MICROWAVE PROPAGATION AND PATH SURVEYS

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers and other interested parties with technical information which can be used in making preliminary paper designs and economic studies for microwave systems. It discusses in particular the theory of radio path propagation and methods of making microwave path surveys. The reader is referred to REA TE & CM-930, "Use of Point-to-Point Radio (Microwave) in Telephony," for additional information relating to microwave system components and equipment costs.

2. CHARACTERISTICS OF MICROWAVE TRANSMISSION

2.1 Microwave frequencies are generally defined as those frequencies which have a wavelength short enough to display many of the properties of light waves. A wavelength of 30 centimeters or less is considered to be in the microwave region. Microwave energy may be refracted, diffracted or reflected. The direct rays of the radiated energy travel essentially in a straight line and there is little reflection from the ionospheric layers in the upper atmosphere. Because of the short wavelength of microwaves, the radiated energy can be concentrated by relatively small antennas into a narrow beam similar to that of a searchlight. Microwave energy can be obstructed or attenuated by solid objects such as trees, buildings, and mountains. It is for these reasons that microwave communication is almost always limited to unobstructed line-of-sight paths.

3. LOCATION OF STATIONS

3.1 As soon as the points are determined between which microwave communication will be established, topographic maps should be obtained that show the contour lines of the area over which the microwave path is to traverse. Topographical maps for areas west of the Mississippi River can be ordered from the U. S. Geological Survey, Distribution Section, Federal Center, Denver, Colorado, 80225. Map orders from areas east of the Mississippi River should be addressed to the U. S. Geological Survey, Distribution Section, Washington, D. C. 20242. State index circulars and a folder describing topographic maps are furnished free on request to the above-mentioned addresses.

3.2 In general, the stations should be located on high points so that there will be a line-of-sight path with some clearance over the intervening terrain between the transmitting and receiving antennas. The clearance required at any point along the path will depend upon the frequency used and the distance of the point from the ends of the path. The method of determining the clearance is discussed in paragraph 10.

3.3 The site's contour and soil characteristics, accessibility by all-weather roads, and availability of primary power should be determined and evaluated with respect to cost. In most cases it is less expensive to provide a taller tower at a site that is easily accessible than to build roads and power lines to a point of higher elevation. Passive repeaters can be used to an advantage in many cases. The active equipment can be placed near roads and power while at the same time adequate clearance (for the proposed path) is provided by the passive repeater. Passive repeaters are radio reflecting surfaces placed in a microwave path to reflect the signal around or over some obstruction. Passive repeaters are particularly effective in mountainous regions and in urban areas where nearby obstructions such as a mountain or building can be used to an advantage as a support for the passive repeater. The total path loss when passive repeaters are used is a function of the product of the individual leg lengths. Because of this, passive repeaters are most often used near the end of the path. Application manuals can be obtained from the suppliers of passive repeaters.

3.4 A site should be considered with respect to the availability and cost of land and applicable zoning regulations.

3.5 The proximity of a potential site to an airport should be determined. Part 17 of the Federal Communications Commission rules should be consulted to determine the maximum tower height allowed at the location chosen.

3.6 Possible radio interference should also be a prime consideration in the selection of microwave sites. Before any large amounts of money are expended for the acquisition of sites or final path engineering, a study should be made of existing and proposed microwave systems in the area and alternate sites selected if a possibility of harmful interference exists. After a study of existing microwave systems is made, frequencies can be selected and sites located which will reduce the interference from other stations.

4. PATH PROFILE

4.1 If the selected station sites appear desirable from the general considerations under paragraph 3, the profile of the terrain between the proposed tower sites should be plotted.

4.2 The path profile may be plotted on rectangular graph paper or on special curved coordinate graph paper. The three basic profile plotting methods are discussed in paragraph 4.4.

4.3 The potential tower sites for each microwave terminal station should first be accurately located on a recent topographical map. A straight line path should be drawn between the two sites and marked off in increments of one mile. The elevation points at the ends of the path and at each one mile increment are then transferred to the graph paper on which the profile is being plotted. If there are high elevation points between the one mile increment marks, these points should also be plotted on the path profile. After the straight line path between the two sites has been plotted, it can be determined if a line-of-sight path can be achieved without requiring excessively tall towers. If the first path profile reveals that a path is not possible using that route, alternate path routes between the two sites should be plotted to determine if a more feasible path is possible. If a direct path between the sites cannot be provided, locations for active or passive repeater stations should be determined at points of high elevation. Profile plots can then be made between each end of the path and the potential repeater points and the path selected which will provide adequate clearance with minimum tower heights. The repeater location should be chosen on the basis of path clearance and the considerations of paragraphs 3.3, 3.4, and 3.5.

4.4 The three methods generally used when plotting microwave path profiles are discussed in the following paragraphs:

4.41 The path profile can be plotted on transparent rectangular graph paper which represents a flat earth. Templates with curves which take into account the earth's curvature and the effects of refraction (refer to paragraph 5) on the beam are available from most microwave equipment manufacturers. It is extremely important that the vertical and horizontal scales indicated on the templates not be changed since errors are introduced if this is done. The line representing the beam would have a curvature of KR, where K is an equivalent earth factor accounting for the effects of refraction and R is the radius of the earth. The transparent graph paper with the profile plotted to the same scale as the template can be laid over the appropriate curve and critical points marked on the path profile. Figure 1 shows an example of a profile plot on rectangular paper with the microwave beam drawn with a true earth curvature (K = 1). (The points A, B, C, D and the Fresnel zone clearances shown on Figures 1, 2 and 3 will be discussed in paragraph 10.)

4.42 A second method also using rectangular graph paper to plot the path profile is sometimes used. This method uses calculated corrections to account for the earth's curvature and refraction rather than a curved beam. Corrections are added above objects in the path to account for the curvature of the earth and refraction. The microwave beam is then drawn as a straight line. The correction to be added above a point in the path may be obtained from the following formula:

$$H = \frac{2\, d_1 d_2}{3K}$$

Where the added height "H" is in feet, d_1 and d_2 (the distances from the point to each end of the path) are in miles. "K" is the equivalent earth radius factor. Therefore, trees and other high points of a path would be increased by the amount of "H" to take into consideration the earth's curvature and refraction. Corrections for the case of true earth curvature (K = 1) are indicated on Figure 2 by the dashed line AB. The earth profile is the same as used in Figure 1.

4.43 A third method of plotting profiles is to use curved graph paper which represents the appropriate KR curvature to account for refraction and the earth's curvature. The microwave beam is drawn as a straight line. This curved graph paper can be obtained from some suppliers of microwave equipment. No corrections are necessary since the curved paper has already accounted for refraction and the earth's curvature. Figure 3 shows a typical path profile plotted with a true earth curvature ($K = 1$). The center of the path must be centered on the curved graph paper to avoid errors. Figure 3 is the same earth profile as used for Figures 1 and 2.

4.5 The proposed path should be checked in the field since the contour lines on the map could be in error or obstructions such as trees or buildings not shown on the map may be in the path. Such obstructions should be taken into consideration in determining the tower locations and tower heights. The possibility of future building construction should also be considered at this time. A sensitive barometric altimeter may be used to take elevation readings along a proposed path. When a barometric altimeter is used, the manufacturer's instruction pertaining to the use of the instrument should be carefully followed to reduce errors.

4.6 The path may also be checked at night by the use of lights mounted on portable towers or balloons. Mirrors can be used to advantage during daylight hours. If a long path is checked by optical means, it should be done when the air is in motion rather than still since normal propagation is prevalent on windy days when the atmosphere is thoroughly mixed.

4.7 Microwave path planning kits can be obtained from most microwave equipment suppliers at no charge. These kits contain the necessary graph paper and information to plot a path profile. Not all microwave suppliers use the same technique to account for earth curvature and refraction, but one of the three procedures mentioned in the preceding paragraphs is used by major equipment suppliers.

4.8 The methods discussed should be adequate for making a preliminary survey to determine the feasibility of using microwave as well as to locate potential station sites. If the preliminary survey does indicate feasibility, it may be desirable to have an organization specializing in laying out microwave systems make a more detailed survey. In most cases the microwave equipment supplier will make a detailed survey before installation of the system.

5. REFRACTION

5.1 Refraction is one of the factors that must be considered when determining microwave path clearance. Under normal propagation conditions refraction results in the bending of the microwave beam beyond the optical horizon in the direction of the earth's curvature.

