RADIO ENGINEERING

MOBILE RADIO

ESTIMATES OF EXPECTED COVERAGE

CONTENTS PAGE

1. GENERAL

1.01 This section describes a computational method for estimating the coverage performance of FM land vehicular mobile and VHF maritime radio systems. Fundamental aspects of radio propagation are combined with empirical concepts and conclusions based on judgment and experience to culminate in a practical working method which permits some recognition of the variety of factors of significance in coverage performance. The resulting method is intended to be useful both for estimating the coverage of systems of specified design and for developing system designs to furnish desired coverages. While the principal consideration is that of two-way coverage between base and mobile stations, information is included for mobile-to-mobile and base-to-base transmission estimates, which are of interest in some instances.

1.02 In broad terms, the method described is one of subtracting from the effective radiated power of the transmitting station the computed loss of the transmission path to the receiver for derivation of the received signal power. This power is then compared with the signal power level needed to override electrical noise at the receiver site for an indication of the expected transmission performance. Alternately, signal power requirements at a receiving location are used to estimate the maximum path loss which may be tolerated with a given radiated power, or to determine the radiated power needed with a given path loss. In either case, the major effort involved is that of estimating the path loss.

1.03 Except under idealized conditions, path losses, which are the principal factor, are not amenable to precise calculation. Also, electrical noise levels at receivers and the resulting levels of required signal power vary widely, and, in the absence of measurements, are not known with accuracy. As a consequence, the procedures described in this section should be regarded as constituting a useful guide to the design of mobile systems, but not as a substitute for actual field tests where a precise or completely reliable evaluation is required. Caution should be exercised in accepting computed coverages where these seem incompatible with experience in similar situations, or where particular circumstances are judged to add an unusual degree of uncertainty.

1.04 Specific information for evaluating each of the factors which enter into estimates of coverage performance is given in Parts 4 through

8. Preceding this in Part 2 is a brief outline of relevant propagation theory, followed in Part 3 by a description of the method by which the subsequent information is intended to be applied. An illustrative example, some convenient nomographs, a discussion of special situations, and references to related published material are given in concluding Parts 9 through 12.

1.05 Information in this section was formerly covered in Section 940-200-103.

2. PROPAGATION THEORY

2.01 It is helpful, as a starting point, to consider the transfer of energy from one antenna to another over plane earth. This can be represented by the four transmission "lines" shown in Fig. 1. The direct wave, or free space wave, is shown by line 1 and the wave reflected from the ground is shown by line 2. In the mobile services, the ground-reflected wave is usually destructive in that it arrives with some phase opposition to the direct wave. With great antenna heights, as in air-to-ground service, the reflected wave may either cancel or aid the direct wave. The surface wave, shown by line 3, consists of the electric and magnetic fields associated with the current induced in the ground and hence its magnitude depends on the ground constants and the type of polarization. The sum of these three paths, taking into account both magnitude and phase, is called the ground wave.

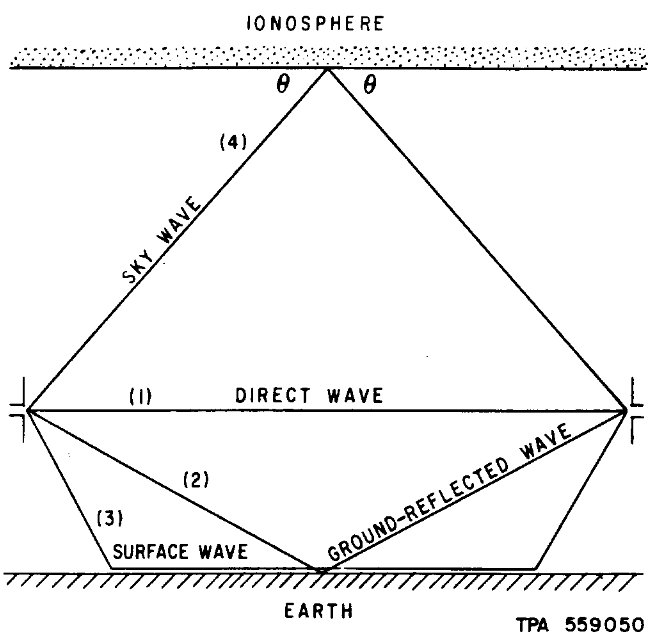

Fig. 1—Transmission Paths Between Two Antennas

The three components are not actually separate entities but are merely considered to exist in order to facilitate the analysis of propagation over a plane earth. The sky wave path denoted by line 4 depends on the presence of an ionized region, called the ionosphere, which reflects back to earth some of the energy that otherwise would be lost in outer space. Sky wave transmission is generally confined to frequencies under about 60 MHz, and thus for mobile services is of interest only in the 40 MHz band. In this band, sky wave transmission is undependable except over short periods, and is of importance only to the extent that it constitutes a source of intermittent long-range interference, as discussed in Section 940-200-106.

2.02 Transition from the concepts applicable to ***plane*** earth to those for ***smooth*** spherical earth requires recognition of the effects of earth curvature. To do this, a radius of earth curvature 4/3 that of the actual radius is assumed as a means of accounting for the fact that refraction effects resulting from nonuniformity of the atmosphere normally tend to bend waves around the earth's curvature. Actually, this effect varies quite widely with atmospheric conditions, but these variations are of small consequence at distances as short as those usually of interest in land mobile service. Also, since the concept of a direct and a ground-reflected wave loses meaning at distances for which earth curvature blocks line of sight, the theory of diffraction over a spherical surface must be applied. All of these concepts may be combined and shown by simple graphs of smooth earth propagation with distance. This is done in Part 5. At distances far beyond the horizon, the forward scatter mode of propagation becomes controlling. This is of no interest for mobile service since the losses at such distances require antenna gains and transmitter powers well in excess of those which are practical for this service.

2.03 For most situations in the mobile service, actual transmission losses exceed those for propagation over smooth earth. This results principally because of topographic irregularities, but the presence of buildings, trees, and other objects is frequently a significant cause. This requires the addition of what may be termed "obstruction loss" to the smooth earth loss. The added loss resulting from obstructing hills and similar opaque objects may be estimated from the theory of knife-edge diffraction, a simplified version of which is presented in a readily usable form in Part 7B.

Building and tree conditions are difficult to define and, moreover, their effects cannot be estimated by any known practical method of computation. Accordingly, these must be taken into account solely on the basis of experimental data. Information for doing this, in an approximate manner, is given in Parts 7C and 7D.

2.04 For mobile system considerations, it is convenient to describe propagation in terms of path loss, or the loss between the transmitting antenna at one terminal of the radio path and the receiving antenna at the other. In this section, all path loss information is related to the use of half-wave dipole antennas at both terminals as a common reference condition. Specifically, then, the path loss is a ratio of (a) the signal power available to a matched receiver from a dipole and (b) the power input to the transmitting dipole antenna producing the signal. The half-wave dipole is used as a reference because it is the most familiar basic type in the mobile field. These path losses may, of course, be readily adjusted for any antenna type simply by adding or subtracting the loss or gain, with respect to a dipole, of the antenna in question. The ground wave path loss is reciprocal; that is, for any two antennas separated by any transmission path, the path loss is the same regardless of which antenna is used for transmitting and which for receiving. This fact often simplifies calculations for two-way mobile service. It does not mean, of course, that transmission performance is necessarily the same in both directions since this will be affected by the relative ambient noise conditions at the two terminals and by any disparity in transmitter powers.

2.05 In this section all power levels are expressed in terms of dB with respect to 1 watt, which is abbreviated as dBW. This permits the path loss in dB to be subtracted directly from the effective radiated power expressed in dBW to obtain the received signal power in dBW. In other literature, radio field strengths are commonly expressed in terms of microvolts per meter or, frequently, dB from 1 microvolt per meter. The relationship between received signal power, as used in this section, and field strengths in microvolts per meter is shown by the conversion chart of Fig. 2, and is explained as follows: A radiated field with an intensity of E microvolts per meter will induce in a favorably oriented half-wave dipole antenna an "open circuit" voltage of $\frac{E\lambda}{\pi}$ microvolts, where λ is the wavelength in meters. The maximum useful power that can be delivered to a receiver is represented by one-half this induced voltage impressed across a receiver having an input resistance matching the radiation resistance of the antenna. Ideally, the resistance of a dipole is 72 ohms, but practical dipoles are typically nearer 50 ohms. The maximum received signal power assuming 50 ohms is $\left(\frac{E\lambda 10^{-6}}{2\pi}\right)^2 \frac{1}{50}$ or $\frac{E^2\lambda^2}{1974}10^{-12}$ watts. In dBW this is $20\ \text{LOG.}\frac{E\lambda}{44.4} - 120$ or, in terms of the frequency in megahertz rather than wavelength, $20\ \text{LOG.}\frac{6.75E}{f(\text{MHz})} - 120$.

3. COVERAGE ESTIMATING METHOD

3.01 Strictly speaking, the coverage of a land mobile system can be expressed only in statistical terms as, for example, some stated percentage of possible car locations at which transmission is satisfactory. This is because under most practical conditions the path loss between base and mobile stations does not change with distance in a smooth or uniform manner, but instead undergoes abrupt and frequent excursions above, and sometimes below, the smooth earth values. This results from the shadowing and reflecting effects of hills, trees, buildings, and other objects. These effects fall into two categories: (1) gross effects, caused by prominent terrain features which typically influence path losses over a large area and (2) fine-grain effects resulting from interference patterns set up by objects in the immediate vicinity of the mobile station and producing appreciable variation in path loss within distances of several feet. Thus, it is usually impossible to draw a distinct boundary separating areas in which all points are covered and those with no coverage at all. Transmission paths over water, as in VHF maritime service, may of course be essentially free from such variables, and the coverage more susceptive to precise definition.

3.02 Information in this section recognizes these terrain and obstacle effects, but not in a manner which permits coverage estimates to be associated with any specific statistical index. Gross effects are evaluated specifically for the situation at hand in each individual instance, and

HALF-WAVE DIPOLE ANTENNA
50 Ω

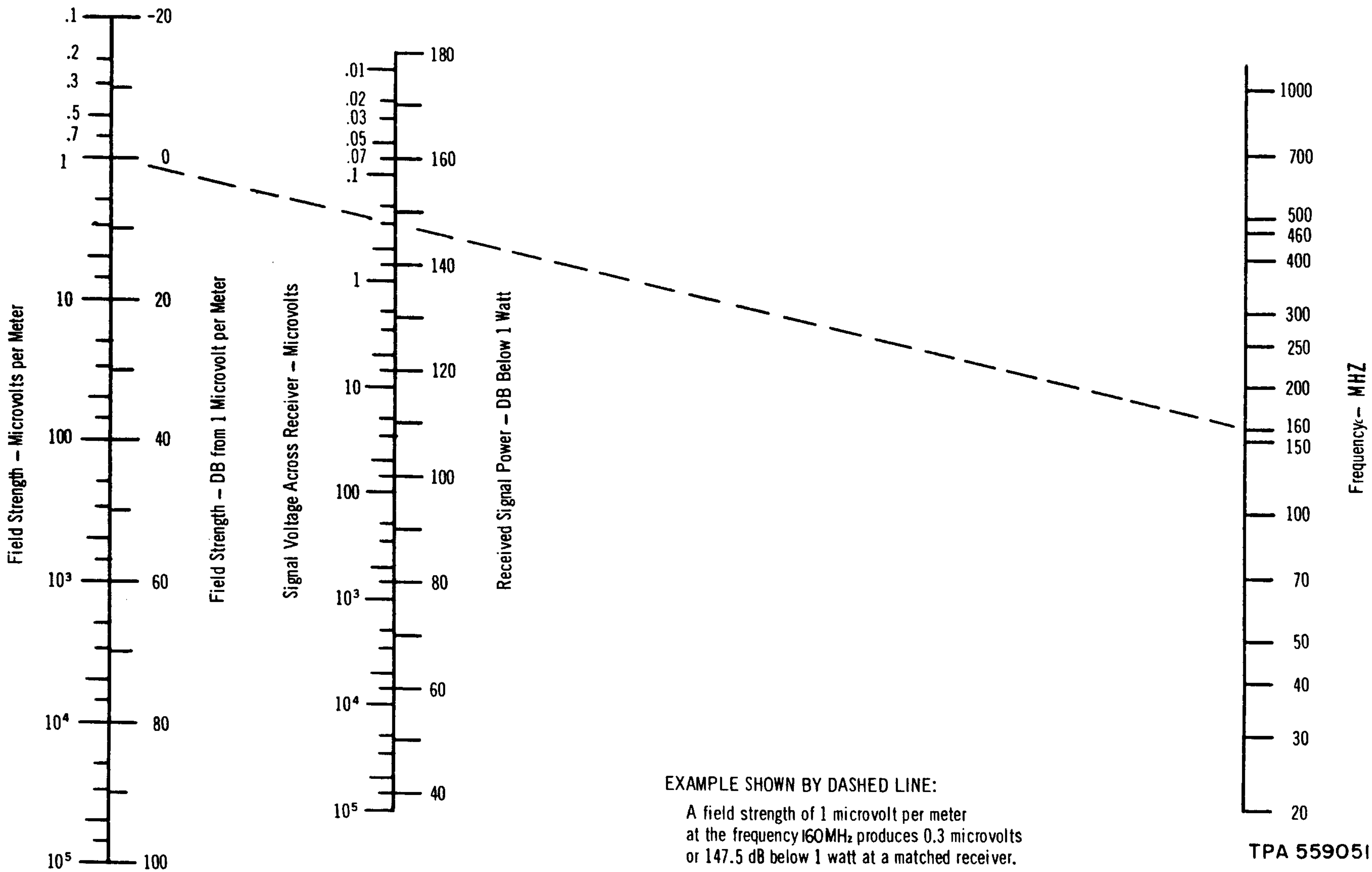

Fig. 2—Relationship Between Field Strength and Received Signal Power

order-of-magnitude allowances representing median losses are used for fine-grain effects. The use of median losses is a reasonable procedure so long as it is assumed that the mobile station is in motion and is using frequency modulation. This, of course, is typically the case. The path loss changes continually as the vehicle moves about, and the fast-acting AGC action obtained automatically with FM minimizes the effect on the listener of these fluctuations. In judging talking performance, the use of median path losses is accompanied by the use of median values of required received signal power. The end result is an estimating method which has been found to yield quite useful indications of coverage areas. The degree of reliability cannot be pinpointed but is reasonably high.

3.03 In broad terms, the method described herein consists of computing path losses between a base transmitter or receiver and mobile stations at a number of selected outlying points throughout the area of interest. Estimates of the received signal power are made for each point, and these are compared with the signal powers judged to be necessary for an acceptable grade of transmission. With these calculated indications of the coverage performance at specific points as a basis and with the aid usually of topographic maps, the coverage of adjoining areas is estimated by considering the changes in path loss likely to attend a move in location. A little familiarity with the manner in which path losses vary enables this to be done largely by making intuitive comparisons, supplemented perhaps with some spot-check calculations. The entire coverage area of a base station is estimated by application of this procedure around the compass or as needed. In flat or uniformly rolling terrain, the coverage area may be closely circular in outline, and its size estimated from only a few calculated points. In mountainous terrain, the coverage area will typically have an irregular boundary, the determination of which requires a relatively large number of calculated points. In the latter, too, it is frequently unrealistic to picture coverage by a single line on a map because of the presence of deeply shadowed pockets in areas otherwise satisfactorily covered.

3.04 The key to good application of this method lies first of all in the selection of points for computation. These should be chosen from several standpoints.

(a) To permit evaluation of the effects on propagation of the topographic features of the area.

(b) To recognize the presence of built-up areas, (with tall buildings) and heavily wooded rural areas.

(c) To include locations where high electrical noise interference levels are likely to prevail, as a result of highway traffic density, industrial operations, or other activity.

(d) To consider the traveling habits of mobile users. Heavily traveled locations are important; points inaccessible to vehicles or unlikely to be traveled may be ignored.

With regard to (a), evaluation of the effects of topography requires examination of the profile of the terrain along a radial path from the base station to each selected point. This is discussed in detail in Parts 6 and 7. In general, the position of these radials is chosen so that each is representative, from a propagation standpoint, of a sector of the area of interest which differs in some important respect from other parts of the area. It is frequently helpful to include a number of points on a common radial. The number of radials required to give a picture of the whole coverage area depends largely on the topographical variations present within the area. A few radials may suffice for a station in flat country whereas a large number may be required with hilly, irregular terrain. Few situations are alike, but each is considered with the common objective of estimating a coverage area on the basis of the coverage, or lack thereof, calculated at a number of representative points.

3.05 Path losses between a base station and selected points are calculated by adding directly in dB the smooth earth path losses from Part 5, the small-sector median adjustment, and the shadow loss for the intervening terrain from Parts 7A and 7B and, where appropriate, the losses associated with buildings or heavy tree conditions from Part 7C or 7D. The sum, adjusted if necessary for antenna gain as described in paragraph 3.06, is regarded as the median path loss in the local area of the computed point. Use of the smooth earth path loss charts of Part 5 requires consideration of the "effective" antenna height at the base station. This height may be either more or less than the physical height above ground at the base station site since it is influenced markedly by topography and other factors in the vicinity of the base station. Part 6 is devoted to procedures, largely empirical, for determining the effective height to be used in various practical situations.

