COLLINS HIGH-FREQUENCY ANTENNAS

. . . SELECTION

. . . APPLICATIONS

1 May 1961

PREPARED BY
RESEARCH DIVISION
COLLINS RADIO COMPANY

COLLINS

COLLINS RADIO COMPANY
Cedar Rapids, Iowa

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COLLINS HIGH-FREQUENCY ANTENNAS

1. INTRODUCTION

This publication describes high-frequency antennas that have been designed, developed, and evaluated by Collins Radio Company and are available for all types of circuit requirements. These antennas include both omnidirectional and unidirectional types designed to operate over wide frequency ranges. Special broadband antennas resulting from application of logarithmically periodic principles have been developed recently by Collins Radio Company. Applications and descriptions of these antennas are included in this publication.

Since the design of antennas is dictated by propagation considerations, a summary of radio wave propagation in the high-frequency range is included for background information.

2. HIGH-FREQUENCY RADIO WAVE PROPAGATION

2.1 PROPAGATION CHARACTERISTICS IN THE 2- TO 30-MC RANGE

Propagation of electromagnetic waves in the frequency range of 2 to 30 mc may occur in either of two principal modes. These are commonly referred to as the ground-wave mode and the sky-wave mode. The ground wave is propagated beyond the horizon as a surface wave. The atmosphere plays little part in the propagation of this wave. The surface wave dies out exponentially with increasing distance at a rate which becomes larger at higher frequencies. Also, only vertical polarization produces a surface wave of any consequence. The attenuation in the hf frequency range is so large that the ground wave cannot be used for long-distance propagation, except over sea water where attenuation is low. Ground-wave propagation is practical up to 500 miles over sea water.

The sky wave results from the presence of layers of ionized air at heights greater than about 70 km. A wave incident on the ionized air induces currents in the medium which changes the effective velocity of propagation. The free electrons in the ionized medium have a much higher mobility than the ions of molecular mass, so that virtually all the current results from the motion of electrons. In the simplest case, where the effect of the magnetic field of the earth is neglected and where the atmospheric pressure is so low that collisions of electrons with heavy particles may be neglected, the medium is found to have a phase velocity given by:

$$v = c/\sqrt{1 - 81N/f^2} \quad (1)$$

where c is the velocity in a vacuum (practically the same as in neutral air), N is the electron density per cubic meter, and f is the frequency. This equation shows that the phase velocity is greater than c and that it becomes infinite when

$$f = \sqrt{81N} \quad (2)$$

Since the electron density normally increases with increasing altitude, a wave propagated vertically may reach an altitude at which equation (2) is satisfied. At this altitude the wave is totally reflected. However, if the wave frequency is so high that $\sqrt{81N}$ is less than f even at the level of maximum electron density, the wave penetrates the ionosphere and goes into space.

When the wave is propagated obliquely, the higher portion of the wave front is located in a region of higher electron density and phase velocity, so that the wave front changes direction. The wave normal (essentially the direction of propagation) becomes more nearly horizontal as the wave progresses upward. Hence, the wave is refracted and the direction of propagation is changed so that it becomes more and more nearly horizontal. This bending of the rays may be determined accurately by ray tracing methods. Total reflection occurs at the level where the ray direction is horizontal. The ray then proceeds downward along a path similar to the upgoing path.

The highest frequency at which a vertically propagated wave can be reflected is known as the critical frequency of the ionosphere, given by

$$f_c = \sqrt{81 N_{max}} \qquad (3)$$

The highest frequency at which an obliquely incident wave can be reflected is known as the maximum usable frequency (muf). This always is greater than the critical frequency. For a flat earth and a horizontally stratified ionosphere, it is given by:

$$\text{muf} = f_c \sec \theta_o \qquad (4)$$

where θ_o is the angle of incidence at the bottom of the ionosphere, or the angle between the ray and the vertical at the antenna (see figure 1).

When the magnetic field of the earth is taken into consideration, each electron is subject to two forces. The first acts in the direction of the E vector of the incident wave and is proportional to the strength of the E field. The second acts perpendicular to the direction of motion and to the direction of the steady magnetic field, and it is proportional to the product of the velocity, the magnetic field, and the sine of the angle between them. These two forces cause the electrons to execute rather complicated motion. One effect is a peculiar resonance which occurs at the gyrofrequency, in the general vicinity of 1.5 mc. The electron velocity tends to become extraordinarily large near the gyrofrequency. If the frequency is close to the gyrofrequency, the absorption becomes very great since each electron can absorb a large amount of energy from the wave. A second effect of the complicated electron motion caused by the magnetic field is that the wave is split into two components. These are called the ordinary and the extraordinary rays which have different phase velocities and suffer different attenuations. Because of this separation into two components, a wave that has passed through an ionized region will have both vertically and horizontally polarized components. The vertical and horizontal polarizations will, in general, not be in the same phase; therefore, the wave will be elliptically polarized.

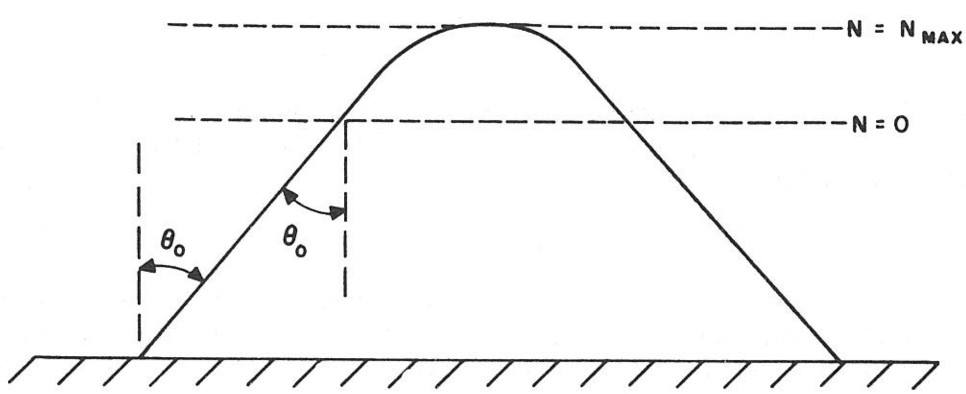


Figure 1. Path of a Wave Reflected from the Ionosphere

Since the density of the air decreases with increasing altitude, the mean distance between molecules becomes greater and the probability of a collision between an electron and a heavy particle becomes less. Above an altitude of about 150 km, the probability of electron collisions is so small that the electrons move essentially as in a vacuum. In this case, the wave is propagated with negligible absorption. However, at altitudes less than 100 km, the probability of collisions becomes rather great. At each collision, an electron loses essentially all of the directed energy which it has acquired from the field. Therefore, the wave loses energy to the medium, and the wave is said to suffer absorption. The ideal condition would be to have no ionization present below 100 km. However, during daylight hours, the ionizing radiation (principally sunlight radiation) has sufficient penetrating power and intensity to cause substantial ionization down to altitudes as low as 70 km. Most of the absorption of radio waves occurs as they traverse the region below 100 km.

Because of the inertial properties of electrons, their average velocity (well above the gyrofrequency) decreases as the frequency increases. It is this reduced average velocity at the higher frequencies which accounts for the gradual reduction of the refracting power of the medium and the existence of a maximum usable frequency. However, at the same time, the reduced velocity results in less energy loss per collision and less absorption. Therefore, it is expedient to choose a relatively high frequency to reduce the absorption which the wave undergoes in traversing the region below 100 km. The net result is that the best choice of wave frequency is a value which lies within a rather narrow range below the muf. This requires that the operating frequency be changed quite often.

2.2 STRUCTURE OF THE IONOSPHERE

For most purposes, one may assume that the ionosphere is horizontally stratified. The electron density existing at a given level depends upon the atmospheric density and composition, and upon the intensity and ionizing power of the radiation penetrating to this level. During daylight hours, various regions and layers may be distinguished, as shown in figure 2. The region below 100 km, known as the D region, is ionized slightly compared with higher layers and has no significant refractive effect. The ionization nevertheless is sufficient to cause quite substantial absorption, especially at the lower end of the hf range. The layers from which total reflection can occur, in ascending order of altitude, are the E, F_1, and F_2 layers. At night, the profile of electron density becomes simpler, as shown in figure 2. The E and F_1 layers disappear, and the density in the D region becomes so small that the absorption is generally negligible. At the same time, the maximum electron density is less than in the daytime, so that the F_2 muf also may be low compared with the daytime value.

The altitude of the layer from which reflection occurs increases with the frequency. The waves of relatively low frequency are reflected from the E layer. As the frequency increases, the E-layer muf is exceeded, and the waves are reflected from the F_1 layer. Again, with a further increase of frequency, the F_1-layer muf is exceeded, and the waves are reflected from the F_2 layer.

As a general rule, reflection from the F_2 layer may be used by selection of a sufficiently high frequency. This always is the most desirable condition since the absorption is at a minimum. Under exceptional circumstances, the E-layer muf may exceed the F_2-layer muf, and reflection from the F_2 layer will be impossible. This can occur only on a daytime path, and it is most likely to occur on a short path with the sun near the zenith and at a time near sunspot maximum. There is also a phenomenon known as sporadic-E ionization, in which clouds or patches of unusually intense ionization exist at E-layer height. Sporadic-E ionization seems to be of nonsolar origin, since it can occur at night. It may occur at all latitudes but it is most prevalent in regions of high latitude. The sporadic-E muf may exceed 15 mc a large percentage of the time at certain periods. Daytime sporadic-E ionization of great intensity is not sufficiently common to make it an important consideration in the design of hf antennas. If it occurs at night, the trapping of the wave below E-layer altitudes does not seriously increase the absorption on the path.

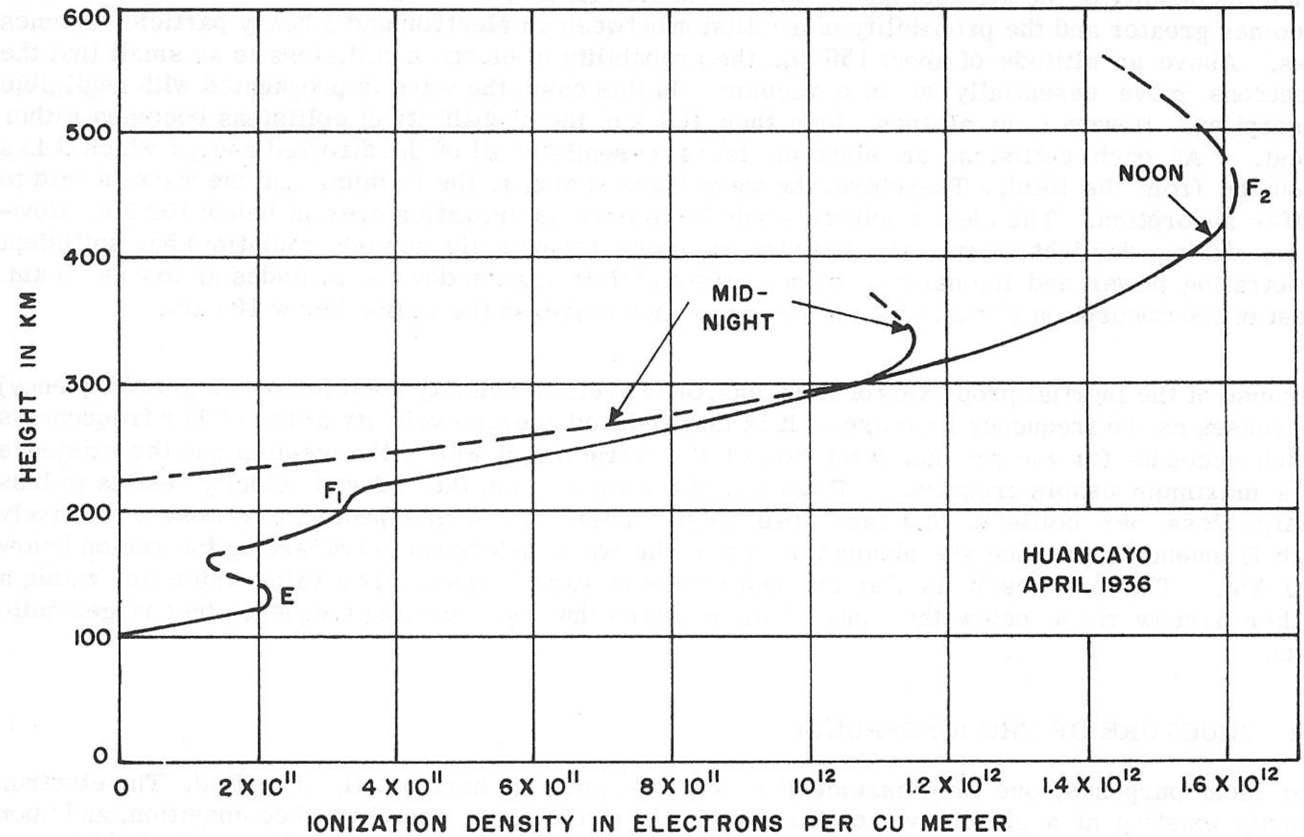


Figure 2. Variation in Density of Ionosphere with Height

2.3 CHOICE OF OPERATING FREQUENCY

Equation (4) shows that the muf depends upon the maximum electron density and the angle of incidence of the ray at the ionosphere. The angle of incidence, in turn, is a function of the path length and the height of the F_2 layer. Consequently, if the operating frequency is to be chosen at the highest practical value, the path length, the layer height, and the maximum electron density, or the critical frequency must be taken into consideration. In this section, the path length will be assumed to be fixed and relatively short, so that conditions resemble those depicted in figure 1; the layer height will be assumed to vary over a rather limited range (approximately 250 to 400 km); and the variation of the critical frequency will be discussed.

It has been seen already that the critical frequency varies throughout the day. In addition, there is a variation over the sunspot cycle, which has a period of about 11 years, and with the month of the year. The 12-month running average sunspot number plotted as a function of time over one cycle is shown in figure 3. It has been found that an approximate linear relation exists between the F_2 layer critical frequency and the sunspot number. Thus it is apparent that the muf may vary rather widely over a period corresponding to a sunspot cycle.

The typical variation of muf with time of day for two seasons is shown in figure 4. It is seen that the diurnal variation is large in winter and is considerably smaller in summer. The muf tends to be a maximum shortly after noon and to be a minimum some time not long before sunrise. However, the simple solar control of the E layer and the F_1 layer does not extend to the F_2 layer. The electron density in the F_2 layer is influenced in a complicated way by the geomagnetic field and by tidal motions in the upper atmosphere.

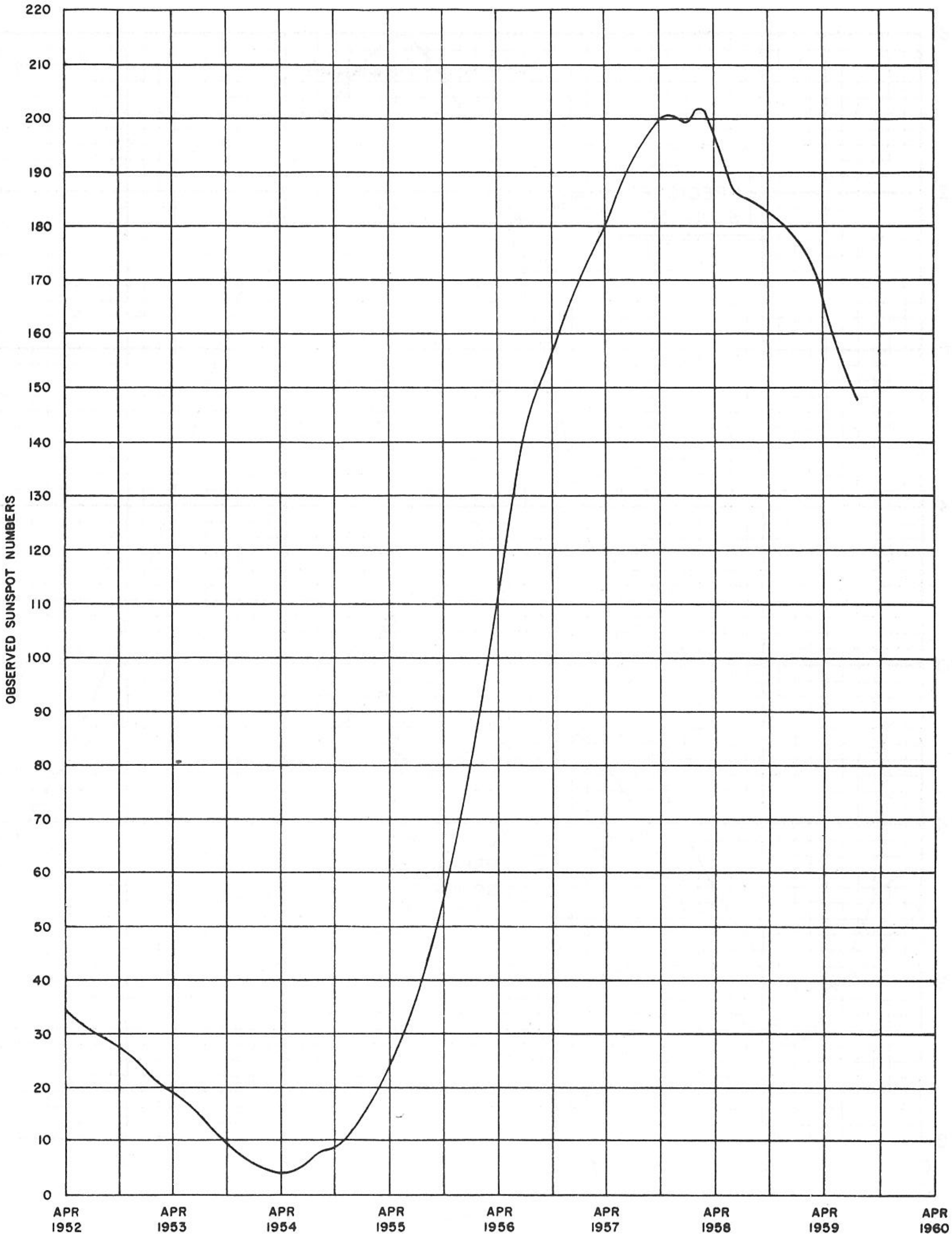


Figure 3. Sunspot Cycle

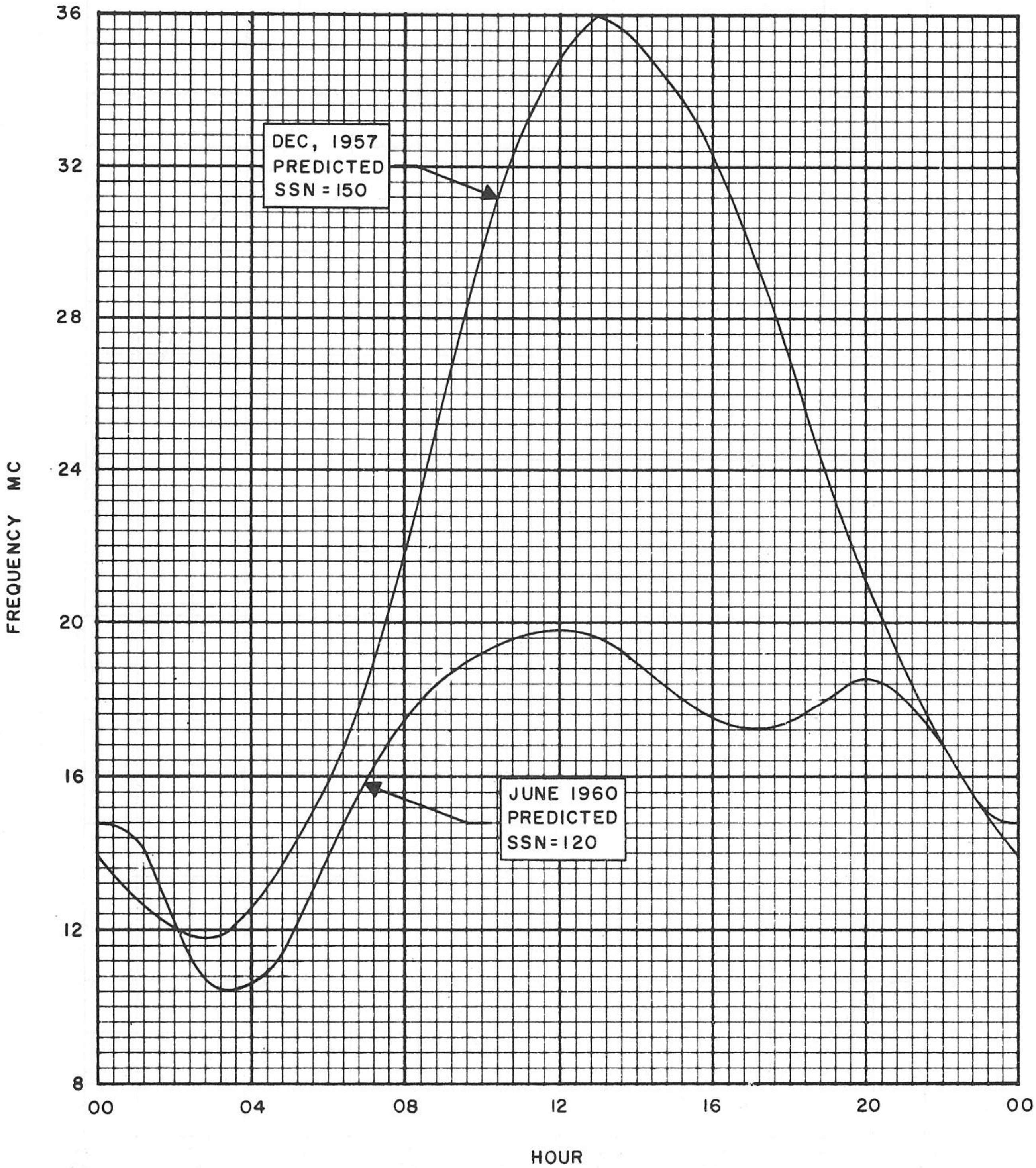


Figure 4. Diurnal Variation of MUF for Northern USA for a Distance of 1500 Miles

In order to predict the F_2-layer muf for a given path, it is necessary to have charts available showing the critical frequency and the M-3000 factor as a function of latitude, longitude, and time of day for the period for which a prediction is desired. The M-3000 factor is the ratio of the muf for a 3000-km path to the critical frequency. The data usually represent median conditions for a particular month. Since there are three independent variables (latitude, longitude, and time), it is impractical to represent the relation completely with a limited number of two-dimensional charts. This problem has been solved in the past by employing a chart with latitude and local time as coordinates and with each chart applying to a limited range of longitude. Reasonably accurate results have been obtained with three or four such longitude zones.

The document upon which predictions in the United States generally are based is the monthly publication of the National Bureau of Standards, known as the Series D. Each issue covers a period of one month and is published three months in advance. The characteristics of the F_2 layer are covered by contour charts of critical frequency (zero distance) or 4000 muf (4000 km distance). Longitude variations are dealt with by dividing the earth into four zones. Thus eight charts are required for a complete representation. The publication also shows charts for E-layer and sporadic-E propagation. Predictions for a specific path generally are made by employing graphical procedures with the aid of these charts. Currently, the National Bureau of Standards is planning to issue tables of numerical coefficients occurring in the power-series representations of the critical frequency and M-3000 factor charts. Collins Radio Company has developed a program for an IBM 650 computer employing such numerical tables. This will permit making predictions of F_2 muf for any path with little effort. The FOT (optimum traffic frequency) must be selected somewhat lower than the median muf, since the actual muf may fluctuate from day to day. It is customary to choose the FOT equal to 0.85 of the monthly median muf.

The operating frequency can be changed only a small number of times per day for practical reasons. The operating frequency must not exceed the FOT, yet it should not be chosen unnecessarily low if serious absorption is to be avoided. It is rarely feasible to employ more than four different frequencies over a 24-hour period. However, the choice of these frequencies may vary with the season and with the year. Considering all variations of muf with time, geographical location, and path length, it is necessary to provide for frequencies ranging from about 4 mc to at least 30 mc. A serious handicap for sky-wave communication systems in the past has been the lack of antennas with constant impedance and directional properties over this wide range of frequencies.

2.4 RADIATION ANGLE AND MODES OF PROPAGATION

Sky-wave propagation between two points on the earth's surface is the result of reflections from ionospheric layers and the earth. A mode of propagation constitutes a particular combination of reflections. Examples of various modes are shown in figure 5.

This figure shows that each mode requires a particular elevation angle of radiation. This angle depends on the height of the reflecting layer, length of transmission path, and the number of hops. For a symmetrical reflecting layer, the angle of arrival is equal to the angle of departure. Both of these angles decrease as the path length increases. Therefore, a limiting path length is obtained for a specified mode of propagation. The limiting distances, shown in figure 5, for one-hop E and one-hop F modes are approximately 2400 and 4000 km, respectively.

When the path length is specified, it is possible also to specify the number of hops for best results. This is the least number which avoids very small values of the takeoff angle, Δ . With the path length and number of hops specified, the only variable in the problem of selecting the required radiation angle is the height of the reflecting layer. If the position of the lobe maximum of the antenna can be made essentially independent of frequency, then the design can be chosen so that normal variations in layer height cause little change in over-all system loss.

2.5 FADING

Signals received over ionospheric paths may vary in intensity over short periods of time. There are several causes for such fading. The signal may reach the receiver over several paths of different and varying lengths. This is termed multipath propagation. At one time, the various components may combine with relative phases and a large signal is produced. At another time, the interference may be largely destructive and a weak signal is produced. A second cause of fading is the magneto-ionic splitting of the wave in the ionosphere. The resultant field at the receiving antenna is elliptically polarized, with the major axis of the ellipse changing its position as a function of time. When a linear receiving antenna is employed, the induced voltage varies as the polarization ellipse rotates relative to the antenna axis. A third cause of fading applies when the operating frequency is very close to the muf. A change of muf resulting from a change in layer height may cause the wave to be reflected toward the receiving antenna at one time and to a point beyond the receiving antenna at another time. When the frequency is above the muf for a given path, a relatively weak scatter signal often may be received, which fades in a manner characteristic of scatter propagation.

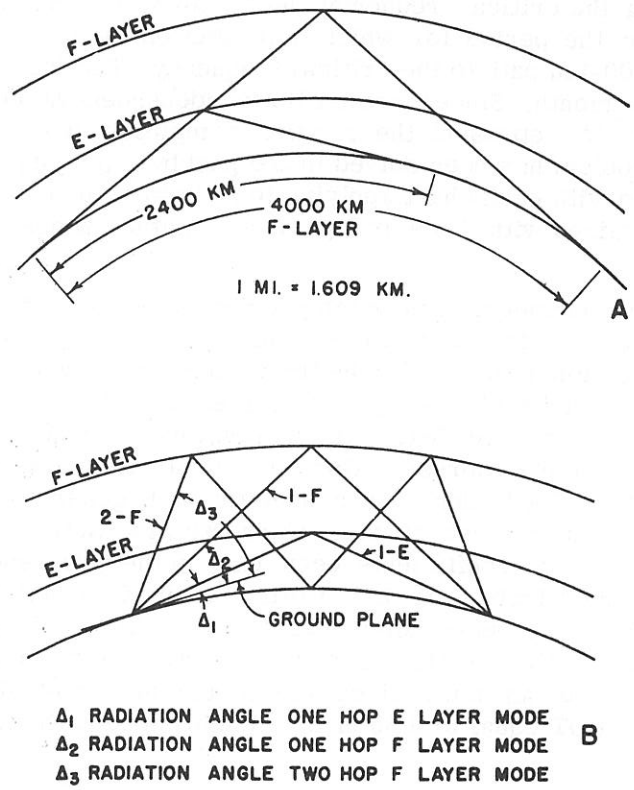


Figure 5. Distance Limitations for Single Reflection Transmission (A) and Modes of Transmission (B)

Multipath propagation is the most important cause for fading. It may occur due to partial reflection from two or more layers or clouds of ionization or due to simultaneous reception of several modes as illustrated in figure 5. Extraordinarily rapid multipath fading tends to occur on paths traversing the auroral zones. Fading due to multipath propagation may cause not only amplitude fluctuations but also distortion. The latter results when the relative delay is large enough to constitute an appreciable fraction of the period of the modulating signal. This is termed selective fading. Severe cases of such fading may occur when one path does not lie in the great-circle plane. It sometimes happens that strong absorption on the great-circle path allows propagation on an alternate path to reach interfering magnitude. This alternate path may be composed of two hops with the ground reflection point replaced by a ground scattering point far off the great-circle path. Because the alternate path may be much longer than any of the possible great-circle paths, the relative time delay is large and severe selective fading may occur. In this situation, a sharply beamed antenna may help to discriminate against one of these signals. A steerable-beam antenna could be used to select the signal due to ground scatter when the attenuation was high on the great-circle path, a condition which is not unlikely on paths traversing the auroral zones. It is ordinarily impossible to reduce multipath effects by attempting to separate signals arriving at different vertical angles unless very elaborate arrays are employed.

At least two forms of diversity reception for reducing the depth of multipath fading have practical significance. Two antennas may be spaced several wavelengths from each other, preferably transverse to the path; or two antennas may be used, one vertically polarized and one horizontally polarized. The fading of the two signals thus received generally is poorly correlated, and combining the outputs of the corresponding receivers fills in the deep fades.

3. BASIC REQUIREMENTS FOR HF ANTENNAS

The previous paragraphs have discussed the variable propagation conditions involved in high-frequency circuits. These conditions require that antennas designed for operation with high-frequency circuits should be capable of satisfactory operation over a broad band of frequencies. This satisfactory operation includes both maintenance of the required radiation pattern and impedance match to a specific transmission line. The antenna should be designed to use the optimum vertical angles and suppress others that contribute to multipath delays and distortion. The pattern should have low side lobes for rejecting interfering signals at the receive site and to avoid interference with other stations at the transmit site. The antenna should be designed for as high a gain as practical in the desired location.

In addition to these general requirements, specific antenna requirements are determined by the propagation considerations for a given circuit. The basic antenna requirements for four basic types of circuits are outlined in the following paragraphs.

(a) Sky-Wave Propagation Between Two Fixed Points. - This type of circuit requires antennas that produce a unidirectional azimuth pattern and a vertical plane pattern that is independent of frequency. The beam must be directed at the vertical angle that is most favorable for the path distance and operating frequency. For long circuits, vertical angles of 5 to 15 degrees generally are the most desirable. For shorter circuits, vertical angles of up to 70 degrees are common. Figure 6 shows vertical radiation angles for one-hop circuits with various distances and virtual heights.

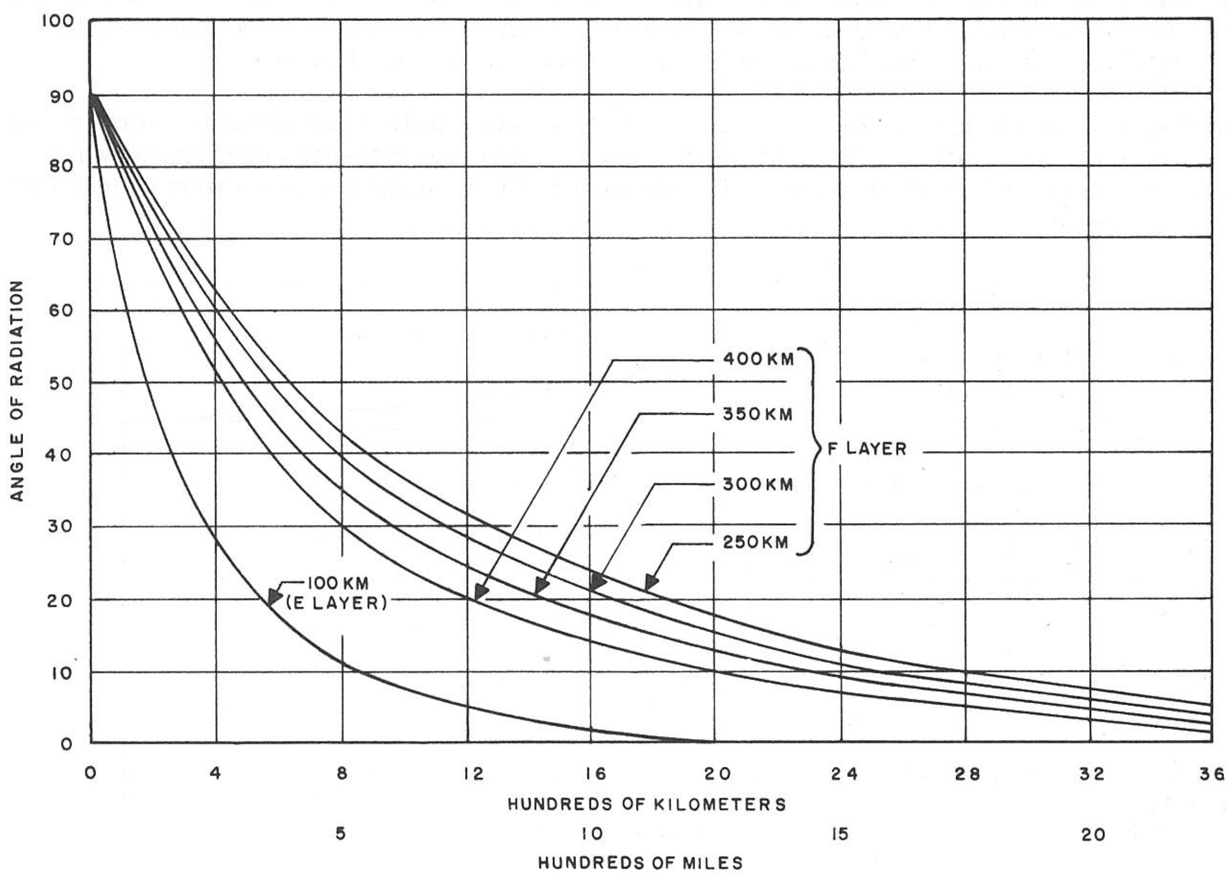


Figure 6. Vertical Radiation Angles for One-Hop Circuits

(b) Sky-Wave Propagation Between a Fixed Site and Mobile Sites or Several Fixed Receiving Sites. - This type of circuit requires an antenna with a steerable beam or several antennas aimed in the required directions. Since various path lengths may be involved with this circuit arrangement, two or more antennas at different heights may be required to provide the required vertical angles.

(c) Ground-Wave Propagation Between Two Fixed Points. - This circuit arrangement requires a unidirectional vertically polarized antenna.

(d) Ground-Wave Propagation Between a Fixed Site and a Ground Mobile Station or Shipboard Station. - This arrangement requires a vertically polarized omnidirectional or steerable beam antenna.

Antenna polarization is an important consideration for high-frequency circuits. Ground-wave propagation requires the use of vertical polarization. However, with sky-wave propagation, the selection of vertical or horizontal polarization will depend on such factors as ground conditions, path length, frequency, required radiation angle, and local noise conditions.

Low-angle radiation is a natural characteristic of vertically polarized antennas. Therefore, lower structures can be used for a given angle of radiation with vertically polarized radiators. If, for example, a 20-degree radiation angle is desired from a horizontally polarized antenna operating at 4 mc, the center of the effective aperture must be approximately 180 feet above the ground. The total height of a vertical monopole would not exceed 60 feet.

The structure height advantage is somewhat offset by higher ground losses associated with vertical polarization. These losses consist of near field losses and reflection losses. For efficient antenna operation, the near field losses must be reduced through the use of a ground radial system. The near field losses are decreased as the length and number of radials is increased.

The reflection loss characteristics for horizontal polarization differ from those for vertical polarization as shown in figure 7. With horizontal polarization, the reflection coefficient (which is the ratio of the reflected field strength to the incident field strength) remains fairly constant for all

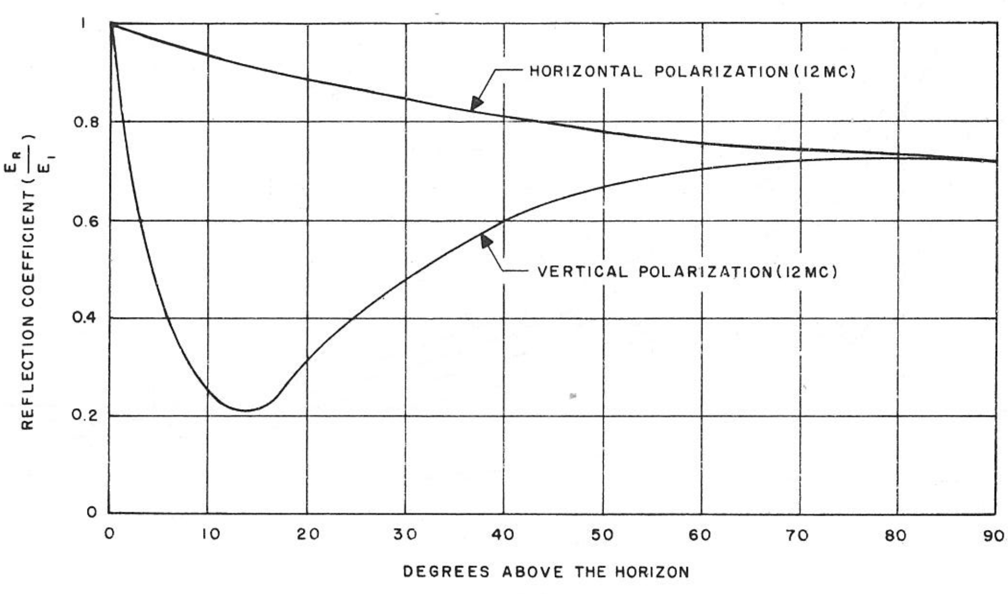


Figure 7. Variation of Reflection Coefficient at 12 Mc with Radiation Angle for Vertical and Horizontal Polarization

radiation angles. However, with vertical polarization, the magnitude of the reflected wave decreases very rapidly as the radiation angle is increased and reaches a minimum at a certain angle, depending on the frequency and ground characteristics. This increase in reflection loss results in an over-all decrease in the received signal strength and also affects the vertical plane pattern of the antenna. The curves shown in figure 7 are for 12 mc and good ground conditions. The reflection losses with vertical polarization will increase with higher frequencies and with poor ground conditions. When propagation is over water, the reflection losses are decreased and vertical polarization can be used with higher frequencies.

One outstanding advantage resulting from horizontal polarization is the reduction in man-made noise at the receiving site. Noise is randomly oriented-electromagnetic waves which may be resolved into horizontally and vertically polarized components. However, since man-made noise sources are close to the earth's surface, attenuation of the horizontal component will be much more than that of the vertical component. This means that less noise will be received by a horizontal antenna.

4. LOG-PERIODIC ANTENNAS

4.1 INTRODUCTION

The preceding paragraphs have pointed out the basic need in hf communications for antenna systems which have radiation patterns and input impedance characteristics essentially independent of frequency. During the past years, there has evolved a type of antenna called the "logarithmically periodic antenna" which is geometrically simple and has radiation patterns and input impedance properties that in free space are independent of frequency. Some of the reports written on the subject of log-periodic antennas since 1957 are listed below:

1. R. H. DuHamel and D. E. Isbell, "Broadband Logarithmically Periodic Antenna Structures," 1957 IRE National Convention Record, Part I, pp. 119-128.

2. V. H. Rumsey, "Frequency Independent Antennas," 1957 IRE National Convention Record, Part I, pp. 114-118.

3. D. E. Isbell, "Non-Planar Logarithmically Periodic Antenna Structures," University of Illinois, Antenna Laboratory TR #30, Feb. 20, 1958, Contract AF 33(616)-3220.

4. R. H. DuHamel and F. R. Ore, "Logarithmically Periodic Antenna Designs," 1958 IRE Convention Record, Part I, pp. 139-151.

5. R. H. DuHamel and D. G. Berry, "Logarithmically Periodic Antenna Arrays," 1958 IRE Wescon Convention Record, Part I, pp. 161-174.

6. R. H. DuHamel and F. R. Ore, "Log Periodic Feeds for Lens and Reflectors," 1959 IRE Convention Record, Part I, pp. 128-137.

7. R. H. DuHamel and D. G. Berry, "A New Concept in High-Frequency Antenna Design," 1959 IRE Convention Record, Part I, pp. 42-50.

8. D. E. Isbell, "Log Periodic Dipole Arrays," IRE Transactions on Antennas and Propagation, Volume AP-8, May 1960, pp. 260-267.

Collins Radio Company has pioneered in the development of log-periodic antennas and various types have been designed for specific applications. Characteristics of these types are discussed in detail in section 5 of this document. The general theory of operation of log-periodic antennas is given in the following paragraphs.

4.2 GENERAL CHARACTERISTICS

The geometry of log-periodic antenna structures is chosen so that the electrical properties must repeat periodically with the logarithm of the frequency. Frequency independence is obtained by making the variation of the properties over one period, and therefore, all periods small.

The log-periodic design principles are illustrated in figure 8. A metal-sheet log-periodic structure with trapezoidal teeth is shown in figure 8A. The two half structures are fed against each other by a generator placed between their vertices. The four sets of teeth are defined by similar curves; the equations for which may be written in polar coordinates as $\theta = g(r)$, where g(r) is some function of r. If θ is plotted versus the ln r in rectangular coordinates, that is, $\theta = f(\ln r)$, then the log-periodic principles demand that f be a periodic function. This is illustrated in figure 8B, where the two curves which define the upper half structure of figure 8A are plotted versus the ln r. Letting $\tau = \frac{R_{n+1}}{R_n}$, where R_n is the distance from the vertex to the outer edge of the tooth, it is seen that the period of the curve is logarithm $\frac{1}{\tau}$. Other shapes of teeth, such as triangular or curved teeth, lead to other types of periodic curves when θ is plotted versus the logarithm of r.

The logarithmic principle implies two conditions. The first is that all similar sets of dimensions, such as R_1, R_2, R_3, etc., must form a geometric sequence with the same geometric ratio τ. The second is that angles are used to a considerable extent in defining the antenna. For example, the extremities of the teeth and the triangular supporting section of the teeth are defined by angles. The distance to the inner edge of a tooth is denoted by r_n, and the ratio of $\frac{r_n}{R_n}$ is denoted by σ. The teeth on the upper right of the structure are scaled from those on the upper left by the factor $\sqrt{\tau}$. Figure 8A is for the special, but most useful, case of $\theta = \sqrt{\tau}$. The lower half structure is identical to the upper except for a 180-degree rotation about its center line.

If the antenna structure of figure 8A is infinitely large and is infinitely precise near the feed point, the structure must look exactly the same to the generator every time the frequency is changed by the factor τ. The current distribution on the structure at τf_o is identical to that at f_o, except that everything is moved out one step. Thus, since the wavelength is changed by a proportionate amount, the radiation pattern and the input impedance must be the same at τf_o and f_o. This is illustrated in figure 8C, where the magnitude of the input impedance varies periodically with the logarithm of frequency. Because of the special left-right asymmetry of the structure of figure 8 ($\theta = \sqrt{\tau}$), the period of the impedance curve is $1/2 \ln 1/\tau$ rather than $\ln 1/\tau$. The radiation pattern also exhibits a similar periodicity with frequency, but with a period equal to $\ln 1/\tau$.

If the variation of the impedance and pattern is small over a period, and therefore all periods because of the repetitive characteristics, the result is essentially a frequency independent antenna. Fortunately, some finite log-periodic structures provide frequency independent operation above a certain low-frequency cutoff which occurs when the longest tooth is approximately one-quarter wavelength long. Frequency independent operation above the cutoff frequency is possible because log-periodic antennas display little end-effect. The currents on the structure decrease quite rapidly past the region where a quarter-wave tooth exists. This means that a smaller and smaller portion of the antenna is used as the frequency is increased. This is another way of saying that the effective electrical aperture (the aperture measured in wavelengths) is essentially independent of frequency. Since it is not possible to extend the antenna to the origin because of the presence of the feed transmission line, a high-frequency cutoff occurs when the shortest tooth is about one-eighth wavelength long.

