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# Interference Predictions for VHF/UHF Air Navigation Aids (Companion Report to IER 26-ITSA 26)

G. D. GIERHART

M. E. JOHNSON

BOULDER, COLORADO
November 1969

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## ESSA TECHNICAL REPORT ERL 138-ITS 95

# Interference Predictions for VHF/UHF Air Navigation Aids (Companion Report to IER 26-ITSA 26)

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# FOREWORD

This report was prepared for the Spectrum Plans and Programs Branch, Frequency Management Division, Systems Research and Development Service, Federal Aviation Administration, under Contract No. FA 68-WAI-145. The views presented are not necessarily those of the FAA and do not reflect FAA Policy. This report does not constitute a standard, specification, or regulation.

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# INTERFERENCE PREDICTIONS FOR VHF/UHF AIR NAVIGATION AIDS

## (Companion to ESSA Technical Report IER 26-ITSA 26)

G. D. Gierhart and M. E. Johnson

Desired-to-undesired signal ratio predictions for the VHF Omnirange (VOR) and Instrument Landing System (ILS) air navigation aids are presented. The parameters involved in these systems are given first. Propagation mechanisms applicable to VHF/UHF and the calculation of transmission loss and its variability are then discussed, and, third, the statistical nature of the desired-to-undesired signal ratio predictions is explained. The results of the study, presented in graphical form, supplement those given by the authors in an earlier ESSA Technical Report on the same subject. In addition to extending the range of variables previously considered, this report considers the glide slope portion of the ILS.

Key Words: ILS, interference, navigation aids, propagation transmission loss, VOR

## 1. INTRODUCTION

This report is a companion to an earlier ESSA Technical Report (Gierhart and Johnson, 1967) on the same subject. It extends the range of distances previously considered, contains curves developed for a 50% reliability, and considers the glide slope portion of the ILS. Parts of the previous report necessary for a general understanding of the subject are repeated here for the convenience of the reader. Other earlier information similar to that presented here has also been published (Gierhart and Johnson, 1965; Radio Technical Commission for Aeronautics, 1955).

Increasing air traffic density and fast, high-flying jets have made reliable air navigation aids more important than ever. In expanding current navigation aids to meet future demands, consideration must be given to potential interference between facilities operating on the same or on adjacent channels. The amount of interference is a function of the desired-to-undesired signal ratio at the aircraft antenna terminals; as both signals vary with time and aircraft location, the ratio varies as well, and interference becomes dependent on time and location. Because of the nature of radio wave propagation in the frequency ranges used, the variations of the received signals and of the interference ratios are best described statistically. The large number of possible conditions requires the use of a digital computer and programs that take into account all variables, as well as the fixed equipment parameters.

The air navigation aids discussed in this report are the Instrument Landing System (ILS) and VHF Omnirange (VOR), which operate in the very high frequency (VHF; 30-300 Mc/s) and ultrahigh frequency (UHF; 300-3,000 Mc/s) bands. At VHF/UHF, propagation of radio frequency energy is affected by the lower atmosphere (the troposphere), specifically by variations in the refractive index of the atmosphere. The terrain along and in the vicinity of the great-circle path between transmitter and receiver also plays an important part.

Within the last decade a number of methods and procedures have been developed for calculating field strength and its variability at VHF/UHF. The work discussed here follows procedures that have been used by the Institute for Telecommunication Sciences (ITS, formerly the Central Radio Propagation Laboratory) to predict statistically the effects of terrain and atmosphere on the variability of field strength, and on the performance of radio systems (Rice, et al., 1967; Longley and Rice, 1968). It is also convenient to use the concept of transmission loss (Norton, 1953 and 1959), which is the ratio of power radiated to the power, usually expressed in decibels, that would be available at the receiving antenna terminals if there were no circuit losses other than those associated with the radiation resistance of the receiving antenna. Methods used for its calculation as a function of path length, terminal heights, and carrier frequency are described in section 3. Computation techniques are discussed in the earlier report (Gierhart and Johnson, 1967 app. II) and are not repeated here.

After some initial calculations, parameters for various systems were assembled into a computer program and desired-to-undesired signal ratios calculated for given probability levels as a function of aircraft location in relation to the desired and the undesired ground stations.

The use in frequency engineering of information such as that presented here is discussed by Hawthorne and Dougherty (1965); information on spectrum engineering for air navigation aids is given by the Joint Technical Advisory Committee (1968), The International Civil Aviation Organization (1968), and the Federal Aviation Administration[1] (1969).

## 2. SYSTEM PARAMETERS

Pertinent parameters for the ILS and VOR are discussed in this section. The transmission line loss associated with the airborne terminal was considered to affect both the desired and undesired signals equally and was neglected.

### 2.1 ILS Parameters

The ILS includes a runway localizer, a glide path, and marker beacons. Previously (Gierhart and Johnson, 1967), we considered only the localizer, since it is most susceptible to cochannel or adjacent-channel interference, and assumed that frequencies were assigned in such a way that VOR facilities would be the only source of adjacent-channel

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[1] When the Federal Aviation Agency became part of the Department of Transportation in April 1967, it was given the new name Federal Aviation Administration.

interference to the ILS. In this report, we consider both localizer and glide slope and present curves relevant to interference from a localizer operating on an adjacent channel.

The ILS localizer operates in the 108 to 112 Mc/s frequency range. Characteristics of four localizers are listed in table 1. Other equipment exists, but consideration of these four examples is sufficient for practical purposes.

Table 1. Characteristics of ILS Localizers.

| | Standard | Directional | Low Cost | AN/MRN-7 |
|---|---|---|---|---|
| Radiated power (a) | + 20 dBW | + 20 dBW | + 10 dBW | + 7 dBW |
| Array type | 8-loop | V-ring | V-ring | 12-dipole |
| Antenna gain (a) | + 4 dB | + 12 dB | + 12 dB | + 18 dB |
| Array height above ground | 5.5 ft | 7.5 ft | 7.5 ft | 4.5 ft |
| Polarization | Horizontal | | | |

---

(a) Radiated power refers to the total power radiated from the carrier antenna array, and antenna gain refers to the main-lobe free-space gain of the carrier antenna array with reference to an isotropic radiator.

Figures 1, 2, and 3 show the relative gain G as a function of azimuth angle $\alpha$ for the carrier portion of the 8-loop (Civil Aeronautics Administration, 1957), V-ring (Federal Aviation Agency, 1964 and 1965), and AN/MRN-7 arrays (Air Force Technical Order, 1968), respectively.

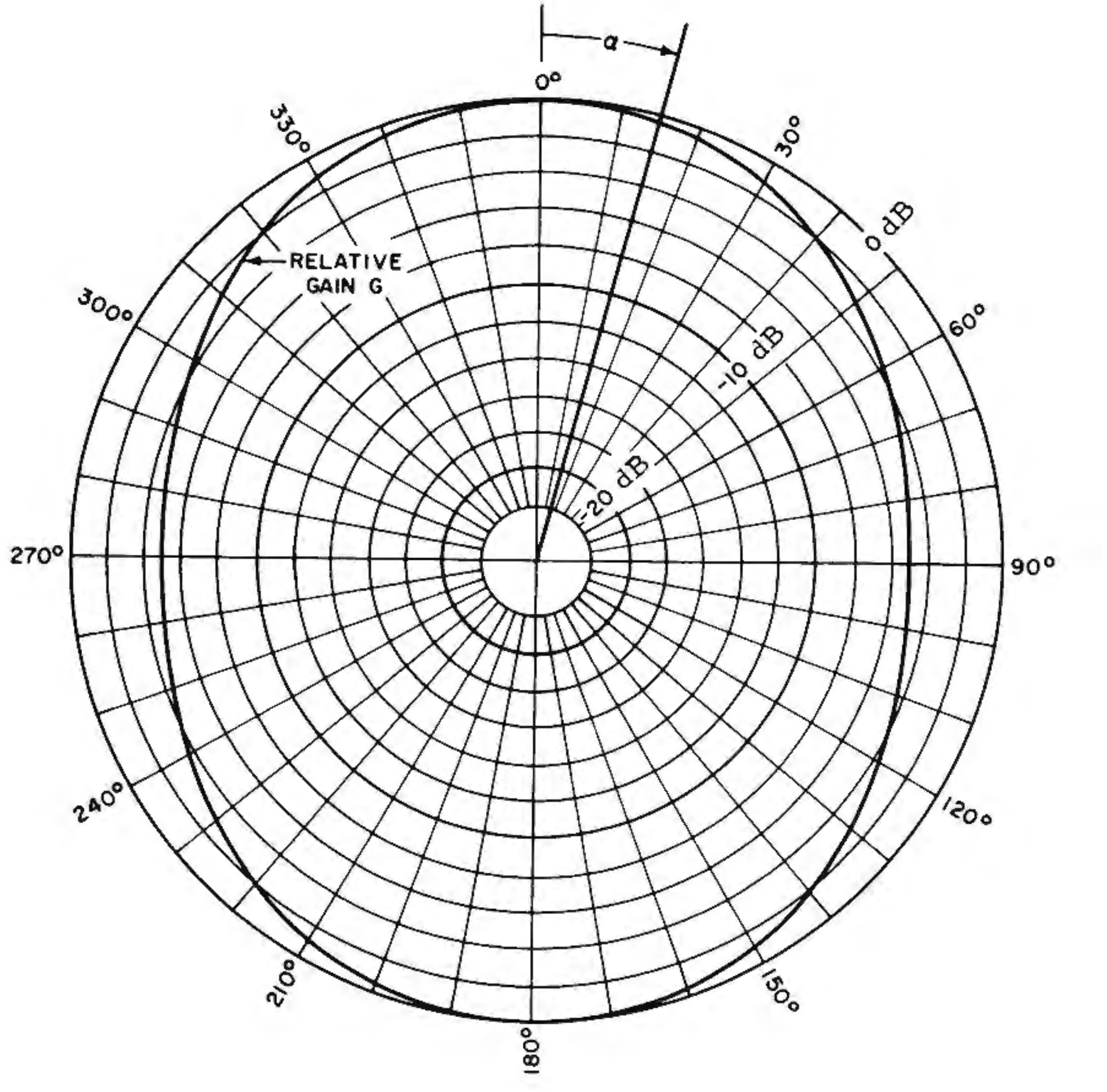


Figure 1. ILS localizer 8-loop array antenna pattern. Free-space gain for the localizer carrier antenna array in the azimuth plane is plotted in decibels relative to the main-lobe maximum. The gain of the main-lobe maximum relative to an isotropic radiator is 4 dB.

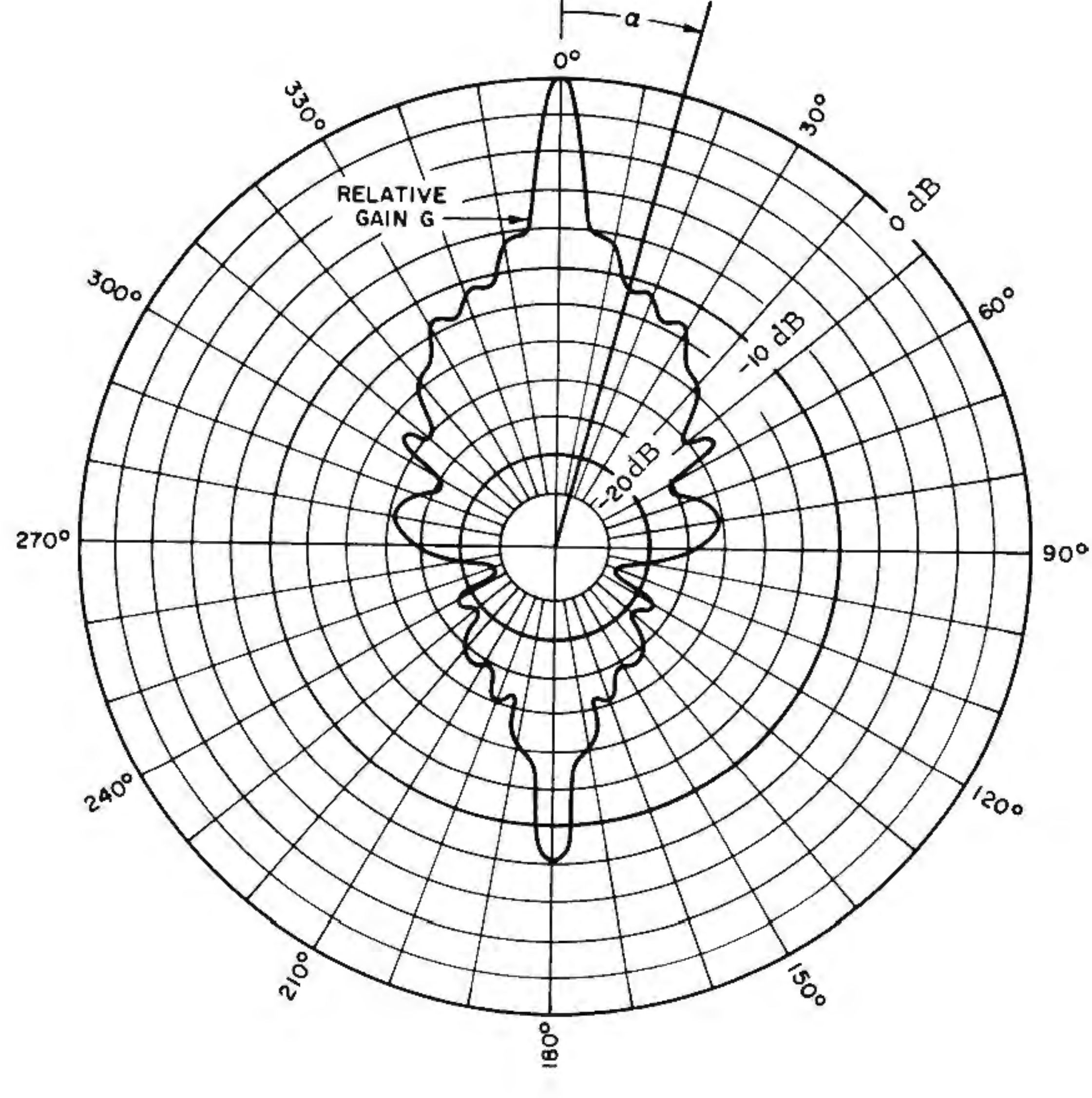


Figure 2. ILS localizer V-ring array antenna pattern. Free-space gain for the localizer carrier antenna array in the azimuth plane is plotted in decibels relative to the main-lobe maximum. The gain of the main-lobe maximum relative to an isotropic radiator is 12 dB. Values plotted are for a V-ring array (type FA-5549X) with a type III element spacing and current distribution.

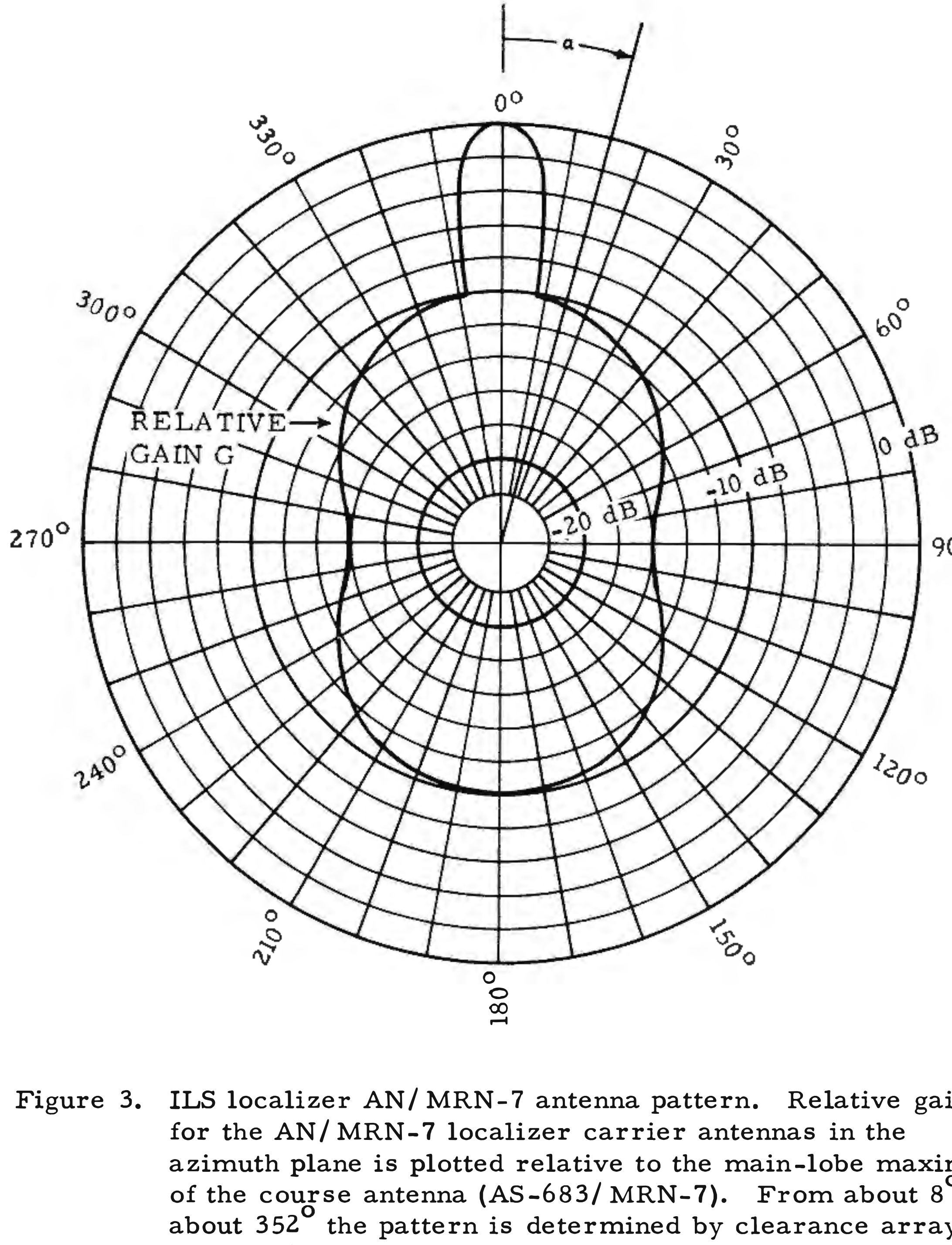


Figure 3. ILS localizer AN/ MRN-7 antenna pattern. Relative gain for the AN/ MRN-7 localizer carrier antennas in the azimuth plane is plotted relative to the main-lobe maximum of the course antenna (AS-683/ MRN-7). From about 8° to about 352° the pattern is determined by clearance array (AS-684/ MRN-7) radiation. Relative effects of antenna input powers and ground reflections are included in this pattern. The free-space main-lobe maximum gain of the course carrier array relative to an isotropic radiator is 18 dB.

