NAVAL
SHORE ELECTRONICS
CRITERIA

HF RADIO ANTENNA SYSTEMS

DEPARTMENT OF THE NAVY
NAVAL ELECTRONIC SYSTEMS COMMAND
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FOREWORD

PURPOSE

This handbook provides an authoritative source of reference data and general technical information concerning high frequency (HF) antenna systems used in Navy shore communications facilities.

The information contained in the handbook is not to be considered as the final, detailed engineering specification for any particular facility or installation project. Rather, the intent is to present criteria and technical information sufficiently broad in scope to cover the major considerations for selecting, designing, and installing HF antenna systems.

SCOPE

The criteria and technical information in this handbook are directly related to HF antennas and their associated system components. Physical and electrical characteristics of antennas, transmission lines and other system components are covered along with antenna selection procedures and installation considerations.

The criteria for the planning, installation and checkout of system and equipment installations at shore communications stations are presented in NAVELEX 0101, 102 — "Naval Communications Station Design". Discussions concerning radio propagation paths and site selection criteria are contained in NAVELEX 0101, 103 — "HF Radio Propagation and Facility Site Selection". This handook treats these subjects to the degree necessary for clarity and continuity of subject matter.

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CHAPTER 1

STANDARDS AND PLANS

1.1 STANDARDS

High frequency (HF) radio antenna systems are used in naval shore communication installations to support many different types of circuits, including ship/shore/ship, broadcast, point-to-point, and ground/air/ground. These diverse applications require the use of various numbers and types of antennas at individual shore activities.

Some of the antenna systems are used primarily for the Navy's tactical requirements, whereas others are dedicated components of the Defense Communications System (DCS), and some are used alternately on Navy and DCS circuits. In order to provide for this versatility, a certain degree of standardization is required.

1.1.1 Navy Engineering-Installation Standards

Although there are detailed standard drawings for many types of antennas, detailed standards for engineering-installation of Navy antenna systems are not prescribed since each engineering and/or installation action is designed to meet specific requirements and each is submitted for separate approval. The technical information and reference data contained in this handbook provide broad guidance for Navy engineering-installation plans.

1.1.2 DCA Engineering-Installation Standards

Since many of the Navy HF antenna systems support DCS circuits, these systems must meet the antenna system standardization requirements set forth by the Defense Communications Agency (DCA). The need for communications systems engineering standards is stated in Chapter I of DCAC 330-175-1 (formerly 175-2A) — "DCS Engineering-Installation Standards" as follows:

> 1.1.3 Need for DCS Engineering-Installation Standards. Interoperability and uniform high quality performance of all DCS components requires that they be engineered to high universal standards. New requirements may be placed upon segments of DCS facilities formerly used by a single military service and not originally designated nor engineered for operation with other systems. These components of the DCS must be reengineered, where necessary, to meet these standards so that interoperability and uniform capability will be assured. Engineering of future DCS facilities must conform with these standards for the same reason.

1.2 PLANS AND SPECIFICATIONS

The Naval Electronic Systems Command (NAVELEX), or one of its designated field activities, is responsible for translating operational-communications requirements into engineering plans and specifications. Such requirements may be identified by any operational command and forwarded to the appropriate NAVELEX activity.

1.2.1 Detailed Planning

A Base Electronic System Engineering Plan (BESEP) is required for each engineering and installation action proposed. A BESEP translates a requirement concept into a statement of resource requirements, and it provides the detailed engineering plan for meeting the project objectives.

Normally, a BESEP is prepared by the Field Technical Authority (FTA), and is coordinated with the Naval Facilities Engineering Command (NAVFAC) Engineering Field Division (EFD). However, requirements for changes to existing antenna facilities may also be made known by an individual station when operational-communications requirements exceed the station's capability, or when antenna facilities need to be updated for other reasons.

Specific details of the content required in a BESEP are contained in NAVELEX Instruction 11000.1 — "The Base Electronic System Engineering Plan (BESEP)."

1.2.2 Implementation of Plans

Upon approval of the BESEP by NAVELEX, detailed specifications and engineering design are undertaken by the designated FTA or EFD as appropriate.

Normally, the design, procurement, construction, and installation of HF antennas are accomplished jointly by NAVELEX and NAVFAC. In certain cases however, e.g., when antennas require large structural subsystems, design and procurement are under the cognizance of NAVFAC based on requirements stated by NAVELEX.

CHAPTER 2

ANTENNA PRINCIPLES

The antenna is a basic component of any electronic system dependent upon free space as the propagating medium. It serves as the connecting link between free space and the transmitter or receiver and is, consequently, of primary importance in determining the performance of the system in which it is used.

Antenna performance is defined in terms of certain characteristics, nearly all of which are frequency dependent. The basic properties that determine the applications of antennas will be discussed briefly in this chapter with a more detailed theoretical treatment left to acknowledged standard texts such as references 24, 25 and 27 listed in appendix C.

2.1 CURRENT DISTRIBUTION

Current distribution on antennas is divided into two general classes: standing wave and traveling wave. Standing-wave distribution is similar to the current distribution along an open-ended transmission line in which the current amplitude varies sinusoidally along the length of the line and is zero at the end. Antennas with this type of current distribution are referred to as resonant antennas.

Traveling-wave distribution corresponds to the current distribution along a transmission line terminated in its characteristic impedance. In this case the current is uniform in amplitude along the line, but the phase changes continuously at the rate of 2π radians per wavelength. The traveling-wave type antenna, also known as a nonresonant antenna, is always terminated with a resistance in a manner similar to matching the character impedance of a transmission line.

2.2 RADIATION PATTERNS, GAIN AND DIRECTIVITY

The radiation pattern of an antenna is of interest as it shows the relative intensity of a radiated signal (or the relative sensitivity to a received signal) in various directions from an antenna. In other words, a radiation pattern is a representation of the directivity of the antenna and, as such, it can be used to select a type of antenna that has the maximum gain in the desired direction, horizontally, vertically, or both. Mathematical derivations of antenna patterns, and patterns for many of the more common types of antennas, are given in standard antenna texts.

The gain of an antenna is defined as the ratio of the maximum power density radiated by the antenna to the maximum power density radiated by a reference antenna when both antennas have equal input powers. The directivity of an antenna, which is sometimes confused with antenna gain, is the ratio of the maximum power density radiated by the antenna to the average power density radiated by the antenna. The distinction between the two terms arises from the fact that antenna gain takes account of antenna losses, whereas directivity does not. Since all antennas have some losses, the directivity of an antenna will exceed the antenna gain. The directivity of an antenna, which is expressed as a ratio, can be obtained from the antenna radiation pattern alone without consideration of antenna losses or absolute power values.

Rhombic antennas which dissipate portions of the antenna input power in the termination resistance will have lower gain values than directivity values by an amount approximately equal to the termination loss. Co-phased dipole arrays have low conductor losses, and directivity only slightly exceeds the gain for such antennas. However, antennas may be constructed to have a considerable difference between directivity and gain. These antennas usually have parallel elements, closely spaced in terms of wavelength, with out-of-phase currents in adjacent elements. In such antennas large currents flow in the elements, and conductor losses are quite appreciable unless large-diameter conductors are used. Both the dipole log-periodic array (LPA) and the Yagi have high directivity characteristics, and differences of a decibel or more between directivity and gain for these antennas are not uncommon.

A theoretically perfect isotropic radiator is used as the basic reference antenna for comparing gain measurements to obtain the gain of a particular antenna. A comparison of the isotropic radiator with several secondary standards is illustrated in figure 2-1. Any of the antenna types listed in the figure can be used as practical radiators for model range work, and for field comparison with other antennas. Usually, the half-wave dipole is considered the most practical reference antenna since it can be constructed from materials normally available at most shore activities, and because installation is relatively simple.

2.3 POLARIZATION

The polarization of the propagated wave is determined initially by the type and arrangement of the transmitting antenna. As a rule, a vertical conductor radiates a vertically polarized wave, and a horizontal conductor radiates a horizontally polarized wave. More complex forms, such as circular and elliptical polarization, in which the direction of maximum voltage rotates in space at the frequency of transmission, are also possible. These complex waves are generated by special antennas, or may be developed unintentionally when linearly polarized waves pass through nonuniform media such as the ionosphere. The wave polarization in free space is always in a plane perpendicular to the direction of propagation. The performance of a receiving antenna is improved if it can be oriented to take advantage of the polarization of the incident wave.

As a consequence of random changing of the polarization of high frequency waves as they travel through the ionosphere, the polarization of the transmitting antenna need not be determined by the characteristics of the remote receiving antennas. There are, however, other factors (discussed in chapter 3) that must be considered relative to the choice between a vertically or a horizontally polarized radiator. Where circuit requirements dictate ground-wave propagation, vertically polarized antennas provide the most effective coverage.

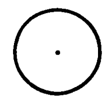
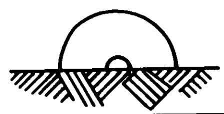
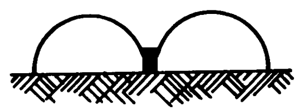
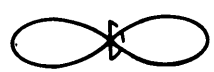
ANTENNA TYPE	VERTICAL PATTERN	mV/M AT 1MILE 1kW RADIATED POWER	POWER GAIN	dB GAIN
ISOTROPIC		107.6	1	0
HEMISPHERICAL		152.1	2	3.01
VERTICAL CURRENT ELEMENT		186.3	3	4.771
1/4 λ VERTICAL		194.9	3.282	5.161
1/2 λ VERTICAL		236.2	4.822	6.832
1/2 λ FREE SPACE		137.8	1.641	2.151
1/2 λ HORIZONTAL 1/2 λ ABOVE EARTH		278.0	6.56	8.17

Figure 2-1. Standard Reference Radiation Patterns

2.4 IMPEDANCE

The impedance of an antenna is comprised of the following components:

- Radiation resistance
- Conductor resistive losses
- Reactive storage field
- Coupled impedance effects from nearby conductors

The radiation resistance determines the amount of energy radiated, and the ratio of the radiation resistance to the radiation resistance plus all other losses determines the antenna efficiency. Although the radiation resistance and the total impedance can be calculated, the computations are extremely cumbersome for antennas other than the most simple types. Such computations are of interest primarily for antenna design.

In practical antenna work, the input impedance specified by the antenna manufacturer is verified at the time of installation by measurements with an impedance bridge. Subsequently, input impedance measurements are made to verify performance or to discover changes in input impedance that indicate the need for corrective maintenance.

The variation of antenna impedance with frequency depends upon the diameters and the electrical length of the antenna elements. Antennas that have small diameters in terms of wavelength have larger storage fields (greater reactive component of input impedance) than do larger diameter antennas. Standing-wave antennas generally exhibit a greater variation of reactive impedance than do traveling-wave antennas. For example, a dipole is capacitive for lengths shorter than one-half wavelength, zero at about a half wavelength, and inductive for lengths between one-half and one wavelength. The reactance continues to alternate cyclically as the dipole is extended in half-wavelength segments. Generally, this reactive behavior makes standing-wave antennas difficult to use at frequencies other than those near resonance where the reactance is zero. Some techniques have been used, however, to modify the impedance variation with frequency so as to extend the useful bandwidth of such antennas. For example, using biconical arms of proper taper for a dipole antenna reduces the reactance and makes the antenna useful over several octaves.

Traveling-wave antennas such as the rhombic and terminated vee have relatively constant input impedance compared to standing-wave antennas. For these antennas restrictions on the useful frequency range are determined by antenna radiation pattern changes with frequency rather than by impedance variations.

2.5 BANDWIDTH

A significant characteristic affecting the choice of an antenna for a particular application is its bandwidth, the frequency range over which the voltage standing wave ratio (VSWR) is within acceptable limits and over which the radiation pattern provides the required performance. The useful frequency range, or bandwidth, of an antenna is dependent upon the extent of the changes that occur in the input impedance or the radiation pattern as the frequency is varied. Either radiation-pattern or input-impedance changes can be the controlling factor. For some antennas, rhombics, for example, the input impedance is sufficiently constant to match the output impedance of a transmitter over a wide band of frequencies with an acceptable VSWR. Use of this type of antenna, however, often must be restricted to only a portion of this satisfactory "impedance bandwidth" because of unacceptable changes in the radiation pattern that occur as the frequency is changed. On the other hand, some antennas, such as the electrically short dipole or monopole, have essentially unchanging radiation patterns over a wide range of frequencies but their use is restricted to narrow frequency bands because the input impedance varies significantly with frequency.

The useful frequency band is determined to some extent by whether the antenna is used for transmitting or receiving. Input impedance limitations are generally more stringent for the transmitting case since a mismatch between a transmitter and its antenna may result in an excessive VSWR which can cause equipment failure. A greater degree of mismatch often is tolerated in the receiving case since, although signal reception may be degraded, a mismatch will not cause equipment failure.

2.6 GROUND EFFECTS

The free-space radiation pattern and the impedance of an antenna are modified when the antenna is placed near ground. The impedance change is small for antennas located at least one wavelength above ground, but the change becomes greater as the height is reduced. Since the ground appears as a lossy dielectric at medium and high frequencies, location of the antenna near ground may increase the losses considerably unless special means, such as ground wires or conductive mats, are used to reduce ground resistance.

Vertical antennas, which are often located with the antenna feed point at or near the ground surface, require a system of radial ground wires extending a sufficient distance from the antenna to provide a low-resistance return path for the ground currents produced by the induction fields. For most vertical antennas, the length of the radials is commonly one-quarter wavelength at the lowest design frequency. Additionally, on some vertical antennas where the fields are intense near the base, a grid-type ground mat, or screen, is used to increase the effectiveness of the connection to the earth. Ground plane radials and screens are discussed further in chapter 3.

Horizontal antennas are usually mounted at least a quarter wavelength above ground and do not require special treatment of the ground to reduce radiation losses.

CHAPTER 3

HF ANTENNA PERFORMANCE

Antenna performance is controlled or influenced by a number of factors. Orientation, polarization and radiation pattern must be considered along with ground plane requirements, feed systems, siting and separation criteria, real estate requirements, and ground constants and conductivity. All of these factors must be considered carefully in order to attain optimum antenna performance in ship/shore/ship, broadcast, ground/air/ground, and point-to-point HF communications systems.

3.1 ORIENTATION AND POLARIZATION

Orientation and polarization requirements vary with the antenna application, and may be different for ship/shore/ship, broadcast, ground/air/ground, and point-to-point communications.

3.1.1 Ship/Shore/Ship and Broadcast Communications

Ship/shore/ship and broadcast HF communications requirements are usually fulfilled by vertically polarized, omnidirectional or sector antennas. Sky-wave propagation is ineffective, generally, for short-range communications because of skip distance associated with this mode of transmission. However, at the low end of the HF band, ground-wave propagation from vertical antennas can be quite reliable within the sky-wave skip distance and beyond, depending upon the ground constants of the path. Vertically polarized ground waves are particularly effective over sea water, and substantial distances can be spanned reliably with operating frequencies up to approximately 5 MHz. There are numerous vertically polarized antennas that are suitable for ship/shore/ship and broadcast HF communications. Those most commonly used for Navy service are discussed in chapter 4.

Although vertical antennas are used for most ship/shore/ship applications, very long distances between terminals may be spanned more effectively by sky-wave propagation. In these circumstances, horizontally polarized antennas such as horizontal LPA's (fixed azimuth or rotatable) and rhombics are normally used.

3.1.2 Ground/Air/Ground Communications

Omnidirectional, broadband HF antennas are essential for effective ground/air/ground communications since aircraft operate at varying distances, bearings and elevation angles from ground terminals, and because numerous and rapid frequency changes are required to maintain reliable communications as the position of the aircraft changes.

Vertically polarized omnidirectional antennas are generally well suited to the propagation requirements of ground/air/ground communications. HF sleeve antennas have been in use for some time in ground/air/ground systems; however, conical monopoles and inverted cones are being installed as programmed replacements for the sleeve antennas because they possess broader bandwidth characteristics than the sleeve antenna.

A greater degree of reliability for ground terminal reception of relatively low power aircraft signals, particularly teleprinter or other digital data transmissions, may be achieved through some type of diversity operation. Unfortunately, the real estate constraints at the receiving location may make space diversity reception impractical. Likewise, frequency diversity transmission from aircraft is generally precluded because of space and equipment limitations in the aircraft. Polarization diversity, however, can be employed by the ground terminal to provide improved signal reception. This type of diversity operation is made possible by using omnidirectional, horizontally polarized antennas in conjunction with vertically polarized antennas. The HF quadrant antenna illustrated in figure 4-28, is one type of horizontally polarized antenna that possesses the omnidirectional broadband qualities necessary for use in conjunction with a vertical antenna in a polarization diversity system.

3.1.3 Point-to-Point Communications

The most commonly used HF antennas for point-to-point communications are horizontally polarized. Usually rhombics and horizontal LPA's are specified since they provide the necessary bandwidth, gain, directivity and reliability for long-distance communications. Their relatively low radiation angle and low ground losses make them well suited to the performance objectives for long distance service. Vertical LPA's are sometimes used for long-distance point-to-point communications, but satisfactory results in this application depend upon the use of a ground plane radial system to keep the radiation angle low.

3.2 ANTENNA RADIATION CHARACTERISTICS

Gain, bandwidth, useful radiation angle and VSWR are major performance factors to be considered along with orientation and polarization. Radiation characteristics, including patterns of several types of antennas, are presented in chapter 4. In addition, typical radiation performance characteristics are included in the Antenna Characteristics Chart, foldout 5-1.

3.3 ANTENNA GROUND PLANE

A ground plane is required for any ground-mounted antenna if the antenna is fed in a manner that makes the earth the return path for current flow. An arrangement of wires comprising a ground plane improves antenna radiation efficiency and provides an improved low-loss path for the return current.

Conical monopoles, discones, inverted cones, sleeves and some vertical LPA's are typical of the antennas requiring ground planes.

Ground planes can be considered in three basic categories: radial grounds, ground mats and counterpoises.

3.3.1 Radial Ground Plane

A radial ground plane is generally considered the most effective grounding configuration for vertical antennas. It is constructed of radial wires originating from a point at the base of the antenna as shown in figure 3-1A. In this case 120 equally distributed radial wires that are at least one-quarter wavelength long at the lowest design frequency are normally used. When a vertically polarized LPA is used the 120 radials are placed in the configuration shown in figure 3-1B. The length of the ground radials for the LPA vary smoothly from at least one-quarter wavelength at the lowest design frequency to one-quarter wavelength at the highest design frequency.

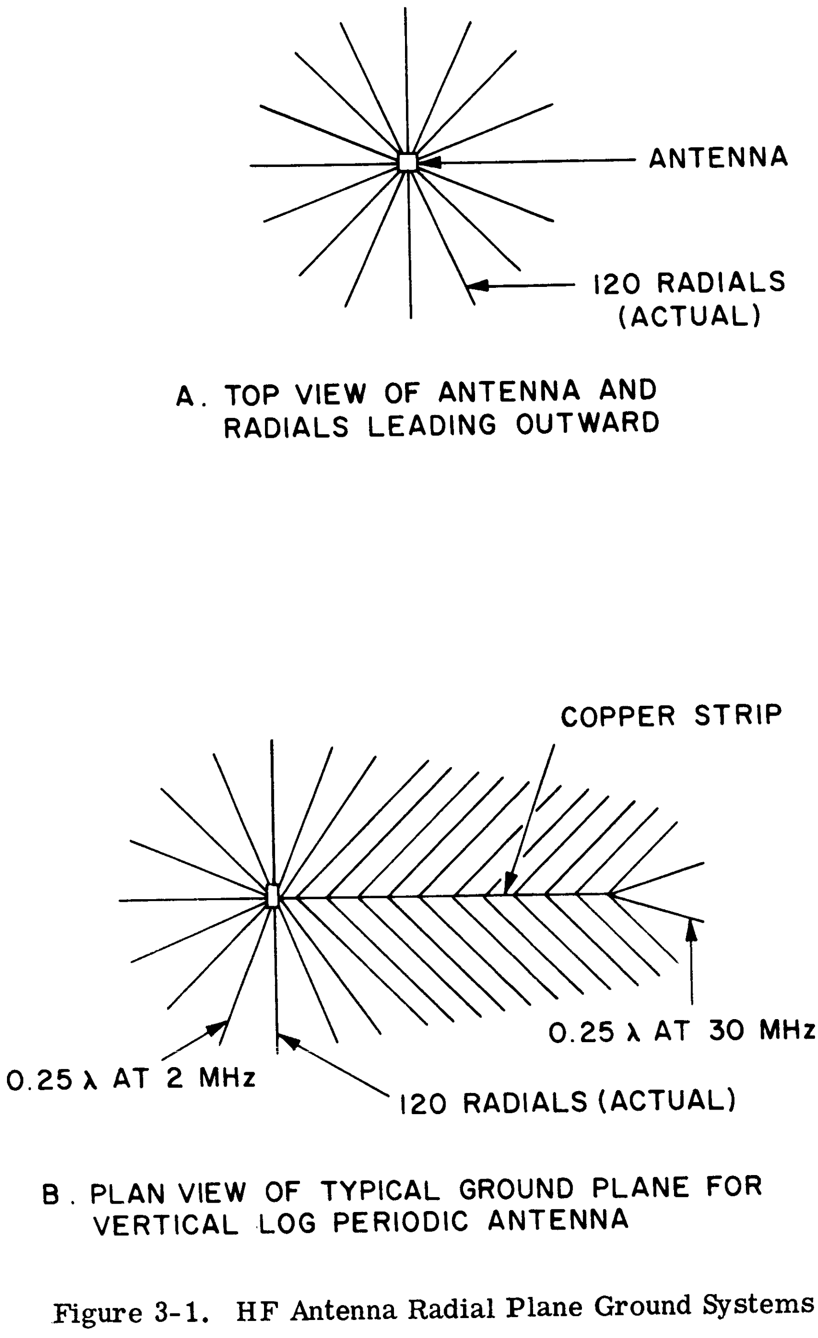


Figure 3-1. HF Antenna Radial Plane Ground Systems

Ground radial kits are supplied as standard items with some vertical antennas; e.g., conical monopoles, inverted cones, and vertical monopole LPA's. General specifications for ground radial materials and installation are as follows:

a. Ground radial wires should be at least one-quarter wavelength long at the lowest design frequency of the antenna. The gauge of the radial wires need only be sufficient to withstand the mechanical stresses of installation. Usually No. 8 or No. 10 AWG annealed copper-clad steel wire is adequate. To increase the ground plane the lengths of the radials should be increased rather than the wire cross-sectional area.

b. Ground radials are most effective when installed on the earth's surface. However, radial wires are normally buried in order to ensure physical protection. The depth of burial varies with frequency and should conform to the following rules:

(1) Frequency $\leq$ 9 MHz - burial depth $\leq$ 6 inches.

(2) Frequency > 9 MHz - burial depth $\leq$ 3 inches.

c. Where terrain or boundary conditions prohibit the desired radial length, connection of each radial to a ground rod is recommended, provided that the rods can be driven at least 3 feet into the ground. Ideally, the rods should be set 10 feet into the earth's surface for maximum effectiveness at most antenna locations. However, the depth of refusal may be so shallow that even the 3-foot depth is not feasible. If such is the case, it will probably be necessary to accept something less than an ideal ground plane.

Peripheral bonding of the radial wires to a closed loop of wire that surrounds the ground plane is recommended, whether ground rods are used or not. Silver soldering, brazing, and exothermic welding are acceptable methods of bonding.

When ground rods are not used, the radial wires should be staked as necessary to ensure physical stability.

d. On installations where location of adjacent antennas can cause ground radials to cross each other, interference may be generated by non-linear junctions formed where the radials overlap. If this condition exists, the following alternatives may be followed as best suited to the particular application:

(1) Bond radials at their crossing points.

(2) Use insulated wire for the radials or insulate the wires at the crossing points.

(3) Substitute a copper mesh ground mat for the radial ground plane. The dimensions of the mesh mat should be determined on an individual case basis.

(4) Bury the ground radials of the affected antennas at different depths at the intersecting points, keeping the higher frequency antenna's radials nearest the surface.

3.3.2 Ground Mat

When high antenna-base currents are present, a copper mesh ground mat is required at the antenna base to further insure against ground system power loss. A typical mat is 12 feet square and is fabricated from expanded copper or from copper wires bonded together to form a grid. Installation practices are the same as those specified for ground radial systems.

a. If a ground mat is used in conjunction with a system of radials, ensure that each radial is bonded to the mat.

b. In the event that local surface characteristics prohibit mat burial, lay the mat on the surface and stake it at frequent intervals to prevent shifting.

c. The primary consideration for the gauge of wire or thickness of expanded copper metal to be used in fabricating the ground mat depends upon the anticipated mechanical stresses.

3.3.3 Counterpoise

A system of conductors elevated above and insulated from the earth constitutes an antenna counterpoise which forms a large capacitance with ground. This counterpoise simulates a ground plane to stabilize antenna impedance. The following considerations should be observed for effective application of a counterpoise:

a. It must be placed directly under the antenna.

b. It must be scaled in size according to operating frequency. The size must be adequate to provide capacitance of a value that will have a low reactance at the operating frequencies, thus minimizing any potential difference between the counterpoise and ground.

3.4 ANTENNA FEED SYSTEMS

HF antenna feed systems must have low voltage standing-wave ratios and may be categorized as either balanced or unbalanced.

a. Balanced feed systems are comprised of open-wire parallel lines, with a nominal impedance of from 300 to 600 ohms, and impedance-matching devices as required.

b. Unbalanced feed systems are comprised of coaxial cable, with a nominal impedance of 50 ohms, and impedance-matching devices as required.

c. The VSWR should not exceed 1.1:1, for either a coaxial cable or an open-wire feed line, over the operating frequency band when the line is terminated in its characteristics impedance.

d. Detailed criteria on HF transmission lines and other antenna associated components are contained in chapter 6, and in reference 14.

3.5 ANTENNA SITING

Factors which must be considered in siting antennas are radiation hazards, environmental factors (topographical and electrical), real estate requirements and ground constants.

3.5.1 Radio Frequency (RF) Radiation Hazards

Careful attention must be given to site selection for transmitting antennas with regard to RF radiation hazards.

a. Hazards of Electromagnetic Radiation to Ordnance (HERO). Siting transmitting antennas in areas in which ordnance materials are located can create potentially hazardous conditions. Therefore, site approval with regard to ordnance materials is required in accordance with NAVFAC Instruction 8020.3 — "Site Approvals for Electromagnetic Wave Generating and Transmitting Equipment," 16 February 1968.

b. Hazards to Fuel. The exposure of fuel to RF radiation is a subject of discussion in NAVORD 3565/NAVAIR 16-1-529 — "Technical Manual, Radio Frequency Hazards to Ordnance, Personnel and Fuel," (U), and in NAVELEX 0101,103.

c. Hazards to Personnel. Safe exposure limits for the protection of personnel from the effects of RF radiation are discussed briefly in chapter 8.

3.5.2 Terrain Considerations

HF antennas should be located on reasonably flat ground. Areas with large concentrations of rock should be avoided since grading and construction problems are magnified by such terrain, and because non-uniform ground constants are likely to exist because of the soil dissimilarities.

Antennas should be sited so that obstructions such as buildings, tall metal structures, and mountains are not in the direction of propagation. The obstruction angle for a given wavepath must not exceed 5° (3° is preferred).

3.5.3 General Considerations

The following general considerations apply in locating HF antennas:

a. Fixed directional antennas, such as rhombics and LPA's (horizontal and vertical), should be sited so that their main beam does not radiate through other HF antenna arrays. This requires that they be located at the antenna park perimeter nearest the azimuth of the intended direction of transmission or reception.

b. Rotatable log-periodic antennas (RLPA's) should be grouped together where possible to reduce any detrimental effect that their supporting towers may have on vertically polarized antennas.

c. Higher frequency antennas, such as RLPA's and some conical monopoles, should be located as close as possible to the transmitter or receiver building to minimize coaxial line losses.

d. HF antennas for which spacing requirements are the same should be grouped together to conserve real estate.

e. In cases where land availability is critical, it is possible to locate a vertically polarized antenna within the area occupied by a rhombic antenna without sacrificing performance. In such installations, the vertically polarized antenna should be located near the center of the rhombic clear of the rhombic curtains, feed pole, and terminating resistance. The rhombic array in which the other antenna is located should have wood supporting structures, and guy wires should be broken up with insulators. Also the rhombic should have a lumped termination resistance in lieu of dissipation lines to afford adequate space for installing the vertical antenna.

3.5.4 Separation From Sources of Interference

Interference from sources of electromagnetic radiation, such as radio and radar transmitters, and noise from electrical devices are of concern in siting HF receiving antennas. In order to minimize the effects of this interference, receiving antennas should be sited in accordance with separation distances specified in table 3-1.

3.6 ANTENNA SEPARATION

Separation of HF antennas is an important factor that affects antenna performance. The criteria for separation are determined by the physical and electrical characteristics of the antennas and by the antenna application (transmitting or receiving).

3.6.1 Separation Requirements for Antennas of Unlike Function

HF antennas of unlike function (transmitting and receiving) should be separated by a minimum distance of 15 miles. If this separation is decreased serious degradation of the receive function may result due to interference created by the transmitters. This interference can be caused by adjacent-channel operation, harmonics, keying transients, and parasitic oscillations. Also, cross-modulation products can be generated in HF preamplifiers and receivers by strong RF fields, even though normal receiving frequencies are widely separated from the frequencies of such fields. Receiving antennas should be separated from transmitting antennas in accordance with the criteria in table 3-1.

3.6.2 Separation Requirements for Antennas of Like Function

The separation distance between any two antennas of like function (all receiving or all transmitting) can be determined from the following spacing criteria. All distances, unless otherwise noted, are based on the antennas lowest design frequency. The larger of the two distances in each case is used as the spacing distance. The points of measurement are between the reference points listed for each type of antenna (except rhombics).

Table 3-1. Receiving Antenna Separation Distances

SOURCES OF INTERFERENCE	MINIMUM DIST
High-power transmitter stations:	
Very low frequency	25 mi
Low frequency/high frequency	15 mi
Other transmitters not under Navy control	5 mi (see Note 1)
High-voltage power transmission lines 100 kV or greater	2 mi
Receiver Station power feeders	1000 ft from nearest Antenna
Airfields and glide paths:	
For general communications	5 mi
For aeronautical receiving at air station	1500 ft
Teletype and other electromechanical systems:	
Low level operation or installed in shielded room	No minimum
High level operation installed in unshielded room	
Large installation (communications center)	2 mi from nearest Antenna
Small installation (1 to 6 instruments)	200 ft from nearest Antenna
Main highways	1000 ft
Habitable areas (beyond limits of restriction)	1 mi
Areas capable of industrialization (beyond limits of restriction, see Note 2):	
Light industry	3 mi
Heavy industry	5 mi
Radar installation	(See Note 3)
Primary power plants	5 mi

NOTE 1: The following NAVELEX requirements also govern distances to non-Navy transmitter stations:

(a) Signal from non-Navy station shall not exceed 10 millivolts per meter (field intensity) at Navy site boundary.

(b) Harmonic or spurious radiation from the non-Navy station shall not exceed 5 microvolts per meter (field intensity) at the Navy site boundary.

NOTE 2: The restriction limit is the protective corridor i.e., that area between the outer limits of antenna field and the site boundary.

NOTE 3: Calculate using "Electromagnetic Prediction Techniques for Naval Air Stations," White Electromagnetics, Inc., Rockville, Md., NObsr 87466.

a. Rhombics. Rhombics should be separated 250 feet from other types of horizontally polarized antennas. The 250-foot distance is measured from the nearest radiating element of the rhombic antenna to the reference point listed for the other antenna. However, rhombics may be located immediately adjacent to other rhombics (including the sharing of common side and/or rear poles) as long as their radiators do not overlap.

Nesting a higher frequency rhombic inside its lower frequency complement (using a common rear pole) is permissible, and is encouraged, in order to reduce land requirements.

Vertically polarized antennas may be placed inside a rhombic as noted in paragraph 3.5.3.e.

b. Vee Antennas. Spacing requirements are the same as for rhombics.

c. Horizontal LPA. Space two wavelengths from the main lobe and one wavelength outside the main lobe, measured from the main supporting structure (midway between supporting structures for two-tower configurations).

d. Vertical LPA. Spacing requirements are the same as for horizontal LPA's.

e. Rotatable LPA. Space two wavelengths from horizontally polarized antennas. The separation requirement from a vertically polarized antenna is determined by the spacing requirement of the vertical antenna. In all cases, spacing must not be less than 150 feet.

f. Yagi. Space one-half wavelength measured from the center of the nearest radiating element.

g. Horizontal Doublet. Space one-half wavelength measured from the feed point.

h. Medium Frequency/Low Frequency Long-Wire. Space 500 feet measured from the feed point.

i. Inverted Cone. Space one wavelength measured from the antenna center.

j. Conical Monopole. Spacing requirements are the same as for inverted cones.

k. Sleeve. Space one wavelength measured from the sleeve element.

l. HF Vertical Radiators. These include vertical doublets and other discrete frequency antennas with a bandwidth of 10 percent or less at the center design frequency. Space one-half wavelength measured from the supporting structure.

m. Vertical Low Frequency Tower. Space 1000 feet from all HF antennas.

n. Sector Log Periodic. Space two wavelengths measured from the main supporting structure.

o. Sector Sleeves (90° and 180°). Space two wavelengths measured from the sleeve element.

p. Selectively Directional Monopole. Space 2 wavelengths measured from each monopole element.

3.7 REAL ESTATE REQUIREMENTS

The amount of land necessary for locating individual HF antennas is based on the following requirements:

a. Directional pattern desired

b. Polarization

c. Operating frequency (antenna size)

Land requirements for most types of HF antennas used in naval shore installations are tabulated in foldout 5-1. These stated requirements do not take into account antenna siting and separation criteria, both of which must be considered separately.

3.8 GROUND DIELECTRIC CONSTANTS AND CONDUCTIVITY

The ground dielectric and conductivity of any intended antenna location should be considered according to individual antenna requirements. As previously discussed in paragraph 2.6 the presence of ground affects the various types of antennas in different ways.

Once the site is selected for an antenna farm, only limited choices are available for location of individual antennas. Ideally, vertically polarized antennas should be installed in an area of high ground conductivity to provide a low-loss return path for ground currents. In actual practice, however, the importance of this is minimized because vertical antennas are usually constructed over a fabricated ground plane to ensure impedance stability and a low-loss return current path. Paragraph 3.3 cites the necessity for ground planes.

Horizontally polarized antennas erected at least one-quarter wavelength above ground do not require ground treatment to reduce dielectric losses or to stabilize impedance characteristics. The primary consideration for height of horizontal rhombics above earth is the useful radiation angle of the antenna. Assuming that the height requirement can be met, the other ground requirements can be satisfied if the surface is level at the antenna location and the ground conductivity is high enough to provide ground reflection for long-range transmission. An ideal location is one where a body of water extends for several miles in front of the antenna.

Ground constant values for many diverse types of soil are available in references 26 and 27 of appendix C. An abbreviated general guide for ground conductivity and dielectric constant is given in table 3-2.

Table 3-2. Typical Ground Constants

TYPE OF GROUND	REL DIELECTRIC CONSTANT	CONDUCTIVITY (MHOS/METER*)
Sea water	81	4.64
Good ground. Pastoral land with good soil	20	3×10^{-2}
Poor ground. Hilly country, moderate vegetation, urban districts	5	1×10^{-3}

*Conductivity in electromagnetic units, emu, is 10^{-11} times the conductivity in mhos/meter.

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.

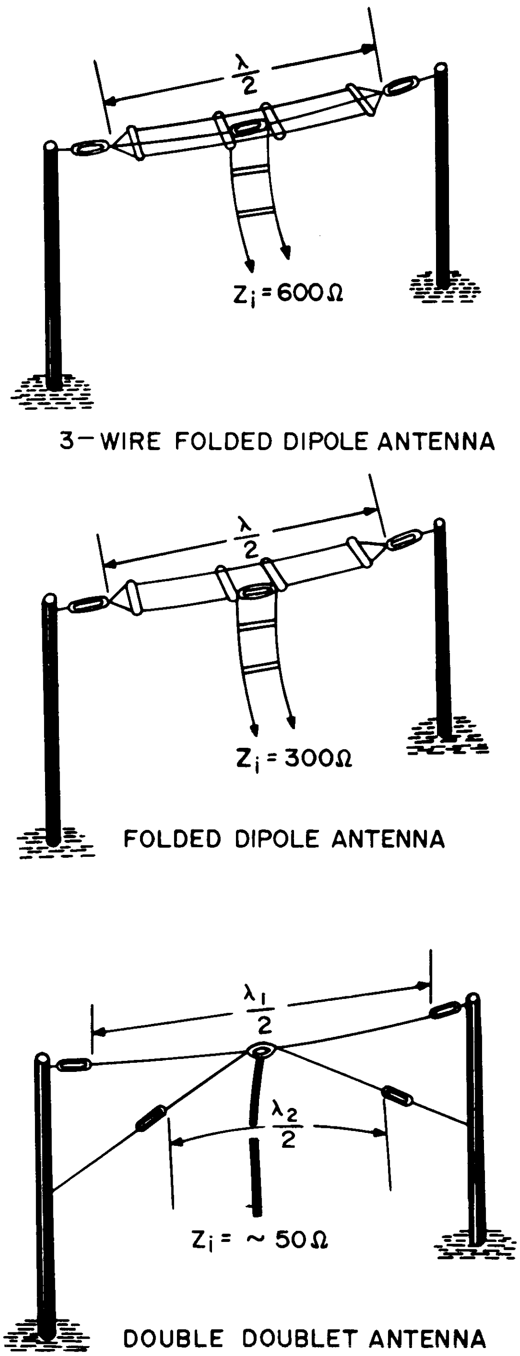


Figure 4-1. Dipole and Doublet Antennas

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 coplanar 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

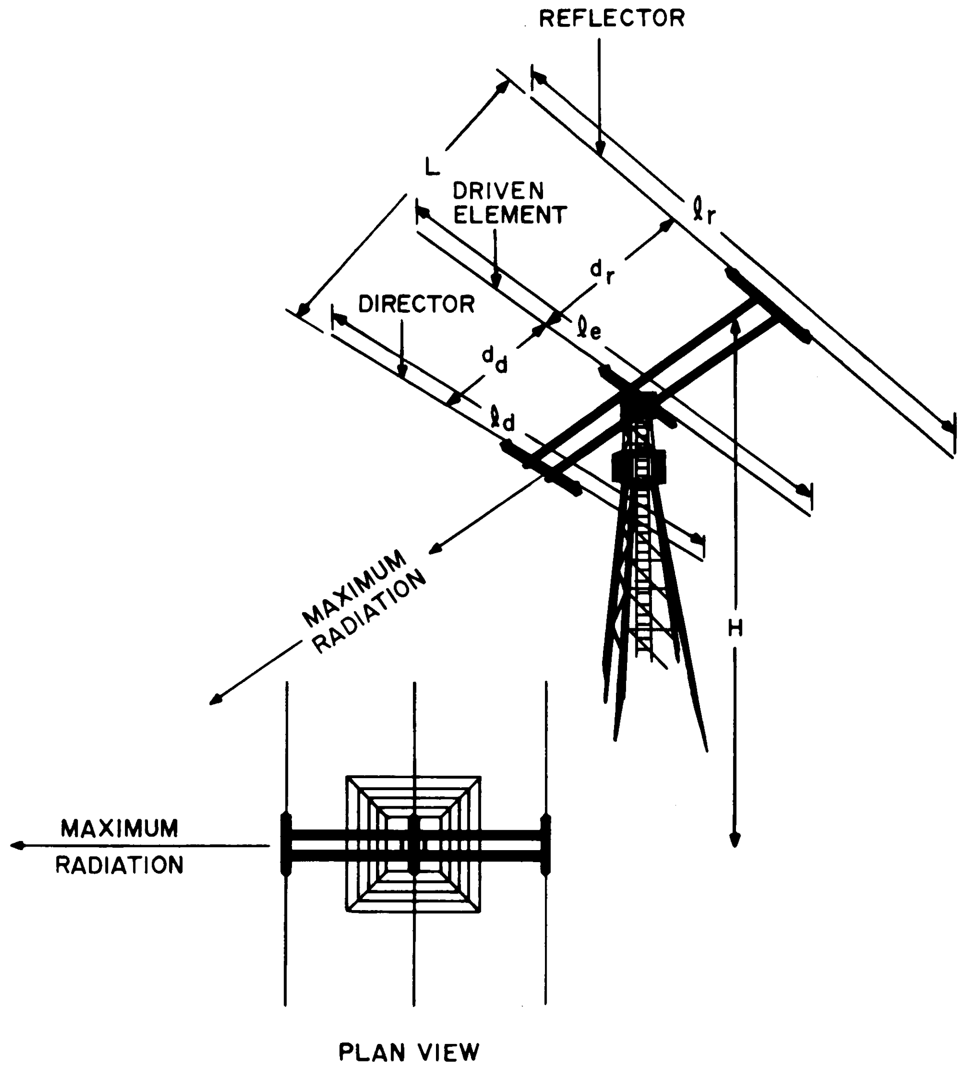


Figure 4-2. Yagi Antenna

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.

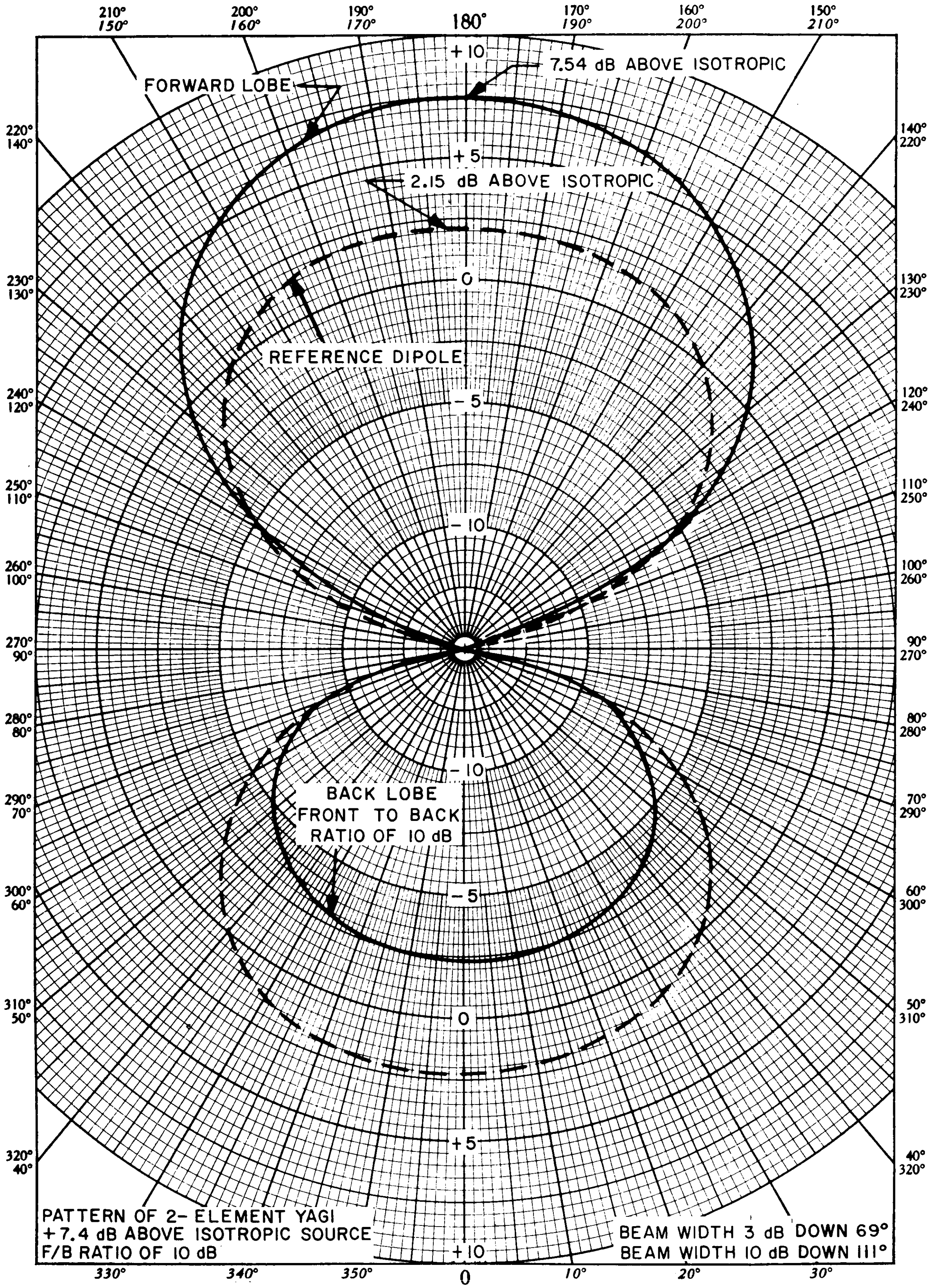


Figure 4-3. Horizontal Two-Element Yagi Antenna Radiation Pattern

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.

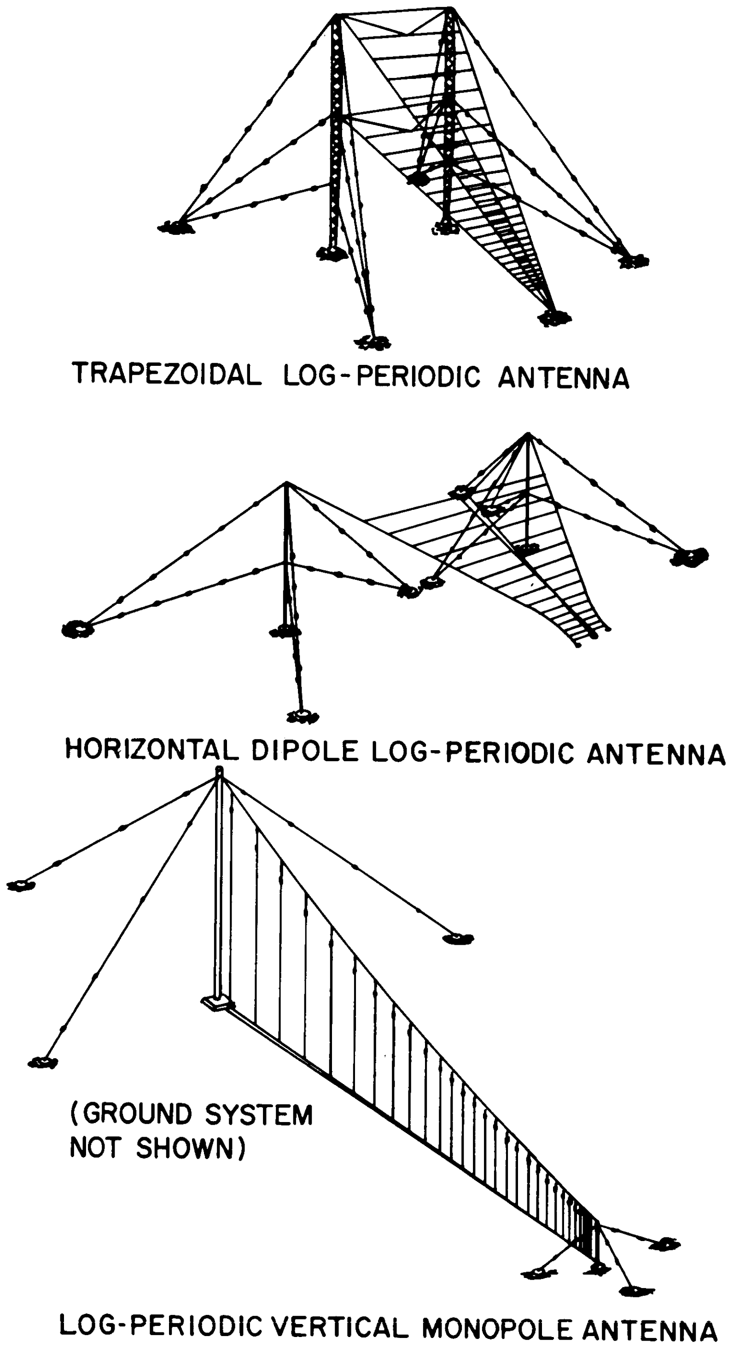


Figure 4-4. Log-Periodic Antennas

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 theLPA 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.

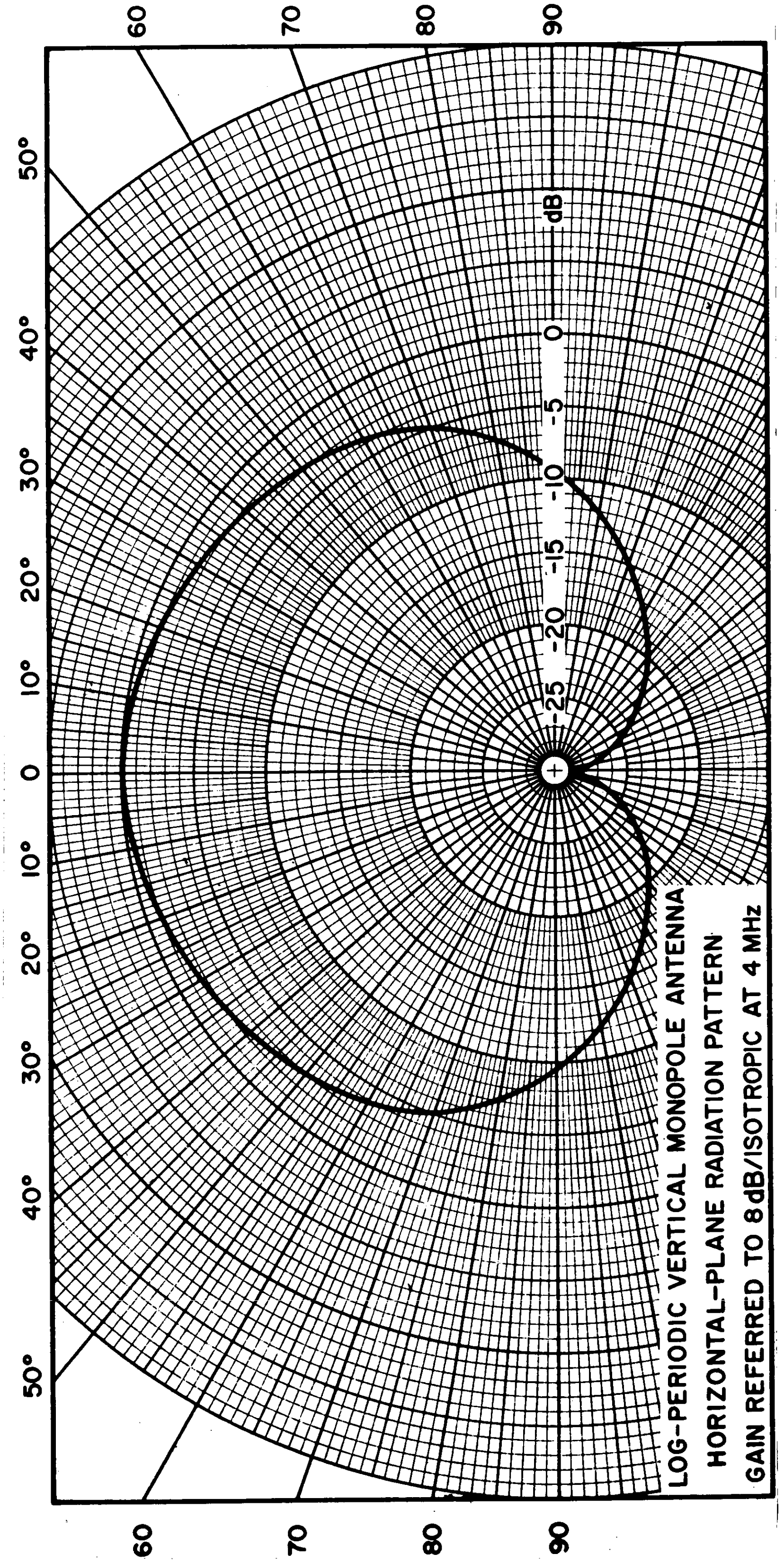


Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 1 of 6)

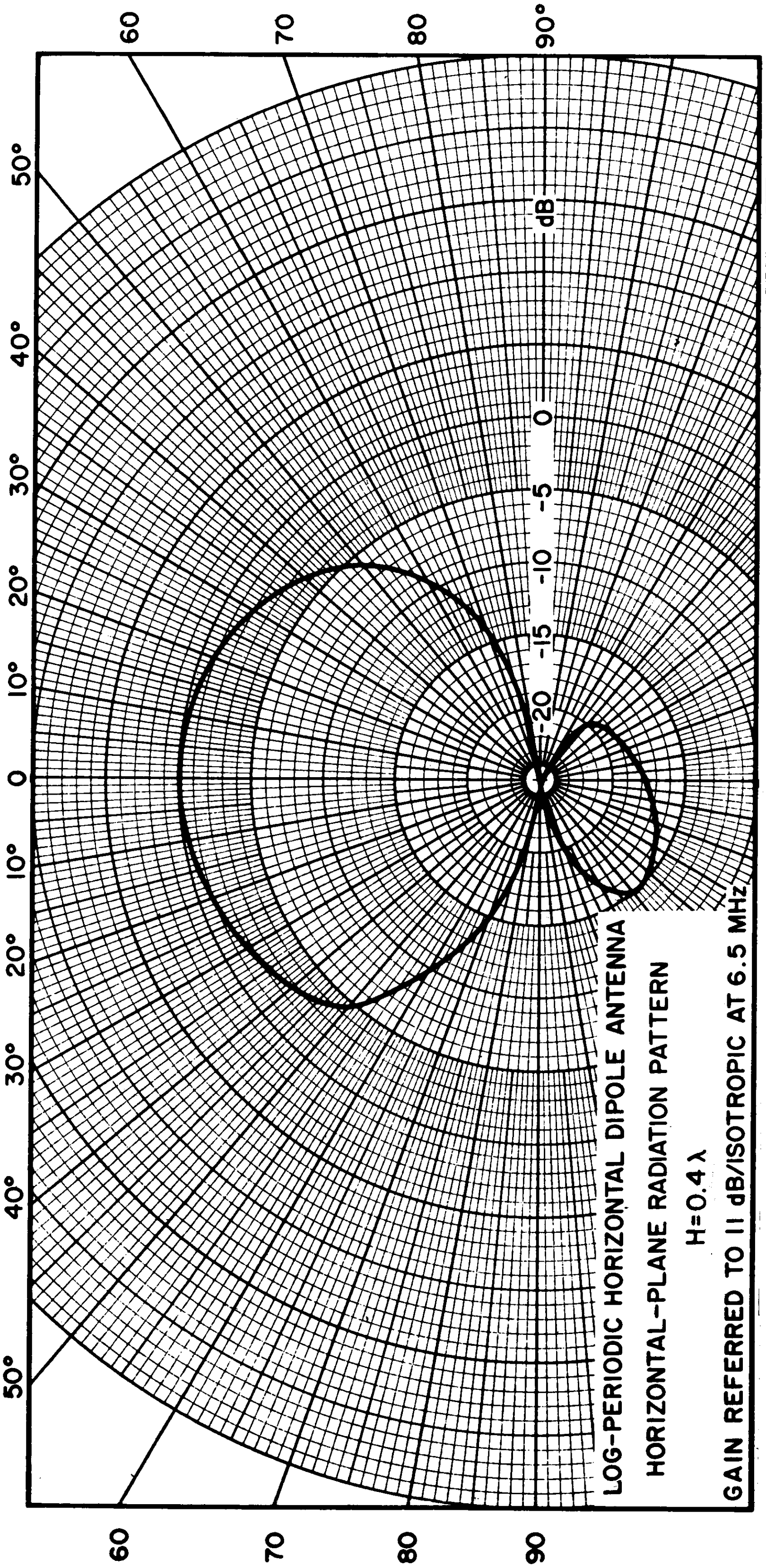


Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 2 of 6)

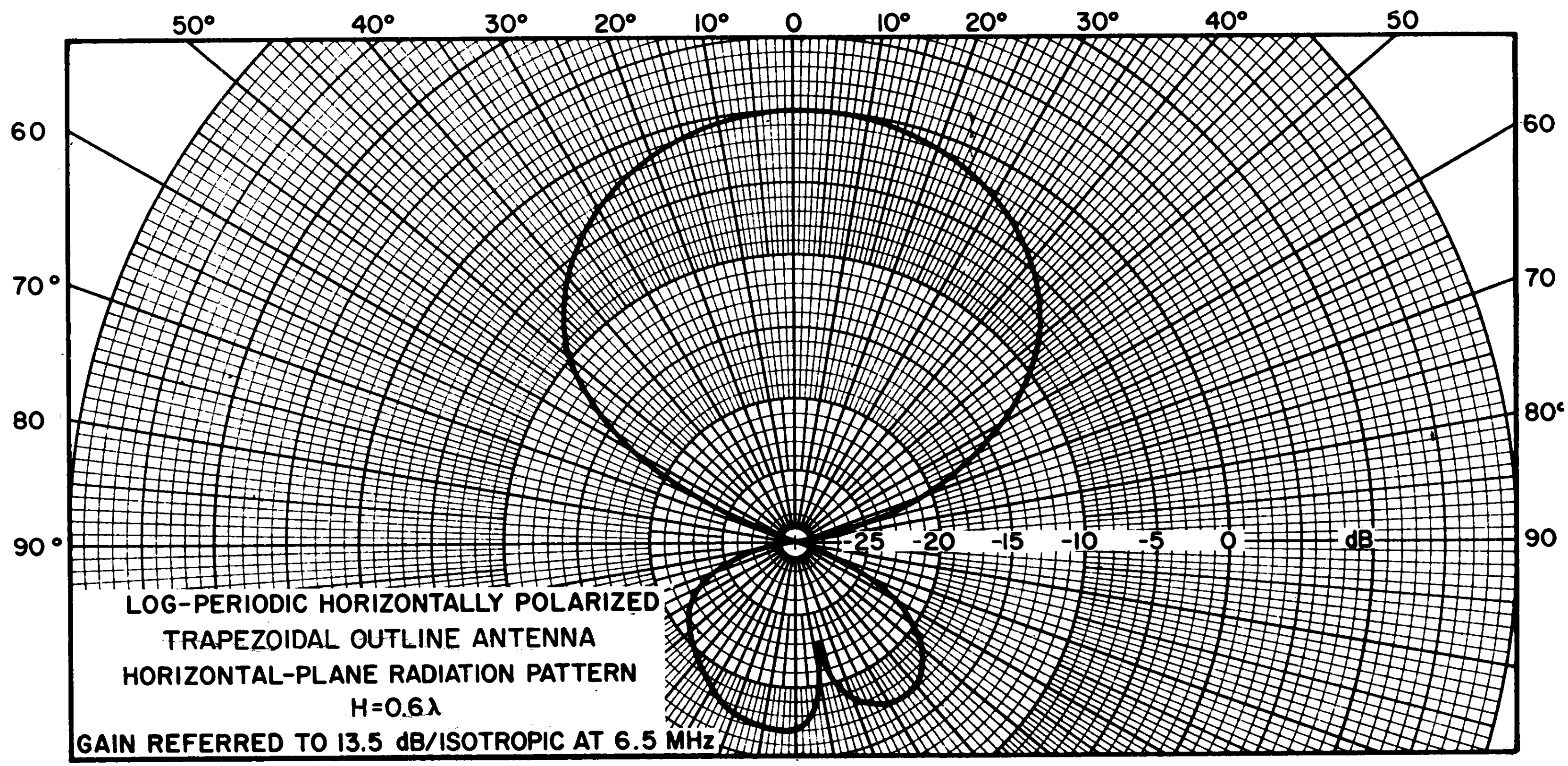


Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 3 of 6)