3.06 Since all path loss data in this section assume half-wave dipole antennas at both terminals as a reference condition, adjustments are necessary where actual antennas have gain or loss with respect to a dipole. Several aspects of this are discussed below.

(a) ***At base transmitting stations,*** the gain of the antenna is most conveniently accounted for by including it in the effective radiated power as discussed in Part 4. Alternately, it may be included as a reduction of the path loss as read for dipoles.

(b) ***At base receiving stations,*** antenna gain increases the signal power delivered to the receiver and may be treated as a corresponding reduction of the path loss. However, other considerations become necessary because the net benefit in transmission performance can range from zero to some value well in excess of the rated antenna gain, depending on the noise situation at the receiving site. No benefit results when the gain in signal power delivered to the receiver is offset by a corresponding increase in the received noise power. This will occur at locations where external noise is controlling, rather than set noise, and the location of noise sources is such that the noise arrives from directions which are encompassed by the principal pattern lobe of the gain antenna. In such instances, inclusion of the antenna gain in the path loss would need to be accompanied by a corresponding increase in the required signal power with no net effect. Benefit is obtained, on the other hand, if the principal external noise arrives at angles outside the pattern lobe or if external noise is sufficiently low in intensity for set noise to prevail. The extent to which the antenna gain exceeds any accompanying increase in received noise power represents a net improvement. In some situations, external noise picked up by a gain antenna may be lower than that which would be received with a dipole, thereby leading to a twofold improvement in performance. This is discussed in paragraph 8.09.

(c) ***At mobile stations,*** the conventional quarter-wave roof-mounted whip antenna may be regarded as equivalent to a half-wave dipole. While under idealized conditions a whip is 3 dB poorer than a dipole, the practical situation at a vehicular installation makes this correction somewhat meaningless. The actual correction is difficult to determine, and will vary with different vehicles since the vehicle itself constitutes part of the antenna system. Generally, the correction is quite small compared to the uncertainties present in estimating path losses. A more serious source of error concerns a whip antenna mounted unsymmetrically with respect to a car's body since this does not radiate uniformly in all horizontal directions. Variations of about 15 dB have been measured for a 40-MHz whip on the rear fender of a passenger car. Information is not available for properly taking this into account. Very likely, however, the effect of this nonuniformity of pattern is often minimized by the presence of multiple signal paths resulting from reflections from hills, buildings, and other objects.

3.07 As noted previously, the computed received signal power which, in conjunction with the required signal power provides the basis for estimating transmission performance, is obtained simply by subtracting the path loss from the effective radiated power. A related consideration is the question of including in the calculations the loss of the receiving transmission line and of any filters or coupling arrangements connected between the antenna and the receiver input. This depends entirely on the prevalence of external noise at the antenna site. In locations where external noise levels exceed the internal set noise in the receiver by an amount equal to or greater than the losses between the antenna and the receiver, such losses may be neglected entirely since they have no net effect on the transmission performance. Where this is not the case, these losses must be regarded as being equivalent to a corresponding increase in the path loss. Gain, as in a receiver bridging amplifier, may be treated as a reduction of the path loss only if the overall effect, considering both external and internal noise levels and the circuit losses, is found to constitute an improvement in receiver sensitivity.

4. EFFECTIVE RADIATED POWER

4.01 The effective radiated power of a transmitting station, in watts, is defined as the product of the antenna power input, in watts, and the antenna power gain. The first of these factors is equal to the transmitter output power minus the losses between the transmitter and the antenna. The latter factor is the gain, in the direction of interest, of the particular antenna in use referred to the radiation of a half-wave dipole in its equatorial plane. When transmitter output power is expressed in dB with respect to one watt (dBW), antenna gain and transmission line and other losses in dB are added algebraically to obtain effective radiated power in dBW.

4.02 The transmitter output power may be determined from manufacturer's specifications or from measurement. It is often realistic to discount the rated power somewhat if experience indicates that some falloff is to be expected during periods between maintenance visits. The power in dBW is 10 LOG. of the power in watts, and may be calculated or read directly from Fig. 3.

4.03 The loss of a transmission line is ordinarily assumed to be the value obtained by applying the manufacturer's rating of dB per 100 feet for the frequency of interest to the actual physical length present. The losses of filters, duplexers, or other elements are likewise usually assumed to be as rated.

4.04 Usually dependence must be placed on the manufacturer's information concerning antenna gain. Some judgment may be called for at times, however, as explained below.

(a) The gain used should be that which is referred to a half-wave dipole in space, not the hypothetical isotropic antenna which is sometimes used as a basis and which is 2.15 dB poorer than the dipole in the best direction. Advertised gains which fail to state their reference base should be questioned.

(b) Any antenna gain is confined to certain directions, and is provided at the expense of reduced radiation in other directions since the total power radiated overall directions is a constant. Differences in the gain at different directions of interest must be considered. With vertically stacked antenna elements, the horizontal pattern of each is retained essentially, but both high- and low-angle radiation is reduced. With horizontally disposed elements or with reflectors, the radiation varies with the azimuth.

(c) Antennas of types which are nondirectional in the horizontal plane may be expected to exhibit nonuniform azimuthal patterns when mounted to the side of a supporting tower or

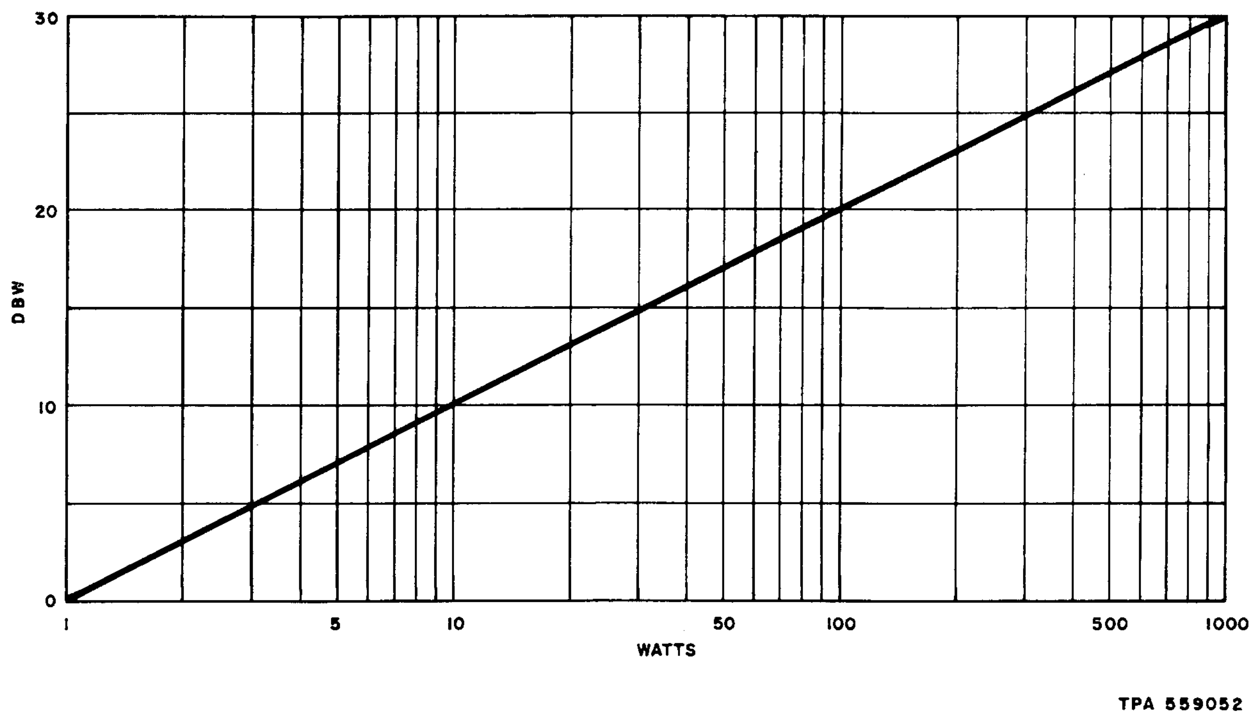

Fig. 3—Power in DBW Versus Watts

structure rather than in the clear on the top. This can lead to some gain in some directions and to rather large losses in other directions. These losses should be recognized in coverage estimates, but there is no general way of computing such pattern effects for the variety of tower forms and sizes. One solution is to use mounting arrangements which approach as closely as possible those for which some information is available. Several antenna manufacturers publish or can furnish the patterns of their antennas in some commonly encountered situations, and in some instances indicate ways of taking advantage of this effect to secure desired nonsymmetrical pattern shapes.

5. SMOOTH EARTH PATH LOSSES

5.01 The various factors which determine the transmission loss of radio frequency energy propagated over a smooth earth have been combined at each of several frequencies representative of the mobile bands, and the results are shown on the path loss charts of Fig. 4 through 9. Path loss in dB for vertical polarization is plotted as a function of the distance in statute miles separating base and mobile stations for a range of base station antenna heights. Each chart also shows the free-space path loss and the loss between two mobile stations. For distances within line of sight, these charts are based on ground wave propagation theory as developed by Burrows and Gray, and are in substantial agreement with the simplified presentation given in "Radio Propagation Fundamentals" by K. Bullington, which is listed as Reference (1) in Part 12. For distances beyond line of sight, path losses are those indicated by Bullington's smooth earth diffraction theory as presented in Fig. 6 of that same reference. Comparisons with path loss information contained in other propagation literature may be expected to show small discrepancies, resulting from the somewhat different efforts of various workers to arrange and present propagation theory in a manner suitable for practical application. Such differences serve as a reminder that propagation calculations are for the most part not exact.

5.02 Several things about the path loss charts of Fig. 4 through 9 are of general interest.

(a) The free-space path loss line included on each chart represents the loss which would result if there were no surface or ground-reflected wave present. This line has a slope of 6 dB for each octave of distance, as a result simply of the radiated power being spread over four times the area. It indicates the lower limit of path loss since a fortuitous in-phase ground reflection is needed for any lower loss to occur, and a single such reflection cannot provide more than 6 dB improvement.

(b) All other curves on these charts include an allowance for the loss, which attends diffraction of a radio wave around the curvature of the earth, on the basis that atmospheric refraction is such as to effectively increase the earth's radius by a factor of 4/3. This loss increases with distance and with frequency. Without it, the plots would be straight lines with a slope corresponding to 12 dB of added loss for each doubling of the path length. A straight line drawn to coincide with any one of the curves at distances under a few miles and then extended across the chart with a 12-dB slope will represent the "plane earth" path loss with the designated antenna heights. This loss may sometimes be of interest in correlating these charts with other propagation literature.

(c) These charts do not show the signal fields which result from atmospheric reflections, commonly referred to as "over the horizon" or "tropospheric scatter" transmission. This mode of propagation is of no use in providing mobile system coverage because much greater transmitter power and antenna gain than is normally feasible would be necessary to overcome fading and provide reliable service. However, scatter signals are of interest in considering interference to mobile system receivers from distant stations since for some of the time they may result in path losses much lower than those indicated by diffraction theory. The charts should not be relied on for interference studies where the distance involved is well beyond line of sight and over about 40 miles if the diffraction-based path loss is more than about 40 dB greater than the free-space value. In recognition of this, dashed lines are used for appropriate portions of some of the curves on the charts. Information for estimating scatter path losses is widely available in propagation literature, including Reference (1) in Part 12.

(d) These path losses may be regarded as constant with time for the distances usually of interest in the mobile service. Diurnal and