Aircraft antenna gain statistics for the localizer were developed from antenna modeling data for an E-cavity type VOR antenna in the vertical stabilizer of passenger-type jet aircraft (Convair, 880 Commercial Jetstar). Only the forward ±20° of azimuth was considered in obtaining statistics for gain toward the desired station, but two sets of statistics were developed for gain in the direction of the undesired station. In one set only the rear ±20° of azimuth was considered; in the other, all azimuth angles were considered equally likely. From these statistics a single cumulative distribution was established for the ratio of antenna power gain in the direction of the desired station to that in the direction of the undesired station. This ratio, expressed in decibels, is denoted by $R_A$, and the cumulative distribution, $R_A(p)$, used to account for aircraft antenna gain is shown in figure 4. This figure also shows two additional cumulative distributions of $R_A$ that resulted from the analysis mentioned above and were used as guides to establish the $R_A$ distribution used in the calculations.

The cumulative distribution involving the rear ±20° of azimuth was developed to assess the effect of constraining azimuth angles to those likely to be of special interest in designing aircraft antenna for ILS use.

## 2.2 ILS Glide Slope Parameters

The ILS glide slope operates in the 329 to 335 Mc/s frequency range. Characteristics for three facility types and five antenna types are given in table 2. Patterns for these antennas are shown in figure 4. Information on the facility types was obtained from a Federal Aviation Agency (1963) handbook and Butts (1963). Antenna data were obtained from a Federal Aviation Agency (1966) specification. Other equipment exists, but consideration of these examples is sufficient for practical purposes.

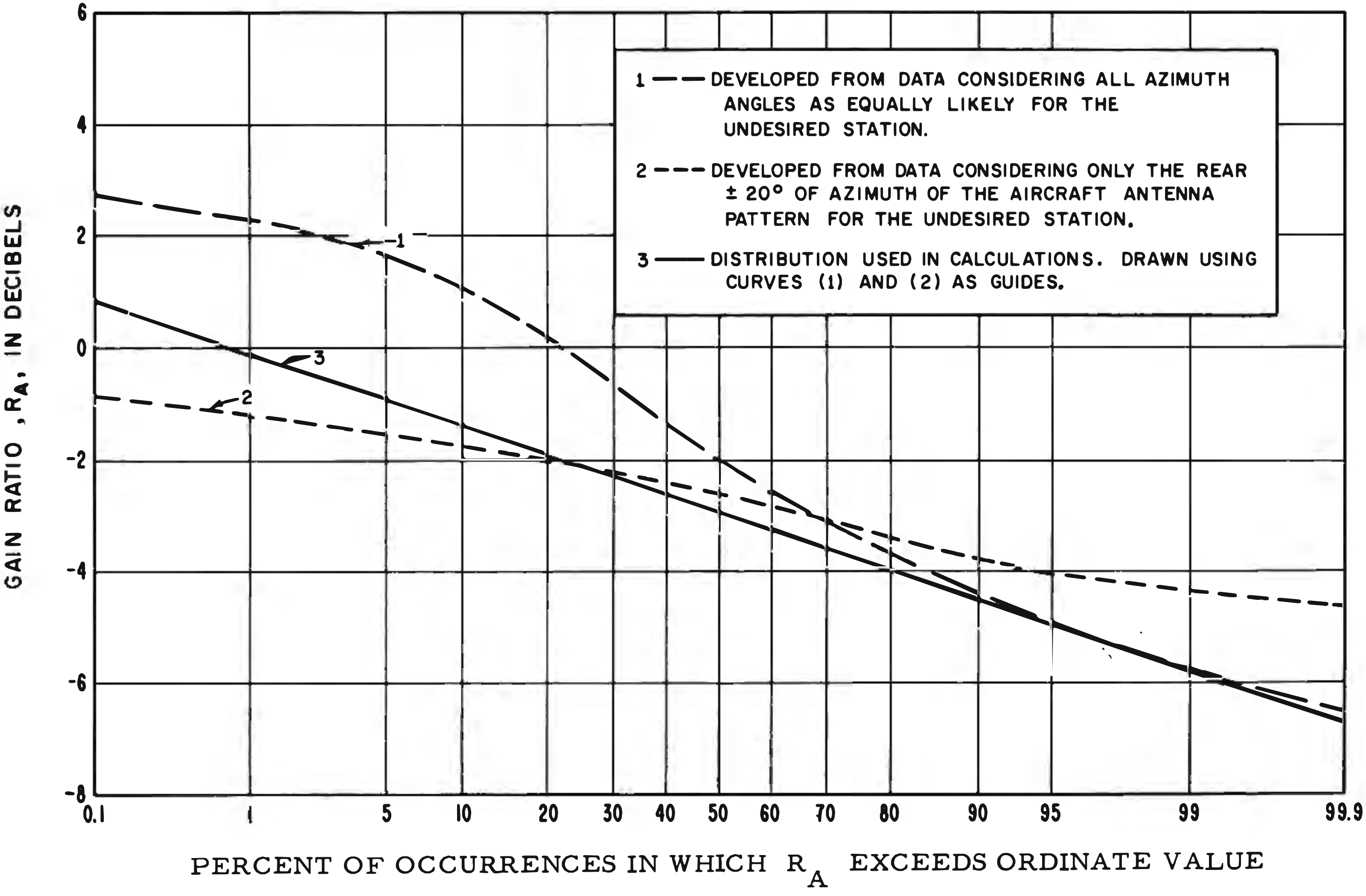


Figure 4. Localizer aircraft antenna gain ratio distributions.

Table 2. Characteristics of ILS Glide Slopes

| Characteristics | Facility Types | | |
|---|---|---|---|
| | Null Reference | Sideband Reference | Capture Effect |
| Transmitter output(a) | 10.8 dBW | 10.8 dBW | 10.8 dBW |
| Coupling loss(b) | 3.5 dB | 6.5 dB | 7.5 dB |
| Antenna input | 7.3 dBW | 4.3 dBW | 3.3 dBW |
| | Antenna Types | | |
| | I or II | III or IV | V |
| Gain(c) | 5.0 dB | 10.0 dB | 7.0 dB |
| Polarization | -------------Horizontal------------- | | |
| Height | Dependent upon frequency and glide slope angle | | |

---

(a) These values are for carrier power, and the primary carrier radiator (lower antenna).

(b) These values are the total carrier power loss between the transmitter output and the primary carrier antenna.

(c) These values are free-space power gains relative to an isotropic radiator; i.e., the directive gain is reduced by the nonradiation loss within the antenna.

Cumulative distributions of $R_A$ for aircraft glide slope antennas, shown in figure 6, were obtained by an analysis similar to that previously discussed for the localizer. However, this analysis included antenna gain data for the Boeing 707 and B-52G; Douglas C-118A, C-124A, C-133A, and DC-8; and Northrop T-38A aircraft.

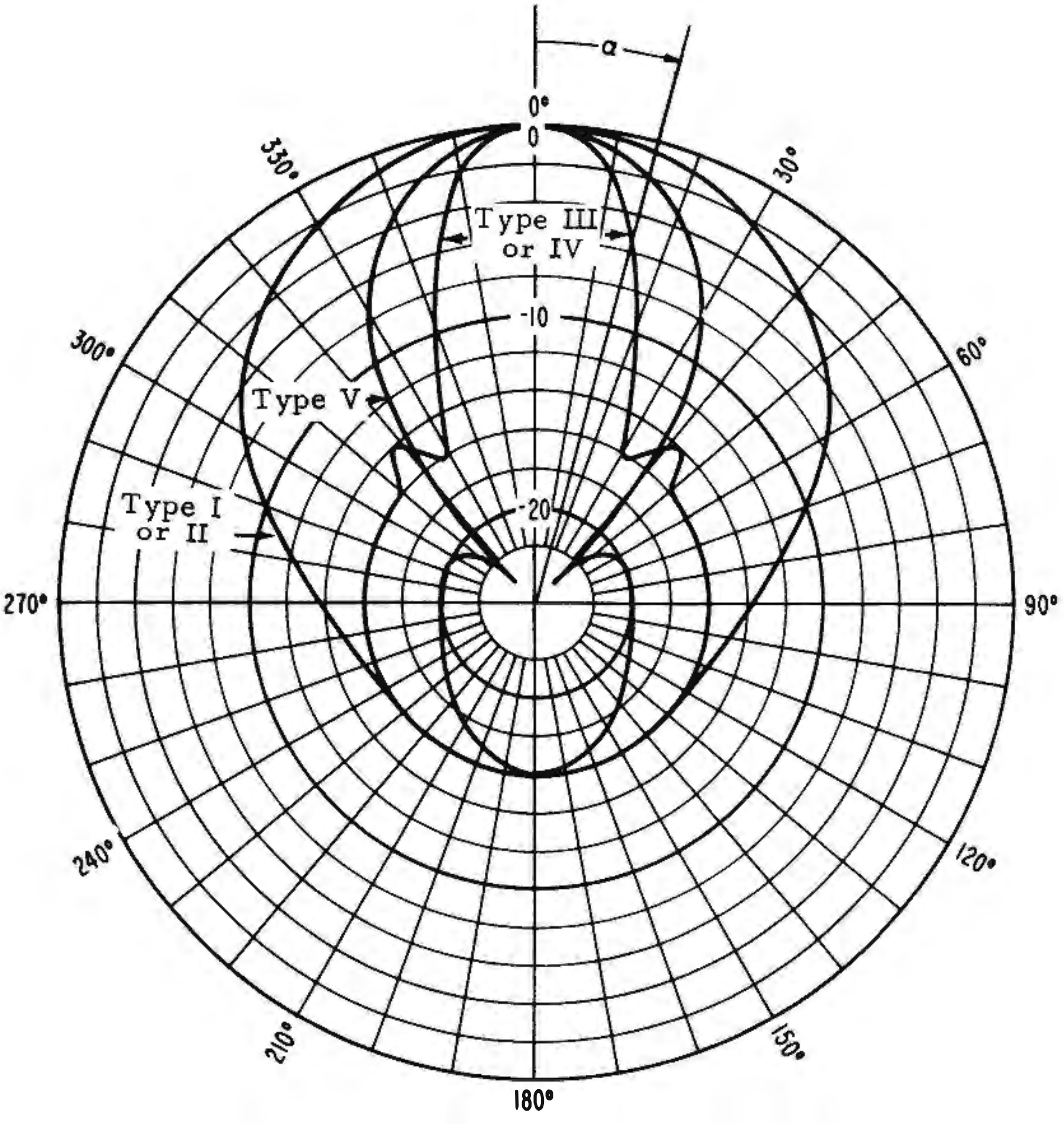
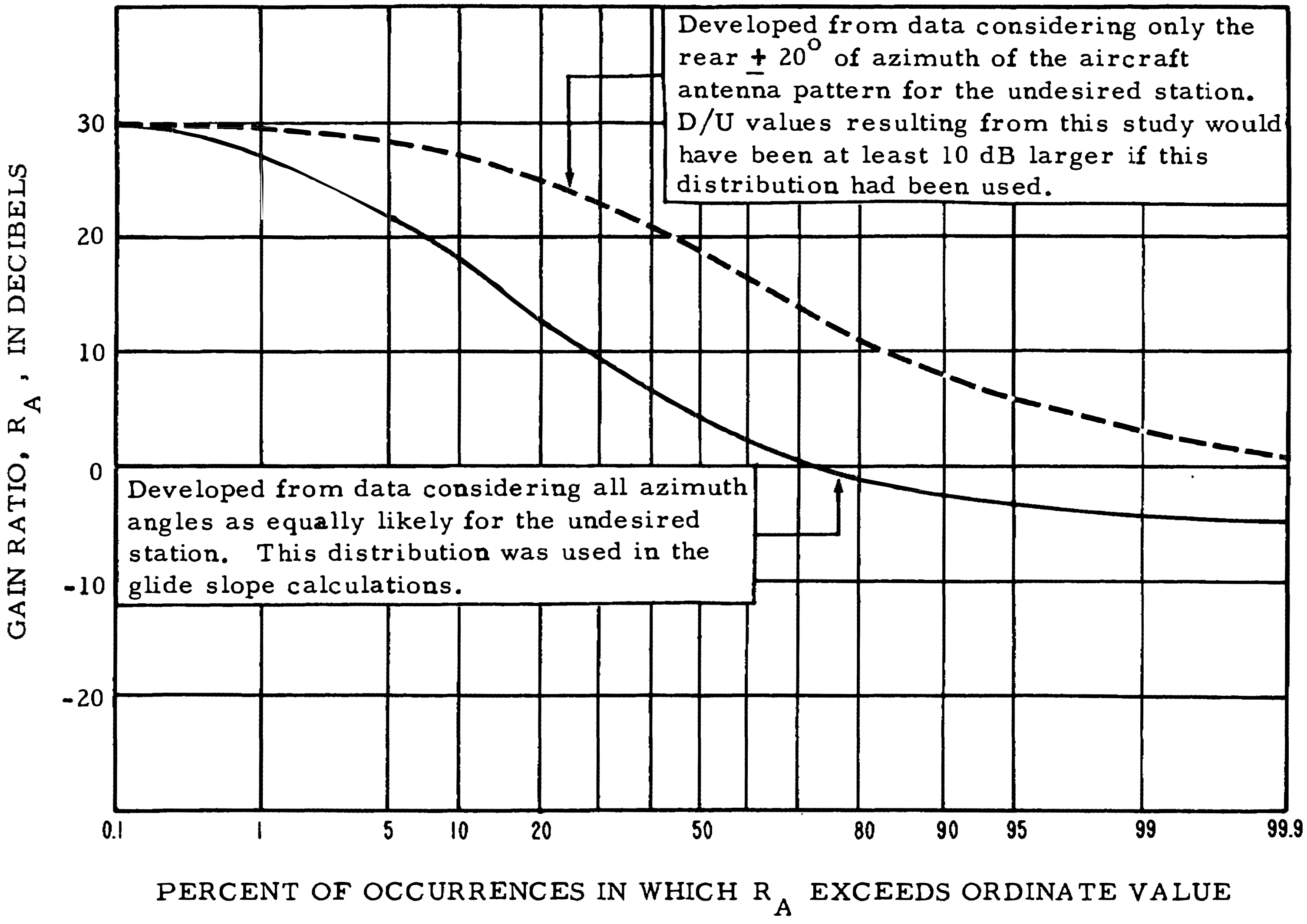


Figure 5. ILS glide slope antenna patterns. Free-space gain for several glide slope antennas in the azimuth plane are plotted in decibels relative to the main-lobe maximum. Main-lobe maximum gains for these antennas are given in table 2, and physical descriptions are given in a Federal Aviation Agency (1966) specification.



Developed from data considering only the rear ± 20° of azimuth of the aircraft antenna pattern for the undesired station. D/U values resulting from this study would have been at least 10 dB larger if this distribution had been used.

Developed from data considering all azimuth angles as equally likely for the undesired station. This distribution was used in the glide slope calculations.

**Figure 6. Glide slope aircraft antenna gain distributions.**

## 2.3 VOR Parameters

The VOR system operates in the 108 to 118 Mc/s frequency range. Table 3 contains other parameters for the VOR.

Table 3. VOR System Parameters.

| | |
|---|---|
| Carrier power radiated from antenna (a) | 20 dBW |
| Polarization | Horizontal |
| Antenna type | 4-loop array (located above counterpoise) |
| Maximum antenna gain relative to isotropic antenna | 2.15 dB |
| Free-space horizontal pattern | Approx. circular |
| Free-space vertical pattern | Similar to a dipole |
| Counterpoise diameter | 52 ft |
| Antenna height above counterpoise | 4 ft |
| Counterpoise height above ground | 12 ft |

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(a) The radiated power is the same as the power delivered to the antenna when other antenna losses are considered negligible when compared with that associated with its radiation resistance.

The aircraft antenna gain was determined as a function of azimuth and vertical angle from a modeling study based on an E-cavity type VOR antenna in the vertical stabilizer of a passenger-type jet aircraft (Convair, 880). Figure 7 shows the distribution of antenna gains at various vertical angles and a sample of the measurement points from which the principal distribution was derived.

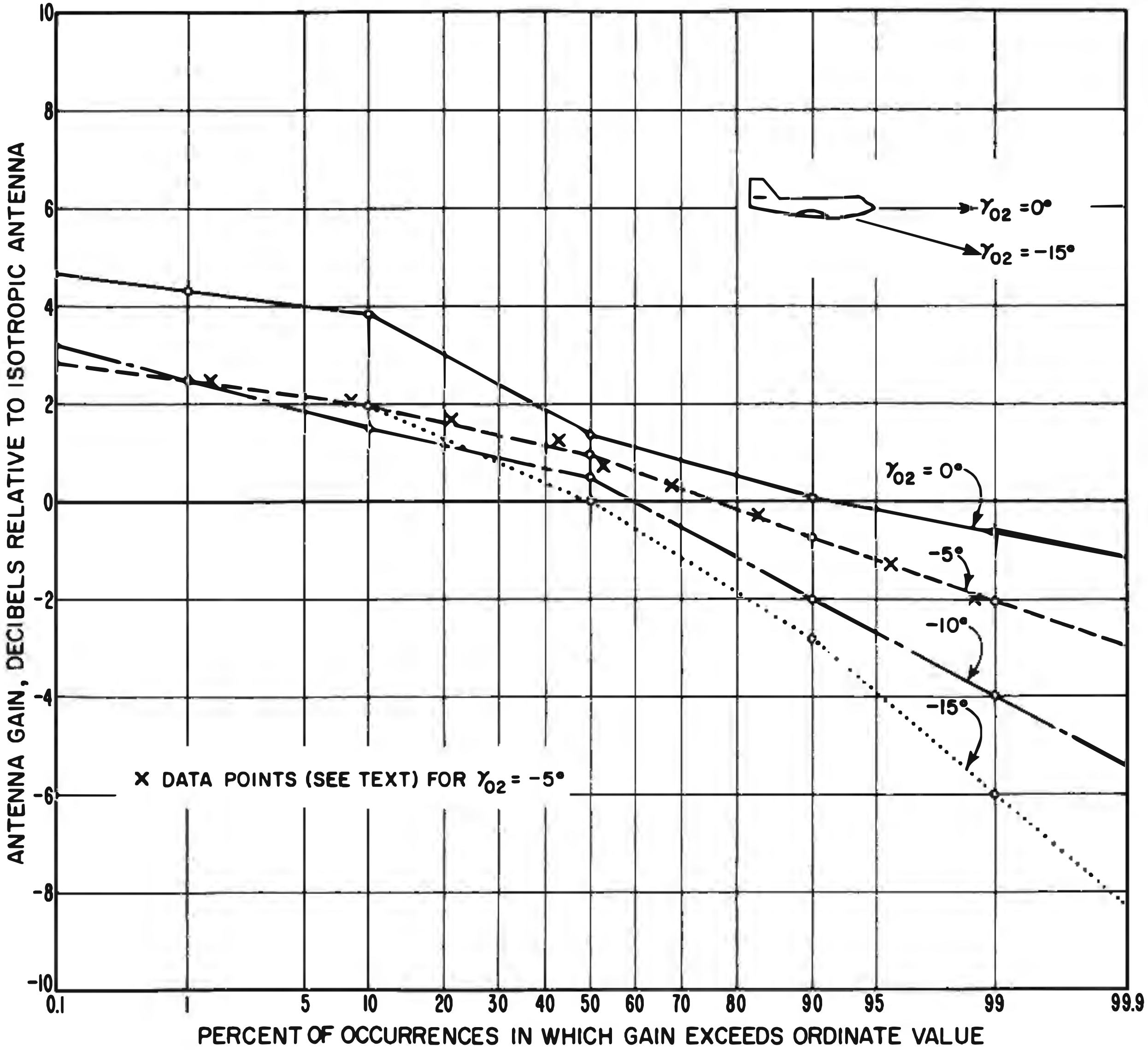

Figure 7. VOR aircraft antenna gain distributions.