5.2 As a radio wave front moves forward, it will travel in a straight line if all points on the front travel at the same velocity. In air of uniform pressure, temperature and relative humidity all points on a wave front would travel at the same velocity. Since the pressure, temperature and relative humidity of the atmosphere are not uniform, but normally decrease with height, the upper portion of the wave front travels slightly faster than the lower portion as it moves forward. The difference in velocity causes the wave, under normal conditions, to be bent or refracted toward the earth. This is the reason that when a path profile is plotted, the radius of the earth must be corrected for refraction by the appropriate "K" factor.

5.3 The greater the difference in velocity between the upper and lower portions of the wave front, the more a wave will be bent toward the air having the highest index of refraction. The amount of bending thus depends upon the index of refraction of the air through which the wave front passes. The index of refraction varies with relative humidity, temperature, pressure, movement of air and other factors. The variation of these factors from minute-to-minute and day-to-day causes the amount of bending of a wave front to fluctuate.

5.4 Since normal atmospheric refraction results in the microwave beam being bent downward, this effect is the same as a change in the earth's radius and is expressed in terms of an equivalent earth radius factor "K". The actual earth's radius multiplied by the "K" factor represents a fictitious earth with a radius which accounts for the refractive index. A factor of $K = 1$ would be the case where the curvatures of the actual earth and the effective earth are equal. A factor greater than $K = 1$, for example $K = 4/3$, would indicate that the effective earth has less curvature or is flatter than the true earth. It is also possible when abnormal propagation conditions exist for the beam to be bent upward which would indicate a K factor less than 1. The K factor varies for different atmospheric conditions, but at microwave frequencies in the 4 GHz, 6 GHz, and 11 GHz common carrier bands a factor of $K = 1$ or $K = 2/3$ is used for most areas of the United States. For frequencies in the 2 GHz band a factor of $K = 4/3$ is normally used. The selection of the K factor is dependent on path location and path length.

5.5 A phenomenon that can be caused by irregular changes in the index of refraction is multipath propagation. This may occur on a still night after a hot, humid day when there are both temperature and humidity inversions.

5.51 Temperature inversion (increase in temperature with height) is caused by the earth and the air adjacent to it cooling faster than the warm air above it. To cause a higher index of refraction in the air at some height above the ground rather than near it, the absolute humidity or vapor pressure at that point must be higher than near the ground. This is called humidity inversion and usually occurs when the air is super-saturated and the excess moisture appears as fog or dew.

5.52 Multipath propagation occurs when there exists a layer of air some distance above the ground which has a higher index of refraction than the air above or below it. Horizontal and vertical variations in temperature, pressure, and humidity cause more than one propagation path to exist between transmitter and receiver. For example, beam 1 in Figure 4 might be close to a layer with a high index of refraction. Another beam, such as 2, could cross the layer at a greater angle and it would be bent enough by the low density air near the earth to also arrive at the receiver.

5.53 Initially the separation would be slight and the electrical path lengths equal. The signal via each path would arrive in phase and the total signal received at the antenna would be double. However, as the paths become more divergent with cooling in the lower atmosphere, the signal will decrease until the energy received via both paths practically cancel. Thus the signal will fluctuate depending upon the difference in the electrical length of the paths. By morning, the temperature in the layer will become cooler and the two paths will come closer together until only one path remains. If the two paths still exist by morning, the sun will warm the earth and air adjacent to it faster than the air in the upper layer so that the temperature inversion will soon cease to exist. Frequency diversity and fade margin are used to substantially reduce the adverse effects of multipath fading. Space diversity can also be used to provide increased propagation reliability but is more expensive than frequency diversity.

6. DIFFRACTION AND WAVE INTERFERENCE

6.1 After correcting the profile of the path to take into consideration the bending of the radio rays by refraction, it is generally necessary that the rays clear the earth and obstacles along the path by a certain amount to prevent excessive attenuation of the signal by diffraction and wave interference.

6.2 Diffraction may be considered as a modification which waves undergo as they graze the surface of the earth, hills, or the edges of any opaque body by which the rays are apparently deflected or bent.

6.3 As a wave front travels from a transmitting to a receiving antenna, some portions of the wave front tend to cancel or reinforce other portions, depending on the difference in path length traveled. This is referred to as wave interference.

6.4 In order to understand the reason for apparent wave bending (diffraction) and wave interference, it is helpful to refer to Huygen's (pronounced Hī'ghŭn) Wavelet Principle.

6.41 According to Huygen's Wavelet Principle, a wave front may be considered to consist of an infinite number of individual secondary radiators. Each of these secondary radiators sends out wavelets in directions away from the original source radiator. For example, assume in either Figure 5 or 6 that T is the primary source of radiation, and that the front will have traveled to position AB. Consider then that each vibrating particle such as 1, 2, and 3 in the wave front is a secondary source of radiation from which spherical wavelets spread out. After a period of time, the surface which envelops (i.e., tangent to) all these wavelets constitutes a new wave front such as CD. The period of time between AB and CD is the time required for the wave front to progress one wavelength.

6.42 The energy that is radiated from each secondary source does not radiate equally in all directions as is the case with a non-directional primary radiator (isotrophic antenna) but radiates in the forward direction only. Also, the amount of energy radiated (from the secondary source) is greatest in the direction of the direc, source ray and diminishes with the divergence from the direction of the primary wave. In Figure 6 the vibrating particle 2 will radiate more energy in the direction of 2P, the direction of the primary ray TR, than it will radiate oblique to the primary ray in the direction 2N. Similarly, particle 1 will radiate less in the direction 1N' than in direction 1P'. Thus the amount of energy in a wavelet decreases as the angle θ between it and the primary ray is increased.

6.5 An example of wave diffraction over a hill is shown in Figure 7. In that figure waves are moving forward in the direction of the primary ray TP. The numerals 1, 2, 3, and 4 represent the crests of the forward moving waves. If A2C represents a hill which is tangent to the primary ray at the grazing point 2, the disturbance at 2 will cause wavelets to be sent out from that point so that some energy will be directed below the horizon such as represented by the ray 2N. If the hill were broad in relation to a wavelength, such as A' 2 C', the amount of energy radiated below the horizon would be much less. On the other hand, if the distance 1-4 were only a fraction of a wavelength, the hill A' 2 C' may appear as sharp at that frequency as the hill A2C appears to the wavelength represented. With other things being equal, the energy diffracted beyond a given hill will increase as the frequency is decreased.

6.6 In 6.41 it was stated that a wave front (such as AB in Figure 8) may be considered to consist of an infinite number of secondary radiators such as 1, 2, and 3. Since the distances from points on the wave front to a receiver R are not equal, the wavelets can arrive in- or out-of-phase, in varying degrees, with the primary ray and result in wave interference. The areas or zones around the axial between the transmitter and receiver that contribute energy either in- or out-of-phase are called Fresnel (pronounced Frā'nĕl) zones.

6.61 The first Fresnel zone is bounded by points through which the distance between the transmitter and receiver is 1/2 wavelength (1/2 λ) longer than the direct ray. The second Fresnel zone is bounded by points through which the distance is 1 λ longer than the direct ray.

6.62 Point 1 in Figure 8 was so chosen that ray T1R is 1/2 λ longer than the direct ray TOR; T2R is 1/2 λ longer than T1R; and T3R is 1/2 λ longer than T2R. Figure 9 is a cross-section of the wave front AB in which points on the circles traverse paths that are 1/2 λ, 1 λ, and 1 1/2 λ longer than the direct ray. The regions between these circles are called Fresnel zones. The diameter of the circles will vary along the radio path forming ellipsoidal envelopes as boundaries between the Fresnel zones as indicated in Figure 10.

6.63 There is an unlimited number of Fresnel zones even though only three are illustrated in the figures. The areas of all zones are equal. The energy received from each zone, however, decreases with distance from the primary ray as explained in Paragraph 6.42. About one-fourth of the energy received from an unobstructed wave front is in the first Fresnel zone. The energy received from the second and other even-numbered Fresnel zones is negative with respect to energy received from the odd Fresnel zones. About half of the total energy received from an unobstructed wave front is cancelled by the waves received from the even numbered Fresnel zones. A sharp obstruction such as a sharply pointed hill, which cuts off most of the energy below the first Fresnel zone, would permit more energy to be received than if the obstruction were not there since part of the out-of-phase energy would be cut off by the obstruction.

6.64 If an obstacle cuts off the first Fresnel zone radius (non-line-of-sight path), some energy will be diffracted around and over the obstacle (Paragraph 6.5) and will be received in the shadow portion of the radio beam. It is for this reason that a certain amount of radio energy is present beyond true radio (refracted) line-of-sight when the path is intercepted by the earth. In general, the lower the frequency, the farther the signal is diffracted beyond the point of interception.

