DEVELOPMENT OF THE HIGH-FREQUENCY RADIO RANGE

PART II

TESTING OF THE ULTRA-HIGH-FREQUENCY RADIO RANGES ON TOWERS

By

P B King
and
T A Kouchnerkavich
Technical Development Division

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JESSE H JONES, *Secretary*

CIVIL AERONAUTICS ADMINISTRATION

CHARLES I STANTON, *Administrator*

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INFORMATION
AND STATISTICS

DEVELOPMENT OF THE ULTRA-HIGH-FREQUENCY RADIO RANGE
PART II - TESTING OF UHF RADIO RANGES ON TOWERS

SUMMARY

This report covers further developments of the ultra-high-frequency radio range, discusses the factors affecting the usefulness of radio ranges from a theoretical standpoint, discusses the effect of reflections from the ground and from a counterpoise, shows the effect of height on distance range and continuity of signal, describes the apparatus used, and presents the data obtained at Indianapolis, Ind., and Van Nuys, Calif., during the latter part of 1941.

The investigation was begun using only vertical polarization at 63 megacycles on a 16-foot wooden tower, first without a counterpoise and then with a 30-foot counterpoise. Tests were made using both vertical and horizontal dipole radiators on the high tower.

The second stage of the investigation was carried on at 125 megacycles using pure horizontal polarization. Tests were made on the 125-foot steel tower with a counterpoise, on a 30-foot pole without a counterpoise, on a 30-foot wooden tower with a 30-foot counterpoise, and then on a 22-foot steel tower with a 35-foot counterpoise.

The investigation was carried on in two separate locations, Indianapolis, Ind., and Van Nuys, Calif. The results obtained at Indianapolis are representative of what may be expected in flat country, while the results obtained at Van Nuys indicate what may be expected when an installation is made immediately adjacent to extremely mountainous terrain. The Van Nuys work was done using an improved ultra-high-frequency radio range antenna system with pure horizontal polarization on a 22-foot steel tower with a 35-foot counterpoise. This antenna system was still further improved and reinstalled on the steel tower at Indianapolis which had been shortened from 125 feet to 22 feet with the same counterpoise.

The ultra-high-frequency range characteristics are contrasted to those of the lower frequency ranges in extremely rugged country.

The conclusions reached as a result of this investigation are that the high tower is impractical because of multiple low-angle lobes produced by reflections from the ground, the low tower is most satisfactory, and a counterpoise is essential and should be designed to limit the low-angle lobes to not more than two. With a slight increase in counterpoise diameter the lobes may be further limited.

INTRODUCTION

Early in the development of the ultra-high-frequency radio range[1], it was determined that the height of the supporting structure and the presence of a counterpoise had a definite effect on the factors governing the usefulness of an ultra-high-frequency radio range, namely, distance range, character of the cone-of-silence, course straightness, continuity of signal, and multiple or false courses. The development of the ultra-high-frequency range explored two frequencies, 63 and 125 megacycles, using vertical dipole, horizontal dipole, and horizontal loop antennas on towers varying in height from 16 to 125 feet, with and without a counterpoise. The data accumulated were sufficient for the consideration of the elevation above ground phase of the ultra-high-frequency range problem, and the information has been used in this report to compare actual with theoretical operation.

[1] Hromada, J. C., and King, P. B., "Development of the Ultra-High-Frequency Radio Range. Part I - The Four-Course Aural Radio Range." C. A. A. Technical Development Report No. 42, July 1944.

Some early tests using several types of counterpoises at Indianapolis and Pittsburgh, and using a counterpoise mounted atop a 125-foot steel tower at Washington, D C., have been described in a previous report[2] These tests showed the desirability of a counterpoise because the reduction of high-angle lobes was quite pronounced. However, the results of these tests did indicate the necessity for further study of the problem

THEORETICAL DISCUSSION

The Electric Field Pattern in a Vertical Plane

From an analytical point of view there is no formal difference between the Maxwellian electromagnetic theory and the classical theory of light. Radio wave propagation problems can be readily solved if certain simplifying assumptions regarding the physical properties of the media involved are made

Complex and cumbersome equations are obtained if an attempt is made to take account of the spatial variation of the ionization in the Kenelly-Heavyside layer, the varying electrical properties, and the curvature of the earth's surface The simplified theory used in this report gives useful qualitative information as to the radiated electromagnetic field within the optical horizon

In the radiation field the E and H vectors are in simple relationship, and it is sufficient to give, for example, the electric field intensity E. For investigation of the effect of the counterpoise and of the earth's surface on the radiation field, it is sufficient to consider the electric intensity in a vertical plane

One of the major factors determining the usefulness of a radio range system is its service area. Increasing the altitude of the receiving and the transmitting antennas naturally increases the unobstructed optical path and, hence, the useful distance range of the system. In a simple case of point-to-point communication, it is possible to control the local conditions so that the most satisfactory circuit is obtainable The problem of aircraft navigation is far more complicated. There is no definite point-to-point path, the height of the receiver is variable, and the horizontal distance separating the transmitter and the receiver is continually changing. The problem, therefore, becomes one of determining the effect of all factors in all directions, in all planes Interference patterns set up by the ground and by objects near the antenna must be analyzed and their influence on the vertical and horizontal radiation fields considered At any given installation the height of the transmitting antenna above ground is the one factor which is under the control of the engineer. Local conditions, such as terrain, buildings, and vegetation, must be accepted largely as they are

It has been found that at frequencies higher than 60 megacycles the radiated waves are rarely reflected by ionized regions or layers in the upper atmosphere; hence, there is seldom any skip effect as observed with lower frequencies However, reflection does occur from the earth's surface, and due consideration must therefore be given to the reflecting medium and its effect on the radiation pattern

In the simplest case of an antenna above a plane reflector of infinite area the vertical field pattern may be easily calculated. The field strength at any point in space is the vector sum of the direct ray and the reflected ray

$$F = F_0 \ (1 + Ke^{-j\Delta}) \qquad (1)$$

Where F_0 = electric field strength of the direct ray at a point in space

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[2] See reference 1 on page 1

F_0 depends on the configuration of the antenna system and its current distribution, and on the direction and distance of the reference point.

$K = Ae^{j\psi}$ = reflection coefficient of the earth's surface A is the ratio of the amplitudes of the reflected to the incident ray The phase shift caused by the reflection is given by the angle ψ.

$$\Delta = \frac{4\pi H}{\lambda} \sin \phi \qquad (2)$$

Δ = phase shift between the direct and the reflected rays due to difference in path length, at distances where the direct and reflected rays may be considered as parallel

H = height of center of the antenna above the reflecting plane
λ = wave length.
ϕ = angle between the direct ray and the ground plane

In general, it can be said that the attenuation of the electric field along the ground at low grazing angles at a fixed height above the ground varies inversely with the square of the distance, while at any fixed angle above the ground the attenuation will vary according to the inverse distance law

Before examining the reflection coefficient K in more detail, a short digression is made to explain terminology

The plane of incidence is the vertical plane through the direct and reflected rays. According to Fresnel's equations, the reflection coefficient depends on whether the E (or H) vector is parallel or perpendicular to the plane of incidence. In the case of vertical dipole antennas the E vector is parallel to the plane of incidence. For horizontally polarized waves produced by loop antennas, the electric field always is at right angles to the plane of incidence. In the case of an electromagnetic field produced by horizontal dipoles, the electric intensity has in general both a parallel and a normal component to the plane of incidence The relative magnitude of the two components depends on the angle between the plane of incidence and the dipole axis

When the electric field strength vector is either perpendicular or parallel to the plane of incidence, the variation of the amplitude ratio A as a function of the angle of elevation ϕ for a perfectly conducting ground plane and for an insulating ground plane of dielectric constant $\epsilon = 9$ (dry earth) is shown in figure 1

It will be noted that in the case of the perfect conductor the amplitude ratio A is unity for both perpendicular and parallel polarization The phase angle ψ is 180° at zero or low grazing angles. This is equivalent to a perfect negative image

In the case of transmission over a non-conductor or dielectric ground, the attenuation of the perpendicularly polarized ray is gradual, finally reaching a value of 0.5 at normal incidence (for $\epsilon = 9$) The phase angle ψ is 180° upon reflection from a pure dielectric In the case of the parallel polarization the ratio A decreases rapidly and at a critical angle of approximately 18.5° (for $\epsilon = 9$) reaches zero. For a non-conducting ground of conductivity, $\sigma = 0$, this critical angle is known as Brewster's angle The cotangent of this angle is equal to the square root of the dielectric constant At this angle the reflected ray is perpendicular to the refracted ray, and the phase change ψ of the incident ray on reflection is 90° At low grazing angles ψ is 180° Above the critical angle no phase shift occurs and is 0°. Above the critical angle the value of A for parallel polarization increases slowly to a value of 0.5 at normal incidence. At normal incidence the ray parallel to the plane of incidence has no vertical component, thus the reflection coefficients for rays having both perpendicular and parallel polarization are equal in magnitude but opposite in sign.

When the reflecting medium is partially conducting the situation is somewhat different, especially for the case of parallel polarization For a fixed dielectric constant, the critical angle, point of minimum reflection, becomes smaller as the conductivity increases or as the frequency is decreased For very low frequencies the critical angle may be a fraction of a degree. At no angle does the reflected ray become zero[3,4]

In general, it can be said that the vertical pattern for horizontal polarization will be more uniform with changes in incident angle.

For the purpose of investigating the vertical pattern, let us consider for a moment equation (1) and calculate the radiation characteristics of a vertical and a horizontal doublet as a function of the angle of incidence.

Using subscripts v and h for vertical and horizontal polarization, respectively, we obtain from equation (1)

$$F_v = F_{ov}\left[1 + A_v \, e^{-j(\psi_v + \Delta)}\right] \tag{3}$$

$$F_h = F_{oh}\left[1 + A_h \, e^{j(\psi_h - \Delta)}\right] \tag{4}$$

$$K_v = A_v \, e^{-j\psi_v} \tag{5}$$

$$K_h = A_h \, e^{j\psi_h} \tag{6}$$

As shown by K. A. Norton[5], the phase angle ψ_h of the coefficient of reflection K_h is 180° lagging at grazing angles and decreases with increase in incident angle. Thus ψ_h is positive and the phase angle Δ due to path difference is subtracted from ψ_h. For K_v, the phase angle ψ_v is 180° leading at grazing angles and decreases with increase in incident angle. Therefore ψ_v is negative and Δ is added to it to decrease its lead.

The geometric solution of the two vectors in each equation results in the following resultant field strength vectors.

$$F_v = F_{ov}\sqrt{1 + A_v^2 + 2\,A_v \cos(\psi_v + \Delta)} \tag{7}$$

$$F_h = F_{oh}\sqrt{1 + A_h^2 + 2\,A_h \cos(\psi_h - \Delta)} \tag{8}$$

Taking equation (8) for horizontal polarization, since the amplitude ratio and phase angle remain more nearly constant for various angles of incidence, and assuming $A_h = 1$ and $\psi_h = 180$, the expression for the field pattern in the vertical plane becomes

$$F_h = 2F_{oh} \sin\left[\frac{2\pi H}{\lambda} \sin\phi\right] \tag{9}$$

This equation also holds true for F_v at low grazing angles.

From this equation it can easily be seen that F_h will become maximum or minimum as the bracketed portion becomes equal to odd or even multiples of $\pi/2$, and the function will go through greater numbers of maxima and minima for variation of ϕ as H is increased

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[3] Trevor, Bertram, and Carter, P S., "Notes on Propagation of Waves below Ten Meters in Length," Proc. I R.E , vol. 21, p. 387, March 1933.

[4] Feldman, C.B., "The Optical Behavior of the Ground for Short Radio Waves," Proc. I R E., vol 21, p. 764, June 1933.

[5] Ground Wave Propagation, Federal Communications Publication No. 47475, Feb. 1941.

Thus the vertical pattern will have as many maxima and minima as H is a multiple of $\lambda/2$. The angles at which these occur are not easily obtained by inspection Figure 2 gives a graphical method of obtaining the approximate values of the angles for any height of horizontally polarized antenna. Values up to seven wavelengths are shown. This figure can also be used with fair accuracy in the case of vertical polarization at angles of incidence less than the critical angle. For angles of incidence greater than the critical angle the maxima and minima must be interchanged when considering vertical polarization Of course, the correct amplitude ratio must be used for each angle It will be seen that as H is increased more maxima and minima are added to the vertical pattern. As H is increased the lowest lobe is depressed nearer to the ground As A_h and A_v at higher angles are not equal to unity, the minima in the pattern will not go to zero and the vertical pattern will be scalloped with its amplitude oscillating from maximum to minimum around a value equal to the field due to the direct ray. For horizontal polarization these oscillations or pattern scalloping will be more or less uniform for varying angles of ϕ from grazing to normal incidence. For vertical polarization the scalloping will be greatest at low grazing angles, will diminish as the critical angle is reached, and then will increase as ϕ approaches normal incidence. An airplane flying through such a pattern will experience surges and fades in the signal as it cuts through the maxima and minima Thus, increasing the height of the transmitting antenna to increase the distance range introduces an undesirable condition of surges and deep fades at considerable distances from the station

Use of a Counterpoise

In the case of a radio range installation, it is desirable to produce a field pattern with the fewest possible irregularities. The major part of the radiation should be at low angles, and no signal should be radiated vertically Inspection of figure 2 will show that any antenna which is located at any multiple of one-half wavelength above ground will radiate such a field The higher the antenna the lower will be the angle of the first maximum and, at the same time, the number of lobes in the vertical pattern will be greater in number If a perfectly conducting counterpoise is placed one-half wavelength under the antenna, the maximum intensity of signal will be at 30° elevation and no signal will be radiated vertically, thus insuring a good cone-of-silence above the range Signals passing over the edge of the counterpoise will be reflected from the ground Thus, in considering the vertical pattern, due cognizance must be taken of the surface from which reflection takes place Two "ground factor" equations must be used to describe the radiation in the vertical plane The sine function in equation (9) must be replaced by

$$G_g = \sin \left[(\beta_1 + \beta_2) \sin\phi \right] \quad \text{when } \phi < \tan^{-1} \frac{\beta_2}{\gamma} \tag{10}$$

$$G_c = \sin \left[\beta_2 \sin\phi \right] \quad \text{when } \phi > \tan^{-1} \frac{\beta_2}{\gamma} \tag{11}$$

where $\beta_1 =$ the height of the counterpoise above ground in electrical radians $= \frac{2\pi h_1}{\lambda}$

$h_1 =$ the height of counterpoise above ground

$\beta_2 =$ the height of the antenna above the counterpoise in electrical radians $= \frac{2\pi h_2}{\lambda}$

$h_2 =$ the height of the antenna above the counterpoise

$\gamma =$ the radius of the counterpoise in electrical radians

$\phi =$ the elevation angle

The two values of the ground factor are based on the assumption that at elevation angles less than $(\tan^{-1} \frac{\beta_2}{\gamma})$ all reflection takes place from the ground and only G_g applies.

At elevation angles greater than $(\tan^{-1} \frac{\beta_2}{\gamma})$ all reflection takes place from the counterpoise and only G_c applies Strictly speaking, there is not an abrupt change in field strength at this critical angle. Imperfect reflection at the edge and diffraction over the edge of the counterpoise cause a gradual change in the pattern produced. At any given installation slight irregularities in terrain make any mathematical analysis of the situation only approximate The ground factors given above are based on assumptions that the reflection coefficients of both the earth and the counterpoise are unity and that the phase change at reflection is 180° Rigid application of accurate factors in the computation of the vertical pattern is purely of academic interest.

The results obtained during test flights agree fairly well with the above theory when the variations from the ideal case are considered. These variations may be briefly summarized as follows: (a) Uneven terrain causes large deviations from the ideal plane, especially in the case where there is a focusing action; (b) no account of the edge effect of the counterpoise has been considered; (c) irregularities in the vertical pattern of the airplane receiving antenna could not be accurately determined; (d) variations of piloting, even in ideal weather, were sufficient to introduce errors. In the case of an actual installation it has been found that values of $|K| < 1$, diffraction over the edge of the counterpoise and slight irregularity in the ground, reduce the low-angle surges to fades ratio. The characteristics of the signal are, therefore, considerably better than those indicated by the calculated patterns where $|K| = 1$ (figs. 3 and 4).

General Propagation Characteristics

As stated in the introduction, the test of the ultra-high-frequency radio ranges on towers was carried on concurrently with the development of the ultra-high-frequency range system. Therefore, much of the test data was applicable to both problems. A review of the general propagation characteristics at this point will aid in the proper interpretation of the data which will be presented in this report

As stated above, the counterpoise improves the radiation characteristic in the vertical plane, and by placing the antenna one-half wavelength above the counterpoise a good cone-of-silence is insured and surges and fades are greatly reduced for elevation angles greater than $\left(\tan^{-1}\frac{\beta_2}{\gamma}\right)$. Since the maximum of the signal is at a relatively high elevation angle, 30°, a counterpoise of too large a diameter not only will be costly to construct but also will restrict lobes at low grazing angles. The signal from these low-angle lobes will be received in aircraft flying at a distance from the station and at low elevation (for example, the angle of elevation of an airplane flying at 2,000 feet at 20 miles distance is approximately 1°). The design of the counterpoise is a compromise of radiation and economic considerations.

After considerable study and tests on the 125-foot tower it was decided that a counterpoise of such diameter and height as to premit only two low-angle lobes to be reflected by the ground would produce a satisfactory field pattern. It was found that at a frequency of 125 megacycles a counterpoise 30 feet in diameter would be quite suitable when the entire structure is only three to four wavelengths above ground. A 30-foot counterpoise with an antenna one-half wavelength above it will radiate all waves at incident angles greater than 14.7°. If the counterpoise is 30 feet high, only two lobes will be reflected under this transition angle. Figures 3 and 4 show the vertical field pattern computed for both a high and a low tower. The reflection coefficient is assumed to be unity The transition angle $\left(\tan^{-1}\frac{\beta_2}{\gamma}\right)$ is shown. It can be seen that the high tower will produce seven lobes under the transition angle, whereas the low tower will produce only two lobes. The maximum of the lobes is limited by the form factors of the horizontal loop antenna which is approximately equal to cosine ϕ.

If it were possible to place a radiator over a perfectly conducting plane, it would be an easy matter to predict its wave propagation characteristics regardless of its operating frequency. If simple reflectors were placed at random near this ideal station, it would still be possible to predict its characteristics. Following the same line of reasoning as in calculating the vertical field pattern, it may be seen that a wave interference pattern will be set up The resulting field will be scalloped with maxima and minima in both horizontal and vertical planes. Complex scalloping will be caused by the reflectors placed along the ground. Simple scalloping will occur because of the height of the antenna above ground. In the horizontal plane the distance between maxima caused by complex scalloping is related to the wavelength of the transmitted signal. In the case of a 300-kilocycle signal this distance might be as great as several miles, while in the case of a 125-megacycle signal the distance would be only a few feet It has been shown[6] that scalloping in the on-course region of a low-frequency radio range is easily detected because at normal flying speed the effect would last an appreciable time. At ultra-high frequencies, say 125 megacycles, the irregularities of the field pattern are so close together in space that they will be noticed only as a fluttering signal.

The problem is made very complex in the actual case where uneven ground, mountains, and varying degrees of vegetation are present It may be said, in general, that objects, in order to become reflectors or reradiators, must be of the order of a wavelength in at least one dimension. A hill several miles long might reflect an appreciable amount of energy of a 300-kilocycle signal At this low frequency small surface variations have little effect on the reflector as a whole, since the entire surface of the hill acts to distort the pattern However, the same hill would appear as an almost infinite number of reflectors at random angles for an ultra-high-frequency signal Considering the laws of probability, it is logical to assume that the resulting pattern might be scalloped but, in general, would average out almost as if the hill were not present. At ultra-high frequencies, then, small irregularities in terrain may be considered as causing a diffusion of the signal, while at low frequencies such a surface may be considered flat and an actual distortion in the radiated field may exist. A range of mountains no doubt would cause irregularities in the field of a low-frequency range of such magnitude as to cause multiple and bent courses[7,8]

Recent improvements in ultra-high-frequency range antennas have reduced the probability of irregularities in the on-course region This result is effected by decreasing the mid-quadrant signal and, hence, the signal which is reflected into the courses by objects within the quadrants.

The flight measurements made at Indianapolis and Van Nuys agree well with the above theory. The recordings of cross-course flights of ultra-high and low-frequency ranges in mountainous terrain show the great improvement in course characteristics obtained by use of ultra-high frequency. A detailed description of these recordings and tests follows.

APPARATUS

The 63-Megacycle Transmitter

A type TXI transmitter was rebuilt for use at the tower installation. The tube line-up used is shown in figure 5. An unmodulated carrier output of 300 watts was easily obtained, although during most of the tests the output was limited to approximately 150 watts modulated 90 percent The first two stages (807 tubes) comprised the exciter unit[9].

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[6] See reference 1 on page 1.

[7] "Multiple Course of Radio Range Beacons Investigated," Air Commerce Bulletin, Vol. 6, No 3

[8] "Radio Phenomena at Salt Lake Range Station Studied by Bureau," Air Commerce Bulletin, Vol. 8, No. 3

[9] Jackson, C.H., "Development of an Improved Crystal Exciter Unit," CAA Technical Development Report No. 26, July 1940.