## 3. TRANSMISSION LOSS CALCULATIONS

The prediction of interference conditions requires a knowledge of the time distributions of transmission loss or field strength at many points in space.

Figure 8 shows a typical configuration of an aircraft (representing the receiving terminal), a desired navigational transmitting facility, and an undesired navigational transmitting facility. All three are aligned along a great-circle path and for simplicity assumed to be above a smooth surface. In the example drawn, the aircraft is within the radio horizon of the desired facility but beyond the radio horizon of the interfering station. The distances along the great circle path from a point vertically below the aircraft to the desired and the undesired station are denoted by $d_D$ and $d_U$, respectively. The aircraft is at a height $h_2$ above the earth. The angle $\theta$ between the horizon rays from the aircraft and the interfering station is an important parameter in calculating transmission loss for beyond-the-horizon paths (Norton et al., 1955a). Figure 8 is oversimplified because radio rays may only be drawn as straight lines under special conditions, one of which is that $h_2$ must be less than 5000 feet.

Transmission loss calculations were accomplished by (a) calculating a reference value of transmission loss, (b) calculating a cumulative distribution for long-term variations, (c) calculating a cumulative distribution for short-term variations, and (d) calculating the cumulative distribution of transmission loss by combining the results of previous calculations. More detail on these four steps follows.

(a) Within the radio horizon, reference transmission loss was calculated by geometric optics methods, including interference between the direct and the ground-reflected ray. For desired station

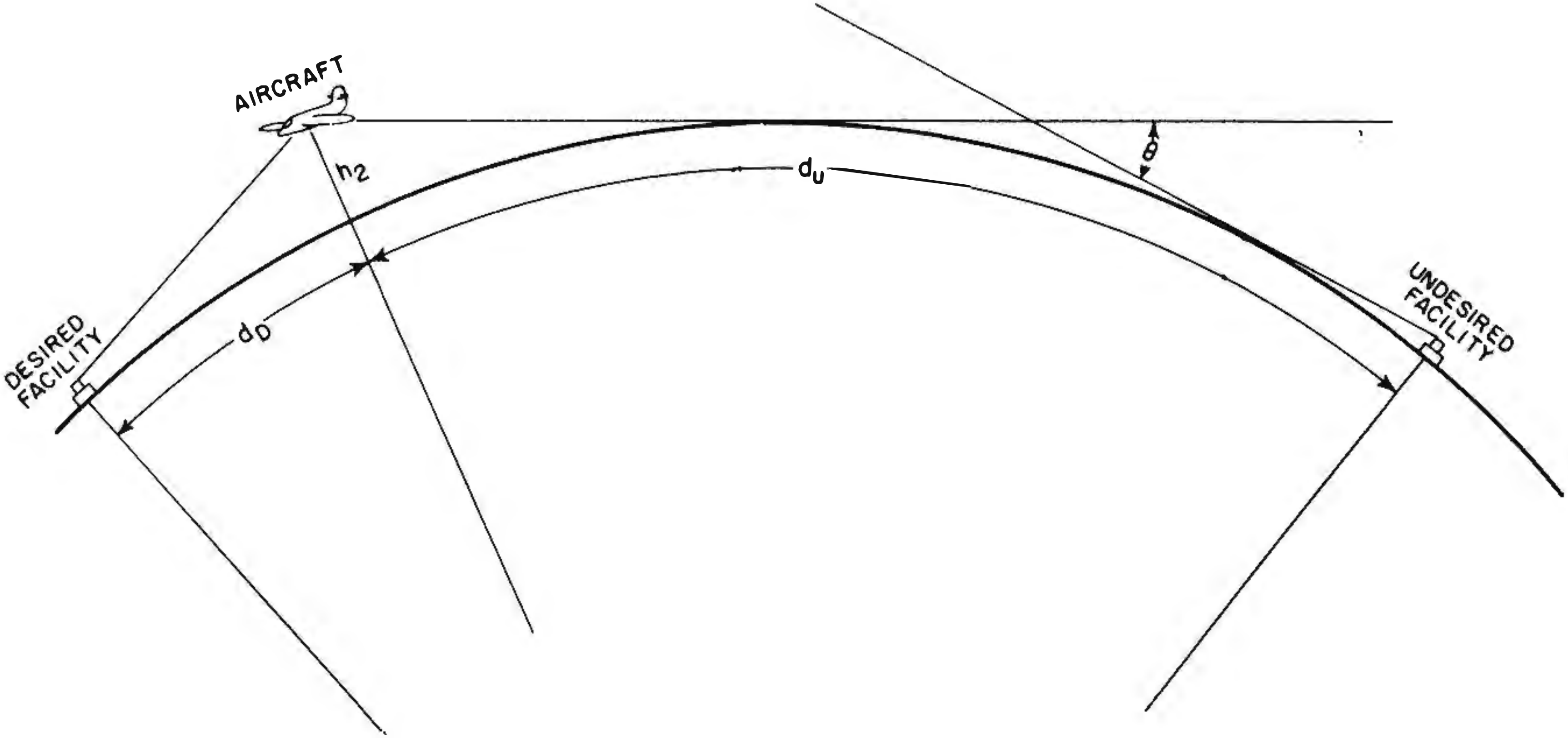

Figure 8. Sketch showing relative positions of aircraft and navigational aids over a smooth earth.

propagation models, specular reflection was assumed. Because of the irregular terrain (including buildings, etc.) surrounding undesired ILS stations, specular reflection from the earth was considered less dominating, and a combination of specular and diffused reflection was assumed. The primary effect of this assumption was lower transmission loss values for the undesired ILS under line-of-sight conditions than for the desired ILS. This is discussed further in appendix A.

In calculating reference transmission loss beyond the radio horizon, smooth-earth diffraction or forward scatter models are used, depending on the path distance involved. Since diffracted field decreases very rapidly beyond the radio horizon, especially at the glide slope frequencies, the forward scatter model is more important. The calculations for both models and the method of properly combining diffraction and scatter fields, if they are of comparable magnitude, are based on procedures given by Rice et al. (1967).

(b) Long-term variations in basic transmission loss were estimated for a continental temperate climate by means of the time availability function V(p, d)[2], which was used as the cumulative distribution with time of

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[2] The curves presented in this report were developed during the time when prediction methods given by Rice et al. (1967) were evolving. In particular the function V(p, d), used in all calculations involving the ILS localizer, is identical with the function $V(0.5, d_e) + Y(q, d_e)$ used by Rice, et al. (1967, tables III.2 to III.4) for a continental temperate climate. An earlier version of this V(p, d) function was used in calculations based on exclusive consideration of the VOR. These versions of V(p, d) are very similar and are identical for beyond-the-horizon paths. Because another function V(p, θ), similar to V(p, d), was derived primarily from data in the 100 Mc/s range, we followed the recommendation that it be used when $\theta \geq 0.01$ radians (Air Force Technical Order, 1961) in our calculations for VOR exclusively. For the glide slope calculations the constants from Rice et al. (1967, tables III.5 to III.7) were used. This formulation for variability became available after the first localizer calculations were completed and is based on a larger body of empirical data than other formulations.

hourly median transmission loss for all hours of the year relative to the reference values calculated under (a) above as functions of path length, terminal height, and carrier freqeuency.

(c) In addition to the distributions of hourly medians representing long-term variations, short-term (usually within-the-hour) distributions of the received signal levels had to be estimated. Short-term variations in this particular application stem principally from two causes. One is the inherent short-term fluctuation of the tropospheric signal ascribed to phase interference of rays reflected from small layers or scattered from refractive index discontinuities or from ground irregularities. The second is the pattern of the aircraft antenna; numerous small lobes cause gain changes with varying bearings that can be represented by a cumulative distribution of antenna gain with time as the aircraft moves through space. For ILS, however, it was more efficient to neglect the effect of the aircraft antenna gain in the initial transmission loss calculations, and include it in later calculations as the $R_A$ (p) distribution, discussed in section 2. Short-term fading was described by cumulative distributions (Norton, et al., 1955b) based on fading range data given by Janes (1955).

(d) To obtain the cumulative distribution of transmission loss the functions discussed in (a), (b), and (c) above were combined. The mechanics of combining cumulative distributions have been discussed earlier (Gierhart and Johnson, 1967, app. II).

Note that the 1-hour period taken as the dividing line between long-term and short-term variations is somewhat arbitrary. This is convenient in view of the available empirical time variability functions, which are based on data analysis in terms of hourly median values.

## 4. INTERFERENCE BETWEEN TWO STATIONS

As shown in figure 8, both the desired and the undesired signals arrive at the aircraft over propagation paths characterized by the distances, $d_D$ and $d_U$, and by the aircraft height. The distances are measured along the great-circle path. Both signals vary with time, and the distributions of signal levels were calculated in accordance with the procedures outlined in the preceding section. Then the ratio of desired-to-undesired signal exceeded for given percentages of time at a particular aircraft location was determined.

The desired-to-undesired signal ratio can be expressed as the decibel difference between desired and undesired signal levels and is obtained from calculated transmission loss values and other system parameters. The distribution of this ratio will be denoted D/U(p), where p is that percentage of time during which a given value of D/U is reached or exceeded. The aircraft being in motion, time variations also include variations in space. Since the actual time distribution of D/U may vary from installation to installation because of terrain characteristics and other factors not taken into account in this analysis, the time availability p may be interpreted as an expression of reliability for a typical installation. The concepts of "prediction uncertainty" and "service probability" were not used in the sense defined by Barsis et al. (1962). It is important to understand that there is an uncertainty associated with the D/U predictions in this study and that this uncertainty will increase under conditions where the assumed propagation models become less valid.

As an example, D/U(95) = 10 dB means that for a typical installation the ratio of the desired-to-undesired signal is equal to or greater than 10 dB 95% of the time. Values of D/U(95) are associated with the variables used in the calculations. These include:

(a) system type (localizer, glide slope, or VOR), (b) interference type (cochannel or adjacent channel), (c) aircraft altitude, (d) station separation, and (e) aircraft distance from the desired station.

To obtain the time availability of the desired-to-undesired ratio at any point in space it was necessary to properly combine the cumulative distributions of (a) transmission loss from the desired station, (b) transmission loss from the undesired station, and, for ILS, (c) the antenna power gain ratios, $R_A$ (p). Actually the ILS calculations resulted in a cumulative distribution of a normalized D/U. The process for converting actual D/U to normalized D/U values is discussed in sections 5.2 and 5.3.

## 5. RESULTS

Correct interpretation of the prediction curves presented in this section requires some knowledge of the system parameters, propagation models, and computation techniques discussed in the preceding sections. In particular, the predictions include estimates of received power levels of desired-to-undesired signal ratios that are expected to be realized or exceeded 95% of the time (95% reliability). A lower reliability requirement would result in an apparent increase in power received from the desired station. For example, if the difference in power received from desired and undesired ILS stations could be characterized simply by the aircraft gain ratio distribution shown by curve 3 in figure 4 then reliabilities of 95, 50, and 5% would correspond to desired-to-undesired signal ratios of -5, -3, and -1 dB, respectively.

The results are in the form of prediction curves. Two basic types of predictions presented here deal with service limitations caused by (1) insufficient power available from the desired station and (2) interference from one cochannel or adjacent-channel station, without consideration given to the available power limitation. A single-curve format is used for the first type (sec. 5.1), and two formats are used for the second type of predictions (secs. 5.2 through 5.5).

### 5.1 Available Power Service Limitations

When the service range is not limited by co-channel or adjacent-channel interference, it is limited by other types of interference or a received power level that is insufficient compared with the noise level of the receiver. The former is beyond the scope of this report; the latter is the topic of this section.

The radiated power for a ground station can be stated in terms of the power required at the terminals of a reference antenna located at the maximum specified service range. Curves developed for the VOR show service range limitations imposed by this type of specification, when the radiated powers discussed in section 2 are used. The assumed specifications can be summarized as follows:

VOR and ILS localizer ground station radiated power - The radiated power shall not be less than that required to insure that the power available at the terminals of a loss-free horizontally polarized half-wave dipole located at the maximum specified range will be -112 dBW or greater 95% of the time.

ILS glide slope ground station radiated power - The radiated power shall not be less than that required to insure that the power available at the terminals of a loss-free horizontally polarized half-wave dipole located at the maximum specified range will be -97 dBW or greater 95% of the time.

The combination of available power selected for the VOR specification and a power of 20 dBW radiated by a ground station results in a maximum range slightly greater than 130 nm at 18,000 ft. If we assume that a VOR receiver with a usable sensitivity of 5 $\mu$V across

50 Ω in an airborne environment can be built, then the -112 dBW available power quoted above is excessive by about 11 dB. This "power margin" can be used in engineering the airborne terminal to account for such things as (a) difficulty in obtaining an aircraft antenna with 2.15-dB gain (half-wave dipole), (b) line and mismatch losses, and (c) difficulty in obtaining a usable receiver sensitivity of 5 μV across 50 Ω in an airborne environment.

Since the receiving equipment required for the ILS localizer is similar to that for VOR, identical available power requirements were assumed, allowing the requirement for power radiated by the ground station for the two systems to be covered in a single statement.

The available power selected for the ILS glide slope specification has a "power margin" of 14 dB at 15 nm when a usable receiver sensitivity of 20 μ V across 50 Ω in an airborne environment is assumed. A capture effect facility with type I antennas (lowest effective isotropic radiated power of any combination considered; see table 2) has a radiated power sufficient to satisfy this available power requirement at 15 nm.

The Federal Aviation Administration is preparing a document on the "U.S. National Common System Component Characteristics for the VORTAC System," which will contain ground station power requirements similar to those stated above. The preliminary version made available to us, however, expresses the required ground station power in terms of that required to produce a given power density ($dBW/m^2$) at maximum specified range. To make comparison with documents of this type easier, we prepared table 4, where the power density equivalents of the available power requirements are listed for pertinent frequencies. These equivalents were calculated by subtacting $10 \log_{10}$ of the effective area of a half-wave dipole from the reference power (in dBW). For this conversion method to be valid, the incoming electromagnetic

Table 4. Power Density Equivalents.

| | Localizer | | | VOR | | Glide Slope | |
|---|---|---|---|---|---|---|---|
| Frequency (Mc/s) | 108 | 110 | 112 | 113 | 118 | 329 | 335 |
| Effective area (dB) | 0.03 | -0.13 | -0.28 | -0.38 | -0.74 | -9.65 | -9.81 |
| Reference power (dBW) | ------------ | | -112 | ----------- | | -97 | -97 |
| Power density ($dBW/m^2$) | -112.0 | -111.9 | -111.7 | -111.6 | -111.3 | -87.3 | -87.2 |

wave must approximate a uniform plane wave over an area somewhat larger than the antenna's effective area, and the antenna must be oriented so that its maximum gain is used. These requirements are met for regions of interest here.[3]

The above specification was used in calculating nominal service ranges for the ILS localizer types mentioned in section 2.1. Table 5 lists these as a function of altitude.

All ILS glide slope configurations implied by the equipment characteristics given in table 2 were considered with respect to the above specification. For a nominal service range of 15 nm the radiated power from these configurations is at least equal to or in excess of the minimum required.

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[3] Some antennas used for tropospheric propagation paths have such a large effective area that their full free-space gain for the path is not realized.

Table 5. Nominal ILS Localizer Service Range.

| Altitude (ft) | Range (nm) | | | |
|---|---|---|---|---|
| | Standard | Directional | Low Cost | AN/MRN-7 |
| 500 | 22 | 31 | 23 | 22 |
| 1,000 | 31 | 39 | 32 | 31 |
| 2,000 | 46 | 55 | 47 | 46 |
| 3,000 | 59 | 68 | 60 | 58 |
| 4,000 | 66 | 78 | 67 | 65 |
| 6,250 | 77 | 105 | 79 | 75 |
| 12,000 | 95 | 128 | 997 | 93 |
| 18,000 | 111 | 153 | 113 | 108 |

Service volumes defined by the system parameters (sec. 2.3) and the available power requirements of the above specifications are shown in figure 9 for the VOR with a plot of the radio horizon. In the volume defined by the revolution of the curve about its ordinate axis, the reference antenna would deliver the required power at least 95% of the time. However, unsatisfactory service exists in the airspace (cone) immediately above VOR.

