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RADIO ENGINEERING
MICROWAVE RADIO
ANTENNAS AND REFLECTORS
ARRANGEMENTS

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1. INTRODUCTION

(A) General

1.01 *Reason For Reissue:* To correct Figures 12, 14, and 15 and, consequently, references to these figures in the text. A typographical error in a formula in Paragraph 2.26 has also been corrected. Marginal arrows have been omitted.

1.02 Following this first introductory portion, the second part of this practice discusses periscope antenna arrangements. The third part discusses passive repeaters.

1.03 For the most part, the antennas used in the periscope antenna combinations are assumed to have circular apertures. However, some information is given that may be used for antennas having other than circular apertures. Much of the information given here is based on theoretical investigations, however, experience indicates that actual results will agree closely with the theoretical.

1.04 In order to obtain line-of-sight transmission paths, microwave systems generally require elevated antennas, Due to the optical properties of microwaves, however, the antennas may be mounted on the ground and directed at an elevated plane (flat) or curved reflector which is so oriented as to redirect the transmitted energy to a distant radio station. Reciprocally, the elevated reflector may be used to intercept incoming energy and redirect it to the antenna below. These antenna-reflector combinations are known as "periscope antennas."

> *Note:* **While this practice will discuss antenna-reflector combinations where the reflector is mounted above the antenna (which is the general case in actual use), it does not necessarily have to be mounted in this manner. The reflector may be mounted to the side of or even below the antenna. In any case, however, the methods discussed here to find gain, size, etc, of the antenna-reflector systems will remain the same.**

1.05 When using an antenna-reflector combination, it is possible to achieve some advantages over a system where the transmitting and receiving equipment are located on the ground and the respective antennas are mounted aloft using interconnecting waveguide. These advantages include:

(1) A possible reduction of transmission loss over the loss of a waveguide transmission line.

(2) A possible reduction of expense of providing and installing the transmission line.

(3) Reduction of envelope delay distortion effects due to long waveguide runs.

(4) Reduction of klystron "pulling" effects in those cases where a modulated klystron connects to a long waveguide that contains no isolator.

Offsetting the advantages above are:

(1) Expense of making, installing, and orienting the reflector.

(2) Requirement of a somewhat stiffer tower because of icing and wind loading (or "sail" effect) of a large plane surface.

1.06 Reflectors may be used for either horizontally or vertically polarized signals. Tests indicate that a reflector introduces no material loss in the cross-polarization discrimination of an antenna.

1.07 When using antennas on a tower, difficulty may be encountered due to energy from one antenna cross-coupling into another antenna. This may cause excessive noise or distortion in the desired channel. Limited cross-coupling tests between parabolic antennas have shown that coupling losses vary considerably between different antennas, however, the cross-coupling discrimination may be as low as 50 db. This is due primarily to direct coupling between antennas and to reflections from near-by objects back to the antennas. At a repeater point, where transmitting and receiving frequencies are normally separated by 80 megacycles or more, there should be no difficulty encountered. When using Western Electric Co. type TD-2 microwave radio equipment, where transmitting and receiving frequencies are normally shifted by only 40 megacycles, 77 db or more of cross-coupling discrimination should be obtained. If 77 db is not obtained with antenna discrimination alone, the 574A IF bandpass filters and/or shielding between the antennas may be used to get it.* (See note.)

******Note:*** The 574A IF bandpass filters, which are used for TD-2 interstitial channels, are designed for 20-megacycle rejection and they do not provide as much discrimination at 40 megacycles. Tests have indicated that an additional 6 to 15 db coupling loss can be obtained in this manner. Approximately the same range of discrimination can be obtained by the use of shielding between the antennas. However, the position of the shield between the antennas has been found to be very critical. Also, the shielding loss seems to be frequency sensitive, and the correct position for one frequency is not necessarily correct for a different frequency. Therefore, the shielding coupling loss for more than one frequency may be only one-half or less than it could be for one frequency when the shield is placed in its optimum position for all frequencies used.

The use of the same frequency for transmission or reception in two directions should not be attempted with a periscope antenna system at a two-way repeater point, because of the low front-to-back discrimination of the reflectors.

2. PERISCOPE ANTENNA ARRANGEMENTS

(A) Field Distribution Beneath a Reflector

2.01 In order to study the effect of a reflector system, consider a 45 degree plane reflector intercepting incoming energy and directing it downward to an antenna mounted below as shown in Fig. 1. The reflector is assumed to be plane (flat) with an elliptical periphery, so that when mounted at 45 degrees to the horizontal the projected reflector area is circular. The radius of this circular area is equal to the radius of a circle whose area is equal to the projected area of the reflector. For receiving, the incoming field is assumed to be a uniform plane wave of field intensity E_0. With the antenna located beneath the reflector, the received power output is designated P_1. With the antenna located in the position occupied by the reflector (i.e., subject to the incoming plane wave E_0) the received power output is designated P_2.

2.02 If the reflector intercepts a uniform plane wave, the reflected wave behaves as though it had passed through an aperture in a perfectly absorbing screen, the area of the aperture being equal to the projected area of the reflector. This constitutes a case of Fresnel or Fraunhofer diffraction, depending upon the distance from the reflector being considered. The cross-sectional distribution of the field intensity beneath a reflector is indicated in Fig. 2. At the left of Fig. 2 is indicated the reflector whose projected diameter is 2R and beneath the reflector at various distances, d, are indicated the locations b, c, e, f, g, and h, where the plots of field intensity are shown at the right. At very short separations, as for example, at b, where the distance, d, is only $(2R)^2/60\lambda$, the field intensity is quite uniform across the projected diameter and furthermore, most of the energy is confined to the projected area (diameter 2R). At the greatest distance shown at h, the field intensity is no longer uniform across the projected diameter and considerable energy is dispersed outside of the projected area. For an antenna at any given distance beneath the reflector, the integrated total field over the antenna aperture (and consequently the power P_1 received by the antenna) will thus depend on the values of:

R = projected radius of the reflector.
a = radius of the antenna aperture.
d = antenna reflector separation.
λ = wave length of frequency used.

(B) Efficiency of Periscope Antenna Systems

2.03 Fig. 3 shows the ratio of the power received by an antenna beneath a flat reflector (P_1) to the power which would be received by the same antenna at the reflector location (P_2). This ratio is expressed in db and denoted η, and plotted against the parameter $1/K = \lambda d/4R^2$ for various values of $\ell = a/R$. Fig. 4 is the same as Fig. 3 except the curves are plotted using a curved reflector instead of a flat one. These curves may be regarded as efficiency curves of the particular antenna-reflector combination, since they give the gain or loss of the antenna-reflector combination with respect to the same antenna alone at the location of the reflector. The abscissa 1/K is proportional to the separation d, and it may be noted that for large separations (1/K greater than about 2.5) the curves for all values of ℓ (ratio of antenna diameter to reflector diameter) have become asymptotic to a straight line and have reached the inverse square law of loss versus distance. The equation for the straight line portion of the curves is $\eta = 20 \log \pi R^2/\lambda d$.

2.04 The efficiency curves of Figs. 3 and 4 show that for various values of "ℓ" equal to or less than 0.8 and "1/K" less than 0.8, the power received by the antenna under the reflector exceeds that which the same antenna would receive if it were mounted at the reflector location. Gains of 2 to 4 db are possible using practical antenna and reflector sizes. For example, from Fig. 3, about 2.5 db gain is indicated at d = 140 feet, f = 3950 mc, 2R = 10 feet, and 2a = 5 feet.

2.05 ***It must always be kept in mind that the values shown in Figs. 3 and 4, of gains or losses (η), represent the gains or losses of the reflector system as compared with the same antenna in free space at the reflector location.*** Thus, while a given reflector with a very small antenna produces a large value of η, a larger antenna used with the same reflector might provide a more effective combination even though the value of "η" is less.

2.06 The curves of Figs. 3 and 4 may be used to derive other curves showing trends as changes are made in antenna diameter, antenna-reflector separation, or reflector size; for use in a particular system under study. To illustrate the usefulness of the curves of Figs. 3 and 4 for this purpose, three examples are shown in Figs. 5, 6 and 7. Since the methods of calculating efficiency of periscope antenna systems is the same for both flat and curved reflectors, Fig. 3 (flat reflectors) will be used to illustrate these three examples.

(a) Fig. 5 shows the trend in a specific system as the diameter of the antenna under the reflector is varied. Assume that the system is operating at a frequency of 11,200 mc, with a projected reflector radius of 4 feet, and with an antenna-reflector separation of 150 feet. Then $1/K = \lambda d/4R^2 = 0.21$ and from Fig. 3 along the line $1/K = 0.21$ values of η can be obtained for various values of $\ell = a/R$. The values of "η" so obtained show the gain or loss of the antenna under the reflector relative to the same antenna at the reflector location. However, in the case shown in Fig. 5, the power received by the antenna under the reflector (P_1) is compared with the power (P_2) received by an antenna of a fixed diameter of 5 feet mounted at the reflector location. Therefore, the values of "η" must be adjusted for the difference in free space gain of the antennas. In other words, the values shown in Fig. 5 are for $P_1/P_2 = \eta + 20 \log 2a/5$ feet. It may be seen from Fig. 5 that with this antenna-reflector system using an antenna diameter of 3.7 feet, it is possible to obtain performance equal to the 5-foot antenna at the reflector location. The maximum gain obtainable with the system over the 5-foot antenna at the reflector location is 3.45 db using an antenna diameter of about 10 feet. It will be noted that although increasing antenna size may give increased gain, the gain increase is much less than occurs when antenna size is increasing at the top of the tower. For example, the increase is only 2.2 db in going from 5 to 10 feet dish at base, but the same increase in size of antenna at top of tower would give 6.0 db increase.

(b) Fig. 6 shows the trend as the antenna-reflector separation is varied in a system where the projected reflector radius is 4 feet, the antenna diameter is 5 feet, and the frequency is 11,200 mc. This curve is obtained from Fig. 3 by reading the values of η along the curve ℓ = a/R = 0.625 at points where 1/K corresponds to the selected distance, "d". In this case, the antenna under the reflector and the antenna at the reflector location are both fixed at 5 feet and consequently, $P_1/P_2 = \eta$. It may be seen from Fig. 6 that performance equal to the 5-foot antenna at the reflector location can be obtained up to a separation d= 440 feet, or the maximum gain obtainable over the 5-foot antenna at the reflector location is 1.6 db which occurs at a separation d = 250 feet.

(c) Fig. 7 is derived from Fig. 3 in a similar manner to show the trend as the projected reflector diameter (2R) is varied while the other variables are held constant at f = 11,200 mc, d = 150 feet, and 2a = 5 feet. With a 6.25-foot (projected diameter) reflector, equal performance to that expected with a 5-foot antenna at the reflector location would be realized. Using about an 8.5-foot (projected diameter) reflector, a maximum gain of about 1.3 db is obtained relative to the 5-foot antenna at the reflector location.

2.07 The required size of a reflector will be determined by the received signal strength requirements for the radio path or system under consideration and reference to the efficiency curves of Figs. 3 or 4 or one of the curves derived from them. For example, if a given radio system is laid out with a satisfactory received signal strength, by assuming the use of a certain size elevated antenna, it is possible to use the efficiency curves to select an antenna-reflector combination which will give equal or better performance.

2.08 For theoretical computations, the shape of the reflectors has been taken to be elliptical. There are some such reflectors available on the market. However, a practical reflector mounted above an antenna would generally be rectangular in shape with one side approximately equal to $\sqrt{2}$ times the other side.

2.09 The focusing effect of the curved reflector periscope system makes it more sensitive to changes in frequency or separation. It will also be more sensitive to wind and ice loading. In general, the curved reflector has lower side-lobe levels and deeper nulls than the flat reflector, which tends to reduce stray radiation and provide greater immunity to interference.

2.10 Figs. 8, 9 and 10 are curves showing antenna-reflector system gain versus antenna-reflector separations for the more generally used sizes of antennas and reflectors. These curves were developed from Figs. 3 and 4. Gain curves for other sizes of antennas and reflectors can be developed relatively easy by the use of Figs. 3 and 4. Fig. 8 gives gain curves for periscope antenna systems at 3950 megacycles while Figs. 9 and 10 give similar curves at 6175 and 11,200 megacycles respectively.

(C) Construction of Reflectors

2.11 The surface of a reflector should be a good electrical conductor, such as aluminum, which is not subject to excessive corrosion. The reflector must be braced at sufficient intervals to maintain a plane surface. Deviations from a plane surface will cause scattering of energy and phase variations in the reflected wave which, in turn, will increase the loss of the reflector system. Practically, the reflector should be built and braced to maintain flatness within 1/8 wave length over its surface.

2.12 Reflectors have been perforated in an effort to reduce wind loading, but icing makes the problems of bracing or stiffening to maintain a flat surface become greater. The icing and stiffening problems are serious even with the maximum permissible perforations (1/8 wave length), and consequently the solid reflector is favored. Experience with solid aluminum reflectors has been quite satisfactory in climates where both wind and icing are moderately severe. Horizontally mounted parabolic antennas used with reflectors must be kept clear of ice and snow. Preferably, an all weather protection cover (radome) should be provided for the antenna. If it is not, drainage holes should be inserted at the lowest point of the antenna and in climates subject to icing, some form of heater should be provided to keep the antenna clear of ice and snow.

2.13 There may be occasions when a reflector is required for a one-time or short-period temporary service. Under such conditions, a temporary reflector may be constructed using an ordinary piece of 3/4-inch marine plywood covered with a suitable conductive covering. Perhaps the most suitable covering is a thin aluminum sheet or foil which may be fastened to the plywood by means of an adhesive such as "Bostitch No. 1021" manufactured by the B. B. Chemical Company, Cambridge, Massachusetts. The adhesive should be applied to both the metal and wood surfaces, allowed to dry about 10 minutes and then pressed together. This treatment will usually cause warping or bending of the plywood, resulting in transmission loss, unless an aluminum sheet is also glued to the opposite face of the plywood. Copper sheet or foil may also be used in place of the aluminum sheet. Next in order of desirability would be painting the plywood with a paint such as Du Pont Silver Paint No. 4817. This is rather expensive and not very durable. The paint will probably peel off after several months exposure. Also, it introduces some attenuation. Finally, copper screen of the household variety could be tacked to the plywood. The screen might also be subject to ratner short life due to deterioration at the crossover points in the screen. If left exposed to the weather over long periods it should be inspected at frequent intervals to detect any harmful deterioration. Mounting details for such a reflector will probably be the prime difficulty.