This unit was mounted with its power supply in a relay rack adjacent to the transmitter The output of the exciter was link-coupled through a coaxial line to the grids of the HK-54 doubler. This tube furnished ample excitation to the push-pull power-amplifier consisting of two HK-254 tubes All tank circuits with one exception were solenoidal inductances and standard semicircular plate condensers. A hairpin inductance and disc-type condenser were used in the plate circuit of the final stage. Inductive coupling to the output circuit was used The output of the transmitter was fed through a short length of coaxial line to the interlock relay, which was mounted on the rear wall of the building The keying device and rectifier for the relay were mounted in the relay rack with the exciter unit.

The interlock relay was an AC74 link circuit relay rebuilt for ultra-high-frequency operation. The modification consisted of reducing the size of the contact mounts and the diameter of the contact surfaces and replacing the massive bronze supports with isolantite mounting posts. Particular care was taken in the design of this relay to avoid variable contact resistance and to keep the capacity between radio-frequency current-carrying parts as low as possible.

The 125-Megacycle Transmitter

The 125-megacycle transmitter used was excited by an 807 oscillator-tripler controlled by a 5208.33-kilocycle crystal. The oscillator was followed by an 807 doubler. These two tubes and their power supply comprised the exciter unit, which was mounted in a relay rack with the keyer and the interlock relay rectifier The exciter was link-coupled to the transmitter proper by means of a flexible coaxial line The transmitter was built in a type TII frame and consisted of two HK-54 (triode) doublers followed by a final amplifier consisting of two HK-254 triodes operated in push-pull. Link coupling was used between each stage The final amplifier tank was of the loaded transmission line type. All other tuned circuits used coils and condensers. The high voltage power supply for the Hk-54 and the HK-254 tubes was supplied by a bridge type selenium dry disc rectifier. This rectifier was made up of 28 stacks of 32 plates each and supplied 1650 volts to the transmitter. The power input to the final stage was 330 watts (unmodulated). The plates of the power amplifier were modulated 90 percent at 1020 cycles. A block diagram of the transmitter is shown in figure 6 The high voltage power supply was mounted in a second relay rack which was placed adjacent and to the right of the exciter rack. A third rack placed between the transmitter and the exciter rack was used as a frame to support the various radio-frequency networks used to feed the antenna system.

Because of the remote location of the station, poor voltage regulation of the power source, and intermittent loads on the line, it was necessary to use a voltage regulator to secure satisfactory service. This regulator was an automatic unit of three kva rating of the saturating core type. It had the very desirable characteristic of drawing but 300 watts when the output terminals were short-circuited, thus eliminating the need for heavy line fuses or circuit breakers. The normal operating characteristics were as follows Output voltage 115 volts plus or minus 1 1 volts, with input voltage of 115 plus or minus 16 volts The full load power factor was 90 percent, and an efficiency of 85 percent was realized.

The 16-Foot Tower and Counterpoise

The 16-foot tower was a wooden structure which supported the center of the vertical dipoles 20 feet above ground. One-quarter of a wavelength (at 63 megacycles) below the center of the dipoles was a round counterpoise, 30 feet in diameter, made of 2-inch-square galvanized iron mesh

The 125-Foot Tower and Counterpoise

The 125-foot tower and the 35-foot circular counterpoise structure were supplied and erected on contract. The 15-foot-square base of the structure was anchored to concrete piers buried to a depth of 8 feet Adequate allowance in design was made for wind and ice loading. Figure 7 is a photograph of the tower showing its construction and location with respect to the station building

The counterpoise on top of the tower was supported by a structural steel framework so constructed that it was fastened to the tower at only four points. This was done so that the entire counterpoise could be insulated from the steel tower if it were found advisable. The counterpoise consisted of sections of expanded metal mesh fastened to a steel framework with "J" bolts Steel strips were used to hold the mesh around the periphery Special squeeze-on clips were used to join the seams which occurred between frame members. The counterpoise was circular in shape and had a diameter of 35 feet The expanded metal mesh was of a diamond pattern, the axes of which measured approximately 2 by 5 inches A ladder was provided between the platform of the tower and a hatchway in the counterpoise Some trouble was experienced with the method of fastening the mesh with "J" bolts. A piece of mesh under one radiator which had not been properly replaced after the antenna had been installed caused variable contact between the mesh and counterpoise framework It was found that this defect had been causing difficulty in the balancing of the antenna currents. Special care to insure tightness of the "J" bolts was necessary

The 30-Foot Tower and Counterpoise

The 30-foot tower structure was fabricated entirely of wood Four 30-foot poles located at corners of a square supported a circular counterpoise 30 feet in diameter.

The counterpoise was covered with a 1/2-inch-square galvanized iron mesh. A frame building located under the counterpoise housed the transmitter and associated equipment Figure 8 is a view of the station

The 22-Foot Steel Tower and 35-Foot Counterpoise

The Van Nuys tower and counterpoise was originally the same as the 125-foot steel tower at Indianapolis. The results of the experiment on the 125-foot structure led to the conclusion that a low tower was more suitable and, consequently, the Van Nuys structure was cut down to a height of two bays of the original, making the height 22 feet Figure 9 shows the modified structure. The ladder in the center was used to support the transmission lines, while that on the east side was used to gain access to the top As at Indianapolis, the diamond-expanded metal mesh was anchored with "J" bolts, and the electrical properties of the counterpoise were found equally unsatisfactory because of the "J" bolts After the Van Nuys tests, the 125-foot Indianapolis tower was cut down to the same height as the Van Nuys tower

Transmission Lines, Interlock Relay and Phasers

Throughout the tall tower test the antennas were fed by 66-ohm coaxial transmission lines Since the interlock relay was in the transmitter building, it was necessary to run two lines from the relay to the top of the tower These lines were run up the outside of the tower leg nearest to the transmitter. They were held parallel to the tower by strap iron clamps spaced at 10-foot intervals. These clamps were designed to flex slightly with expansion and contraction of the lines.

During the test conducted with the single horizontal loop antennas on 125 megacycles, it was necessary to use a two-wire line which was balanced to ground In the case of the tall tower installation, the two coaxial lines were used together as a balanced two-wire line

During the tests of the four-loop and five-loop antenna systems on the 30-foot and the 22-foot towers, shielded two-wire transmission line, having a surge impedance of 175 ohms, was used. One line was used to feed the center loop and two lines were used to feed the A and N pairs of loops. A double-pole relay was built from a standard interlock relay. It was necessary to redesign the contact system, and in the new design it was possible to completely shield and isolate all radio-frequency conductors Figure 10 shows the double-pole interlock relay.

The five-loop antenna system required very exact adjustments of phase and amplitude of the various radiator currents. A trombone-type adjustable phasing line was built to phase each pair of corner loops (A and N pairs) with respect to the center loop. These lines were built from telescoping tubing and were of such a length that the phase could be varied over a range of about 120° The sizes of tubing used were selected so that the characteristic impedance of the section would be the same as that of the two-wire line. Figure 11 is a view of the phasing units and the shielded interlock relay used at the Van Nuys installation The two units in the foreground are in the lines to the corner loops (A and N), the one in the background is in the line to the center loop The interlock relay is shown in an inverted position from that shown in figure 10.

The arrangement shown differs from that used in the original installation on the 30-foot tower in the use of the individual phasers in the A and N lines With this arrangement it is possible to adjust the lengths of the A and N lines independently to obtain an untuned condition in the unused pair of loops during keying and thus restrict the amount of parasitic current in them. The third phasing section in the center element permits adjustment of its phase with respect to the others The section bridged across the center line is a quarter-wave section and is used to adjust the power in the center element.

The 22-foot tower installation which followed the Van Nuys installation differs from that described above for Van Nuys in that quarter-wave power varying stubs were also bridged on the A and N lines ahead of the phasers In addition, all three lines were terminated with building-out matching sections behind the phasers. Figure 12 is a view of the 22-foot tower station at Indianapolis

All transmission line inner conductor sections were joined together by means of silver solder All junctions of the outer conductors or shields were connected with Raybould solderless couplings, ells, and tee junction boxes. These connectors were found to be very easily applied, in that only two wrenches were required Their construction is such that when tightened the connection is sealed to the tubing by means of a rubber sleeve, much as any gland or stuffing box This rubber sleeve has copper rings moulded on each end to insure a good electrical contact and to prevent the rubber from cold flowing into the threads or the tubing.

All junctions in the antenna assembly and junctions to which solderless couplings and fittings could not be applied were soldered with 95-5 hard solder It was found advantageous to apply a small amount of 50-50 solder to the joints just as the hard solder set This application removed any possibility of gas leakage. When necessary, the lines were dried and kept moisture-free by means of dry nitrogen gas under pressure.

Antennas

Vertical antenna (63 megacycles)[10] The vertical dipoles making up the four-course range used on the 16-foot tower were of the coaxial, end-fed variety, and each pair of diagonally oposite dipoles could be adjusted to reduce the standing waves, inside as well as outside the coaxial lines, to a negligible value. By adjusting the lower telescoping sleeve on the dipoles, the standing waves on the outer conductor of the transmission line can be reduced to a negligible value independently of the standing waves on the inner conductor A line-shunting condenser and the upper dipole telescoping sleeves are then adjusted to obtain a minimum standing wave ratio on the inner conductor This antenna system has given very good results. The diagonal spacing of elements of the array was 0.2 wavelength, which not only made the antenna small physically but provided sharper courses. Figure 13 shows this antenna mounted above the 30-foot circular counterpoise on the 16-foot tower.

The four-course vertically polarized antenna used on the 125-foot steel tower was designed for mechanical and electrical stability rather than simplicity of construction. Figure 14 is a view of this antenna installed in place. Every effort was

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[10] See reference 1 on page 1

made to make the assembly suitable for operation in adverse weather conditions. The tuning and balancing networks were inclosed in sealed compartments, as were the connections to the end-seals of the coaxial lines The entire antenna assembly was supported in the center by means of a 6-inch copper pipe through which the four lines were run to the main junction casting The four end-seals of the lines were screwed into this casting. At the lower end of the pipe the lines were terminated in special fittings and connected to the two lines running up the tower. Quarter-wave, two-to-one matching sections were inserted in the lines between the tower lines and the special fittings for the purpose of matching the impedance of the feeder lines to the parallel lines feeding the antennas.

The single coaxial lines were coupled to the dipole radiators through balancing networks These networks were contained in the cast housings at the centers of the dipoles and at the ends of the supporting arms. The required 180° phase shift for feeding opposite radiators was obtained by connecting the center conductor of the feeding line to the upper antenna element on one dipole and to the lower element on the opposite dipole. Figure 15 is a diagram of a network It may be seen that this network is an impedance-transforming T section. It is used in an unconventional way in that the ordinarily high side of the section is grounded. When so connected it becomes a balancing device and permits the dipole to be balanced to ground, even though fed from an unbalanced system. Since it was desired to balance the antenna to ground, it was necessary to make the network simulate a transformer with a one-to-two voltage step-up so that the voltage between the output terminals of the network would be twice the voltage between the inner conductor of the line to ground. The networks were designed accordingly and their performance was checked in the laboratory before installation on the tower. It was found possible to obtain a very good balance of antenna currents by adjusting condenser C_1 (fig. 15) to a value that would resonate with the two inductances L_1 and L_2 connected in parallel and disconnected from the antenna Inasmuch as the impedance transformation of the network was 1 4 from input to output, it was not possible to feed the antenna directly at the two inside ends of the dipole (The transmission line impedance was 66 ohms and the center impedance of the dipoles arranged as used was $20 + j\,46$ ohms) Therefore, it was necessary to bridge the center of the antennas with an inductance L_3 (fig. 15) The lengths of the dipoles then had to be adjusted to compensate for the added impedance at the center. Final adjustment of the circuit resulted in a ratio of antenna currents of 1.1 to 1 and an impedance match between line and load sufficiently close to result in a standing wave ratio of 1 2 to 1

Horizontal antenna (63 megacycles). The antenna used for horizontally polarized radiation consisted of a pair of crossed dipoles fed with a trombone matching and phasing network Figure 16 is a diagram of this antenna. Since the impedance and phase relationships are inherently correct, no adjustment, other than that of radiator lengths, was made after assembly in the shop The radiating elements were adjusted for maximum antenna current after installation on the tower The maximum to minimum ratio of these currents was approximately 1.1 to 1

Loop antenna (125 megacycles) For the tests on 125 megacycles, a single loop-type antenna similar to those used on the Indianapolis instrument landing system was used This type of antenna radiates purely horizontally polarized waves. The measurements, therefore, are directly applicable to any purely polarized system The mechanical details of such an antenna can be seen in figure 17 The supporting structures used were (a) the 30-foot wooden tower with a 30-foot counterpoise, (b) a 30-foot wooden pole, and (c) the 125-foot steel tower with a 35-foot counterpoise

The data obtained on tests of the foregoing antenna systems were used to supplement the data obtained during the development of the ultra-high-frequency five-loop aural radio range. The five-loop range was developed at Indianapolis on the 30-foot wooden tower with the 30-foot counterpoise This range was then moved to Van Nuys, Calif , and installed on the 22-foot steel tower with a 35-foot counterpoise. Following the tests at Van Nuys the antenna system was returned to Indianapolis and installed on a similar steel tower The antennas were mounted in a wooden framework (see fig 17) As at the original Indianapolis installation, the spacing between each diagonally opposite pair of loops is 360° During the development of the five-loop radio range on the 30-foot tower, a roof was built over the loops (see fig 8) At Van Nuys, wooden boxes, weatherproofed with tar paper, were slipped on over the loops to protect them from the weather (see fig. 9). This was found particularly convenient during tune-up and an economical means of protection for a temporary installation.

The final installation on the 22-foot steel tower at Indianapolis was intended to be a permanent installation for demonstration purposes, and a 12'x 12'x 8-3/4' house of 3/16-inch masonite was built over the loops to duplicate the installation of the commercially manufactured equipment on the Chicago-New York airway. Figure 12 shows the tower and house.

Receivers and Airplane Antennas

Flight tests of the 63-megacycle vertically polarized range were begun during the latter part of August 1939. Airplane NC-80 (Stinson Reliant), equipped with the CAA modified RUB receiver[11], was used for these tests. The antenna, a quarter-wave whip, was installed on the center line of the ship midway between the leading and the trailing edges of the wing. A tuned circuit at the base of the antenna was used to match the flexible transmission line feeding the receiver.

Early in September, airplane NC-80 was grounded for a major overhaul and NC-17 (Waco N) was used in its place. The CAA modified RUB receiver was used on this airplane, also. The antenna system was similar to that of NC-80 with the exception that the whip was installed approximately 5 feet aft of the trailing edge of the upper wing.

Upon completion of the test with vertically polarized antennas, a series of measurements was made using horizontally polarized radiators at 63 megacycles. A horizontal dipole, oriented to have maximum pickup along the direction of flight, was installed above the cabin at the leading edge of the wing. The line to this antenna was connected directly to the inside ends of the elements. No stubs or matching networks were used. The dipole was used only because no loop for 63 megacycles was available. It was unfortunate that the field pattern of this antenna was such that cross-course measurements could not be made with accuracy. However, as will be explained later, the purpose of the horizontal measurements did not make cross-course flights necessary.

For all of the 125-megacycle tests, the CAA tunable ultra-high-frequency receiver[12] and the horizontal loop antenna[13] mounted above the cabin of airplane NC-80 were used. This receiver is a superheterodyne using tuned coaxial line input circuits and a tunable coaxial line radio-frequency oscillator of high stability. The receiver has a tuning range of 60 to 132 megacycles, and its stability is excellent after a warm-up period of approximately 1 minute.

Recorder

Recordings of signal strength were made on an Esterline-Angus type AW recording milliammeter. The sensitivity of this instrument, 5 milliamperes full scale, was sufficient to give adequate deflection without the use of an additional amplifier. The recorder was equipped with a copper oxide instrument rectifier for rectifying the 1020-cycle audio signal. The paper feed was in all cases operated at the rate of 6 inches per minute.

The altitudes of test flights at Indianapolis are referred to ground level. The altitudes of test flights at Van Nuys, unless otherwise noted on the records, are all referred to sea level. The elevation of the antenna at Van Nuys was approximately 750 feet above sea level.

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[11] See reference 1 on page 1.

[12] McKeel, P.D., "An Ultra-High-Frequency Aircraft Receiver," CAA Technical Development Report No. 17, September 1938.

[13] See reference 1 on page 1.

TEST PROCEDURE

Adjustment Test (Ground Patterns)

In addition to the usual antenna current measurements for antenna current balance and the standing wave measurements for termination purposes, horizontal patterns were taken to determine the antenna orientation for proper course alignment. Figure 18 represents the horizontal field pattern of the 63-megacycle vertically polarized system as finally adjusted on the 125-foot tower.

Because of the height of the tower and antenna it was necessary to employ a unique method of taking "ground" field patterns so that they would represent field strength in a horizontal plane through the antenna. A 20-foot wooden radius arm was arranged to swing around the central supporting pipe of the antenna assembly. A pair of rubber-tired wheels was mounted at the end of the arm just inside the edge of the counterpoise. These wheels carried most of the weight of the beam and permitted it to be adjusted rapidly to any desired azimuth. An auxiliary 10-foot pole was secured to the arm and a vacuum tube field meter was mounted on the extreme end. The radius from the center of the antenna to the field meter was 30 feet. The meter was read through a pair of field glasses from underneath the counterpoise. A pair of wires was run from the keying device up to the counterpoise and a push button connected so that the operator could change from A to N quadrant at will. This setup made it possible to take accurate readings for a field pattern in a time of approximately 15 minutes.

Figure 19 is a ground field pattern of the horizontally polarized five-loop 125-megacycle radio range tested on the 22-foot tower at Van Nuys, Calif. The spacing between the two loops of each pair was 360°. The outside loops were in phase and the center loop was out of phase with them by 180°. The current ratios are shown in figure 19. The course sharpness is slightly better than that which was obtained with the first installation on the 30-foot tower at Indianapolis, and the quadrant signal strength is slightly less. This is due to the fact that the center loop current was only 1.8 times the current value in one outside loop.

When the five-loop range was reinstalled at Indianapolis on the 22-foot steel tower, the loop spacing in each outside pair was made 416°. The center loop is out of phase with the outside loops by 180°, and its current is adjusted to twice that in a corner loop. The parasitic current in the unused loops was kept to a minimum and is well below one-half of 1 percent. This adjustment results in slightly broader courses but eliminates any quadrant reversal effects near the cone-of-silence[14].

Flight Test

Cross-course flights. Cross-course flights were made in order to establish the true position of each course. Flights were made across the courses in two directions to establish their positions accurately and to determine if any pushing of the course was evident. In many of the recordings shown, the quadrant signals have been removed and only the envelope of these signals is indicated. This is done to show more clearly any tendency toward multiple courses.

Distance range. The maximum distance at which a usable signal could be received was determined for various altitudes above ground.

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[14] See reference 1 on page 1.

Cone-of-silence characteristics The cone-of-silence characteristics were obtained by flying a constant gyro course along the center of a quadrant directly over the station. The width of the cone at various altitudes and its freedom from course reversals in the cone were determined by these flights. To check the depth of the cone, the interlock relay was locked and flights were made for about 8 miles either side of the station

Course straightness To check the course straightness, flights were made on a constant gyro heading from an on-course indication 10 or 15 miles out, directly over the station; that is, the airplane was flown exactly where the course should have been When the course was perfectly straight an on-course indication was recorded, but if the course was bent, the indications varied from N to A, or vice versa, according to the bends. Similar tests were made on both the high and the low antenna stations Most of the records plainly showed the quadrant signals, but in some cases near the on-course region, the aural signal gave a more accurate indication The records reproduced in this report are marked to correspond to the aural identification received at points that appear questionable.

Pushing and circling[15] Pushing or pulling of the course (shift in course position for flights in opposite directions) was determined by cross flights at right angles to the course. Circling was investigated by executing a flat 360° turn about 10° off course. Circling effect (reversal of the quadrant identification as the heading of the airplane is changed) was almost universally observed with the crossed dipole antenna.

The above tests were performed on both the vertically and the horizontally polarized antennas except for cross-course measurements on the horizontal crossed-dipole assembly. Cross-course checks were not practicable on the crossed dipoles because of the orientation of the dipole antenna installed on the airplane

Many tests were made in addition to the regular test flights described above. Test flights on the single 125-megacycle loop antenna were made to determine its vertical radiation characteristics when mounted on structures of various heights. These tests were made by flying in a straight line directly over the various antenna installations. Distance tests were also made to determine the effect of operating the antenna at one-quarter and at one-half wavelength above a counterpoise. Further measurements were made with the loop antenna on a 30-foot pole without a counterpoise and with a dipole antenna one-quarter wavelength above ground placed 200 feet south of the 125-foot tower. Figure 21 is an index of the flight tests that were made at Indianapolis.