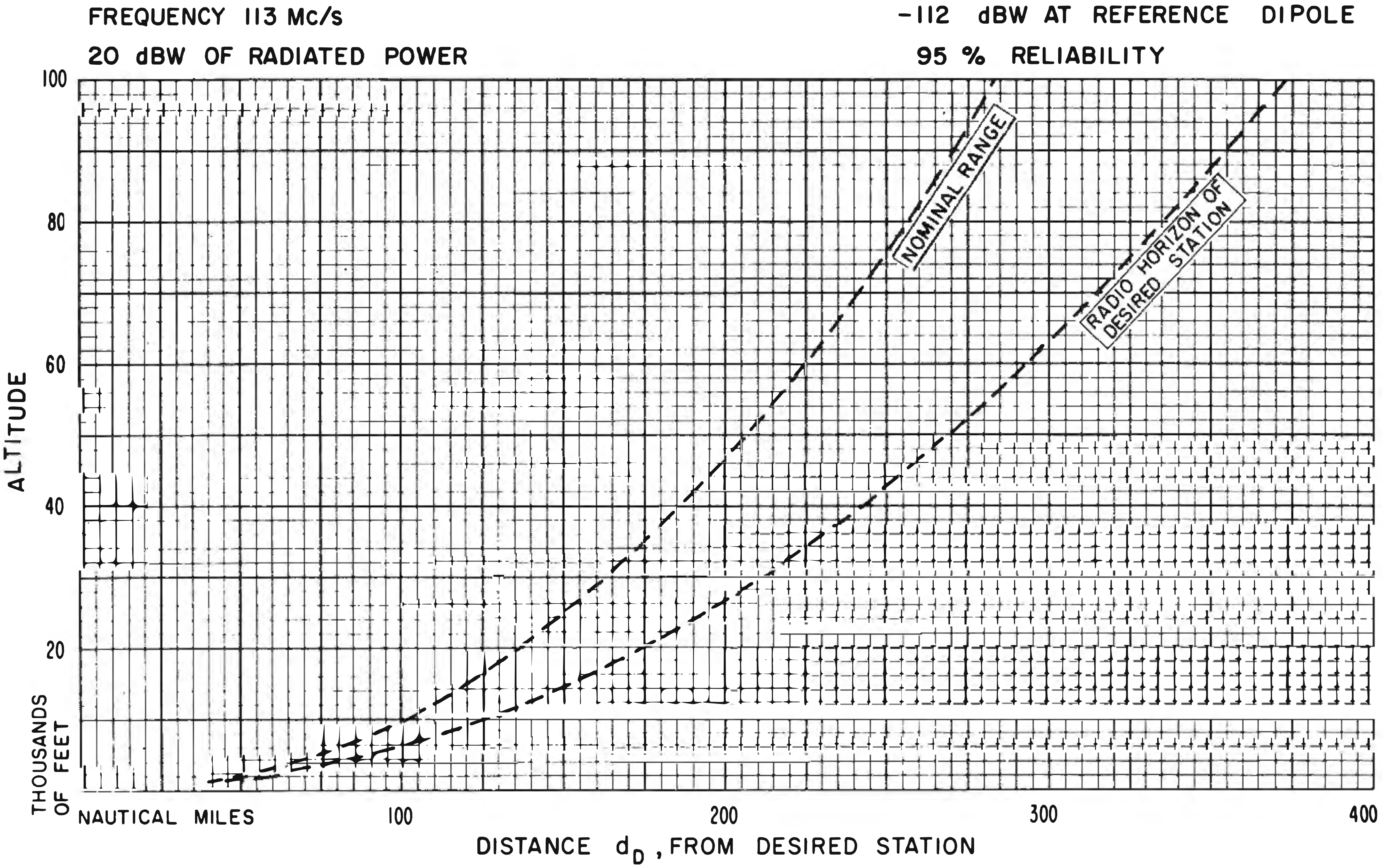

Figure 9. VOR service volume without interference.

## 5.2 ILS Localizer Signal Ratios

The results of the study of the ILS localizer are in the form of normalized prediction curves. These can be used to estimate the service limitations imposed on localizer installations by cochannel and adjacent-channel interference. Other limitations, such as man-made noise at the receiver and self-interference caused by reflections from airport structures or other aircraft, were not considered in this study. An "acceptable" desired-to-undesired signal ratio does not imply that the desired signal is strong enough for operational use (see sec. 5.1).

Values of normalized D/U(p) are denoted by the symbol $N\{D/U(p)\}$ where p (% reliability) may be 50 or 95. These normalized values were calculated for the case when the two ground stations and the aircraft are on the same great-circle arc. Where the assumed great-circle alignment is not valid, $N\{D/U(p)\}$ values can also be obtained by properly interpreting the station separation shown on the curves. Regardless of the shortest distance between the ground stations, the station separation S shown on the curves should always be regarded as the algebraic sum of the distance from the aircraft to the desired station $d_D$ and the distance from the aircraft to the undesired station $d_U$, i.e., $S = d_D + d_U$.

Curves of $N\{D/U(p)\}$ applicable to cochannel or adjacent-channel localizer interference are given at the end of this section. Figures 10 through 16 are for ILS (desired)/ILS (undesired), and figures 17 through 20 are for ILS (desired) / VOR (undesired). Station rather than interference types should be used to determine which curve is appropriate for a particular application; the list of figures given at the beginning of the report should be helpful in this determination.

Desired values of D/U(p) can be converted to values of $N\{D/U(p)\}$, which can be read from the curves by the following procedure:

(a) Determine the value of the station combination factor $C_f$ from table 6.

(b) Determine the azimuth angle $\alpha$ between main lobe maximum of localizer carrier antenna at the undesired station and the aircraft.

(c) Using $\alpha$ and the antenna pattern (fig. 1, 2, or 3) appropriate for the undesired localizer type, determine the gain factor G of the undesired localizer carrier antenna in the direction of the aircraft. Use G = 0 if the undesired station is a VOR.

(d) Calculate $N\{D/U(p)\}$ from

$$N\{D/U(p)\} = D/U(p) - C_f + G. \tag{1}$$

Table 6. ILS Localizer $C_f$ Values in Decibels.

| Desired | Undesired | | | | |
|---|---|---|---|---|---|
| | Standard | Directional | Low Cost | AN/MRN-7 | VOR |
| Standard | 0 | -10.5 | -0.5 | -0.5 | 1.8 |
| Directional | 9.5 | -1.0 | 9.0 | 9.0 | 11.4 |
| Low Cost | -0.5 | -11.0 | -1.0 | -1.0 | 1.4 |
| AN/MRN-7 | -0.5 | -11.0 | 0 | 0 | 1.4 |
| VOR | -1.8 | -12.3 | -2.3 | -2.4 | 0 |

The values of $C_f$ in table 6 were calculated from information given in tables 1 and 2 via the equation

$$C_f = P_D - P_U + A_D - A_U + H_D - H_U , \tag{2}$$

where

$P_D$ = carrier power radiated by desired station in dBW,

$P_U$ = carrier power radiated by undesired station in dBW,

$A_D$ = free-space antenna gain referred to an isotropic radiator for the main lobe of the desired station carrier antenna array, in dB;

$A_U$ = antenna gain similar to $A_D$ but for undesired station.

$H_D$ = height gain factor for desired station, i.e.,

$H_D$ = 0 dB for ILS array height of 5.5 ft (8-loop),

$H_D$ = 1.5 dB for ILS array height of 7.5 ft (V-ring),

$H_D$ =-1.5 dB for ILS array height of 4.5 ft (AN/MRN-7); and

$H_U$ = height gain factor for undesired station, i.e.,

$H_U$ = 0 dB for ILS array height of 5.5 ft (8-loop),

$H_U$ = 2.5 dB for ILS array height of 7.5 ft (V-ring),

$H_U$ =-0.5dB for ILS array height of 4.5 ft (AN/MRN-7).

Values of G read from figure 1, 2, or 3 represent the gain of the undesired localizer carrier antenna in the direction of the aircraft relative to the gain of the same antenna in the direction of the main-lobe maximum. Because of this, values of G are always non-positive and $N \{D/U(p)\}$ values will be worst (highest) for a particular pattern when G is 0. The service range $d_D$ usually decreases as $N \{D/U(p)\}$ increases.

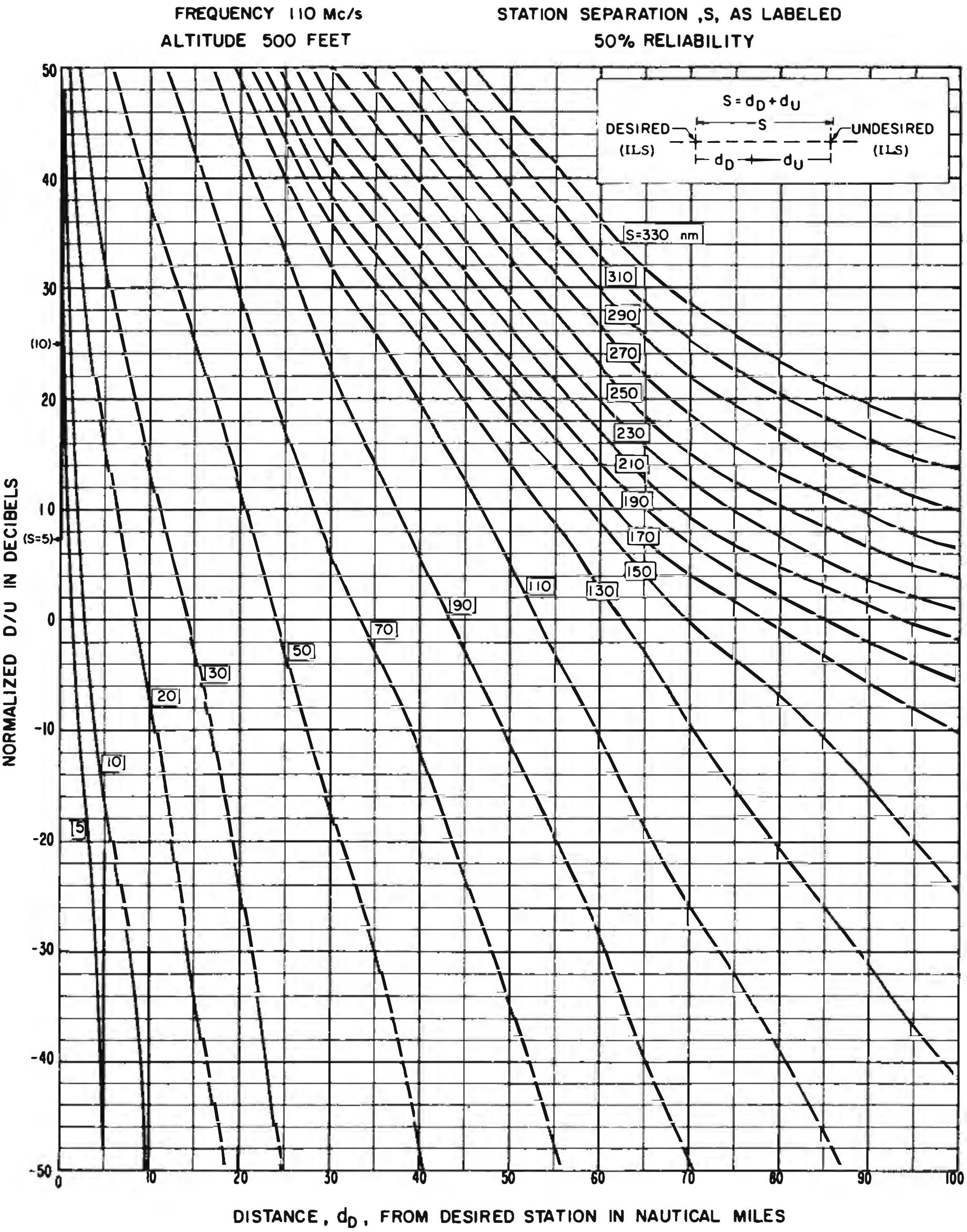

Figure 10. Localizer signal ratios; ILS/ILS; 500 ft; 50%.

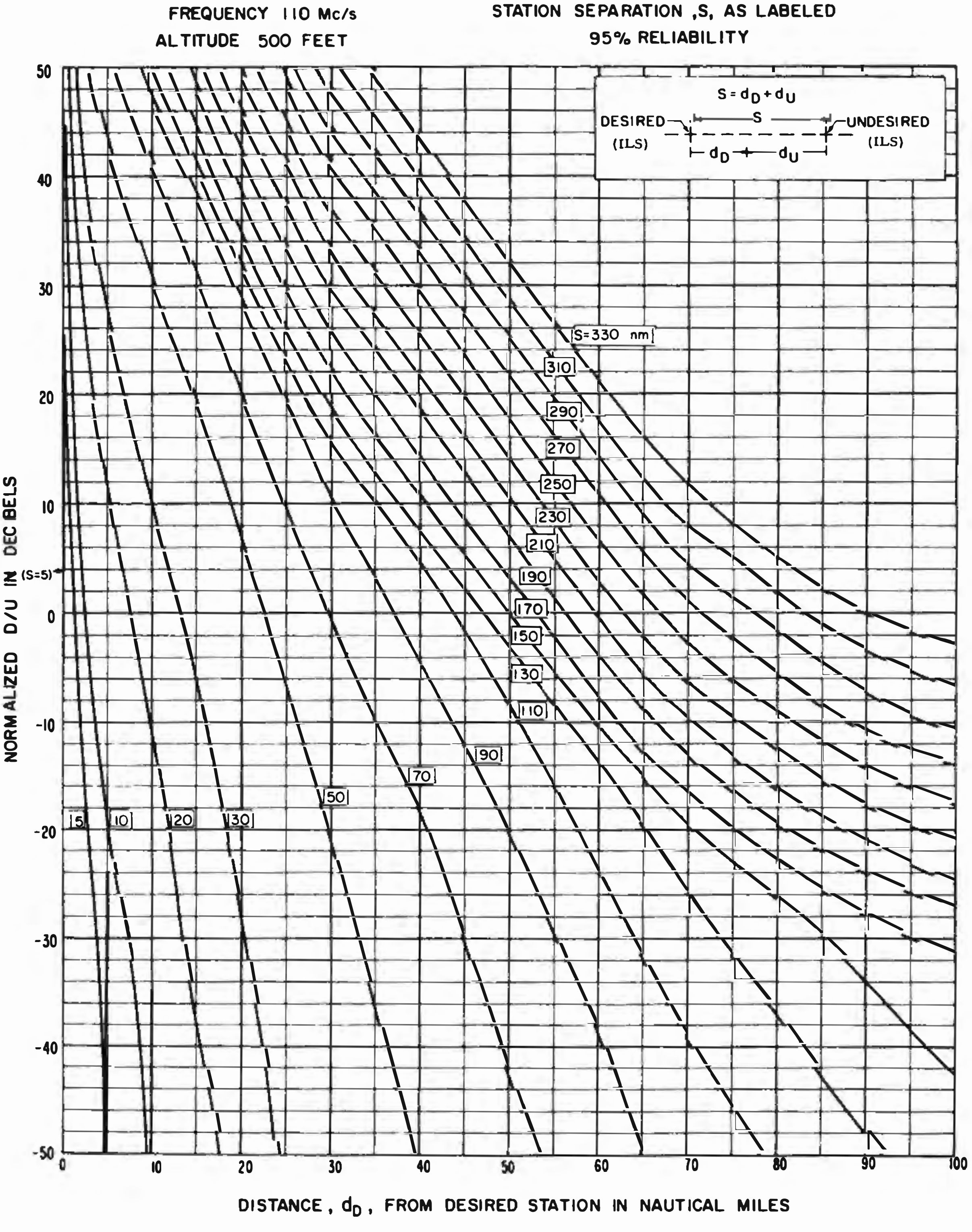

Figure 11. Localizer signal ratios; ILS/ILS; 500 ft; 95%.

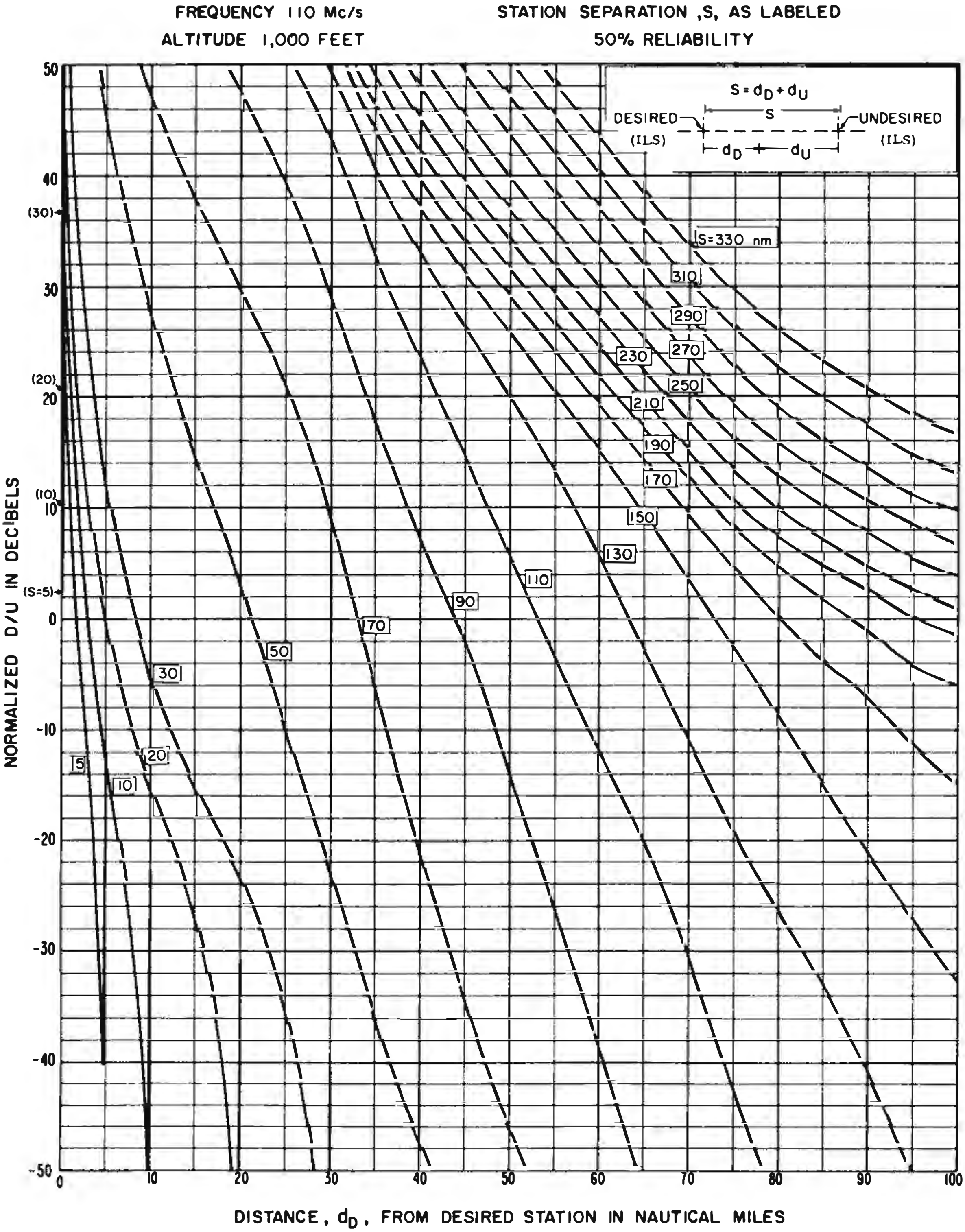

Figure 12. Localizer signal ratios; ILS/ILS; 1,000 ft; 50%.

