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Technical Note 139

SITING CRITERIA FOR HF COMMUNICATION CENTERS

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Contents

ABSTRACT

This note is intended to provide an engineering guide for the siting of radio terminals for use in long-range HF communication systems. A brief summary of ionospheric effects upon HF radio signals is presented. Various factors required for an ideal site such as Fresnel zone size and smoothness, noise, antenna height, vertical radiation angle and the electrical characteristics of the ground are discussed. Standards to guide compromises for practical cases of siting are considered. A partial bibliography which may be useful for those desiring a greater depth of understanding of the various subjects considered is provided.

SITING CRITERIA FOR HF COMMUNICATION CENTERS

by

W. F. Utlaut

1. Purpose

Electrical and topographical characteristics of terminal sites are of considerable importance in their effects on radio propagation, and reception, for long-range ionospheric communication. It is the purpose of this report to provide an engineering guide for the siting of such radio terminals based on the current state of knowledge of propagation factors and communication techniques. Aspects of siting such as ground conductivity and dielectric constant; Fresnel zone requirement, size and clearance; ambient noise level, vertical angle of radiation; and other factors for an ideal site will be considered and standards to guide compromises for practical circumstances will be given.

2. Nature of high frequency propagation

2.1 Propagation path classification

The energy radiated from a transmitting antenna may reach the receiving antenna over any of several propagation paths. These are generally divided into three classes; the space wave, the ground wave, and the sky wave. The space wave generally consists of two components, one traveling the direct path from transmitter to receiver, the direct wave, and the other, the ground-reflected wave, reaching the receiver after one (or more) reflections from the ground. Additional space-wave energy can reach the receiver through scattering from various physical objects such as trees and hills and due to diffraction around the earth's surface and refraction in the upper atmosphere. Space-wave communication accounts for most communication above thirty megacycles, ionospheric scatter propagation excepted.

The ground wave is guided along the earth's surface, with the earth carrying an induced current, much as an electromagnetic wave is guided by a transmission line and energy is abstracted from the ground wave to supply losses in the earth. Above 1600 kilocycles (kc/s) the ground wave is attenuated to such an extent that its effect is negligible at any appreciable distance from the transmitter.

For radio waves having frequencies between those propagated by the space wave and the ground wave most propagation is via the sky wave. The sky wave is one which leaves the transmitter at angles above the horizon travelling outward from the earth until it reaches the ionosphere at heights of 80-400 km (50-250 miles) where it is reflected back toward the earth's surface. It is this mode of propagation utilized for high frequency (3-30 Mc/s) communications between terminal sites of which this report is concerned.

2.2 Ionospheric characteristics

A knowledge of some of the more important characteristics of the ionosphere will aid in an intelligent over-all design of a communication system. The ionosphere is that region of the earth's atmosphere in which some of the constituent gases are ionized by various means such as ultraviolet light from the sun, cosmic rays, meteors, and perhaps other mechanisms. This ionized region extends from 50-500 km or greater and although some ions and electrons are in existence to some extent throughout the entire range the structure of the ionosphere seems to be characterized by several layers, or areas, in which the ion density is greater than it is immediately above or below this level. The character of these layers although having diurnal, seasonal, and geographical variations is well enough defined to be distinguishable at most times and layers are classified according to ascending heights as the D, E, F1 and F2 regions. Each of these regions is capable of reflecting some frequency range of radio waves, however, for high frequency considerations, the D region does not act as a reflecting layer but rather as an ionized region below the E layer where its main effect on HF communication is the daytime absorption, or attenuation, of radio waves in the lower portion of the high-frequency spectrum.

If an HF radio wave leaves the earth at a small angle, a considerable distance can be covered before it comes down again after reflection from E or F regions of the ionosphere. Under normal conditions and with reflection from the F2 layer a radio wave emanating from a transmitter at the earth's surface can reach a point about 4000 km (2500 miles) away. With sufficient power much greater distances may be achieved by a process of multiple reflections or "hops" between the earth and the ionosphere. Because of the lower height of the E region the greatest distance a single hop E region-reflected radio wave can cover is about 2000 km (1250 miles). Figure 1 shows a probable distribution of ion density as a function of height along with some possible ray paths indicating reflections from ionospheric layers.

The mechanism of reflection and refraction of radio waves by the ionosphere is very dependent upon frequency. The highest frequency which will be reflected at the ionosphere increases both with the angle between the vertical and the ray path at the ionosphere and the ion density of a layer. For any given frequency and ionization density there is a maximum angle, above the horizon, at which a wave sent to the ionosphere will be reflected back to the earth. Waves travelling at greater angles above the horizon will not be reflected but continue on into space. Ray path 3 in figure 1 represents this latter condition. Because of this critical condition of reflection there exists then some minimum ground distance which may be covered by a sky wave of a given frequency and this distance is known as the skip distance. Correspondingly there is a maximum frequency which may be used to send energy a certain distance away and this is known as the maximum usable frequency (MUF). Thus the skip distance and the MUF are inseparably related and dependent upon ionospheric conditions.

It has been mentioned that the D region primarily acts as an attenuator for high frequencies which are reflected from higher levels. Above the D region, at a height of 90 to 130 km (55-80 miles), is the E layer in which the level of maximum ionization density remains fairly constant throughout the day, as well as seasonally, but for the most part disappears at night. Because of its comparatively low height and maximum ion density, the transmission range which can be achieved by reflection from the E layer is limited and useful propagation is provided, mainly, for frequencies under ten megacycles.

In addition to the regular layer at E region heights it is found that regions of much higher ion density exist at random times and locations and are known as sporadic-E clouds. These over-dense areas are at times capable of supporting propagation at frequencies considerably greater than the normal E layer is, but because the present state of knowledge does not allow prediction of their occurrence at any particular place and time their potential usefulness in radio communication is not realizable.

The F region exists above the E region, extending up to heights in excess of 400 km (250 miles), in which the F1 and F2 layers are either separate or merged into a single layer depending upon the time of day. By convention when only a single layer is present it is designated as the F2 layer. In general the F2 layer is the most important layer for long distance high frequency communications because of its height and greatest ion density which contribute to higher MUFs and to greater transmission distances.

All of the layers exhibit variations, both regular and irregular in nature, and unfortunately the F2 layer tends to exhibit a greater variability than any of the others. The irregular variations are due to many different causes which are essentially random in nature and thus lead to a degree of unpredictability of ionospheric conditions. Variations which tend to be more regular are of three types: diurnal, seasonal and long-term.

These changes in all of the layers are related to the solar zenith angle, and thus the amount of energy reaching the layers, but this fact is not easily expressible by a simple law for all regions. In particular the F2 layer diurnal maximum ionization lags behind the altitude of the sun and ionization densities, and MUFs are higher during the northern hemisphere winter than they are in summer. By contrast, the D, E, and F1 layers have maximum ion densities in the summer and the diurnal variations tend to relate to the solar zenith angle more closely with ion density rising rapidly at sunrise, remaining high through the midday, and declining again in the early evening.

Long term variations in ionization density in the various layers tend to rise and fall, for a given hour and season, with the mean annual sunspot number. These sunspot numbers follow a cycle which averages about eleven years in length and during years of sunspot maxima ion densities are high and higher MUFs prevail. D-region absorption also increases, but the net effect is to increase the usable range of frequencies. The opposite effect is produced during periods of sunspot minima and the useful high frequency radio spectrum is reduced in width.

Prediction methods for obtaining the MUF existing between any two points on the earth at any time of day are available and are based upon a large accumulation of data from past years and a prediction of the average sunspot number. One such prediction service is provided by the National Bureau of Standards CRPL Series D frequency predictions. Bulletins of MUF prediction are available monthly three months in advance and methods of their utilization are given in NBS Circular 462 and Signal Corps Technical Report No. 9.

3. Elements of siting

Inasmuch as the high frequency band nominally covers the frequency range of 3 to 30 Mc, a wide range of propagation path lengths prevails at any given time if proper frequencies are utilized. In general, for short distances the lower frequencies and high-angle radiation from antennas is required; for long distance communications higher frequencies and low-angle antenna radiation is needed. Site requirements necessary to align properly and to form antenna lobes are dependent upon the communication path length and radio frequency used. From these, antenna beam elevation angle, height of antenna, and ground reflection characteristics can be established.

3.1 Angle of departure and arrival

In order to design the best antennas for use at a communication center, knowledge concerning the angles of departure or arrival of a radio signal for the prevalent mode or modes of propagation is necessary. The antenna radiation angle required for propagation optimization then determines the required height of the antenna above the reflecting surface as well as the amount of radio-smooth area needed in front of the antenna.

3.1.1 Single-hop transmission

The angle of arrival or departure usually assumed for single-hop transmission is that obtained from the geometry of a triangular path over a curved earth with the apex of the triangle placed at the height at which it is assumed that reflection of the radio wave occurs. This technique of course is only approximate and there are many variable ionospheric conditions which cause the angle of arrival to change even though the communication path terminals are fixed.

In order to estimate the desired radiation angle of antennas for any path less than 4000 km in length figure 2 may be used. In this figure, a straight line drawn between the point on the left hand distance scale, corresponding to the path length, and a point on the virtual height scale, corresponding to the assumed height of reflection, is extended to the point of intersection with the vertical line corresponding to the path length. This point of intersection then lies on or between parametric angle curves from which the radiation angle may be found. For propagation by E-layer reflection a height of around 110 km can be assumed for the virtual height. A virtual height of from 300 - 350 km may usually be assumed when the propagation is via the F2 layer.

3.1.2 Transmission over distances greater than one-hop

The maximum range for single-hop propagation by any ionospheric layer would appear to be determined by the earth's curvatuve and the height of the reflecting layer. For angles of arrival and departure equal to zero this distance for F2 layer reflection, at various frequencies, may range from 3500 to 5000 km or greater. Beyond the single-hop range a simple, but incomplete, picture involves propagation by a number of geometric hops as indicated in figure 1. Empirically, however, it has been observed in a number of cases of long-path multi-hop propagation that geometric modes are not clearly defined. Horizontal gradients of ionization density effectively create tilts in the ionosphere or cause ionospheric roughness which contribute to scattering of the radio wave. These and other phenomena which exist in the normal ionosphere provide reasons why simple geometric modes may not exist for long-distance propagation.