6.65 The radius of the first Fresnel zone varies along the radio path. It is maximum at the midpoint between the transmitter and receiver and can be calculated by the formula:

$$F_m = 1140 \sqrt{\frac{D}{f}}$$

Where "F_m" is the radius in feet of the first Fresnel zone at the midpoint of the path, "D" is the distance in miles between the receiver and transmitter, and "f" is the frequency in MHz. The first Fresnel zone radius at any point "x" miles from one end of the path is:

$$F_x = 2280 \sqrt{\frac{x\ (D-x)}{fD}}$$

6.66 Paragraph 10 discusses the application of the above formula in determining the necessary tower height for proper Fresnel zone clearance. It is desirable to receive as much of the first Fresnel zone energy as possible and still keep the cost of towers as low as possible. At frequencies of 4 GHz and higher, a clearance of 0.6 first Fresnel zone radius with K = 1 is a good design objective for most areas of the United States with hops of 25 miles or less. A more conservative design for hops greater than 25 miles to account for possible upward beam bending (earth bulging) would be 0.3 first Fresnel zone with K = 2/3. At 2 GHz, a value of K = 4/3 with a 0.6 first Fresnel zone clearance is a typical design.

7. REFLECTION

7.1 If the terrain between the antennas reflects radio waves efficiently, it is possible to receive strong reflected waves, either in or out-of-phase with the direct wave, depending on the difference in the lengths of the direct and reflected wave paths. If we assume complete reflection with the reflected wave equal in magnitude to the direct wave, the resultant energy received would vary, depending on the location of the point of reflection, between zero and twice that of the direct path energy according to the following formula:

$$E = 2\,E_d \,\text{Sin}\ \frac{2\pi}{\lambda}\ \frac{d'}{2}$$

E_d is the direct ray field strength and d' is the geometric length difference between the direct and reflected wave paths. E and E_d are in the same units, such as microvolts/meter. Wavelength λ is in the same units as d'. Thus in Figure 10, the second Fresnel zone signal received from the reflection path TPR would practically cancel the signal from the direct path TR. If the reflecting plane were moved upward to P' so that it permits only the first Fresnel zone to be received, the reflected signal TP'R would then be added to the direct signal TR. The path difference d' is approximately:

$$d' = 2\ h_r h_t / d$$

Where h_r and h_t are the heights of the receiving and transmitting antennas above the <u>reflecting plane</u> and d is the distance between transmitter and receiver in the same units as h_r and h_t.

7.2 Since the distance T1R in Figure 8 is 1/2 λ longer than TR, the energy received from 1 as a secondary ray would be 180° out-of-phase with the primary ray TR. Also, the energy received would be less than that of the primary ray, as discussed in Paragraph 6.42. If, on the other hand, 1 were on a reflection plane, a reflected primary ray 1R would arrive at R in phase with the direct primary ray TR. The reason for its arrival in phase is that there is approximately 180° phase shift when a wave is reflected. If the reflecting plane were a perfect reflector, large enough, and of the correct slope to reflect the energy in several Fresnel zones, almost as much energy would be received at the Receiver from the reflected wave as from the direct wave.

7.3 If one of the heights such as h_r is varied so that E goes through a maximum and minimum, the difference in the two values of h_r is sometimes used as the spacing between two receiving antennas on a tower.

7.4 When two antennas are placed on a tower with this separation, the reception of the two signals and the selection of the stronger of the two is called space diversity reception. If one antenna is receiving a minimum signal, the other in all probability will be receiving a stronger signal. A particularly difficult problem exists when the reflection point is over tidewater which causes variations in the length of the reflected wave path contingent on the tidal change in water level. The amount of separation used on a space diversity system should be determined by someone very familiar with this type of design.

7.5 Where it is impossible to obtain adequate clearance for two separate antennas with a tower of reasonable height, frequency diversity reception may be accomplished by using two frequencies in each direction. The difference between frequencies is generally limited to 2% or 3% of the lower frequency but may be as much as 5% for best improvement. The amount of separation is determined by the available frequency spectrum and degree of reliability required. Since frequency diversity operation utilizes duplicate RF equipment, equipment reliability is increased in addition to path reliability improvement.

7.6 Reflections are greatest when the point of reflection is over calm water, level moist earth, desert sand, and other types of smooth terrain. It is desirable to adjust the tower heights or to reroute the radio path so the reflection point will be over rough terrain. Radio energy striking rough terrain will be either absorbed or scattered. Thus the amount of reflected energy reaching the receiver will be only a small percent of the total energy. The point of reflection can be determined by trial and error from the path plot. At the point of reflection the angle of incidence will equal the angle of reflection.

7.7 With zero clearance over a non-reflecting obstacle such as a hill covered with trees or brush, the signal will be 6 or 7 db below the loss that would exist between two antennas in free space. If, however, the top of the hill were broad and barren and the soil had good reflection characteristics, the loss could be more than 16 db greater than free space loss. Microwave systems should not be engineered for grazing paths except by someone with extensive experience in the area of microwave propagation and path design.

8. FADING

8.1 Fading is a condition which occurs during propagation of radio frequency energy that causes a reduction in the power being received. It may be caused by refraction, diffraction or reflection or by a combination of these conditions.

8.2 In general, variations in received signals are greater in summer than in winter and greater during nighttime than daytime. These variations are smallest when the air is in a state of turbulence which prevents the formation of stratified layers of air.

8.3 The magnitude of the received signal varies continuously. The signal output level of the radio receiver is kept approximately constant by the circuits in the receiver. However, when a fade causes a weak signal at the receiver input the noise level in the receiver increases. This results in a reduced signal-to-noise ratio.

8.4 If the system is designed with an adequate fade margin, the noise will be infrequent and not objectionable. Under extreme conditions a fade can cause service failure, but transmission usually returns to normal in a short time The adverse effects of fading can be reduced through the use of frequency diversity or space diversity and by provision of adequate fade margin.

9. MICROWAVE PATH LOSSES AND GAINS

9.1 The system losses over a radio path can be calculated even though some of the loss factors, particularly those caused by atmospheric fades, may be difficult to obtain or estimate. Because of this, fade margins are added to the calculated normal losses to provide adequate reserve system gain to compensate for fluctuating atmospheric fades. If losses are calculated beginning with the transmitter, the levels at various points along the path can be obtained by the steps outlined in the following paragraphs.

9.2 The power of most microwave transmitters is given in watts. This can be converted to db above or below a given reference. One milliwatt is a commonly used reference in telephony. If the transmitter power (P) is above one milliwatt, the power in dbm will be:

$$+\text{ dbm} = 10 \log \frac{P}{.001}$$

(i.e., db above 1 milliwatt). If the power is less than one milliwatt, then

$$-\text{ dbm} = 10 \log \frac{.001}{P}$$

The values may be obtained directly from the curve of Figure 11 for transmitter power greater than 1 milliwatt.

9.3 After the power, if the transmitter is converted to dbm, the losses in the transmission line between the transmitter and the antenna are subtracted. The losses in db per 100 feet of the most commonly used transmission lines are given in the following table. Coaxial cable is normally used for frequencies up to 2 GHz and in some cases a special coaxial cable is used at frequencies above 2 GHz. Waveguide is generally used at 4 GHz and above.

Typical Loss in db per 100 Feet of Transmission Line

	2 GHz	4 GHz	6 GHz	11 GHz
7/8" Coaxial Cable (Air dielectric)	2 db	-----	-----	------
1 5/8" Coaxial Cable (Air dielectric)	1 db	-----	-----	------
Flexible Elliptical Waveguide	-----	1 db	1.5 db	3.5 db
Rigid Copper Waveguide	-----	1 db	2 db	3.5 db

9.4 Power is effectively increased at the antenna. Microwave antenna gains are referred to a theoretical isotropic antenna which radiates energy equally in all directions. The following table shows the typical gain in db of some commonly used parabolic antennas:

Antenna Size	2 GHz	4 GHz	6 GHz	11 GHz
4 foot	25	31	35	40
6 foot	29	35	38	43
8 foot	31	37	41	46
10 foot	33	39	43	48

9.5 In some cases rather than using a long transmission line between the transmitter and its antenna, a reflector is used at the top of a tower to reflect radio waves in the desired direction from a transmitting antenna located at the base of the tower. The gain or loss of a reflector for a given frequency depends mainly upon the size of the reflector, the size of the parabolic antenna and the distance between the parabolic antenna and reflector. The size of the reflector is generally chosen so that it intercepts most of the energy in the first Fresnel zone at the reflector location. It is possible to get gains up to 5 db from a reflector-antenna combination as compared to an antenna alone. The amount of gain or loss to be expected for a given set of conditions should be obtained from data or curves supplied by the reflector manufacturer.