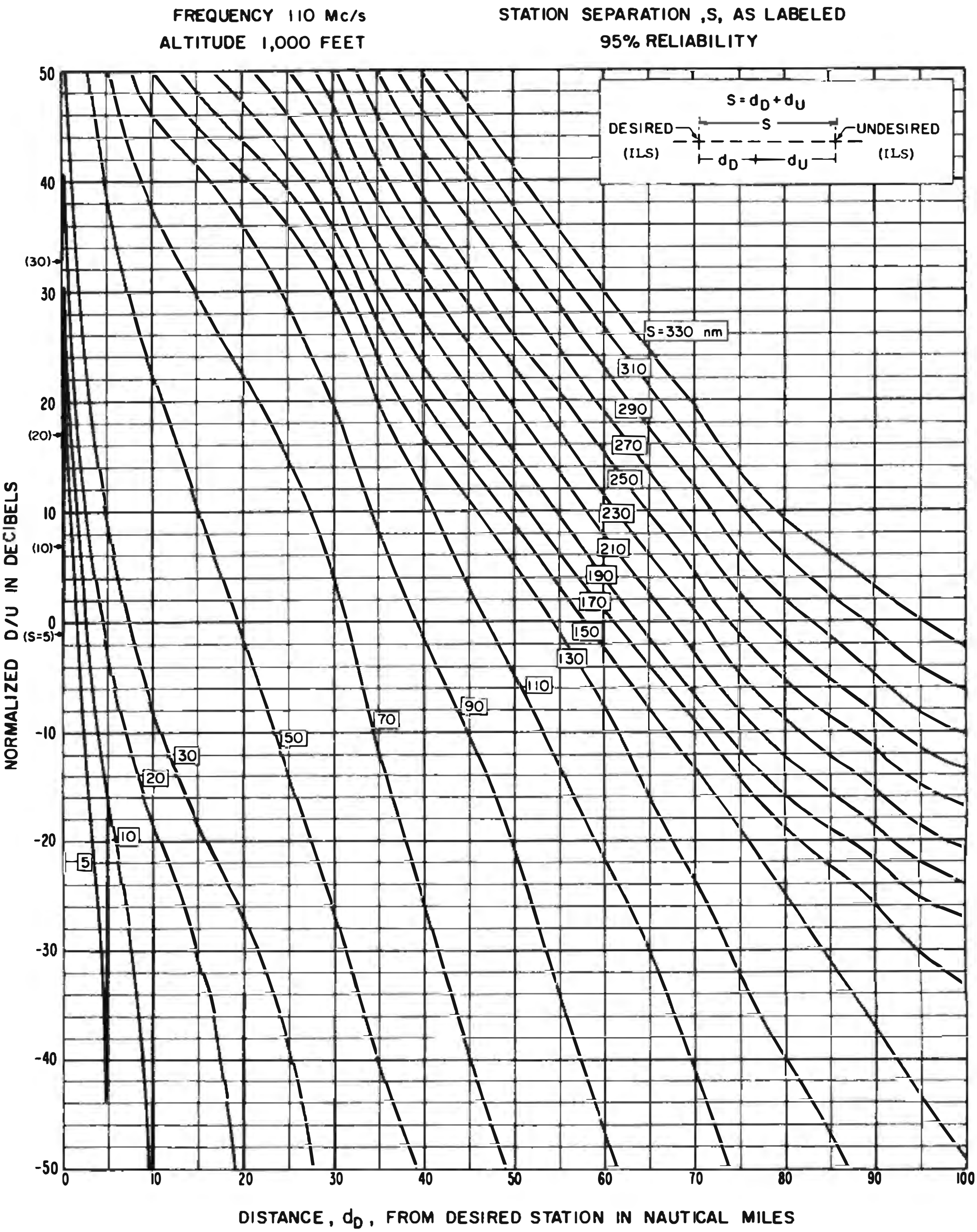

Figure 13. Localizer signal ratios; ILS/ILS; 1,000 ft; 95%.

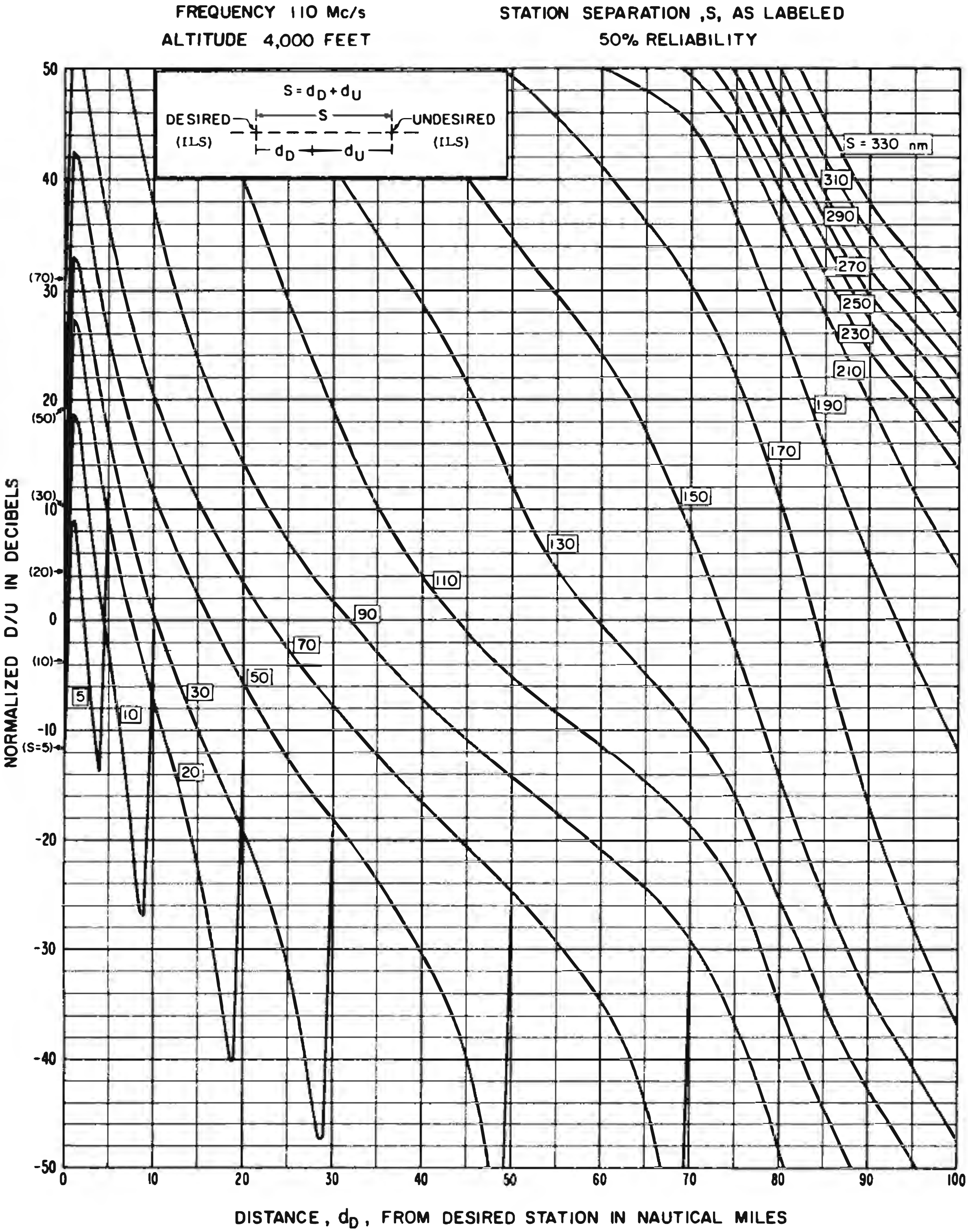

Figure 14. Localizer signal ratios; ILS/ILS; 4,000 ft; 50%.

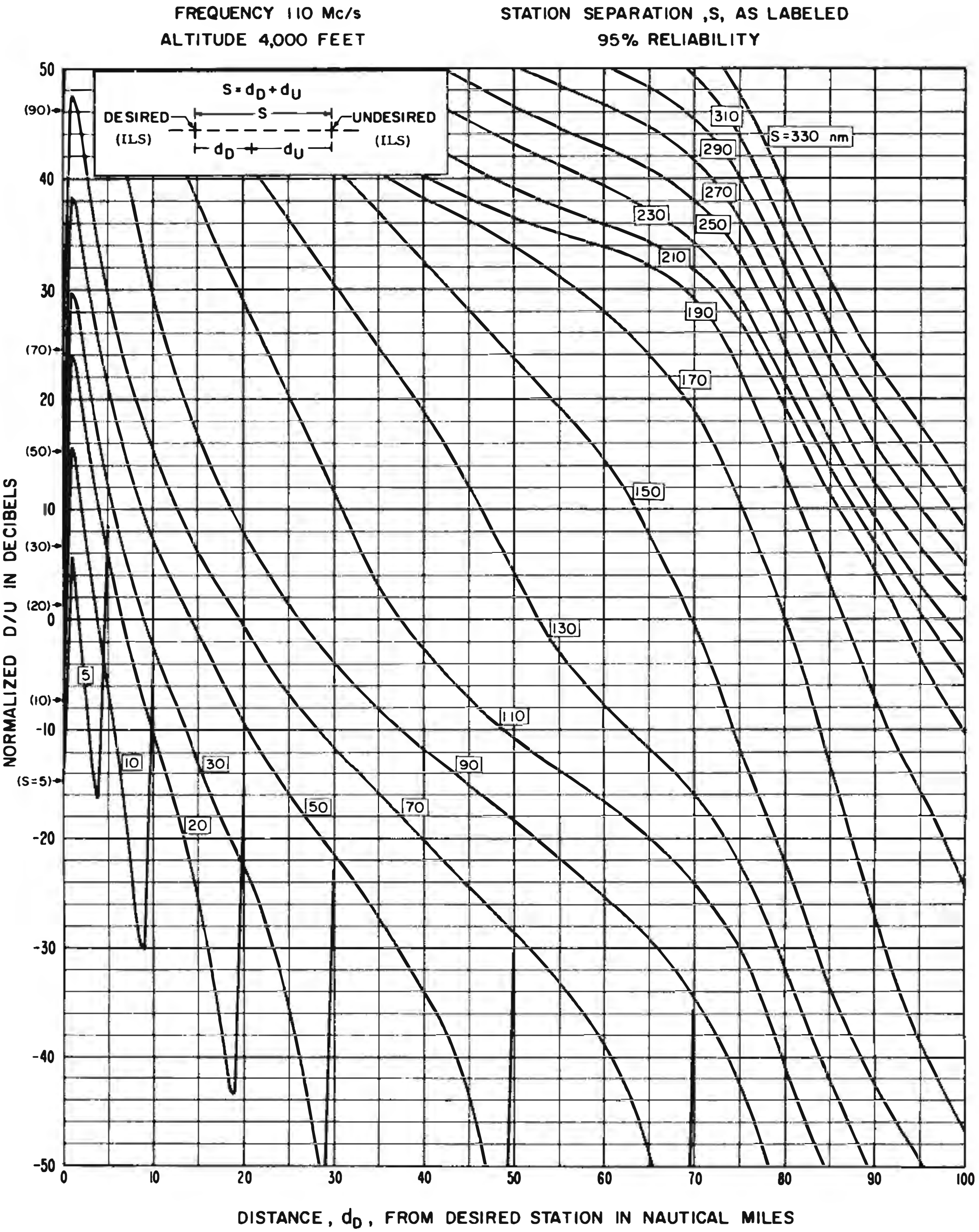

Figure 15. Localizer signal ratios; ILS/ILS; 4,000 ft; 95%.

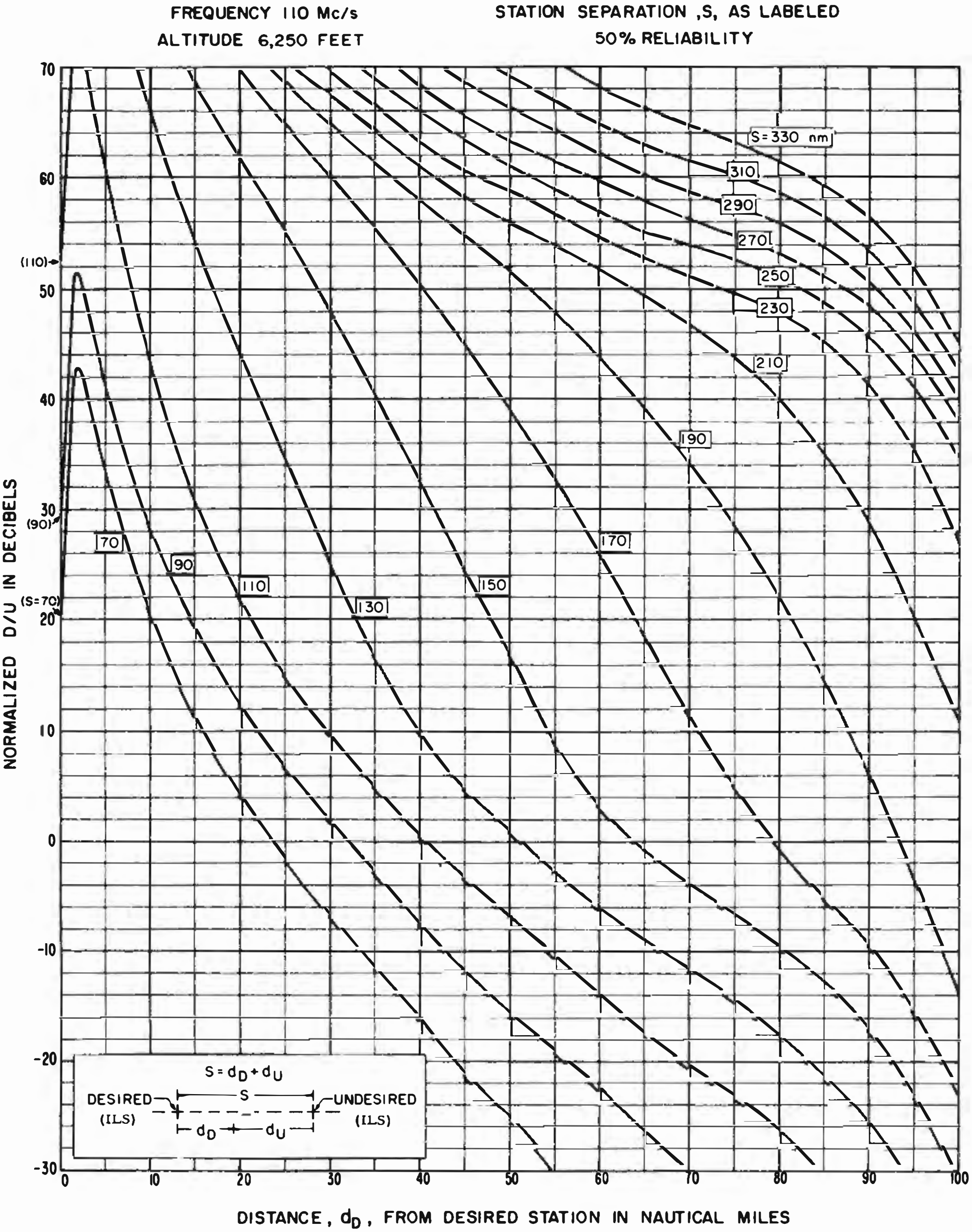

Figure 16. Localizer signal ratios; ILS/ILS; 6, 250 ft; 50%.

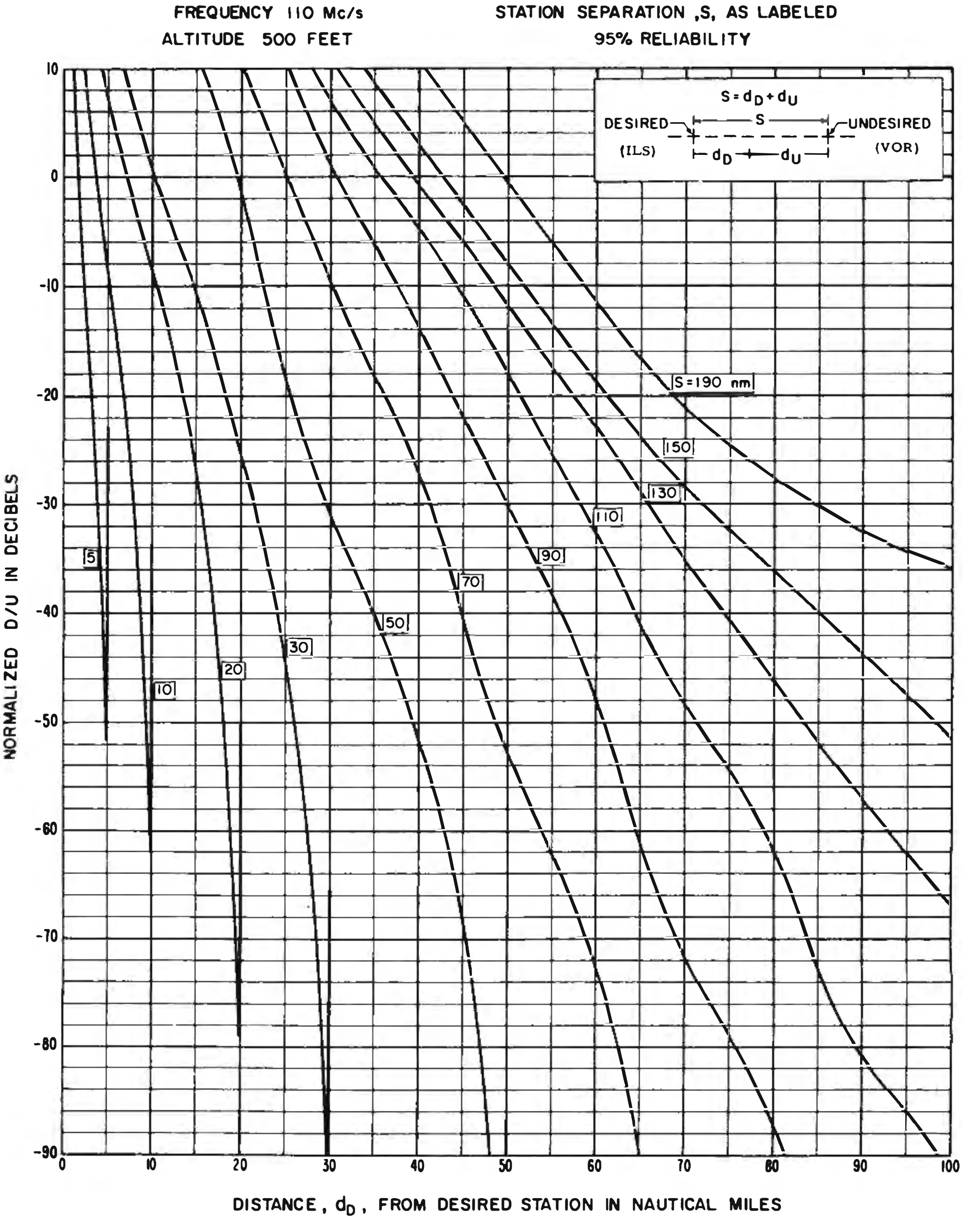

Figure 17. Localizer signal ratios; ILS/VOR; 500 ft; 95%.