Observations of long-path radio signals have shown that the greatest number of hours of propagation over a given path is afforded when low-radiation-angle antennas are used. In addition, frequently greater signal intensity is received by low-angle antennas than by antennas with radiation angles optimized for geometric modes. Although signals via geometric modes may predominate at times, most modern communication systems have adequate power available so that it is most desirable to obtain the greatest number of hours of system operation; and to provide antennas with the lowest possible angles of radiation. Angles of 5° or less are recommended. In designing low radiation angle antennas the effect of the ground reflection in producing nulls and maxima in the antenna pattern is very important and it is necessary to have the antenna at heights several wavelengths above ground.

3.2 The effect of ground

When an antenna is situated over flat ground, the field radiated downward is reflected from the ground and combines in a certain manner with the field from the direct wave forming an interference pattern with the latter so that at certain angles field reinforcement takes place while at other angles the combined fields cancel thus forming lobes of the antenna radiation pattern. The effect of the presence of the ground on the vertical radiation pattern may be obtained by use of the image principle. An example of lobe formation using the geometry of the image antenna concept is shown in figure 3.

The reinforcement of the direct wave by the ground is of great importance. Under favorable conditions, the reflected ray may be of comparable intensity to the direct ray and thus the received field strength may be approximately doubled (6 db increase) in places where the two rays have the same phase.

In order to obtain a better insight of the problems encountered in reflection it is desirable to analyze this very complex phenomenon in simpler constituents. First, the incident radiation field is resolved into plane wave components of which there are two types,each forming a ray which strikes the reflecting surface within some small area called the reflection point. The manner in which such rays are affected by the ground upon reflection is dependent upon the plane of polarization relative to the reflecting surface. In radio field work the direction of the electric vector is used to define this state of polarization. When the electric vector of the electromagnetic wave is parallel to the reflecting plane the wave is said to be horizontally polarized; if the electric vector is in the plane of incidence the polarization is known as vertical polarization. If the irregularities of the ground reflecting surface are comparable to a wavelength, the reflected field may be very complex even though the incident field is linearly polarized and if the reflecting surface is sufficiently rough, diffuse reflection may result which is ineffective in reinforcing the direct wave. Whether or not diffuse reflection occurs depends primarily upon the size of irregularities of the reflecting surface in comparison to the height of the antenna above the reflecting surface. This problem will be discussed in more detail in section 3. 5. 2.

By definition the reflection coefficient for either horizontally or vertically polarized waves is the ratio of any field quantity in the reflected wave to the same quantity in the incident wave. By this definition it may be shown that the complex reflection coefficient is of the form

$$R = \rho e^{-j\phi}$$

where ρ is the amplitude and ϕ is the lag in phase of the reflected wave with respect to the incident wave at the point of reflection. The parameters ρ and ϕ are dependent upon the angle of incidence, α, i.e. the angle between the incident ray and the reflecting surface, and upon the ground constants, conductivity and dielectric constant, of the reflecting body. They are quite different for the two types of polarization.

Although extensive investigations of soil conductivity and dielectric constant have been made it is quite difficult to catalog, according to soil type, or other parameters, values of these constants which might be universally applied throughout the world. Generally speaking, however, moist soil, marshy land, or water surfaces make the best reflecting surfaces showing much higher values of conductivity and dielectric constant than does a chalky or very dry type of soil. Because of the dependence of the soil constants upon moisture content marked seasonal changes may be anticipated for a given locality. For those cases where horizontal polarization is utilized, the problem of ground reflection from various types of ground is somewhat simplified. This is so because the reflection coefficient is very nearly equal to minus one for all types of soils and range of incident angles normally encountered on long distance communication circuits. Figures 4 and 5 show the variation in magnitude and phase of the reflection coefficient for a horizontally polarized wave as a function of the incident angle at various frequencies for a relatively good conducting earth. For a sea water reflecting surface, values of ρ would be greater and ϕ nearer 180° than the curves shown while for a poorly conducting earth ρ would be somewhat smaller and ϕ further from the 180° phase angle.

The coefficients of reflection and phase angle for vertical polarization vary rapidly with frequency and incident angle. These variations are shown in figures 6 and 7 and it may be seen that the results are quite different from those for horizontal polarization. As in the case of horizontal polarization for angles of incidence near grazing, $\alpha = 0$, the magnitude of the reflected wave is equal to the incident ray and 180 degrees out of phase with it. This is true for all frequencies and ground conductivities. As the value of α increases from zero, however, both the magnitude and phase of the reflected wave rapidly decrease until the magnitude reaches a minimum value and the phase angle is at -90 degrees. The incident angle associated with this minimum magnitude is known as the Brewster angle. At angles of incidence above the Brewster angle the reflection coefficient magnitude increases and the phase angle approaches zero.

Frequently, although not always, elevated antennas horizontally polarized are used for communication circuits in the high frequency band. There are several advantages of utilizing such antennas among which are (1) less response to locally generated man-made noise which propagates as a predominately vertically polarized surface wave, (2) convenience of antenna excitation, (3) less ground system loss than with ground-based vertical antennas, and (4) some control over the vertical radiation pattern by selection of the proper height of the antenna above the reflection surface. Factors affecting the vertical radiation pattern are discussed in the next section.

3.3 Vertical angle of beam

The vertical pattern of an antenna, i.e. a relative plot of field strength or power as a function of elevation angle in a vertical plane passing through the antenna, in the absence of a reflecting surface is referred to as a free-space pattern. The vertical directivity of an actual antenna then is modified by the local terrain. In the discussion to follow immediately assumptions of horizontal polarization and a smooth, good reflecting local terrain are made. The effect of the presence of the ground on the vertical radiation pattern can be obtained by use of the image principle and the principle of pattern multiplication. Briefly, this means that the ground is replaced by an image antenna located a distance of 2h below the actual antenna where h is the height above the ground at the reflecting point of the actual antenna. The polarity of the image antenna is opposite to that of the actual antenna. The field of this image antenna is then added to that of the actual antenna to yield the resultant field. In this analysis the relative horizontal pattern remains unchanged. For horizontal antennas, in the vertical plane perpendicular to the axis of the antenna, the free-space pattern can be multiplied by the factor

$$2 \sin\left(\frac{2\pi h}{\lambda} \quad \sin \alpha\right) \tag{3.3-1}$$

to account for the effect of the ground where the symbols h and α have the meaning indicated in figure 3. The height of antenna, h, and the wavelength of the operating frequency, λ, must be in identical units.

Lobe maxima occur whenever the sum of the phase shifts caused by reflection and path difference from actual and image antenna points equal an even number of π radians and lobe minima or nulls occur when the total phase shift is equal to an odd multiple of π radians.

Lobe maxima and minima are found at angles corresponding to

$$\alpha = \sin^{-1} \frac{n\lambda}{4h}, \quad n = 1, 2, 3 \ldots \qquad (3.3\text{-}2)$$

with n odd giving lobe maxima and n even the nulls.

For the case of vertical polarization no simple factor by which the antenna free-space pattern can be multiplied to give the vertical directivity pattern can be given because of the variability of reflection coefficient with antenna height, however, lobe maxima and minima can be determined approximately after determining the phase of reflection, ϕ, by the formula

$$\alpha = \sin^{-1} \frac{n + \phi/\pi - 1}{4h} \qquad (3.3\text{-}3)$$

The above formulas apply strictly only to the case of a plane earth. The reflection of a beam of radiation from a spherical earth causes divergence or spreading of the wave and reduces the magnitude of the reflected wave.

3.4 The Fresnel zone

A complete understanding of Fresnel-zone theory is not essential to successful siting of ionospheric communication terminals and therefore only salient results of the theory which are pertinent for use in practical siting work are briefly presented below.

The concept of a first Fresnel zone is introduced to describe an area required in front of an antenna in order to effectively form the lowest ground reflection lobe. The ground for a considerable distance in front of the antenna plays an important part in the formation of the vertical plane radiation pattern; this distance increasing rapidly as the angle of arrival or departure decreases.

With the aid of figure 8 the first Fresnel zone is defined with respect to a reference ray as the area of ground, assumed to be a smooth plane, in front of a point antenna A from within which all contributions of reflected energy in a plane-wave front, advancing in the direction of the reference ray, differ in phase by 180 degrees or less from the phase of the reference ray. Horizontal polarization only is considered in order that lobe formation not be complicated by the large variations in ground-reflection coefficient associated with low angle, vertical polarization transmissions. The antenna is assumed to be a point source and the ground-reflected wave is assumed to have the same amplitude as the incident wave but to undergo a 180-degree phase change at reflection.

Utilizing geometric optics, with the origin of the coordinates, O, coinciding with the ground reflection point for the reference ray the following equations may be shown to express the important dimensions of the first Fresnel zone.

The height of an antenna above the Fresnel zone for maximum radiation in the direction of the ionospheric reflection point is, for horizontal polarization,

$$h = \frac{\lambda}{4 \sin \alpha} \quad . \tag{3.4-1}$$

The distance from the antenna base, B, to the geometric ground-reflection point, O, is given by,

$$d = \frac{h}{\tan \alpha} \quad . \tag{3.4-2}$$

The distance from the antenna base B to the near edge of the Fresnel zone may be calculated from the equation

$$d_N = \frac{h}{\tan \alpha}\left(3 - \frac{2\sqrt{2}}{\cos \alpha}\right) , \tag{3.4-3}$$

and the distance to the far edge of the Fresnel zone is determined from the relationship

$$d_F = \frac{h}{\tan \alpha} \left(3 + \frac{2\sqrt{2}}{\cos \alpha} \right) . \qquad (3.4\text{-}4)$$

The maximum width of the zone is

$$w = 4\sqrt{2}\, h = 5.66\, h \quad . \qquad (3.4\text{-}5)$$

The shape of the Fresnel zone, for a plane-earth case, is that of an ellipse with the major axis oriented in the direction of propagation. The effect of the curvature of the earth on the first Fresnel zone has the quantitative result of reducing in size the elliptical area and altering it into an elongated egg shape with the broad end near the antenna. The value of d_N is almost unaffected, while the distance d is reduced somewhat and the distance d_F reduced considerably. The maximum width is reduced only slightly but occurs somewhat nearer the antenna. Earth curvature does have an important practical effect of reducing the height, h, required for formation of the first lobe at a specified angle. All of the effects of earth curvature are appreciable only when the angle of arrival or departure, α, is very small, 3 degrees or less. The relationship between antenna radiation angle and the antenna height and first Fresnel-zone dimensions for the plane-earth case are shown in figures 9 through 13 for representative high frequencies. The accuracy obtained from these curves is adequate for practical siting problems.

