RADIO ENGINEERING
MICROWAVE RADIO
PROPAGATION
OBSTRUCTION FADING AND CLEARANCE CONSIDERATIONS

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1. INTRODUCTION

A. General

1.01 This section provides methodology pertinent to computer calculation of obstruction fading outage time and determination of appropriate tower heights on line-of-sight microwave radio paths. Tower height design specifications are stated for daytime transmission and for transmission in the presence of obstruction fading. Heretofore, this section provided the route design engineer with physical theory and meteorological approximations sufficient for generalized clearance determination for good, bad, and average propagation conditions. Recent efforts combining meteorology and radio science have yielded a new path engineering tool for estimation of obstruction fading incidence in a specific geographic location which allows parametric design of tower heights to meet obstruction outage requirements. As will become evident, from information contained herein, this new method represents a considerable refinement over previous methodology in that transmission performance is quantitatively related to tower height. Application of the new method to path engineering requires use of a computer program named OBSFAD, which is available in the AT&T Long Lines CMS2 time-share system.

1.02 This section is being revised to reflect a new methodology pursuant to obstruction outage calculation as embodied in the OBSFAD computer program. Since this is a total revision, change arrows will be omitted.

B. The OBSFAD Program

1.03 The occurrence of obstruction fading (earth bulge) requires adequate clearance (antenna centerline heights) to assure reliable transmission on microwave radio paths. In the OBSFAD program, obstruction fading is estimated individually for each path (hop). The variables determining the amount of obstruction fading are the centerline heights of the antennas, path geometry, radio frequency, fade margin, and a new set of statistical parameters that provide a geophysical and meteorological description of the path. These new parameters are the means and the standard deviations of the probability distributions of positive refractivity gradients. Users of the program can determine the refractivity means and standard deviations for their paths from the United States contour maps prepared for this purpose. These maps are included with instructions on the use of the program which is distributed to operating company frequency coordination representatives. The procedure for acquiring these parameters is described in Part 9.

1.04 Engineering judgement is presumed in the application of the results obtained from the method described in this document. In the case of economic or technical constraints, the quantitative new methodology for obstruction fading design permits parametric and tradeoff studies to determine the best course of action.

2. PERFORMANCE OBJECTIVES

A. General

2.01 Microwave radio performance objectives for a hop in long-haul service differ from those for the same hop in short-haul service. Since the new method relates antenna heights to performance objectives, corresponding differences in antenna heights are possible in some cases, as specified by the objective allocations. This represents a change from previous practice, where one set of clearance rules applied to both long-haul and short-haul services.

2.02 The Bell System total annual two-way outage objective for long-haul service is 0.02 percent on a 4000 mile route (short-haul outage objective is 0.02 percent on a 250 mile route). For route design purposes, a new allocation of outage time has been established. The new allocation will be 0.01 percent for multipath, 0.005 percent for obstruction fading, and 0.005 percent for equipment failure, human error, and other causes. Obstruction fading will now be recognized as a major cause of radio system outage.

B. Long-Haul Service

✓ [illegible]

2.03 For long-haul service, the transmission performance objective is an annual all-cause, two-way transmission unavailability less than 0.02 percent on a 4000-mile route. Prorated to a 25-mile hop, this becomes 40 seconds per year. For the purpose of route engineering, 20 seconds of this is allocated to multipath fading, 10 seconds to obstruction fading, and 10 seconds to equipment failure, human intervention, and other causes. The 20-second allocation to multipath fading (10 seconds one way) has been in existence for some time. The new 10-second allocation to obstruction fading gives it recognition as a major cause of transmission impairments. This allocation is both two way and one way, since obstruction fading affects both directions of transmission simultaneously. The revised 10-second allocation to equipment, human intervention, and other causes is made possible by the increased reliability of solid-state equipment. When used as a design criterion, the 10-second obstruction fading allocation is prorated to the length of the switching section. For example, the allocation to a switching section containing three 25-mile hops is 30 seconds. The hops are permitted to contribute unequally to the 30-second total. A design where two hops contribute 5 seconds each and the third hop contributes 20 seconds would therefore be satisfactory.

C. Short-Haul Service

✓ 250 mi

2.04 For short-haul service, the annual all-cause, two-way transmission unavailability objective of 0.02 percent applies to a 250-mile route (630 seconds per year prorated to a 25-mile hop). Two options are available for allocating a part of this objective to obstruction fading. The choice of option, based on technical and economic factors, is a prerogative of the route planner and the route designer. When used as design criteria, the short-haul obstruction fading allocations are prorated to the length of the switching section or route segment between terminals or drop and add points.

First Option

2.05 The first option is an obstruction fading allocation of 10 seconds per year prorated to a 25-mile hop. The resulting antenna centerline heights can be used for any radio system in a given frequency band, and long-haul traffic can share the antennas. The antenna heights are "universal" because they reduce obstruction fading to negligible proportions (10 seconds or less out of 630 seconds). Because of this, previous design practices regarding multipath fading, rain, and equipment can remain unchanged.

Second Option

2.06 A second short-haul option is a prorated obstruction fading allocation of 160 seconds per year for a 25-mile hop. This retains the standard one-to-sixteen ratio of per-mile performance between long-haul and short-haul service for an impairment that affects all radio systems. The resulting centerline heights of the antennas are smaller than those obtained from the 10-second allocation. This option can be used ***only*** when the characteristics of the communications traffic and the radio system are sufficiently firm and permanent to be incorporated into antenna height requirements. In cases where the estimated obstruction fading is less than the allocation, the unused portion of the allocation can be applied to other categories of impairments.