9.6 Free Space Loss - The major loss between a transmitter and receiver is through the space between the antennas. The following formula gives the free space loss in db:

$$A = 96.6 + 20 \log_{10} f + 20 \log_{10} d$$

Where "f" is the frequency in GHz and "d" is the distance between the antennas in miles. The nomograph in Figure 12 may also be used to obtain the free space loss. This loss may be increased or decreased somewhat by the type of path through which the radio waves travel. A free space loss condition exists only when the antennas are high enough that the ground and other obstacles and unusual air conditions do not affect the received signal.

9.7 The signal will be increased at the receiving end of the radio path by the gain of the receiving antenna. If there is a reflector, its gain or loss should also be included. The transmission line loss between the antenna and receiver should then be subtracted.

9.8 Miscellaneous losses from circulators, radomes, and antenna system misalignment should be accounted for in making fade margin calculations. The amount of miscellaneous loss will vary with systems but a value of 2 db per radio channel end is typical. (Radomes are discussed in REA TE & CM-930.)

9.9 The result of subtracting the losses and adding the gains between the transmitter and receiver will give the signal power in dbm at the receiver input. The fade margin is the difference between the received power level and the power level required to produce a given signal-to-noise (S/N) ratio. The S/N is measured in the highest frequency multiplex channel in the baseband at the receiver output. This S/N ratio is commonly 30 db flat weighted in the telephone industry.

9.10 The receiver noise level will increase as more channels are added and the frequency of the highest channel is increased. Therefore, the signal required to provide an output S/N of 30 db (flat) at the receiver for the number of channels to be used should be obtained from the manufacturer.

10. ILLUSTRATIVE EXAMPLE OF CALCULATION OF MICROWAVE ANTENNA HEIGHT AND FADE MARGIN

10.1 To illustrate the considerations involved in selecting a suitable microwave path, assume that the profile of the earth is AB in Figures 1, 2, and 3. All plots represent the same path profile. Figure 1 is plotted on rectangular paper with the microwave beam drawn with a curvature which represents the true earth's radius (K = 1). Figure 2 is plotted on rectangular paper with corrections made for true earth's radius. Figure 3 is the same path plotted on curved graph paper. Assume that the equipment to be installed operates in the 6 GHz band.

10.2 To determine the required antenna heights at A and B, the profile of the earth is first plotted directly on the graph paper. The profile should be plotted with the midpoint of the path centered on the graph paper.

10.3 When the path is plotted on rectangular paper with corrections added for earth curvature and refraction, the corrections are calculated from the formula in paragraph 4.42 and added to the profile plot. The corrections are shown by the dotted line in Figure 2.

10.4 At the high points in the path, the height of any obstructions such as trees or buildings should be added. The maximum height of trees is assumed to be 40 feet in this example.

10.5 The next step is to calculate the first Fresnel zone clearance for the high points in the path. In this example 0.6 of the first Fresnel zone is used. The required clearance at the high points is calculated from the formula in Paragraph 6.65, that is

$$.6F = .6 \left(2280 \sqrt{\frac{x\ (D - x)}{fD}} \right)$$

For example, at point "P" on the profile the clearance required above the tree would be

$$.6 \left(2280 \sqrt{\frac{6\ (28 - 6)}{6000\ (28)}} \right) = .6\ (63.5) = 38.1 \text{ ft.}$$

A safety factor of 10 feet or more is often added to the calculated Fresnel zone clearance to account for future tree growth and survey inaccuracies. Using a safety factor of 10 feet, the clearance at point "P" would be 48 feet.

10.6 The corrections for earth curvature and refraction are drawn on the profile as shown in Figure 2, and the Fresnel zone clearance is calculated and shown with the safety factor on all profile plots as in Figures 1, 2, and 3. The next step is to draw a line representing the microwave beam between the ends of the path. The beam line is drawn so that it clears all of the critical points marked on the profiles. When drawing a curved beam line using a template, the grid lines of the template and the grid lines of the profile graph paper must be parallel at all times to avoid errors. The distance AC (135 ft.) is the antenna height required at one end of the path while BD (70 ft.) is the antenna height required at the other end. If it is assumed that the antennas are mounted 5 feet below the top of the towers, the tower height at A and B would be 140 feet and 75 feet, respectively. If it is more desirable to have the antenna lower at A, the straight line DC in Figures 2 and 3 can be pivoted counterclockwise about point "P" to determine a lower tower at A and a taller tower at B. When a template is used to draw the curved beam line, the template can be moved horizontally to the left while keeping the grid lines on the template and profile paper parallel and a shorter tower determined at A.

10.7 The gains and losses of radio energy between the transmitter and receiver are calculated in the following steps. Assume that the equipment operates in the 6 GHz band, that the transmitter output is 1 watt, and that the receiver requires a radio signal of -80 dbm for a voice channel S/N ratio of 30 db (flat) in the worst channel.

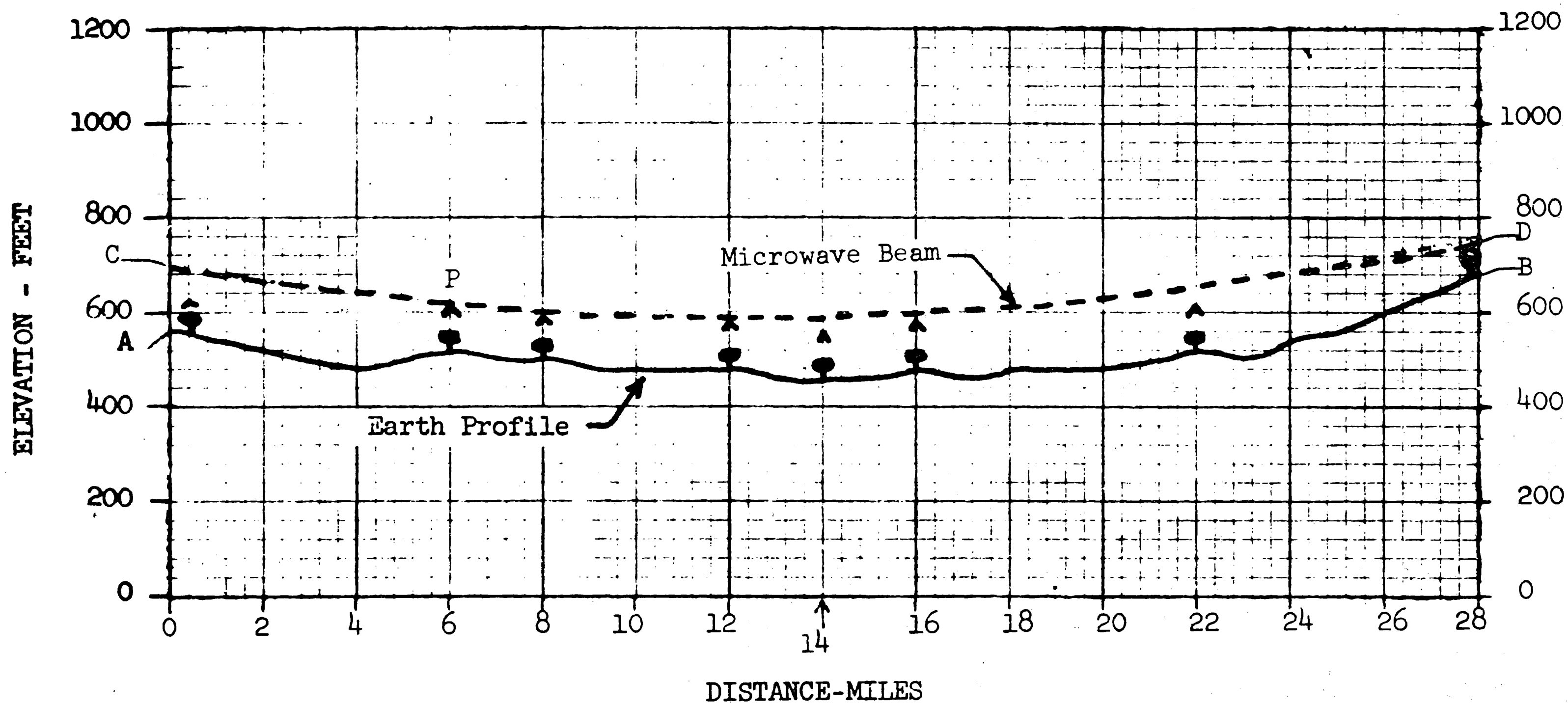
Transmitter "A" Output Power = 1 Watt	=	+30.0 dbm	(Figure 11)
Transmitter "A" Waveguide Loss (145 Feet)	=	- 2.9 db	(Paragraph 9.3)
		+27.1 dbm	
Transmitter "A" Antenna Gain (8' Diameter)	=	+41.0 db	(Paragraph 9.4)
		+68.1 dbm	
Free Space Loss (28 Miles)	=	-141.1 db	(Figure 12)
		-73.0 dbm	
Receiver "B" Antenna Gain (8' Diameter)	=	+41.0 db	(Paragraph 9.4)
		-32.0 dbm	
Receiver "B" Waveguide Loss (80 Feet)	=	- 1.6 db	(Paragraph 9.3)
		-33.6 dbm	
Miscellaneous Losses at "A" and "B"	=	- 4.0 db	(Paragraph 9.8)
CALCULATED RECEIVED RF LEVEL	=	-37.6 dbm	