The Van Nuys station was located nearly midway between the Santa Monica and the Verdugo mountains The terrain within an 8-mile radius of the station was almost perfectly flat A dirt road ran east and west, adjacent to the south side of the transmitter building, and a barbed-wire fence ran along the south side of the road A rural power line on 35-foot poles, terminated approximately 600 feet west of the station, ran west and parallel to the road Figure 9 is a photograph of the station

The courses were aligned so that the northeast leg lay along the Newhall pass between the Verdugo and the Santa Susana mountains. Because of the location of the station, this was the only leg that could be compared with one of a low-frequency range Figure 20 shows the location of the station, the course alignment, points at which cross-course flights were made to check the courses, and points where other flights were made to check the propagation characteristics in mountainous regions At the Van Nuys installation, cross-course flights were made on all legs of the ultra-high-frequency range at intervals of 10 miles to the limits of the service area Recordings were made at altitude intervals of 1,000 feet from 7,000 feet to the lowest altitude at which the signal could be used. In all of these tests particular attention was given to course width and to any tendency toward split or multiple courses Similar but not as extensive tests were made on the low-frequency range for comparison.

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[15] See reference 1 on page 1.

A second series of flights was made to record the cone-of-silence characteristics and to determine the number and seriousness of false cones and the presence or absence of quadrant reversals. Further tests were made to investigate the propagation characteristics of the 125-megacycle signals in the vicinity of mountains and, where possible, in the valeys behind ranges of mountains

Measurements of the low-frequency Newhall range were made using the Western Electric type 14-B receiver which was a part of the airplane's regular equipment. Figure 22 is an index of the flight tests that were made at Van Nuys.

Tests on the Indianapolis five-loop range consisted of cross-course checks to establish courses, mid-quadrant flights through the cone-of-silence, and on-course flights to check fades, surges, and, in general, the reflection characteristics of the counterpoise.

RESULTS

The Indianapolis Test

The 125-foot tower range was found to have approximately the same amount of pushing and circling as other ultra-high-frequency ranges using similar antenna systems. Since these effects are known to be dependent on polarization[16], their presence or absence cannot be attributed to the height of the antenna. The primary reason for elevating the antenna was to increase the distance range of the station. The results obtained are shown in figure 23. Increasing the height of the antenna from 16 feet (curve 1) to 125 feet (curve 2) increased the useful range of the station from 51 miles to slightly over 74 miles for flights at 1,000 feet, and from 87 miles to 119 miles for flights at 4,000 feet

It must be borne in mind that these tests were made over very flat country. It is to be expected that other topographical conditions would cause wide variations in these figures. The data for figure 23 were taken under as nearly similar conditions as possible in order to obtain true comparisons of signal strength The input powers to the 16-foot and 125-foot installations were adjusted to the same value (300 watts), and during the distance flight tests the transmitters were put on the air alternately according to a prearranged schedule.

The curves represent altitudes for reception of signals sufficiently strong to be used for navigation even in the presence of moderate ignition noise. Comparison of curves 1 and 7 will show that the counterpoise on the 16-foot antenna materially reduced the effective range of the station. The observations with no counterpoise (curve 7) were made several days later than those with the counterpoise (curve 1), and it is possible that the improvement may be exaggerated because of uncontrollable conditions Curve 2 is representative of the 125-foot tower range for vertical and horizontal antennas and for a horizontal antenna with the counterpoise covered with sheet metal. Curves 5 and 6, shown for 125 megacycles, represent the results obtained with slightly less power in the antenna, approximately 120 watts. Curves, 3, 4, 5, and 6 indicate the increase in range by raising the antenna from one-quarter wave to one-half wave above the counterpoise for both the 30-foot and the 125-foot towers It is interesting to note that the proportional increases for the two towers are approximately the same. The increase can be explained by examining equation (9) The vertical field pattern can be closely approximated by multiplying this equation by the form factor of the antenna, $M_\phi = \cos \phi$. Substituting the values of H in equation (9) shows that at low angles equation (9) increases in value more rapidly for $H = \lambda/2$ than for $H = \lambda/4$, and reaches a maximum at an angle of 30°.

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[16] See reference 1 on page 1

A comparison of curves 6 and 4 or 5 and 3 of figure 23 indicates the increase in range due to raising the antenna from approximately 30 to 125 feet. It is also interesting to note that an antenna one-half wavelength above a counterpoise on a 30-foot tower has a greater range than an antenna one-quarter wavelength above a counterpoise on a 125-foot tower.

The irregularities in the cone-of-silence and the discontinuities in the range courses in the vicinity of the station are the most serious conditions introduced by elevating the antenna to 125 feet The results of the flight tests shown in figure 24 illustrate the multiple surges and fades received when approaching and leaving the station. These recordings clearly show the high ratios of nulls to surges encountered in the vicinity of the station. It would be quite possible to mistake any of the nulls for the actual cone-of-silence At this stage of the development there seems to be no practicable way to eliminate these irregular patterns The presence of nulls detracts from the usefulness of the cone-of-silence method of locating the range station

A secondary effect caused by this wave interference phenomenon is that of course irregularities. In the case of the simple dipole above the level earth, the vertical field pattern could be calculated quite accurately If two such antenna systems were used to make a range, the vertical patterns would be exactly alike and the resulting range course would be perfectly straight Now if some local object, such as a tree or fence, were introduced in the field of one antenna and not the other (say the center of one quadrant), a reflection might take place which would distort the vertical pattern of only one antenna This distortion might result in a slight shift of the lobes or perhaps elimination of some of the lobes altogether. It is obvious that the resulting course would be bent or discontinuous at the points in space where one set of lobes was shifted.

The recordings reproduced in figure 25 show the course discontinuities actually encountered on the 125-foot tower range. It is interesting to note that discontinuities are present to an equal degree with both horizontal and vertical polarization. In the actual case the field patterns are greatly complicated by uneven ground, the probability of many small reflecting bodies, and the possibility of excitation and reradiation from the steel tower. The presence and unpredictable nature of these course discontinuities greatly detract from the usefulness of the range in the vicinity of the station. The course discontinuities encountered on the 125-foot tower installation contrast greatly with the smooth uninterrupted course obtained with the antenna system mounted above a counterpoise 16 feet above ground. A recording taken on the 16-foot tower installation is also shown on figure 25 for comparison

The test of the 125-megacycle horizontal loop antenna on the 125-foot tower, 30-foot pole, and 30-foot-high counterpoise (fig. 26) substantiated the results obtained on the lower frequencies. Figure 26 also shows the scalloping of the vertical field patterns radiated by the horizontal loop antenna on the various supporting structures

A series of flights was made over a horizontal dipole antenna one-quarter wave above ground in order to obtain a vertical field pattern of the airplane's 125-megacycle horizontal loop antenna. The pattern obtained is shown in figure 27. The irregularities in the pattern are caused by shielding effects in the airplane structure, since all signals at large angles of elevation are received through the structure. The recordings of the flight tests are the product of the transmitting and receiving antenna patterns. Consequently, the number of surges and fades shown may vary slightly from those actually radiated. Qualitatively, however, it is seen that both the tall tower and the 30-foot pole without a counterpoise are quite unsuitable for use as supports for 125-megacycle antennas.

During the flight over the dipole one-quarter wave above ground, several recordings were made to observe reflections from the steel tower. The dipole was oriented to radiate maximum energy toward the tower. The distance between tower and dipole was 200 feet. Figure 28 shows the interference pattern produced in the vertical plane through the antenna and dipole. It is interesting to note that the scalloping does not occur while the airplane is in the shadow of the tower, with respect to the dipole. It is also evident that the scalloping is not deep, showing that the amount of energy reflected from the tower is small compared to the direct signal.

Figure 29, which shows the cones-of-silence recorded from the horizontally polarized 63-megacycle crossed-dipole range on the 125-foot tower, also shows the effectiveness of the mesh counterpoise used. Very little difference can be noted between the signal intensities as received from the solid and from the mesh counterpoises.

The Van Nuys Test

Multiple Courses The Van Nuys ultra-high-frequency range was found to have characteristics which were almost identical to those of the five-loop station developed at Indianapolis. The most striking characteristics were the sharp courses and lack of multiples above the mountains and in the passes.

The flights in the Newhall pass region were conducted to compare the quality of the course between the mountains with the course of the low-frequency range along the same path. This comparison is clearly shown in the recordings of cross-course flights of the two stations, figures 30 and 31 It should be noted that the variations in signal strength of the Van Nuys ultra-high-frequency station are in general very rapid, while those of the Newhall low-frequency station are slow. The rapid variations may be attributed to the rugged hills at the entrance to the pass which lie in the path of the signal and obstruct the line of sight path Although the ultra-high-frequency signal is subject to considerably more fluctuation than the low-frequency, there is no tendency toward false courses. The A and N signals are affected the same way by the various reflectors and apparently maintain their original ratio. This is definitely not the case with the low-frequency range, since both northwest and southeast legs show false courses and cross-overs. Figures 32 and 33 are cross-course recordings of the northeast and southwest legs of the Van Nuys range.

Distance Range. The distance range of an ultra-high-frequency installation may be said to depend almost entirely upon the terrain in which it is located. The profile map, figure 34, shows the altitudes of some of the flights with respect to the earth's surface and optical line of sight[17]. The radius of the earth used in these calculations was 5,284 miles (approximately 1.33 times the earth's radius), which is the figure frequently employed to account for refraction in radio problems. On figure 34 are spotted, with circled numerals, the locations and altitudes at which flight tests were made. The numerals indicate the figure on which the results of the flight test are shown.

The measurements over Long Beach (30 miles distant on the southeast leg) show that some diffraction of the signal is caused by the intervening mountains. The recordings (fig. 35) taken at an altitude of 800 feet above sea level indicate that the maximum amount of bending that may be expected is 1,500 feet at 30 miles or about 33 minutes of angle. This checks very closely the diffraction of light (35 minutes) and indicates that the line of sight lines shown on figure 34 are drawn fairly accurately The signal at this point is very unsteady and could hardly be used for navigational purposes. However, the recording at the next higher altitude (2,000 feet above sea level) is easily read. The aural signals were unmistakable and easily used to locate the course. This point is 300 feet below the optical horizon. The

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[17] The curved surface of the earth has been drawn to permit the plotting of altitudes along straight vertical lines from the earth's datum, and distances along a straight horizontal line. This is in accordance with an unpublished memorandum dated September 7, 1937, "Graphical Methods for Representing a Straight Line Above the Surface of the Earth," by J. D. Sarros of the Bell Telephone Laboratories Sarros' method of plotting profiles is based on an elliptic coordinate system and is suitable for profiles covering a range of 400 to 500 miles with reasonable accuracy.

data for the records shown in figures 30C and 30D were taken in the Newhall pass and clearly indicate how the signal is completely cut off by intervening mountains. The whole record was taken below the line of sight The data for figure 36, as indicated on figure 21, were made while flying from behind a mountain into an unobstructed optical path and back behind the mountain. The very rapid increase in field strength is striking.

Pushing and Circling. Every effort was made at the time of installation to eliminate any trace of vertical component in the emitted signal. No trace of vertically polarized signals could be detected with the vacuum tube field meter 500 feet from the station During the flight tests there was no evidence of a circling effect, and pushing was less than 0.5° on all legs.

Cone-of-silence. The cone-of-silence characteristics were much the same as those found on the 30-foot wooden tower at Indianapolis. As previously stated, the current in the center loop was 1.8 and not exactly two times the current in a corner loop, and the parasitic current in the unused loops was approximately 10 percent. Quadrant reversal took place at high angles within the cone-of-silence. This could be detected only when the receiver was operated with maximum sensitivity and was not considered disadvantageous in view of the increased signal on course. During normal operation of the receiver this effect would not be detected. The recording shown in figure 37 shows the cone-of-silence as received along the northwest-southeast legs of the range. Figure 38 shows the quadrant identification through the cone and along the two quadrant axes with the receiver set at maximum sensitivity.

The Indianapolis UHF Range

Tests on the ultra-high-frequency range after its installation at Indianapolis gave results which substantiated those obtained with the 30-foot tower at Indianapolis and with the 22-foot tower at Van Nuys, Calif. The parasitic currents in the unused pair of loops were reduced to zero. As a result, no reversals could be found in the cone-of-silence when the receiver was operated at high gain. The range showed no evidence of multiple courses

CONCLUSIONS

As a result of this investigation it is concluded that:

1. Although a decided increase in distance range can be obtained by increasing the height of the tower, the introduction of multiple lobes due to reflections from the ground with the resulting surges, fades, course discontinuities, and false cones-of-silence, nullifies the usefulness of the range as an aid to aerial navigation.

2. Although the use of a counterpoise will reduce the multiple lobes at high angles, the size of the counterpoise for a high tower installation would have to be prohibitively large to effectively eliminate the low-angle lobes. This is demonstrated in figure 39, which shows the diameter of counterpoise for any height tower from 0 to 40 feet required to restrict the low-angle lobes to one and two lobes.

3. The most practical tower structure is a low tower between 20 and 30 feet with a 30-foot to 45-foot counterpoise, with the antenna located one-half wave above the counterpoise.

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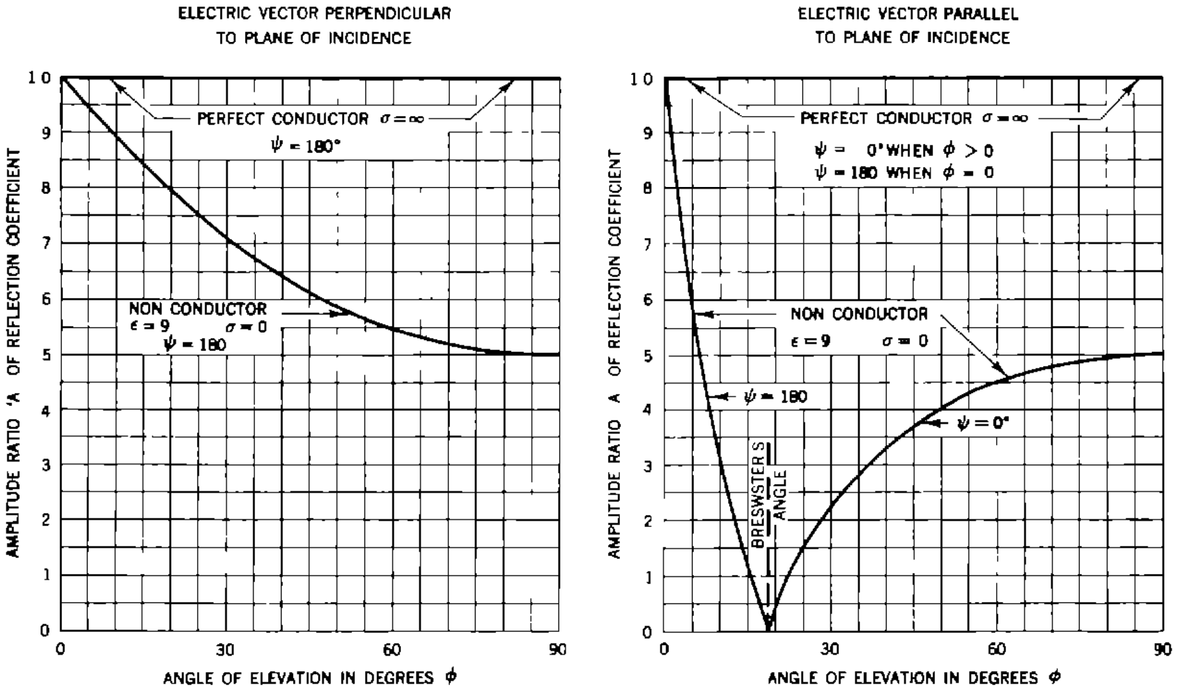
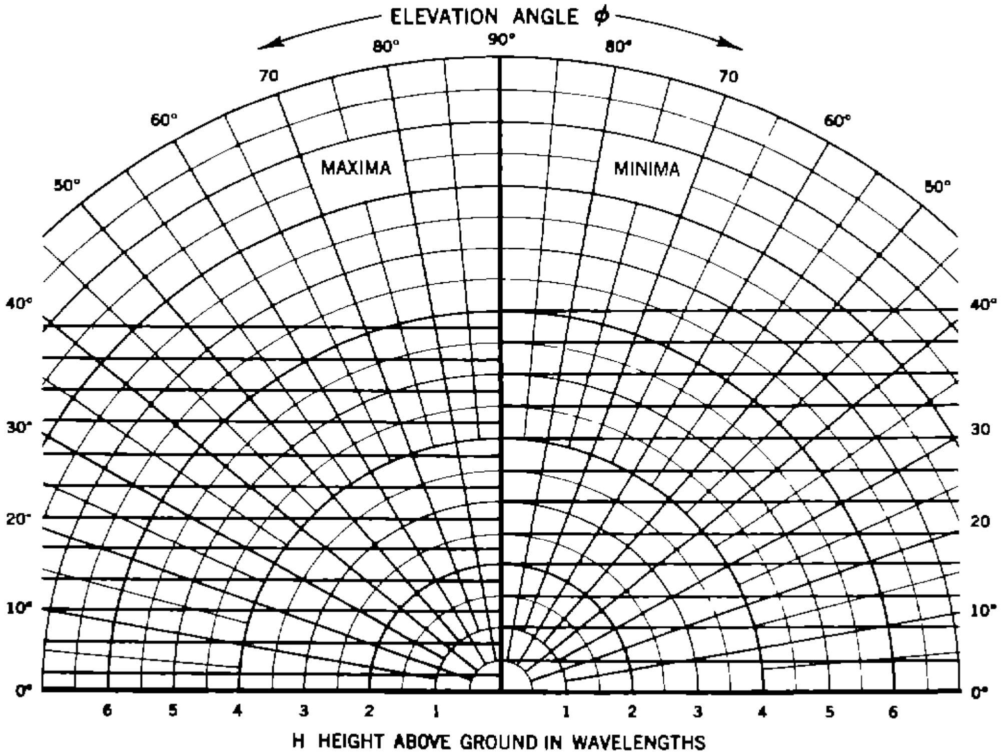


Figure 1 Reflection Coefficient Versus Elevation Angle



HORIZONTAL POLARIZATION ONLY WITH PHASE CHANGE OF 180° ON REFLECTION

EXAMPLE

TO FIND ANGLES OF MINIMA FOR ANTENNA TWO WAVE LENGTHS ABOVE GROUND READ ANGLES AT WHICH MINIMA LINES INTERSECT CIRCLE WITH RADIUS H=2 THE ANGLES ARE 14°, 30° 48° 90°

Figure 2 Angles of Maxima and Minima in Vertical Radiation Field of Antenna Above Reflecting Surface

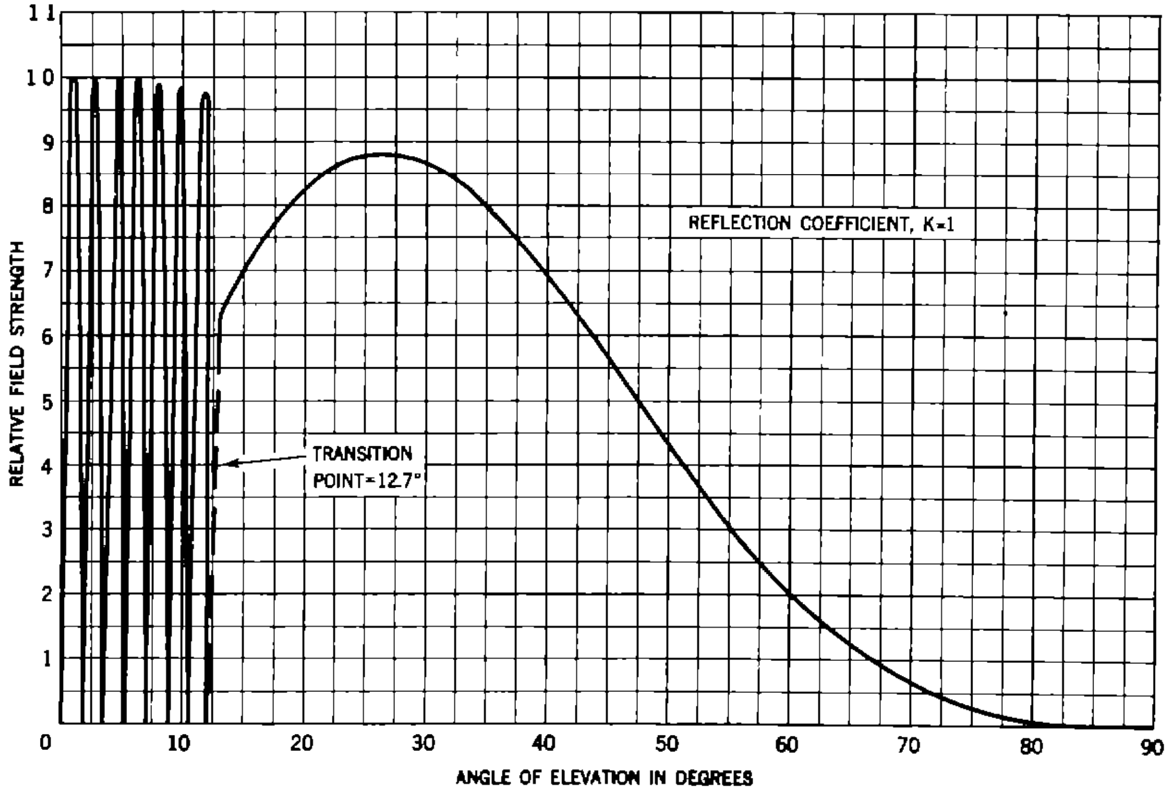


Figure 3 Vertical Field Pattern 125-MC Loop Antenna $\lambda/2$ Above 35-Foot Counterpoise on 125-Foot Tower