(D) Orientation

2.14 The problem of orienting an antenna-reflector system is the same as that of orienting an antenna in that the object is to adjust for maximum received signal. However, the complexity of orienting the reflector system is somewhat greater than orienting an antenna. An antenna will receive maximum signal when the plane of the face of the antenna is oriented perpendicular to the main transmission path. Maximum signal from a reflector system, with the antenna directly under the reflector and in line with the main beam, will be obtained when the reflector surface is perpendicular to a line bisecting the angle formed by the intersection of the main transmission path and the path from the reflector to the antenna, and when at the same time the plane of the face of the antenna is oriented perpendicular to the path from reflector to antenna.

2.15 The procedure for orienting periscope antenna systems is much the same as for orienting antennas, that is, first set the reflectors and antennas on their approximate bearings. A method for determining the proper bearings for the reflector will be discussed later. The antenna should be located so that the plane of its face is perpendicular to the path from the reflector to the antenna.

2.16 A relatively simple method of aiming the antenna is by visual means using an L-shaped, 24-inch carpenter's square. Place the long side (24-inch) of the square under the rim of the antenna. Sight up along the short side of the square toward the reflector and swing the square so that the short side scribes an arc across the reflector. Adjust the antenna until this arc cuts through the center of the reflector. Then move the square 90 degrees around the antenna and repeat the procedure outlined above. With this completed, the antenna should be pointed directly at the center of the reflector.

2.17 The azimuth and elevation angles of a reflector and the necessary change in the polarization angle of its associated antenna may be found using the curves shown in Figs. 11, 12 and 13. These curves were derived directly as a function of the ground position of the antenna. They are plotted for a horizontal beam and various antenna positions in increments of one-tenth the tower height out to a radius from the tower base equal to the tower height.

2.18 Fig. 11 gives the elevation angle (e) of the reflector as a function of the radial distance of the antenna from the tower base, expressed as a decimal fraction of tower height, and of the angular displacement (δ) of the antenna from the path of the beam. The elevation angle (e) is measured from the horizontal. It can be converted to a measurement from the vertical simply by subtracting from 90 degrees.

2.19 Fig. 12 gives the azimuth angle (θ) through which the reflector must be swung for the same conditions as listed above in Paragraph 2.18. This is the angle between the path and the projection in the horizontal plane of the normal (perpendicular) to the reflector surface. In typical cases, this is considerably less than half the angular displacement of the antenna.

2.20 Fig. 13 gives the change in polarization ($\Delta\phi$) for the same conditions. These curves are set up so that if the incident wave is vertically polarized, the curves give the angle of polarization directly as measured with respect to the vertical plane and looking along the beam towards the reflector. For quadrants A and B, as shown in sketch in Fig. 13, negative angles are counterclockwise. For quadrants C and D, negative angles are clockwise. For waves polarized at other angles, the resultant angle of polarization after reflection is that given by the curves in Fig. 13 changed by the same amount and in the same sense as the amount the incident wave differed from the vertical, looking towards the reflector in both cases.

2.21 An example, as follows, may help to illustrate the use of Figs. 11, 12 and 13. In this example (see Fig. 14) let:

- q = Distance in feet of the dish, from the tower base, along the microwave path.
- p = Distance in feet of the dish, from the tower base, at right angles to the path.
- r = Distance in feet of the dish radial from the tower base.
- h = Tower height in feet.
- k = Radial distance of dish as a decimal fraction of the tower height.
- δ = Angle of dish from path in degrees.
- e = Elevation angle of reflector in degrees measured from the horizontal
- θ = Azimuth angle of swing of the reflector from the path in degrees.
- $\Delta\phi$ = Change in polarization angle at the dish as a function of its ground position.

Assume that q = 40 feet, h = 200 feet, p = 69 feet, and the dish is located in quadrant "A". Also, the incoming beam is vertically polarized.

2.22 The necessary calculations that must be made to use Figs. 11, 12 and 13 are as follows:

$$\tan\delta = p/q = 69/40 = 1.725$$
$$\delta = 60^\circ$$
$$r = q/\cos\delta = 40/\cos 60^\circ = 40/0.5 = 80 \text{ feet}$$
$$k = r/h = 80/200 = 0.4$$

Then, to get the elevation angle of the reflector (e), enter Fig. 11 at k = 0.4 and read b′ = 53.2° off the δ = 60° curve. To get the azimuth swing angle of the reflector (θ), enter Fig. 12 at k = 0.4 and read θ = 15.4° off the δ = 60° curve. The change in polarization angle ($\Delta\phi$) may be found by entering Fig. 13 at k = 0.4 and read $\Delta\phi$ = −42° off the δ = 60° curve (this is counterclockwise with respect to the vertical plane, looking along the beam toward the reflector).

2.23 If all conditions are the same as in the foregoing example except the polarization of the incoming beam is 30° clockwise from the vertical (looking toward the reflector), the change in polarization at the dish ($\Delta\phi$) will be −42° + 30° = −12°.

2.24 This is equivalent to starting at a reference point of +30° and backing off −42°. The thing to note here is that while $\Delta\phi$ is negative, the sense of change with positive change in polarization is also positive, looking toward the reflector in both cases.

2.25 If the values calculated for k and δ in any specific case do not fall on the curves given in Figs. 11, 12 and 13, the required values of θ, e, and $\Delta\phi$ may be found by interpolation between the curves with reasonable accuracy. However, if greater accuracy is desired, formulas for calculating azimuth, elevation and polarization angles are given below.

2.26 The formulas given here are based on the nomenclature for angles and distances as shown in Fig. 15. The BCA portion of Fig. 15 is a segment of a sphere whose center is at the reflector (at P) above the tower base and is formed by three planes. The incoming and reflected beams determine one plane that cuts the sphere at a compound angle (BPA plane). Another is determined by a vertical plane through the incoming beam (YOZ plane). The third is determined by a vertical plane through the reflector and the antenna (POQ plane). The nomenclature used here is the same as that used in Paragraph 2.21 for Fig. 14, plus the following:

a = Angle the incoming beam makes with the vertical line PO. For a horizontal incoming beam, a is equal to 90 degrees.

b = Angle the reflected beam makes with the vertical line PO.

c = Angle between the incoming and reflected beams.

α = Angle between the BPA plane and the POQ plane.

β = Angle between the BPA plane and the YOZ plane.

Distances p, q and h and angle a are known. The distance r and the angles δ and b can be calculated as follows:

$$r = \sqrt{p^2 + q^2}$$

$$\tan \delta = p/q$$

$$\tan b = r/h$$

Then, from spherical trigonometry, the following formulas can be derived.

$$\cos c = \cos a \cos b + \sin a \sin b \cos \delta$$

$$\sin \alpha = \frac{\sin a \sin \delta}{\sin c}$$

$$\cos \alpha = \frac{\cos a - \cos b \cos c}{\sin b \sin c}$$

(This formula is used to determine the sign of α)

$$\cos e = \cos c/2 \cos a + \sin c/2 \sin a \cos \beta$$

(This formula gives the angle of tilt of the reflector plane from the horizontal.)

$$\sin \theta = \frac{\sin c/2 \sin \beta}{\sin e}$$

(This formula gives the azimuth swing of the reflector.)

$$\Delta\phi = \alpha + \beta$$

(This formula gives the polarization change. Observe the sign of $\Delta\phi$, and if it is negative, the feed horn should be rotated counterclockwise looking toward the reflector from the antenna.)

2.27 **The following list is the recommended sequence of steps to take when calculating the azimuth, elevation, and the change in polarization angles necessary for an antenna-reflector combination.**

(1) Calculate the distance r.

(2) Calculate the angle δ. Look up sin δ and cos δ. Take sin δ as positive and cos δ as positive if the antenna is in front of the reflector (looking along the incoming beam), otherwise cos δ should be negative.

(3) Look up sin and cos of the angle a. Take sin a as positive and cos a as negative if the incoming beam is above horizontal, otherwise take cos a as positive. (For a horizontal incoming beam, cos a is zero.)

(4) Calculate the angle b. Look up sin b (positive) and cos b (positive if reflector is above the antenna).

(5) Calculate cos c and observe sign. Look up the angle c, sin c (positive), sin c/2 and cos c/2 (both positive).

(6) Calculate sin β (positive). Look up the angle β and cos β (positive if reflector is above the antenna).

(7) Calculate sin α. Look up the angle α.

(8) Calculate cos α to determine the sign of the angle α.

(9) Calculate cos e and look up the angle e. This is the angle of elevation of the reflector as measured from the horizontal and will always turn out positive for practical cases even though cos a may be negative. Look up sin e (positive).

(10) Calculate sin θ and look up the angle θ (positive). This is the angle of azimuth swing of the reflector as measured from the projected path in the horizontal plane.

(11) Calculate the angle $\Delta\phi$ and observe the sign. This is the change in polarization of the reflected beam. A negative angle means a counterclockwise rotation of the antenna feed looking from the antenna to the reflector.

3. PASSIVE REPEATERS

(A) General

3.01 The preceding part of this practice has described periscope antenna systems where a reflector is used with an antenna a short distance away. However, there are certain other arrangements using reflectors and antennas that may be practical and useful on occasion. These are known as passive repeaters.

3.02 A passive repeater is any microwave radio station that has no active (powered) elements associated with it, and is used to redirect a microwave beam around, or over, some obstruction in a radio path. This includes the use of a reflector (or combination of reflectors) or two antennas tied back-to-back with waveguide. The use of reflectors will probably be more common.

3.03 The generally accepted separation between an antenna and reflector where the reflector ceases to be a part of a periscope antenna arrangement and becomes a passive repeater is where the reflector passes from the near field of the antenna to its far field. This point may be approximated by:

$$d = \frac{2B^2}{\lambda}$$

where: d = distance in feet.

B = largest linear dimension of the antenna or projected dimension of the reflector in feet.

λ = wave length of frequency used in feet.

3.04 Due to the nature of passive repeaters, there is considerable attenuation in a microwave path in addition to the attenuation in the same path without a passive repeater. Only the amount of energy falling on the passive repeater is available for retransmission. A reflector, for all practical purposes, is 100 per cent efficient and, generally, no loss is introduced due to inefficiency. An antenna, however, is not 100 per cent efficiency and additional loss is added to the path by its use.

3.05 When a passive repeater is used in a radio path, the loss in each section of the path can be calculated. That is, the loss can be calculated for the section between the transmitter and the passive repeater plus the loss for the section between the passive repeater and the receiver. The loss in each section, including the transmitting or receiving antenna, is given by:

$$\text{Loss in db} = 10 \log \frac{\lambda^2 D^2}{A_1 A_2}$$

where: λ = wave length of frequency used in feet.

D = separation between transmitting or receiving antenna and passive repeater in feet.

A_1 and A_2 = effective area of transmitting or receiving antenna and passive repeater in square feet. Effective area is equal to actual area times its efficiency.

3.06 Efficiency values for antennas and reflectors normally used are as follows:

TYPE OF ANTENNA	AVERAGE EFFICIENCY IN PER CENT
Flat Reflector	100
Parabolic Dish	57
Delay Lens	45
Horn Reflector	68

(B) Received Signal Strength Calculations

3.07 The received signal that can be expected in any microwave path that includes a passive repeater may be calculated in a number of different ways. However, two methods that will prove adequate for nearly all conditions are given here. The first method, which will probably be used for most cases, is to find all the losses and all the gains in the path and add them together. The second method uses the equation given in Paragraph 3.05 from which the loss in each section of the path may be calculated. This method is given, primarily, for those cases where the actual gain of antennas used is not known or readily available.

3.08 The first method of calculating the normal received signal strength in a radio path that has a passive repeater in it is to use what is defined here as the straight line method. This method is where all the individual losses and all the individual gains in the path are found and added together.

3.09 The normal losses and gains found in a radio path are:

Losses

(a) Free space path loss between the transmitting antenna and the passive repeater.

(b) Free space path loss between the passive repeater and the receiving antenna.

(c) Transmitting and receiving waveguide losses.

(d) Transmitting and receiving waveguide component losses.

Gains

(a) Transmitter power output.

(b) Transmitting antenna gain.

(c) Passive repeater gain.

(d) Receiving antenna gain.

The free space path losses and the passive repeater gain may be obtained by using Figs. 16 and 17 respectively. Antenna gains and waveguide and waveguide component losses may be found in appropriate Bell System Practices or related information from Independent Manufacturers.

3.10 An example showing the use of the straight line method is as follows. Assume that a TL radio path is 15 miles long. A reflector with 200 square feet of projected area is located 1 mile from one end of the path. The radio frequency used is 11,200 megacycles. The transmitter power output is 1/10 watt. Ten-foot parabolic antennas with 25 feet of waveguide are used at each end of the radio path. Then:

D_1 = Loss in 14-mile path (Fig. 16) = 140.5 db

D_2 = Loss in 1-mile path (Fig. 16) = 117.5 db

A_1 = Transmitting antenna gain = 48.0 db

A_2 = Passive reflector gain (Fig. 17) = 110.2 db

A_3 = Receiving antenna gain = 48.0 db

W = Waveguide losses = 2.0 db

WC = Waveguide component losses = 4.0 db

P_t = Transmitter power output = 20.0 dbm

Total gains $= P_t + A_1 + A_2 + A_3$
$= 20.0 + 48.0 + 110.2 + 48.0$
$= 226.2$ db

Total losses $= D_1 + D_2 + W + WC$
$= 140.5 + 117.5 + 2.0 + 4.0$
$= 264.0$ db

Received Signal $= 226.2 - 264.0 = -37.8$ dbm

3.11 Fig. 18 is given as an added aid in using the straight line method for calculating received signal strength. These curves give the path attenuation in db between isotropic radiators including various sizes of reflectors that are used as passive repeaters in the path. It should be noted that the formula (shown in Fig. 18) derived for these curves is not dependent on frequency. Therefore, they can be used for any frequency. Any reading taken from these curves includes the free space path loss for both sections of the path plus the passive repeater "gain". Then, by adding the transmitting and receiving antenna gains, the filter and waveguide losses, and the transmitter power output; the received signal strength is obtained.