CALCULATED FADE MARGIN = CALCULATED RECEIVED RF LEVEL MINUS RECEIVED LEVEL NECESSARY FOR 30 db S/N RATIO

CALCULATED FADE MARGIN = -37.6 dbm - (-80 dbm) = 42.4 db

This fade margin would provide a path with a theorectical propagation reliability of more than 99.99% for a nondiversity system and more than 99.999% for a frequency diversity system. This would exceed the requirements of REA Specification, Form 397d.

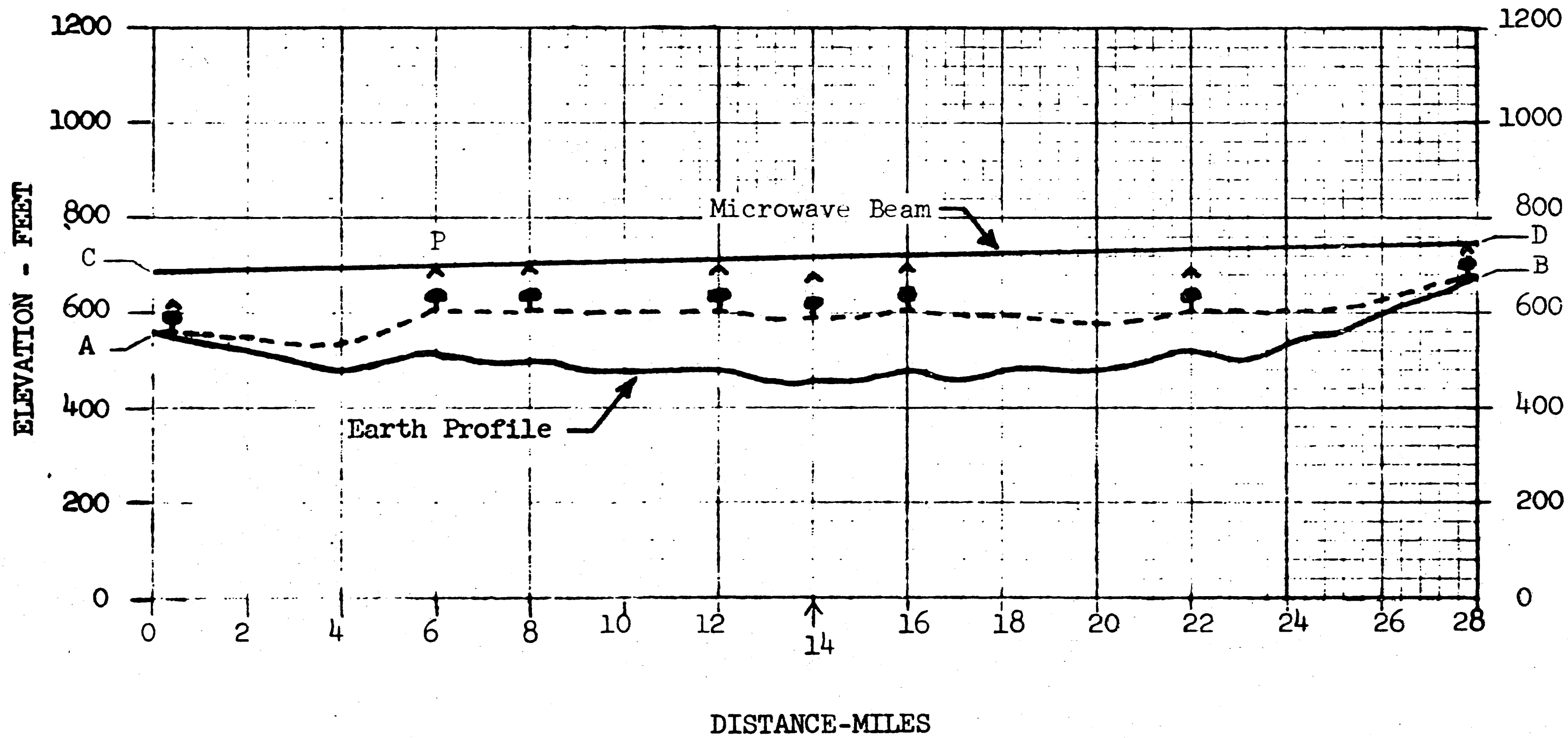
PATH PROFILE
RECTANGULAR GRAPH PAPER
(Curved Microwave Beam)



Scale:
Path Distance: 1" = 4 miles
Elevation: 1" = 400'
K = 1
Tree (40')
.6 First Fresnel Zone
Clearance plus 10'

FIGURE 1

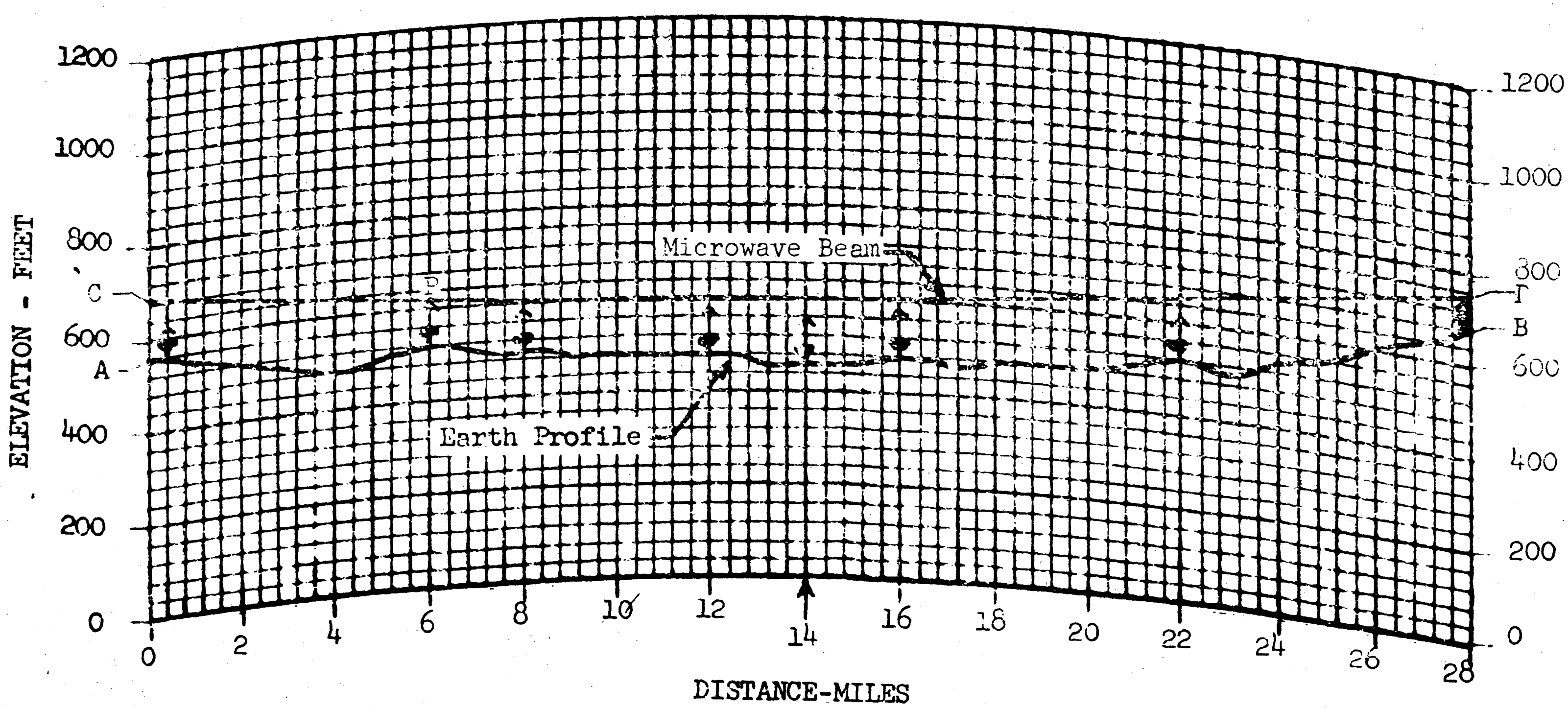
PATH PROFILE
RECTANGULAR GRAPH PAPER



Scale:
Path Distance: 1" = 4 miles
Elevation: 1" = 400'
K = 1
Tree (40')
.6 First Fresnel Zone Clearance Plus 10'

