approximately 5 dB over the omnidirectional sleeve. Other electrical characteristics, with the exception of beamwidth and directivity, are essentially the same as the omnidirectional and 180° sector sleeves. A system of extended ground radials is required for the corner reflector configuration in order to achieve the gain and front-to-back ratio desired. Generally, the radials are 2.5 wavelengths long at the lowest design frequency. This ground plane is also shown in figure 4-10.
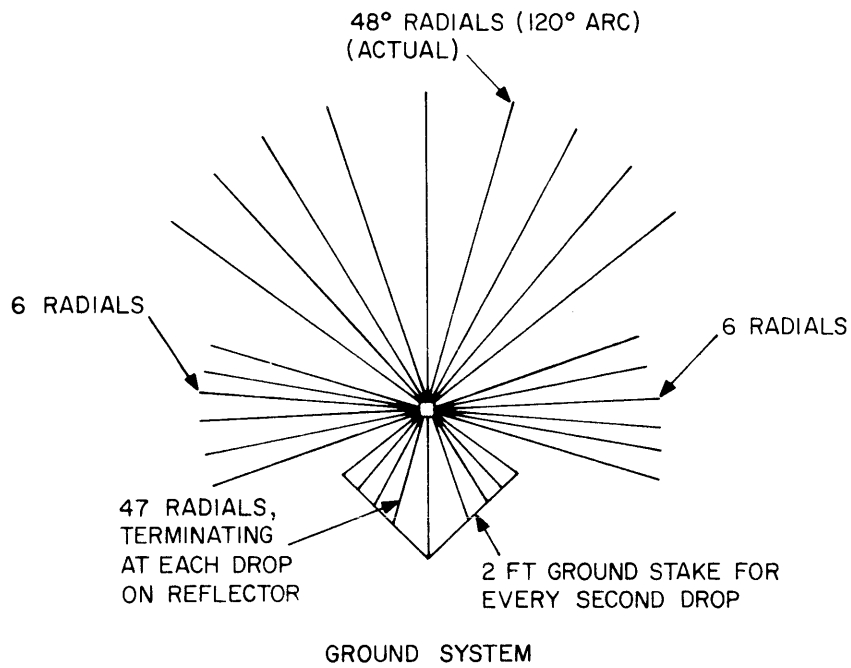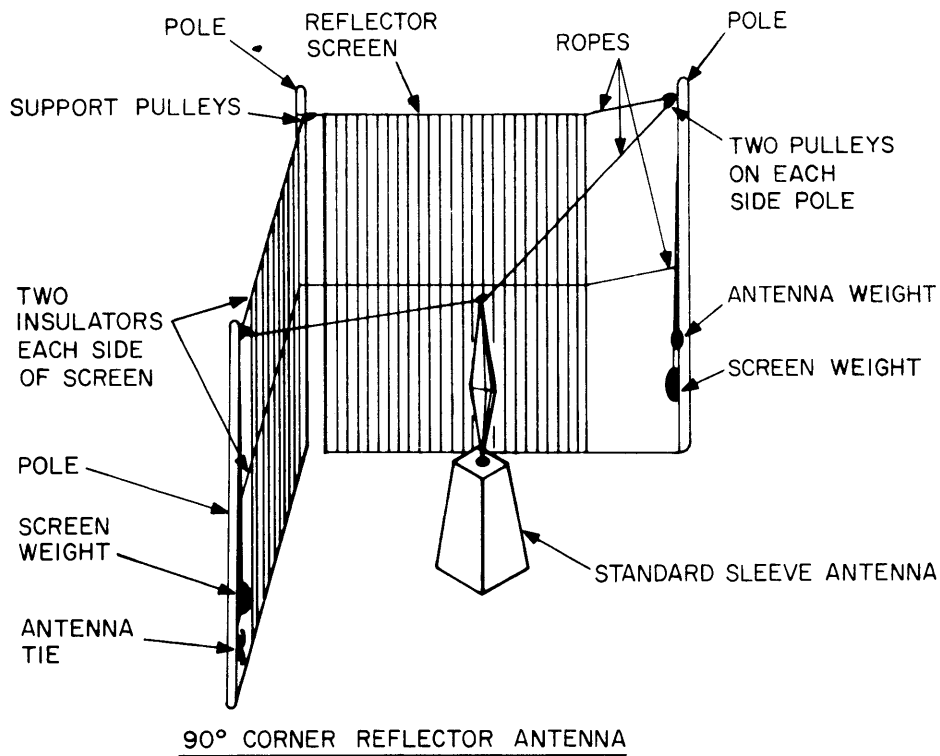
POLE REFLECTOR SCREEN ROPES POLE

SUPPORT PULLEYS

TWO PULLEYS ON EACH SIDE POLE

TWO INSULATORS EACH SIDE OF SCREEN

ANTENNA WEIGHT

SCREEN WEIGHT

POLE

SCREEN WEIGHT

ANTENNA TIE

STANDARD SLEEVE ANTENNA

90° CORNER REFLECTOR ANTENNA

48° RADIALS (120° ARC) (ACTUAL)

6 RADIALS

6 RADIALS

47 RADIALS, TERMINATING AT EACH DROP ON REFLECTOR

2 FT GROUND STAKE FOR EVERY SECOND DROP

GROUND SYSTEM

Figure 4-10. 90° Corner Reflector Sleeve Antenna and Ground System

4.5.4 Summary

Sleeve antennas are classified as relatively low-power, broadband, low-angle radiators of moderately low cost. The basic omnidirectional sleeve exhibits electrical characteristics very similiar to those of the conical monopole and discone type antennas. Due to their relatively low power handling capabilities, sleeves are used primarily as receiving antennas.

4.6 DISCONE ANTENNAS

Discone antennas are vertically polarized, omnidirectional radiators that present an exceptionally uniform impedance over a wide frequency range. These antennas may or may not be installed with ground radials in the earth. When ground radials are not installed in the earth the function of the ground plane is served by disc radials located above the antenna. The type of discone shown in figure 4-11 is an elevated discone that uses disc radials located above the upper conic surface. Typical vertical radiation patterns (ref. 14) are illustrated in figure 4-12.

4.6.1 Physical and Electrical Characteristics

Geometrically, the discone antenna is an upright truncated cone topped with a circular disc that is perpendicular to and symmetrical about the axis of the cone. For HF applications, the conic surface is formed of appropriately spaced wires, and the disc is usually formed of radially spaced self-supporting tubing. The coaxial transmission line is connected between the top base of the truncated cone and the center of the horizontal disc. At the lower end of the HF band, the top disc becomes unwieldy and excessively large; therefore, it is common to invert the discone configuration for frequencies below approximately 10 MHz.
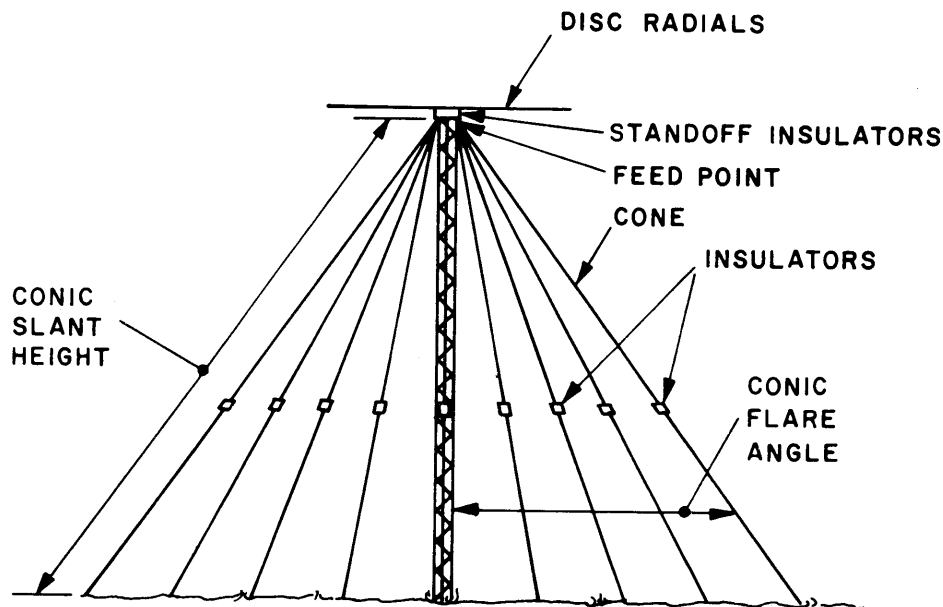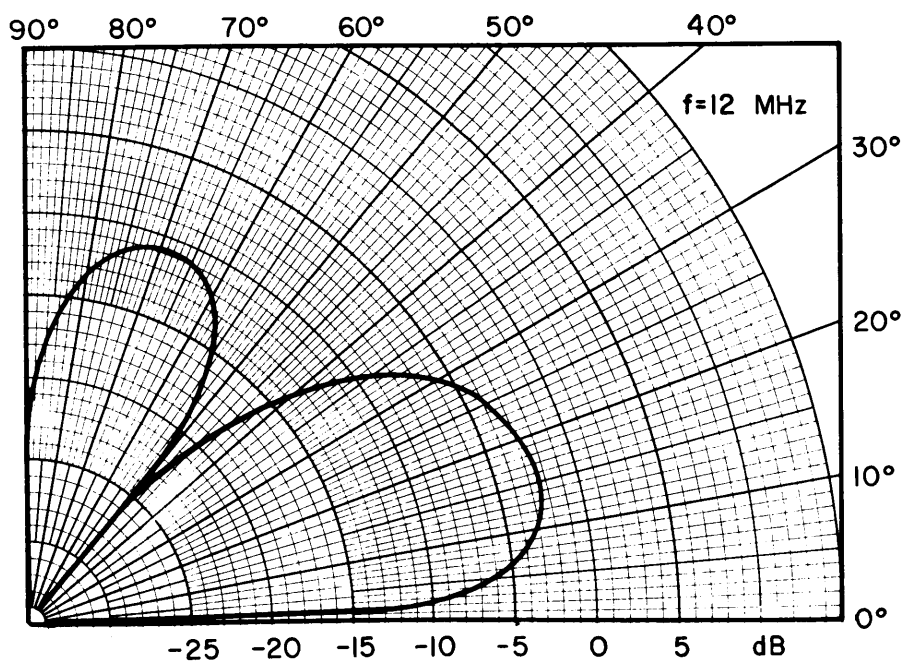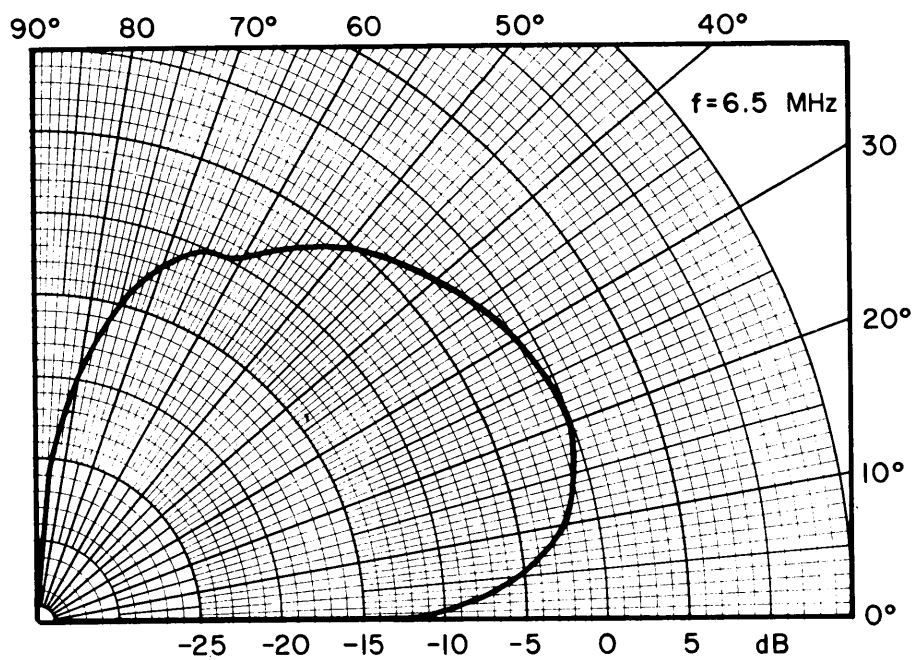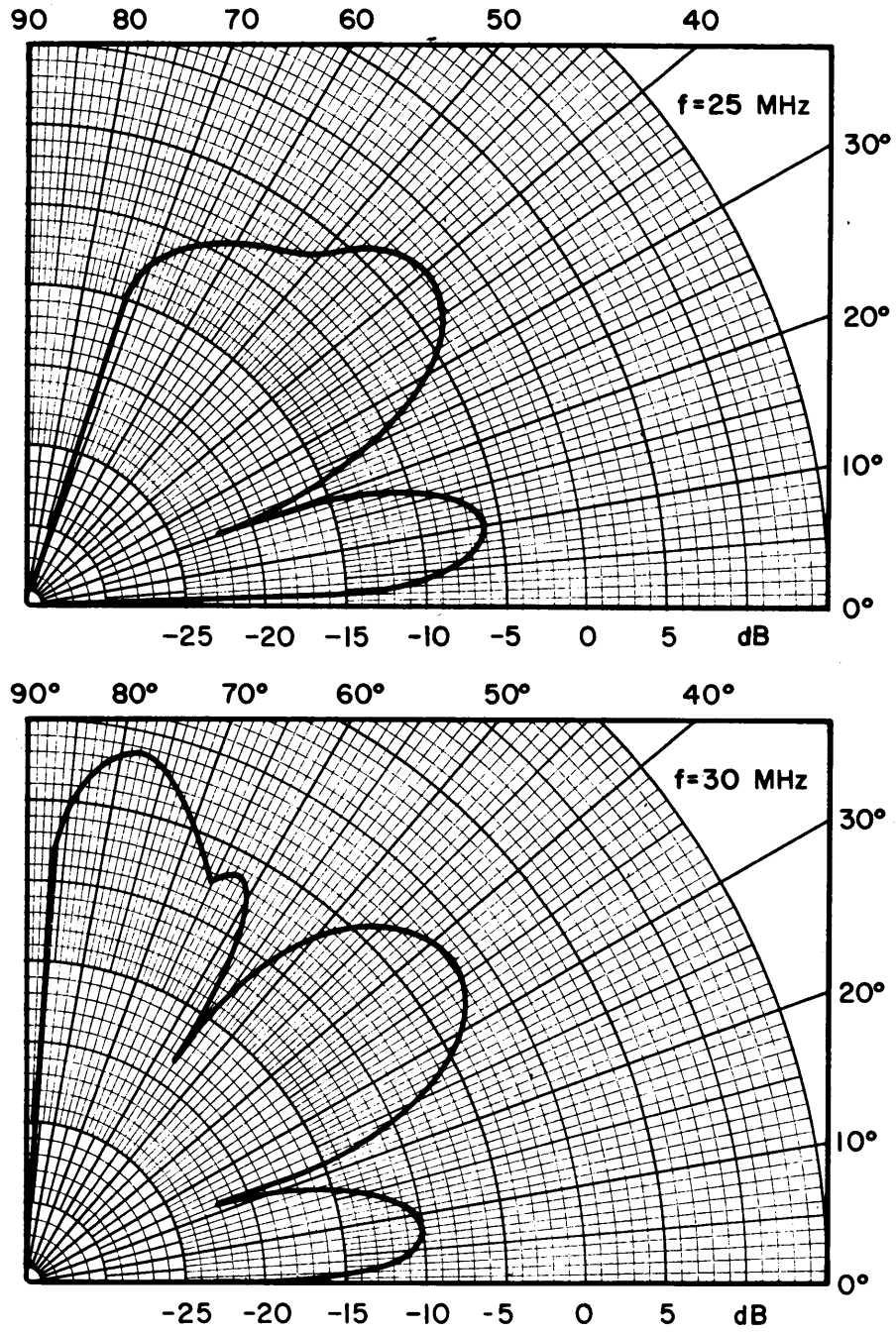

Figure 4-11.   Elevated Discone Antenna

DISCONE ANTENNA
VERTICAL RADIATION PATTERN
FOR EXAMPLE DESIGN

OVER AVERAGE EARTH (ϵ =15, σ=10^{-2} MHOS/METER)
(GAIN REFERRED TO MAXIMUM GAIN/ISOTROPIC AT 6.5 MHz)

Figure 4-12. Discone Antenna Vertical Radiation Pattern
(Sheet 1 of 2)

DISCONE ANTENNA
VERTICAL RADIATION PATTERN
FOR EXAMPLE DESIGN

OVER AVERAGE EARTH ($\epsilon = 15$, $\sigma = 10^{-2}$ MHOS/METER)
(GAIN REFERRED TO MAXIMUM GAIN/ISOTROPIC AT 6.5 MHz)

Figure 4-12. Discone Antenna Vertical Radiation Pattern
(Sheet 2 of 2)

Maximum power-handling capability of the discone antenna is limited primarily by spacing of the conic and disc sections, and by the size of the coaxial transmission line.