3.12 There is a practical limit to the size of reflectors that may be mounted on a tower. It would be extremely difficult to mount and maintain stability of a large size (say 10′ by 20′ or larger) reflector. As the distance between a passive repeater and its nearest terminal increases, the size of the reflector must increase to maintain a given received signal strength. Therefore, in general, the use of passive repeaters will probably be limited to a distance of 1 to 2 miles from one end of a radio path and located so that they may be mounted on the ground.

3.13 When the angle between the incident and reflected rays (ϕ) from a passive repeater becomes large, the size of a single reflector may become prohibitively large in order to maintain a desired signal level. If this occurs, two smaller reflectors in place of one large one may become attractive both from a mounting and transmission standpoint. Figs. 19(a) and 19(b) illustrate the type of physical layouts that can be used with two reflectors.

3.14 Fig. 19(a) shows a microwave radio path using two reflectors as a passive repeater to redirect a radio beam where the angle between the incident and reflected beams is large. The methods used to calculate the received signal for paths using one reflector may also be used in this case by adding an additional loss for the transfer losses incurred due to the separation (h) between the reflectors. Fig. 20 gives curves showing the additional loss due to the transfer of energy between reflectors. These curves assume that the projected width of each reflector in its respective line of propagation is the same. For those values of 2h/d not covered by the curves, 0.8 db may be used as the minimum loss.

3.15 There are some geometrical considerations of the two reflector arrangement which leads to designs having the least reflector surface and least separation between the reflectors. Fig. 19(b) gives an expanded view of the two reflector arrangement in Fig. 19(a). Definitions of the nomenclature used in Fig. 19(b) are as follows:

- d = projected length of each reflector (taken to be equal).
- α = the transfer angle (angle between incoming and outgoing beams subtracted from 180°).
- ℓ_1, ℓ_2 = the actual length of each reflector.
- θ = the angle of incidence at the first reflector.
- h = the reflectors separation, measured between their centers.
- L = the length of a single reflector equivalent to the double reflector system.

3.16 It is assumed that α and d are given. Then the variation of $\ell_1 + \ell_2$ and h with θ can be studied. The method of design chosen here should be such that the two reflectors are as close together as possible, that is, the line (AB) joining the inner ends of the reflectors in Fig. 19(b) makes an angle α with the incident ray.

3.17 Given d and α, the variation of total reflector length ($\ell_1 + \ell_2$) with θ is shown in Fig. 21, together with the length (L) of a single reflector for comparison. The values of θ for which $\ell_1 + \ell_2$ is less than L can be obtained by inspection from these curves. For example, if $\alpha = 40°$, $\ell_1 + \ell_2$ is less than L when θ is equal to or less than 55°.

3.18 Fig. 22 shows the variation of the reflector separation, h, with θ and α. For a given α it will be noted that there corresponds a value of θ for which h is a minimum.

3.19 These curves are useful in choosing θ for a particular location. The actual layout can then be accomplished with the help of the following relations:

$$\ell_1 = \frac{d}{\cos\theta}$$

$$\ell_2 = \frac{d}{\cos\left(\theta - \frac{\alpha}{2}\right)} \leq \ell_1$$

$$h = \frac{d}{2}\left(\frac{\cos\alpha + \tan\theta\sin\alpha + 1}{\sin(2\theta - \alpha)}\right)$$

3.20 The angle between the two reflectors in Fig. 19(b) is 1/2 α. The normal at C to reflector ℓ_2 passes through the point B on reflector ℓ_1.

3.21 All the information given on passive repeaters here has been in connection with reflectors. As stated previously, however, antennas tied together with waveguide may be used as passive repeaters [Fig. 19(c)]. Methods of calculation for the received signal used previously for reflectors may also be used for antennas. However, since the size of available antennas is limited and they are not as efficient as reflectors, the use of antennas will probably be limited to a small percentage of cases where passive repeaters are involved.

4. FIGURES

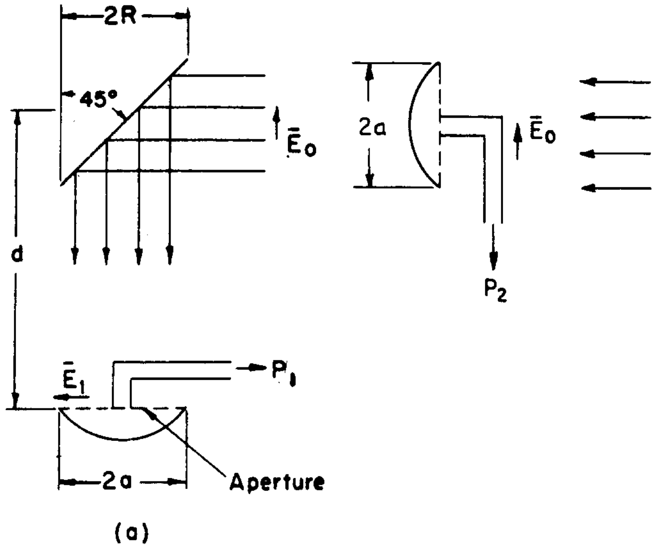
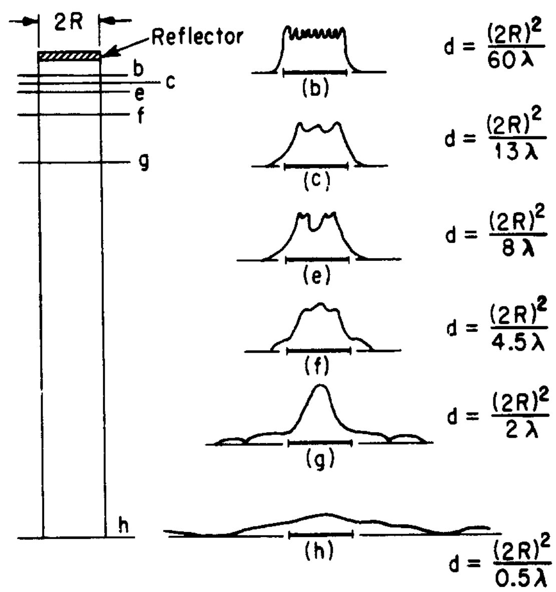