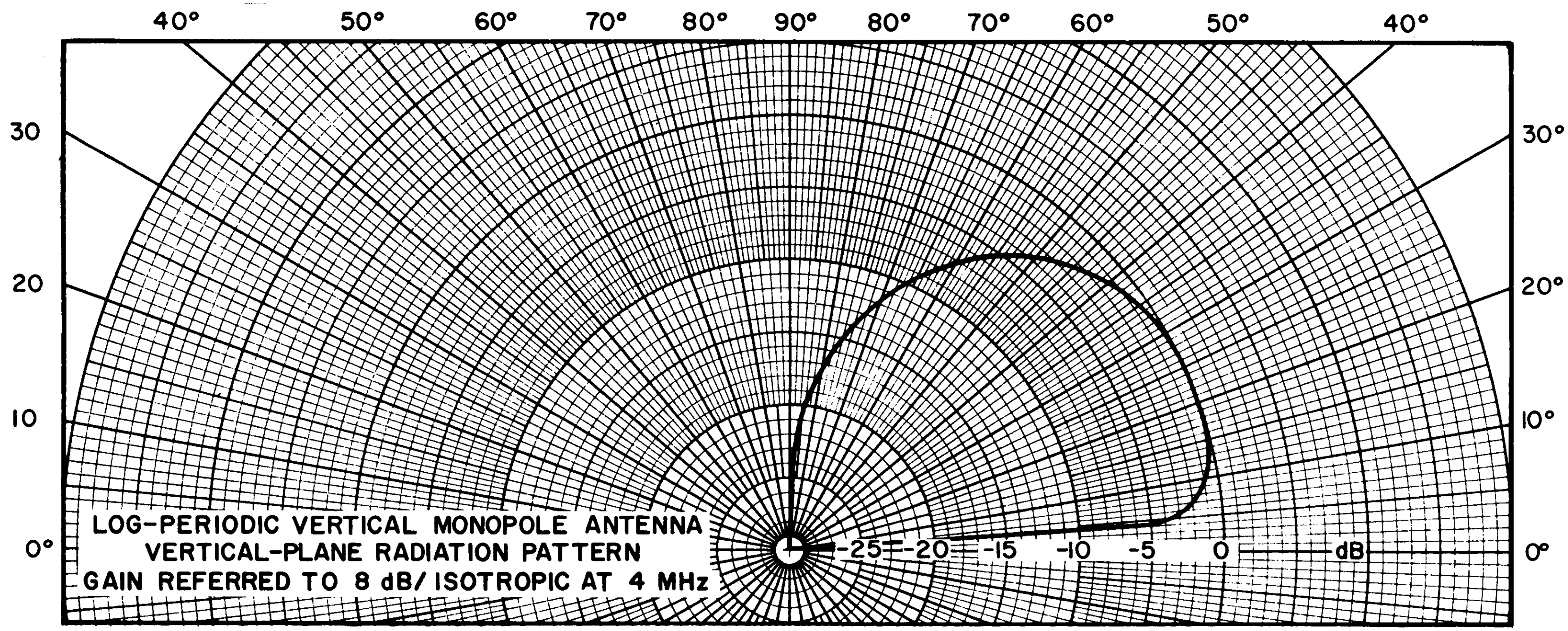


Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 4 of 6)

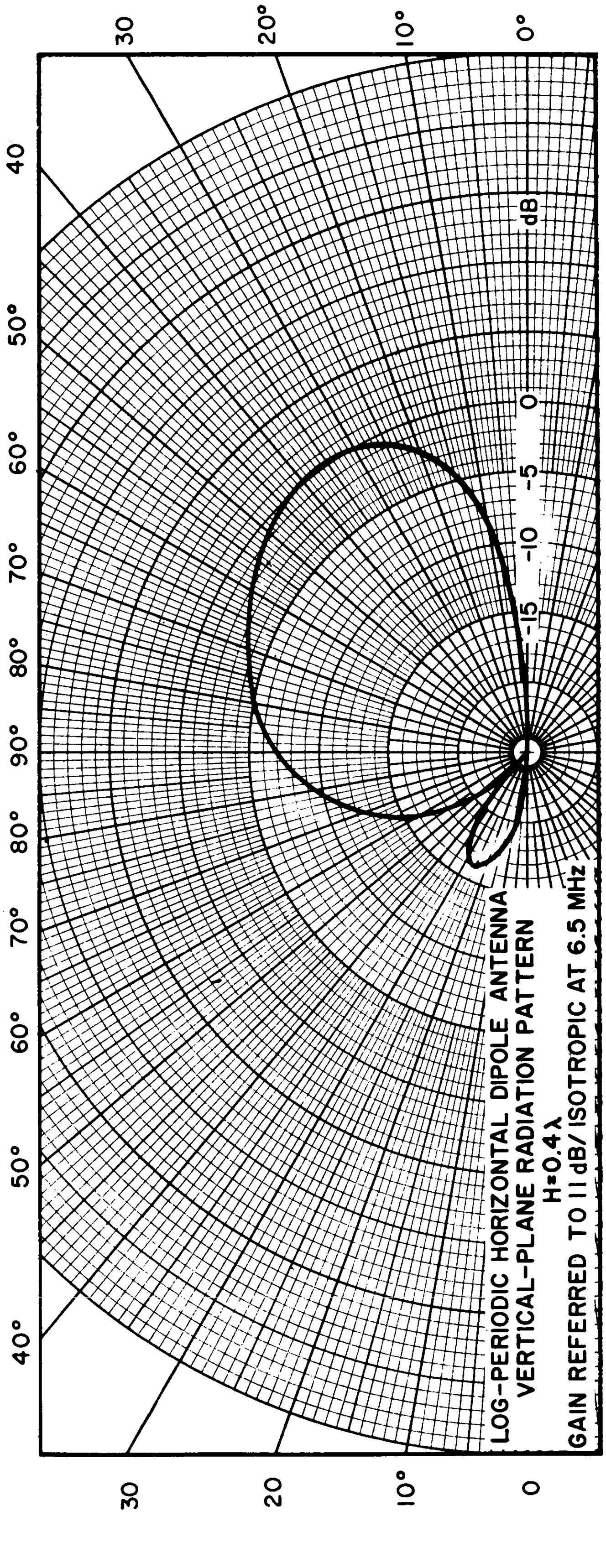


Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 5 of 6)

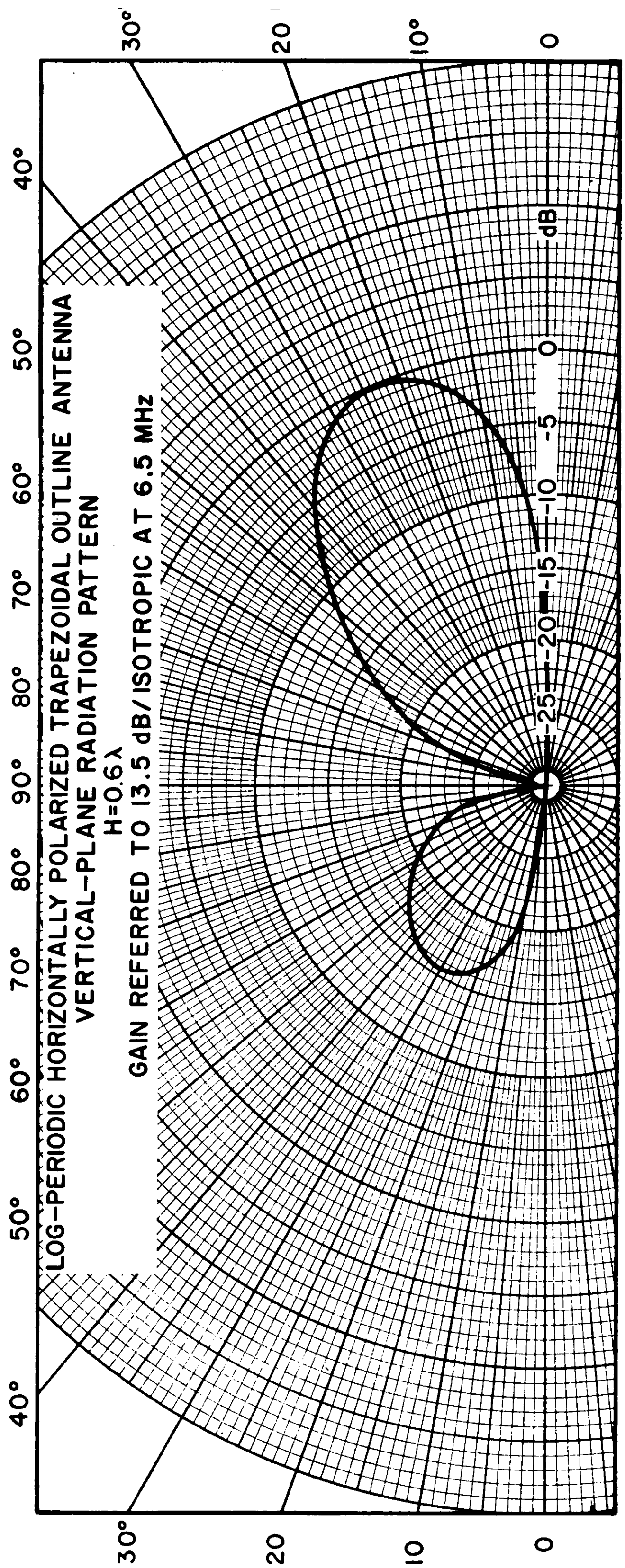


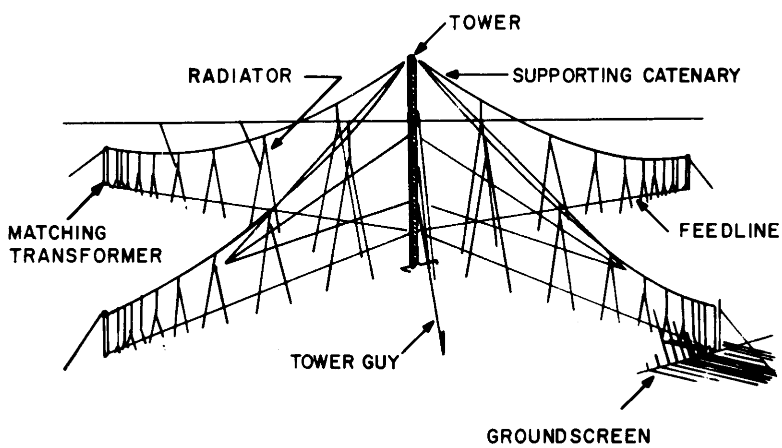
Figure 4-5. Log-Periodic Antenna Radiation Patterns (Sheet 6 of 6)

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.



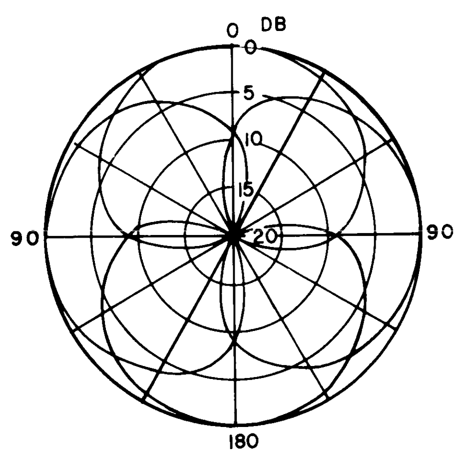


Figure 4-6. Sector LPA and Horizontal Radiation Pattern

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.

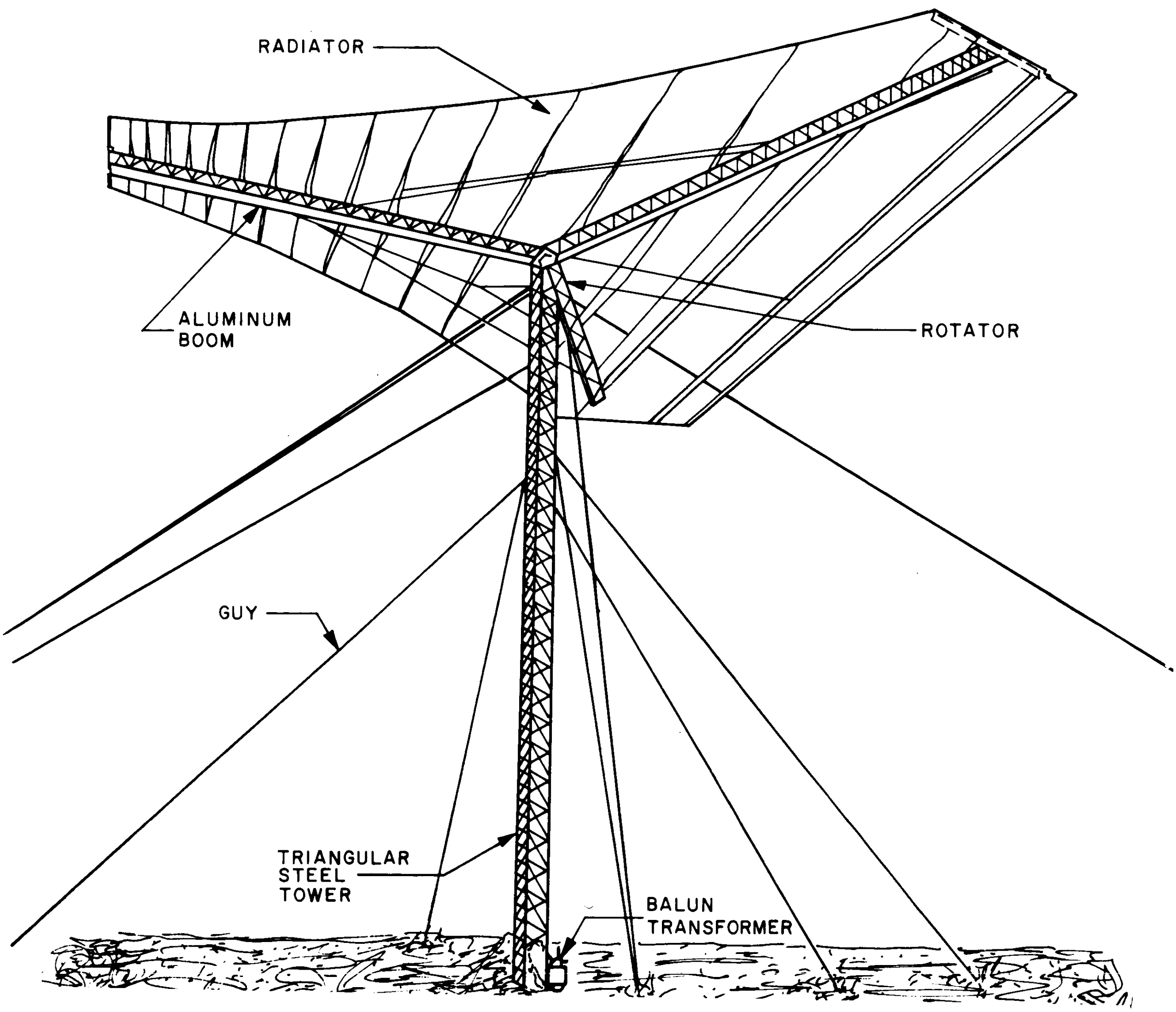


Figure 4-7. Rotatable Log-Periodic Antenna

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

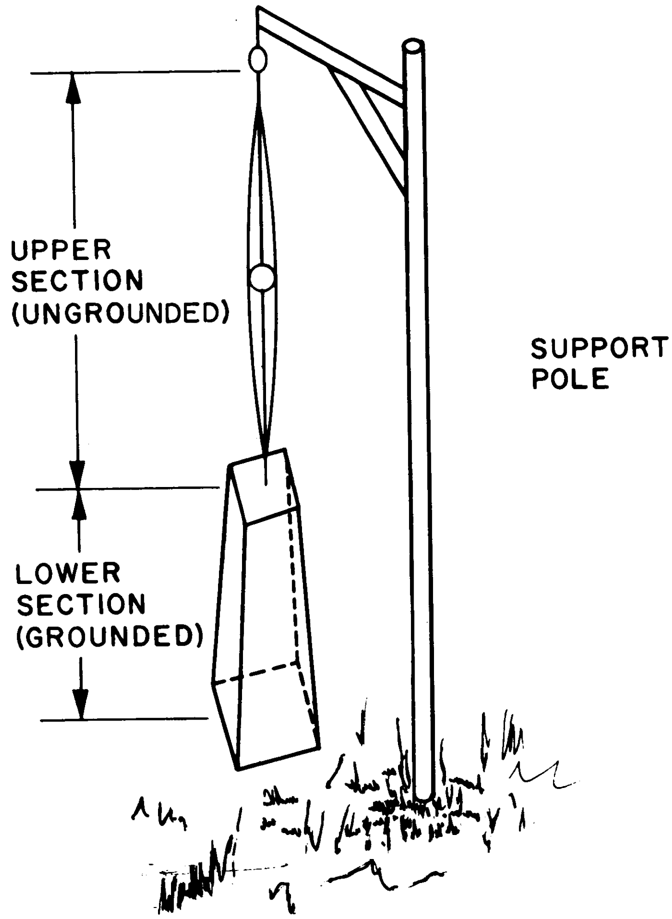


Figure 4-8. Sleeve Antenna

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.

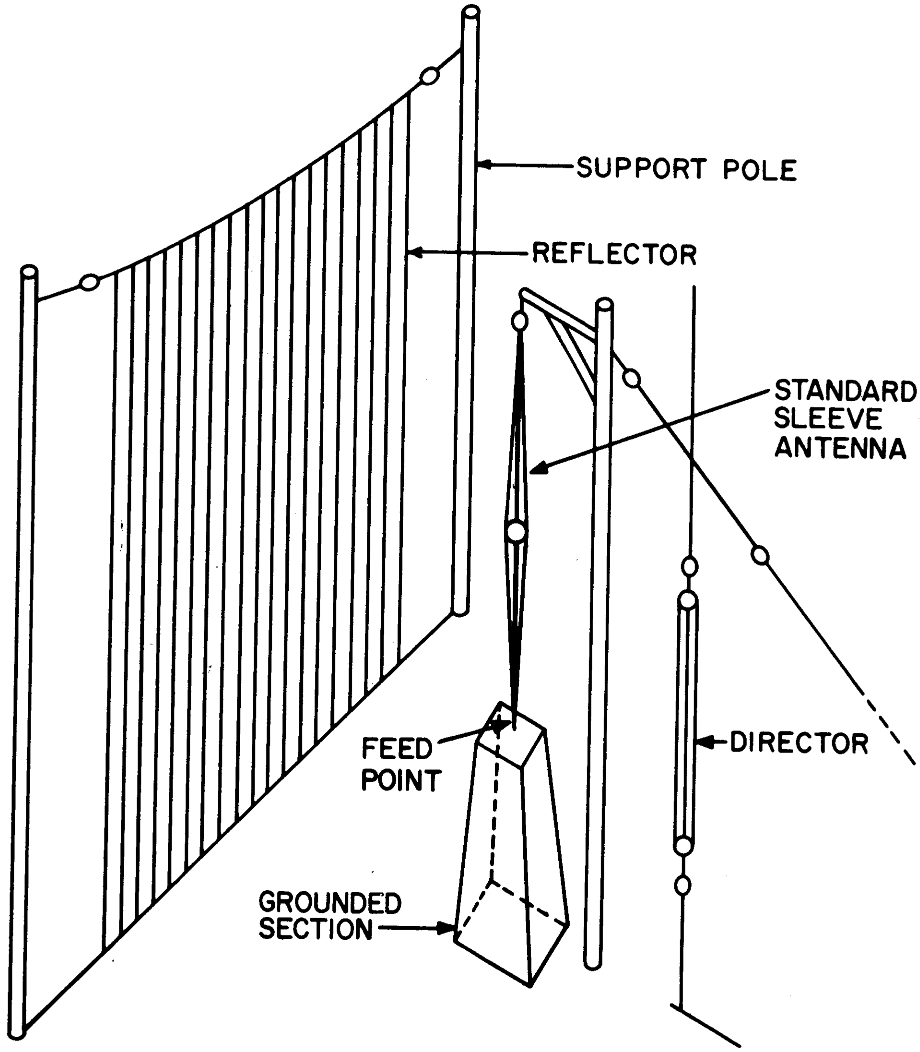


Figure 4-9. 180° Sector Sleeve Antenna

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.

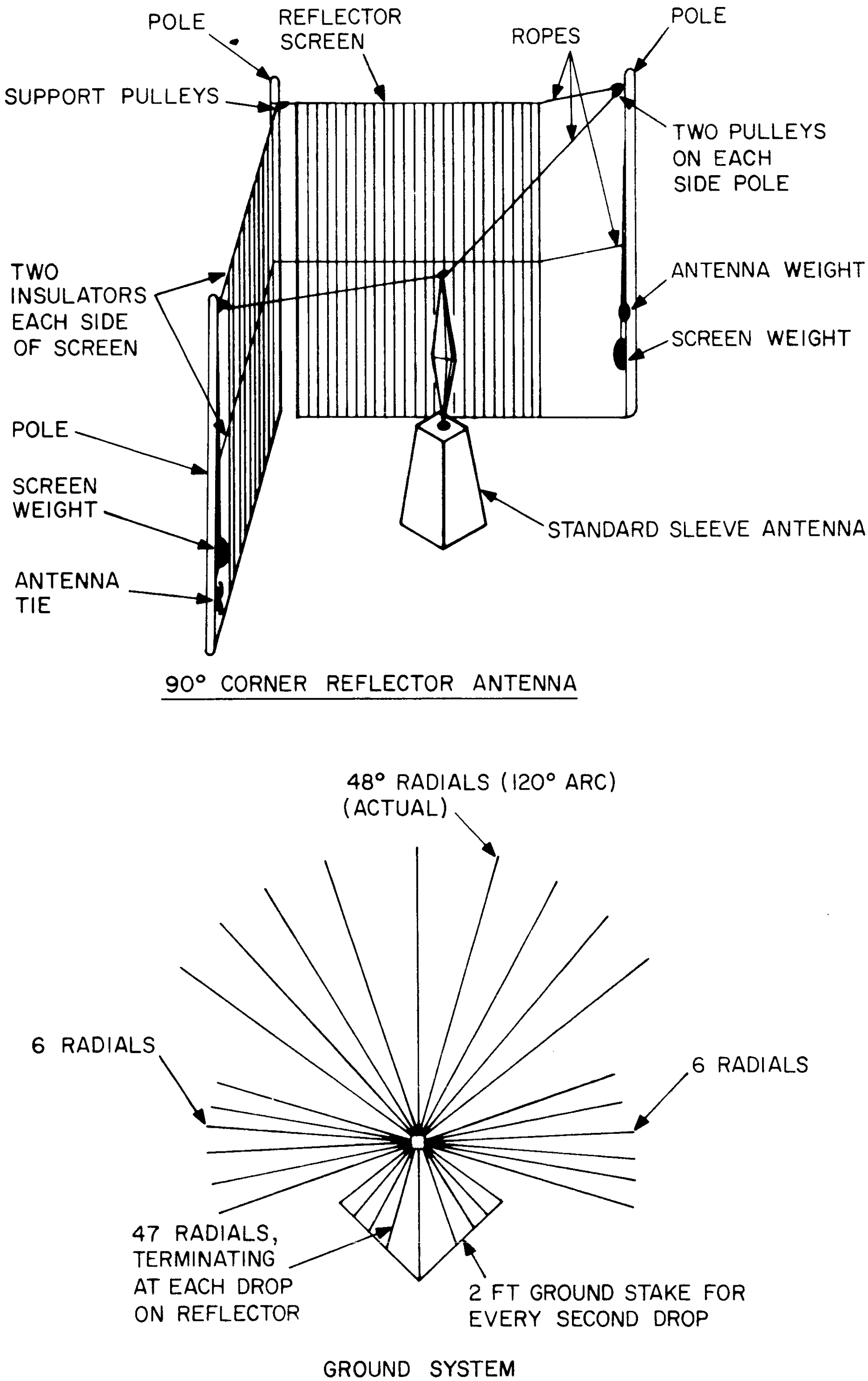


Figure 4-10. 90° Corner Reflector Sleeve Antenna and Ground System

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.

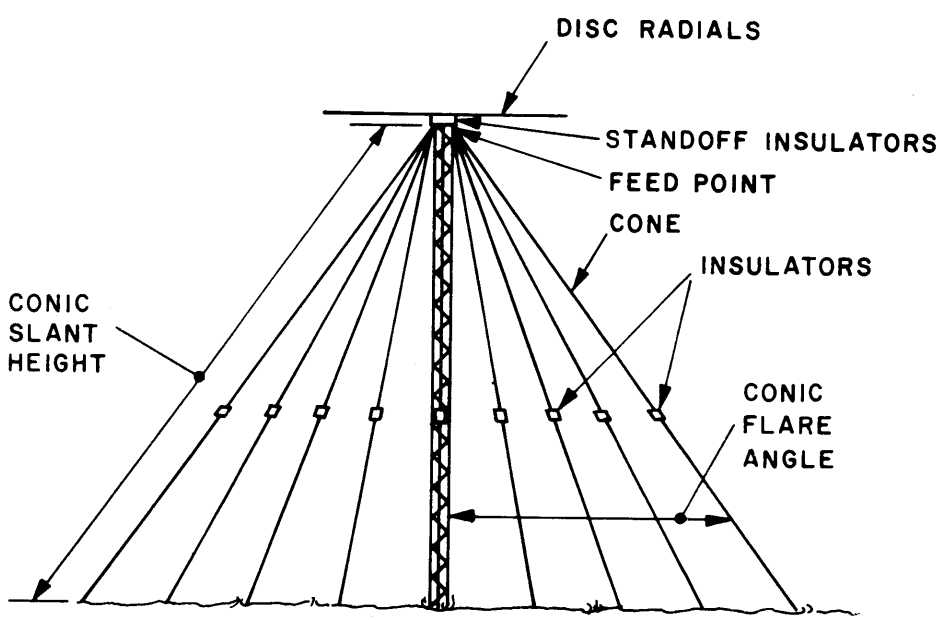


Figure 4-11. Elevated Discone Antenna

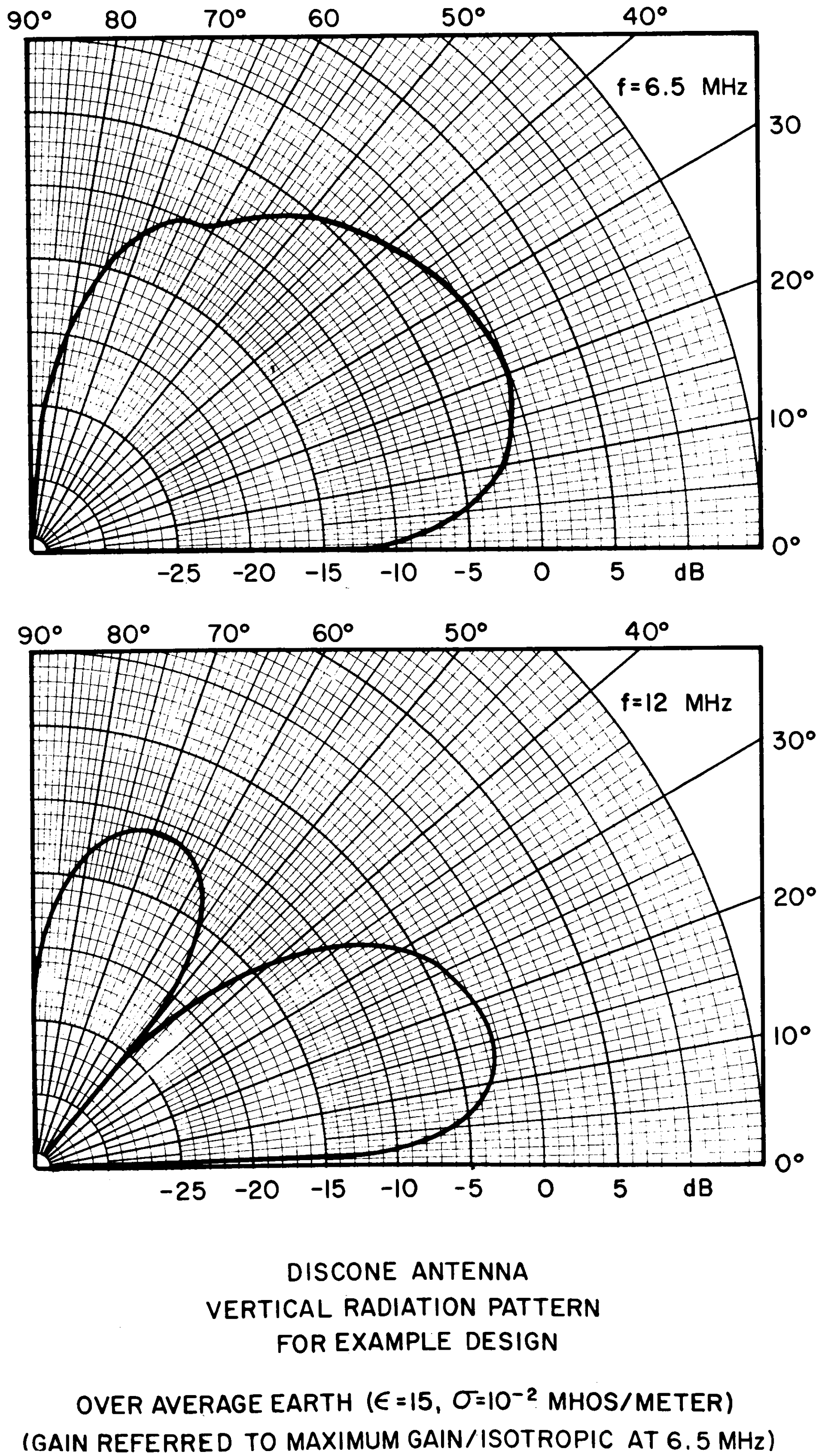
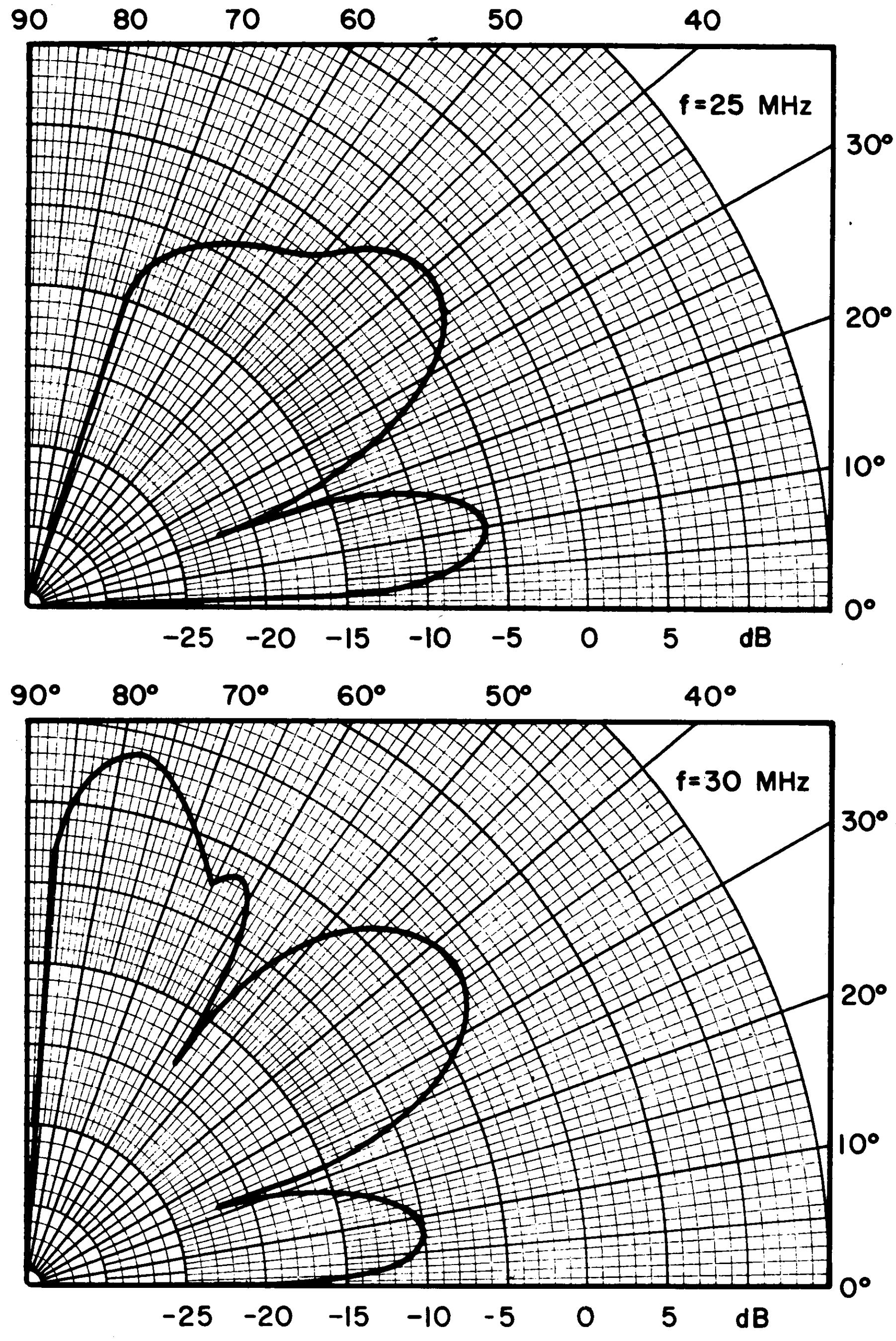


Figure 4-12. Discone Antenna Vertical Radiation Pattern (Sheet 1 of 2)



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 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

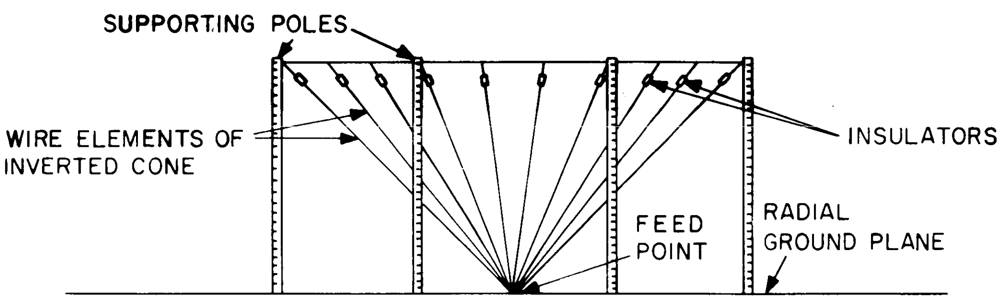


Figure 4-13. Inverted Cone Antenna

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

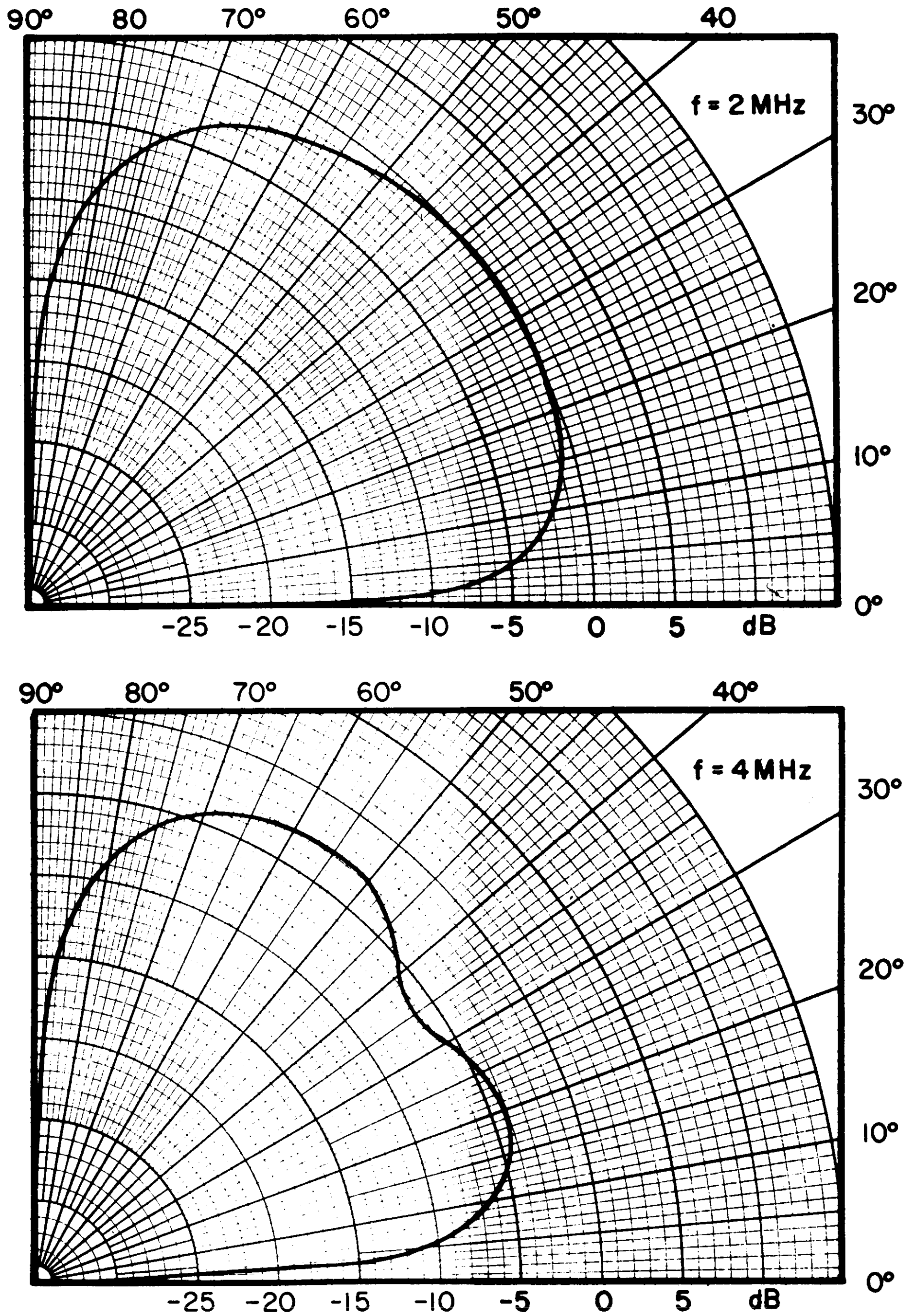
HF inverted cones are electrically similar to discone and conical monopole antennas. They can be characterized as medium-to-high-power omnidirectional radiators of extremely broad bandwidth. Inverted cones generally are more expensive than other commonly used HF omnidirectional vertical antennas.

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.

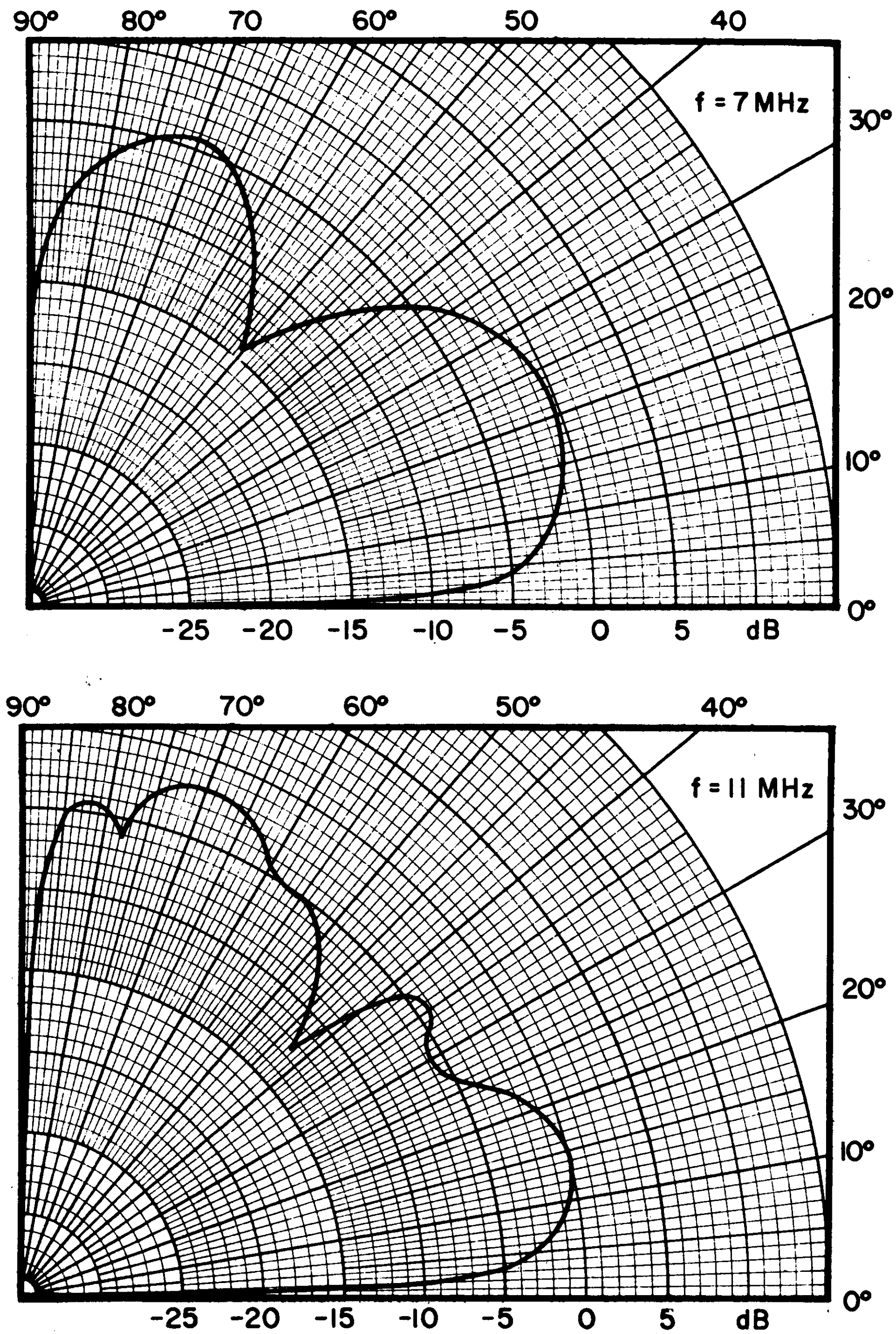
4.8.1 Physical and Electrical Characteristics

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)

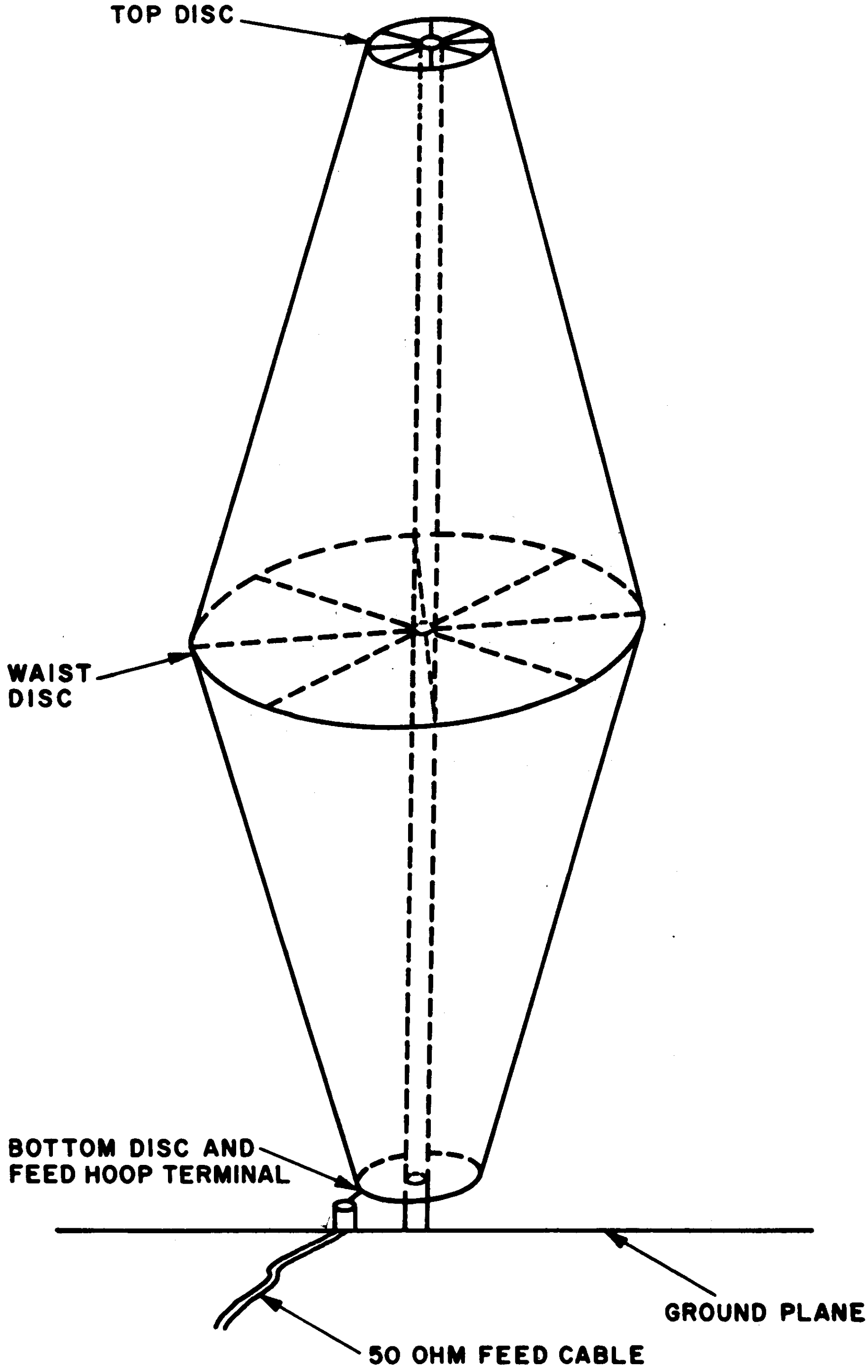
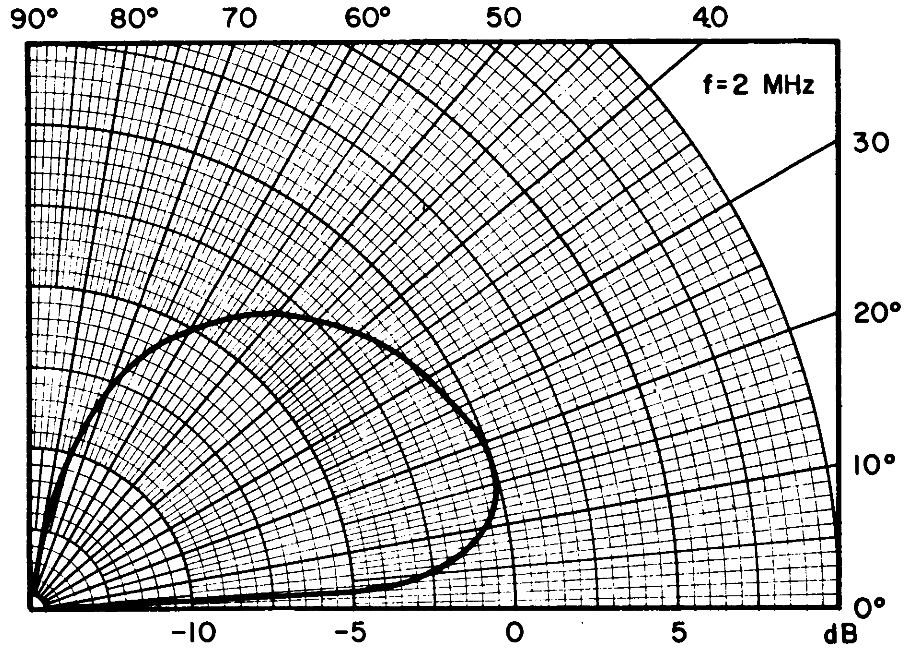
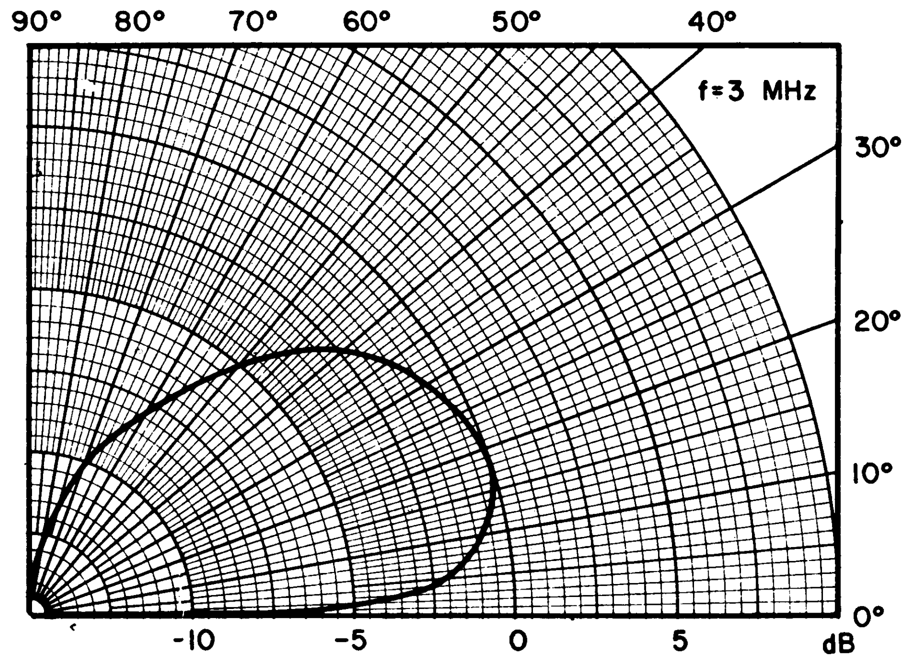


Figure 4-15. Conical Monopole

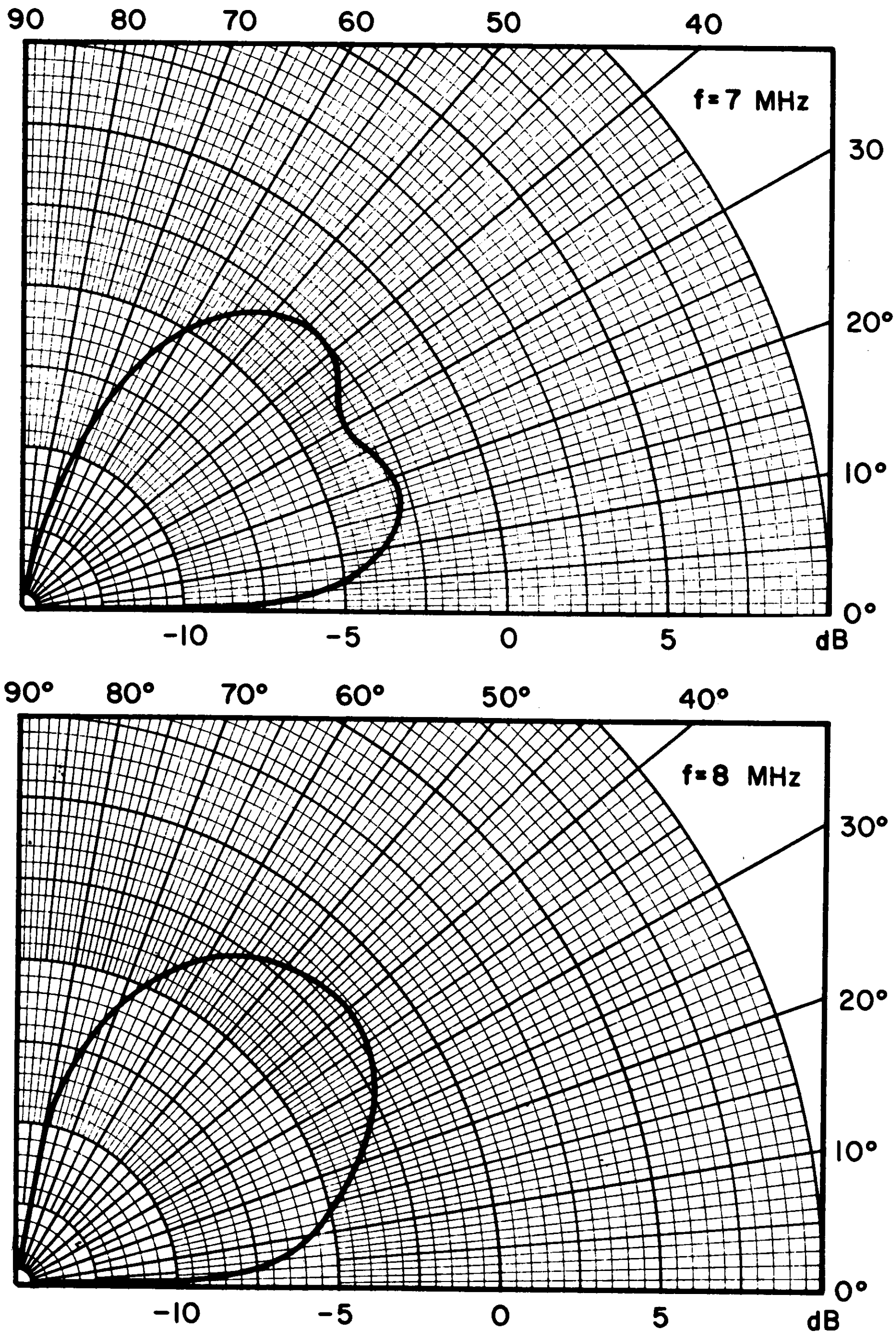




CONICAL MONOPOLE ANTENNA
VERTICAL RADIATION PATTERN
FOR EXAMPLE DESIGN

OVER AVERAGE EARTH (ϵ=15, σ=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 (ϵ=15, σ=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

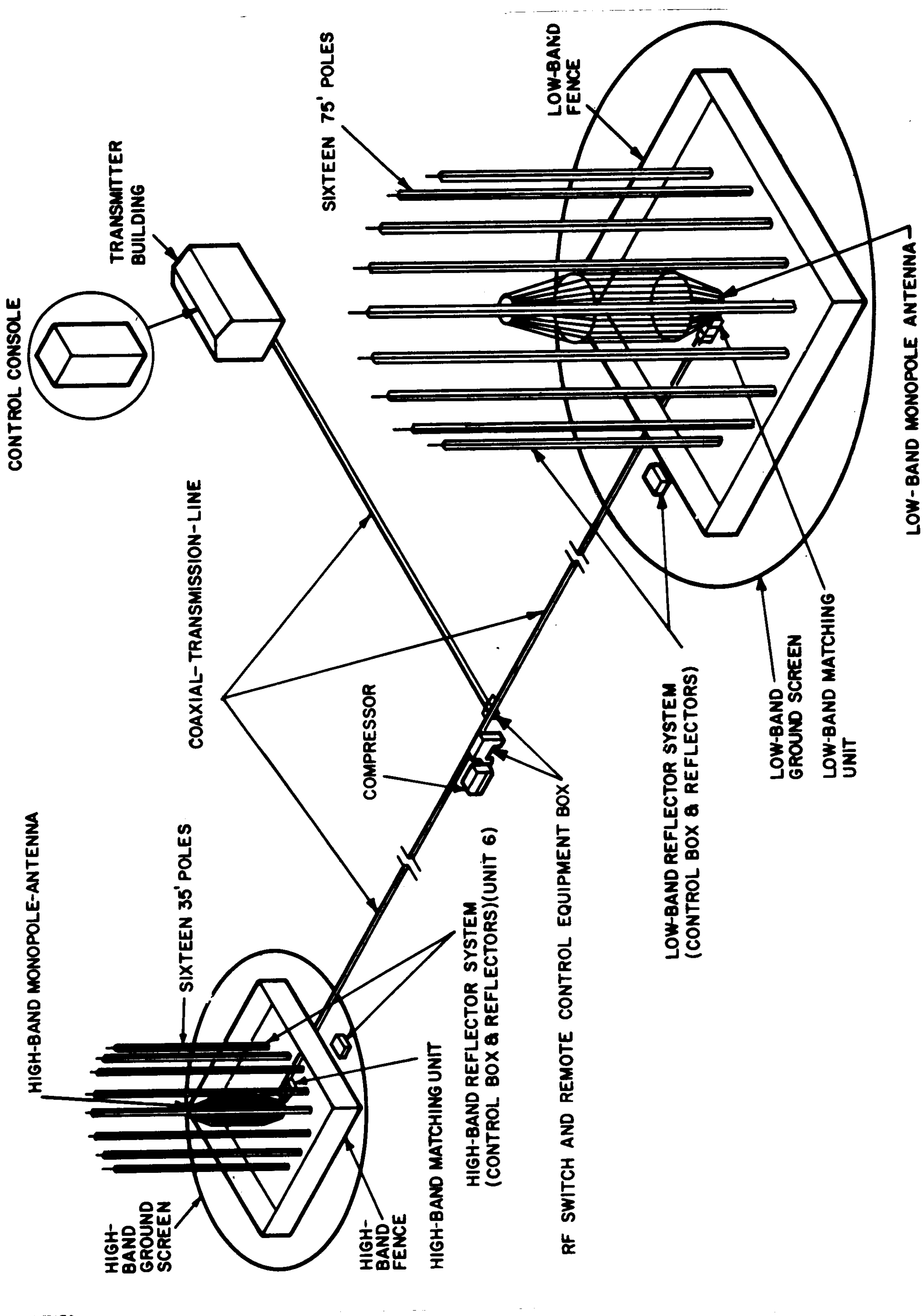


Figure 4-17. Antenna Set, AN/FRA-109

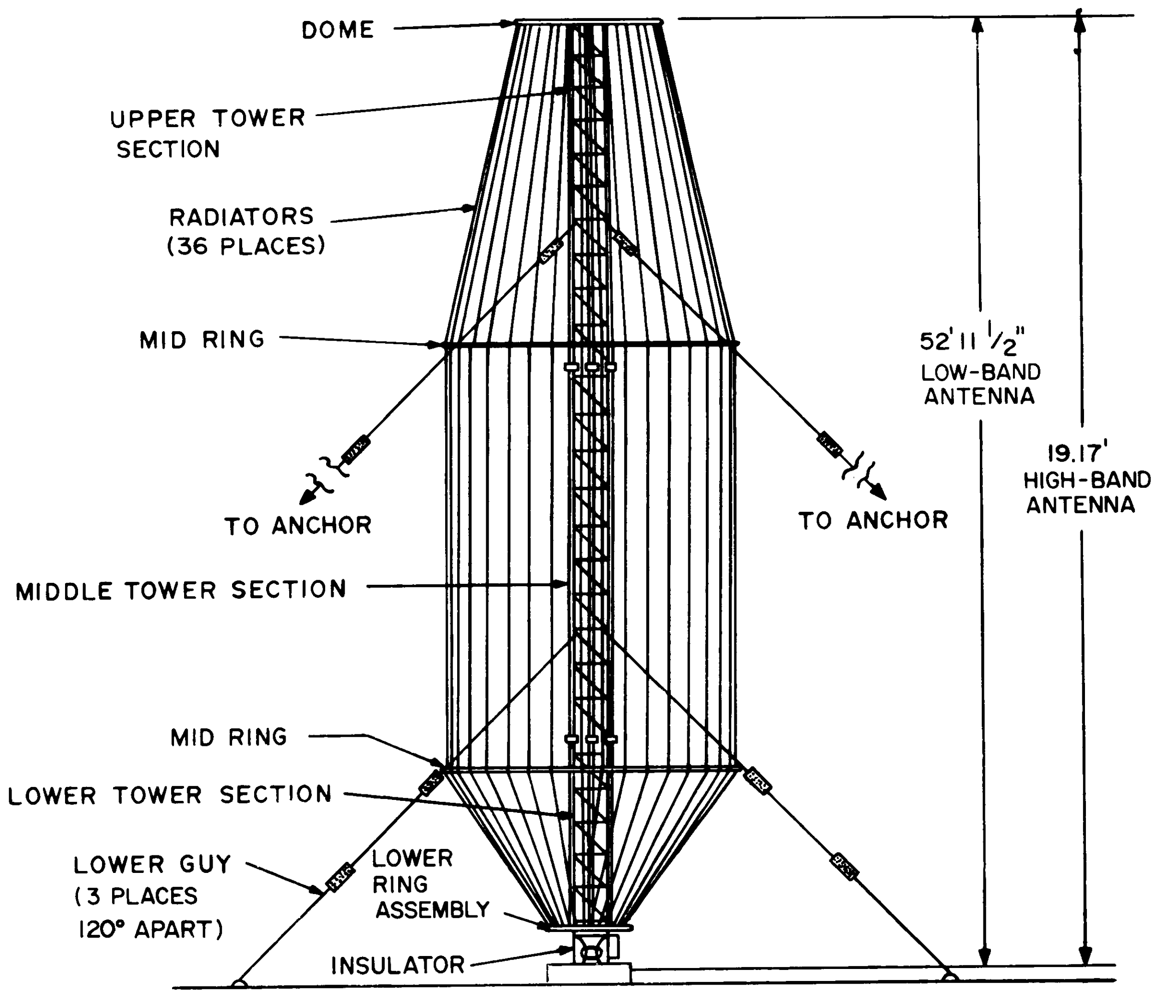


Figure 4-18. Low- and High-Band Monopole Antenna

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 introduced into a reflector, the air pressure overcomes the spring tension, and the switch contacts 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 transmitter 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 location 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.