The shape and size of the antenna is designed specifically for the required vertical radiation pattern,bandwidth ratio, and input impedance.

The discone antenna has a maximum gain ranging from 2 dB to 5.5 dB above isotropic. At frequencies more than three octaves above the cutoff frequency, the vertical beamwidth is 50 ° or more, and the vertical radiation pattern has high-angle multiple lobes of substantial amplitude.

The salient electrical characteristic of the discone is its very broad bandwidth. The VSWR normally rises above 3:1 only when the operating frequency approaches (as a lower limit) the frequency at which the antenna slant height is one-quarter wavelength. The rate at which the VSWR rises when the lower cutoff frequency is approached is determined primarily by the cone flare angle. The upper limit of the useful bandwidth of the discone is not limited by VSWR; if vertical pattern distortion at bandwidth ratios greater than 3:1 can be tolerated, the antenna can be operated at a VSWR of less than 2.5:1 for several octaves above the cutoff frequency. Discone antennas typically have a nominal impedance of 50 ohms.

4.6.2 Summary

HF discones are generally classed as medium-power, broadband, omnidirectional antennas that are relatively expensive. Their application in Navy communications is rather limited since both the inverted cone and conical monopole are better suited to the Navy's shore communications needs.

4.7 INVERTED CONE ANTENNA

Inverted cone antennas similar to the one illustrated in figure 4-13, possess many characteristics of discone antennas, in that they are also vertically polarized, omnidirectional, very broadbanded radiators. Inverted cones are widely used in Navy HF communications in ship/shore/ship, broadcast, and ground/air/ground applications. Typical
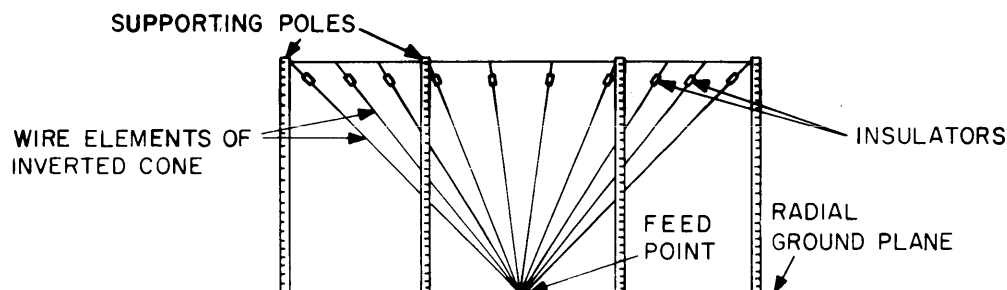

Figure 4-13. Inverted Cone Antenna

antennas in actual use are the AS-2212/FRC (NAVELEX Drawing RW 66B 306), the AS-2213/FRC (NAVELEX Drawing RW 66B 307), and the AS-2214/FRC (NAVELEX Drawing RW 66B 308). These antennas are designed for frequency ranges of 2 to 30 MHz, 2.5 to 30 MHz, and 3 to 32 MHz, respectively. Typical radiation patterns of inverted cones (ref. 14) are shown in figure 4-14.

4.7.1 Physical and Electrical Characteristics

Inverted cone antennas are installed over a ground plane radial system and are supported by poles as shown in figure 4-13. The equally spaced vertical radiator wires terminate in a feed-ring assembly located at the lower conic surface where a 50-ohm coaxial transmission line is connected.

The radial ground plane that forms the ground system for inverted cones is typical of the requirement for vertical ground-mounted antennas. The radial wires are one-quarter wavelength long at the lowest design frequency, and are spaced 3° apart. Approximately 2 to 4 acres of land are required for the antenna and the ground plane depending on the design frequency coverage.

Inverted cones typically have gains of from 1 to 5 dB above isotropic over the HF range, with a VSWR of no greater than 2:1.

The power handling capability of inverted cone antennas is typically 40 kW (average power).

4.7.2 Summary

HF inverted cones are electrically similar to discone and conical monopole antennas. They can be characterized as medium-to-high-power omnidirectional radiators of extremely broad bandwidth. Inverted cones generally are more expensive than other commonly used HF omnidirectional vertical antennas.

4.8 CONICAL MONOPOLE ANTENNA

Conical monopoles are used extensively in HF Navy communications. They were developed to fulfill a need for efficient broadband, vertically polarized, omnidirectional antennas that are compact in size. Their comparatively short height is a definite asset to be considered in conjunction with their excellent power handling capabilities and broad bandwidth. Conical monopoles are readily adaptable to ship/shore/ship, broadcast, and ground/air/ground service. A basic conical monopole configuration is illustrated in figure 4-15. Typical radiation patterns (ref. 14) are shown in figure 4-16. The AS-2205/FRC, with a frequency range of 7 to 28 MHz, is representative of conical monopoles currently in use.

4.8.1 Physical and Electrical Characteristics

Conical monopoles are in the shape of two truncated cones connected base-to-base. The basic conical monopole configuration shown in figure 4-15 is composed of equally spaced wire radiating elements arranged in a circle around an aluminum center-tower. Usually
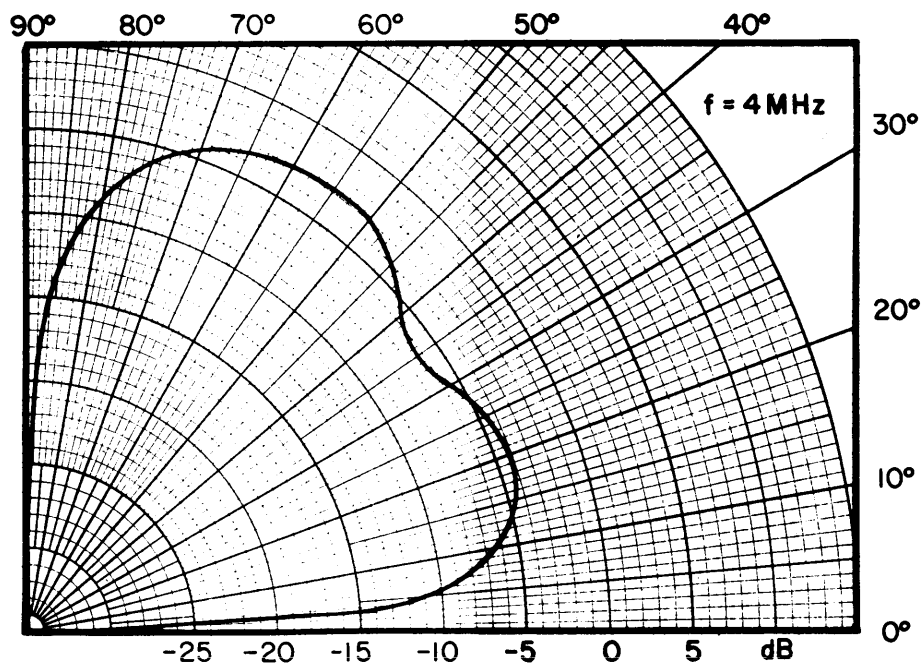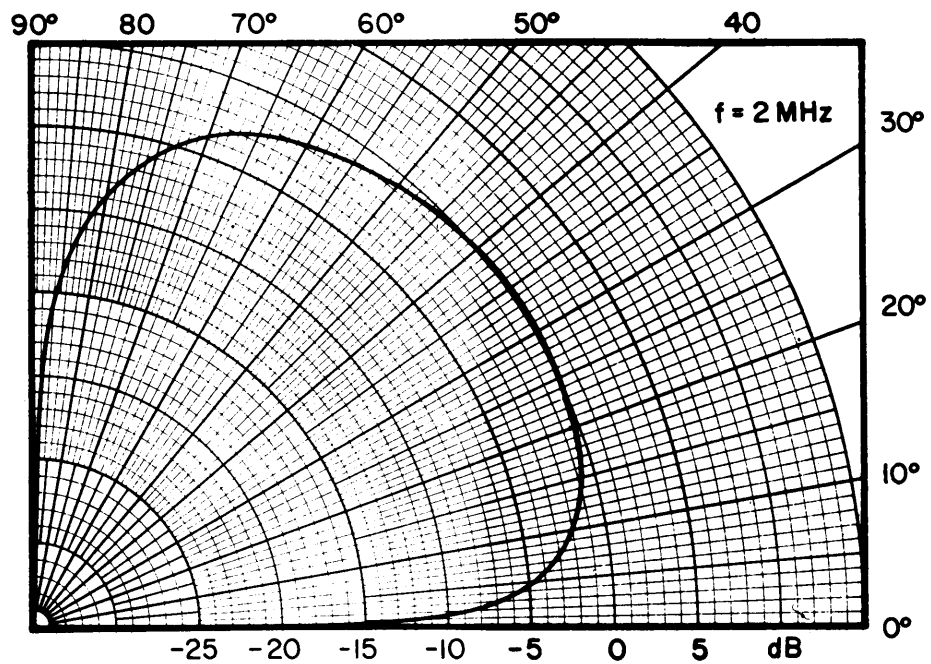
FOR EXAMPLE DESIGN — OVERALL SUMMARY CHART
OVER AVERAGE EARTH (ϵ=15,σ=10^{-2}MHOS/METER)
(GAIN REFERRED TO MAXIMUM GAIN/ISOTROPIC AT 2 MHz)

Figure 4-14. Inverted Cone Antenna Vertical Radiation Pattern
(Sheet 1 of 2)
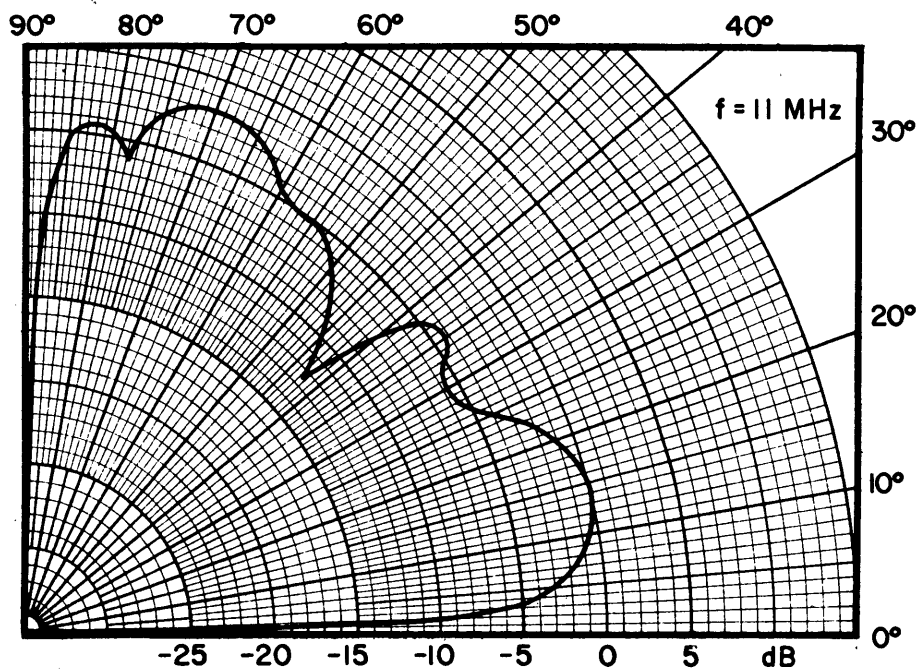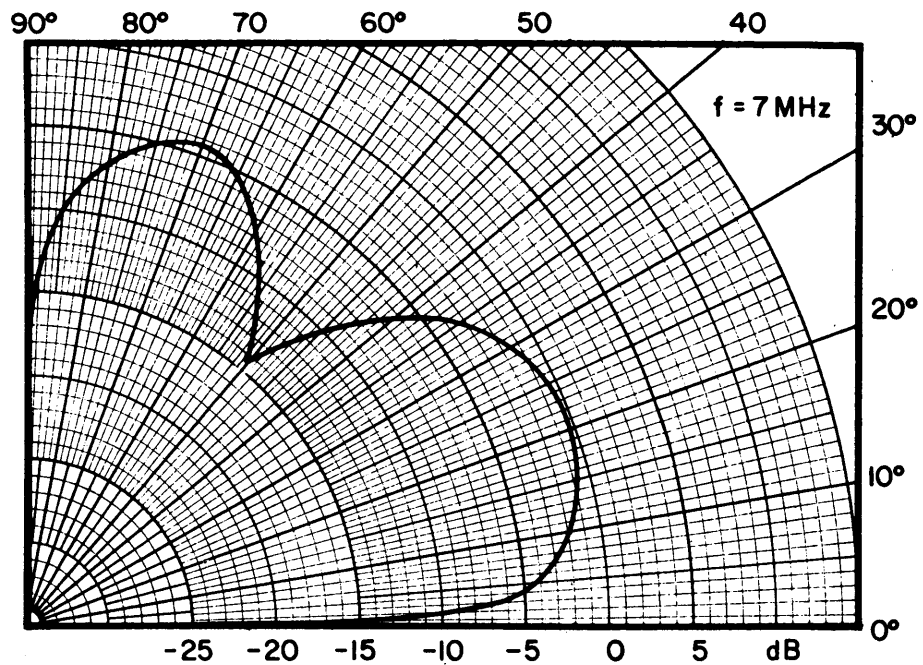
FOR EXAMPLE DESIGN — OVERALL SUMMARY CHART
OVER AVERAGE EARTH(ϵ=15,σ=10^{-2}MHOS/METER)
(GAIN REFERRED TO MAXIMUM GAIN/ISOTROPIC AT 2 MHz)