FIGURE 2

PATH PROFILE
CURVED GRAPH PAPER



SCALE:
PATH DISTANCE: 1" = 4 miles
ELEVATION: 1" = 400'
K = 1
Tree (40')
.6 First Fresnel Zone Clearance Plus 10'

FIGURE 3

EXAMPLE OF MULTIPATH PROPAGATION BY REFRACTION

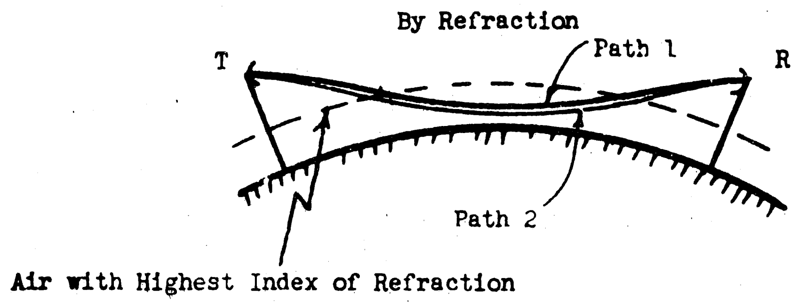


FIGURE 4

HUYGEN'S WAVELETS

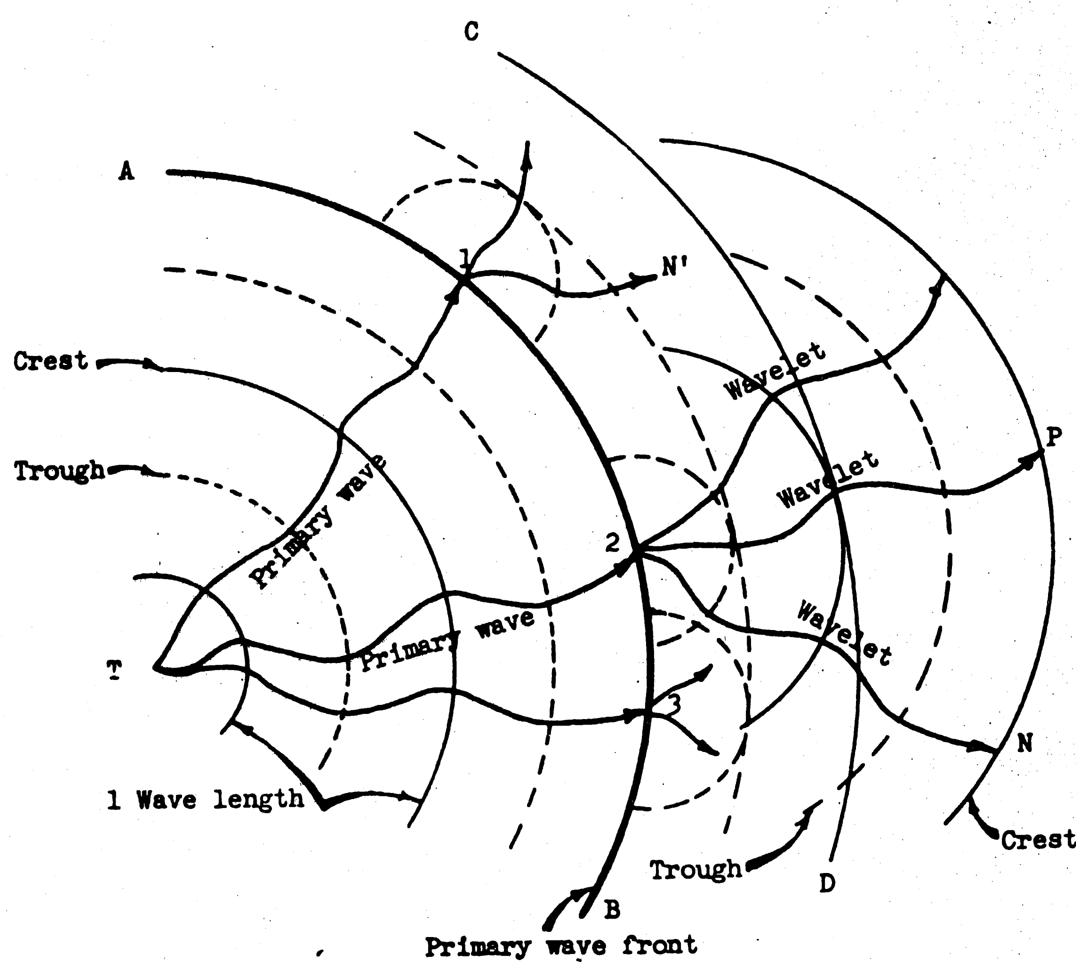


FIGURE 5