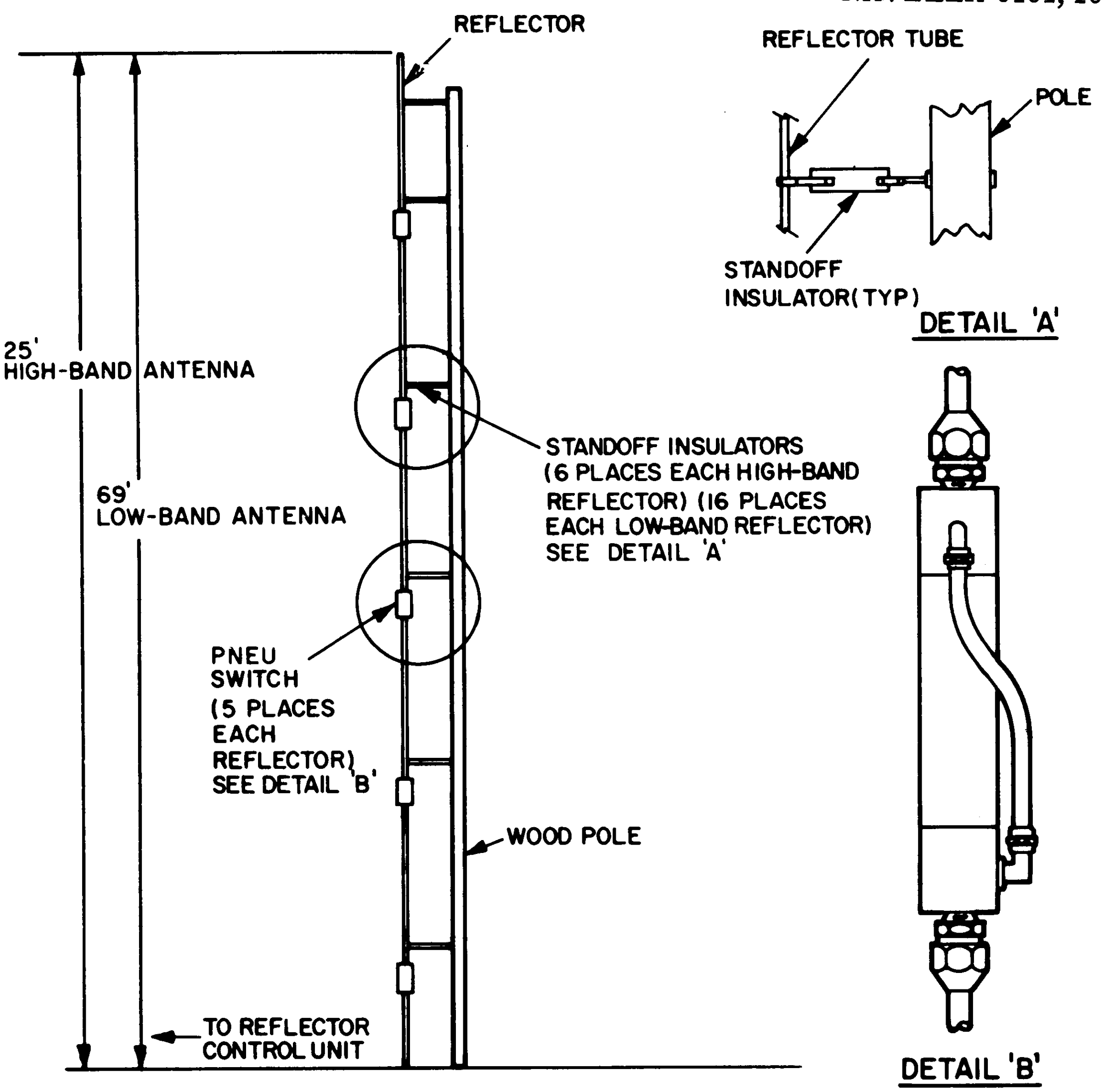


Figure 4-19. Individual Low- and High-Band Reflectors

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.

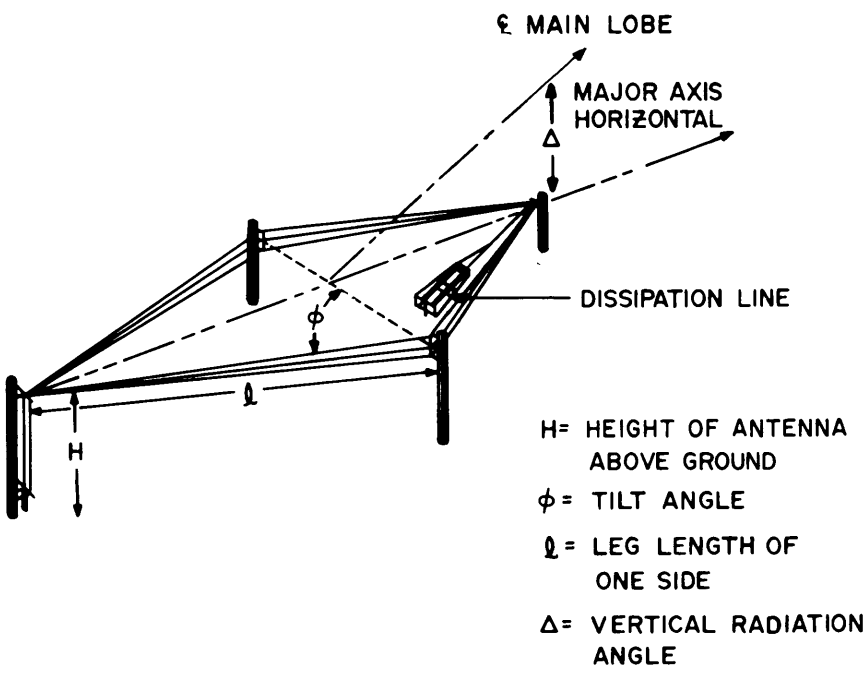


Figure 4-20. Non-Resonant Horizontal Three-Wire Rhombic

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.

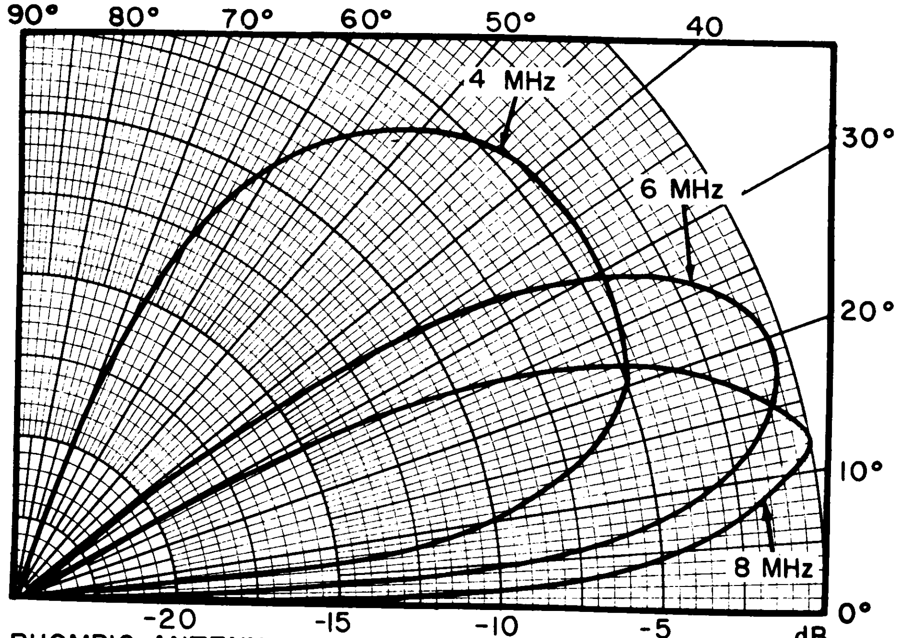
Since the rhombic is a system of long-wire radiators which depends upon radiated wave interaction for its gain and directivity, the physical size of the antenna is large. The rhombic generally requires more land than any other commonly used HF antenna, usually between 5 and 15 acres of level ground. 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°.

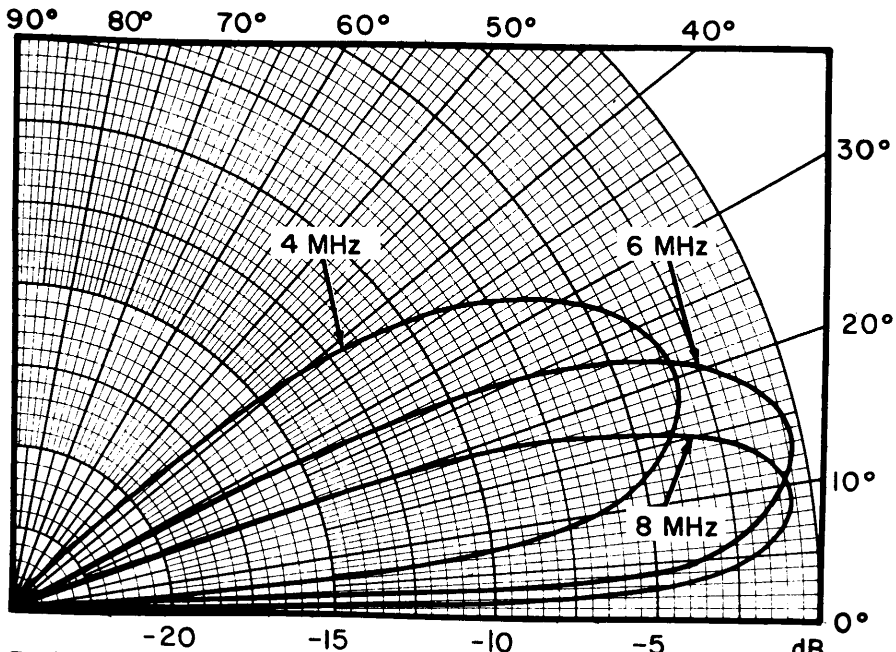
Since the vertical radiation angle and vertical directivity vary considerably with frequency, it is apparent that a single antenna is not likely to maintain a satisfactory power gain or lobe orientation over the entire HF spectrum. Consequently, it is normal to cover the major portion of the spectrum 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

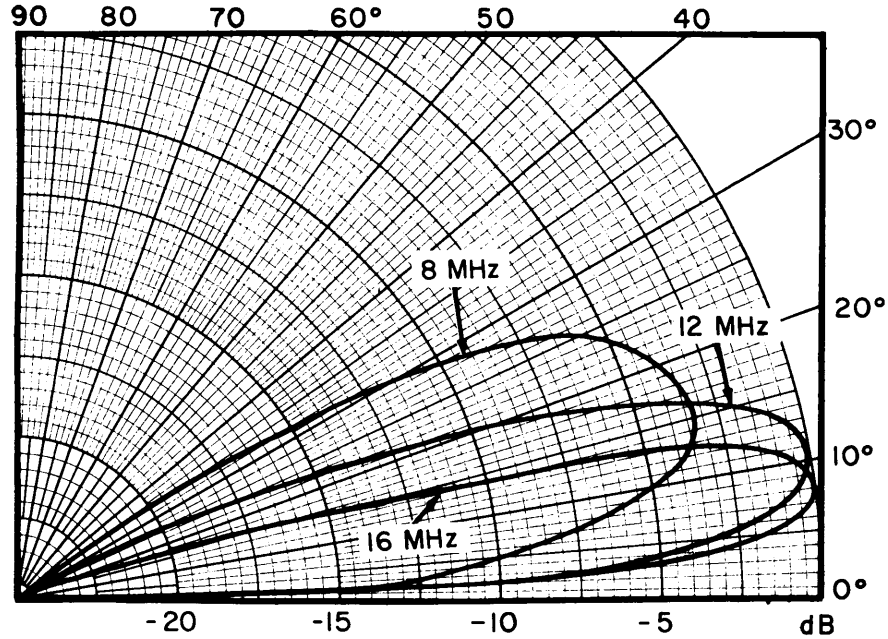


RHOMBIC ANTENNA DESIGN NO.1
ℓ = 328 FEET
H = 98 FEET
Ø = 54°

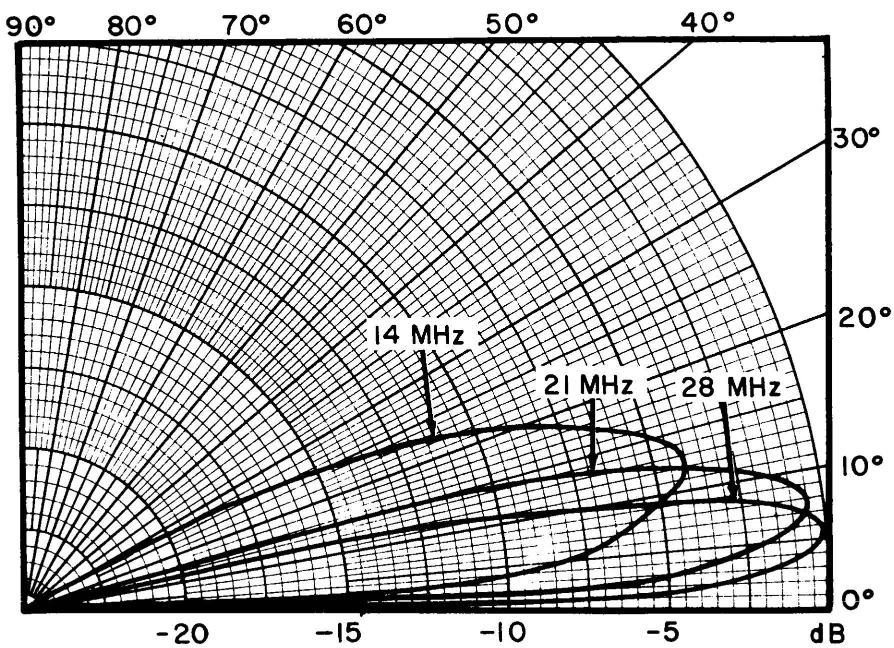


RHOMBIC ANTENNA DESIGN NO.2
ℓ = 350 FEET
H = 148 FEET
Ø = 54

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
Ø = 62°



RHOMBIC ANTENNA DESIGN NO.4
ℓ = 235 FEET
H = 75 FEET
Ø = 68°

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

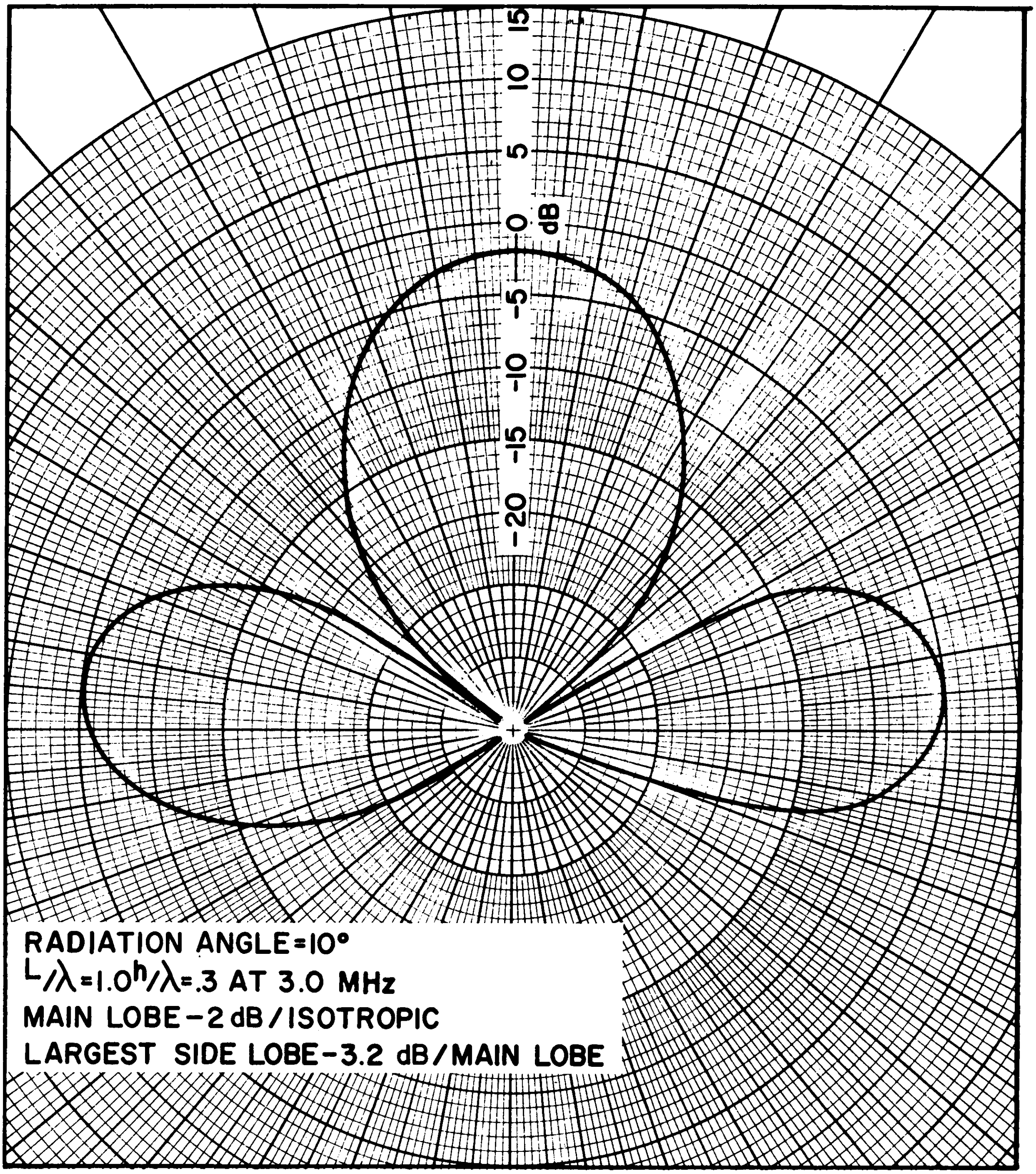


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 1 of 10)

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.

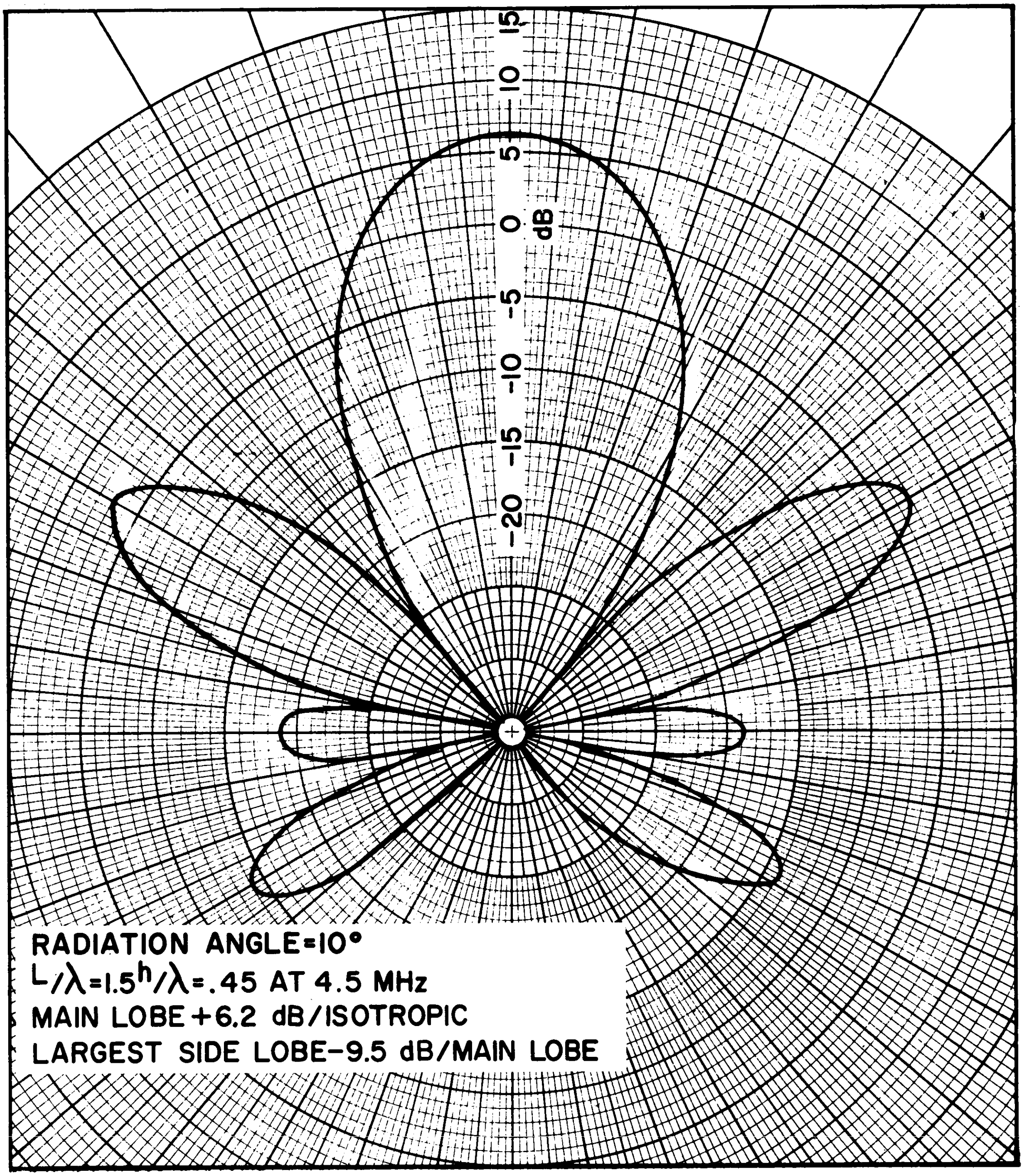


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns (Sheet 2 of 10)

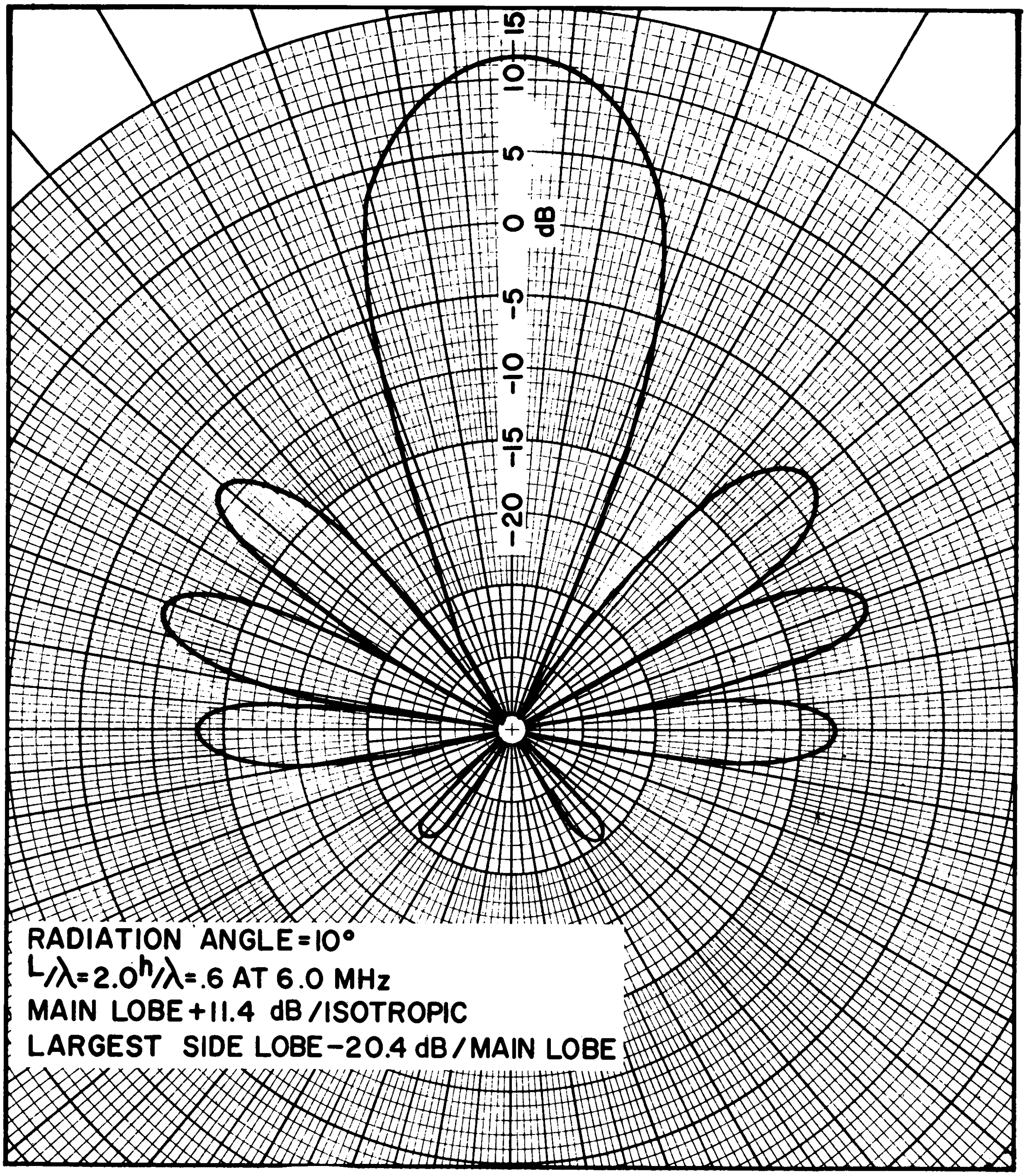


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 3 of 10)

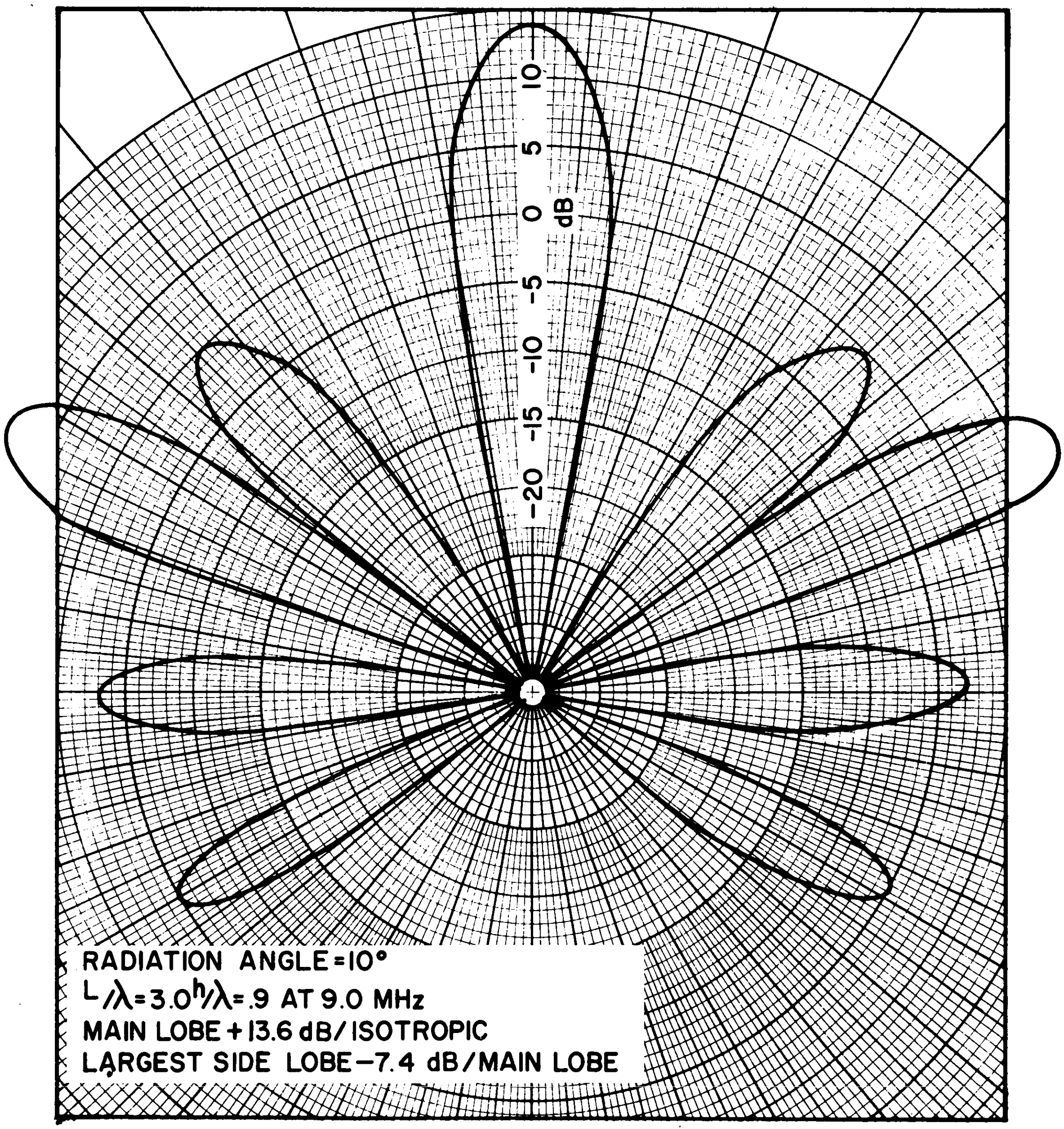


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 4 of 10)

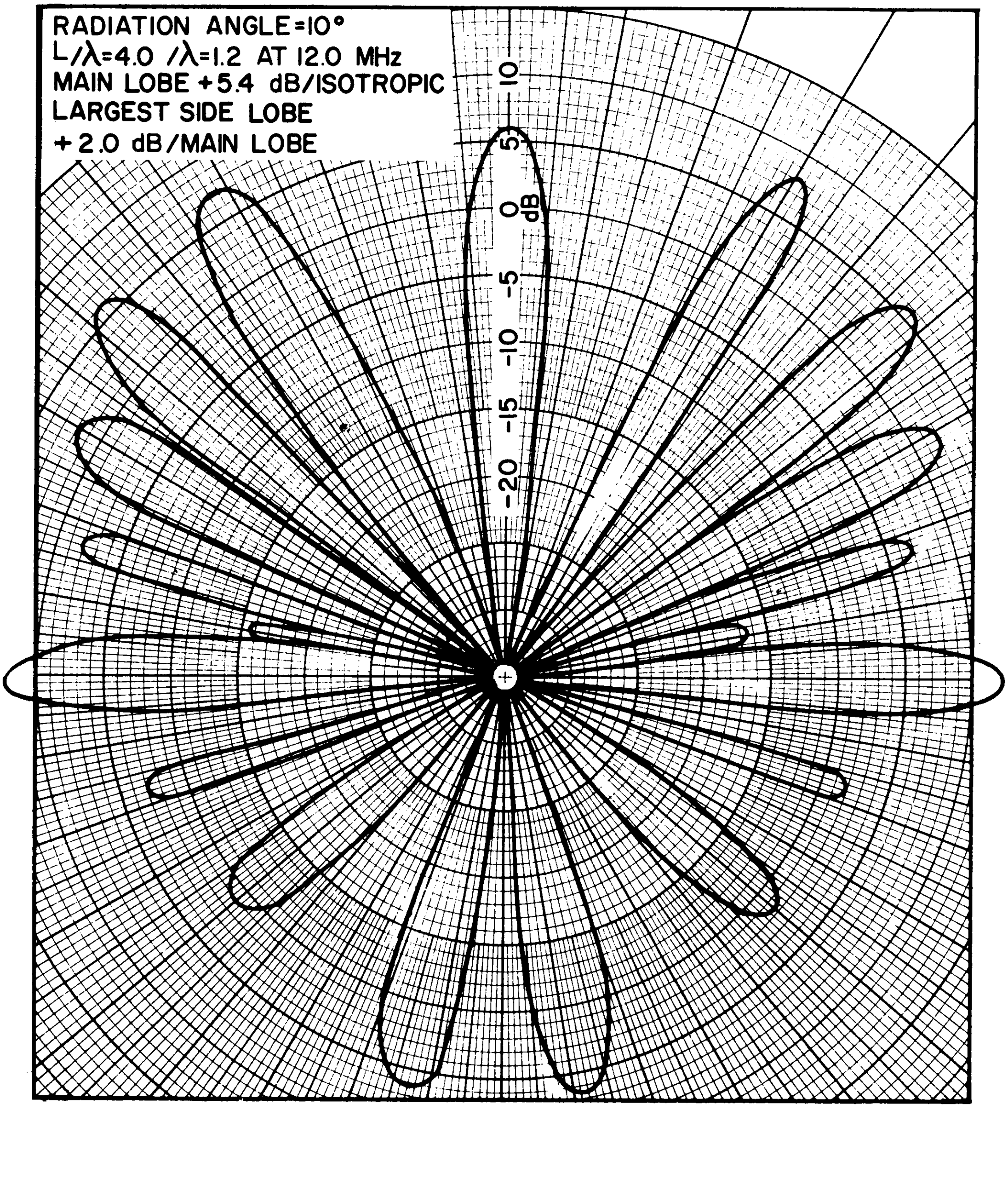


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 5 of 10)

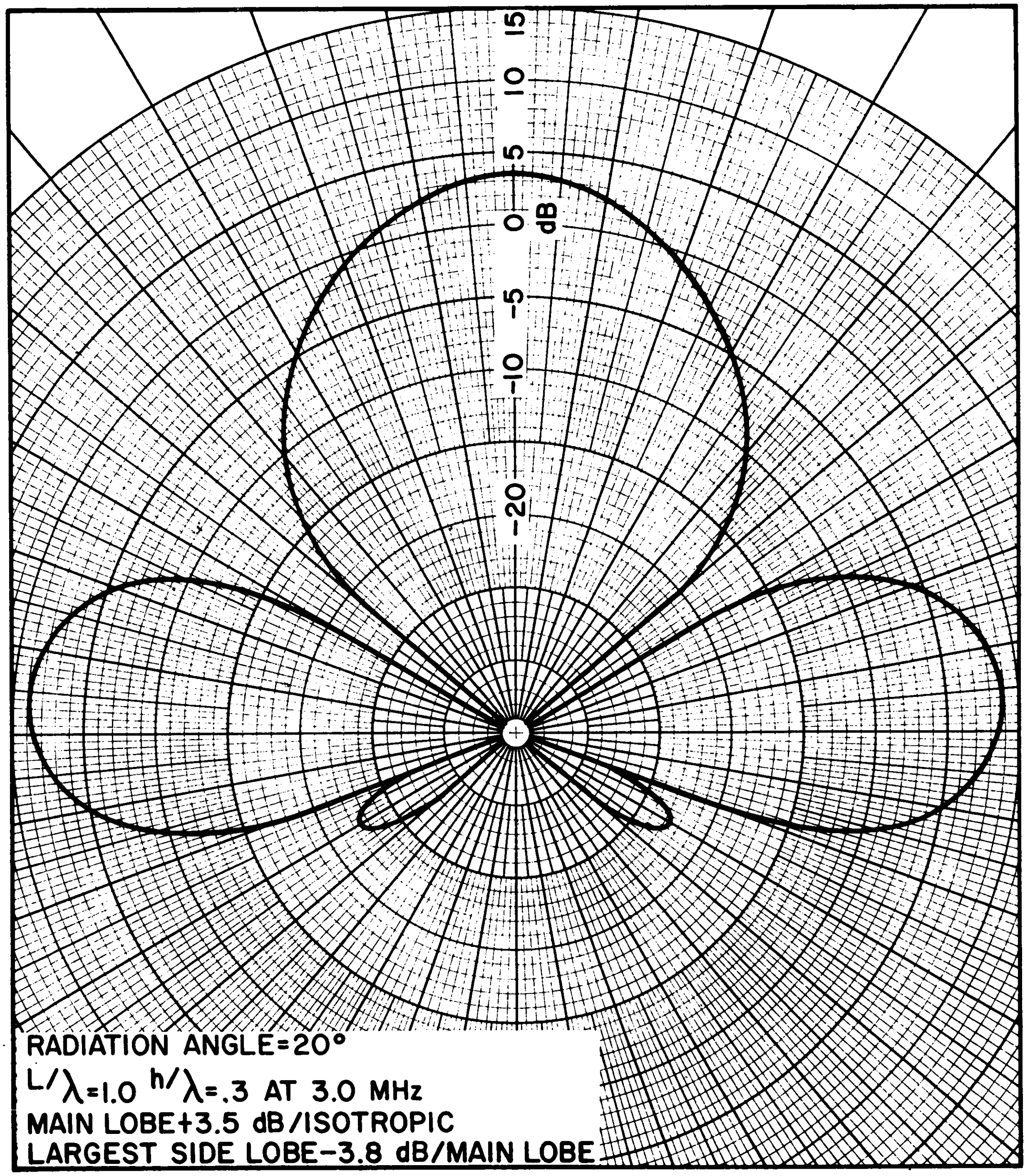


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 6 of 10)

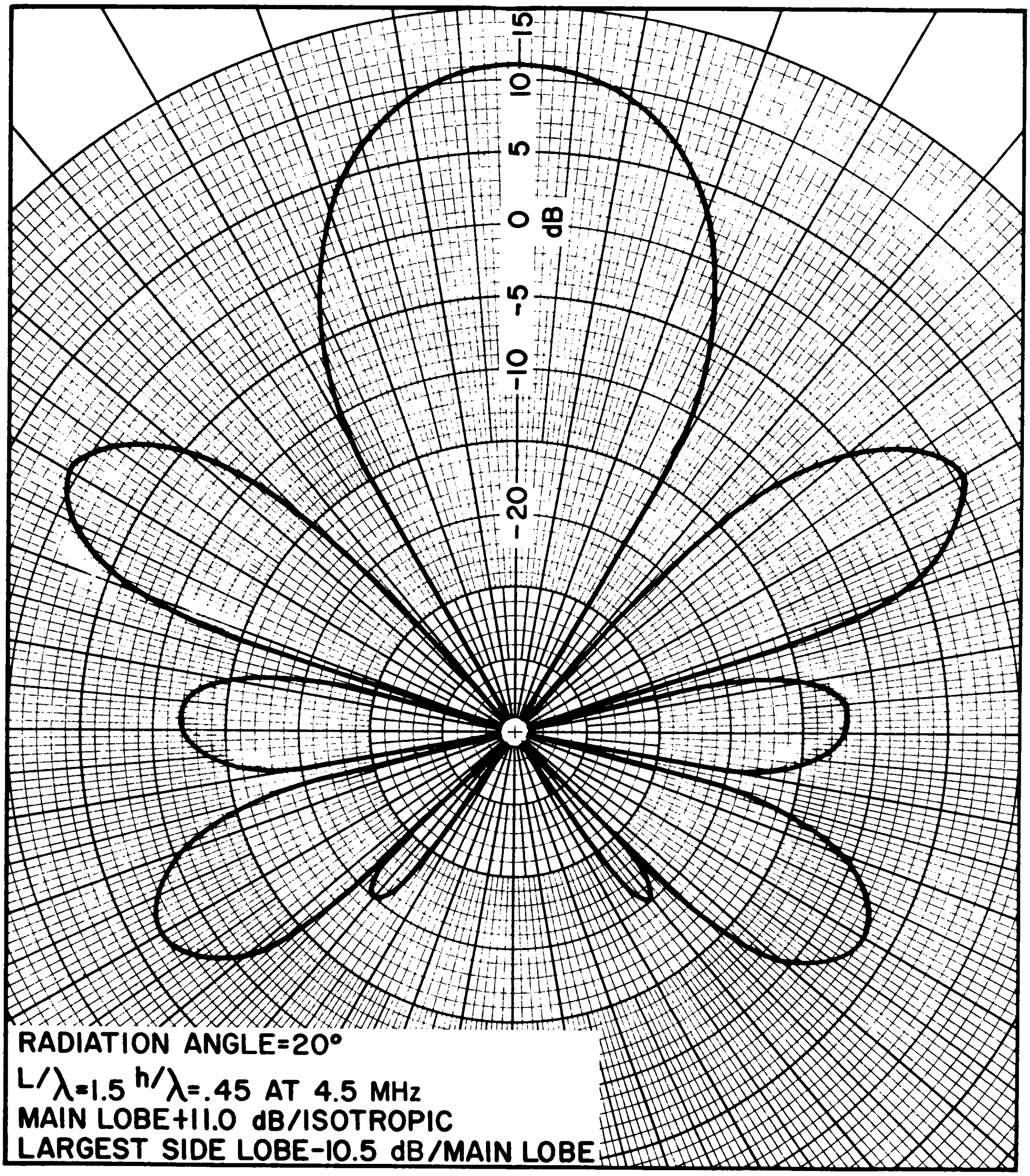


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 7 of 10)

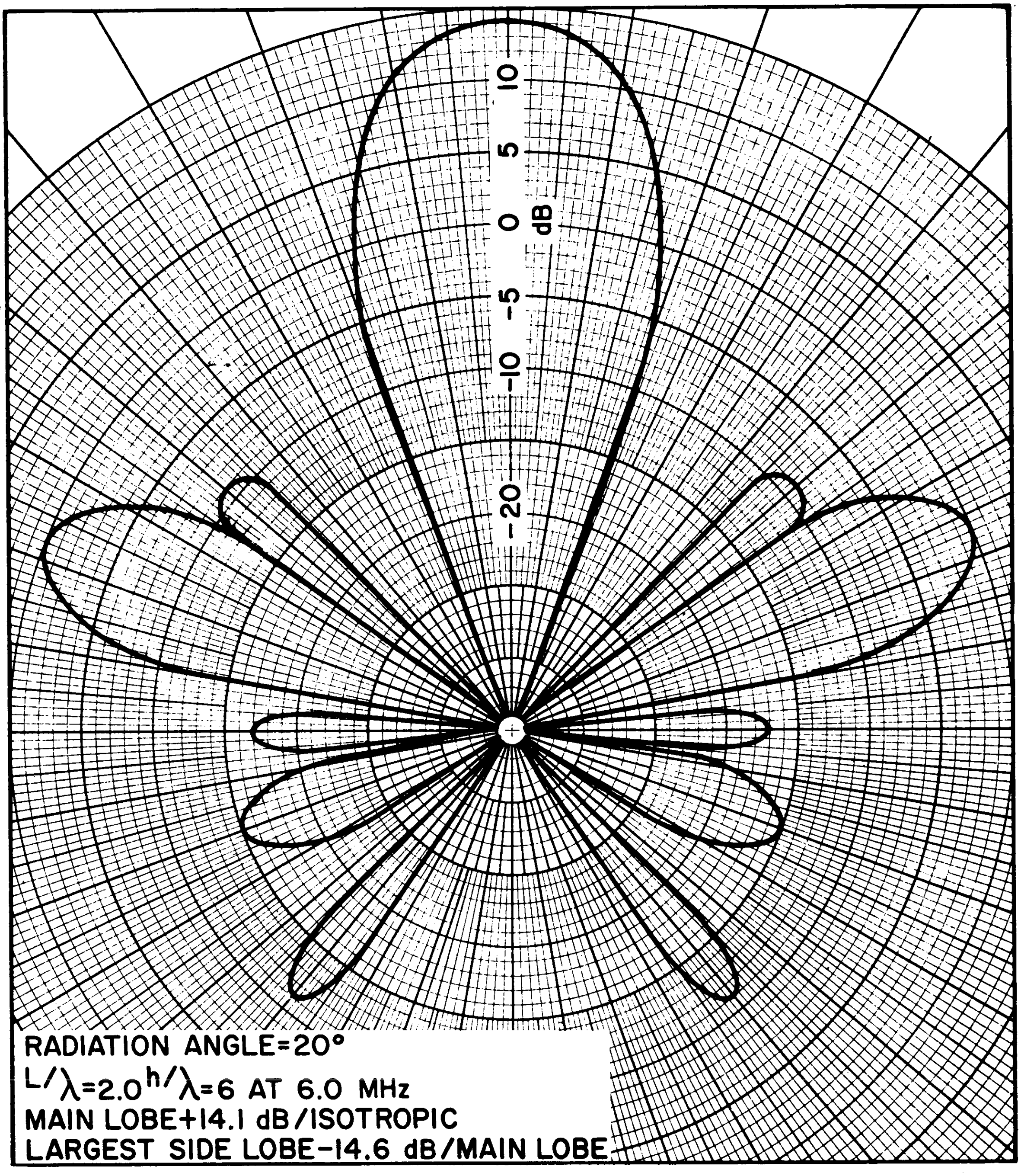


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 8 of 10)

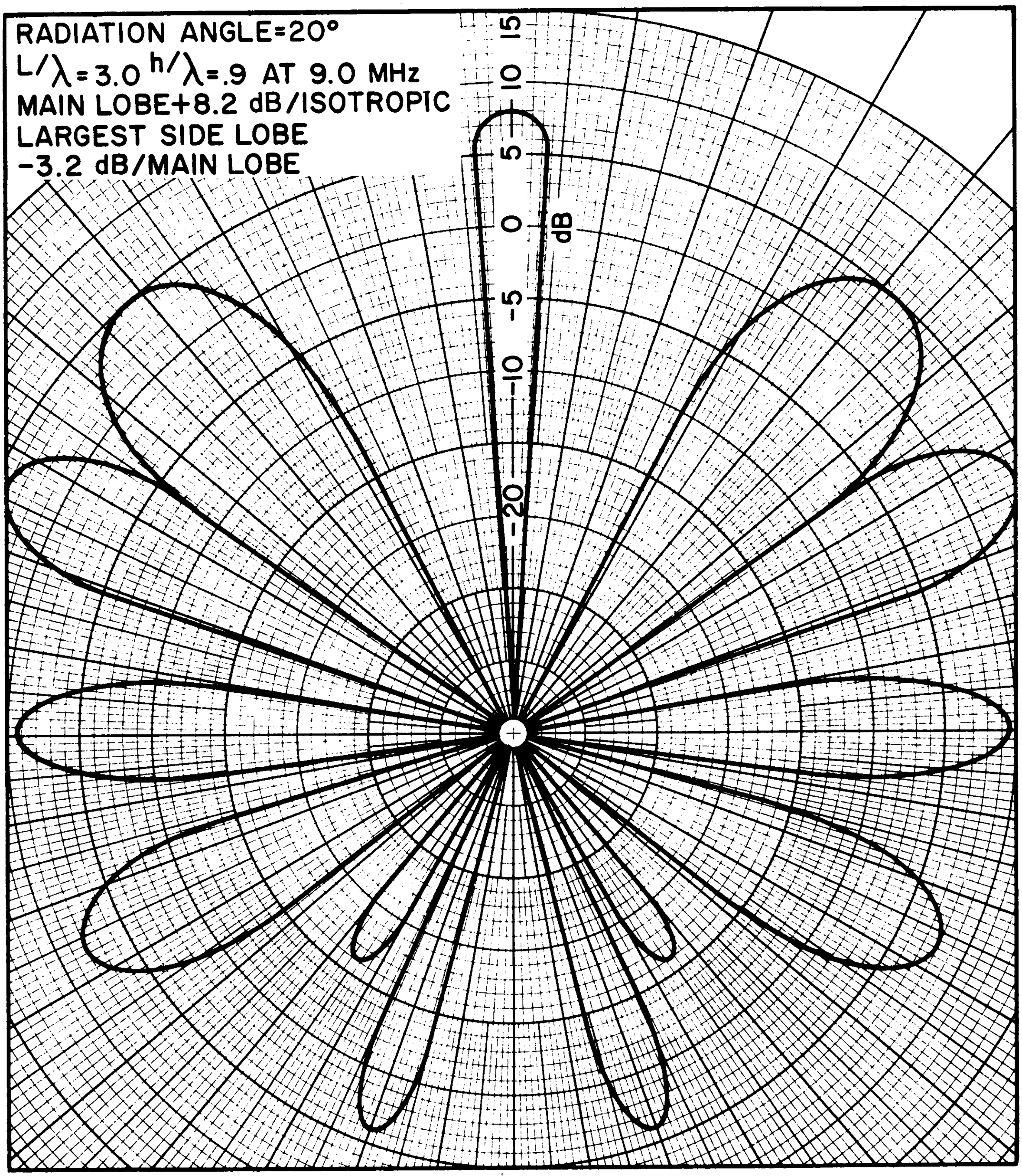


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 9 of 10)

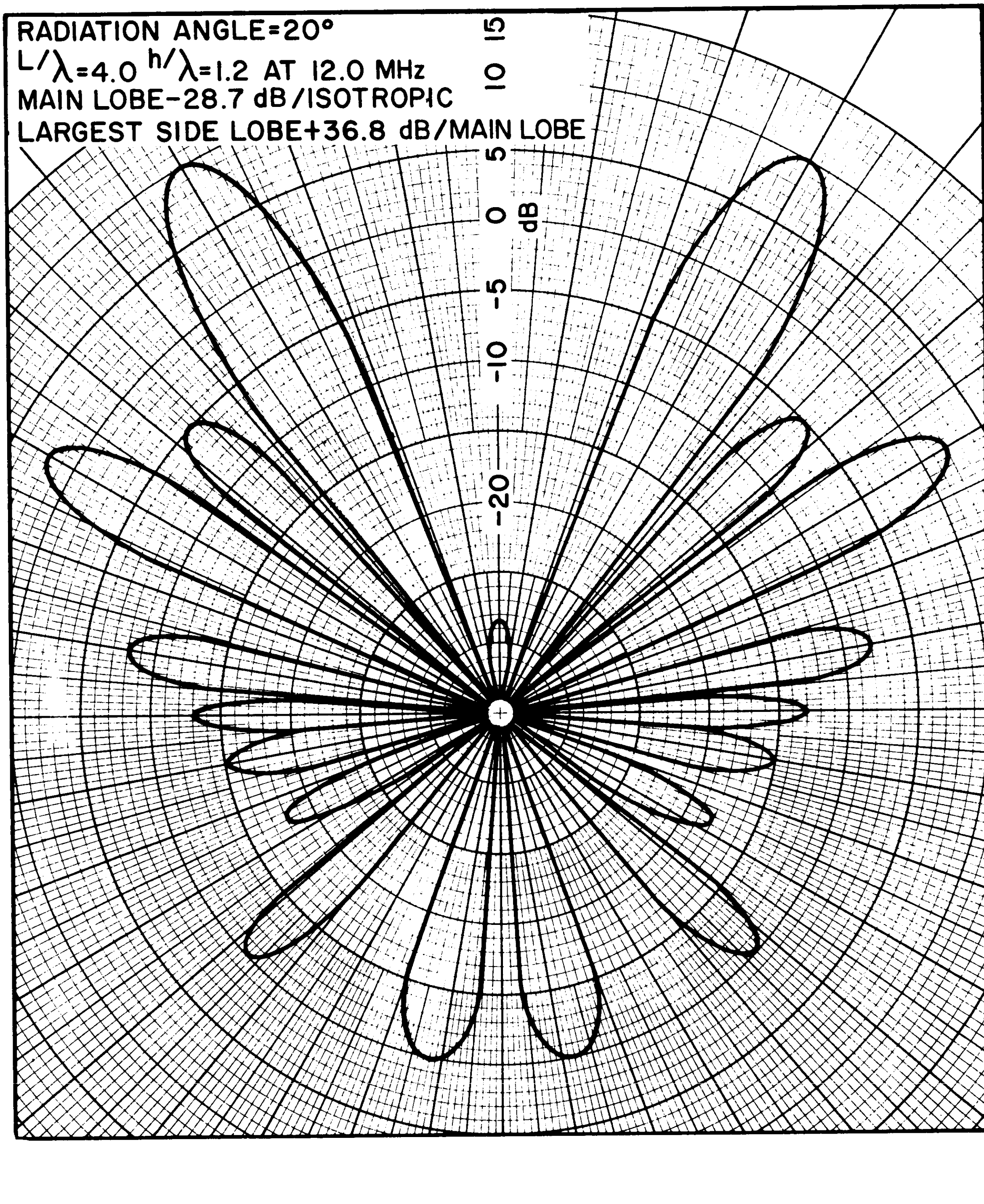


Figure 4-22. Horizontal Rhombic Antenna Radiation Patterns
(Sheet 10 of 10)

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

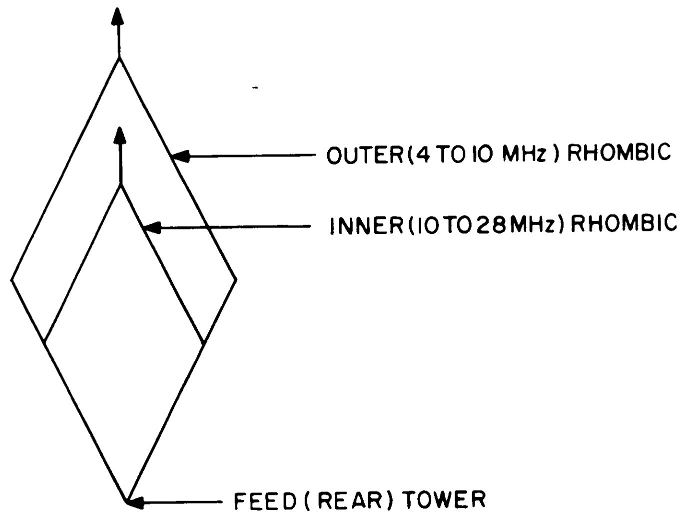


Figure 4-23. Nested Rhombic Configuration

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.