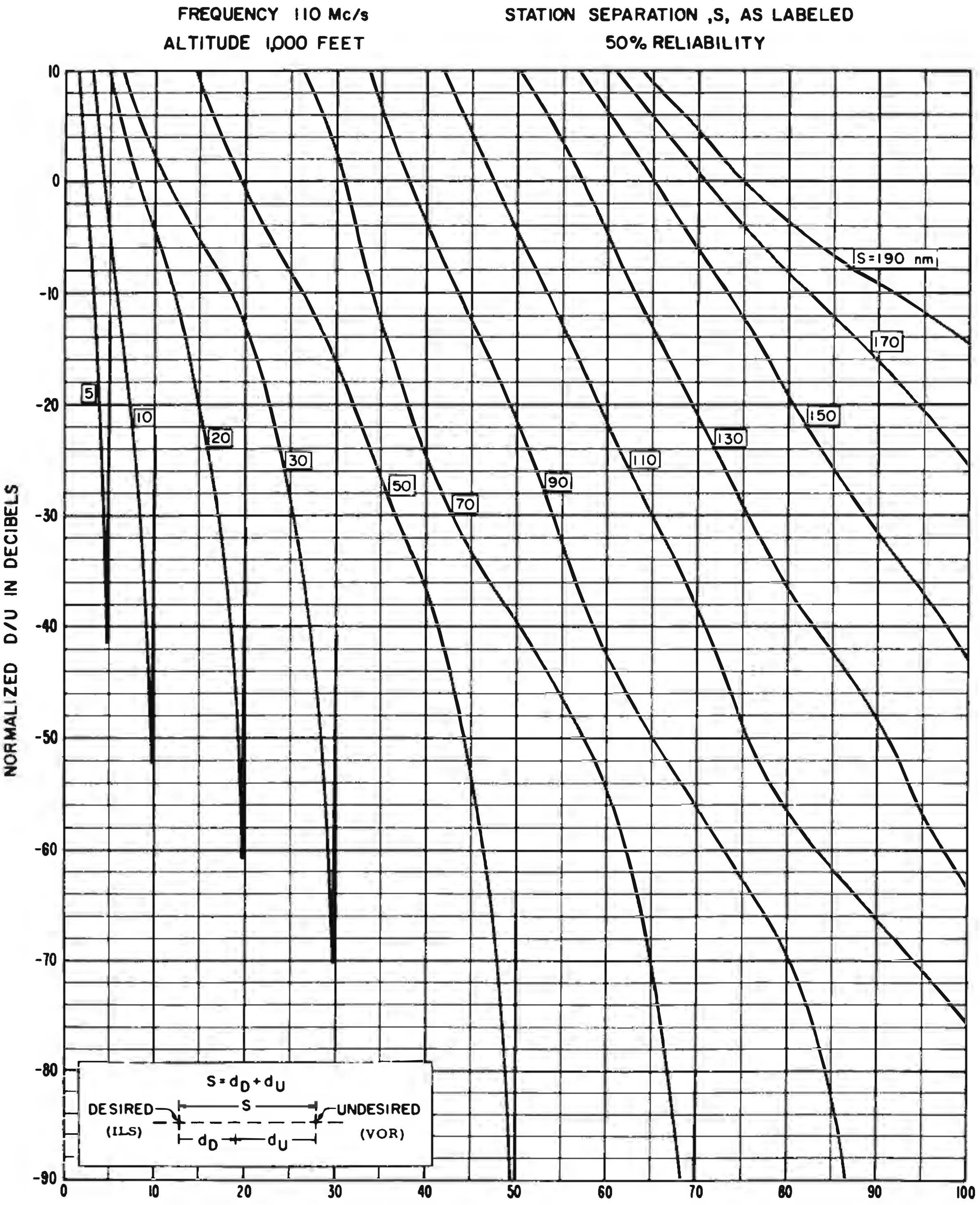

Figure 18. Localizer signal ratios; ILS/VOR; 1,000 ft; 50%.

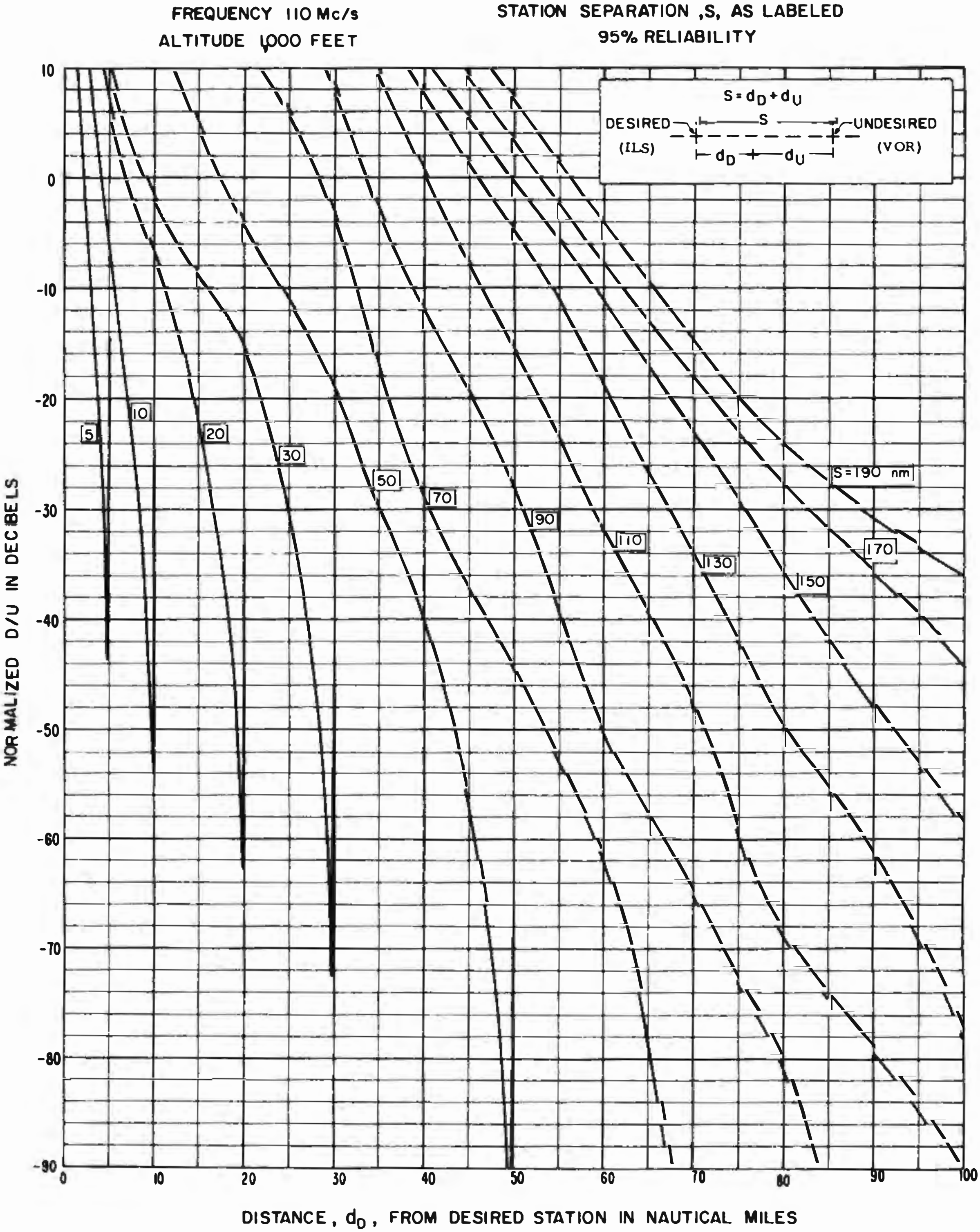

Figure 19. Localizer signal ratios; ILS/VOR; 1,000 ft; 95%.

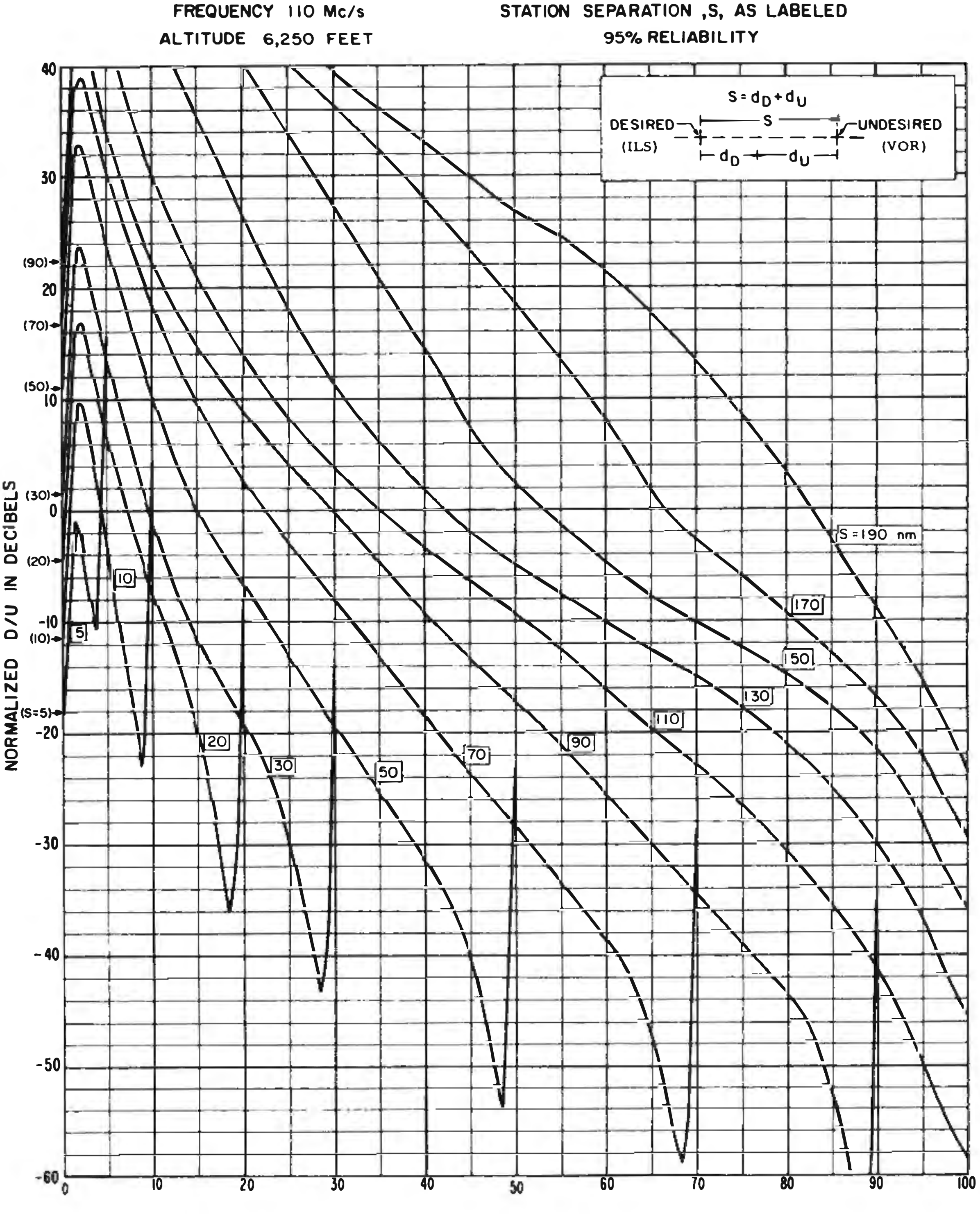

Figure 20. Localizer signal ratios; ILS/VOR; 6,250 ft; 95%.

For example, if a cochannel D/ U(50) of 12 dB or greater at an altitude of 500 ft is required for satisfactory service, then satisfactory service is expected for $d_D \leq 10$ nm when (a) both ground stations are of the "standard" type, (b) the ground stations and aircraft are on the same great-circle arc, and (c) $G \leq 0$, and (d) $S \geq 30$ nm. This conclusion follows from figure 10 when $N \{D/U(95)\}$ is determined from (a) with $C_f = G = 0$; i.e., $N \{D/U(50)\} = D/U(50) = 12$ dB.

### 5.3. ILS Glide Slope Signal Ratios

The results of the study of the ILS glide slope are presented as normalized curves in figures 21 and 22 for reliability at 50% and 95%, respectively. The method discussed in section 5.2 for converting desired D/ U(p) values to $N \{D/U(p)\}$ values can be used, provided that G values are determined from figure 5, and $C_f$ values are obtained from table 7. These $C_f$ values were obtained from the equipment characteristics given in table 2 by use of (2) with $H_D = H_U = 0$.

### 5.4 VOR Service Volumes

Service volume curves shown in figure 23 for VOR illustrate the effect of interference from another VOR on service volumes when the aircraft is located above the great-circle path between the desired and the undesired station at a distance $d_D$ from the desired station. The geometry is shown by a small diagram in the figure. Station separations S ranging from 30 to 695 nm and aircraft altitudes from 1,000 to 100,000 ft were considered. This figure is applicable to D/ U(50) = 23 dB. For example, D/ U(50) = 23 dB means that the desired signal is at least 23 dB greater than the undesired signal 50% of the time along the solid curve that forms the boundary of service volume. In these figures, the limitation imposed by ground station power output and the available power requirements (see sec. 5.1) is described only by the dashed curve

## Table 7. ILS Glide Slope $C_f$ Values in Decibels

| Desired | | Undesired | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Facility[a] | Antenna | Null Reference | | | Sideband Reference | | | Capture Effect | | |
| | | I, II | III, IV | V | I, II | III, IV | V | I, II | III, IV | V |
| Null Reference | I, II | 0.0 | -5.0 | -2.0 | 3.0 | -2.0 | 1.0 | 4.0 | -1.0 | 2.0 |
| | III, IV | 5.0 | 0.0 | 3.0 | 8.0 | 3.0 | 6.0 | 9.0 | 4.0 | 7.0 |
| | V | 2.0 | -3.0 | 0.0 | 5.0 | 0.0 | 3.0 | 6.0 | 1.0 | 4.0 |
| Sideband Reference | I, II | -3.0 | -8.0 | -5.0 | 0.0 | -5.0 | -2.0 | 1.0 | -4.0 | -1.0 |
| | III, IV | 2.0 | -3.0 | 0.0 | 5.0 | 0.0 | 3.0 | 6.0 | 1.0 | 4.0 |
| | V | -1.0 | -6.0 | -3.0 | 2.0 | -3.0 | 0.0 | 3.0 | -2.0 | 1.0 |
| Capture Effect | I, II | -4.0 | -9.0 | -6.0 | -1.0 | -6.0 | -3.0 | 0.0 | -5.0 | -2.0 |
| | III, IV | 1.0 | -4.0 | -1.0 | 4.0 | -1.0 | 2.0 | 5.0 | 0.0 | 3.0 |
| | V | -2.0 | -7.0 | -4.0 | 1.0 | -4.0 | -1.0 | 2.0 | -3.0 | 0.0 |

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[a] Values for antenna input power and antenna power gain from table 2 were used along with (2) to develop this table. For these calculations $H_D = H_U = 0$.

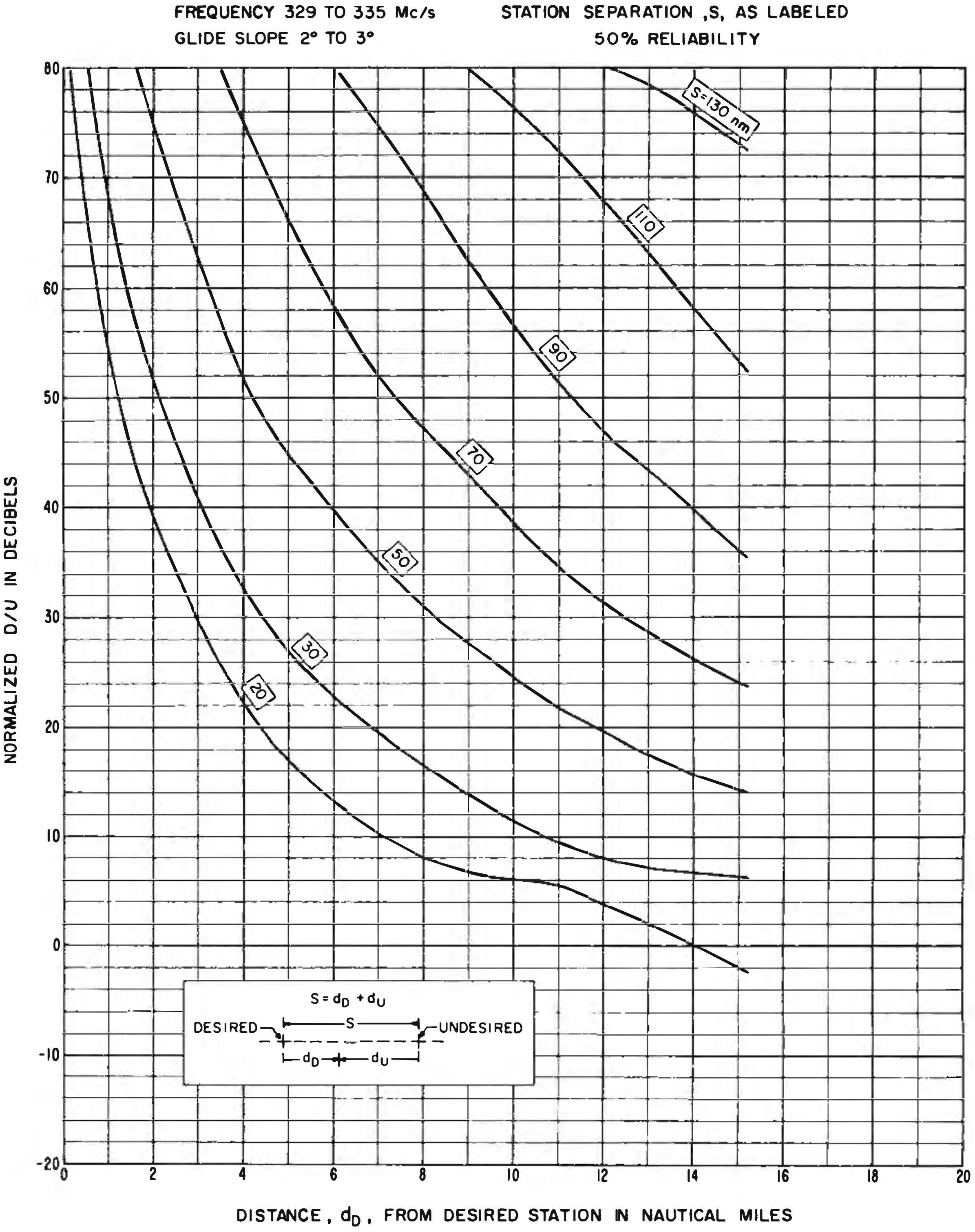

Figure 21. Glide slope signal ratios; 50%.