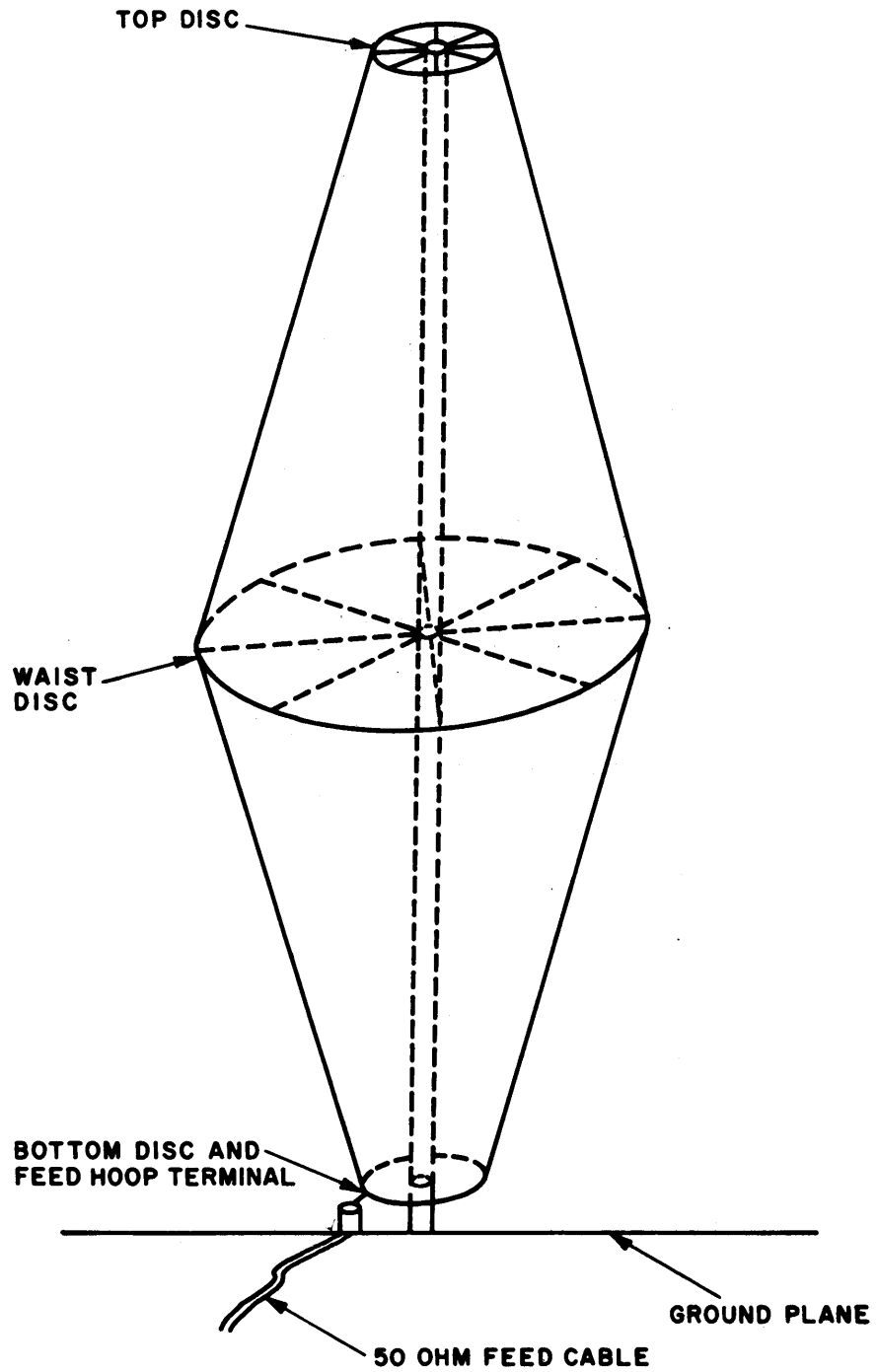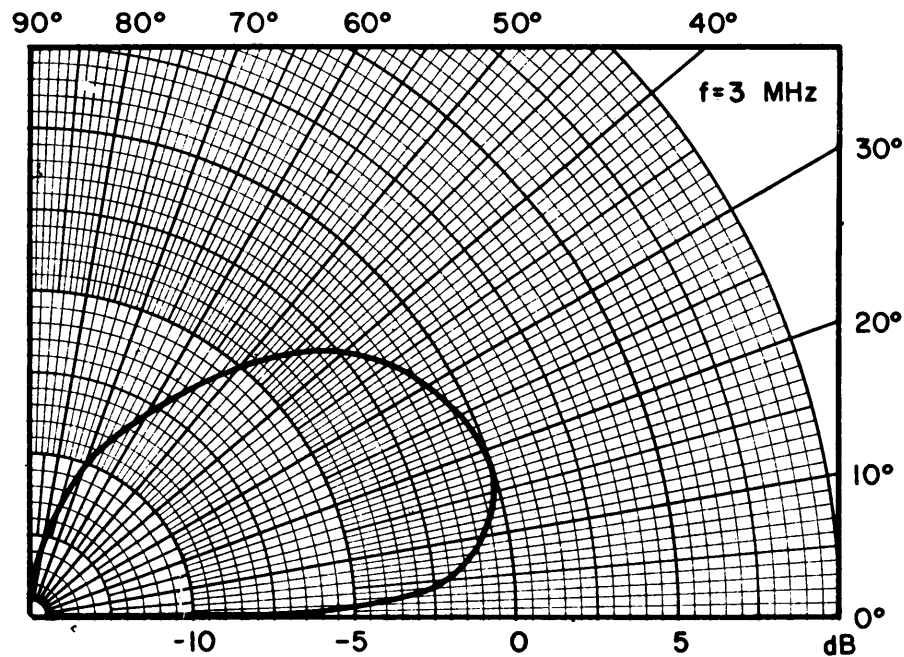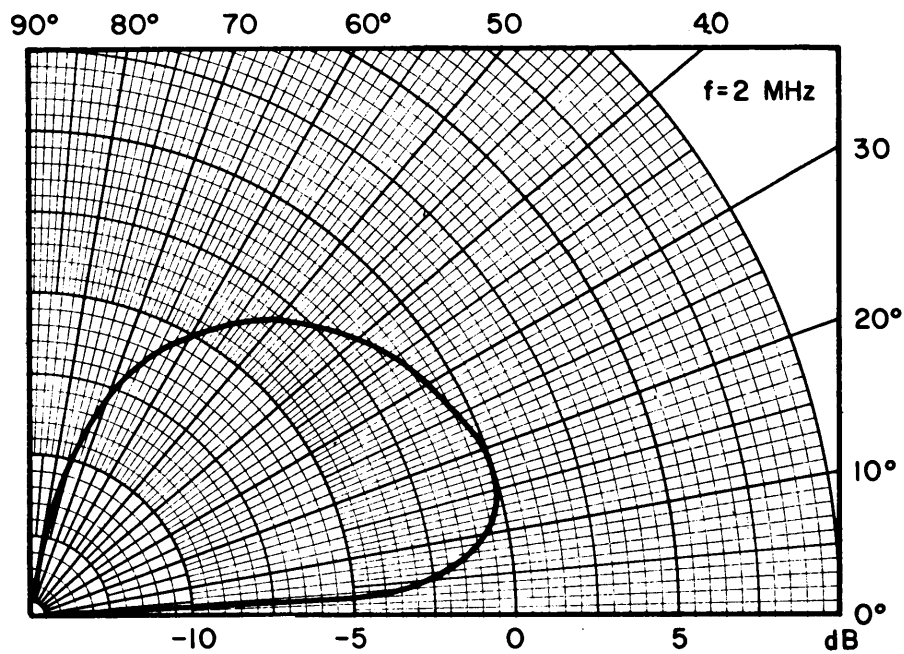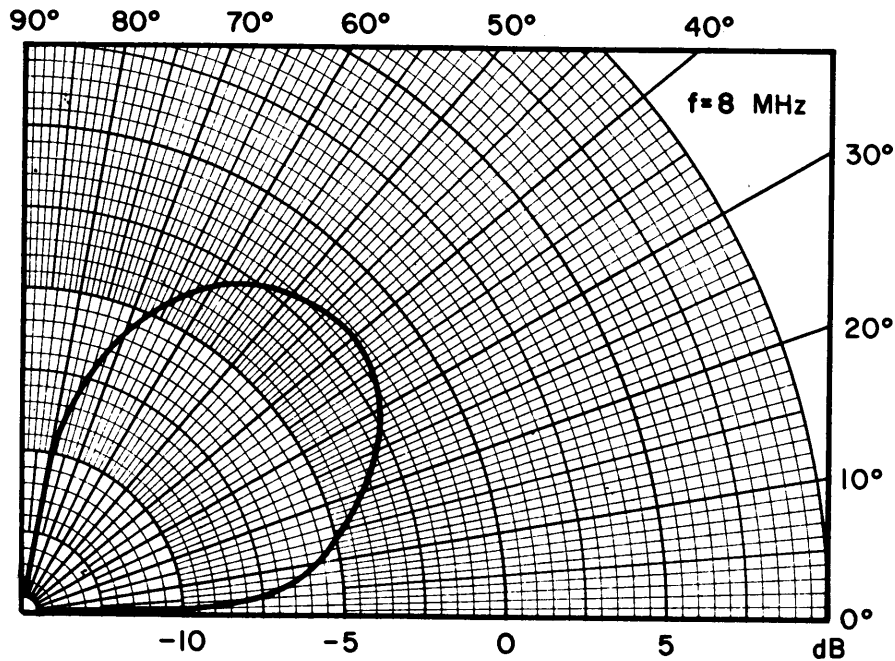Figure 4-14. Inverted Cone Antenna Vertical Radiation Pattern
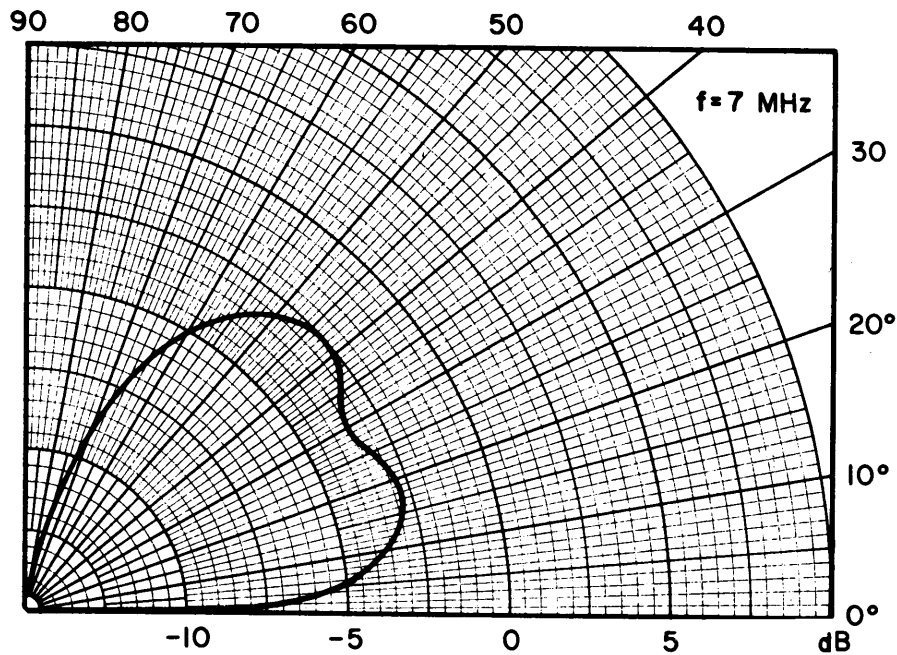(Sheet 2 of 2)

Figure 4-15. Conical Monopole

CONICAL MONOPOLE ANTENNA
VERTICAL RADIATION PATTERN
FOR EXAMPLE DESIGN

OVER AVERAGE EARTH ($\epsilon = 15$, $\sigma = 10^{-2}$ MHOS/METER)
(GAIN REFERRED TO MAXIMUM GAIN/ISOTROPIC AT 2 MHz)

Figure 4-16. Conical Monopole Antenna Vertical Radiation Pattern
(Sheet 1 of 2)

CONICAL MONOPOLE ANTENNA
VERTICAL RADIATION PATTERN
FOR EXAMPLE DESIGN

OVER AVERAGE EARTH ($\epsilon = 15$, $\sigma = 10^{-2}$ MHOS/METER)
(GAIN REFERRED TO MAXIMUM GAIN/ISOTROPIC AT 2 MHz)

Figure 4-16. Conical Monopole Antenna Vertical Radiation Pattern
(Sheet 2 of 2)

the radiating elements are connected at the top and bottom discs. However some conical monopole configurations, such as the AS-2205/FRC, have the radiating elements terminated at the waist disc rather than the top disc.

The coaxial transmission line is terminated at the bottom disc in a terminal assembly. The transmission line is connected directly to the antenna without benefit of an impedance matching device. Most of these antennas used in transmitting applications are designed for 40 kW average power operation.

In addition to the wide bandwidth and high power features of conical monopoles, physical size is a distinct advantage. Supporting towers for 7 to 28 MHz antennas are about 24 feet high.

Conical monopoles require a ground plane radial system similar to that used with inverted cones and some types of discones.

The gain of conical monopoles is usually slightly less than that of discones and inverted cones, typically −2 to +2 dB. This antenna is very effective for Navy communications, with a VSWR of up to 2.5:1.

4.8.2 Summary

Conical monopoles are omnidirectional antennas that are capable of high power operation. They provide broad bandwidth capability, and are relatively inexpensive to procure and install. The short supporting structure and direct feed are primary advantages of these antennas.

4.9 SELECTIVELY DIRECTIONAL MONOPOLE ANTENNA

The latest model of this antenna has been accepted and placed in service for Navy HF transmitting applications as the AN/FRA-109. It is a high power radiator capable of operating either omnidirectionally, or directionally, as selected.

4.9.1 Physical and Electrical Characteristics.

The AN/FRA-109 antenna system consists of two separate monopole antennas plus auxiliary equipment as shown in figure 4-17.

One monopole (the low-band) covers the 4 to 11 MHz range, while the other monopole (the high-band) covers the 11 to 30 MHz range. The two antennas are identical in construction except for differences in physical size dictated by frequency. The monopole is illustrated in figure 4-18.

Both monopole antennas are surrounded by sixteen equally spaced reflectors which can be activated to direct the transmitted signal into a wide or narrow beam in any of the eight compass bearings (N, NE, E, SE, S, SW, W, NW). A single reflector consists of six lengths of copper tubing mounted end-to-end and separated by five pneumatic switches
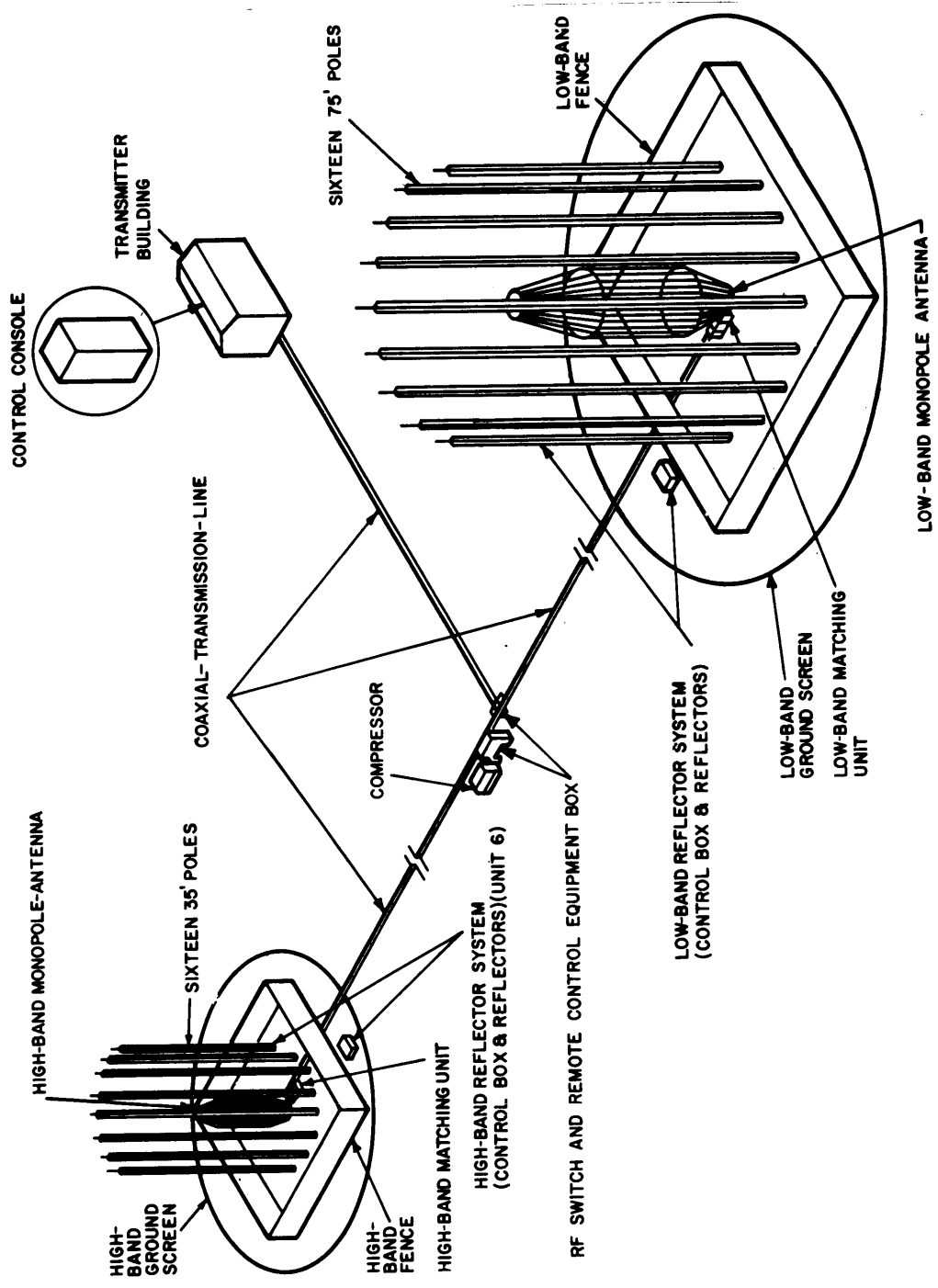
Figure 4-17. Antenna Set, AN/FRA-109