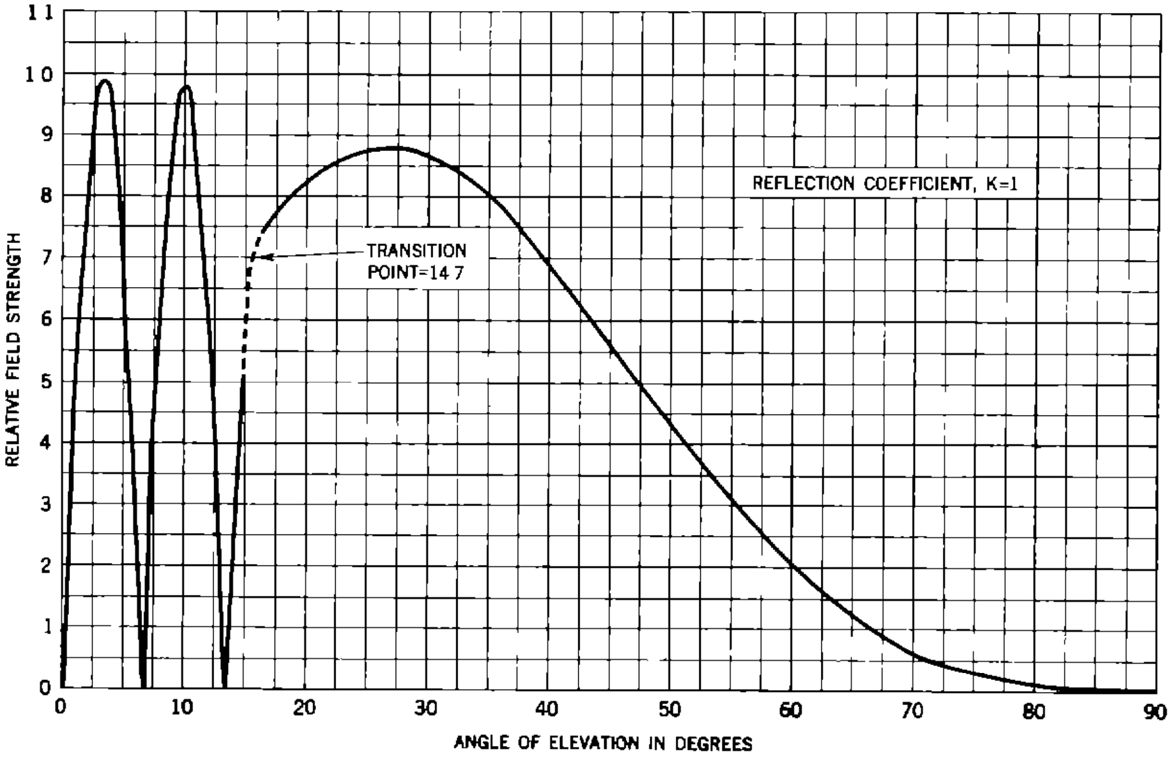


Figure 4 Vertical Field Pattern 125-MC Loop Antenna $\lambda/2$ Above 30-Foot Counterpoise on 30-Foot Tower

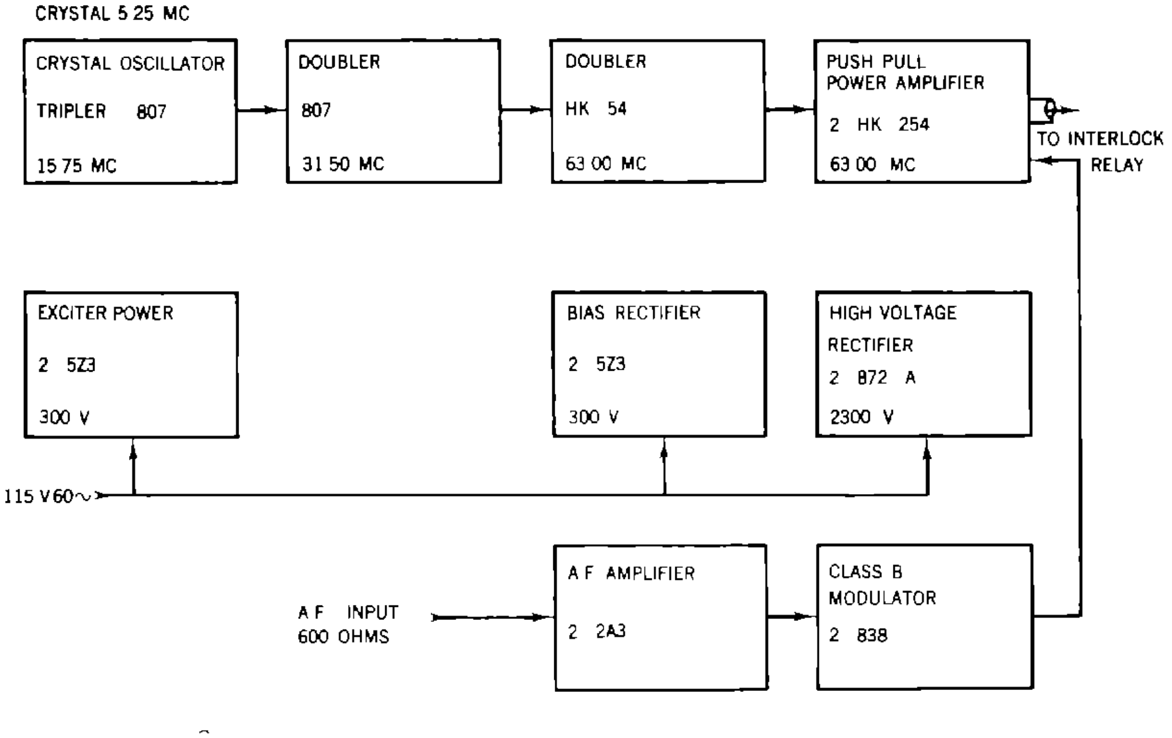


Figure 5 Block Diagram of 63-MC Transmitter

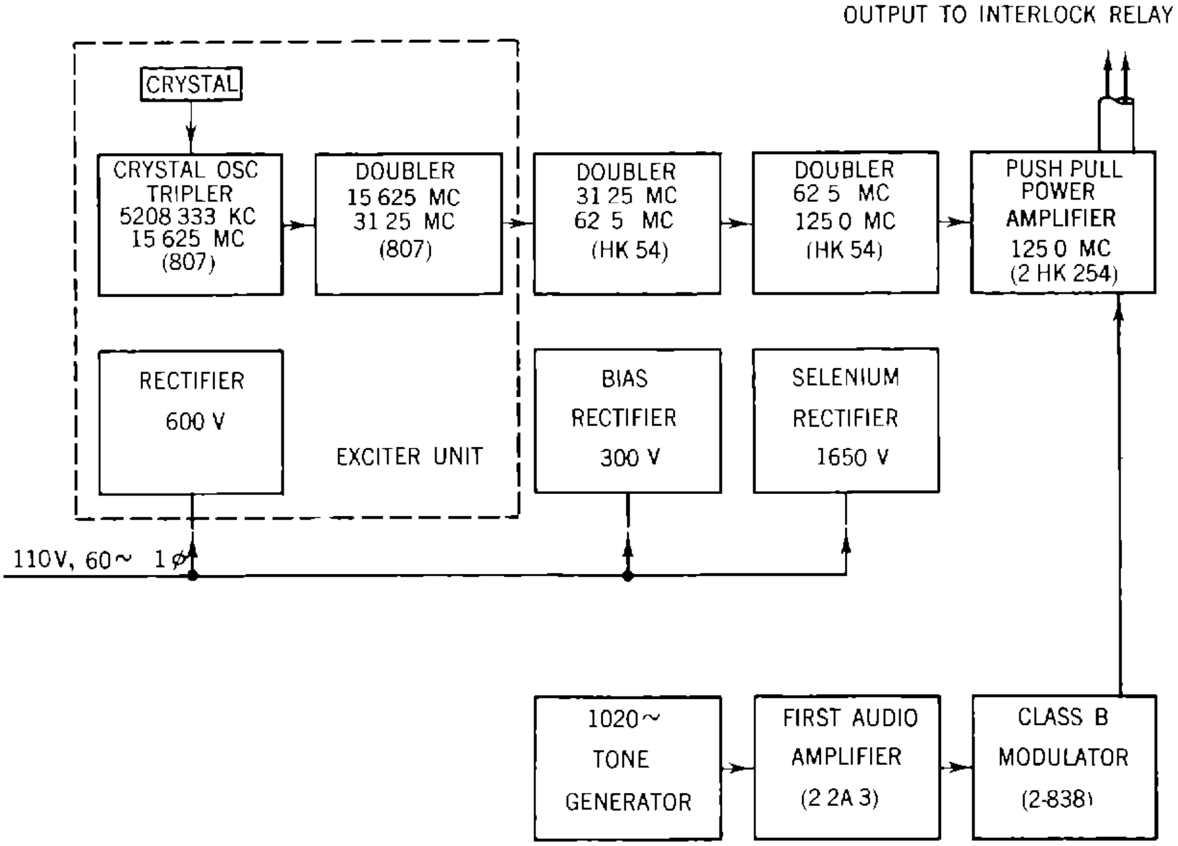


Figure 6 Block Diagram of 125-MC Transmitter

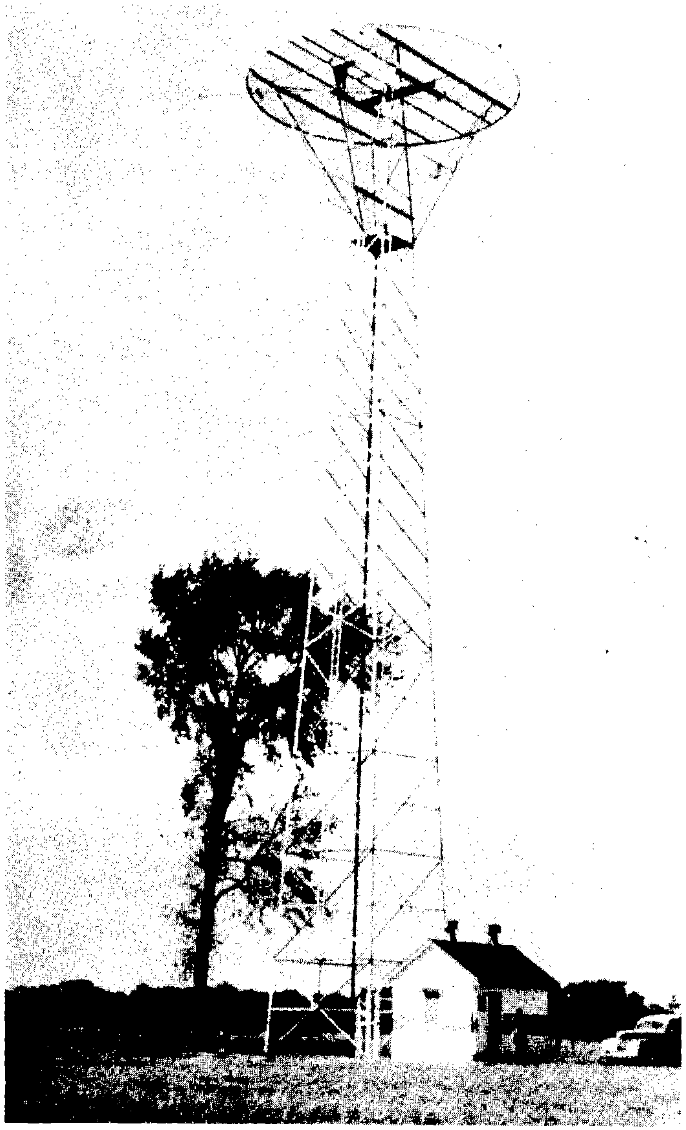


Figure 7. The 125-Foot Tower Station, Indianapolis, Indiana.

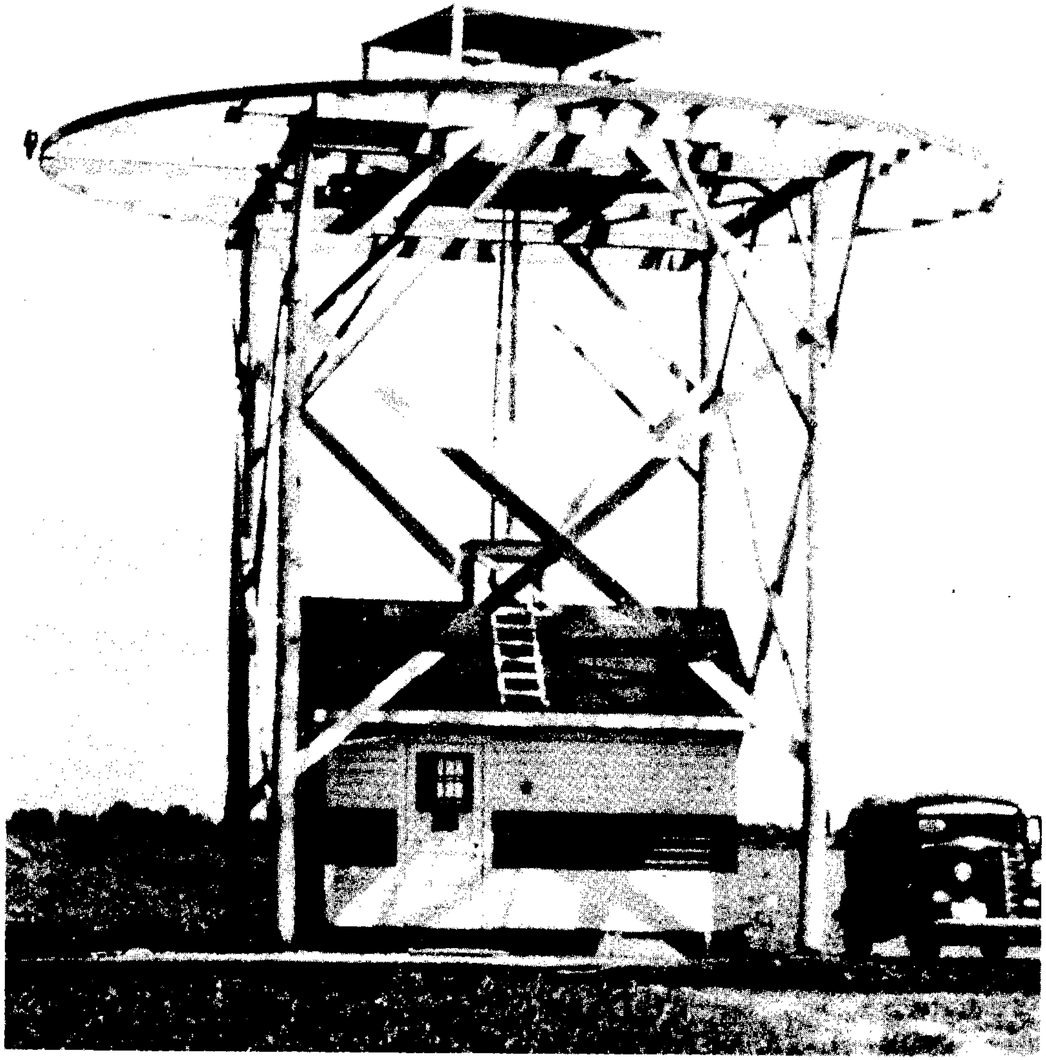


Figure 8. The 30-Foot Tower Station, Indianapolis, Indiana.

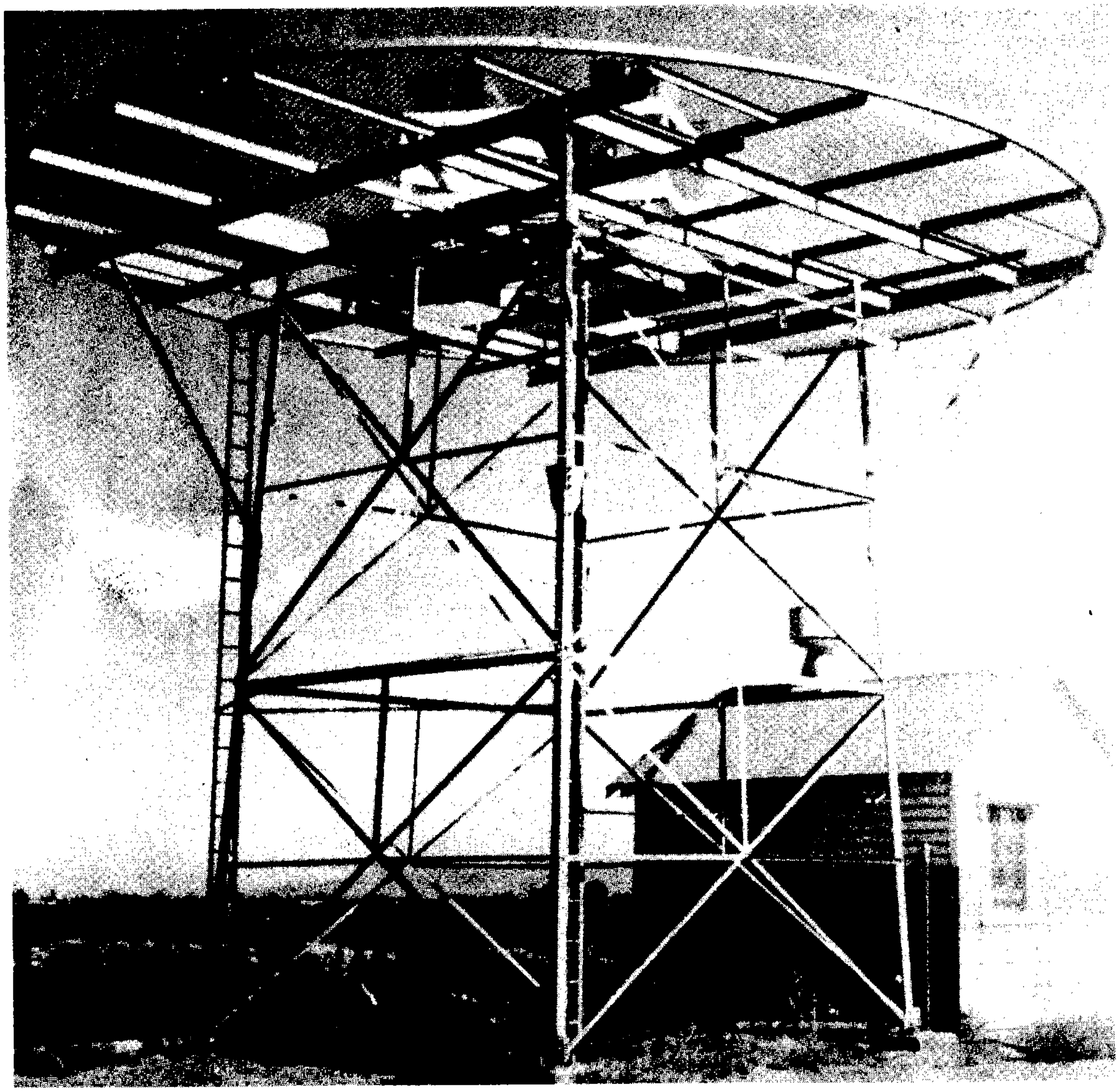


Figure 9. The 22-Foot Tower Station, Van Nuys, California.

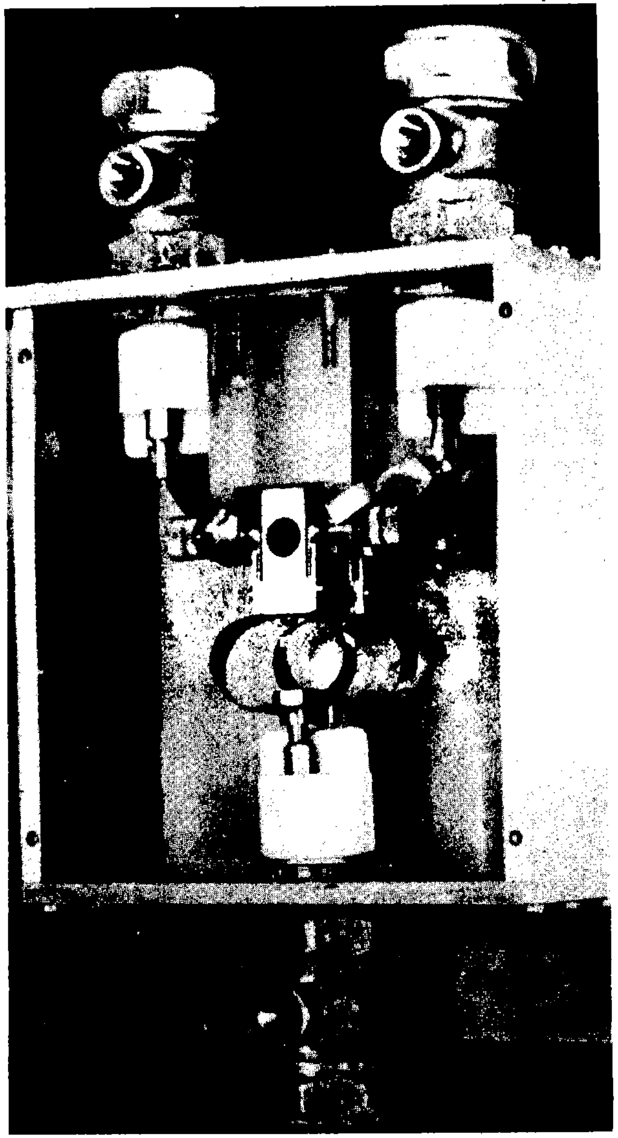


Figure 10. Dual Contact Interlock Relay.