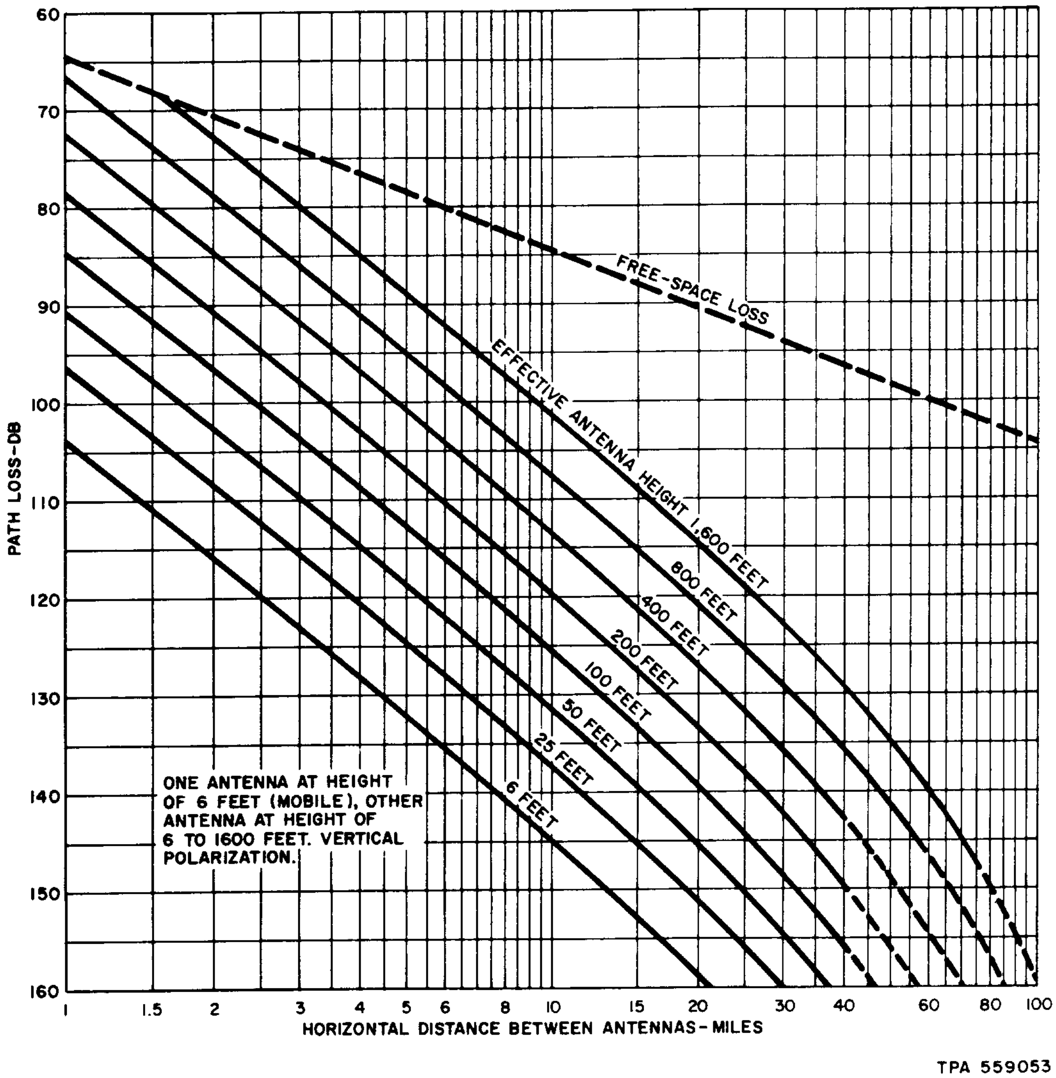

Fig. 4—Path Loss Between Half-Wave Dipoles Over Smooth Earth—40 MHz—Poor Soil

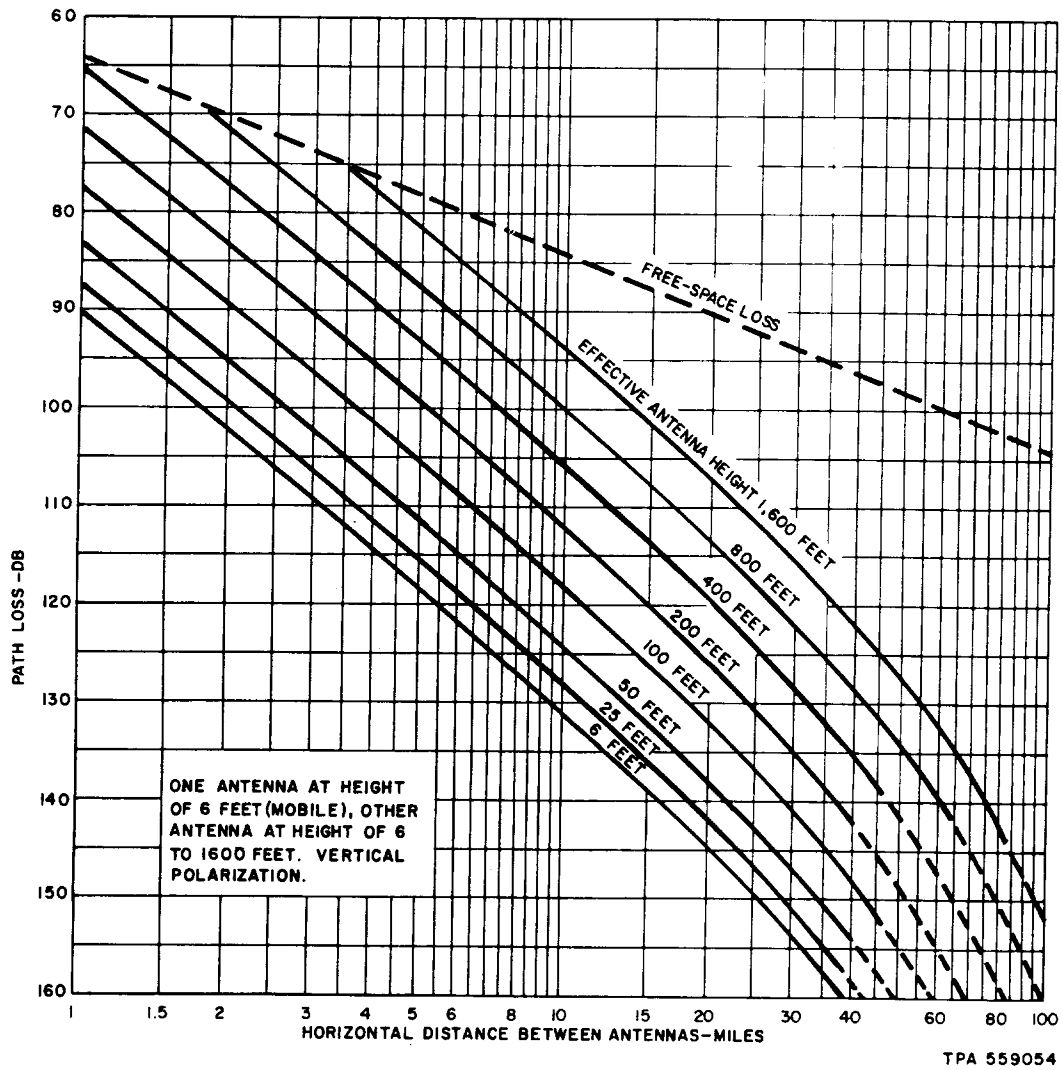

Fig. 5—Path Loss Between Half-Wave Dipoles Over Smooth Earth—40 MHz—Good Soil

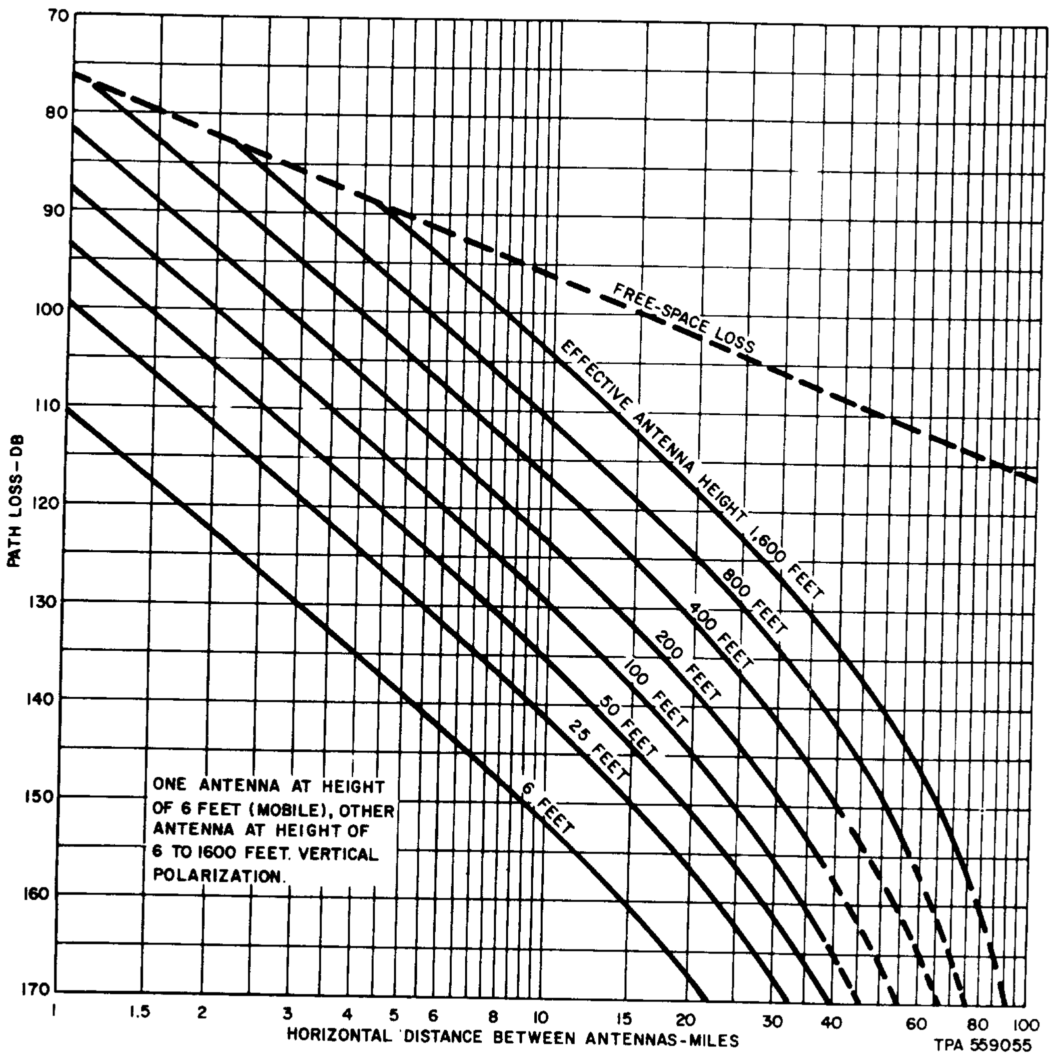

Fig. 6—Path Loss Between Half-Wave Dipoles Over Smooth Earth—160 MHz—Land

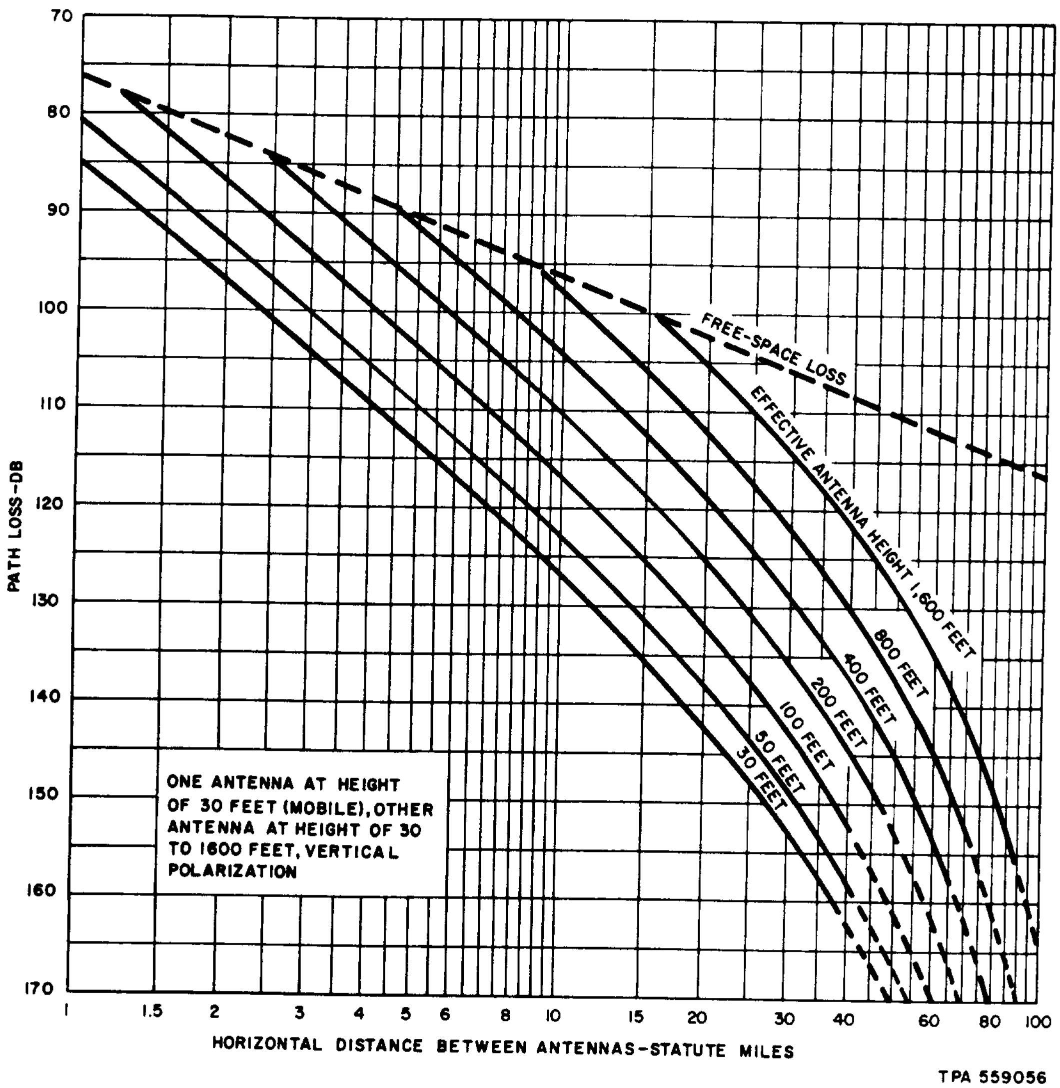

Fig. 7—Path Loss Between Half-Wave Dipoles Over Smooth Earth—160 MHz—Fresh Water

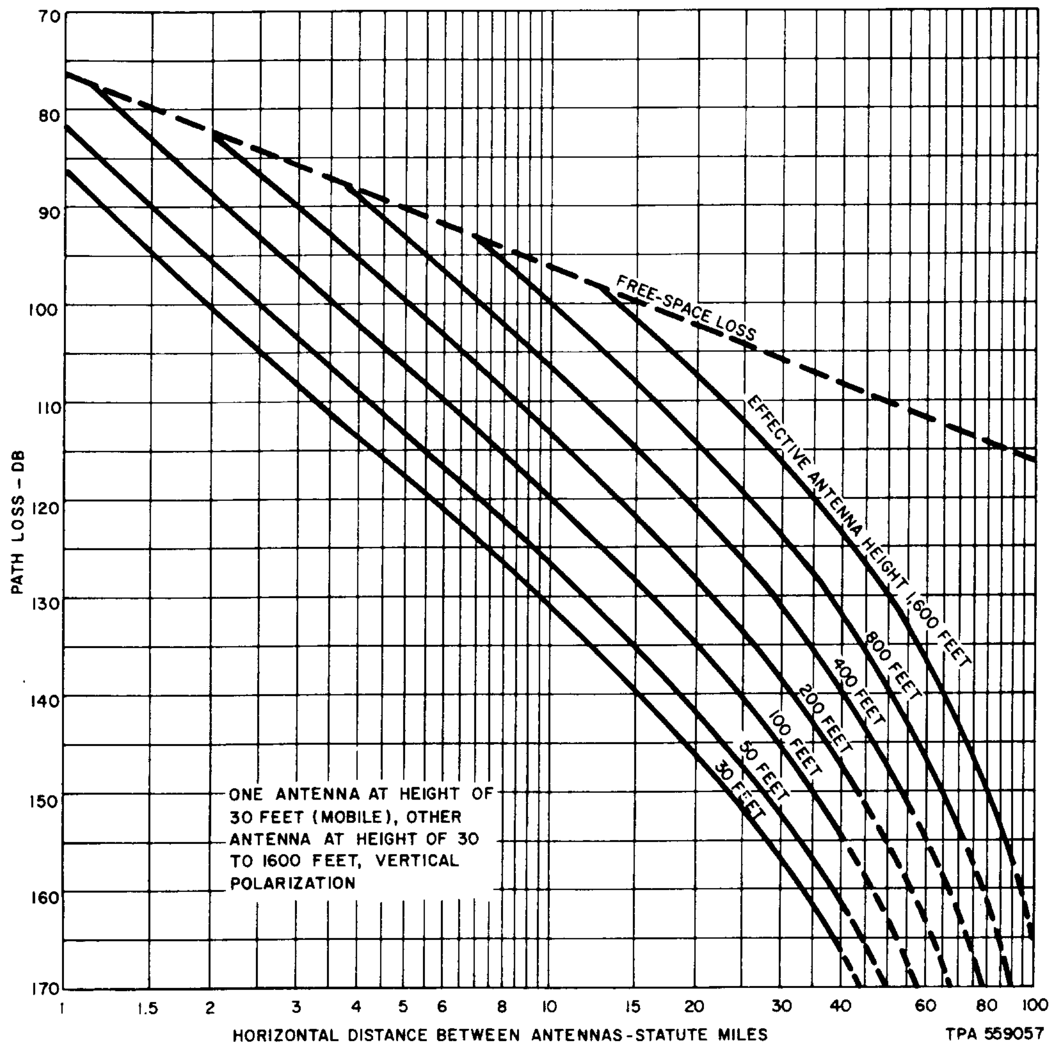

Fig. 8—Path Loss Between Half-Wave Dipoles Over Smooth Earth—160 MHz—Sea Water

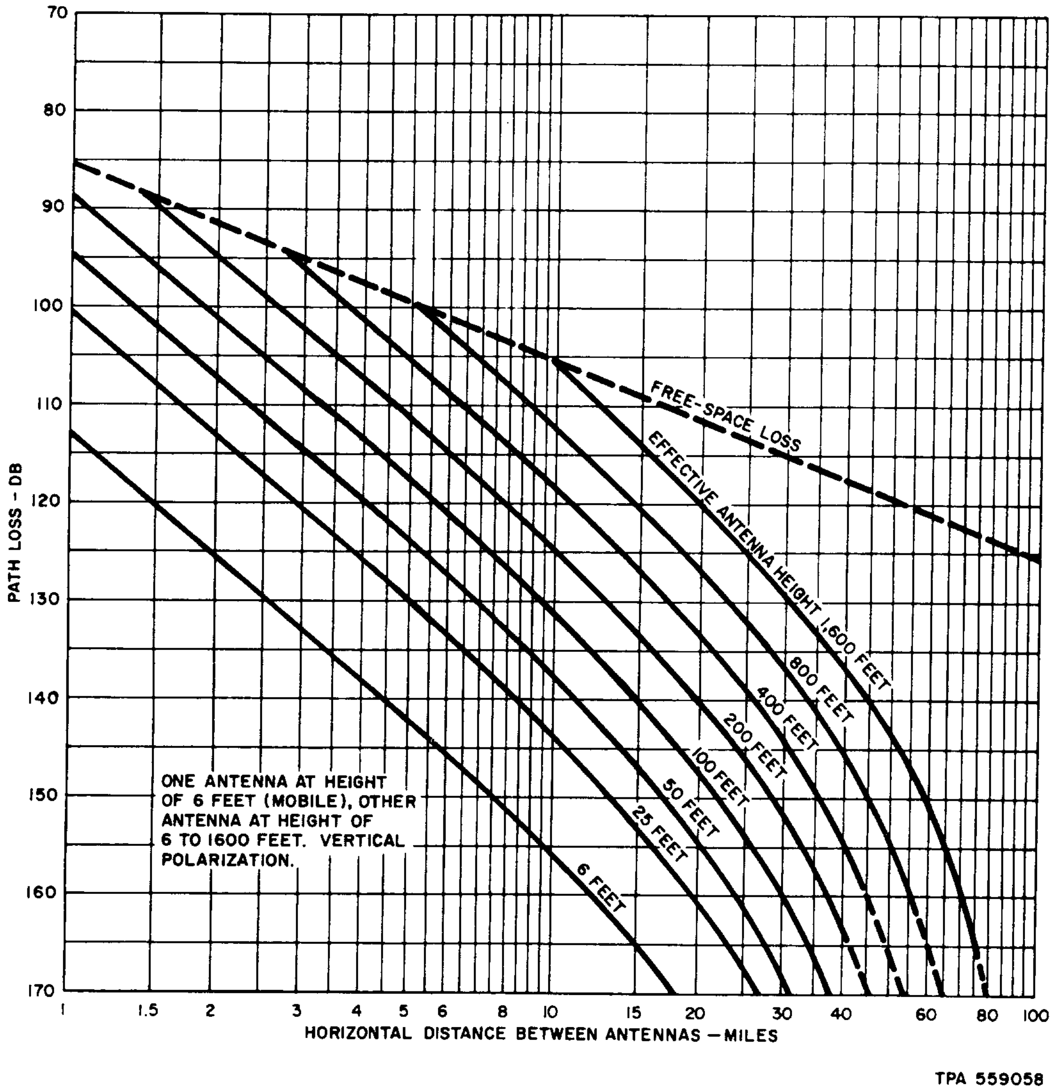

Fig. 9—Path Loss Between Half-Wave Dipoles Over Smooth Earth—460 MHz—Land

seasonal variations may be detected at 30 or 40 miles, but significant changes are confined to longer distances.

5.03 Where one or both antennas are close to the ground in terms of wavelengths, the surface wave is a principal factor, and path losses are affected appreciably by the conductivity and dielectric constant of the ground along the transmission path. Soils of good conductivity, such as clay, loam, and swampland, result in lower losses than poorly conducting sand, gravel, or rock. In view of this, for 40 MHz, separate path loss charts are provided for "good" soil (dielectric constant of 30, conductivity .02 mhos per meter) and "poor" soil (dielectric constant of 4, conductivity .001 mhos per meter). Losses for soils of intermediate character may be estimated by interpolation. Typical soil conductivities for various sections of the country are shown on a map, Fig. R3 in Part 3 of the FCC rules. In higher frequency mobile bands, differences in loss are small for propagation over land with antennas at heights of 6 feet or more, and a single chart of the average path losses for good and poor soil is sufficient. Sea water has very high conductivity and dielectric constant with the result that, at the lower frequencies, path losses are substantially less than those for land paths if either antenna is at a low elevation. This effect is present to some extent at 160 MHz, and a separate path loss chart, Fig. 8, is included for use in considering VHF maritime coverage over sea water. Fresh water, although comparable to land in conductivity, has the same high dielectric constant as salt water with the result that path losses with low antennas are also less than those over land. These are shown by the chart of Fig. 7 for the VHF maritime band.