FIG. 1



CROSS SECTIONS OF
FIELD INTENSITY BENEATH A REFLECTOR

FIG. 2

Fig. 1 – Periscope Antenna System Compared With Separate Antenna System

Fig. 2 – Cross Sections of Field Intensity Beneath a Reflector

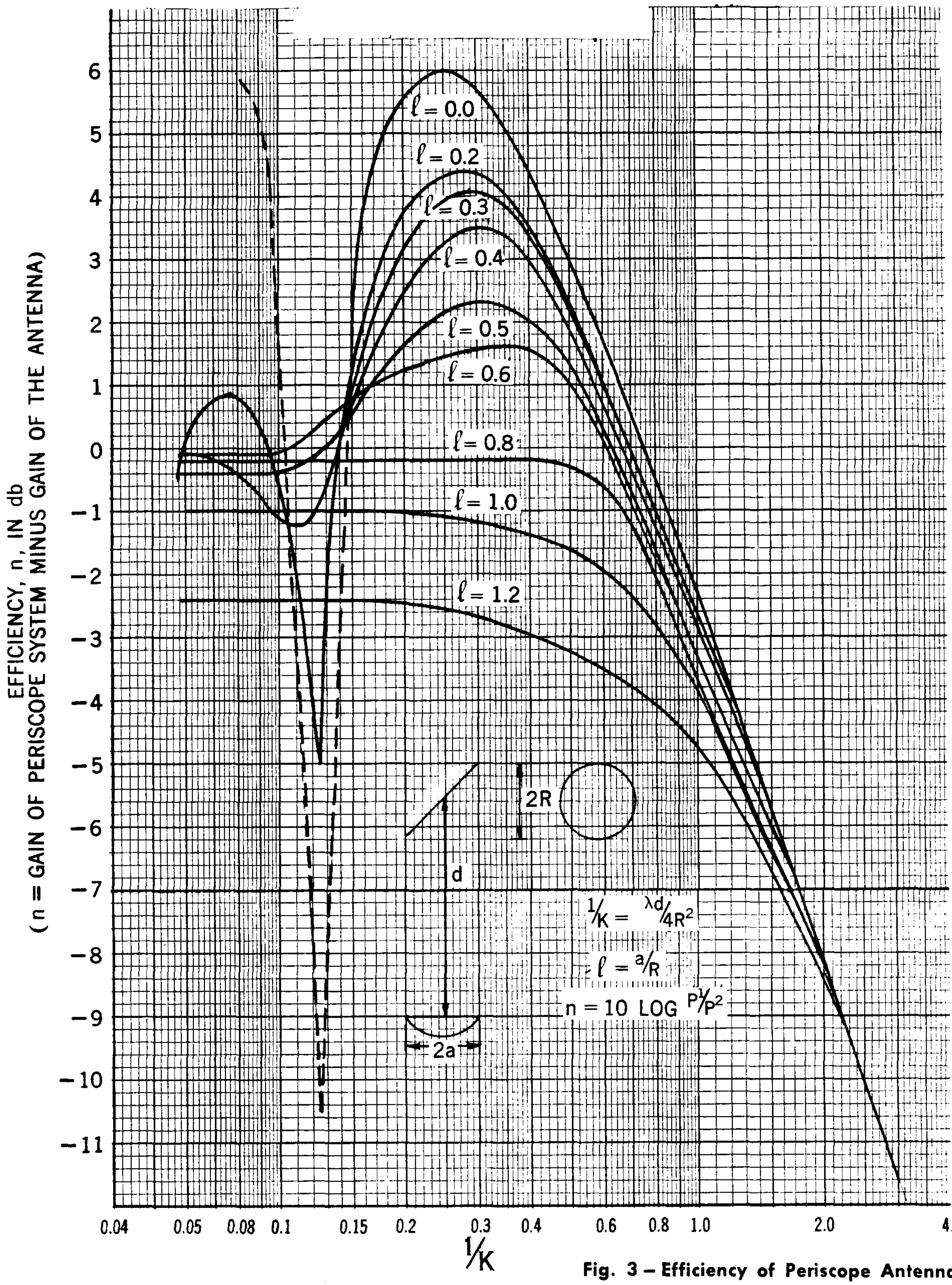


Fig. 3 – Efficiency of Periscope Antenna System Employing Plane (Flat) Reflector

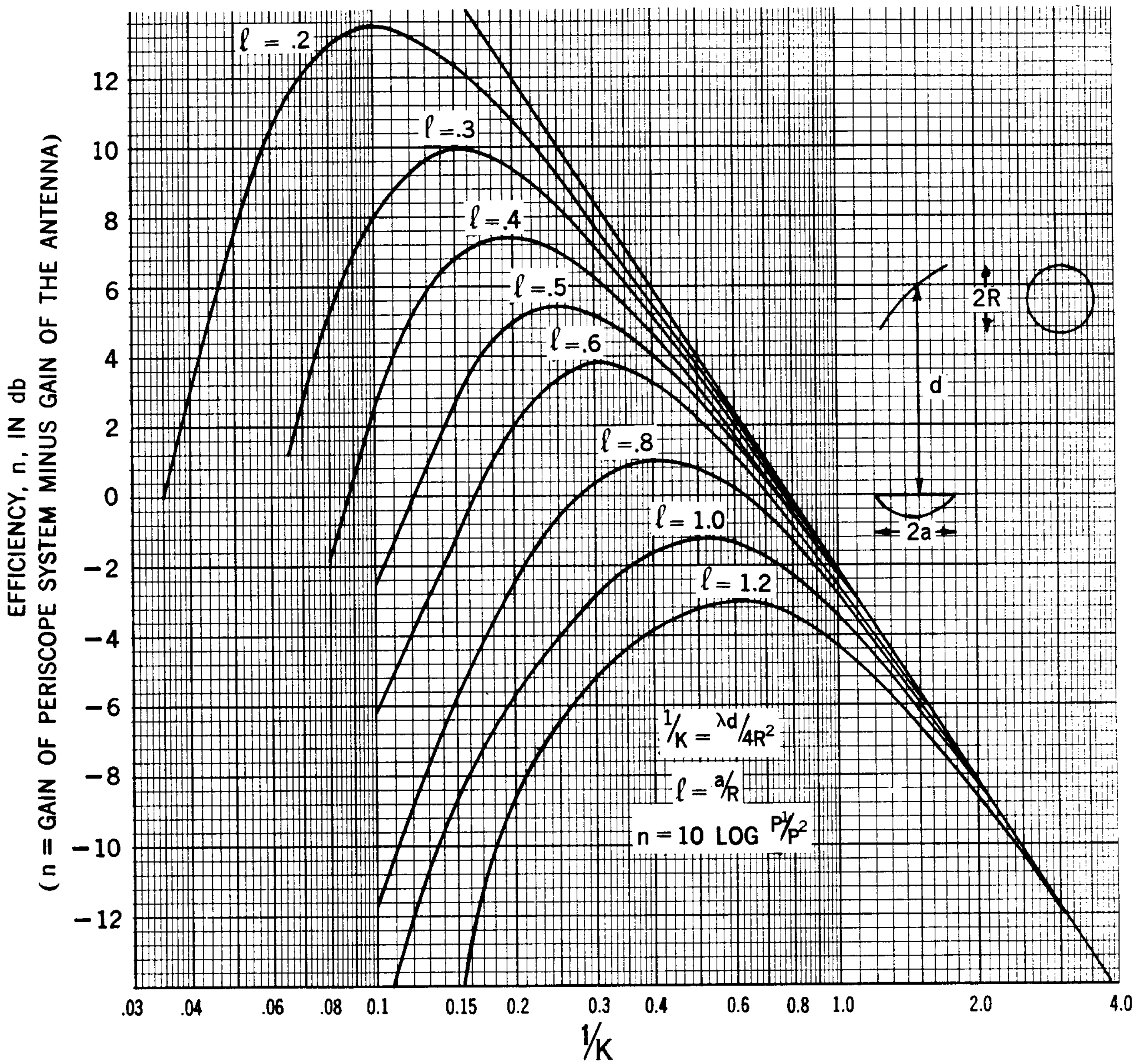


Fig. 4 – Efficiency of Periscope Antenna System Employing Curved Reflector

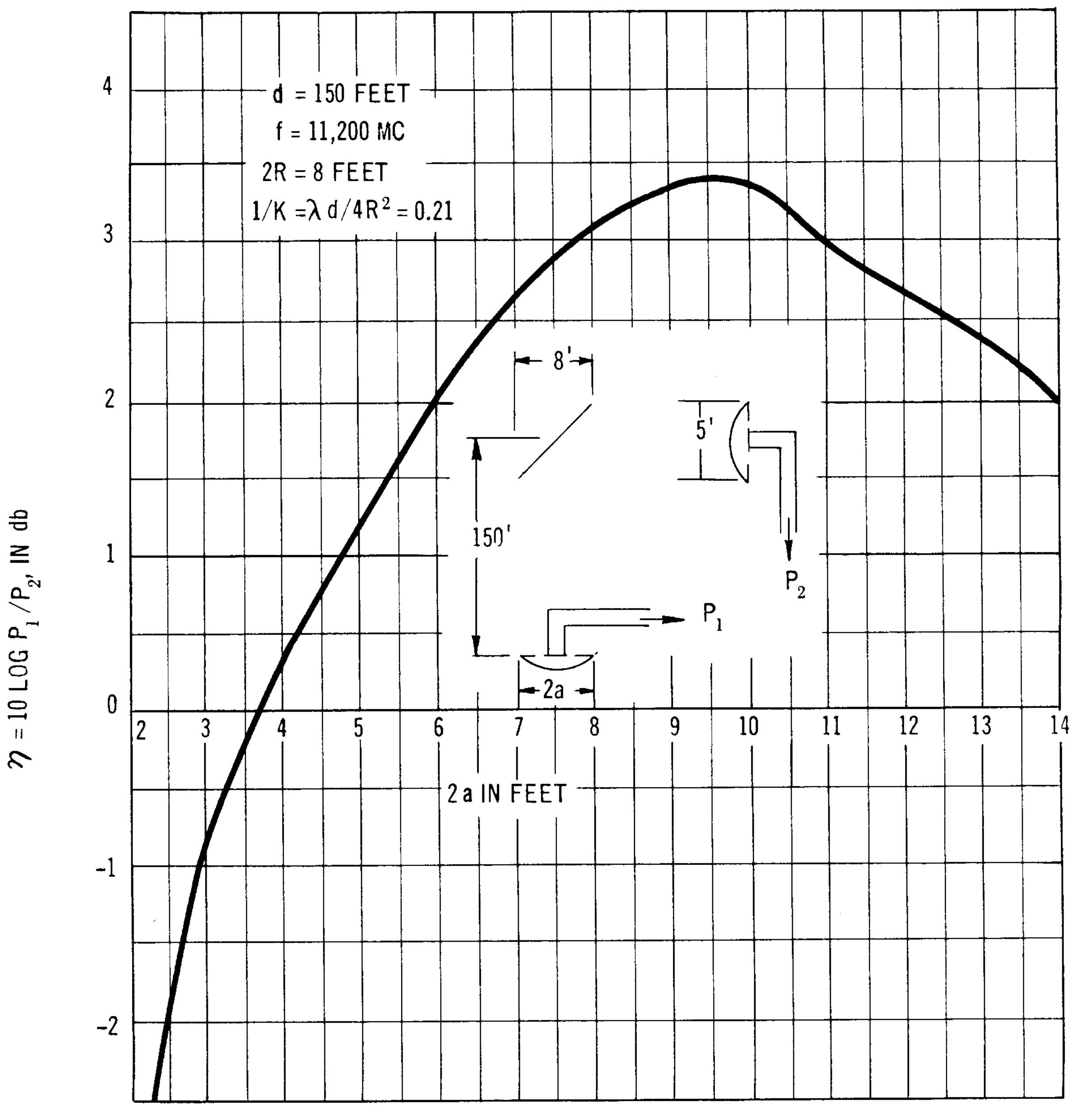


Fig. 5 – Antenna-Reflector Efficiency v. Antenna Size Compared to 5-Foot Antenna at Top of Tower in Place of Reflector

ANTENNA-REFLECTOR EFFICIENCY VS. SEPARATION (D)

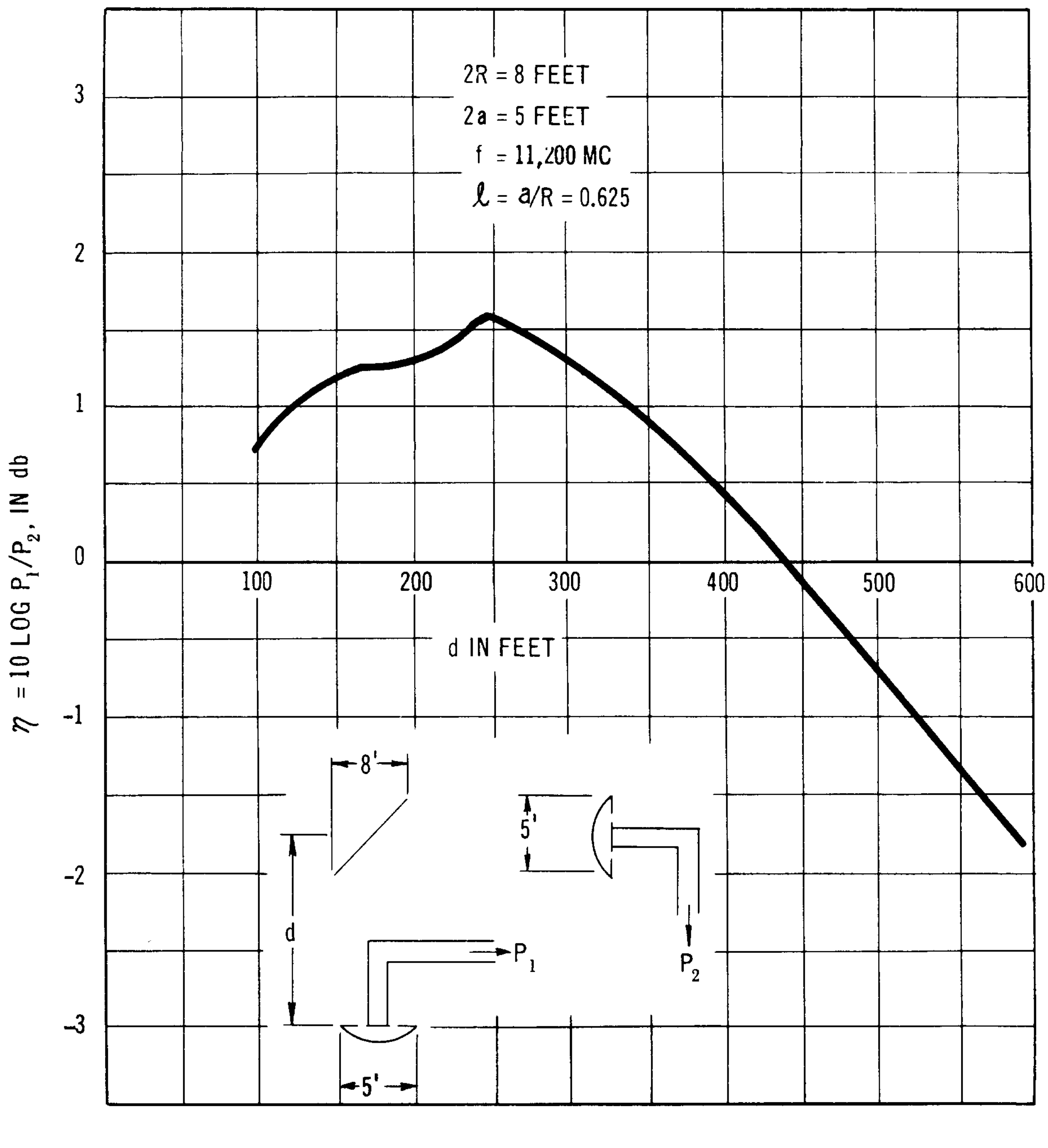


Fig. 6 — Antenna-Reflector Efficiency v. Separation (D)

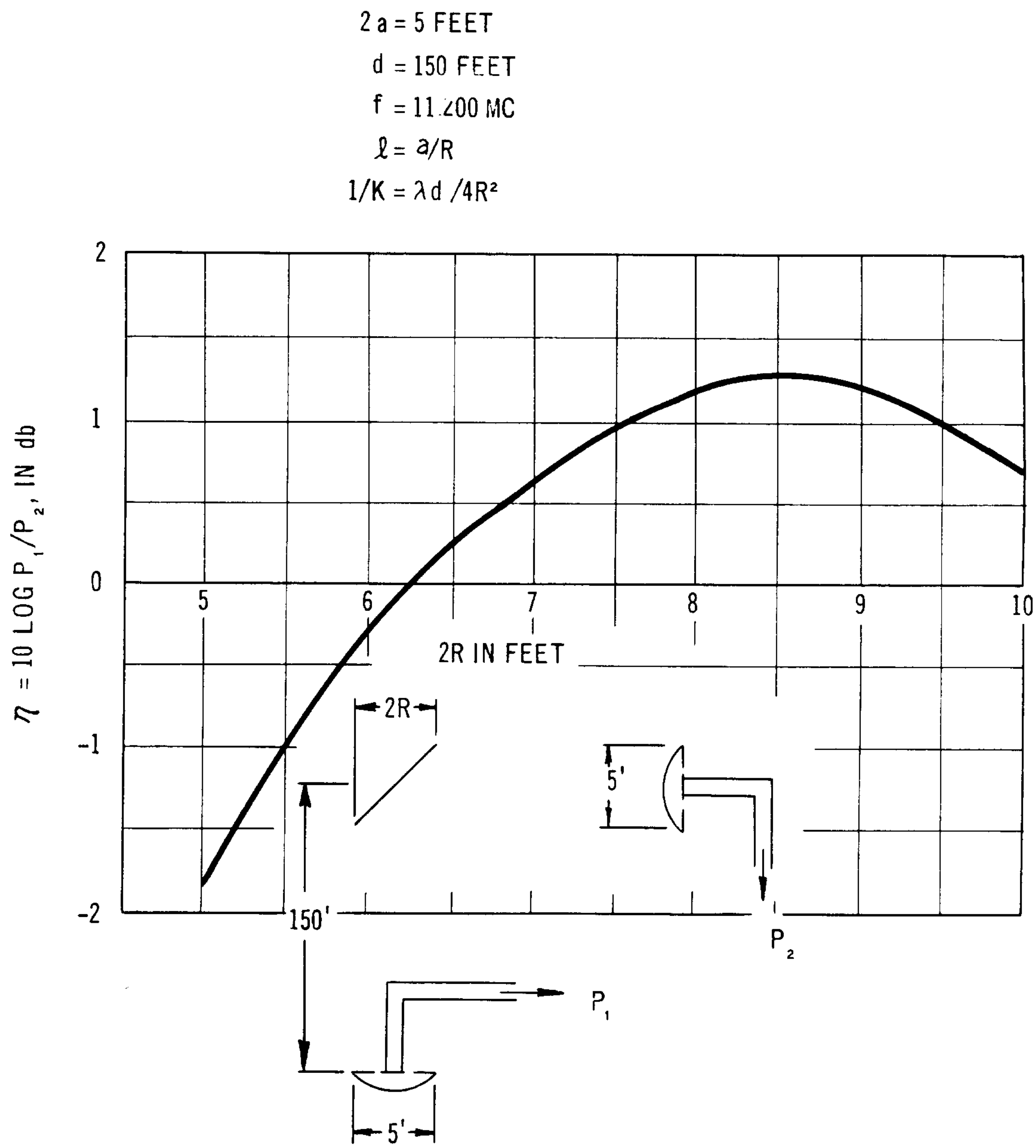


Fig. 7 – Antenna-Reflector Efficiency v. Reflector Size

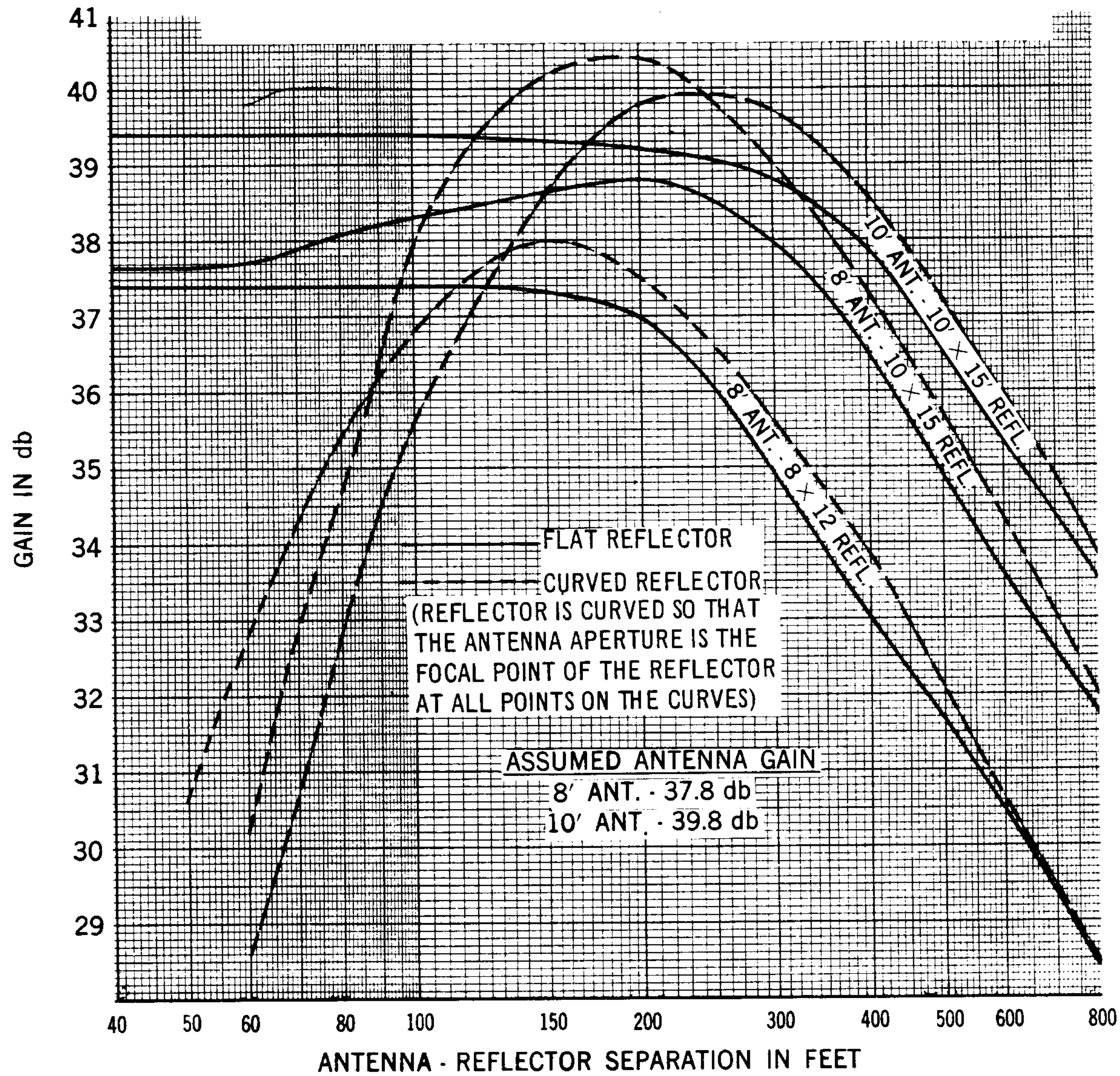


Fig. 8 — Antenna-Reflector Combinations Theoretical Gain Over an Isotropic Antenna at 3950 Mc