The structure of figure 8A is horizontally polarized and has a bidirectional beam, with the beams pointing into and out of the taper. If the input impedance is plotted on a Smith chart over a frequency range of several periods, the locus forms a circle with the center lying on the zero reactance line. The characteristic impedance of the log-periodic structure is defined as the geometric mean

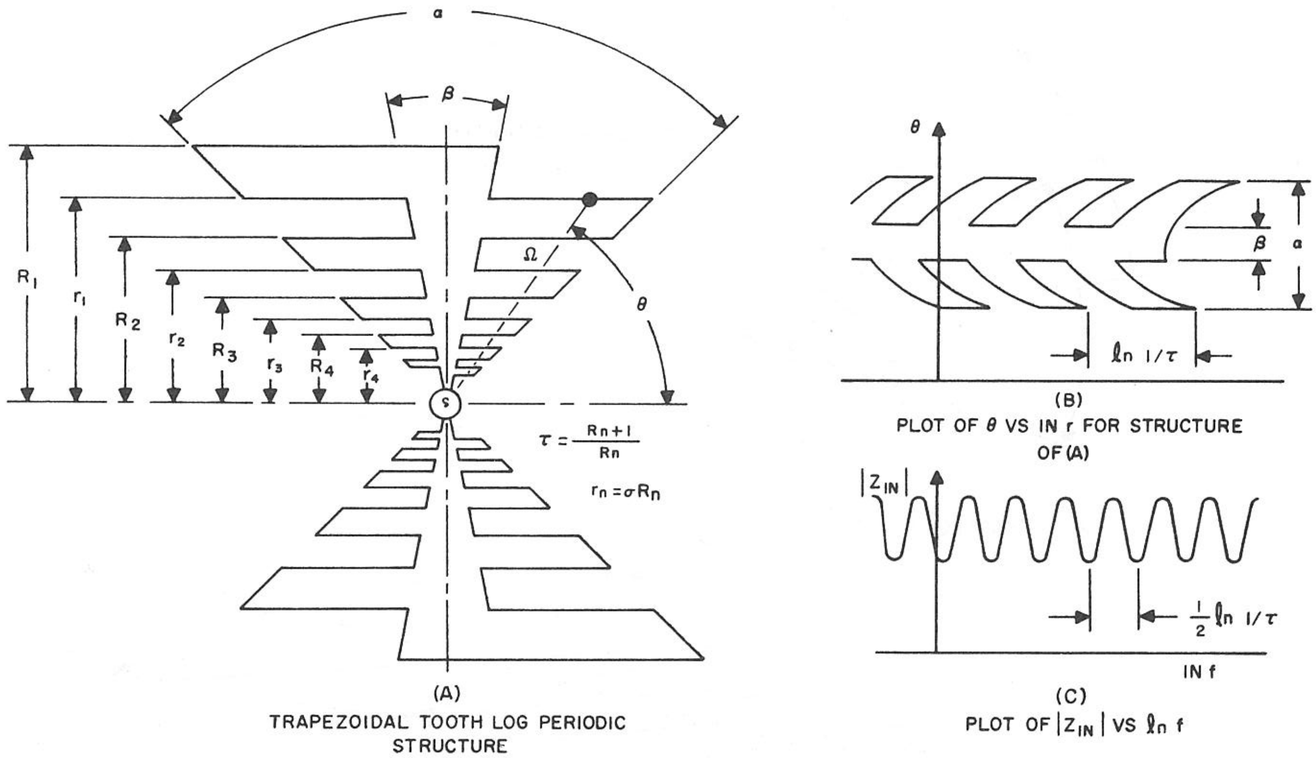


Figure 8. Log-Periodic Antenna Characteristics

of the maximum and minimum real values on the locus. The vswr referred to this characteristic impedance is equal to the ratio of the maximum impedance to the characteristic impedance.

4.3 PRACTICAL STRUCTURES

There is an infinite variety of log-periodic structures. Three successful structures are illustrated in figure 9. Figures 9A and 9B show wire versions of log-periodic structures with trapezoidal and triangular teeth, respectively. The angle α defines the extremities of the teeth. All of the various structures illustrated have similar radiation pattern and impedance characteristics. The radiation is due mostly to currents flowing in the teeth, and hence the polarization is transverse to the center line of the half structure.

By orienting the two half structures at an angle ψ with respect to each other, as shown in the non-planar arrangements of figure 9A or 9B, a unidirectional beam pointing along the positive Y axis is formed. The two half structures in each case form a balanced antenna. The antenna may be fed with a balanced two-wire line with wires attached to the vertices of the half structures and placed to minimize distortion of the radiation pattern. For unidirectional structures, the transmission line usually is brought in along the line bisecting the center lines of the two half structures. The antennas also may be fed with a coaxial line which is brought in along the center line of, and bonded to, one half structure. A dummy cable usually is added to the other half structure to keep the antenna balanced. This type of feed forms, in effect, a frequency independent balun.

Figure 9C shows another basic type of log-periodic antenna. Basically this antenna consists of an array of dipole elements arranged and energized according to log-periodic principles. Excitation of the dipoles is accomplished by a balanced transmission line. The elements are connected alternately to each line of the balanced system giving the effect of transposing the balanced line

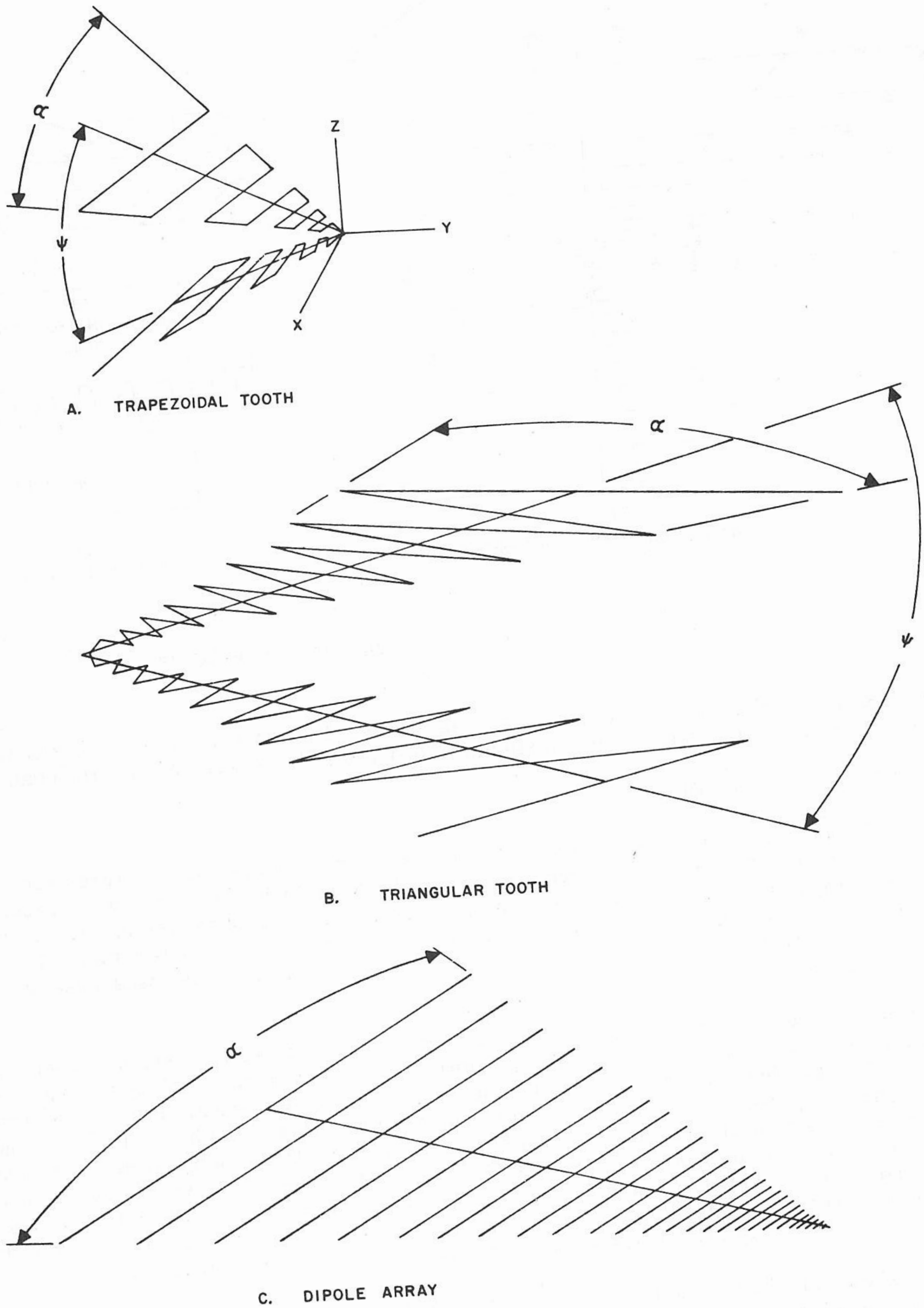


Figure 9. General Types of Log-Periodic Structures

between dipoles. The dipole array also may be considered as a limiting case of the structure of figure 8A where the tooth width and angle β approach zero and the two half structures are folded together so that the angle ψ approaches zero. Letting the tooth width approach zero is equivalent to letting σ approach one.

Since log-periodic antennas are too complex to analyze by present-day theoretical methods, they must be investigated by logical experimental methods. However, their repetitive nature greatly simplifies the initial experimental investigation because the characteristics need only be measured over one or two periods of frequency. The operation over other periods may be predicted readily.

4.4 ELEMENT CHARACTERISTICS

Radiation properties of log-periodic structures may be better understood when it is realized that each of the half structures produces a unidirectional beam by itself. As mentioned previously, the absence of end-effect implies a unidirectional pattern. Although it is necessary to feed two half structures against each other, or one against the ground, in order to obtain wide-band operation, it has been demonstrated by special measurement techniques that the half structure does produce a unidirectional beam pointing in the direction of its center line. Figure 10 demonstrates the variation of the E- and H-plane beamwidths of a single half structure with wire trapezoidal teeth as a function of the design parameter α . The E plane is defined as the plane which includes the half structure, and the H plane is the normal plane which includes the center line of the half structure.

For a given α angle, there is a minimum value of the design ratio which can be used. For values of τ smaller than this minimum, the pattern breaks up considerably, and for larger values the beamwidths will decrease. The approximate minimum value of τ which can be used is plotted in figure 10 (solid curve) as a function of the parameter α . The E- and H-plane beamwidths for this minimum value of τ also are shown as solid lines. The dashed curves for the E- and H-plane beamwidths correspond to the dashed curve for τ , which is somewhat larger than the minimum value. As shown, the E-plane and especially the H-plane beamwidths decrease as α is decreased and τ is increased. For a given lower frequency limit, which implies that the last transverse element length remains fixed, then decreasing α and increasing τ means that the length of the structure and the number of transverse elements, respectively, are increased. The pattern behavior for the other types of half structures is very similar to that shown in figure 10.

The phase center of a log-periodic half structure lies some distance, d, behind the vertex. Figure 11 shows the distance of the phase center from the vertices as a function of α for wire trapezoidal tooth structures. For a fixed structure, the distance as measured in wavelengths is essentially independent of frequency. For values of α less than 60 degrees and for values of τ above the minimum value of τ given in figure 11, the position of the phase center is essentially independent of τ . Measurements indicate that d depends upon τ in a complex manner for α greater than 60 degrees. The phase center lies on the center line of the half structure at a point near where a half-wave transverse element exists.

5. COLLINS HF ANTENNAS AVAILABLE FOR VARIOUS APPLICATIONS

5.1 INTRODUCTION

The following paragraphs include detailed descriptions of hf antennas which have been developed by Collins Radio Company and are now available to meet the broadband requirements for hf circuits. The selection of operating frequency ranges for such types of antenna have been made to conform with spectrum allocations in the high-frequency band. For discussion purposes, the antennas are grouped according to their directional properties.

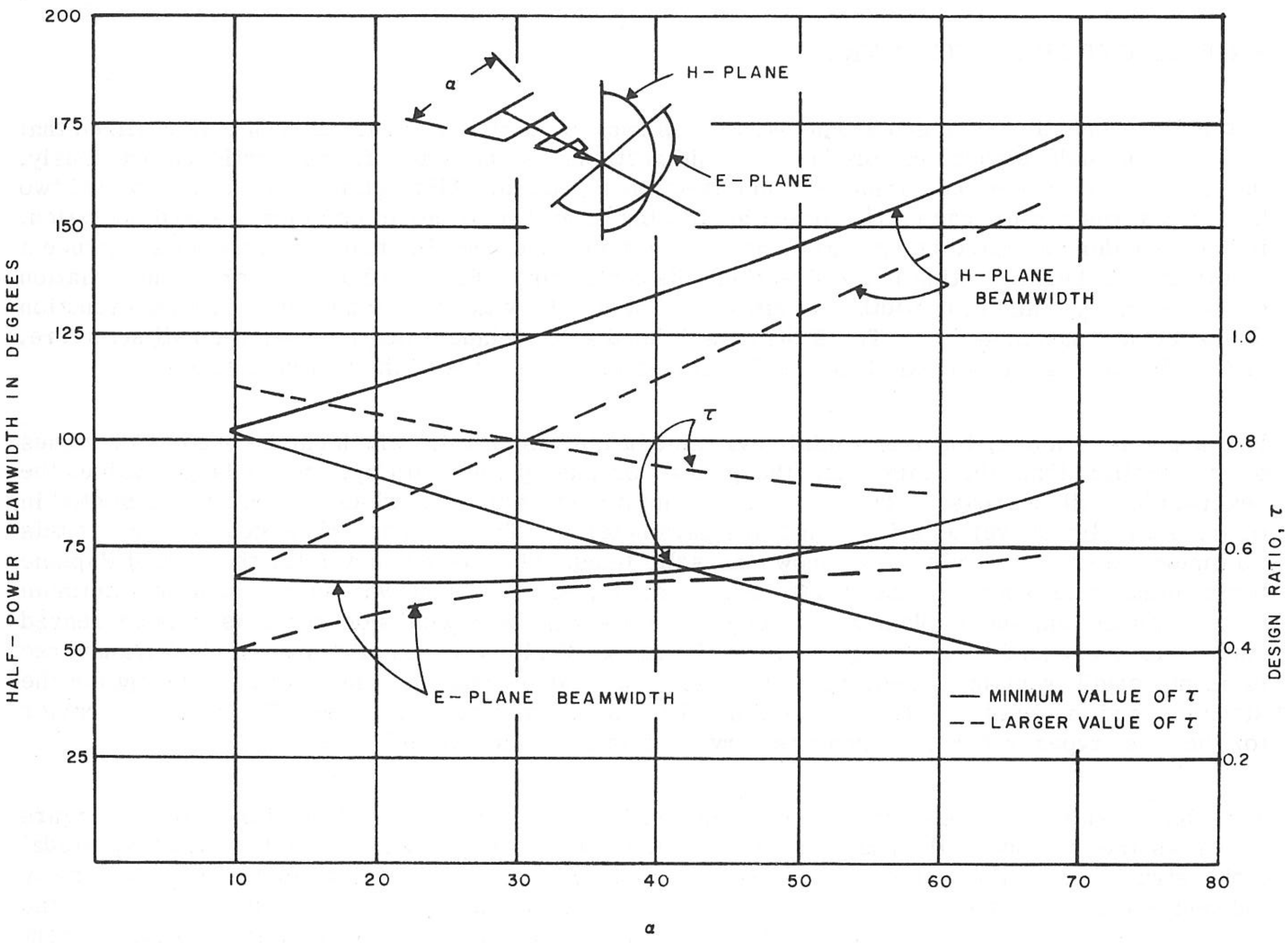


Figure 10. Variation of E- and H-Plane Beamwidths with α for Various Values of Design Ratio

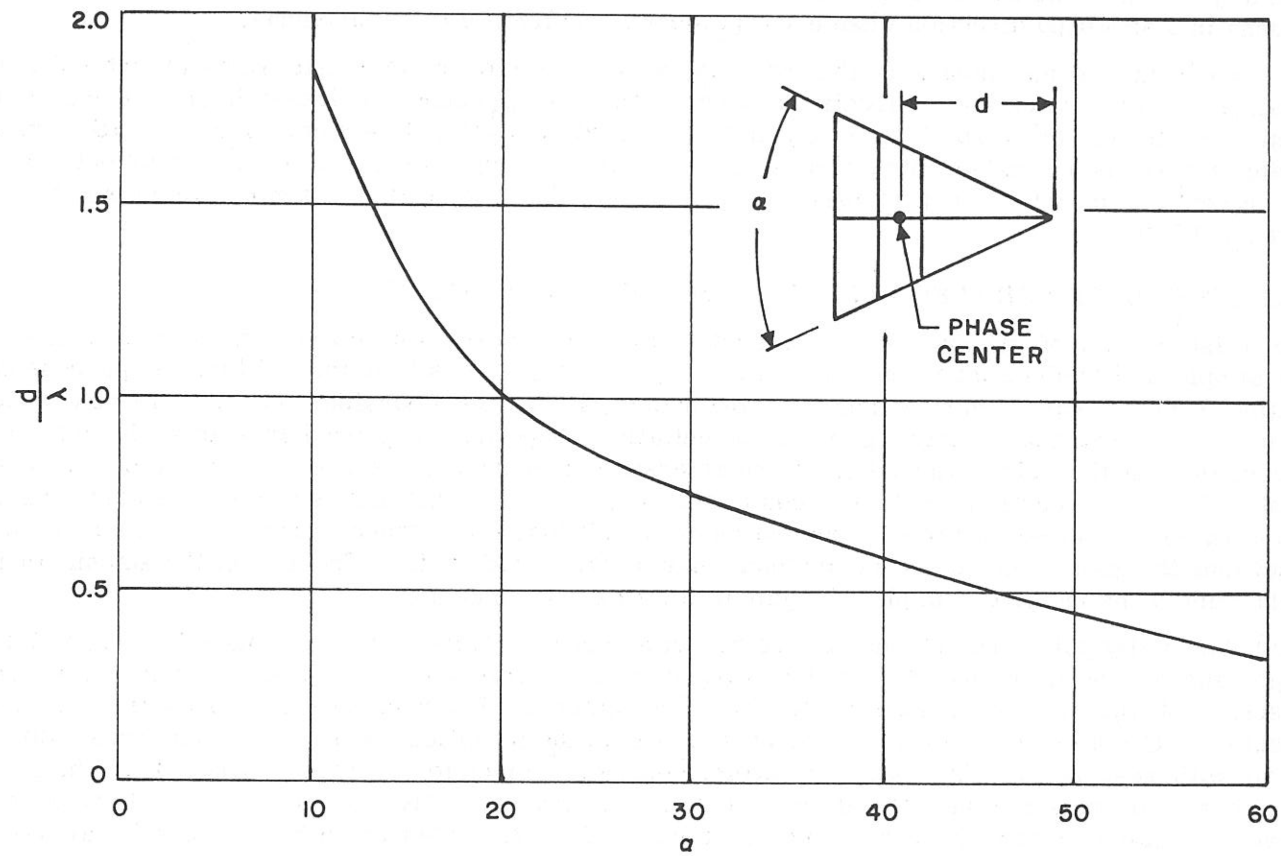


Figure 11. Distance to Phase Center from Vertex as a Function of α

5.2 ANTENNA GAIN DEFINITIONS AND SPECIFICATION TECHNIQUES

When planning and evaluating a radio circuit, it is necessary to know the gain of the antennas. To avoid confusion these gains must be defined and specified correctly. The following paragraphs provide definitions as used in this publication and describe the procedure used for specifying the gain of Collins hf antennas.

5.2.1 DEFINITIONS

The power gain or gain in db of an antenna in a specified direction is the ratio, expressed in db, of the radiation intensity of the antenna in that direction to the intensity produced by an isotropic antenna when equal powers are delivered to the two antennas. Radiation intensity is defined to be the power radiated per unit solid angle from the antenna. Although the isotropic antenna does not exist in practice, the radiation intensity may be calculated easily for a given power input. The gain is a function of direction and polarization and there will be some direction or directions for which the antenna has its maximum gain. The maximum gains of some elementary antennas are listed below:

isotropic source: 0 db
lossless short dipole: 1.76 db (free space)
half-wave dipole: 2.15 db (free space)
lossless short monopole over perfectly conducting ground plane: 4.76 db
quarter-wave monopole over perfectly conducting ground plane: 5.15 db

The relative gain of an antenna in a specified direction is the ratio, expressed in db, of the radiation intensity of the antenna in that direction to the intensity produced by the reference or standard antenna in a specified direction when equal powers are delivered to the antennas.

The directivity of an antenna is the ratio expressed in db, of the maximum radiation intensity to average radiation intensity. Directivity does not take into account heat losses in an antenna. For lossless antennas the directivity is equal to the maximum gain. However, for electrically small antennas there is a considerable difference. For example, loop antennas which are commonly used for reception in vlf through hf bands have a directivity of several db but gains which may be as poor as -90 db.

5.2.2 PROCEDURE FOR SPECIFYING GAIN OF COLLINS HF ANTENNAS

The relative gain of the antennas described in this publication is specified with respect to one of two simple and well-defined antennas which may be installed easily in the field for the purpose of making relative gain measurements. Fortunately, it has been possible to choose the reference antennas so that the relative gain is essentially independent of ground constants. In addition, information on the gain of the antennas and reference antennas for average ground (dielectric constant = 15 and conductivity = 10^{-2} mhos per meter) is given. This allows a basis for comparison of the various antennas and the determination of circuit loss for average ground. For other ground conditions the gain of the reference antennas may be calculated easily. The gain of the antenna then is the sum of the relative gain plus the gain of the reference antenna.

For horizontally polarized antennas the reference antenna is a half-wave dipole placed at a specified height above ground so that the vertical direction of the first lobe of the dipole coincides with the direction of the maximum lobe of the specified antenna. The relative gain is specified for this direction. Graphs showing vertical plane patterns of the specified and reference antennas plotted in db with respect to a free space isotropic source are given for average ground. Thus the gain of either antenna for other elevation angles may be read directly from these plots. In addition, curves are given showing the variation of maximum gain of the antennas with frequency for average ground.

For vertically polarized antennas the reference antenna is a quarter-wave monopole fed against a ground wire system consisting of 60 quarter-wave radial wires. The direction of maximum gain of the vertically polarized antennas does not, in general, coincide with that of the monopole. For the 237N series, the directions to coincide and the gain information is given in the same form as that for the horizontally polarized antennas. For the discone antennas the direction of maximum gain differs considerably, especially at the higher frequencies, from that of the monopole. Rather than specify relative gain, which would be rather complex, gain information is given in the form of vertical plane patterns for the discones and monopoles for various frequencies.

The gain values given in the following pages were obtained by theoretical and experimental means. Although the values are approximate, the error is less than one db. The gains were determined as follows: The gain of the antenna over perfect earth was calculated by pattern integration. This required either calculated or measured free space patterns of the antenna. The reduction of gain due to a finitely conducting earth was determined from the values of the appropriate plane wave reflection coefficient for the earth. Except for the quarter-wave monopole, it was assumed that the input resistance of the antenna was the same for average and perfect earth. For the monopole, the change of input resistance was taken into account.

5.3 COLLINS UNIDIRECTIONAL ANTENNAS

5.3.1 TYPE 237C, 237D, AND 237E POINT-TO-POINT ANTENNAS

5.3.1.1 DIRECTIONAL CHARACTERISTICS

These antennas make up a family of horizontally polarized log-periodic antennas which exhibit elevation plane radiation patterns essentially independent of frequency. This characteristic makes them especially applicable for point-to-point communications over wide frequency ranges.

The elevation plane radiation pattern is made independent of frequency by mounting the log-periodic structure in an inclined position with the feed point near the ground at the vertex. As the frequency is increased above the low-frequency limit, the radiating portion of the structure moves toward the feed point. Therefore, the radiating elements remain a constant electrical distance above ground as the operating frequency is varied.

Typical elevation-plane radiation patterns for the 237C, 237D, and 237E Antennas are included in figures 12, 13, and 14. Superimposed on these patterns are curves which indicate the angle of radiation for single-hop circuits as a function of path length and height of the ionospheric layers. The 105-km curve represents the average E-layer height. The 350-km and 200-km curves represent the approximate maximum and minimum heights of the F2 layer. Lines from the origin to the half-power points on the pattern intersect the virtual height curves at various distances.

The path lengths over which these antennas will provide reliable operation are determined by two factors: the elevation angles associated with the half-power beamwidth and the maximum variation in height of the ionospheric layers. The combined curves in figures 12, 13, and 14 can be used to determine the range of path lengths through which the received signal will remain within 3 db of beam maximum throughout the assumed virtual height range. The maximum path length for which the antenna gain will always remain within 3 db of maximum is determined by the intersection of the lower half-power line and the minimum virtual height curve. The minimum path length is determined by the intersection of the upper half-power line and the maximum virtual height curve.

For example, in figure 12 the angle of the lower half-power point for the 237C Antenna is approximately 18 degrees. This is the angle of arrival or departure for a 1040-km single-hop F2 path with the F2 layer at its minimum height. The angle of the upper half-power point, 69 degrees, is approximately the angle of arrival or departure for a 200-km path with the F2 layer at its maximum height. Therefore, the 237C Antenna may be used consistently over paths from 200 to 1040 km with maximum deviation no greater than 3 db. Actually, the path length over which the 237C will exhibit gain within 3 db of maximum could extend as far as 1650 km or be as short as 120 km. The greater distance is realized when the F2-layer is at its maximum height and propagation is by way of the lower half-power angle. A 120-km path length occurs when propagation is via the upper half-power angle and the F2-layer is at its minimum height. Therefore, with the F2-layer at 350 km, the antenna would cover the range of 200 to 1650 km; and with the F2-layer at 200 km, the range would be 120 to 1040 km.

Figures 13 and 14 give similar path length information for the 237D and 237E Antennas. The elevation-plane patterns for these antennas have lower angles of beam maximum and greater directivity than that shown for the 237C. This makes the 237D and 237E usable over longer circuits.

As would be expected, the dimensions of the antennas in terms of wavelength increase as the pattern becomes more directive for longer distances. However, for these longer distances, use of the lower frequencies in the hf range would be unlikely, and therefore the sizes are not prohibitive.

Typical azimuthal plane patterns obtained for the 237C, D, and E Antennas are given in figures 15, 16, and 17. Characteristics pertaining to the elevation and azimuth plane patterns are summarized in the following table.

CHARACTERISTIC	ANTENNA		
	237C	237D	237E
Azimuthal plane half-power beamwidth (average)	71°	63°	65°
Vertical plane half-power beamwidth (average)	51°	28°	15°

CHARACTERISTIC	ANTENNA		
	237C	237D	237E
Vertical angle of beam maximum	40°	25°	15°
Angle of upper half-power point above horizon	69°	39°	22°
Angle of lower half-power point above horizon	18°	11°	7°
Front-to-back ratio (average)	14 db	16 db	17 db
Cross polarization (average)	-16 db	-18 db	-17 db
Optimum path length for F2 single hop (miles)	125 to 650	500 to 1000	800 to 1500

5.3.1.2 GAIN CHARACTERISTICS

An elevation-plane pattern for a reference dipole antenna is drawn with the elevation-plane patterns for the 237C, D, and E Antennas. This makes it possible to determine antenna gain with respect to a practical reference at any elevation angle. In each case, the reference antenna is placed at the height required to make the angle of the first lobe coincide with the angle of beam maximum for the specified antenna. The required heights of the reference antenna in wavelengths are given on each figure along with assumed ground conditions, and the frequency at which the pattern was determined. Average ground conditions with dielectric constant equal to 15 and conductivity equal to 10^{-2} mhos per meter are assumed. Gains at beam maximums as determined from these patterns are as follows:

ANTENNA	GAIN AT BEAM MAXIMUM	
	RELATIVE TO ISOTROPIC	RELATIVE TO REFERENCE DIPOLE
237C	11 db	4.5 db
237D	13.5 db	6 db
237E	15.5 db	9 db

Variation of maximum gain with frequency for the specified and reference antennas is shown in figure 18. In these plots the physical height of the reference dipole is changed to maintain the electrical height at the height required for coincidence of the direction of the first lobe and direction of beam maximum. As shown in these figures, the variation in gain of the 237C, D, and E with frequency is very small.

5.3.1.3 GENERAL CHARACTERISTICS

Dimensions and general structural details for the 237C, D, and E Antennas are given in figures 19, 20, and 21. All of the antennas are of the sloping-wire type and use steel towers for support.

Frequency ranges for each type, chosen with regard to FCC frequency allocations and propagation considerations, are given on the general layout drawings. Over their operating ranges, the antennas have a vswr of less than 2:1 and power handling capacity of 50 kw peak or 25 kw average. The average input impedance for the antennas is as follows:

237C - 150 ohms, unbalanced,

237D - 200 ohms, balanced,

237E - 300 ohms, balanced.

For installations requiring 50-ohm unbalanced input, wide-band balun transformers are available.

5.3.2 TYPE 237A GENERAL PURPOSE ANTENNAS

Collins Unidirectional Antennas 237A-1A, 237A-2, and 237A-3 are designed for operations requiring communications from one fixed site to mobile sites or several other fixed sites. Their moderate size permits mounting on a rotary pipe mast to provide 360 degrees azimuthal coverage. Since they are logarithmically periodic antennas, their radiation patterns and impedance characteristics are essentially independent of frequency through their particular operating range. They provide performance comparable to a three-element Yagi but over an extremely wide frequency range.

These antennas are composed of rigid aluminum elements, and aluminum and galvanized steel booms, as shown in figure 22. The elements are arranged in two planes of triangles, separated by an included angle of 37 degrees. The three structures vary in size to cover the 6.5- to 60-mc, 11.1- to 60-mc, and 19- to 60-mc frequency ranges, respectively. General dimensions of the antennas are given in the following table:

ANTENNA	FREQUENCY RANGE	LONGEST ELEMENT	BOOM LENGTH	OVER-ALL HEIGHT
237A-1A	6.5 to 58 mc	70 feet	52.5 feet	105 feet
237A-2	11.1 to 60 mc	46.8 feet	41.0 feet	84 feet
237A-3	19.0 to 60 mc	26.1 feet	24.5 feet	56 feet

Figure 23 is a typical azimuth-plane pattern for the 237A Antenna. The average azimuthal half-power beamwidth is approximately 65 degrees. The back lobes are more than 16 db down throughout the operating range.

Figure 24 shows elevation-plane patterns for various frequencies with average ground conditions. An elevation plane-pattern for a reference horizontal dipole is included on each plot. Dipole height required for the given reference pattern is shown with each drawing along with the assumed ground conditions.

The change in gain and vertical angle of beam maximum with frequency is shown in figure 25. The gain over average ground relative to an isotropic radiator varies from approximately 13.5 db to 14.5 db over the 6.5- to 30-mc range. Gain of the reference dipole is shown for comparison.

The characteristic impedance of these antennas is 150 ohms. However, the associated input coaxial line is tapered in steps to transform this impedance to 50 ohms. The vswr is less than 2 to 1 over the operating range of the antenna for the 237A-2 and 237A-3. The maximum vswr for the 237A-1 is 2.25 to 1 over its operating range. The vswr of the 237A-1 was compromised to this extent in order to achieve a low-frequency cutoff approximately 15 percent lower than is obtained conventionally with a structure of the same size. The peak power handling capacity of each antenna and associated transmission line is 50 kw.

5.3.3 TYPE 237B GENERAL PURPOSE ANTENNAS

The 237B-1 and B-2 Antennas are unidirectional log-periodic structures of the planar type, designed to cover the frequency range 6.5 to 40 mc and 13 to 40 mc. Dimensions and general construction features are shown in figure 26. Both types can be mounted on existing structures or can be supplied with a tower, rotator, and remote control unit. Although polarization generally is horizontal, they also may be mounted for vertical polarization. Compactness of the 237B-2 makes transportable applications possible and a special model, 237B-2X, is available for this purpose.

The impedance characteristics and radiation patterns are essentially constant throughout the particular operating range. Antenna input impedance is 50 ohms unbalanced. The vswr through each operating range does not exceed 2:1. Power handling capacity is 50-kw peak for the 237B-1 and 10-kw peak for the 237B-2.

Typical radiation patterns over average ground are given in figures 27, 28, and 29. The elevation patterns also include patterns for a reference dipole at the specified heights for direct gain comparisons at various elevation angles. Figure 30 shows the change in gain and vertical angle of beam maximum with frequency for both types of antennas. As shown, gain of the B-1 relative to an isotropic radiator over average ground is approximately 13.6 db, and gain of the B-2 is approximately 14 db.

5.3.4 TYPE 237N VERTICALLY POLARIZED ANTENNAS

The 237N-1 and 237N-2 Antennas are vertically polarized unidirectional log-periodic antennas which have frequency-independent radiation patterns and impedance characteristics over the frequency range of 2 to 30 and 4 to 30 mc. Throughout their frequency range, the antennas have an input vswr of less than 2:1 and an average front-to-back ratio of 18 db.

Figures 31 and 32 show typical elevation and azimuth plane patterns for the 237N-1 Antenna. A pattern for a reference quarter-wave monopole is included with the elevation plane pattern for comparison. The change in gain at beam maximum with frequency for the 237N-1 and quarter-wave monopole is shown in figure 33. As shown, gain of the 237N Antenna is approximately 7 db over a quarter-wave monopole throughout the operating range.

The moderate size and the moderate cost of the structures, in addition to the good performance characteristics over their respective bandwidths, make the antennas desirable for many applications. With the lower and upper half-power points of the vertical plane pattern located at 7 degrees and 40 degrees respectively, a station can communicate from very short distances to several hundred or several thousand kilometers without any significant loss in gain. Communication over short distances is by ground wave. Communication over long distances is established by sky-wave propagation. With the forthcoming minimum in the sun spot cycle when lower frequencies are necessary for communications, the 237N-1 and 237N-2 antennas will have considerably more gain at the lower frequencies than conventional rhombics.

Figure 34 is a drawing showing the 237N-1 Antenna and its supporting structure. Because of the length of the antenna, a support tower which also is an integral part of the radiating system is placed midway along the length. The support tower is not used on the 237N-2 Antenna.

The vertical conductors of the antenna are supported by a catenary which is suspended between a steel tower behind the antenna and a short wooden post in front of the antenna. Both the catenary and the guy wires used to support the wooden post are made of dacron rope. Due to the length of the guy wires which are needed to support the steel tower and to the eventual sag which the dacron rope will exhibit, conventional steel cables are used as support members. The appropriate guy wires are broken up with insulators to eliminate any adverse effect on the antenna performance.

As shown in figure 34, a series of boxes are connected to the antenna transmission line along its length. Each of these boxes contains a factory-tuned circuit that adjusts the phase of the currents in the radiating elements so that they produce frequency-independent unidirectional radiation characteristics and impedance properties.

The entire antenna structure is placed over a ground wire system that reduces earth current losses in the immediate neighborhood of the antenna. The ground system consists of individual wires that can either be buried or placed on top of the ground. Except in the area directly beneath the transmission lines, the ground need not be perfectly flat. A slope of within ±10 degrees of horizontal is considered satisfactory.

Dimensions of the 237N Antenna are given in the following table.

	237N-1	237N-2
Maximum Tower Height	141 feet	80 feet
Antenna Length	340 feet	180 feet
Length Between Extremes of Guy Wire Footings	580 feet	285 feet
Width Between Extremes of Guy Wire Footings	243 feet	139 feet

5.3.5 TYPE 237F-1 BILLBOARD ANTENNA

The radiation from a single dipole element can be made unidirectional by the use of a reflecting screen. This combination of reflecting screen and radiator is commonly referred to as a "billboard" antenna. The reflecting screen is normally made up of a curtain of equally spaced wires parallel to the dipole as shown in figure 35. With a single half-wave dipole spaced a quarter-wave from the screen, a gain of about 5.5 db over a free-space half-wave dipole can be realized. The half-power beamwidth in the plane of polarization is about 60 degrees with essentially no secondary lobes. More directivity and consequently higher gain can be achieved by using an array of dipoles in front of the screen. Billboard antennas with passive screens of practical dimensions provide good gains in the forward direction and suppression of backward radiation.

The Collins Type 237F-1 Antenna, shown in figure 36, is a horizontally polarized billboard antenna for operation through the 9- to 27-mc frequency range. The radiator consists of two vertically stacked broadband folded dipoles. The 237F-1 provides high gain at low angles of radiation, a characteristic desirable for long-range communication. The elevation plane patterns at 9, 15, and 25 mc are illustrated in figure 37 for an antenna height of 120 feet. In each case the pattern for a reference dipole at a specified height also is shown for comparison. Azimuth patterns for the same frequencies are given in figure 38.

The gain and angle of first lobe maximum as a function of frequency for an antenna height of 120 feet are shown in figure 39A. With this antenna height, the angle of first lobe maximum varies from 18 degrees at 9 mc to 6 degrees at 27 mc. Gain figures at various frequencies as determined from figure 39 for the 120-foot antenna are as follows:

FREQUENCY (mc)	GAIN RELATIVE TO ISOTROPIC RADIATOR	GAIN RELATIVE TO REFERENCE DIPOLE
9	14.5 db	7 db
15	17 db	9 db
25	16 db	8 db

The decrease in gain at higher frequencies results from the broader directional pattern caused by an increase in electrical distance between the radiator and reflecting screen. A 100-foot structure is available for applications requiring a higher angle of radiation, or where antenna height is limited to 100 feet. Change in gain and angle of first-lobe maximum for antenna height of 100 feet is shown in figure 39B.

On the basis of the vswr on the input line not exceeding 2 to 1, the input impedance of the 237F-1 Antenna remains satisfactory from 9 through 27 mc. Up to 28 mc and down to 8.8 mc, the maximum vswr is 2.5 to 1. Where a higher vswr may be tolerated, or where impedance matching techniques are used, the antenna may be operated beyond its normal range within the limits set by the desired directional pattern. The power handling capacity for the 237F-1 is 50 kw peak.

5.4 COLLINS OMNIDIRECTIONAL ANTENNAS

5.4.1 GENERAL THEORY OF OPERATION FOR DISCONE ANTENNAS

A discone antenna is a vertically polarized omnidirectional radiator. It is intended for use primarily where performance similar to that of a vertical dipole is desired but over a much wider frequency range. This type of antenna is used where large frequency range coverage and simplicity of design and installation are required. A properly designed discone will operate over a frequency range of approximately 3 to 1 without appreciable change in input impedance or directional characteristics. It requires no tuning or matching networks.

The general structure of a discone antenna is shown in figure 40. The basic discone consists of a disc, connected to the inner conductor of the coaxial feed line, and a cone which is common to the outer conductor of the coaxial feed line. The disc, or hat as it is often called, is perpendicular to and symmetrical with the axis of the cone.

For a given height above ground, the more important parameters of discone design are the cone angle, slant height of the cone, and the diameter of the disc. The input impedance is determined chiefly by the effective cone angle and slant height which is the parameter L in figure 40. Slant height determines the low-frequency end of antenna operation. At the low-frequency end of antenna operation, L is approximately a quarter wavelength. Below this frequency, the discone behaves somewhat like a high-pass filter in that it has an effective cutoff frequency beyond which the input impedance is no longer satisfactory. As a result, a high standing-wave ratio appears on the feed line. Above the cutoff frequency, however, the antenna input impedance is matched to that of the line, and this condition exists over an extremely wide frequency range. Vertical plane pattern performance, for a given height above ground, depends primarily on the effective cone angle. The upper frequency limit of antenna operation is determined by deterioration of the vertical plane pattern. Therefore, unsatisfactory vertical plane pattern characteristics usually limit the high-frequency end of antenna operation.

The diameter of the disc is not as critical as the cone angle and slant height. Experiments have indicated that for a 50-ohm feed system, a hat diameter of approximately 0.7, that of the base of the cone, is adequate. For a given slant height therefore, the diameter of the disc depends somewhat upon the cone angle. Effective cone angles from 50 to 90 degrees are common.

Since dimensions of the disc and cone are an appreciable part of a wavelength at the lowest operating frequency, it is impractical to construct the antenna from solid surface conduction material. Instead, for hf application, these surfaces are simulated with tubular and wire elements as illustrated in figure 41. This type of structure causes the effective cone angle to be somewhat less than the physical angle which is compensated for by other factors in antenna design.

Discone antennas designed for use at the higher frequencies normally are installed with the hat elevated above the cone. Figure 41 illustrates this method of construction. At lower frequencies in the hf region, the hat is too large to be supported in this manner. As the frequency range is lowered and the hat size increases, it becomes more practical to invert the discone as shown in figure 42. This type construction essentially places the disc at ground level. The cone is supported by a cable strung between wooden poles. Considering proper design of antenna parameters, the operating characteristics of the inverted discone are comparable to those of the conventional upright or elevated discone. Since the inverted discone is at ground level, it will exhibit somewhat higher angles of radiation than the elevated type structure.

5.4.2 TYPE 237H DISCONE ANTENNAS

Collins 237H-1 and 237H-2 Antennas are vertically polarized omnidirectional antennas of the discone type designed for operation through the frequency ranges of 6.5 to 25 mc and 10 to 30 mc, respectively. A transportable version, the 237H-1X, also covers the 6.5- to 25-mc range. The 237H-1 and 237H-1X Antennas may be operated well above 25 mc if some vertical plane pattern degradation can be tolerated.

As shown in figure 43, the 237H Antennas are designed conventionally with the disc located above the apex of the cone. The cone consists of wire elements which also serve as guys for the supporting tower. Below the active portion of the cone, the guy wires are broken electrically with guy insulators so that normal behavior of the antenna is not affected. The disc consists of self-supporting tubular elements insulated from the tower and guys. The actual radiator therefore is at an appreciable height above ground. This results in a large amount of desirable low-angle radiation.

The azimuth plane pattern for each type is omnidirectional to within ±0.5 db. In the elevation plane, the directional patterns are dependent, to a large extent, upon the effective height of the antenna above ground and the electrical properties of the ground in the vicinity of the antenna. Elevation plane patterns for each of the antenna types at several representative frequencies and with average ground conditions are illustrated in figures 44, 45, and 46. A reference pattern is included in each plot for gain comparisons. The reference antenna is a quarter-wave monopole fed against a ground system consisting of 60 quarter-wave radial wires.

The 237H Antennas may be fed directly with standard 50-ohm coaxial lines. The vswr does not exceed 2:1 over the quoted frequency ranges and remains satisfactory to frequencies much higher than 30 mc. Power-handling capacity for the 237H-1 and H-2 is 50-kw peak. The transportable 237H-1X is capable of handling 20-kw peak.

5.4.3 TYPE 237G-1 AND 237G-2 DISCONE ANTENNAS

The Collins 237G-1 and 237G-2 Antennas are vertically polarized inverted discone types designed to operate in the lower portion (2 to 11 mc and 3 to 16 mc) of the high-frequency range.

Figure 47 shows the important dimensions and general structure of the 237G type antennas. The structures are simple in design and do not require baluns or impedance transforming devices. The cone, elevated above the disc, consists of wire elements supported by a catenary cable strung between eight equally spaced wooden poles arranged in the form of an octagon. Ground radials which constitute the disc run at a gradual taper from an elevated platform at the center of ground. The antenna is fed unbalanced at the top of the five-foot high platform with standard 50-ohm coaxial transmission line. Coaxial fittings (3-1/8 inch diameter) are provided at the feed point of the structure so that r-f power up to 50 kw may be applied.

Coverage in the azimuth plane is essentially omnidirectional through the operating range of each type of antenna. Elevation patterns depend upon ground characteristics in the vicinity of the antenna. Elevation plane patterns at several representative frequencies over average ground are illustrated in figures 48 and 49. A reference pattern is included in each plot for gain comparison. The reference antenna is a quarter-wave monopole fed against a ground system consisting of 60 quarter-wave radial wires.

The average input impedance is approximately 50 ohms. The vswr on the 50-ohm line does not exceed 2:1 over the operating band and remains satisfactory at frequencies well above the specified upper limit. However, at these higher frequencies the vertical plane patterns deteriorate rapidly, resulting in a large number of high angle secondary lobes.

5.4.4 TYPE 237W ANTENNAS

Collins 237W-1 and 237W-1X are vertically polarized omnidirectional antennas designed to cover the following frequency ranges.

237W-1	2.5 to 30 mc
237W-1X	3.5 to 30 mc

Dimensions and general construction features are shown in figures 50 and 51. Each antenna combines an elevated discone for the higher frequencies with a folded cage monopole covering the lower frequencies. The discone is fed unbalanced at the top of the supporting column. The cage is fed unbalanced against a ground screen at the base of the column. A switching system is employed to select either the discone or monopole mode of operation. Gain for both antennas in the monopole mode is comparable to a quarter-wave monopole, and gain in the discone mode is comparable to a half-wave vertical dipole at the same height above ground. The 237W-1 is designed for fixed-station operation and is capable of handling r-f power up to 50 kw. The 237W-1X is designed for transportable operation and may be erected in the field without heavy equipment. It will handle r-f power up to 10 kw. Input impedance is 50 ohms unbalanced and the vswr does not exceed 2:1 over the specified ranges.