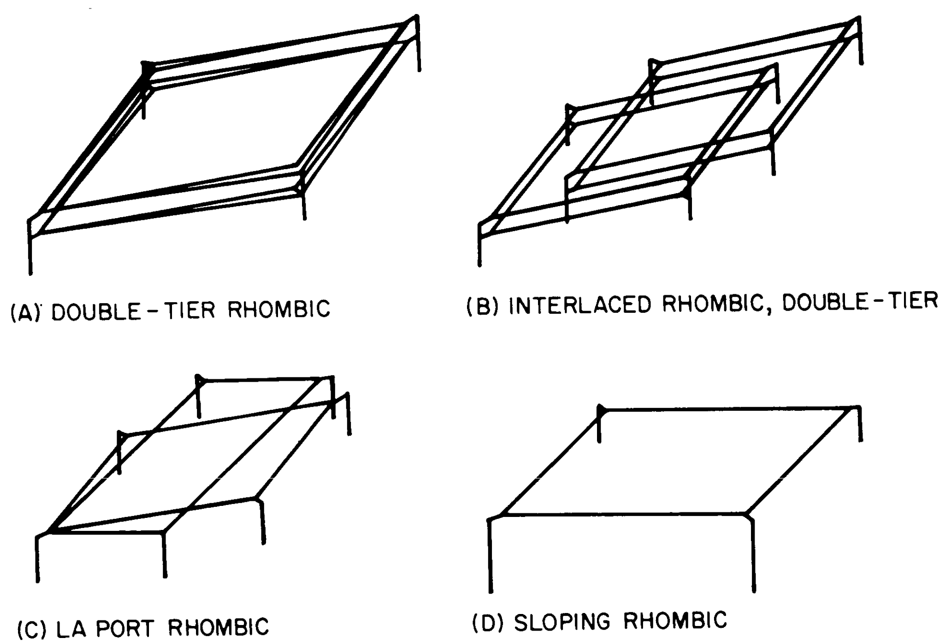


Figure 4-24. Special Rhombic Antenna Configurations

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.

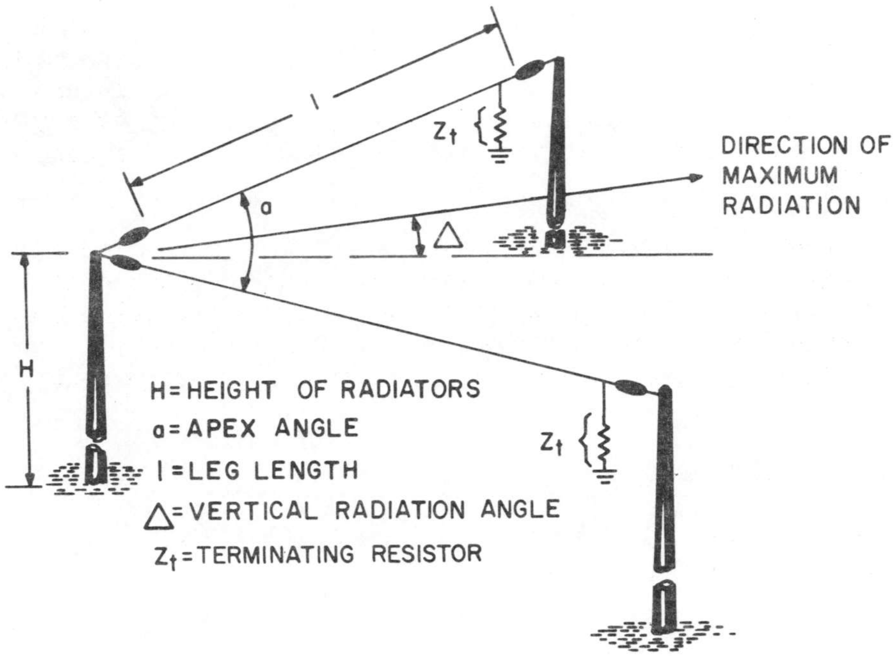


Figure 4-25. Non-Resonant Horizontal Vee Antenna

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.

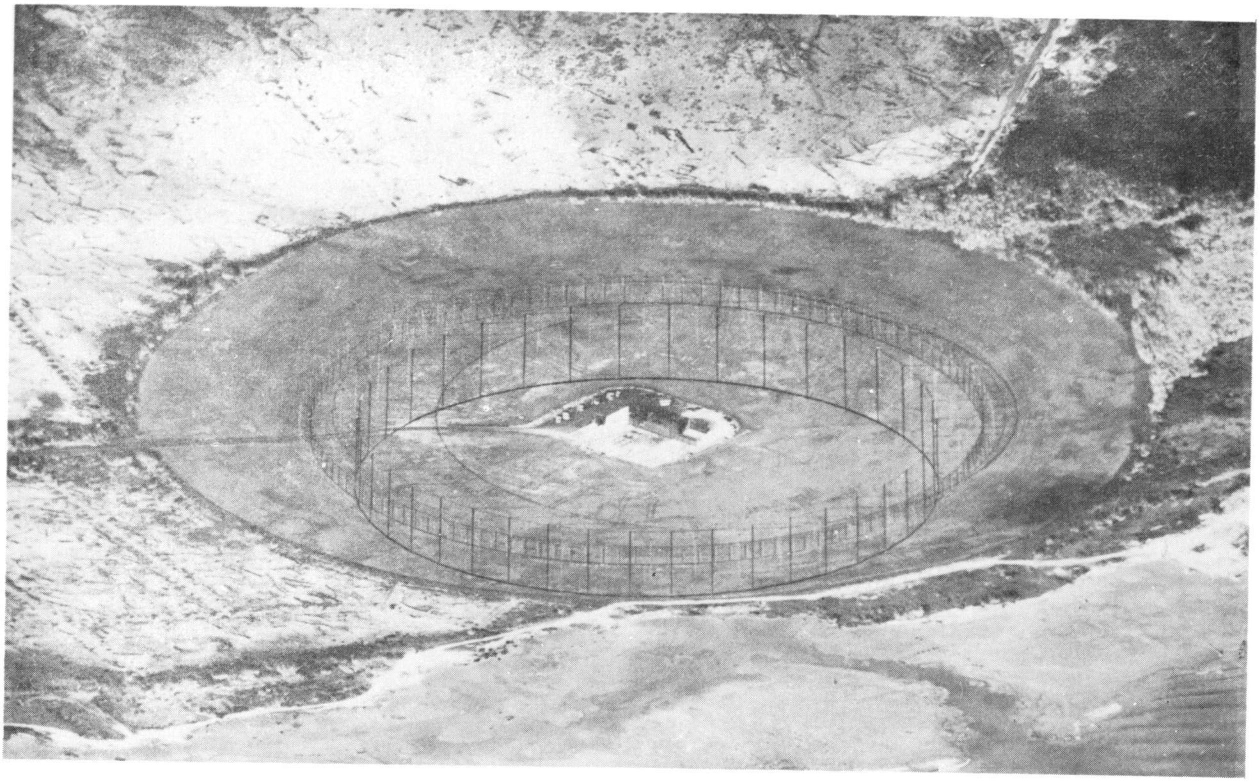


Figure 4-26. Navy Wullenweber Antenna Array

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

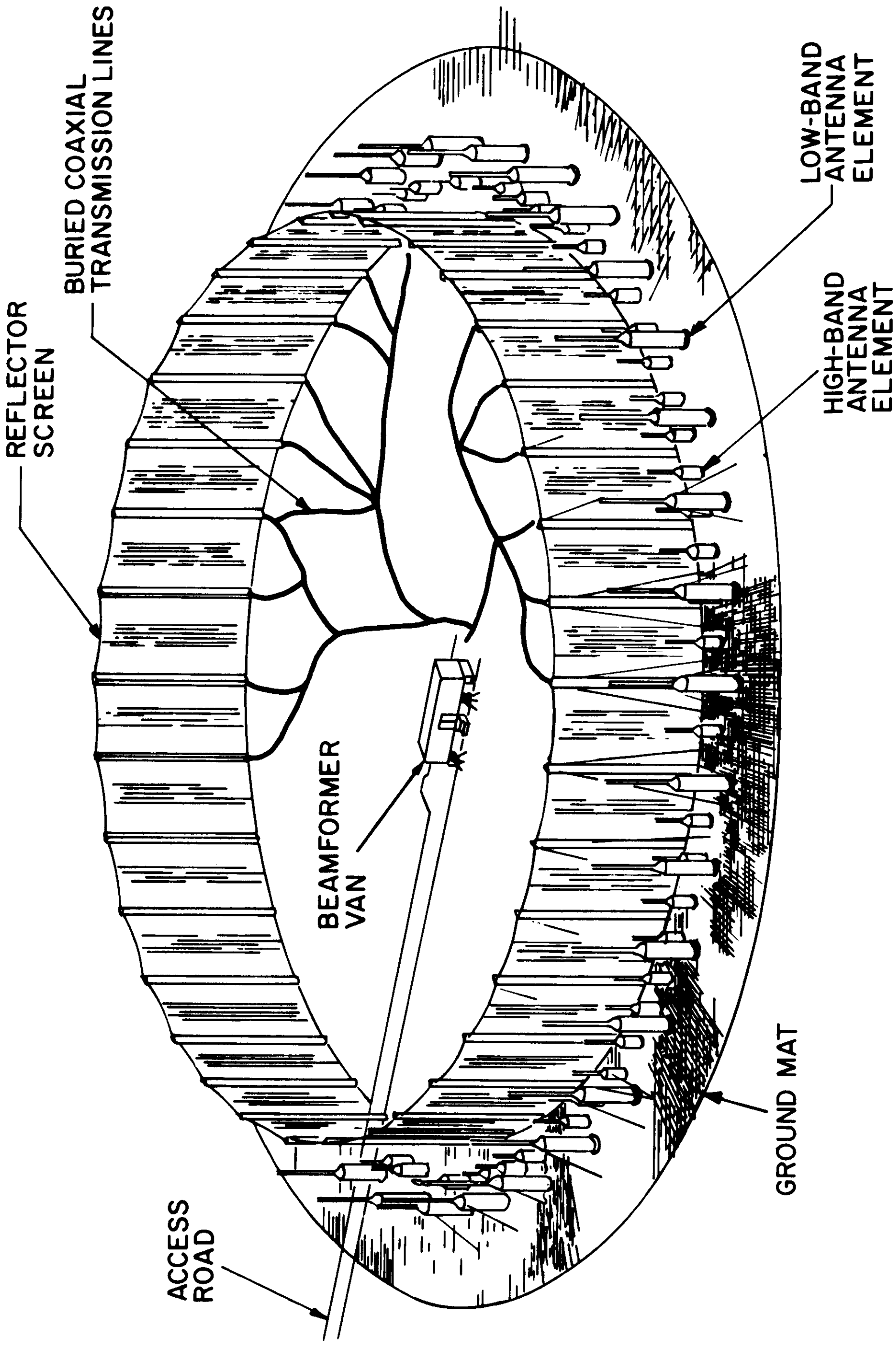


Figure 4-27. Antenna Group AN/TRA-40

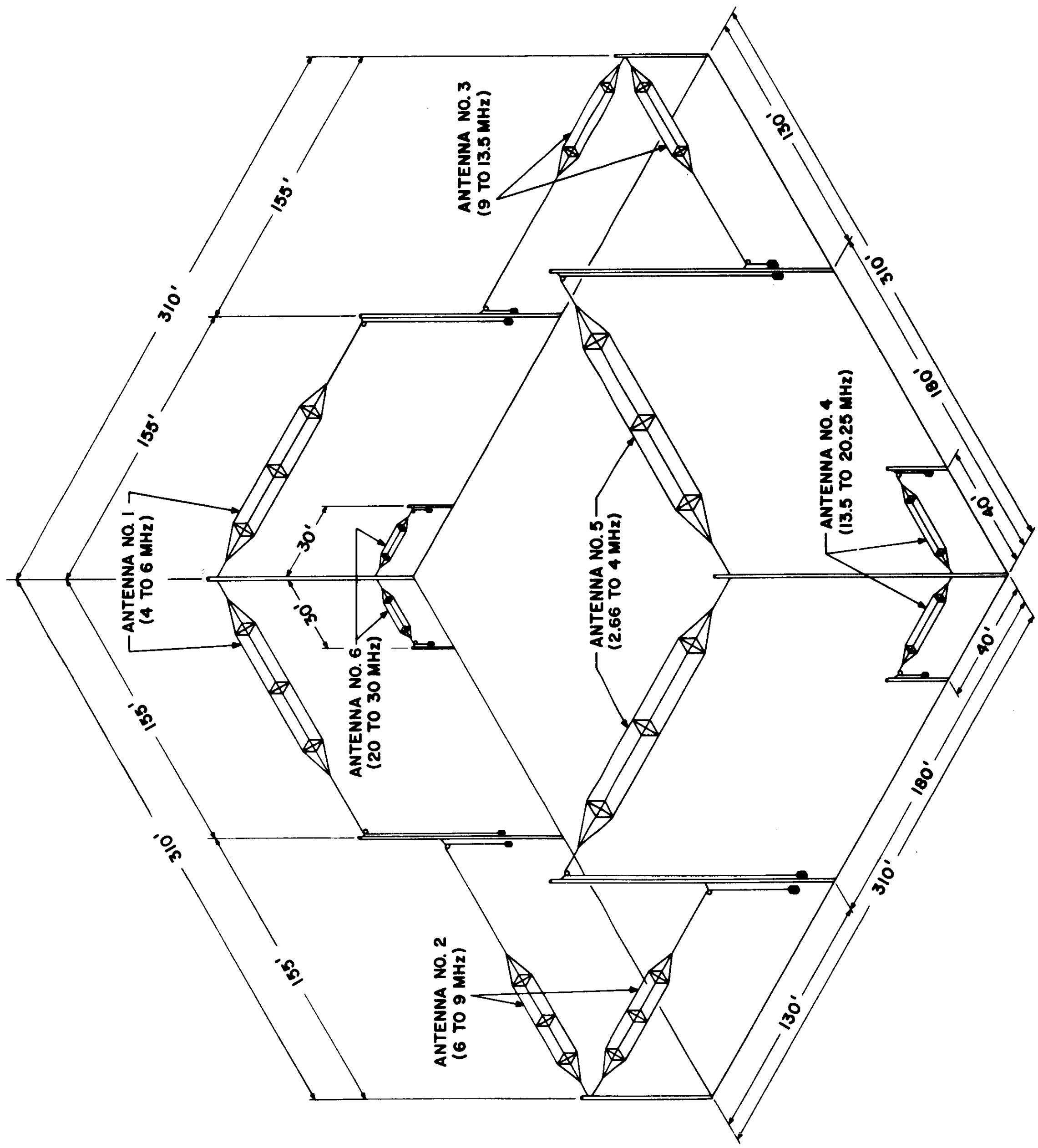


Figure 4-28. HF Quadrant Antenna

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.

CHAPTER 5

ANTENNA SELECTION

The most suitable antenna for the shore terminal of an HF radio path is selected on the basis of the propagation mode (sky-wave or ground-wave propagation), the physical characteristics of the terminal site, and the type of service (point-to-point, ship/shore/ship, ground/air/ground, or broadcast). Major considerations are the operating frequency and radiation angle requirements, which are determined by a propagation path analysis, and antenna characteristics such as gain, directivity, polarization, power handling capability, VSWR limitations, sidelobe suppression, and physical size.

5.1 PROPAGATION PATH ANALYSIS

An analysis of the propagation path is, basically, a statistical prediction procedure based on data accumulated by various agencies over the years. Prediction procedures for both sky-wave and ground-wave propagation are discussed in reference 2, and a brief summary is given below for convenient reference.

5.1.1 Sky-Wave Propagation Prediction

In the case of sky-wave propagation, predictions of the long-term behavior of the ionosphere are used to determine the complement of frequencies and radiation angles most promising for reliable communications over a given path for the life of the communications requirement. Predictions of losses (signal attenuation) and the noise at the receiver site are also included in the evaluation of HF transmission over a sky-wave path so that the path effective power (transmitter power plus antenna gains) required to sustain a specified degree of signal transmission reliability may be estimated. The effect of propagation predictions, then, is to establish the basis for trade-off considerations between transmitter power and antenna gain, and to prescribe a range of operating frequencies and radiation angles necessary for the most effective use of the propagation path. Usually, the result of the analysis is aimed at finding a set of frequencies that will satisfy the communications requirement with the smallest possible spread of radiation angles. For long-term flexibility in the assignment of operating frequencies it is desirable to have many frequencies usable within a narrow range of radiation angles. On the other hand, the number of operating frequencies needed for a short-term, a day or a season, should be as few as possible to avoid numerous frequency changes.

The outcome of such deliberations can be summarized in a matrix such as that in figure 5-1, taken from reference 2. Each "X" in this figure represents a combination of a frequency and a radiation angle for which the probability of satisfactory ionospheric propagation is predicted to be 90 percent. The dashed line encloses a relatively narrow range of radiation angles that can be used, with proper selection from a wide band of frequencies, to maintain communications. Predictions such as this can be used to choose or design an antenna with a radiation angle/frequency pattern that matches the matrix and with gain characteristics suitable for the effective power required to overcome the path losses and noise.

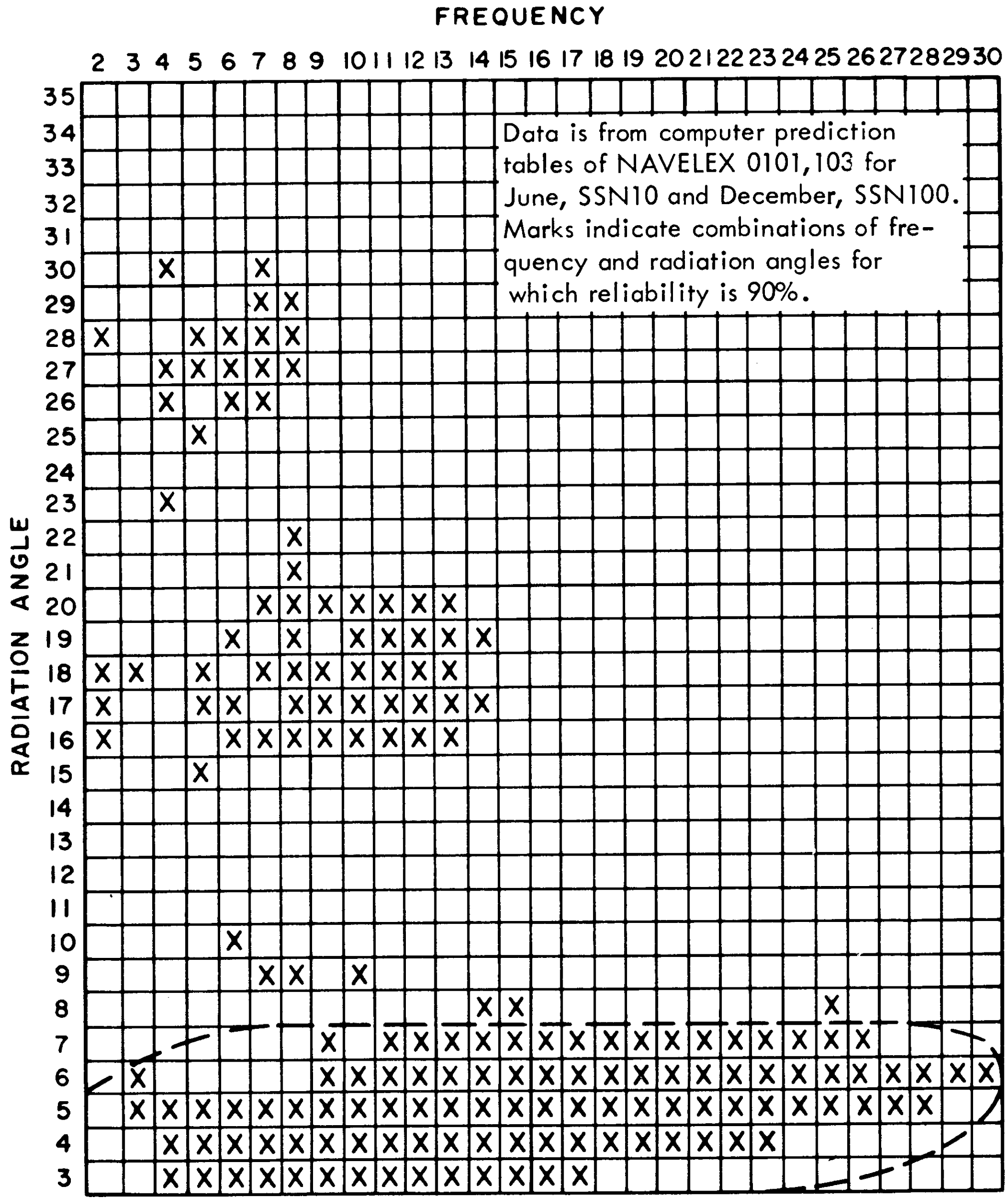


Figure 5-1. Radiation Angle/Frequency Matrix

Although the principal concern with sky-wave propagation predictions is for point-to-point communications, the same general procedure can be used to estimate the propagation path requirement between shore and ship terminals. The application of the prediction methods in such cases, however, is limited by the voluminous calculations that would be required to predict the performance of the many paths corresponding to the movements of the mobile terminal. In order to confine the problem within reasonable bounds, predictions for ship/shore/ship communications circuits are usually made for a geographic ship-movement area, and the shore terminal antennas are selected to provide area coverage.

5.1.2 Ground-Wave Propagation

For ground-wave propagation, the basic consideration for antenna selection is the fact that the electrical characteristics of the earth's surface cause horizontally polarized waves to be attenuated much more rapidly than vertically polarized waves. Because of this, vertically polarized antennas must be used for ground-wave transmission distances of more than a few miles.

Prediction procedures for ground-wave propagation depend upon propagation curves that show the expected signal field intensity, as a function of frequency and distance, based upon certain specified assumptions concerning the type of antenna and the power radiated.

Sets of curves are available for various combinations of ground conductivity and dielectric constant. These ground constants represent the electrical characteristics of the earth's surface and have a major effect on the propagation of radio waves over the earth's surface. To make a prediction, the field intensity at a specified distance for a given frequency is obtained from the set of curves for the ground constants that most nearly match the ground constants for the propagation path being considered. The result is then adjusted to compensate for the differences between the actual situation and the type of antenna and the radiated power assumed for the curves. The procedure is illustrated in reference 2 by examples which include consideration of the noise and the required signal-to-noise ratio at the receiving location.

5.2 SELECTION CONSIDERATIONS

The most useful combination of operating frequency, radiation angle, and power gain are dictated by the requirements of the propagation path as determined by the path analysis. The other factors of major importance in selecting the most effective antenna are related to certain antenna characteristics discussed below.

5.2.1 Polarization

Antenna polarization is a necessary consideration in the antenna selection process. For example, commonly used types of vertically polarized antennas such as conical monopoles and inverted cones are capable of providing sufficiently low radiation angles if they are located near earth of high conductivity, or near sea water. If, however, they are located in an area of poor ground conductivity antenna losses are high and the lower radiation angles are unusable. On the other hand, horizontally polarized antennas require only that the earth's surface be reasonably flat under the antenna and in the direction of propagation. Rhombic antennas, for instance, have useful vertical radiation angles from approximately 3^{o} to 35^{o}, with the angle largely unaffected by the electrical characteristics of the ground, when they are erected one-quarter wavelength or higher above the earth's surface.

5.2.2 Power Handling Capability

Antennas under consideration must match the transmission line so as not to exceed the VSWR limitations. Transmitting antennas must be capable of operating at required power levels without being susceptible to current or voltage breakdown.

5.2.3 Sidelobe Suppression

The antenna radiation pattern should have sufficiently low sidelobe levels to minimize the probability of interfering with other propagation paths or communications services, and to minimize reception of unwanted signals.

5.2.4 Antenna Size

The size of antennas must be considered in view of the real estate necessary for installation and the area needed to comply with antenna separation requirements. Real estate and antenna costs should not be overlooked. This is not to imply, however, that cost considerations should take precedence over the requirements defined by the propagation analysis.

5.3 SUMMARY

The antenna system selected must be capable of operation at the assigned frequencies, and must provide sufficient power gain at the correct radiation angles while suppressing energy at the higher angles to minimize possible multipath distortion (discussed in reference 2). To assist in the final choice among antenna types under consideration, typical performance limits and characteristics of the antennas discussed in chapter 4 are presented in tabular form in the Antenna Characteristics Chart, foldout 5-1. This chart includes those antennas in common use and some other types that fall into special purpose categories.

In some cases the most logical technical selection cannot be implemented due to space limitations, insufficient funds, or other reasons. In this event, the planner must adopt the compromise that results in the least reduction of efficiency or reliability.

CHAPTER 6

ASSOCIATED ANTENNA COMPONENTS

The performance of any antenna system is dependent not only upon the antenna, but also upon the components used with the antenna. Transmission lines, impedance matching devices, dissipation and terminating devices, multicouplers, and lightning protection devices must be properly designed and installed in order to achieve satisfactory antenna performance.

6.1 TRANSMISSION LINES

The type of transmission line chosen for a particular application depends primarily upon the operating power level, characteristic impedance, line losses, and susceptibility to RF interference.

There are two basic types of transmission lines; balanced and unbalanced.

6.1.1 Balanced Transmission Lines

Balanced lines consist of two separate conductors operated at equal and opposite potentials. Balanced lines are usually open-wire configurations except where shielding may be a requirement; e.g., at building entry points, or for RF distribution inside the building.

Open-wire lines provide good balance, constant characteristic impedance and low loss, and they are capable of handling very high power levels. Although coaxial cable has largely replaced open-wire lines at HF radio installations, open-wire lines still provide a practical, relatively low-cost solution to RF-power transmission requirements. This is particularly true for high-power applications when unusually long distances between the transmitter and antenna are necessary.

a. Physical and Electrical Characteristics. The most commonly used balanced transmission line is the 600-ohm open-wire configuration consisting of two No. 6 AWG copper-clad steel wires spaced 12 inches apart, but there are variations, including those illustrated in figure 6-1, which will provide greater power handling capability. For example, compared to the two-wire line, the side-connected four-wire line has a lower characteristic impedance, higher power handling capability, and lower attenuation. By adjusting the wire size, and the number and arrangement of conductors the open-wire transmission line can be designed with the desired power handling capability, characteristic impedance, and attenuation. No. 6 copper-clad steel wire has the necessary tensile strength and degree of conductivity; however, care must be taken during installation to insure that the copper coating is not broken since such damage can result in rust and ultimate failure of the line. Some naval shore stations have used No. 8 wires spaced 6 inches apart for interior runs to minimize coupling and conserve space. In such cases the line is tapered gradually to meet No. 6 wires, spaced 12 inches apart, outside the transmitter building, thus changing to the lower attenuation and greater tensile strength of the larger diameter wire.

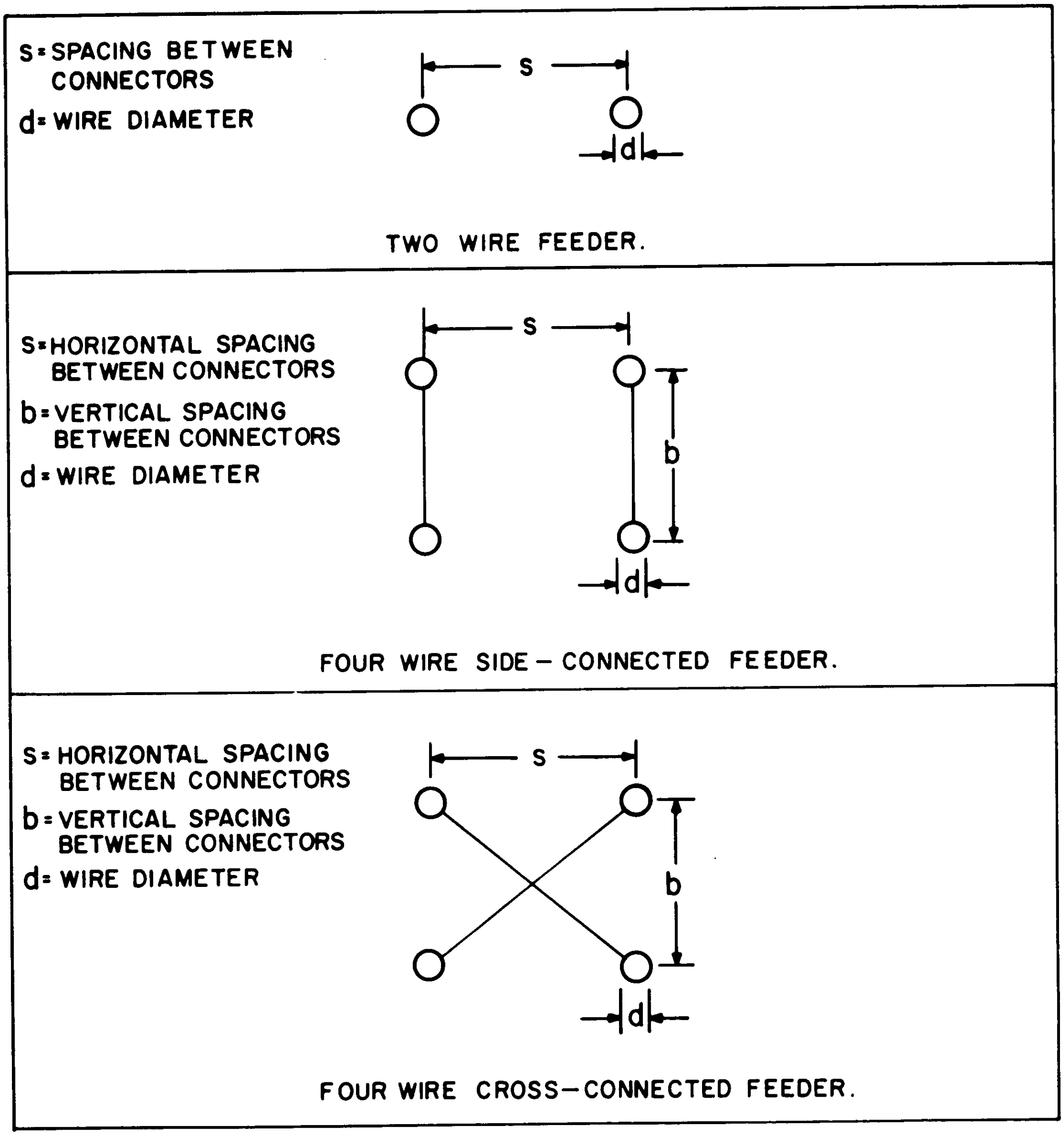


Figure 6-1. Open-Wire Transmission Line Configurations

(1) Power Losses. Losses from a balanced transmission line include direct radiation from the line, insulation losses (leakage), and losses due to the resistance of the wire (copper losses). Radiation losses are usually negligible if the line is terminated at or near its characteristic impedance. Leakage losses are determined to a great extent by the configuration, materials, and the care exercised in construction, and these losses will also vary with the condition of insulators and with weather effects such as icing. Leakage losses in a long open-wire transmission line can range from approximately 20 to 70 percent of the resistance losses which are determined by the wire size and the frequency of the current in the wire. Attenuation of a two-wire copper line, excluding insulator and radiation losses, is given by the expression:

$$a = \frac{14.4\sqrt{f}}{dZ_o} \text{ dB/1000 ft.} \qquad (6\text{-}1)$$

where a = attenuation in dB per 1000 feet of two-wire line
f = frequency in MHz
d = diameter of conductors in inches
Z_o = characteristic impedance of the line

For the Navy standard 600-ohm line using No. 6 wire this reduces to:

$$a = 0.148\ \sqrt{f} = \text{dB/1000 ft.} \qquad (6\text{-}2)$$

This equation is plotted in figure 6-2 to illustrate how attenuation varies with frequency, and to show the range of values to be expected over the HF band.

(2) Characteristic Impedance. The characteristic impedance of an open-wire transmission line varies directly with the spacing between the wires, inversely with the diameter of the wires, and inversely with the square root of the dielectric constant of the insulating material. Since air is the insulating material and its dielectric constant is 1, this factor is not normally considered in the design of open-wire lines. The characteristic impedance can also be affected by the height of the line above ground but the effect is negligible as long as the transmission line is suspended at least 10 feet above the ground.

(3) VSWR. The VSWR of open-wire lines must not exceed 1.1:1 over the operating frequency bandwidth.

(4) Power Handling Capability. Voltage, rather than current, is the principal factor limiting the power on open-wire transmission lines. The maximum RF voltage that can be applied safely on an open-wire line depends upon:

(a) The spacing of the wires

(b) The type, size, and condition of insulators

(c) Height above sea level, temperature, and humidity (which, in turn, affect the voltage level where corona discharge and voltage breakdown occur).

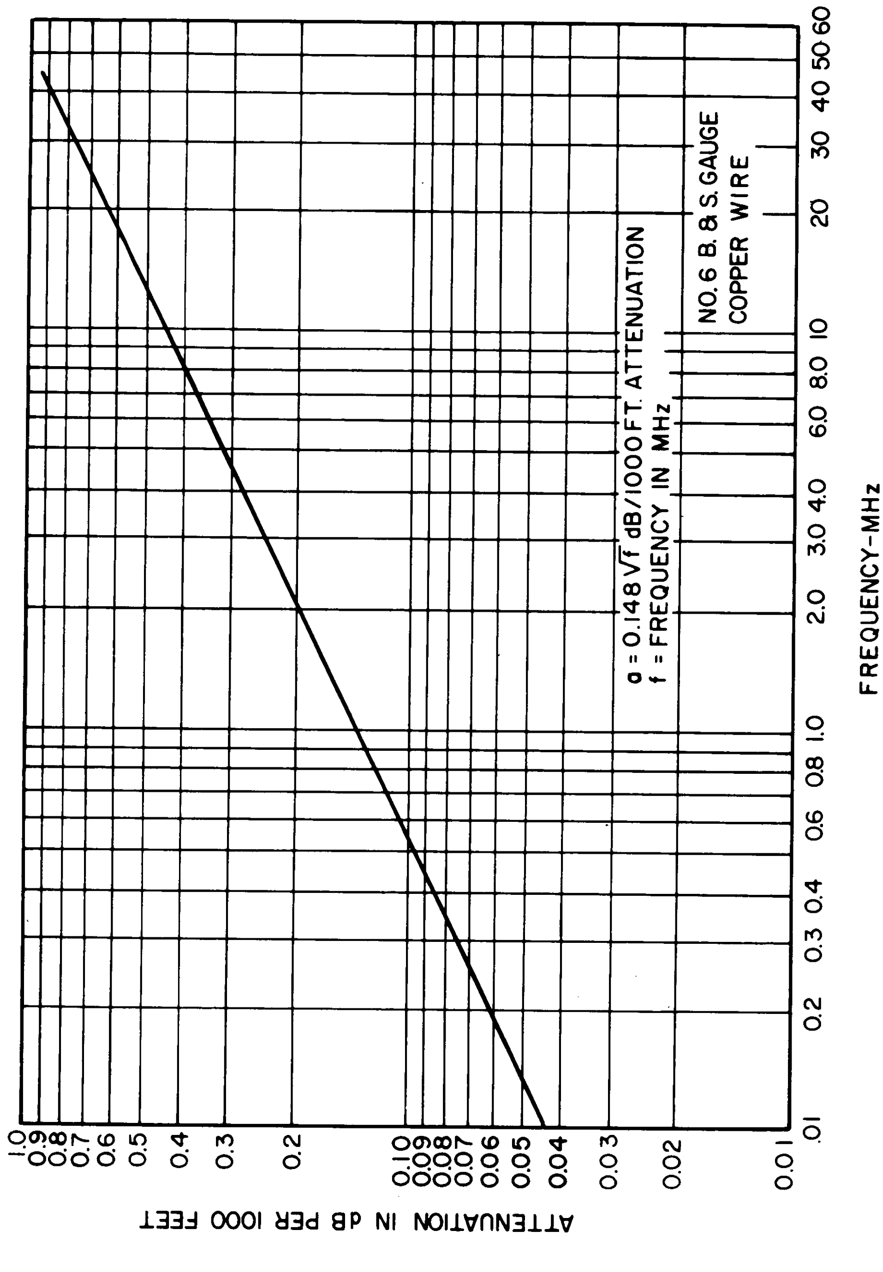


Figure 6-2. Attenuation of 600-Ohm Parallel Wire Line

Figure 6-3 shows that the standard 600-ohm line constructed of No. 6 wire is capable of handling average power inputs of about 90 kW. The data in figure 6-3 allow a 2.5 safety factor which should accommodate most variations of temperature, humidity, and atmospheric pressure. The 90 kW capacity of the standard two-wire line constructed of No. 6 wire, with 12-inch spacing between conductors has been found to be sufficient for most Navy installations. In the event that an installation requires an open-wire line with greater power handling capability, the four-wire side- or cross-connected variations shown in figure 6-1 should be considered.

b. Installation and Construction Considerations. Installation of open-wire systems is not contemplated for new facilities because all new transmitters and receivers are designed for 50-ohm transmission lines. However, it is likely that existing open-wire lines will continue to fulfill requirements for some time to come. For this reason and for special requirement contingencies, the significant factors for installing and maintaining a well-designed two-wire open transmission line are included here. Detailed construction and installation information is contained in BUSHIPS Drawing RE 10F 2143 Rev. G, and the procedures for matching open-wire lines to half-wave antennas are presented in appendix A.

(1) Choose wire of sufficient mechanical strength to withstand the stresses of wind, ice, etc. (refer to table 7-5 for the breaking load of different wire sizes).

(2) Choose wire with acceptable resistance losses.

(3) Space the conductors adequately to prevent corona and voltage breakdown between conductors. (Standard spacing for No. 6 copper-clad steel wire is 12 inches.)

(4) Keep the total length of each conductor of a balanced line exactly equal.

(5) Make no connections that will unbalance the line. If connectors or tie-wires are installed on one conductor, install the exact duplicate on the other conductor at the same electrical point.

(6) To minimize ground losses, install open-wire lines at least 10 feet above ground.

(7) To minimize mutual coupling, maintain a vertical separation of at least 10 feet between transmission lines, and ensure that there is a horizontal distance of at least ten line-spacings between centers of all lines.

(8) Avoid sharp turns or bends. Any necessary turn should take the form of a gradually curving path.

(9) To avoid undesirable coupling, do not run open-wire lines under antennas or parallel to pole-mounted power or telephone lines.

(10) To reduce the possibility of resonant line sections, stagger individual span-lengths so that no parallel spans are the same length.

(11) For installation of new equipment designed for 50-ohm coaxial transmission lines, use baluns to connect open-wire lines to coaxial lines inside the building.

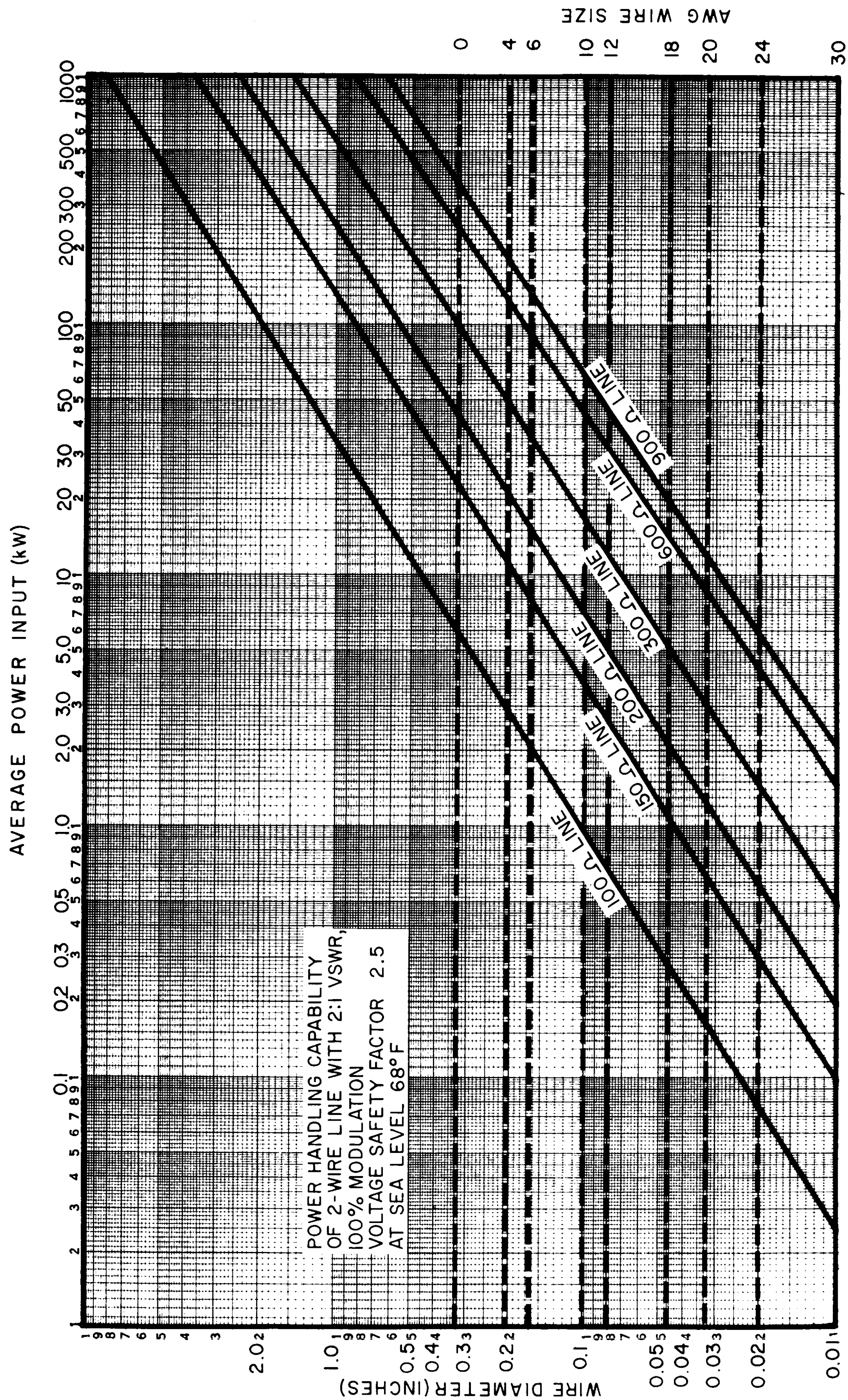


Figure 6-3. Power Handling Capability of Two-Wire Lines

6.1.2 Unbalanced Transmission Lines

Coaxial cables used in HF transmitter and receiver installations operate with the center conductor at a potential above ground and the shield (outer conductor) at ground potential, and, therefore, are unbalanced transmission lines.

Even though coaxial cable is more expensive and has a higher attenuation per unit length than the open-wire transmission lines, the advantages of coaxial lines normally outweigh those of the open-wire lines. Some of these advantages are the relative ease of installation, simplicity of building entry, and elimination of noise pickup over the length of the line. Coaxial lines also make possible a simplified method of switching between transmitters and antennas.

Coaxial transmission lines are used almost exclusively at all receiving installations, and in most transmitting applications. Fifty-ohm cable, the standard characteristic impedance for Navy applications, is available in sufficient variety to meet the requirements for Navy HF transmitter and receiver installations.

Coaxial lines are normally buried for the length of the run from the point of antenna termination to building entry. However, there are some cases in which installations above ground are advantageous.

a. Physical and Electrical Characteristics. Three types of coaxial cables are used for HF transmission lines: flexible, semi-flexible, and rigid. Flexible and semi-flexible cables are commonly used in receiver and transmitter installations, whereas rigid cable is used only for certain applications inside transmitter buildings, and in some very high power installations.

The physical size of coaxial cables varies widely, and signal attenuation generally decreases with increasing diameter. The outer diameter of flexible cable ranges from approximately 1/8 to 1-1/4 inches; semi-flexible cable may be as large as 8 inches; and rigid cable varies from 6 to 9 inches. At 30 MHz, the attenuation in dB per 1000 feet ranges from 2 to 30 for the 1/8 to 1-1/4 inch sizes, is approximately 0.4 for a 5-inch semi-flexible line, and is approximately 0.3 dB for the 6- to 9-inch rigid sizes. The attenuation rates for many of the conventional coaxial cables, calculated over a 1 to 100 MHz incremental frequency range, are listed in table 6-1. Obsolete cable types are included in the table to aid in cross-reference identification with new cable data.

A nominal value of characteristic impedance is designed into each cable type. This value, and other significant physical and electrical data on preferred RF cables are presented in table 6-2, and in reference 16. If it becomes necessary to determine the characteristic impedance of a cable the calculation may be made by using the following equations:

For air dielectric cable,

$$Z_o = 138 \log_{10} \frac{s}{d} \qquad (6\text{-}3)$$

For solid dielectric cable,

$$Z_o = \frac{138 \log_{10} \frac{s}{d}}{\sqrt{\epsilon}} \tag{6-4}$$

where
Z_o = characteristic impedance
ϵ = dielectric constant
s = inner diameter of outer conductor
d = outer diameter of inner conductor

Flexible and semi-flexible cables may be procured in continuous lengths to match the length of transmission line needed to avoid splices, and they may be stored on reels until time for installation. Rigid cable is manufactured in standard 20-foot lengths and it comes equipped with interconnecting flanges.

Most rigid lines and some semi-flexible lines are first purged and then pressurized to reduce attenuation and increase the maximum permissible voltage rating. Purging is usually accomplished with dry nitrogen gas although dry air may be substituted when the size of the cable makes the use of nitrogen extremely expensive. Once a coaxial cable has been purged, pressure is usually maintained on the line with a dry air system. Operating the cable under pressure also helps prevent moisture from entering the line and thereby lowering the insulation resistance.

(1) Power Losses. Power losses in coaxial transmission lines are caused primarily by the resistance of the center conductor. In a high quality coaxial cable, attenuation loss is approximately three times that of a properly designed and installed two-wire balanced line. Other factors which contribute to coaxial line power losses are:

(a) Impedance mismatches in the line

(b) Excessive distance between the antenna and the transmitter or receiver

(c) Installation deficiencies (sharp bends, improper splices, faulty end-seals and connectors, etc.)

(2) Characteristic Impedance. For Navy applications, coaxial cable with a characteristic impedance of 50 ohms has been adopted as standard in accordance with BUSHIPS letter 9670/1-2, serial 679D-34 of 2 February 1962, "Radio Frequency Coaxial Cable Transmission Line; standardization on characteristic impedance of." Since the terminal impedance of various system components affects the design of other components as well as the design and performance of the overall system, adoption of a standard impedance is both technically and economically prudent.

(3) VSWR. The VSWR of coaxial transmission lines must not exceed 1.1:1 over the operating frequency bandwidth.

Table 6-1. Attenuation of Conventional Coaxial Cables in dB per 100 Feet

RG-( )/U	1 MHz	10 MHz	30 MHz	100 MHz
*5	0.21	0.77	1.5	2.9
*5A	0.16	0.66	1.25	2.4
5B	0.16	0.66	1.25	2.4
*6	0.21	0.78	1.46	2.8
6A	0.21	0.78	1.46	2.9
*7	0.17	0.65	1.20	2.4
8	0.16	0.55	1.0	2.0
*8A	0.16	0.55	1.0	2.0
9	0.16	0.57	1.02	2.0
9A	0.175	0.61	1.12	2.1
*9B	0.175	0.61	1.12	2.1
10	-	0.55	1.0	2.1
10A	0.16	0.55	1.0	2.0
11	0.18	0.66	1.2	2.3
11A	0.18	0.66	1.2	2.3
12	-	0.62	1.15	2.1
12A	0.18	0.66	1.2	2.3
13	0.18	0.66	1.2	2.3
*13A	0.18	0.66	1.2	2.3
14	0.12	0.41	0.74	1.4
*14A	0.12	0.41	0.74	1.4
15	0.17	0.31	0.86	1.58
16	-	-	-	1.2
17	0.066	0.225	0.41	0.80
*17A	0.066	0.225	0.41	0.80
17B	NEW NOMENCLATURE RG-177/U			
18	0.066	0.225	0.41	0.80
*18A	0.066	0.225	0.41	0.80
19	0.04	0.17	0.33	0.68
*19A	0.04	0.17	0.33	0.68
20	-	-	-	0.68
*20A	0.04	0.17	0.33	0.68
21	1.4	4.4	7.4	13.0
*21A	1.4	4.4	7.4	13.0
22	0.41	1.3	2.4	4.3
22B	0.42	1.3	2.2	4.0
23	-	0.4	0.8	1.7
23A	-	0.4	0.8	1.7
24	-	0.4	0.8	1.7
24A	-	0.4	0.8	1.7
*29	0.33	1.2	2.2	4.4
34	0.065	0.29	0.6	1.3
34A	0.065	0.29	0.6	1.3
34B	-	0.22	0.42	0.85
35	0.07	0.24	0.43	0.85
35A	0.07	0.24	0.43	0.85
35B	-	0.22	0.42	0.85
*42	1.8	5.6	-	17.0
54A	0.18	0.74	1.4	3.1
55	0.36	1.3	2.4	4.8
55A	-	1.3	2.4	4.8
55B	-	1.3	2.4	4.8
57	-	-	1.4	3.0
57A	-	0.71	1.4	3.0
58	0.33	1.25	2.35	4.65
58A	0.42	1.6	3.0	6.2
58B	-	1.0	2.0	4.2
58C	0.42	1.6	3.0	6.2
59	0.34	1.1	1.85	3.4
59A	0.34	1.1	1.85	3.4
59B	-	1.1	2.0	3.8
62	0.25	0.85	1.5	2.7
62A	0.25	0.85	1.5	2.7
62B	-	0.83	1.5	2.7
*63	0.19	0.61	1.05	2.0
63A	-	0.6	1.1	2.0
63B	0.19	0.61	1.05	2.0
65	5.5	21.5	40.0	-
65A	5.5	21.5	40.0	-
71	0.25	0.85	1.5	2.7
71A	0.25	0.85	1.5	2.7
71B	-	0.83	1.5	2.7
74	-	0.38	0.73	1.5

RG-( )/U	1 MHz	10 MHz	30 MHz	100 MHz
74A	-	0.38	0.73	1.5
79	-	0.61	1.1	2.0
79B	-	0.6	1.1	2.0
83	0.2	0.80	1.45	2.8
*87	0.18	0.60	1.08	2.05
*87A	-	0.52	0.98	2.0
89	-	0.61	1.05	2.0
*94	-	-	-	-
94A	-	-	-	-
111A	-	1.3	2.2	4.0
114	0.95	1.35	1.72	2.90
114A	0.95	1.35	1.72	2.90
115	0.17	0.59	1.05	2.05
115A	0.17	0.59	1.05	2.05
*116	0.18	0.60	1.08	2.05
*117	0.067	0.245	0.45	0.90
117A	-	0.20	0.40	0.85
*118	0.067	0.245	0.45	0.90
118A	-	0.20	0.40	0.85
119	0.125	0.43	0.78	1.5
120	0.125	0.43	0.78	1.5
122	0.40	1.70	3.3	7.0
126	3.2	9.0	15.0	25.0
140	-	1.03	1.8	3.3
141	0.34	1.13	2.0	1.8
141A	-	1.12	2.0	3.8
142	0.34	1.13	2.0	1.8
142A	-	1.12	2.0	3.8
142B	-	1.12	2.0	3.8
143	0.25	0.83	1.45	2.8
143A	-	0.77	1.33	2.5
144	-	0.53	0.95	1.80
147	-	-	-	0.68
148	-	-	-	2.1
164	-	0.22	0.42	0.85
165	0.18	0.6	1.08	2.05
166	0.18	0.6	1.08	2.05
174	-	2.3	4.3	8.0
177	-	0.24	0.45	0.95
178B	-	4.0	6.6	12.8
179B	-	3.8	5.1	7.9
180B	-	2.2	3.7	6.6
187	-	3.8	5.1	7.9
187A	-	3.8	5.1	7.9
188	-	2.7	4.1	7.7
188A	-	2.7	4.1	7.7
195	-	2.2	3.7	6.6
195A	-	2.2	3.7	6.6
196	-	4.0	6.6	12.8
196A	-	4.0	6.6	12.8
211A	-	0.20	0.40	0.85
212	-	0.66	1.25	2.4
213	-	0.55	1.0	2.0
214	-	0.59	1.1	2.9
215	-	0.55	1.0	2.0
216	-	0.62	1.15	2.2
217	-	0.38	0.73	1.5
218	-	0.24	0.45	0.95
219	-	0.24	0.45	0.95
220	-	0.17	0.33	0.68
221	-	0.17	0.33	0.68
222	-	4.4	7.6	14.0
223	-	1.3	2.4	4.8
224	-	0.38	0.73	1.5
225	-	0.52	0.98	2.0
227	-	0.52	0.98	2.0
228A	-	0.20	0.40	0.85
301	-	9.0	15.0	25.0
302	-	1.03	1.8	3.3
303	-	1.12	2.0	3.8
304	-	0.77	1.33	2.5
316	-	2.7	4.1	7.7

*Obsolete

Table 6-2. Guide to Selection of Preferred RF Cables

Class of cables	JAN type	Inner conductor	Dielectric material	Nominal diameter of dielectric	Shielding braid	Protective covering	Nominal over-all diameter	Weight	Approximate impedance	Nominal capacitance	Maximum operating voltage	Remarks
				Inch			Inch	lb/ft	Ohms	$\mu\mu$f/ft	Volts/(rms)	
GENERAL PURPOSE	RG-6A/U	21 AWG copper covered steel	A	0.185	Inner, silver coated copper; Outer; copper	IIa	0.332	---	76.0	20.0	2,700	Small size, video and communication cable
	RG-11A/U	7/26 AWG tinned copper	A	0.285	Copper, single braid	IIa	0.412	---	75.0	20.5	5,000	Medium size, flexible video cable
	RG-12A/U	7/26 AWG tinned copper	A	0.285	Copper, single braid	IIa with armor	0.475	---	75.0	20.5	5,000	Similar to RG-11A/U but with armor
	RG-34B/U	7/0.0249 in. copper	A	0.460	Copper, single braid	IIa	0.630	0.231	75.0	21.5	6,500	Large size, high power, low attenuation, flexible cable
	RG-35B/U	.1045 in. copper	A	0.680	Copper, single braid	IIa with armor	0.945 (max)	0.480	75.0	21.5	10,000	Large size, high power, low attenuation, video and communication cable
	RG-55B/U	.032 in. silver covered copper	A	0.116	Silver covered copper, double braid	IIIa	0.206	0.032	53.0	28.5	1,900	Double braid small size cable
	RG-58C/U	19/.0071 in. tinned copper	A	0.116	Tinned copper, single braid	IIa	0.195	0.029	50.0	28.5	1,900	Small size, flexible cable
	RG-59B/U	.0230 in. copper covered steel	A	0.146	Copper, single braid	IIa	0.242	---	75.0	21.0	2,300	General purpose, small size, video cable
	RG-84A/U	.1045 in. copper	A	0.680	Copper, single braid	IIa with lead sheath	1.000	1.325	75.0	21.5	10,000	Same as RG-35B/U except lead sheath instead of armor for subterranean installations
	RG-85A/U	.1045 in. copper	A	0.680	Copper, single braid	IIa with lead sheath and special ar.	1.565 (max)	2.910	75.0	21.5	10,000	Same as RG-84A/U with special armor for subterranean installations
	RG-164/U	.1045 in. copper	A	0.680	Copper, single braid	IIa	0.870	0.490	75.0	21.5	10,000	Same as RG-35B/U except without armor
	RG-212/U	.0556 in. silver covered copper	A	0.185	Silver coated copper; double braid	IIa	0.332	0.093	50.0	28.5	3,000	Small size, microwave cable. Formerly RG-5B/U.
	RG-213/U	7/.0296 in. copper	A	0.285	Copper, single braid	IIa	0.405	0.120	50.0	29.5	5,000	Medium size, flexible cable. Formerly RG-8A/U.
	RG-214/U	7/.0296 in. silvered copper	A	0.285	Silver coated copper; double braid	IIa	0.425	0.158	50.0	30.0	5,000	Special, medium size, flexible cable. Formerly RG-9B/U.
	RG-215/U	7/.0296 in. copper	A	0.285	Copper, single braid	IIa with armor	0.475 (max)	0.160	50.0	29.5	5,000	Same as RG-214/U but with armor. Formerly RG-10A/U.
	RG-216/U	7/.0159 in. tinned copper	A	0.285	Copper, double braid	IIa	0.425	0.121	75.0	20.5	5,000	Medium size, flexible video and communication cable. Formerly RG-13A/U.