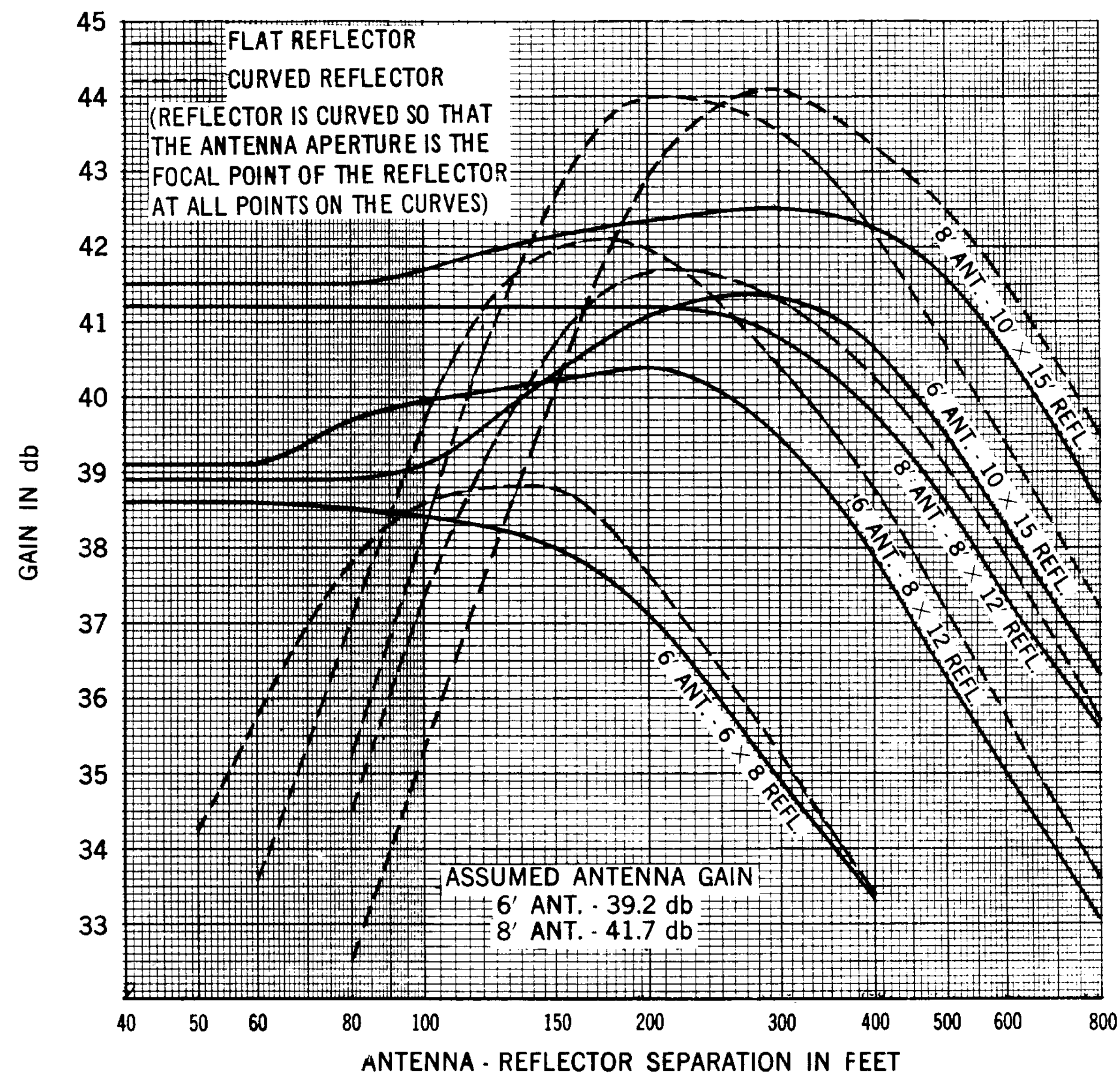


Fig. 9 — Antenna-Reflector Combinations Theoretical Gain Over an Isotropic Antenna at 6175 Mc

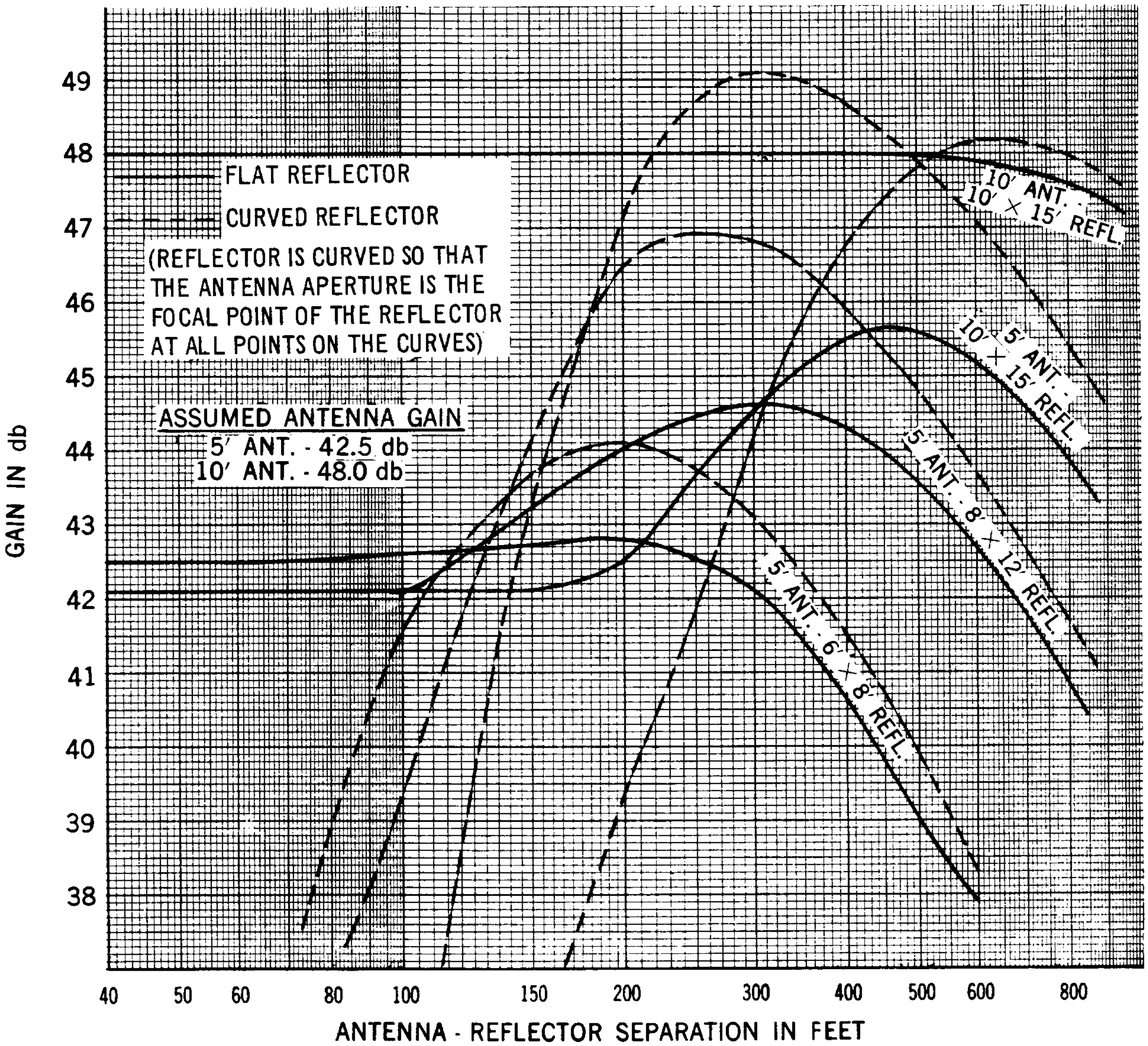


Fig. 10 – Antenna-Reflector Combinations Theoretical Gain Over an Isotropic Antenna at 11,200 Mc

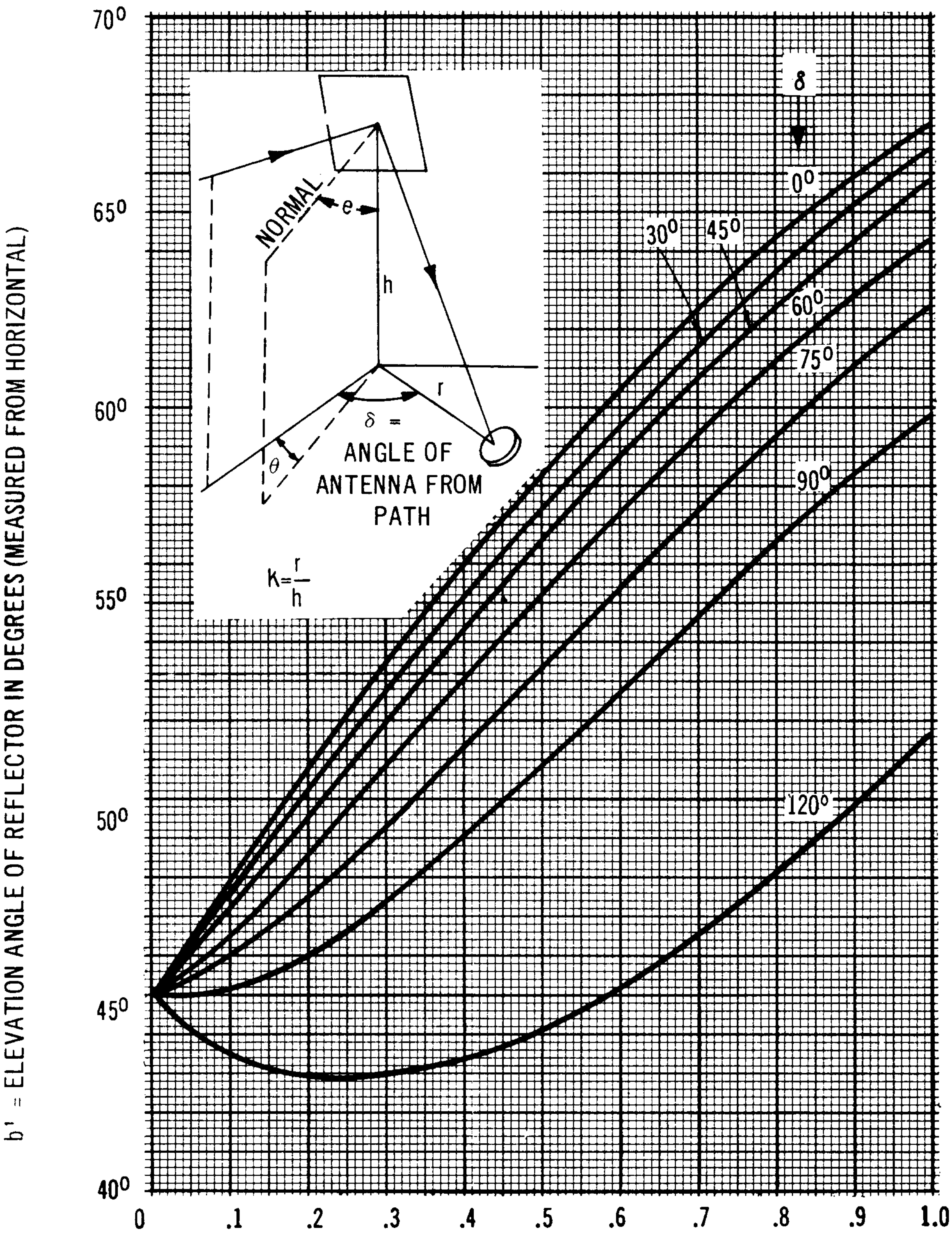


Fig. 11 – Reflector Elevation Angle v. Antenna Ground Position (Horizontal Incoming Beam)

