NBS REPORT

7652

TRANSMISSION LOSS VARIABILITY AND FADING CHARACTERISTICS FOR LONG KNIFE-EDGE DIFFRACTION PATHS

by

Albrecht P. Barsis

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

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ABSTRACT

In this report transmission loss data in the 750-900 Mc/s range from three long knife-edge diffraction paths (in Colorado, Alaska, and Europe) are evaluated and analyzed in terms of power fading (long-term variability) and short-term variability represented by prolonged space-wave fadeouts. A comparison is made of calculated and measured cumulative distributions of hourly median transmission loss values. It appears that long-term variability over a knife-edge diffraction path can be estimated by convoluting the distributions of hourly medians for the two component line-of-sight paths, and that short-term variations represented by space-wave fadeouts are more prevalent when substantial phase interference due to ground reflections in the vicinity of the terminal is likely to exist.

1. INTRODUCTION

During the period December 1959 to January 1960, transmission loss measurements on 751 Mc/s were performed on a 223 kilometer knife-edge diffraction path in Colorado, with 4292 meter high Pikes Peak forming the diffracting knife edge. Results of these measurements were described in a paper by Barsis and Kirby [1961]. More recently, additional measurements from this path and from two other long knife-edge diffraction paths have become available for analysis. It is the purpose of this paper to compare transmission loss variability and fading characteristics, as far as derivable from the available data, for the three paths, and apply the results to the prediction of circuit performance over paths of this type.

An extensive bibliography on knife-edge diffraction phenomena was contained in the paper by Barsis and Kirby [1961]. The present work deals essentially with three paths: the Pikes Peak path already discussed, a path along the coast of Alaska across the Fairweather range (data for which were supplied by Western Electric Co.), and a knife-edge diffraction path across the Alps in Europe. Transmission loss data for the latter were obtained by ITT Federal Laboratories under contract to the U. S. Army Strategic Communications Command.

Figures 1, 2, and 3 are terrain profiles for the three paths, and Table I shows important geometric parameters for the same paths. As the terminal locations for the European path are classified, they can be identified only by code numbers.

Table I

Comparison of Path and Equipment Parameters

	Colorado	Alaska	Europe
Path Distance, km	223.3	302	404.1
Angular Distance, milliradians	64.4	62.6	55.0
Terminal Elevations Above Mean Sea Level, Meters			
Transmitter	1905 (Beulah)	16 (Yakutat)	1485 (Site 11.1)
Receiver	1666 (Table Mesa)	488 (Hoonah)	1020 (Site 46)
Antenna Height Above Ground, Meters			
Transmitter	7.3	21	7
Receiver	8.2	42	7
Height of Common Horizon Above Mean Sea Level, Meters	4292	3429	3950
Carrier Frequency, Mc/s	751	900	875
Polarization	Horizontal	Horizontal	Vertical

Table I (Continued)

	Colorado	Alaska	Europe
Antennas			
Transmitting	4.3m Dish	3m Dish	4m Dish
Receiving	3m Dish	3m Dish	4m Dish
Antenna Gain Values, db (relative to isotropic)			
Transmitting	26.7	26.5	28.5
Receiving	23.6	26.5	28.5

The angular distance values in Table I were determined using pertinent minimum monthly surface refractivity values for the areas concerned. The calculation procedure for angular distance is outlined in a recent document supplied by the United States to the CCIR Study Group V [1962]. It was also assumed that free-space antenna gains are realized over a knife-edge diffraction path.

At the Table Mesa receiving site a corner reflector antenna mounted on a telescopic tower was used in addition to the 3-m dish. Experiments using this antenna at various heights will be discussed in more detail below; its free-space gain is 14.6 db relative to an isotropic radiator.

In the succeeding sections of this report the following studies will be discussed:

(a) Comparison of the Colorado data taken in August 1962 with previous results.

(b) Comparison of the variability of hourly median transmission loss data for all three paths.

(c) Comparison of fading characteristics for the Alaska and the Colorado path. Equivalent data for the European path are not available.

In addition to the evaluation of measurement results, a comparison of calculated and measured transmission loss values will also be made. Transmission loss calculations were performed in accordance with the procedures given by the U.S.-CCIR Document referred to [1962].

2. COMPARISON OF THE 1960 AND 1962 COLORADO DATA

2.1 Hourly Median Distributions and Correlation

In order to establish the continuity of the Colorado measurements, the Pikes Peak knife-edge diffraction path was operated during the week of August 27-31, 1962, with the antennas arranged in the same way as during the June 6-17, 1960, measurement period. Thus the 751 Mc/s carrier transmitted from Beulah was received simultaneously on the 3-m dish at 8.2 m above ground and on the corner reflector at 22.3 m above ground. Cumulative distributions of hourly median basic transmission loss for both antennas and for both periods are shown in Fig. 4. The distributions for the dish differ by several decibels; this variation is probably due to a change in the circuit parameter assumptions and recalibration of the signal generator used, since the expected month-to-month and year-to-year variability of transmission loss might be expected to account only for 2 db or less.

Cross-correlation coefficients of hourly transmission loss medians for the two periods are compared in Fig. 5. The correlation coefficient between hourly transmission loss medians resulting from the two verti- [illegible] antennas is 0.65 for the August 1962 period versus 0.72 for the June 1960 period. These two results are not significantly different.