Table 6-2. Guide to Selection of Preferred RF Cables (Continued)

Class of cables	JAN type	Inner conductor	Dielectric material	Nominal diameter of dielectric	Shielding braid	Protective covering	Nominal over-all diameter	Weight	Approximate impedance	Nominal capacitance	Maximum operating voltage	Remarks
				Inch			Inch	lb/ft	Ohms	$\mu\mu f/ft$	Volts/(rms)	
GENERAL PURPOSE	RG-217/U	.106 in. copper	A	0.370	Copper, double braid	IIa	0.545	0.236	50.0	29.5	7,000	Medium size, power transmission line. Formerly RG-14A/U.
GENERAL PURPOSE	RG-218/U	.195 in. copper	A	0.680	Copper, single braid	IIa	0.870	0.491	50.0	29.5	11,000	Large size, low attenuation, high power transmission line. Formerly RG-17A/U.
GENERAL PURPOSE	RG-219/U	.195 in. copper	A	0.680	Copper, single braid	IIa with armor	0.945 (max)	0.603	50.0	29.5	11,000	Same as RG-218/U but with armor. Formerly RG-18A/U.
GENERAL PURPOSE	RG-220/U	.260 in. copper	A	0.910	Copper, single braid	IIa	1.120	0.745	50.0	29.5	14,000	Very large, low attenuation, high power transmission cable. Formerly RG-19A/U.
GENERAL PURPOSE	RG-221/U	.260 in. copper	A	0.910	Copper, single braid	IIa with armor	1.195 (max)	0.925	50.0	29.5	14,000	Same as RG-220/U but with armor. Formerly RG-20A/U.
GENERAL PURPOSE	RG-223/U	.035 in. silver covered copper	A	0.116	Silver covered copper, double braid	IIa	0.216	0.036	50.0	28.5	1,900	Double braid small size cable. Formerly RG-55A/U.
GENERAL PURPOSE	RG-224/U	.106 in. copper	A	0.370	Copper, double braid	IIa with armor	0.615 (max)	0.282	50.0	29.5	7,000	Same as RG-217/U but with armor. Formerly RG-74A/U.
HIGH TEMPERATURE	RG-115/U	7/.028 in. silver covered copper	F-2	0.250	Silver covered copper, double braid	Teflon tape moisture seal with double braid type V jacket	0.375	---	50.0	29.5	5,000	Double braid medium size cable, for use where expansion and contraction are a major problem.
HIGH TEMPERATURE	RG-140/U	.025 in. silver coated copper covered steel	F-1	0.146	Silver covered copper, single braid	Teflon tape moisture seal with single braid type V jacket	0.233	0.045	75.0	21.0	2,300	Similar to RG-59/U, except cable core is teflon
HIGH TEMPERATURE	RG-141A/U	.039 in. silver coated copper covered steel	F-1	0.116	Silver covered copper, single braid	Teflon tape moisture seal with single braid type V jacket	0.190	0.030	50.0	28.5	1,900	Small size flexible cable
HIGH TEMPERATURE	RG-142A/U	.039 in. silver coated copper covered steel	F-1	0.116	Silver covered copper, double braid	Teflon tape moisture seal with single braid type V jacket	0.206	0.045	50.0	28.5	1,900	Small size flexible cable
HIGH TEMPERATURE	RG-143A/U	.059 in. silver coated copper covered steel	F-1	0.185	Silver covered copper, double braid	Teflon tape moisture seal with double braid type V jacket	0.322	0.102	50.0	28.5	3,000	Similar to RG-212/U except cable core is teflon
HIGH TEMPERATURE	RG-144/U	7/.0179 in. silver coated copper covered steel	F-1	0.285	Silver covered copper, single braid	Teflon tape moisture seal with double braid type V jacket	0.410	0.120	75.0	20.5	5,000	Similar to RG-11A/U except cable core is teflon

Table 6-2. Guide to Selection of Preferred RF Cables (Continued)

Class of cables	JAN Type	Inner conductor	Dielectric material	Nominal diameter of dielectric	Shielding braid	Protective covering	Nominal over-all diameter	Weight	Approximate impedance	Nominal capacitance	Maximum operating voltage	Remarks
				Inch			Inch	lb/ft	Ohms	μμf/ft	Volts/(rms)	Remarks
HIGH TEMPERATURE	RG-211A/U	.190 in. copper	F-1	0.620	Copper, single braid		0.730	0.450	50.0	29.0	7,000	Semi-flexible cable operating at temperatures -55° to 200° C. Formerly RG-117A/U.
	RG-225/U	7/.0312 in. silvered copper	F-1	0.285	Silver covered copper; double braid	Teflon tape moisture seal with double braid type V jacket	0.430	0.176	50.0	29.5	5,000	Semi-flexible cable operating at temperatures -55° to 200° C. Formerly RG-87A/U.
	RG-226/U	19/.0254 in. silver covered copper wire	F-2	0.370	Copper; double braid		0.500	0.247	50.0	29.0	7,000	Double braid medium size cable for use where expansion and contraction are a major problem. Formerly RG-94A/U.
	RG-227/U	7/.0312 in. silvered copper	F-1	0.285	Silver covered copper; double braid	Teflon tape moisture seal with double braid type V jacket with armor	0.490	0.224	50.0	29.5	5,000	Same as RG-225/U but with armor. Formerly RG-116/U.
	RG-228A/U	.190 in. copper	F-1	0.620	Copper; single braid		0.795	0.600	50.0	29.0	7,000	Same as RG-211A/U but with armor. Formerly RG-118A/U.
PULSE	RG-25A/U	19/.0117 in. tinned copper	E	0.288	Tinned copper double braid	IV	0.505	0.205	48.0	50.0	10,000	High voltage cable
	RG-26A/U	19/.0117 in. tinned copper	E	0.288	Tinned copper single braid	IV with armor	0.505	0.189	48.0	50.0	10,000	High voltage cable
	RG-27A/U	19/.0185 in. tinned copper	D	0.455	Tinned copper single braid	IV with armor	0.670	0.304	48.0	50.0	15,000 peak	Large size cable
	RG-28B/U	19/.0185 in. tinned copper	D	0.455	Inner tinned copper; outer galv. steel	IV	0.750	0.370	48.0	50.0	15,000 peak	Large size cable
	RG-64A/U	19/.0117 in. tinned copper	E	0.288	Tinned copper double braid	IV	0.475 (max)	0.205	48.0	50.0	10,000	Medium size cable
	RG-88/U	19/.0117 in. tinned copper	E	0.288	Tinned copper Four braids	IIa	0.515	---	48.0	50.0	10,000	Four braid, medium size; multi-shielded high voltage cable
	RG-156/U	7/21 AWG tinned copper	First layer A, second layer H.	0.285	Inner, tinned copper;	IIa	0.540	0.211	50.0	30.0	10,000	Taped inner layers, first layer type K and second layer type A-1R, between the outer braid of the outer conductor and the tinned copper shield. Tri-axial pulse cables.
	RG-157/U	19/24 AWG tinned copper	First layer H, second layer A, third layer H.	0.455	outer, galvanized steel. Double braid	IIa	0.725	0.317	50.0	38.0	15,000	
	RG-158/U	37/21 AWG tinned copper	First layer H, second layer A, third layer H.	0.455	Tinned copper outer shield	IIa	0.725	0.380	25.0	78.0	15,000	

Table 6-2. Guide to Selection of Preferred RF Cables (Continued)

Class of cables	JAN type	Inner conductor	Dielectric material	Nominal diameter of dielectric	Shielding braid	Protective covering	Nominal over-all diameter	Weight	Approximate impedance	Nominal capacitance	Maximum operating voltage	Remarks
				Inch			Inch	lb/ft	Ohms	$\mu\mu f/ft$	Volts/(rms)	
PULSE	RG-190/U	19/0.0117 in. tinned copper	First layer H, second layer J, third layer H.	0.380	Inner, tinned copper;	VIII over one wrap of type K	0.700	0.353	50.0	50.0	15,000	Taped inner layers, 2 wraps of type K and 2 wraps of type L, between the outer braid and tinned copper shield.
PULSE	RG-191/U	30 AWG tinned copper. Single braid over supporting elements 0.485 in. max	First layer H, second layer J, third layer H.	1.065	outer, galvanized steel. Double braid. Tinned copper shield	VIII over one wrap of type K	1.460	1.469	25.0	85.0	15,000	Pulse cable
SPECIAL CHARACTERISTICS	RG-22B/U	Two conductors 7/.0152 in. copper	A	0.285	Tinned copper; double braid	IIa	0.420	0.116	95.0	16.0	1,000	Small size, balanced, twin conductor cable
	RG-62A/U	.0253 in. solid copper-weld	A	0.146	Copper; single braid	IIa	0.242	0.382	93.0	14.5	750	
	RG-63B/U	.0253 in. copper covered steel	A	0.285	Copper; single braid	IIa	0.405	0.082	125.0	10.0	1,000	Medium size, low capacitance air-spaced cable
	RG-65A/U	No. 32 formax F .128 in. dia. (helix)	A	0.285	Copper; single braid	IIa	0.405	0.096	950.0	44.0	1,000	High impedance video cable, high delay line
	RG-71B/U	.0253 in. copper covered steel	A	0.146	Tinned copper; double braid	IIIa	0.250 (max)	---	93.0	14.5	750	Low capacitance cable
	RG-79B/U	.0253 in. copper covered steel	A	0.285	Copper; single braid	IIa with armor	0.475 (max)	0.138	125.0	10.0	1,000	Same as RG-63B/U but with armor
	RG-111A/U	Each conductor 7/.0152 in. copper	A	0.285	Tinned copper; double braid	IIa with armor	0.490 (max)	0.145	95.0	16.0	1,000	Same as RG-22B/U but with armor
	RG-126/U	7/.0203 in. Karma wire	F-1	0.185	Karma wire; single braid	Teflon tape moisture seal with double braid type V jacket	0.280	0.076	50.0	29.0	3,000	High attenuation cable
	RG-130/U	Each conductor 7/.0285 in. plain copper wire	A	0.472	Tinned copper; single braid	I	0.625	0.220	95.0	17.0	8,000	Same as RG-57/U, except inner conductors twisted to improve flexibility
	RG-131/U	Each conductor 7/.0285 in. plain copper wire	A	0.472	Tinned copper; single braid	I with aluminum armor	0.710	0.295	95.0	17.0	8,000	Same as RG-130/U but with armor

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Table 6-2. Guide to Selection of Preferred RF Cables (Continued)

Class of cables	JAN type	Inner conductor	Dielectric material	Nominal diameter of dielectric	Shielding braid	Protective covering	Nominal over-all diameter	Weight	Approximate impedance	Nominal capacitance	Maximum operating voltage	Remarks
				Inch			Inch	lb/ft	Ohms	$\mu\mu f$/ft	Volts(rms)	
SPECIAL CHARCTERISTICS	RG-181/U	Two conductors 7/26 AWG copper	A	0.210	Copper, inner braids. Copper common braid	IIa	0.640	---	125.0	12	3,500	Filled to round transmission unbalance cable. Twin-coaxial.
	RG-187A/U	7/.004 in. annealed silver covered copper covered steel wire	F-1	0.060	Silvered copper; single braid	VII	0.110	---	75.0	---	1,200	High temperature miniaturized cable
	RG-188A/U	7/.0067 in. annealed silver covered copper covered steel wire	F-1	0.060	Silver covered copper; single braid	VII	0.110	---	50.0	---	1,200	High temperature miniaturized cable
	RG-195A/U	7/.004 in. annealed silver covered copper covered steel wire	F-1	0.102	Silver covered copper, single braid	VII	0.155	---	95.0	---	1,500	High temperature miniaturized cable
	RG-196A/U	7/.004 in. annealed silver covered copper covered steel wire	F-1	0.034	Silver covered copper; single braid	VII	0.080	---	50.0	---	1,000	High temperature miniaturized cable

Dielectric materials:

- A Polyethylene
- D Layer of synthetic rubber between two layers of conducting rubber
- E Layer of conducting rubber plus two layers of synthetic rubber
- F-1 Teflon (solid)
- F-2 Teflon (semi-solid or taped)
- H Conducting synthetic rubber
- J Insulating Butyl-rubber

NOTE 1. Requirements for listed cables are in Specification MIL-C-17

Jacket types

- I. Polyvinyl chloride (colored black)
- IIa. Noncontaminating synthetic resin
- IIIa. Noncontaminating synthetic resin (colored black)
- IV. Chloroprene
- V. Fiberglass, silicone-impregnated varnish
- VII. Polytetrufluoroethylene
- VIII. Polychloroprene

(4) Power Handling Capability. The average RF power than can be transmitted through a coaxial cable is dependent upon the temperature rise that can be tolerated within the cable and not cause insulation resistance breakdown. The heating effect in coaxial cable is caused by electrical losses in the center conductor, the shield, and the dielectric material. The power rating of a coaxial cable is defined as the input power that will produce a maximum safe center conductor temperature under steady-state conditions when the cable is terminated in its characteristic impedance.

Polyethylene dielectric flexible cables are used almost exclusively when the maximum center conductor temperature will not exceed 85° C (185° F) (ref. 16). Cable type RG-212/U, -213/U, and -214/U are typical of this group.

Teflon dielectric flexible cables are normally used in applications when the center conductor temperature rise is expected to range from 85° to 250°C (185° to 482° F) (ref. 16). Cable types RG-117/U, -118/U, and -119/U are typical of this group.

Table 6-2 categorizes the coaxial cable types as "general purpose," "special characteristics," "high temperature," and "pulse." The table may serve as a guide for the selection of transmission lines to meet specific requirements.

Some recently developed semi-flexible coaxial cables not listed in table 6-2 have high power ratings and have been put to Navy use. The HF Transmitter Facility, Naval Communications Station, Northwest Cape, Australia, is a case in point. This Facility uses RG-367/U, a 5-inch semi-flexible air dielectric cable, in a 200 kW (PEP) application, and also uses RG-322/U, a 3-inch cable, similarly constructed, for the 40 kW (PEP) transmitter system. Both transmission line configurations are operated as dry-air pressurized systems.

The power rating of a coaxial cable should be carefully evaluated against the anticipated operational environment. Some of the factors which can influence power ratings follow:

(a) VSWR. A mismatch between load and line impedance will produce standing waves along the line and will limit the amount of power than can be transmitted. In such a case, the average power rating of the line should be derated to compensate for the VSWR as follows:

$$\text{Derated Power} = \frac{\text{Rated Power}}{\text{VSWR}} \qquad (6\text{-}5)$$

(b) Modulation. Amplitude modulation of the transmitter also causes the power input to exceed the cable power handling capability because sideband power is added to the initial carrier power. In the case of amplitude modulation, the total power transmitted is:

$$P_{\text{total}} = P_{\text{carrier}} \left(1 + \frac{\%\ \text{Modulation}}{200}\right) \qquad (6\text{-}6)$$

Therefore, the power rating should be reduced by the factor:

$$\frac{1}{1 + \frac{\% \text{ Mod}}{200}} \qquad (6\text{-}7)$$

For military applications, modulation of 40 percent is used as a standard. Therefore, the allowable power would be:

$$\text{Derated Power} = \frac{\text{Rated Power}}{1.2}$$

(c) Duty Cycle. Duty cycle refers to the percentage of time that power is applied to the cable. Since the basic power rating applies to a steady-state condition, a minor upgrading in cable power rating may be applied when transmitters are on the air only intermittently, or where modulation is applied only occasionally. However, the manufacturer's specifications for the particular cable must be carefully checked to determine to what extent overloading in this manner is permissible.

(d) Frequency. Dielectric absorption (i.e., dielectric heating) increases as frequency is increased. Because of this, frequency is a factor in the rating of coaxial cable. For some solid dielectrics, there are charts available that give approximate cable power rating adjustments, provided the power rating at one frequency is known (ref. 16).

(e) Location. Most coaxial transmission lines are buried because burial limits the amount of temperature variation caused by external conditions and affords a degree of physical protection. For adequate heat dissipation, lines buried in a common trench should be separated as recommended in paragraph 6.1.2.b(5).

b. Coaxial Cable Installation Considerations. Installation considerations for coaxial transmission lines are partly dependent upon the individual requirements and environmental factors at each site. Basic considerations are:

(1) Transmission Line Length. If other siting considerations permit, the higher frequency antennas should be located nearest the transmitter or receiver building (since attenuation losses increase with line-length and frequency).

(2) Cable Storage. Cable-ends are to remain sealed during storage, and until final permanent connections are made, to prevent moisture and dirt from entering the cable.

(3) Cable Bending Radii. Bending radii must not be smaller than ten times the cable diameter, and the bend should be in one direction only (no reversals). If a degree of flexure is considered necessary, cable that provides the adequate inner conductor and shield flexibility, and dielectric elasticity, should be selected. Right angle changes of direction in rigid and semi-flexible cable should be accomplished only by cutting the cable and installing appropriate flanges, elbows, and fittings.

(4) Connecting Cable Lengths. A continuous length of coaxial cable should be used for the entire run if at all possible. When this is not possible, approved splicing kits available from cable manufacturers should be used to splice the cables.

(5) Trenching and Cable Placement. When coaxial cable is to be buried, the trench depth depends upon soil conditions, the frost line, and upon other uses of the land area through which the trench must pass. Usually a depth of 2-1/2 feet provides sufficient cable protection. Pending the development of specific criteria for cable separation distances, the general rule to ensure adequate separation is to separate cables by a distance equal to twice the diameter of the largest cable. Figure 6-4 illustrates a typical trench layout. Sand should be used as the cable bed in case the trench bottom is rocky or uneven, and should cover the cables to a depth of 6 inches. A 1-1/2 inch plank, treated to resist insect damage and burial deterioration, is placed on top of the sand as added protection. The remainder of the trench is then tamped and backfilled.

If buried lines are to cross under primary access roads, adequate provision for maintenance and protection from physical damage must be made. Cable to be routed under traffic areas other than primary access roads should be placed in galvanized iron conduit buried at least 30 inches.

Where buried lines are to be routed under cultivated fields, an added safety margin of trench depth should be considered.

(6) Cable Route Marking. Buried transmission line routes must be clearly identified with permanent concrete or steel markers. These markers should be placed at each road crossing, bend or splice, and at 200-foot intervals along the transmission line route. One type of marking stake is shown in figure 6-5.

(7) Cable and Cable Fittings. All coaxial cables and fittings are to be selected in conformance with the standards in reference 16.

(8) Above-Ground Installation of Transmission Lines. Where soil or terrain conditions make excavation of trenches impractical, coaxial transmission lines can be "installed" above ground in a manner that affords protection similar to burial. One line, or a group of lines, can be placed on a layer of sand approximately 3 inches deep on the ground surface between the antenna and the transmitter or receiver building. The line and sand bed are then covered with concrete covers for the length of the line. The same general considerations for cable separation, identification and access apply to above-ground installation as for below-ground installation. Plans and details for one method of above ground transmission line installation are given in NAVFAC Atlantic Division Drawing 1198055.

6.2 DISSIPATION DEVICES

In HF antenna systems, dissipation devices may be used to provide a substitute or dummy load to absorb transmitter power, or to provide a terminating impedance for traveling-wave antennas.

A dummy load presents to a transmitter an impedance equal to that of the antenna, and is used to absorb the transmitter power when antenna radiation is undesirable.

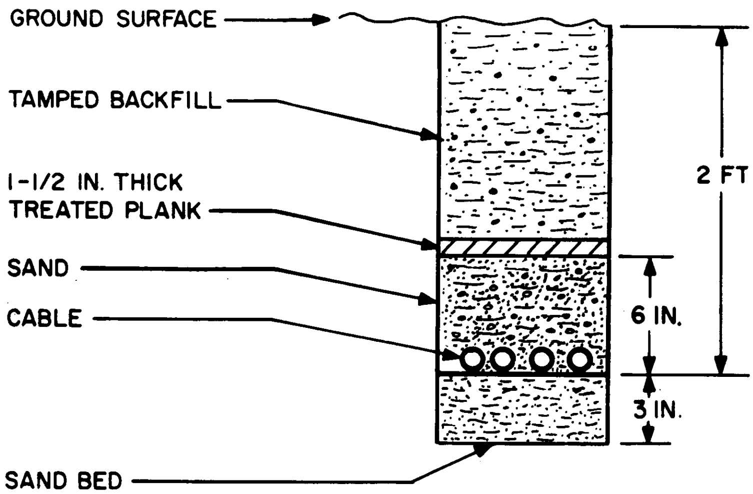


Figure 6-4. Cable Trench Layout

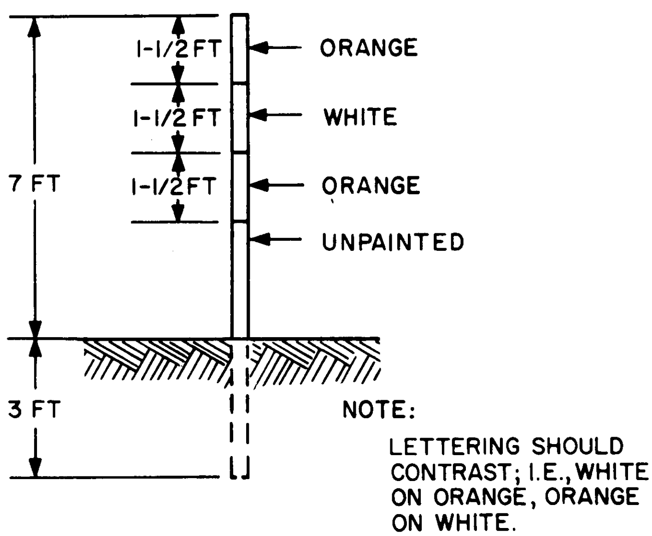


Figure 6-5. Buried Cable Marker

A termination device is installed at the forward end of an antenna, and is used to absorb power that would otherwise cause reflected waves. This terminating impedance is a major consideration for rhombic and vee antennas. Although the forward direction radiation pattern is little affected by the presence or absence of the termination, radiation in the backward direction is directly dependent upon whether or not power is absorbed at the forward end of the antenna. If no termination is used, about one-half of the transmitted power will be radiated in the forward traveling wave, and one-half in the reflected wave. On the other hand, a resistive termination at the forward end of the antenna will absorb the power that would be radiated in the reflected wave. The resultant backlobe suppression gives the desired unidirectional pattern, reduces undesirable radiation, and thereby reduces the probability of interference with other nearby antennas and communications devices.

There are two basic types of dissipation devices: distributed and lumped.

6.2.1 Distributed Dissipation Devices

Distributed dissipation devices, commonly known as dissipation lines, have their attenuating resistance distributed along the length of the line. These dissipation lines are actually transmission lines specially designed to have a high attenuation per unit length. Dissipation lines, used primarily to provide termination impedance for traveling-wave antennas, are capable of absorbing the output of very high power transmitters.

a. Physical and Electrical Characteristics. Dissipation lines are usually fabricated from No. 10 to No. 14 AWG solid, stainless steel wire. These wire sizes and types provide the heat dissipation and impedance characteristics required, and they are highly resistant to weather damage. The dissipation line is shorted and grounded at the end distant from the power source to terminate the line at zero potential. Figure 6-6 illustrates a typical rhombic antenna dissipation line arrangement. Detailed construction and installation plans may be found in NAVELEX Drawing RW 66D 295.

The following characteristics are usually specified for dissipation lines:

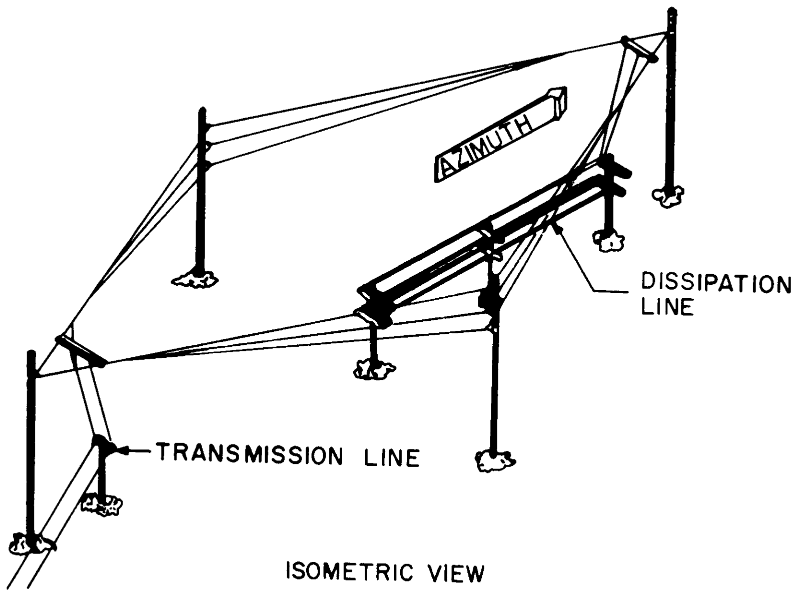
(1) Height. Minimum height above ground should be 12 feet to prevent personnel from contacting the line.

(2) Attenuation and Dissipation. Lines for low- and medium-power transmitters are inexpensive. For this reason they should be designed to dissipate the full, overdriven transmitter output. Lines for transmitters operating in excess of 50 kW average power should be designed on the basis of rated average power and the radiation efficiency at planned operating frequencies.

(3) Characteristic Impedance. Characteristic impedance is normally 600 ohms for balanced configurations, but it may vary according to application.

(4) VSWR. Should not exceed 1.1:1 over the operating frequency band.

(5) Wire Spacing. Spacing between individual wires of the dissipation line must be maintained in the same manner as the open-wire transmission line to ensure a constant characteristic impedance.



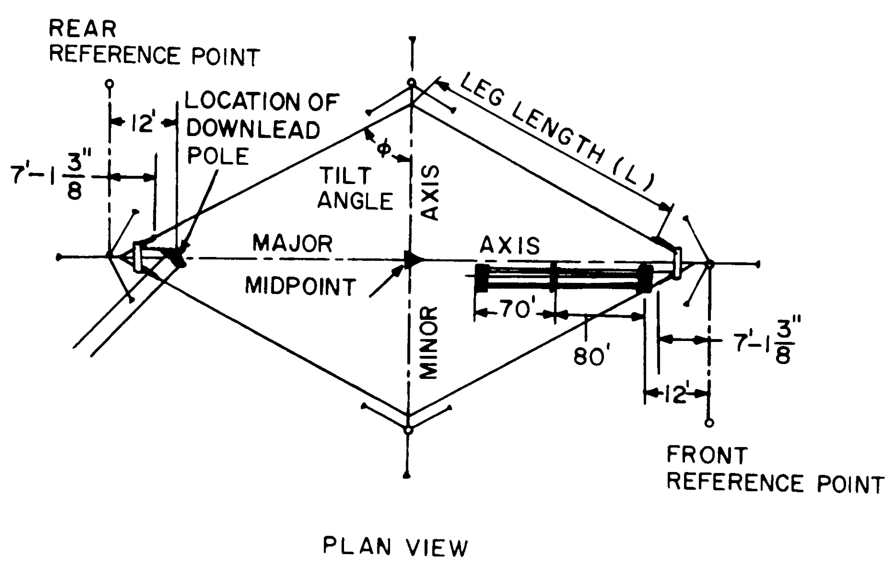


Figure 6-6. Typical Dissipation Line Arrangement

(6) Balance. Line balance requirements may vary according to the application, but balance must be within 10 percent for rhombic antennas.

6.2.2 Lumped Dissipation Devices

Lumped devices provide a means of termination and power dissipation in a manner similar to that of a dissipation line. The principal difference is that in a lumped device the attenuating resistance is lumped and installed in an enclosure which is located at the antenna or in a position convenient to the transmitter output switching matrix, depending on whether it is to serve as an antenna termination or a transmitter dummy load.

a. Physical and Electrical Characteristics. Lumped devices are basically non-inductive resistors and are available commercially in power ratings from low to very high power ranges. The lumped devices used in very high power transmitter systems normally require a cooling system for effective heat dissipation. For most dummy load applications, lumped attenuation devices may be procured as auxiliary components of the transmitter, with selection being made on the basis of transmitter characteristics: power rating, characteristic impedance, VSWR, frequency range, etc.

Generally, the cost of lumped dissipation devices does not compare favorably with the cost of dissipation lines for application in the high and very high power ranges because sophisticated cooling systems are required to maintain resistive characteristics of the load. For this reason, consideration should be given to a combination of lumped and distributed devices that will overcome distributed capacity effects. In this type of combined termination impedance, a dissipation line can be truncated and terminated in a lower power lumped device. This type of dissipation arrangement is capable of providing the necessary power dissipation, impedance, VSWR, frequency range, and balance characteristics.

For termination impedance applications, the following characteristics are usually specified for lumped dissipation devices:

(1) Attenuation and Dissipation. Lumped devices should be capable of dissipating the average power output of the associated transmitter. These attenuating resistors must also have a high enough impulse rating to prevent changing resistance caused by induced currents from lightning.

(2) Characteristic Impedance. Characteristic impedance is normally either 50 or 600 ohms according to the impedance level of the installation.

(3) VSWR. The VSWR should not exceed 1.1:1 over the operating frequency band.

(4) Balance. Balance should be within 10 percent for rhombic antennas.

6.3 LIGHTNING PROTECTION

Since antennas are usually located at a height above other structures at a transmitter or receiver site, they are likely to be in the path of lightning discharges to earth. They should, therefore, have suitable direct-stroke lightning protection as well as a static-charge drain so that such a lightning discharge will not pass through vulnerable system components. Protection systems should be capable of preventing lightning strokes from breaking down dielectric materials in antennas and transmission lines, and should also prevent damage to all other components in the transmitting and receiving systems. In any system of lightning protection, a path to ground must be provided that will offer less resistance and inductance than any other alternate paths.

Grounded metal towers and support structures create a lightning protection effect called the cone of protection. Since a direct lightning stroke tends to take the lowest resistance path to ground, these tall, grounded structures will draw lightning strokes and thus protect surrounding objects from a direct hit. This protection is usually effective for objects within a cone centered on the grounded structure and with a base radius of one to two times the tower height. Thus, metal towers can provide a degree of protection for the antennas they support as well as for transmission lines within the immediate area.

6.3.1 Lightning Rod Systems

Lightning rod systems are relatively simple protective grounding systems used to provide a low-resistance, low-inductance path to the earth. Their principal application is on wooden support poles. A typical installation consists of a lightning rod mounted on the top of the pole, a down-conductor wire, and a ground rod as shown in figure 6-7.

Lightning rod systems are not necessary on metal support towers if the resistance of the tower structural members, measured from top-to-base, is 10 ohms or less. A tower may be grounded by connecting any convenient point on the tower to a ground rod of the type shown in figure 6-7.

A satisfactory lightning rod system can be obtained by adhering to the following:

a. Lightning Rod. Fabricate the lightning rod from copper or copper-clad steel rod at least 3/4-inch in diameter, and 5 feet long. Install the rod so that it will project two feet or more above the top of the pole.

b. Down-Conductor Wire. For the down-conductor wire, use at least No. 2 AWG copper or copper-clad steel wire to afford the necessary low-resistance, low-inductance path to ground.

The down-conductor wire must be a straight, continuous length from the lightning rod connection to the ground rod. On wooden poles, this continuous length should never be broken up with discharge gaps since an arcing gap could set the pole afire. At connection points, and points where changes of direction are unavoidable, bending radii of the wire must be at least 8 inches, and the bend must be no greater than 90°.

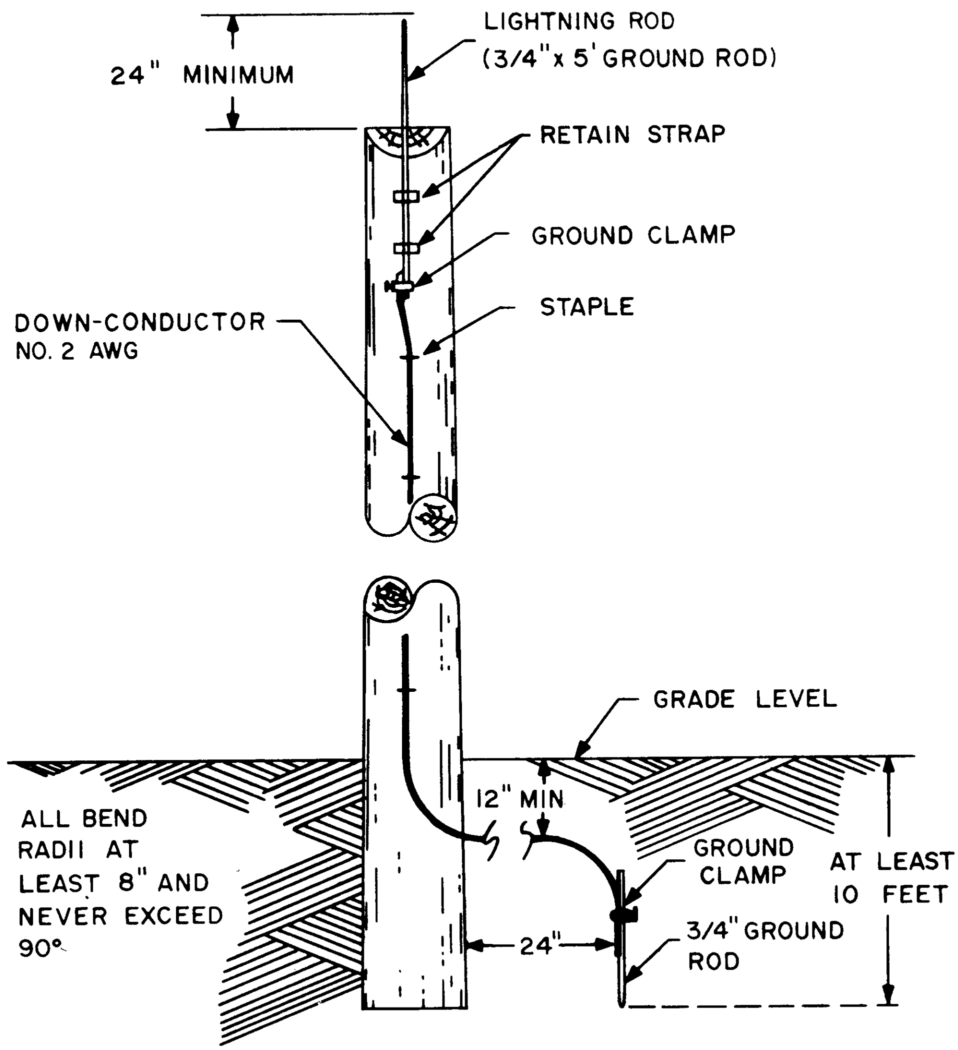


Figure 6-7. Typical Lightning Rod and Down-Conductor Arrangement

c. Other Metal Objects. If other metal objects such as hoisting-arms or obstruction lights, are installed on top of the pole, ground them by connecting them to the down-conductor with wire of the same size and type as the down-conductor. Run power wiring to these objects in metal conduit bonded to the down-conductor at random intervals of not more than 10 feet.

d. Connectors. Use copper or bronze bolted-type connectors to secure the down-conductor to the lightning and ground rods.

e. Ground Rod. Fabricate the ground rod from copper-clad steel rod at least 3/4 inches in diameter and 10 feet long. Ideally, the rod should be set in the ground so that its entire length is below grade as shown in figure 6-7. In the event that the desired depth cannot be reached and the depth of refusal is so shallow that the ground rod will be ineffective, an acceptable protective ground termination can be made by wrapping at least 25 feet of No. 2 AWG (or larger) copper wire around the base of the structure at the lowest point possible below grade.

Interconnection of the down-conductor and ground rod should be made below grade as shown in figure 6-7.

6.3.2 Discharge Gaps

Discharge gaps, installed at the junction of the antenna and transmission line, are used to protect HF antennas and their associated components against high-voltage surges resulting from lightning. Gaps should also be installed across the terminating resistance of terminated antennas and at the point of building entry of open-wire transmission lines.

There are three basic types of discharge gaps: point, ball, and horn gap. All three serve the same purpose, in that the gap resistance breaks down and permits current flow to the earth in the event of a lightning strike, thus providing a degree of over-voltage and current protection to connected equipment.

The point gap device will break down at a lower voltage than the others, so it is generally well-suited for receiving antennas. The ball gap has roughly three times the breakdown voltage rating of the point gap, and it may be used on either receiving or transmitting antennas. The horn gap is the most commonly used of the three types. It has approximately the same breakdown voltage rating as the ball gap, and it is also self-quenching; that is, an arc across the electrodes will not be sustained by transmitter RF power.

A typical horn gap installation for antenna down-leads is illustrated in figure 6-8.

The gap electrodes are made from nickel-plated brass rod or hard-drawn solid copper at least 1/4 inch thick, and the electrodes are connected to antenna down-leads, down-conductor wires, or other conductors, with copper or bronze bolt-type connectors. The requirements for the down-conductor and the ground rod are the same as those for a lightning rod system.

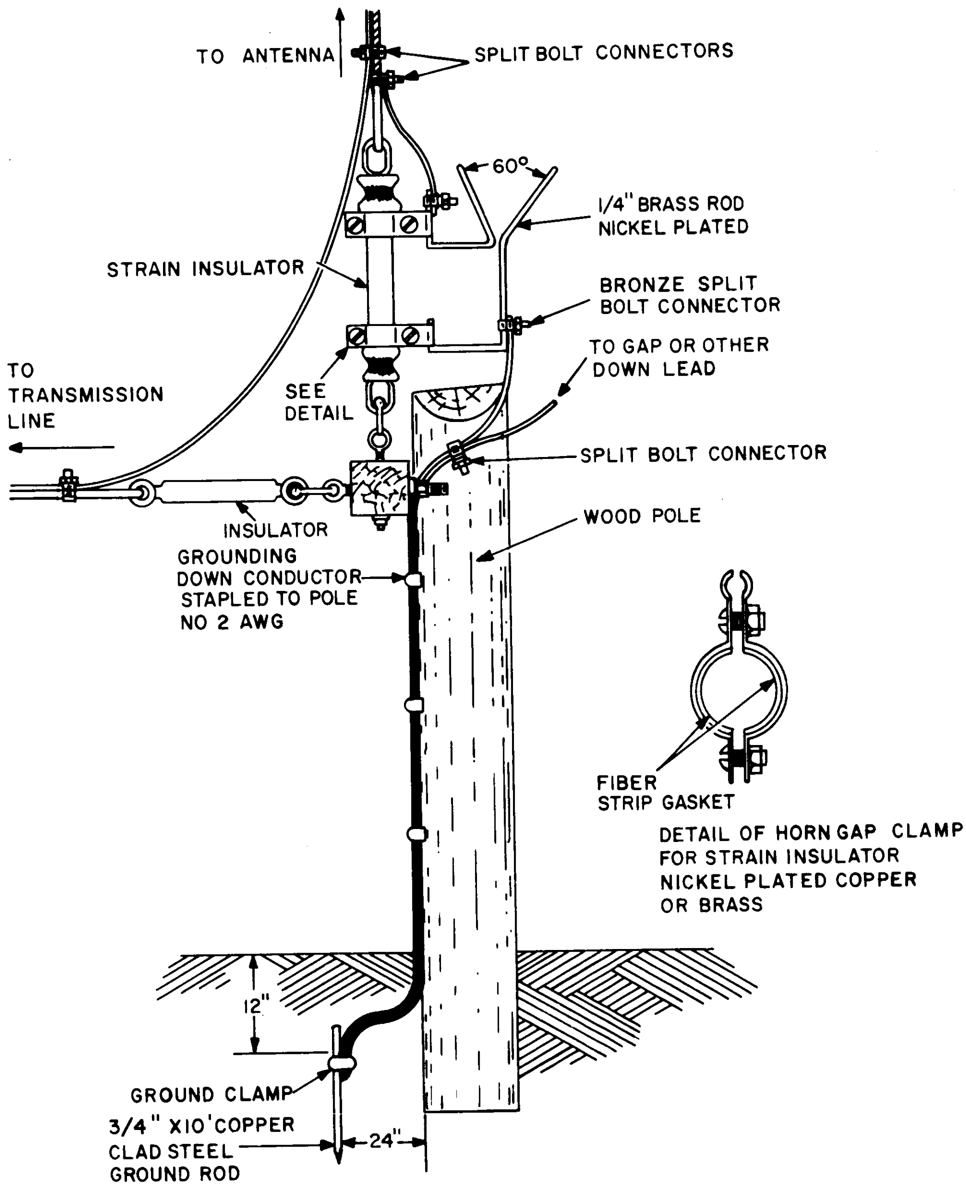


Figure 6-8. Typical Horn Gap Arrangement for Antennas

The minimum voltage at which the gap will break down and divert current flow to ground is determined by electrode spacing. The desired breakdown voltage is attained by spacing the electrodes at the distance for which the full power output of the transmitter (at 100 percent modulation) produces an arc and then increasing the spacing an additional 1/4 inch.

6.4 GUYWIRES AND INSULATORS

In any HF antenna system, guys and insulators can affect antenna operating efficiency. The type of guys used (metal wire or non-conducting materials), placement of guys relative to radiation fields, and positioning of insulators on metal guys must be considered in order to achieve desired antenna efficiency. Most HF antenna poles and metal towers are supported by several guys attached to different points on the structure and anchored in the ground. Guys made from metal wire may be resonant at some operating frequencies and, therefore, may act as reradiating or parasitic antennas. Detrimental effects of guywires usually can be prevented by observing the following precautions:

a. Guywire Location. Place guywires in a location where the radiation field from the antenna is weakest.

b. Break-Up Insulators. Place break-up insulators at random intervals on the guywire to interrupt the resonant lengths. This is particularly important if the guys cannot be located in a weak radiation field. The longest uninterrupted length should not exceed 0.1 wavelength at the highest design frequency of the antenna.

c. Non-Conducting Guys. In some antenna installations, the use of break-up insulators to prevent resonance of metal guys may be expensive and impractical. If a large number of break-up insulators is required, consideration should be given to using guys made from nonconducting materials. Although the cost of nonconducting guys is normally more than for stranded steel wire of comparable strength, the overall cost, with the high tensile strength insulators eliminated, could favor nonconducting materials. Mylar and fiberglass are suitable nonconducting materials for guywire applications. Manila rope may also be used, but only for temporary guying arrangements.

6.5 BALUNS

A balun is a type of transformer that can be used both for impedance matching and for interconnecting balanced and unbalanced transmission lines. They are often used for balanced-to-unbalanced interconnections regardless of whether an impedance transformation is required to match impedances for maximum power transfer. That is, the impedances of the interconnected lines, or other components, may be equal or they may differ. In the case of differing impedances, the necessary impedance transformation is incorporated in the balun.

A core-type RF balun is used in most Navy HF antenna systems to attain the desired impedance transformation between balanced antennas (typically 600 ohms) and unbalanced transmission lines (50 ohms). Other types of baluns are described in reference 14.

Both transmitting and receiving antennas employ baluns for the impedance transformation at the interconnection point between the antenna and the transmission line. Baluns can also be used at building entry points to change from balanced open-wire lines to coaxial lines; however, most Navy transmitter sites that are still using open-wire lines have them run directly into the transmitter.

Some antennas are purchased complete with balun matching devices. In such cases, the antenna manufacturer selects a device in conformance with Navy-furnished system performance specifications.

Other antennas, notably rhombics, use HF balun transformers such as the CU-1699/FRT Line Coupler for transmitting, and the CU-1706/FRR for receiving applications. Standard installation plans for balun transformers on both transmitting and receiving antennas are contained in NAVELEX Drawing RW 66D 295.

6.5.1 Transmitting Balun Performance Specifications

Typical system performance specifications for transmitting baluns are as follows:

Power handling capability	Transmitter continuous average power output with load VSWR of 2.5:1 when loaded with "white noise" (noise with a spectrum continuous and uniform as a function of frequency), and when intermodulation requirements are met.
Frequency range	The design frequency band of the antenna.
Impedance transformation	Dictated by system design; usually a 12:1 balance-to-unbalance ratio.
Insertion VSWR	1.25:1 maximum (with 1:1 VSWR load).
Load VSWR	2.5:1 maximum (continuous operation).
Insertion loss	0.15 dB maximum over the operating frequency range at rated power.
Unbalance	5 percent maximum over the operating frequency range.
Intermodulation	50 dB minimum below transmitter average power output (with load VSWR of 2.5:1 and loaded to rated power with "white noise").

The CU-1699/FRT is typical of balun transformers which will meet the preceding performance specifications. It is an oil-filled transformer capable of operating from 2 to 32 MHz at power levels up to 50 kW (PEP). The transformer is contained in a cylindrical aluminum tank that is suitable for pole or tower mounting. Internal cooling is accomplished by natural convection with transformer oil. The transformer is cooled externally by natural convection of surrounding air.

6.5.2 Receiving Balun Performance Specifications

Receiving baluns are physically and electrically similar to transmitting baluns except for the smaller physical size and lower power handling capability. The following system performance specifications are typical:

Insertion loss and dynamic range	0.3 dB maximum over the operating frequency range (with an input between 2 microvolts and 2 volts).
Impedance transformation	12:1 over the operating frequency range.
Insertion VSWR	1.2:1 maximum over the operating frequency range.
Load VSWR	3:1 maximum over the operating frequency range.
Dynamic input range	60 dB minimum (at a 2-volt reference level).
Unbalance	5 percent maximum over the operating frequency range.
Intermodulation	50 dB minimum below the desired signal level over the operating frequency range.

The CU-1706/FRR is typical of receiving balun transformers that will meet the above performance specifications. It is capable of providing the necessary balance-to-unbalance transformation over a 4 to 24 MHz frequency range.

6.6 HF MULTICOUPLERS

Multicouplers are used in both transmitting and receiving applications to allow more effective utilization of available antennas. They permit the output of more than one transmitter to feed a single antenna and permit operation of as many as eight receivers from a single antenna with excellent RF signal quality.

Transmitting multicouplers are capable of providing separate impedance-matched paths for the transfer of RF power from two or more transmitters to a common antenna for simultaneous operation. The usual method of isolating one transmitter from another employs frequency-separating bandpass filters within the multicoupler as shown in figure 6-9.

All transmitting multicouplers are passive networks consisting of reactive and resistive elements in which no signal amplification occurs. Receiving multicouplers, on the other hand, may be either passive or active.

Passive multicouplers are not widely used in HF receiving systems because they do not amplify the RF input from the antenna, and because interchannel isolation is likely to drop below 40 dB if more than two output channels are coupled from the unit.

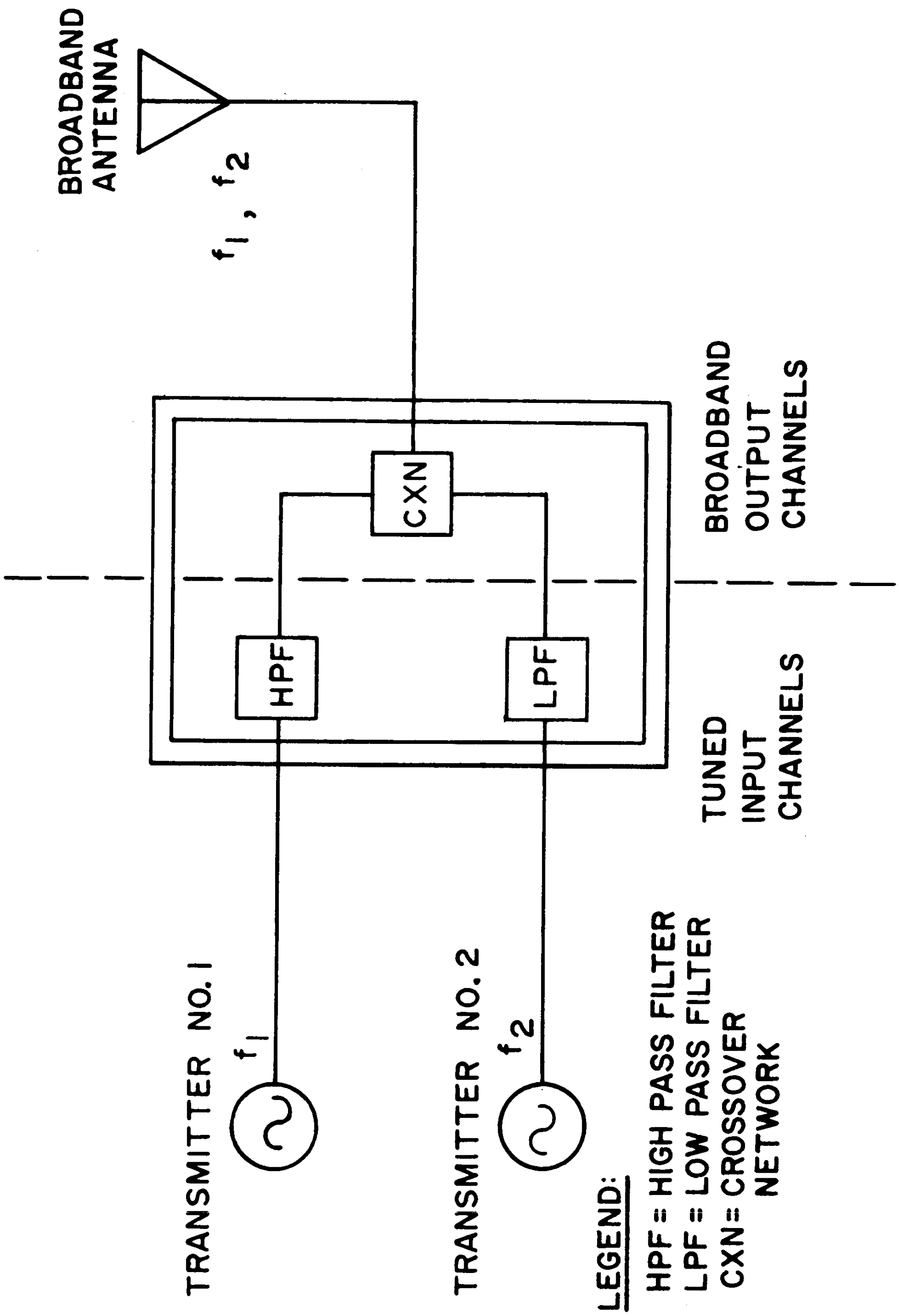


Figure 6-9. Typical Transmitting Multicoupler Arrangement

Active multicouplers such as the CU-656/U, which employs electron tube circuitry, and the CU-1382( )/FRR, a transistorized unit, are widely used in HF receiving systems. They are capable of power gains sufficient to compensate for line losses, usually from 1 to 3 dB over the 2 to 32 MHz frequency band, and they provide the correct impedance match between the transmission line and receivers. For the most part, procurement of HF receiving multicouplers is now limited to transistorized units that conform to MIL-A-28729A (EC), "Antenna Coupler Group (HF Broadband, Wide Dynamic Range)". A typical receiving multicoupler circuit flow diagram, showing one RF input and 8 outputs, is illustrated in figure 6-10.

6.6.1 Transmitting Multicoupler Performance Specifications

In most cases, transmitting multicouplers are selected as part of a transmitting system in conformance with Navy-furnished performance specifications. All transmitting multicouplers are required to meet the following minimum performance specifications:

Frequency range	All frequencies in the 2 to 30 MHz range regardless of the number of inputs.
Power handling capability	System rated power levels (with the load VSWR as high as 2.5:1).
Input and output impedance	50 ohms (unbalanced).
VSWR	1.2:1 maximum between the input channel and transmitter over the channel bandpass frequency.
Channel isolation	45 dB minimum between channels.
Insertion loss	0.5 dB maximum over the total passband (with a 1:1 insertion VSWR).

6.6.2 Receiving Multicoupler Performance Specifications

Active receiving multicouplers are required to meet the following minimum performance specifications:

Frequency range	2 to 30 MHz.
Impedance	50 ohms (unbalanced), input and output.
VSWR	2:1 maximum over the input frequency range.
Channel isolation	40 dB minimum between outputs.
Intermodulation	60 dB minimum below the output level (measured against a 0.5-volt input test signal).
Gain	Between 1 and 3 dB over the 2 to 30 MHz frequency range.

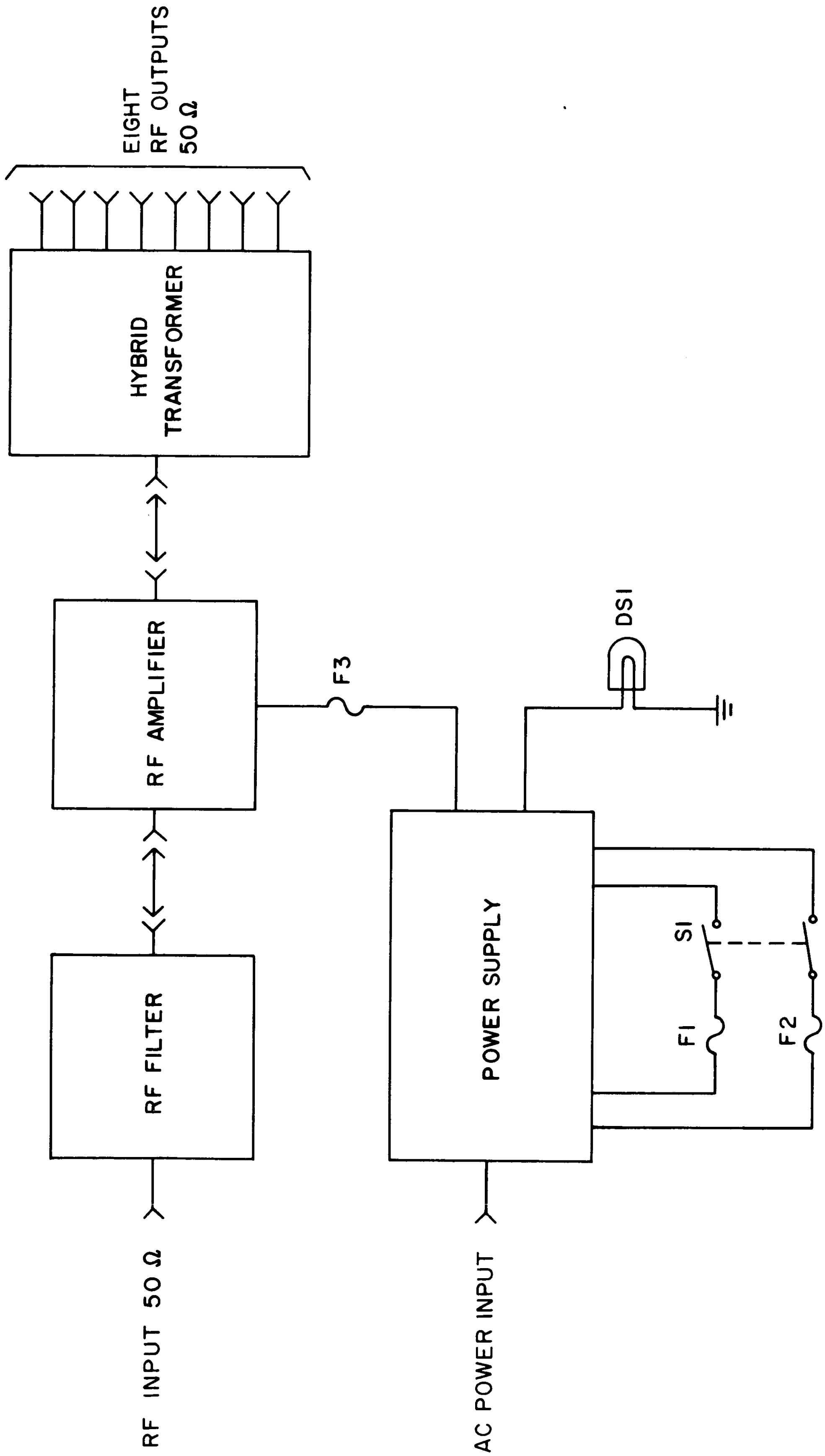


Figure 6-10. Typical Receiving Multicoupler Circuit Diagram

HF ANTENNA INSTALLATION

The tasks associated with shore station antenna installations such as design, survey, construction and site preparation are normally accomplished under the supervision of the NAVELEX FTA and the NAVFAC EFD as directed by NAVELEX and NAVFAC. Individual shore station personnel may assist in the planning and actual installation by coordinating activities or otherwise ensuring an installation of benefit to the government.

A site survey conducted prior to determining the general suitability of a site establishes the location of property lines and access points, develops data concerning topography and soil conditions, and establishes an accurate base line from which antenna azimuths can be determined. The data obtained from this survey, together with the antenna drawings and specifications constitute the basis for developing site preparation, construction, and antenna installation plans.

7.1 REFERENCE BASE LINE

The azimuthal accuracy of HF directional antennas is normally required to be within one-tenth of a degree. Since the base line established during the site survey, or later during site development, is used as a reference point for determining azimuths, it is essential that the base line markers be protected from movement or loss during construction activity. These markers should be of a permanent nature as specified in NAVFAC DM-5 — "Civil Engineering."

When additional antennas are to be installed in an existing antenna park, the original base line markers should be used as a point of reference. If the original markers cannot be located, a new base line must be established by solar observation, or, in the northern hemisphere, by observation of Polaris. Usually, at least six observations are required to ensure adequate base line accuracy. When the base line has been established, record its position on the site plan, and retain all significant notes and calculations.

Once the base line is established, lay out and mark the antenna foundation and anchor points. When several antennas are to be installed close together these markers must be identified appropriately as to a particular antenna. The positions marked for poles or towers that affect the accuracy of the antenna bearing should be rechecked at least once.

7.2 FOUNDATIONS

Foundations for antenna supporting structures are designed and constructed in accordance with NAVFAC DM-2 — "Structural Engineering" and NAVDOCKS DM-7 — "Soil Mechanics, Foundations, and Earth Structures," and as defined by NAVFAC.

Foundation requirements can be determined only after the soil design characteristics have been ascertained by field observation, boring, sampling, and analysis as specified in NAVDOCKS DM-7. The data thus obtained are considered in conjunction with the type of supporting structure and the stresses resulting from such factors as wind and ice loading, temperature changes and other weather conditions that affect structural stability.

7.3 CONCRETE CONSTRUCTION

The concrete work for antenna structure foundations is usually done by a contractor in conformance with NAVFAC Specification 13Y — "Concrete Construction," or in accordance with other standards designated by NAVFAC.

7.3.1 Concrete Tests

If the local cement, aggregate, or concrete is of unknown quality, sample test cylinders of the mix are required before construction commences. In most cases, field testing of the concrete mix is not practical, and the services of a laboratory will be needed. Where concrete tests are necessary, they should be conducted in accordance with the American Society for Testing Materials (ASTM), specifications No. C31 and C39, or with other specifications furnished by NAVFAC.

When construction is started, slump tests of the concrete are required to ensure correct consistency (the ratio of water to cement) of the mix as it is being placed. The correct amount of water is determined at the time of mixing according to the weight of the portland cement. As water is added, the slump increases and the mix will pour more easily; however, the ultimate strength of concrete is decreased if more than the correct proportion is used. Frequent slump measurements aid in achieving a consistent quality of concrete and provide a means of eliminating inferior quality mixes. Many of the companies who supply pre-mixed concrete use a form of quality certification which is intended to serve as a guarantee of each delivery of pre-mixed concrete. The acceptability of such certifications should be checked with the nearest NAVFAC field activity or with a local government office. An acceptable certification can eliminate or reduce the need for on-site testing, thereby expediting construction progress.

7.3.2 Concrete Forming

The elevation of antenna foundations is particularly important in the construction and installation of HF antennas that have multiple supports separated by considerable distances. Tower and foundation specifications usually provide for a maximum tolerance of ±1/2-inch if adjustment may be made by grouting.

The following general procedures should be followed to assure correct forming of concrete structure foundations and anchors:

a. Tie Wires. Where reinforcing steel is to be placed in the forms, use tie wires to hold the reinforcements and forms in position.

b. Anchor Positioning. Position the forms and pour concrete anchors so that the front face of the anchor will be poured against undisturbed earth if possible. Anchor shafts are to be positioned directly in line with the tower at the specified design angle.

c. Attachment Points. Eye bolts or similar hardware to aid in rigging, tower erection and maintenance should be placed in the concrete form by setting them in a template that will ensure correct position and alignment.

d. Placing Concrete. Place the concrete as near as possible to its final position. It should be distributed in layers and worked into place by spading or vibrating to eliminate voids and stone pockets. Ensure that all reinforcing steel is well embedded in the concrete, and bring only enough fine mix to the surface to produce the finish desired.

e. Filling Voids. After the forms have been stripped from the formed concrete, fill all voids and tie wire break pockets with cement mortar.

f. Backfill. Backfill materials are selected and placed in accordance with specifications provided by NAVFAC. Place backfill around completed foundations and anchors in well tamped layers. Avoid using rocks, muck, sod, and light-weight materials. After backfilling, grade the area to prevent erosion and to eliminate water collection spots.