3.5 Fresnel zone siting

Because of the importance of the Fresnel zone in forming the first lobe, particular attention must be given in a siting survey to this zone for both transmitting and receiving antenna sites. In general idealized conditions will not be found and thus compromises must be made. The intent of this section is to offer guidance for acceptable compromises but it should be well understood that compromises will result in a degradation of service and that a compounding of compromises may result in a site which would provide completely unsatisfactory performance. Factors to be considered for each antenna are the dimensions of the Fresnel zone, terrain irregularities within this zone and the horizon clearance, in the propagation direction, from all portions of the zone.

3.5.1 Limited ground reflection areas

As indicated earlier, figures 9 to 13 show the required dimensions of the first Fresnel zone. In some cases it may be impossible to obtain a site having dimensions as large as those indicated but which may otherwise be desirable. The following factors are suggested as a guide when compromise is necessary and are obtained by considering the dimensions, in limiting cases, of that portion of the first Fresnel zone which includes phase shifts of the reflected ray up to $\lambda/4$, or 90°. While these factors may prove useful where it is impossible to find an adequate Fresnel zone it should be recognized that degradation in system performance by as much as 2 db (37% reduction in power) is to be expected at each site where compromise is made. The quantities listed below indicate the range of values by which the Fresnel zone dimensions may be altered in this compromise.

(a) d_F may be decreased in length from 1 to 0.6 times full value
(b) d_N may be increased in length from 1 to 1.6 times full value
(c) w may be reduced from 1 to 0.7 times full value

3.5.2 Fresnel zone roughness

The preceding discussion of Fresnel zones was based on reflecting surfaces which were ideally smooth. Because the earth is not necessarily radio-smooth, consideration to the effects of surface irregularities upon the ground reflecting properties must be given. In order to estimate how closely the ground approximates the condition of an ideal reflecting surface for radio waves, guidance is obtained from optical theory developed by Rayleigh. Rayleigh's criterion indicates that a transition region between specular reflection and scattered reflection occurs when the height of an irregularity exceeds a value of

$$H = \frac{\lambda}{16 \sin \alpha} \qquad (3.5.-1)$$

Hence a rule of thumb for determining maximum heights of deviations (above or below) from the average terrain profile, which will still allow specular reflection, may be shown to be equal to one-quarter of the antenna height.

$$H = \frac{h}{4} \qquad (3.5\text{-}2)$$

This is admittedly an approximation but does give an indication of the size of tolerable irregularities of terrain.

When the relative contribution of energy from the various portions of the Fresnel zone and the fact that the angle at which a given ray strikes the ground varies over the zone are taken into account, it is clear that permissible deviations increase with distance from the antenna. An exact solution to the problem, however, is difficult. The following table is suggested as a guide when compromise must be made with regard to terrain roughness and presents upper limits of departure from the ideal smooth Fresnel zone. The Fresnel zone has been divided into three regions determined approximately by the geometry reflection point, the far $\lambda/4$ point, and the zone extremities.

Compromise Roughness Criteria

Limit of departure from average smooth terrain	Region of Fresnel zone
$h/4$	d_N to $0.2\ d_F$
$h/2$	$0.2\ d_F$ to $0.6\ d_F$
h	$0.6\ d_F$ to d_F

The amount of service degradation produced when the above compromise is made is not known but it is certain that there will be some. This criterion ignores the surface shape of the obstacles and while an obstacle may be within the height criteria given it may still eliminate a major portion of the reflected energy, for example sharp depressions or low hills. The criteria given above applies to cases where the entire first Fresnel zone is rough. When a major portion of the zone is smooth it is likely that somewhat larger obstacles may be tolerated if they do not cover more than say 5 percent of the area. Extreme caution should be used in selecting sites where compromise in both area size and roughness must be made simultaneously.

3.5.3 Sloping sites

For very long distance communications it is most desirable to use very low angle radiation, as has been pointed out, and thus it is important to utilize terrain advantages, where possible, to minimize antenna construction cost. Antenna tower heights may be substantially reduced if antennas are located where the Fresnel zone area slopes downward in the direction of the propagation path. The effect of sloping terrain downward in front of the antenna is to give an apparent increase in antenna height and resultant decrease in radiation angle. An additional advantage is a reduction in Fresnel zone dimensions. Figure 14 represents the geometry of reflection from a sloping site where β is the angle between the horizontal and the terrain. From this it is easily seen that the effective antenna height above ground for sloping terrain, h_s', is given for horizontal polarization by

$$h_s' = \frac{\lambda}{4 \sin (\alpha + \beta)} \qquad (3.5\text{-}3)$$

and the actual height above ground is

$$h_s = \frac{h_s'}{\cos\beta} \qquad (3.5\text{-}4)$$

If the terrain slopes in the opposite direction, i.e., upward in the direction of propagation then the antithesis of the above arguments is true and β is taken to be negative.

When sloping terrain is utilized equation 3.5-3 is used to find h_s' and this value in turn is then used in conjunction with figures 9 to 13 to obtain values of d_N, d_F and w, for the Fresnel zone dimensions.

3.5.4 Elevated sites

Another obvious method of reducing antenna construction cost and still provide low angle radiation is to make use of elevated terrain sites such as hills, mesas, or cliffs which overlook the Fresnel zone. The effective height of the antenna is then the vertical distance measured between the antenna and a horizontal line passing through the geometric reflection point.

3.5.5 Horizon

In order effectively to form the lower portion of the first vertical lobe the horizon in the direction of propagation as viewed from the entire Fresnel zone ideally must be free of obstructions. Satisfactory conditions will probably prevail if the horizon as seen from all parts of the Fresnel zone does not extend up beyond angles of $\alpha/2$ degrees. If compromise in horizon clearance is required the criterion of horizon less than $\alpha/2$ degrees should be met for at least the $\lambda/4$ phase points of the zone while the remainder of the zone should have clearance of horizon less than α degrees.

4. Radio noise and interference

4.1 Types of radio noise

Noise and interference from other communication systems are two factors limiting the useful operating range of all radio equipment and must be considered in selecting a receiver site. External radio noise, i.e., other than receiver set noise, consists of three types; namely, atmospheric, man-made, and galactic. Each type has different characteristics which are briefly discussed below.

4.1.1 Atmospheric noise

Most of the atmospheric noise in the world originates in thunderstorms. Of the three noise types, atmospheric noise is the most erratic in nature consisting of short, randomly occurring pulses superimposed upon a background of random noise. At a given location the atmospheric noise is made up of noise from nearby noise centers, such as local thunderstorms, plus noise which has been propagated over great distances from one of the principle noise centers, such as the active thunderstorm areas in equatorial Africa, Central America, and the East Indies. The activity of the various noise centers vary with time of day and season and so also do propagation conditions which transmit the noise. Major thunderstorm centers tend to shift above and below the equator from summer to winter and even though ionospheric absorption is greater in the summer, increased storm activity seems to predominate and as a result received noise tends to be highest in the summer and lowest in the winter.

Received noise level varies with frequency, in general decreasing with increasing frequency. There are variations also with geographical location, highest noise levels being encountered in equatorial regions and the lowest levels in polar regions.

4.1.2 Man-made noise

Man-made noise may arise from any number of sources such as power lines, industrial machines, diathermy machines, ignition systems, etc., and thus its characteristics vary over a wide range of limits. Much of the noise energy from sources of this type are propagated to the receiver over power lines or by ground wave propagation. In general the level of man-made noise decreases with increasing frequency due in part to the source spectrum and in part to propagation factors.

4.1.3 Galactic noise

Galactic noise has a characteristic similar to thermal noise with a Gaussian amplitude-time distribution. The intensity of galactic noise decreases with increasing frequency. The amount of energy impinging upon an antenna, in part, is dependent upon the portion of the sky seen by the antenna lobes. Great noise sources are found in the direction of the constellations Sagittarius and Cassiopeia. Since the galactic noise source is external to the ionosphere the noise level received is dependent upon ionospheric absorption characteristics and the relationship of the operating frequency to the critical frequency. In arctic regions, where very low critical frequencies are often encountered and noise from atmospheric and man-made sources is low it is expected that at times galactic noise may be the principle external noise source in the HF band. At temperate and tropical latitudes, where critical frequencies are higher and atmospheric noise stronger, galactic noise is usually negligible below 15 or 20 Mc.

4.1.4 Interference from nearby radio stations

Radio transmitters located within several miles of a receiving station may create serious interference due to harmonics, keying transients, parasitic oscillation or co-channel operation. It is of course also possible, when receiver sites are in strong radio frequency fields, that cross-modulation products may be generated in receivers even though transmitter frequencies are greatly different from the normal receiving frequency. Existing, and even proposed, sources of radio interference must be taken into account in the overall evaluation of a site.

4.2 Site evaluation with regard to radio noise

The above paragraphs have briefly indicated sources and characteristics of noise and radio interference. Optimumly, the noise levels at sites chosen for high frequency receiving terminals should not exceed that due to natural causes of atmospheric or galactic noise. The expected values of atmospheric or galactic noise levels in the HF band on a world-wide basis for all times of day and seasons of the year may be found in the International Radio Consultative Committee (CCIR) report No. 65. While only through a noise measurement program can it be ascertained whether natural or man-made sources are the principle contributors of noise at a given site there are obvious man-made environments near which a receiver site should not be located. Some of these are enumerated below.