2.2 Height Dependence of Transmission Loss

A height-gain run at the Table Mesa receiving site was originally made on March 25, 1960, using the corner reflector antenna on the telescopic tower. Results of this experiment were discussed in the previous paper [Barsis and Kirby, 1961], and it was pointed out that [illegible] height dependence bears no resemblance to calculated curves using four-ray optics and diffraction over the knife-edge. A new height-gain run was made on October 16, 1962, in the same manner as the previous one. This run confirmed earlier results, as shown in

Fig. 6. The shape of the height gain curve is almost identical to the one obtained previously; the overall shift in the transmission loss level is again within the range of expected month-to-month or year-to-year variations. A satisfactory geometric-optics model based on the terrain profile still has not been found which would explain the shape of this height dependence curve.

3. VARIABILITY OF HOURLY MEDIANS OF TRANSMISSION LOSS

In the analysis of tropospheric propagation data and in the application of such data to performance predictions for communication systems it has been found convenient to distinguish between long-term and short-term variations in transmission loss or field strength. The time interval of one hour has been chosen more or less arbitrarily as the dividing line between long-term and short-term variations. Short-term variations within the hour, more recently termed "phase-interference fading," are taken into account in the specification of required predetection signal-to-noise ratios for any specific application. Long-term variations, or "power fading," are defined in terms of variations of hourly median values of transmission loss.

It has already been explained in the previous paper [Barsis and Kirby, 1961] that for the purpose of studying power fading over knife-edge diffraction paths, any such path can be considered to consist of two within-the-horizon paths in tandem. The diffracting knife-edge is of course the common horizon and constitutes a common terminal for both paths. The variability of hourly median transmission loss for each of the two within-the-horizon paths may be characterized by functions $V_1(p)$ and $V_2(p)$, which are the decibel differences between a reference level and the medians exceeded during p% of all hours. For any particular hour, the variation $V(p)$ on the diffraction path would be expected to be the sum $V_1(p) + V_2(p)$, with all V's expressed in decibels. The cumulative distribution of all $V(p)$ values for the entire path may then be determined by a convolution process involving the individual cumulative distributions of $V_1(p)$ and $V_2(p)$ [Davenport and Root, 1958].

For the calculation of basic transmission loss hourly medians and their variability the methods given by CCIR [1962] previously referred to were used. For each of the three paths considered, the reference value L_{bd} of basic transmission loss was computed first. This was done on the basis of a single diffracting knife-edge without taking possible reflections from terrain into consideration. Next, the variability of hourly medians for the individual path segments was determined. These were appropriately combined as outlined above; for the convolution of the cumulative distributions an electronic computer was used. The total time variability of hourly basic transmission loss medians is then determined by

$$L_b(p) = L_{bd} - V(p) \tag{1}$$

for each path, where $L_b(p)$ is the hourly median basic transmission loss not exceeded during p percent of all hours of the year, L_{bd} is the calculated reference value, and $V(p)$ is the time variability function obtained by convoluting the time variability functions $V_1(p)$ and $V_2(p)$ for each of the two segments for each path.

In accordance with the service probability concept outlined by Barsis, Norton, and Rice [1962], 90% confidence limits were also determined for each resulting distribution; these reflect the uncertainty in predicting transmission loss.

Figure 7 shows the calculated distributions of hourly median transmission loss values for the three paths together with their 90% confidence limits. The distribution of the measured hourly medians is also shown. On each graph the solid curve is the calculated expected distribution corresponding to a service probability $q(\lambda) = 0.5$. The dash-dotted curves are for service probability values of $q(\lambda) = 0.05$ and 0.95, respectively, thus they include the 90% confidence band. The heavy dashed lines are the measured distributions.

It is quite evident that there is little agreement between absolute levels of calculated and measured basic transmission loss.* However, if ranges of transmission loss medians are defined as the decibel differences between values exceeded during 10% and 90%, or during 1%

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* The term "measured basic transmission loss" is here interpreted as a conversion of measured transmission loss values to basic transmission loss under the assumptions that antenna circuit losses are negligible and free-space antenna gains are realized.

and 99% of all hours, the calculated and the expected range values are in much better agreement. The discrepancy in the absolute levels may be ascribed to the already mentioned fact that for the purpose of this study possible reflections from the terrain in the vicinity of the terminals have not been taken into account in the calculation of the expected transmission loss distributions. Barsis and Kirby [1961] have already discussed the effects of the assumption of a "rounded" knife-edge as the diffracting obstacle.

In Table II below, overall medians and ranges of hourly medians are listed for both the calculated and the measured distributions shown on Fig. 7.

Table II

Comparison of Calculated and Measured Basic Transmission Loss Values

	Basic Transmission Loss, Decibels		
	Pikes Peak 751 Mc/s 223.3 km	Alaska 900 Mc/s 302 km	Europe 875 Mc/s 404.1 km
Overall Median of Distributions			
Calculated $L_{bc}(50)$	178.3	184.7	185.7
Measured $L_{bm}(50)$	197.7	202.8	202.2
Difference $L_{bc}(50) - L_{bm}(50)$	-19.4	-18.1	-16.5
10 - 90% Range of Distributions			
Calculated $\Delta_c(10) = L_{bc}(90) - L_{bc}(10)$	10.2	7.7	9.8
Measured $\Delta_m(10) = L_{bm}(90) - L_{bm}(10)$	7.5	11.2	9.1
Difference $\Delta_c(10) - \Delta_m(10)$	2.7	- 3.5	0.7

Table II (Continued)

	Basic Transmission Loss, Decibels		
	Pikes Peak 751 Mc/s 223.3 km	Alaska 900 Mc/s 302 km	Europe 875 Mc/s 404.1 km
1 - 99% Range of Distributions			
Calculated $\Delta_c(1) = L_{bc}(99) - L_{bc}(1)$	19.9	13.8	21.0
Measured $\Delta_m(1) = L_{bm}(99) - L_{bm}(1)$	12.9	20.7	16.5*
Difference $\Delta_c(1) - \Delta_m(1)$	7.0	- 6.9	4.5

* Extrapolated.