7.4 ANTENNA TOWERS

Towers are usually provided and installed by the antenna manufacturer, or by a contractor experienced in structural rigging. The task of assembling, erecting, and guying steel towers should not be undertaken by inexperienced personnel.

To facilitate expeditious procurement of standard, commercially manufactured steel radio towers of 300 feet or less in height, towers that meet the specification and design requirements of Electronic Industries Association (EIA) Standard RS-222 may be used. NAVFAC must be consulted, on an individual project basis, for installation criteria on towers over 300 feet high. Also, NAVFAC should be consulted for adequate tower and foundation design criteria, and for review of other heights of towers and antenna types. Steel materials used in towers must conform to the requirements in NAVFAC DM-2 or as further defined by NAVFAC.

7.4.1 Guyed Towers

The most commonly used guyed towers are fabricated from steel in untapered sections 10 to 20 feet long. These constant dimension sections are erected one above the other to form the desired height. Structural stability for this type of tower is provided by attaching guywires from the tower to ground anchors.

Base supports for guyed towers vary according to the type of tower to be installed. Three commonly used base-types are the tapered tower base, the pivoted tower base, and the composite base. All three are shown in figure 7-1. A tapered tower base concentrates the load from multiple tower legs to a small area on the foundation. The pivoted base is used primarily on lightweight structures for ease of tower erection. A composite base is generally used with heavier towers since it affords much more supporting strength than the other two types.

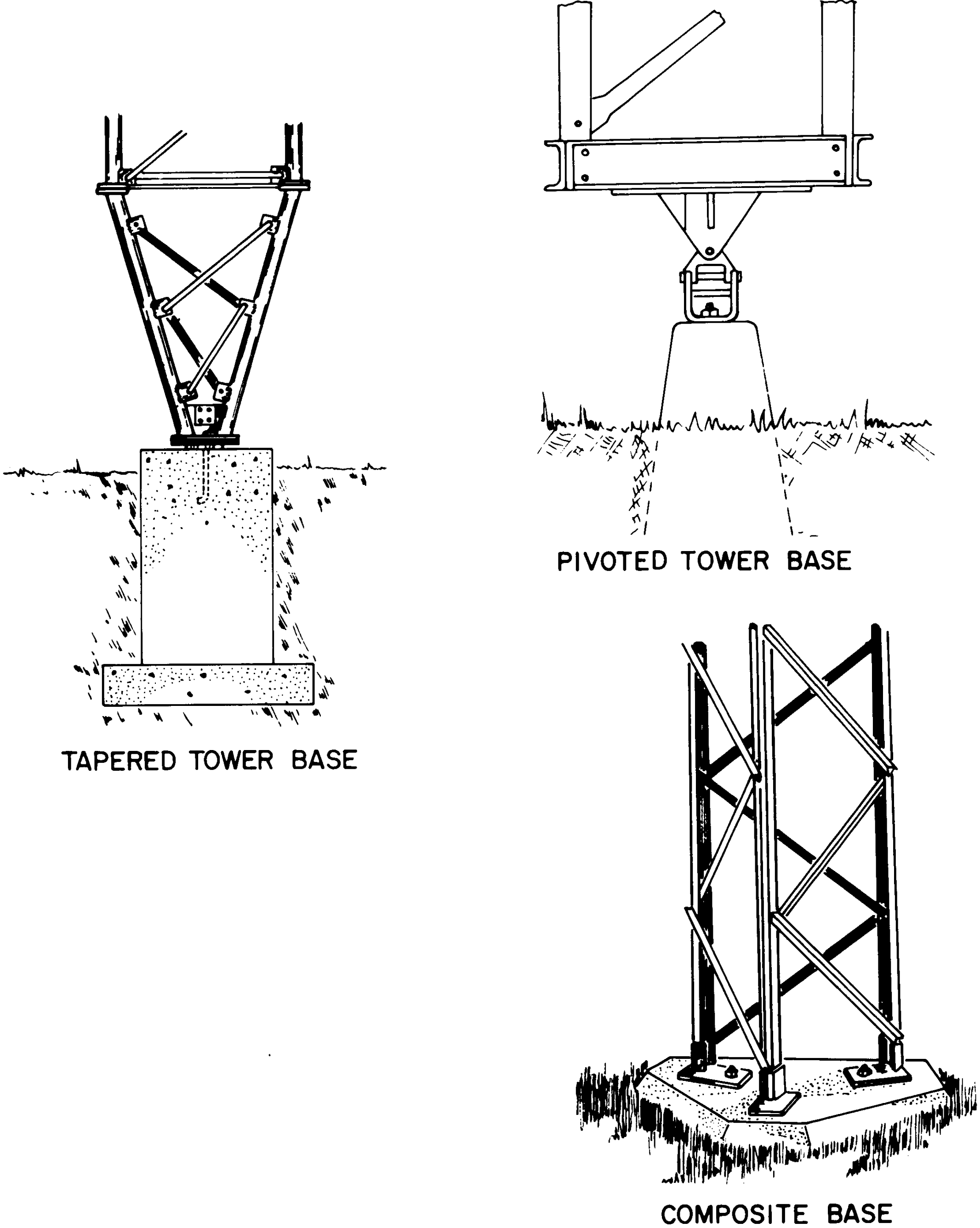


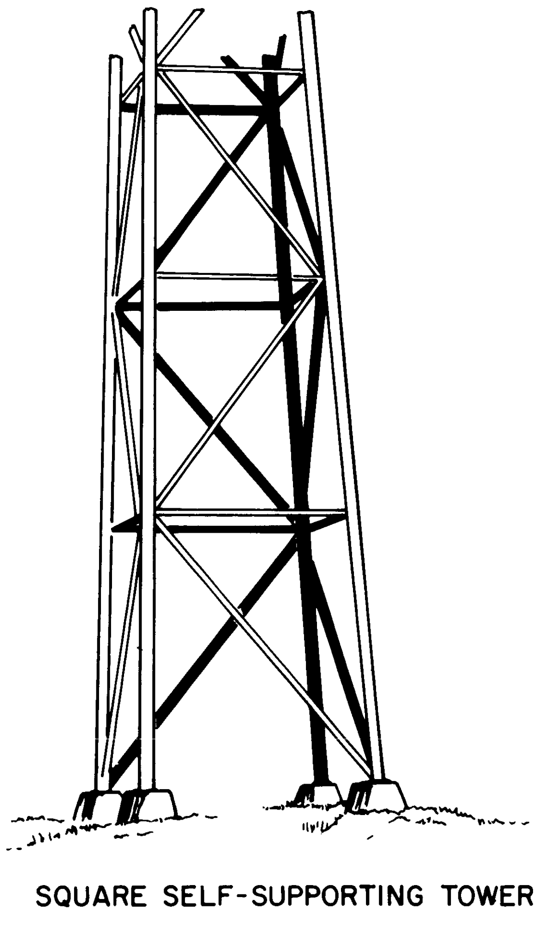
Figure 7-1. Base Supports for Guyed Towers

Sections for lightweight towers are usually preassembled prior to delivery in order to expedite final tower assembly whereas heavier weight towers must be assembled completely in the field.

Tower bracing should include diagonal bracing and horizontal struts in the plane of each tower face, for the full tower height. Procedures to be followed and engineering requirements for effective bracing are contained in NAVFAC DM-2.

7.4.2 Freestanding Towers

Freestanding, or self-supporting, steel antenna towers are characterized by heavier construction than guyed towers and by a shape that tapers in toward the top from a wide base. Freestanding towers exert much greater weight-bearing pressure on foundations than most guyed towers; consequently, deeper foundations are required (because of the greater size, weight, and spread of tower legs) to provide sufficient resistance to uplift. Each leg of a freestanding tower must be supported by an individual foundation. Figure 7-2 shows a typical individual foundation for a freestanding tower and figure 7-3 illustrates a foundation plan for a triangular steel freestanding tower. Bracing and material specifications for these towers are the same as for guyed towers.



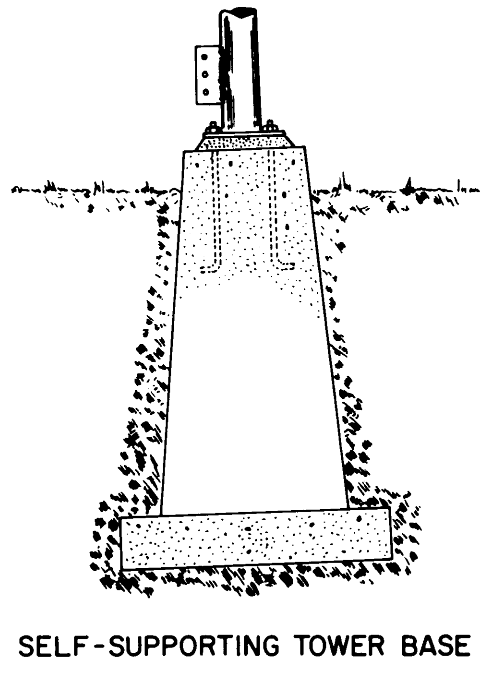


Figure 7-2. Square Self-Supporting Tower and Base

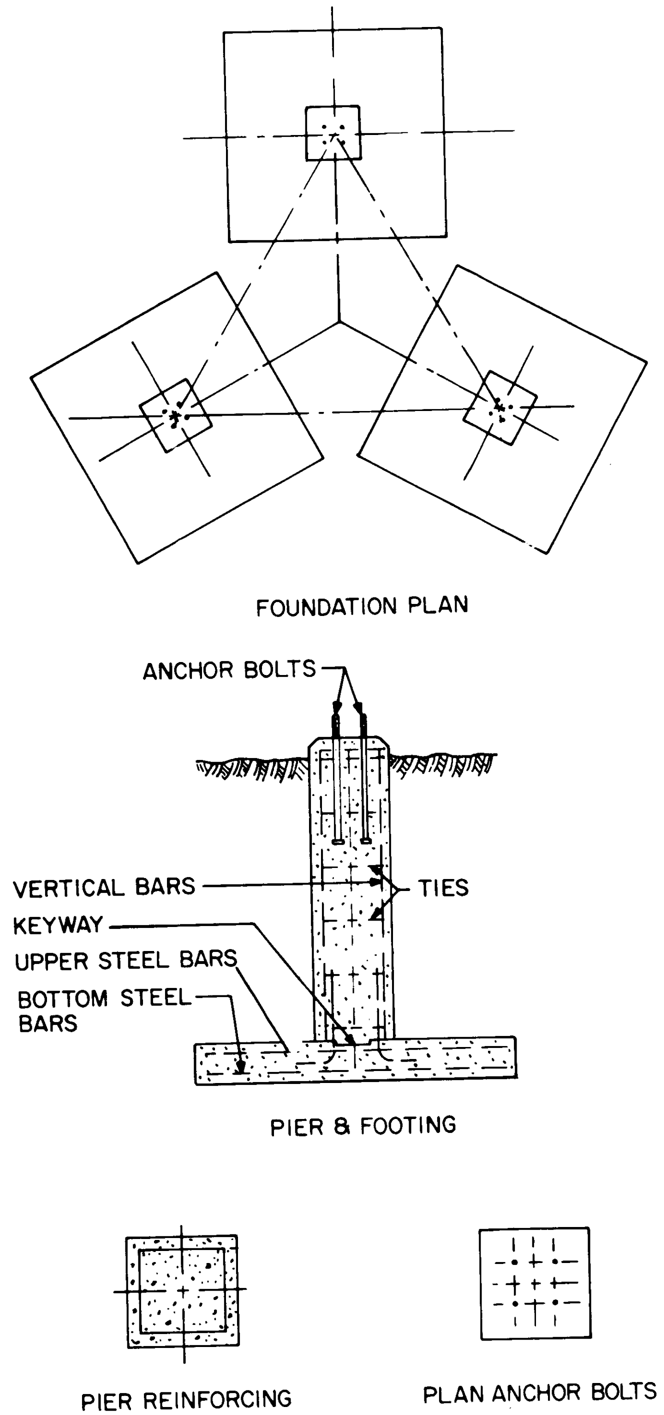


Figure 7-3. Triangular Tower Foundation

7.4.3 Tower Assembly

Advance planning for tower assembly and erection is essential to completion of the project safely and correctly. Both the installation plan and the manufacturer's instructions should be studied to gain a complete understanding of the tower assembly and erection methods to be employed. The following general procedures and practices should be observed for the assembly and erection of towers:

a. Ground Assembly. Assemble the tower sections on well-leveled supports in order to avoid building in twists or other deviations. Any such deviations in one section will be magnified by the number of sections in the complete assembly.

b. General Preservation. Check all surface areas for proper preservation. Cover all holes and dents in galvanized materials with zinc chromate or other acceptable preservatives to prevent deterioration.

c. Bolts and Hardware. If any bolts or other hardware must be provided from on-site material ensure that they meet the specifications of NAVFAC DM-2.

d. Tightening Bolts. When high-strength bolts are used in tower assembly, place a hardened steel washer under the nut or bolt head, whichever is to be turned. Care must be exercised not to exceed the maximum torque limit of the bolt. Maximum torque values of several different sizes and types of bolts commonly used in antenna towers are listed in table 7-1.

Table 7-1. Bolt Torques (Foot Pounds)

Size	Mild Steel	High-Strength Steel	Aluminum 24 ST-4	Stainless Steel 18-8
3/8" - 16----	17	----	12	30
1/2" - 13----	38	105	26	43
5/8" - 11----	84	205	60	92
3/4" - 10----	105	370	82	128
7/8" - 9-----	160	530	184	194
1" - 8-----	236	850	---	---
1-1/8"-7-----	340	1100	---	---
1-1/4"-7-----	432	1800	---	---

7.4.4 Erection of Guyed Towers

The safety precautions for steel erection set forth in NAVSO P-2455, "Safety Precautions for Shore Activities," are to be observed at all times during the erection of antenna towers. The following paragraphs of this section present methods that have been successfully used to erect guyed towers. The most practical method for any particular tower will be determined by the size, weight, and construction characteristics of the tower and by the hoisting equipment available.

a. Davit Method. Lightweight guyed towers are frequently erected with a davit hoist which is anchored to the previously erected section, providing a pivoted hoisting arm. The davit arm is swung away from the tower in hoisting the added section, and swung centrally over the tower in depositing the section prior to bolting up the splice plates. Figure 7-4 shows a ground assembled unit being hoisted for connection to a previously erected tower section. A snatch block secured to the tower base transmits the hoisting line to a source of power or hand winch. A tag line secured to the base of the section being hoisted avoids possible contact with the erected portion of the tower.

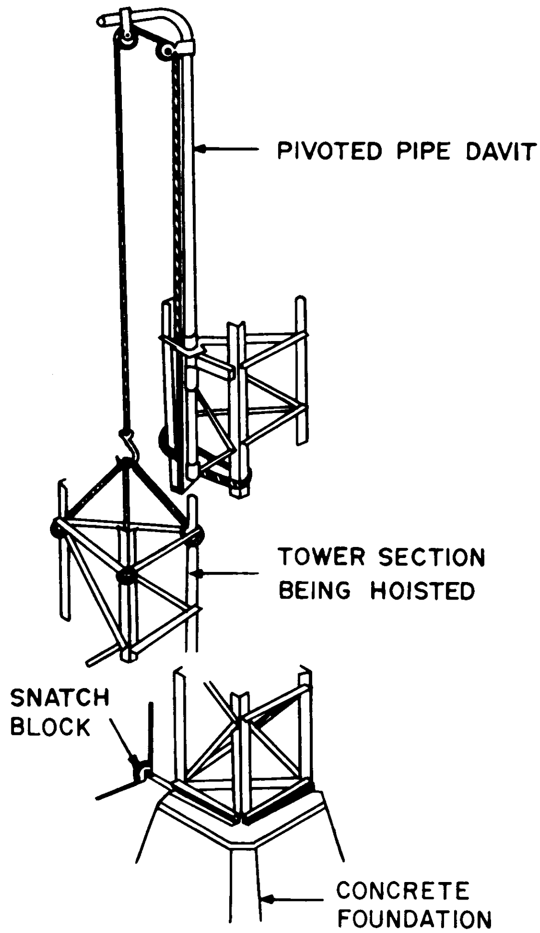


Figure 7-4. Typical Davit Installation

b. Gin Pole Method. Light triangular guyed towers furnished with a pivoted base may be completely assembled on the ground and then raised to a vertical position with the aid of a gin pole. Figure 7-5 illustrates the lower section of a tower which has an attached pivoted base in a horizontal position preparatory to hoisting. The thrust sling shown counteracts the thrust on the base foundation from hoisting operations. Rigging operations and location of personnel essential to the raising of a pivoted base tower are detailed in Figures 7-6 and 7-7. Light towers in lengths of approximately 80 feet may be raised with a single attachment of the winch line. However, longer towers frequently are too flexible for a single attachment, and, in this case, a hoisting sling furnished with a snatch block allows for two points of attachment. The gin pole is mounted close to a concrete tower base and is provided with a top sheave to take the winch line. Permanent guys attached to the tower at three elevations are handled by personnel during hoisting operations as shown in figure 7-6. Temporary rope guys provided with snatch blocks anchored to dead men furnish the necessary lateral stability. As the mast approaches a vertical position the permanent guys are fastened to the guy anchors installed prior to erection.

c. Auxiliary Mast Method. Guyed towers of heavier construction require erection equipment of greater rigidity than the light davit previously described. A mast or gin

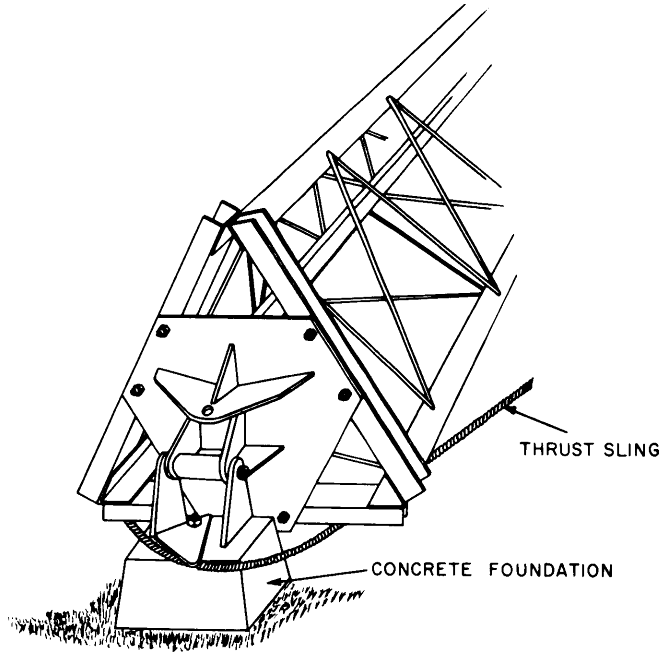


Figure 7-5. Pivoted Tower Hoisting Preparation

pole furnished with a swiveled "T" head is shown in figure 7-8. At the top of the mast and at right angles to it, is a revolving pin-supported head with the hoist line running over two separated sheaves. Tower sections are completely bolted on the ground, hoisted by the rig to the right elevation, kept away from the completed structure by means of a tag line, and then swung into place. After each new section is securely bolted, the mast is relocated and the process repeated until the full height is reached.

d. Hand Assembly. Erection without a davit or gin pole may be accomplished by assembly of individual members piece by piece as the tower is erected. The assembler climbs inside the tower and works with the lower half of his body inside the previously assembled construction. He then builds the web of the tower section around him as he progresses upward. As each member is bolted in place the assembler should tighten all connections immediately so that at no time is he standing on or being supported by any loose member.

Frequently, temporary guying is required in the erection of guyed towers. Such guying is often necessary where several sections are erected before the elevation of the permanent guy level is reached. Requirements for temporary and permanent guying are presented in paragraph 7.6.

7.4.5 Erection of Self-Supporting (Freestanding) Towers

Erection of self-supporting towers is most effectively accomplished with a mobile crane if the height of the tower is within the height range of the crane. For high towers, the lower portion may be erected with a crane and the upper section handled with the basket boom rig illustrated in figure 7-9. The pole for the basket boom is supported at the top and bottom by guys attached to the column struts by reeved blocks. This is a flexible

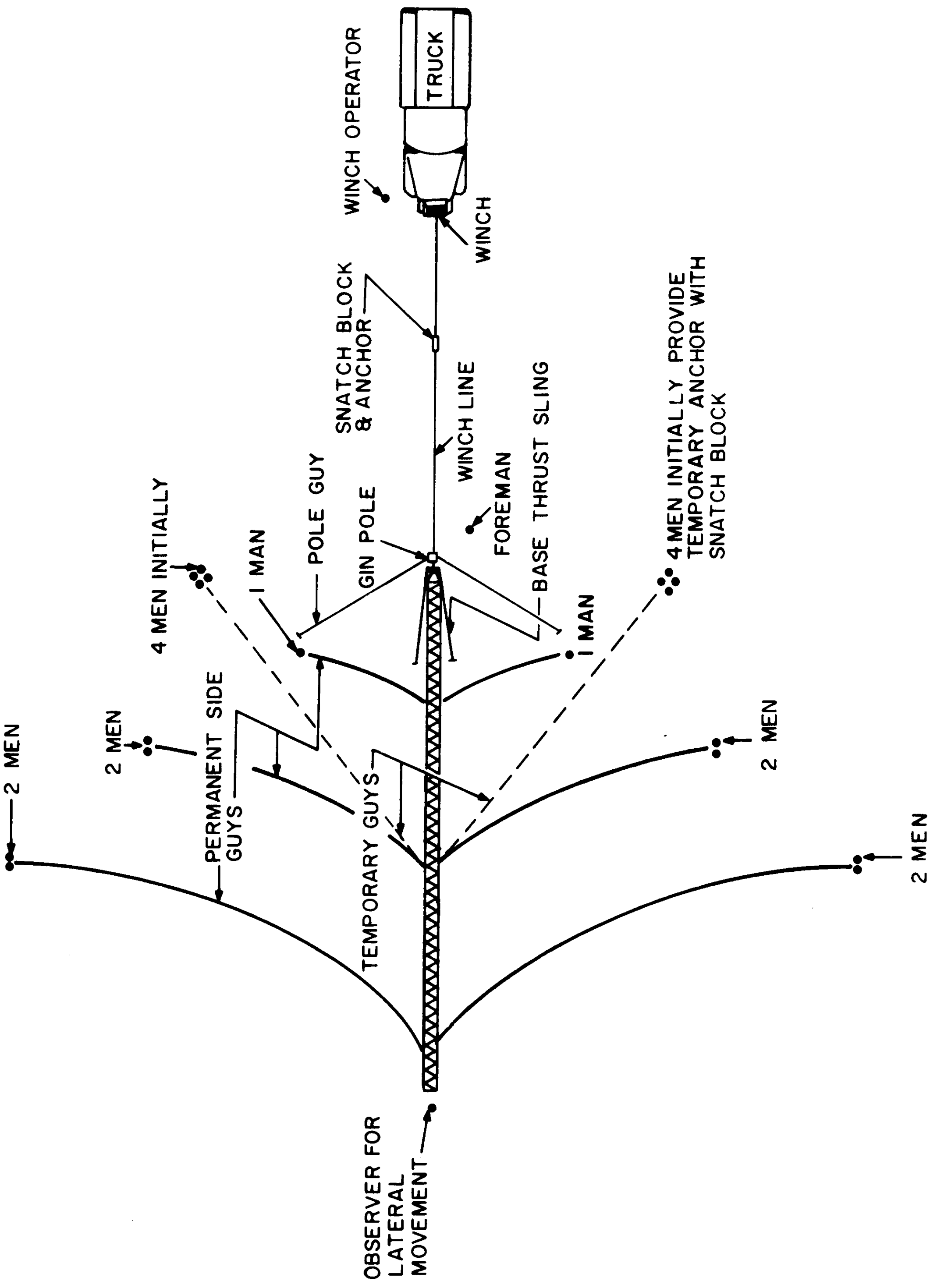


Figure 7-6. Erection Plan for Pivoted Tower

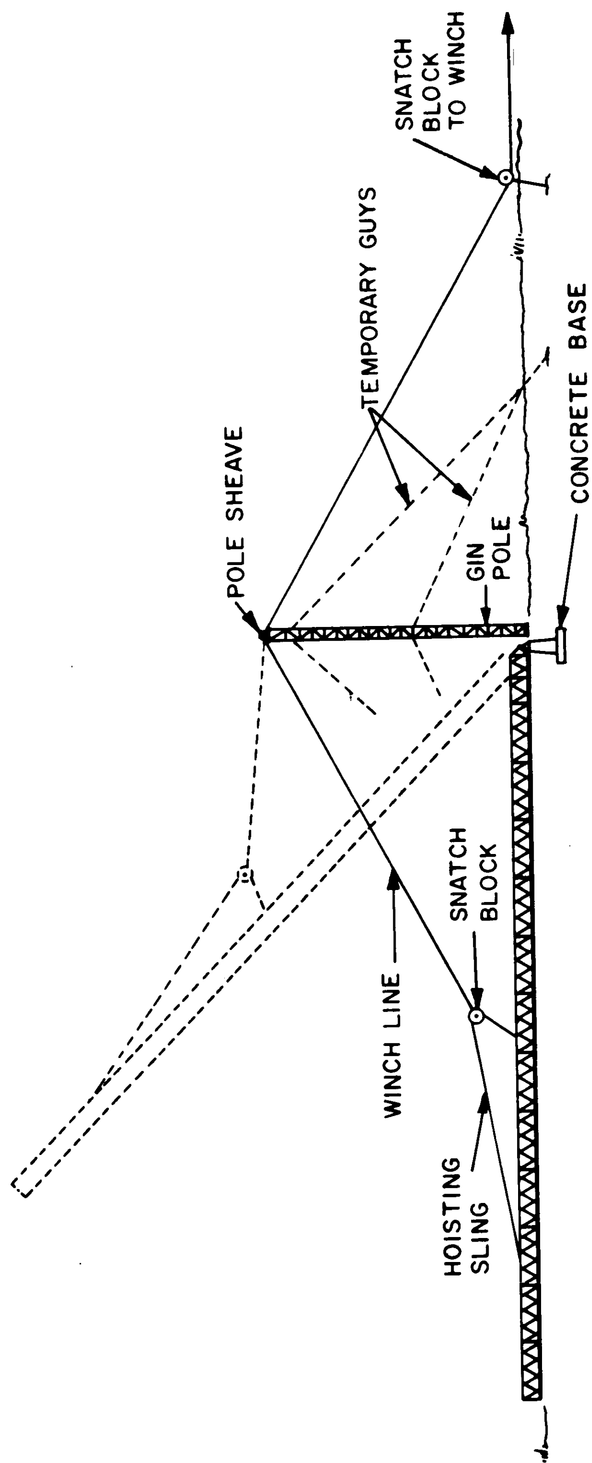


Figure 7-7. Erection of Pivoted Guyed Tower

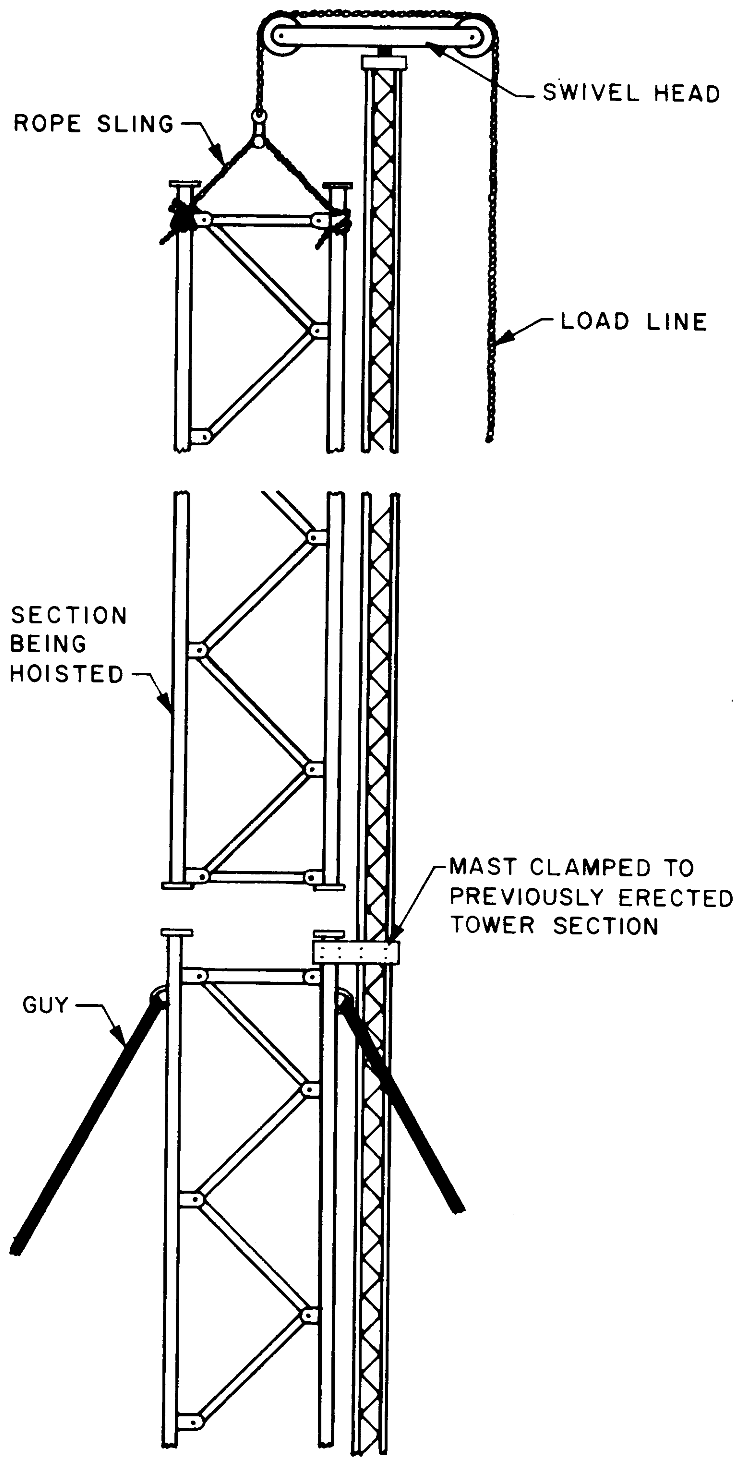


Figure 7-8. Tower Erection with Auxiliary Mast

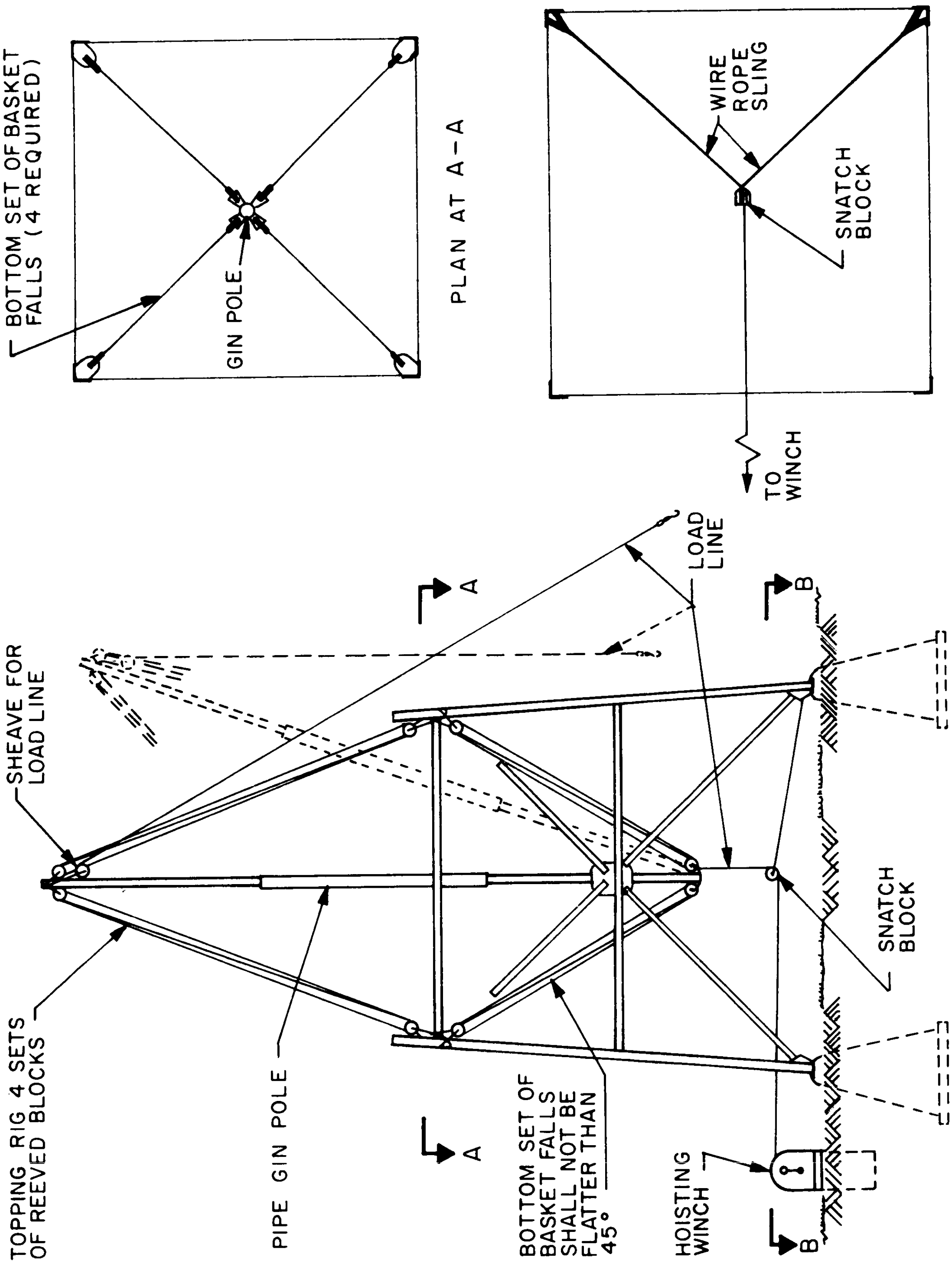


Figure 7-9. Basket Boom for Erecting Self-Supporting Towers

arrangement which facilitates erection by allowing the pole to be moved quickly to any work location. Where cross obstructions hinder hoisting, the pole can be placed at an angle to raise material outside the structure. When erection of the structure has reached a height at which the gin pole is no longer useful, the pole must be lifted to a new position at a higher level.

7.5 WOOD ANTENNA POLES

Wood poles used as HF antenna supports will vary in size according to the characteristics of the antenna; e.g., antenna height above ground and length, size, and weight of the antenna wire. The selection of wood poles for antenna supports is based on species, length and class of pole, and type of wood treatment. Poles selected are cut and prepared under the specifications of the American Standards Association (ASA), and are treated in accordance with the specifications of the American Wood Preserving Association Standards (AWPA). Where special requirements are anticipated, or when there is a conflict between specifications and requirements, NAVFAC must be consulted.

7.5.1 Wood Pole Characteristics

Wood antenna poles are characterized by classes ranging from 1, which has the greatest transverse breaking stress, to 10 which has the lowest. Typical pole sizes and breaking loads for the classes acceptable for antenna uses are given in table 7-2.

Table 7-2. Transverse Breaking Loads Of Poles

Class	Transverse Breaking Load (Pounds)	Typical Minimum Dimensions for Southern Pine Creosoted Poles, Top Circumference (Inches)
1	4700	27
2	3700	25
3	3000	23
4	2400	21
5	1900	19

All wood poles used as antenna supports are required to meet the following requirements:

a. Standard Poles. Poles must be either Douglas Fir or Southern Pine and are to conform to ASA specification 0.51.

b. Roof. Poles must be cut at the top to form a one-way roof with a 15° slope.

c. Steps. Standard hook pole steps, 5/8-inch in diameter and 10 inches long are required. Hook steps should be installed so that the first step is approximately 3 feet above ground, and all others are 18 inches above each other. The steps are placed alternately on opposite sides of the pole.

d. Preservative Treatment. Poles must be treated to prevent decay and insect damage. Treatment consists of the Full Cell Pressure Process in accordance with AWPA Standards C1 and C4. The preservative to be used is a solution of creosote and coal tar. The creosote must meet the requirements of AWPA Standard P13. The creosote-coal tar solution must meet the requirements of AWPA Standard P12.

e. Final Retention. Final retention of the preservative must be at least 16 pounds per cubic foot for Douglas Fir, and 20 pounds per cubic foot for Southern Pine.

7.5.2 Preparation for Erecting Wood Poles

A truck-mounted power-driven auger may be used to dig the holes for wood antenna poles. The hole must be large enough to admit the pole freely and to permit the use of tampers when backfilling. The hole depth required to provide adequate strength for a pole is determined by total length of the pole, height of the pole above ground, and the soil conditions. A tabulation of hole depths required for average soil conditions is given in table 7-3. If soil conditions are such that the hole may cave in, shoring should be forced into the hole as the soil is removed. A barrel with the heads removed is a practical device to use for shoring.

All preliminary pole work such as drilling, roofing, and gaining is to be accomplished on the ground before the pole is erected and set in place.

Antenna pole erection is accomplished most practically by using a power-driven winch or derrick. In most cases, this equipment is truck-mounted, as is the auger used in drilling the hole. The actual technique to be used in raising the pole to the setting-in position with this power equipment depends upon the size and weight of the pole. The

Table 7-3. Pole Depth Setting Data (Feet)

Total Length	Height Above Ground	Depth Set
20	15.5	4.5
25	20	5
30	24	6
35	29	6
40	33.5	6.5
45	38	7
50	42.5	7.5
55	47.5	7.5
60	52	8
65	56.5	8.5
70	61	9
75	65.5	9.5
80	70	10
85	74.5	10.5
90	79	11
95	83.5	11.5
100	88	12
110	97	13

following methods of pole erection are commonly applied. Use the method that is best suited in consideration of pole size and weight, type of power equipment, and the number of personnel available.

a. Truck Derrick Method. One of the most satisfactory methods of erecting and setting a pole is with the use of a truck-mounted pole derrick. The truck is moved into position with the derrick centered over the hole; then the derrick supports are put into place. The winch line is fastened just above the balance point of the pole and the pole is slowly raised as shown in figure 7-10. The butt is then guided until it is centered over the hole. The pole should be raised until the winch hook is less than 1 foot from the sheave at the end of the derrick. If the pole is so tall that it cannot be raised sufficiently by the derrick, the truck should be moved slightly away from the hole and the butt of the pole should be set in the hole at an angle. Then the truck can be moved slowly back to its original position, and the pole can be lowered into place. Plumbing, backfilling, and tamping complete the job.

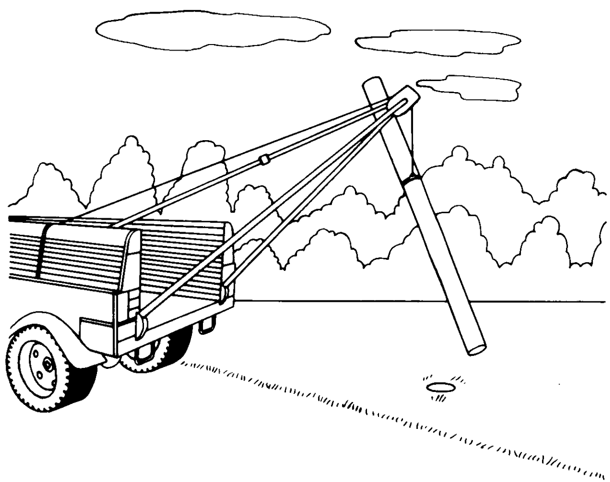


Figure 7-10. Pole Erection with a Truck Derrick

b. Gin Pole Method. The gin pole is an improvised derrick somewhat longer than half the length of the pole to be set. The gin pole is erected, as shown in figure 7-11, as close as possible to the hole in which the pole is to be set. The gin pole is guyed in four directions, pulley blocks are attached, and the pole is raised as in the pole derrick method. The butt is then guided into the hole, and the pole is set and plumbed. Backfilling and tamping can then be completed.

c. A-Frame Method. Figure 7-12 illustrates the use of an A-frame with a power winch for pole erection. The A-frame is constructed of two short poles or timbers that are bolted or lashed together. A power winch on a truck is used as the pulling force for pole erection. The purpose of the A-frame is to change the direction of the pulling force that is exerted on the pole during the initial raising. When this method is used, an inclined trench is dug into the pole hole, and a butting board is placed vertically in the hole. The pole is laid in the trench and the butt is pushed against the board. The necessary lines are rigged, including a line to a power winch on the truck, and the pole is raised by means of the winch. As the pole is raised, the guy lines are used to keep the pole steady. The A-frame is removed when the pole has been raised sufficiently so that the

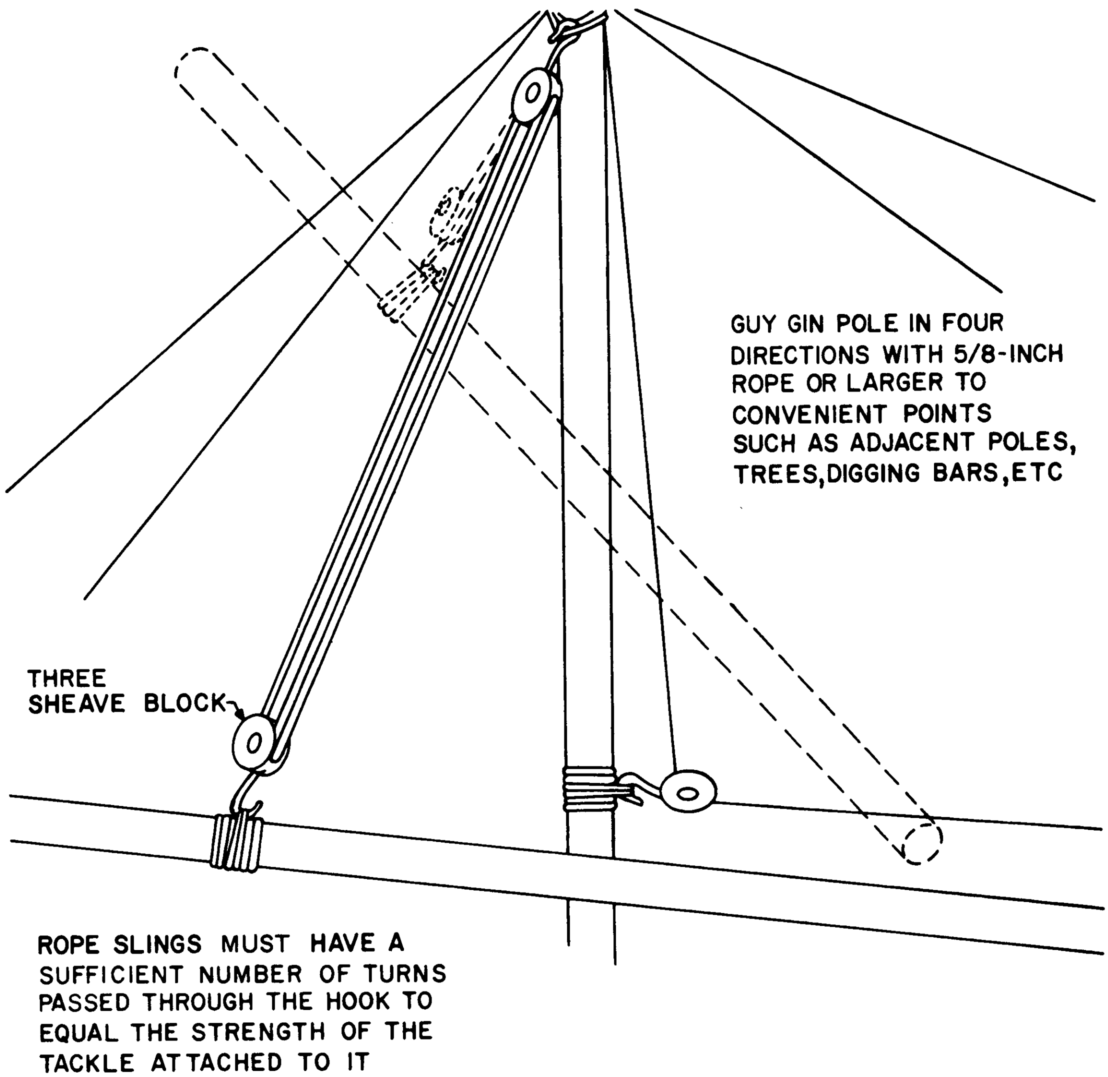


Figure 7-11. Pole Erection with a Gin Pole

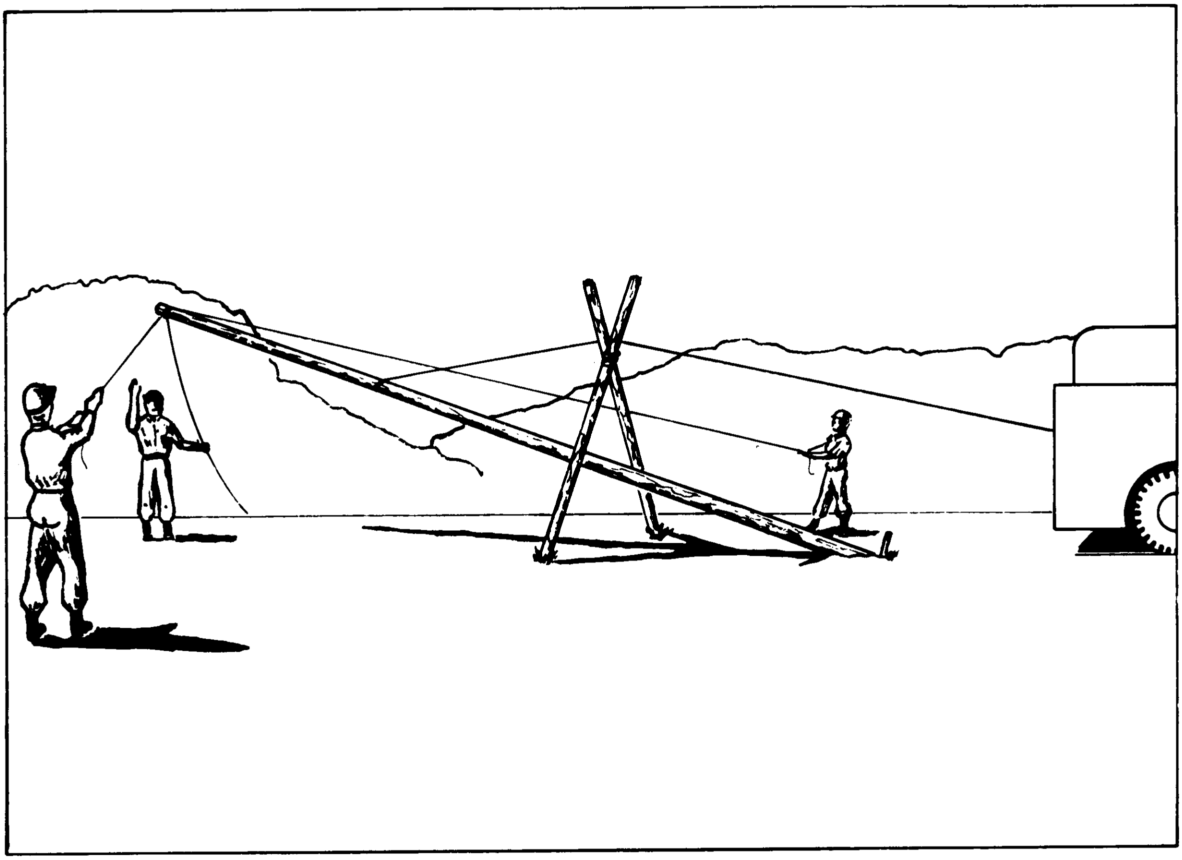


Figure 7-12. Pole Erection with an A-Frame

pulling line no longer touches it. The rear guy line is used to prevent the pole from falling in the direction of the truck as the pole is raised further to a vertical position. The butting board can then be removed and the pole can be plumbed. Backfilling and tamping complete the installation.

7.6 GUYING

Guying steel towers and wood antenna poles is done in two phases: temporary guying during the erection of the tower or pole, and permanent guying in conjunction with plumbing the structure.

Wood poles that are erected and set to their specified depth are reasonably self-supporting under normal wind conditions. However, high winds can move a pole from its vertical position. Therefore, wood antenna poles must be temporarily guyed during construction and installation, and then must be permanently guyed.

Temporary guying of steel towers is always necessary where more than one tower section is erected. Under no circumstances should the tower be advanced more than two sections without guying. Permanent guys are to be installed before the temporary ones are removed.

7.6.1 Guy Anchors

Guy anchors are selected by the antenna manufacturer or installing contractor in accordance with NAVDOCKS DM-7 and other specifications defined by NAVFAC. The antenna design and installation plans specify the anchor type, location, and hole depth required.

Anchor shafts, or rods, must project above grade sufficiently to keep all connecting guywire attachments free of vegetation and standing water. Shafts and connecting attachments should be thoroughly cleaned, and then coated with a petroleum preservative to retard effects of weather.

Soil conditions, anticipated wind and ice loading of the antenna, and the stresses placed on the guys by the wind loading and weight of the structure are determining factors in the selection of guy anchors. The following types of anchors are representative of those commonly used in antenna installations.

a. Screw Anchor. The screw anchor shown in figure 7-13 may be used for temporary guying and for anchoring guys for lightweight towers. This anchor is installed by screwing it into the ground in line with the direction the guy will take.

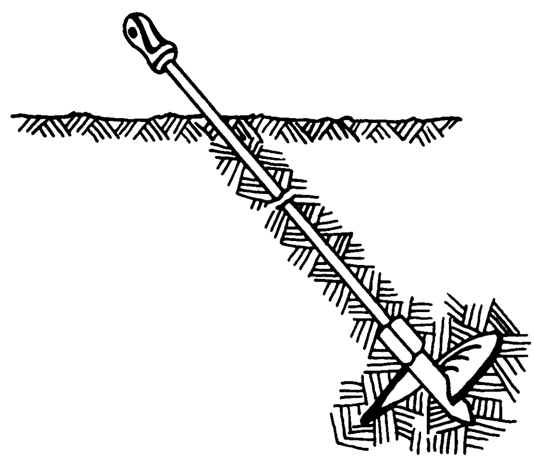


Figure 7-13. Typical Screw Anchor

b. Expansion Anchor. The expansion anchor shown in figure 7-14 is suitable for practically all guying applications where the soil is firm. This anchor is placed with its expanding plates in the closed position in an auger-drilled, inclined hole not less than 3 feet deep. The plates are expanded into the firm, undisturbed sides of the hole by striking the expanding bar at point B with a hammer and thereby forcing the sliding collar downward the distance D shown in figure 7-14. The anchor installation is completed by backfilling the hole with thoroughly tamped backfill.

c. Concrete Anchors. Poured-in-place concrete anchors are normally used for high stress applications, and where multiple guys are attached to a single anchorage.

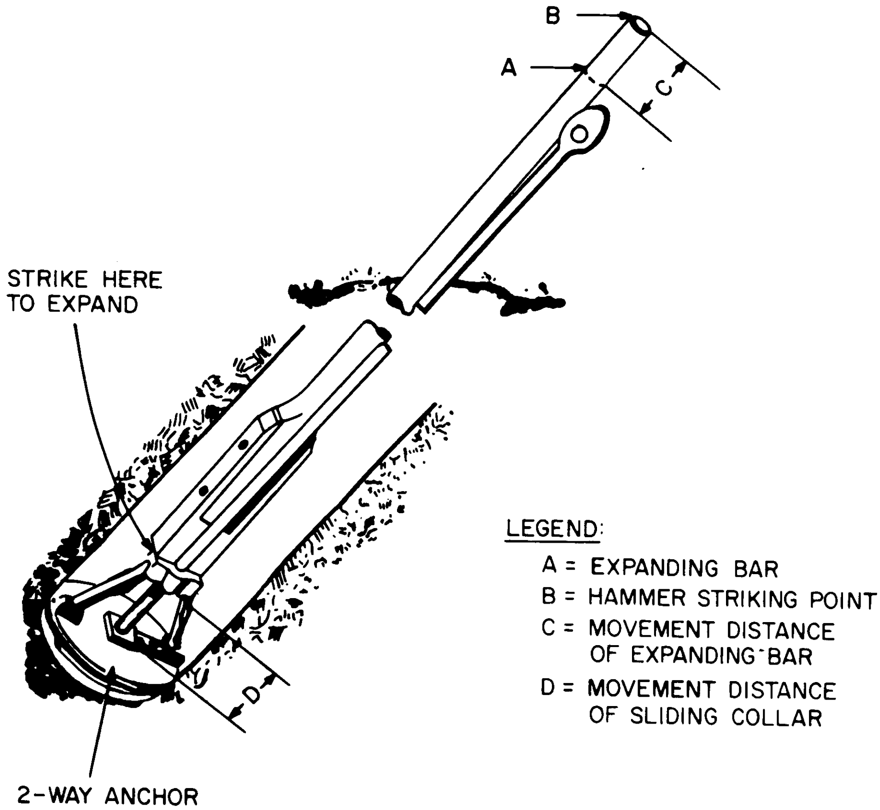


Figure 7-14. Expansion Anchor

7.6.2 Temporary Guying

Several materials, including stranded wire, wire rope, and fiber rope are acceptable for temporary guying. New manila rope is the most suitable because of its strength and ease of handling. The size of guy material required is determined by the height and weight of the structure to be guyed and by weather conditions at the installation site.

Secure the temporary guys to the permanent guy anchors, to temporary-type anchors, or to any nearby structure that provides the required supporting strength. Leave the temporary guys in place until the structure is permanently guyed and plumbed.

7.6.3 Permanent Guying

Antenna structures are permanently guyed with steel cables or fiberglass guy sections to pre-positioned anchors in conformance with the installation plan.

Figure 7-15 illustrates two methods of guying triangular steel towers. Guys A, B, and C are secured to a single anchor, while guys D, E, and F are secured to individual anchors. Both arrangements are satisfactory; however, the anchor that terminates guys A, B, and C must be capable of withstanding much greater stresses than the

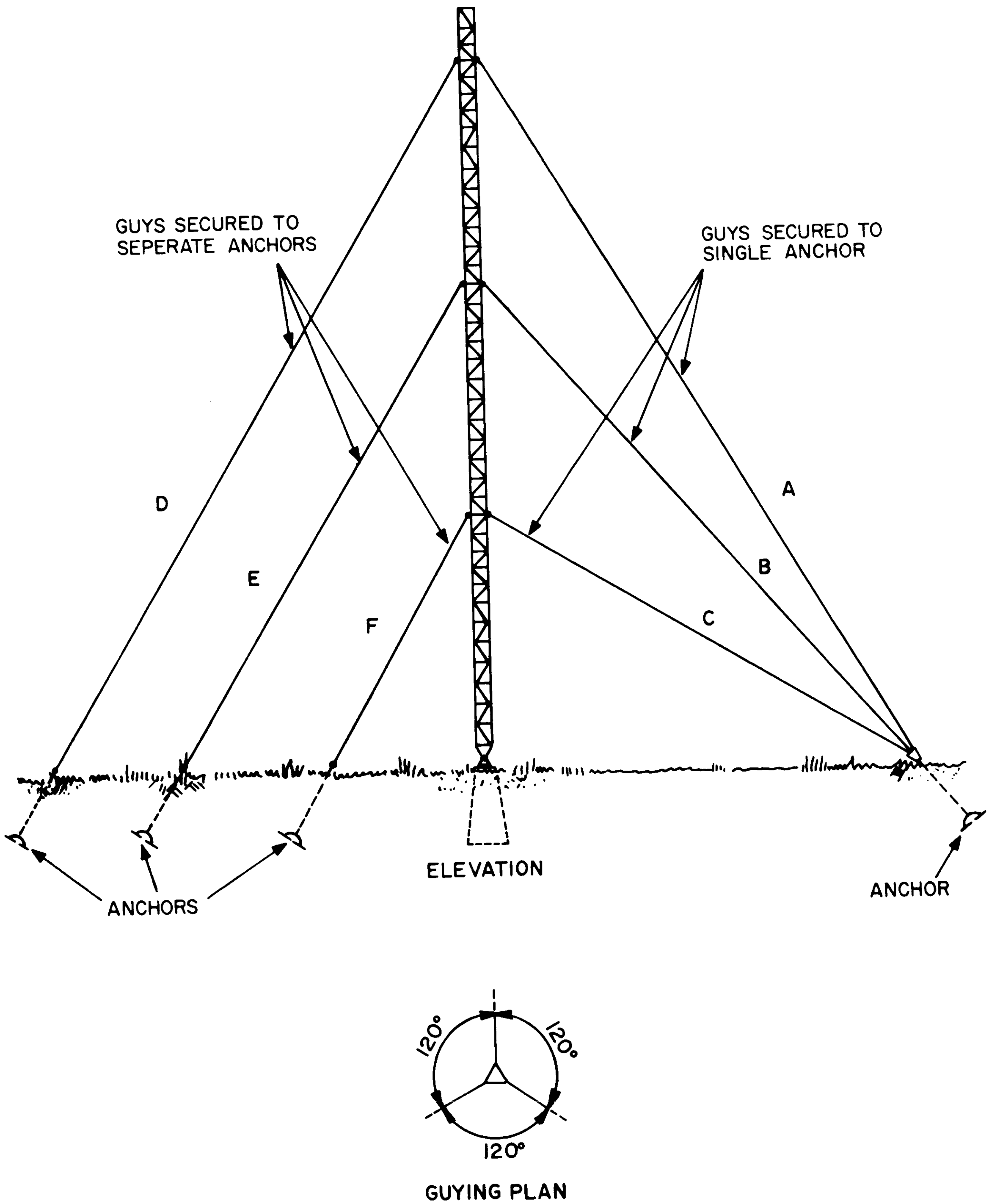


Figure 7-15. Tower Guying Arrangements

individual guy anchor arrangement. Triangular tower guys are arranged so that three guys are spaced 120° apart at each level of guying as shown in figure 7-15. Square towers require four guys spaced 90° apart at each guying level. The following general elevation requirements apply to guy attachments for towers.

a. Single-Guy Layer. The cable attachments are placed in position at approximately two-thirds the tower height.

b. Two-Guy Layers. For towers with two-guy layers, cable attachments are placed in positions at approximately 30 and 80 percent of the tower height.

c. Three-Guy Layers. For towers with three-guy layers, cable attachments are placed in positions at approximately 25, 55, and 85 percent of the tower height.