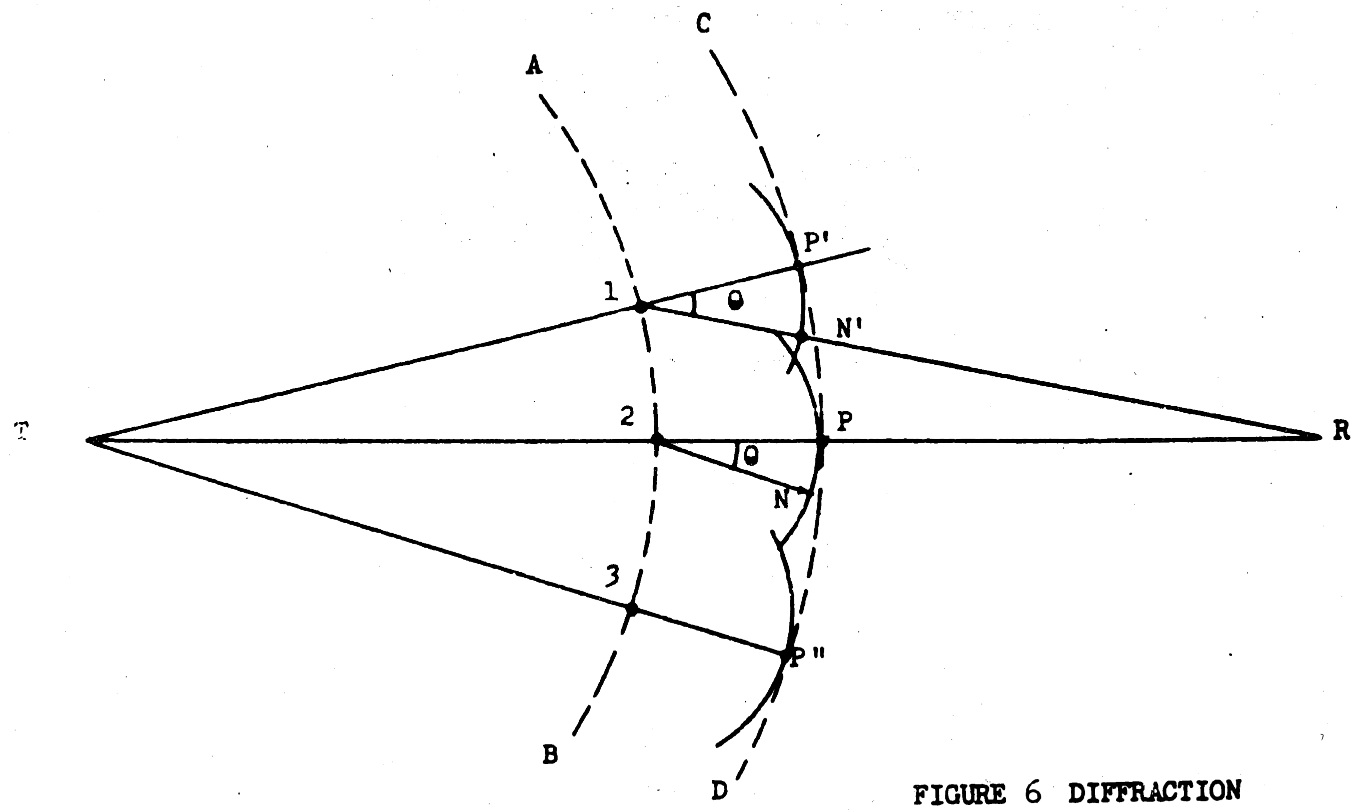


FIGURE 6 DIFFRACTION

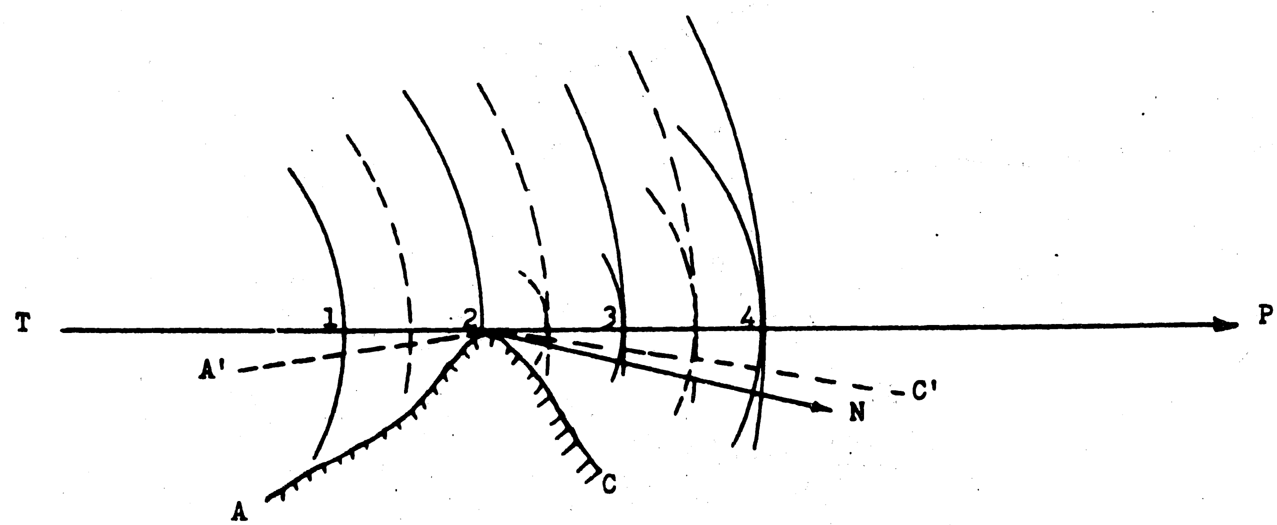


FIGURE 7 DIFFRACTION OVER A HILL

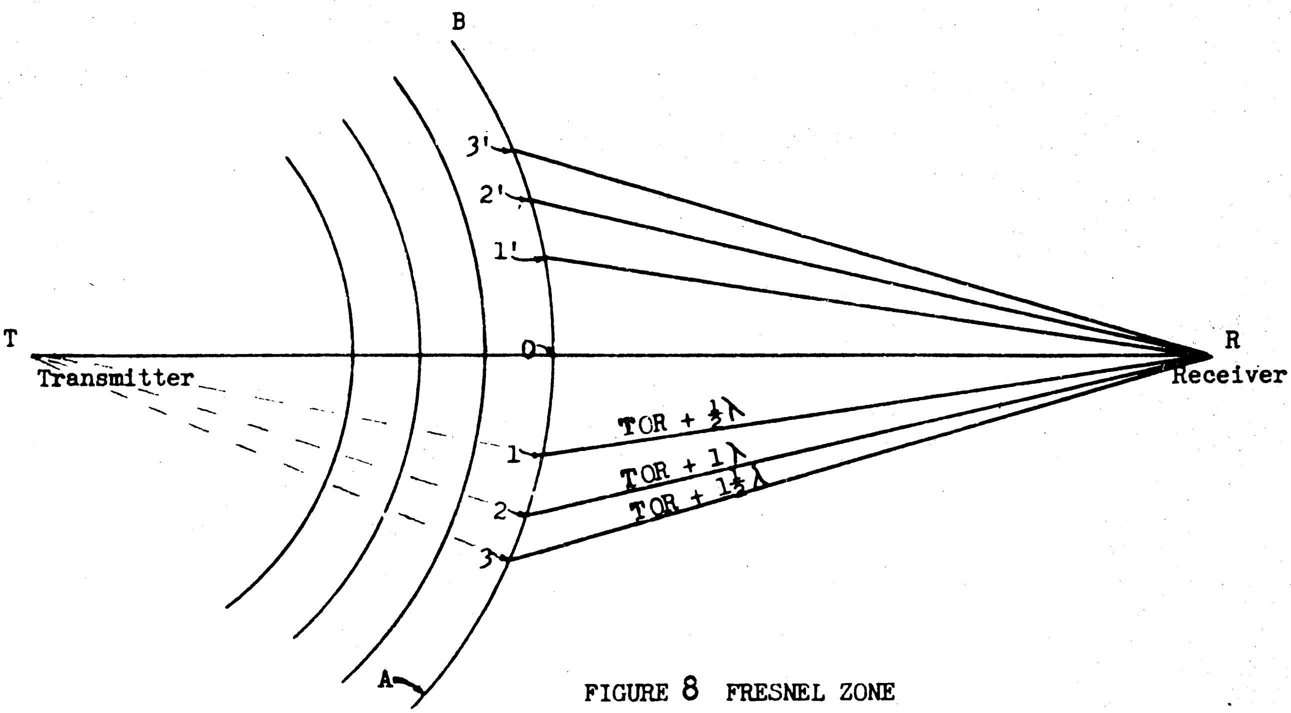


FIGURE 8 FRESNEL ZONE

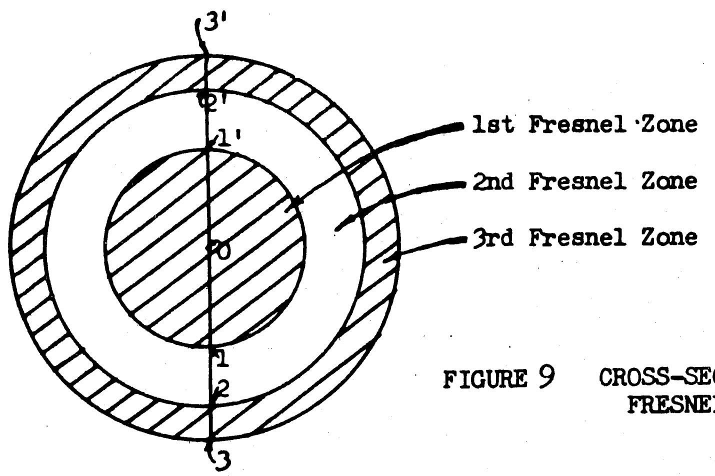


FIGURE 9 CROSS-SECTION OF FRESNEL ZONE

Cross section of wave front AB