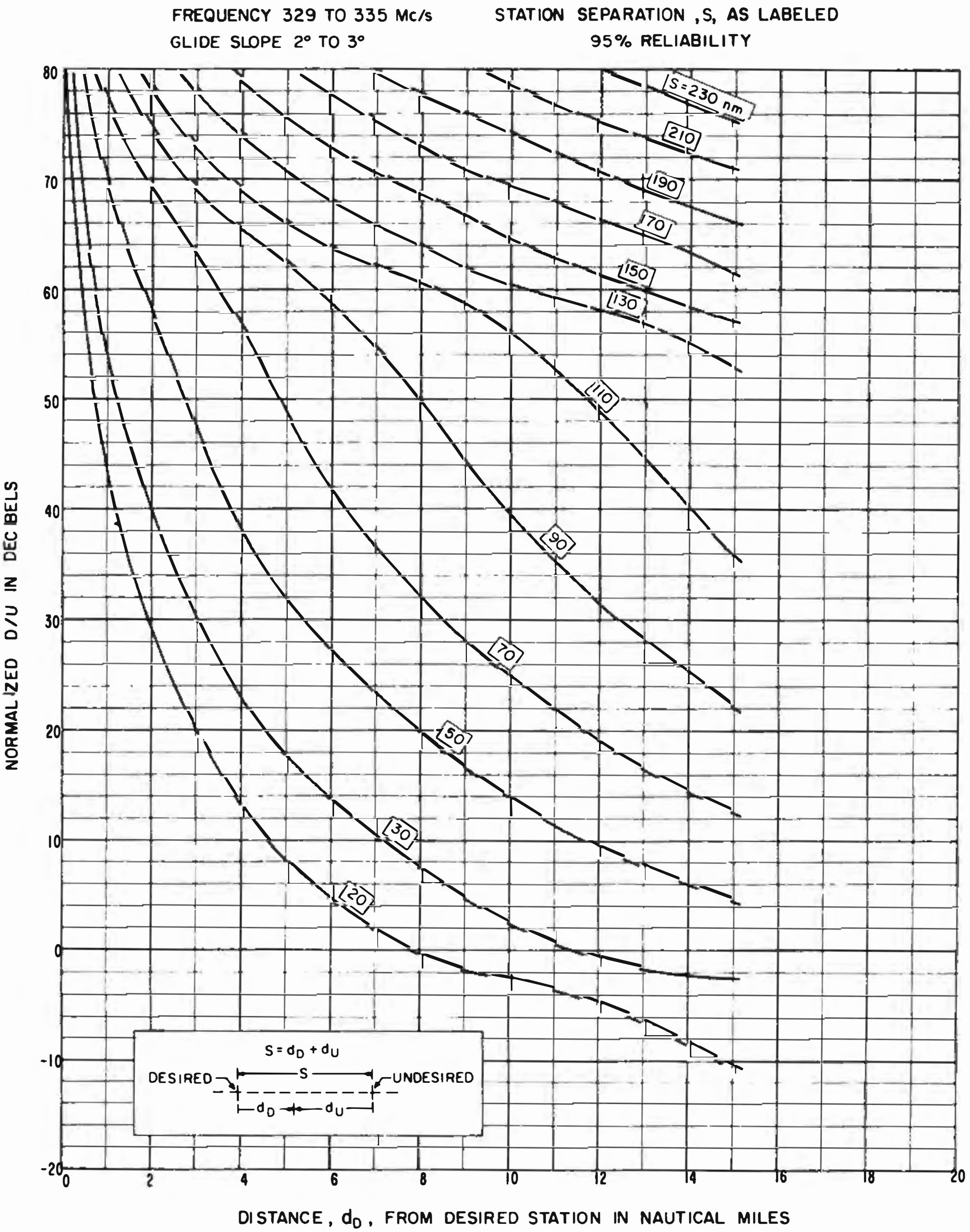

Figure 22. Glide slope signal ratios; 95%.

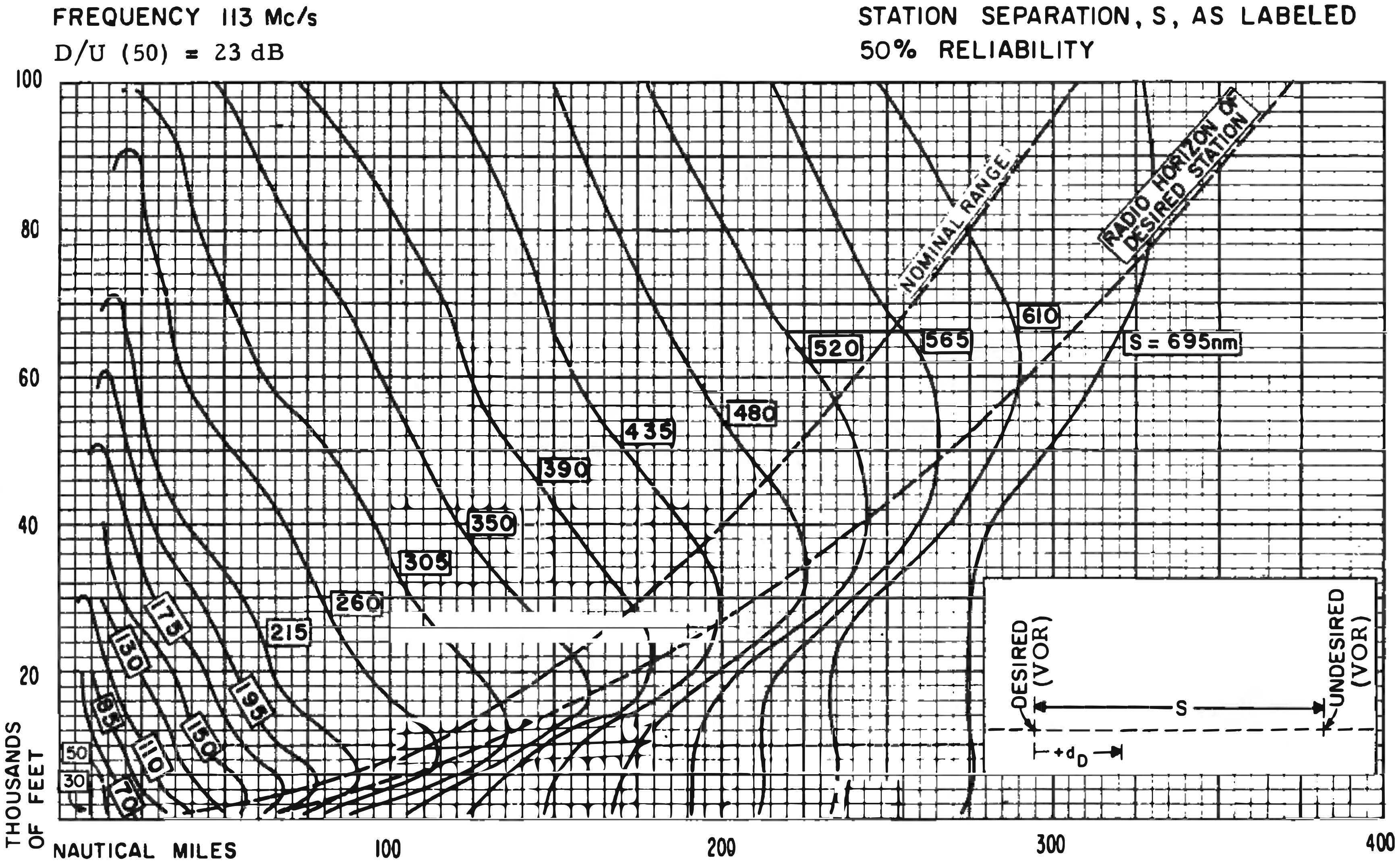

Figure 23. VOR service volumes; D/U (50) = 23 dB.

labeled "nominal range". Since this curve is also for a reliability of 50%, it differs from the without interference curve given in figure 9 for 95%.

The volume defined by rotating the appropriate curve about the ordinate axis represents a volume in which service reliability (see sec. 4) is 50% or greater since each curve represents the smallest $d_D + d_U$ value possible for particular ground station separations (see sec. 5.2). Similarly, if service is limited by interference from several VOR stations, the volume defined by rotating the most restrictive curve (the curve appropriate to the closest interfering station) about the ordinate axis represents a volume in which the service reliability is generally 50% or greater, but not always.

### 5.5 VOR Signal Ratios

Signal ratio curves applicable to interference from another VOR are given in figures 24 and 25 for reliabilities of 50% and 95%, respectively. Both figures are for an aircraft altitude of 1,000 ft.

Signal ratio curves applicable to interference from a localizer are given as normalized curves in figures 26 through 29. The method discussed in section 5.2 for converting desired D/U(p) values to $N\{D/U(p)\}$ values can be used, provided the $C_f$ values are obtained from table 6. These $C_f$ values were obtained from the equipment characteristics given in tables 1 and 3.

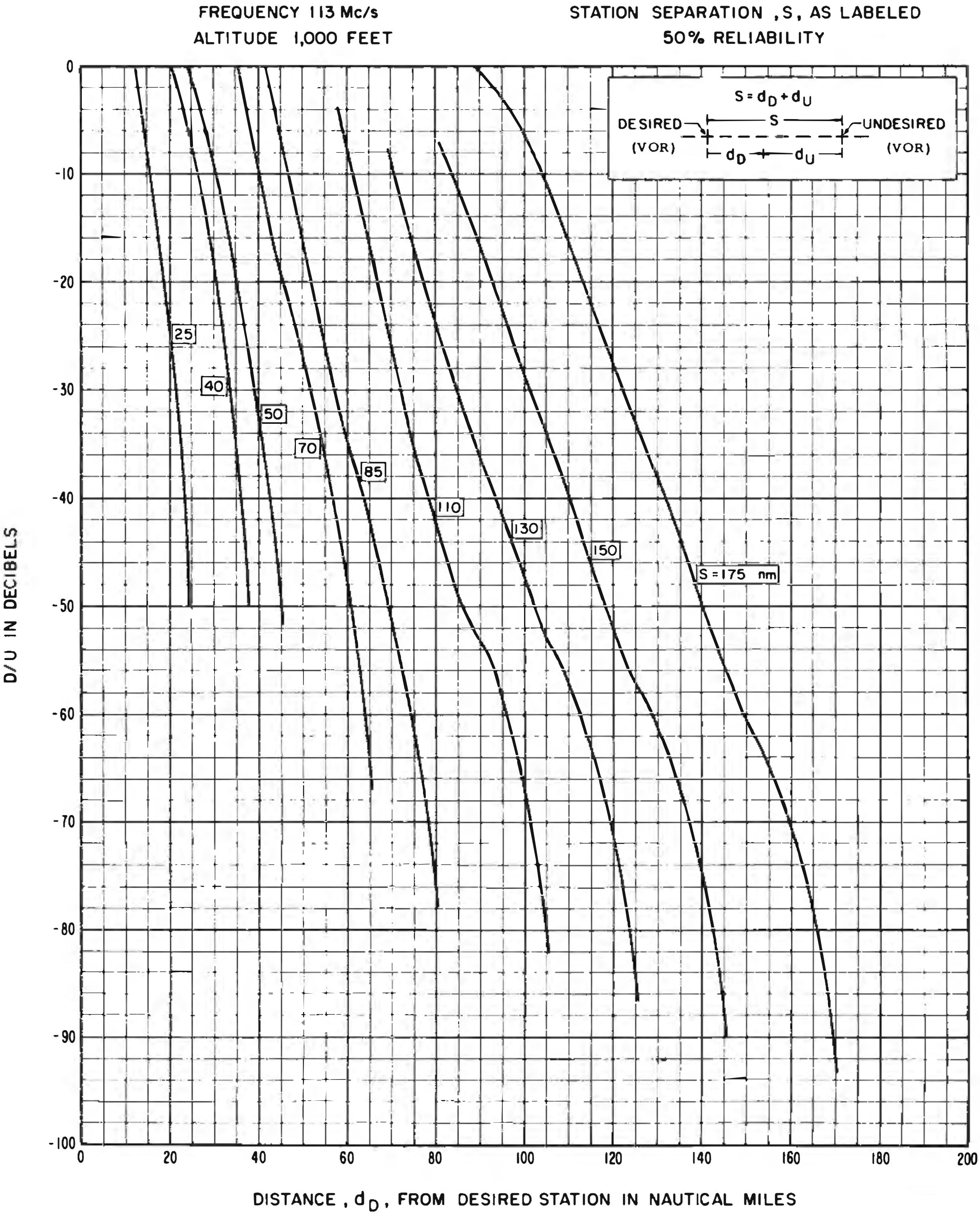

Figure 24. VOR signal ratios; 1,000 ft; VOR/VOR; 50%.

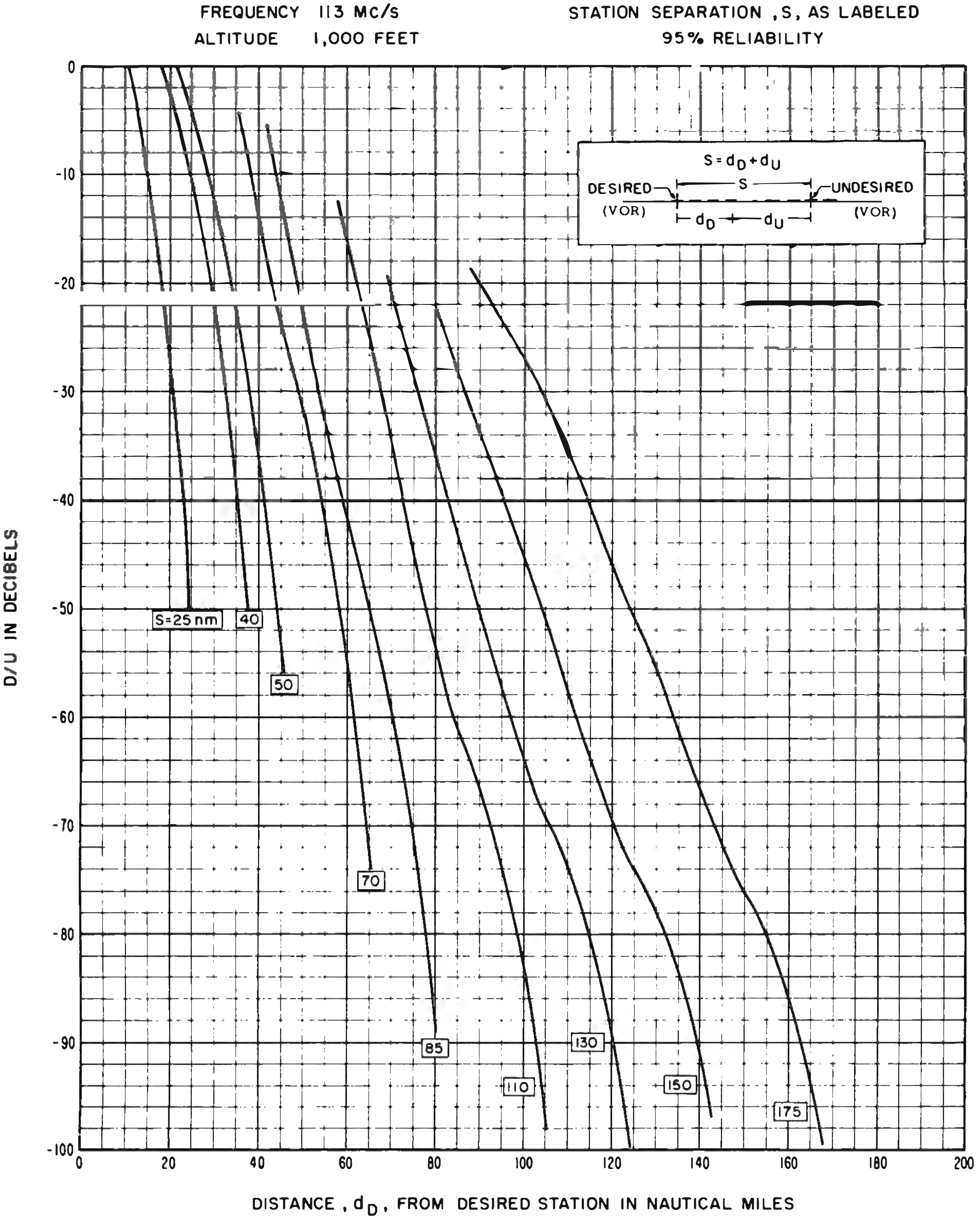

Figure 25. VOR signal ratios; 1,000 ft; VOR/VOR; 95%.