5.04 The charts of overland propagation, Fig. 4, 5, 6, and 9, give computed path losses over smooth earth between two vertical half-wave dipole antennas, one at heights ranging from 6 feet to 1600 feet, and the other at a height of 6 feet. The latter is intended to be generally representative of an installation on a motor vehicle. As discussed in paragraph 3.06(c), the customary whip antenna at a mobile station may be regarded as roughly equivalent to a dipole. Accordingly, path losses for base-to-car transmission may be determined directly from the curve for the base station antenna height involved, or from interpolation of the curves for heights above and below the height in question. Car-to-car path losses may be read from the 6-foot curve. The charts of Fig. 7 and 8 give similar computed path losses for salt and fresh water, assuming that one antenna is at a height of 30 feet. This height, rather than the 6-foot height assumed for the land charts, is used in order to be more nearly representative of typical shipboard installations.

5.05 In situations where the antenna at neither terminal is at a height of 6 feet in the case of overland paths or at 30 feet in the case of overwater paths, the path loss as read from these charts should be corrected. This will occur, for example, on a path between two base stations or, in the land mobile service, on a path between a base station and a car with its effective antenna height enhanced by being situated on the brow of a hill. Figures 10 and 11 are provided for this purpose subject to the limitations discussed in paragraph 5.06. These plots show corrections applicable to each of the path loss charts for heights ranging from 3 feet to 400 feet. In applying these corrections, it is important to recognize the fact that the minimum path loss possible, regardless of antenna heights, is 6 dB less than the free-space loss. Where the use of a height correction from Fig. 10 or 11 results in a path loss more than a few dB less than the free-space loss for the distance in question, the correction should be discounted accordingly.

5.06 For distances beyond line of sight, the use of Fig. 10 and 11 in conjunction with the path loss charts is not the most accurate way of estimating path losses between elevated antennas, because the gain resulting from increased antenna height is no longer independent of distance. It is preferable to disregard the path loss charts and height corrections of this section and to use, instead, the method given in Fig. 6 in Reference (1) or (6) of Part 12. Line of sight, in statute miles, over smooth earth with 4/3 radius extends as far as $\sqrt{2H_1} + \sqrt{2H_2}$, where H_1 and H_2 are the heights in feet of the antennas at the two terminals.

5.07 In the marine field, a widely accepted method for computing overwater path losses at 160 MHz is that given in Appendix F of the report of Special Committee No. 19 of the Radio Technical Commission for Marine Services, dated February 21, 1956. It seems desirable to use this information

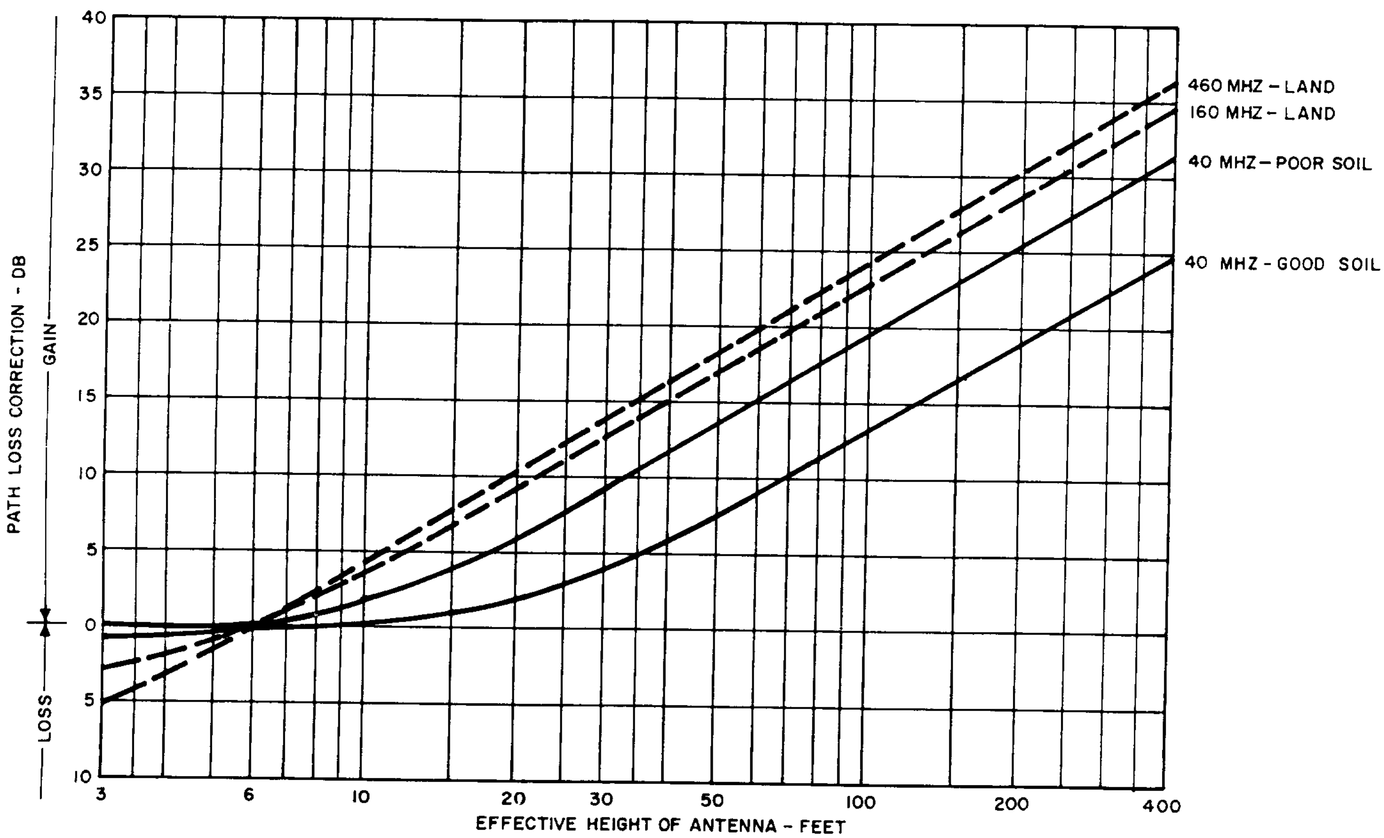

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Fig. 10—Path Loss Correction for Antenna Heights Other Than 6 Feet—Vertical Polarization—Over Land

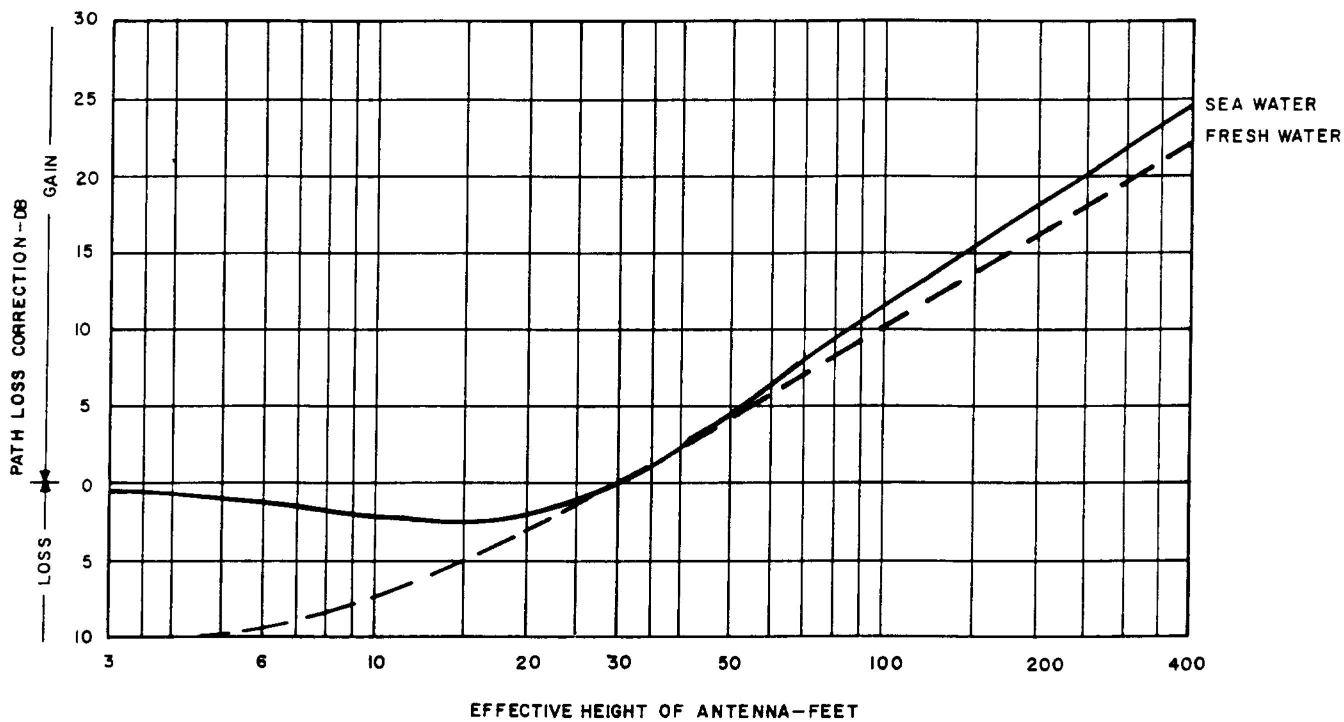

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Fig. 11—Path Loss Correction for Antenna Heights Other Than 30 Feet—Vertical Polarization—Over Water—160 MHz

rather than that given herein where collaboration is necessary with persons not having access to this section and where the authenticity of overwater coverage estimates is an issue. The two methods yield results differing by as much as 5 dB for some distances and antenna heights.

5.08 Comparative path losses over land and over water at 160 MHz are strongly dependent on antenna heights as can be seen by comparing the appropriate path loss and height correction charts. Path losses over water are not always lower than those for the same distance and antenna heights over land. If the antennas at both terminals of the path are at a very low height, path losses over water are much less than over land as is often assumed. With heights of 6 feet, for example, this difference is about 18 dB for sea water paths more than a few miles in length, and 7 dB for fresh water. As antenna heights are raised, this difference becomes less, and if both antennas are elevated several hundred feet, path losses become about the same. In the case of sea water, the path loss change with height is not uniform, as may be seen from Fig. 11, with the result that with one antenna at the assumed shipboard height of 30 feet, path losses are somewhat greater than those over land or over fresh water, unless the other antenna is very low. Path losses over fresh water with one antenna at 30 feet are practically the same as those over land if the antenna at the other terminal is elevated more than about 30 feet.

6. EFFECTIVE ANTENNA HEIGHTS

6.01 The base station antenna heights to be used with the path loss charts are the "effective" heights, or the heights for which the path loss is indicative of the manner in which the surface wave and the direct and ground-reflected waves pictured in Fig. 1 combine to form the total signal field. In practical situations involving terrain which is irregular or whose surface is occupied with buildings or other objects, the "effective" height which determines the path loss is frequently quite different from the physical height of the mast or structure supporting the antenna. Rigorous determination of the effective height is impractical if not impossible in many situations. The "height above average terrain" appearing in the FCC Rules serves as a broad index; however, this ignores some important aspects and is incompatible with the methods for estimating path losses presented in this section. A number of considerations which offer suitable basis for effective height estimates in a variety of situations are discussed in the following paragraphs.

6.02 In situations comparable to the ideal case of an antenna supported by a mast over smooth unobstructed terrain or water, the effective height is closely represented by the actual physical height of the center of the antenna above the ground or water. This is pictured in Fig. 12A-1. Where small terrain irregularities result in the immediate foreground being of somewhat higher elevation than the base of the mast, it is reasonable to regard the effective height as being the height of the center of the antenna above this higher ground as shown in Fig. 12A-2.

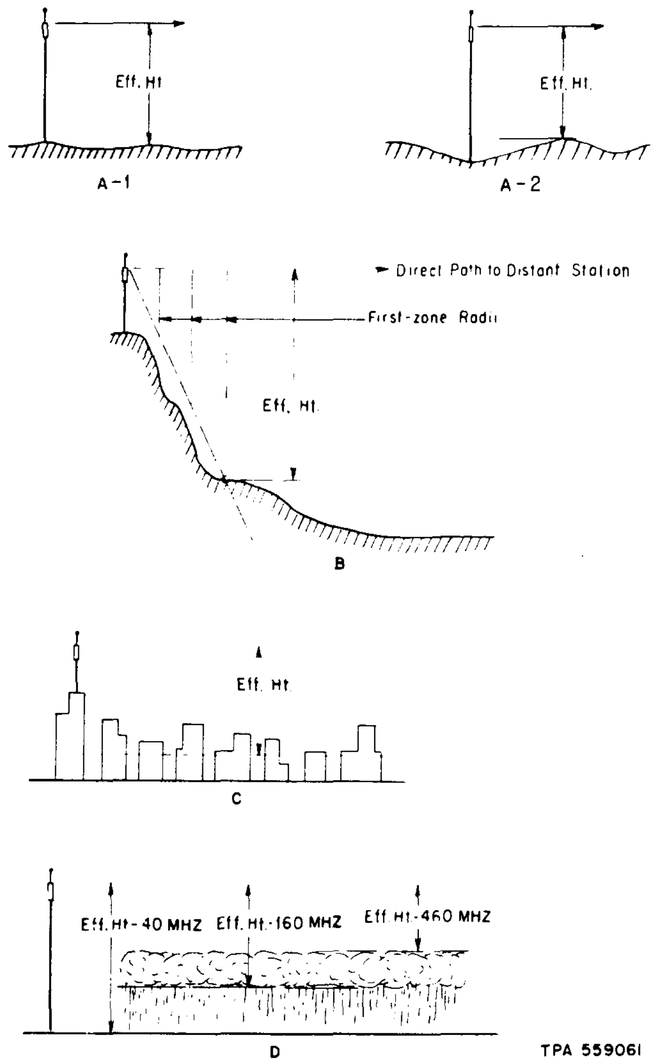


Fig. 12—Representative Terrain Features

6.03 Where the ground falls away in the immediate foreground as shown in Fig. 12B, the effective height of the antenna is usually greater than the height of the mast or supporting structure. A conservative way to estimate this increased height is to examine a topographic profile of the terrain along the path to the distant station, and to assume that the effective height of the antenna is the difference between its elevation and the ground elevation of the point on this profile where, moving away from the base of the antenna support, the ground first intrudes on the first Fresnel-zone radius. This radius represents the clearance necessary for reflections from the point in question to arrive at the antenna in phase with the direct wave. Plots of first Fresnel-zone clearance for points close to an antenna are given in Fig. 13 for each of the frequency bands considered in this section.

6.04 In applying the Fresnel-zone clearance method, the required clearances from Fig. 13 are subtracted from the elevation of the line representing the direct path from the antenna to the distant station as indicated in Fig. 12B. This direct path line may slope upward if a higher hill intervenes, or downward to a station in the valley, or may be horizontal as shown in the diagram. Effective heights determined in this manner are conservative inasmuch as a partial lack of Fresnel-zone clearance does not imply a total lack of height advantage. Hilltop sites which provide a large part of the optimum clearance may be assumed to increase the effective height by a large part of the difference in elevation between the top and bottom of the hill. The effective height will frequently be different for different radials from the same site because of dissimilar fallaway in various directions.