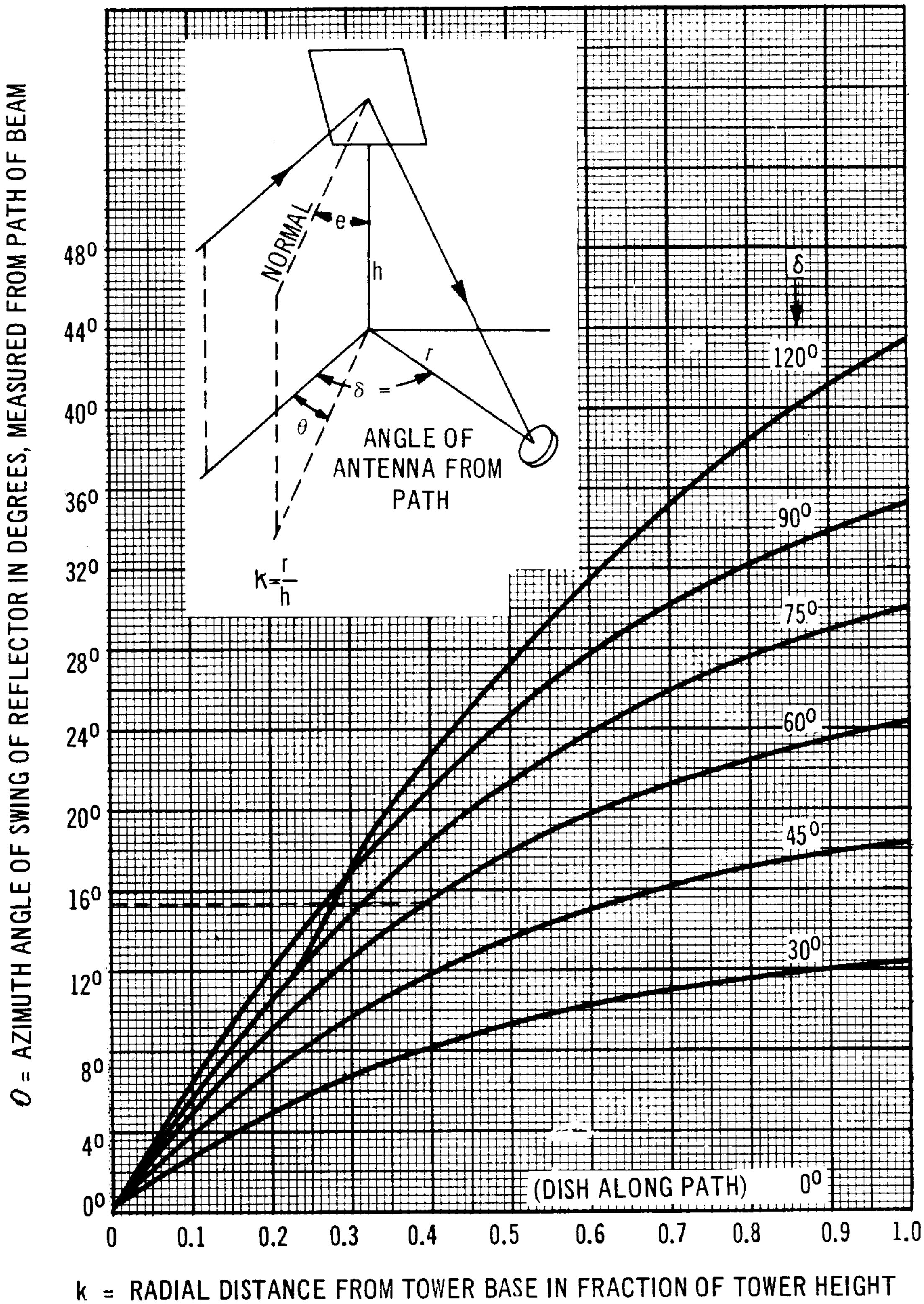
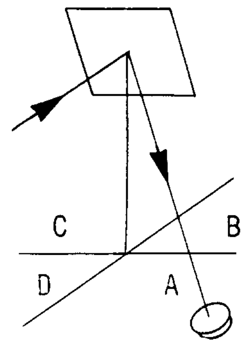


Fig. 12 – Reflector Azimuth Angle v. Antenna Ground Position (Horizontal Incoming Beam)

CONVENTION: FOR QUADRANTS A & B, NEGATIVE ANGLES ARE COUNTER CLOCKWISE, LOOKING TOWARDS REFLECTOR ALONG THE BEAM. ANGLES MEASURED WITH RESPECT TO THE VERTICAL PLANE. FOR QUADRANTS C & D NEGATIVE ANGLES ARE CLOCKWISE.



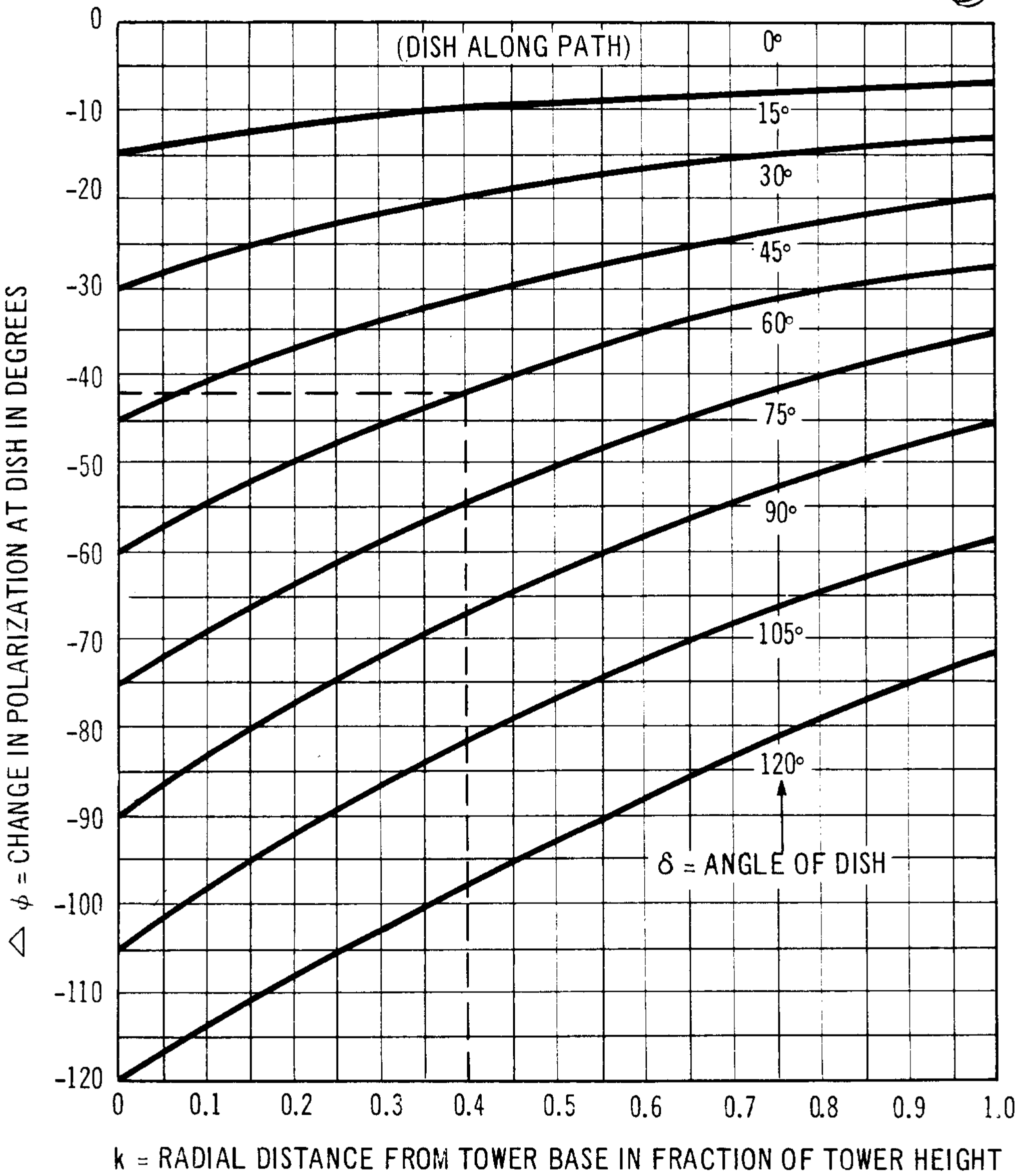
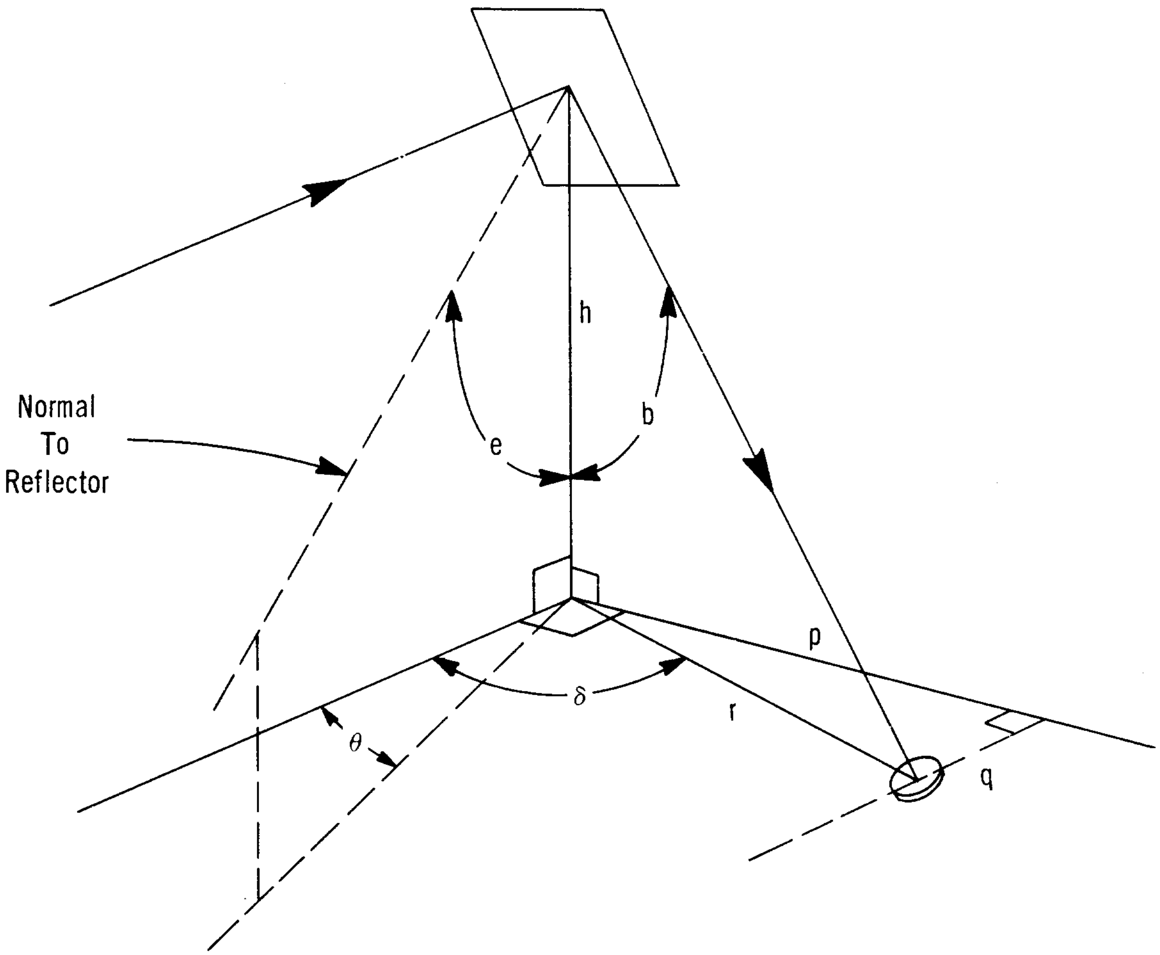


Fig. 13 – Change in Polarization Angle v. Antenna Ground Position (Horizontal Incoming Beam)

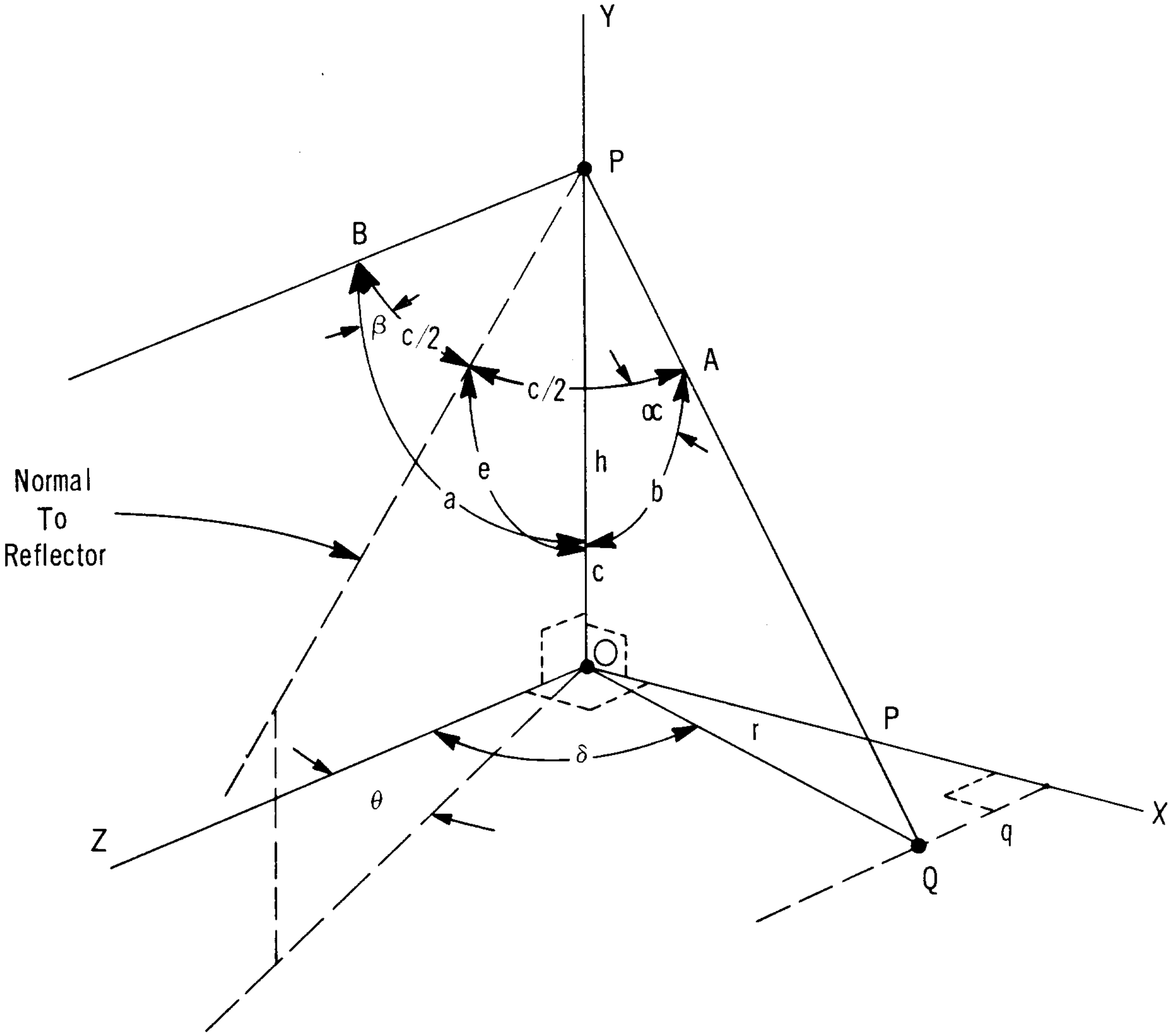


$$r = \sqrt{p^2 + q^2}$$

$$\text{Tan } \delta = \frac{p}{q}$$

$$\text{Tan } b = \frac{r}{h}$$

Fig. 14 – Periscope Antenna System With Antenna Offset From Base of Tower — Physical Layout