The overall median data indicate a long-term hourly median basic transmission loss value between 16 and 20 db greater than calculated for knife-edge diffraction paths of the type discussed here. Thus it appears that on the average a 18 db allowance for the effects of foreground terrain, rounding of the knife-edge, and finite dimension of the knife-edge could be made when estimating long-term median values for such paths. This estimate is based on a rather limited sample of data; additional studies are in progress now.

In order to illustrate the behavior of the range of hourly medians, the measured distributions of Fig. 7 have been replotted on Fig. 8 together with the 90% confidence bands of Fig. 7, but with the overall median of each measured distribution made to coincide with the applicable calculated overall median. In this way the measured distribution is shown to lie well within the 90% confidence limits, and the agreement of the range of hourly medians with estimates is quite good. Note that these confidence bands would even be wider if the finite length of the measurement period had been taken into account [Barsis, et al., 1962]. Thus it appears that the convolution process referred to above may be used to estimate long-term ranges of power fading for knife-edge diffraction paths, although agreement of the long-term median level between calculated and measured values is lacking.

4. FADEOUT CHARACTERISTICS FOR THE COLORADO AND ALASKA PATHS

The original recording charts for the European path were not available for detailed analysis; thus short-term fading characteristics could only be compared between the Colorado and the Alaska paths. Short-term variability is evaluated in terms of space-wave fadeouts, similar to the procedure used on within-the-horizon paths [Bean, 1954; Barsis and Johnson, 1962]. A space-wave fadeout is defined here as a drop in signal level to 5, 10, 15, ... db below a specified long-term median value, if it lasts for at least one minute. The requirement of the one-minute minimum duration is chiefly due to the chart speed used for the Alaska data, where shorter fadeouts could not be measured accurately. One may also consider a fadeout essentially to represent slow signal variations; thus a distinction is made between fadeouts and the more rapid fading observed on tropospheric scatter paths. As a space-wave fadeout can conceivably last longer than one hour, it constitutes a short-term variability definition which is different from the more general approach described in Section 3 above; the effect of long fadeouts is also reflected in the variability of hourly medians.

The long-term reference levels for the Colorado data are the overall medians for each five-day measurement period during the summer months of 1960 (May - October), which vary over a 4-5 db range. For the Alaska data, the overall median for the entire two-week measurement period in June, 1958, served as a reference level. Only summer data from the Colorado path were compared with the Alaska data; complete fadeout data for the Colorado path were given in the earlier paper by Barsis and Johnson [1962].

A comparison of the fadeout characteristics for the two paths is shown in Table III below. The total number of hours, the total number of observed fadeouts at all levels, the number of fadeouts normalized to 100 hours, and the fadeout duration in percent of the total recording time are compared in this table. It should be kept in mind that the occurrence of fadeouts is not evenly distributed throughout the day. Previous studies for the Colorado path [Barsis and Johnson, 1962] have shown diurnal trends for the fadeout incidence; as an example, 5 db fadeouts are most prevalent in the morning hours (0600 to 1300 local time). Days without any fadeouts at all have also been observed. Table III, however, does not include a breakdown of the data into time blocks for the study of diurnal trends. It only serves to show a substantial greater fadeout incidence for the Alaska path on the basis of the normalized figures and presents a comparison of the total fadeout time.

Table III

Comparison of Fadeout Incidence for Colorado and Alaska Paths, Summer Data

	Colorado		Alaska
	3-m Dish	Corner Reflector	
Total Number of Hours of Data	613	624	158
Number of Fadeouts Observed at Indicated Levels			
5 db	376	490	206
10 db	36	56	129
15 db	12	7	65
20 db	0	0	19
Number of Fadeouts at Indicated Levels Normalized to 100 Hours			
5 db	61	78	130
10 db	6	9	82
15 db	2	1	41
20 db	0	0	12
Percentage of Total Time Signal Remains Below Indicated Levels for at Least One Minute			
5 db	3.32	4.19	27.0
10 db	0.31	0.31	8.54
15 db	0.061	0.026	1.83
20 db	-	-	0.39

It is seen that the normalized fadeout incidence and percent fadeout time are both substantially greater for the Alaska path. This will be discussed further later on. It is also of interest to note that no 20 db fadeouts at all appeared on the Colorado path, and that there were much fewer 10 and 15 db fadeouts in relation to the number of 5 db fadeouts on this path than on the Alaska path. The possibility of different mechanisms being responsible for 5 db fadeouts and deeper fadeouts, respectively, has been mentioned in the earlier paper by Barsis and Kirby [1961].

Fig. 9 shows plots of cumulative distributions of the fadeout durations for the two paths. The curves shown here have a slightly different appearance from equivalent curves shown in earlier reports, due to a different analysis method. The distributions shown here are also based on those fadeouts which are longer than one minute at that level by which the curves are identified; thus all fadeouts (100%) are at least one minute long, and the curves extend asymptotically along the abscissa axis toward the 100% point, which is at infinity for the type of graph paper used. Many additional fadeouts shorter than one minute at the 10, 15, or 20 db level actually exist which exceed one minute's duration at the 5 db level. Those are not included here due to the limitation on the definition of a fadeout discussed above.

Fadeout duration distribution graphs have the duration as the ordinate and the percent of fadeouts as the abscissa; the curves are labelled with the total number of fadeouts at the level considered. For the Alaska path, as an example, 10% of the 129 10 db fadeouts observed are at least 17.5 minutes long, and 10% of the 65 15 db fadeouts observed are at least 7.2 minutes long.