3. FUNDAMENTAL CONSIDERATIONS

A. Meteorology and Refractive Index

3.01 The propagation path from a transmitting antenna to a receiving antenna is affected by the microwave index of refraction of the atmosphere, which is a function of humidity, temperature, and pressure. The index of refraction (n) is usually described in terms of refractivity (N), which is defined as:

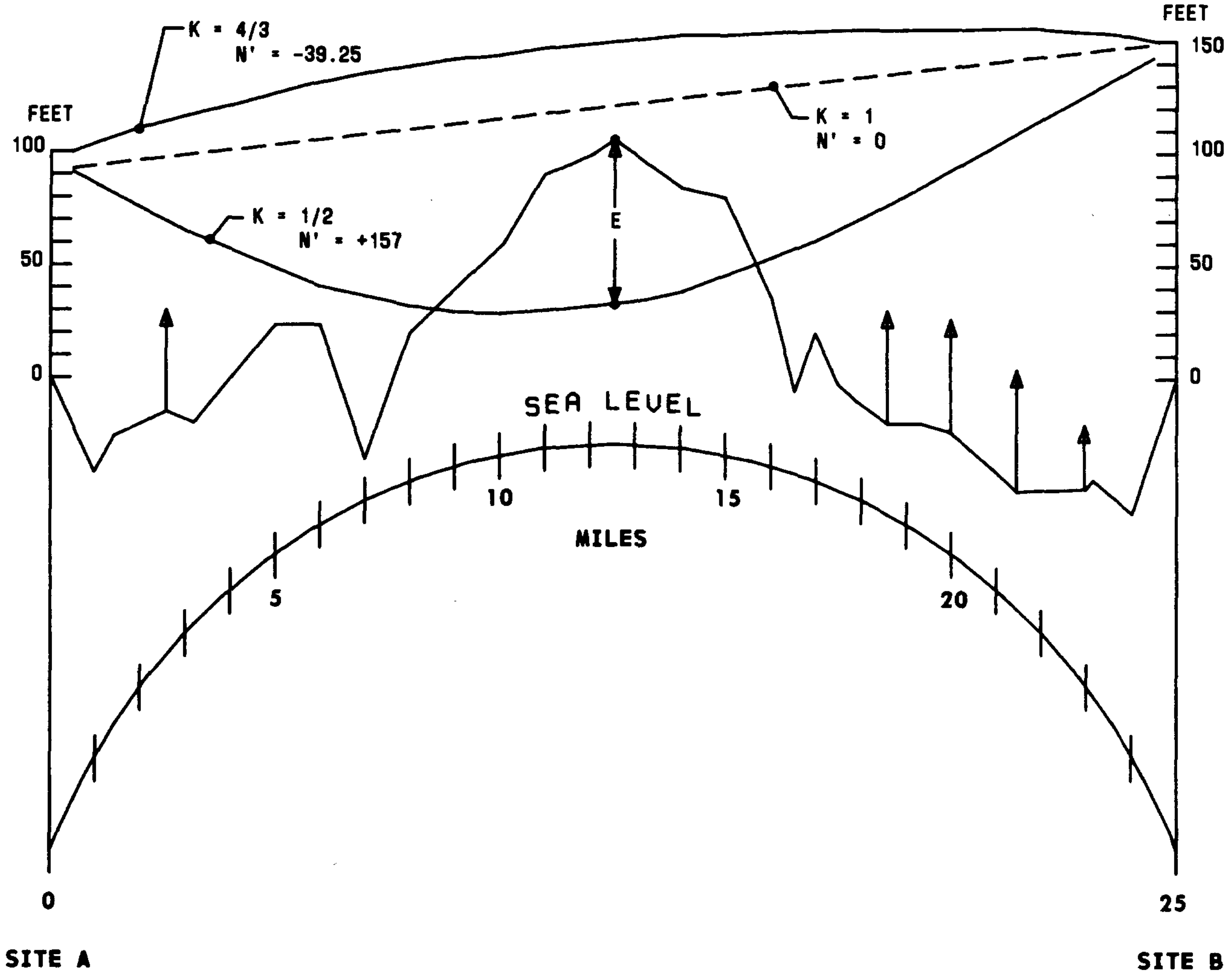
$$N = (n - 1) 10^6$$

The units of refractivity are called N-units. As an example, a value of 1.000300 for the index of refraction corresponds to a refractivity of 300 N-units.

3.02 Microwave radio beams are bent (refracted) as a result of vertical changes in the refractivity of the atmosphere. The influence of refractive bending on the propagation path (ray path) between two stations is illustrated in Fig. 1. In the absence of an atmosphere, the ray path would be a straight line (dashed line). When the refractivity decreases with height, as it usually does in the daytime, the ray path is refracted down, which increases clearance (upper curve in Fig. 1). When the refractivity increases with height, which can temporarily happen in the lowest layer of the atmosphere at night, the ray path is refracted up. Under such conditions, the ray path can become a virtual (blocked) path as illustrated by the lower curve in Fig. 1. This is the cause of obstruction fading. Figure 1 also demonstrates that, at the transmitting antenna, different departure angles (launch angles) are necessary to reach the receiving antenna under differing atmospheric conditions. Beamwidths of standard antennas usually are sufficient to accomodate the required range of launch angles.

3.03 The vertical change in refractivity, denoted by N′ and referred to as the refractivity gradient, is described in terms of N-units per kilometer. The value of N′ in a "standard" daytime atmosphere is −39.25 N-units/km. Refraction is broadly classified as superrefraction (N′ more negative than −39.25) or subrefraction (N′ less negative than −39.25).

3.04 Blockage of transmission can occur when atmospheric stratification temporarily creates



ARROWS ON TERRAIN PROFILE DENOTE TREE COVER.
CURVATURE OF SEA LEVEL CORRESPONDS TO ACTUAL
EARTH CURVATURE (K=1)

Fig. 1—Ray Paths Between Antennas for Two Refractivity Gradients

strong positive refractivity gradients. A major cause of this is an increase in humidity with height above ground. A severe positive refractivity gradient of 200 N-units per kilometer corresponds to a 20 percent increase in relative humidity across a vertical distance of 100 meters at about 62°F. Moist air flowing on top of drier air can produce such gradients. Figure 2 illustrates the production of positive refractivity gradients as a function of temperature and relative humidity.

B. Equivalent Earth Radii

3.05 Engineering practice is to describe the refractivity gradient in terms of a factor K, which describes a transformation of the path profile to a geometry where the vertical ray-to-terrain distances are retained, but where the ray path is not bent. This transformation introduces an equivalent earth that has no atmosphere, but which has a radius that is K times that of the actual earth. Negative refractivity gradients result in an increased equivalent earth radius, visualized as earth flattening, while positive refractivity gradients result in a contracted equivalent earth radius where the earth bulges upward toward the ray path, giving rise to the term "earth bulge."

3.06 The relationship of K and the gradient, denoted by N′, is

$$K = 1/(1 + N'/157)$$

where N′ is expressed in N-units per kilometer. The "standard" value of K for a daytime atmosphere is 4/3, which corresponds to a gradient of −39.25 N-units/km.

3.07 The value of K becomes infinite when N′ is −157 N-units/km. Propagation in this special case appears to be over a "flat earth," because the ray path and the actual earth have the same curvature. The value of K becomes negative when N′ is more negative than −157 N-units/km. Negative K indicates that clearance is temporarily very large, and that a variety of propagation phenomena may be present.