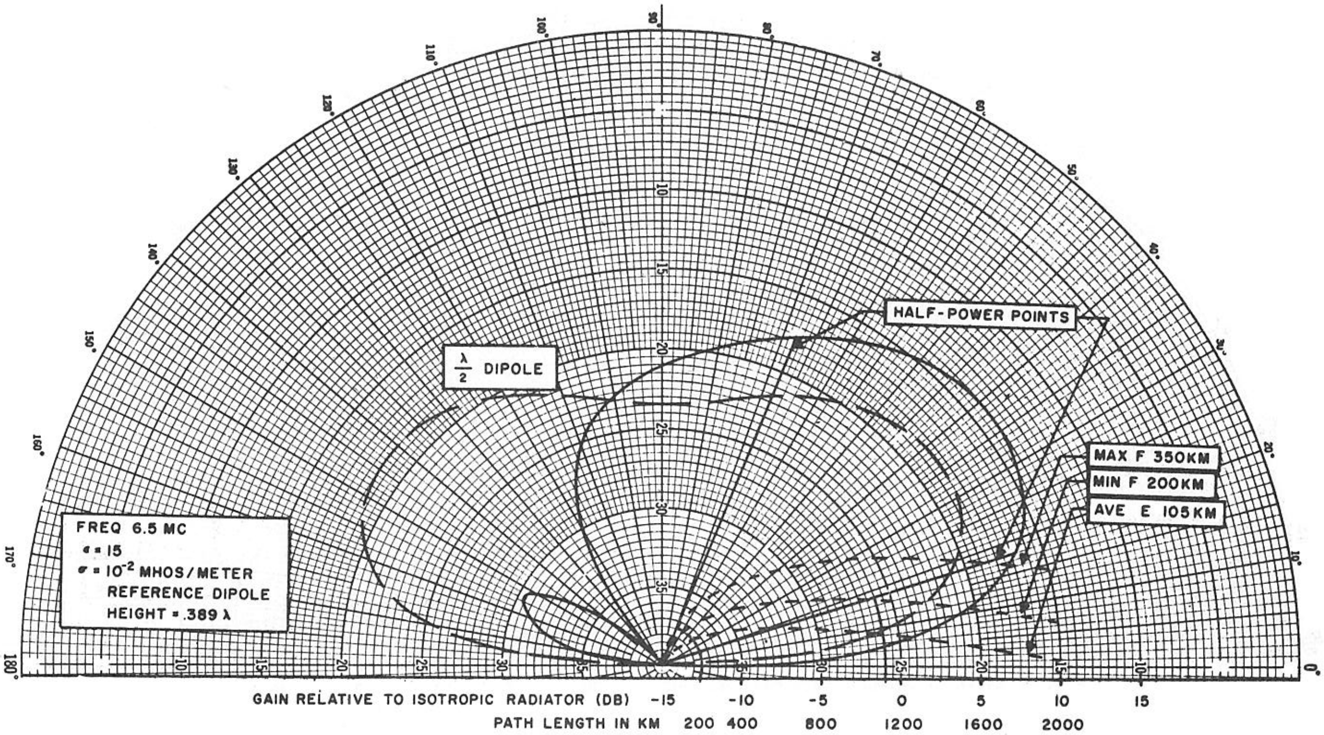


Figure 12. Elevation Plane Pattern, 237C Antenna

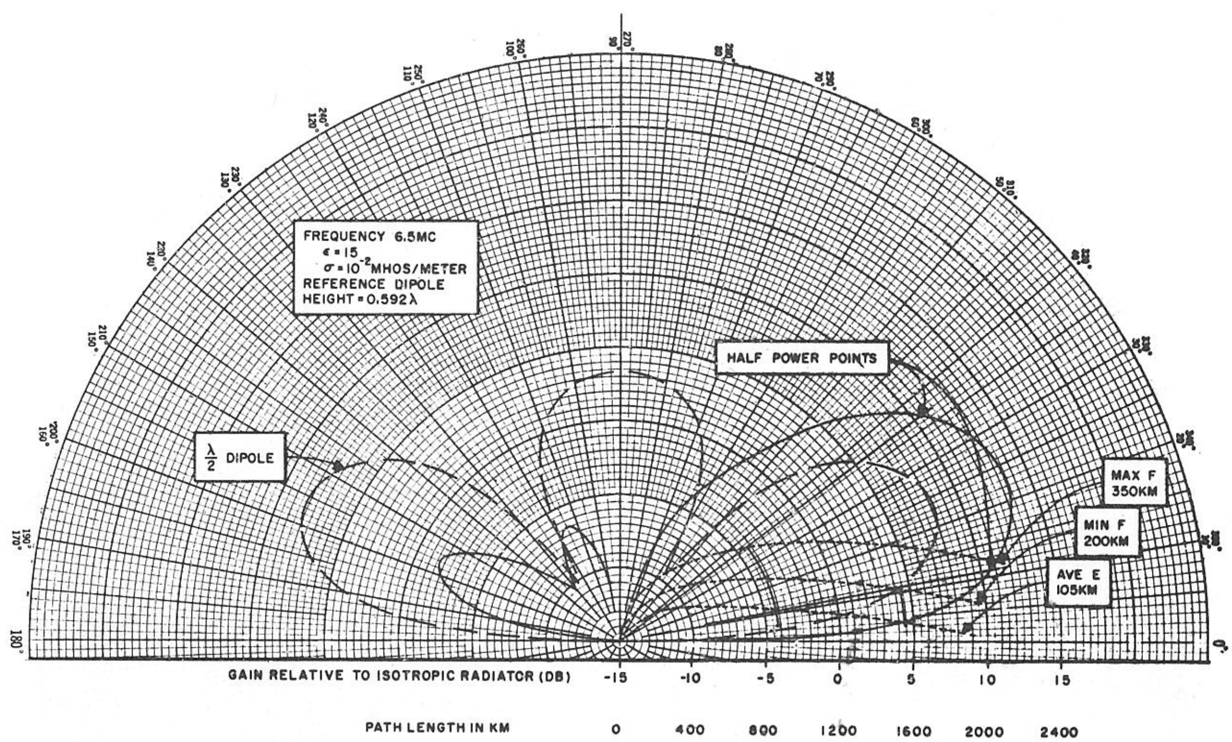


Figure 13. Elevation Plane Pattern, 237D Antenna

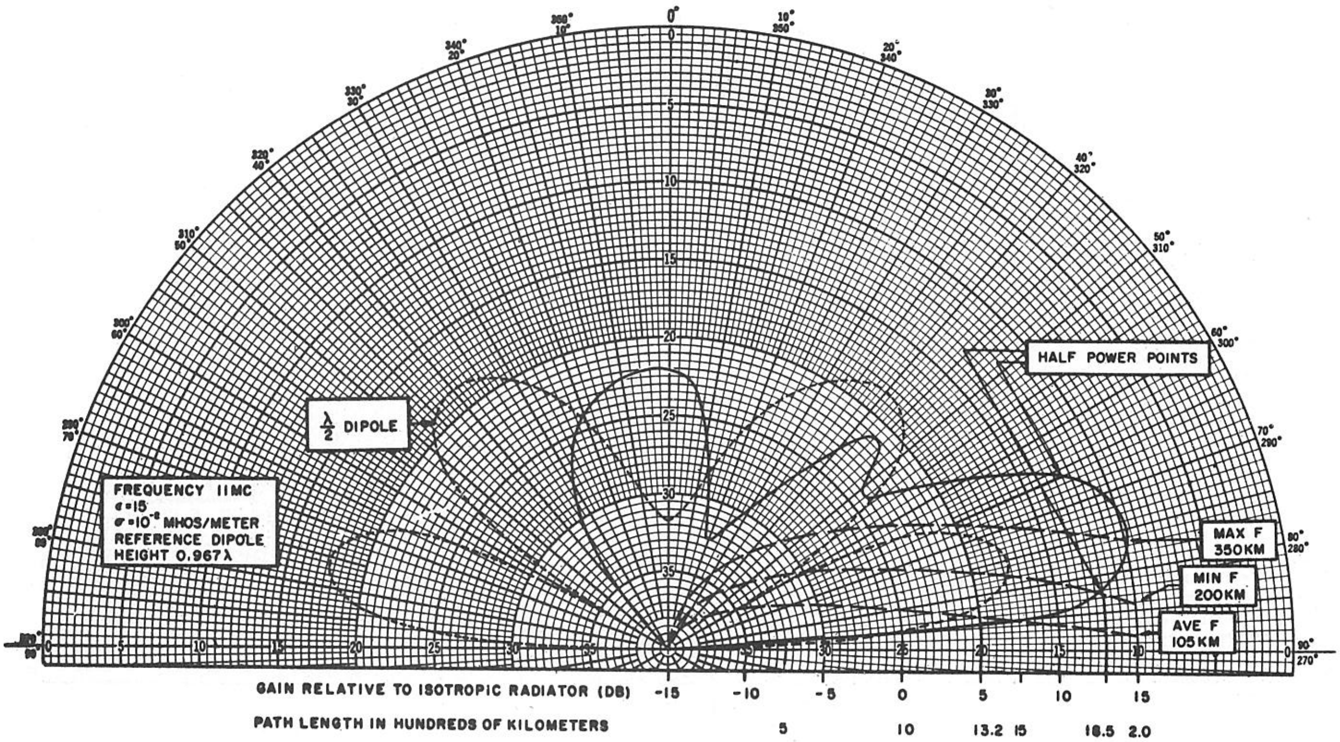


Figure 14. Elevation Plane Pattern, 237E Antenna

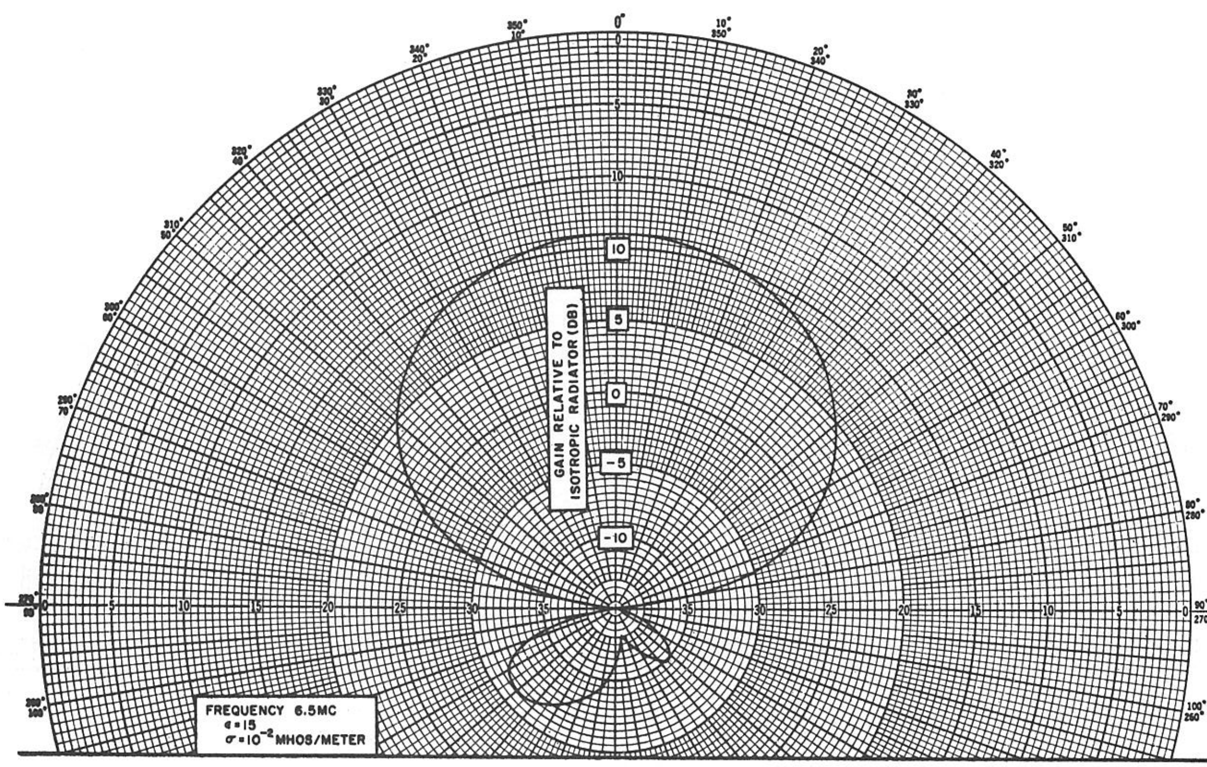


Figure 15. Azimuth Plane Pattern, 237C Antenna

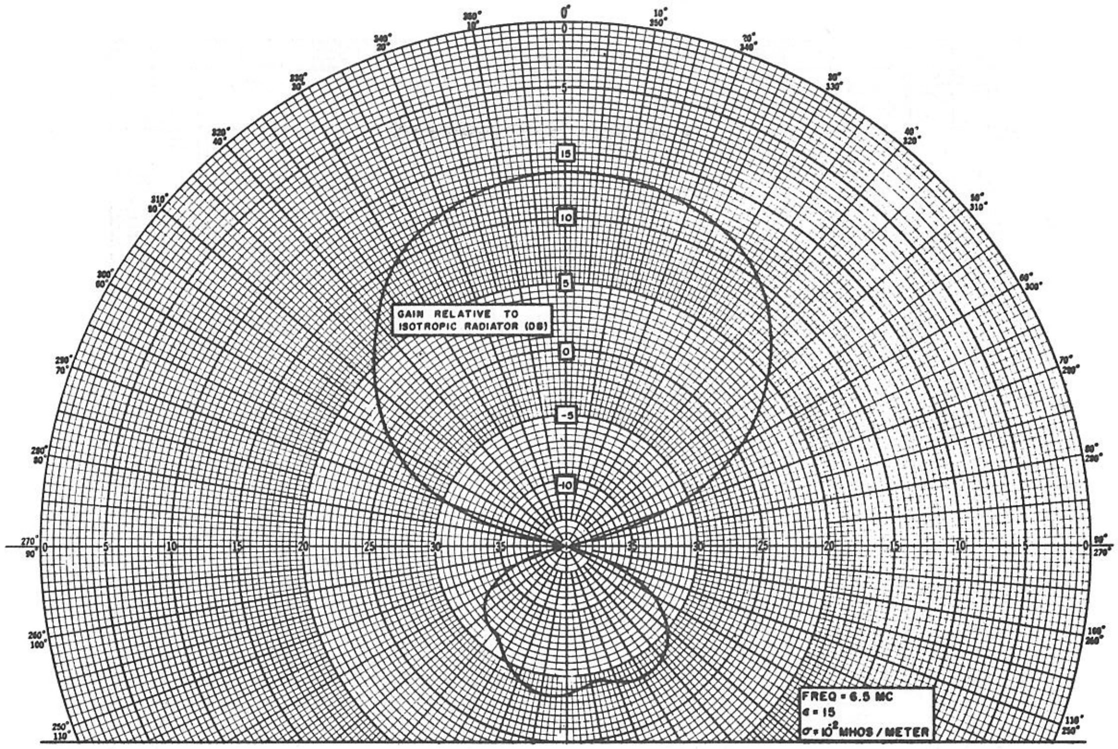


Figure 16. Azimuth Plane Pattern, 237D Antenna

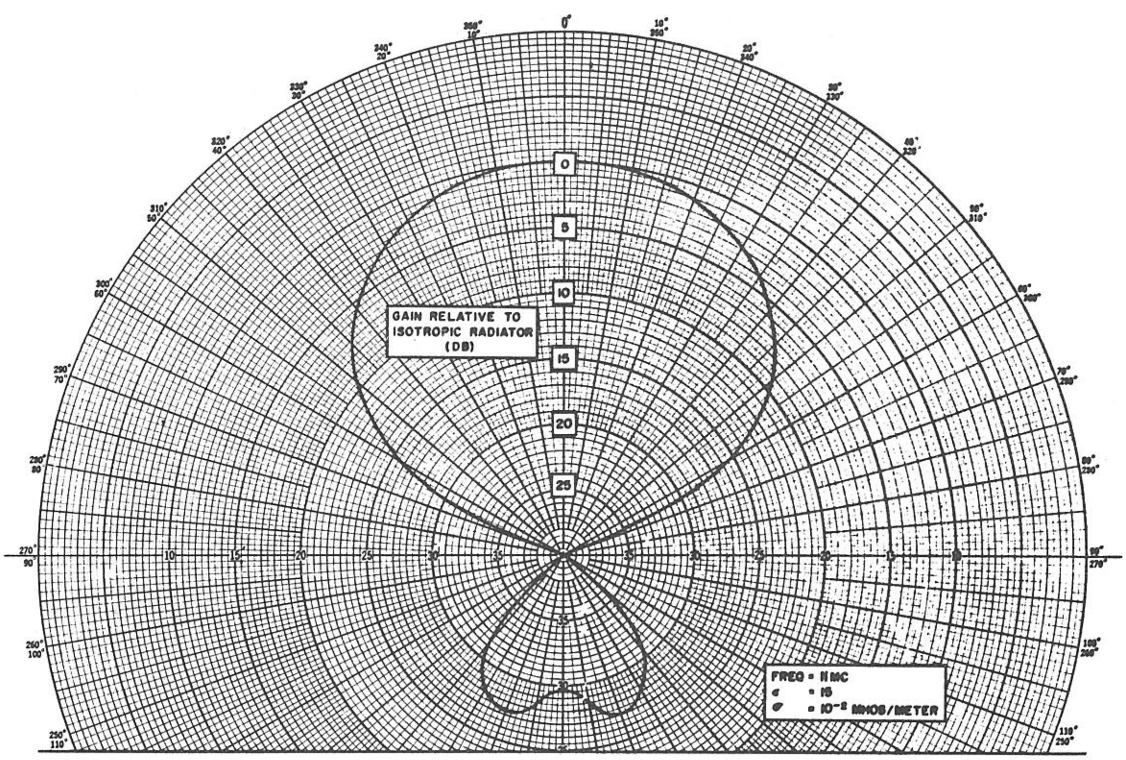


Figure 17. Azimuth Plane Pattern, 237E Antenna

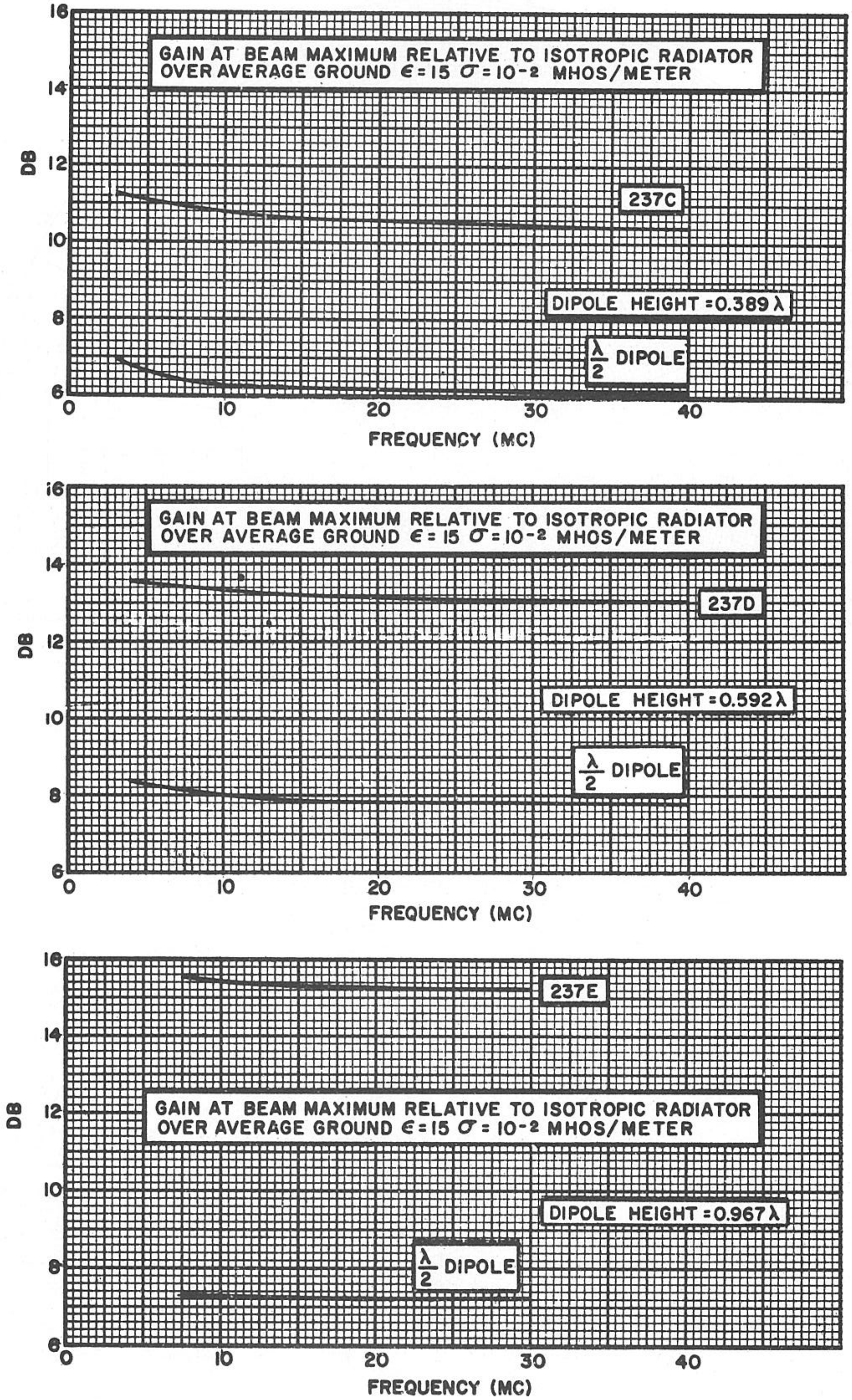
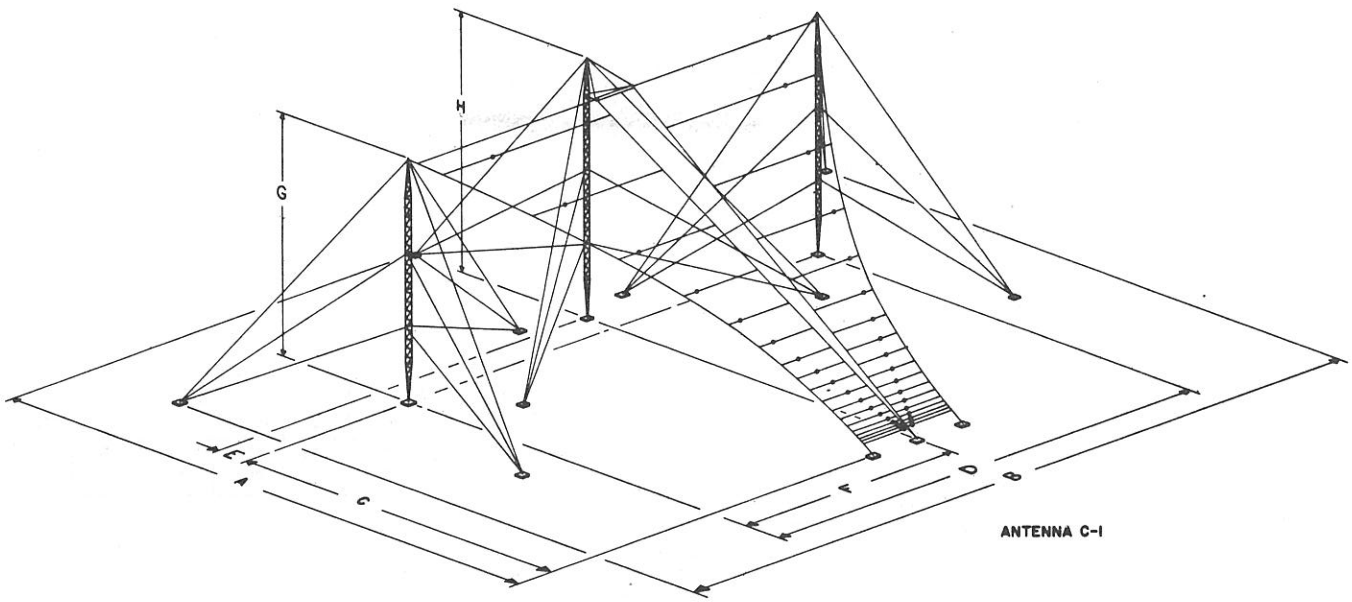


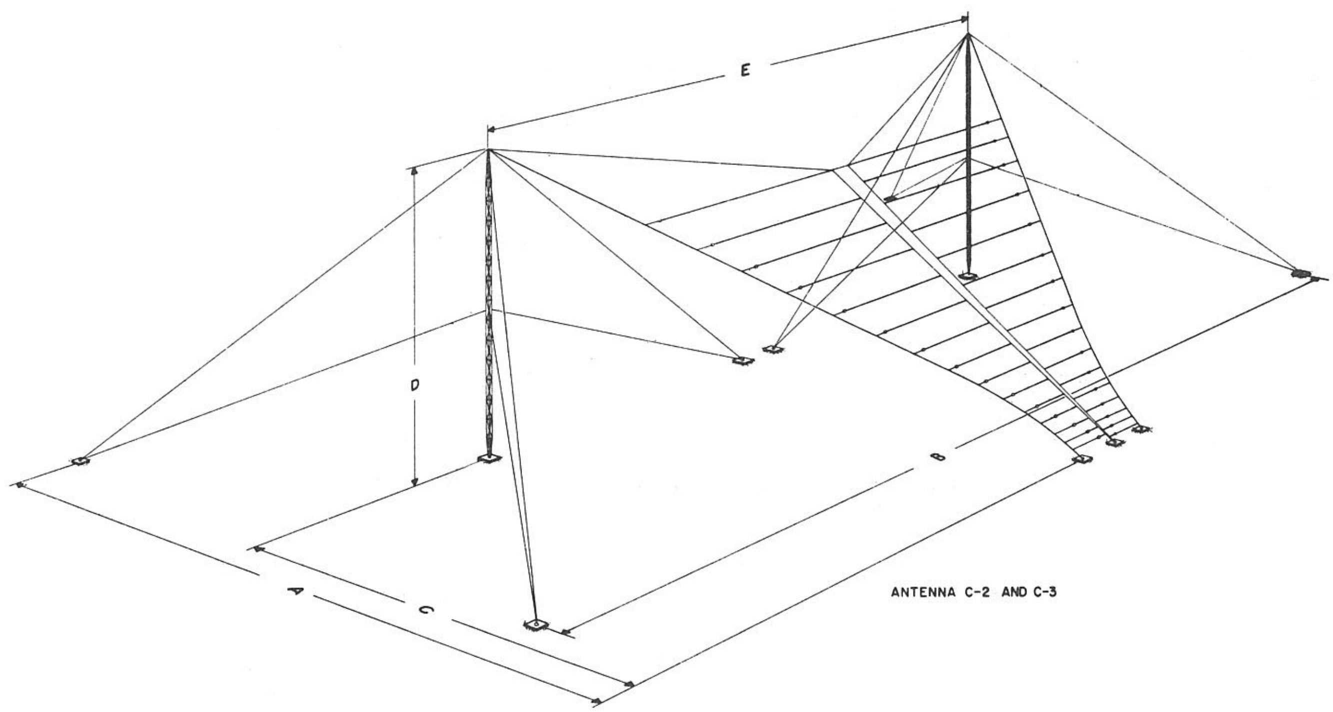
Figure 18. Gain at Beam Maximum Vs Frequency, 237C, D, and E Antennas



TYPE	FREQ (MC)
237C-1	3-40

DIMENSIONS IN FEET							
A	B	C	D	E	F	G	H
286	363	173	234	15	117	130	140

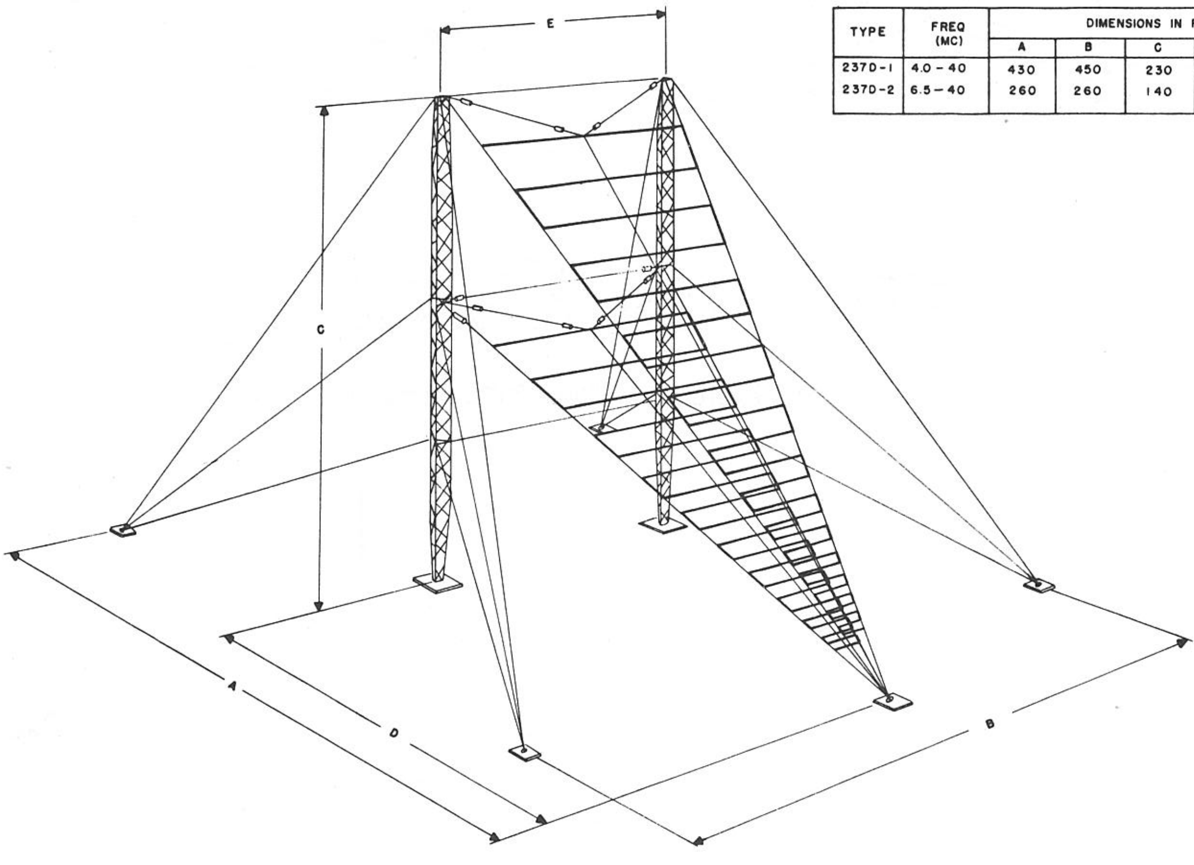
Figure 19A. Dimensions for Type 237C Antennas



TYPE	FREQ (MC)
237C-2	4-40
237C-3	6.5-40

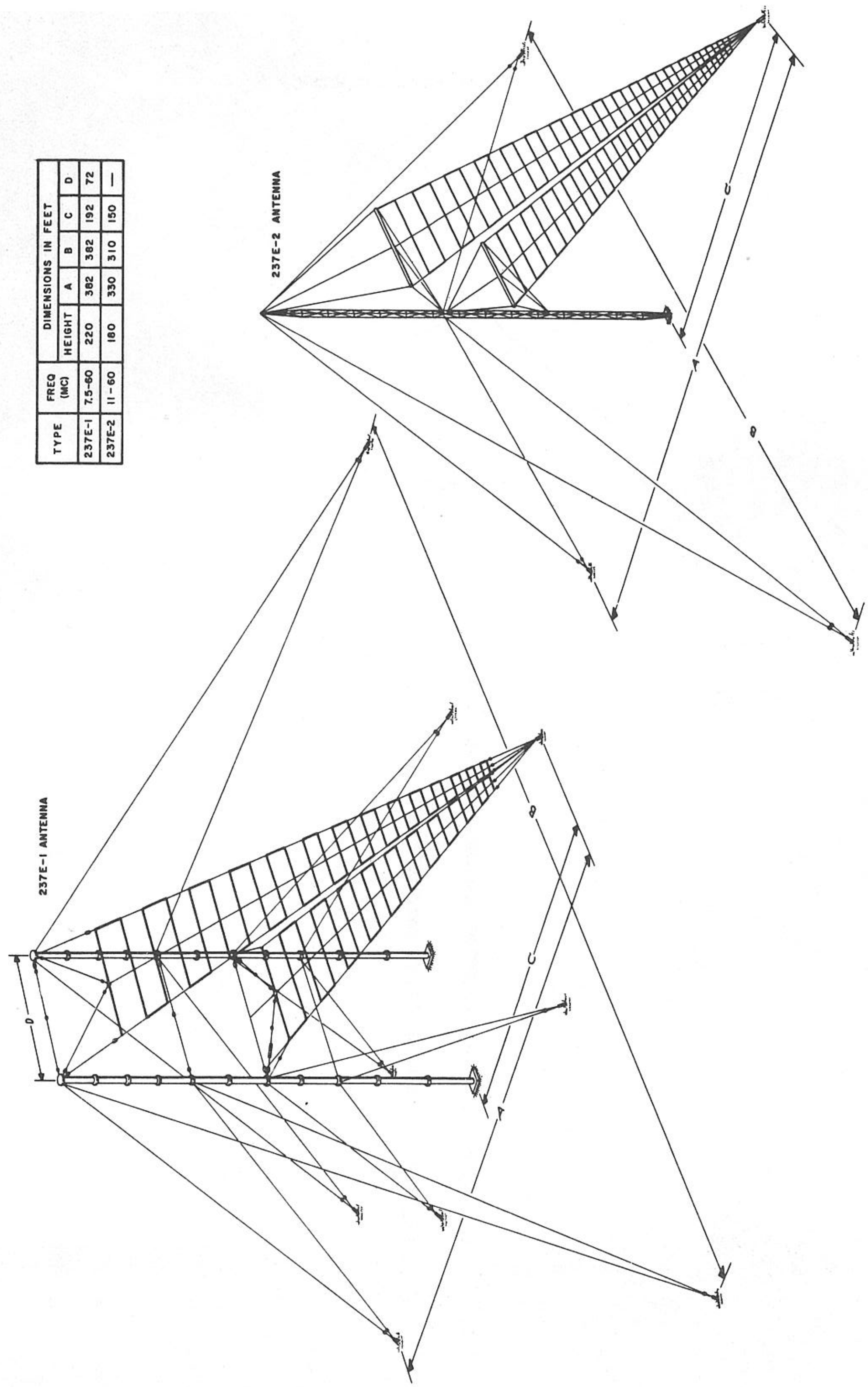
DIMENSIONS IN FEET				
A	B	C	D	E
265	330	160	120	207
176	240	106	80	123