DOME

UPPER TOWER
SECTION

RADIATORS
(36 PLACES)

MID RING

52' 11 $\frac{1}{2}$"
LOW-BAND
ANTENNA

TO ANCHOR

TO ANCHOR

19.17'
HIGH-BAND
ANTENNA

MIDDLE TOWER SECTION

MID RING

LOWER TOWER SECTION

LOWER GUY
(3 PLACES
120° APART)
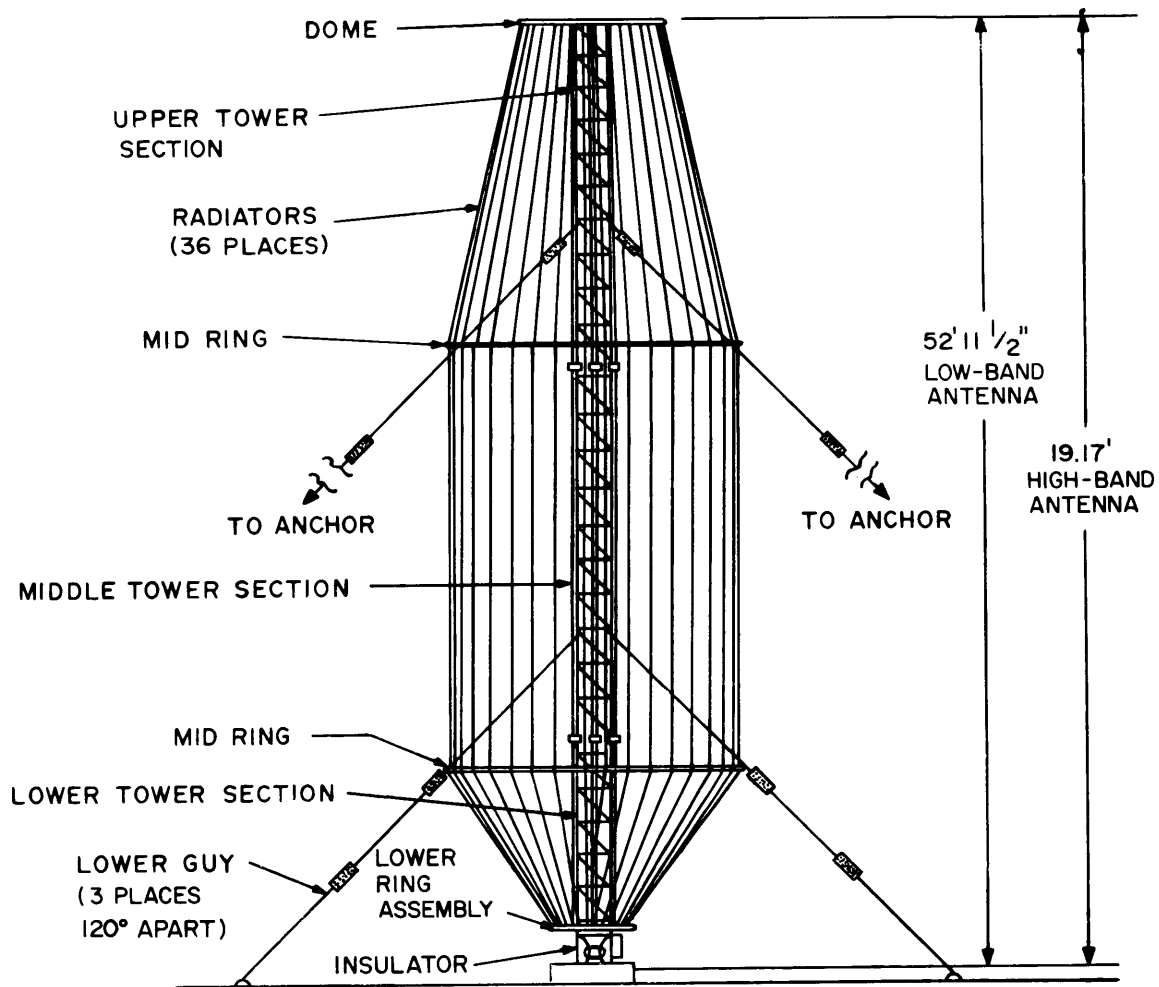
LOWER
RING
ASSEMBLY

INSULATOR

Figure 4-18. Low- and High-Band Monopole Antenna

as shown in figure 4-19. Air pressure from a compressor controls a movable contact
within each of the switches. The contact is held open by a spring. When air is intro-
duced into a reflector, the air pressure overcomes the spring tension, and the switch con-
tacts close, thereby activating the reflector. By decreasing the air pressure, the switches
open, and the reflector is deactivated. The reflector control units located in the trans-
mitter building establish the directional and beamwidth characteristics of the antenna by
activating groups of reflectors selectively. The beamwidth is established by the number
of reflectors activated and the direction of radiation is determined by the physical loca-
tion of the activated reflectors in relation to the monopole antenna. If all the reflectors
are deactivated, the antenna radiates omnidirectionally. The reflector assemblies are
mounted on wood poles attached by standoff insulators as shown in figure 4-19. The
reflectors for both high- and low-band are identical except for length.

Both monopoles require separate ground plane systems of wire radials. The radials are
welded to a perimeter bonding-wire which is connected to ground rods. The diameter of
the low-band ground plane configuration is 246 feet; the high-band is 90 feet in diameter.
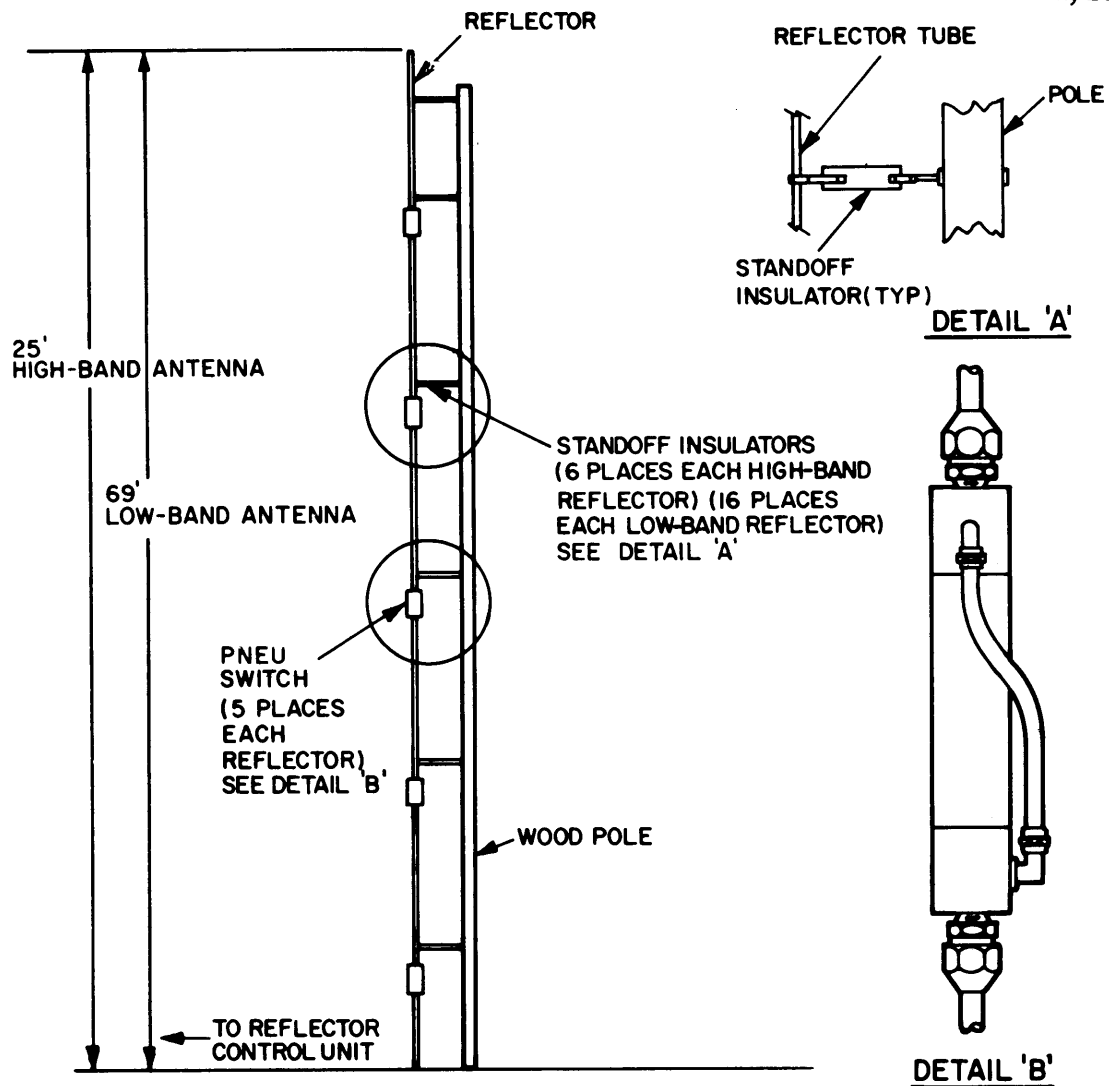
Figure 4-19. Individual Low- and High-Band Reflectors

The power handling capability of the AN/FRA-109 system is 300 kW average power over the 4 to 30 MHz frequency range.

Directive gain for the system is not less than 4.5 dB in the omnidirectional mode, and not less than 8.5 dB and 9.5 dB in the wide (180°) and narrow (45°) directive modes, respectively.

The monopoles are fed with 50-ohm coaxial transmission lines. VSWR is 2:1 or less throughout the design frequency range.

4.9.2 Summary

The selectively directional monopole system may be characterized as a complex, high-power, broadband vertically polarized HF transmitting antenna which provides either omnidirectional or selected directional radiation as desired. From 5 to 8 acres of land are required for siting. These antennas are expensive in comparison with other HF vertical radiators.

4.10 HORIZONTAL RHOMBIC ANTENNAS

Horizontal rhombic antennas are the most commonly used antennas for point-to-point HF naval communications.

In its basic configuration, a rhombic is composed of four long horizontal conductors or legs, arranged in the shape of a rhombus. One apex of the rhombus is connected to a transmission line. The opposite apex is normally connected to a termination resistance in order to make the antenna unidirectional and nonresonant.

4.10.1 Physical and Electrical Characteristics

The characteristic impedance appearing at the apexes of the fundamental rhombic configuration is moderately variable with frequency, with a mean value of approximately 800 ohms. For maximum suppression of backward radiation, the value of the terminating resistance should exactly match the characteristic impedance appearing at the apex. However, this characteristic impedance exceeds that which would match a 50- or 600- ohm transmission line. The antenna characteristic impedance (and consequently, the antenna input impedance) can be lowered and made almost constant over a frequency range of better than 2:1 when the antenna legs are constructed of properly spaced multiple conductors. Such multiple conductor construction is illustrated in figure 4-20 which is a sketch of the three-wire non-resonant horizontal rhombic. The spacing between these conductors increases from zero at the apexes to a maximum of several feet at the side poles, so that radiator capacitance varies in a manner which maintains constant impedance along the length of the antenna. A nominal 600-ohm input impedance can be obtained in this manner.

℄ MAIN LOBE

MAJOR AXIS HORIZONTAL

Δ

DISSIPATION LINE

H = HEIGHT OF ANTENNA ABOVE GROUND

ϕ = TILT ANGLE

ℓ = LEG LENGTH OF ONE SIDE
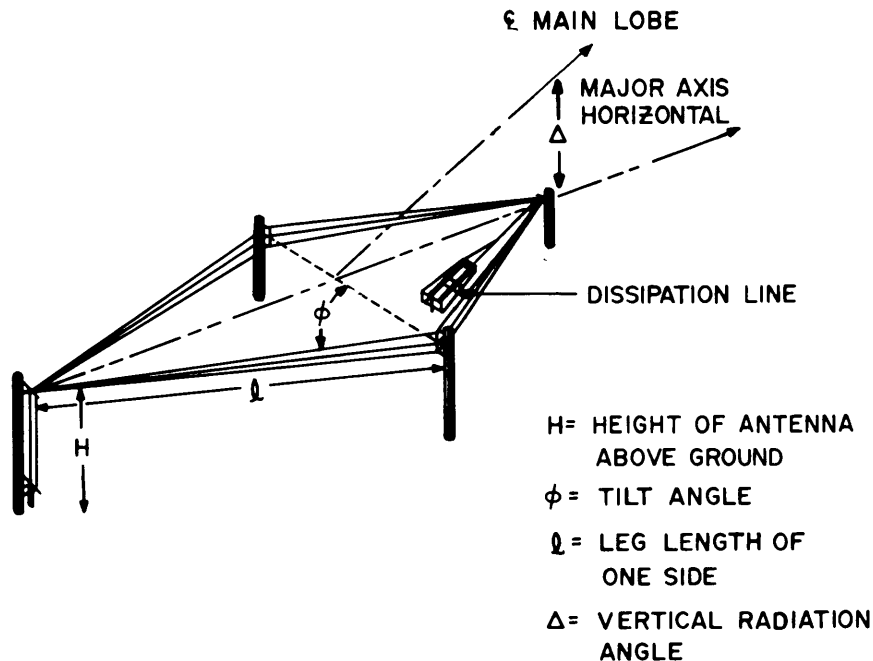
Δ = VERTICAL RADIATION ANGLE

Figure 4-20. Non-Resonant Horizontal Three-Wire Rhombic

When the rhombic is terminated in its characteristic impedance, the rhombic and its associated components does not have the high voltage standing waves typical of resonant antennas and the overall power gain of the rhombic remains relatively high because of the increased directivity afforded by the termination. Average radiation efficiency of a rhombic terminated in its characteristic impedance is approximately 67 percent.

The radiation pattern and power gain of a rhombic antenna vary widely, not only with frequency but also with physical shape and dimensions. Physical data and performance characteristics of the rhombic antenna, therefore, generally include the height of the antenna above ground level, the tilt angle (one-half the interior obtuse angles at the side poles), the leg length of one of the four sides and the vertical radiation angle as shown in figure 4-20.

Since the rhombic is a system of long-wire radiators which depends upon radiated wave interaction for its gain and directivity, the physical size of the antenna is large. The rhombic generally requires more land than any other commonly used HF antenna, usually between 5 and 15 acres of level ground. The rhombic develops its maximum directivity and lowest radiation angle when its length and height are large in terms of wavelength. Maximum power gain of the rhombic antenna typically ranges from 8.0 dB to 23.0 dB depending on the operating frequency and physical characteristics. The horizontal beamwidth varies somewhat with frequency, and the vertical beamwidth is dependent upon the height of the antenna in wavelengths above ground. Figure 4-21 illustrates typical vertical radiation patterns (ref. 14) calculated for a rhombic design.