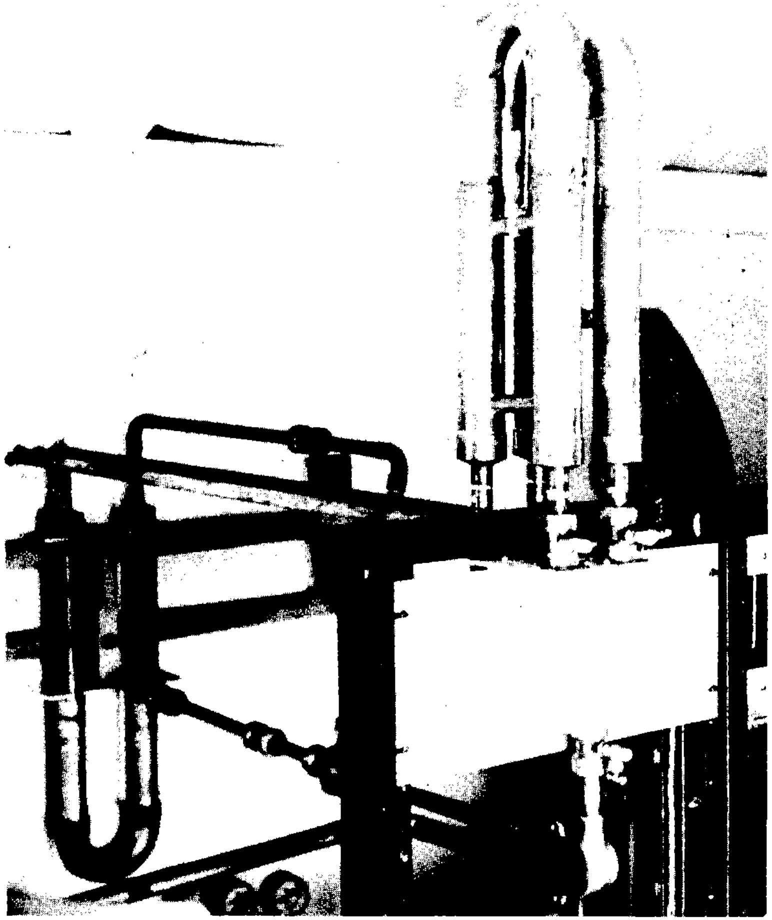


Figure 11. Phasing Network-125 MC Radio Range, Van Nuys, California.

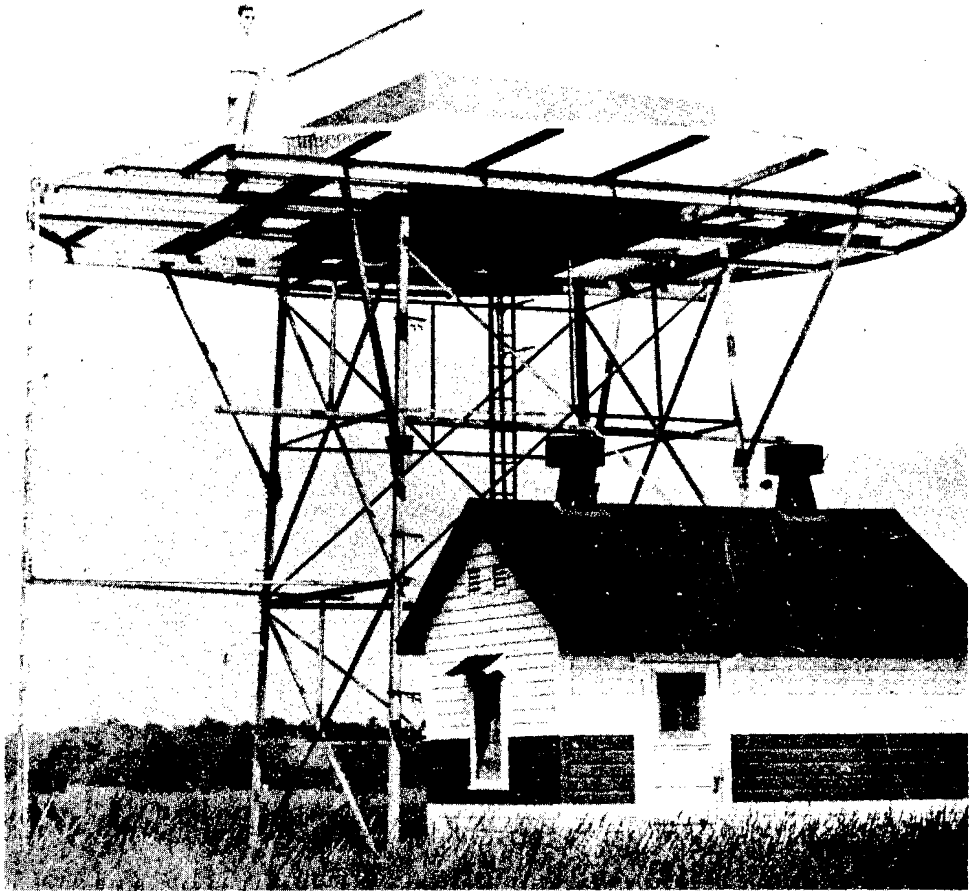


Figure 12. The 22-Foot Tower Station, Indianapolis, Indiana.

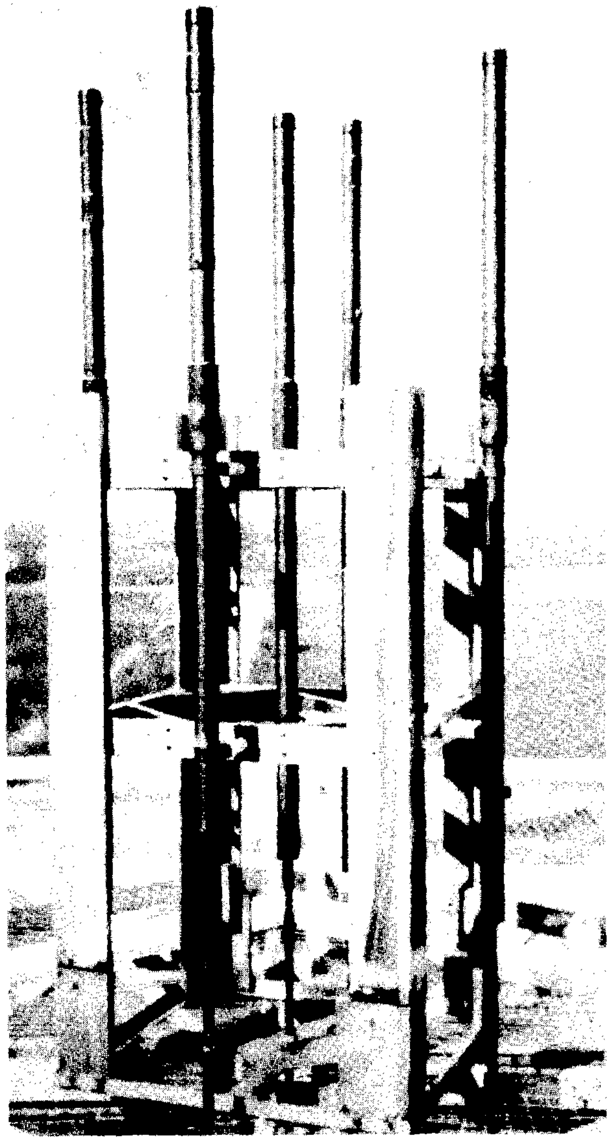


Figure 13. 63-MC Vertically Polarized Antenna Mounted Above a 30-Foot Circular Counterpoise 16 Feet Above Ground.

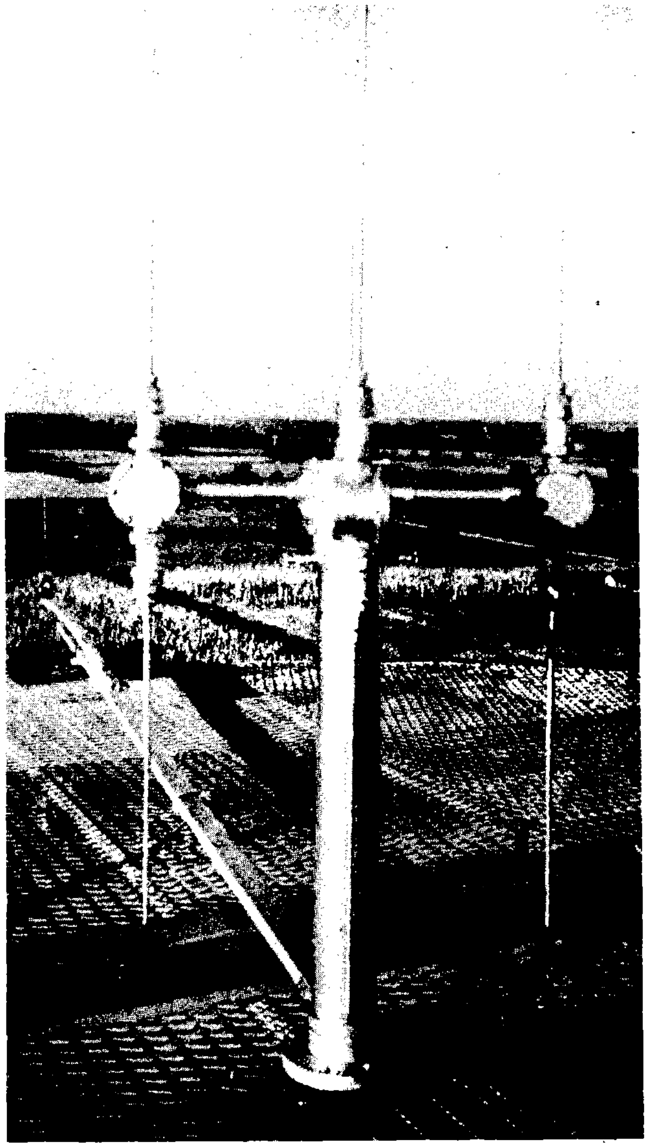


Figure 14. 63-MC Radio Range 4-Course Vertically Polarized Antenna, Indianapolis, Indiana.

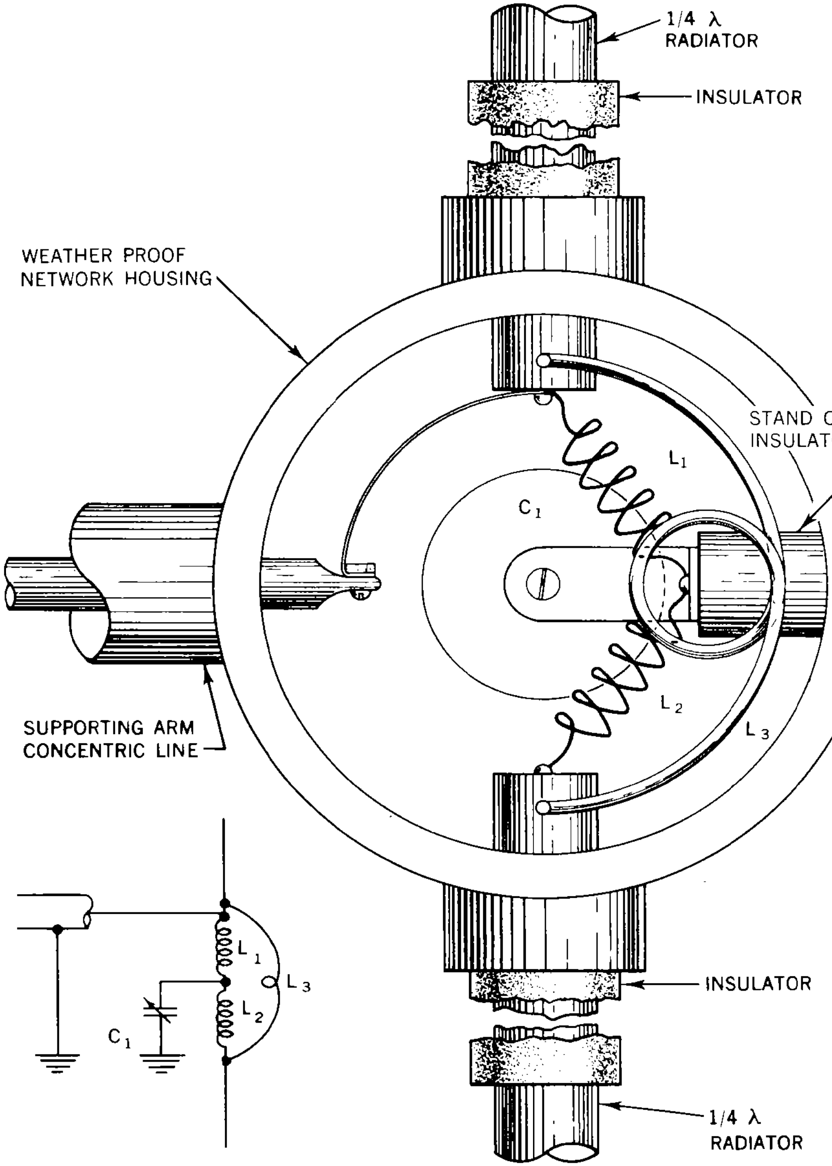


Figure 15. Matching and Balancing Network 63-MC Radio Range.

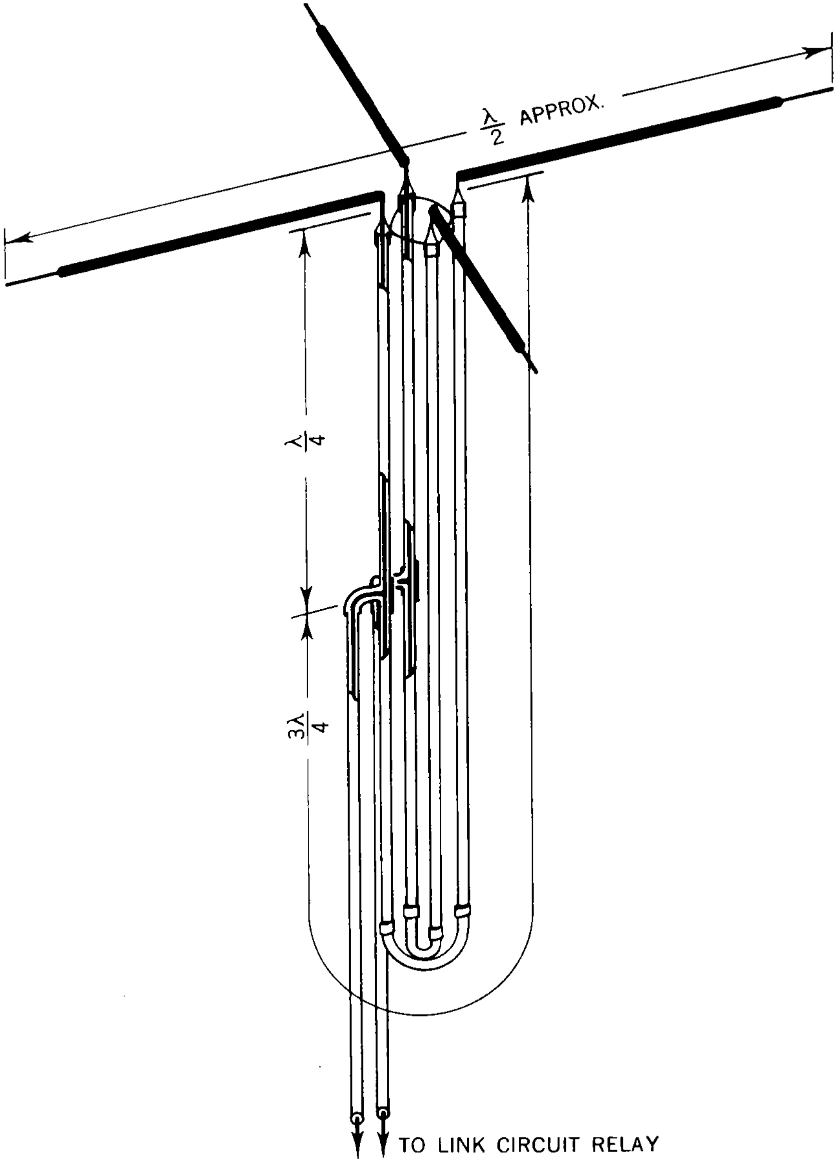


Figure 16. Cross Dipole 4-Course UHF Range Antenna.

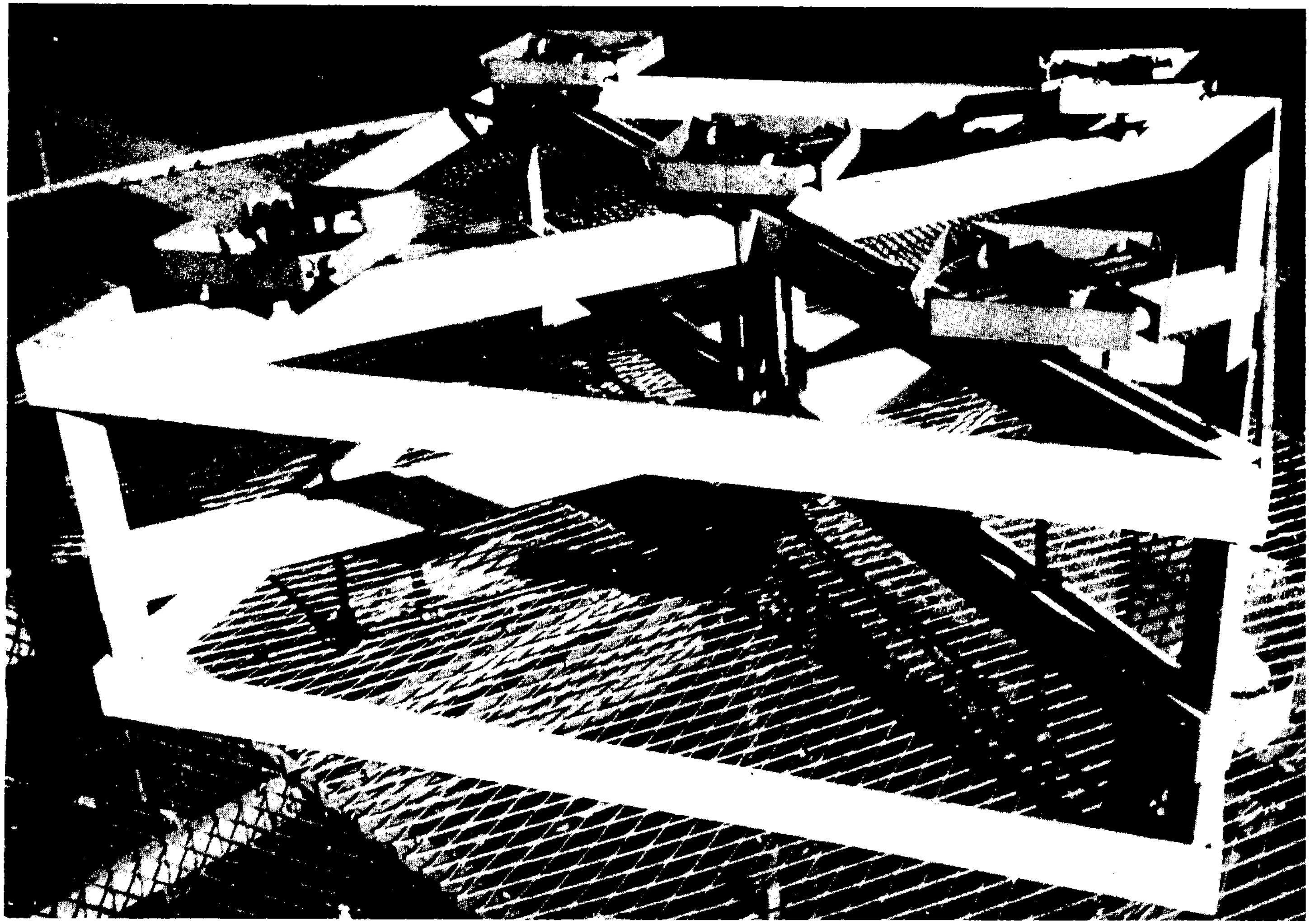


Figure 17. 125-MC Radio Range 5 Horizontal Loops, Van Nuys, California.