Figure 19B. Dimensions for Type 237C Antennas



TYPE	FREQ (MC)	DIMENSIONS IN FEET				
		A	B	C	D	E
237D-1	4.0 – 40	430	450	230	230	130
237D-2	6.5 – 40	260	260	140	140	75

Figure 20. Dimensions for Type 237D Antennas



TYPE	FREQ (MC)	DIMENSIONS IN FEET				
		HEIGHT	A	B	C	D
237E-1	7.5-60	220	382	382	192	72
237E-2	11-60	180	330	310	150	—

Figure 21. Dimensions for Type 237E Antennas

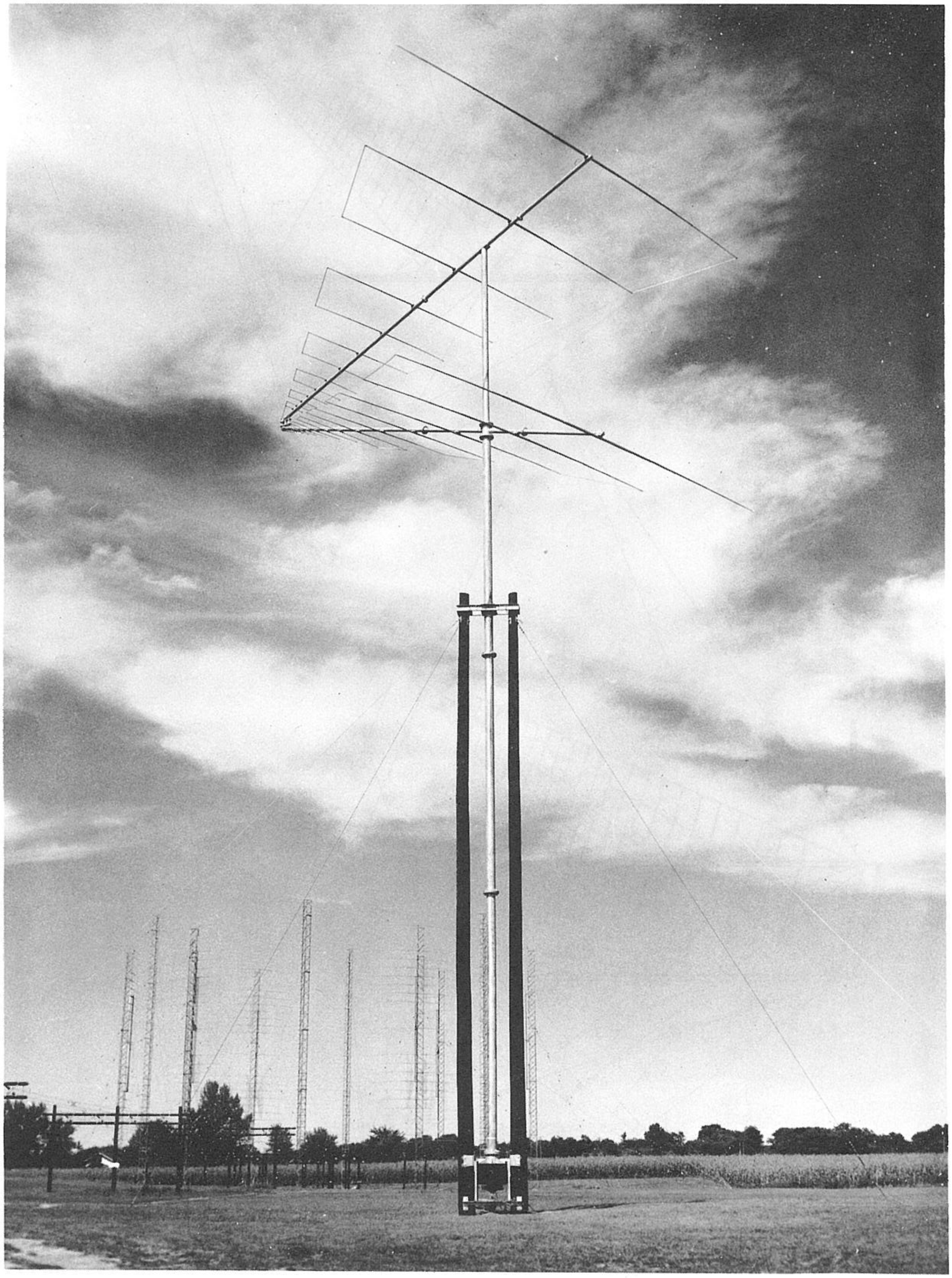


Figure 22. 237A-1 Antenna

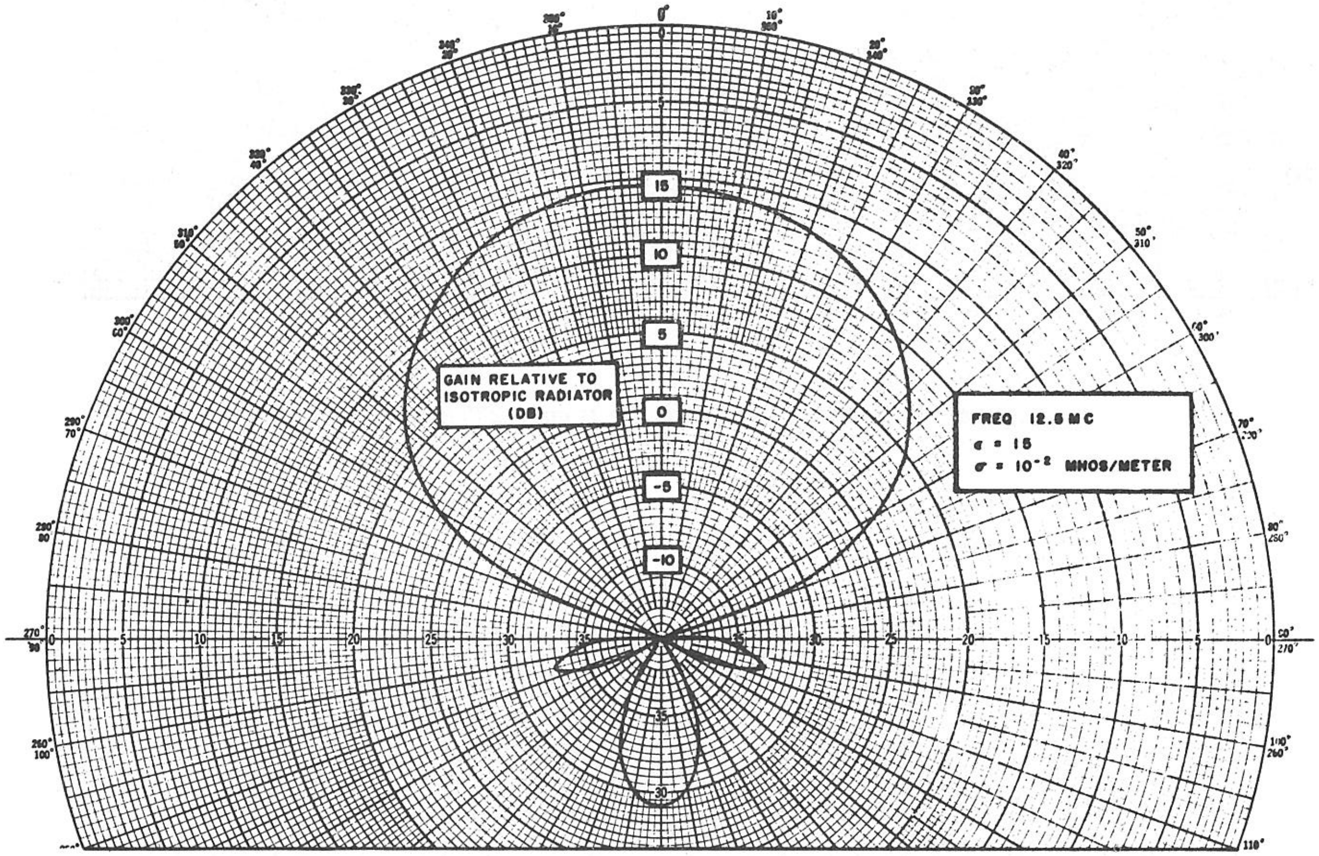


Figure 23. Typical Azimuth Plane Pattern, 237A-1A Antenna

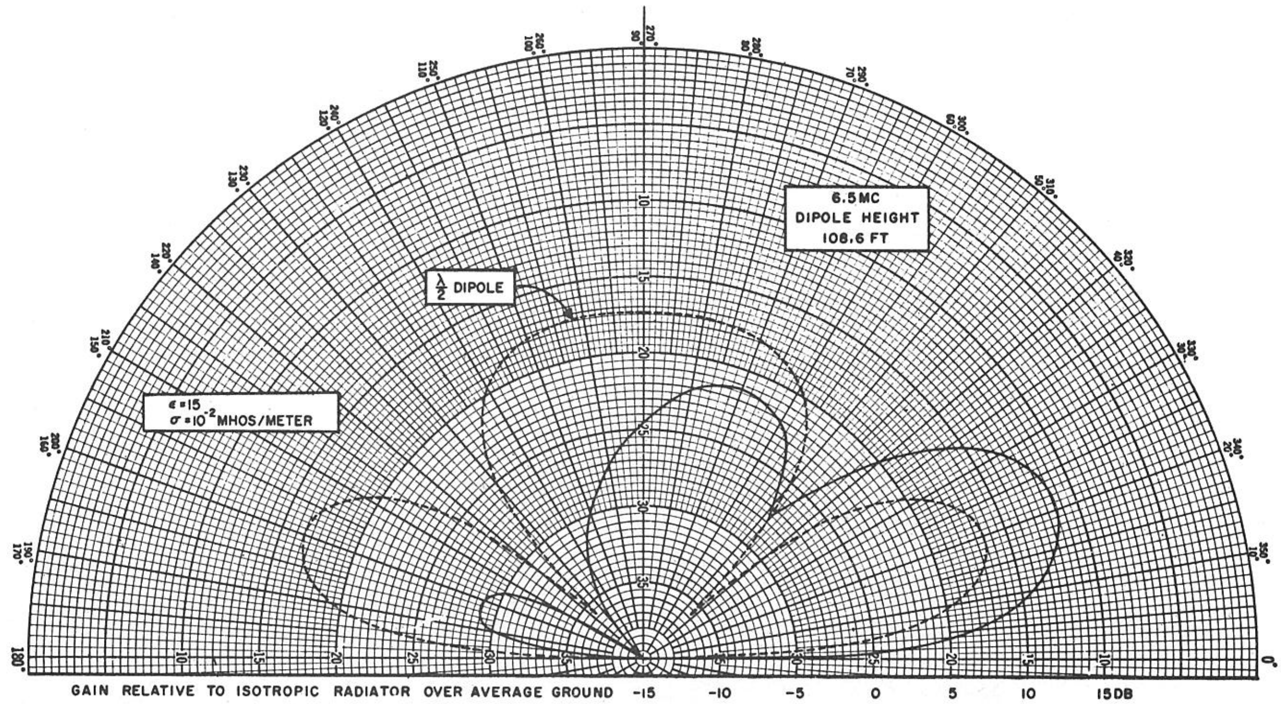


Figure 24A. Elevation Plane Patterns, 237A-1A Antenna

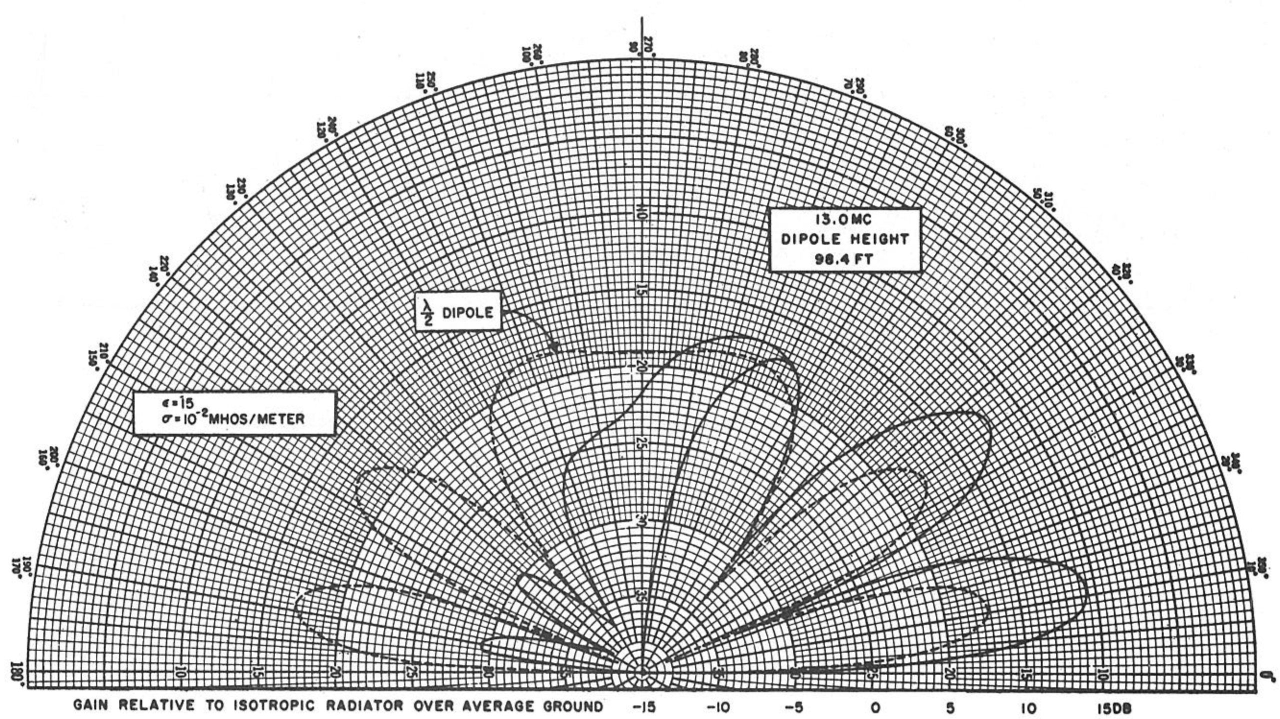


Figure 24B. Elevation Plane Patterns, 237A-1A Antenna

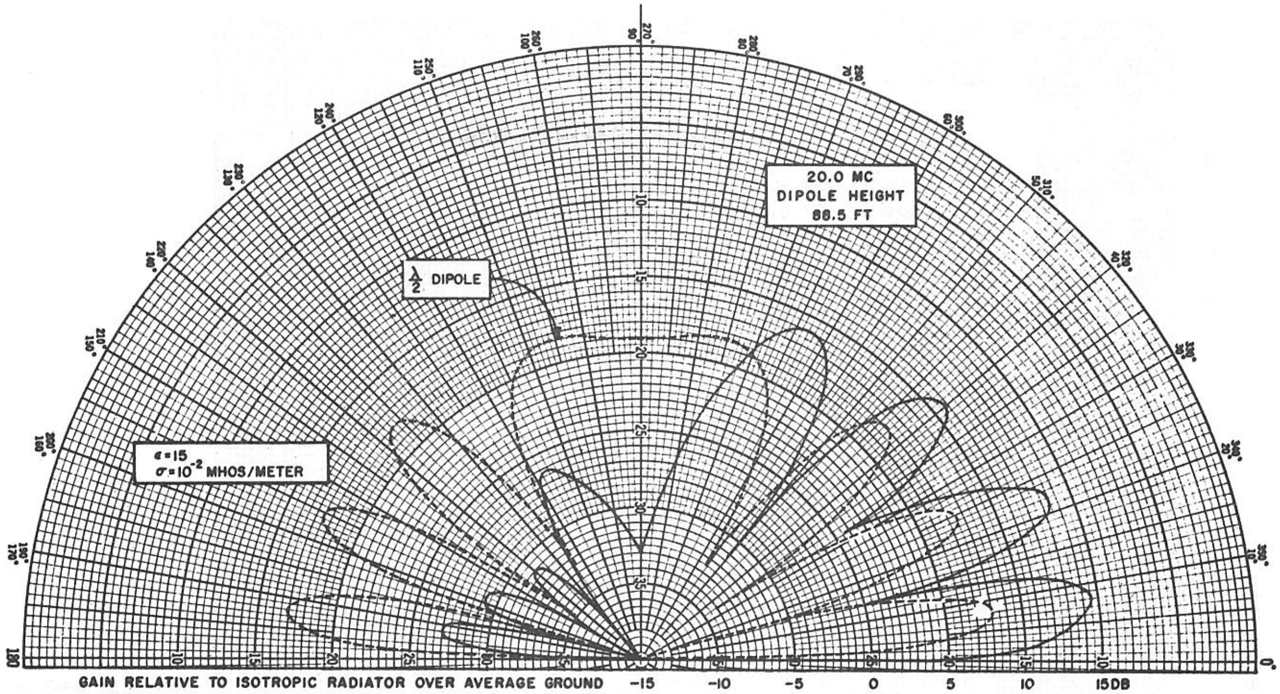


Figure 24C. Elevation Plane Patterns, 237A-1A Antenna

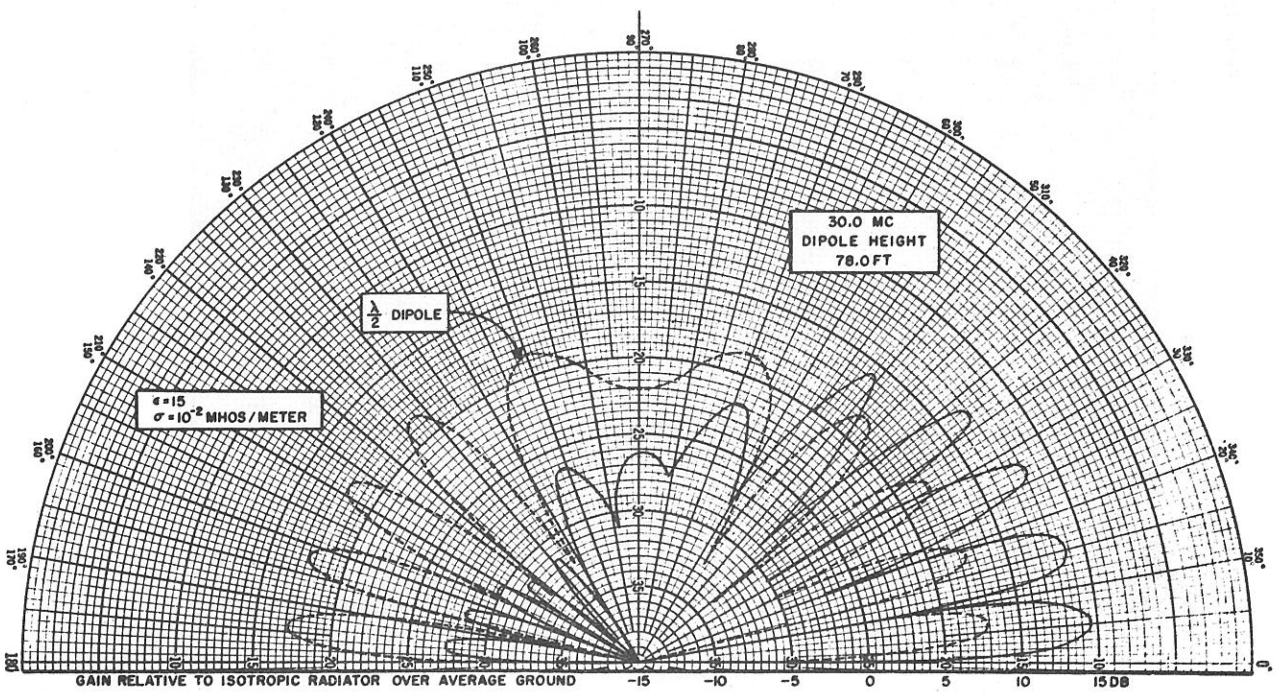


Figure 24D. Elevation Plane Patterns, 237A-1A Antenna

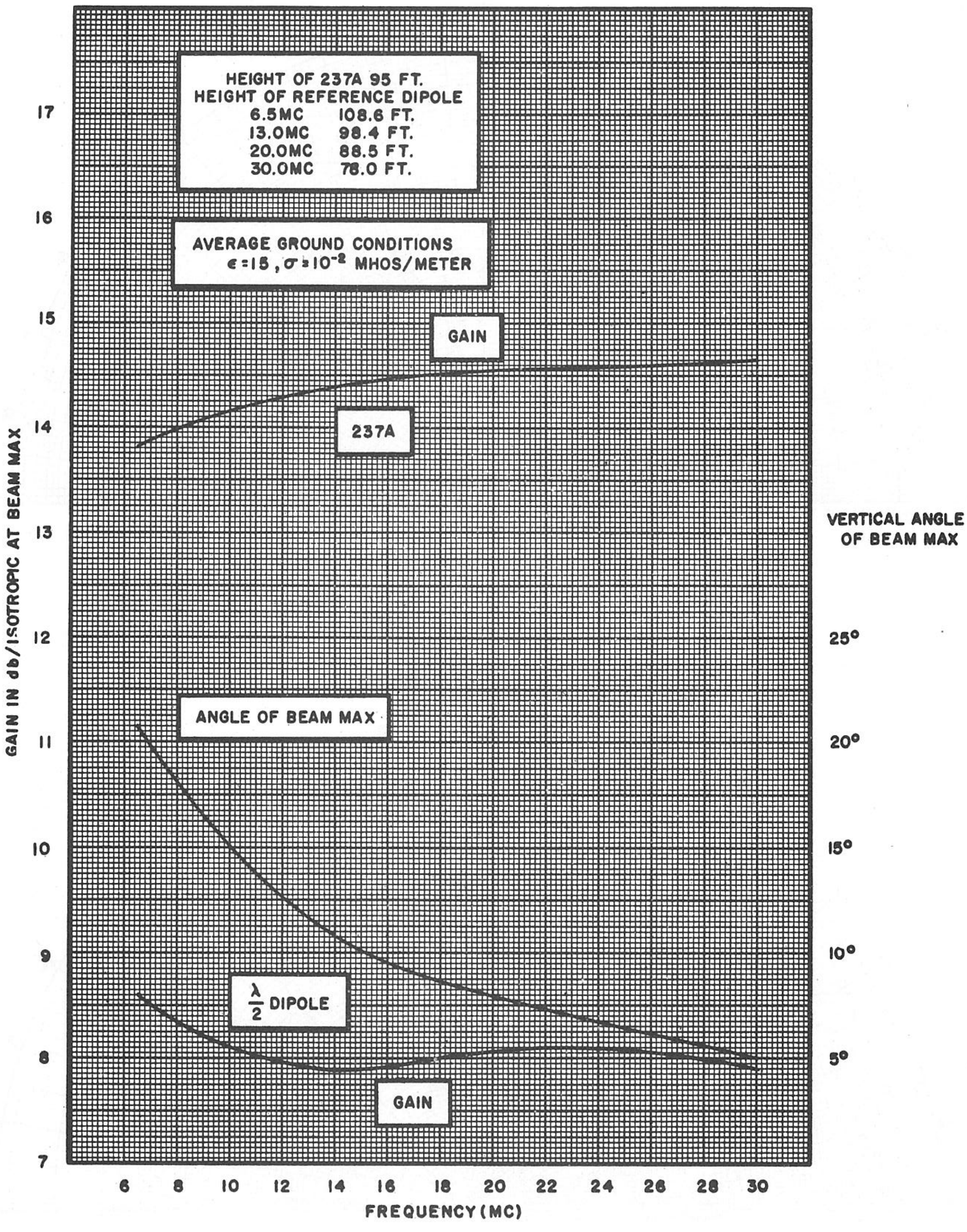


Figure 25. Change in Gain and Vertical Angle of Beam Maximum with Frequency, 237A Antenna

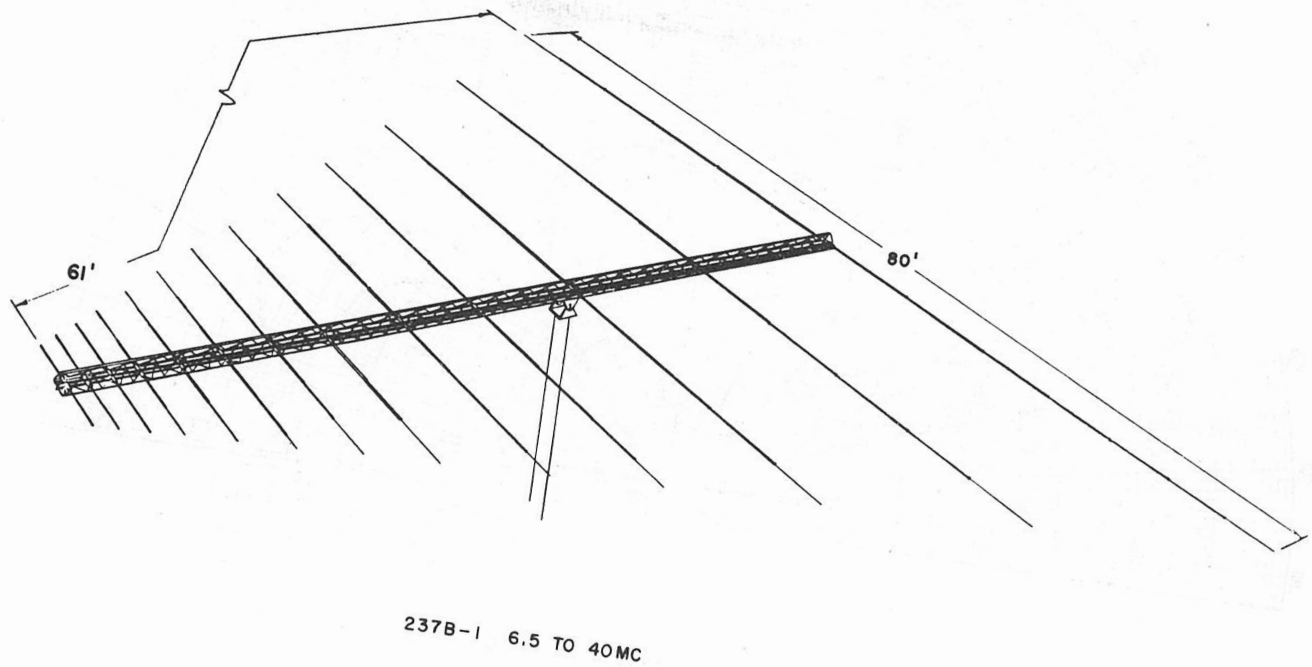


Figure 26A. Dimensions for Type 237B Antennas

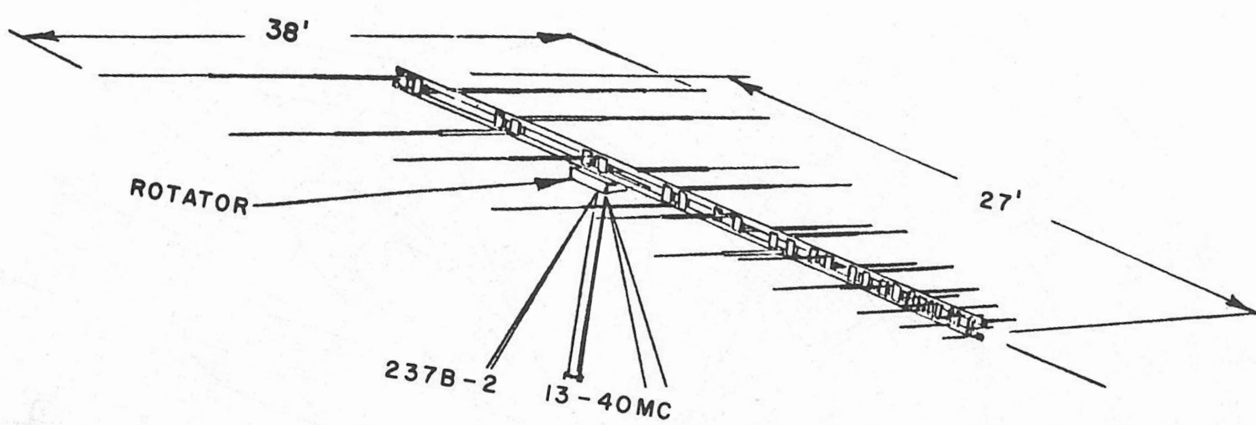


Figure 26B. Dimensions for Type 237B Antennas

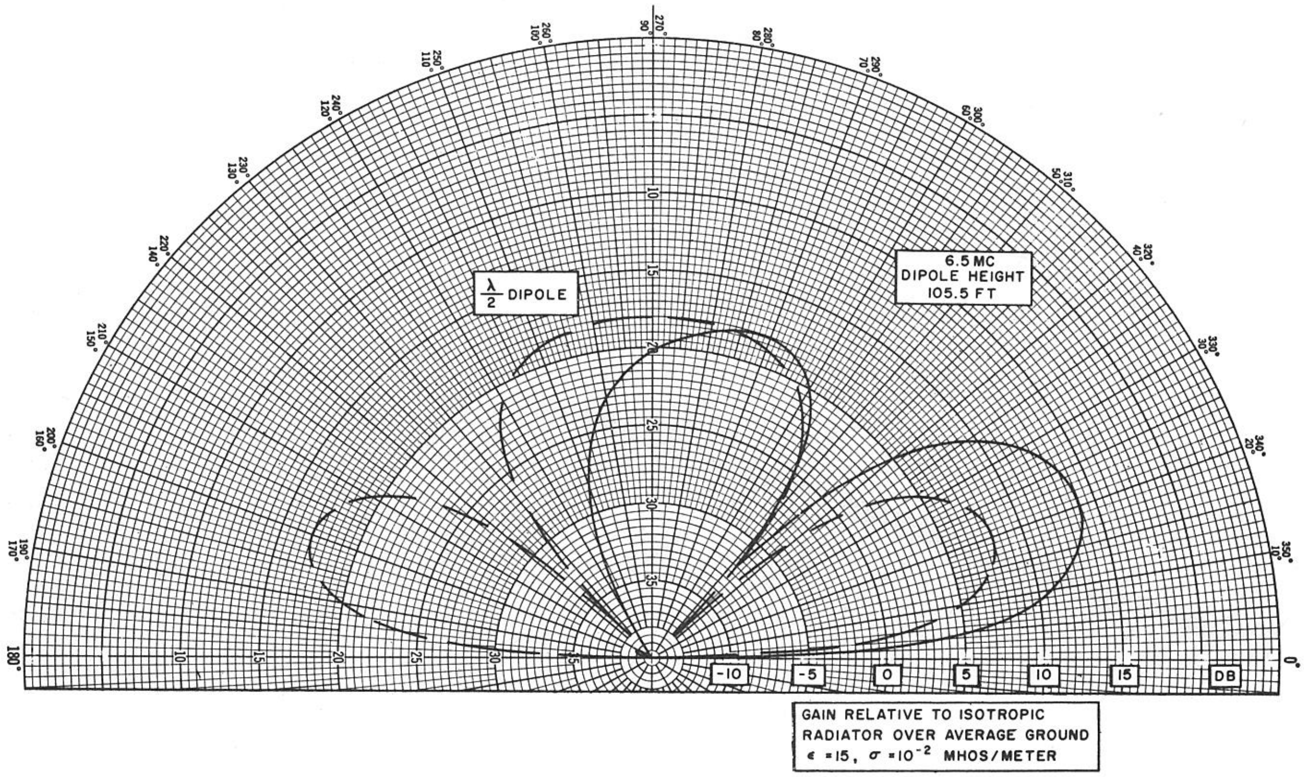


Figure 27A. Elevation Plane Patterns, 237B-1 Antenna

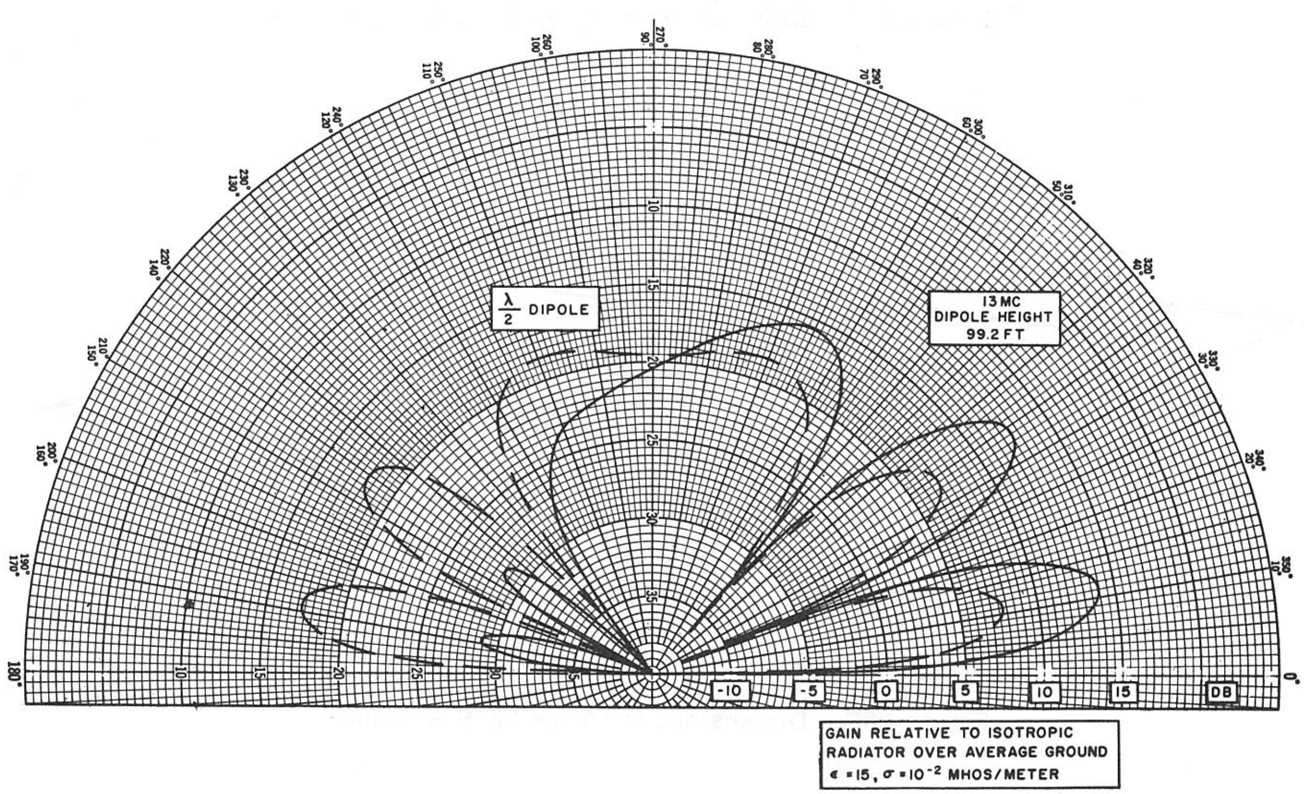


Figure 27B. Elevation Plane Patterns, 237B-1 Antenna

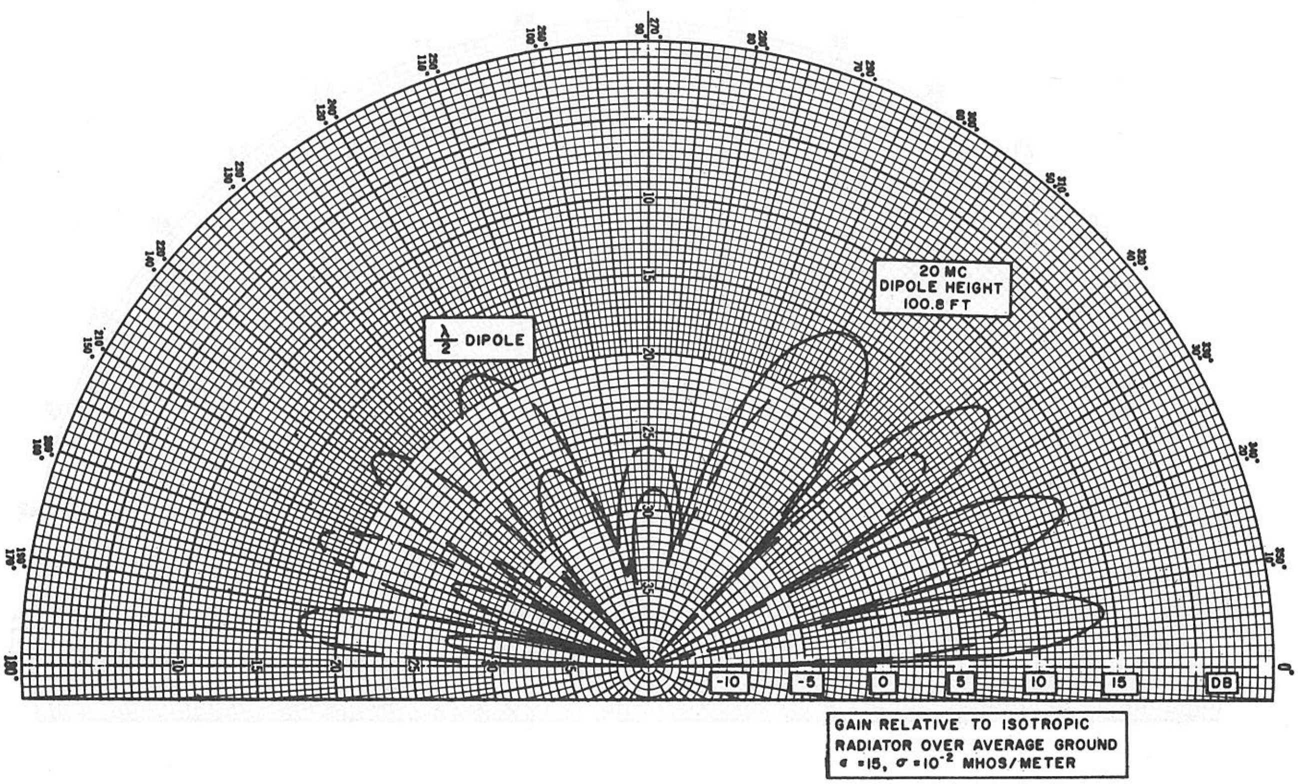


Figure 27C. Elevation Plane Patterns, 237B-1 Antenna

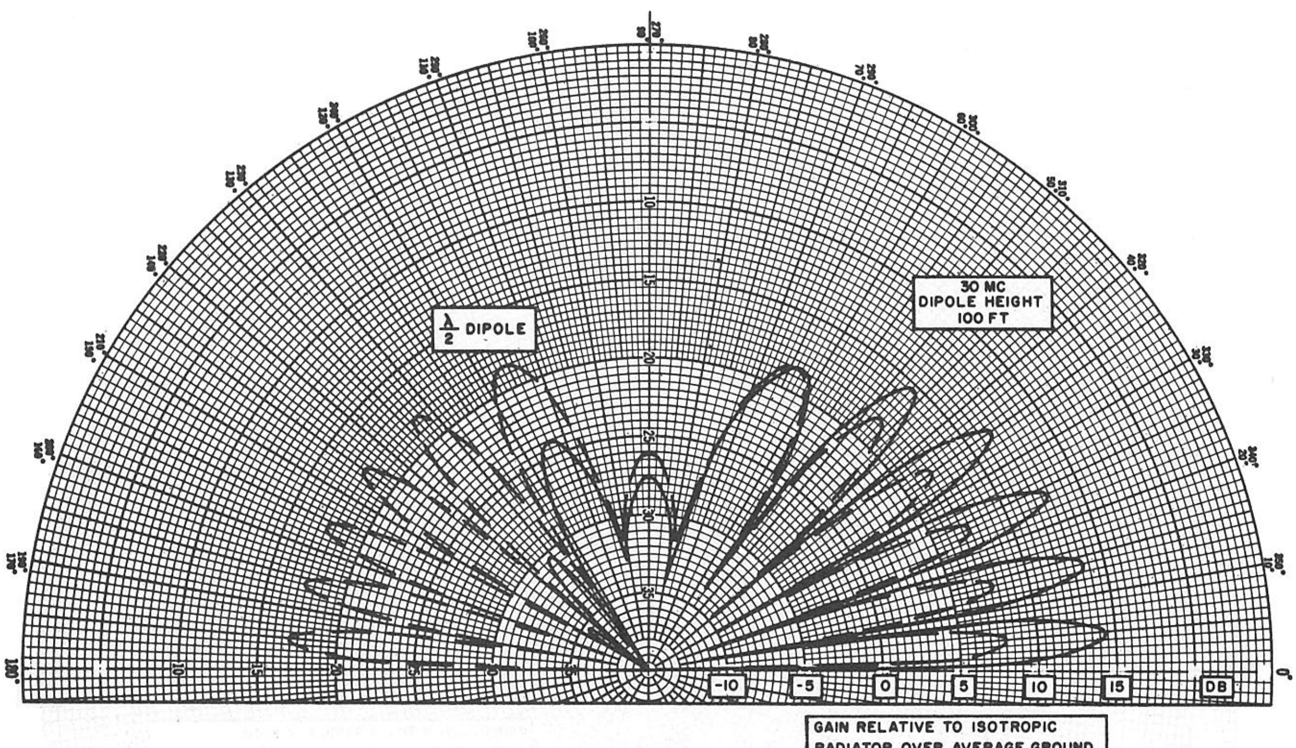


Figure 27D. Elevation Plane Patterns, 237B-1 Antenna

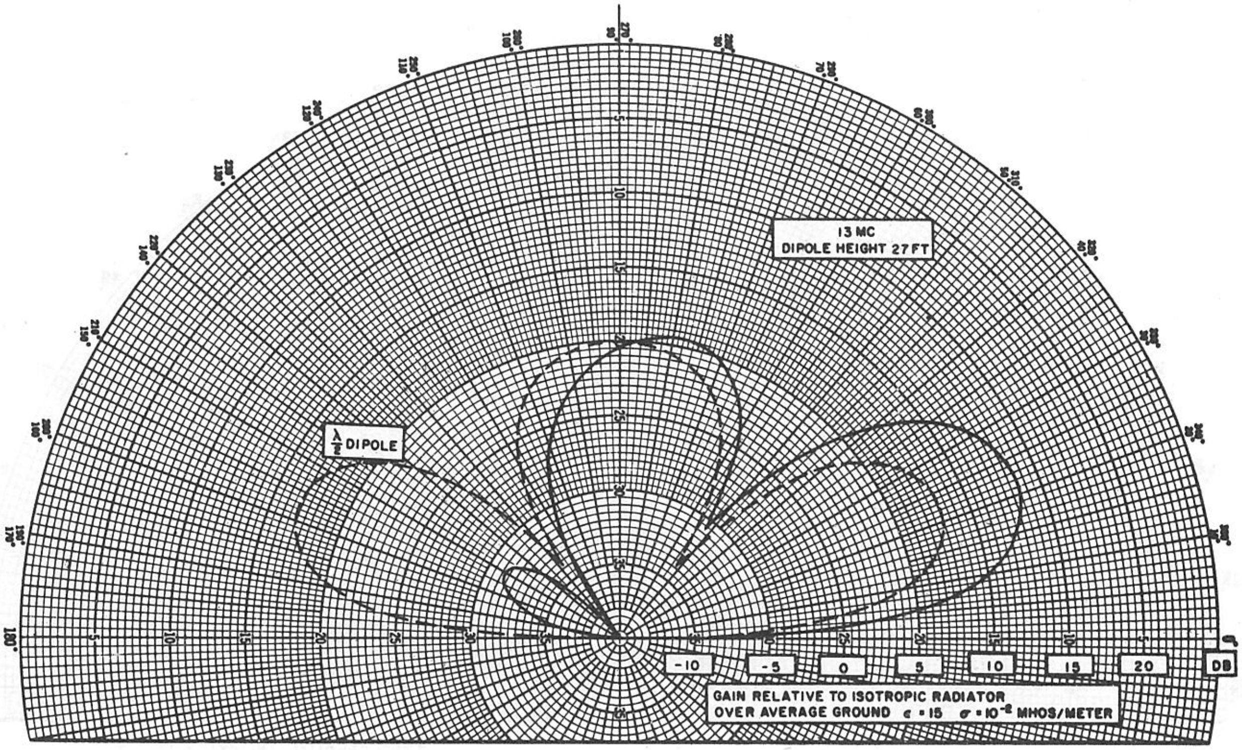


Figure 28A. Elevation Plane Patterns, 237B-2 Antenna

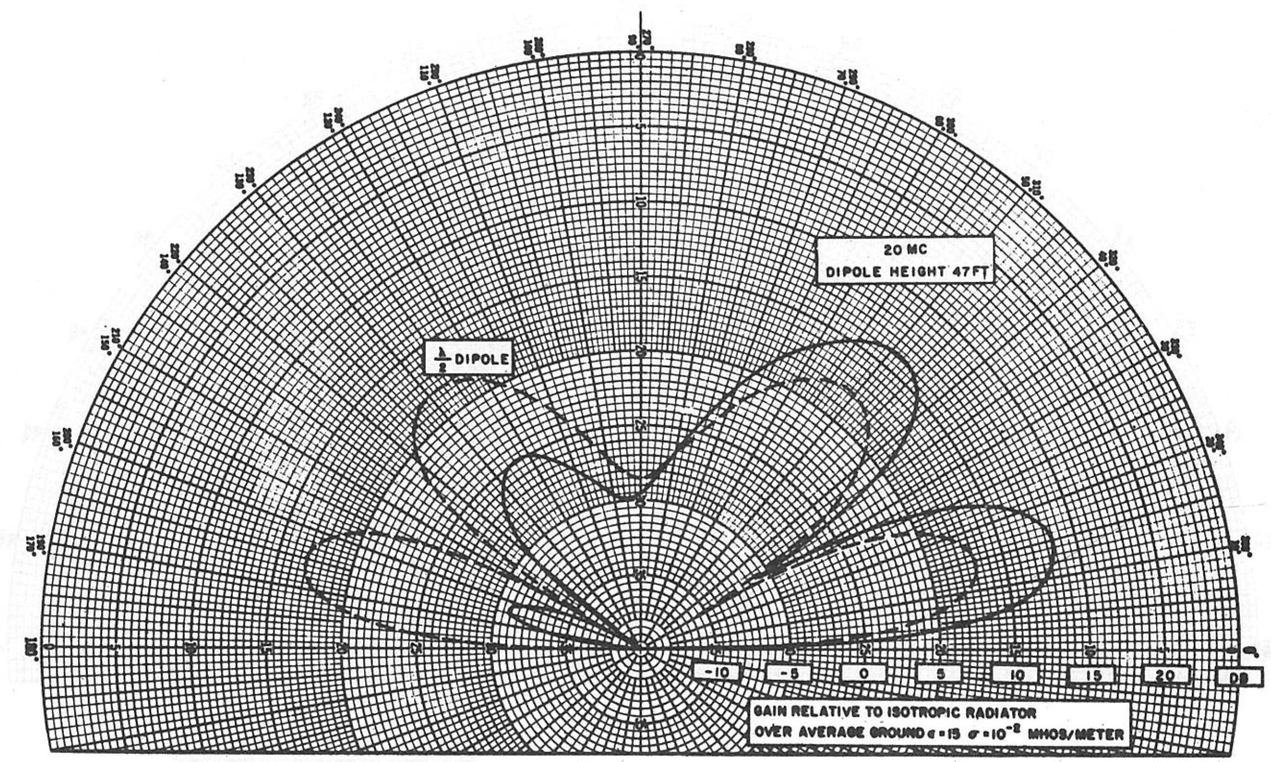


Figure 28B. Elevation Plane Patterns, 237B-2 Antenna

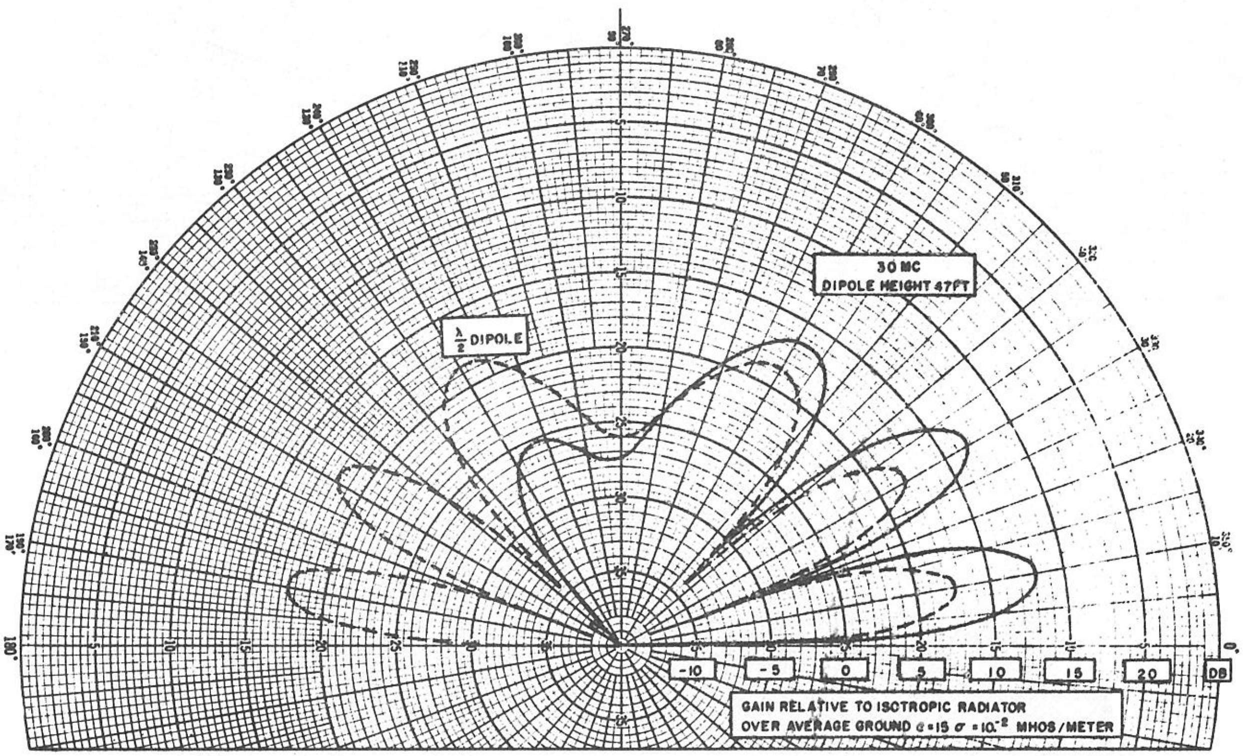


Figure 28C. Elevation Plane Patterns, 237B-2 Antenna

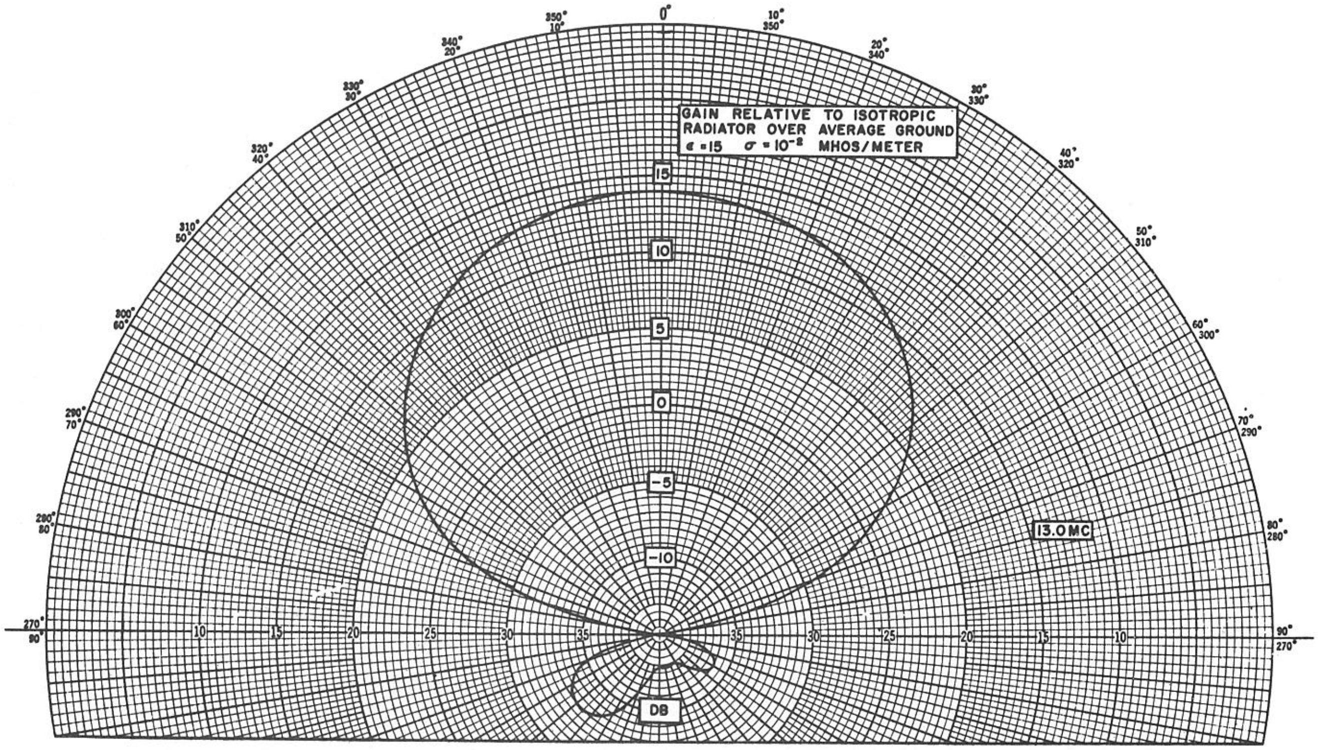


Figure 29A. Azimuth Plane Patterns, 237B Antennas

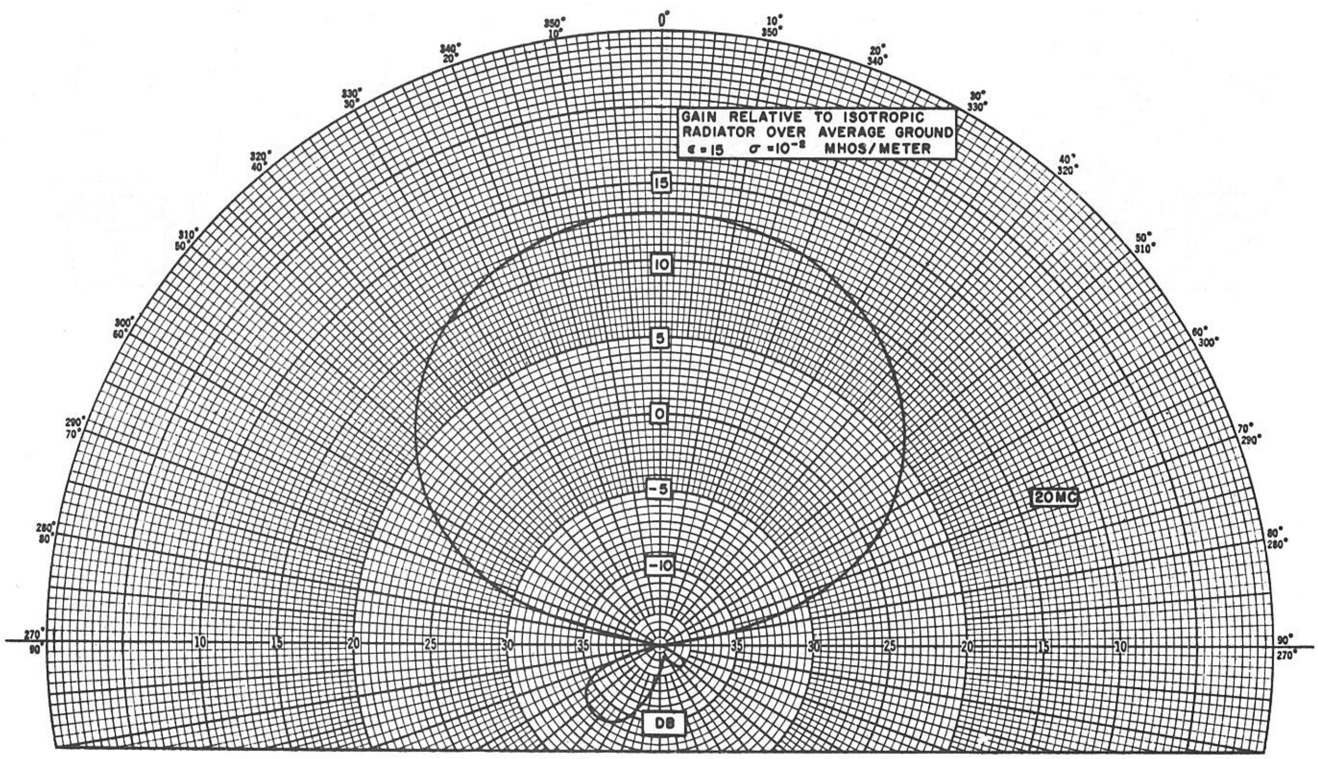


Figure 29B. Azimuth Plane Patterns, 237B Antennas

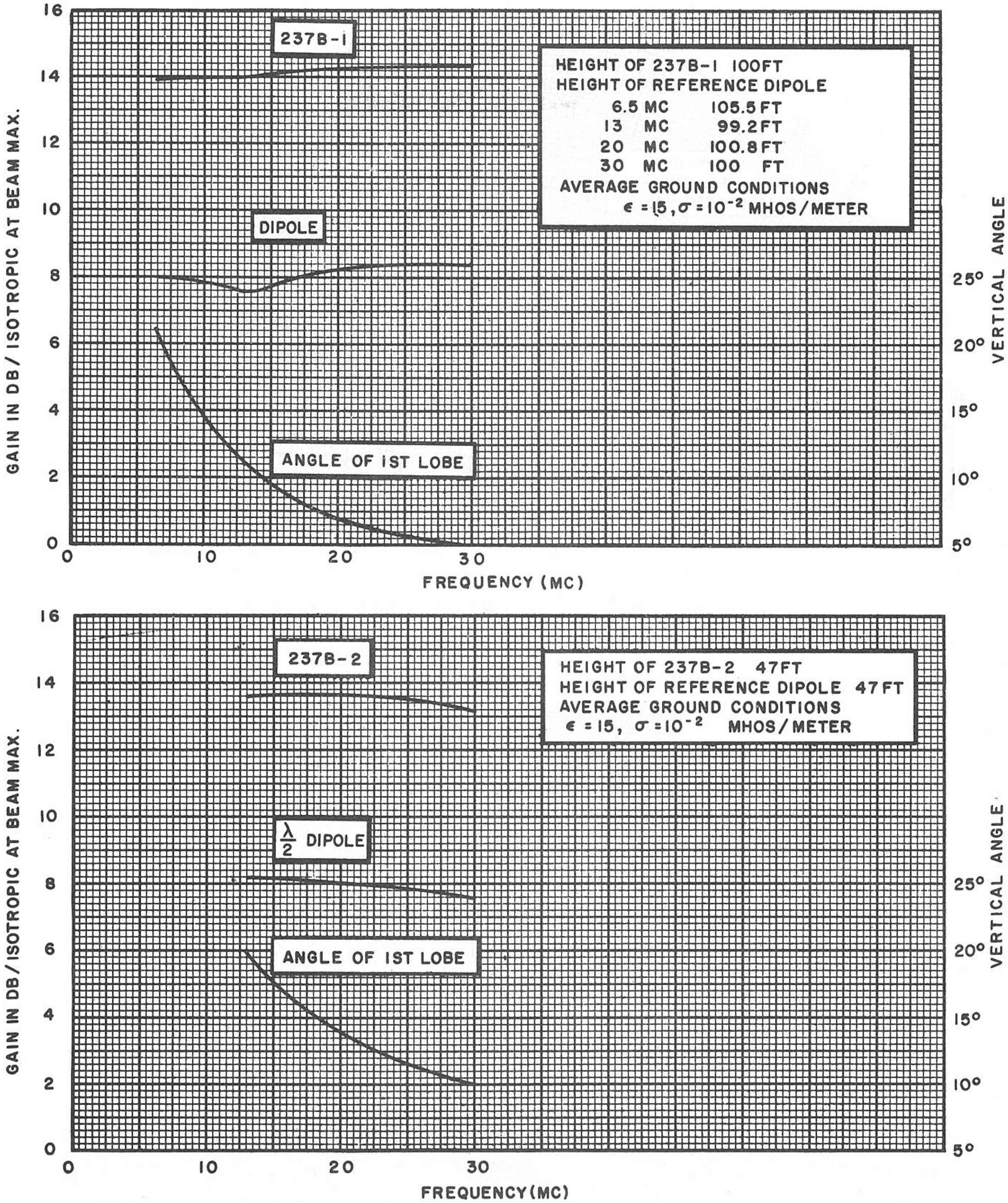


Figure 30. Change in Gain and Vertical Angle of Beam Maximum with Frequency, 237B Antennas