Where propagation conditions and path length require very high vertical radiation angles at the low end of the HF spectrum, design of a rhombic antenna to operate at an acceptable power gain with adequate side lobe suppression is difficult. At very low radiation angles at the high end of the HF spectrum, a rhombic antenna becomes excessively directive in the vertical plane, thus providing a circuit extremely vulnerable to ionospheric layer variations. Consequently, other antenna types should be considered where the transmission path requires vertical radiation angles below 3° and above 35°.

Since the vertical radiation angle and vertical directivity vary considerably with frequency, it is apparent that a single antenna is not likely to maintain a satisfactory power gain or lobe orientation over the entire HF spectrum. Consequently, it is normal to cover the major portion of the spectrum with two or three rhombic antennas of different dimensions. The calculated vertical-plane main-lobe patterns for four rhombic antenna example designs, shown in figure 4-21, illustrate the manner in which vertical directivity and radiation angle vary with antenna geometry and operating frequency. In the figure, maximum antenna gain is referred to 0 dB at the optimum radiation angle and frequency.

The nominal bandwidth of the horizontal rhombic antenna is usually greater than 2:1. Although a properly terminated rhombic antenna presents to the transmission line an input impedance which is virtually insensitive to frequency variations up to 5:1, the useful bandwidth is limited by the allowable radiation pattern variation and minimum minor-lobe suppression.

For frequency variations appreciably greater than 2:1, the sidelobe suppression, lobe alignment, and directivity deteriorate rapidly. The horizontal patterns of figure 4-22 (ref. 14) calculated for a low-band rhombic antenna, illustrate the effects of operation of a rhombic antenna beyond the nominal 2:1 bandwidth. This particular antenna was designed for operation from 4.5 to 9.0 MHz at vertical radiation angles ranging from 10° to 30°. Horizontal patterns are shown for operation from 1.5 MHz below to 3 MHz above

RHOMBIC ANTENNA DESIGN NO.1
ℓ = 328 FEET
H = 98 FEET
Ø = 54°

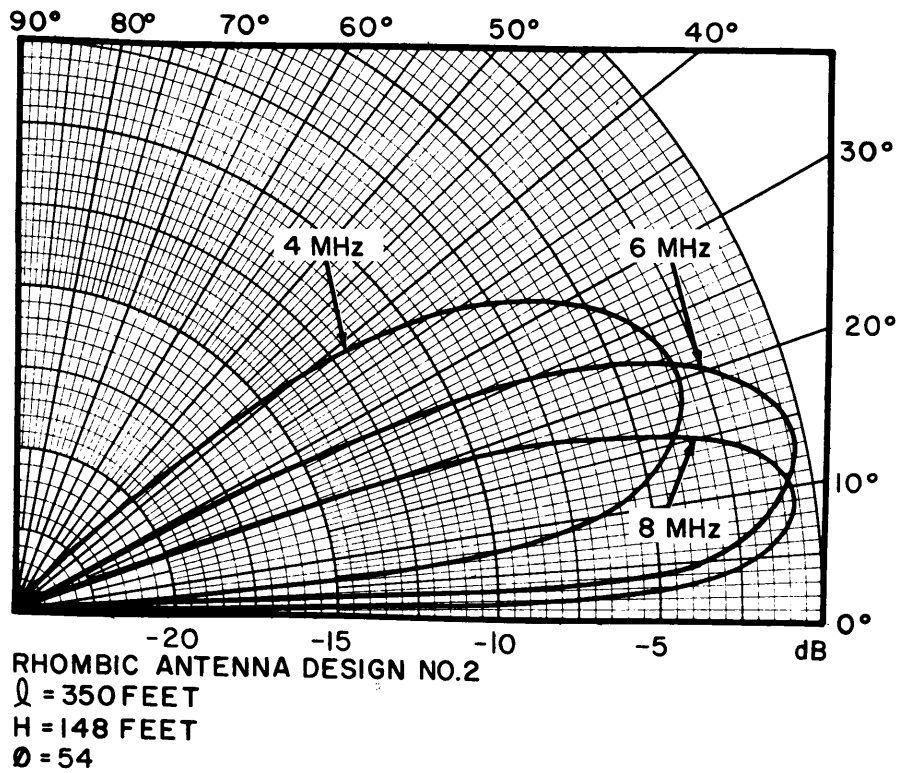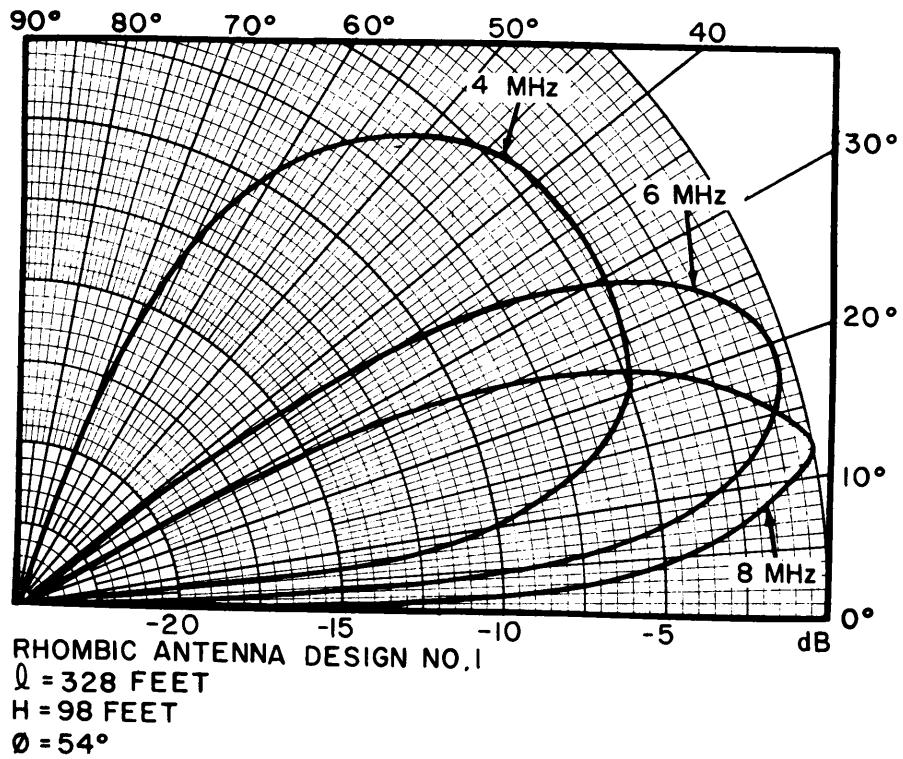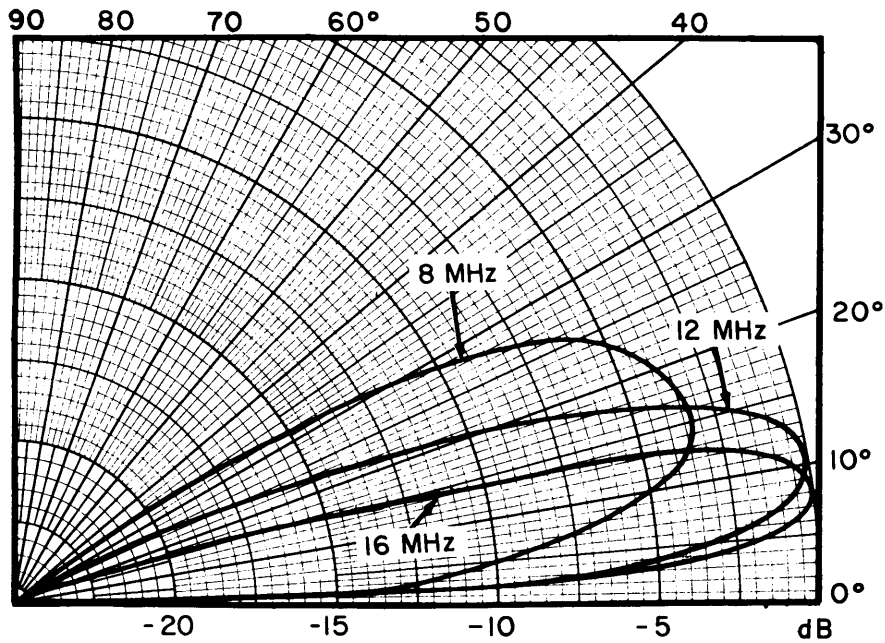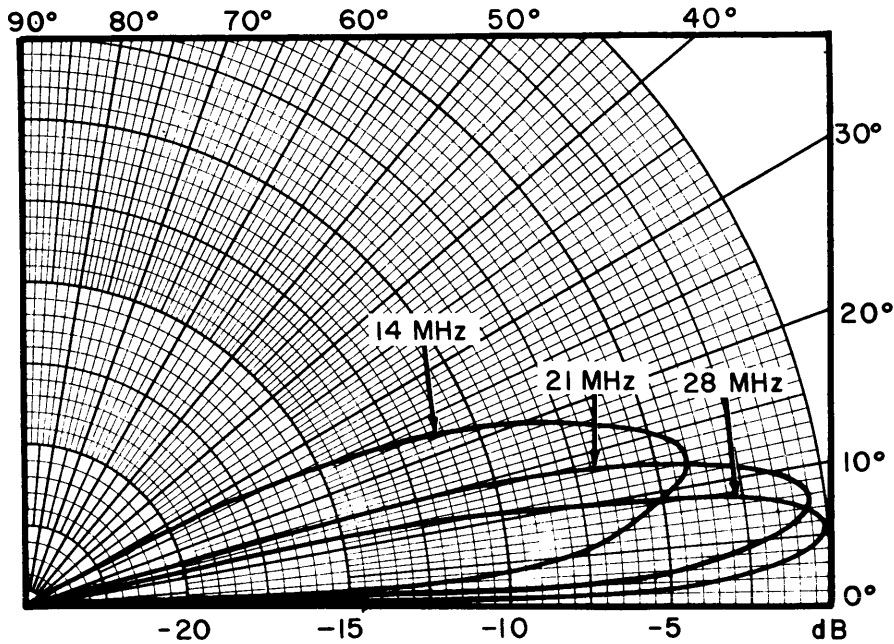RHOMBIC ANTENNA DESIGN NO.2
ℓ = 350 FEET
H = 148 FEET
Ø = 54

Figure 4-21. Calculated Vertical Radiation Patterns
for Rhombic Design Example

(Sheet 1 of 2)

RHOMBIC ANTENNA DESIGN NO.3
l = 282 FEET
H = 90 FEET
$\emptyset$ = 62°

RHOMBIC ANTENNA DESIGN NO.4
l = 235 FEET
H = 75 FEET
$\emptyset$ = 68°

Figure 4-21. Calculated Vertical Radiation Patterns
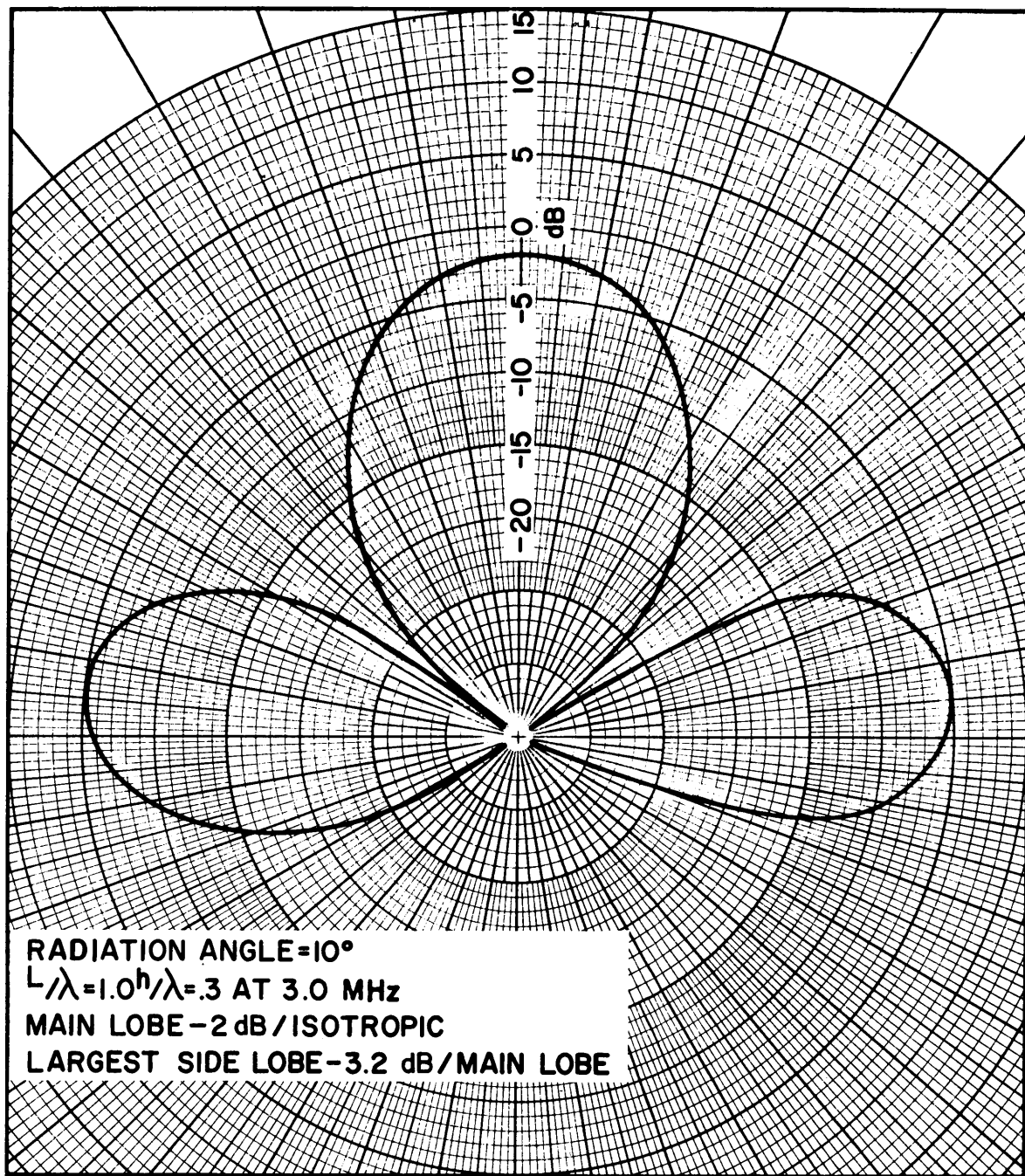for Rhombic Design Example
(Sheet 2 of 2)