An alternate method for presenting fadeout statistics has been demonstrated in the paper by Barsis and Kirby [1961]. Analysis of the data now being collected over the Pikes Peak path in accordance with this method will be contained in later reports.

Table IV, below, shows pertinent values taken from the graphs of Fig. 9. The Colorado data include those measurement periods during which the corner reflector was at 22.3 m above ground (June 6-17, 1960).

Table IV

Comparison of Fadeout Durations for Colorado and Alaska Paths, Summer Months

	Fadeout Duration in Minutes at Indicated Levels			
	5 db	10 db	15 db	20 db
Colorado Path				
Corner Reflector:				
Duration exceeded by 10% or all fadeouts	6.8	3.8	2.0	-
Duration exceeded by 50% of all fadeouts	2.0	1.5	1.2	-
3-meter Dish:				
Duration exceeded by 10% of all fadeouts	6.0	5.2	2.5	-
Duration exceeded by 50% of all fadeouts	1.9	1.8	1.7	-
Alaska Path				
10% of all Fadeouts	27.0	17.5	7.2	4.6
Median Fadeout	4.7	3.8	2.6	2.2

As demonstrated by Table III, Fig. 9 and Table IV confirm that the Alaska fadeouts are deeper and longer than those observed on the Colorado path besides being relatively more frequent. It is quite likely that the Alaska fadeouts are at least partially caused by phase interference phenomena. Although height gain data for the Alaska path are not available, a study of the terrain profile (Fig. 2) shows a strong potential for ground (or water surface) reflections from the foreground of the Yakutat terminal. The entire path between Yakutat and the diffracting mountain obstacle extends over low, flat coastal areas, or over water. Assuming a 0.95 effective reflection coefficient from such a surface, a height gain curve for the Yakutat terminal has been calculated and is shown in Fig. 10. The actual antenna height used for the measurements falls into a "null" of the calculated height-gain pattern; thus relatively small changes in the surface refractivity may cause noticeable changes in the transmission loss, which are reflected in the observed fadeouts. It is also of interest that the overall median of measured basic transmission loss values agrees quite well with the value determined from the height gain calculations. This overall median is also shown on Fig. 10, together with the values exceeded during 1 and 99% of all hours.

It has already been pointed out that no substantial height gain variations were observed on the Colorado path; therefore the fadeouts observed there can only to a very small extent be due to phase interference phenomena.

For the Alaska measurements, surface values of temperature, pressure, and humidity are available, which were taken at both terminals three or four times per day. From these data, the surface refractivity N_o (referred to sea level) was calculated, and an attempt was made to correlate the fadeout statistics with these refractivity values. No really significant dependence was found to exist; the only trend suggested by the studies showed that fadeouts may be more likely to occur when the surface refractivity at the path terminals differs by more than 10 N-units. This is demonstrated in Table V below, where the analysis is made in terms of two-hour periods characterized by the difference in N_o values at the terminals, and by the occurrence or absence of 5 and 10 db fadeouts.

Table V

Fadeout Dependence on Differences in the Surface Refractivity, N_s, Measured at the Terminals

5 db Fadeouts	Total Number of Two-Hour Periods	Number of Periods With Fadeouts		Number of Periods Without Fadeouts	
Difference in N_o	Investigated	5 db	10 db	5 db	10 db
< 10	21	9	7	12	14
> 10	9	8	8	1	1

It may be significant that fadeouts appear for eight out of nine periods characterized by a difference in N-units greater than 10.

B. R. Bean* suggested that fadeout occurrence may depend on the difference of surface refractivity values between readings taken at midday and midnight (indicative of duct formation). No such dependence was found using the available data. It was observed, however, that the surface refractivity at the Yakutat terminal increased between noon and midnight during 5 out of 7 days for which data were available, while a corresponding decrease was noted at the Hoonah terminal during 4 of these days (no data available for the other days).

5. CONCLUSIONS

The comparison of transmission loss measurements over three knife-edge diffraction paths, all relatively long and widely separated in geographical location, showed the following results:

(a) The overall measured transmission loss medians are 16-20 db greater than the values calculated on the basis of the Fresnel-Kirchhoff diffraction theory, neglecting the effects of the terrain near the terminals.

(b) The range of power fading on a knife-edge diffraction path can be estimated by convoluting the distributions of hourly medians for the two individual line-of-sight paths which make up the total path.

(c) Prolonged space-wave fadeouts have been found to be more severe on a knife-edge diffraction path (the Alaska path) where substantial phase-interference due to ground reflections in the vicinity of the terminals is likely to exist. However, space-wave fadeouts also exist on the Colorado path where no pronounced transmission loss variations are observed as a function of antenna height.

The results of this study also suggest re-evaluation of the criteria used to determine the effects of the terrain between the antenna and its horizon where the terrain is too rough to permit its approximation by

* Private communication.

a single reflecting surface. The criteria outlined in the U. S. -CCIR Document referred to [1962] do not seem to be applicable in the case of the three paths discussed here.

6. ACKNOWLEDGEMENTS

Personnel of the Spectrum Utilization Research Section, Troposphere and Space Telecommunications Division, National Bureau of Standards, Boulder, Colorado, participated in the collection, analysis, and evaluation of the Colorado data, and in the analysis and evaluation of the Alaska data. The cooperation of Western Electric Company in supplying data and related information for the Alaska path is gratefully acknowledged. The data for the European path were obtained by ITT Federal Laboratories, and supplied by the U. S. Army Strategic Communications Command. The author is indebted to R. S. Kirby and B. R. Bean for their review and suggestions.