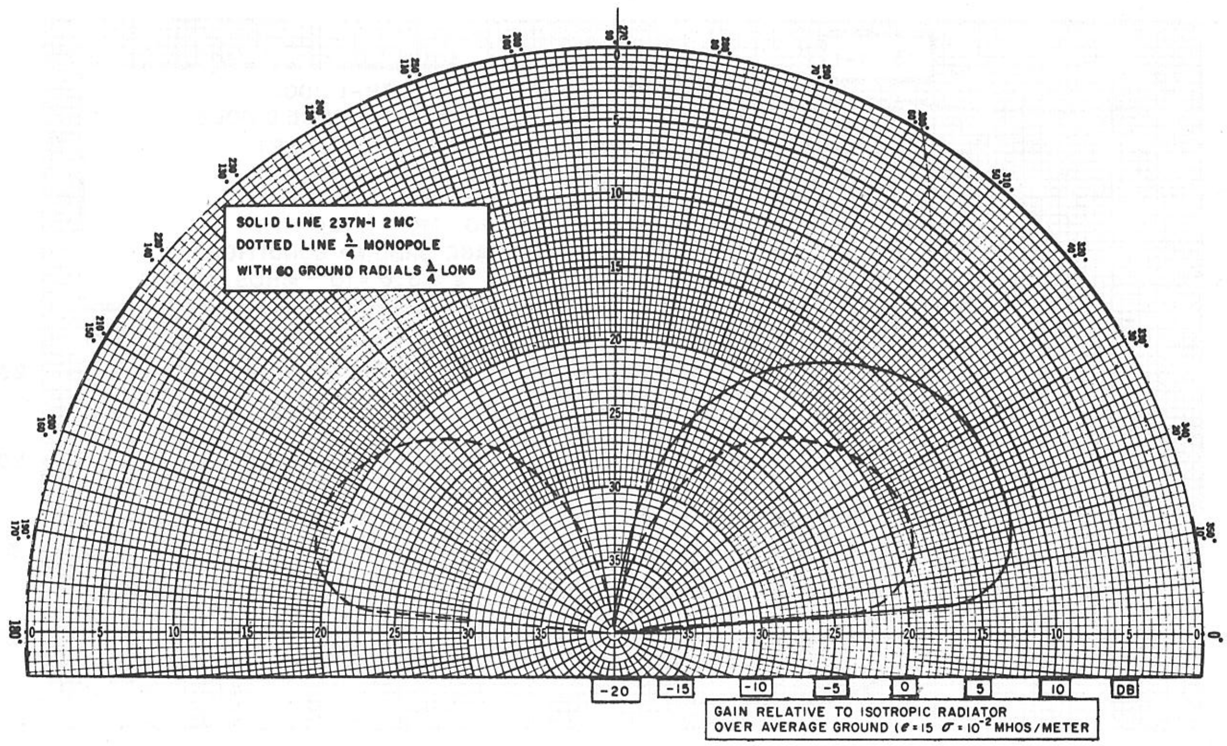


Figure 31. Elevation Plane Pattern, 237N-1 Antenna

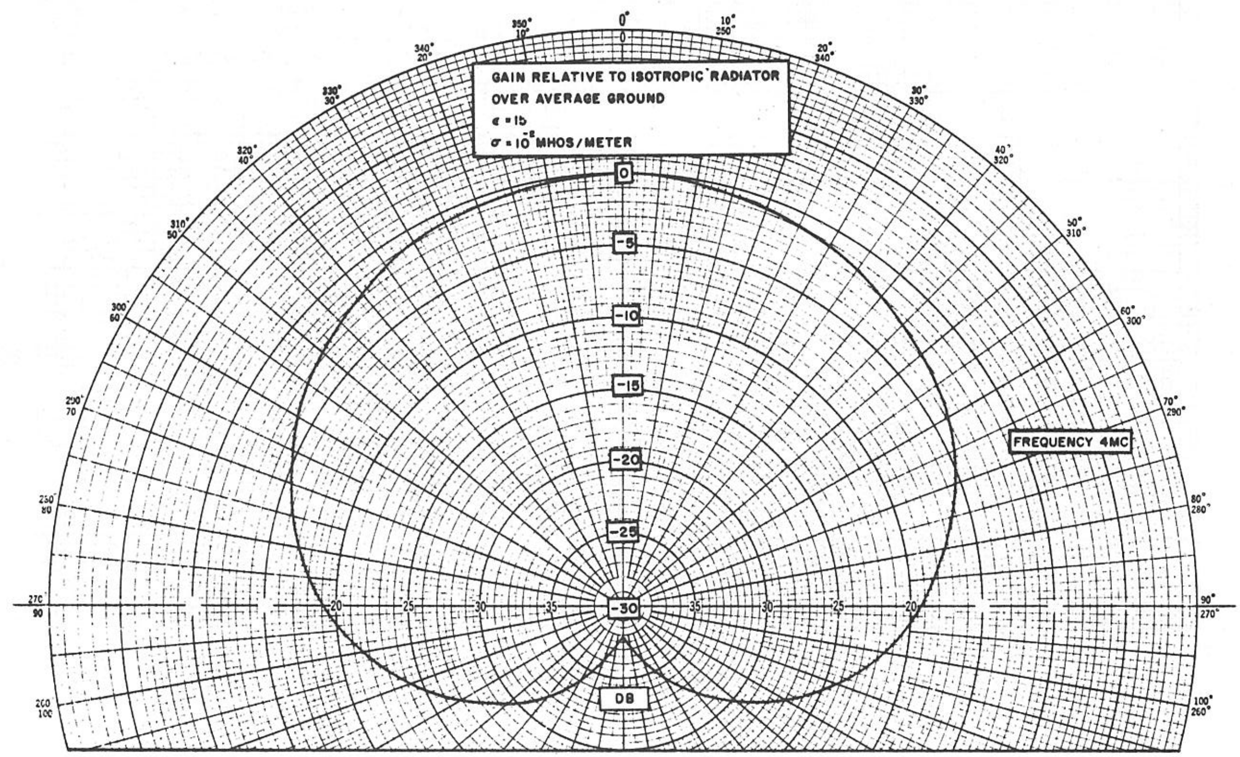


Figure 32. Azimuth Plane Pattern, 237N-1 Antenna

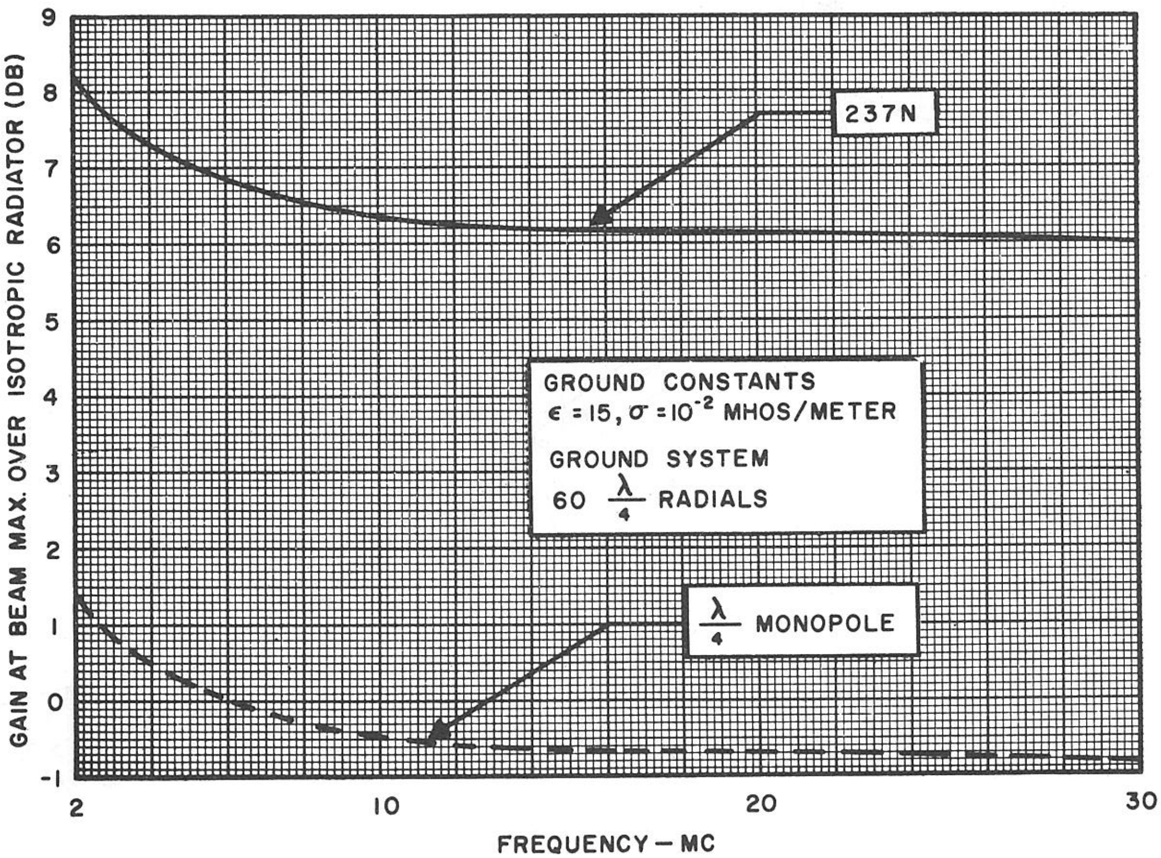


Figure 33. Change in Gain at Beam Maximum with Frequency
237N Antenna and Quarter-Wave Monopole

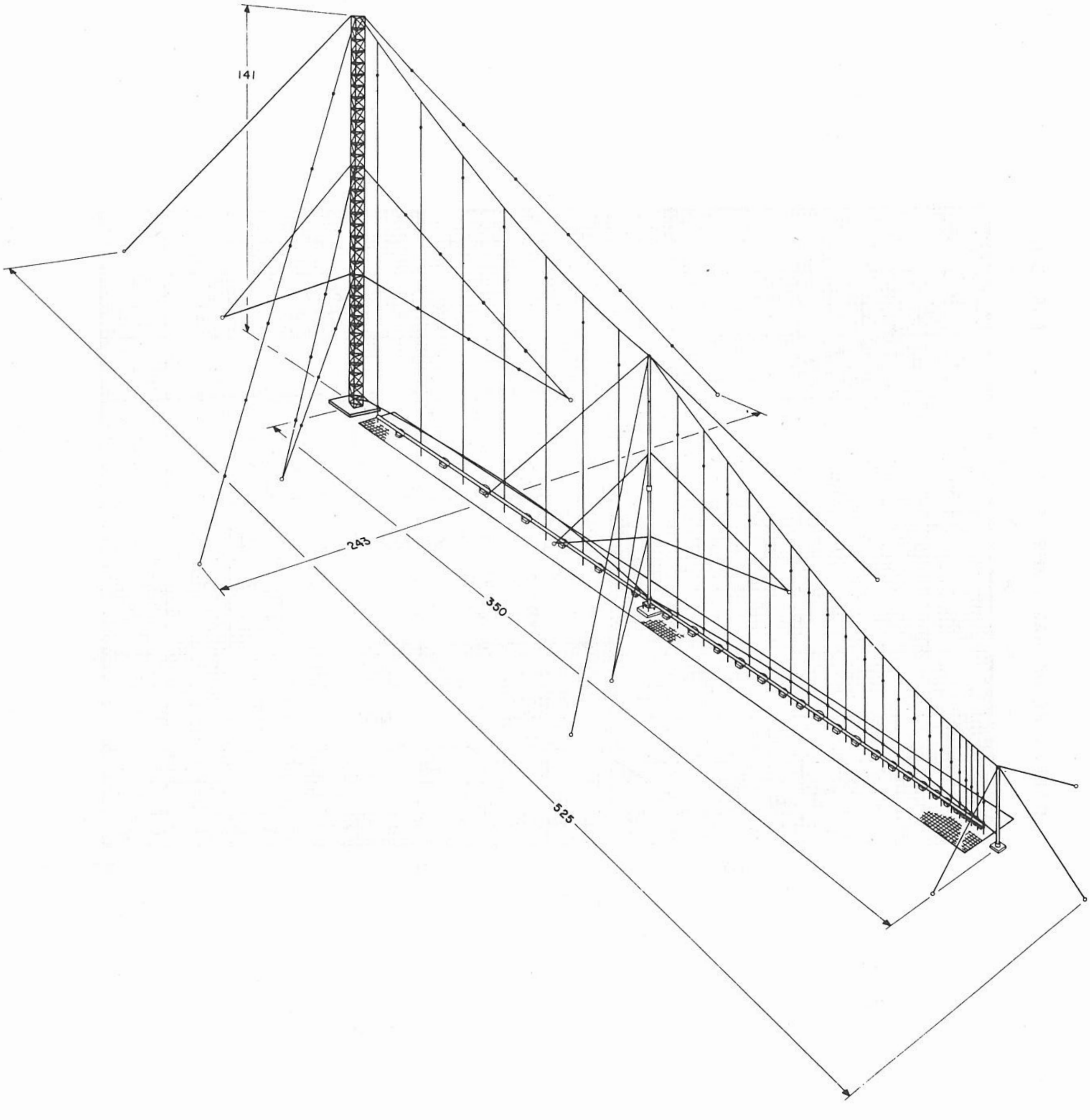


Figure 34. General Layout of 237N-1 Antenna

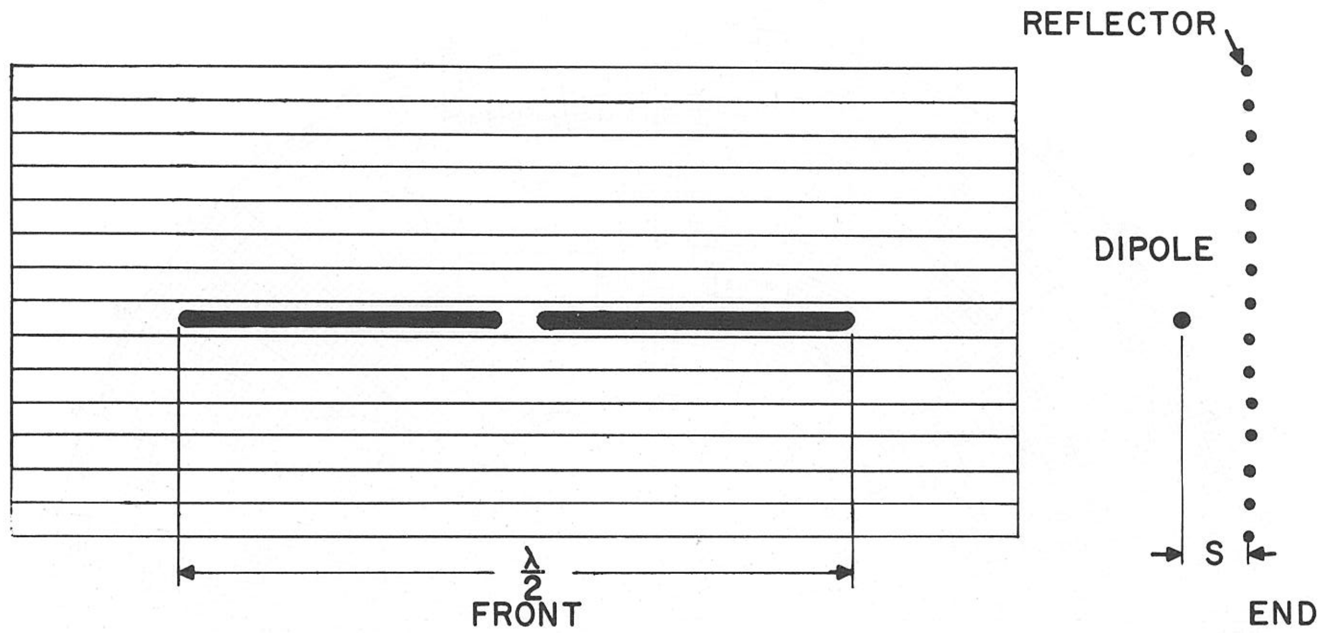


Figure 35. Billboard Antenna

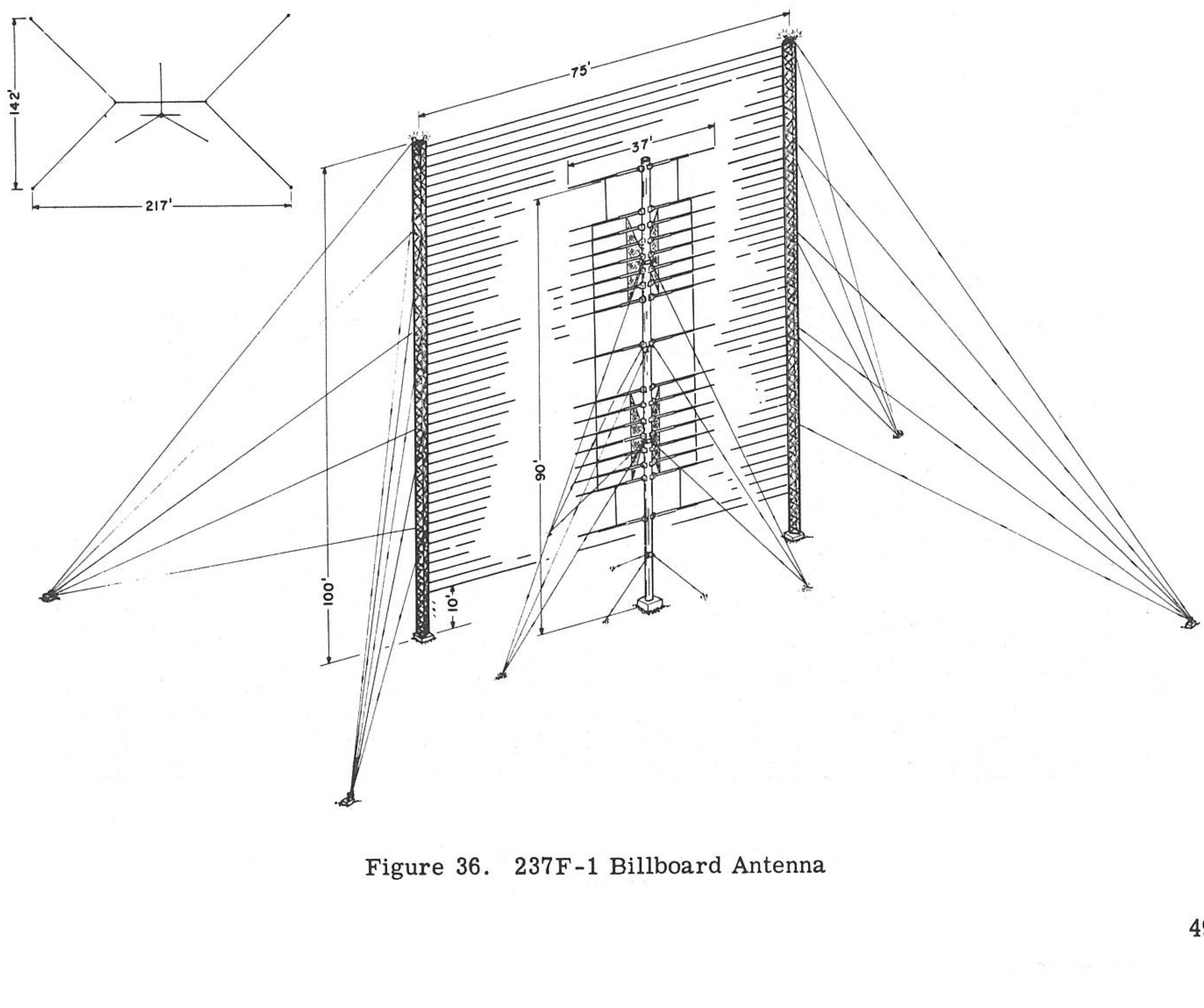


Figure 36. 237F-1 Billboard Antenna

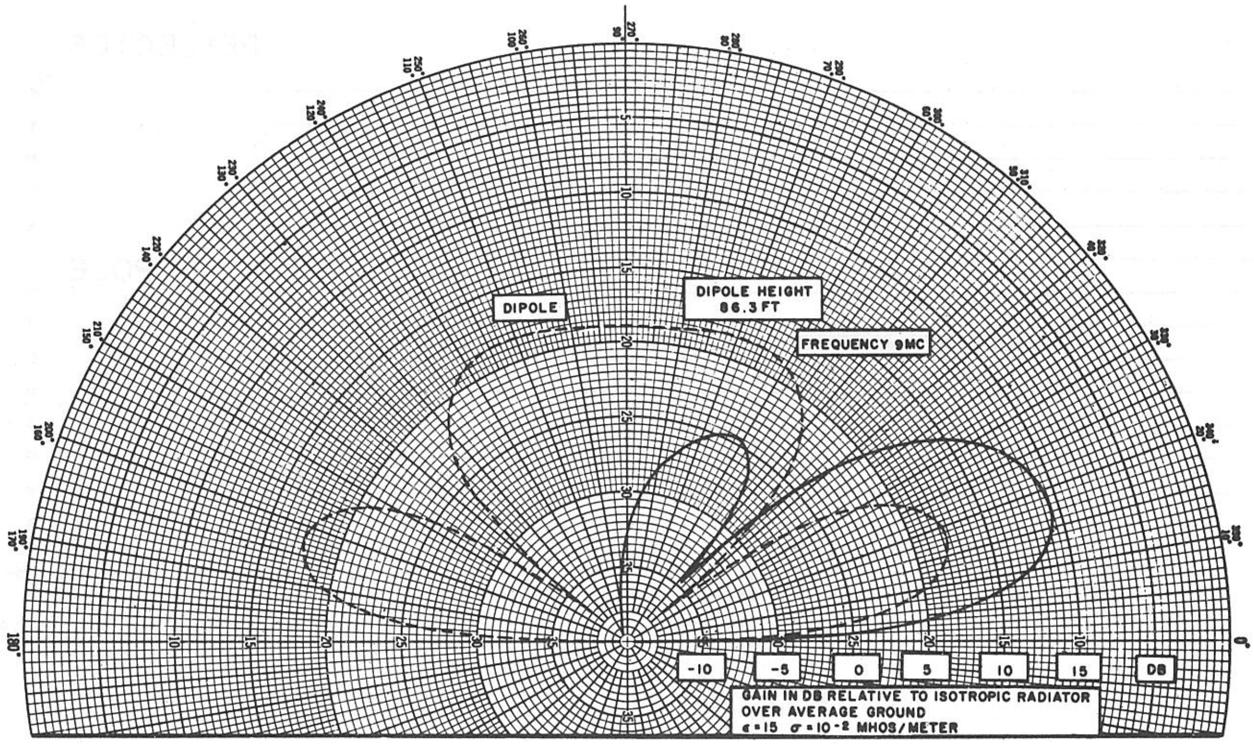


Figure 37A. Elevation Plane Patterns, 237F-1 Billboard Antenna

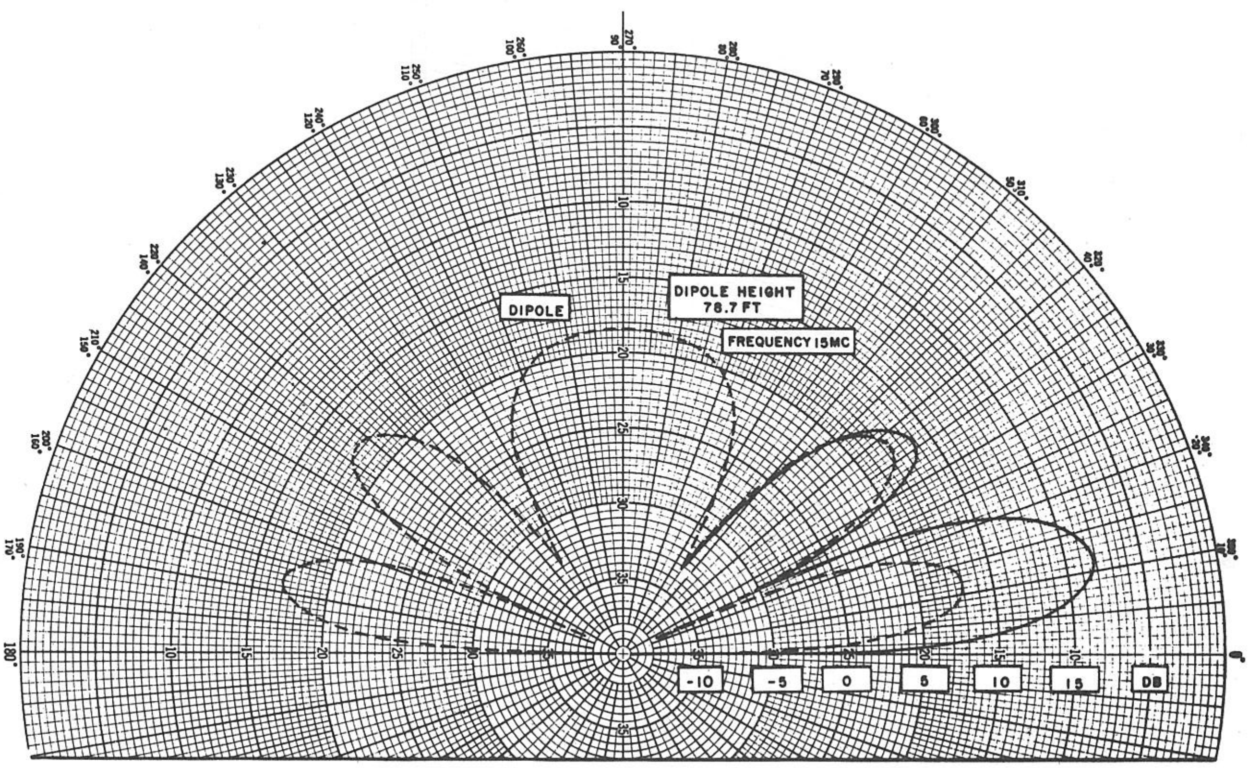


Figure 37B. Elevation Plane Patterns, 237F-1 Billboard Antenna

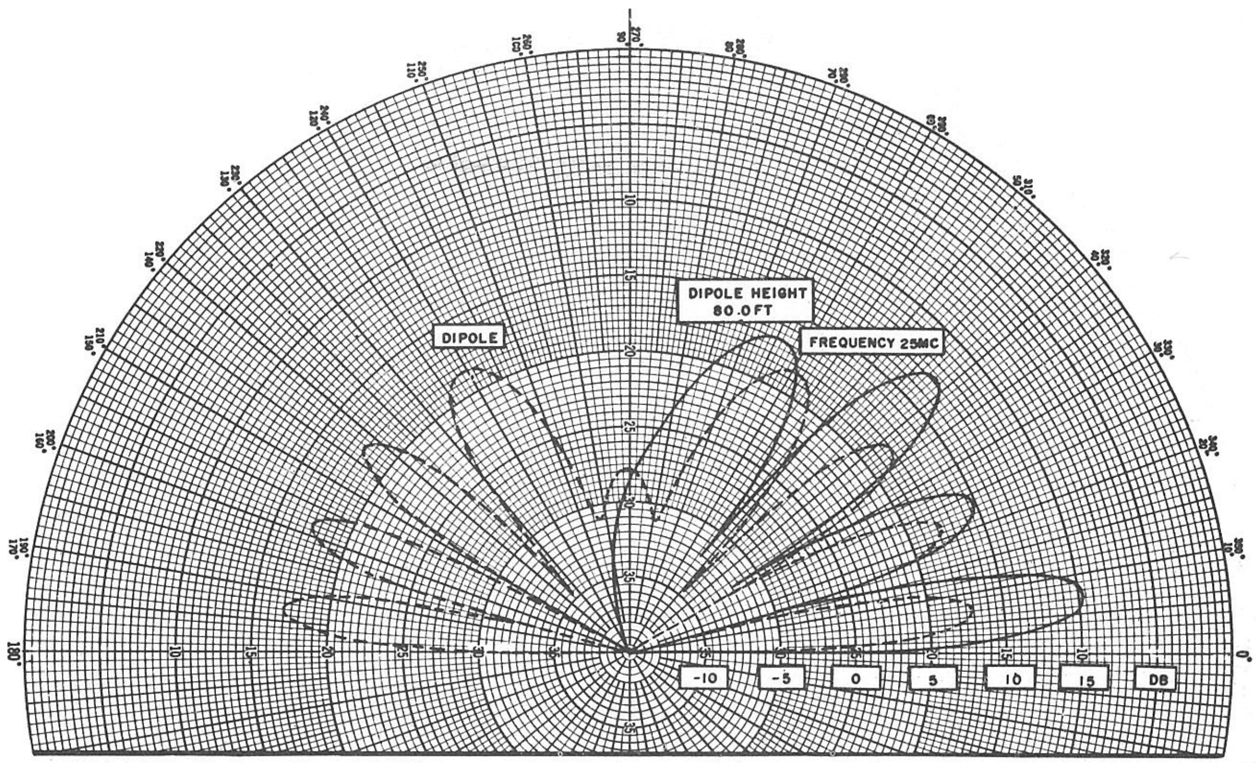


Figure 37C. Elevation Plane Patterns, 237F-1 Billboard Antenna

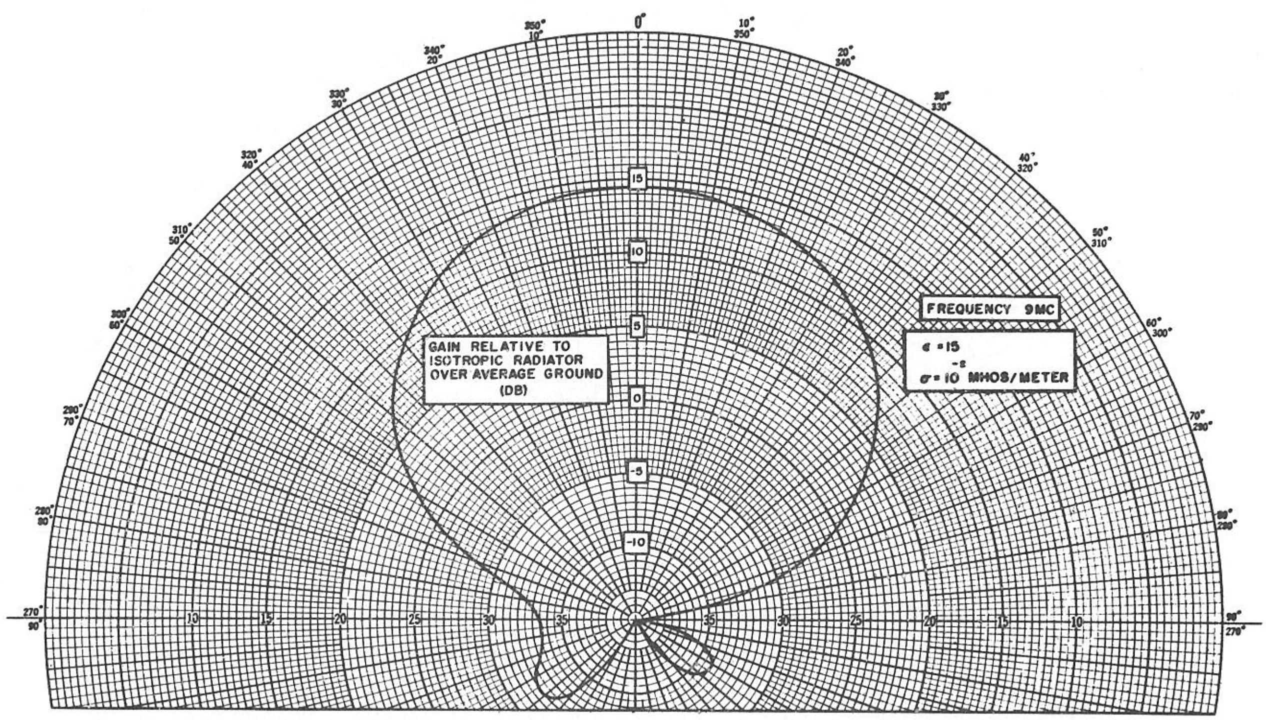


Figure 38A. Azimuth Plane Patterns, 237F-1 Antenna

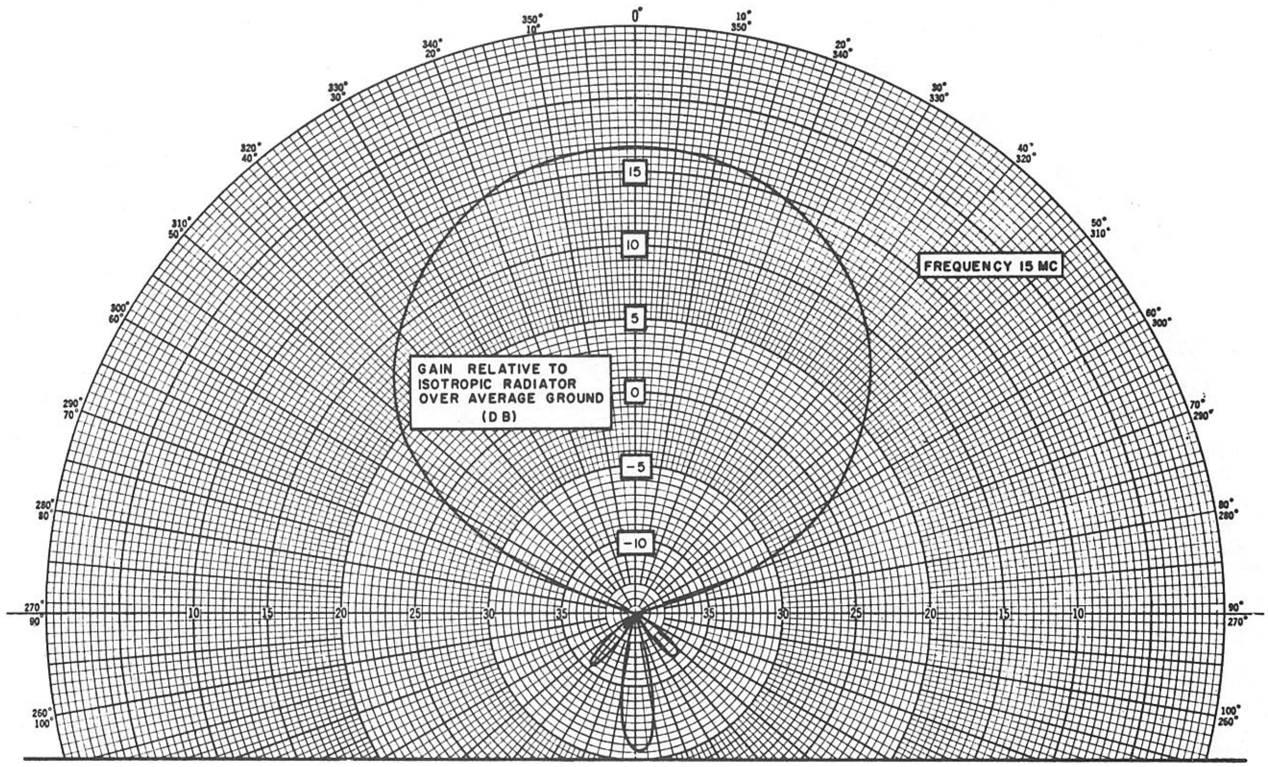


Figure 38B. Azimuth Plane Patterns, 237F-1 Antenna

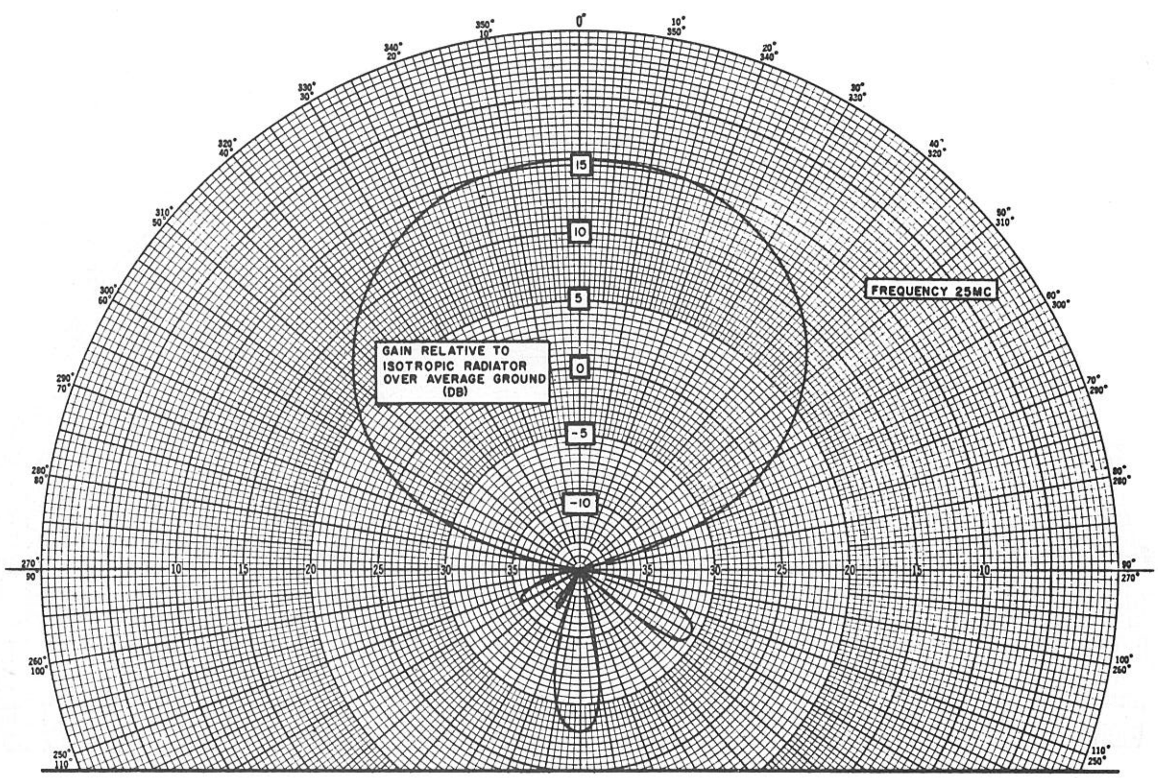


Figure 38C. Azimuth Plane Patterns, 237F-1 Antenna

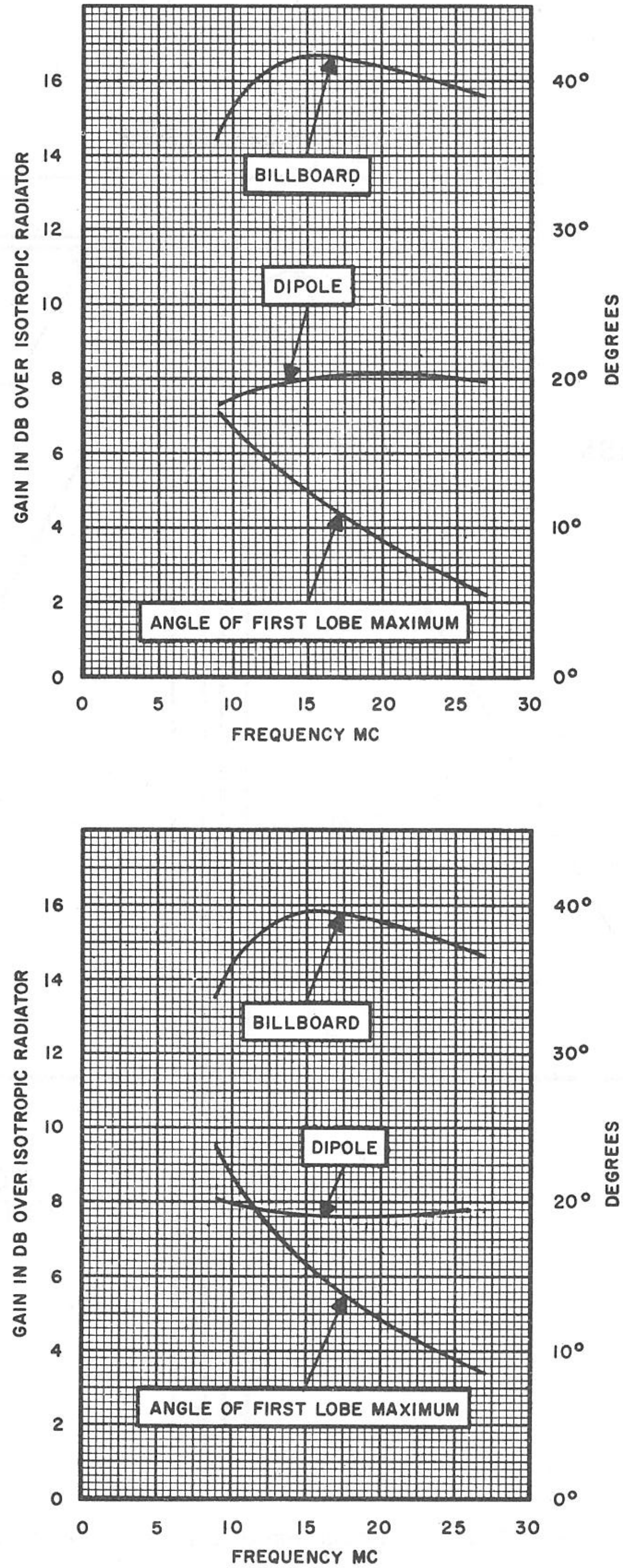


Figure 39. Change in Gain and Angle of Beam Maximum with Frequency, 237F-1 Antenna