3.08 Positive refractivity gradients that produce obstruction fading correspond to values of K that are smaller than unity. As an example, K of 1/2 corresponds to a refractivity gradient of +157 N-units/km.

4. GRADIENT PROBABILITY

4.01 Recent advances have made possible the prediction of the occurrence of positive refractivity gradients for any microwave radio path in the United States, based on the meteorological and geophysical description of the path. The annual probability that the gradient N′ exceeds a particular value S is expressed as:

$$P(N'>S) = (1/4) \sum_{i=1}^{4} P_i\,(N'>S)$$

where the P_i (N′>S) describes the seasonal occurrence of positive gradients. Each seasonal probability consists of two components:

$$P_i\,(N'>S) = 0.8\,P_{m,i} + 0.2\,P_{s,i}$$

where the subscript m refers to the daytime (mixed) atmosphere and the subscript s refers to the nighttime (stratified) atmosphere. Both $P_{m,i}$ and $P_{s,i}$ are Gaussian probability functions specified by their means and standard deviations. Seasonal contour maps of these parameters for the United States have been prepared for use in conjunction with OBSFAD.

5. OBSTRUCTION FADING

A. Definition of Fade Time (T_h)

5.01 The decrease of received signal power caused by blockage of the ray path between the antennas is referred to as obstruction fading. It is described in terms of fading time during which the received signal is below a prescribed fade level. The geometry of the microwave radio path relates the fade level to a value of the refractivity gradient. The annual obstruction fade time for a microwave radio hop can therefore be expressed, in seconds per year, as:

$$T_h = T_0 P(N'>S)$$

where T_0 is the number of seconds in a year, and where the value of S is specified by the fade level, radio frequency, and the heights of the antenna centerlines. The relationships providing this specification are summarized in paragraphs 5.02 through 5.04.

5.02 The fade level is a function of the vertical distance from the top of the controlling obstruc-

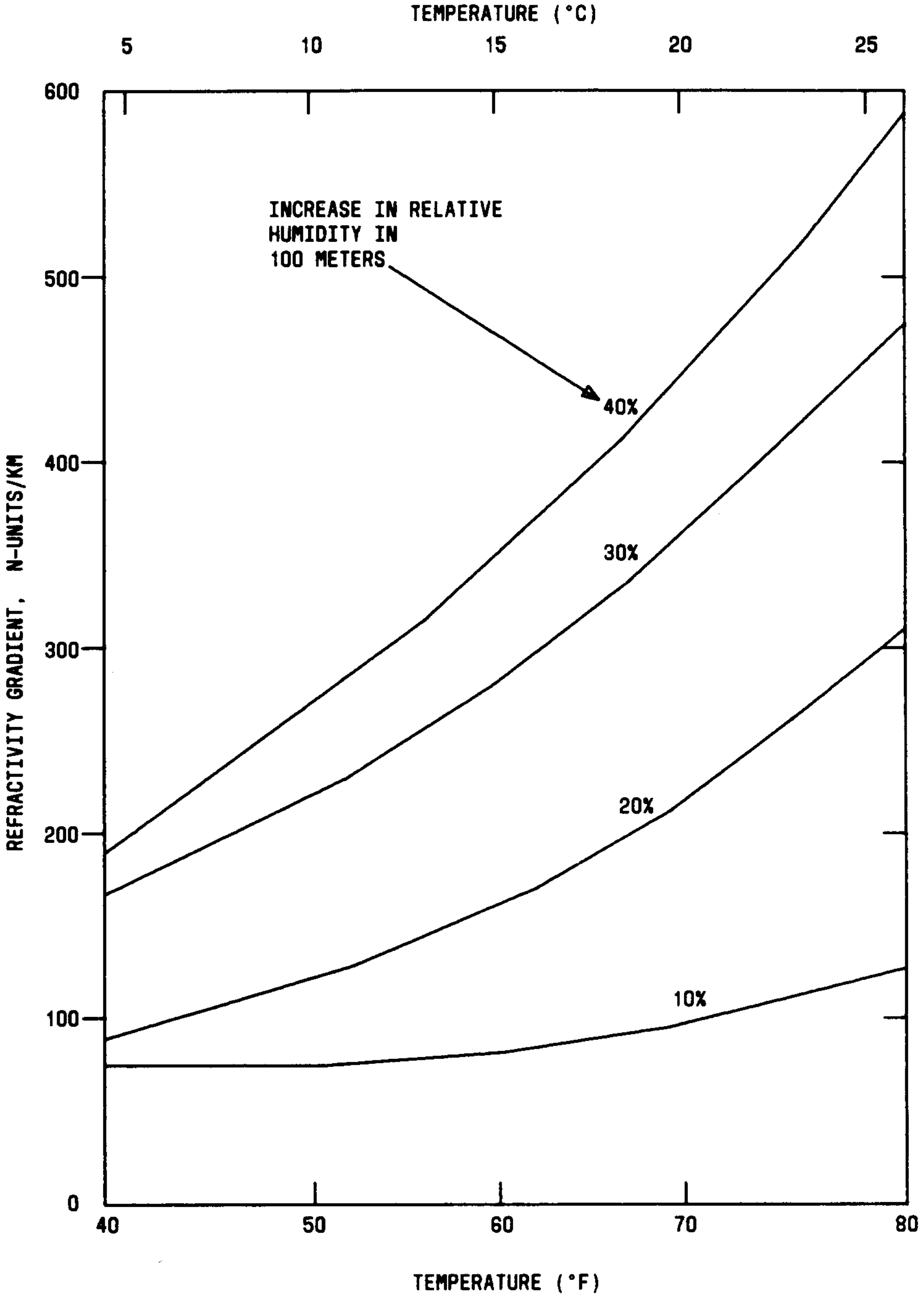


Fig. 2—Refractivity Gradient as a Function of Temperature and Relative Humidity

tion to the virtual ray. This distance is described by E (measured in feet) in the example of Fig. 1. In the case of tree covered terrain, the maturity height of trees is part of E. For deep obstruction fading, the fade level in dB relative to the "free-space" level is:

$$M = -10 + 20E/F_1$$

where, to signify blockage of transmission, the value of E is negative. The term "free space" refers to a signal level that would be attained in the absence of atmospheric effects and without the proximity of the terrain. The quantity F_1 is the radius of the first Fresnel zone (in feet):

$$F_1 = 72.1(D_1D_2/fD)^{1/2}$$

where f is the radio frequency in GHz, D is the path length in miles, and D_1 and D_2 are the distances from the controlling obstruction to the ends of the path, also expressed in miles. The controlling obstruction is one for which the dimensionless clearance E/F_1 has the greatest negative value.