Permanent guying of wood poles that are set to the required depth in firm soil is done primarily to counteract stresses (as opposed to towers, where guys are used to provide vertical support). Locate wood pole guys 120° apart at each level of guying as specified in the installation plan, and as determined by pole height and anticipated stresses. Position guys on the pole so that a 45° angle is formed from the pole attachment point to the anchor.

7.6.4 Tower Guy Tension

Setting guy tension and plumbing a tower is done at the same time and only when wind forces are light. Guy tension adjustment and tower plumbing is done as follows:

a. Initial Tension. All guys should be adjusted gradually to the approximate tensions specified in the antenna installation details. If tensions are not specified, guy tension should be adjusted to 10 percent of the guystrand breaking strength as tabulated in table 7-4. (If fiberglass guys are installed, tensions must be set strictly in accordance with the manufacturer's specifications.) The tension on all guys is adjusted while ensuring that the tower is in a stable, vertical position.

b. Final Guy Tension. In one procedure used for final tensioning of tower guys the final tension is measured with a dynamometer as shown in figure 7-16. Carpenter stoppers or cable grips of the proper size designed for the lay of the wire must be selected for use in the tensioning operation. Any cable grip assembly which grips the wire by biting into the cable with gripping teeth could penetrate and damage the protective coating of guy cables and should not be used. In step A of figure 7-16, the coffing hoist is shown in series with a dynamometer to measure the tension. A turnbuckle is shown in position to receive the guy tail. In step B, an additional cable grip and hoist or tackle is attached above the cable grip shown in step A. The lower end of this tackle is provided with a second cable grip which is attached to the guy tail previously threaded through the turnbuckle. The second coffing hoist is operated until sufficient tension is applied to cause the reading on the series dynamometer to fall off. Step C shows the guy in final position, secured in place with clamps. With the tower properly plumbed to a vertical position, only one guy at a given level need be tested with the dynamometer.

On some installations, other procedures for tensioning guys may be necessary because of the type of guys and hardware supplied with the antenna. For example, preformed wire helical guy grips are sometimes used for attaching guywires to the adjusting turnbuckles. In such cases, the techniques used for guy assembly, connection of guywire to

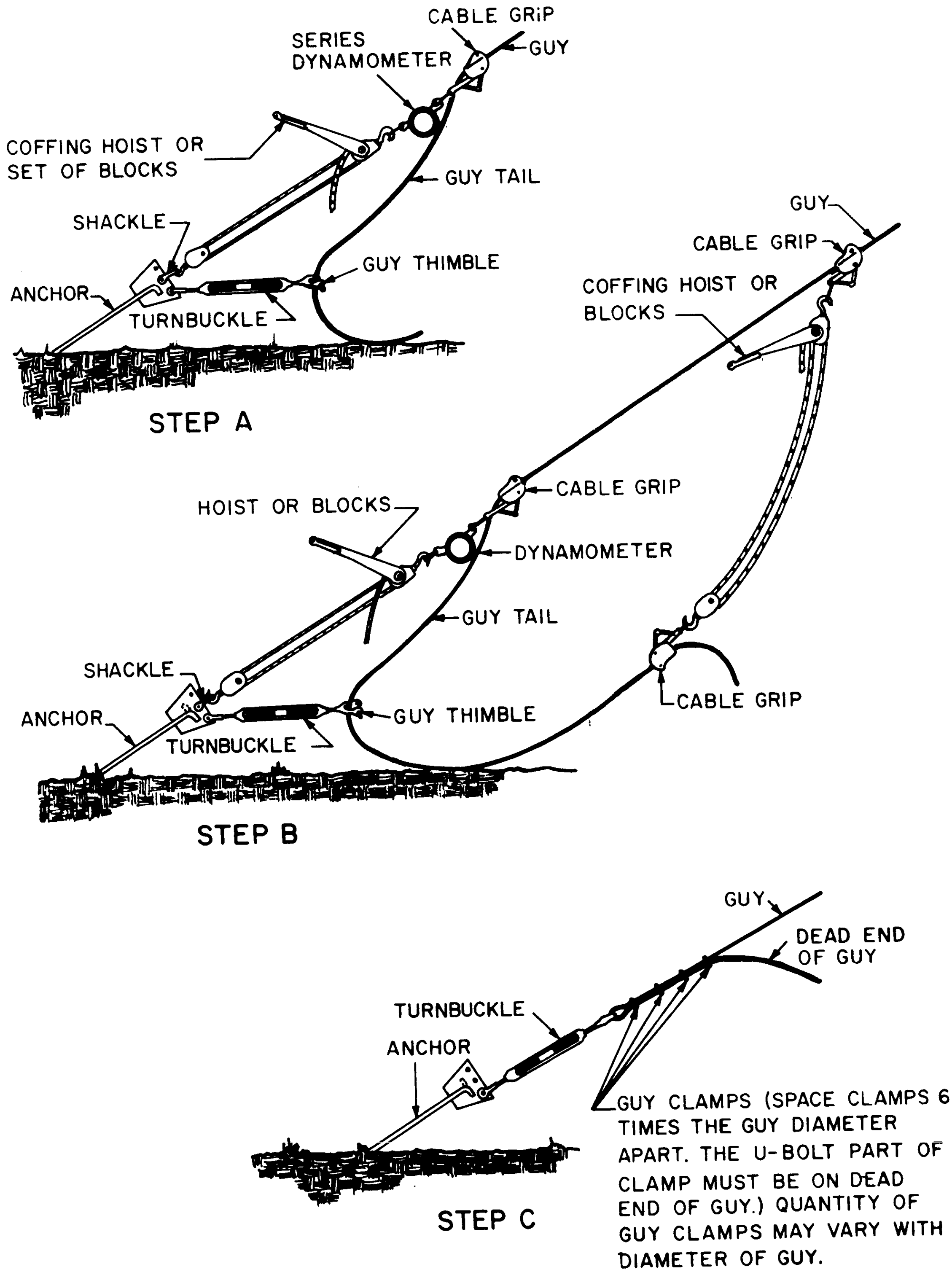


Figure 7-16. Final Tensioning of Guys

Table 7-4. Minimum Breaking Strength (Pounds) of Guystrand

Material	Diameter (Inches)	Wires	Utilities Grade	High Strength	Extra High Strength	Aluminum-Clad Steel Wire Copper-Clad Steel Wire
Steel	0.250	3	3, 150			
Do	0.250	7		4, 750	6, 650	
Do	0.3125	3	6, 500			
Do	0.3125	7		8, 000	11, 200	
Do	0.375	3	8, 500			
Do	0.375	7	11, 500	10, 800	15, 400	
Do	0.500	7	25, 000	18, 800	26, 900	
Do	0.500	19		19, 100	26, 700	
Do	0.625	19		28, 100	40, 200	
Do	0.750	19		40, 800	58, 300	
Aluminum-Clad Steel Wire	0.247	3#9				5, 715
Do	0.349	3#6				10, 280
Do	0.385	7#8				15, 930
Do	0.486	7#6				22, 730
Do	0.546	7#5				27, 030
Do	0.509	19#10				27, 190
Copper-Clad Steel Wire	0.237	7 x 0.079				6, 000
Do	0.360	7 x 0.120				14, 000
Do	0.432	7 x 0.144				20, 000

the anchor, and tension adjustments, must be determined from the detailed installation plan or the appropriate antenna technical manual.

Guys should be checked at least once annually to ensure structural stability, and they should be retensioned whenever the guy cable tension is found to be outside the limits specified in the appropriate technical manual or installation drawings.

c. Plumb Requirements. Antenna towers should be plumbed in accordance with Section 5 of the American Institute of Steel Construction (AISC) Standard Practice (5-149), which is quoted as follows:

> In the erection of structural steel for structures other than bridges and multi-story tier buildings, the individual pieces are considered plumb, level, and aligned if the error does not exceed 1.500 inches.

7.7 ANTENNA ASSEMBLY

HF antennas are assembled in accordance with the manufacturer's detailed plans and drawings, or as specified in NAVELEX standard plans (such as NAVELEX Drawing RW 66D295 for rhombic antennas). A bill of material included in the plans lists structural materials, antenna materials, hardware, and tools required for the complete antenna assembly.

Simple antennas intended for assembly in the field are usually assembled on the ground and then hoisted into position. In this case good work practices and strict attention to the detailed assembly instructions are the main requirements for correct assembly. Some other antennas, such as rhombics and similar curtain-type antennas are, essentially, constructed at the site. In such cases of wire antenna installation the breaking load of the type of wire being used has considerable effect on the measurements and installation of the wire elements.

The length of a wire suspended between supports must be adequate to allow for the sag that corresponds to the correct tension on the wire. Under static conditions, tension on antenna wires is adjusted to approximately 10 percent of their breaking strength without considering wind or ice load. This allows for a fairly generous sag which can compensate for a considerable change in temperature, without increasing the tension to a danger point in very cold periods.

An approximation for sag and tension is given by:

$$S = \frac{W\ell^2}{8T} \qquad (7\text{-}1)$$

$$T = \frac{W\ell^2}{8S} \qquad (7\text{-}2)$$

where
- S = sag in feet
- W = weight in pounds per foot
- ℓ = wire length in feet
- T = tension in pounds

Table 7-5 lists the diameters, breaking loads, and weights per 1,000 feet for various types of copper wire and copper-clad steel wire.

Table 7-5. Breaking Loads and Weights of Copper Wire and Copper-Clad Steel Wire

Material	Dia. (Inches)	Breaking Load (Pounds)	Weight/1000 ft (Pounds)
Solid Copper Wire:			
No. 4 Hard	0.204	1970	126.4
No. 6 Hard	0.162	1280	79.46
No. 8 Hard	0.128	826	49.98
Solid Copper-Clad Steel Wire:			
No. 4 - 40% HS	0.204	3541	115.8
No. 6 - 40% HS	0.162	2433	72.85
No. 8 - 40% HS	0.128	1660	45.81
No. 4 - 30% EHS	0.204	3934	115.8
No. 6 - 30% EHS	0.162	2680	72.85
No. 8 - 30% EHS	0.128	1815	45.81

NOTE 1. HS indicates high strength.
2. EHS indicates extra high strength.

The approximate length of a wire suspended between two points with a small sag in relation to the distance can be determined from the following formula (all dimensions are in feet):

$$\text{Wire length} = d\left[1 + \frac{2}{3}\left(\frac{2S}{d}\right)^2\right] \qquad (7\text{-}3)$$

where d = distance between suspension points
S = sag

Measuring, stretching and cutting wires to the correct length and sag can be simplified by temporarily attaching the wire on the supports at points close to the ground.

7.8 STRINGING TRANSMISSION LINES

Detailed physical and electrical characteristics, and installation requirements for open-wire and coaxial transmission lines are included in chapter 6. This section lists some details pertinent to suspending open-wire transmission lines above ground.

a. Wood Support Poles. The criteria for wood poles suitable for transmission line support is the same as specified for antenna poles in paragraph 7.5.

b. Positioning Poles. When supporting poles are set in place, all curvatures should be in the direction of the transmission line run, and each pole should appear to be perfectly straight when viewed along the line. Figure 7-17 shows the relation of the parts of a pole to its curvature.

c. Facing Poles. After the poles are set-in, turn them so that the cross-arm gains are positioned alternately gain-to-gain and back-to-back. Where the transmission line is on a slope, all gains should face up-grade.

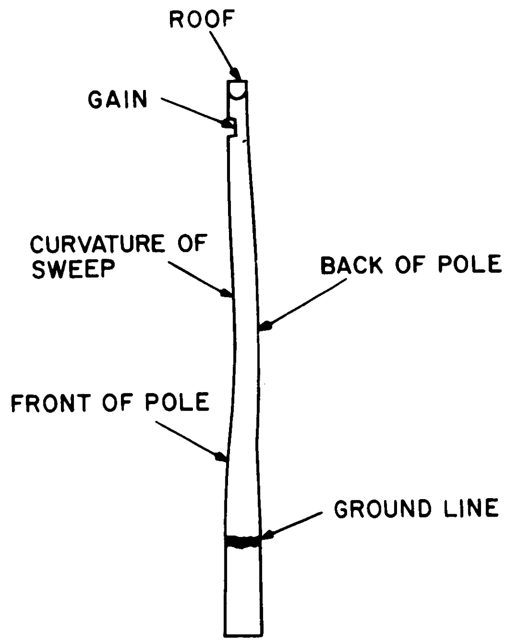


Figure 7-17. Relationship of Pole Parts to its Curvature

d. Line Tension. Set the transmission line tension to 10 percent of the conductor's breaking strength unless local conditions dictate otherwise. Unusual ice and wind loads, or extreme temperatures may require tension and sag adjustments. See table 7-5 for minimum breaking loads of copper wire and copper-clad steel wire.

7.9 POLE AND TOWER LIGHTING

Poles and towers which are a potential hazard to aircraft must be lighted at night by obstruction lights. A typical system consists of a double light fixture, a transfer relay, and a photoelectric control unit which automatically turns the light on at dusk and off at dawn. The double-fixture obstruction light is mounted directly onto the end of the power cable conduit and is located so that it extends above the pole or tower to be lighted. The transfer relay, mounted directly in the conduit run, automatically switches the power to the spare light in the event that the operating light fails. The photoelectric control unit is mounted directly onto the pole by means of lag screws, or is mounted with bolts to a crosspiece that is attached between the legs or braces of a tower. Figure 7-18 illustrates a typical obstruction lighting system.

The number of lights required for a tower depends upon the height of the tower. The FAA- and FCC-approved lighting systems for various tower heights are listed in table 7-6 and illustrated in figure 7-18.

Higher towers require lights of a higher brilliancy and either a rotating red beacon or a beacon flasher to cause the lights to flash on and off.

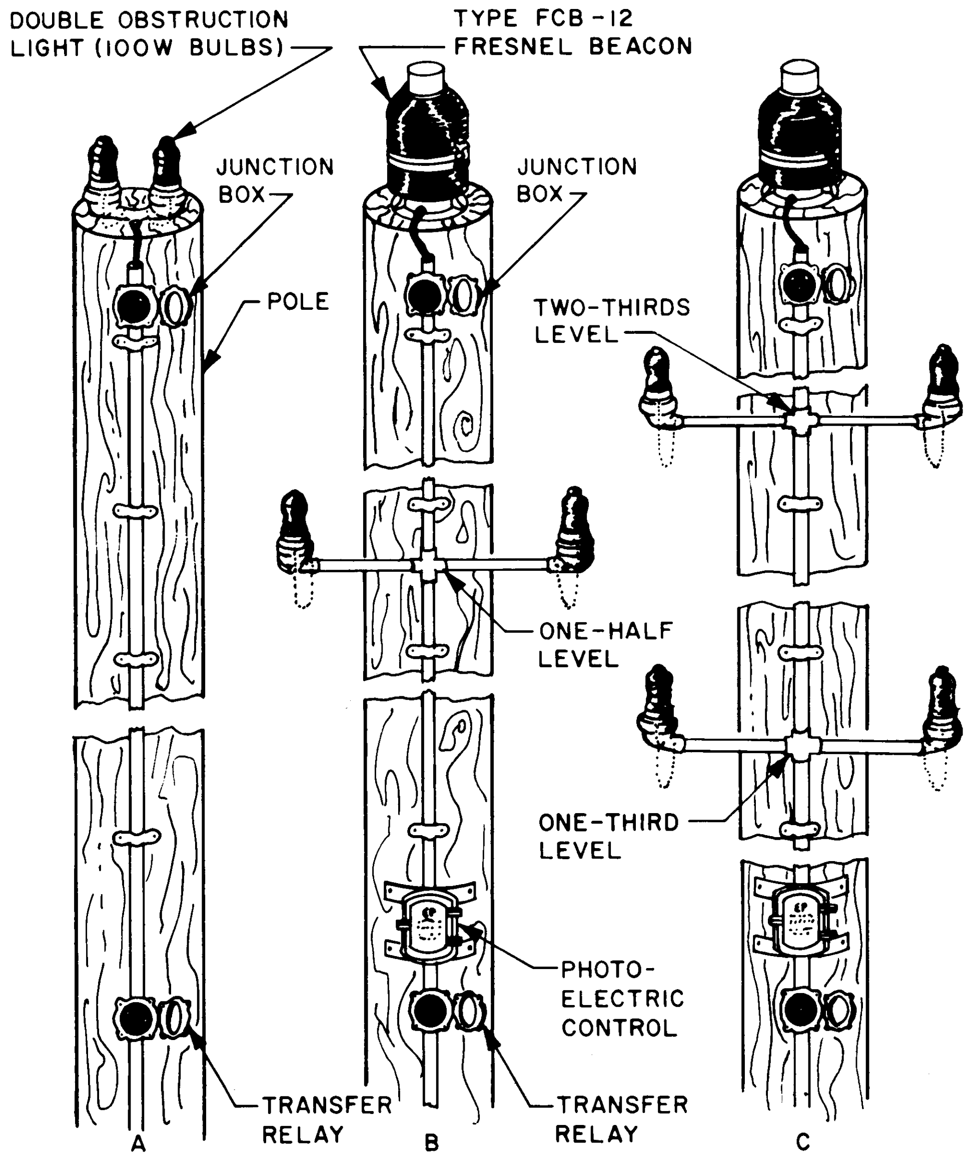


Figure 7-18. Typical FAA- and FCC-Approved Obstruction Lights

Table 7-6. FAA- and FCC-Approved Obstruction Lighting Systems

Tower Height (Feet)	FAA-Approved System Nomenclature	FCC-Approved System Nomenclature	Typical System Detail Figure 7-18
21-150	A-1	17.24	A
151-300	A-2	17.25	B
301-450	A-3	17.26	C

CHAPTER 8

ANTENNA SYSTEM PERFORMANCE TESTS

Physical and electrical checks are required to ensure that installation specifications have been met and that the antenna system will perform within required operational limits. The recorded data from these installation inspections and tests serve to establish reference standards for future preventive and corrective maintenance actions.

Procedures for inspections and general electrical tests of antenna systems, and information on radiation and shock hazards to personnel are discussed in this chapter.

8.1 POST-INSTALLATION INSPECTIONS

Both physical and electrical inspections and tests must be performed at the time of initial antenna installation. The physical inspection of HF antenna systems should be completed before electrical tests commence. Inspections should be conducted using procedures that will detect installation deficiencies and provide reference data for future inspections and maintenance records.

8.1.1 General Inspection Procedures

The following physical checks of antenna systems, subparagraphs a. through f., below, should be conducted. In addition, for each antenna inspected, applicable parts of the antenna inspection checklist (table 8-1) should be completed and incorporated into the permanent maintenance record.

a. Structural Tower Checks. Check tower plumb with a transit at two positions, 90° apart, to determine if the top is out of plumb by more than the width of one leg. In addition,

(1) Check with transit for tower kinks.

(2) Check for loose and missing bolts.

(3) Check for missing and bent members.

(4) Check guying for improper tensioning.

(5) Check antenna-lowering davits for proper operation.

(6) Check for loose material on tower.

(7) Check for faulty lighting system.

(8) Check for corrosion or deterioration.

Table 8-1. Antenna Inspection Checklist

Antenna Type ____________________
Antenna ID ____________________
Inspected by ____________________ Date ____________________

Before Power
Annual
After Storm

Subject	Defects	Remarks	Corrective Action Taken
Antenna			
Elements			
Mounting			
Insulators			
Fastenings			
Downleads			
Connections			
Insulators			
Tie-Down			
Guys			
Tension			
Connections			
Insulators			
Anchors			
Transmission Lines			
Connections			
Tensions			
Insulators			
Poles			
Building Feedthrough Insulators			
Towers			
Plumb			
Fastenings			
Paint			
Base			
Dissipation Lines			
Connections			
Tensions			
Insulators			
Poles			
Terminating Resistors			
Connections			
Hardware			
Grounding and Lightning Protection			
Horn Gap at Building			
Horn Gap at Antennas			
Ground System			

b. Tower Support Checks. Check concrete bases for settling, cracking and tilting. In addition,

(1) Check tower anchors for loose emplacement in ground.

(2) Check guy wires for insecure clamps, clips, and turnbuckles.

(3) Check guy wires for broken strands, rusting, and excessive sagging.

(4) Check tower ground rods for broken or missing wires.

c. Antenna Installation Checks. Check antenna for installation items not in accordance with plans and specifications. In addition,

(1) Check for insecure and incorrect hardware mounting.

(2) Check insulating material for cleanliness; remove any paint or other material that may cause a loss of insulating properties.

(3) Check for bonding and grounding that is not in accordance with applicable plans and specifications.

d. Rotatable Antennas. Inspect rotatable antennas as follows:

(1) Check for proper physical clearances.

(2) Check for proper operation of mechanical and electrical stops.

(3) Check slip rings on rotating cable assemblies for electrical contact.

(4) Check for binding through entire range of travel.

(5) Check for excessive swaying during antenna rotation.

(6) Check antenna deenergizing switches, located at the antenna for proper functioning.

e. Obstruction Lights. Check power wiring at antenna structures for loose cables and conduit. In addition,

(1) Check lighting for broken glass and defective bulbs.

(2) Check photoelectric switch for proper operation. (Covering the glass front and allowing for required time delay should activate the switch.) Check for dirt on the glass which could obscure passage of light.

(3) Check flasher for correct number of flashes per minute.

(4) Check junction boxes for moisture, dirt, rust, and loose hardware, and for improperly placed gaskets, covers, and wiring.

f. Pressurized Coaxial Transmission Lines. Pressurized lines should be inspected for leaks. Leaks usually will be indicated by a decrease in normal operating pressures observed at the pressurizing system manifold line gauges and by the dehydrator unit running continuously. Since most coaxial-line pressurizing systems service several lines, it is necessary to isolate each line from the dehydrator and from the other lines, in order to identify the leaking line. As each transmission line is isolated, the pressure gauge for the isolated line is observed for a decreasing pressure reading. When the faulty line is identified and isolated in this manner, one of the following methods may be used to locate the leak:

(1) Soap-and-Water Method. This method is usually effective only on large leaks, because the soap solution will probably dry before a small leak can be detected. If it is suspected that the leak is small, the methane- or freon-gas method should be used. The procedure for detecting transmission line leaks using the soap-and-water method is as follows:

STEP 1: Apply a liberal solution of soap and water (liquid soap can also be used) to all accessible parts of the faulty line, and watch for the formation of bubbles.

STEP 2: Repeat step 1 on all highly suspect parts of the line, such as joints, connections, and fittings, until the leak is located, or until it is determined that the leak must be located by the use of other detection methods.

(2) Methane-Gas Method. This method of detecting leaks in a coaxial transmission line is particularly effective for the portions of the cable buried below ground. The suspected leak is located by charging the faulty cable with methane gas and using a special testing device to detect the gas fumes that escape to the earth's surface.

WARNING

Methane gas is flammable and must be handled with extreme caution. The procedure for locating transmission line leaks using this method is as follows:

STEP 1: Charge the transmission line with methane gas to the normal operating pressure.

STEP 2: Use a Davis Vapotester, Model D-1, to search for underground leaks by following the path of the buried cable. Escaping methane-gas fumes can be detected by the Vapotester within a relatively small area.

STEP 3: Expose the buried cable in the area where escaping gas fumes are detected to locate the leak.

STEP 4: When the leak is pinpointed, discharge remaining gas from the transmission line and make the necessary repairs.

STEP 5: Purge the transmission line with the normal pressurizing agent and test the line for residual traces of methane gas at accessible points until no fumes can be detected with the Vapotester.

STEP 6: Recharge the transmission line to the correct operating pressure with the normal pressurizing agent.

(3) Freon Gas Method

WARNING

The freon gas method of detecting leaks in pressurized transmission lines can be used only if the normal pressurizing agent is inert gas. Freon will arc in the presence of RF energy and thereby cause deterioration of the line; therefore, all power must be removed before starting the tests. The procedure for using freon gas to detect transmission line leaks is as follows:

STEP 1: Admit a small amount of freon-22 gas through the dehydrator unit intake. Allow approximately one hour for the freon to diffuse through the line.

STEP 2: Use a halide detector torch to check all accessible parts of the line for leaks. If a leak exists, the torch flame will change color from yellow or blue to bright green.

STEP 3: After the leak is located and repaired, purge the transmission line with the normal pressurizing agent. The halide detector should then be used at the escape valve farthest from the dehydrator unit to determine when all traces of freon gas have been purged.

STEP 4: Recharge the transmission line to the correct operating pressure with the normal pressurizing agent.

The foregoing physical checks for antenna systems are broad in scope and are applicable to HF antennas generally. Conscientious use of the checklists will expedite detection and correction of installation errors.

8.2 ELECTRICAL TESTS OF ANTENNA SYSTEMS

Electrical tests must be made after completion of the installation to ensure proper performance. These tests should be made after correction of the deficiencies discovered during physical inspections.

The test plan should be such that the same procedures and methods can be used for post-installation checkout and for conducting future maintenance tests.

8.2.1 General Antenna System Tests

The following test procedures were developed for HF vertically polarized LPA's. The testing format is applicable, however, to HF antennas in general. These tests should be performed when an installation has been completed, and when required during periods of routine and corrective maintenance. Additional test procedures may be found in Addendum No. 1 to DCAC 330-175-1. Significant test results should be recorded each time a test is conducted to provide a history which can be used to evaluate the operational condition of the antenna.

a. Insulation and Loop Resistance. Conduct resistance measurements of antenna systems to determine insulation resistance to ground, and insulation resistance between conductors. The following steps outline the procedure to be followed and the equipment required.

(1) Make certain that the antenna connector at the RF patch panel in the building is open. To make the measurements, an insulation resistance megger, such as the Biddle Model 7679, and an AN/URM-90 Impedance Bridge, or their equivalents, are required. Refer to figures 8-1 and 8-2 for typical test equipment arrangements and format to be used in recording the measurements.

(2) Disconnect the antenna feed line from the transformer. Disconnect the end of the antenna from any matching stubs which may be grounded. Measure the resistance of each wire of the antenna feed line to ground. The resistance reading should approach infinity.

(3) Disconnect the coaxial line from the transformer. Connect the megger to the coaxial line and measure insulation resistance. The resistance reading should approach infinity.

(4) Reconnect the end of the feed line stub to ground.

(5) Connect the impedance bridge across the ends of the antenna feed line and measure loop resistance. The resistance reading should approach zero ohms.

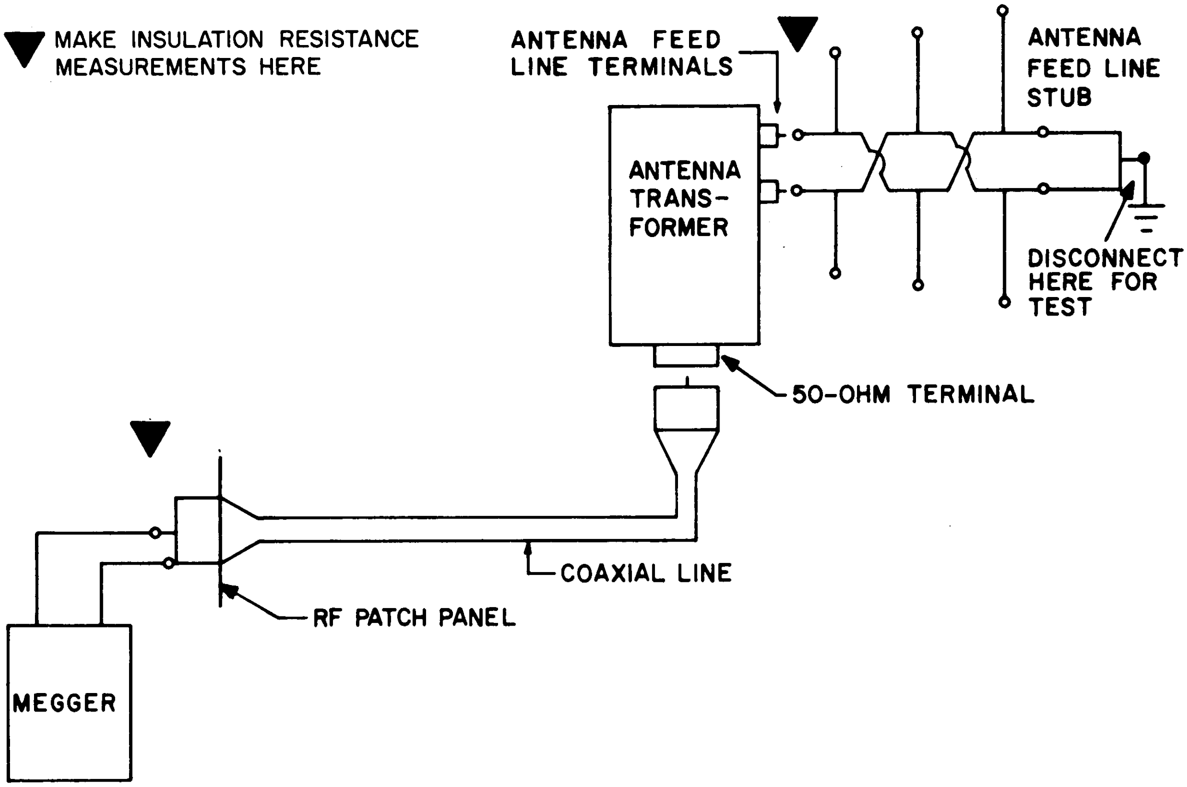
(6) Connect the impedance bridge to the 50-ohm terminal of the antenna transformer and measure loop resistance. The resistance reading should approach zero ohms.

(7) Connect the impedance bridge to the antenna transformer output terminals and measure loop resistance. The resistance reading should approach zero ohms.

(8) Connect a short jumper across the transformer end of the coaxial cable and using the impedance bridge, check loop resistance of the coaxial cable from the RF patch panel in the building. The resistance reading should approach zero ohms.

(9) Reconnect the antenna feed line to the transformer. Reconnect the coaxial cable to the transformer.

(10) Connect the impedance bridge to the coaxial connector at the building end of the coaxial cable, and measure the system loop resistance. The resistance should equal the sum of the resistances of preceding subparagraphs (6) and (8).



Insulation Resistance Measurements   Date:______________

1. Antenna feed line to ground: Left Wire ____________ megohms.

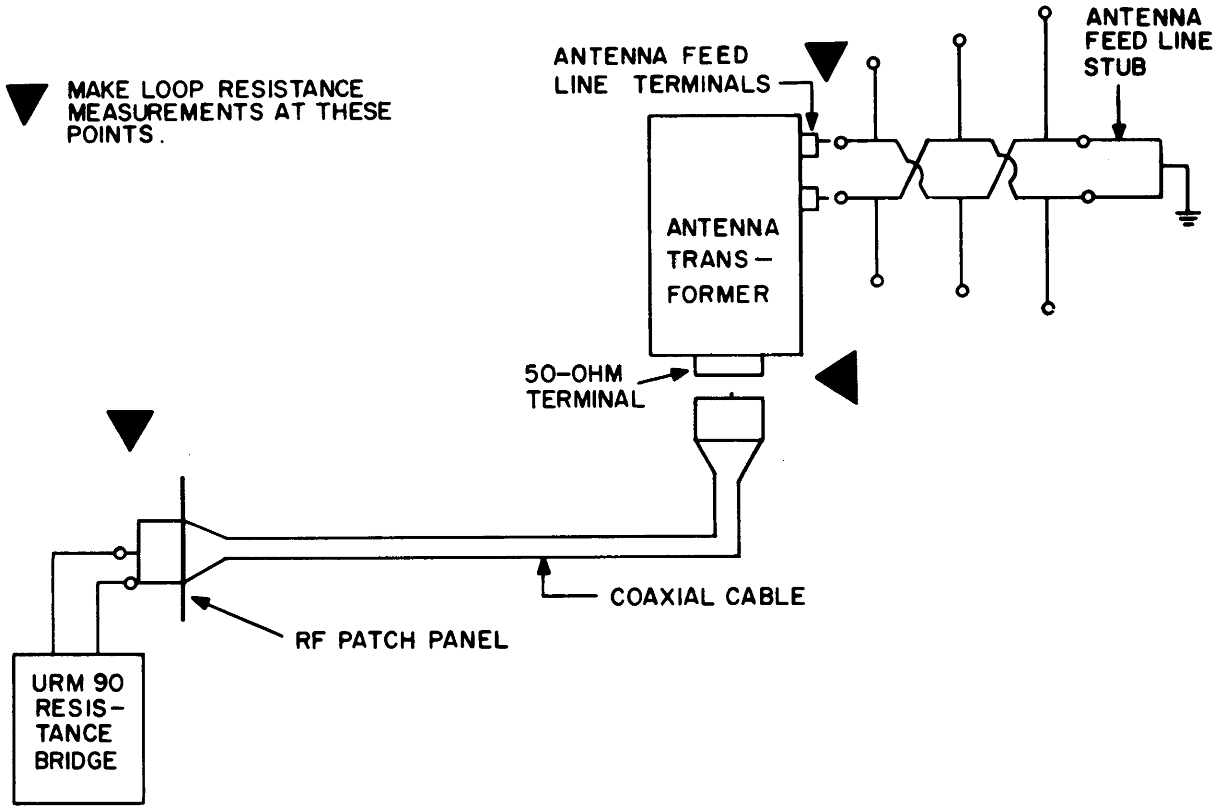
   Right Wire ____________ megohms.

2. Coaxial Cable Insulation Resistance __________ megohms.
3. Equipment used: ____________________________
4. Remarks: ____________________________

   ____

5. Measurements made by: ____________________________

Figure 8-1. Insulation Resistance Measurements



Loop Resistance Measurements Date:______________

1. Antenna transformer loop resistance (50 ohm terminal)____ohms.
2. Antenna transformer loop resistance (secondary terminals) ______ ohms.
3. Antenna feed line loop resistance ____________ohms.
4. Coaxial cable loop resistance (measure from patch panel with antenna end short circuited) _________ohms.
5. Antenna system loop resistance from coaxial connector at RF patch panel with antenna and transformer connected ____________ ohms.
6. Equipment used: _______________ Serial: ________________
7. Coaxial Cable Type ____________ Length: ____________ feet
8. Remarks: ____

Measurements by: __________________________________

Figure 8-2. Loop Resistance Measurements

(11) Record all measurements in appropriate spaces provided on figure 8-1 and figure 8-2.

b. Ground Resistance. The effectiveness of ground connections for antenna systems is determined by measuring ground resistance.

(1) Measure ground resistance with a Null-Balance Earth Megger, Evershed and Vignoles, Ltd., Model No. 1643342 or equivalent. Arrange the test equipment as shown in figure 8-3. The two 18-inch test rods are placed in the earth to establish auxiliary grounds. Distances D1 and D2 are determined by the dimensions of the ground system being tested. An alternating voltage is applied between the auxiliary grounds and the ground being tested. The voltage drop across these points, and the current between

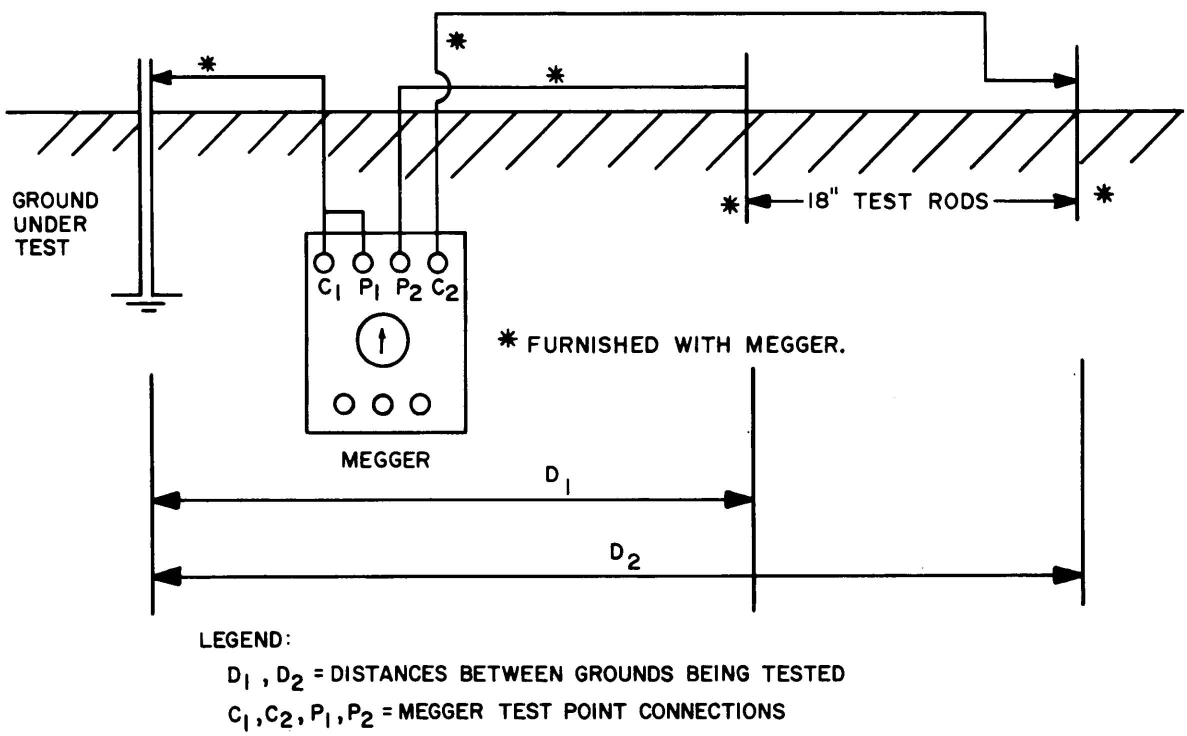


Figure 8-3. Test Arrangement for Ground Resistance

them is measured. The unknown resistance value is then determined by dividing the voltage drop by the current. Refer to the Earth Megger Pamphlet "How to Use Earth Megger Testers" for further details. Record the measurement on the form shown in figure 8-4.

c. Antenna Impedance. To determine the VSWR of an antenna, the input impedance of the antenna must be known. To measure this impedance in HF antennas, the following equipments, or acceptable substitutes, are required:

Date ________________

1. Ground Measurement Point: ____

2. D_1 ______________ feet

   D_2 ______________ feet

3. Measured resistance ________________ ohms

4. Sketch of equipment & ground stake set-up.

5. Equipment used.

6. Remarks

7. Measurements by: ________________________________

Figure 8-4. Ground Resistance Measurements

(1) RF Bridge, General Radio Type 1606A,

(2) RF Signal Generator, AN/URM-25, and

(3) RF Detector, Radio Receiver R-390A/URR.

Normally, an RF Bridge is used to measure impedances of unbalanced type antennas, whereas an admittance bridge usually is more suitable than the RF bridge for measuring the input impedance of balanced type antennas.

To determine the true impedance at the feed point of an antenna, when the measurements are made at the antenna patch panel, it is necessary to make additional measurements from the patch panel with the coaxial cable short-circuited at the antenna as shown in figure 8-5. Measurements of the shorted transmission line are necessary to determine the effect that the transmission line has on the antenna impedance measurements. Since these measurements must be made at the same frequencies at which the antenna impedance measurements are made, an accurate means of frequency calibration must be available. The built-in frequency calibrator of the R-390A/URR provides a suitable means for accomplishing this.

A test arrangement suitable for most RF impedance measurements is shown in figure 8-5. Detailed instructions on RF bridge test procedures and methods of connection for various purposes are given in the equipment instruction manual.

Measure the impedance at 1 MHz intervals across the frequency bandwidth of the antenna and at known operating frequencies. Record these impedance values for VSWR calculations.

d. VSWR. The VSWR of an antenna may be computed if the impedance is known, or may be obtained readily by plotting the measured load impedance on a Smith chart. To calculate the VSWR determine the absolute value of the reflection coefficient K as follows:

$$K = \frac{Z_k - Z_o}{Z_k + Z_o} \qquad (8\text{-}1)$$

With K determined, the VSWR can be found from the relationship:

$$VSWR = \frac{1 + K}{1 - K} \qquad (8\text{-}2)$$

where Z_k = measured impedance of load

Z_o = characteristic impedance of transmission line.

The VSWR may be determined by use of a Smith chart as shown in the following example.

Assume that the measured impedance Z_k of an antenna is 48+j38 ohms and the characteristic impedance of the associated transmission line is 50 ohms. Determine the VSWR as follows:

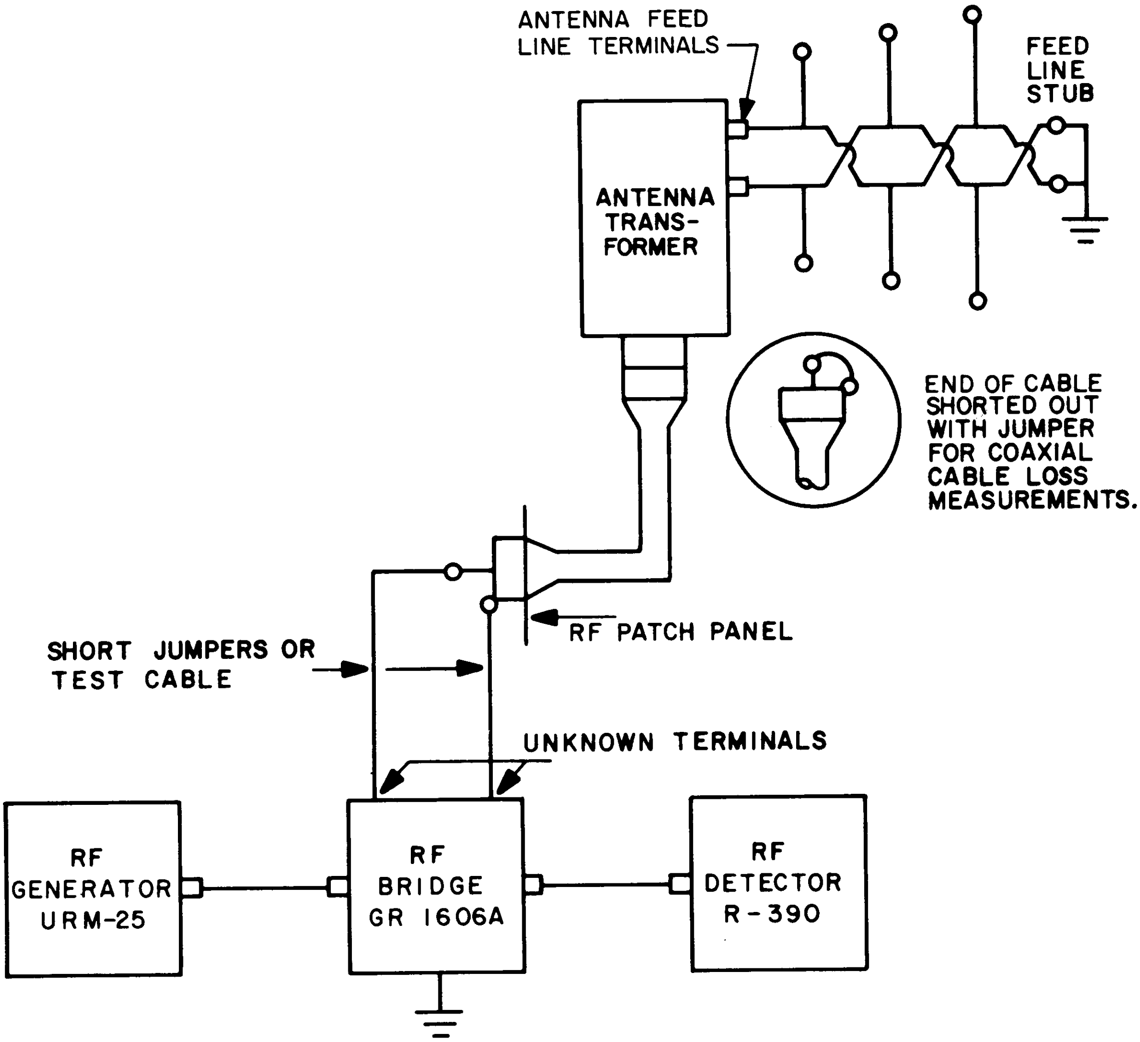


Figure 8-5. Test Arrangement for RF Impedance Measurements

(1) Normalize the measured antenna impedance to the Z_o of the transmission line.

$$Z_n = \frac{48+j38}{50} = 0.96+j0.76 \qquad (8\text{-}3)$$

(2) Plot $Z_n = 0.96 + j0.76$ on a Smith chart as shown in figure 8-6.

(3) Draw an arc of a circle with its center located at the center of the chart and passing through the plotted Z_n and the resistance axis. The intersection of the arc and the pure resistance axis indicates the value of the VSWR, 2.1:1.

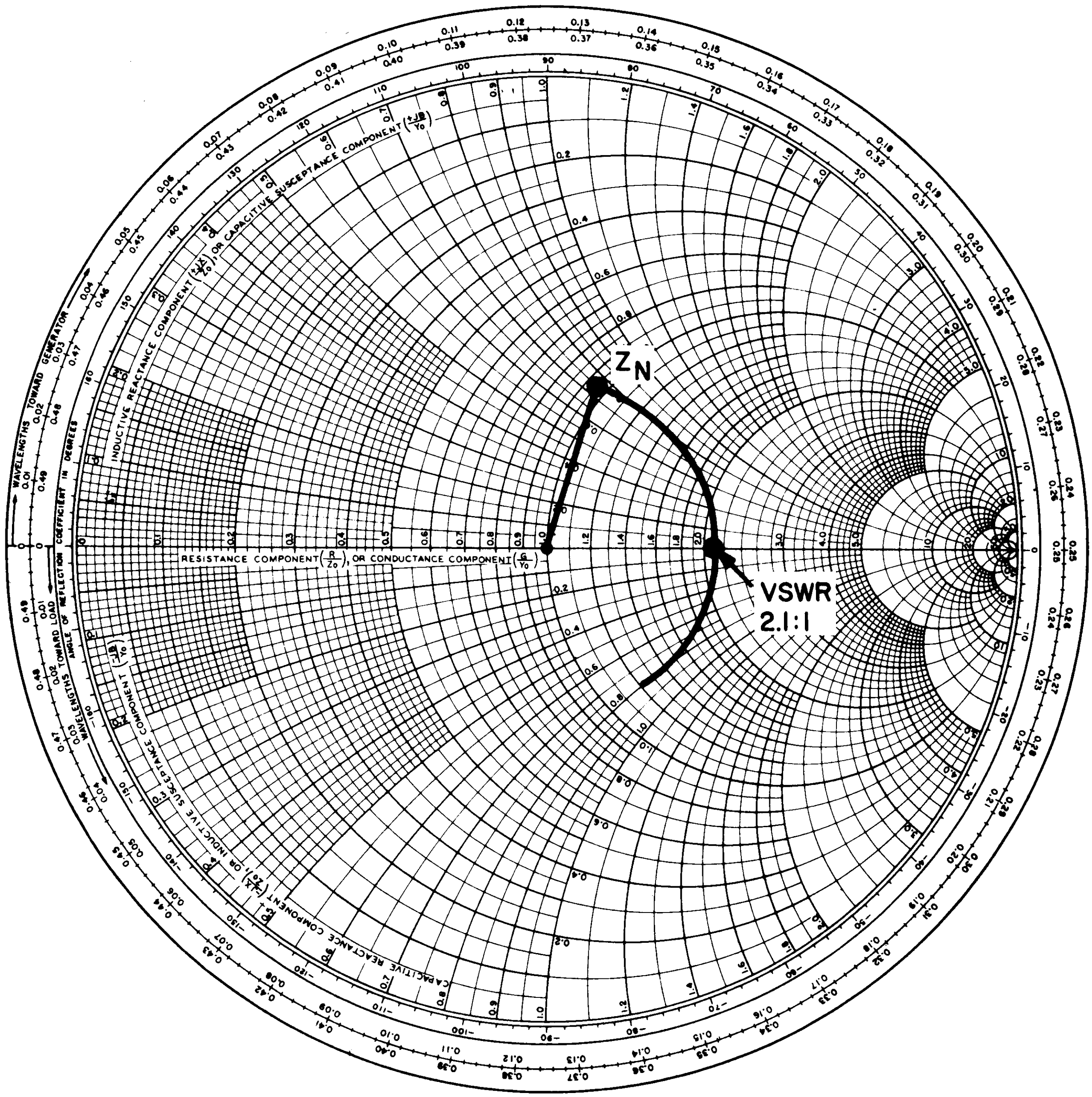


Figure 8-6. Smith Chart VSWR Calculation

Normally, the Smith chart is used to determine VSWR due to its simplicity. This method of determining antenna system characteristics is discussed in greater detail in Addendum No. 1 to DCAC 330-175-1.

e. <u>Radiation Pattern Measurements.</u> Radiation pattern measurements normally are not required for every antenna installation. Usually, the antenna radiation patterns provided for the particular antenna by the manufacturer are sufficient to satisfy Navy requirements. Therefore, NAVELEX determines the necessity for pattern measurements on an individual project basis.

8.3 SYSTEM TESTS AND PREVENTIVE MAINTENANCE

After an HF antenna system has been placed in service, periodic tests and inspections should be conducted to determine the operating efficiency of all components in the system. The data recorded during the post-installation physical and electrical checks provide the base line for comparison with conditions as they presently exist. The data gathered at the time of installation, used in conjunction with manufacturer's specifications, form the basis for preventive maintenance and are a valuable source of information during periods of corrective maintenance.

The individual communications activity establishes a program of system tests, and usually incorporates these tests into the preventive maintenance program.

8.4 RF RADIATION AND SHOCK HAZARDS TO PERSONNEL

RF radiation and electrical shock from HF transmitting antennas are potential hazards to personnel. The basic standards for protection of personnel against radiation hazards are contained in NAVORD 3565/NAVAIR 16-1-529. This publication also contains HERO and fuel hazard information. The application of these standards in relation to HF antennas is discussed in the following portions of this section.

8.4.1 Radiation Hazards to Personnel

Presently known detrimental effects of overexposure to RF radiation are associated with the average power of the absorbed radiation, are thermal in nature, and are observed as an increase in overall body temperature, or as a temperature rise in certain sensitive organs of the body. It has been determined that normally for any significant effect to occur, a person's height would have to correspond to at least one-tenth of a wavelength of the radiation frequency.

The Bureau of Medicine and Surgery has established safe limits based on the power density of the radiation beam and the exposure time of the human body in the radiation field as follows:

a. Continuous Exposure. Average power density is not to exceed 10 milliwatts per square centimeter.

b. Intermittent Exposure. Incident energy level is not to exceed 300 millijoules per square centimeter per 30 second interval.

c. Hazardous Areas. All areas in which the RF levels exceed prescribed safe limits are considered hazardous, and they must be identified with appropriate "RF Hazard" warning signs in accordance with NAVSO P-2455. The area in the vicinity of HF transmitting antennas is hazardous and should be restricted to prevent inadvertent entry. In all cases, entry of personnel into hazardous areas must be controlled to prevent exposure of personnel to either continuous or intermittent power levels in excess of the prescribed safe limits.

8.4.2 Electrical Shock Hazards

In addition to potential radiation hazards from HF transmitting antennas, some antennas are potential shock hazards for personnel because the antenna feed point or some of the radiating elements are located at, or near, ground level. Where ever any such installation exists, the hazardous area should be enclosed within a protective fence that will isolate the area from people unaware of the danger.

8.4.3 Protective Fences

Only non-conducting materials are suitable for constructing protective fences for antennas. Redwood or cypress is preferred. Usually, a wood fence that is from 4 to 6 feet high will provide the required degree of protection. Any gates in the fence must be designed and installed so that accidental entry into the hazardous area is not possible. Appropriate "High Voltage" warning signs must be permanently and conspicuously posted in hazardous areas in accordance with NAVSO P-2455.

APPENDIX A

MATCHING AND TUNING DOUBLETS

A.1 GENERAL CONSIDERATIONS

When a resonant two-wire doublet, or half-wave antenna, is connected to a 600-ohm transmission line, standing waves will exist along the transmission line between the antenna and the transmitter. These standing waves are objectionable because (1) they cause radiation losses, (2) they make transmitters unstable or difficult to tune, and (3) they cause intermodualtion problems due to radiation from the line.

The simplest way to reduce these standing waves to a minimum is to connect a short-circuited transmission line stub to the main transmission line at an appropriate point near the antenna. Techniques for determining the length of such a stub and its proper location on the transmission line are discussed here for certain doublet antenna configurations. Since both the location and length of any stub are frequency dependent, the work involves conversions between linear dimensions in feet and the same dimensions expressed in terms of wavelength or electrical degrees. The conversion relationships used in the following discussions are:

$$\text{Wavelength (in feet)} = \frac{984}{\text{Frequency (in MHz)}} \quad \text{(A-1)}$$

$$\text{Feet per degree} = \frac{2.73}{\text{Frequency (in MHz)}} \quad \text{(A-2)}$$

Although an RF milliammeter may be inductively coupled to the transmission line to determine the standing wave ratio, the use of such an instrument may lead to false readings in antenna fields where other nearby antennas induce strong currents into the line. Since most Navy shore installations have an AN/PRM-25 or equivalent receiver available, a shielded loop may be used with such an instrument for this type of measurement. Since the AN/PRM-25 is frequency discriminative, and the loop itself is shielded against extraneous pickup, relatively accurate readings may be obtained in fields of strong off-frequency RF. Details of a shielded probe and pad to adapt the AN/PRM-25 for this service are shown in figure A-1.

A.2 SINGLE-STUB METHOD FOR MATCHING A FOLDED DOUBLET ANTENNA

a. The shielded loop is moved along the transmission line near the antenna to detect the locations of current minima and to measure the standing wave ratio. To ascertain that correct null locations are found, several consecutive null points along the transmission line should be located and the distances between null points should be measured to verify that the nulls are equally spaced along the line.

b. The standing wave ratio (SWR), calculated from measurements of current maxima and minima, is used as the entry into the graph of figure A-2 to determine the length of the stub and its proper distance from the current null nearest the antenna. Formula (A-1) is used to convert the length and distance from fractions of a wavelength to feet.