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 1 of 10)

the design bandwidth. Within the design bandwidth, the poorest sidelobe suppression
occurs at 9 MHz; at this frequency, the main lobe exhibits a maximum gain of 13.4 dB at
a vertical angle of 10°, while the largest sidelobe at any vertical angle occurs also at
10° with a gain of 6 dB, which is 7.4 dB below the main lobe. At the high end of the design
bandwidth, the main lobe diminishes rapidly with increasing vertical angle while sidelobes
remain relatively constant. To properly evaluate sidelobe suppression, it is necessary to
compare the maximum values of the main and the largest minor lobe at each frequency of
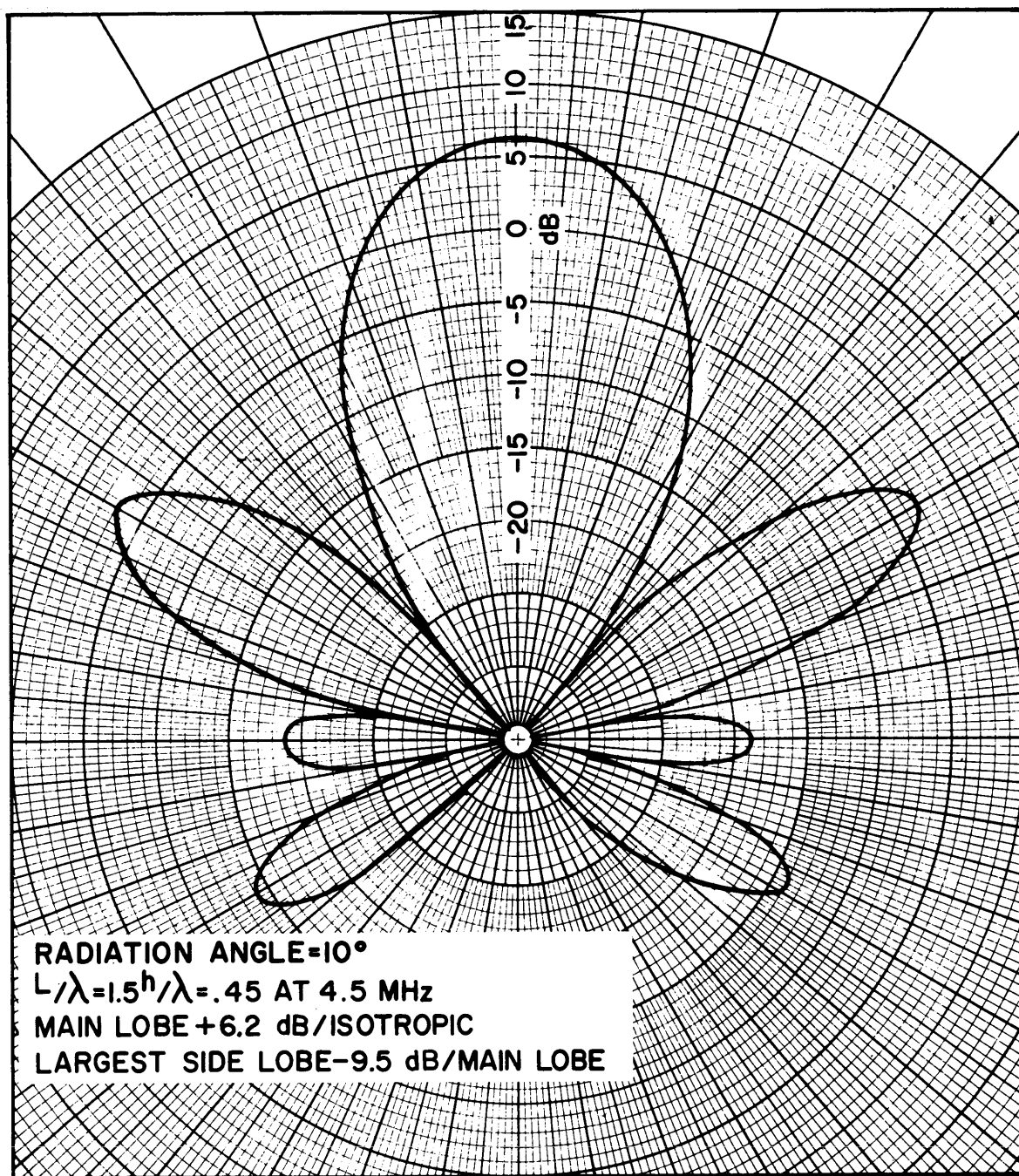interest and at whatever vertical angle each occurs.
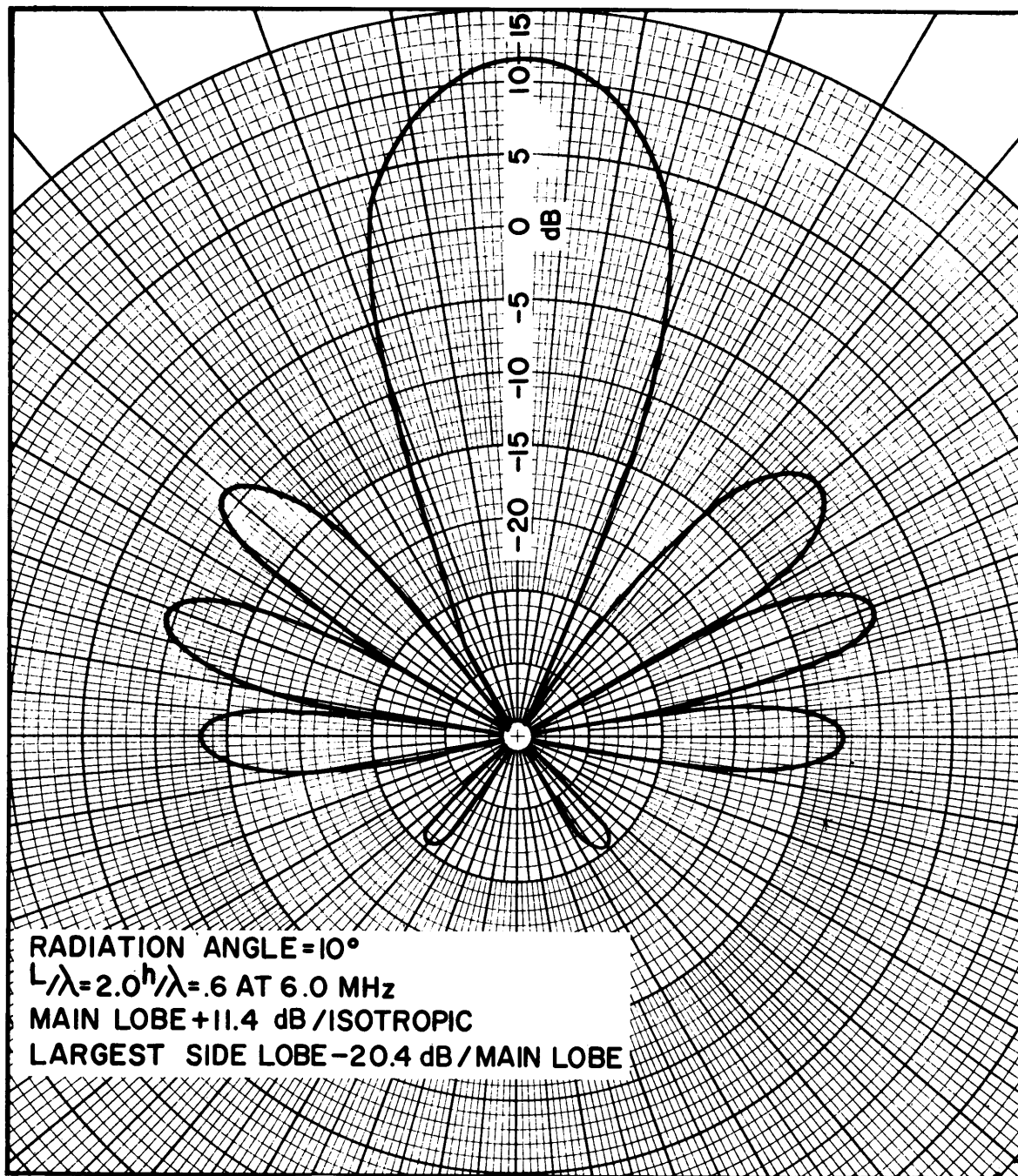
RADIATION ANGLE=10°
L/λ=1.5 $^h/\lambda$=.45 AT 4.5 MHz
MAIN LOBE+6.2 dB/ISOTROPIC
LARGEST SIDE LOBE−9.5 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 2 of 10)

RADIATION ANGLE=10°
L/λ=2.0 $^h/\lambda$=.6 AT 6.0 MHz
MAIN LOBE+11.4 dB/ISOTROPIC
LARGEST SIDE LOBE-20.4 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 3 of 10)

RADIATION ANGLE=10°
L/λ=3.0 $^h/\lambda$=.9 AT 9.0 MHz
MAIN LOBE + 13.6 dB/ISOTROPIC
LARGEST SIDE LOBE −7.4 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns

(Sheet 4 of 10)

RADIATION ANGLE=10°
L/λ=4.0 /λ=1.2 AT 12.0 MHz
MAIN LOBE +5.4 dB/ISOTROPIC
LARGEST SIDE LOBE
+2.0 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 5 of 10)

RADIATION ANGLE=20°

L/λ=1.0 h/λ=.3 AT 3.0 MHz

MAIN LOBE+3.5 dB/ISOTROPIC

LARGEST SIDE LOBE-3.8 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns

(Sheet 6 of 10)

RADIATION ANGLE=20°

L/λ=1.5 h/λ=.45 AT 4.5 MHz
MAIN LOBE+11.0 dB/ISOTROPIC
LARGEST SIDE LOBE-10.5 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 7 of 10)

RADIATION ANGLE=20°
L/λ=2.0 $^h/\lambda$=6 AT 6.0 MHz
MAIN LOBE+14.1 dB/ISOTROPIC
LARGEST SIDE LOBE-14.6 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 8 of 10)

RADIATION ANGLE=20°
L/λ=3.0 h/λ=.9 AT 9.0 MHz
MAIN LOBE+8.2 dB/ISOTROPIC
LARGEST SIDE LOBE
−3.2 dB/MAIN LOBE

Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 9 of 10)

RADIATION ANGLE=20°

L/λ=4.0 h/λ=1.2 AT 12.0 MHz

MAIN LOBE−28.7 dB/ISOTROPIC

LARGEST SIDE LOBE+36.8 dB/MAIN LOBE
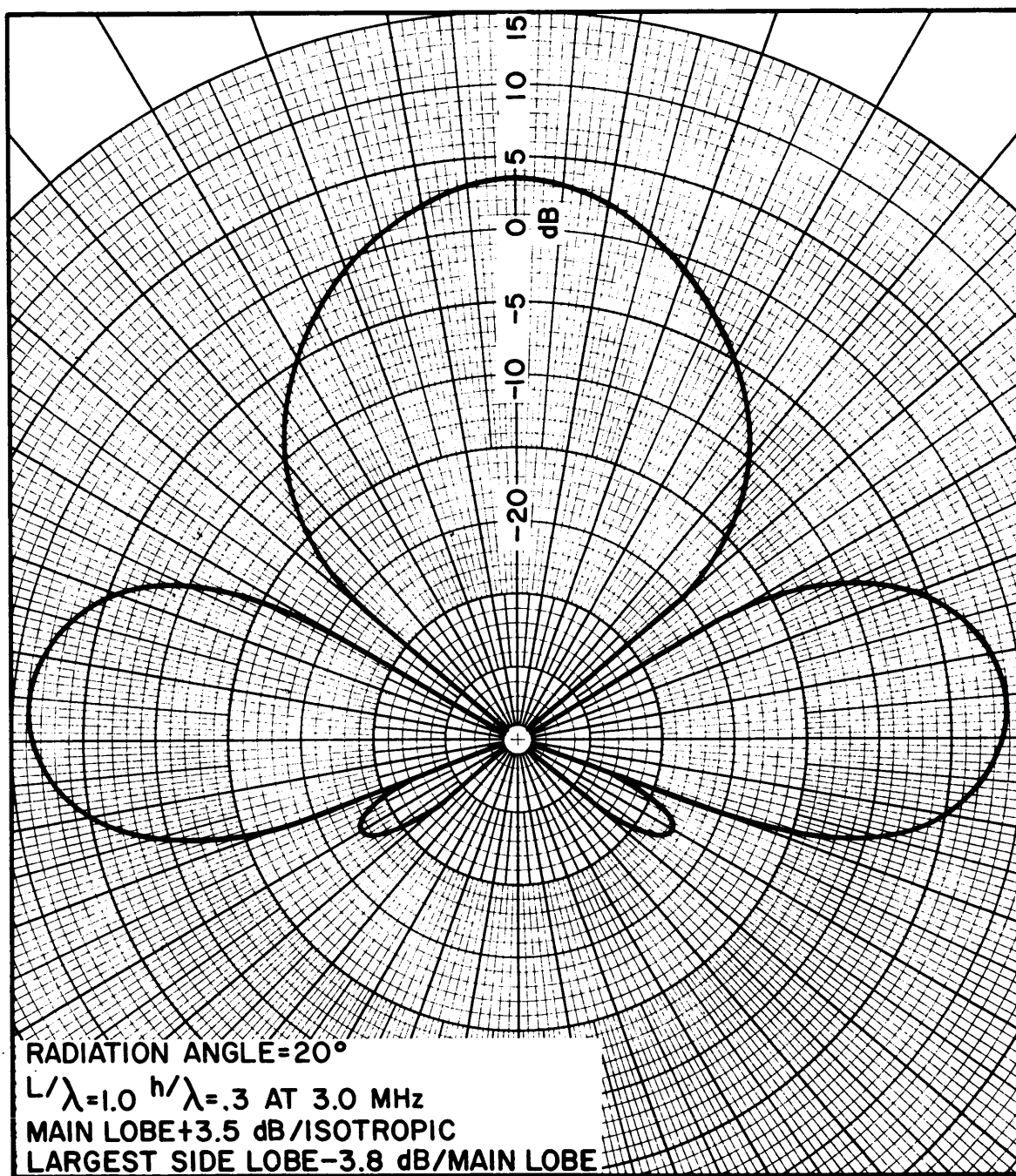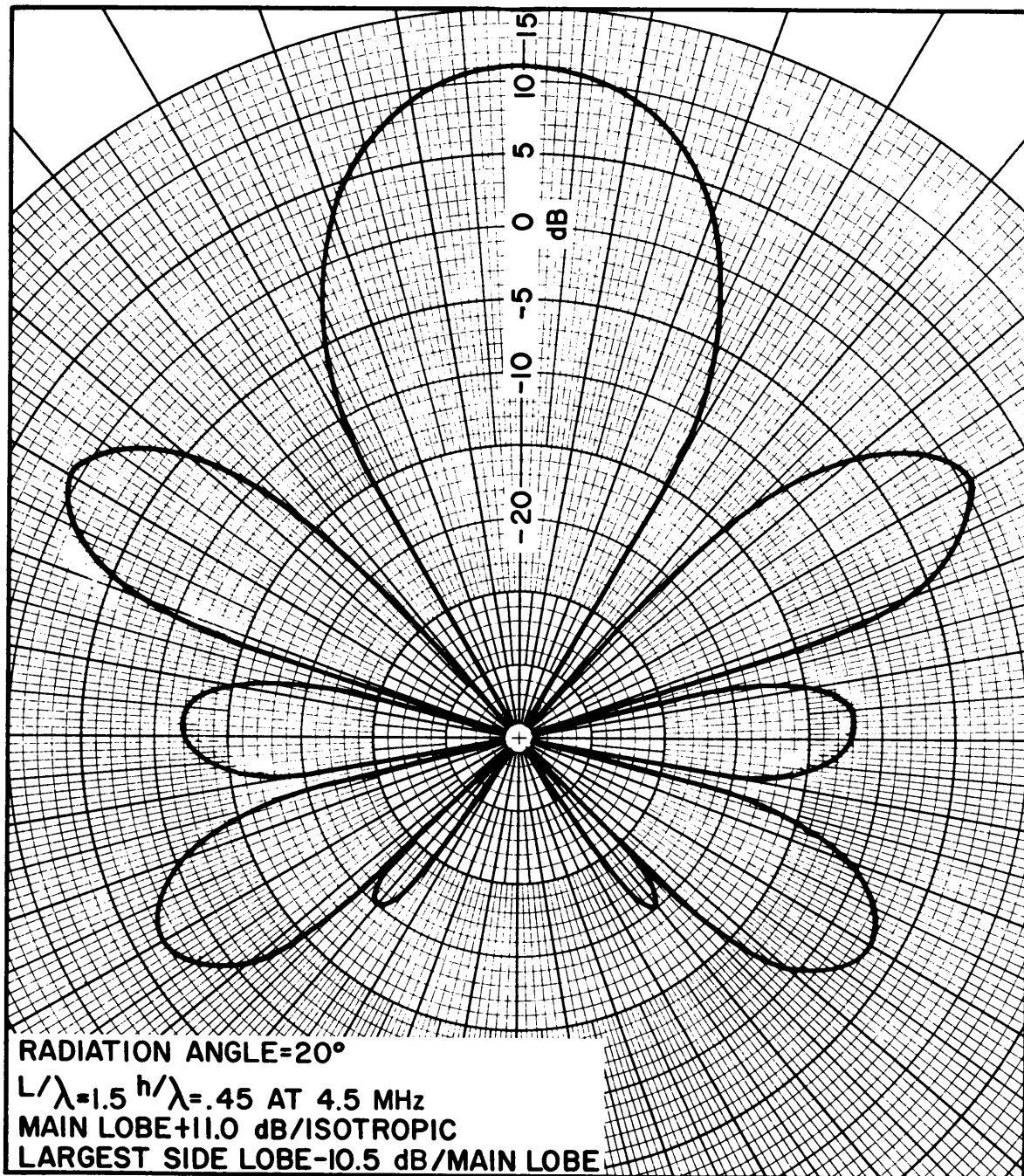
Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 10 of 10)