5.03 The obstruction loss curve described by M in the equation above is located between the curves for diffraction by a knife edge and by a smooth sphere (see Fig. 3). This curve is based on experimental data, and it reflects the fact that, in the equivalent earth formulation, the path profile becomes more wedge-like as the values of K become smaller for deep obstruction fades. This wedge-like accentuation of the central portion of the path permits application of the above loss curve to most paths between 20 and 30 miles in length at frequencies between 2 and 11 GHz. Knife-edge paths (single and multiple) are an exception, but these usually occur in mountainous terrain where obstruction fading is not a problem. In such areas, rough terrain, prevailing winds, and low humidity reduce the occurrence of atmospheric layering.

5.04 To determine the obstruction fade time T_h at a particular fade level, the vertical distance E is obtained from a rearranged obstruction loss formula:

$$E = (1/20)(M+10)F_1$$

The refractivity gradient S that corresponds to this value of E is determined by the antenna centerline heights and the geometry of the path as explained below. With S determined, the fade time T_h is obtained from the probability that the refractivity gradient exceeds S.

B. Refractivity Gradient (S) Determination

5.05 As described in paragraph 3.05, drawings of terrain profiles are constructed to obtain a ray path that is a straight line for a particular value of the earth radius factor (K). This is achieved by a modification of the shape of the sea level, described by a "bulge height."

$$H = D_1D_2/1.5K$$

where H is in feet when D_1 and D_2 are in miles. This is illustrated in Fig. 4, where the profile from Figure 1 is redrawn for K = 1/2.

5.06 The variables used to relate the vertical distance E to a value of the refractivity gradient are summarized and defined in Fig. 4. The ground elevations (G_1 G_2) of the radio stations and the antenna centerline heights determine the variables A and B. The height of the virtual ray at the controlling obstruction is relative to the reference line:

$$Y = A + (B-A)\ (D_1/D)$$

The relationship of the vertical distances at the controlling obstruction is:

$$Y - E = H + G$$

The minus sign arises because E has a negative value when the ray path is blocked. For tree covered terrain, tree heights are included in both E and G, where the latter describes the elevation of the top of the obstruction.

5.07 The above equation is used to determine H when E is specified. The bulge height equation in paragraph 5.05 is then used to determine K, which in turn determines the value of the refractivity gradient (S) that corresponds to E. For example, referring to the equation in paragraph 3.06, if K = 1/2, then S = 157. Objectionable obstruction fading is caused by values of N′ that exceed S.

6. REPRESENTATIVE CALCULATED RESULTS

A. Antenna Height

6.01 The variation of calculated obstruction fade time with antenna height (Fig. 5) is shown for

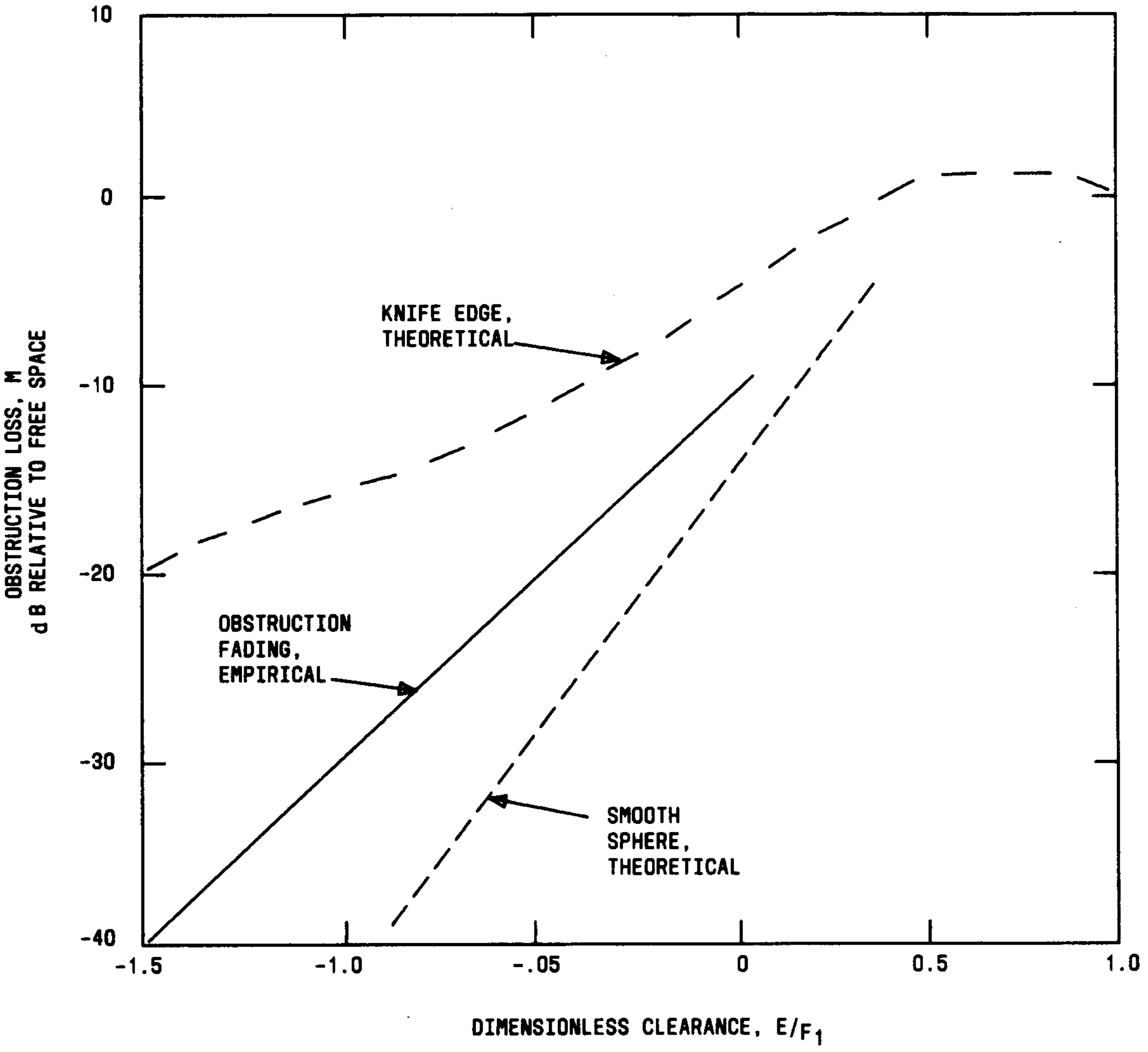


Fig. 3—Obstruction Loss for Deep Obstruction Fading on Line of Site Microwave Radio Paths