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TERRAIN PROFILE FOR COLORADO KNIFE-EDGE DIFFRACTION PATH

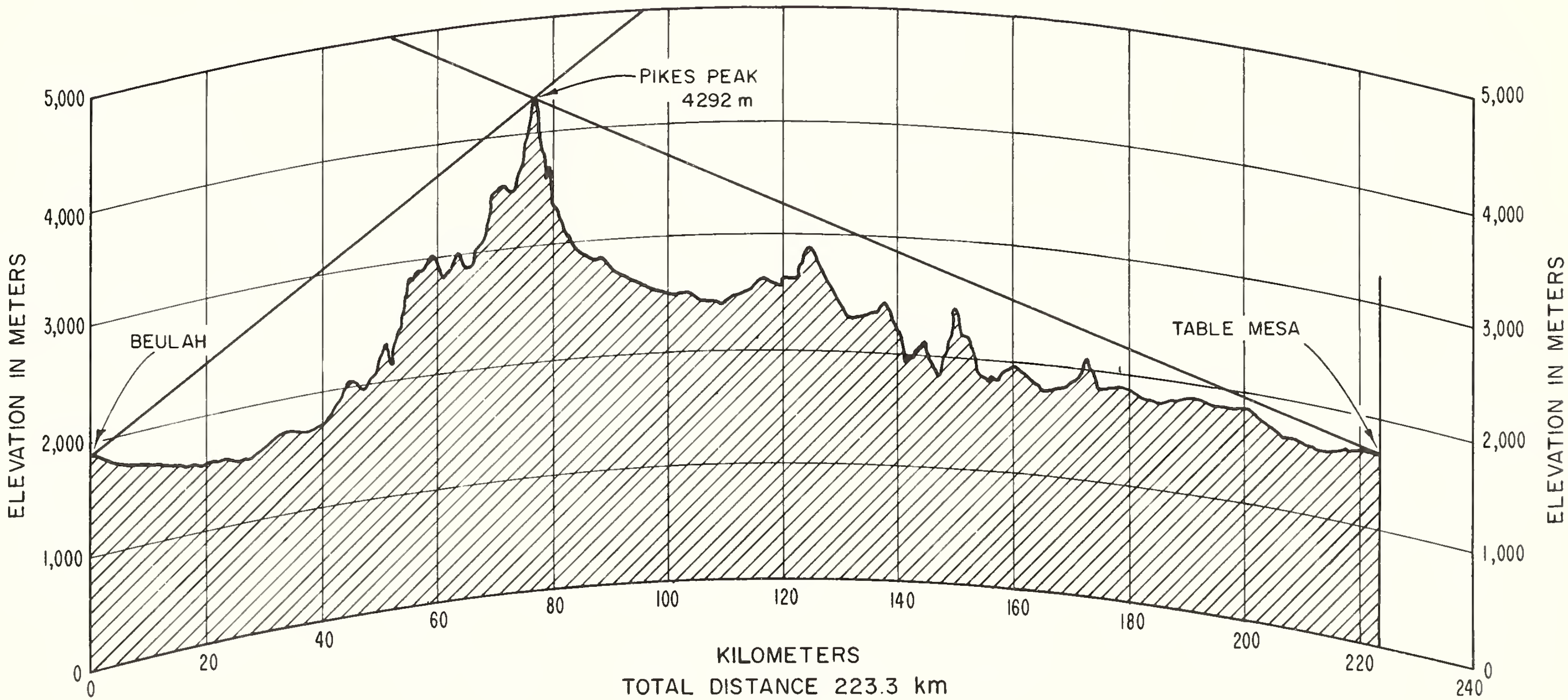


FIGURE 1

B- 37879

TERRAIN PROFILE FOR ALASKA KNIFE-EDGE DIFFRACTION PATH