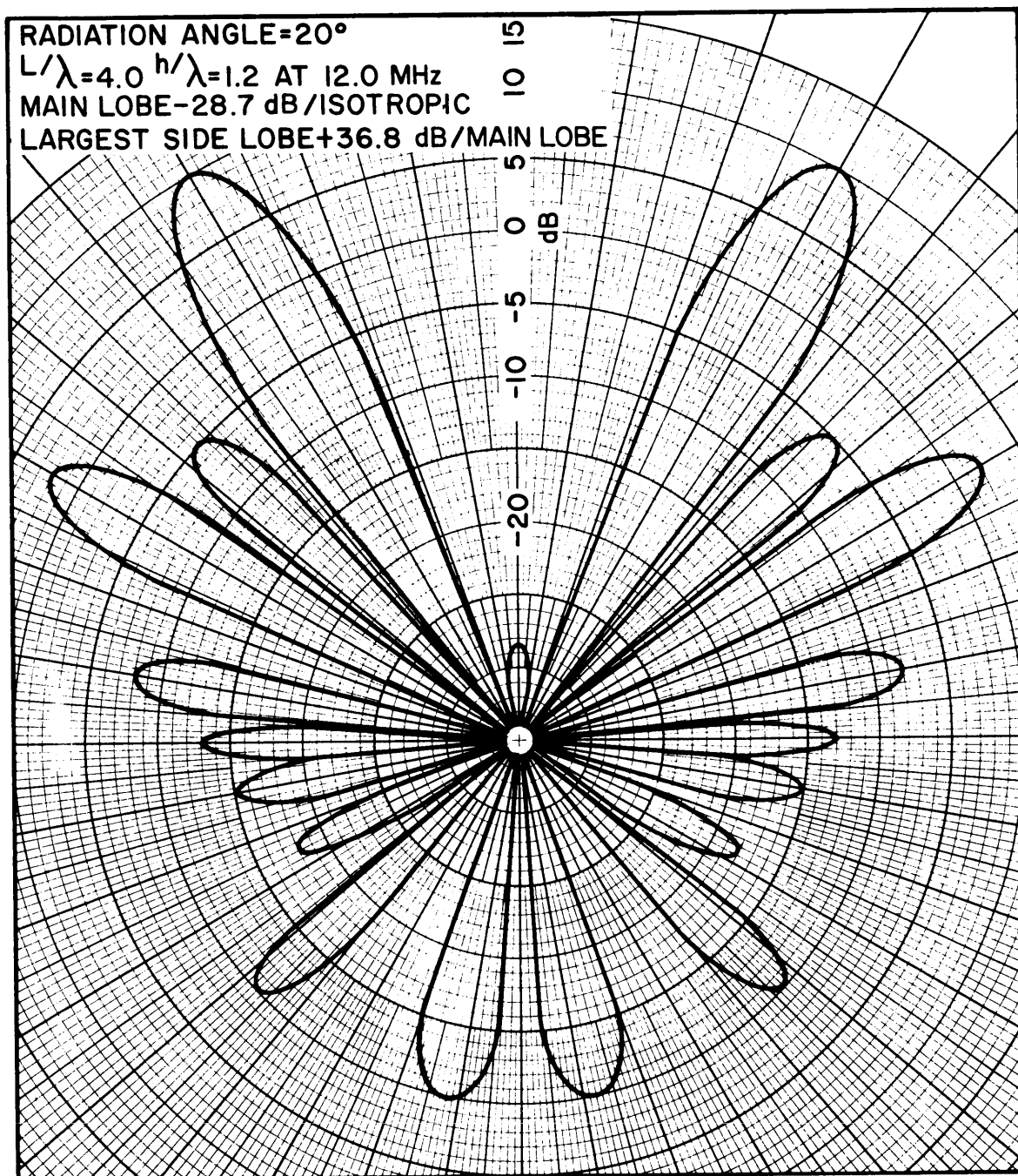In receiving systems, a rhombic antenna can also operate effectively when terminated at both ends. This "double-ended" termination makes possible simultaneous reception of two transmissions separated 180° in azimuth, while the antenna retains its unidirectional characteristics in each direction. The "double-ended" configuration requires that separate coaxial transmission lines from both ends of the antenna be terminated through a matching transformer.

Under very uncommon circumstances, an unterminated rhombic antenna installation may be acceptable; e.g., if antenna resonance at a particular frequency is desirable, and if radiated interference from the resultant backlobes is of no concern.

The standard three-wire rhombic is widely used in Navy HF communications in a "nested-pair" configuration. In this type of installation a smaller, higher frequency three-wire rhombic is placed within the periphery of a larger, lower frequency rhombic. For a typical "nested-pair" as shown schematically in figure 4-23, the inner rhombic might be designed for operation in the 10 to 28 MHz range, and the outer for 4 to 10 MHz. The two rhombics are not connected together physically or electrically; however, both are connected to a common feed (rear) pole. Both antennas can be used simultaneously with negligible interaction as long as reasonable care is used in the selection of operating frequencies. The principal advantages of the "nested" configuration are: reduced installation costs and more effective utilization of land.

4.10.2 Special Rhombic Configurations

There are other configurations, shown in figure 4-24, which are less commonly used than the three-wire standard type, but which are very efficient for certain applications.

a. Tiered Rhombic. The tiered rhombic is comprised of two rhombics arranged in a double-tier and driven in parallel. This configuration reduces the characteristic impedance of the array so that the current in the conductors near the input terminals is decreased. High-angle lobes in the vertical plane are reduced also. This antenna exhibits only 1 to 2 dB higher gain than the single rhombic, but the much-improved vertical pattern is less vulnerable to the effects of multipath propagation and noise arriving from high vertical angles.

b. Interlaced Rhombic. The radiating legs of this system are so oriented that destructive wave interference occurs in almost all directions except along the main beam axis. Such an arrangement, illustrated by figure 4-24B, can produce gain 4 to 5 dB superior to the single rhombic antenna without affecting the beamwidth of the major lobe.

c. La Port Rhombic. This variation of interlacing involves driving two or more rhomboid configurations from a common feed point, as shown in figure 4-24C so that gain is increased through horizontal beamwidth reduction. Such an antenna will exhibit a power gain of approximately 29 dB with respect to an isotropic antenna.

d. Sloping Rhombic. When a rhombic antenna is sloped along its principal axis, so that one apex is nearer the ground than the other, the vertical radiation pattern is altered by the change in relationship between the free-space field and the ground-reflected components. The free-space vertical angle is increased, with corresponding

OUTER (4 TO 10 MHz) RHOMBIC
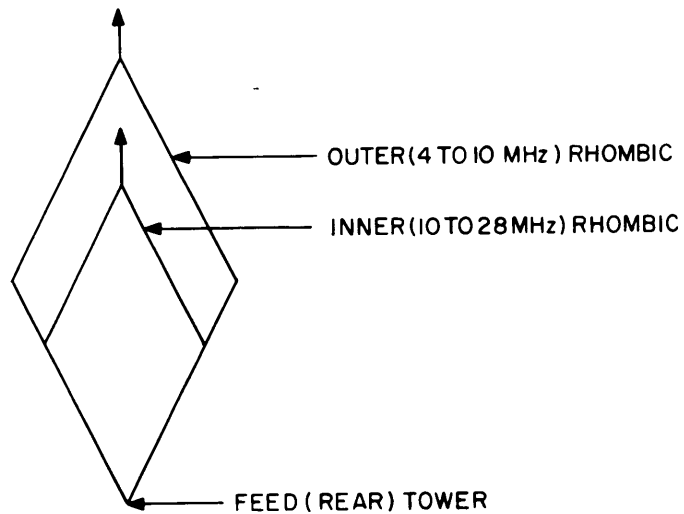
INNER (10 TO 28 MHz) RHOMBIC

FEED (REAR) TOWER

Figure 4-23. Nested Rhombic Configuration

decrease or increase in the reflection angle, depending on whether the slope is up or down in the direction of the principal beam. The end effect of sloping the antenna is a broadening of the vertical pattern and a slower rate of change of the vertical angle of maximum radiation with changing frequency.
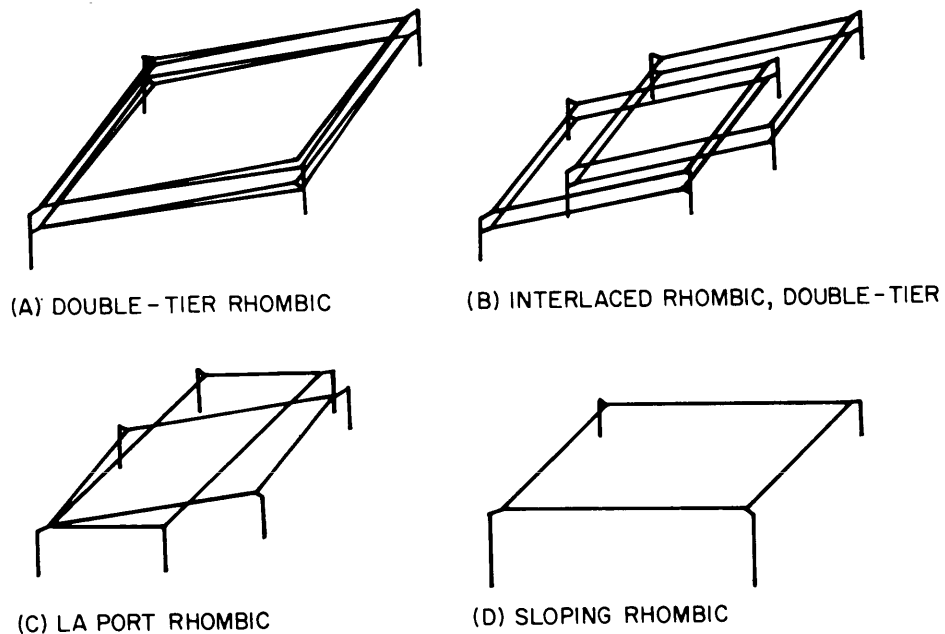

(A) DOUBLE-TIER RHOMBIC

(B) INTERLACED RHOMBIC, DOUBLE-TIER

(C) LA PORT RHOMBIC

(D) SLOPING RHOMBIC

Figure 4-24. Special Rhombic Antenna Configurations

4.10.3 Summary

Rhombic antennas can be characterized as high-power, low-angle, high-gain, horizontally polarized, highly directive, broadband antennas of simple, inexpensive construction. A properly designed rhombic antenna presents to the transmission line an input impedance which is insensitive to frequency variations up to 5:1, and maintains a power gain above 9 dB anywhere within a 2:1 frequency variation. At the design-center frequency, a power gain of 17 dB is typical.

The radiation pattern produced by the four radiating legs of a rhombic antenna is modified by reflections from the earth under, and immediately in front of the antenna. Because of the importance of these ground reflections in the proper formation of the main lobe, the rhombic antenna should be installed over reasonably smooth and level ground. The main disadvantage of the rhombic antenna is the requirement for a large land area.

4.11 HORIZONTAL VEE ANTENNA

The horizontal Vee antenna is a type of long-wire radiating system with characteristics very similar to those of the rhombic.

4.11.1 Physical and Electrical Characteristics

The Vee antenna consists of two horizontal long-wire radiators arranged in a "V" shape with the apex of the Vee connected to the transmission line. Each of the two wires contributes a field to the resultant bi-directional radiation pattern. In order to make the system non-resonant and unidirectional, the legs of the Vee are terminated with non-inductive 400 to 600 ohm resistors as illustrated in figure 4-25.

The radiation efficiency of the Vee antenna, substantially less than that of the rhombic, is typically 35 to 50 precent. The radiation pattern and power gain vary widely with frequency and with physical shape and dimension. The important physical parameters, shown in figure 4-25, include the height of the radiators above ground, the apex angle, the leg length and vertical radiation angle.

The Vee antenna requires approximately one-half as much land area as the rhombic antenna, typically between 3 and 7 acres of level ground. Supporting structure heights range from 50 to 150 feet.

Although the Vee exhibits many of the desirable characteristics of the rhombic, it does not perform as well as the rhombic in regard to maximum gain and directivity.

4.11.2 Summary

A terminated Vee antenna is characterized as a high-power, low-angle, medium-gain, horizontally polarized, highly directive broadband antenna of simple, inexpensive construction. The directive gain is approximately 3 dB below that of a rhombic of the same leg length. It is moderately insensitive to frequency variations up to 3:1. At the design center frequency, a power gain of 9 dB is typical.
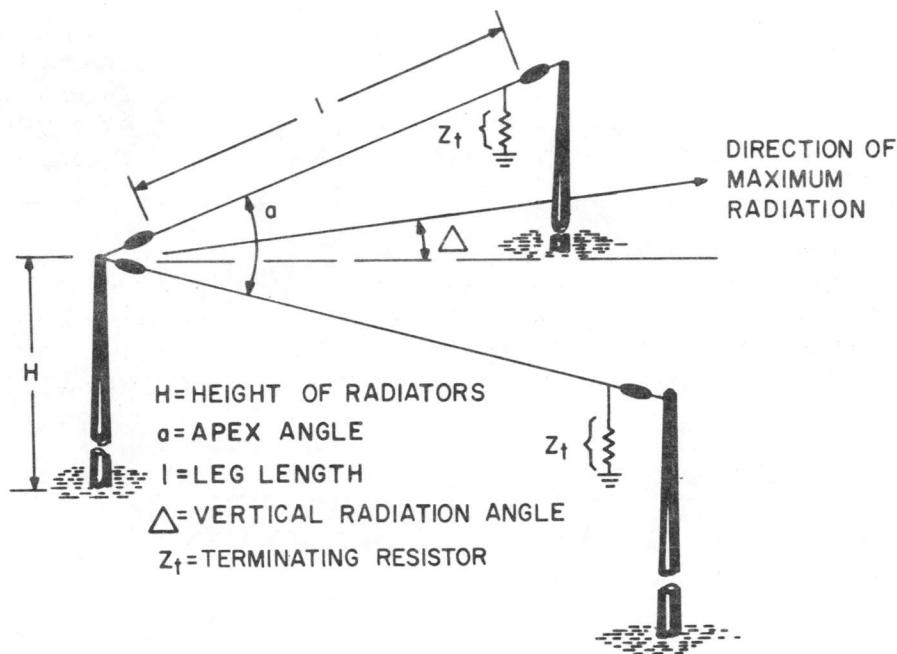
H = HEIGHT OF RADIATORS
a = APEX ANGLE
l = LEG LENGTH
△ = VERTICAL RADIATION ANGLE
Z_t = TERMINATING RESISTOR

Figure 4-25. Non-Resonant Horizontal Vee Antenna

4.12 WULLENWEBER ANTENNA ARRAY

The Wullenweber array is an effective vertically polarized antenna for Navy HF receiving systems. Although its initial development was for high frequency direction finder applications, the Wullenweber has been accepted for service as a point-to-point communications antenna. The Wullenweber is capable of providing omnidirectional coverage, sector coverage of rather broad beamwidth, or highly directive beams, separately or simultaneously, as desired.