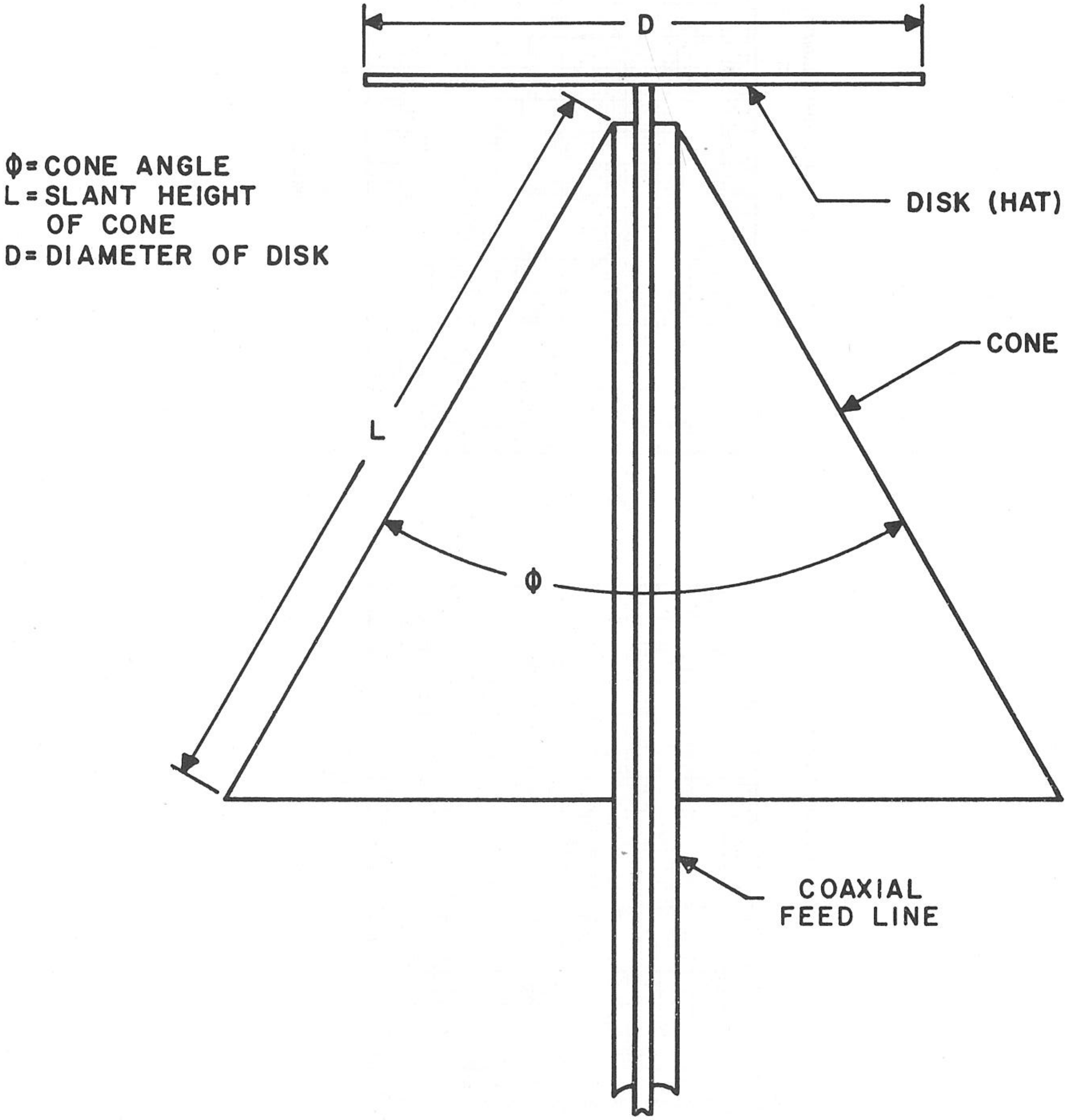


Figure 40. Basic Construction of a Discone Antenna

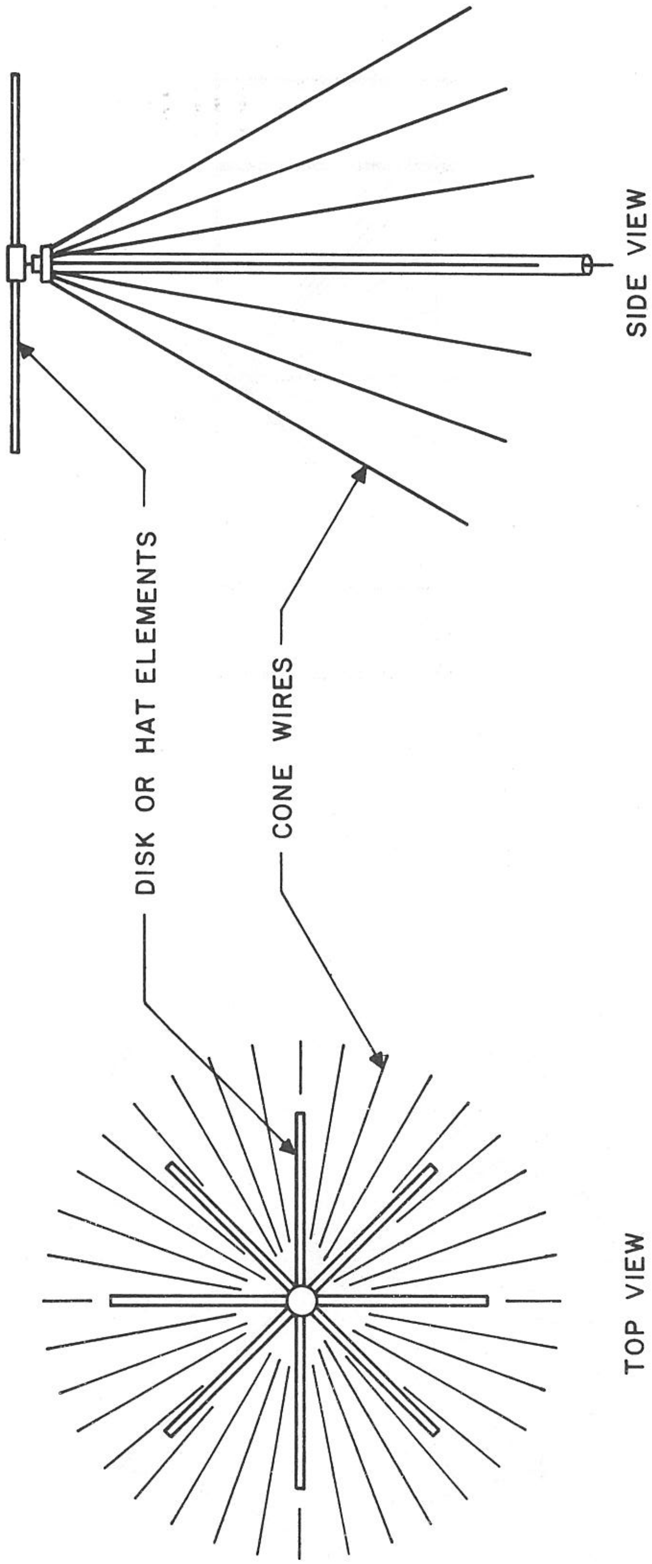


Figure 41. Normal Discone Construction for HF Applications

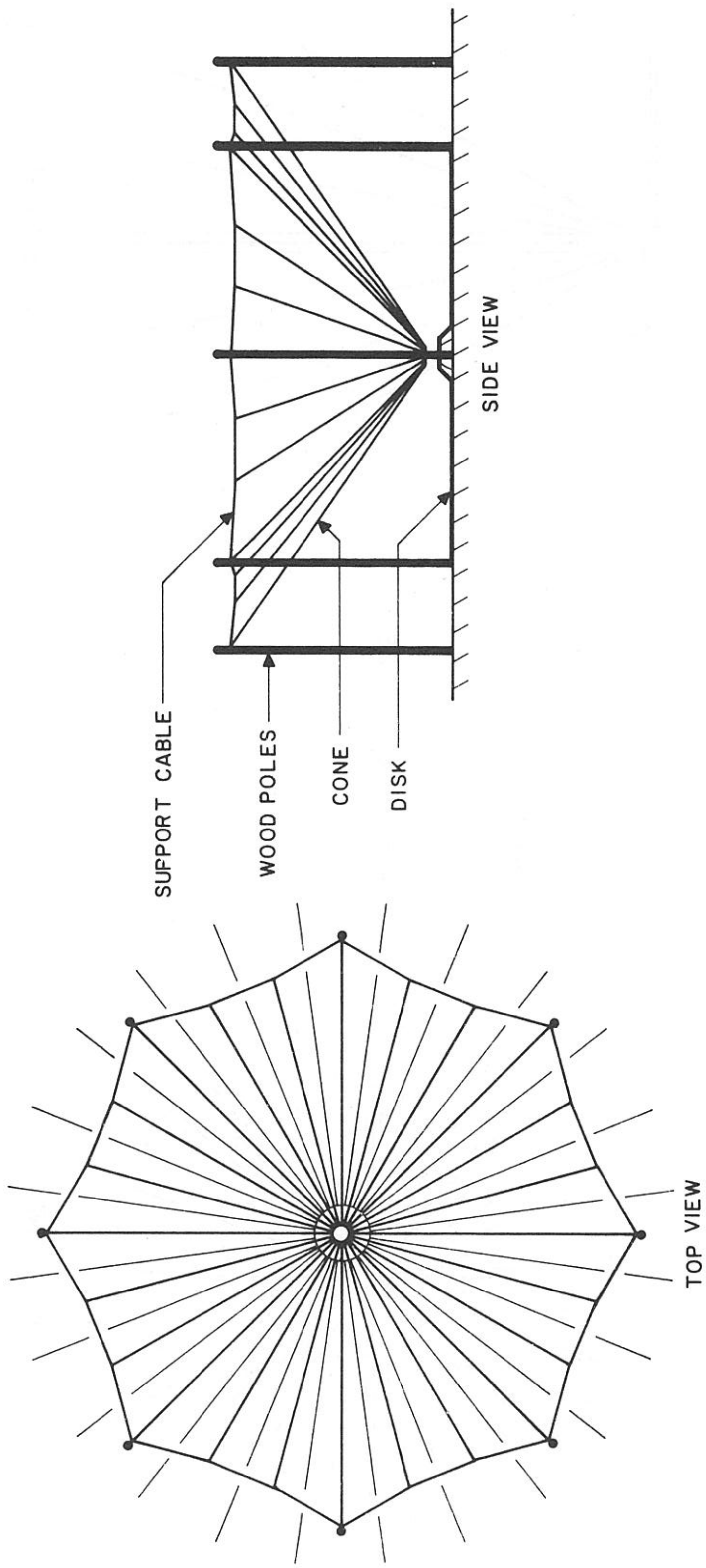
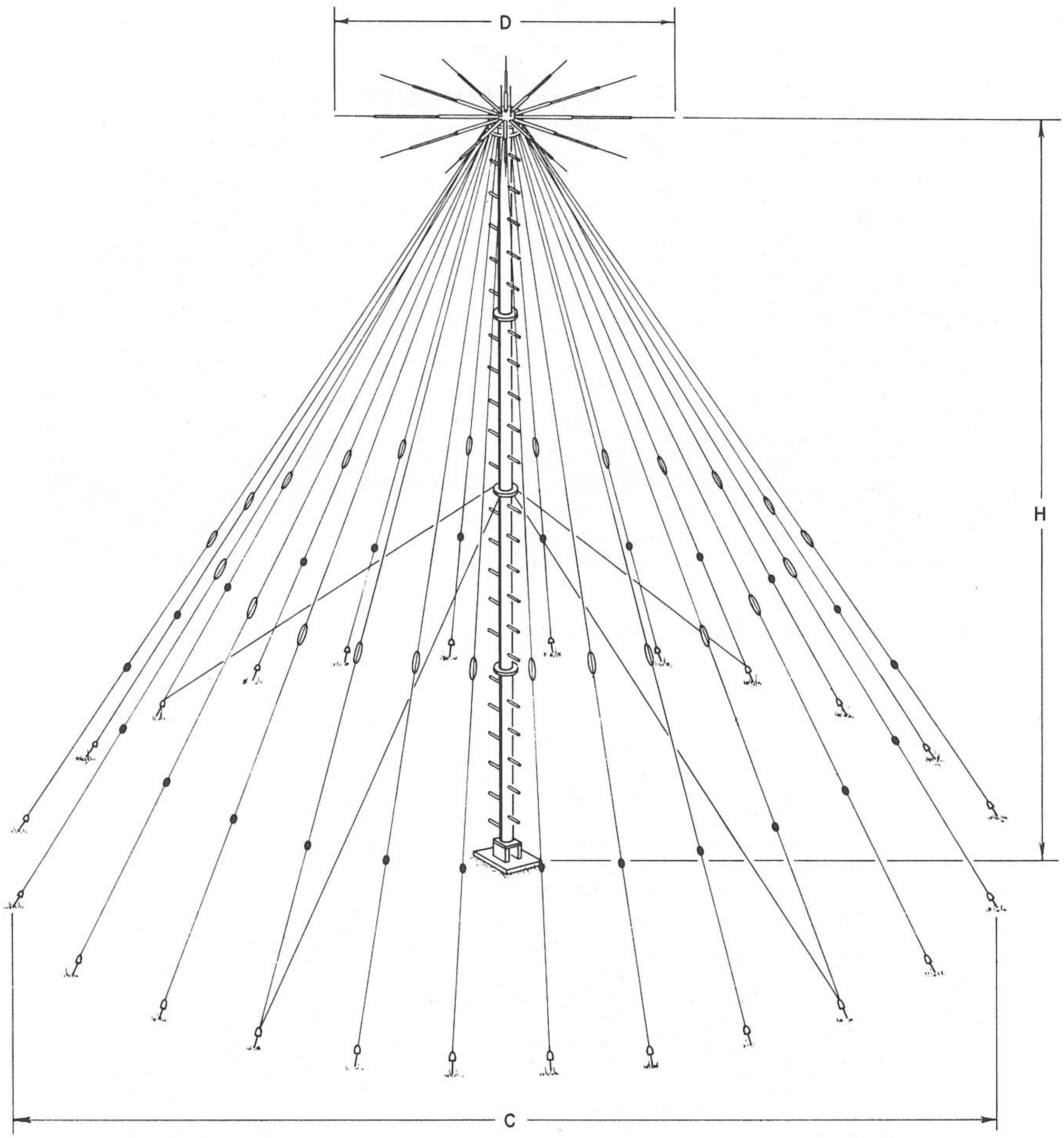


Figure 42. Inverted HF Discone Antenna



ANTENNA	D (FEET)	C (FEET)	H (FEET)
237H-1	36	106	80
237H-2	26	128	80
237H-1X	34	72	55

Figure 43. 237H-1 Discone Antenna

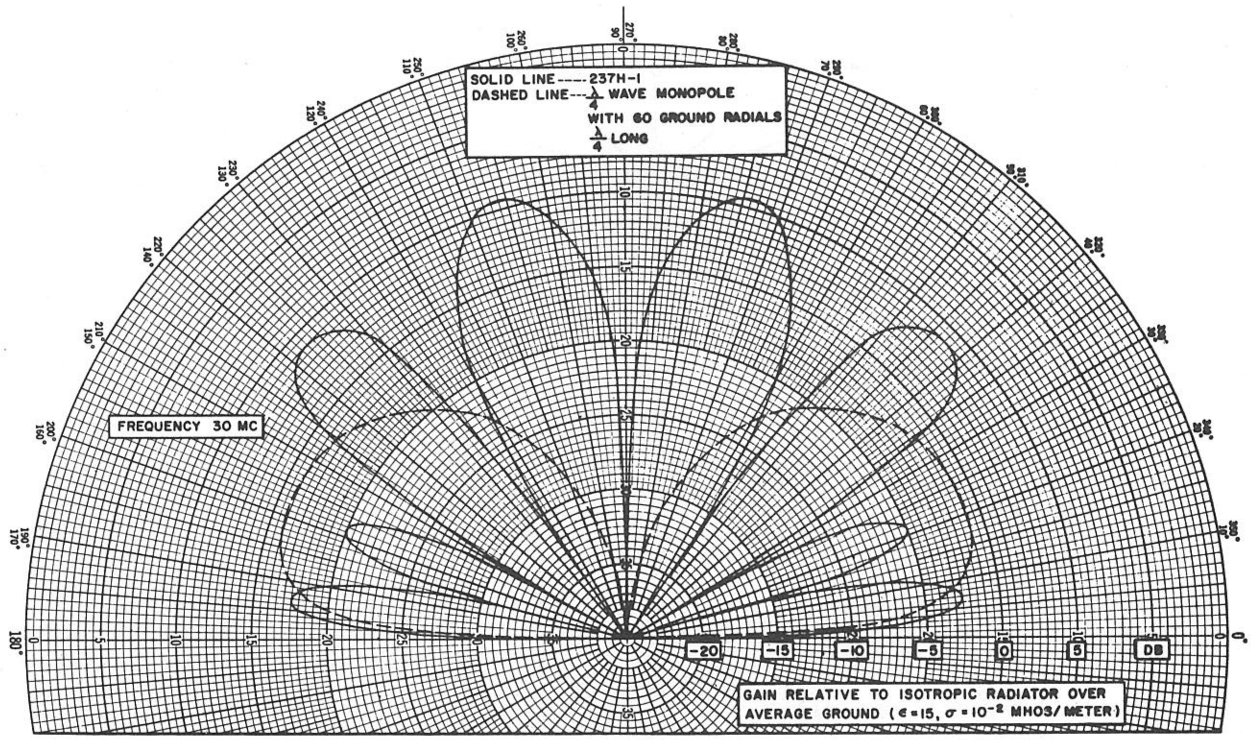


Figure 44A. Elevation Plane Patterns, 237H-1 Discone Antenna

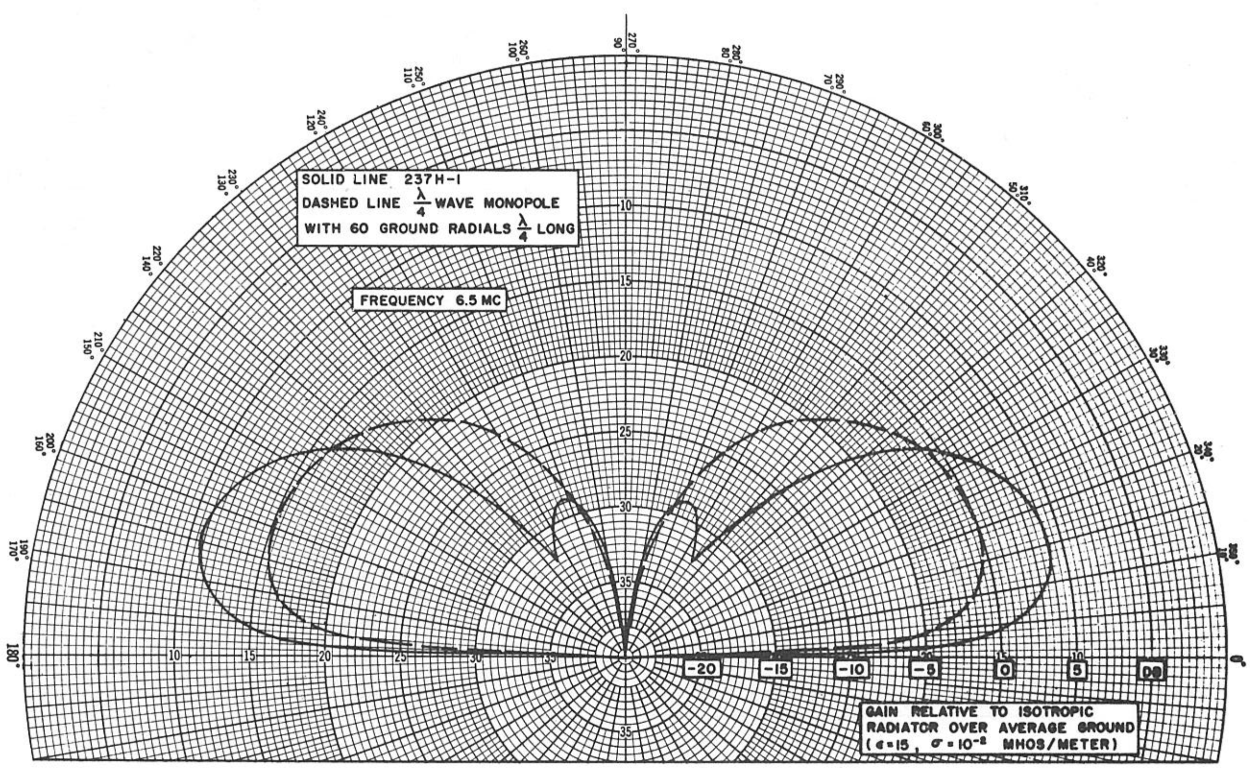


Figure 44B. Elevation Plane Patterns, 237H-1 Discone Antenna

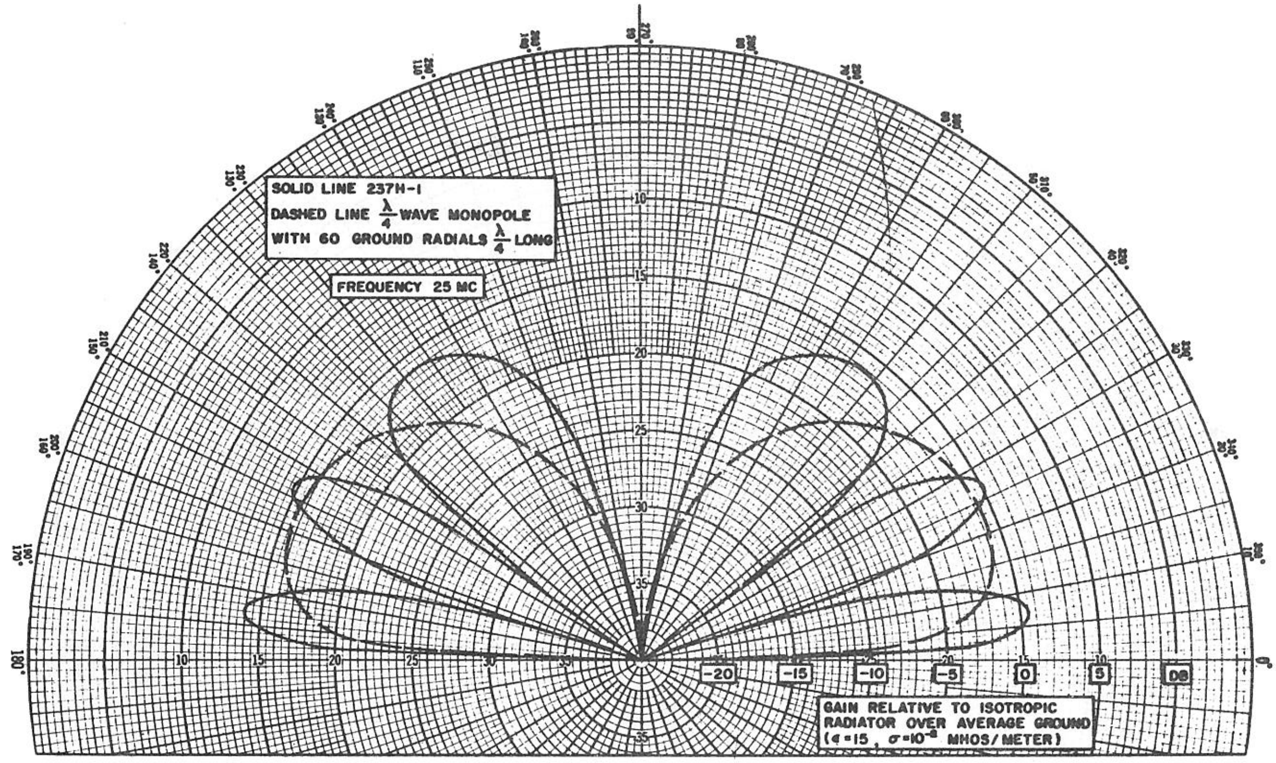


Figure 44C. Elevation Plane Patterns, 237H-1 Discone Antenna

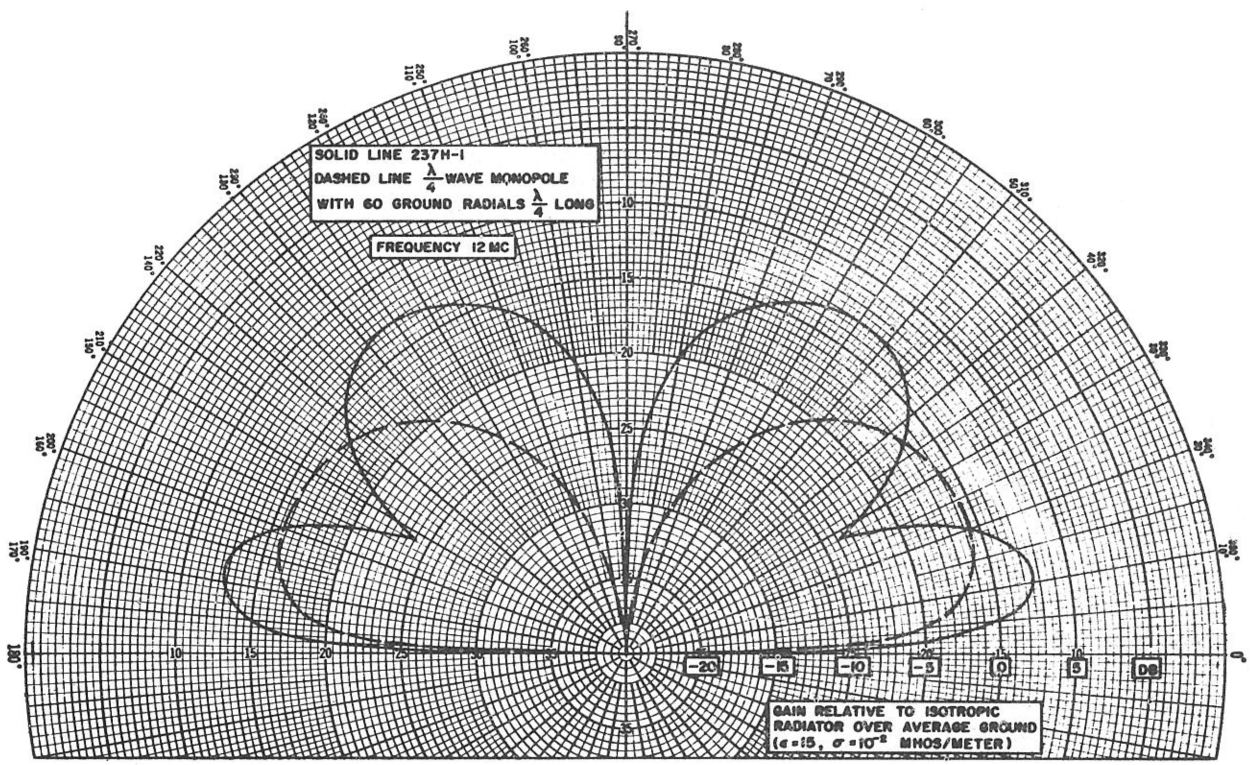


Figure 44D. Elevation Plane Patterns, 237H-1 Discone Antenna

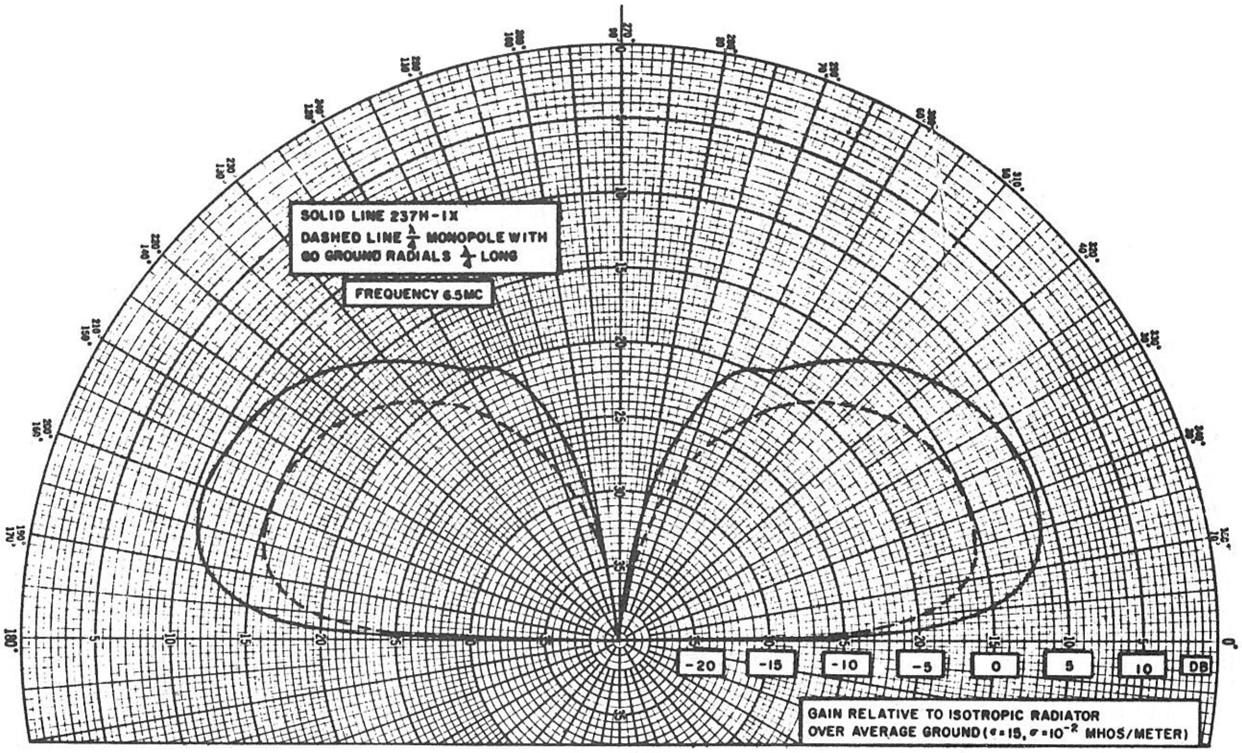


Figure 45A. Elevation Plane Patterns, 237H-1X Discone Antenna

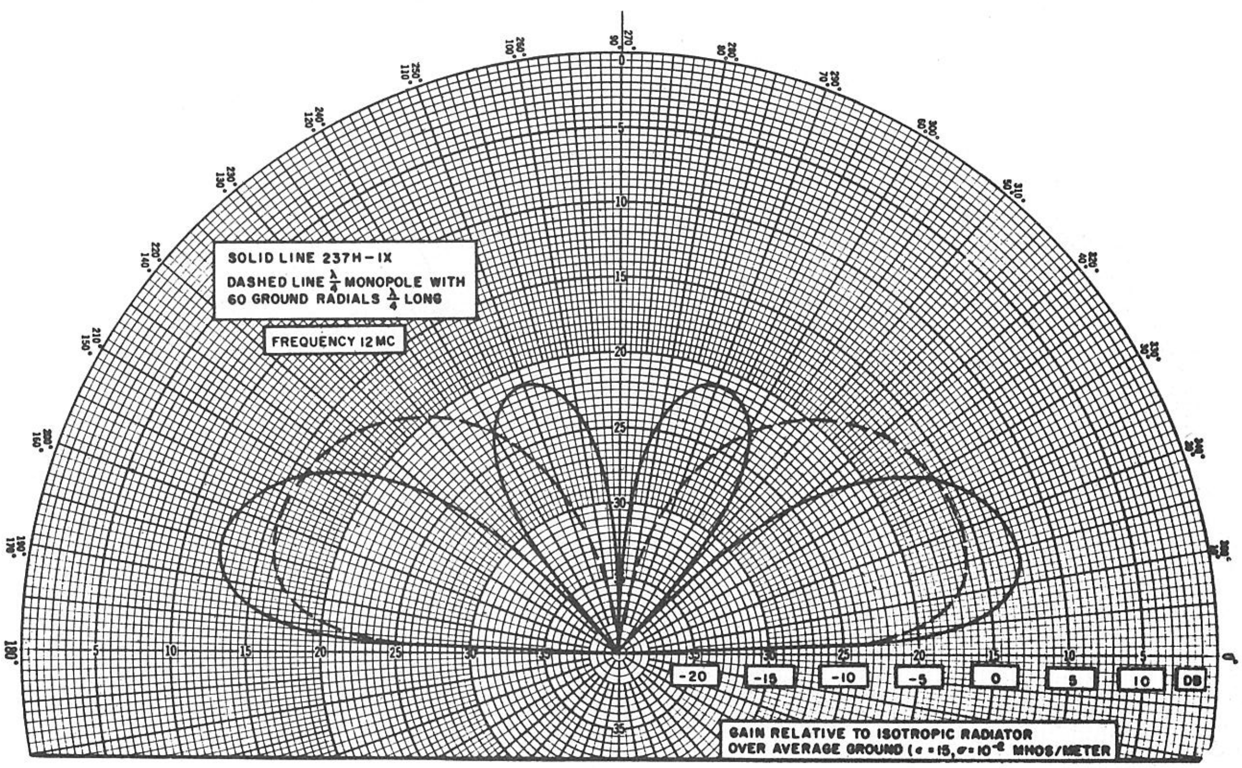


Figure 45B. Elevation Plane Patterns, 237H-1X Discone Antenna

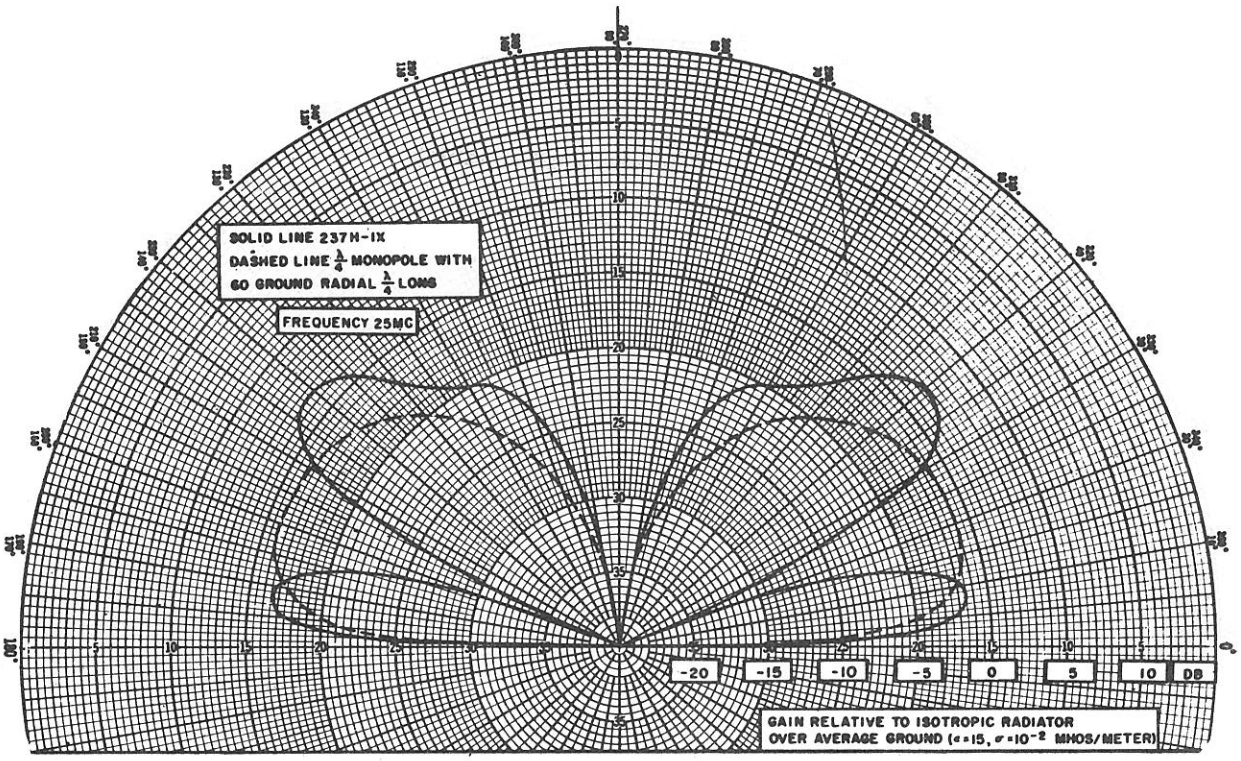


Figure 45C. Elevation Plane Patterns, 237H-1X Discone Antenna

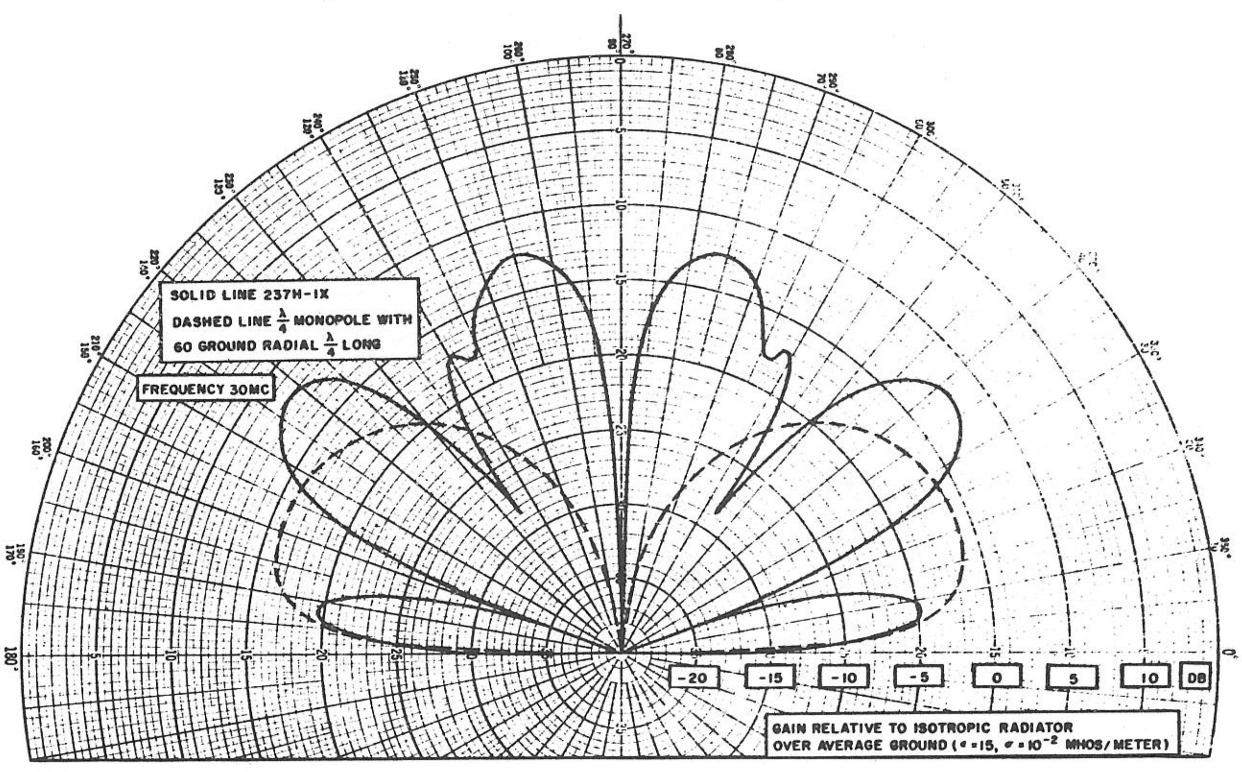


Figure 45D. Elevation Plane Patterns, 237H-1X Discone Antenna

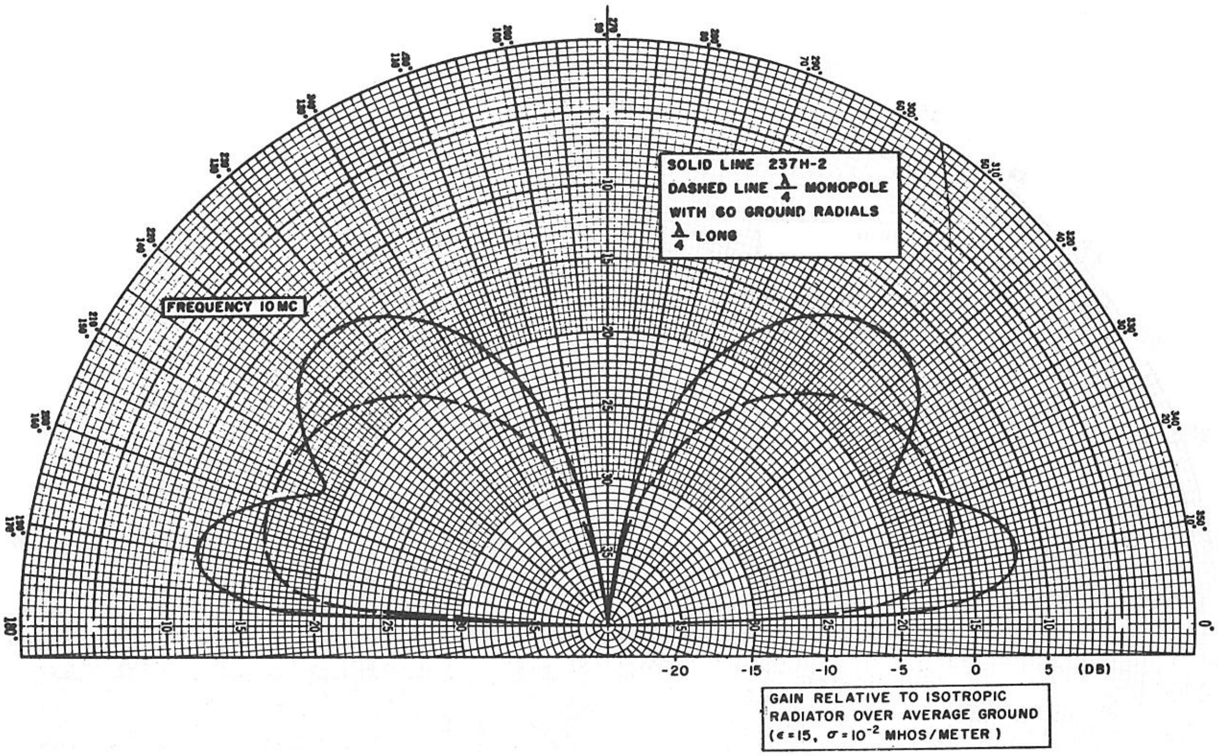


Figure 46A. Elevation Plane Pattern, 237H-2 Discone Antenna

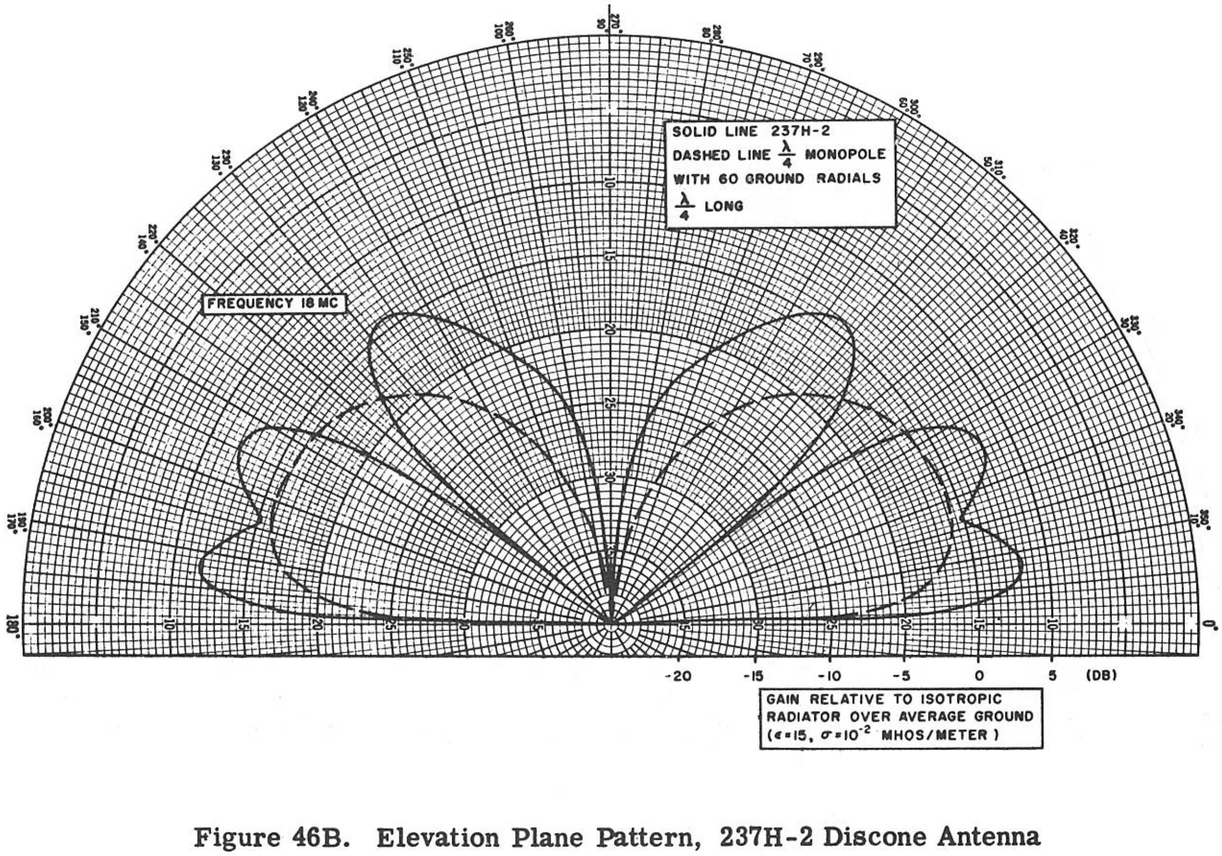


Figure 46B. Elevation Plane Pattern, 237H-2 Discone Antenna

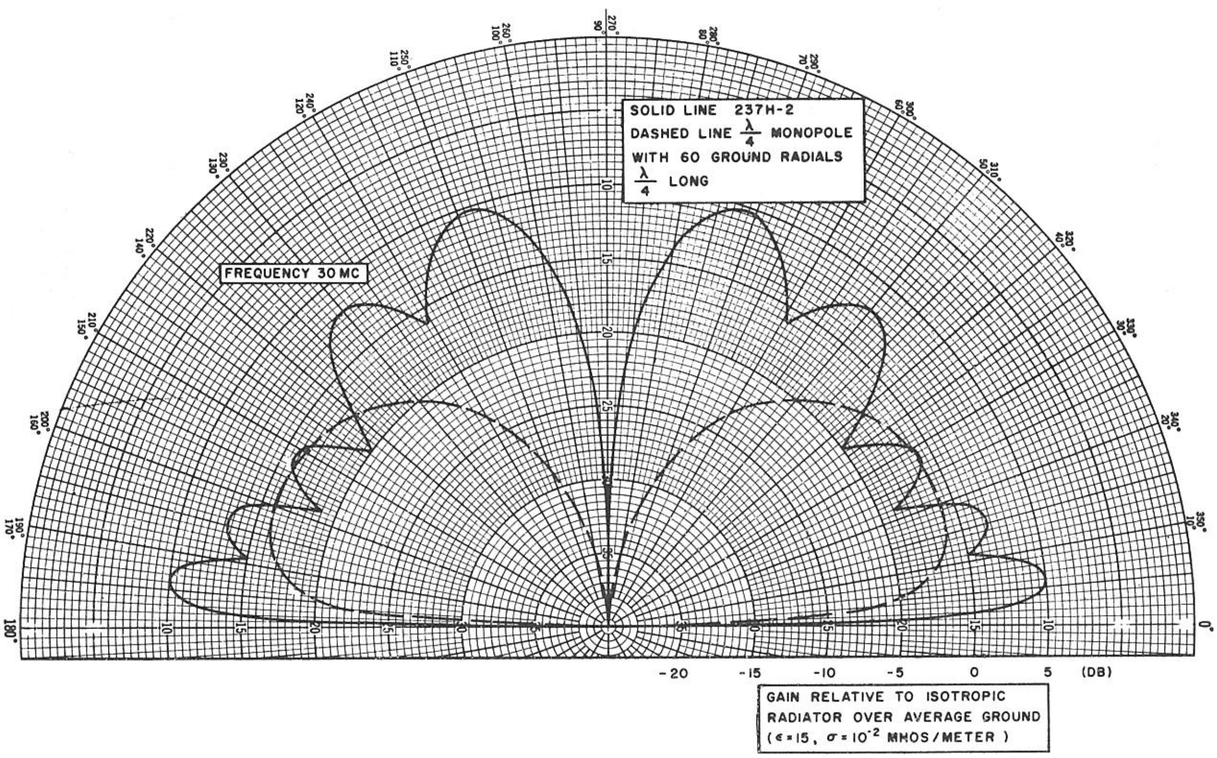
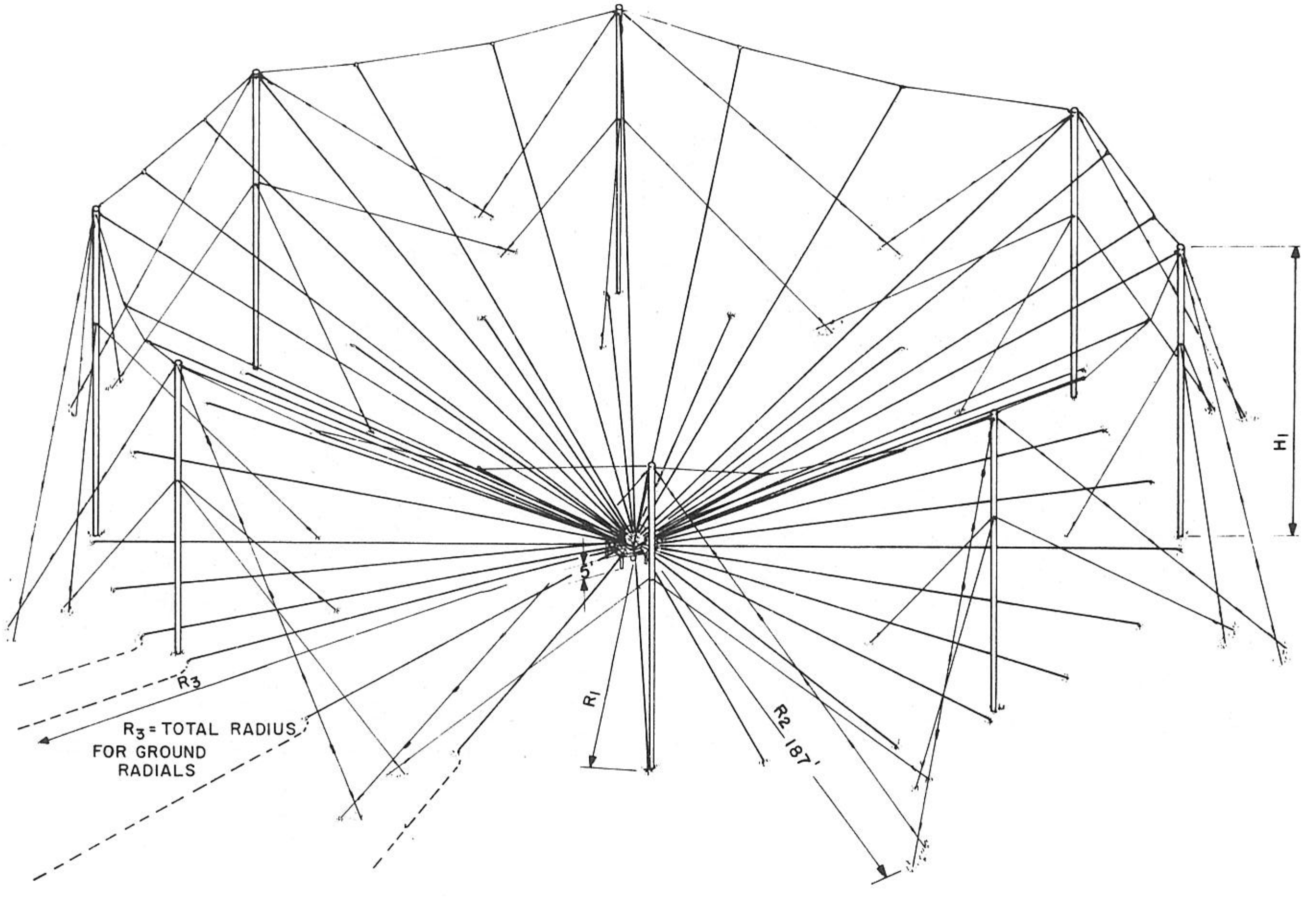