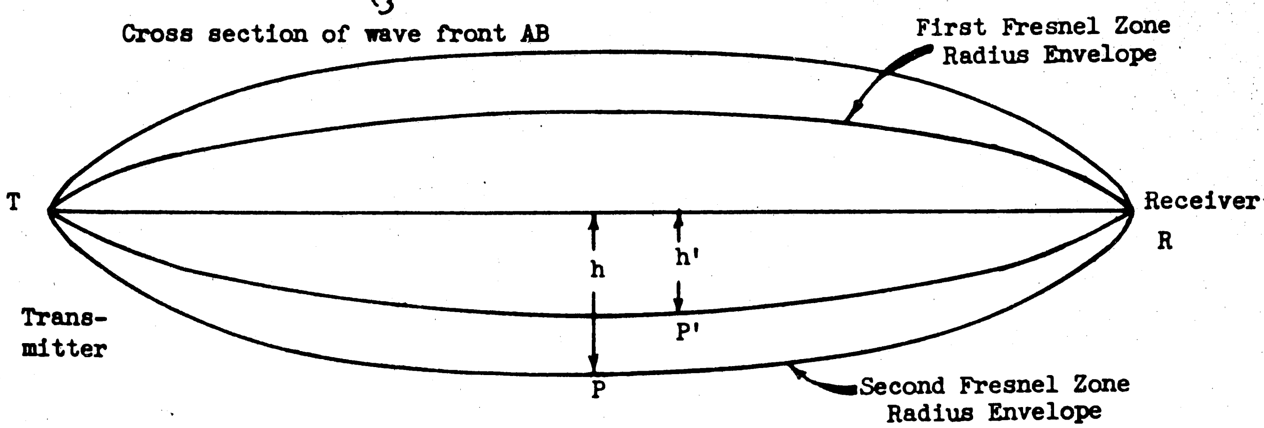


FIGURE 10 FRESNEL ZONE ENVELOPES

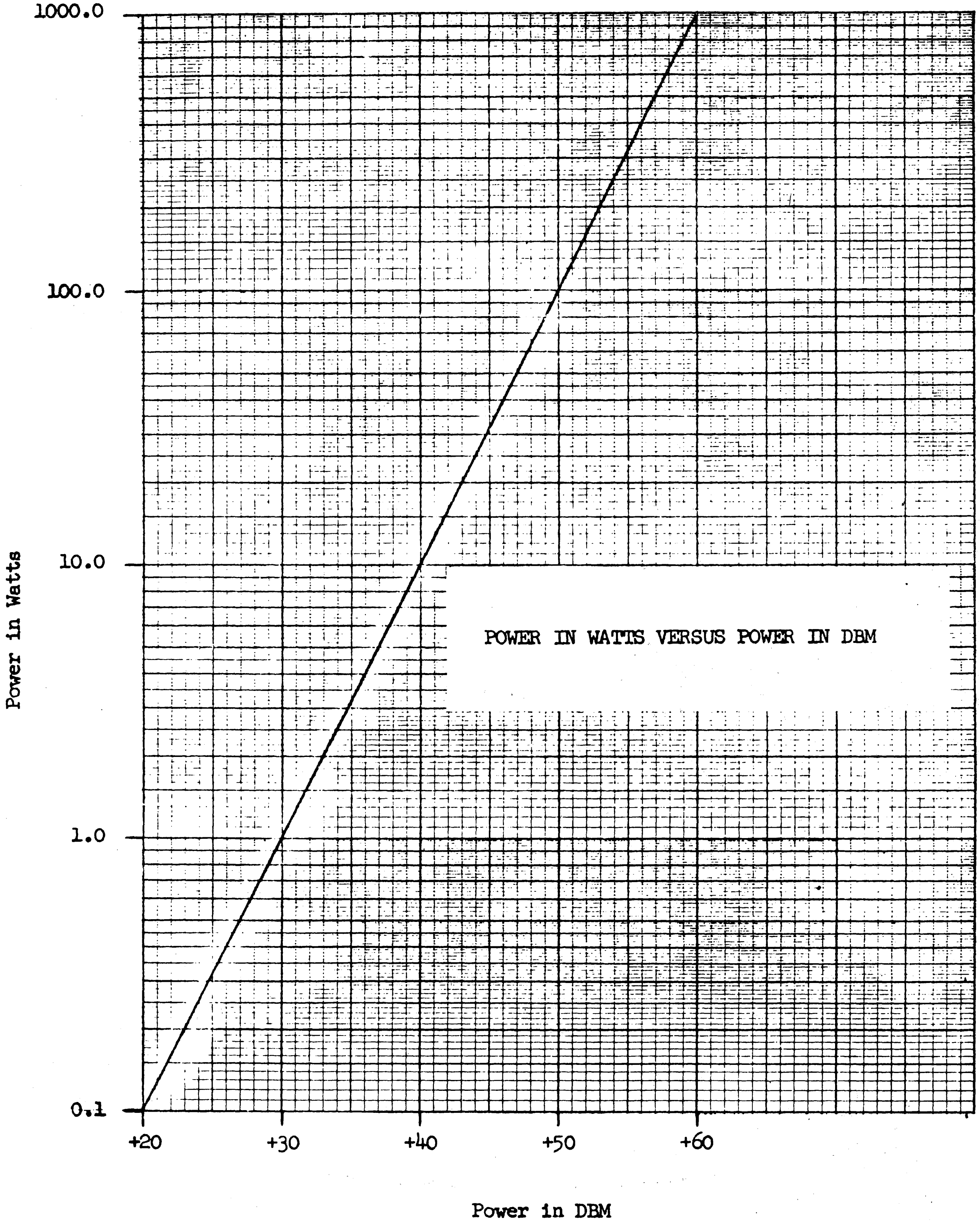
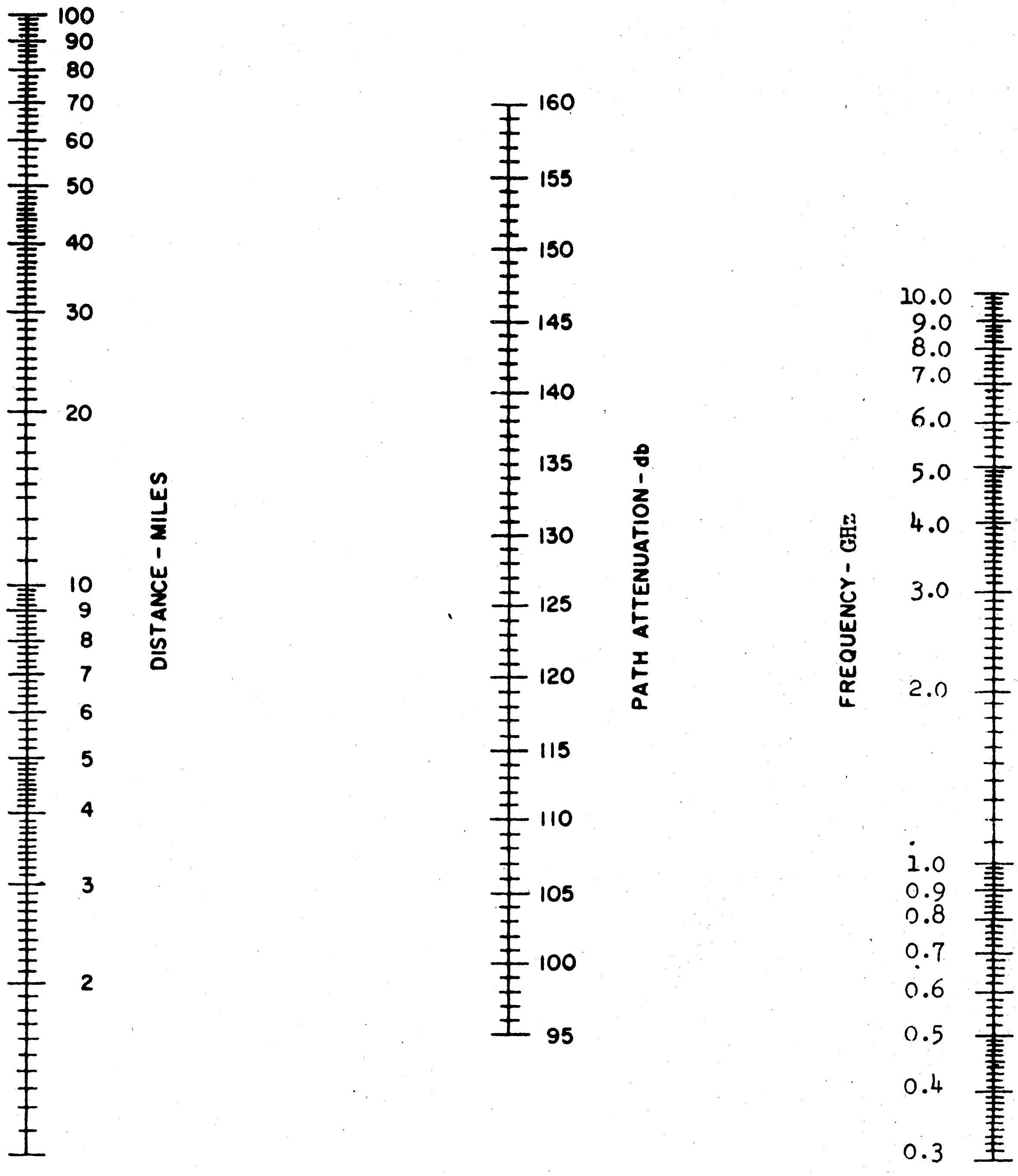

1000.0
100.0
10.0
1.0
0.1
Power in Watts
POWER IN WATTS VERSUS POWER IN DBM
+20
+30
+40
+50
+60
Power in DBM

FIGURE 11



FREE SPACE PROPAGATION PATH ATTENUATION BETWEEN ISOTROPIC ANTENNAS

Figure 12