4.2.1 Vehicular traffic

Since this is a major source of radio noise it is most desirable to choose receiving sites in locations where there is a minimum of nearby vehicular traffic and it is especially important that no traffic pass immediately in front of the receiving antennas. A reasonable distance of clearance between a heavily travelled highway and a receiving antenna, in the direction of the main lobe, is probably three miles or more. Somewhat smaller distances may be tolerated in other directions as determined by the horizontal pattern of the antennas used.

4.2.2 Industrial areas

Manufacturing areas, areas near power plants or power substations, medical facilities of diathermy and X-ray, street lighting systems and high-voltage overhead power lines are examples of environments likely to generate radio noise. This noise may be radiated in a manner similar to that in which radio waves are radiated from antennas or it may be conducted over an appreciable distance by power lines and radiated by those which pass near the receiving site.

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REPRESENTATIVE ELECTRON DENSITY DISTRIBUTION AND RAY PATHS

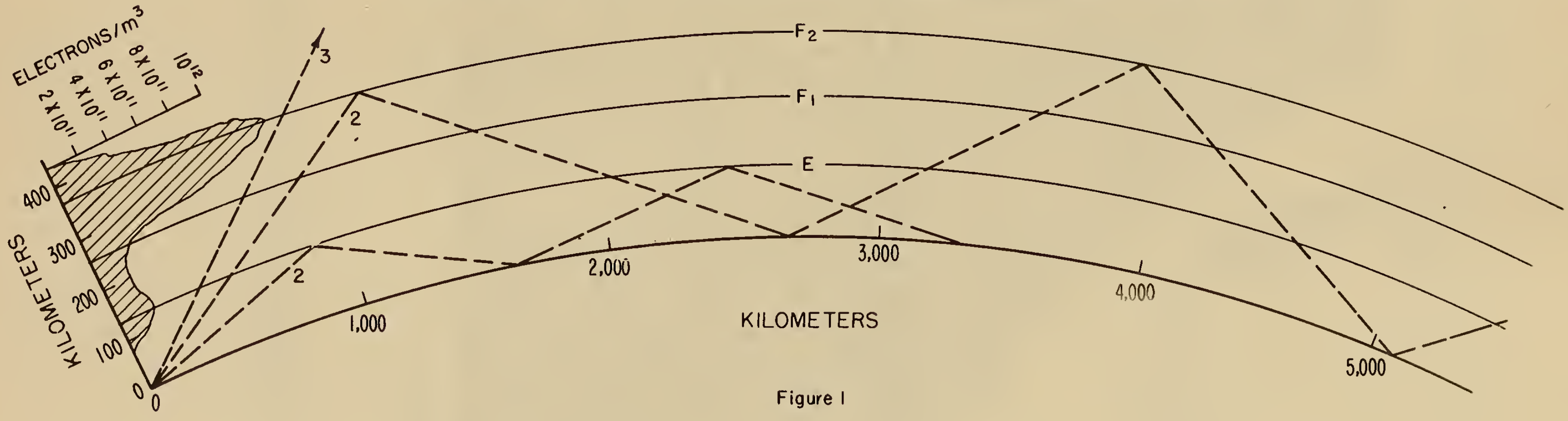


Figure I

RADIATION ANGLE AS A FUNCTION OF RANGE AND IONOSPHERIC REFLECTION HEIGHT

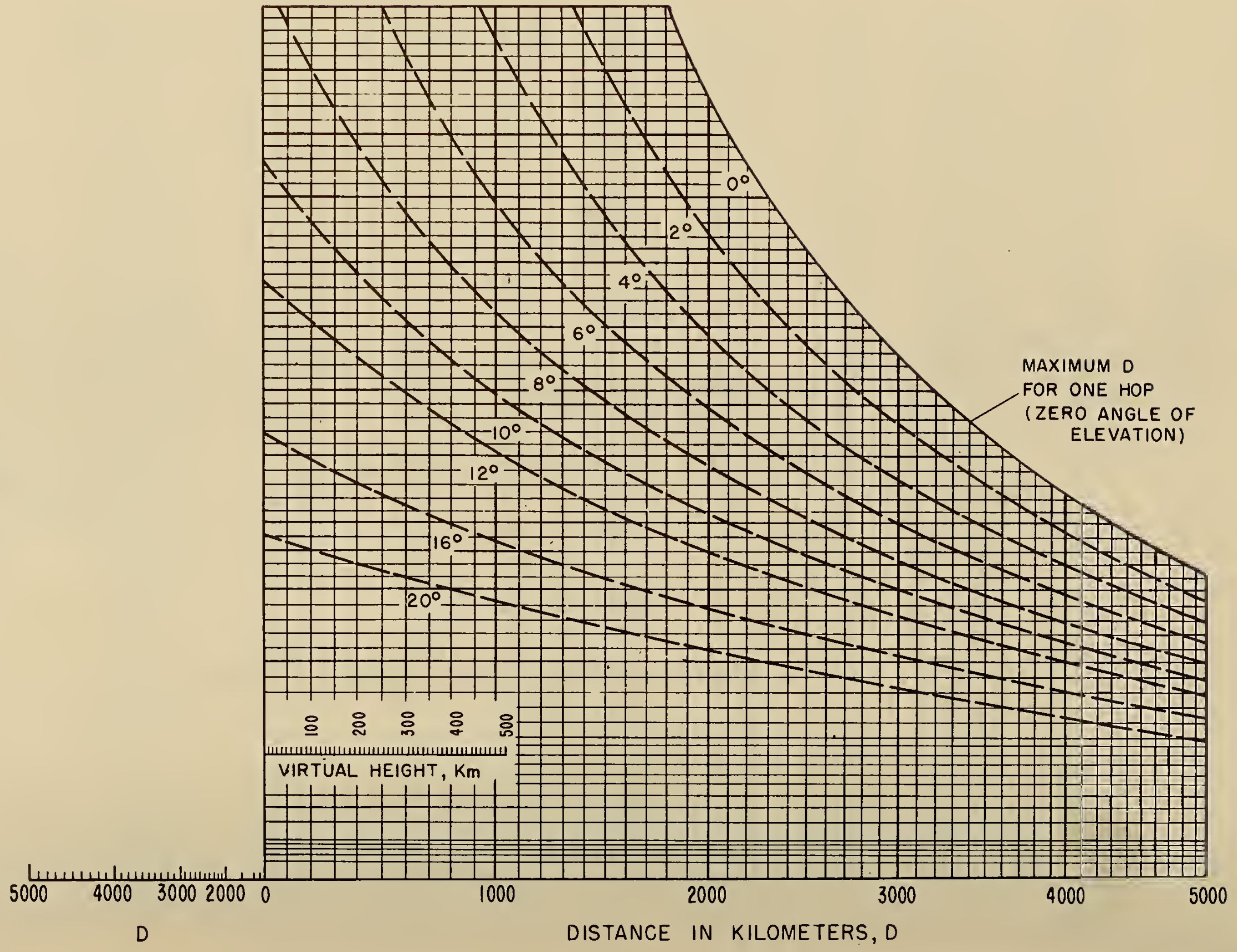
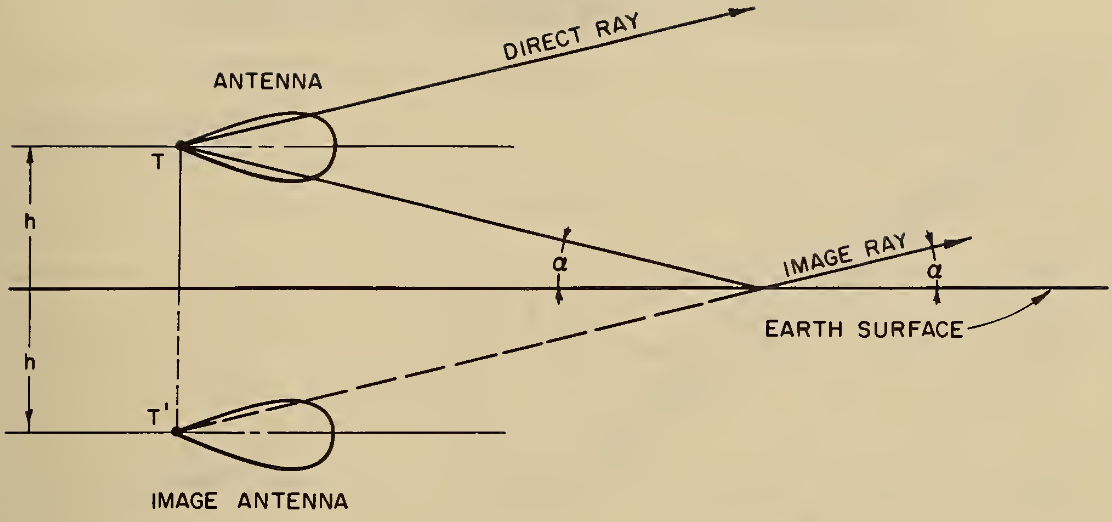


Figure 2



(a)

IMAGE ANTENNA CONCEPT – IMAGE ACTS AS VIRTUAL SOURCE FOR THE GROUND REFLECTED RAY

(b)