Figure 46C. Elevation Plane Pattern, 237H-2 Discone Antenna



FREQ RANGE	DIMENSIONS				TYPE NUMBER
	H_1	R_1	R_2	R_3	
3 - 16MC	65'	74'	124.5'	133'	237G-2
2 - 11MC	98'	111'	187'	200'	237G-1

Figure 47. 237G Discone Antenna

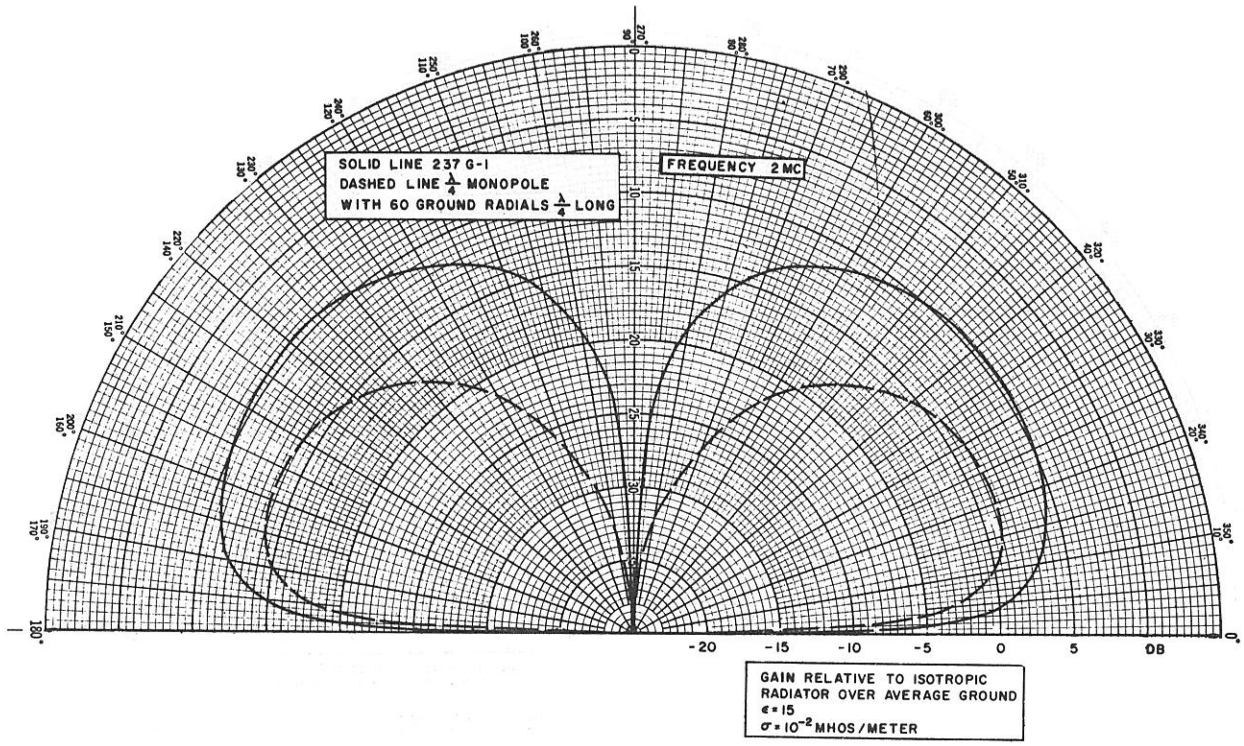


Figure 48A. Elevation Plane Patterns, 237G-1 Discone Antenna

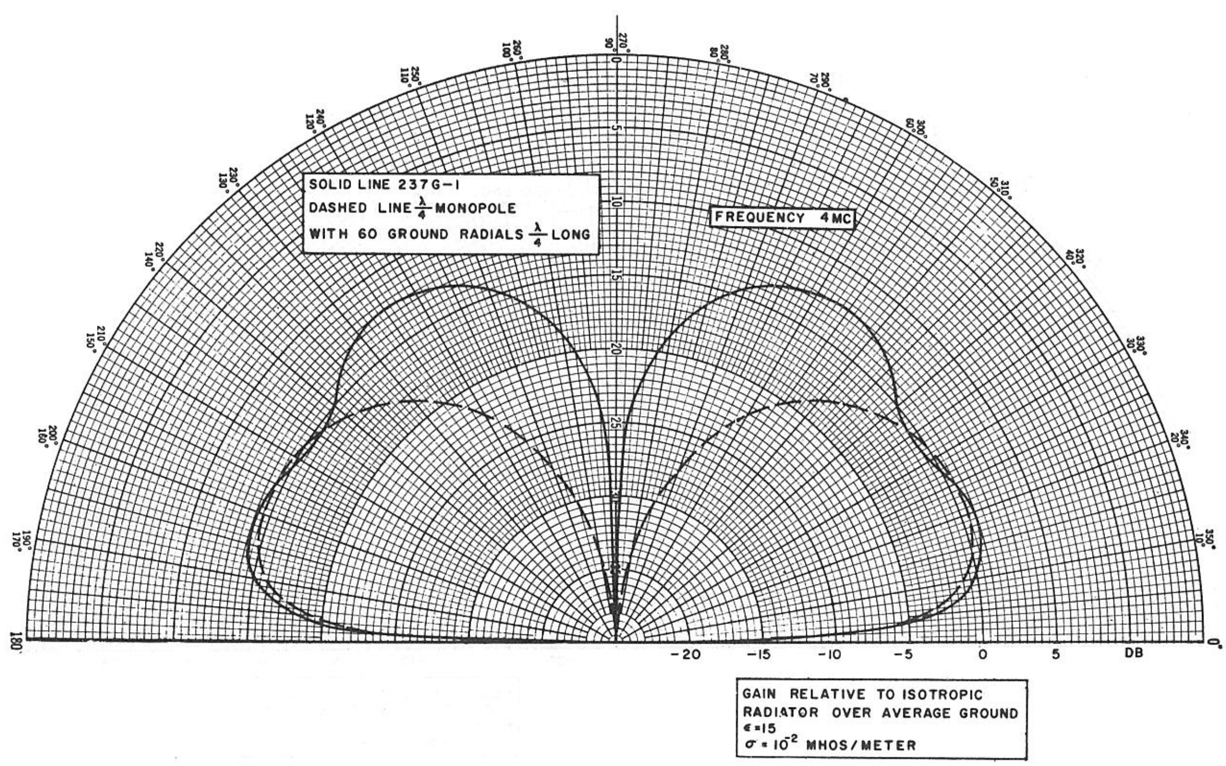


Figure 48B. Elevation Plane Patterns, 237G-1 Discone Antenna

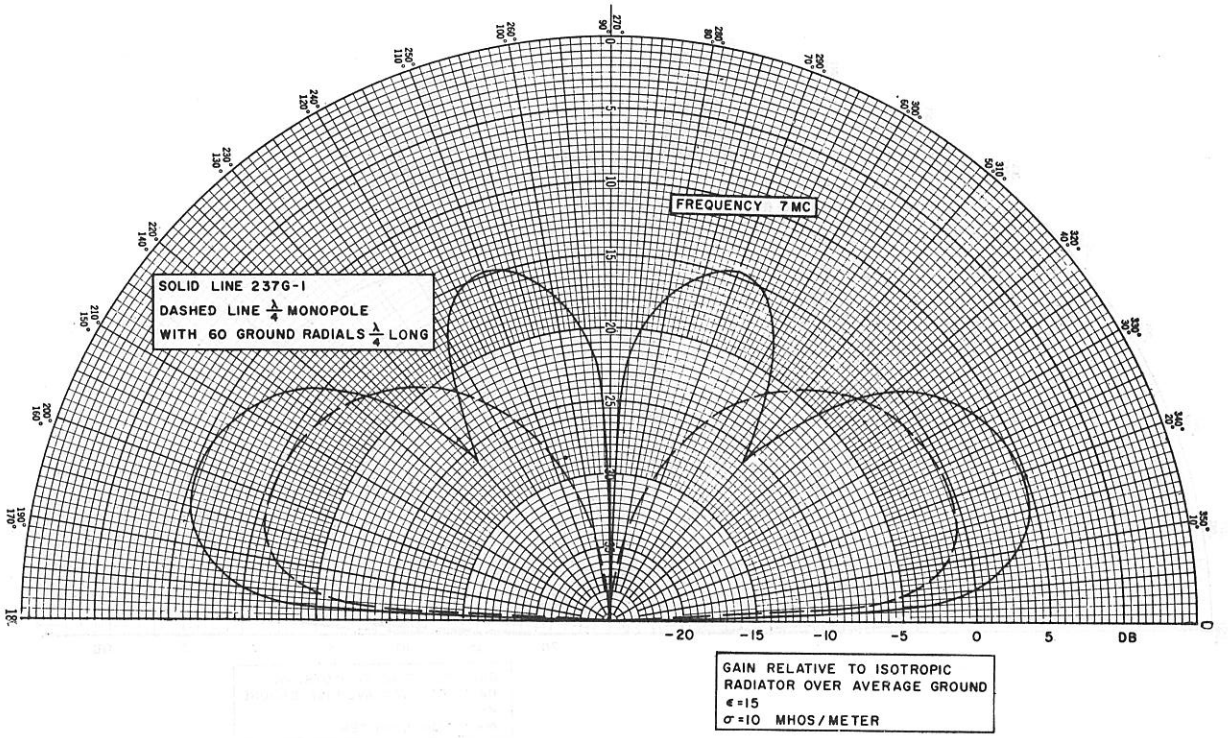


Figure 48C. Elevation Plane Patterns, 237G-1 Discone Antenna

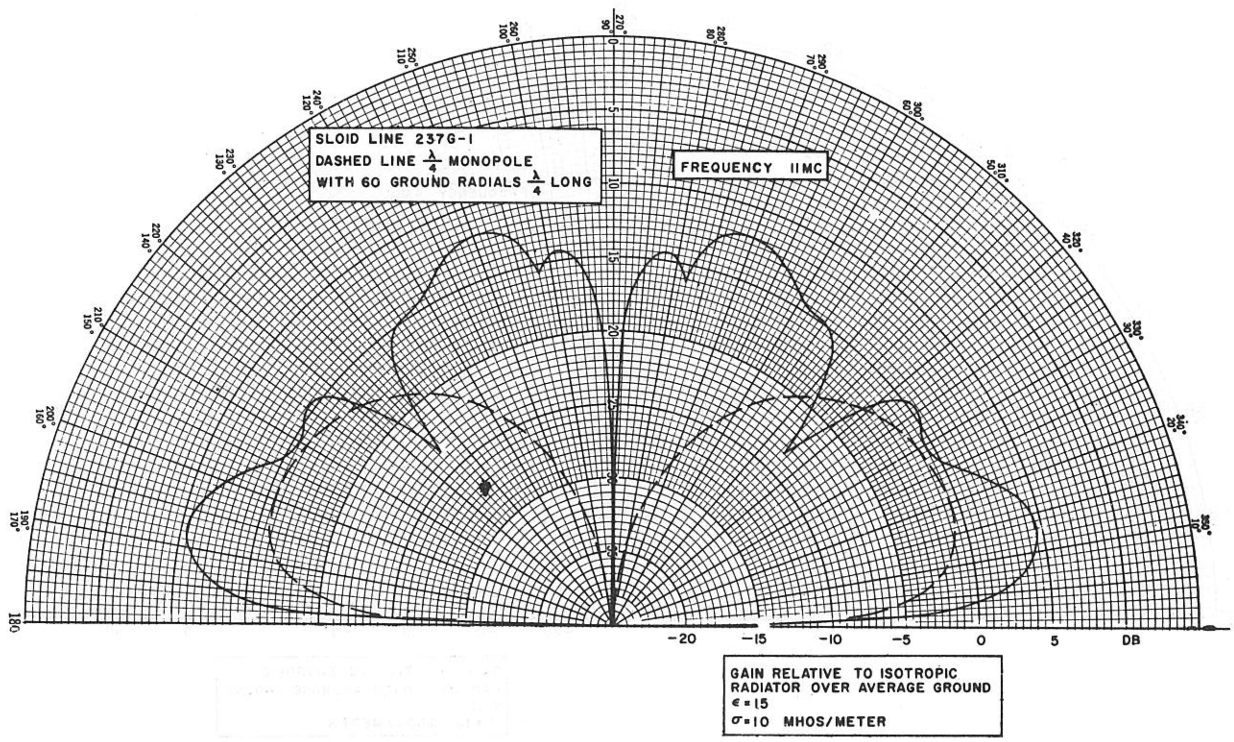


Figure 48D. Elevation Plane Patterns, 237G-1 Discone Antenna

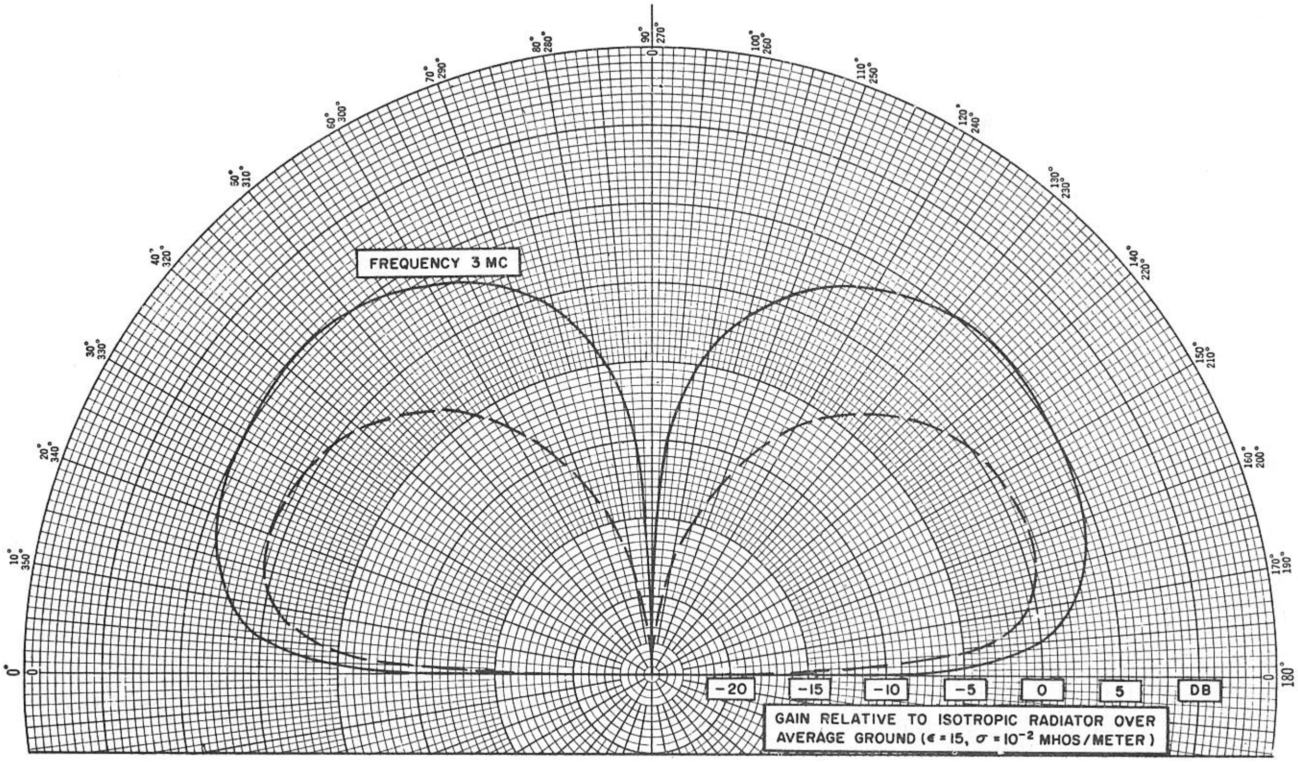


Figure 49A. Elevation Plane Patterns, 237G-2 Discone Antenna

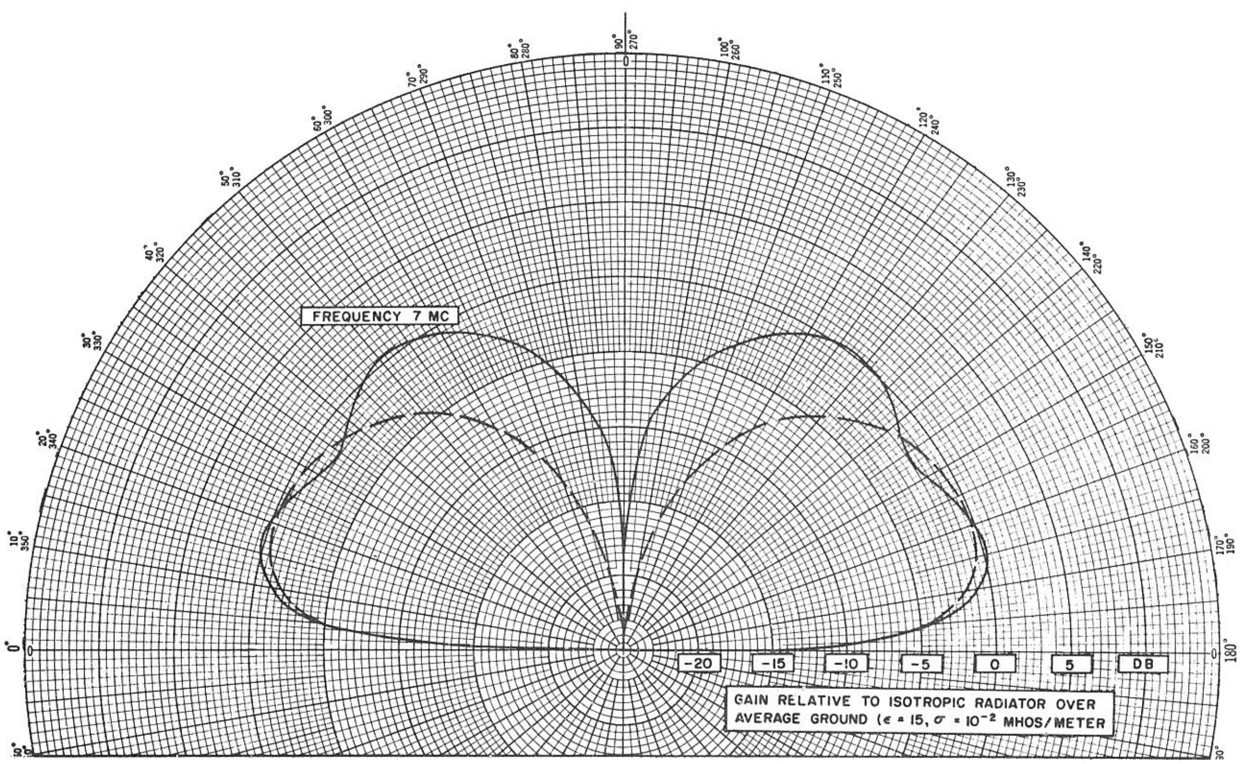


Figure 49B. Elevation Plane Patterns, 237G-2 Discone Antenna

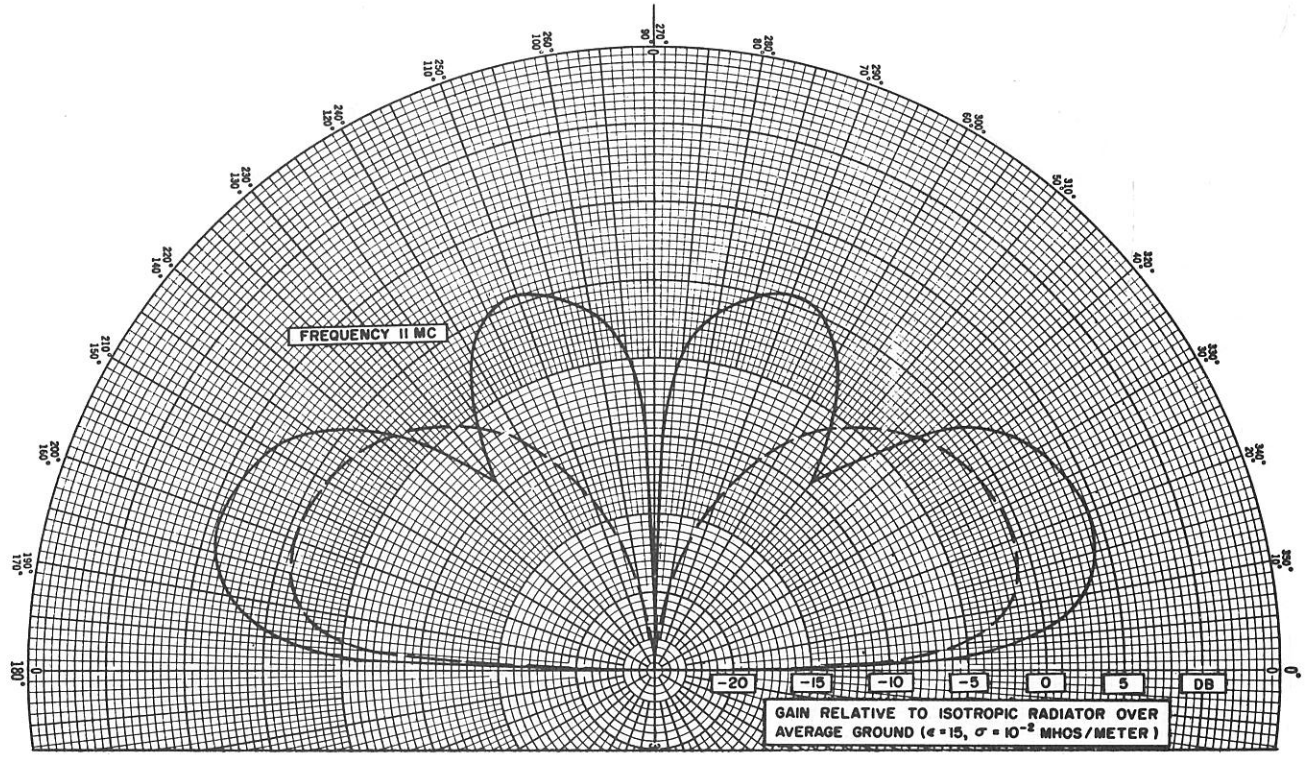


Figure 49C. Elevation Plane Patterns, 237G-2 Discone Antenna

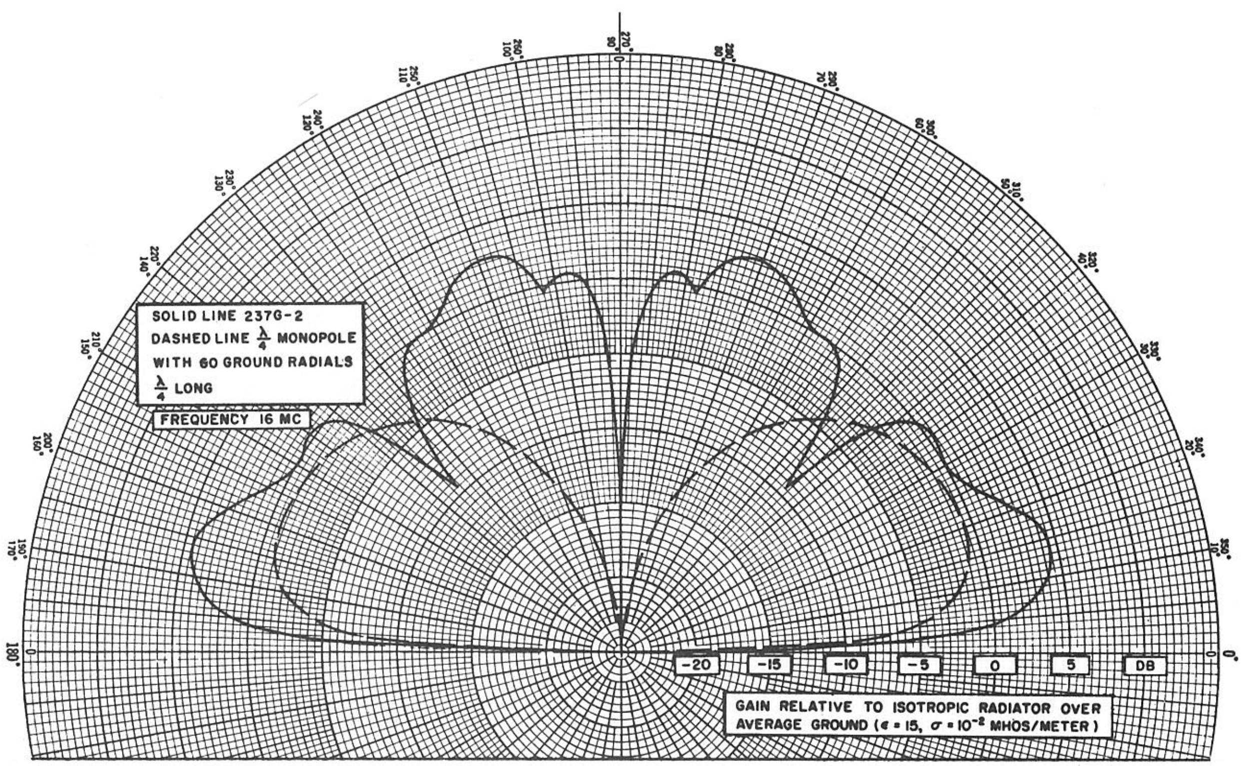


Figure 49D. Elevation Plane Patterns, 237G-2 Discone Antenna

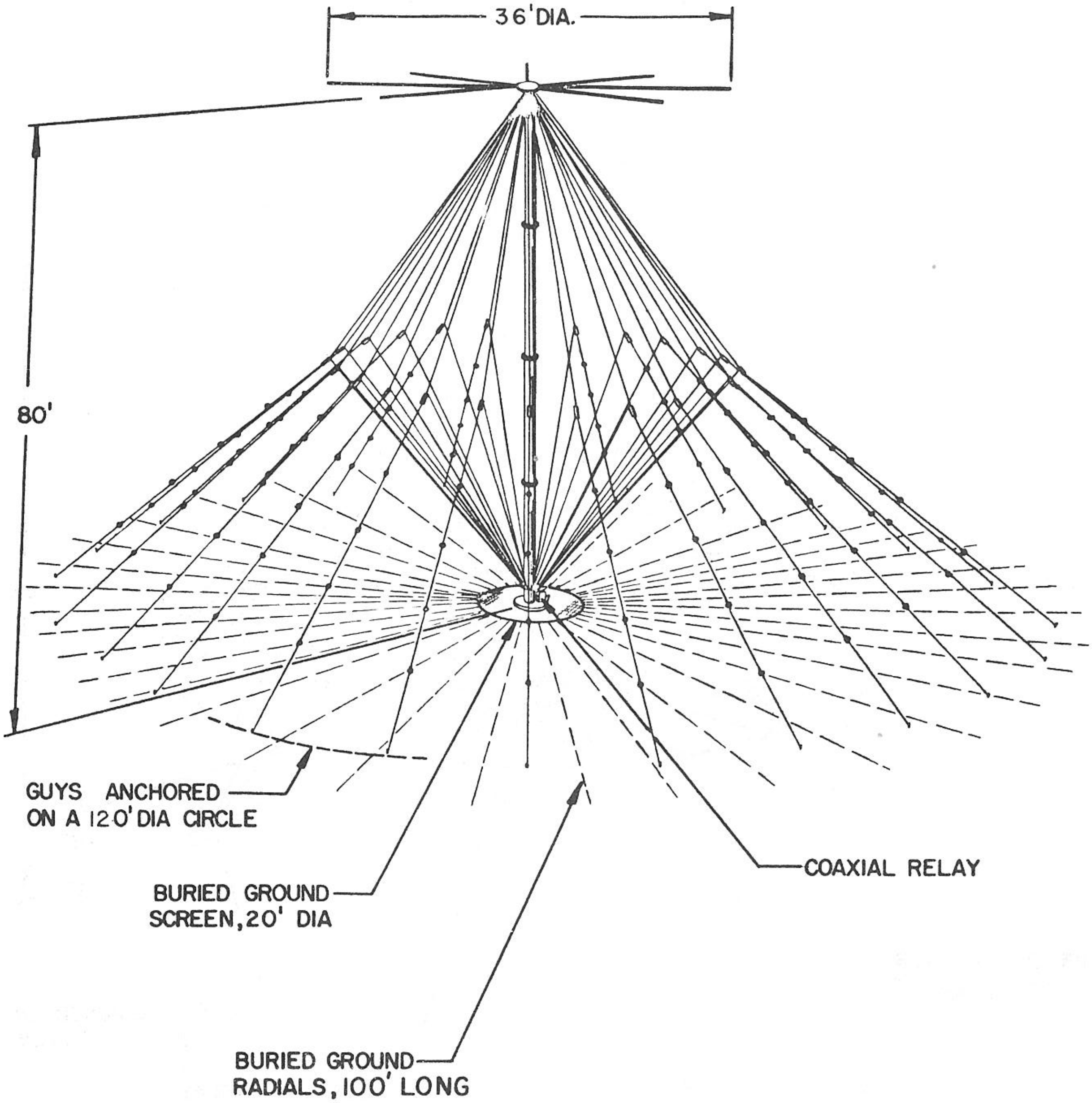


Figure 50. 237W-1 Antenna

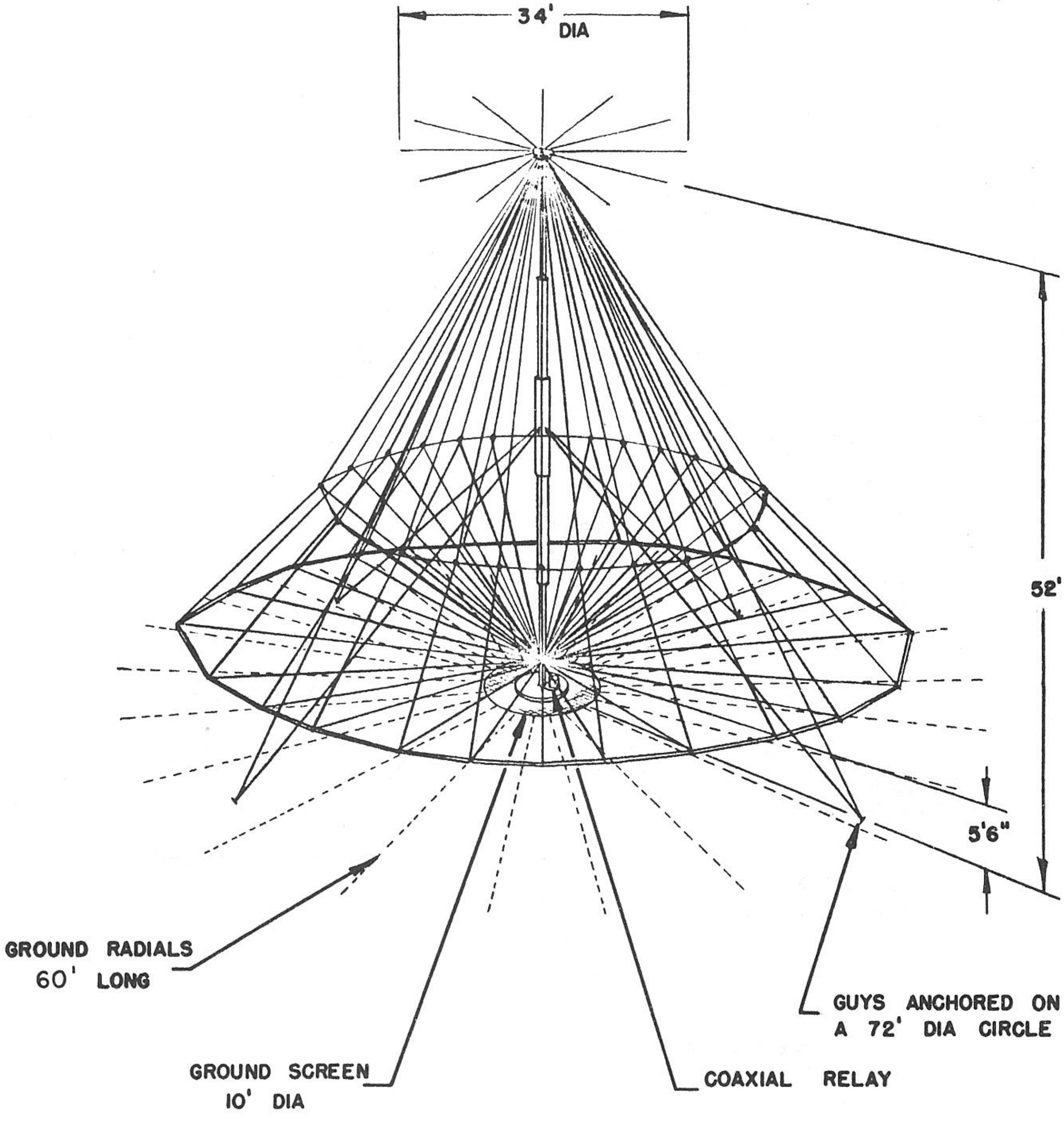


Figure 51. 237W-1X Antenna

6. ANTENNAS WHICH CAN BE SUPPLIED FOR SPECIAL APPLICATIONS

6.1 V ANTENNAS

Two long wires arranged in the form of a "V" will, where the apex angle is optimum, provide a more directive pattern than a single long wire. The two wires are fed at the apex of the V by means of a balanced line, so that equal currents of opposite phase flow in corresponding parts of the two wires. The apex angle is so chosen that the main lobes of the two long wires reinforce along the bisector of the V and tend to cancel in other directions. In figure 52, lobes 1' and 1" add to form lobe 1 of the resultant pattern; lobes 3' and 3", add to form lobe 3. The remainder of the major and minor lobes of the individual wires tend to cancel each other. The result is a bidirectional pattern as shown. The directional pattern is sharper in both the horizontal and vertical planes than the patterns of the individual wires. Maximum radiation in both planes is along the line bisecting the V. The factors which determine the actual directional pattern and gain properties are length of the sides, the apex angle, and the height above ground. The angle at which radiation from the major lobe is maximum is determined by the height above ground and leg-length.

The gain of a V antenna can be increased about 3 db by stacking two V's a half wavelength apart. The array then is fed so that the legs on each side are in phase and out of phase with the legs on the other side. This also results in a lower angle of radiation. The bottom V should be at least a quarter wavelength above the ground.

The general characteristics of a V antenna are as follows:

a. Basic structure is simple and economical.

b. High gain is obtained at relatively low cost.

c. Requires low supporting structures, but large areas.

d. Horizontal beamwidth and beam elevation are not separately controllable, but are mutually dependent on geometry of array. Beam elevation varies with frequency.

6.2 RHOMBIC ANTENNAS

A rhombic antenna consists of four long-wire radiating elements arranged in the shape of a rhombus as shown in figure 53. The rhombic antenna is sometimes described as two V antennas connected back to back and terminated to give a unidirectional pattern. The terminating resistance is chosen to make the system nonresonant.

The best application of a rhombic antenna is for long-distance communications where low-angle transmission or reception is wanted. When the angle is higher than approximately 30 degrees, the gain is low, and the desired performance usually can be obtained more economically with other types of antennas.

The important dimensions of a rhombic antenna are the leg-lengths L, the tilt angle ϕ, height above ground, and the terminating resistance R. These parameters are optimum for only one frequency or narrow band of frequencies. The input impedance may be uniform over a frequency range of 8 to 1, but the radiation characteristics are seldom satisfactory over more than a 2-to-1 frequency range.

The optimum tilt angle for a given radiation angle is a function of leg-length in wavelengths as shown in figure 54. As shown, an increase in electrical length of the legs caused by an increase in frequency results in reduced radiation angle for a given antenna configuration. If the frequency is increased further, pattern deterioration causes a reduction in antenna directivity. The curve marked "optimum length" in figure 54 shows the leg-length at which maximum gain is obtained for a given radiation angle.

A rhombic antenna offers the advantage of relatively high gain with simple construction. On the other hand, a large amount of land is required for a given installation. Also, the radiation pattern changes with frequency, and the horizontal and vertical patterns cannot be controlled separately.

6.3 YAGI ANTENNAS

An array consisting of one driven dipole element and one or more parasitic dipole elements is commonly known as a parasitic array or Yagi antenna. One of the more popular arrays for high-frequency operation is the horizontal three element Yagi shown in figure 55. This array produces a unidirectional pattern similar to the one shown. The director is about 5 percent shorter, and the reflector is about 5 percent longer than the resonant driven element.

The problem of determining optimum element spacing and lengths to result in maximum gain, maximum front-to-back ratio, maximum bandwidth, and a specific input impedance becomes extremely difficult because of the large number of variables. In general, when one of these factors is maximized, the others cannot be.

Figure 56 shows typical gain versus element spacing curves for the three-element Yagi. Although the actual gain depends on many variables, an average gain of approximately 8 db above that of a half-wave dipole can be expected. The azimuth half-power beamwidth is approximately 50 degrees. The vertical pattern is broad, and the radiation angle depends chiefly on antenna height. The substantially unidirectional characteristic and simple electrical and mechanical configuration make this type of antenna useful in systems that require rotation of the beam for aiming in a desired direction.

A front-to-back ratio of about 18 db is typical of practical installations. This characteristic changes more rapidly than gain with a change in operating frequency, and increases with increased electrical spacing between elements.

In general, the bandwidth with respect to input impedance becomes smaller when the impedance is smaller. This becomes lower when the spacing between elements is decreased. Hence, close spacings usually are associated with small bandwidths.

In no case can a conventional parasitic array qualify as a broadband antenna. Even with the use of extremely large diameter elements, a moderate change in frequency seriously upsets the reactance and phase relationships of the various elements. This, in turn, affects the directional and impedance characteristics.

6.4 SIX-SIDED BILLBOARD ANTENNA

The structure shown in figure 57 consists of six horizontally polarized billboard antennas arranged in a hexagon. This arrangement provides radiation in six distinct azimuthal directions. The six panels may be operated separately or simultaneously and at the same or different frequency. The antenna operates in the 9- to 27-mc frequency range.

6.5 HF STEERABLE BEAM ANTENNA SYSTEM

If a number of individual billboard antennas are arranged as shown in figure 58, and the proper switching is employed, an antenna system with a rotatable or steerable beam is achieved. The structure shown covers the 3.5- to 14-mc range with electrical characteristics desirable for long path ionospheric propagation, providing high gain at low angles of radiation.

Two separate and independent arrays are combined in the structure shown in figure 58. The lower frequency array (3.5 to 7 mc) is vertically polarized, while the upper frequency array (7 to 14 mc) is horizontally polarized. The system maintains a gain comparable to that of a class A rhombic antenna.

Additional structures of this type are designed for both transmitting and receiving applications for frequencies up to 30 mc.