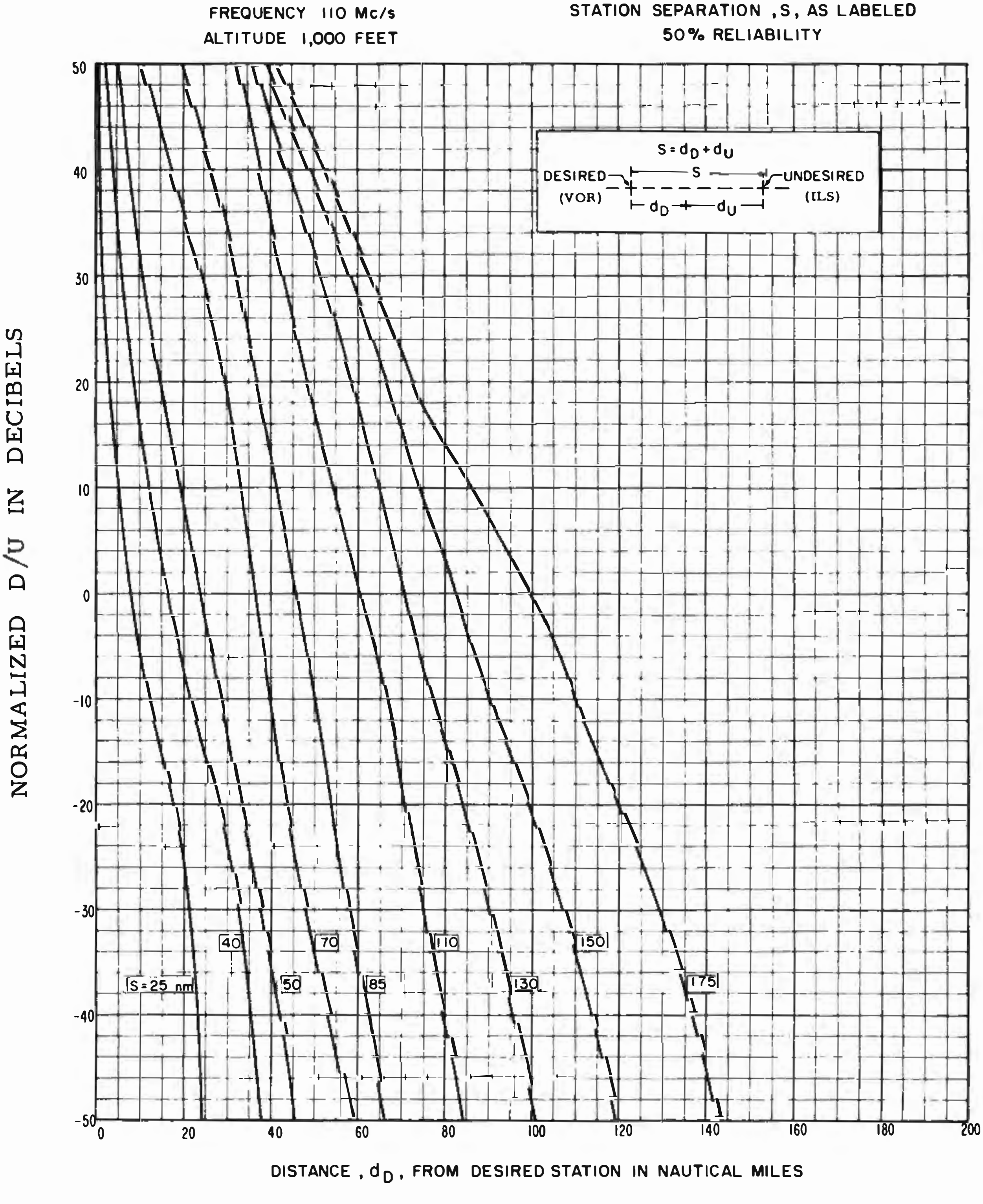

Figure 26. VOR signal ratios; 1,000 ft; VOR/ILS; 50%.

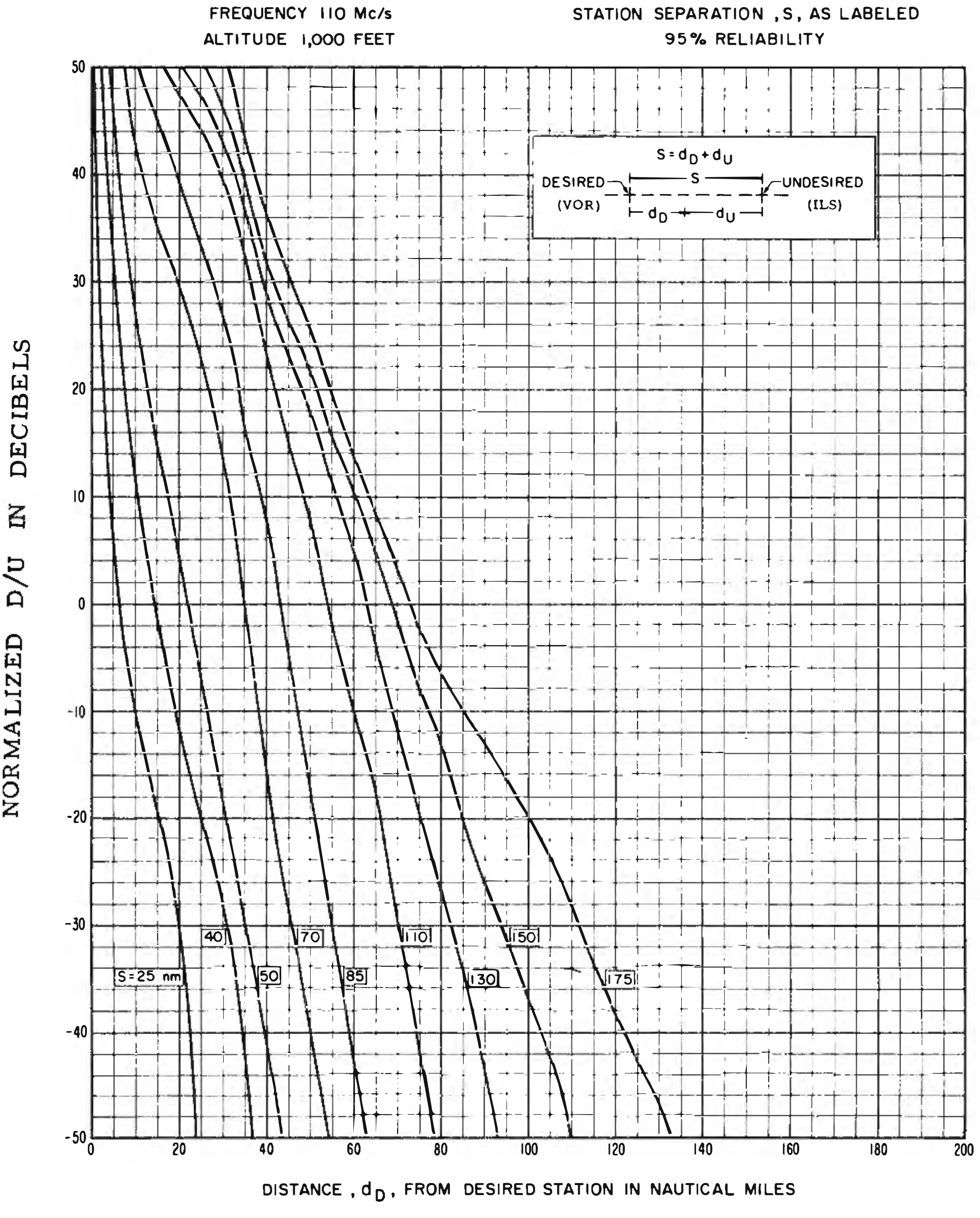

Figure 27. VOR signal ratios; 1,000 ft; VOR/ILS; 95%.

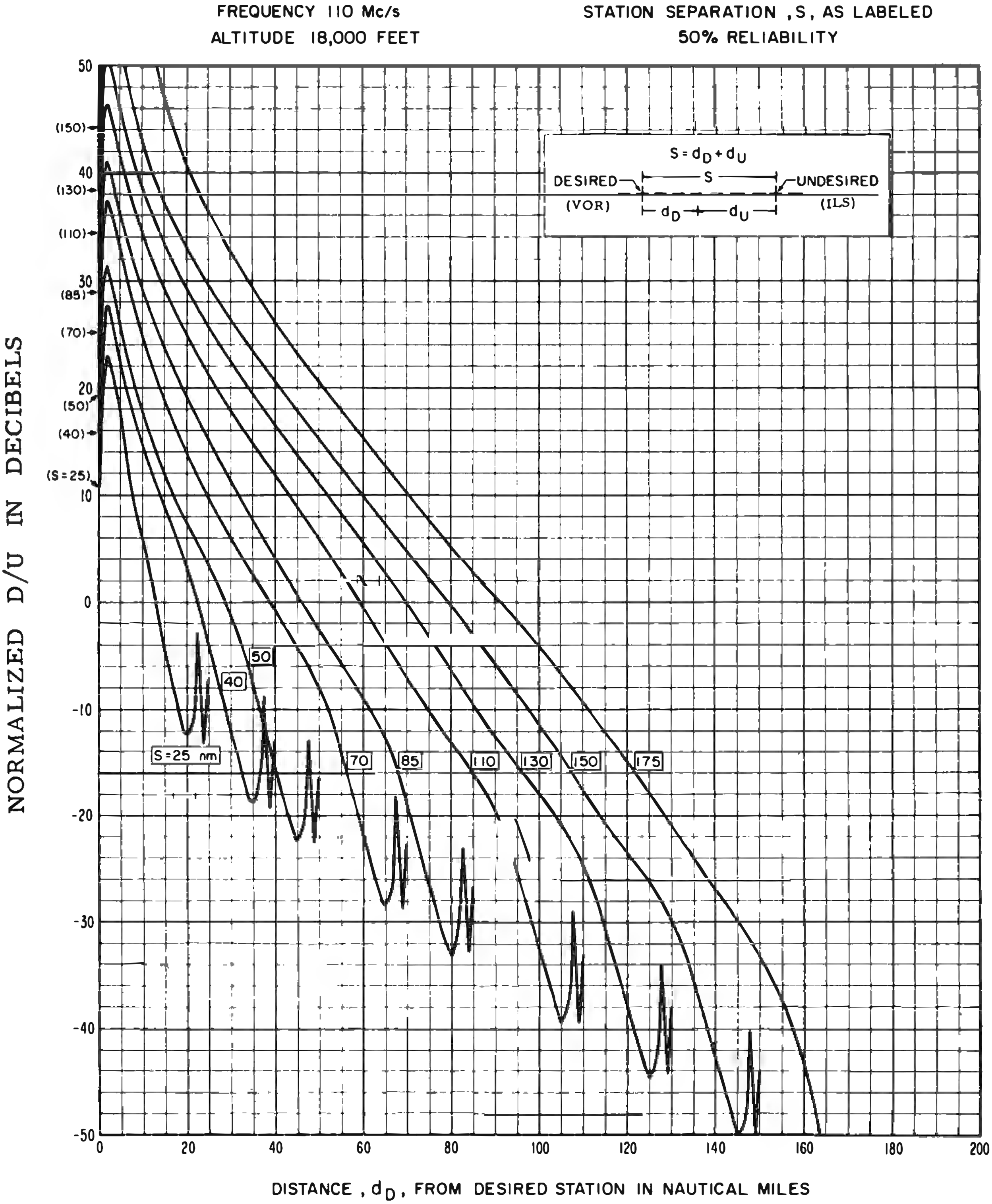

Figure 28. VOR signal ratios; 18,000 ft; VOR/ILS; 50%.

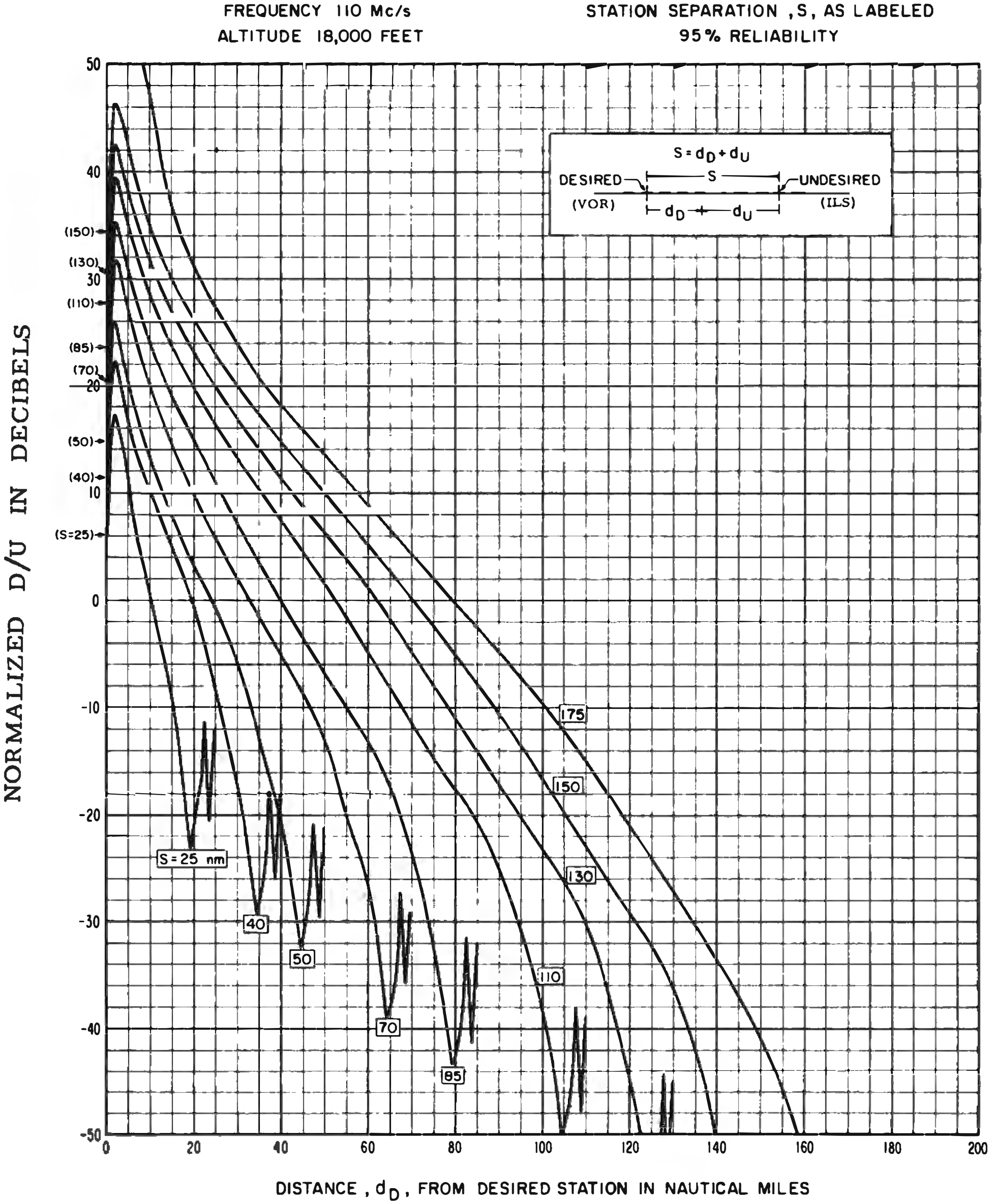

Figure 29. VOR signal ratios; 18,000 ft; VOR/ILS; 95%.

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# APPENDIX A. PROPAGATION MODELS

General characteristics of and models for propagation at VHF/UHF are discussed by Kirby et al. (1952), Kerr (1964), Rice et al. (1967), and Longley and Rice (1968). Some of these models were programmed by Johnson (1967) and used by the authors (Gierhart and Johnson, 1969) to develop an atlas of transmission loss curves for VHF/UHF/SHF propagation.

The propagation models and computation techniques used in this study are very similar to those described earlier (Gierhart and Johnson, 1967). Only those aspects of our models that differ significantly from the earlier models will be discussed here.

## A.1 Modifications for Aircraft-to-Station Proximity

We modified our earlier models (Gierhart and Johnson, 1967) for this study to obtain curves valid for aircraft-to-station proximity; e.g., for an aircraft directly over a station. This was accomplished by (a) extending the reference transmission curves to an aircraft-to-station distance of zero, and (b) including an allowance for the change in medium aircraft antenna gain associated with low aircraft-to-station elevation angles.

We extended the desired ILS localizer and VOR transmission loss curves to zero distance by (a) obtaining curves for our earlier models (Gierhart and Johnson, 1967), and (b) modifying them so that the lobing for short distances was not allowed to produce a loss greater than about 18 dB of the minimum (full antenna gain) free-space level for the particular distance considered. We extended undesired ILS localizer curves by using values obtained from our model (Gierhart and Johnson, 1967) for aircraft-to-station elevation angles greater than about $-30^{\circ}$ and using the modified curves obtained for the desired ILS localizer otherwise.

The allowance made for aircraft antenna gain characteristics for a desired VOR was based on the data mentioned in section 2.3. Since these data did not include aircraft-to-station angles less than -60°, an extrapolation to -90° was made so that at -90° the variance was only slightly greater than that of $R_A$ (fig. 4), and the median level was -10 dB.

For a desired ILS, the allowance was made by adjusting the median level of the $R_A$ distribution (fig. 4) only for aircraft-to-station angles less than -20°. For an aircraft directly over a station, the median value of $R_A$ is then -11 dB if the station is desired, 11 dB otherwise.

When an aircraft is directly above an undesired station, the modified models yield a D/U(50) about 29 dB greater than would be realized if the undesired station antenna were pointed directly at the aircraft and propagation from it characterized by free space. Empirical data for an aircraft above a VOR (Anderson and Wonnell, 1954; Anderson and Frederich, 1956; Anderson and Flint, 1960) indicate that this value is reasonable.

## A.2 ILS Glide Slope Models

Parameters for the desired and undesired glide slope facilities were selected to yield the lowest D/U(p) values (worst case) expected under current operating conditions. The desired station was assumed to have a glide slope angle of 3° and a frequency of 335 Mc/s, while 2° and 329.6 Mc/s were used for the undesired station.

The computational method used to obtain D/U(p) from transmission loss curves and aircraft antenna gain statistics is the same as that described by the authors (Gierhart and Johnson, 1967) for the ILS localizer, except that parameter values applicable to the glide slope were used. Figure 6 shows the $R_A$ distribution used in glide slope calculations; the two models used to calculate transmission loss are discussed below.

In this study we assume that the aircraft is using the desired glide slope and that its location in space is determined by the glide path and its distance from the station. Installation of a glide slope requires that the height of the primary carrier antenna above ground be such that the maximum of its first lobe (due to ground reflection) is directed along the required glide slope. Under these conditions a very simple model for desired station-to-aircraft transmission loss is approximate; e.g., simply decreasing the free-space transmission loss by 6 dB.

Transmission loss curves for the undesired station were forced to increase monotonically with increasing distance from the station (aircraft altitude fixed) by using, except for a transition region, either (a) free-space transmission loss minus 3 dB or (b) the model we described (Gierhart and Johnson, 1967) for the undesired localizer with approximate parameters. A frequency of 329.6 Mc/s and an antenna height of 21 ft above ground were used. Curves resulting from these two methods were blended together in the transition region.