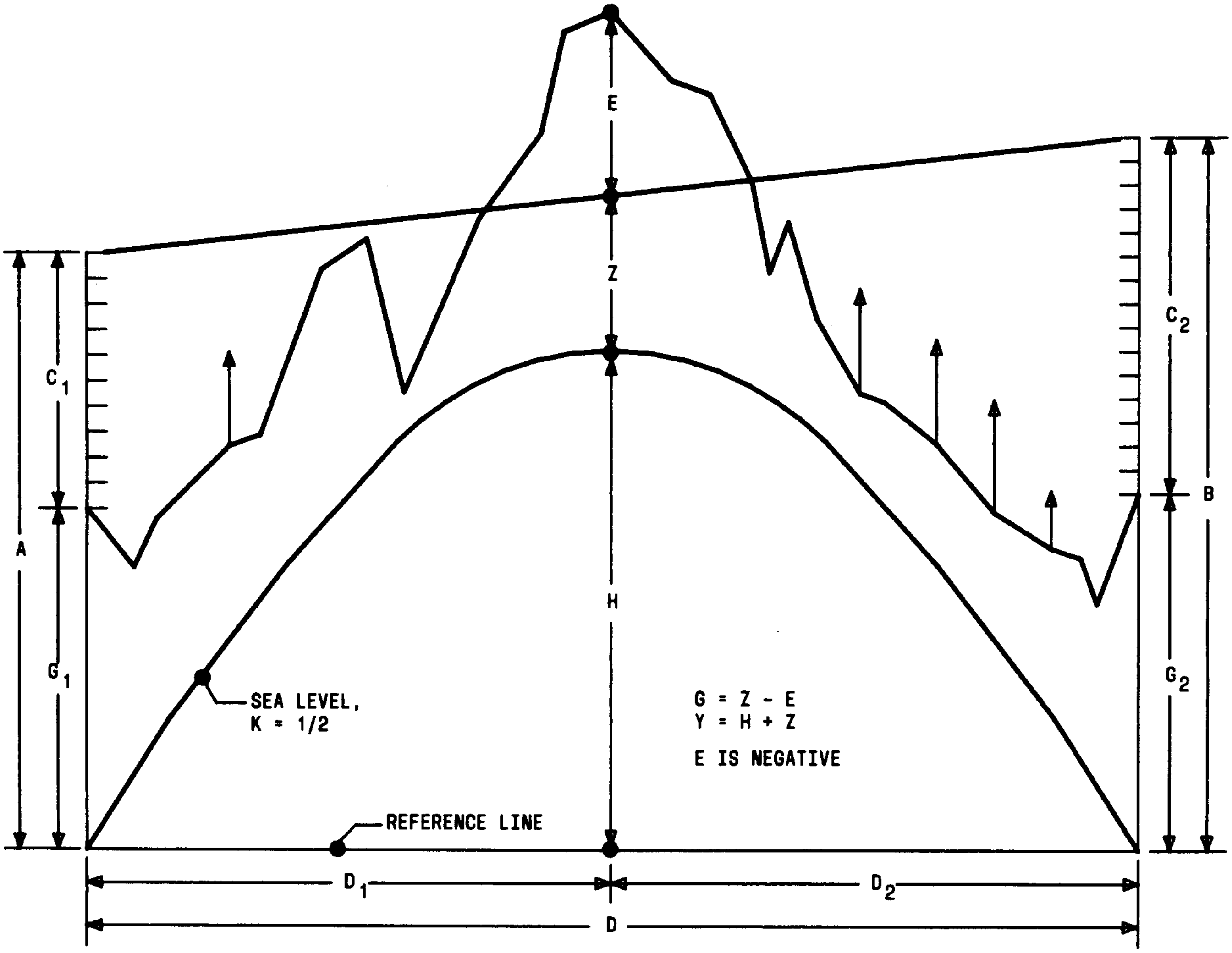
a 24.3 mile path in northern Florida between locations denoted as station J and station H. The ground elevations of these stations are 15 and 40 feet, respectively. The controlling obstruction at 11.9 miles from station J consists of 50-foot tree cover on ground that has an elevation of 15 feet. The antenna height at station H is 270 feet above ground. The annual fade time at a fade level of −35 dB varies by more than two orders of magnitude as the antenna height at station J is varied from 200 to 400 feet above ground.

B. Frequency Dependence

6.02 The frequency dependence of obstruction fading is illustrated for the same path with antenna centerline heights of 350 and 325 feet above ground at station J and station H, respectively, (Fig. 6). When the radio frequency is varied from 2 to 11 GHz, the fade level at 10 seconds per year varies over a range of almost 20 dB. This variation is a consequence of the E/F_1 dependence of the obstruction loss. The obstruction loss increases with frequency because, as illustrated in Fig. 7, the blockage of Fresnel zones increases with frequency.

C. Geographic Variability

6.03 Table A illustrates the geographic variability



THE VARIABLES E AND G INCLUDE TREE HEIGHT IN THE CASE OF TREE-COVERED OBSTRUCTIONS. THE VALUE OF G IS OBTAINED FROM PATH PROFILE DATA

Fig. 4—Summary of Geometrical Variables

of obstruction fade time on a hypothetical 25-mile test hop designed to provide "average" clearance according to clearance rules in the previous issue of this section. The fade times for the Florida locations (Key West, Miami, Jacksonville) illustrate the variability in a region where a uniform clearance requirement was used in the past.