REPRESENTATIVE LOBE FORMATION RESULTING FROM DIRECT AND IMAGE RAY INTERFERENCE

Figure 3

MAGNITUDE OF PLANE WAVE REFLECTION COEFFICIENT FOR HORIZONTAL POLARIZATION AS A FUNCTION OF INCIDENT ANGLE AND FREQUENCY

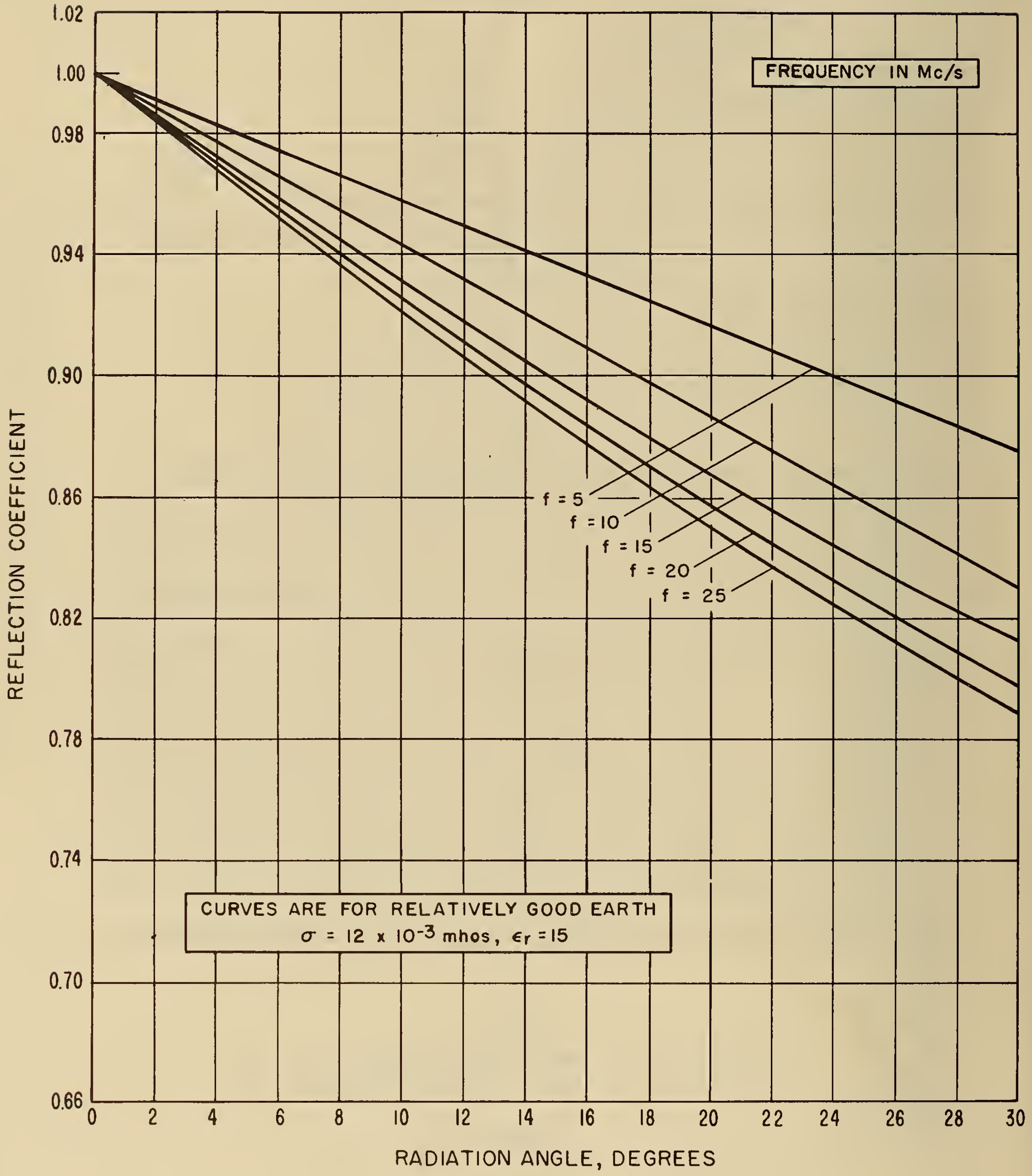
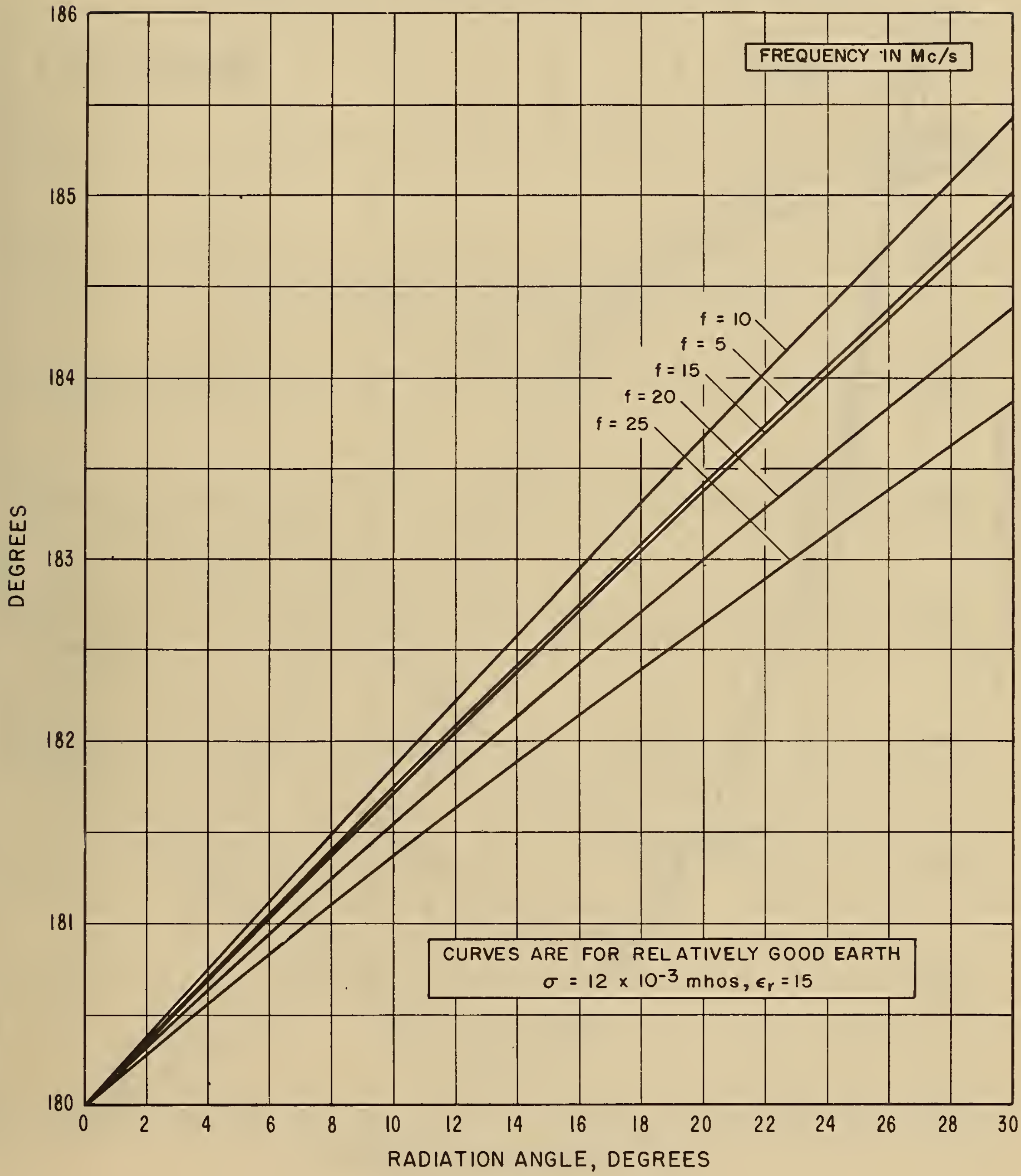


Figure 4

PHASE OF PLANE WAVE REFLECTION COEFFICIENT FOR HORIZONTAL POLARIZATION AS A FUNCTION OF INCIDENT ANGLE AND FREQUENCY



CURVES ARE FOR RELATIVELY GOOD EARTH
$\sigma = 12 \times 10^{-3}$ mhos, $\epsilon_r = 15$