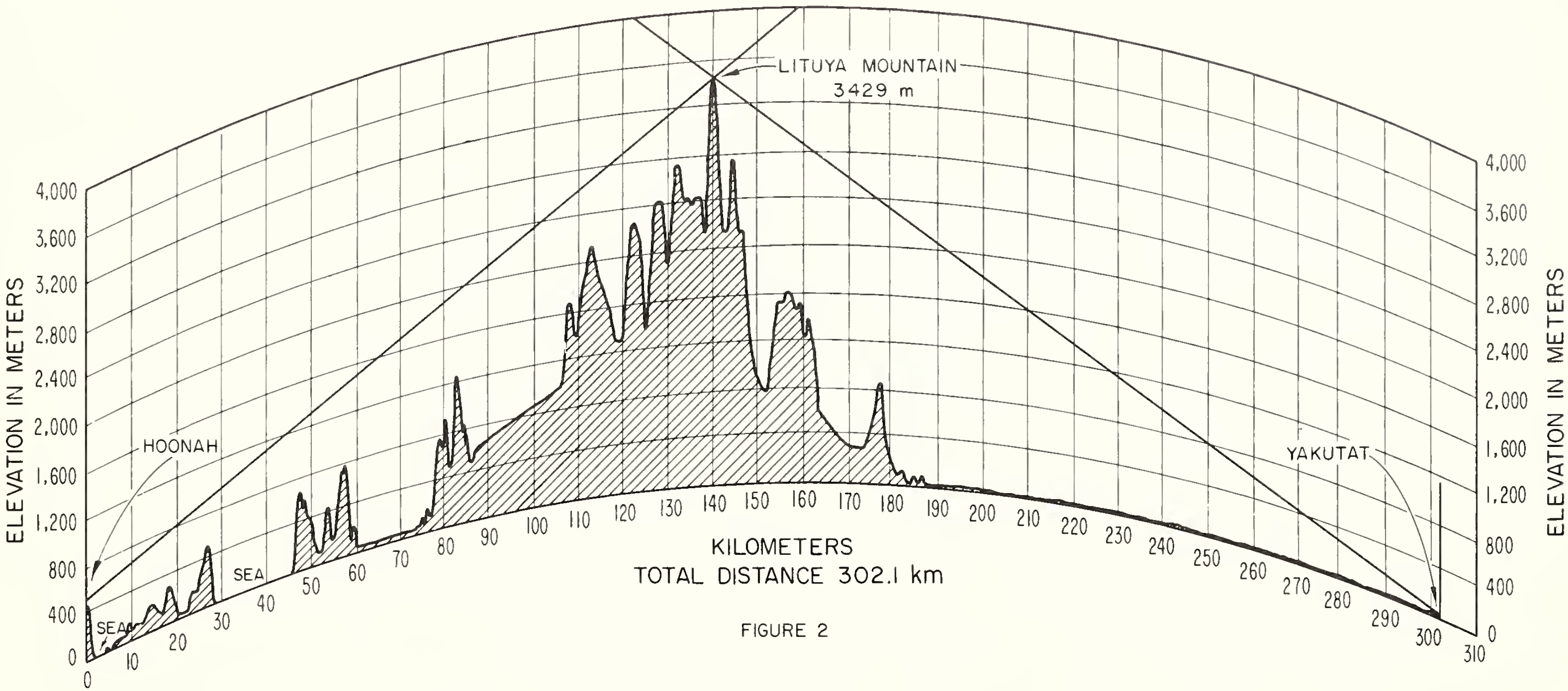


FIGURE 2

B- 37881

TERRAIN PROFILE FOR EUROPEAN KNIFE-EDGE DIFFRACTION PATH

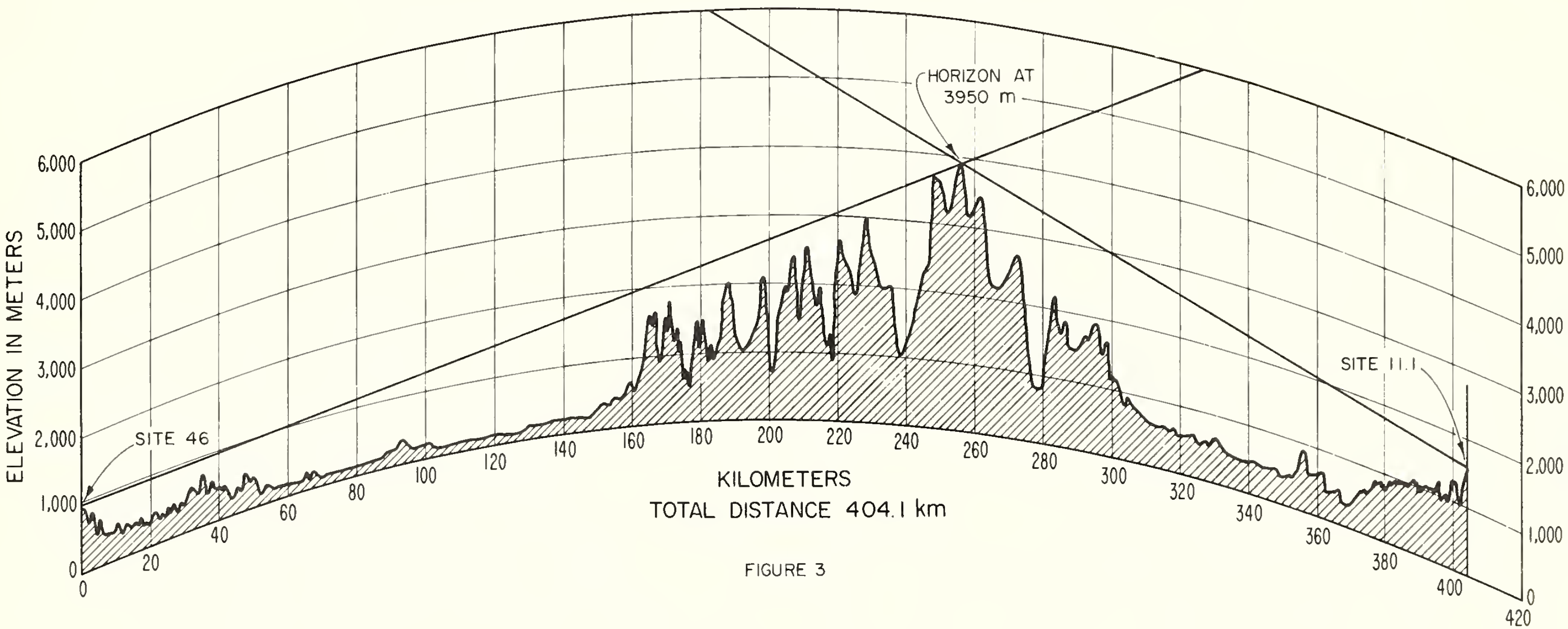


FIGURE 3

B-37882