From Spherical Trigonometry:

$$\cos c = \cos a \cos b + \sin a \sin b \cos \delta$$

$$\sin \propto = \frac{\sin a \sin \delta}{\sin c}$$

$$\cos \propto = \frac{\cos a - \cos b \cos c}{\sin b \sin c}$$ (used to determine Sign of ∝)

$$\cos e = \cos\frac{c}{2} \cos a + \sin\frac{c}{2} \sin a \cos \beta$$ (used to determine angle of tilt of reflector plane from horizontal)

$$\sin \theta = \frac{\sin\frac{c}{2} \sin \beta}{\sin e}$$ (used to determine Azimuth Setting)

$$\Delta \Phi = \propto + \beta$$ (polarization change)

Fig. 15 – Periscope Antenna System With Antenna Offset From Base of Tower — Geometric Layout

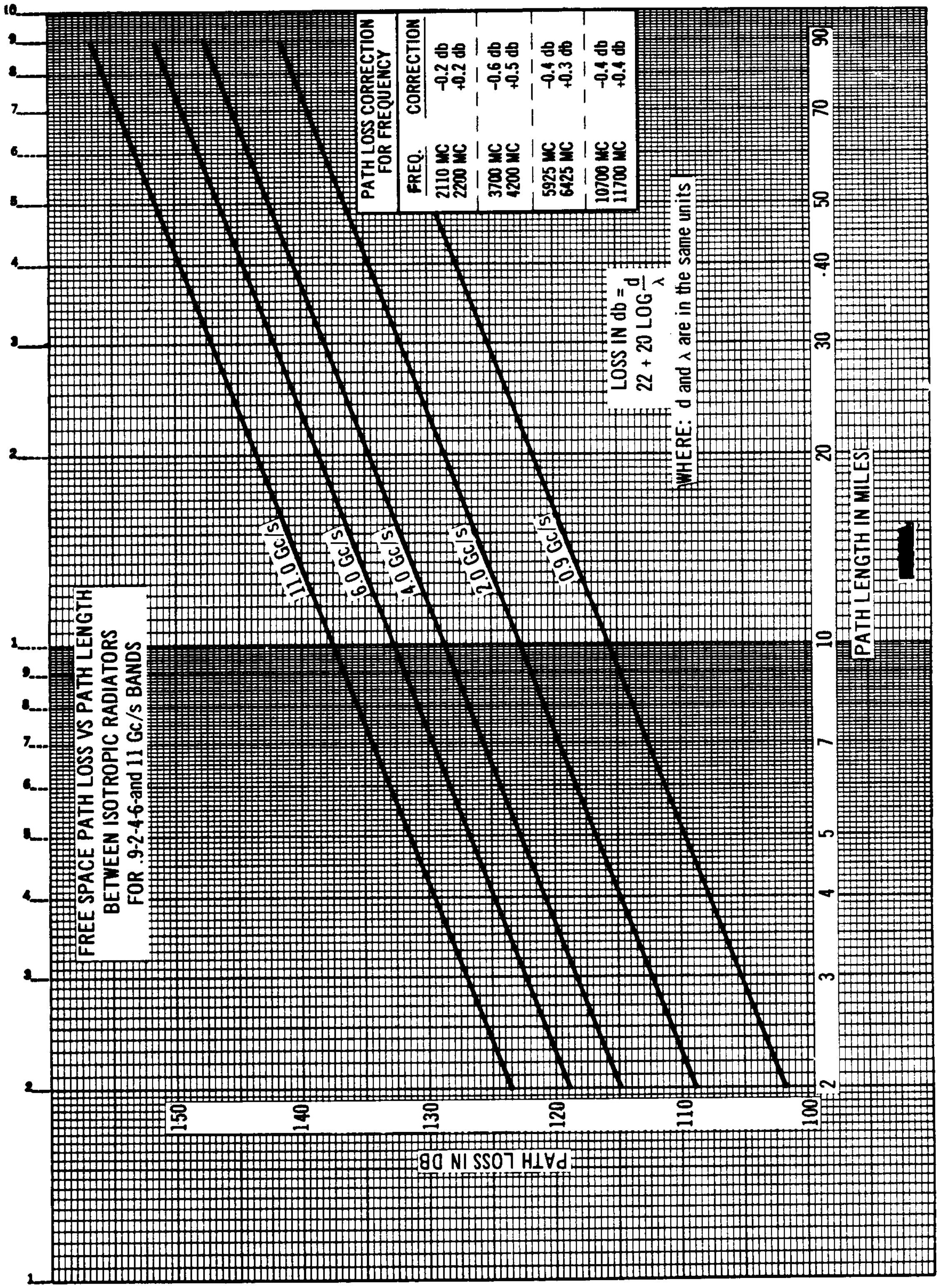


Fig. 16 – Free Space Path Loss Between Isotropic Radiators

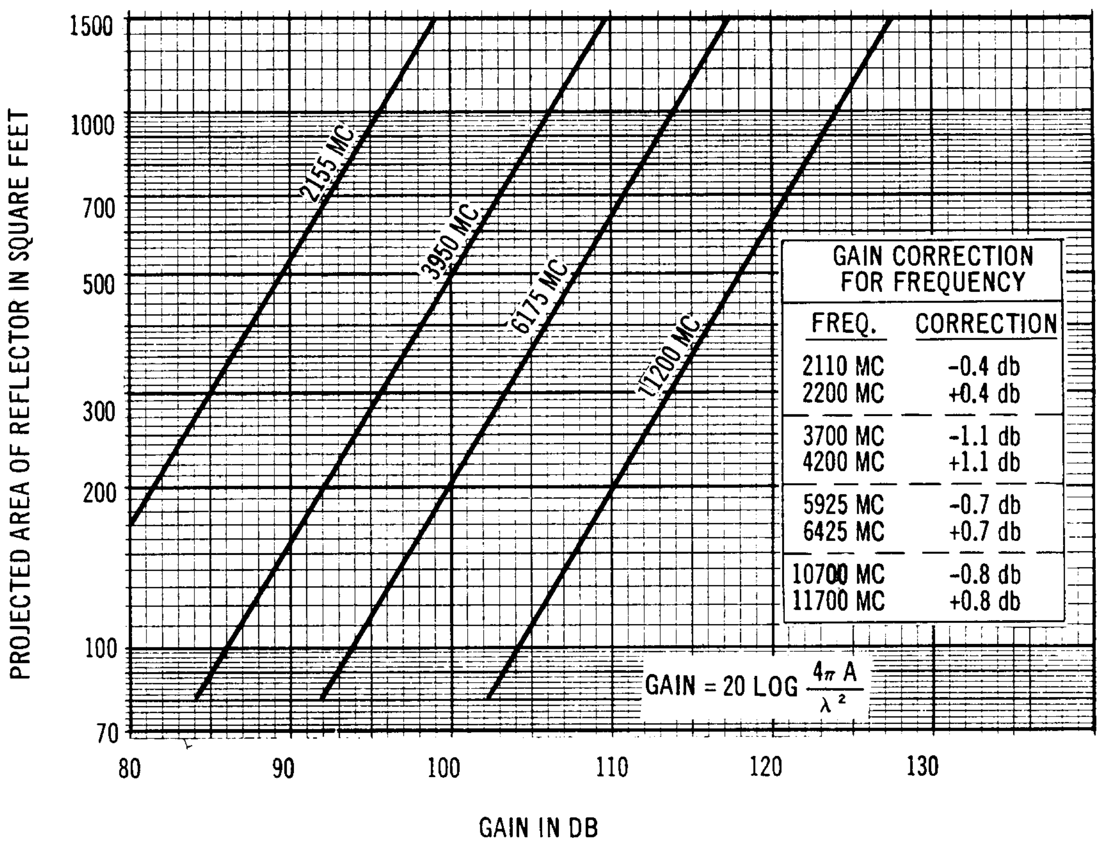


Fig. 17 – Reflector Gain v. Projected Area

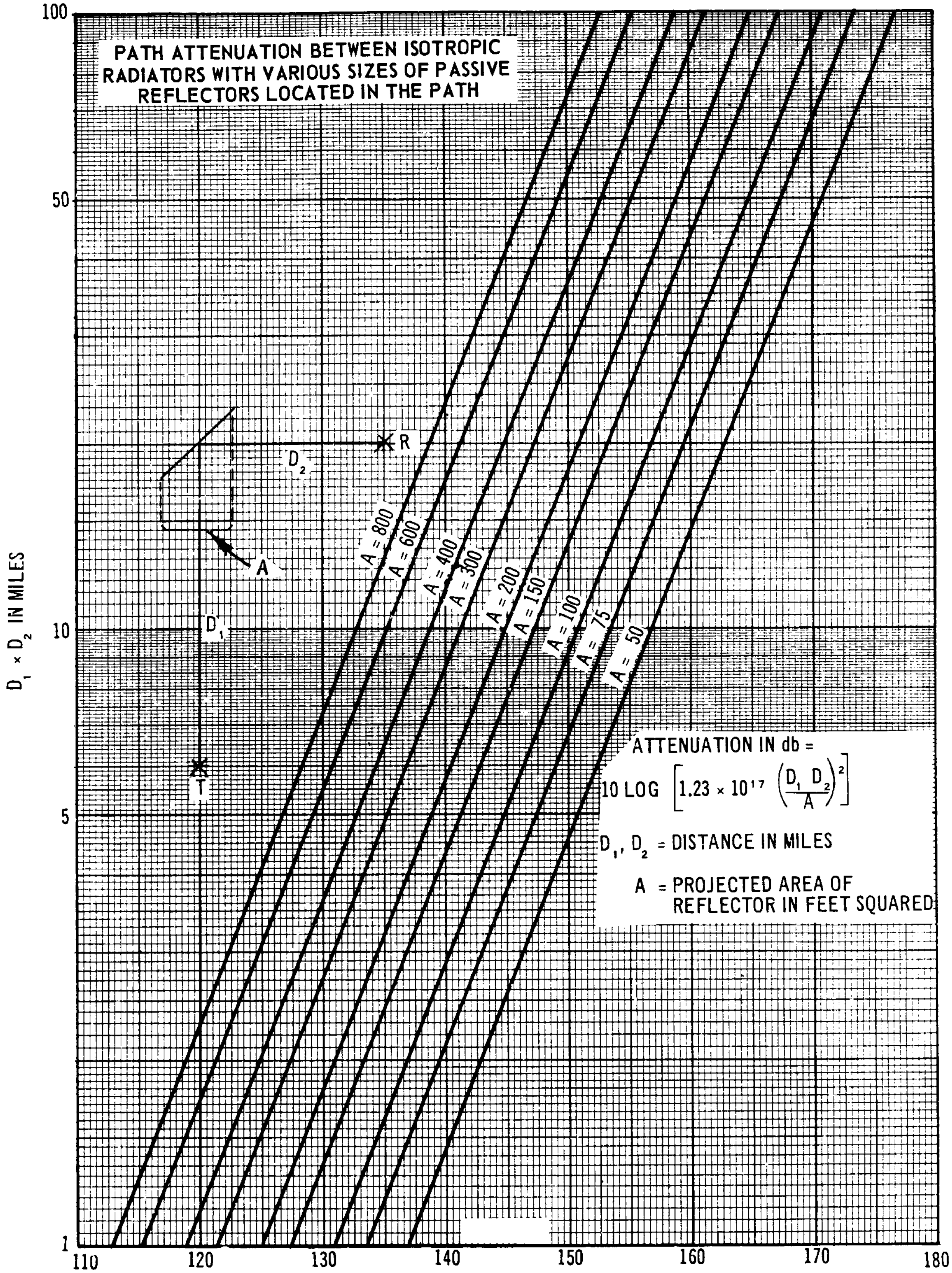
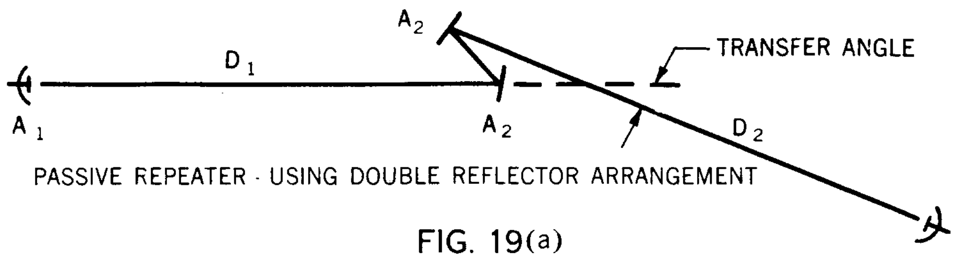
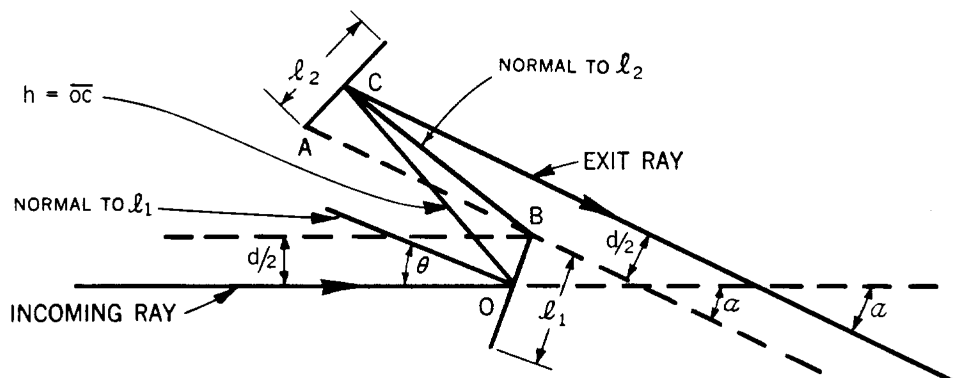