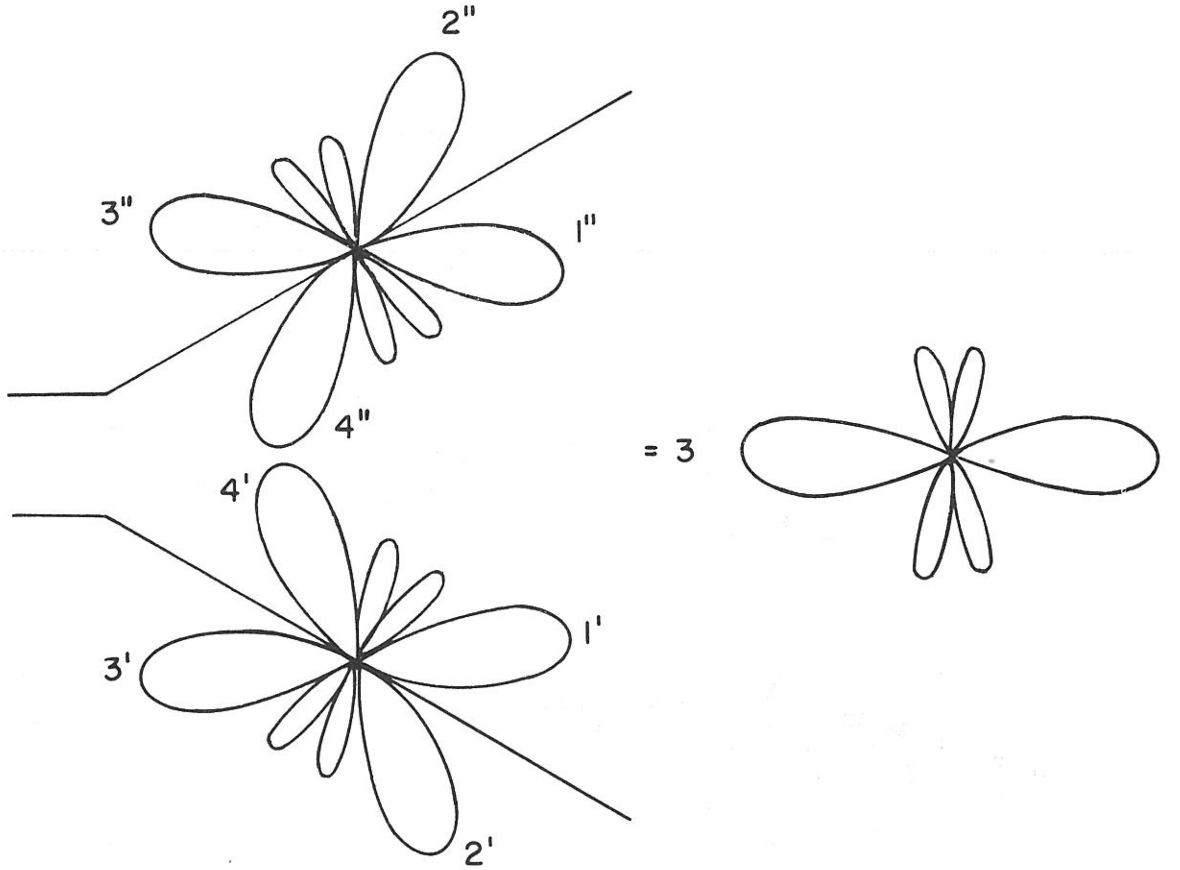


Figure 52. Pattern Formation with a V Antenna

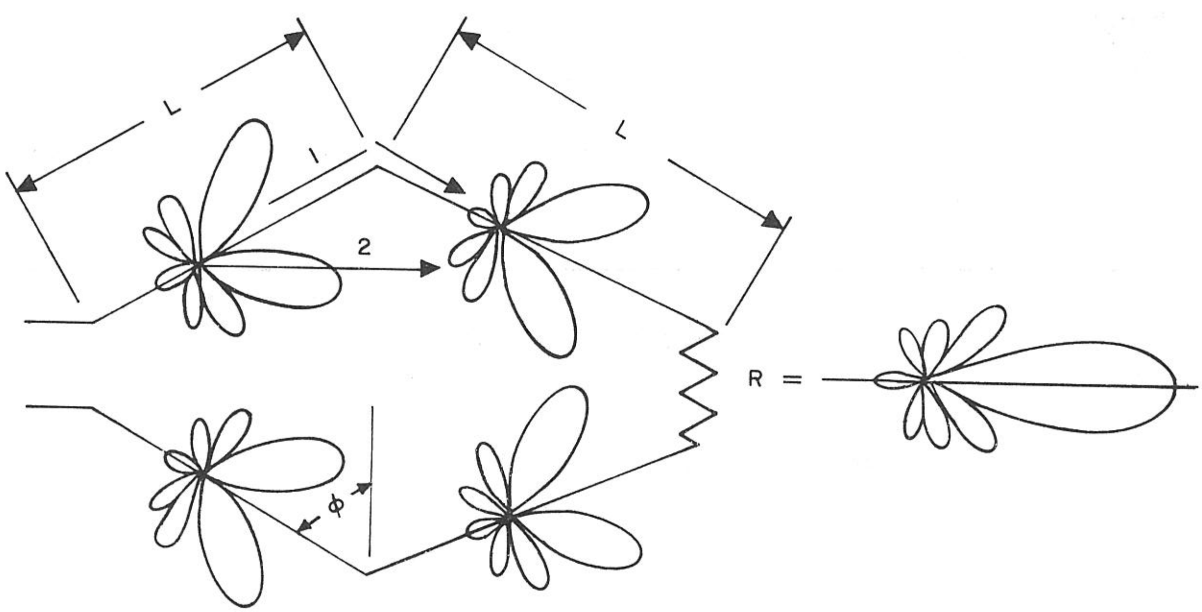


Figure 53. Pattern Formation with a Rhombic Antenna

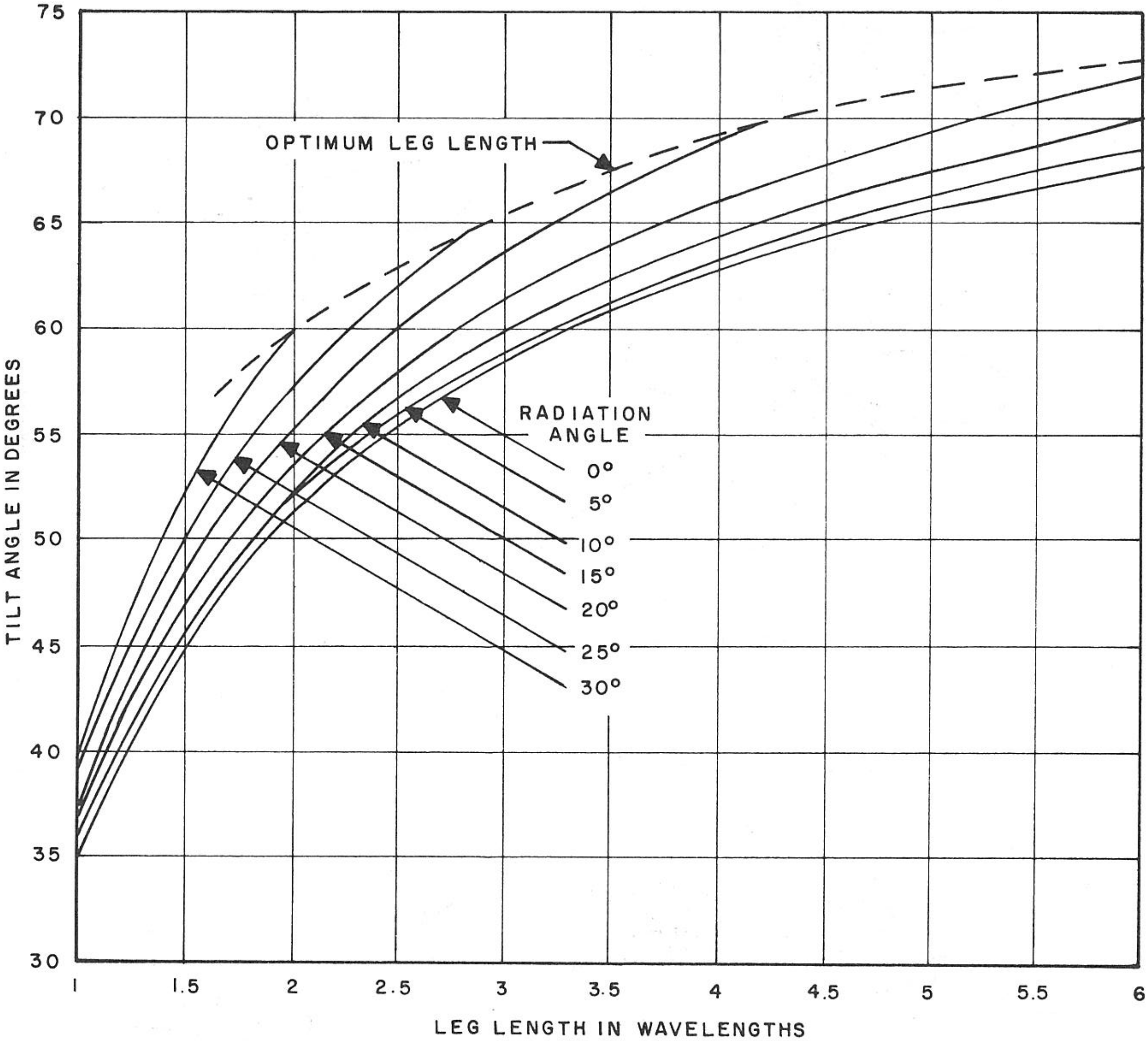


Figure 54. Design Chart for Rhombic Antennas

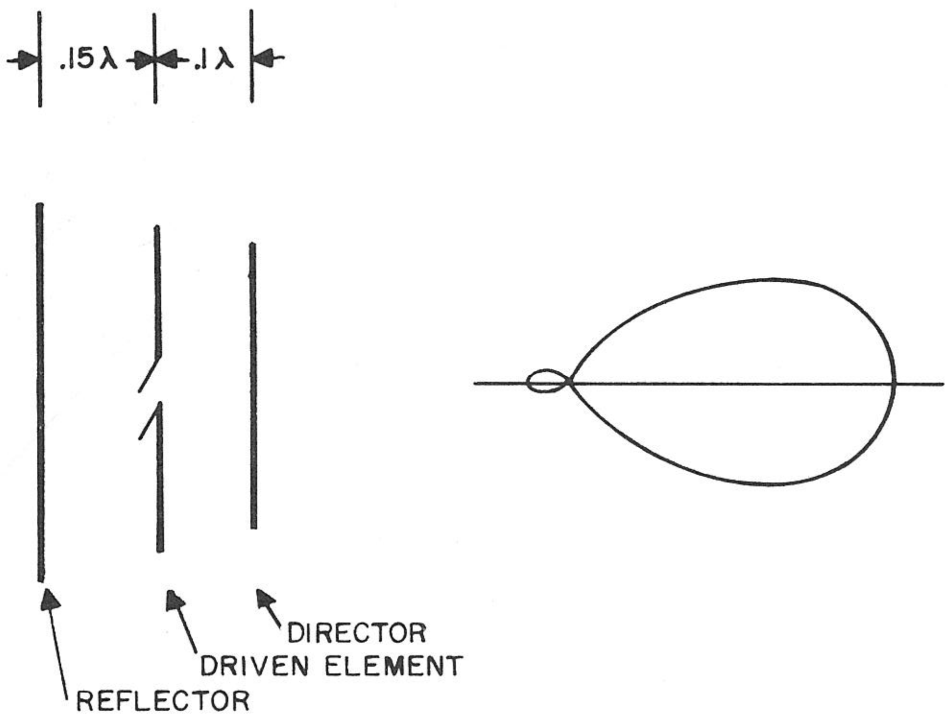


Figure 55. Three-Element Parasitic Array

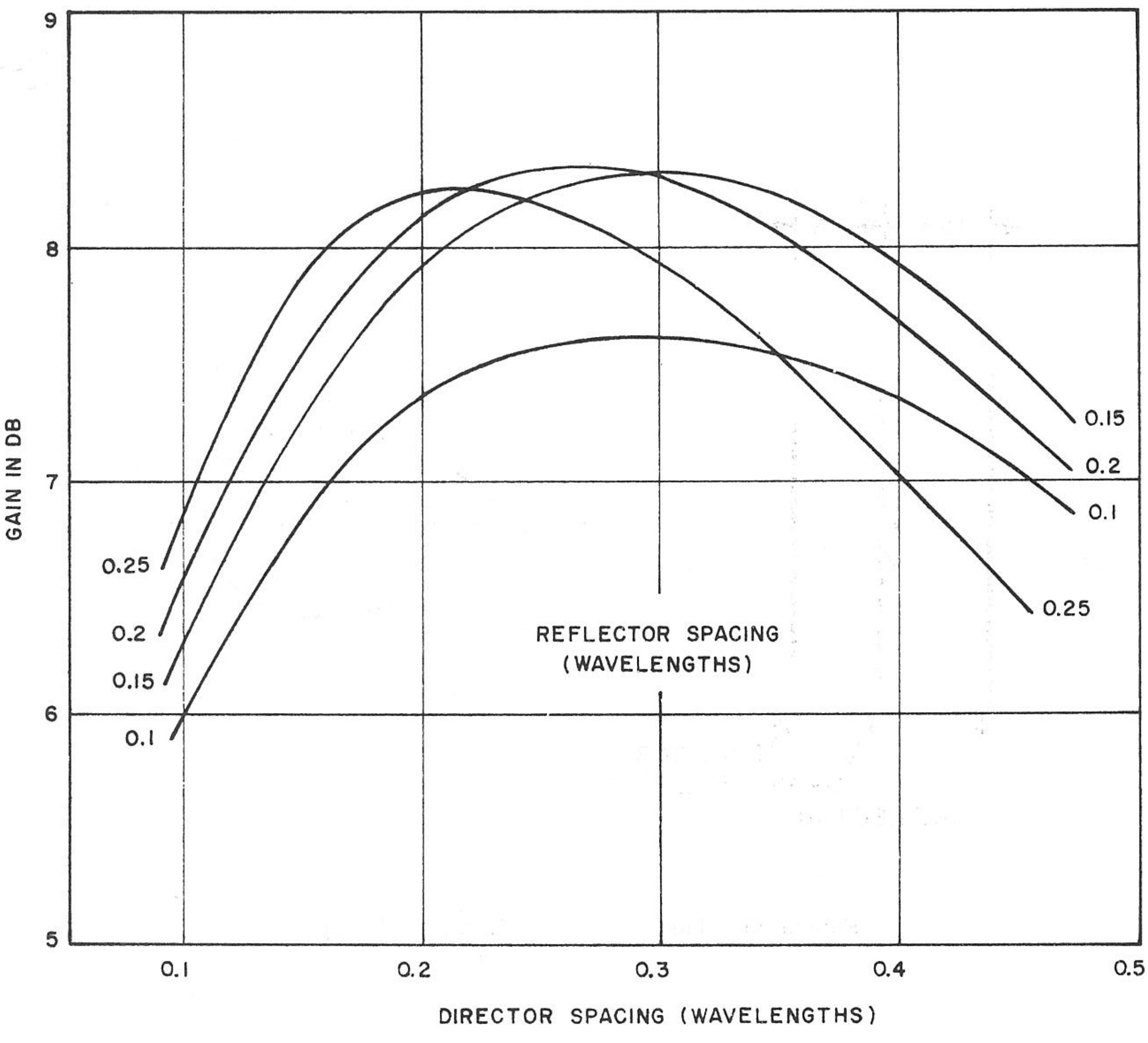


Figure 56. Gain as a Function of Element Spacing for Three-Element Array

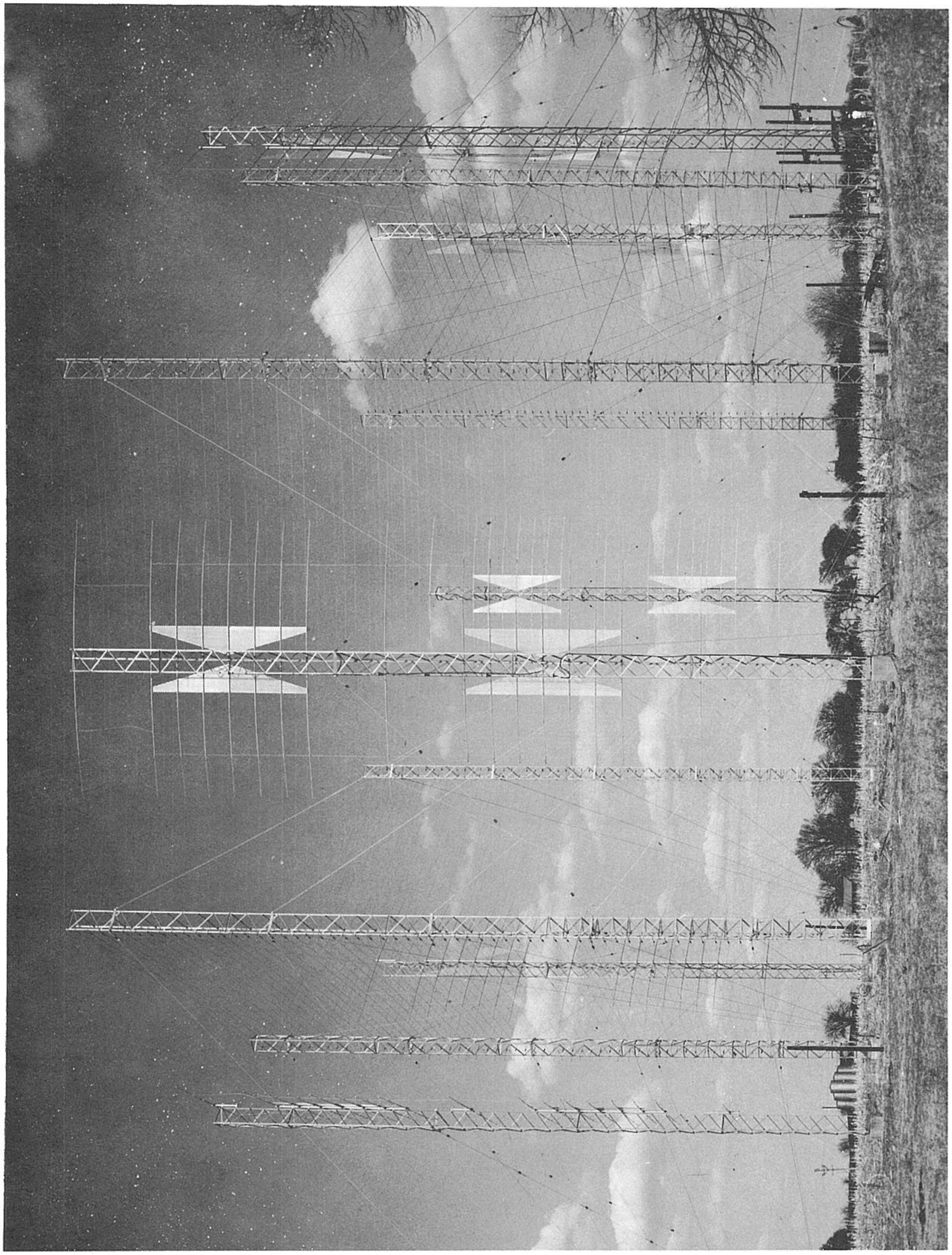


Figure 57. Typical Installation of a Six-Directional Billboard Antenna Combination

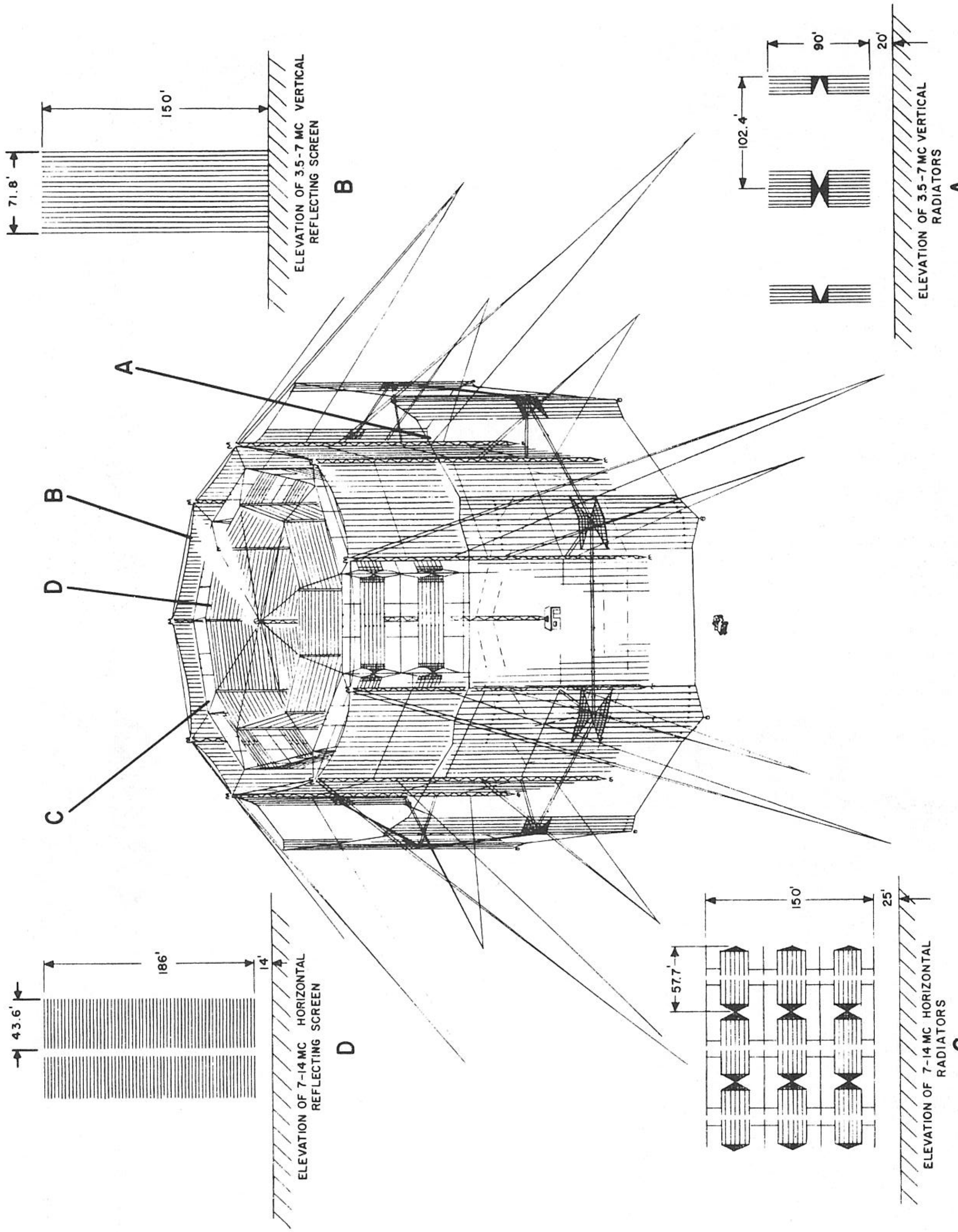


Figure 58. Typical Installation of a HF Steerable Beam Antenna System

7. COMPARISON OF COLLINS LOG-PERIODIC ANTENNAS WITH STANDARD MILITARY RHOMBIC ANTENNAS

7.1 INTRODUCTION

Military designations for types of rhombic antennas designed for optimum performance over particular path lengths have been established. These designations are types A through G, and "RD" types 1 through 7. The performance of each of these types at the radiation angles required for a given path length is optimum at only certain frequencies within the hf band.

A comparison of these military rhombics with the Collins log-periodic antennas designed for the same type of point-to-point service shows that the log-periodic antennas provide a more constant gain across the hf band. Also, this improved performance is obtained with reduced land area requirements. Comparisons of the gain characteristics and area requirements for the log-periodic antenna and military type rhombic antennas are given in the following paragraphs.

7.2 GAIN CHARACTERISTICS

Gain comparisons for various path lengths are given in figures 59 through 63. In each case, the log-periodic antenna and rhombic antenna which provide optimum gain at the radiation angles required for the given path length were selected for comparison. Variation in virtual height of the F layer between the limits of 200 and 350 km was assumed and the gain curves were drawn for the radiation angles required for single-hop propagation at these limits for the given path lengths. The virtual height actually may vary beyond these limits, however they are sufficient for comparison purposes. The gain figures given are all relative to an isotropic radiator in free space.

At certain selected frequencies within the hf range, the rhombic antennas have greater gain than the comparative log-periodic antennas. However, the variation in rhombic gain is great, and throughout most of the frequency range the gain of the rhombic antennas is much less than that of the log-periodic antennas. For example, in figure 62, the type RD-5 rhombic shows peak gain of approximately 18 db at 9 mc and radiation angle of 10 degrees. The gain of the 237E-1 Log-Periodic Antenna at this same frequency and radiation angle is approximately 14 db. However, at 15 mc and 10 degrees the gain of the type RD-5 rhombic drops to approximately -4 db, while the gain of the 237E-1 Log-Periodic remains constant at 14 db. Similar comparisons can be made for the 237C-1 and 237D-1 and other type rhombics using figures 59 and 60. The constant gain characteristic of the log-periodic antennas allows changes in operating frequency to provide for optimum performance with changing propagation conditions.

Another significant advantage of the log-periodic antennas is that the difference in gain between the two radiation angles at the vertical height limits is small and remains constant over the hf range. For example, in figure 62, the difference in gain between the two radiation angles for the 237E-1 Antenna is only 2 db. This means that even if the F layer were to vary between the vertical heights of 200 and 350 km, the variation in antenna gain for any frequency would be slight if 237E-1 Antennas were used on the circuit. The variation in gain of the Type RD-5 rhombic with the same F-layer variation would be large. For example, at 20 mc the gain varies from +15 db at 15 degrees to -3.5 db at 10 degrees. Similar changes in gain with radiation angle for the other rhombics are shown in the other gain curves.

The gain curves in figures 61, 62, and 63 show the lower operating limit of the 237E-1 Antenna as 7.5 mc. As shown in figure 61, the 237N-1 Log-Periodic Antenna can be used with the 237E-1 to provide operation below 7.5 mc. Under conditions where a small structure is required, and vertical polarization can be used, the 237N-1 can be used across the entire hf band with some reduction in antenna gain.

7.3 LAND AREA REQUIREMENTS

The log-periodic antennas provide optimum circuit performance with less land area requirements than rhombic antennas. A comparison of the area requirements for the log-periodic and Type RD rhombic antennas is given in figure 64. The figure takes into account additional area required for guying the structures. In general, the rhombic antennas are lower structures, but require much greater over-all area for each installation. The reduced area requirements resulting from use of log-periodic antennas becomes even more significant in large multiple antenna installations.

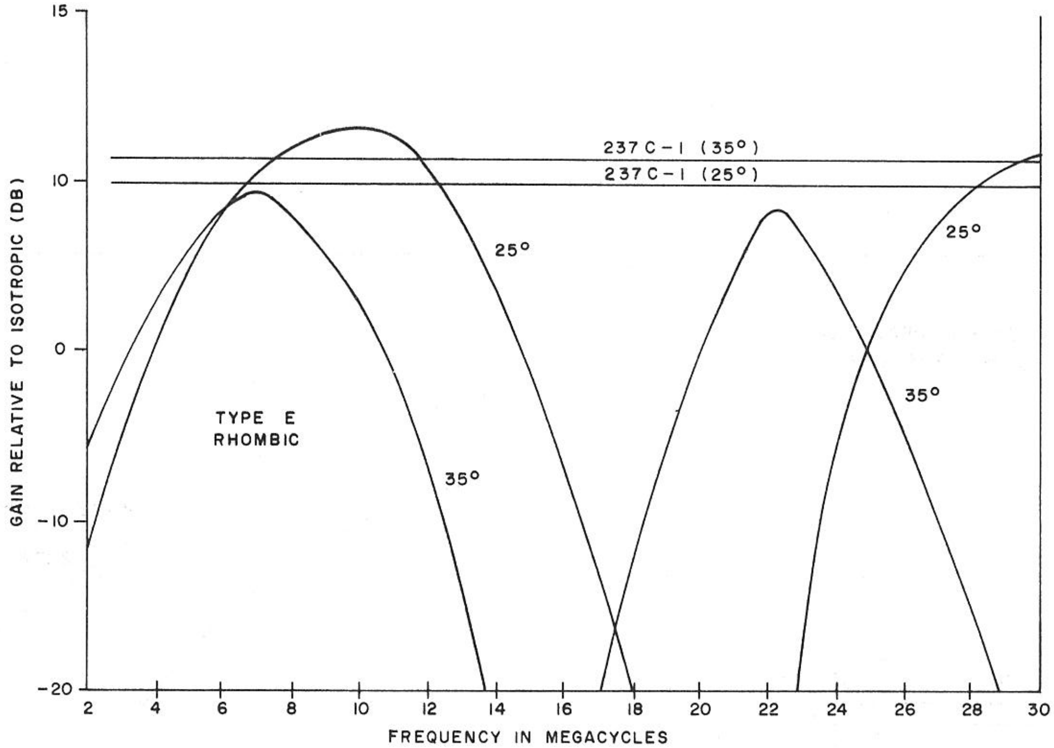


Figure 59. Gain Comparison of 237C Log-Periodic and Type E Rhombic for 600-Mile Circuit

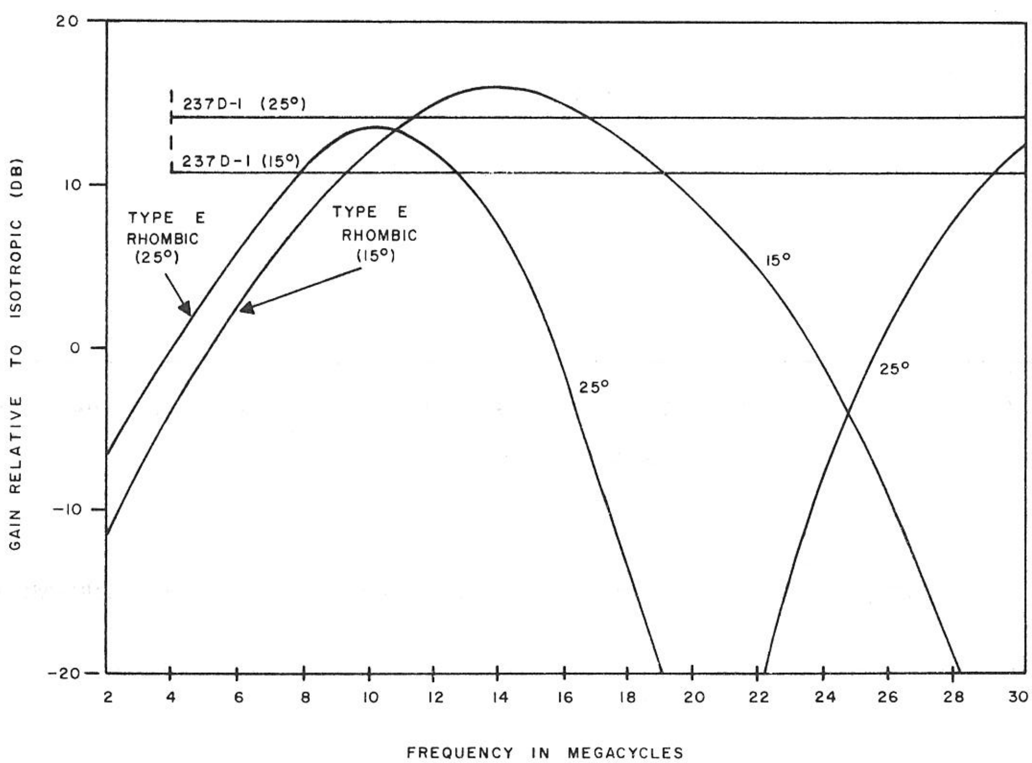


Figure 60. Gain Comparison of 237D Log-Periodic and Type E Rhombic for 900-Mile Circuit

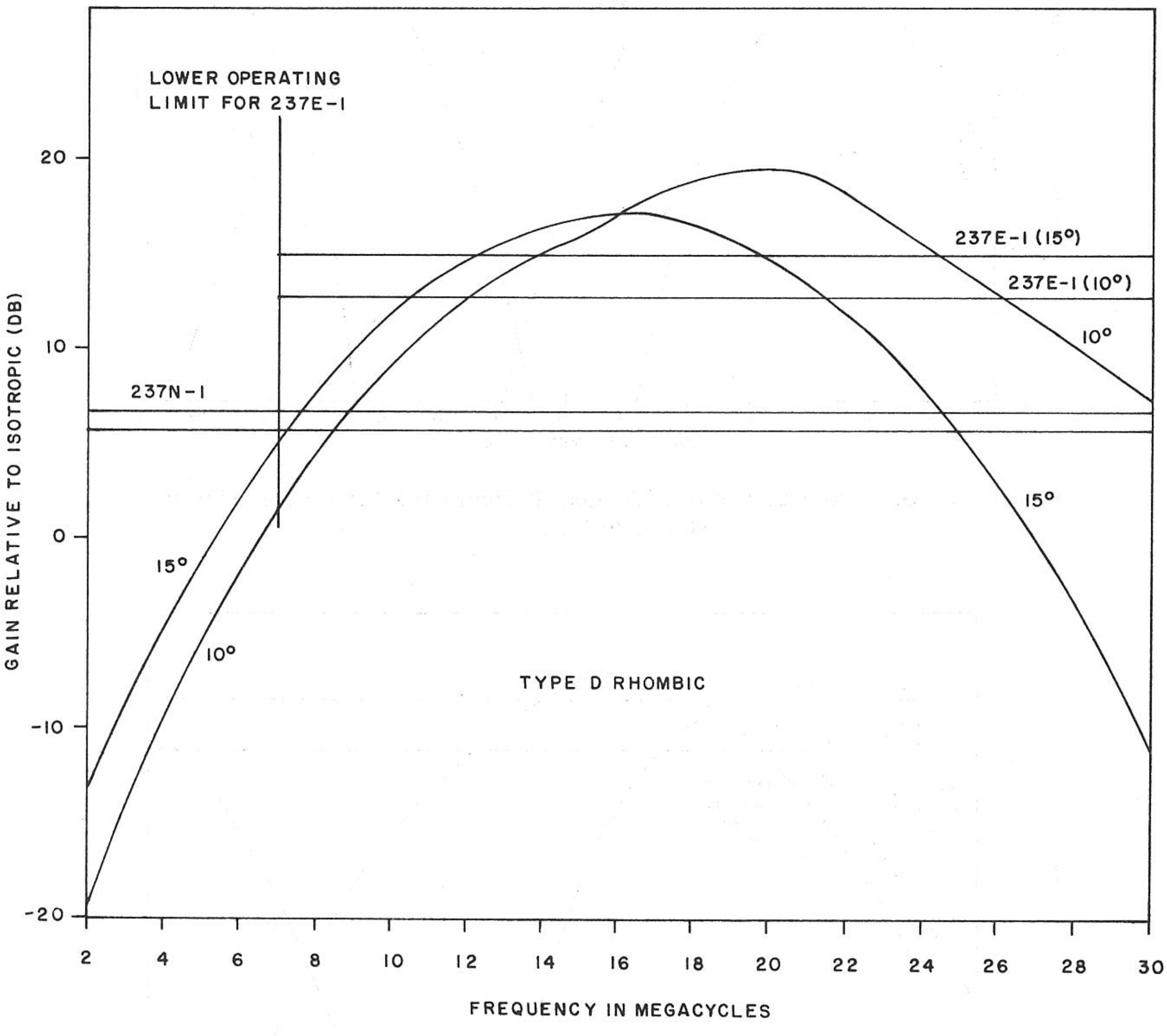


Figure 61. Gain Comparison of 237E Log-Periodic and Type D Rhombic for 1200-Mile Circuit

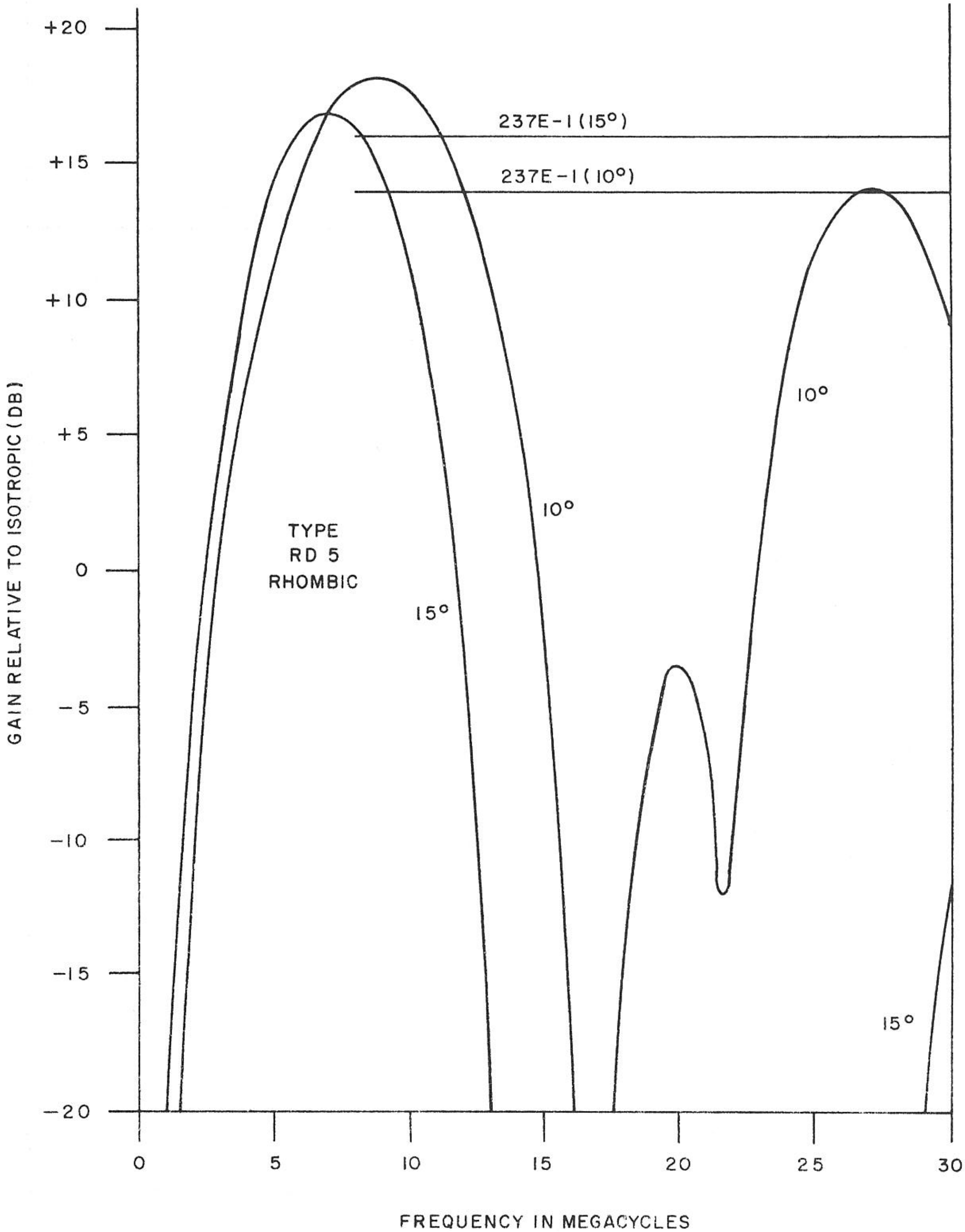


Figure 62. Gain Comparison of 237E and Type "RD-5" Rhombic for 1200-Mile Circuit

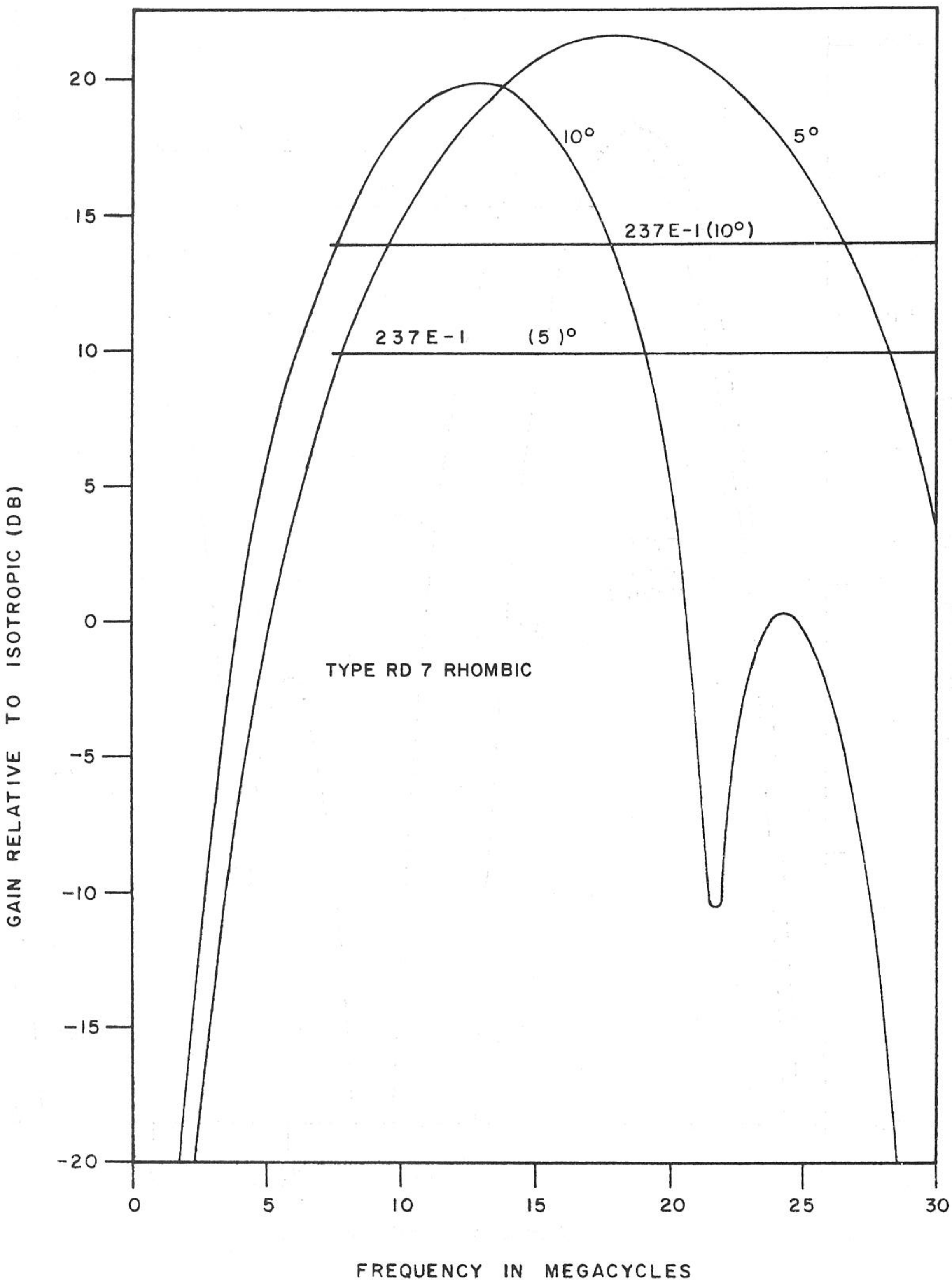
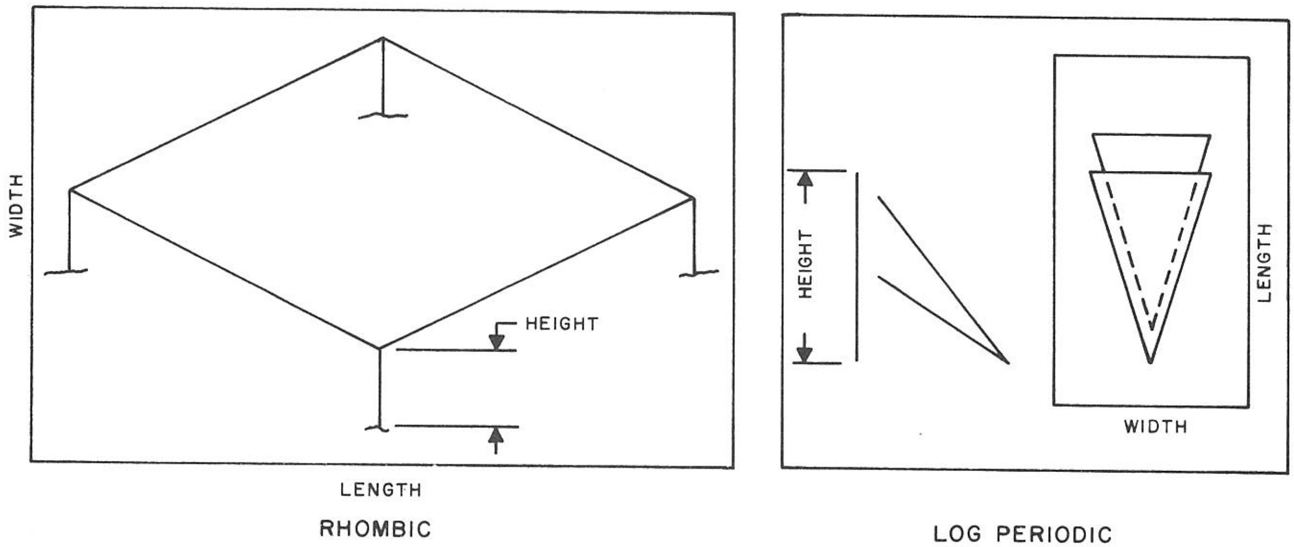


Figure 63. Gain Comparison of 237E Log-Periodic and Type "RD-7" Rhombic for 1800-Mile Circuit



ANTENNA TYPE	DIMENSIONS IN FEET			APPROXIMATE REQUIRED AREA IN ACRES
	LENGTH	WIDTH	HEIGHT	
Collins Log Periodics				
237C-1	293	413	160	2.8
237C-2	220	310	120	1.6
237C-3	146	206	80	0.7
237D-1	430	450	230	4.5
237D-2	260	260	140	1.6
237E-1	384	382	220	3.4
237E-2	330	312	180	2.4
Rhombics, Type "RD"				
1	996	575	130	13.3
2	1001	560	130	13.1
3	1005	556	130	12.9
4	1016	521	130	12.3
5	1054	693	130	16.3
6	1068	654	130	16.2
7	1105	568	130	14.3
Rhombics, Type A	838	393	65	7.7
B	782	366	60	6.4
C	710	336	57	5.6
D	650	338	55	4.7
E	600	340	53	4.5
F	542	334	51	4.2
G	494	331	50	3.8

Figure 64. Comparison of Dimensions for Log-Periodic and Rhombic Antennas