COMPARISON OF HOURLY MEDIAN TRANSMISSION LOSS DISTRIBUTIONS
COLORADO KNIFE-EDGE DIFFRACTION PATH, 751 Mc/s

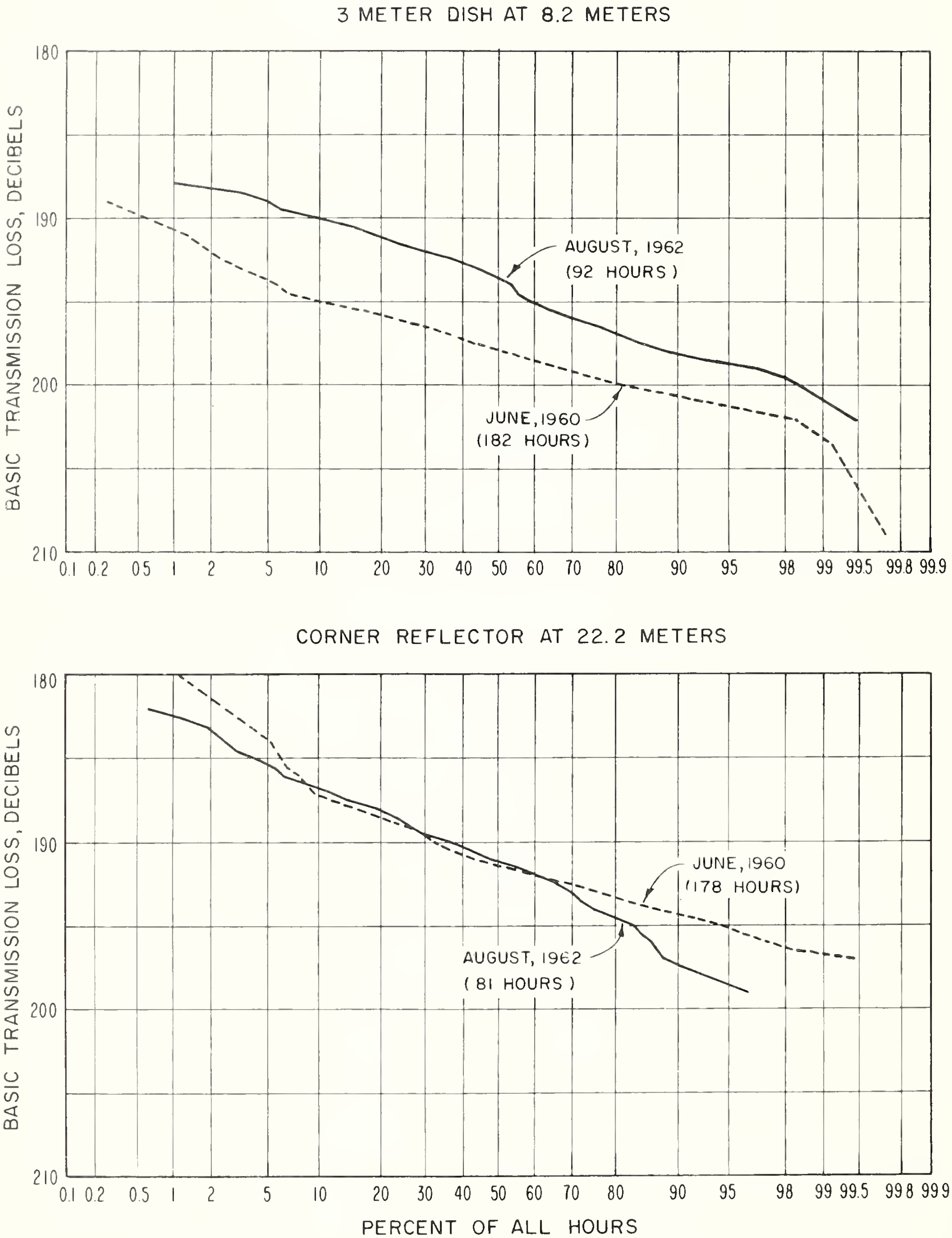


FIGURE 4

B-37874

CORRELATION OF HOURLY MEDIANS FOR ANTENNAS SPACED VERTICALLY BY 14.1 m