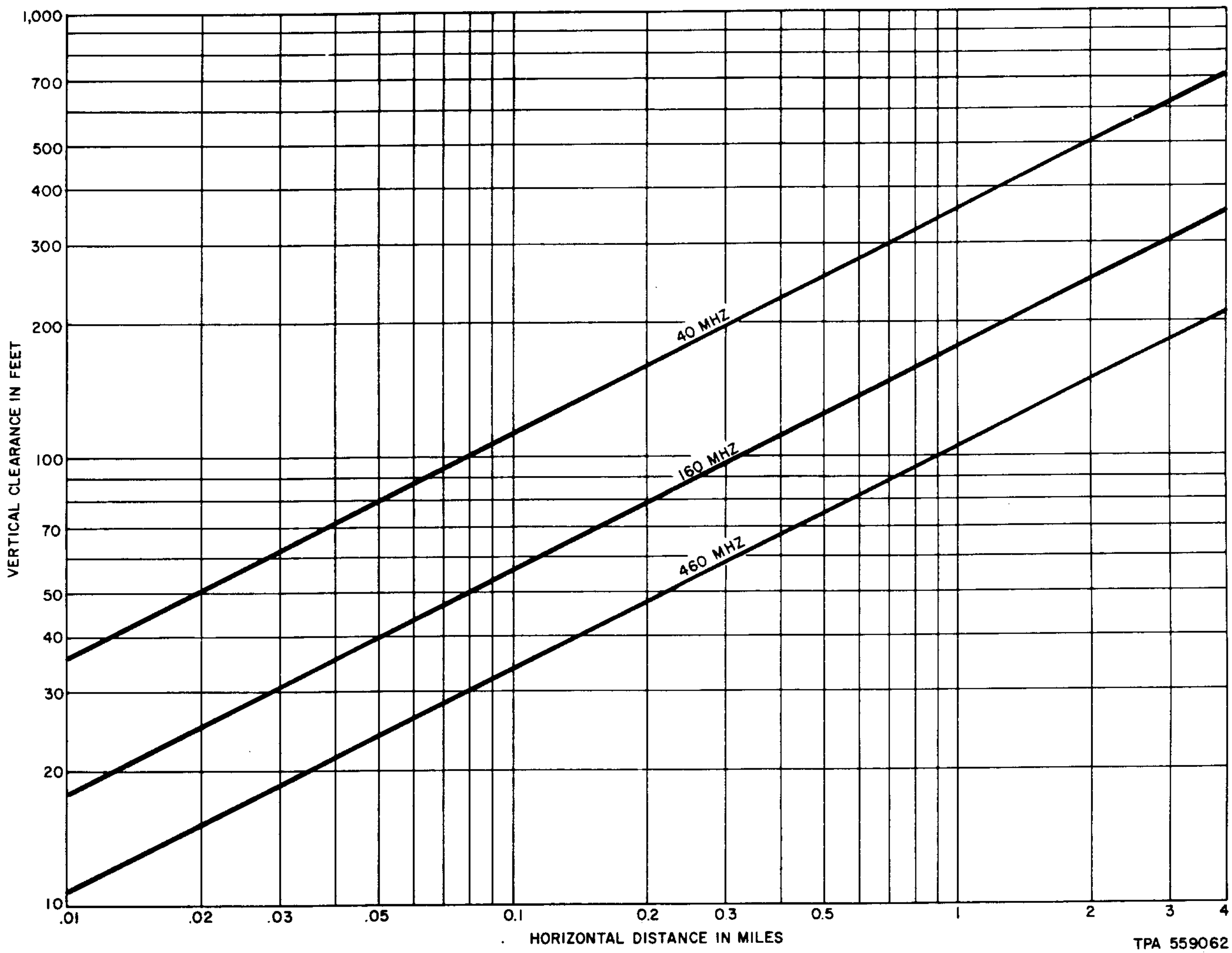


Fig. 13—First Fresnel-Zone Clearance (for Distance Negligible Compared to Total Path Length)

6.05 In built-up areas, the effective height of a base station antenna is usually less than the elevation of the antenna above the street. The effective height should be, however, somewhat greater than the antenna's elevation above the rooftops since most buildings are only partially opaque at the frequencies used for mobile services, particularly those in the lower bands. In the absence of any more accurate basis for estimating the effective height, it is commonly assumed that the effective ground plane is above actual ground level at a height equal to about one-half the average height of the buildings along the transmission path as shown in Fig. 12C. This assumption admittedly gives only a very approximate evaluation. Where good assurance is required that actual path losses will not exceed those calculated, the use of an effective height based on the height of the antenna above the full average building heights is appropriate, especially for paths in the 460 MHz band.

6.06 Where an antenna is situated above the treetop level of a thick woods, some reduction of effective height is to be expected as a result of the tendency of the trees to constitute a reflecting surface. This reduction is believed to be significant at the higher mobile frequencies. Since a sound basis for taking this into account is not available, it is suggested that path loss calculations include arbitrary effective height corrections as described below and illustrated in Fig. 12D.

(1) For the 40 MHz band, assume that the effect is minor and make no correction.

(2) For the 160 MHz band, assume that the effective ground plane is above the actual ground at a height equal to half the average tree height.

(3) For the 460 MHz band, assume that the effective ground plane is at the average tree height.

7. OBSTRUCTION LOSSES

7.01 As previously noted, obstructions such as hills, buildings, trees, and other objects in the transmission path affect the path loss and require the addition of corrections to the smooth earth path losses computed from Parts 5 and 6. Almost always, the effect of intervening obstructions is a reduction of the received signal power, although for some special cases both experience and theory show that "obstacle gains" are possible. No attempt is made here to consider the latter type of situation since it does not occur frequently enough to be a factor in mobile system design.

7.02 Except under unusually favorable conditions as in the case of paths over water or open prairie, the median path loss will exceed the value computed for smooth earth. The difference may range from almost nothing to 30 dB or more for the variety of conditions commonly encountered. As outlined in Part 3, a reasonable procedure for taking this into account in coverage estimates is to compute the effects of gross or large scale features of the particular transmission path, and to add a fixed adjustment for the local or small sector effects which are not susceptive to specific analysis. Small sector adjustments are discussed in Subpart A, and gross features of hills, buildings, and heavy tree growths are considered separately in Subparts B, C, and D, respectively.

A. Small Sector Median Adjustment

7.03 This adjustment is made in the absence of any other step to recognize the probability that the variety of objects usually found in the immediate proximity of a land mobile station will result in excursions of the path loss with small changes in location and that the median signal level will, in consequence, be lowered. For average conditions, suggested adjustments are 3 dB for the 40 MHz band, 5 dB for 160 MHz, and 7 dB for 460 MHz. These are to be added to the losses for gross terrain features from Subpart B in estimating the total obstruction loss. They should not be included in situations which call for the use of a large loss in recognition of the effects of tall buildings at the mobile location as given in Subpart C since such losses already contain small sector variations. Also, the small sector adjustment need not be included where the mobile station is truly "in the open."

B. Shadow Loss of Hills

7.04 A simplified version of the optical theory for diffraction of waves over a knife-edge obstruction provides very useful order-of-magnitude indications of the effects of the topography along a transmission path. Losses based on this theory, appropriately termed "shadow losses," may be obtained from the charts of Fig. 14, 15, and 16. These charts show, for each of the mobile frequency bands, the shadow loss as a function of the height of the obstruction and its location with respect to

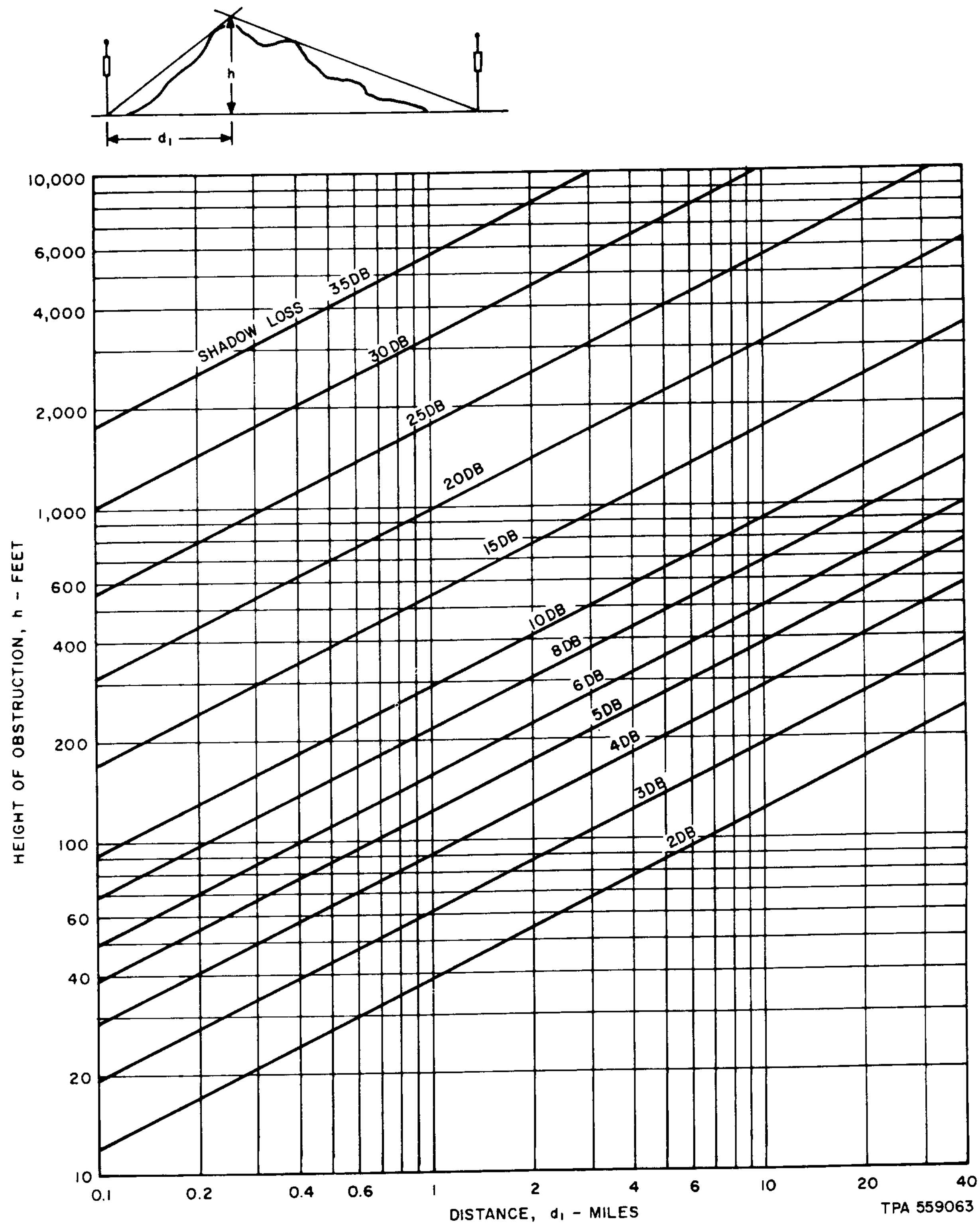


Fig. 14—Shadow Loss to be Added to Path Loss—40 MHz

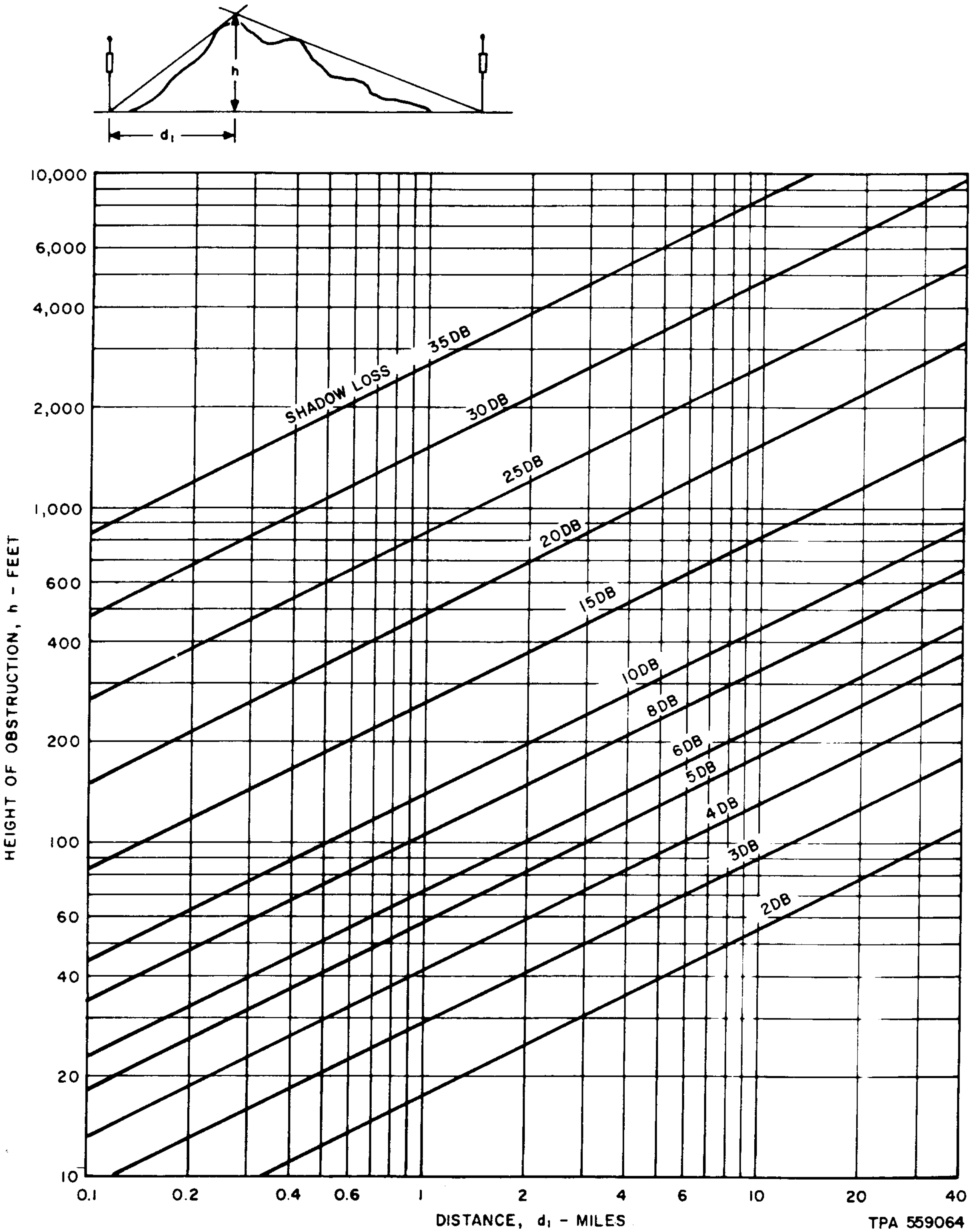


Fig. 15—Shadow Loss to be Added to Path Loss—160 MHz

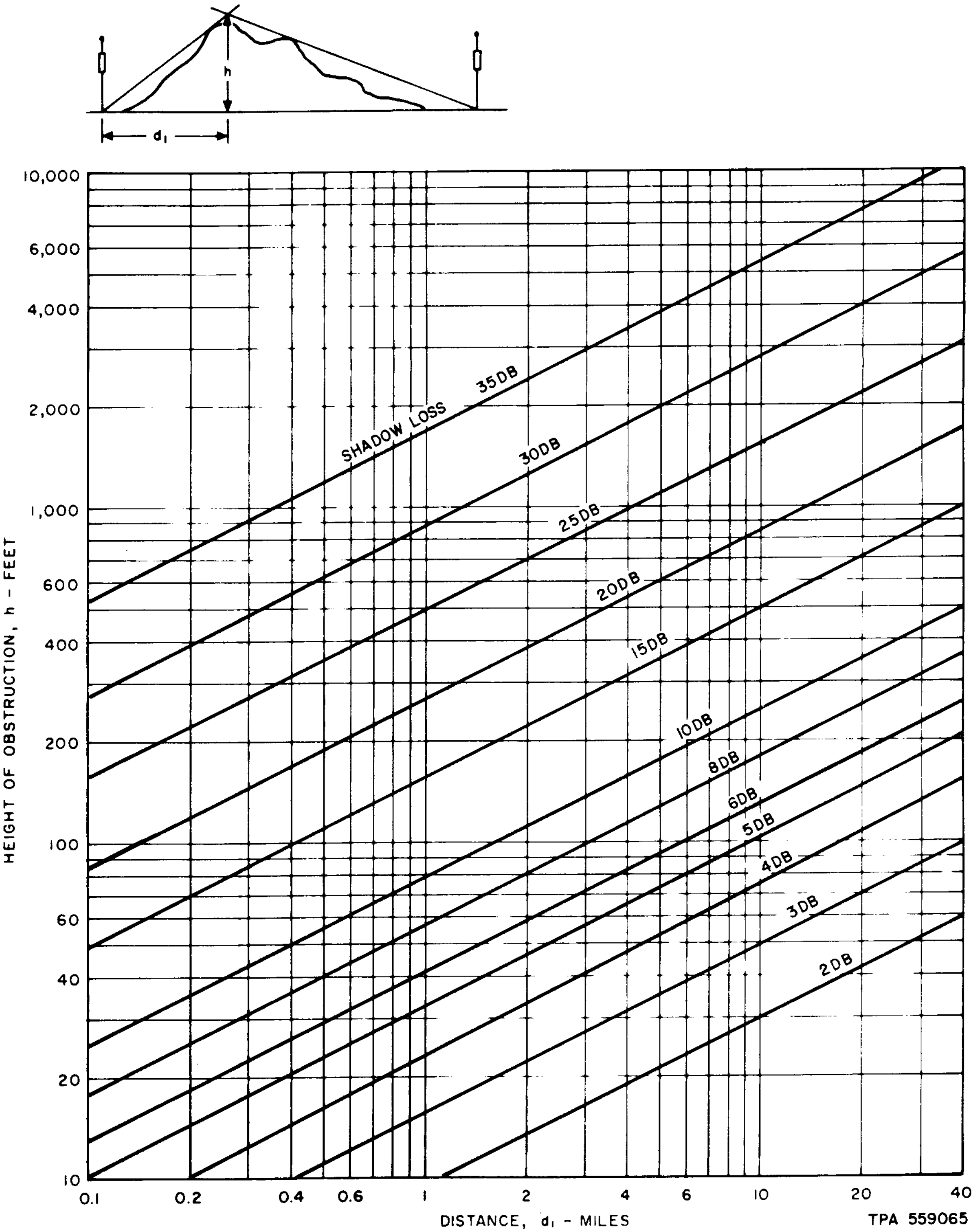


Fig. 16—Shadow Loss to be Added to Path Loss—460 MHz

the nearer terminal of the radio path. Some limitations on the reliability of these charts are discussed in paragraph 7.08.