Figure 5

MAGNITUDE OF PLANE WAVE REFLECTION COEFFICIENT FOR VERTICAL POLARIZATION AS A FUNCTION OF INCIDENT ANGLE AND FREQUENCY

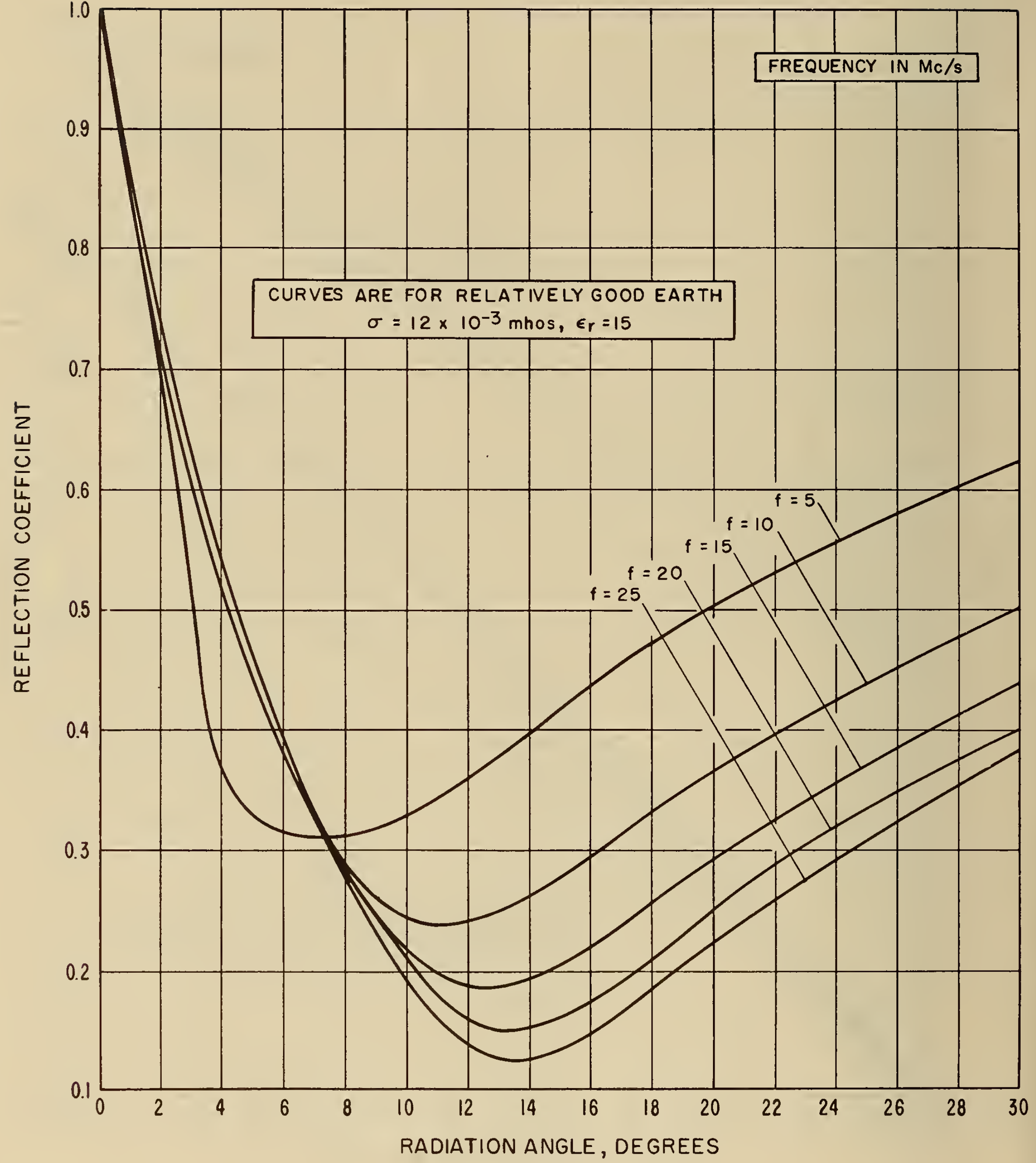


Figure 6

PHASE OF PLANE WAVE REFLECTION COEFFICIENT FOR VERTICAL POLARIZATION AS A FUNCTION OF INCIDENT ANGLE AND FREQUENCY

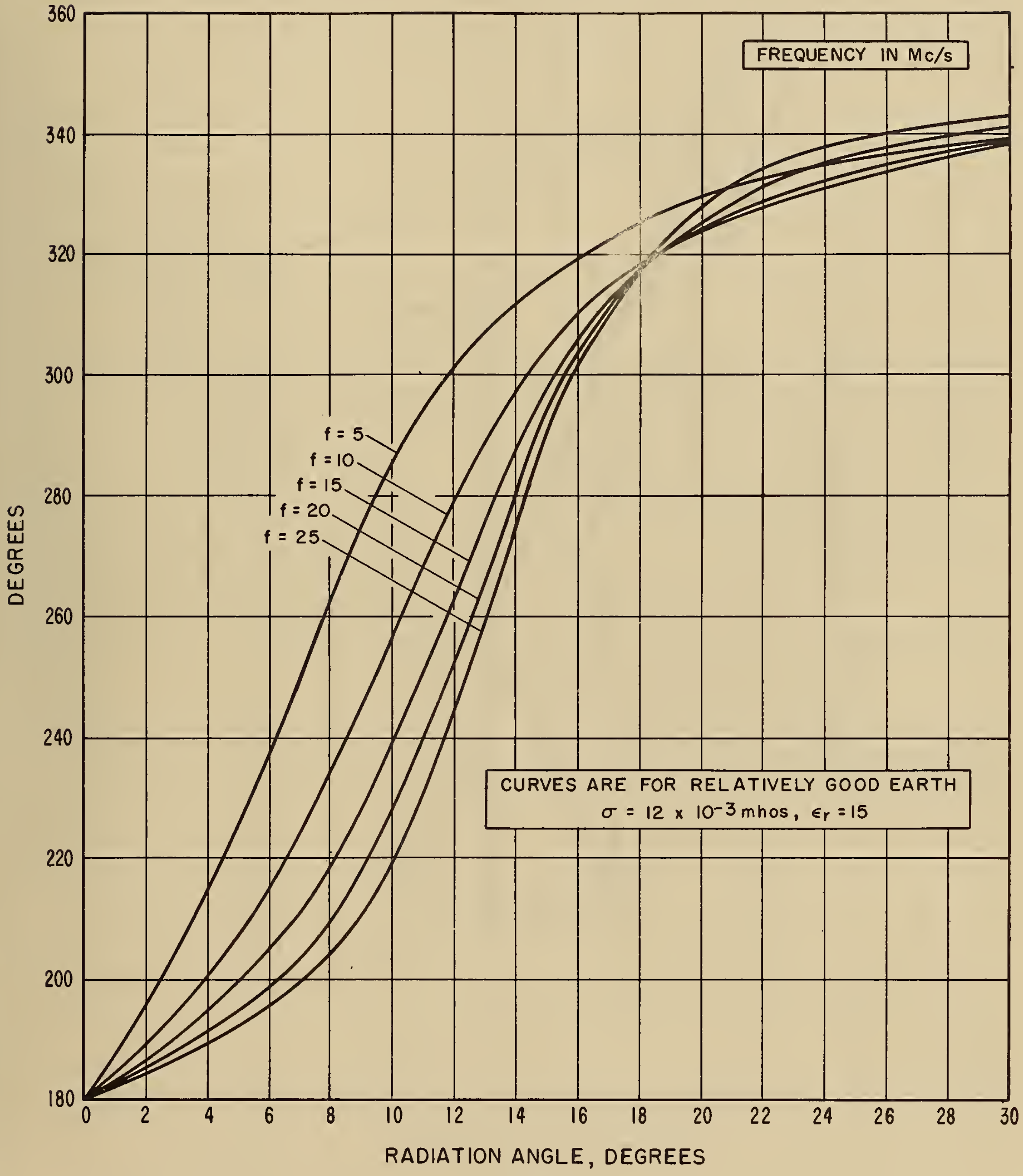


Figure 7

GEOMETRY OF FIRST FRESNEL ZONE

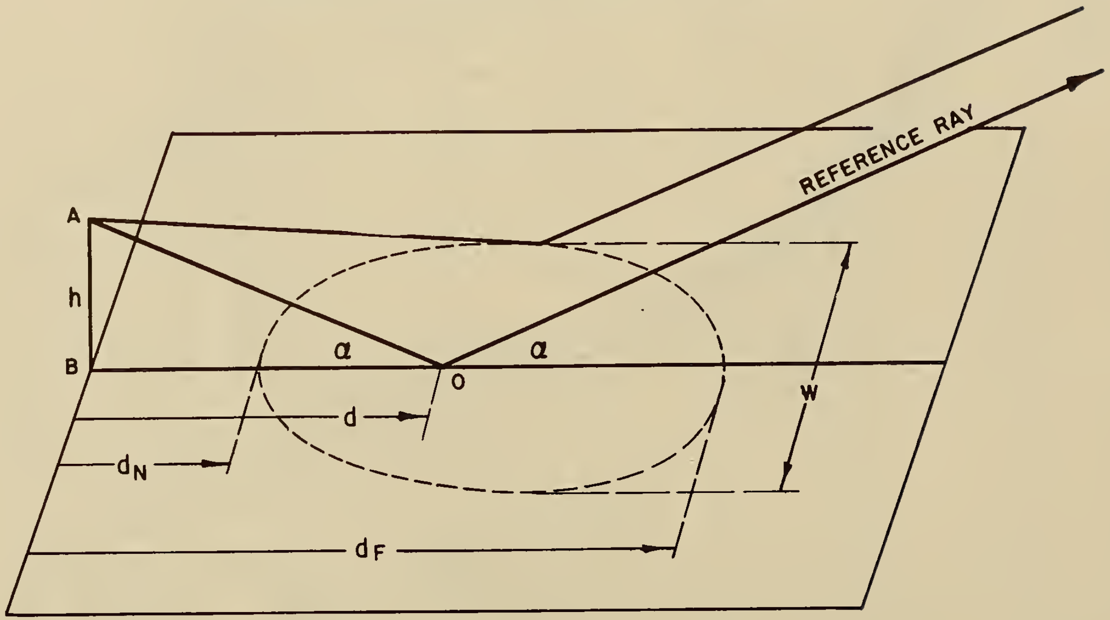
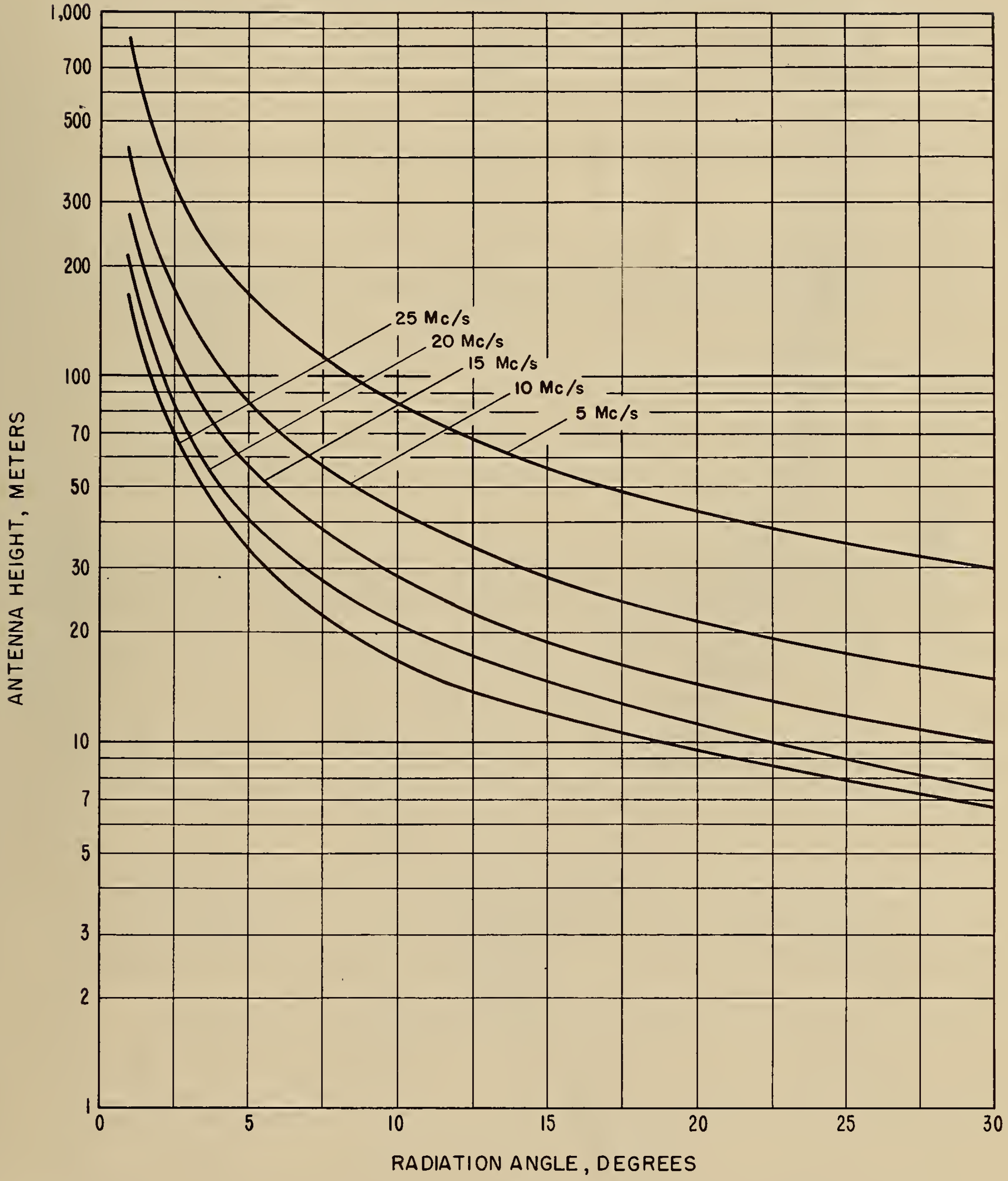