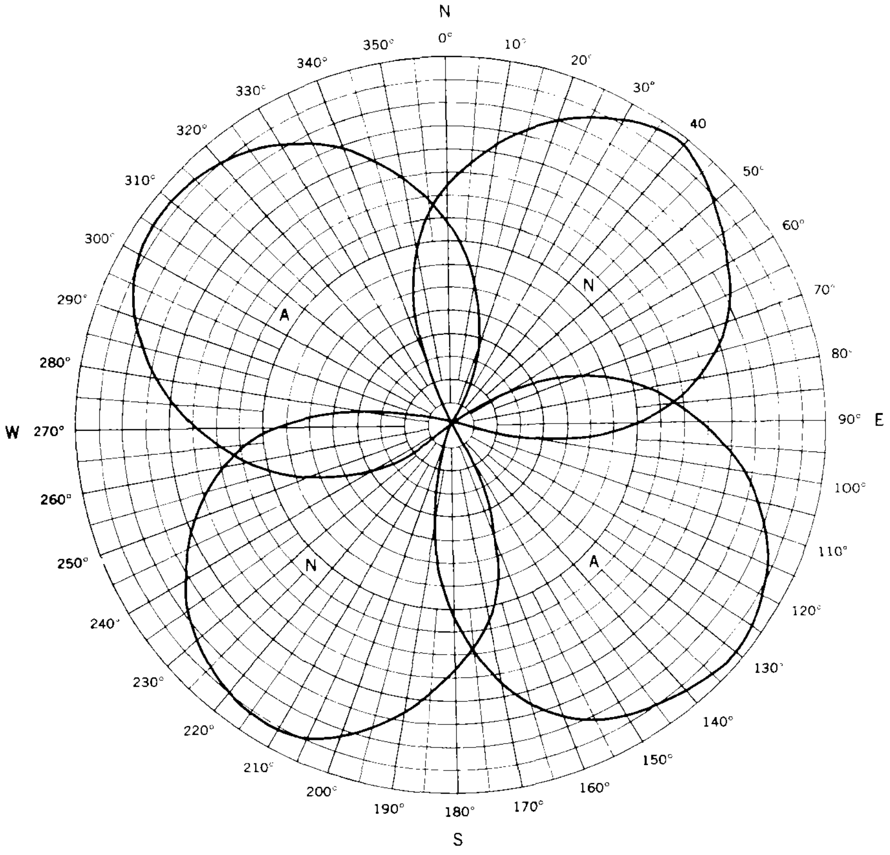
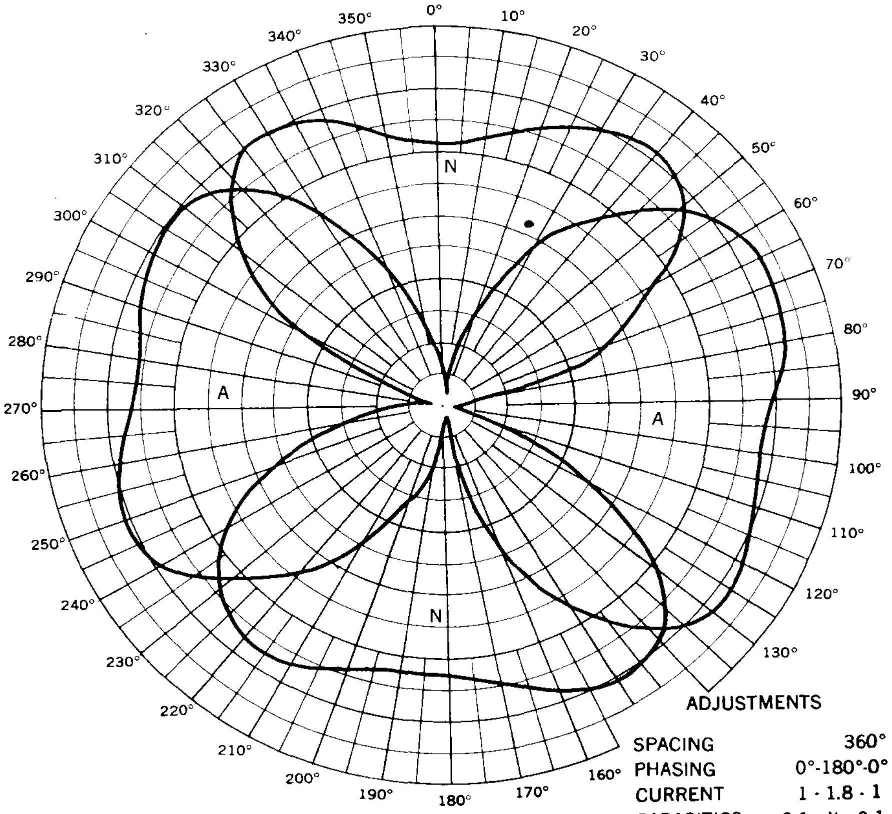


Figure 18. Horizontal Field Pattern of Four-Course Vertical Antenna (63-MC).



ADJUSTMENTS

SPACING 360°
PHASING 0°-180°-0°
CURRENT 1 - 1.8 - 1
PARASITICS 0.1 - X - 0.1

JULY 1940

Figure 19. Horizontal Field Pattern of 125-MC Radio Range, Van Nuys, California.

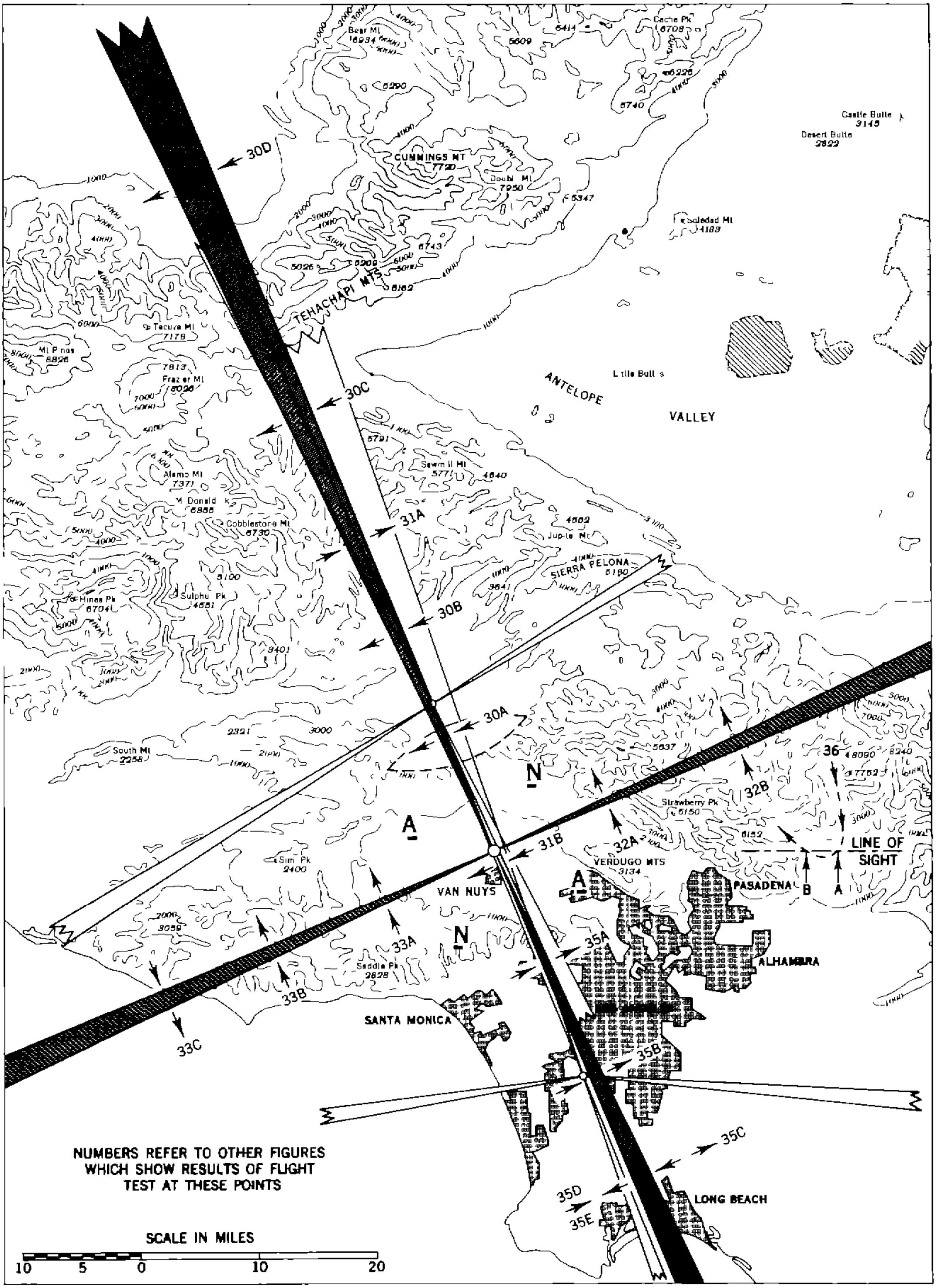


Figure 20 Course Alignment and Location of Flight Tests 125-MC Radio Range, Van Nuys, California

FREQUENCY (MC)	TYPE ANTENNA	HEIGHT ABOVE COUNTERPOISE (λ)	HEIGHT TOWER (FEET)	TYPE COUNTERPOISE	TEST	FIGURE	CURVE
63	VD	1/4	125	35′ E	CONE-OF SILENCE	24	
					COURSE STRAIGHTNESS	25	
					DISTANCE RANGE	23	2
63	HD	1/2	125	35′ E	CONE OF SILENCE	29	B
					COURSE STRAIGHTNESS	25	
					DISTANCE RANGE	23	2
63	HD	1/2	125	35′ S	CONE OF SILENCE	29	A
					DISTANCE RANGE	23	2
63	VD	1/4	16	30′ W	CONE OF SILENCE	24	
					COURSE STRAIGHTNESS	25	
					DISTANCE RANGE	23	1
63	VD		16	N	CONE OF SILENCE	24	
					DISTANCE RANGE	23	7
125	HL	1/2	125	35′ E	CONE-OF SILENCE	26	C
					DISTANCE RANGE	23	5
125	HL	1/4	125	35′ E	CONE-OF SILENCE	26	D
					DISTANCE RANGE	23	6
125	HL	1/4	30	30′ P	CONE OF SILENCE	26	A
					DISTANCE RANGE	23	4
125	HL		30	N	CONE-OF SILENCE	26	B
125					VERTICAL PATTERN OF AIRPLANE S HORIZONTAL LOOP RECEIVING ANTENNA	27	
125	HD	1/4*			REFLECTION FROM TOWER	28	
125	HL	1/2	30	30′ P	DISTANCE RANGE	23	3

V VERTICAL
H HORIZONTAL
D DIPOLE
L LOOP
E EXPANDED METAL MESH

* ABOVE GROUND
W WIRE MESH 3/4′ SQUARES
S SHEET IRON GALVANIZED
N NO COUNTERPOISE
P WIRE MESH 1/2″ SQUARES

Figure 21 Index of Flight Test at Indianapolis on 63 and 125 MC

COURSE LEG	DIRECTION	QUADRANT	TEST	FIGURE	CURVE
NW	245	N TO A	CROSS-COURSE FLIGHTS THRU NEWHALL PASS	30	A
	245°	N TO A	NO MULTIPLE COURSES OBSERVED		B
	245	N TO A			C
	250	N TO OC			D
SE	65	N TO A	CROSS-COURSE FLIGHTS NO MULTIPLE COURSES	35	A
	65	N TO A	OBSERVED		B
	245	A TO N			C
	245	A TO N	CROSS-COURSE FLIGHTS OBSERVE DIFFRACTION		D
	65	N TO A	BY MOUNTAINS IN PATH		E
NW	65	A TO N	CROSS-COURSE FLIGHT NEWHALL 209 KC RANGE	31	A
SE	245	A TO N	*MULTIPLE COURSES OBSERVED*		B
NE	335	A TO N	CROSS COURSE FLIGHT NO MULTIPLE COURSES	32	A
	335°	A TO N	OBSERVED		B
SW	335	N TO A	CROSS-COURSE FLIGHT NO MULTIPLE COURSES	33	A
	330°	N TO A	OBSERVED		B
	155	A TO N			C
		A	SHADOW EFFECT OF MOUNTAINS	36	
	NE SW		ON COURSE CONE OF SILENCE CHARACTERISTIC	37	
		N	CENTER QUADRANT FLIGHTS QUADRANT REVERSAL	38	A
		A	WITHIN CONE OF SILENCE		B

Figure 22 Index of Flight Tests at Van Nuys California on 125-MC

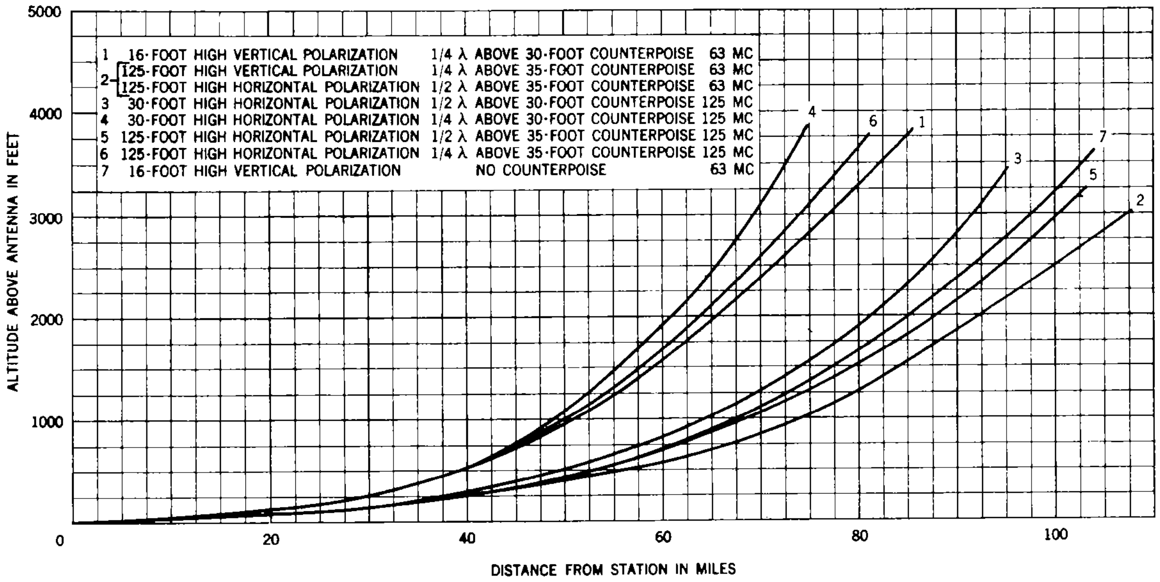
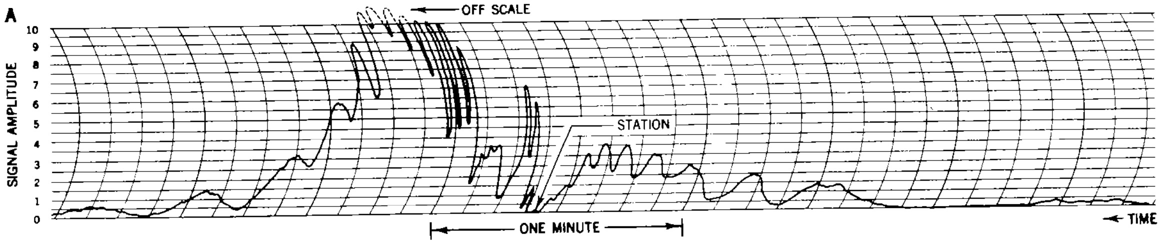
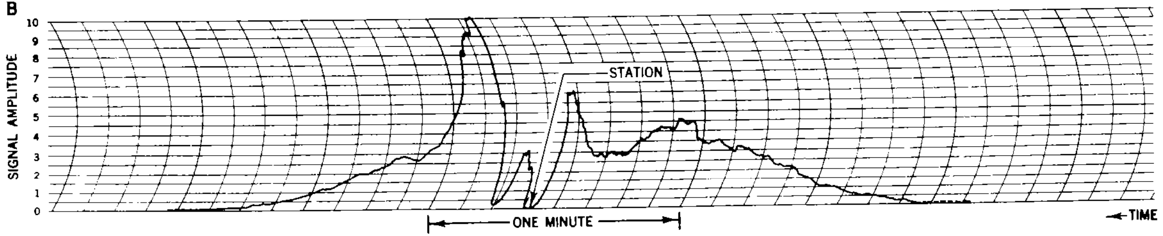


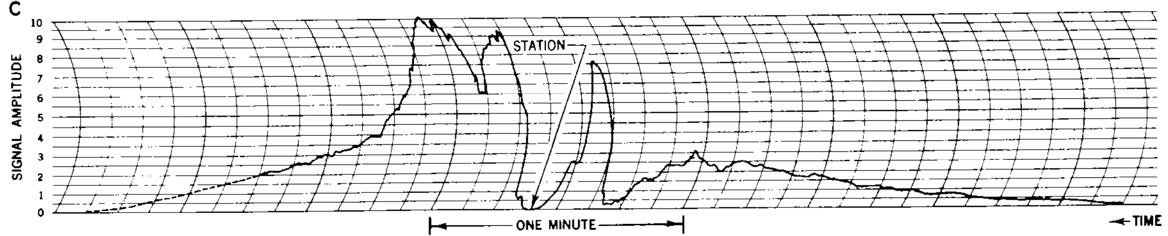
Figure 23. Distance Versus Altitude UHF Range Stations.



125-FOOT ELEVATION
VERTICAL POLARIZATION
35-FOOT COUNTERPOISE



16-FOOT ELEVATION
VERTICAL POLARIZATION
30-FOOT COUNTERPOISE

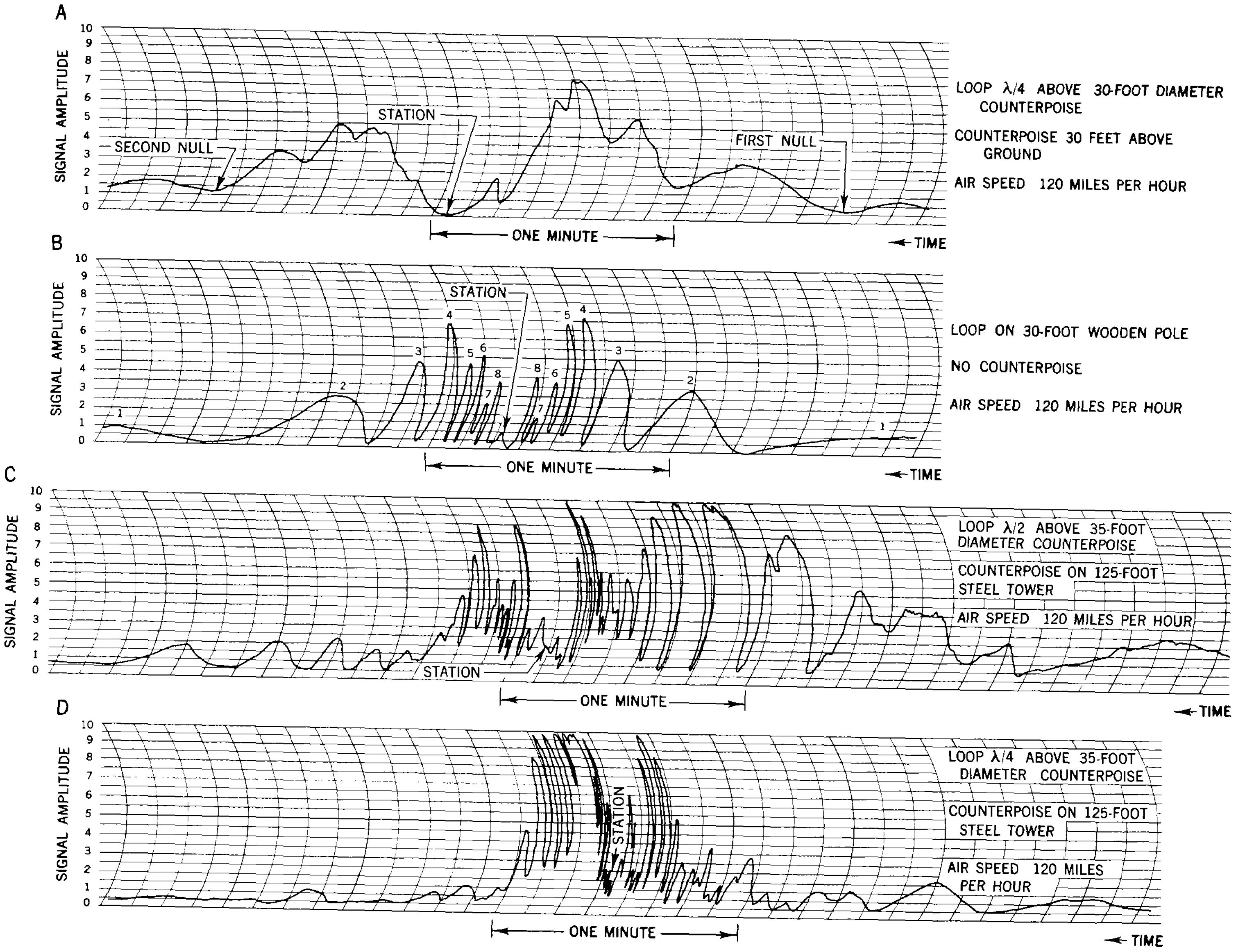


16-FOOT ELEVATION
VERTICAL POLARIZATION
WITHOUT COUNTERPOISE

DISTANCE APPROXIMATELY 10 MILES

NOTE: RECORDINGS MADE WHILE FLYING AT 2000 FEET
IN CENTER OF QUADRANT OVER STATION
WITH GYRO HEADING OF 315°

Figure 24. Cones-of-Silence 63-MC Radio Range Vertical Polarization.