7.05 Use of these shadow loss charts requires the preparation of profiles of the transmission paths, such as those illustrated in Fig. 17, using contour maps or other available information. These profiles should be drawn on rectangular coordinates (neglecting earth curvature) since the diffraction loss resulting from the earth's curvature is included in the smooth earth path loss curves of Part 5. There are no restrictions as to the scale of plotting except that the height and distance scales should be sufficiently dissimilar to greatly magnify the terrain variations for ease and accuracy in plotting. The common variety of graph paper with 10 lines to the half-inch is usually convenient to use, particularly if the topographic maps have a scale of 1 mile to the inch and an engineer's scale graduated in tenths of an inch is used for scaling. Usually, it is not necessary to plot a profile for the entire path since only the portions which determine shadow loss and effective height are of interest.

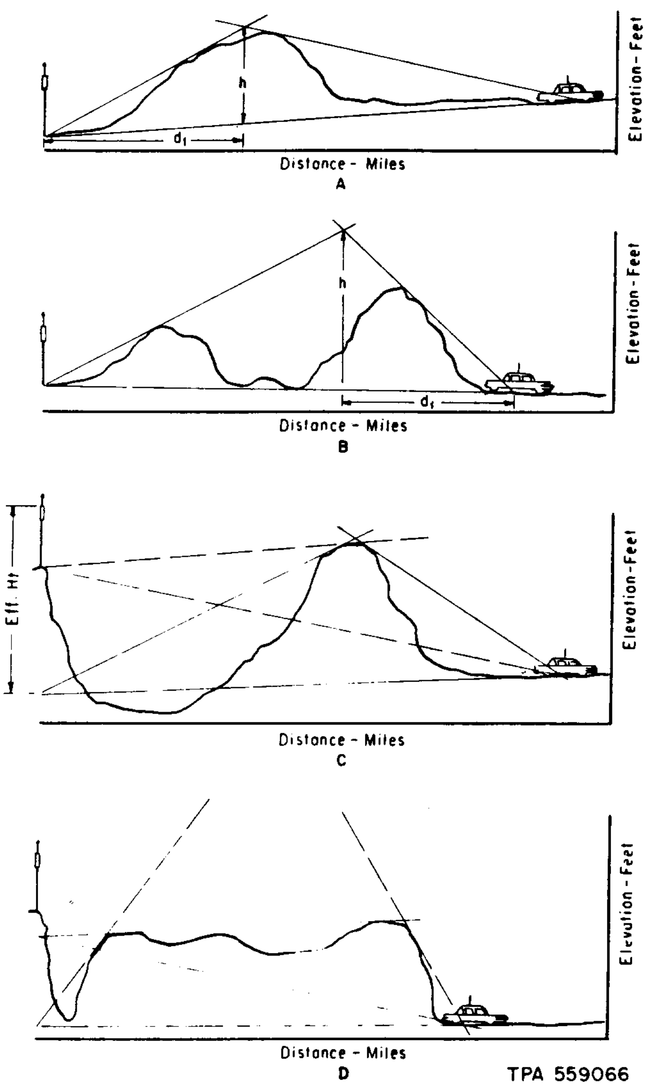


Fig. 17—Shadow Loss Profiles

7.06 Following the preparation of a profile, a triangle is constructed to determine the shadow aspects of the path, as illustrated in Fig. 17A. The base of this triangle is a line linking the "bases" of the two antennas, that is, the points directly below the antennas whose elevations are those of the effective ground planes used in developing effective antenna heights as discussed in Part 6. One side of the triangle is a line drawn upward from the base of one antenna with a slope to just graze the intervening obstruction. The other side is a similar line from the "base" of the other antenna. The height "h" used with the shadow loss charts is the height of the apex of the triangle above its base. The distance "d_1" is the horizontal distance between the apex and the nearer antenna, regardless of whether this antenna is used for transmitting or receiving. The same procedure is used for constructing a triangle where different hills obstruct the path as viewed from the two terminals, as illustrated in Fig. 17B. The total shadow loss in the path is assumed to be the loss indicated on the charts for the equivalent single hill resulting from this graphical construction.

7.07 Inasmuch as shadow losses are computed on the basis of the height of the obstruction with respect to the "base" of each antenna, with many profiles the size of the computed shadow loss will be affected significantly by the value of effective antenna height assumed in estimating the smooth earth path loss. For the profile shown in Fig. 17C, for example, the use of less effective height than that justified by the considerations discussed in Part 6 will result in less shadow loss as indicated by the dashed line triangle. Such profiles should be examined to determine which combination of effective height and associated shadow loss results in the lowest overall computed path loss. In general, it is permissible to use the lowest path loss so obtained in estimating system performance, provided that the shadow triangle constructed on this basis is not grossly unrepresentative of the actual situation. For the profile of Fig. 17D, for example, it seems preferable to discount the effective height and compute on the basis of the solid-line triangle rather than to base a performance estimate on the unrealistic looking equivalent hill represented by the dashed-line triangle.

7.08 Use of the shadow loss charts in this manner has been found to yield close agreement with measured losses when the experience for a large number of profiles is averaged. However, some disparity is to be expected in most individual instances and quite large differences in some. One reason for this is the presence in hilly terrain of reflections from neighboring hills to the side of or beyond the direct transmission path. Multiple signal paths may result with some reflected signals comparable to and possibly stronger than those diffracted over the hills obstructing the direct path. Also, some evidence seems to indicate that actual diffraction losses are frequently larger than the theoretical in deeply shadowed locations and smaller in lightly shadowed situations. These considerations suggest that a better approach might be some statistical analysis of observed distribution of shadow loss magnitudes. Such information is presented in Fig. 11 of Reference (1) listed in Part 12, and this may be of value in some instances. This does not appear to be generally suitable, however, because it does not permit evaluations which recognize specific circumstances of interest. The distribution of shadow loss throughout a hilly area, for example, is of little practical interest if the only sections accessible to vehicles are roads lying entirely in deeply shadowed valleys.

C. Effect of Buildings

7.09 The shadow losses resulting from obstructing buildings are not entirely comparable to those caused by hills for two reasons. The first is that buildings are more transparent to radio waves than the solid earth, with the result that the signal energy which passes through a building may exceed that which is diffracted over the top or around the sides. At 160 MHz, for example, a radio wave will pass through a brick wall with about 2-1/2 to 10 dB attenuation, depending on whether the bricks are dry or wet. Wooden structures have very little attenuation. The loss through a window pane is from 1/2 to 3 dB, depending on the type of glass. These losses vary with frequency and, compared to 160 MHz, are about half as large at 40 MHz and almost twice as great at 460 MHz. The second reason for building shadows differing from those caused by hilly terrain lies in the certainty of multiple reflections in built-up areas, particularly in the case of a mobile station traveling a street with buildings on ***both*** sides. In city locations which are deeply shadowed along the direct path, the signal arriving by reflection is very often greater than the signal energy passing through or diffracted around the obstructions in the direct path. The beneficial effects of reflections are more prominent at higher frequencies since diffraction and attenuation losses in the direct path are higher, giving a net effect which is less frequency-dependent than that for hills. Moreover, with shorter wavelengths the nulls and peaks in the signal distribution pattern, resulting from interference between multiple transmission paths, are more closely spaced and therefore more effectively "averaged-out" by a mobile station in motion.

7.10 The shadow loss charts, Fig. 14, 15, and 16 discussed in Subpart B, have application in situations where multiple reflections are not likely to be a factor as, for example, where the outlook from a base station antenna is obstructed by a building or large storage tank, or where an isolated building or other structure shadows a mobile station. Losses so estimated may be excessive where the size and construction of the building make it partially transparent. In drawing shadow loss triangles as described in paragraph 7.06, diffraction around the sides of a building, rather than over the top, may be assumed where the dimensions are such that this results in a lower indicated loss.

7.11 For city streets and other deeply shadowed built-up areas where multiple reflections are likely to be controlling, it is necessary to estimate the loss from measurements made in New York City and reported in Reference (2) of Part 12. These show the median loss to exceed the smooth earth value by about 25 dB for 160 MHz, and by several dB more than this on the average for 460 MHz. A loss several dB smaller is believed to be appropriate for 40 MHz. These values may be taken as representative of the downtown areas of large cities and adjusted downward for less severe conditions. Where buildings do not exceed three or four stories in height, values half as large seem reasonable. Several related points should be noted in using these losses in coverage computations.

(1) The base station antenna must be elevated well above neighboring buildings as was the case in tests from which the losses were derived. Otherwise, considerably larger losses may apply.

(2) The base station antenna height used in determining the smooth earth path loss to which street losses are to be added should be determined without regard to surrounding building heights; that is, the effective height adjustment pictured in Fig. 12C should be ignored.

(3) The small sector loss discussed in Subpart A should not be added to a street loss since the latter is all inclusive.

(4) In view of the very wide variation from median losses at some points, reliable coverage to stopped or parked vehicles may require some additional path loss allowance.

D. Losses Caused by Trees

7.12 Trees affect path losses by attenuating and scattering some of the signal energy. The resulting losses are not readily amenable to generalized quantitative evaluation, but are known to be of such magnitude in some instances as to seriously impair the usefulness of coverage calculations if they were ignored. Available information leads to several conclusions:

(1) The tree conditions in the vicinity of the mobile stations are of principal concern since base station antennas are normally elevated above tree level. Trees distant from both terminals of a transmission path have negligible effect.

(2) Occasional scattered trees near a mobile station cause signal variations which may usually be regarded as adequately accounted for by the inclusion in path loss calculations of the small sector loss of Subpart A.

(3) Except possibly for the 40 MHz band, any screening by trees in depth necessitates the inclusion of a specific loss allowance, the size of which is determined by a number of factors. Some guides are discussed in paragraph 7.13.

7.13 Suggestions for estimating the loss added by other than lightly screening trees at a mobile station location are outlined below. These are based on fragmentary experimental evidence, of which that reported in Reference (4) is an important part. They cannot be regarded as more than a basis for broadly recognizing a sometimes significant factor in coverage performance.

(1) As a point of reference, assume that the following losses apply in flat terrain for dense woods adjacent to the mobile station and extending at least 500 feet or so in the direction of the base station.

FREQUENCY BAND	LOSS
40 MHz	4 dB
160 MHz	12 dB
460 MHz	18 dB

For other conditions, adjust these values as discussed below.

(a) For smaller expanses of trees, assume smaller losses, but not proportionally so since the loss in dB per unit distance decreases with increased distance. Reduce losses in dB by a factor of 0.5 for, say, 100-foot depth of screening.

(b) Reduce losses by a factor of 0.5 for thinned-out stands of trees, especially where underbrush is absent.

(c) Reduce losses where a cleared area intervenes between the mobile station and the trees. Use a factor of 0.5 for several hundred feet of clearing, and ignore tree loss with 1000 feet or more of cleared space.

(2) In uneven terrain, additional considerations may apply.

(a) Where intervening trees lie on a downward slope from the mobile station, only those which project into the transmission path need to be regarded as of significance.

(b) Where intervening trees lie on an upward slope for which a large shadow loss from Fig. 14, 15, and 16 has been included, it may be unrealistic to add tree losses at full weight. Use of the suggestion in (3) may be helpful.

(3) Regard as an upper limit the loss indicated by the shadow charts of Fig. 14, 15, and 16 when these are used on the basis that a tree screen constitutes a solid obstacle.

(4) For deciduous trees, it may be assumed that losses in the winter in dB are reduced by a factor of about 0.2.

(5) With horizontal polarization which is not ordinarily used for mobile service, tree losses for the 40 MHz and 160 MHz bands are substantially lower than with vertical polarization.

8. REQUIRED SIGNAL POWER

8.01 Estimated received signal powers, based on the information in foregoing parts, may be translated into expected coverage performance by making direct comparisons with the signal levels needed under prevailing electrical noise conditions to provide reception with a suitable audio speech-to-noise ratio at the receiver output. Noise conditions vary widely for different receiver locations, making specific considerations of required signal powers necessary.

8.02 The controlling noise at a mobile system receiver is usually man-made noise from external sources fed to the receiver by the receiving antenna system. Where such ambient noise is of very low intensity, thermal or tube noise in the receiver itself, termed "set noise," becomes controlling. In the 40 MHz band, cosmic noise may at times be a limiting factor at otherwise quiet sites. Man-made noise originates in a variety of sources and varies considerably in intensity and character with place and, in some instances, time. In general, the density of population or degree of industrialization is a measure of the noise level to be expected. At mobile receivers, the density and speed of surrounding vehicular traffic, together with the noise generating properties of the vehicle in which the receiver is carried, are very important factors. Few places except those in open country remote from roads and power lines are totally free from the effects of man-made noise. In general, the effect of man-made noise diminishes with frequency, and in the mobile service is of least significance in the 460 MHz band. Set noise, on the other hand, increases with frequency.

8.03 Measurement of audio speech-to-noise ratios in a way which reflects interfering effects in a meaningful manner is difficult for the kinds of noise often encountered at mobile system receivers. For this reason and as a matter of convenience, a subjective rating of the interfering effect of the noise using the term "circuit merit" is commonly used in place of metered measurements. This method uses a scale of five steps to describe performance. These are listed and defined in Table A. The speech-to-noise ratios in dB included in this table are arbitrary numbers which apply if both speech and noise are measured on either a 2B noise measuring set with F1A line weighting or a 3A noise measuring set with C-message weighting. In making such measurements, noise is measured in the normal manner and speech volume is read by the method used with a VU meter.

TABLE A

CIRCUIT MERIT	DEFINITION	SPEECH-TO-NOISE RATIO dB NOMINAL VALUE	SPEECH-TO-NOISE RATIO dB RANGE
CM5	Perfectly readable, negligible noise.	—	Above 30
CM4	Perfectly readable but with noticeable noise.	22	16 to 30
CM3	Readable with only occasional repetition (commercial).	12	9 to 16
CM2	Readable with difficulty, requires frequent repetition (noncommercial).	7	5 to 9
CM1	Unusable, presence of speech barely discernible.	—	Below 5

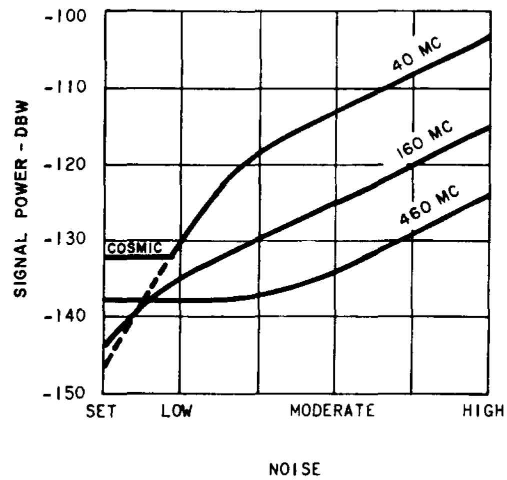
8.04 Circuit merit 3 is generally regarded as the minimum acceptable for public mobile telephone service, and is used as a basis for drawing coverage boundaries. Where necessary, CM2 may be found tolerable for occasional calls, but this grade of transmission is clearly unsuitable as a service offering. In typical service areas so defined, users will experience transmission as poor as CM3 only when the mobile station is situated near the fringes of the area. They will enjoy better transmission throughout the bulk of the coverage area and, as a usual consequence, on most of their calls. Situations in which fringe coverage areas pass through important localities heavily frequented by local mobile stations should be avoided since users may not find CM3 agreeable if experienced on any large proportion of their calls.

8.05 The interfering effect of radio frequency noise on speech reception in an FM receiver depends not only on the noise power but also on the character of the noise and, to some extent, on the characteristics of the receiver. These factors are difficult to evaluate, and it is much more direct and meaningful to express RF noise conditions in terms of the RF signal powers which their presence requires rather than in terms of absolute noise properties. Manufacturer's specifications of receiver sensitivity, for example, are universally given in terms of the RF signal voltage input needed to reduce the audio noise output by a stated amount. The signal power required in any situation may be accurately determined by tests, made by connecting both the antenna and a signal generator to the input of a receiver at the site, then adjusting the generator output voltage while noting the effect on the audio noise output. This differs from the usual bench sensitivity test only in that the antenna picks up and adds whatever site noise is present. This highly informative procedure may require considerable time and effort, particularly at mobile stations or where diurnal or longer term variations in the noise are involved. An alternative for coverage estimating purposes is to assume values of required signal power based on experience in situations which appear to be comparable. This is discussed in subsequent paragraphs.

8.06 For coverage estimates involving any normal receiving situations, presently available information suggests use of the required signal powers shown in Fig. 18 in the absence of measurements or other relevant information. These are median levels for CM3 performance, that is, for estimating the limits of acceptable coverage. Appropriate adjustments for other grades of transmission are discussed in paragraphs 8.10 and 8.11. This information assumes the following general conditions: (1) narrow-band operation with ± 5 kHz deviation in the 40 MHz and 160 MHz bands, and wide-band operation with ± 15 kHz deviation in the 460 MHz band, (2) modulation of base and mobile transmitters as specified in appropriate system lineup practices, and (3) transmitters and receivers closely aligned in frequency.