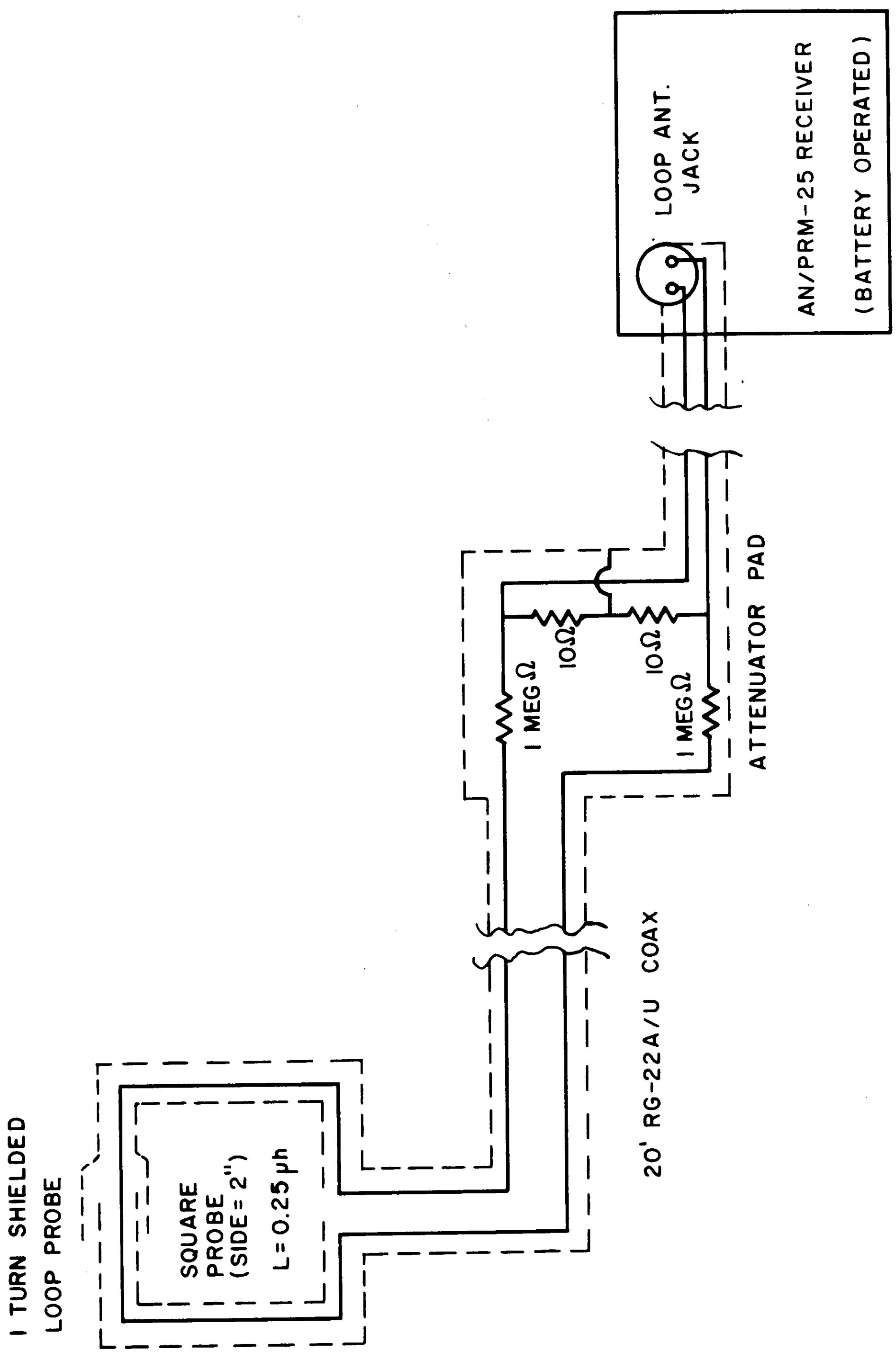


Figure A-1. Details of Shielded Probe and Pad

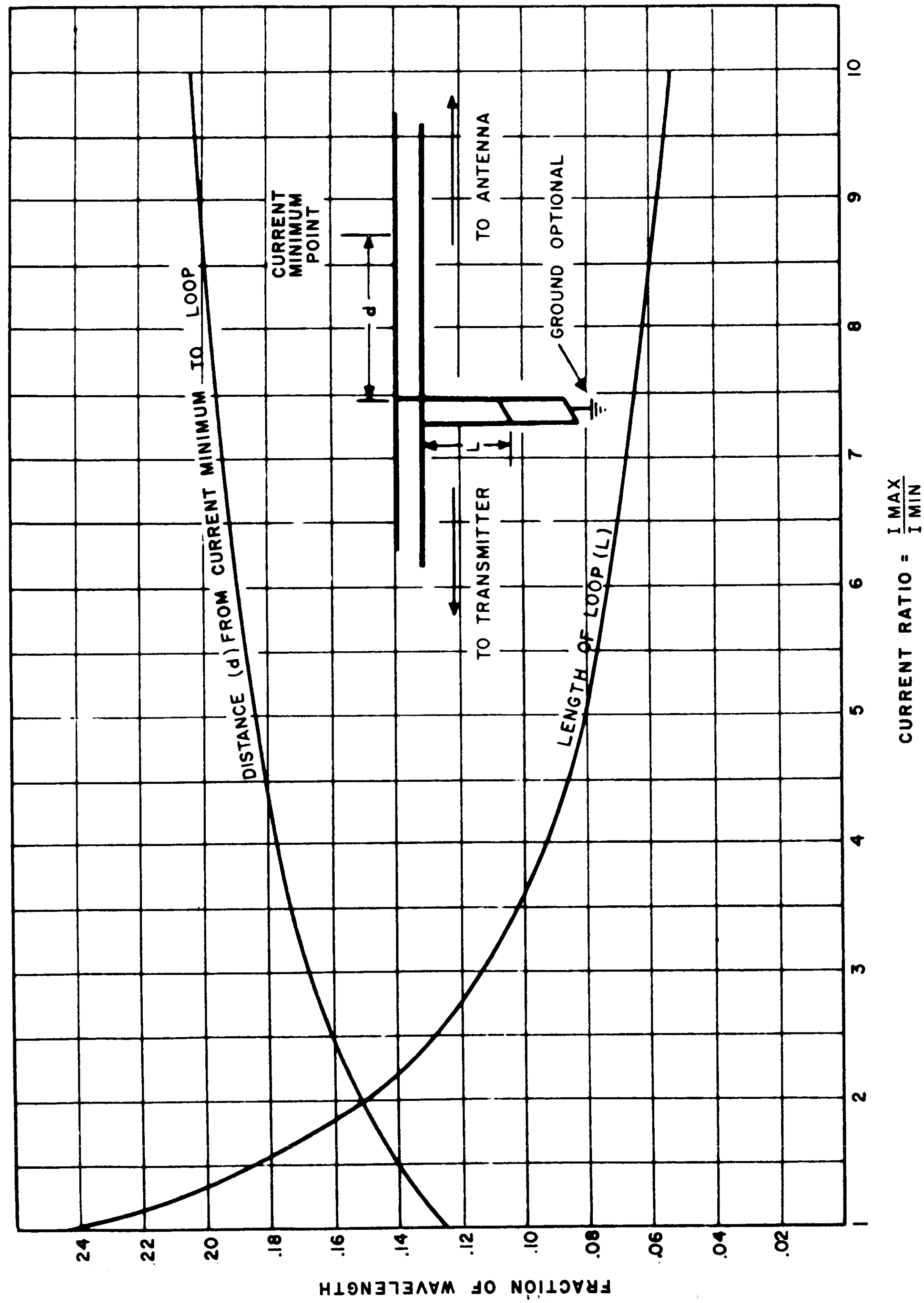


Figure A-2. Doublet Stubbing Chart

c. For adjustment purposes the stub should be cut somewhat longer than the length indicated by the graph. The stub is attached to the transmission line at the point indicated by the graph, and the positions of the stub and shorting wire on the stub are marked to establish reference points for later adjustments.

d. Next, the transmitter tuning is readjusted to compensate for attaching the stub to the line, and the resultant standing wave ratio is obtained and recorded.

e. To further reduce the standing wave ratio, adjustments are made in the positions of the stub and the shorting wire. An organized record of the positions of the stub and shorting wire, together with the SWR for each adjustment, should be kept as the stub and shorting wire are moved in small increments away from their starting positions. For example:

Stub Pos.	Short Pos.	I Max	I Min	I Ratio
Start	Start	120	80	1.50
3" to Antenna	3" down	100	80	1.25
3 " from Antenna	3" up	100	90	1.11

Measurement of the standing wave ratio after each adjustment will indicate whether the change was in the right direction. Adjustments should be continued by this trial-and-error process until the standing wave ratio is minimum.

f. The time involved in this trial-and-error process can be reduced somewhat by making adjustments in the following sequence:

(1) Adjust the shorting wire on the stub to get equal line currents at one-eighth and three-eighths wavelength positions away from the stub toward the transmitter. This resonates the antenna and the stub. Record the stub adjustment and the corresponding standing wave ratio.

(2) Take a series of readings with the shorting wire moved up and the stub connection moved away from the antenna by exactly the same amount (a few inches). Record the distances and current readings. If the SWR increases consistently as a result of these adjustments, return to the adjustment in step (1) above. Then make a series of adjustments in the opposite directions, that is, by moving the shorting wire down and the stub connection toward the antenna by exactly the same amounts. Record the data as before.

(3) By roughly graphing the data in the field, the best positions for the stub and shorting wire will be indicated.

An alternate method of establishing the initial positions of the stub and shorting wire is to use data compiled from a number of actual installations. Analysis of the results of stubbing 19 vertical doublet antennas shows that, on the average, a good starting point is to connect a stub 26.5 degrees long at a point 210 degrees from the antenna terminals as illustrated in figure A-3. (Formula A-2 gives the relationship between degrees and linear dimensions.) With these values as a guide, it is possible to specify the stub length and location on the installation plans, and, thereby minimize the time and effort spent on final tuning of the antenna. This method of determining the approximate stub length and location is particularly advantageous during the construction and installation of antennas since it may be awkward, or impossible, to set up a test transmitter to excite the antenna during the construction period.

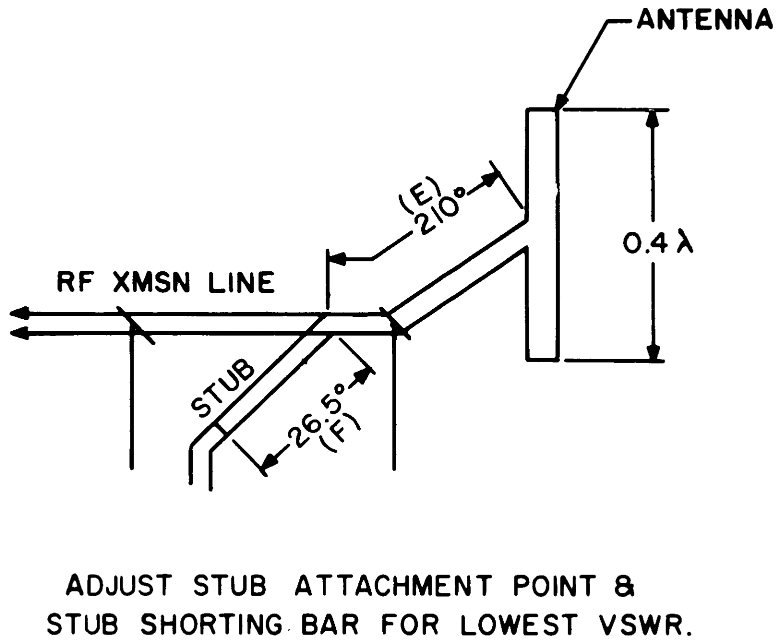
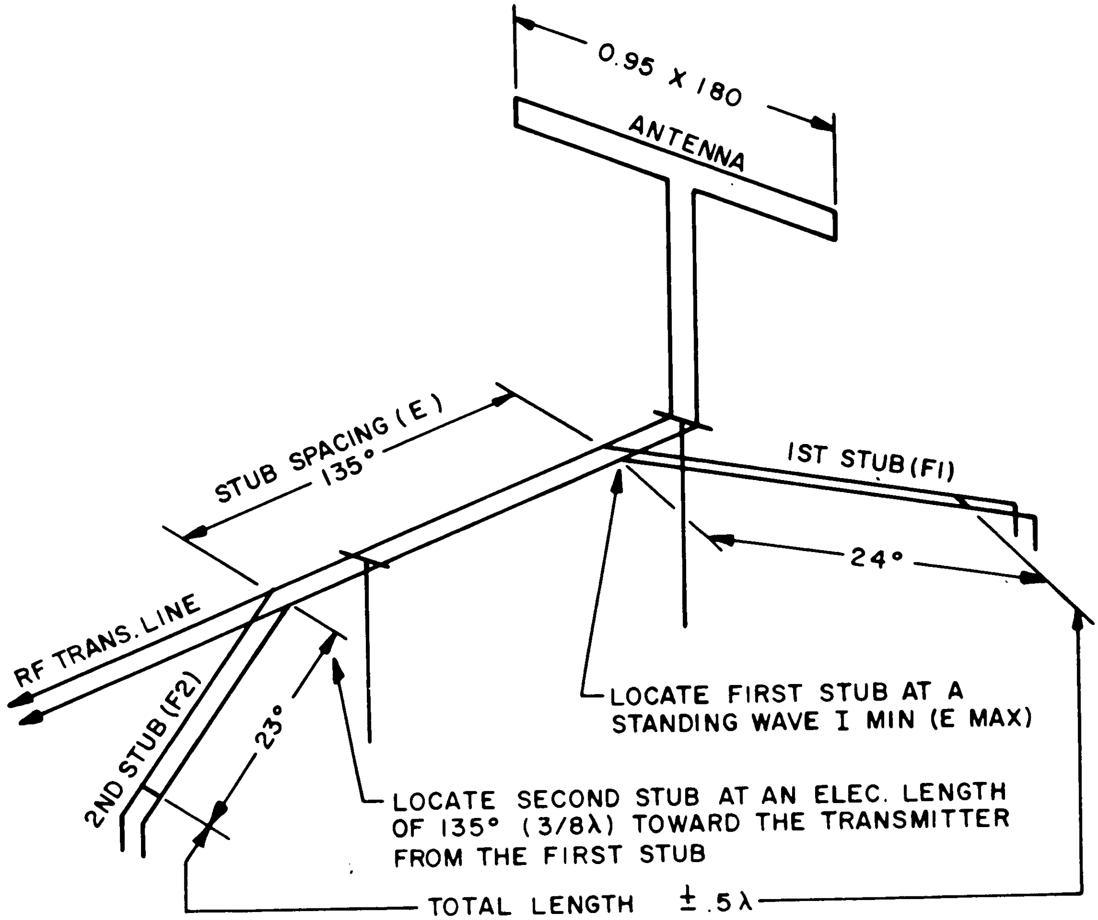


Figure A-3. Approximate Method of Determining Stub Length and Location

A.3 DOUBLE-STUB METHOD FOR MATCHING A FOLDED DOUBLET ANTENNA

Although the single-stub method for matching a folded doublet antenna to its transmission line is simple and effective, the length required for the matching stub becomes greater as the design frequency for the antenna is lowered. For doublet antennas in the 2- to 5-MHz frequency range it is convenient to use two matching stubs, as illustrated in figure A-4, to reduce the effective length of the stubs required. Double stubs are also more convenient to adjust, since matching is accomplished by moving the location of the stub shorting bars without changing the point of stub attachment at the transmission line.

a. The double-stub impedance match may be considered to be a half-wave transformer extending from closed stub to closed stub. On a balanced system a current loop will exist in the shorting bar of each stub. The length of stub nearest the antenna may be adjusted to tune out antenna reactance while the other stub is adjusted to provide the transmission line "match." The two stubs cannot, however, be adjusted independently; when one stub is lengthened the other must be shortened to maintain an approximate half-wavelength of transmission line between the two shorting bars.



ADJUST THE STUB SHORTING BARS FOR LOWEST VSWR (STUB LENGTHS SPECIFIED ARE MEDIAN VALUES)

$$\text{LENGTH IN FEET} = \frac{2.73\,D}{\text{FREQUENCY IN MHz}}$$

WHERE D = THE ELECTRICAL LENGTH IN DEGREES

DOUBLE STUB METHOD FOR 2 TO 5.5 MHz

HORIZONTAL AND TILTED FOLDED DOUBLETS

Figure A-4. Double Stub Method

b. Spacing between the two stubs, (F1 and F2 in figure A-4), determines the range of impedance that can be matched by the double-stub transformer. At a spacing (E) of 90 degrees (one-quarter wavelength), a 600-ohm transmission line can be matched to any antenna load in the range of 600 ohms to infinity. With a spacing of 135 degrees (three-eighths wavelength), a 600-ohm transmission line can be matched to any antenna load in the range of 300 ohms to infinity. Half-wave (180 degree) spacing is not useful, since all transformer action is lost. Therefore, double-stub spacing of 135 electrical degrees (three-eighths wavelength) is most useful in matching two-wire folded doublets to a 600-ohm transmission line.

c. The location of the first stub, F1, in relation to the standing wave pattern of the unstubbed transmission line, determines the amount of reactance which must be tuned out by the double-stub transformer. The best range of adjustment is obtained by attaching stub F1 at a standing current minimum (voltage peak). Calculation of the stub length is greatly simplified for this stub location, because antenna reactance is zero at a current minimum.

d. The active lengths for double-stubs spaced three-eighths wavelength apart and located in accordance with subparagraph c, above, may be calculated from the following formulas:

$$\text{Cot F1} = 1 \pm \sqrt{\frac{2R-1}{R}} \tag{A-3}$$

$$\text{Cot F2} = 1 \pm \sqrt{2R1} \tag{A-4}$$

where F1 and F2 are the electrical lengths in degrees for stubs F1 and F2, and where R is the measured standing wave ratio of the unstubbed transmission line connected to its antenna. For example, if the measured VSWR is 2.0, the calculated stub lengths are 24 and 20 degrees.

e. The active lengths for double-stubs spaced one-quarter wavelength apart and located in accordance with subparagraph c, may be calculated from the following formulas:

$$\text{Cot F1} = \sqrt{\frac{R-1}{R}} \tag{A-5}$$

$$\text{Cot F2} = \sqrt{R-1} \tag{A-6}$$

A.4 TUNING PROCEDURE FOR HIGH FREQUENCY TWO-ELEMENT VERTICAL DIRECTIONAL ANTENNA ARRAY

The vertical directional array, also known as a driven, or phased array, consists of two half-wave vertical doublets spaced at 90 degrees (as shown in figure A-5). The feeders to each doublet branch off the main transmission line at points 90 degrees (one-quarter wavelength) apart. Therefore, the current in the front doublet leads that of the rear doublet by 90 degrees. As the two doublets radiate, these currents add, giving the array a 3 dB gain over a single doublet in a cardioid pattern.

To bring about this 90-degree phase shift between the two doublets, a quarter-wave point on the transmission line must be found and the rear doublet feeders must be connected at this point. This is done as follows:

NOTE

The branch feeders to the individual doublets must be electrically equal in length. Mechanical requirements might require that one feeder be physically longer than the other. The additional length, disregarding velocity factors, should be a multiple of a half-wavelength.

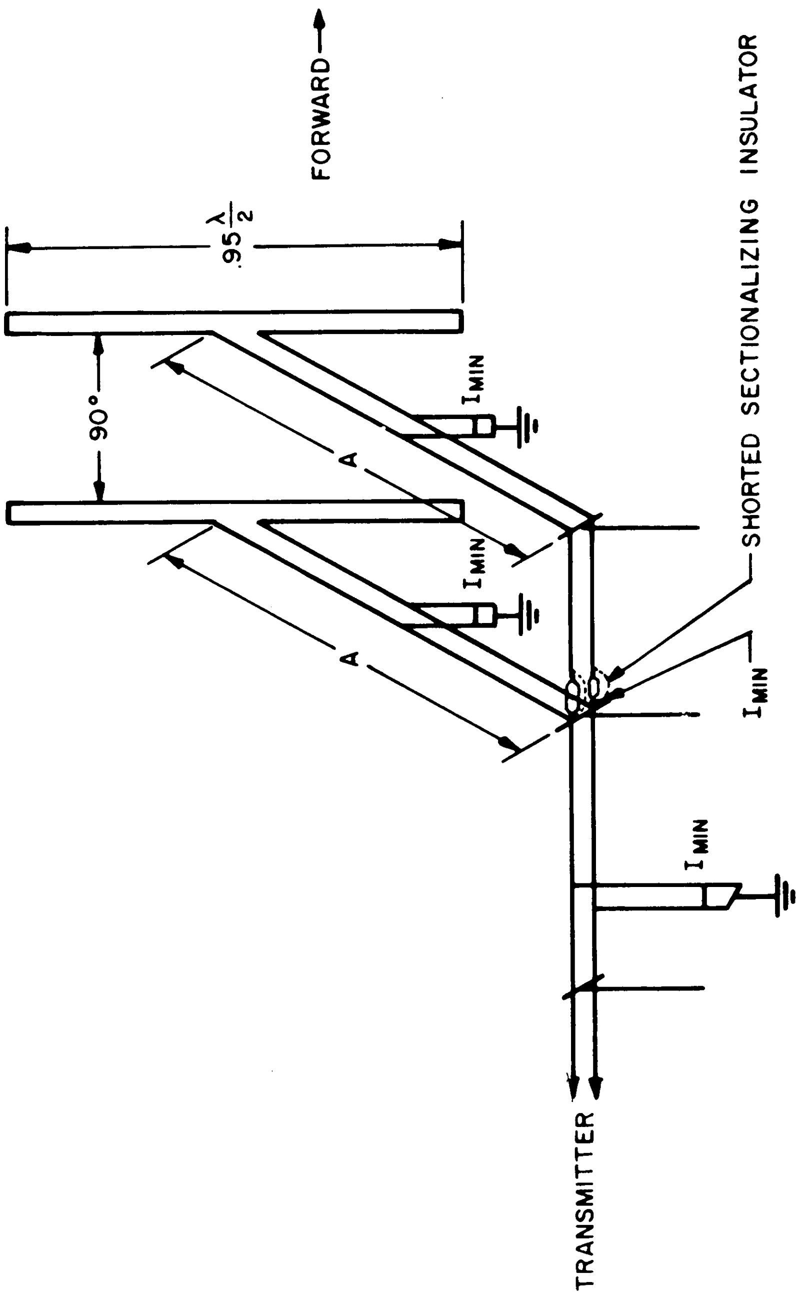


Figure A-5. Driven or Phased Array

a. Disconnect both branch feeders from the main transmission line and short the end of the main transmission line.

b. Feed the main transmission line with low power (50 to 100 watts) at the desired frequency.

c. Locate the current null nearest the antenna end of the transmission line with an RF milliammeter or a field intensity meter inductively coupled to the line, as previously described in paragraph A.2.

d. Install a twelve-inch bar insulator (NT 61374 or equivalent) in series with each wire of the main transmission line so that the shackle nearest the transmitter end of the line will lie at the minimum current point determined in subparagraph c above. Remove the short at the end of the main transmission line.

e. Short-circuit and ground the front doublet and its transmission line at two or three points to minimize intercoupling with the rear doublet. The feeders to the rear (away from the desired direction of transmission) doublet can now be temporarily installed on the transmission line at the current minimum point determined in subparagraphs c and d above.

f. Stub the rear doublet feeder and adjust for the minimum VSWR, using the stubbing methods outlined in paragraph A.2

g. Disconnect the rear doublet feeders from the main transmission line and short out the rear doublet as described in subparagraph e.

h. Permanently strap out the insulators previously installed in the transmission line by paralleling them with No. 6 wire, wrapped and secured at each end, in accordance with standard installation practices.

i. Remove short circuits and grounds from the front doublet (in the direction of desired transmission) and permanently connect the feeders to the end of the transmission line.

j. Match the front doublet to the transmission line with the stub as was done with the rear doublet in subparagraph f above.

k. Remove shorts and grounds from the rear doublet and make permanent connections to the transmission line as described for the temporary installation in subparagraph e above.

l. Measure from the stub shorting bar of one of the antennas up the stub and up the feeder a few feet toward the antenna, and mark this point. Take identical measurements on the other doublet feed line. These are physical measurements.

m. Apply power to the array and use two RF milliammeters, or two AN/PRM-25 field intensity meters, to measure the current (using the techniques described in paragraph A.2) as follows:

(1) Place one meter at each marked point on the two branch feeders, and note the readings. The front doublet current should initially read somewhat lower than that of the rear doublet. Therefore, it is necessary to equalize these currents.

(2) Equalize the two currents by readjusting the stubs to each antenna. In every case the matching stub's point of connection to the feed line, and the position of its shorting bar, are changed by measured distances to keep the distance from the stub shorting bar to the doublet the same. Otherwise the system will be detuned and further adjustments will be complicated. Currents should be equalized by decreasing the load resistancies; i.e., raise both shorting bars, and move both stubs toward the main transmission line in small increments. In all cases, RF milliammeters should not be moved on lines because any movement will cause erroneous indications.

n. After completing the previous steps, standing wave ratios up to 4:1 may be expected on the main transmission line. To remove or minimize these standing waves, consider the sectionalizing insulator point, described in subparagraph d above, as the load. Follow normal stubbing procedures and place the stub on the main transmission line at the nearest current minimum point towards the transmitter and adjust for minimum SWR.

A.5 ADJUSTMENT OF A FOLDED DOUBLET WITH TUNED PARASITIC ELEMENT

Two-element directional parasitic arrays consist of a folded doublet driven element and a parasitic element, also a folded doublet. The latter is called either a reflector or director depending on the electrical length of the element. With spacings between the two doublets of approximately 90 degrees (one-quarter wavelength), the parasitic element is preferably tuned as a reflector and the following tuning procedure applies. See figure A-6.

a. Set the shorting bar on the parasitic element tuning line to approximately 225 degrees (five-eighths wavelength) from the parasitic doublet.

b. Follow the stubbing procedure given in paragraph A.2, to match the driven element to the transmission line with a minimum SWR. Since readjustment will be necessary later, this may be set roughly. A SWR of approximately 2:1 is satisfactory at this point.

c. If two AN/PRM-25 or similar field intensity meters are available, set up one 500 feet or more in line with and in the forward direction of the array and set up the second a similar distance in the opposite direction. These positions should be well clear of other antennas and transmission lines in the field, and the other antennas in the field should not be radiating. The loop antenna should be used with the AN/PRM-25 to insure that direct bearing readings are obtained. If only one field intensity meter is available, the two positions should be marked with stakes, and readings should be taken at both positions for each change in array adjustment.

d. Adjust the shorting bar on the parasitic element tuning line for a minimum reading in the back (parasitic element) direction and a maximum reading in the forward (driven element) direction. The final ratio of readings should be in the order of 3:1 or better.

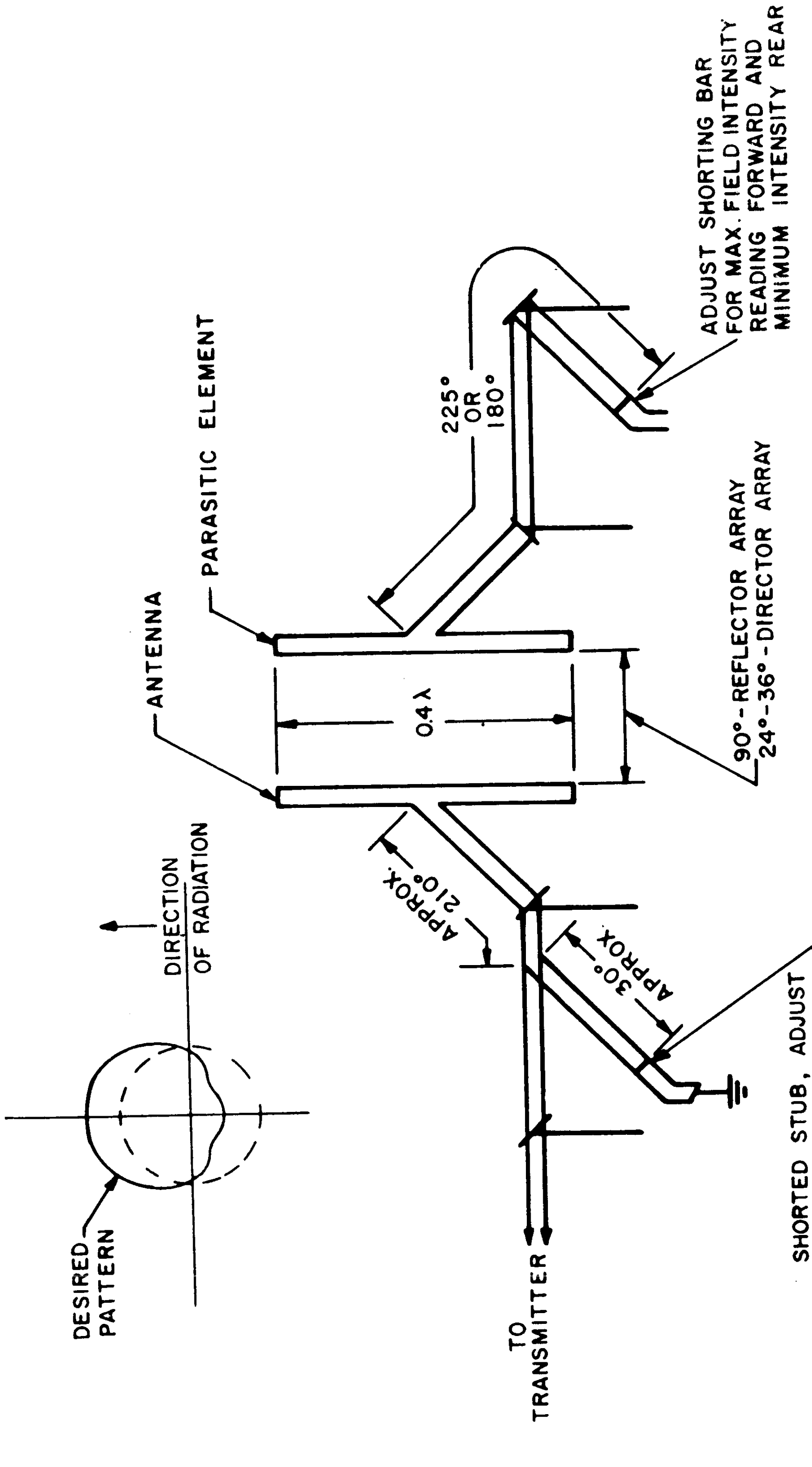


Figure A-6. Stubbing Adjustment of Parasitic Arrays

e. Readjust the stub on the driven element transmission line for a minimum SWR and recheck the field strength. Some readjustment of the shorting bar on the parasistic tuning line may be required to attain an optimum pattern.

f. Field strength should be checked next in a radius around the array to roughly determine the horizontal pattern. Some readjustment may be required if the radiation lobe does not meet required sector coverage. Uniform gain in a sector approximating 180 degrees with attenuated radiation to the rear is usually the most serviceable pattern. The pattern shown in figure A-6 is typical of that normally desired. However, this ideal pattern may be very difficult to achieve because of electrical obstructions in the field, stray couplings, and compromises in measurement techniques. Therefore, arrays should be tuned to best meet local requirements.

g. It may be necessary from a clearance or physical location requirement to reduce the spacing between the driven element and the parasitic element. In such cases, spacings of from .1 wavelength to .15 wavelength are recommended and the parasitic element may be tuned as a director, i.e., electrically short with respect to the driven element.

h. In using the parasitic element as a director, the distance to the initial position of the shorting bar on the tuning line should be set at approximately 180 degrees (one-half wavelength) and tuning should then proceed as outlined above, except that field intensity readings should indicate maximum current in the direction of the parasitic element and minimum current in the direction of the driven element.

APPENDIX B

DEFINITIONS

The following definitions have been taken from "Transactions on Antennas and Propagation," published by the Institute of Electrical and Electronics Engineers (IEEE), May 1969.

Adaptive Antenna System.

An antenna system having circuit elements associated with its radiating elements such that some of the antenna properties are controlled by the received signal.

Adcock Antenna.

A pair of vertical antennas separated by a distance of one-half wavelength or less and connected in phase opposition to produce a radiation pattern having the shape of the figure eight.

Antenna (Aerial).

A means for radiating or receiving radio waves.

Antenna Effect.

In a loop antenna, any spurious radiation effect resulting from the capacitance of the loop to ground.

Antenna Efficiency, of an Aperture-Type Antenna.

For an antenna with a specified planar aperture, the ratio of the maximum effective area of the antenna to the aperture area.

Antenna Pattern.

See Radiation Pattern.

Antenna Resistance.

The real part of the input impedance of an antenna.

Aperture, of an Antenna.

A surface, near or on an antenna, on which it is convenient to make assumptions regarding the field values for the purpose of computing fields at external points.

Note: In the case of a unidirectional antenna, the aperture is often taken as that portion of a plane surface near the antenna, perpendicular to the direction radiation, through which the major part of the radiation passes.

Aperture Illumination (Excitation).

The amplitude, phase, and polarization of the field distribution over the aperture.

Aperture Illumination Efficiency.

For a planar antenna aperture, the ratio of its directivity to the directivity obtained when the aperture illumination is uniform.

Area.

See Effective Area, of an Antenna; Equivalent Flat-Plate Area, of a Scattering Object; Back-Scattering Cross Section (Target Echoing Area).

Array Antenna.

An antenna comprising a number of radiating elements, generally similar, which are arranged and excited to obtain directional radiation patterns.

Array Element.

In an array antenna, a single radiating element or a convenient grouping of radiating elements that have a fixed relative excitation.

Average Noise Temperature, of an Antenna.

The noise temperature of an antenna averaged over a specified frequency band.

Back-Scattering Cross Section (Monostatic Cross Section, Target Echoing Area).

The scattering cross section in the direction toward the source. (cf. Radar Cross Section.)

Bandwidth, of an Antenna.

The range of frequencies within which its performance, in respect to some characteristic, conforms to a specified standard.

Beam, of an Antenna.

The major lobe of the radiation pattern of an antenna.

Beam Steering.

Changing the direction of the major lobe of a radiation pattern.

Beamwidth.

See Half-Power Beamwidth.

Beverage Antenna (Wave Antenna).

A directional antenna composed of a system of parallel horizontal conductors from one-half to several wavelengths long, terminated to ground at the far end in its characteristic impedance.

Boresight.

See Electrical Boresight, Reference Boresight.

Boresight Error.

The angular deviation of the electrical boresight of an antenna from its reference boresight.

Broadside Array.

A linear or planar array antenna whose direction of maximum radiation is perpendicular to the line or plane of the array.

Cheese Antenna.

A reflector antenna having a cylindrical reflector enclosed by two parallel conducting plates perpendicular to the cylinder, spaced more than one wavelength apart. (cf. Pillbox Antenna.)

Collinear Array.

A linear array of radiating elements, usually dipoles, with their axes lying in a straight line.

Conical Scanning.

A form of sequential lobing in which the direction of maximum radiation generates a cone whose vertex angle is of the order of the antenna half-power beamwidth. Such scanning may be either rotating or nutating according to whether the direction of polarization rotates or remains unchanged, respectively.

Corner Reflector.

A reflecting object consisting of two or three mutually intersecting conducting flat surfaces.

Note: Dihedral forms of corner reflectors are frequency used in antennas; trihedral forms with mutually perpendicular surfaces are more often used as radar targets.

Corner Reflector Antenna.

An antenna consisting of a feed and a corner reflector.

Counterpoise.

A system of conductors, elevated above and insulated from the ground, forming a lower system of conductors of an antenna.

Cross Polarization.

The polarization orthogonal to a reference polarization.

Note: If the reference polarization is right-handed circular, the cross polarization is left-handed, and vice versa.

Cross Section.

See Back-Scattering Cross Section, Radar Cross Section, Scattering Cross Section.

Cylindrical Reflector.

A reflector which is a portion of a cylinder. This cylinder is usually parabolic, although other shapes may be used.

Dielectric Rod Antenna.

An antenna that employs a shaped dielectric rod as the significant part of a radiating element.

Dipole.

See Dipole Antenna, Electric Dipole, Folded Dipole Antenna, Magnetic Dipole.

Dipole Antenna (Doublet Antenna).

Any one of a class of antennas producing a radiation pattern approximating that of an elementary electric dipole.

Note: Common usage considers the dipole antenna to be a metal radiating structure which supports a line current distribution similar to that of a thin straight wire so energized that the current has a node only at each end.

Directional Antenna.

An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others.

Directive Gain, of an Antenna.

In a given direction, 4π times the ratio of the radiation intensity in that direction to the total power radiated by the antenna.

Note: The directive gain is fully realized on reception only when the incident polarization is the same as the polarization of the antenna on transmission.

Directivity.

The value of the directive gain in the direction of its maximum value.

Director Element.

A parasitic element located forward of the driven element of an antenna to increase the directive gain of the antenna in the forward direction.

Doublet Antenna.

See Dipole Antenna.

Driven Element.

A radiating element coupled directly to the feed line of an antenna (cf. Parasitic Element.)

E Plane, Principal.

For a linearly polarized antenna, the plane containing the electric field vector and the direction of maximum radiation.

Effective Area, of an Antenna.

In a given direction, the ratio of the power available at the terminals of an antenna to the power per unit area of a plane wave incident on the antenna from that direction, polarized coincident with the polarization that the antenna would radiate.

Effective Height, of an Antenna (high-frequency usage).

The height of the antenna center of radiation above the ground level.

Note: For an antenna with symmetrical current distribution, the center of radiation is the center of distribution. For an antenna with asymmetrical current distribution, the center of radiation is the center of current moments when viewed from directions near the direction of maximum radiation.

Effective Height, of an Antenna (low-frequency usage).

See Effective Length, of an Antenna.

Effective Length, of an Antenna.

For an antenna radiating linearly polarized waves, the length of a thin straight conductor oriented perpendicular to the direction of maximum radiation, having a uniform current equal to that at the antenna terminals and producing the same far-field strength as the antenna. Alternatively, for the same antenna receiving linearly polarized waves from the same direction, the ratio of the open-circuit voltage developed at the terminals of the antenna to the component of the electric field strength in the direction of antenna polarization.

Note 1: The two definitions yield equal effective lengths.

Note 2: In low-frequency usage the effective length of a ground-based antenna is taken in the vertical direction and is frequently referred to as effective height. Such usage should not be confused with Effective Height, of an Antenna (high-frequency usage).

Efficiency.

See Antenna Efficiency, of an Aperture-Type Antenna; Aperture Illumination Efficiency; Radiation Efficiency.

Electric Dipole.

An elementary radiator consisting of a pair of equal and opposite oscillating electric charges an infinitesimal distance apart.

Note: It is equivalent to a linear current element.

Electrical Boresight.

The tracking axis as determined by an electric indication, such as the null direction of a conical-scanning or monopulse antenna system, or the beam-maximum direction of a highly directive antenna. (cf. Reference Boresight.)

Electronic Scanning (Inertialess Scanning).

Scanning an antenna beam by electronic or electric means without moving parts.

Element.

See Array Element, Director Element, Driven Element, Parasitic Element, Radiating Element, Reflector Element.

End-Fire Array.

A linear or planar array antenna whose direction of maximum radiation lies along the line or the plane of the array.

Equivalent Flat-Plate Area, of a Scattering Object.

The area of a flat, perfectly reflecting plate, large compared to the wavelength and parallel to the incident wavefront, which has the same back-scattering cross section as the object.

Note: The equivalent flat-plate area is equal to the wavelength times the square root of the ratio of the back-scattering cross section to 4π.

Excitation.

See Aperture Illumination.

Excitation Coefficients (Feeding Coefficients).

The relative values of the excitation currents of the radiating elements of an array antenna.

Far-Field Region.

That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna.

Note 1: If the antenna has a maximum overall dimension D which is large compared to the wavelength, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength.

Note 2: For an antenna focused at infinity, the far-field region is sometimes referred to as the Fraunhofer region on the basis of analogy to optical terminology.

Feed, of an Antenna.

That portion of an antenna coupled to the terminals which functions to produce the aperture illumination.

Note: A feed may consist of a distribution network or a primary radiator.

Feeding Coefficients.

See Excitation Coefficients.

Folded Dipole Antenna.

An antenna composed of two or more parallel, closely spaced dipole antennas connected together at their ends with one of the dipole antennas fed at its center.

Fraunhofer Pattern, of an Antenna.

A radiation pattern obtained in the Fraunhofer region.

Fraunhofer Region.

The region in which the field of an antenna is focused. (See Note 2 of Far-Field Region for a more restricted usage.)

Fresnel Pattern, of an Antenna.

A radiation pattern obtained in the Fresnel region.

Fresnel Region.

The region (or regions) adjacent to the region in which the field of an antenna is focused, i.e., just outside the Fraunhofer region. (See Note 2 of Near-Field Region, Radiating, for a more restricted usage.)

Front-to-Back Ratio.

The ratio of the directivity of an antenna to its directive gain in a specified direction toward the back.

Gain.

See Directive Gain, Directivity, Power Gain, Relative Gain, Superdirectivity.

H Plane Principal.

For a linearly polarized antenna, the plane containing the magnetic-field vector and the direction of maximum radiation.

Half-Power Beamwidth.

In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half the maximum value of the beam.

Height.

See Effective Height.

Helical Antenna.

An antenna whose configuration is that of a helix.

Note: The diameter, pitch, and number of turns in relation to the wavelength provide control of the polarization state and directivity of helical antennas.

Horn Antenna.

A radiating element having the shape of a horn.

Horn Reflector Antenna.

An antenna consisting of a section of a paraboloidal reflector fed with an offset horn which intersects the reflector surface.

Note: The horn is usually pyramidal or conical.

Illumination.

See Aperture Illumination.

Impedance.

See Input Impedance, Intrinsic Impedance, Mutual Impedance, Self-Impedance.

Inertialess Scanning.

See Electronic Scanning.

Input Impedance, of an Antenna.

The impedance presented by an antenna at its terminals.

Intrinsic Impedance, of an Antenna.

The theoretical input impedance of an antenna for the basic radiating structure when idealized.

Note: The idealized basic radiating structure usually consists of a uniform cross-section radiating element, perfectly conducting ground or imaging planes, zero base capacitance (in the case of vertical radiators), and no internal losses.

Isolation, between Antennas.

A measure of power transfer from one antenna to another.

Note: The isolation between antennas is the ratio of power input to one antenna to the power received by the other, usually expressed in decibels.

Isotropic Radiator.

A hypothetical antenna having equal radiation intensity in all directions. (cf. Omnidirectional Antenna.)

Note: An isotropic radiator represents a convenient reference for expressing the directive properties of actual antennas.

Length.

See Effective Length.

Lens Antenna.

An antenna consisting of a feed and an electromagnetic lens.

Lens, Electromagnetic.

A three-dimensional structure propagating electromagnetic waves, with an effective index of refraction differing from unity, employed to control the aperture illumination.

Line Source.

A continuous distribution of current lying along a line segment.

Linear Array Antenna.

An array antenna having the centers of the radiating elements lying along a straight line.

Loading, of an Antenna.

The modification of a basic antenna, such as a dipole or monopole, by adding conductors or circuit elements that change the current distribution or input impedance.

Lobe.

See Beam, of an Antenna; Major Lobe; Minor Lobe; Radiation Lobe; Side Lobe.

Lobe Switching.

A form of scanning in which the direction of maximum radiation is discretely changed by switching. (cf. Sequential Lobing.)

Log-Periodic Antenna.

Any one of a class of antennas having a structural geometry such that its electrical characteristics repeat periodically as the logarithm of frequency.

Long-Wire Antenna.

A wire antenna that, by virture of its considerable length in comparison with the operating wavelength, provides a directional radiation pattern.

Loop Antenna.

An antenna whose configuration is that of a loop.

Note: If the current in the loop, or in multiple parallel turns of the loop, is essentially uniform and the loop circumference is small compared with the wavelength, the radiation pattern approximates that of a magnetic dipole.

Luneburg Lens Antenna.

A lens antenna with a circular cross section having an index of refraction varying only in the radial direction such that a feed located on or near a surface or edge of the lens produces a major lobe diametrically opposite the feed.

Magnetic Dipole.

An elementary radiator consisting of an infinitesimally small current loop.

Main Lobe.

See Major Lobe.

Major Lobe (Main Lobe).

The radiation lobe containing the direction of maximum radiation.

Note: In certain antennas, such as multilobed or split-beam antennas, there may exist more than one major lobe.

Minor Lobe.

Any lobe except a major lobe.

Monopole.

Any one of a class of antennas constructed normal to an imaging plane to produce a radiation pattern approximating that of an electric dipole in the half-space above the imaging plane.

Monopulse.

In radar, simultaneous lobing whereby direction-finding information is obtainable from a single pulse.

Monostatic Cross Section.

See Back-Scattering Cross Section.

Mutual Impedance.

The mutual impedance between any two terminal pairs in a multielement array antenna is equal to the open-circuit voltage produced at the first terminal pair divided by the current supplied to the second when all other terminal pairs are open-circuited.

Near-Field Region, Radiating.

That region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon distance from the antenna.

Note 1: If the antenna has a maximum overall dimension which is not large compared to the wavelength, this field region may not exist.

Note 2: For an antenna focused at infinity, the radiating near-field region is sometimes referred to as the Fresnel region on the basis of analogy to optical terminology.

Near-Field Region, Reactive.

That region of the field immediately surrounding the antenna wherein the reactive field predominates.

Note: For most antennas the outer boundary of the region is commonly taken to exist at a distance $\lambda 2\pi$ from the antenna surface, where λ is the wavelength.

Noise Temperature, of an Antenna.

The temperature of a resistor having an available thermal noise power per unit bandwidth equal to that at the antenna output at a specified frequency.

Note: Noise temperature of an antenna depends on its coupling to all noise sources in its environment as well as noise generated within the antenna.

Omnidirectional Antenna.

An antenna having an essentially nondirectional pattern in azimuth and a directional pattern in elevation. (cf. Isotropic Radiator.)

Paraboloidal Reflector.

A reflector which is a portion of a paraboloid of revolution.

Parasitic Element.

A radiating element which is not coupled directly to the feed lines of an antenna and which materially affects the radiation pattern and/or impedance of an antenna. (cf. Driven Element.)

Pattern.

See Radiation Pattern.

Pencil-Beam Antenna.

A unidirectional antenna having a narrow major lobe with approximately circular contours of equal radiation intensity in the region of the major lobe.

Phase Center.

In a given direction, the center of curvature of the wavefront of the radiation from an antenna in a given plane.

Phased Array Antenna.

An array antenna whose beam direction or radiation pattern is controlled primarily by the relative phase of the excitation coefficients of the radiating elements.

Pillbox Antenna.

A reflector antenna having a cylindrical reflector enclosed by two parallel conducting plates perpendicular to the cylinder, spaced less than one wavelength apart. (cf. Cheese Antenna.)

Planar Array Antenna.

An array antenna having the centers of the radiating elements lying in a plane.

Polarization, of an Antenna.

In a given direction, the polarization of the radiated wave, when the antenna is excited. Alternatively, the polarization of an incident wave from the given direction which results in maximum available power at the antenna terminals.

Note: When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain.

Polarization, of a Radiated Wave.

That property of a radiated electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation.

Note: In general, the figure is elliptical and it is traced in a clockwise or counter-clockwise-sense. The commonly referenced circular and linear polarizations are obtained when the ellipse becomes a circle or a straight line, respectively. Clockwise-sense rotation of the electrical vector is designated "right-hand polarization" and counterclock wise-sense rotation is designated "left-hand polarization."

Power Gain, of an Antenna.

In a given direction, 4π times the ratio of the radiation intensity in that direction to the net power accepted by the antenna from the connected transmitter.

Note 1 : When the direction is not stated, the power gain is usually taken to be the power gain in the direction of its maximum value.

Note 2: Power gain does not include reflection losses arising from mismatch of impedance.

Note 3: Power gain is fully realized on reception only when the incident polarization is the same as the polarization of the antenna on transmission.

Primary Radiator.

A feed which illuminates a secondary radiator.

Pyramidal Horn Antenna.

A horn antenna, the sides of which form a pyramid.

Radar Cross Section.

That portion of the back-scattering cross section of a target associated with a specified polarization component of the scattered wave.

Radiating Element.

A basic subdivision of an antenna which in itself is capable of effectively radiating or receiving radio waves.

Note: Typical examples of a radiating element are a slot, horn, or dipole antenna.

Radiation Efficiency.

The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter.

Radiation Intensity.

In a given direction, the power radiated from an antenna per unit solid angle.

Radiation Lobe.

A portion of the radiation pattern bounded by regions of relatively weak radiation intensity.

Radiation Pattern (Antenna Pattern).

A graphical representation of the radiation properties of the antenna as a function of space coordinates.

Note 1: In the usual case the radiation pattern is determined in the far-field region and is represented as a function of directional coordinates.

Note 2: Radiation properties include radiation intensity, field strength, phase or polarization.

Radiation Resistance.

The ratio of the power radiated by an antenna to the square of the root-mean-square antenna current referred to a specified point.

Radiator.

Any antenna or radiating element that is a discrete physical and functional entity.

Radome.

An enclosure for protecting an antenna from the harmful effects of its physical environment, generally intended to leave the electric performance of the antenna unaffected.

Reactive Field.

Electric and magnetic fields surrounding an antenna and resulting in storage of electromagnetic energy.

Reference Boresight.

A direction defined by an optical, mechanical, or electrical axis of an antenna established as a reference for the purpose of beam-direction or tracking-axis alignment. (cf. Electrical Boresight.)

Reflector.

See Corner Reflector Antenna, Cylindrical Reflector, Horn Reflector Antenna, Paraboloidal Reflector, Reflector Antenna, Spherical Reflector.

Reflector Antenna.

An antenna consisting of a reflecting surface and a feed.

Reflector Element.

A parasitic element located in a direction other than forward of the driven element of an antenna intended to increase the directive gain of the antenna in the forward direction.

Relative Gain, of an Antenna.

The ratio of the power gain in a given direction to the power gain of a reference antenna in its reference direction.

Note: Common reference antennas are half-wave dipoles, electric dipoles, magnetic dipoles, monopoles, and calibrated horn antennas.

Resistance.

See Antenna Resistance, Radiation Resistance.

Rhombic Antenna.

An antenna composed of long-wire radiators comprising the sides of a rhombus. The antenna usually is terminated in a resistance. The side of the rhombus, the angle between the sides, the elevation, and the termination are proportioned to give the desired radiation properties.

Scanning, of an Antenna Beam.

A repetitive motion given to the major lobe of an antenna.

Scattering Cross Section.

The scattering cross section of an object in a given orientation is 4π times the ratio of the radiation intensity of the scattered wave in a specified direction to the power per unit area in an incident plane wave of a specified polarization from a given direction.

Note: The term "bistatic cross section" denotes the scattering cross section in any specified direction other than back towards the source.

Secondary Radiator.

That portion of an antenna having the largest radiating aperture, consisting of a reflecting surface or a lens, as distinguished from its feed.

Sectoral Horn Antenna.

A horn antenna; two opposite sides of the horn are parallel and the two remaining sides diverge.

Self-Impedance, of a Radiating Element.

The input impedance of a radiating element of an array antenna with all other elements in the array open-circuited.

Note: In general, the self-impedance of a radiating element in an array is not the same as the input impedance of the same element with the other elements absent.

Sequential Lobing.

A direction-determining technique utilizing the signals of partially overlapping lobes occurring in sequence. (cf. Lobe Switching.)

Side Lobe.

A radiation lobe in any direction other than that of the intended lobe.

Side-Lobe Level, Maximum Relative.

The relative level of the highest side lobe.

Side Lobe, Relative Level of.

The ratio of the radiation intensity of a side lobe in the direction of its maximum value to that of the intended lobe, usually expressed in decibels.

Signal-Processing Antenna System.

An antenna system having circuit elements associated with its radiating element(s) which perform functions such as multiplication, storage, correlation, and time modulation of the input signals.

Simultaneous Lobing.

A direction-determining technique utilizing the signals of overlapping lobes existing at the same time.

Sleeve-Dipole Antenna.

A dipole antenna surrounded in its central portion by a coaxial conducting sleeve.

Slot Antenna.

A radiating element formed by a slot in a metal surface.

Spherical Reflector.

A reflector which is a portion of a spherical surface.

Spillover.

That part of the power radiated by a feed not intercepted by the secondary radiator.

Squint Angle.

A small difference in pointing angle between a reference beam direction and the direction of maximum radiation.

Superdirectivity.

The directivity of an antenna when its value exceeds the value which could be expected from the antenna on the basis of its dimensions and the excitation that would have yielded in-phase addition in the direction of maximum radiation intensity.

Note: Superdirectivity is obtained only at the cost of a sharp increase in the ratio of average stored energy to power radiated per hertz.

Surface Wave Antenna.

An antenna which radiates power from discontinuities in the structure that interrupt a bound wave on the antenna surface.

Target Echoing Area.

See Back-Scattering Cross Section.

Turnstile Antenna.

An antenna composed of two dipole antennas, perpendicular to each other, with their axes intersecting at their midpoints. Usually, the currents on the two dipole antennas are equal and in phase quadrature.

Uniform Linear Array.

A linear array of identically oriented and equally spaced radiating elements having equal current amplitudes and equal phase increments between excitation currents.

V Antenna.

An antenna that has a V-shaped arrangement of conductors, balanced-fed at the apex and with included angle, length, and elevation proportioned to give the desired directive properties.

Wave Antenna.

See Beverage Antenna.

APPENDIX C

REFERENCES

1. NAVELEX 0101,102, Naval Communications Station Design, June 1970.

2. NAVELEX 0101,103, HF Radio Propagation and Facility Site Selection, June 1970.

3. NAVELEX High Frequency Direction Finder Criteria; enclosure (1) of letter, serial 04-2, 4 August 1966.

4. NAVELEX Instruction 11000.1, The Base Electronic System Engineering Plan (BESEP): Policy and Procedures for Utilization Of, 8 May 1967.

5. Smith, E. J. "Procedures for Testing the Physical and Electrical Condition of HF Antennas," NAVELEX Central Atlantic Division, February 1968.

6. NAVFAC, DM-2, Structural Engineering.

7. NAVFAC, DM-5, Civil Engineering.

8. NAVDOCKS, DM-7, Soil Mechanics, Foundations, and Earth Structures.

9. NAVFAC Specification 13Y, Concrete Construction.

10. NAVFAC Instruction 8020.3, Site Approvals for Electromagnetic Wave Generating and Transmitting Equipment, 16 February 1968.

11. Electronic Installation Practices Manual for Pacific Missile Range, Point Mugu, Calif, 14 May 1963, Astindman, San Diego, 2125-102.

12. BUSHIPS letter 9670/1-2, serial 679D-34; subject: Radio Frequency Coaxial Cable Transmission Line; standardization on characteristic impedance of, 2 February 1962.

13. DCAC 330-175-1, DCS Engineering-Installation Standards Manual, May 1967.

14. DCAC 330-175-1 Addendum 1, MF/HF Communications Antennas, Defense Communications Agency, 1966.

15. NAVORD 3565/NAVAIR 16-1-529 (Conf), Technical Manual, Radio Frequency Hazards to Ordnance, Personnel, and Fuel (U), Revision 3, 1969.

16. MIL-HDBK-216, Military Standardization Handbook, RF Transmission Lines and Fittings, Defense Supply Agency, 1962.

17. CCTM 105-50, Chapter 2, Telecommunications Engineering-Installation Practices, 21 December 1965.

18. T. O. 31R-1-7. Handbooks, Siting, Engineering, and Installation of High-Frequency Rhombic Antennas, U. S. Air Force, January 1960.

19. GEEIA Technical Manual T. O. 31-10-24, Theory, Principles, and Practices of Grounding Procedures and Lightning Protection for C-E Equipment, Facilities and Systems, 20 December 1968.

20. GEEIA Technical Manual T. O. 30-10-28, Technical Manual, Standard Installation Practices, Erection of Steel Towers, March 1969.

21. NAVSO P-2455, Safety Precautions for Shore Activities, Office of Civilian Manpower Management, Department of the Navy, June 1967.

22. NObsr 87466, Electromagnetic Prediction Techniques for Naval Air Stations, White Electromagnetics, Inc., Rockville, Md.

23. EIA Standard RS-222-A. Structural Standards for Steel Antenna Towers and Antenna Supporting Structures, Engineering Department, Electronics Industries Association, Washington, D.C., November 1966.

24. Jasik, H. "Antenna Engineering Handbooks," 1st ed., New York: McGraw-Hill Book Company, 1961.

25. Kraus, J. "Antennas," New York: McGraw-Hill Book Company, 1950.

26. Terman, F. E. "Radio Engineers Handbook, " New York: McGraw-Hill Book Company, 1943.

27. Terman, F. E. "Electronic and Radio Engineering," 4th ed., New York: McGraw-Hill Book Company, 1955.

28. Institute of Electrical and Electronics Engineers, "IEEE Standard Definitions of Terms for Antennas," New York: May 1969.

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Antenna Types Listed by Azimuthal Patterns and Polarization	Useful Frequency Range (MHz) (Note 1)	Power Gain (Referred to Isotropic)(dB) (Note 2)	Usable Radiation Angles (degrees) (Note 3)	Approximate Land Required (acres)	Power Handling Capability (KW PEP) (Note 4)	Approximate Material Cost (thousands) (Note 5)	Nominal Bandwidth Ratio (Note 6)	Nominal Bandwidth Limited by	Horizontal Beamwidth (-3dB) (degrees)	Horizontal Beamwidth (-10dB) (degrees)	Sidelobe Suppression (dB)	Transmit Maximum VSWR (Note 7)	Nominal Input Impedance (ohms) (Note 8)
UNIDIRECTIONAL PATTERNS													
Horizontal Rhombic	2-30	8 to 23	3-35	5-15	Limited by Termination	5-10	≥2:1	Pattern	6°-26°	11°-46°	≥6	2:1	50/600
Horizontal Terminated V	2-30	4 to 17	5-30	3-7		3-6	≥2:1	Pattern	8°-36°	11°-48°	≥6	2:1	50/600
Horizontal Log-Periodic	2-30	10 to 17	5-45	2-4	40	15-25	≥8:1	VSWR	55°-75°	75°-120°	≥12	2:1	50/300
Horizontal Log-Periodic (Rotatable)	6-32	10 to 12	5-35	<1	40	12-18	≥6:1	VSWR			≥12	2:1	50
Vertical Log-Periodic (Dipole)	2-30	6 to 10	3-25	3-5	40	10-20	≥8:1	VSWR	90°-140°	150°-180°	≥12	2:1	50
Yagi	6-30	6 to 19	5-30	<1	20	5-10	≥3%	VSWR	28°-50°	36°-80°	≥9	1.5:1	50
Vertical Log-Periodic (Monopole)	2-30	4 to 8	3-25	3-5	20	10-20	≥8:1	VSWR	90°-140°	150°-180°	≥12	2:1	50
Horizontal Half-Wave Dipole	2-30	5 to 7	5-80	<1	20	1-2	≥5%	VSWR	80°-180°/lobe	180°/lobe	NA	1.5:1	50
OMNIDIRECTIONAL PATTERNS (VERTICAL)													
Conical Monopole	2-30	-2 to +2	3-45	2-4	40	3-8	≥4:1	Pattern	NA	NA	NA	2.5:1	50
Discone	6-30	2 to 5	4-40	<1	40	5-10	≥4:1	Pattern	NA	NA	NA	2:1	50
Inverted Cone	2-30	1 to 5	5-45	2-4	40	5-10	≥10:1	Pattern	NA	NA	NA	2:1	50
Vertical Sleeve	4-27	-1 to +3	4-40	2-4	10	5-10	≥3:1	VSWR	NA	NA	NA	3:1	50
SECTOR PATTERNS (VERTICAL)													
90° Corner Reflector Sleeve	4-27	5 to 8	4-40	2-4	10	5-10	≥3:1	VSWR	56°-118°		NA	3:1	50
180° Sector Sleeve	4-27	2 to 5	4-40	2-4	10	5-10	≥3:1	VSWR	148°-180°		NA	3:1	50
Sector Log-Periodic	2-32	8 to 11	5-40	4-6	40	15-30	≥8:1	VSWR	4 Sectors 90° apart		NA	2:1	50
SELECTIVE PATTERNS (VERTICAL)													
Selectively Directional Monopole (Transmit only)	4-30	4.5 to 9.5	5-40	5-8	1200	Cost figures not available	≥7:1 (Note 9)	VSWR	360°, 180°, or 45°, as selected		NA	2:1	50
Wullenweber (Receive only)	2-30			32-38	NA	Cost figures not available	≥10:1	NA	360° and various sectors as selected		NA	NA	50
Transportable Wullenweber (Receive only)	3-30	Directive Gain 14 to 19	3-45	10-14	NA	Cost figures not available	≥10:1	NA	360°, 120° sector, 36 narrow beam as selected		NA	NA	50

Note 1 - The useful frequency range is the range of the antenna type, not necessarily the bandwidth of an individual antenna.

Note 2 - Typical power gains are gains of antennas over good earth for vertical polarization and poor earth for horizontal polarization.

Note 3 - Usable radiation angles are typical radiation angles over good earth for vertical polarization and poor earth for horizontal polarization; lower angles may be possible for vertical antennas over better earth, e.g., sea water.

Note 4 - The power limitation criteria apply to the antenna only. The use of certain baluns may result in a lower power limitation. These criteria should be used as a basis of comparison only, since any antenna can be engineered at increased cost, to provide increased power-handling capability.

Note 5 - Approximate material costs include steel towers, guys, and installation hardware. Costs are established only to provide a relative basis of comparison of one antenna against another.

Note 6 - Nominal bandwidth is the ratio of the two frequencies within which the stated VSWR will not be exceeded or within which the desired pattern will not suffer more than 3 dB degradation.

Note 7 - Maximum VSWR for receiving antennas shall not exceed 3:1.

Note 8 - Includes any impedance matching device.

Note 9 - Overall combined bandwidth of low and high band monopoles.

Foldout 5-1. Antenna Characteristic Chart