NOTE: RECORDINGS MADE WHILE FLYING AT AN ALTITUDE OF 2000 FEET WITH AN AIRSPEED OF 120 MILES PER HOUR

Figure 25. Course Straightness 63-MC Radio Range.

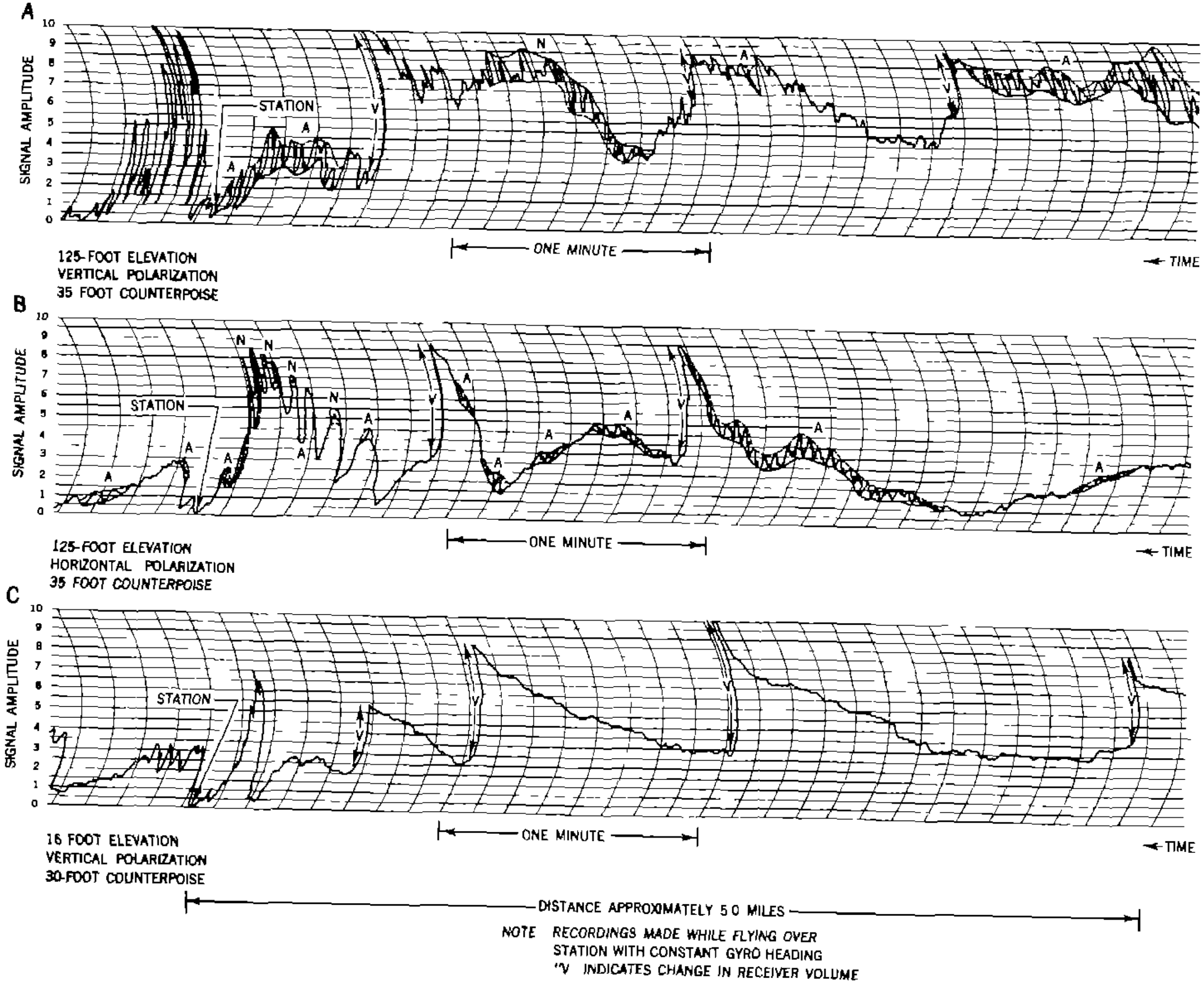
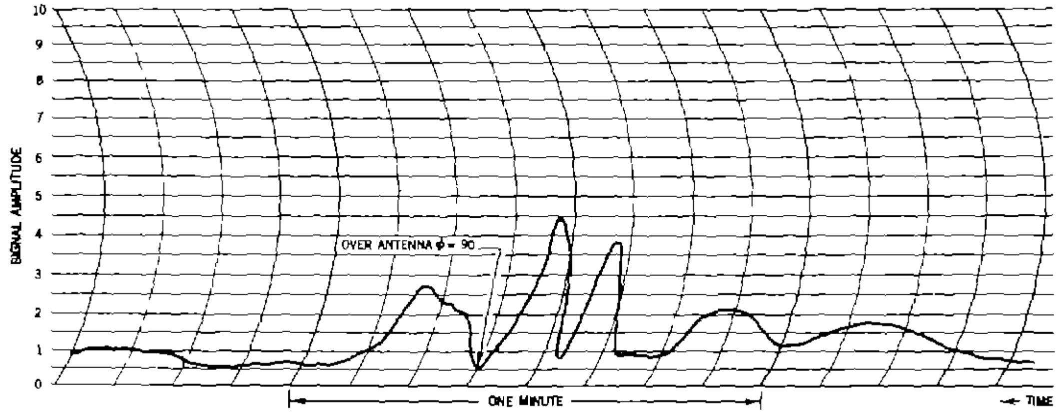
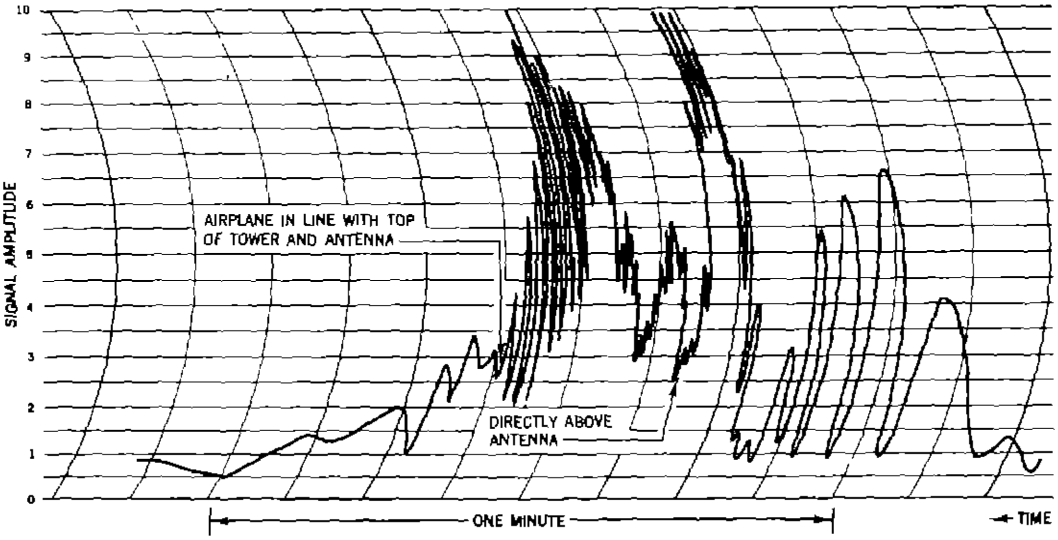


Figure 26 Cones-of-Silence 125-MC Horizontal Loop Antenna



TRANSMITTING ANTENNA $\lambda/2$ DIPOLE, $\lambda/4$ ABOVE GROUND
RECEIVING ANTENNA HORIZONTAL LOOP ABOVE CABIN OF NC-80
DIRECTION OF FLIGHT OVER DIPOLE PERPENDICULAR TO ITS AXIS
ALTITUDE ABOVE GROUND 2000 FEET
GROUND SPEED 125 MILES PER HOUR

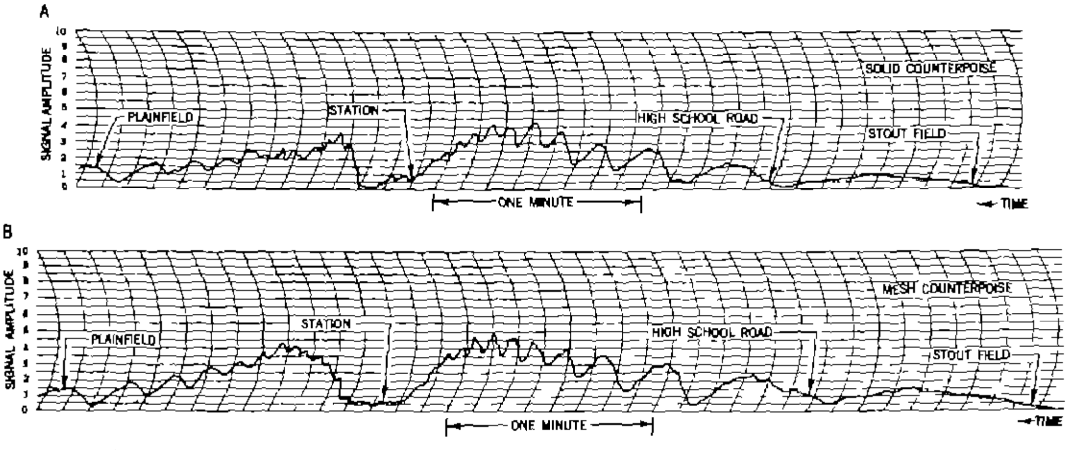
Figure 27 125-MC Airplane Receiving Antenna Vertical Pattern



TRANSMITTING ANTENNA
1/2 λ DIPOLE, 1/4 λ ABOVE GROUND
LOCATED 200 FEET SOUTH OF TOWER
DIPOLE AXIS EAST AND WEST

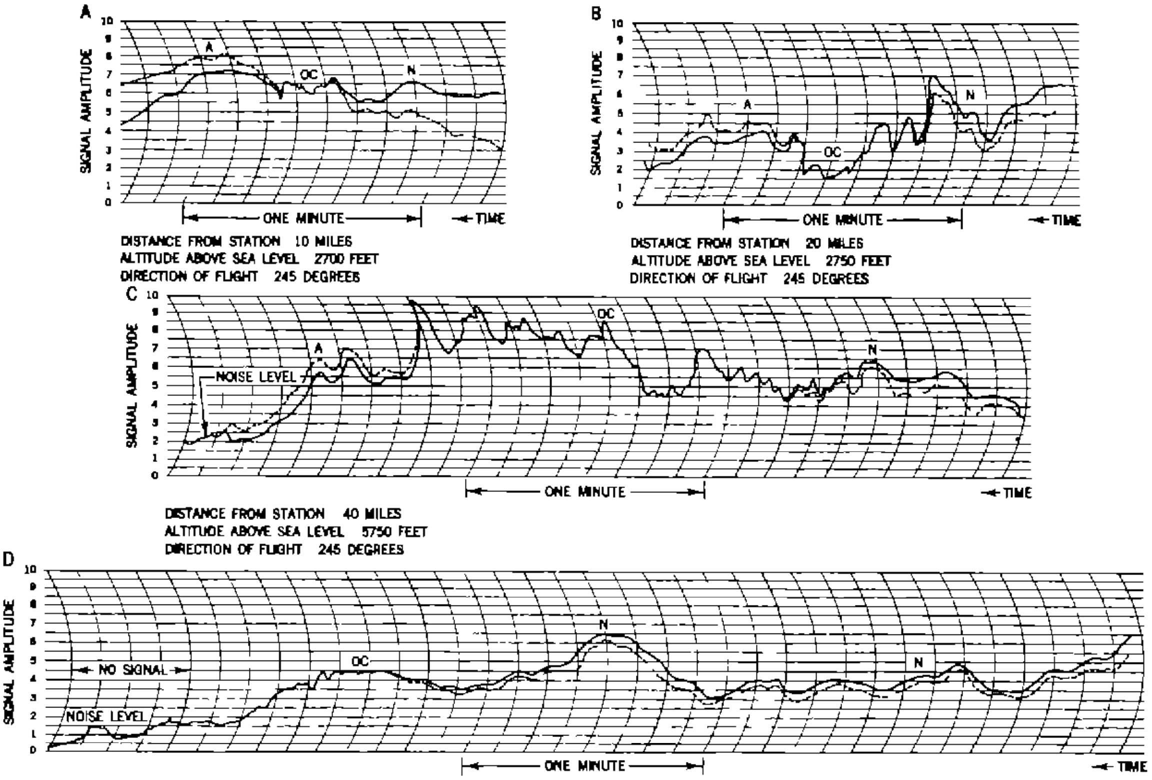
FLIGHT NORTH OVER ANTENNA AND TOWER
ALTITUDE 2000 FEET ABOVE GROUND
AIRSPEED 120 MILES PER HOUR

Figure 28 Reflections from 125-Foot Tower-125-MC



NOTE RECORDINGS MADE WHILE FLYING AT 4000 FEET
ELEVATION ABOVE GROUND AND AT AN ANGLE
OF 45 DEGREES TO A COURSE

Figure 29 Cones-of-Silence 63-MC Radio Range Horizontal Polarization



DISTANCE FROM STATION 10 MILES
ALTITUDE ABOVE SEA LEVEL 2700 FEET
DIRECTION OF FLIGHT 245 DEGREES

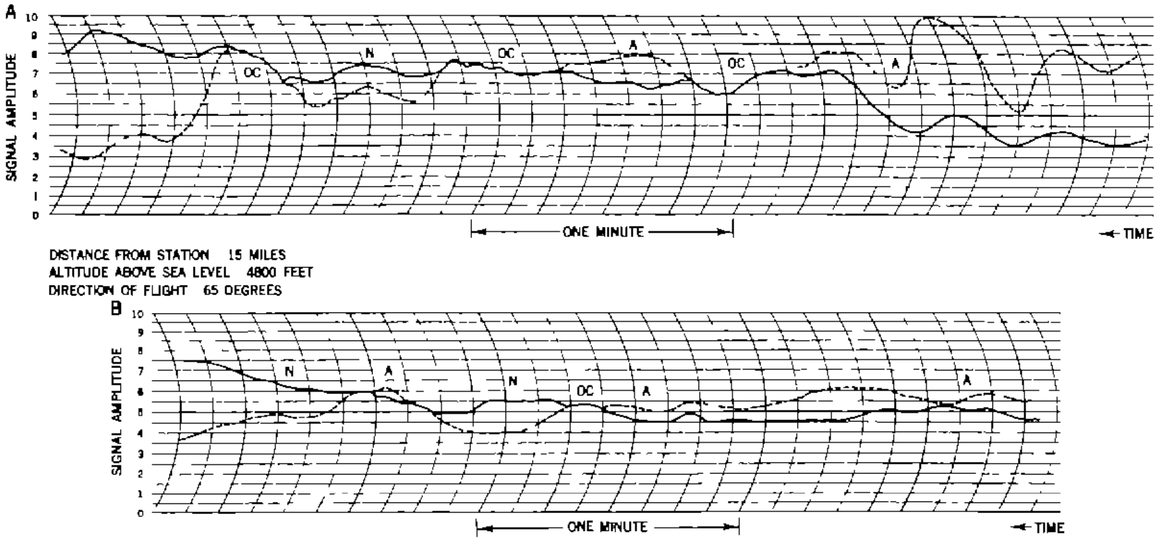
DISTANCE FROM STATION 20 MILES
ALTITUDE ABOVE SEA LEVEL 2750 FEET
DIRECTION OF FLIGHT 245 DEGREES

DISTANCE FROM STATION 40 MILES
ALTITUDE ABOVE SEA LEVEL 5750 FEET
DIRECTION OF FLIGHT 245 DEGREES

DISTANCE FROM STATION 63 MILES
ALTITUDE ABOVE SEA LEVEL 7700 FEET
DIRECTION OF FLIGHT 250 DEGREES

NOTE REFER TO FIGURES 20 AND 34 FOR LOCATION OF FLIGHT TESTS
AIRSPEED ON ALL FLIGHTS WAS 120 MILES PER HOUR

Figure 30 Cross-Course Checks on NW Leg 125-MC Radio Range, Van Nuys, California

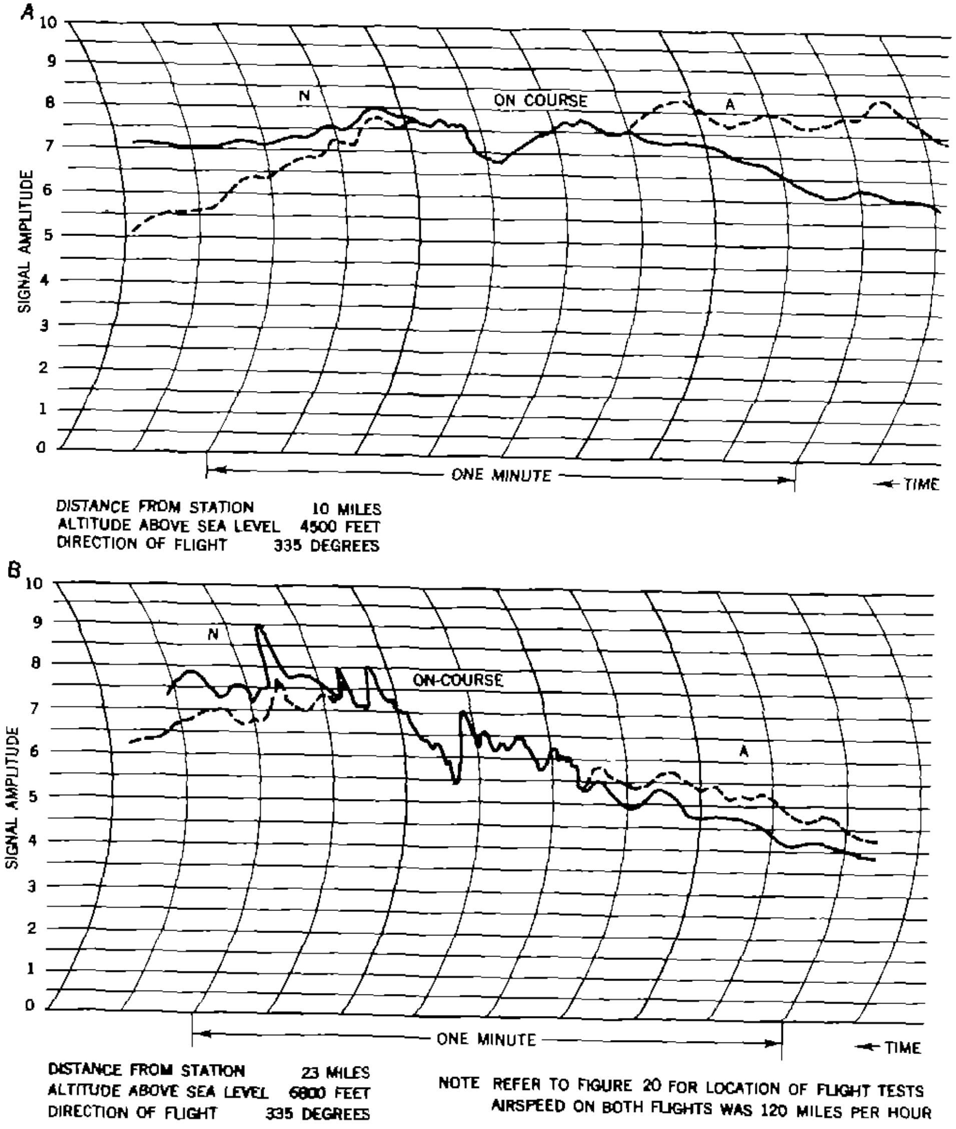


DISTANCE FROM STATION 15 MILES
ALTITUDE ABOVE SEA LEVEL 4800 FEET
DIRECTION OF FLIGHT 65 DEGREES

DISTANCE FROM STATION 15 MILES
ALTITUDE ABOVE SEA LEVEL 3700 FEET
DIRECTION OF FLIGHT 245 DEGREES

NOTE REFER TO FIGURE 20 FOR LOCATION OF FLIGHT TESTS
AIRSPEED ON BOTH FLIGHTS WAS 120 MILES PER HOUR

Figure 31 Cross-Course Checks on NW and SE legs 209-KC Radio Range, Newhall, California