Figure 8



ANTENNA HEIGHT AS A FUNCTION OF RADIATION ANGLE AND FREQUENCY

Figure 9

DISTANCE FROM ANTENNA TO REFLECTION POINT AS A FUNCTION OF RADIATION ANGLE AND FREQUENCY

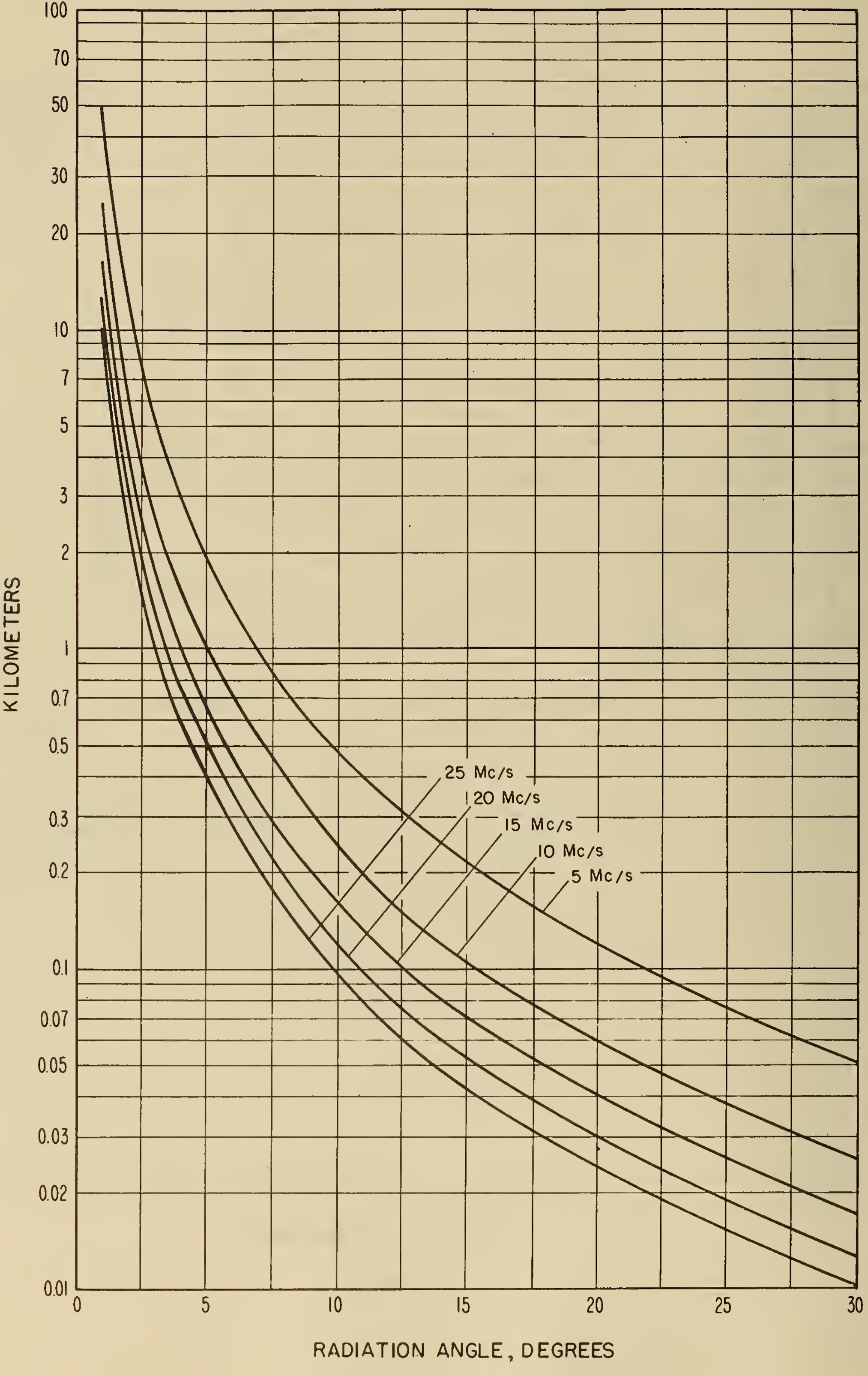


Figure 10

DISTANCE FROM ANTENNA TO NEAR EDGE OF FRESNEL ZONE AS A FUNCTION OF RADIATION ANGLE AND FREQUENCY

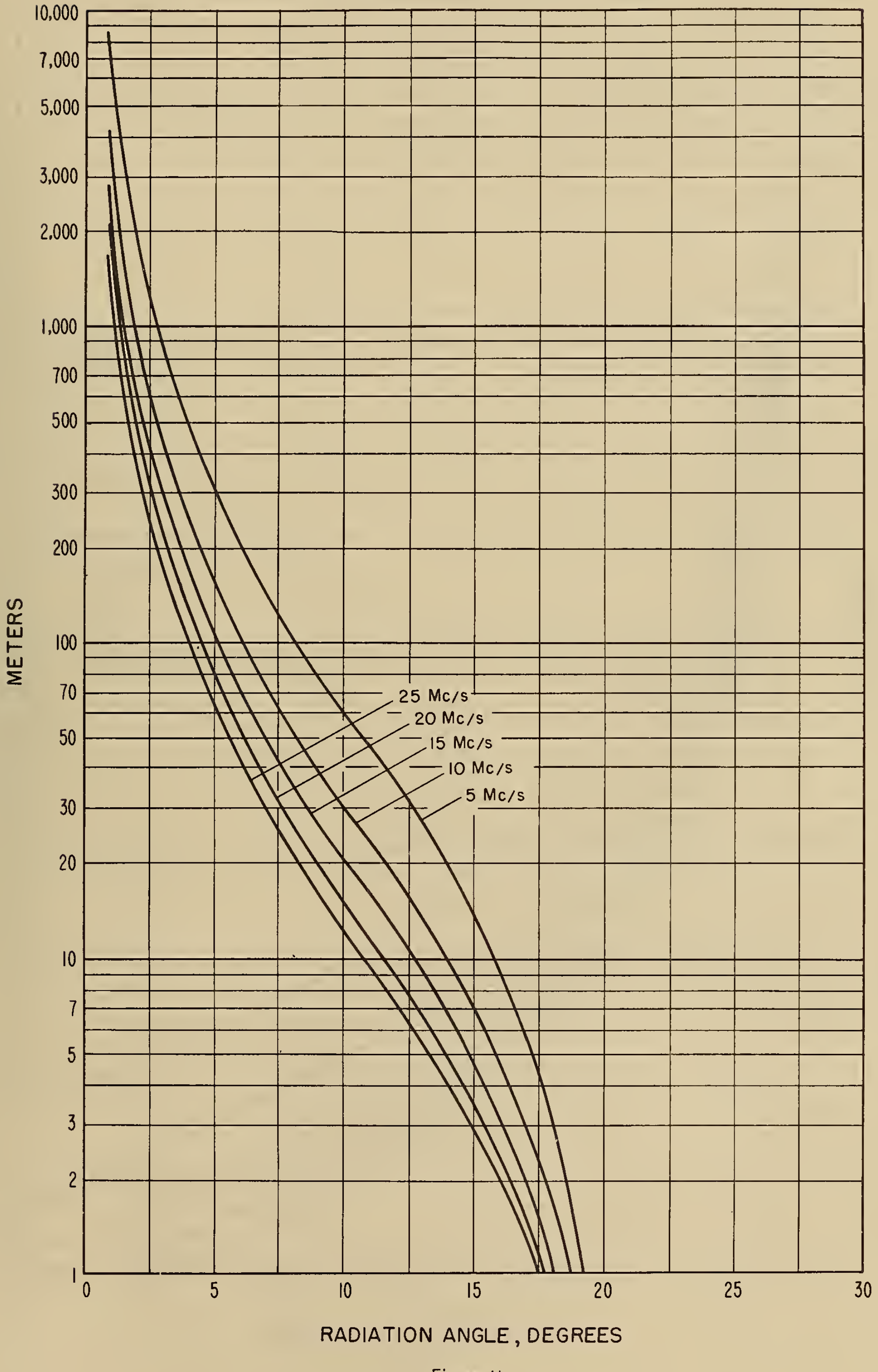


Figure 11

DISTANCE FROM ANTENNA TO FAR EDGE OF FRESNEL ZONE AS A FUNCTION OF RADIATION ANGLE