8.07 Required signal powers shown in Fig. 18 for SET noise are consistent with the rated 20 dB quieting sensitivities of current receivers. In the case of 40 MHz operation, cosmic noise may be controlling in the daytime at quiet locations, and the average upper daily limit of this is shown as obtained from the report by Cottony and Johler of the Bureau of Standards (IRE Proceedings, September 1952). Required powers for MODERATE and HIGH noise are broadly representative of the median values indicated by past experience, and are equivalent to about 15 and 50 microvolts per meter, respectively, for all frequency bands. Powers for LOW noise are assumed somewhat arbitrarily to be less than midway between those for SET and MODERATE. It must be recognized that the signal power requirements shown for HIGH noise do not give protection against strong diathermy, industrial heating, or other interference with an intensity exceeding the general noise level. It is possible for such interference to be sufficiently severe to preclude reception with any reasonable signal power.

8.08 An important reservation to the use of Fig. 18, most likely to concern sites with low noise interference, is the possible presence of unwanted interfering signals. Signals on the receiving frequency can stem from the operation of cochannel stations, from intermodulation between two or more closely coupled transmitters, or from spurious transmitter emissions. A strong signal off the receiving frequency can desensitize a receiver, and two or more such signals properly related in frequency can cause intermodulation interference to be generated within the receiver. Unless these effects are absent or are obscured by prevailing noise interference conditions, they will determine the required power levels of desired signals. Where this seems likely to be a factor, observations with a receiver tuned to the working frequency is a highly important precaution.



NOISE CONDITIONS AT TYPICAL BASE STATION SITES

HIGH: SITES IN DOWNTOWN URBAN OR NOISY INDUSTRIAL AREAS.
MODERATE: SITES IN SUBURBAN LOCATIONS, OR CLOSE TO MAIN ROADS WITH MODERATE VEHICULAR TRAFFIC.
LOW: SITES IN RURAL AREAS SUBJECT ONLY TO NOISE FROM DISTANT SOURCES.
SET: SITES A MILE OR MORE REMOVED FROM HIGHWAYS, NOISY POWER LINES AND ALL OTHER NOISE SOURCES.

NOISE CONDITIONS AT TYPICAL MOBILE STATION LOCATIONS

HIGH: LOCATIONS IN DOWNTOWN URBAN OR NOISY INDUSTRIAL AREAS, OR IN CONGESTED VEHICULAR TRAFFIC.
MODERATE: LOCATIONS IN SUBURBAN AREAS, OR ON MAIN ROADS WITH MODERATE VEHICULAR TRAFFIC.
LOW: STATIONS IN CARS WITH IGNITION NOISE WELL SUPPRESSED, ON LIGHTLY TRAVELED ROADS IN RURAL AREAS.
SET: STATIONS IN CARS PARKED, WITH IGNITION TURNED OFF, IN REMOTE RURAL AREAS DISTANT FROM ALL NOISE SOURCES.

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Fig. 18—Required Signal Power for CM3

8.09 Some adjustment of the required signal powers shown in Fig. 18 may be in order at base receiver sites where a vertically stacked gain-type antenna is to be used. As mentioned in paragraph 3.06(b), the vertical patterns of such antennas discriminate against noise interference arriving from below at steep angles as may occur at an antenna on an isolated tall building. Estimates of this require some knowledge of the location of controlling noise sources which is often lacking. Measurements at a few telephone buildings have indicated the noise pickup advantage of high gain antennas to range from 0 dB to over 8 dB as contrasted with a dipole. Where some such noise advantage is to be depended on for obtaining desired coverage performance, verifying measurements at the site in question appear to be highly advisable.

8.10 The increment in received signal power necessary to improve transmission performance from CM3 to CM4 or CM5 is not a fixed ratio. In an FM receiver, the audio speech output level is substantially constant for the entire range of usable RF signal powers. Increases in RF signal power improve the audio speech-to-noise ratio by decreasing the audio noise output. The amount of quieting obtained by a given increase in RF signal power depends on the amplitude and character of the noise which is present, and on the characteristics of the receiver. These effects are illustrated by the so-called "noise quieting curves" which are commonly used in discussions of FM receiver quieting. In addition, however, with some kinds of noise interference, the character as well as the intensity of the audio noise changes with the amount of quieting, and this leads to different subjective evaluation by different users.

8.11 As a broad general basis for estimating CM4 and CM5 coverage, the corrections to Fig. 18 given in Table B will serve as a useful guide. Corrections in the other direction for CM2 are included for possible use in examining marginal coverage conditions. Corrections are the same for all the mobile frequency bands.

TABLE B

CORRECTIONS TO FIG. 18 IN DB

	SET NOISE	LOW NOISE	MODERATE NOISE	HIGH NOISE
For CM2	−3	−6	−8	−11
For CM4	6	9	12	12
For CM5	17	20	22	22

On this basis, MODERATE noise conditions in the 160 MHz band which require a received signal power of −125 dBW for CM3, for example, will require −133 dBW for CM2, −113 for CM4, and −103 for CM5.

9. EXAMPLE OF COVERAGE ESTIMATE

9.01 The process of applying and combining the information in Parts 4 through 8 in estimating the coverage along a base station radial may best be illustrated by an example. As discussed in Part 3, estimates of the area coverage of a mobile system are made by examining an appropriate number of such radials.

9.02 For this example, it is assumed that a 150 MHz base station with a 50-watt transmitter and a single receiver is to be constructed on high ground overlooking a small city. Use of a 100-foot tower and a single gain-type antenna is contemplated. The profile of one of the radials is plotted in Fig. 19. This radial crosses the city and extends beyond through suburban areas in hilly terrain. Points selected for calculations are designated A through F, where A is at the far edge of the city and B through F are intersections of the radial with important roads carrying moderate vehicular traffic. In the city, buildings are with only few exceptions limited to four or five stories in height; in the outlying suburban areas, structures are of residential and small business character. Trees are scattered and present no screening in depth. Both base-to-mobile and mobile-to-base coverage with 20-watt mobile transmitters are to be estimated.

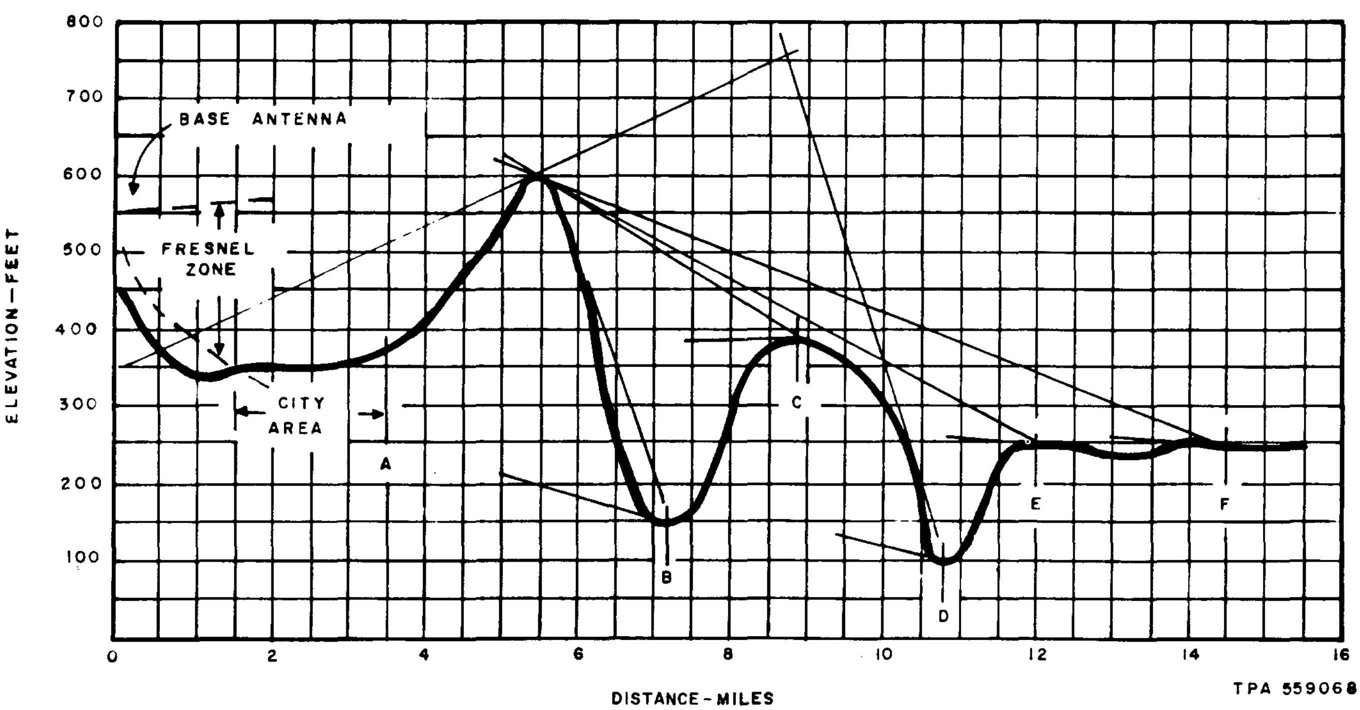


Fig. 19—Coverage Estimation Chart

9.03 Detailed application of the information in each of Parts 4 through 8 to this situation is outlined as follows. (For working calculations, rather than an illustrative example, a suitably condensed tabulation would of course be used.)

(a) *Effective Radiated Power (Part 4)*

Base Transmitter

50 watts output	= + 17.0 dBW
Antenna gain vs dipole	= + 4.8 dB*
Transmission line	= − 2.0 dB*
Duplexer loss	= − 0.8 dB*
ERP	+ 19.0 dBW

Mobile Transmitter

20 watts output	= + 13.0 dBW

*Typical values assumed for this example.

(b) *Effective Antenna Height (Part 6)*

Consideration of this factor is a necessary preliminary to the use of Part 5, since the mast height of 100 feet is enhanced by the fallaway of the ground in the immediate foreground. For paths over the distant hills to the coverage boundary, the Fresnel-zone clearance method (paragraphs 6.03 and 6.04) indicates an effective height of about 200 feet.

(c) *Smooth Earth Path Losses (Part 5)*

Smooth earth path losses as taken from the 200-foot curve of Fig. 6 are tabulated as shown.

POINT	DISTANCE MILES	PATH LOSS — DB
A	3.5	104
B	7.2	117
C	8.9	121
D	10.8	125
E	12.0	127
F	14.5	131

(d) *Obstruction Losses (Part 7)*

Small-Sector Median Adjustment (Part 7A)

This may be omitted for Point A, since the inclusion of a specific building loss allowance is indicated. For points B through F, 5 dB is allowed in accordance with paragraph 7.03.

Shadow Loss of Hills (Part 7B)

The shadow triangle constructions indicated on the profile of Fig. 19 and the corresponding losses from Fig. 15 are as follows:

POINT	d_1 (MILES)	h (FEET)	LOSS — DB
A	—	—	None
B	1.6	420	17
C	3.5	230	9
D	2.1	610	19
E	5.4	300	9
F	5.4	290	9

Effect of Buildings (Part 7C)

For Point A, the discussion in paragraph 7.11 suggests a median loss somewhat more than one-half the 25 dB allowance applicable for taller buildings in big cities. About 15 dB is appropriate. At other points, the small-sector adjustment of 5 dB already included is adequately representative.

Losses Caused by Trees (Part 7D)

Specific allowances are not needed in view of the lack of any heavy screening.

(e) *Required Signal Power (Part 8)*

At Point A, conditions are clearly similar to those classified in Fig. 18 as "HIGH" noise, leading to an estimated required signal power of −115 dBW. For points B through F, MODERATE noise requiring −125 dBW seems appropriate.

At the base receiver, LOW noise conditions may possibly apply but, in view of the proximity and unobstructed path to a growing industrial development in the near fringe of the city, assumption of a required signal power of −130 dBW, intermediate between LOW and MODERATE, seems prudent. It appears reasonable to assume too that if city noise is controlling, the gain of the antenna will affect both signal and noise about equally, leaving the ratio unchanged over what it would be with a dipole. Accordingly, no adjustment of the required signal power to reflect use of a gain-type antenna is needed if the antenna gain is omitted in calculations of mobile-to-base path loss.

9.04 The individual elements of the coverage estimate enumerated in the foregoing paragraph are combined in Table C below.

9.05 The overall conclusion with respect to this example is that two-way coverage will extend to between 13 and 14 miles or almost to Point F with the exception of the lower part of the shadowed valley in the vicinity of Point D. Several detailed conclusions of interest are also available.

(a) At the far extremity of the city (Point A), computed received signal powers exceed those required by a considerable margin. Therefore, good coverage across the breadth of the city seems assured even though noise interference or other factors are actually somewhat more severe than estimated.

(b) Since coverage is obtained at Point B and since all points along the profile out to about 10 miles are less severely shadowed than those close to Point B, in the absence of any large changes in other factors, coverage should be solid over this range.

(c) Since coverage is lost in the vicinity of Point D by a margin about equivalent to the small sector median adjustment, some intermittent coverage is to be expected as a mobile station moves about in this area.

(d) An error of only a few dB in the estimate of required signal power would result in the coverage terminating at Point E on the one hand, or extending beyond Point F if the error were in the other direction. This forcefully demonstrates the inability to pinpoint coverage limits.

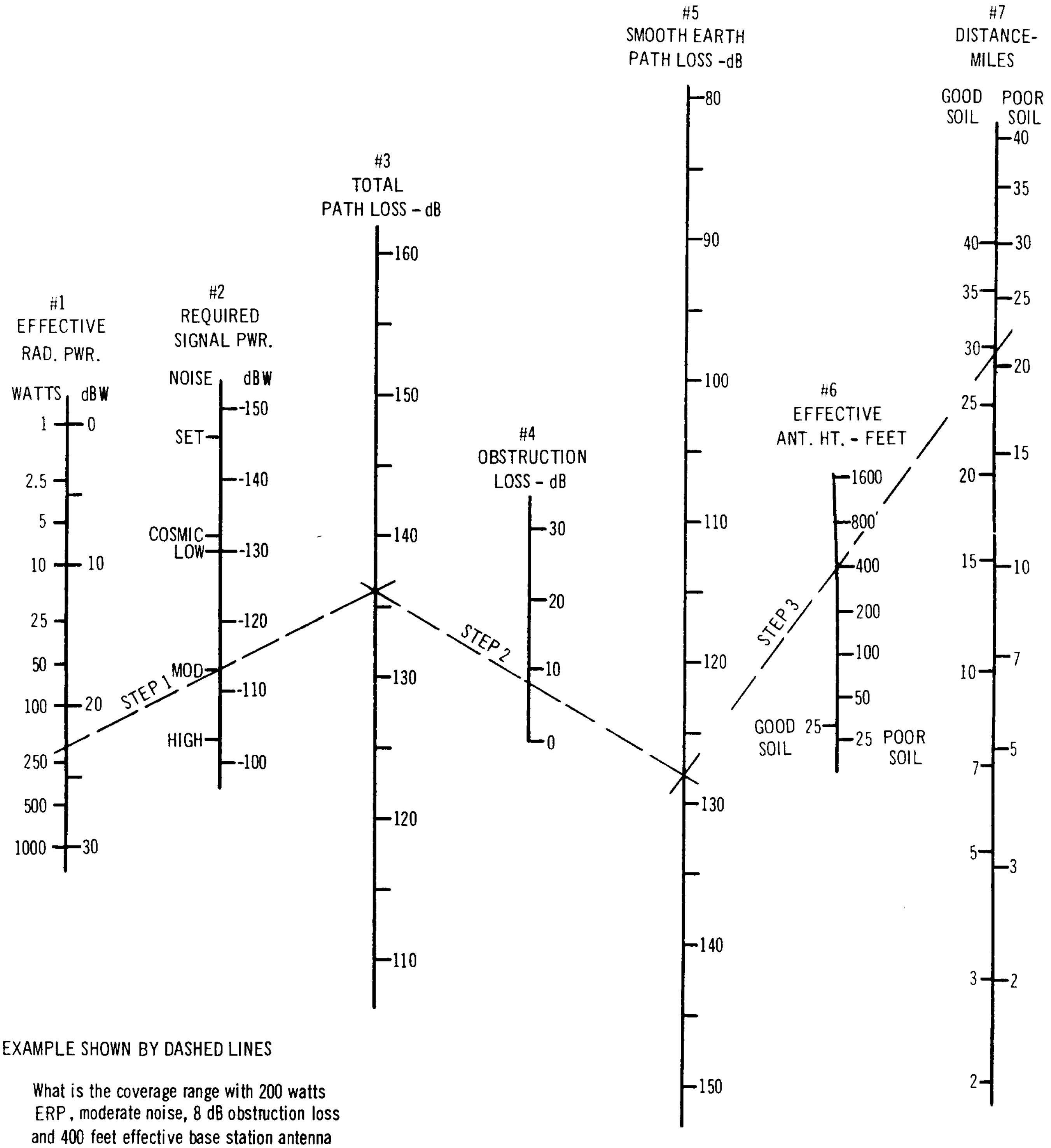
(e) Where the shadow loss and other factors are essentially constant as in moving from Point E through F and beyond, the computed coverage limit may be spotted simply by making adjustments from the smooth earth path loss curve without running through new calculations. For example at Point F, 14.5 miles, 1 dB more received signal is needed for base-to-mobile and 2 dB for mobile-to-base. From the path loss chart (Fig. 6), it is seen that the distance must be moved back from 14.5 miles to 13.8 and 13.2 miles to pick up these decreases in loss. These, then, are the calculated limits. While in this example this adjustment is too small to have real meaning, the technique illustrated is in other instances helpful and time saving. The nomographs of Part 10 may be found helpful in making such adjustments.