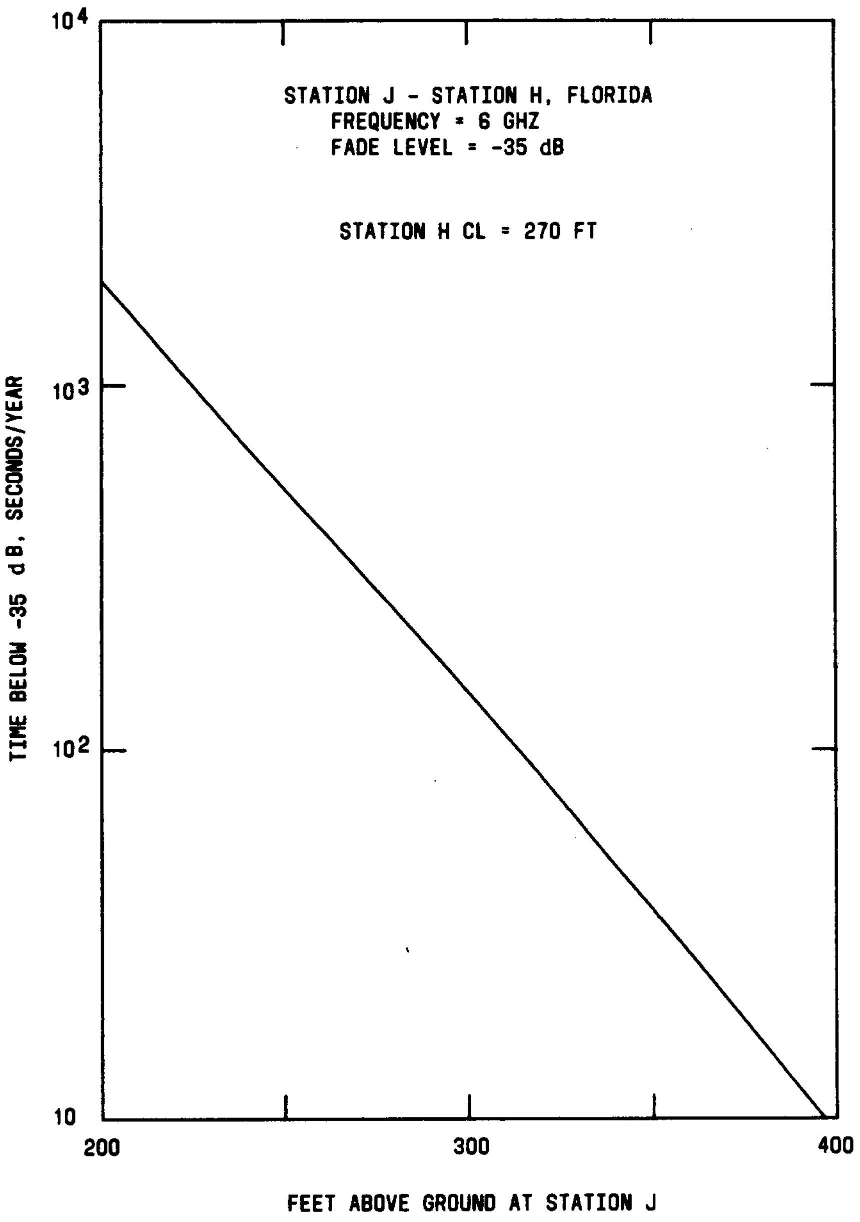


Fig. 5—Variation of Obstruction Fading With Antenna Height

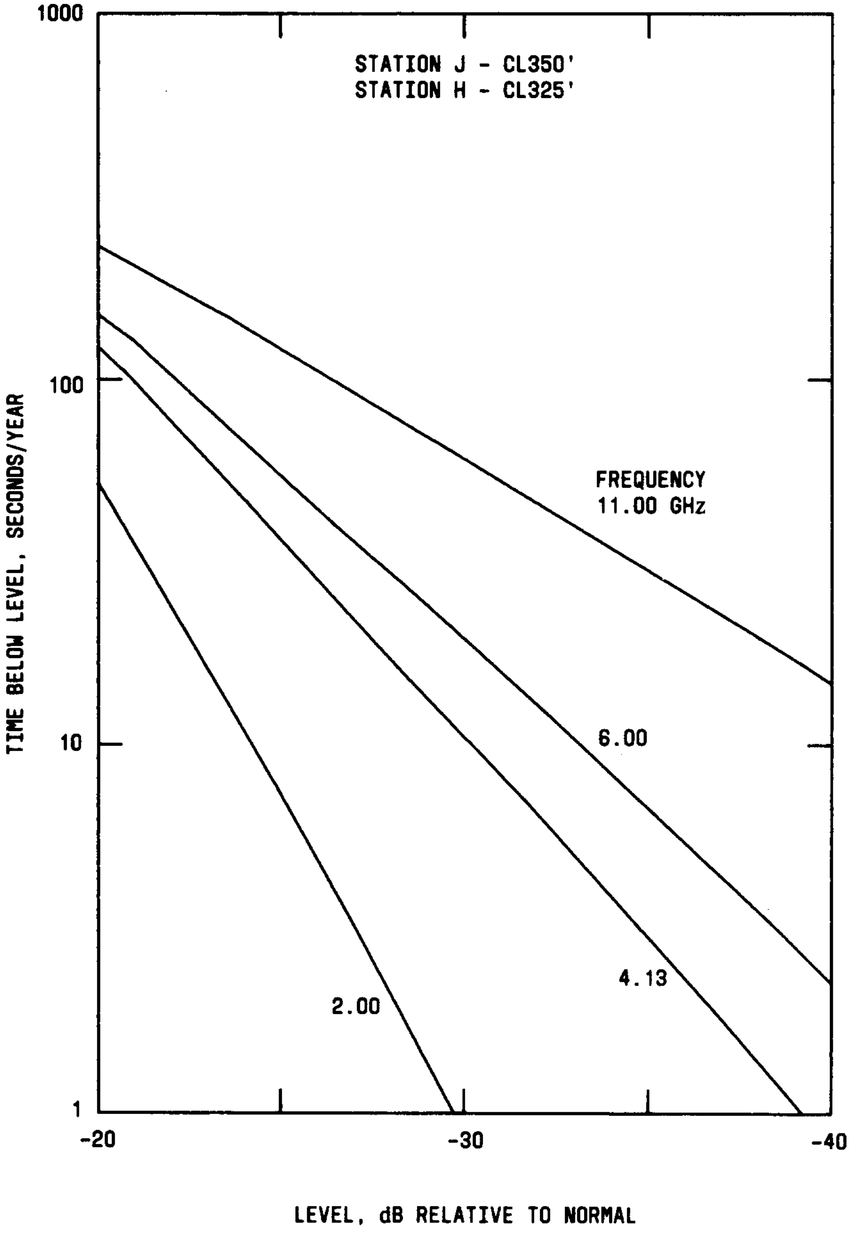


Fig. 6—Calculated Obstruction Fading for Station J—Station H

TABLE A

OBSTRUCTION FADING ON HYPOTHETICAL TEST HOP

Path length = 25.0 miles
Midpath obstruction

Frequency = 4 GHz
Fade level = -30 dB

Design parameters:
K = 2/3
Frequency = 4.0 GHz
Clearance = 0.3 F_1

Tower height = 183 feet

LOCATION	SECONDS/YEAR:
Albuquerque, New Mexico	0.0
Alexander, Arkansas	228.5
Atlanta, Georgia	21.3
Baton Rouge, Louisiana	1282.2
Bismarck, North Dakota	0.0
Boise, Idaho	0.0
Brownsville, Texas	2245.1
Charleston, South Carolina	3713.2
Chicago, Illinois	125.9
Cocoa, Florida	7172.2
Columbia, Missouri	0.4
Denver, Colorado	0.3
El Paso, Texas	0.0
Great Falls, Montana	0.0
Jacksonville, Florida	7558.7
Joliet, Illinois	14.0
Key West, Florida	0.0
Long Beach, California	5.9
Miami, Florida	42.8
Midland, Texas	1990.0
New Orleans, Louisiana	721.9
New York, New York	10.0
Oakland, California	0.0
Oklahoma City, Oklahoma	4.2
Omaha, Nebraska	0.4
Toledo, Ohio	40.7
San Diego, California	24.3
Seattle, Washington	0.0
Washington, D. C.	0.4

7. DESIGN SPECIFICATIONS

A. General

7.01 Main antenna centerline heights should be such that daytime transmission is not obstructed and transmission performance objectives for obstruction fading are met. Since daytime centerline heights may, under certain conditions, provide adequate obstruction fading performance, the climate and, to some extent, the path geometry will determine whether daytime heights or obstruction fading requirements are controlling.

B. Daytime Clearance Requirements

Path Requirements

7.02 The daytime minimum clearance should be full first Fresnel zone (F_1) at $K = 4/3$. That is, for a standard daytime atmosphere, the vertical distance from the ray path between the antennas to the controlling obstruction should be equal to or larger than the radius of the first Fresnel zone. In the case of antennas used for diversity, the daytime minimum clearance should be $0.6\ F_1$ at $K = 4/3$. These requirements should be met in the lowest frequency band utilized or planned, since the radius of the first Fresnel zone increases as the frequency decreases. The F_1 requirement for the main antennas includes a margin for daytime atmospheric variation and for resolution errors in terrain elevation information, since significant obstruction of the path does not begin until the clearance decreases to $0.6F_1$. (Section 940-310-105 covers the subject of Fresnel zones and their application to microwave radio.)

Foreground Clearance