Fig. 18 – Path Attenuation v. Projected Area of Reflector Located in Path



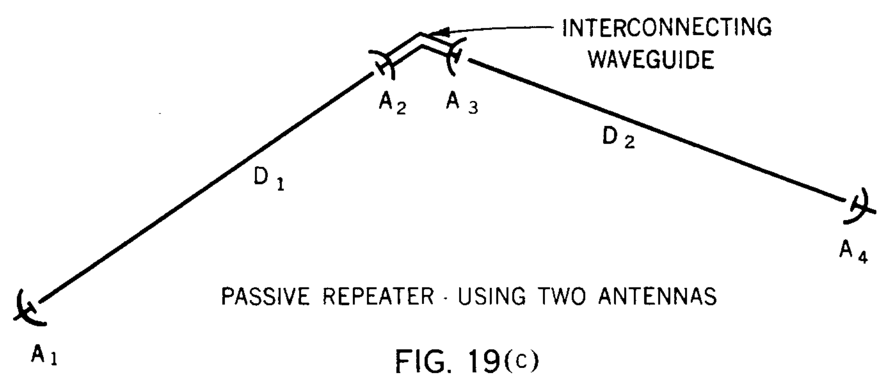
PASSIVE REPEATER - USING DOUBLE REFLECTOR ARRANGEMENT

FIG. 19(a)



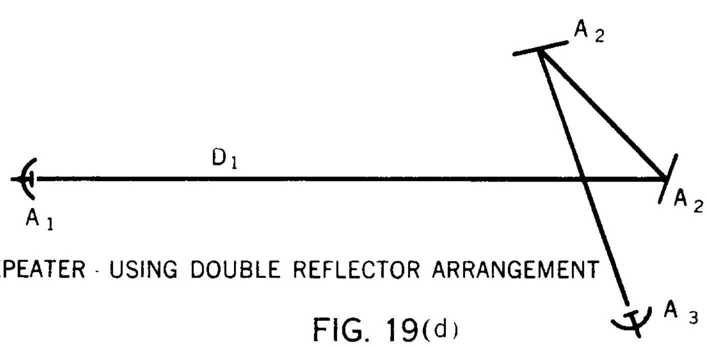
DOUBLE REFLECTOR ARRANGEMENT

FIG. 19(b)



PASSIVE REPEATER - USING TWO ANTENNAS

FIG. 19(c)



PASSIVE REPEATER - USING DOUBLE REFLECTOR ARRANGEMENT

FIG. 19(d)

Fig. 19 – Passive Repeaters

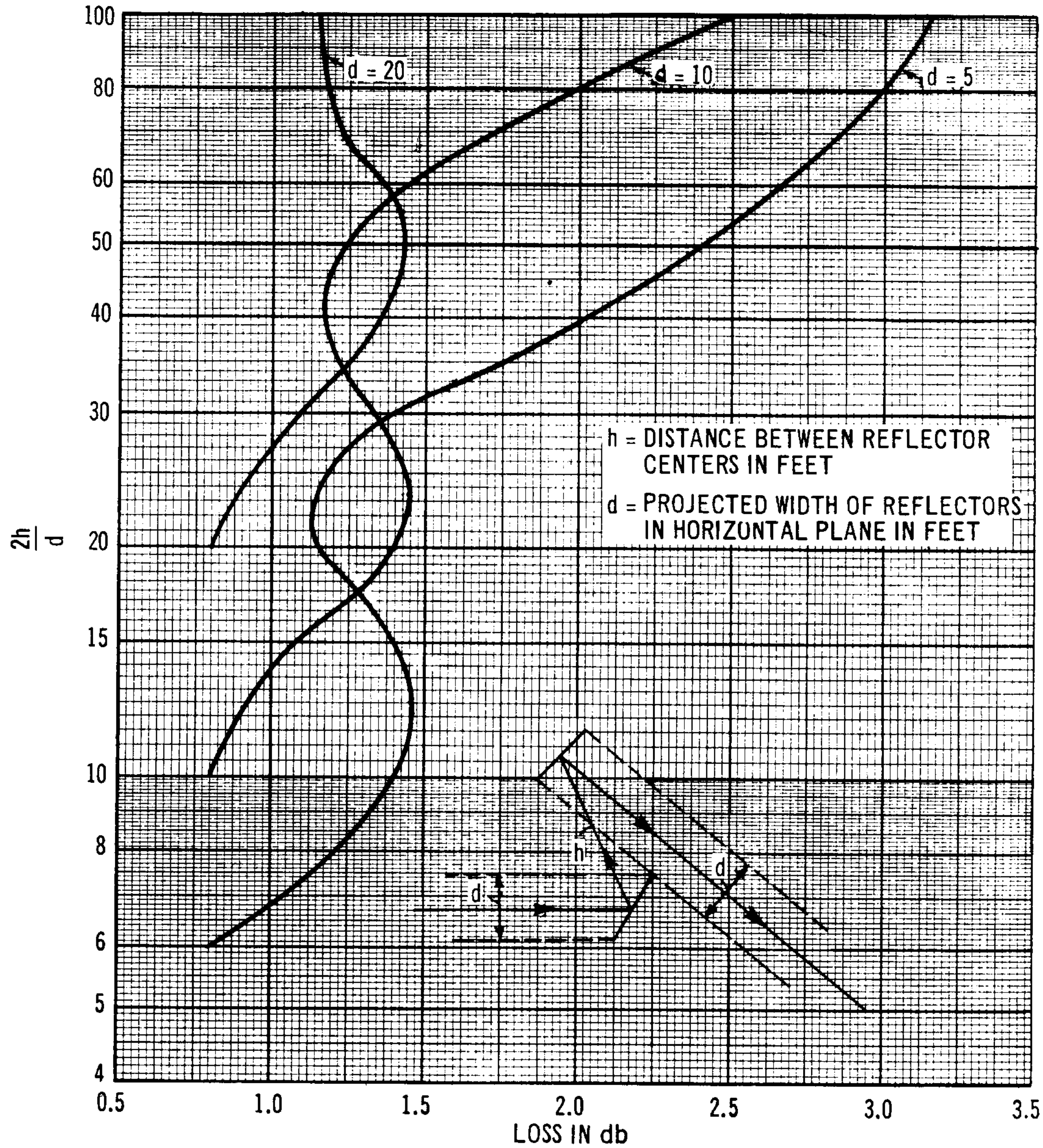


Fig. 20 – Transmission Loss From Double Reflection With Passive Repeaters

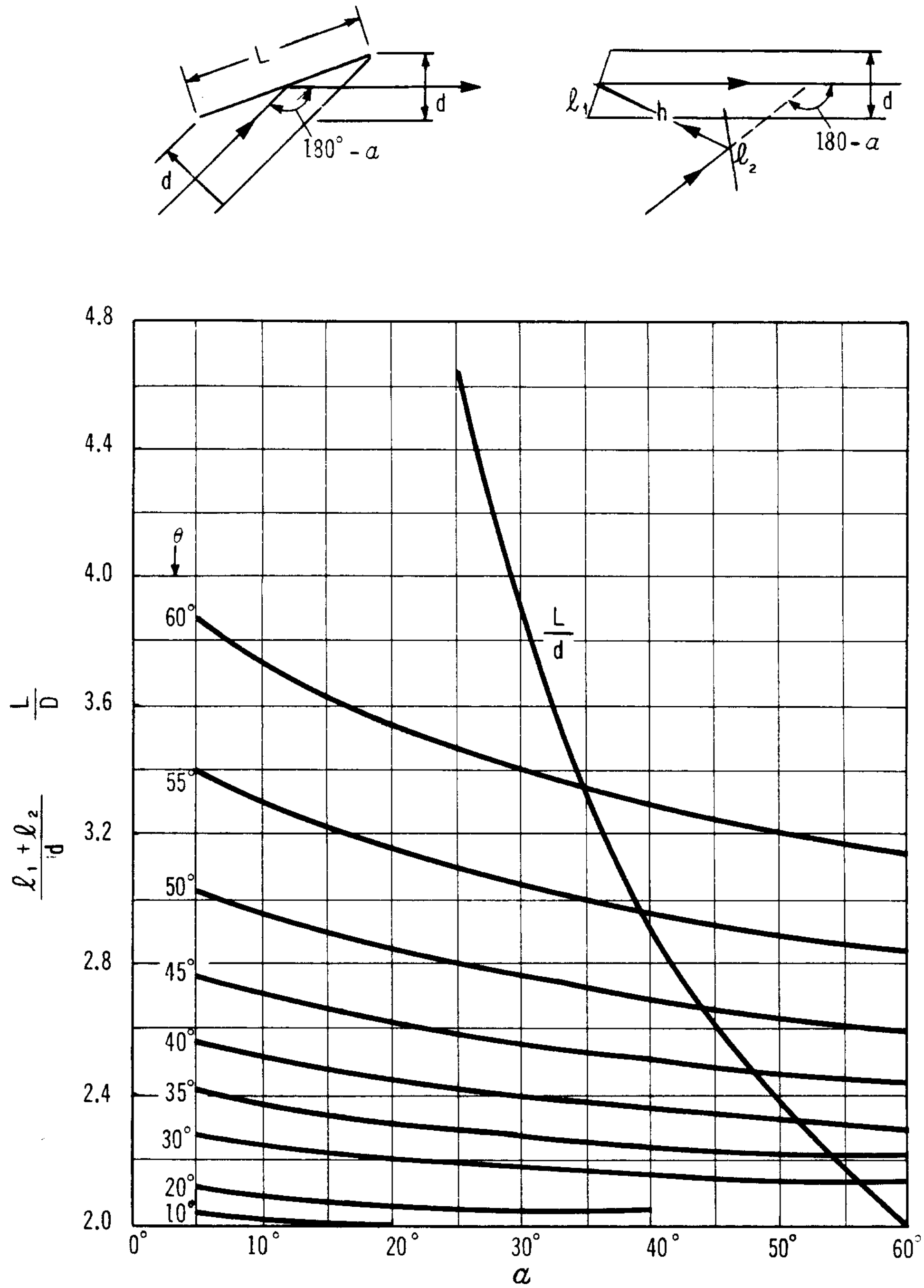
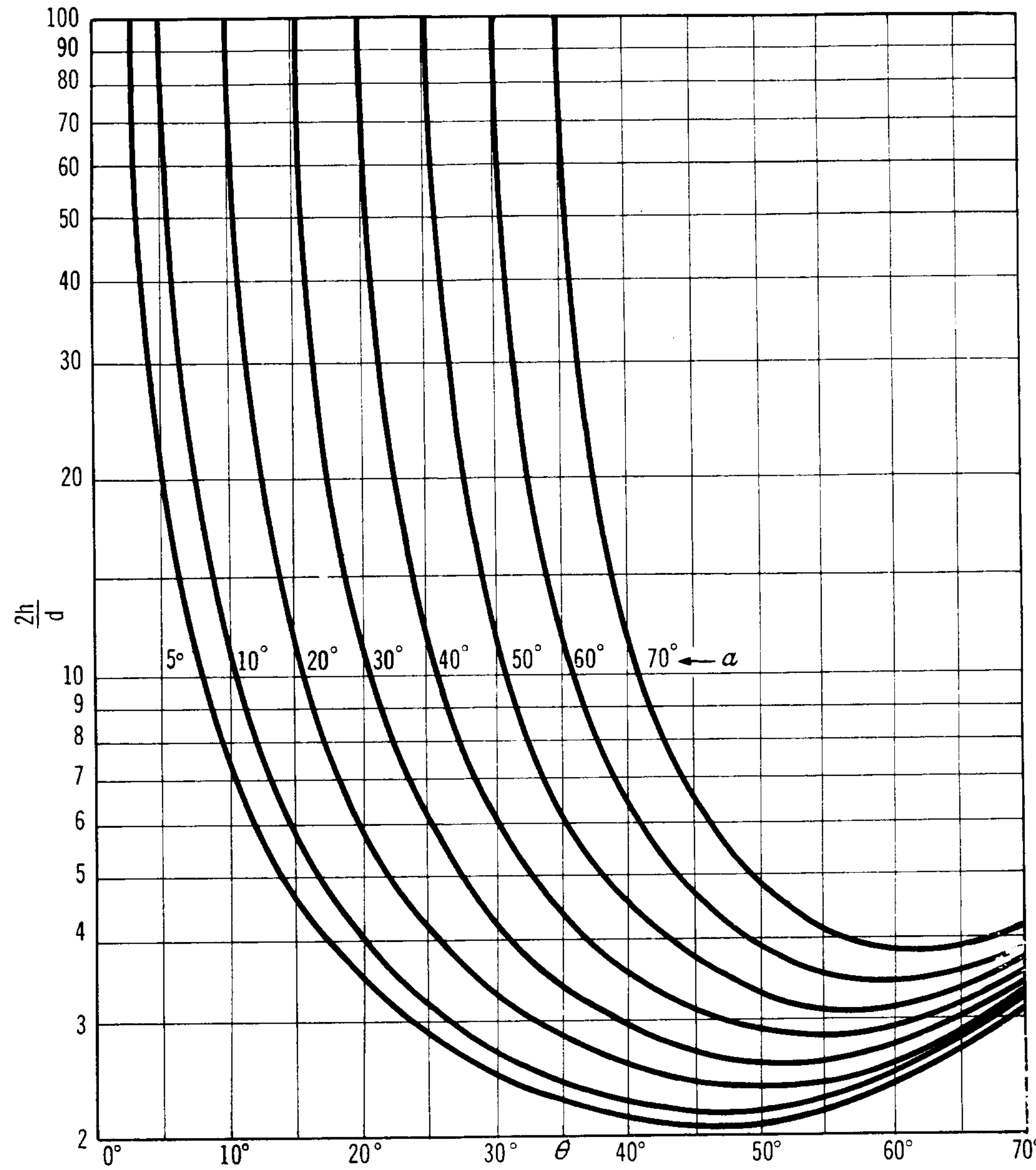


Fig. 21 – Comparison of Double and Single Passive Reflectors



$$\frac{2h}{d} = \frac{1 + \cos\alpha + \sin\alpha \tan\theta}{\sin(2\theta - \alpha)}$$

Fig. 22 – Double Reflector Separation and Angle