10. COVERAGE NOMOGRAPHS

10.01 A convenient means of relating and evaluating the principal factors entering into the coverage performance of land mobile systems is provided by the nomographs of Fig. 20, 21, and 22 for the 40 MHz, 160 MHz, and 460 MHz bands,

TABLE C

POINT	BASE TO MOBILE OR MOBILE TO BASE	ERP DBW	PATH LOSS — DB: SMOOTH EARTH	OBSTRUCTION LOSS: SMALL SECTOR	HILLS	BLDGS	TOTAL	RECD SIGNAL POWER DBW	REQD SIGNAL POWER DBW	COVERAGE?
A	B to M	+19	104	–	–	15	119	–100	–115	Yes
	M to B	+13	104	–	–	15	119	–106	–130	Yes
B	B to M	+19	117	5	17	–	139	–120	–125	Yes
	M to B	+13	117	5	17	–	139	–126	–130	Yes
C	B to M	+19	121	5	9	–	135	–116	–125	Yes
	M to B	+13	121	5	9	–	135	–122	–130	Yes
D	B to M	+19	125	5	19	–	149	–130	–125	No
	M to B	+13	125	5	19	–	149	–136	–130	No
E	B to M	+19	127	5	9	–	141	–122	–125	Yes
	M to B	+13	127	5	9	–	141	–128	–130	Yes
F	B to M	+19	131	5	9	–	145	–126	–125	No?
	M to B	+13	131	5	9	–	145	–132	–130	No?



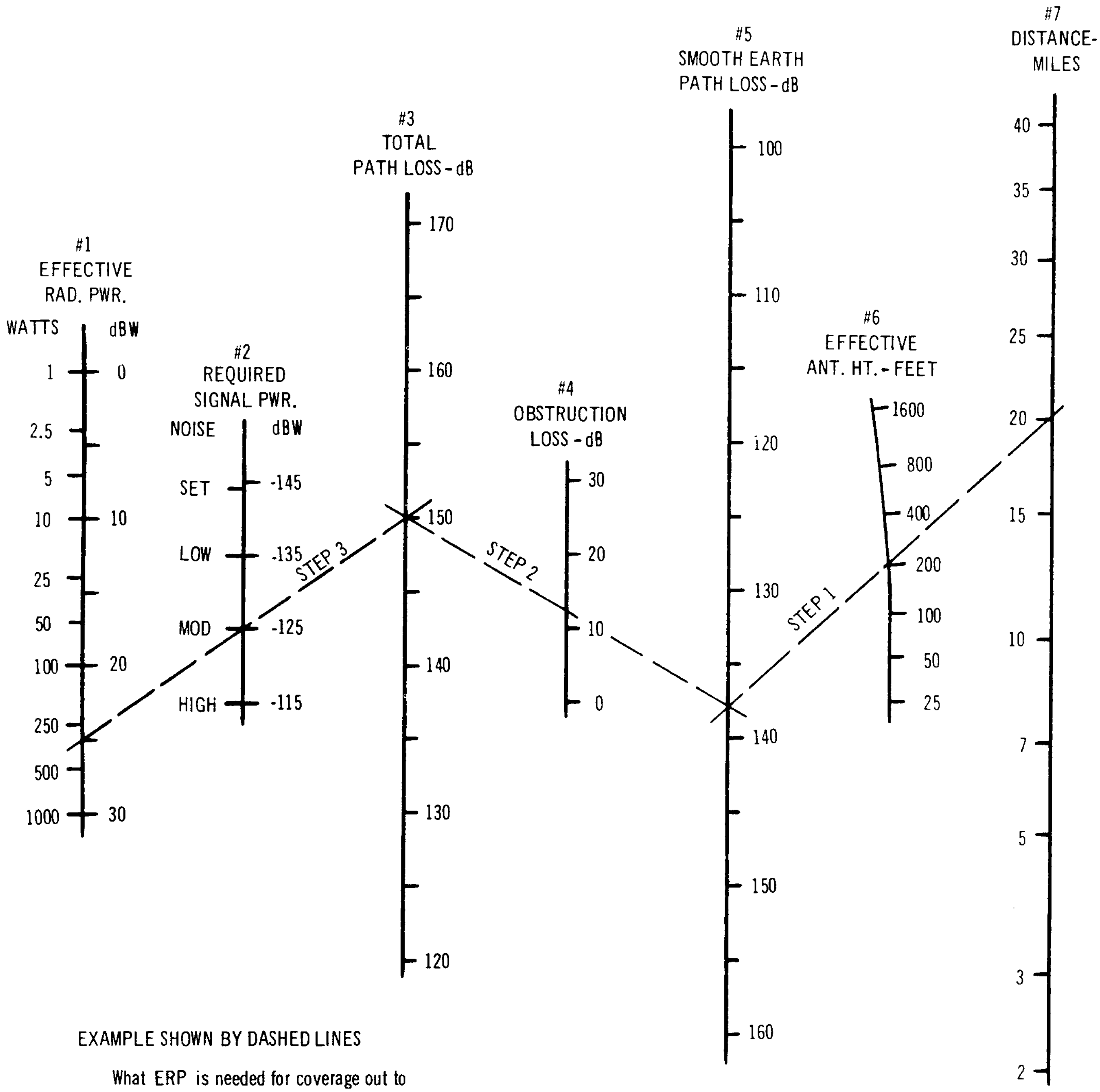
EXAMPLE SHOWN BY DASHED LINES

What is the coverage range with 200 watts ERP, moderate noise, 8 dB obstruction loss and 400 feet effective base station antenna height?

Answer: 29 miles over good soil, 21 miles over poor soil.

TPA 559069

Fig. 20—Land Mobile System Coverage—40 MHz—Good or Poor Soil



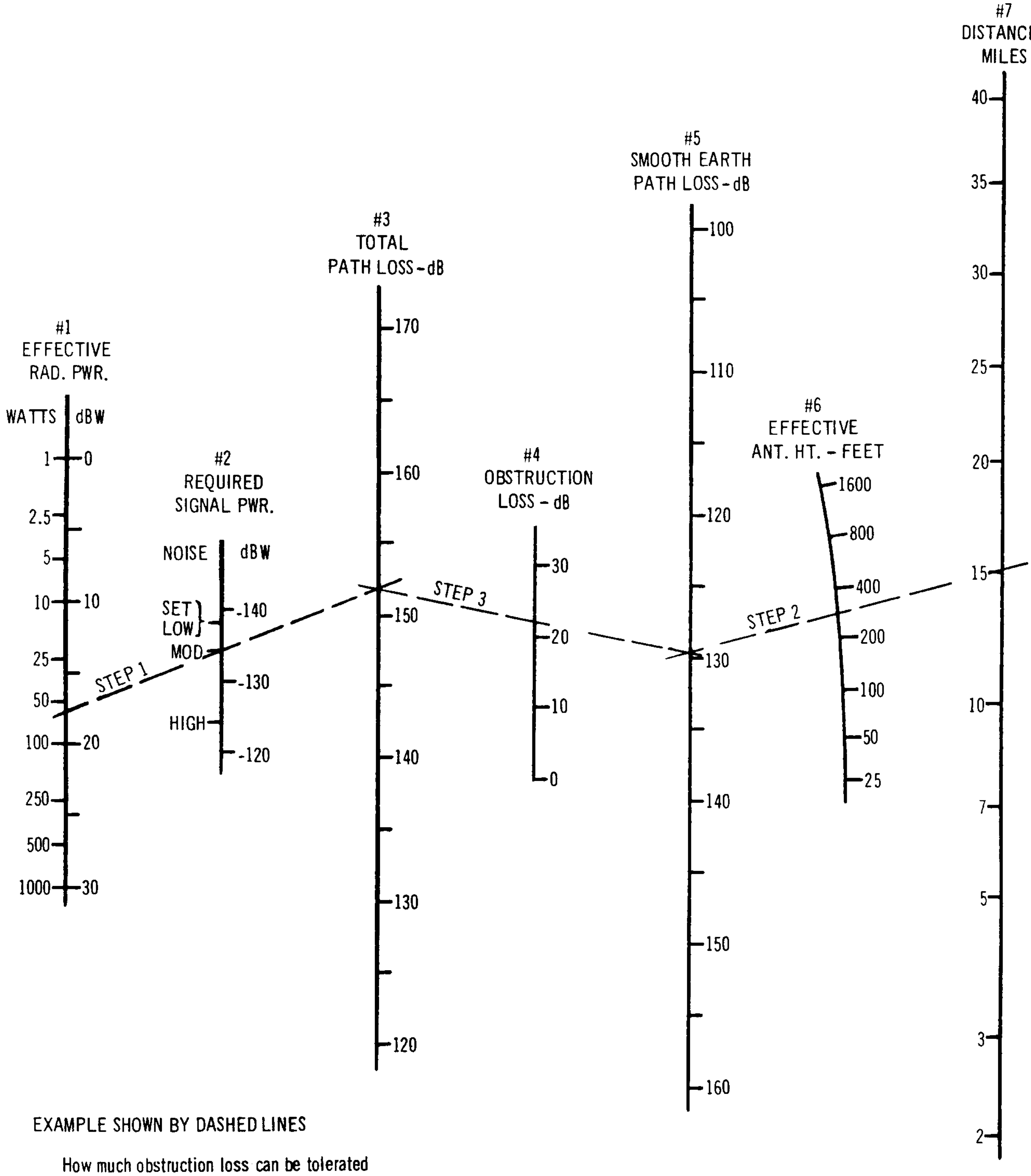
EXAMPLE SHOWN BY DASHED LINES

What ERP is needed for coverage out to 20 miles, with moderate noise, 12 dB obstruction loss and an effective base station antenna height of 200 feet?

Answer: +25 dB or about 300 watts

TPA 559070

Fig. 21—Land Mobile System Coverage—160 MHz



EXAMPLE SHOWN BY DASHED LINES

How much obstruction loss can be tolerated for coverage out to 15 miles, with 60 watts ERP moderate noise and 300 feet effective base station antenna height?

Answer: 22 dB

TPA 559071

Fig. 22—Land Mobile System Coverage—460 MHz

respectively. These nomographs permit quick examination by graphical means of the relationship between five basic variables, namely: effective radiated power, required signal power for CM3, obstruction loss, effective base station antenna height, and distance range. If values are assigned to any three or four of these factors, the graphs may be used to readily obtain the corresponding required values of the remaining factors. With these charts, the detailed procedure illustrated in Part 9 for estimating coverage limits may be avoided if the receiver noise situation is constant and obstruction losses are small or substantially independent of distance. A variety of other useful applications are possible as will be evident from the following discussion.

10.02 These nomographs are used by laying a straightedge across the three scales to the left of a chart, the middle three scales, and the three to the right in whatever order is appropriate for the solution desired. In the three-scale group to the left, the first scale, No. 1, refers to the effective radiated power of the transmitter as determined from Part 4. For base-to-mobile coverage the power of the base transmitter is used, and for mobile-to-base, that of the mobile transmitter. The next scale, No. 2, concerns the required received signal power for circuit merit 3 as shown in Fig. 18 of Part 8 for the frequency band in question. Scale No. 3 represents the dB difference between these two or the total allowable path loss. A straightedge laid across this three-scale group in any position intersects each scale at a point which is in proper relation to the intersections with the other two. Scale No. 4 refers to the total of all the applicable varieties of obstruction losses discussed in Part 7. A straightedge across Scales No. 3, No. 4, and No. 5 relates total path loss, total obstruction loss, and smooth earth path loss. Similarly, the three scales to the right of each chart, Scales No. 5, No. 6, and No. 7 relate smooth earth path loss, effective base station antenna height as determined from Part 6, and distance range in miles as given in the path loss charts of Fig. 4, 5, 6, and 9. The somewhat irregular construction of Scale No. 6 is necessary to recognize the dependence of antenna height gain on the path length. This relationship is not perfectly presented, and distances read from Scale No. 7 with a straightedge positioned to cross Scale No. 6 at the larger antenna heights may differ from those shown by the path loss charts of Part 5 by a few percent. A mobile station antenna height of 6 feet is assumed throughout.

10.03 Scales No. 3 and No. 5 are each common to two of the three-scale groups, and a common point on these scales must be used in relating factors whose scales lie in adjoining scale groups. This is illustrated by the examples shown on the charts. These examples differ on each chart in order to picture several kinds of application without the confusion which might result if several examples were shown on a single graph. In Fig. 20, the example is one of estimating coverage range where all determining factors are known. In Fig. 21, the desired coverage range is known and the question is what effective radiated power is needed. In Fig. 22, the question is how much obstruction loss can be tolerated in obtaining a specified coverage range with given system parameters. This is sometimes a helpful preliminary approach since it aids in making a broad examination of a desired coverage area for the purpose of pointing out which sections of the area are likely to be unsatisfactory or to require more detailed examination. In all cases, the results using the nomographs are, of course, identical to those obtained by direct computation except for graphical inaccuracies and the small error noted in paragraph 10.02 with respect to Scale No. 6.

11. SPECIAL SITUATIONS

11.01 In general, coverage performance cannot be reliably estimated solely by computation where unusually severe shadowing or shielding effects are present. An exception to this may be the performance in city streets for which substantial experimental data are available as discussed in Part 7C. Special consideration is required in situations such as the following:

(1) Locations very close to and shadowed by precipitous topography, roads through narrow steep ravines, or artificially depressed roadways.

(2) Roadways through oil refineries, tank farms, and similarly encumbered areas.

(3) Vehicular tunnels and long underpasses.

(4) Interiors of warehouses and covered piers.

For some cases in the category of (1) and (2), an indication of the maximum probable shadowing effect may be obtained by extending the plots of shadow losses given in Fig. 14, 15, and 16 so as to read the loss for smaller values of d_1. This is permissible mathematically, and can be done accurately since, with the logarithmic scales used in these figures, the plots are straight lines and may be extended accordingly. Difficulty may sometimes be encountered, however, in satisfactorily applying the procedure described in paragraph 7.06 for construction of a shadow loss triangle. Also, where large shadow losses are present in the direct transmission path, it becomes increasingly probable that back or side reflections from other points will have controlling influence on the resultant field strength in the shadowed area. This cannot be satisfactorily computed. Propagation into tunnels and underpasses does occur but neither experience nor theoretical concepts permit any sound coverage prediction for a specific case. For situations typified by (4), the available information relating to Bellboy® coverage in building interiors may be helpful and should be considered. However, variations between individual buildings may be large, and estimates of adequate coverage will be uncertain unless they include a sizable margin for possible error.

11.02 As a rule, measurements offer the only accurate means of examining coverage performance in situations such as those enumerated above. These may be conducted in several ways. A fully informative survey requires the erection of base station facilities and measurement of both the received and the required signal powers, or of signal-to-noise ratios. This is not ordinarily justified unless a detailed understanding of the coverage problem is desired. A simpler and more direct approach is to make talking tests and to record only the observer's judgment of circuit merit. This provides good practical answers subject only to reservations concerning the degree to which noise, interference, and the condition of the radio equipment at the time of the tests were typical of those to be in effect in day-to-day operation. Such reservations apply to any tests.

11.03 Preferably, talking tests in advance of station construction are made with temporary base station facilities which closely simulate the projected final installation. This, of course, is not always practical and in such cases the test results must be adjusted. Changes in effective radiated power can be depended upon to result in a corresponding dB for dB increase in the received signal power, regardless of the character of the transmission path. The effect of changes in antenna height are much less certain, however, particularly where the transmission path is obstructed close to the antenna whose height is to be changed. Best results require that the base station antenna height and location be simulated as closely as possible.

11.04 Base-to-mobile coverage is most accurately measured by transmitting from the proposed base transmitter site to a mobile receiver since this automatically takes into account the noise conditions at the mobile location. Where such an arrangement is not practical, tests from a mobile transmitter to a base receiver placed at the projected base transmitter site are a useful expedient. Such tests should be accompanied by an examination of the relative required signal powers at base and mobile locations since noise conditions may differ widely. Corrections should be made for this as well as for any difference in transmitter powers. Similarly, where necessary, mobile-to-base coverage may be estimated from suitably corrected base-to-mobile measurements.

11.05 One minor problem in making coverage tests of a large area is that of recording and summarizing the volume of detailed observations. A simple way of doing this is to mark a suitable road map with pencils of four different colors, one color for performance poorer than CM3 and one each for CM3, CM4, and CM5. As the test car moves about, its position on the map is marked with lines of appropriate color. The completed map then pictures the whole coverage situation in good detail.

12. REFERENCES

12.01 References mentioned in the foregoing text and others of particular interest are listed below. To an important extent, certain of these contain the basis for material in this section.

(1) "Radio Propagation Fundamentals," K. Bullington

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(3) "Radio Propagation Variations at VHF and UHF,"
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(4) "VHF and UHF Reception — Effects of Trees and Other Obstacles,"
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