7.03 Foreground clearance requirements are expressed in terms related to antenna geometry (Fig. 8). Close-in obstructions in front of an antenna should be at an angle not less than 9 degrees from a projection of the edge of the antenna aperture in the direction parallel to the centerline of the main lobe of the antenna, or 10 feet from that projection, whichever is less. This requirement applies for distances up to a point where F_1 (or $0.6F_1$ for diversity antenna), as measured from the antenna centerline, exceeds the antenna aperture edge projection by 10 feet. The distance at which this transition to daytime clearance requirements takes place varies with frequency. The same requirement applies for both horizontal and vertical foreground clearance.

C. Obstruction Fading Requirements

Main Antenna Requirements

7.04 For obstruction fading, the design objective (T_{obj}) for a switching section (route segment) containing J radio hops is in seconds per year:

$$T_{obj} = \sum_{h=1}^{J} (D_h/25)T_{ref}$$

where D_h is the hop length in miles. The prorated reference time T_{ref} is 10 seconds for long-haul service and either 10 or 160 seconds for short-haul service depending on the applicable short-haul design option. A proposed design is satisfactory when the antenna centerline heights are such that the sum of obstruction fade times T_h for the J hops is equal to or smaller than T_{obj}.

7.05 The obstruction fade time T_h for each hop (obtained from OBSFAD) is estimated for the highest frequency band utilized or planned, since the amount of deep obstruction fading increases with frequency. The fade level used in the estimation is −35 dB for both analog and digital radio systems, when these have thermal noise (flat) fade margins of 35 dB or better. If the thermal noise fade margin of a radio system is poorer than 35 dB, which is unlikely in a properly designed system, then the actual value of this margin is used in the T_h estimation. The −35 dB value is an obstruction fading design parameter. Its purpose is to limit simultaneous occurrences of obstruction fading and multipath fading. Such occurrences are undesirable because the effectiveness of diversity protection is reduced when obstruction fading is present.

Diversity Antenna Requirements

7.06 In the case of the lower antenna of the two vertically separated antennas used for diversity, the obstruction fading allocation prorated to a 25-mile hop is 50 seconds per year for long-haul service and for those hops in short-haul service where the height of the upper antenna is determined by the 10-second allocation. The 50-second allocation is applied on a per hop basis to avoid impairment of space-diversity protection. A design is satisfactory when the obstruction fade time T_h for the lower antenna is equal to or less than $2D_h$ seconds per year.