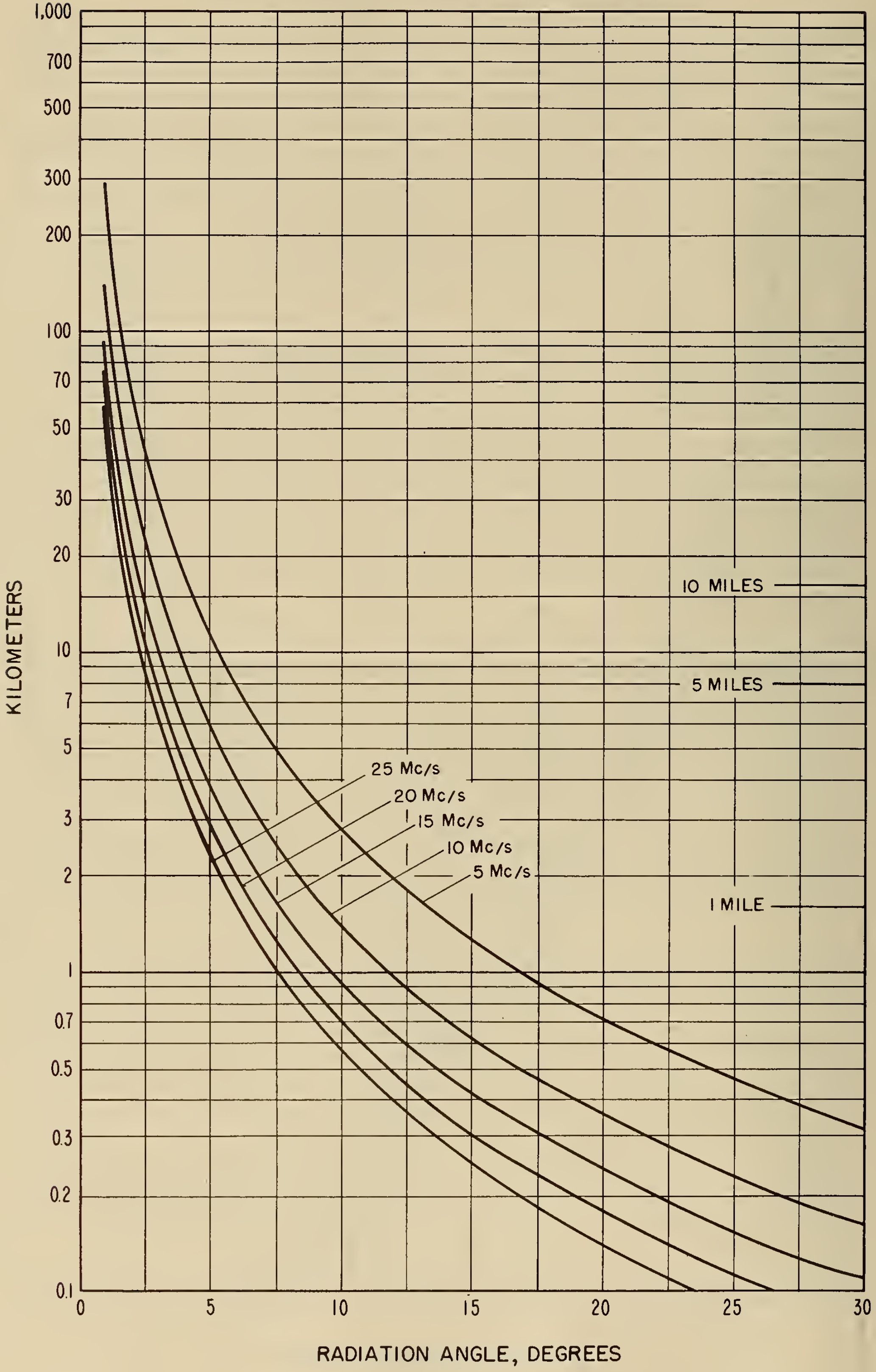


Figure 12

FRESNEL ZONE WIDTH AS A FUNCTION OF RADIATION ANGLE

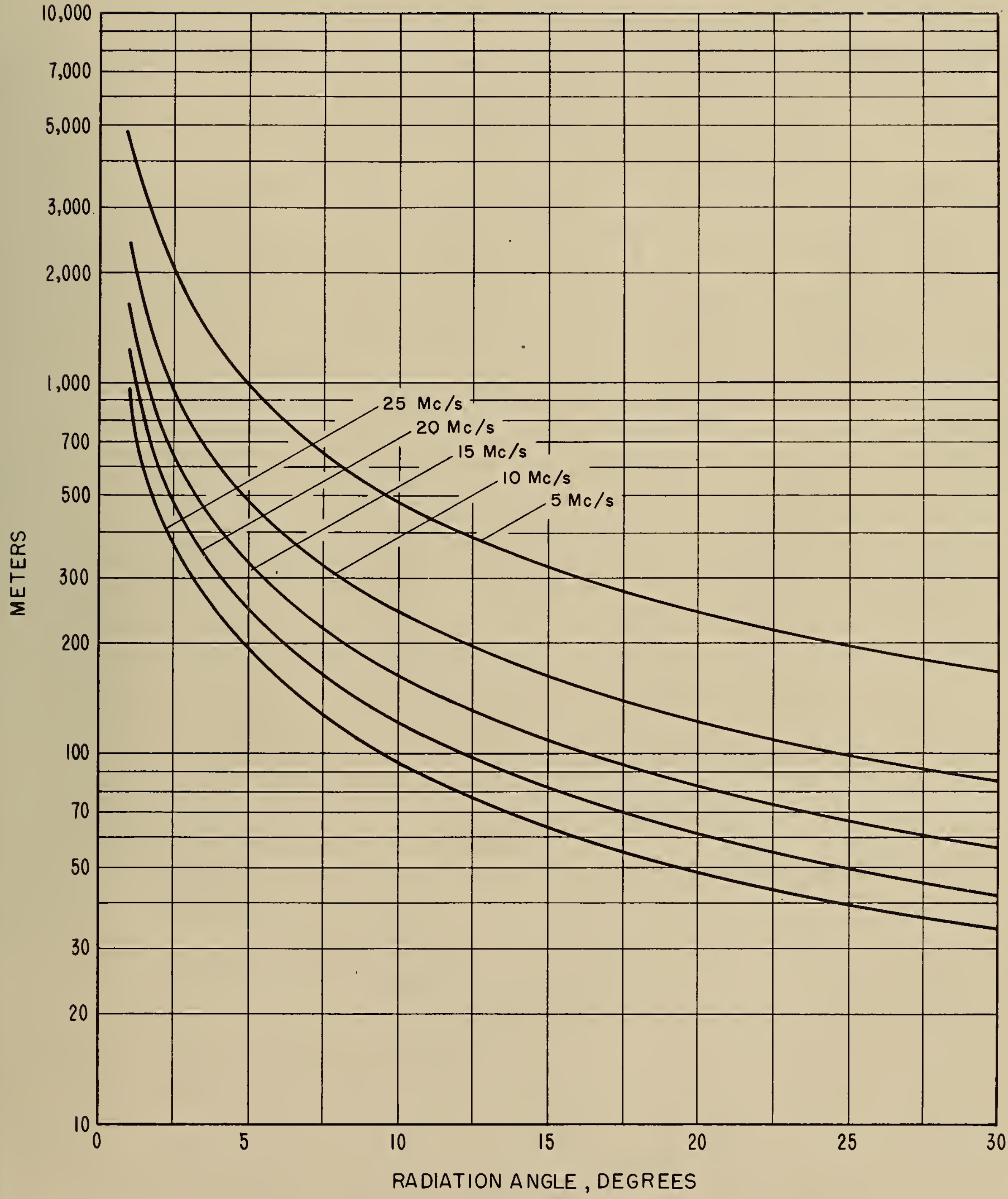


Figure 13

GEOMETRY OF REFLECTION FROM A SLOPING SITE

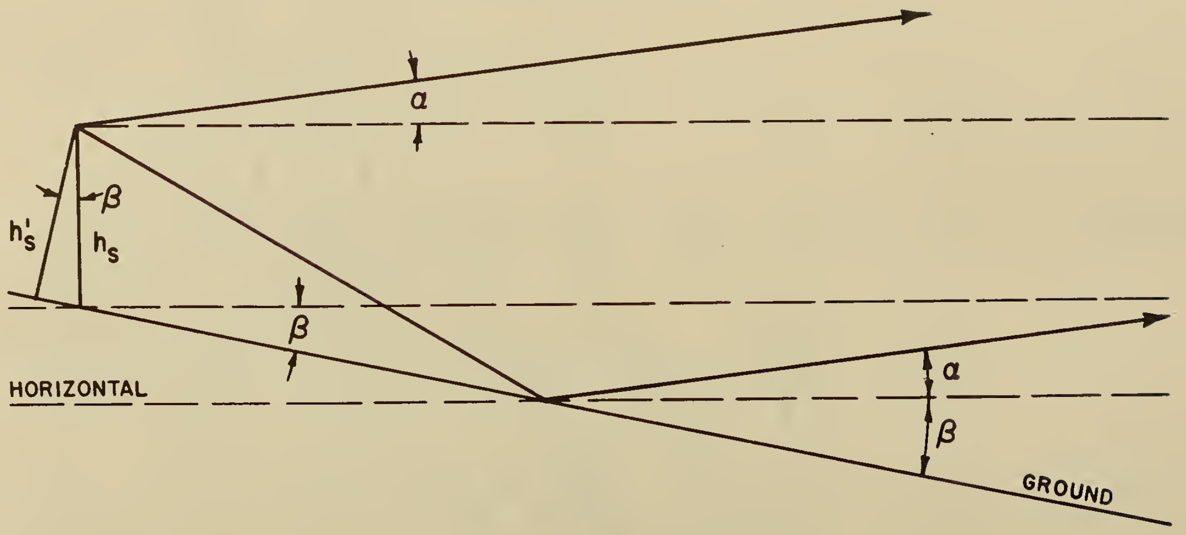


Figure 14

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. Microwave Circuit Standards. Electronic Calibration Center.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