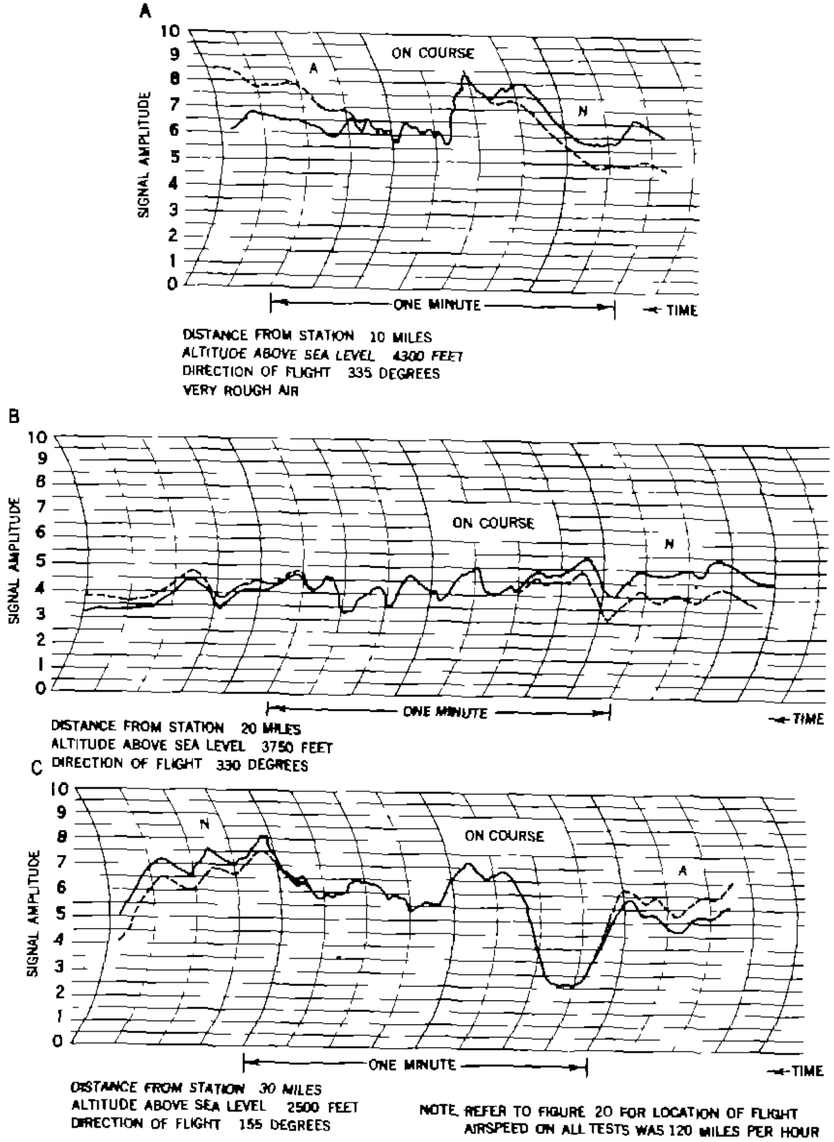


A: DISTANCE FROM STATION 10 MILES
ALTITUDE ABOVE SEA LEVEL 4500 FEET
DIRECTION OF FLIGHT 335 DEGREES

B: DISTANCE FROM STATION 23 MILES
ALTITUDE ABOVE SEA LEVEL 6800 FEET
DIRECTION OF FLIGHT 335 DEGREES

NOTE REFER TO FIGURE 20 FOR LOCATION OF FLIGHT TESTS
AIRSPEED ON BOTH FLIGHTS WAS 120 MILES PER HOUR

Figure 32 Cross-Course Checks on NE Leg 125-MC Radio Range, Van Nuys, California



A: DISTANCE FROM STATION 10 MILES
ALTITUDE ABOVE SEA LEVEL 4300 FEET
DIRECTION OF FLIGHT 335 DEGREES
VERY ROUGH AIR

B: DISTANCE FROM STATION 20 MILES
ALTITUDE ABOVE SEA LEVEL 3750 FEET
DIRECTION OF FLIGHT 330 DEGREES

C: DISTANCE FROM STATION 30 MILES
ALTITUDE ABOVE SEA LEVEL 2500 FEET
DIRECTION OF FLIGHT 155 DEGREES

NOTE REFER TO FIGURE 20 FOR LOCATION OF FLIGHT
AIRSPEED ON ALL TESTS WAS 120 MILES PER HOUR

Figure 33 Cross-Course Checks on SW Leg 125-MC Radio Range, Van Nuys, California

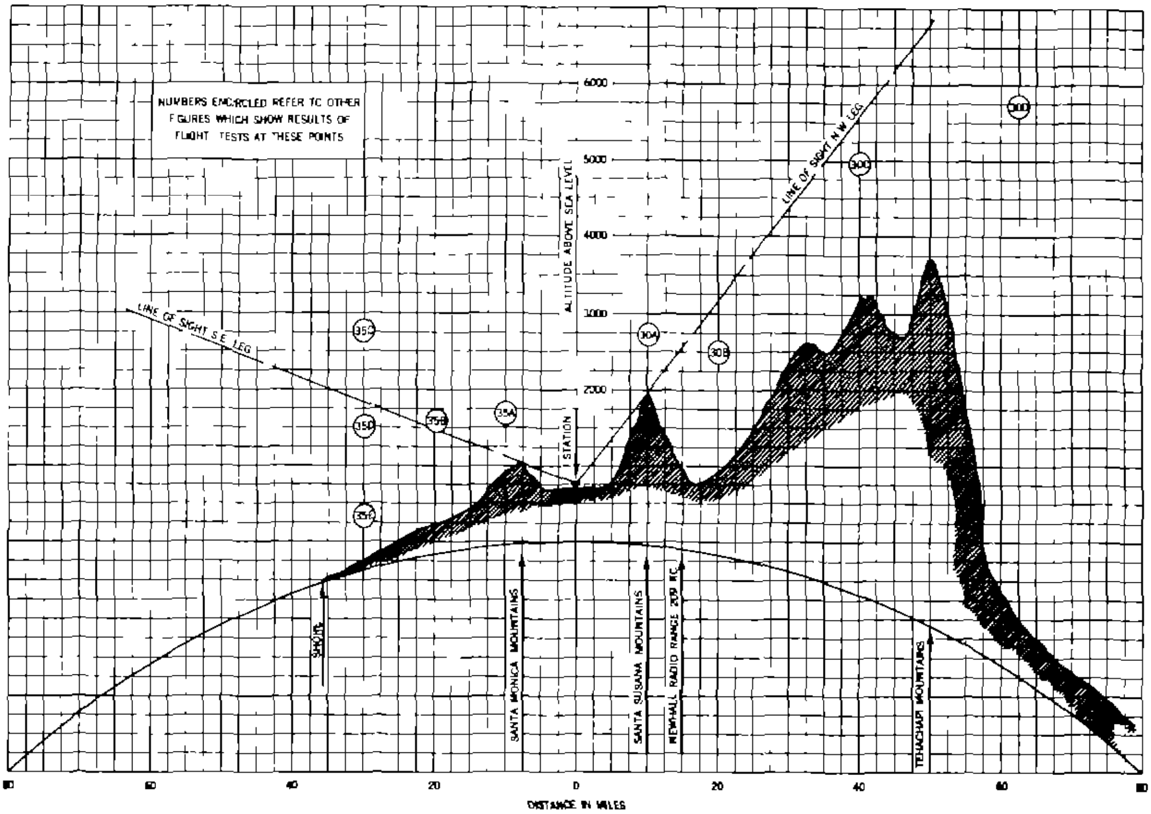
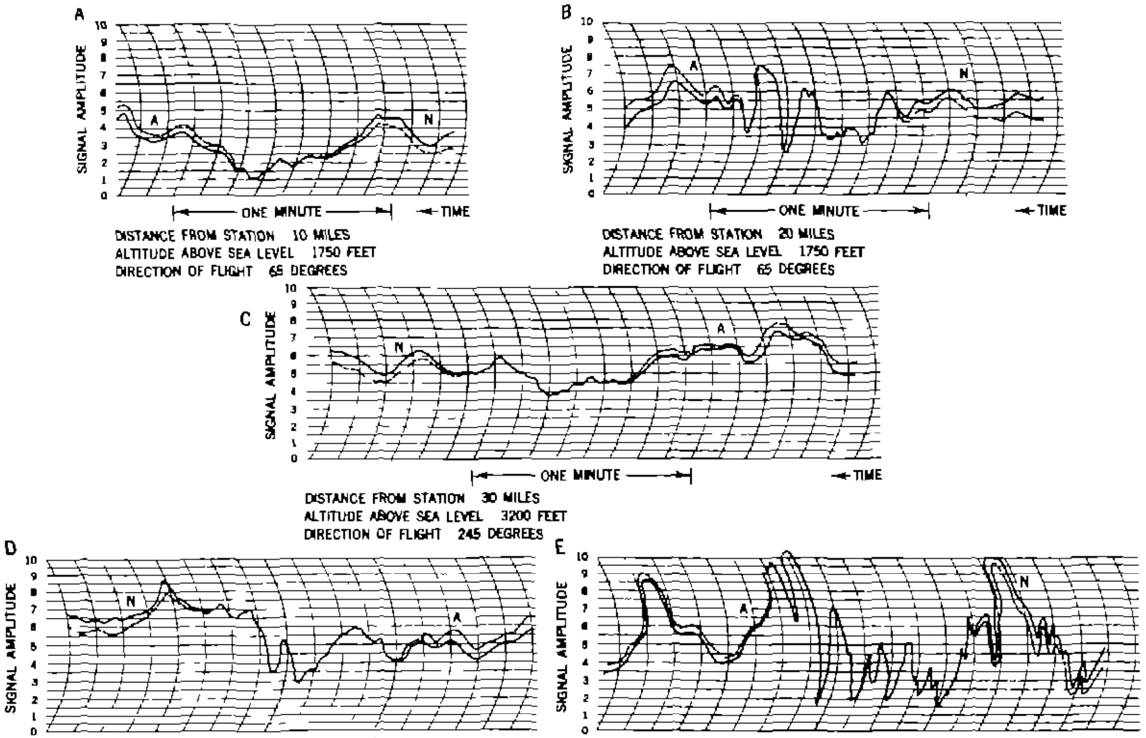


Figure 34 Profile Map Showing Propagation Paths 125-MC Radio Range, Van Nuys, California



A
DISTANCE FROM STATION 10 MILES
ALTITUDE ABOVE SEA LEVEL 1750 FEET
DIRECTION OF FLIGHT 65 DEGREES

B
DISTANCE FROM STATION 20 MILES
ALTITUDE ABOVE SEA LEVEL 1750 FEET
DIRECTION OF FLIGHT 65 DEGREES

C
DISTANCE FROM STATION 30 MILES
ALTITUDE ABOVE SEA LEVEL 3200 FEET
DIRECTION OF FLIGHT 245 DEGREES

D
DISTANCE FROM STATION 30 MILES
ALTITUDE ABOVE SEA LEVEL 2000 FEET
DIRECTION OF FLIGHT 245 DEGREES

E
DISTANCE FROM STATION 30 MILES
ALTITUDE ABOVE SEA LEVEL 800 FEET
DIRECTION OF FLIGHT 65 DEGREES

NOTE REFER TO FIGURES 20 AND 34 FOR LOCATION OF FLIGHT TESTS
AIRSPEED ON ALL TESTS WAS 120 MILES PER HOUR

Figure 35 Cross-Course Checks on SE Leg 125-MC Radio Range, Van Nuys, California

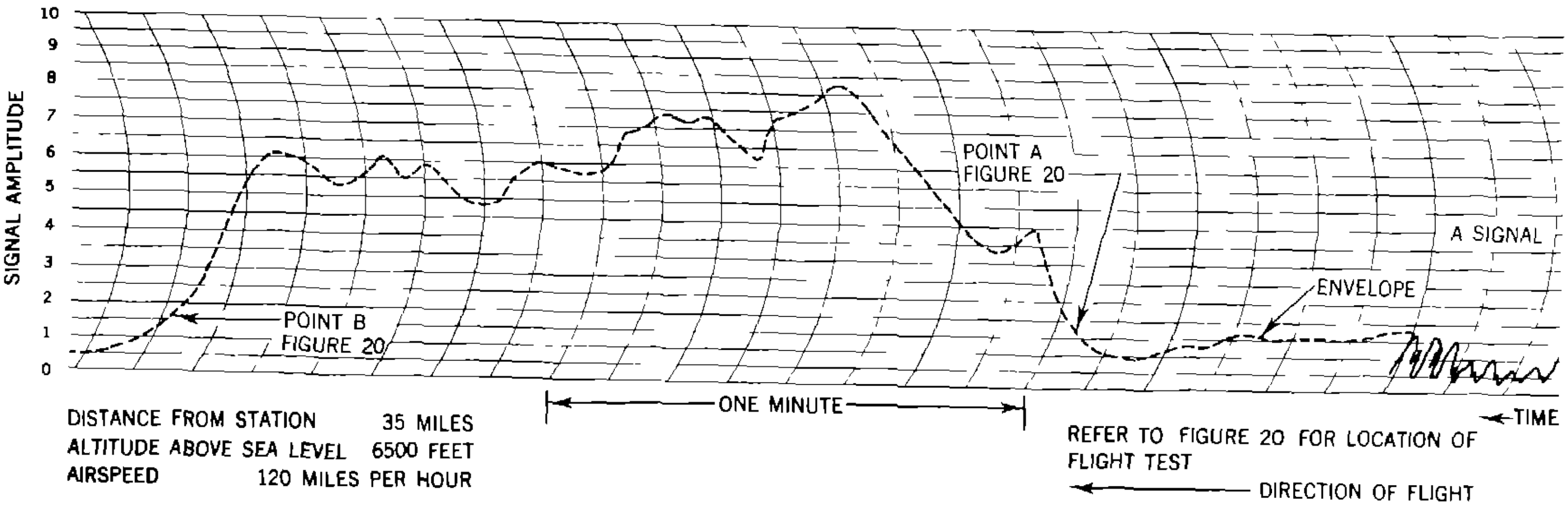


Figure 36 "A" Quadrant Near Monrovia, California, 125-MC Radio Range, Van Nuys, California

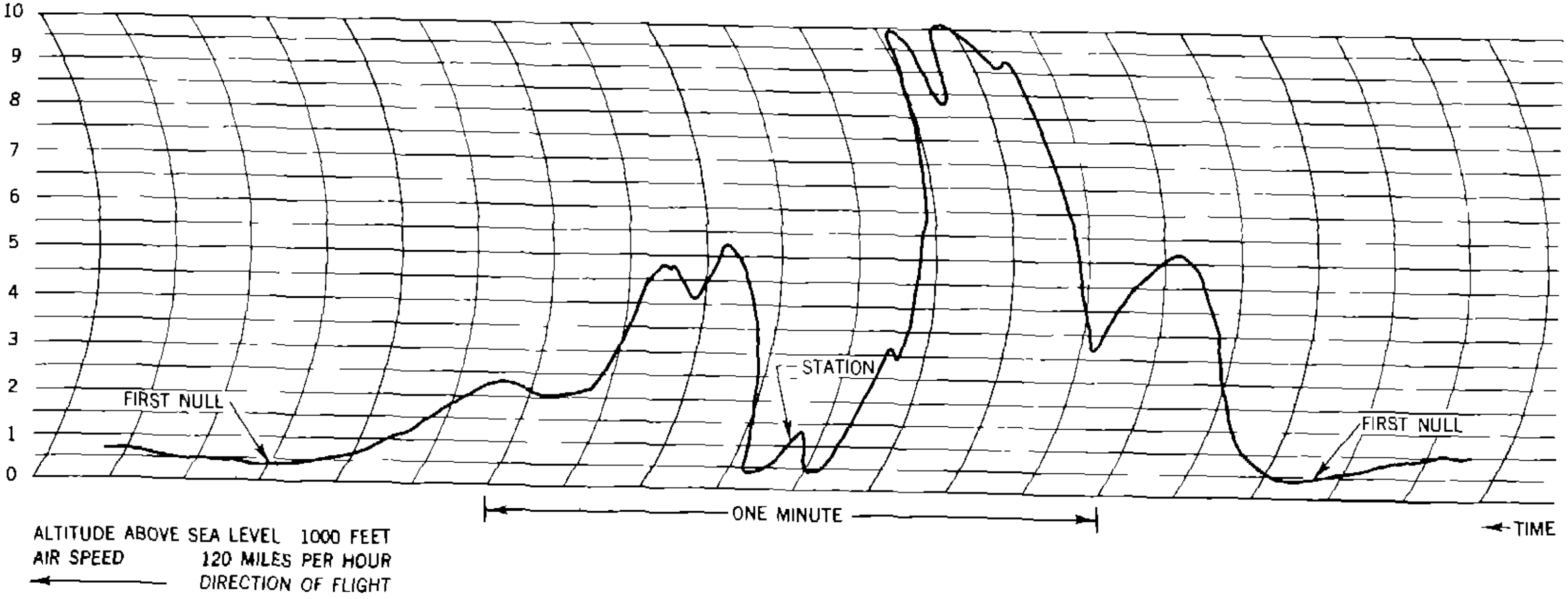


Figure 37 Cone-of-Silence 125-MC Radio Range, Van Nuys, California

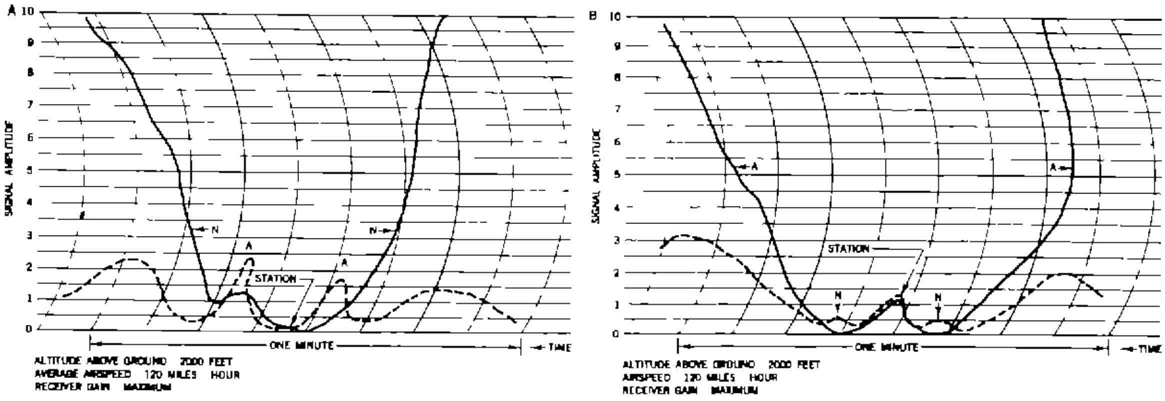


Figure 38 Quadrant Identification in Cone-of-Silence 125-MC Radio Range, Van Nuys, California

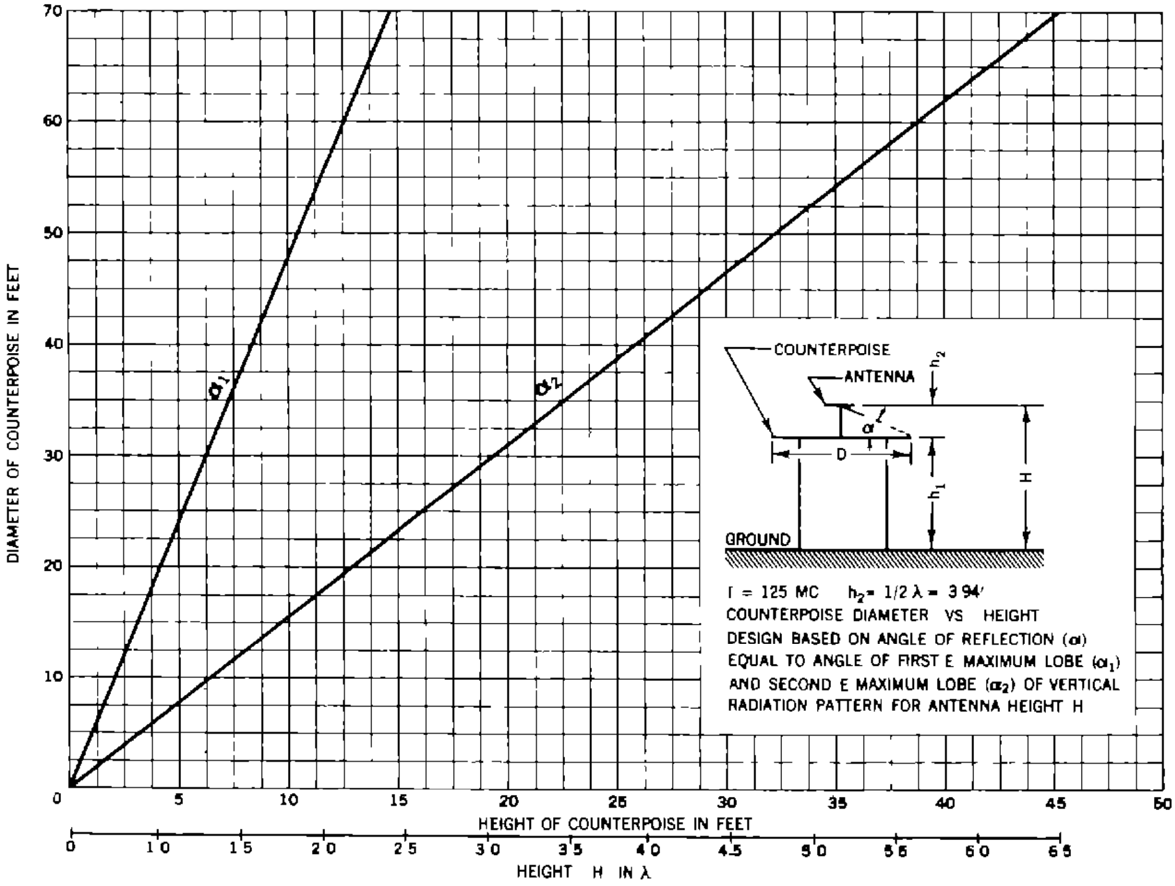


Figure 39 Counterpoise Diameter Versus Height for 125-MC