7.07 A separate allocation for the lower antennas is not made when the 160-second allocation is

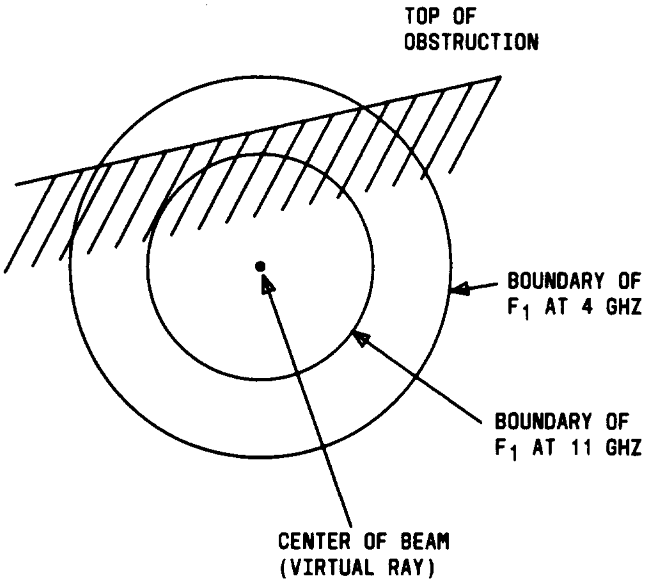


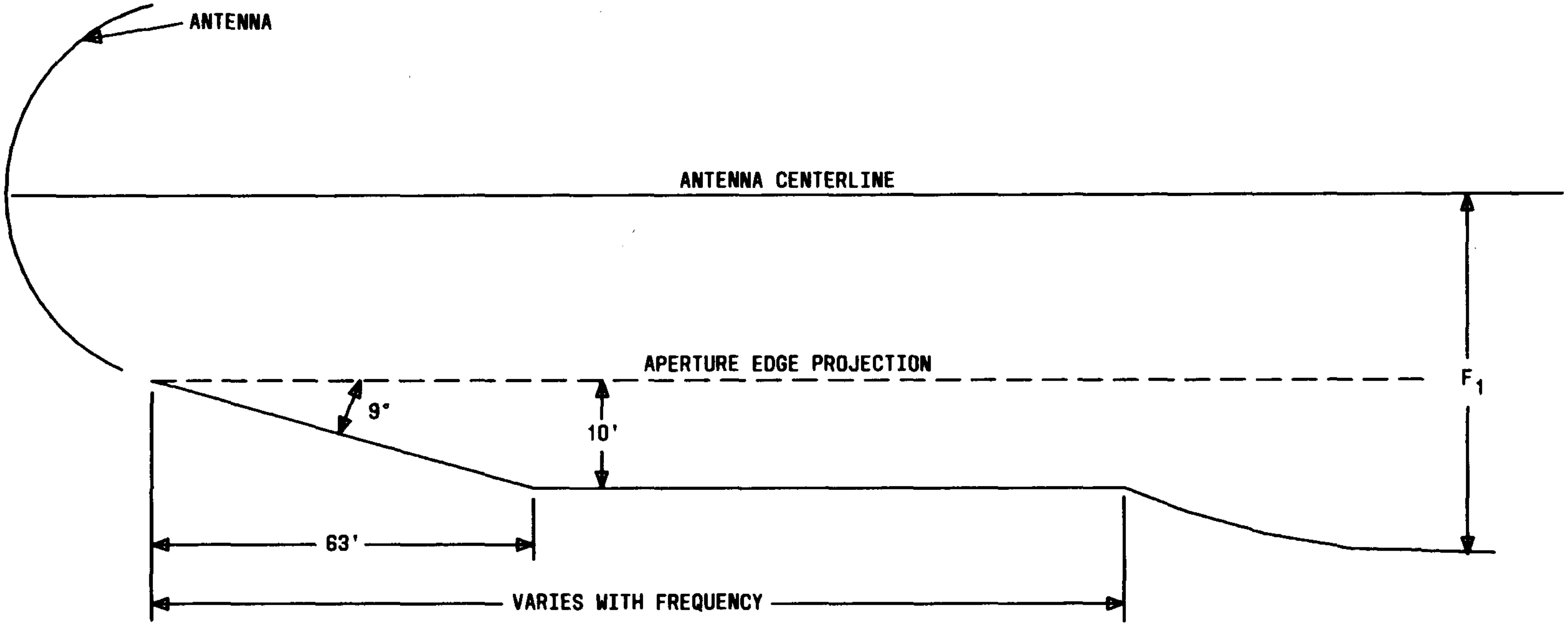
Fig. 7—Illustration of Blockage

used to design short-haul hops, since this allocation represents a design limit. The 160-second allocation, prorated to the length of the switching section or route segment, applies to the transmission path through the lower antenna when space diversity is used.

7.08 The fade level used in the estimation of the fade time T_h for diversity antennas includes signal level differences related to antenna gain and system losses. For example, this fade level is −32 dB instead of −35 dB when the diversity antenna has a gain that is 3 dB smaller than that of the main antenna and system losses are equal. If the diversity antenna and main antenna are the same size and the system losses are equal, the fade level will be the same for both antennas. When a waveguide preamplifier is required on a radio hop, both the main and diversity antennas should be equipped with such an amplifier; this will prevent large differences in system level and/or fade margin.

8. EXEMPLARY CALCULATIONS

8.01 The determination of suitable antenna heights is illustrated in Table B for the path between station J and station H which was used as an example in Part 6. The value of T_h is estimated for a number of antenna pairs. To relate these results to operational experience and to permit introduction of engineering judgement, the centerline pairs are associated with grazing values of K, defined as the value of K at which the ray path between the antennas is tangent to the controlling obstruction. The centerline pair of 220 feet at station J and 270 feet at station H has a grazing K that is slightly less than 1/2, but this combination does not meet the design objective of 9.7 seconds per year for this 24.3 mile path, based on the 10-second allocation. The objective is met for centerlines of 350 and 325 feet, for a grazing K that is close to 1/3. A suitable height for a diversity antenna at station J is 300 feet, which provides a 50-foot vertical separation of the antennas.



F_1 = FIRST FRESNEL ZONE RADIUS

Fig. 8—Foreground Clearance Requirements

9. OBSFAD USER DOCUMENTATION

A. Documentation and User Requirements

9.01 Program documentation has been developed for OBSFAD users which contains necessary meteorlogical data. The source of this documentation is controlled by the AT&T Long Lines headquarters prior coordination group. OBSFAD users are required to supply values of μ (refractivity mean) and σ_s (standard deviation) for the appropriate microwave radio path as obtained from this documentation. Requests for μ and σ_s charts should be processed through normal company staff lines of communication.

B. Parameter Acquisition Procedure

9.02 Values of μ and σ_s are acquired for each of four seasons as follows:

(1) Obtain the geographic location of the midpoint of the radio path.

(2) Locate this point on the eight maps in the OBSFAD documentation.

(3) Employ linear interpolation to obtain μ and σ_s values. The linear interpolation procedure is as follows:

(a) When the route segment midpath point lies between isopleths of different value, interpolation is linear between isopleths.

(b) When the midpath point lies between isopleths of the same value, but is not completely enclosed by them, assign a value incremented by 50 percent of the isopleth interval to the locus of points midway between the isopleths and then interpolate linearly.

(c) When the midpath point is completely enclosed by an isopleth, assign a value incremented by 100 percent of the isopleth interval to the center of the enclosing isopleth and interpolate.

TABLE B

STATION J-STATION H OBSTRUCTION FADING

Path length = 24.3 miles
Frequency = 6.0 GHz
Fade level = -35.0 dB

ANTENNA CENTERLINES, FEET ABOVE GROUND J	H	OBSTRUCTION FADE TIME, SEC/YEAR	GRAZING K
220	270	1351	0.4759
270	270	389	0.4236
300	270	175	0.3974
300	300	79	0.3751
300	325	39	0.3584
325	325	19	0.3425
350	325	8	0.3279