Information of a general nature for Wullenweber installations is included in Enclosure (1) to NAVELEX letter Serial 04-2, of 4 August 1966, "High Frequency Direction Finder Criteria".

4.12.1 Physical and Electrical Characteristics

A typical Wullenweber array, as shown in figure 4-26, consists of two reflecting screens and two sets of antenna elements arranged in four concentric circles over a ground plane system of radials and mats. The low-band reflector screen forms the innermost circle; and, proceeding outward, there is the circle of 40 low-band antenna elements, then the high-band reflector screen, and then the circle of 120 high-band antenna elements. The diameter of the Wullenweber array is approximately 875 feet (circle diameter of the high-band antenna elements). However, the ground radials extend beyond this distance.
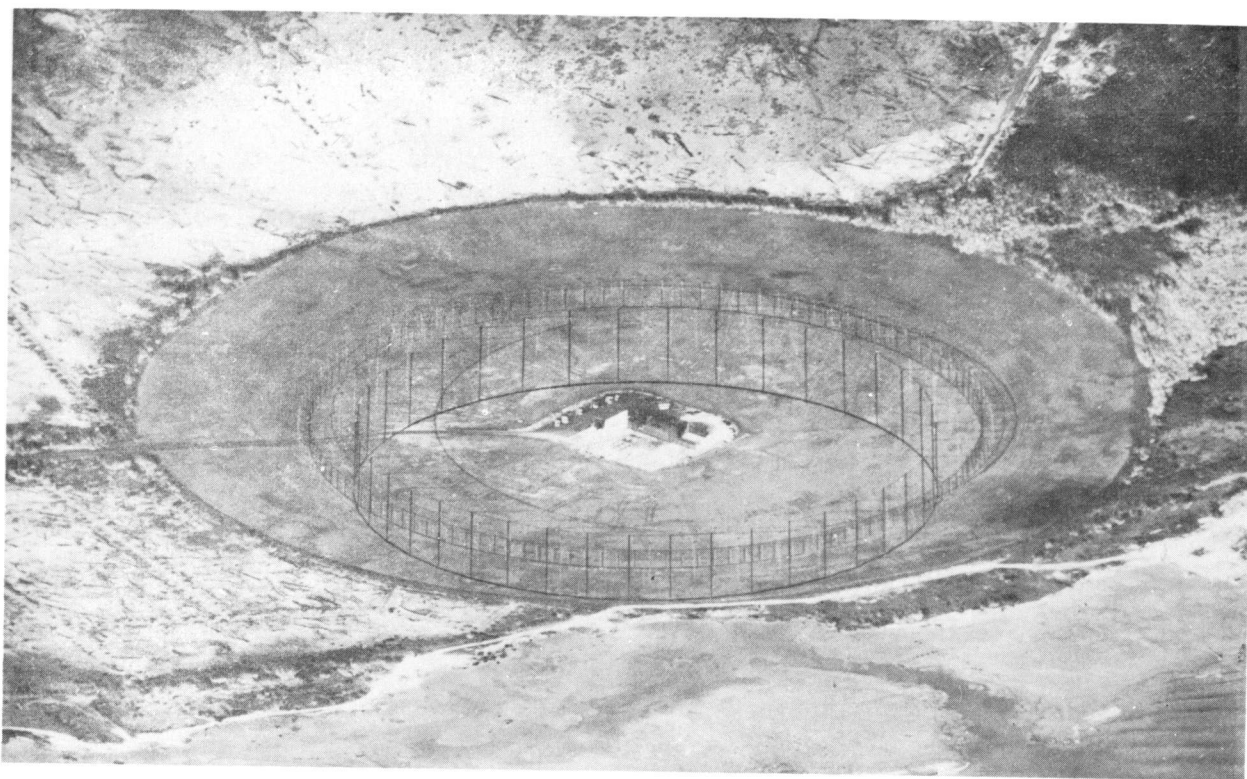
Figure 4-26. Navy Wullenweber Antenna Array

The Wullenweber array is designed to receive HF signals ranging from 2 to 10 MHz on the low-band, and from 10 to 30 MHz on the high-band antenna.

The low and high-band reflector screens are composed of vertical wires attached at the upper end to pole-supported horizontal beams, and connected to the ground plane at the lower end. This vertical screen arrangement contributes to the directional characteristics for the Wullenweber array.

Each low-band and high-band antenna element is connected to a buried coaxial transmission line which is terminated in a receiving multicoupler. All transmission lines must be electrically equal in length to ensure that the phase delay in each line is the same. Outputs of the multicouplers are fed into passive beam-forming networks and into other multicouplers to combine selected antenna elements, thus forming the desired radiation patterns and directivity.

In futhering the application of the Wullenweber array, a transportable model, the AN/TRA-40, was developed, and is presently used as the primary point-to-point receiving antenna at one naval communications station.

4.12.2 AN/TRA-40 Transportable Communications Receiving Antenna

The AN/TRA-40 antenna operates generally in the same manner as the typical Wullenweber array previously described. The main differences are that the AN/TRA-40 has only one reflector screen, has less elements in both arrays, and

is "packaged" as a transportable system utilizing semitrailer vans. Figure 4-27 shows the main units of this type of Wullenweber antenna.

The antenna consists of a reflector screen, 36 low-band antenna elements, 72 high-band antenna elements, a ground mat, a beamformer van, and interconnecting RF cables. The vertical circular reflector screen is 500 feet in diameter, and the high-band and low-band elements are located on larger circles concentric to it. A circular ground mat extends outward from the reflector screen and beyond the elements. Buried transmission lines connect the elements to the van at the center of the array where the beamforming occurs.

The AN/TRA-40 antenna array provides 36 high-gain directional beams, at 10-degree azimuthal increments, in each of two bands which together cover the entire 3 to 30 MHz frequency range. The low-band is 3 to 10 MHz and the high-band is 3 to 10 MHz. The antenna array also provides three 120-degree sector beams and a 360-degree omnidirectional pattern which is effective for the full HF frequency range.

4.12.3 Summary

The Wullenweber array can be characterized as a high gain (12 to 14 dB), wideband (typically 8:1 to 10:1), extremely versatile antenna for HF receiving purposes.

Most Navy receiver sites using the Wullenweber antenna for point-to-point communications do so on a shared basis with other mission requirements. However, one naval communications station has two complete Wullenweber arrays, both of which are dedicated to point-to-point communications services. The two arrays, located at NAVRADSTA (R), Sugar Grove, West Virginia, are separated sufficiently so that space diversity receiving techniques can be employed.

Compared to a rhombic antenna park designed to provide the same capability, the Wullenweber requires much less land area. However, its complex RF distribution and beamforming networks, plus the extensive site preparation necessary, may require much greater time, effort, and expense than other HF antenna systems.

4.13 HF QUADRANT ANTENNA

The HF quadrant antenna is a system of horizontally polarized dipole antennas used at the ground terminal in ground/air/ground communications receiving applications. It can be used in polarization diversity with discones, inverted cones, monopoles, or other vertical antennas to improve reception of signals from aircraft.

The basic configuration of the quadrant antenna is illustrated by figure 4-28. Specific design, construction, and assembly details are available in Bureau of Yards and Docks Drawing 1,046,653, Sheets 1 through 5.

4.13.1 Physical and Electrical Characteristics

The quadrant antenna is a set of six separate horizontal dipoles each of which is bent 90 degrees as shown in figure 4-28, to produce a somewhat omnidirectional
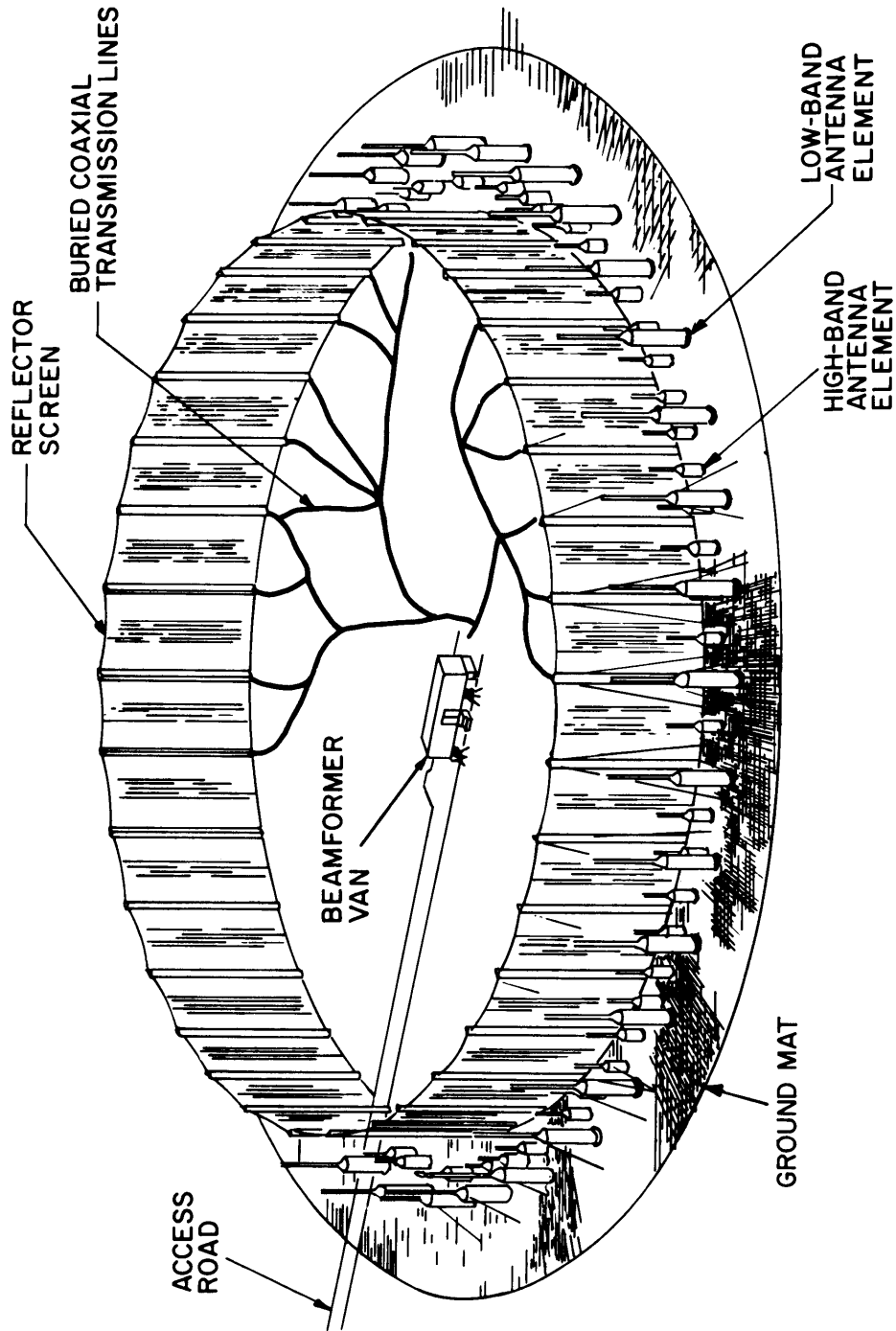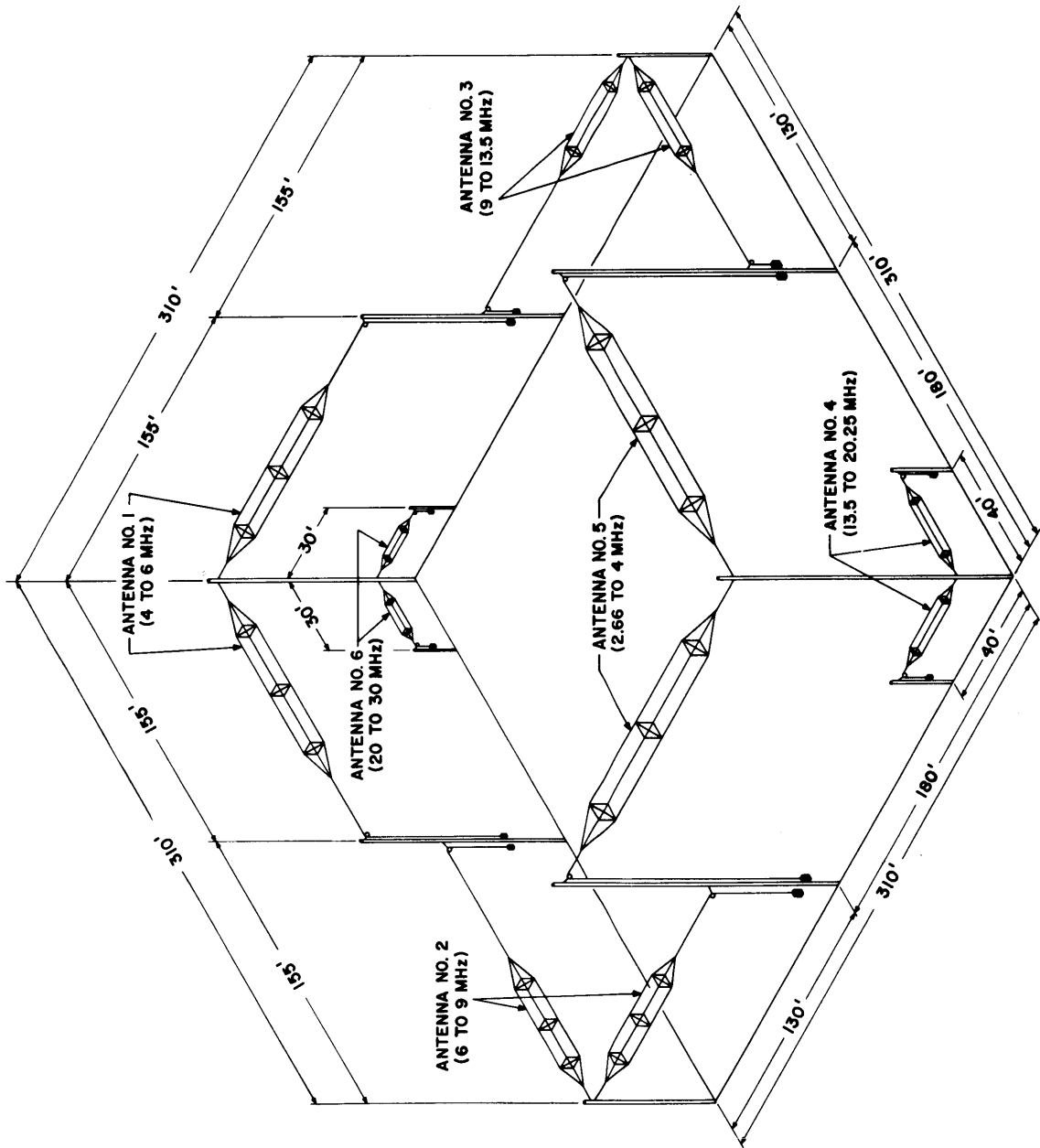
Figure 4-27. Antenna Group AN/TRA-40

Figure 4-28. HF Quadrant Antenna

radiation pattern. The overall frequency coverage provided by the set of antennas is 4 to 30 MHz.

Each antenna is suspended parallel to the earth's surface at a height of approximately one-half wavelength at its design frequency. Consequency, the height varies from approximately 20 feet for the highest frequency dipole, to about 100 feet for the lowest frequency dipole.

Although the six antennas share common supporting structures, they are electrically separate, and they require separate transmission lines. Each antenna set has a balanced input; consequently, it is necessary to use separate balun transformers to match each antenna to its transmission line.

Approximately 2.2 acres of land are required to accommodate the quadrant antenna.

4.13.2 Summary

The HF quadrant antenna is a special purpose receiving antenna used in ground/air/ground communications. It is unique among horizontally polarized antennas because its element arrangement makes possible an azimuthal radiation pattern resembling that of a vertically polarized omnidirectional antenna. Construction and installation of this antenna is complex due to the physical relationships between individual elements, and because of the requirement for a separate transmission line for each dipole.