COLORADO KNIFE-EDGE DIFFRACTION PATH, 751 Mc/s

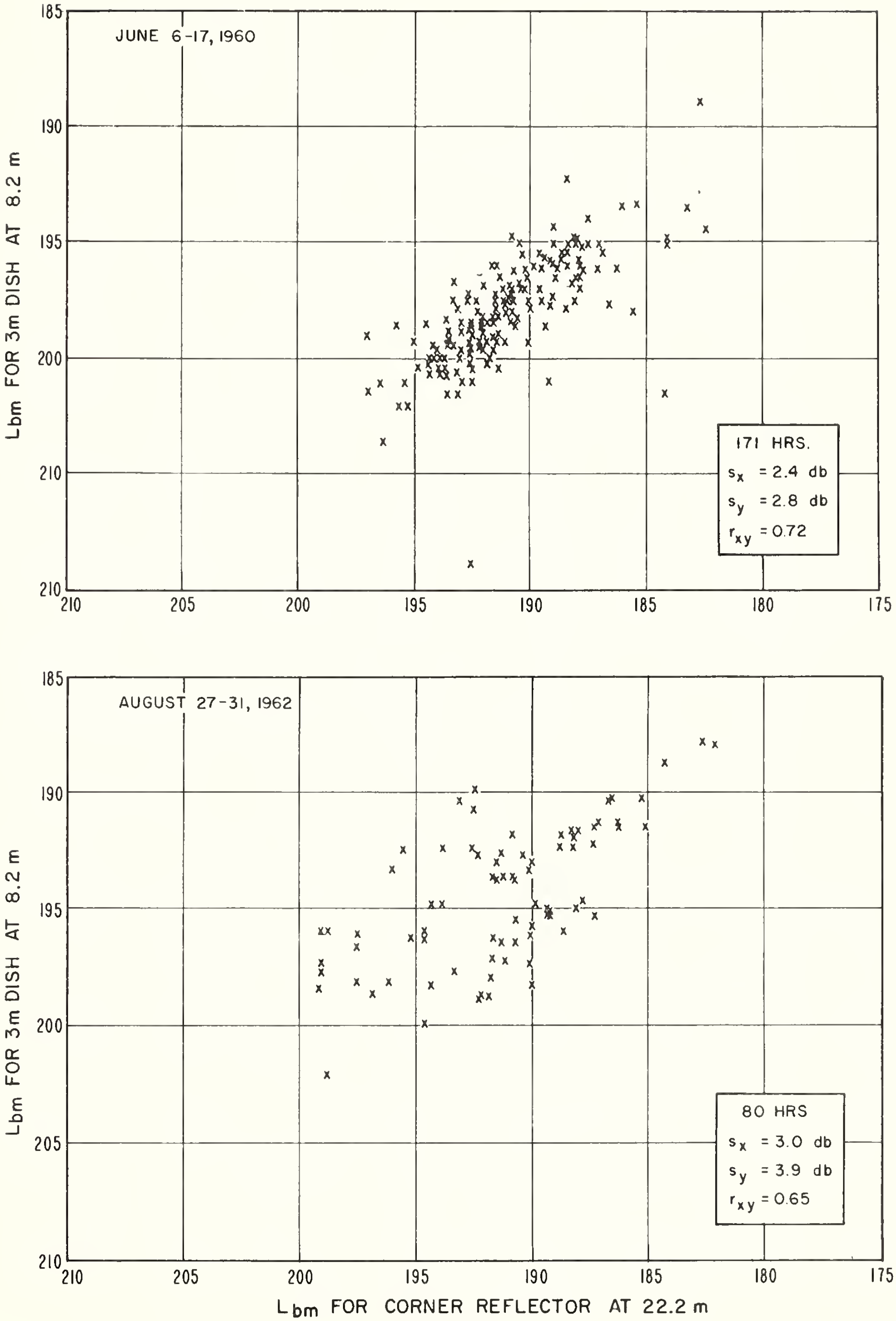


FIGURE 5

MEASURED HEIGHT GAIN FOR COLORADO KNIFE-EDGE DIFFRACTION PATH, 751 Mc/s

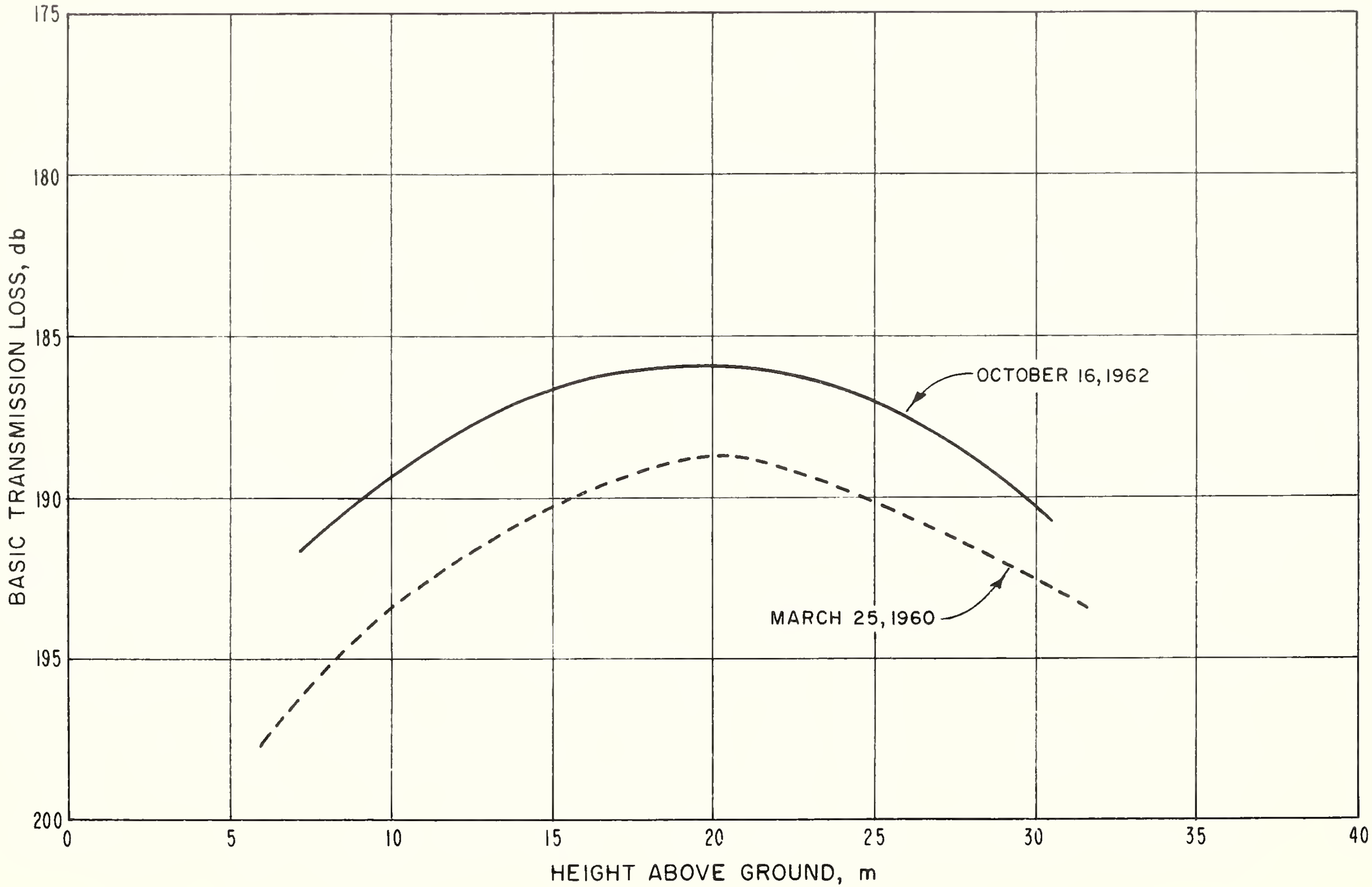
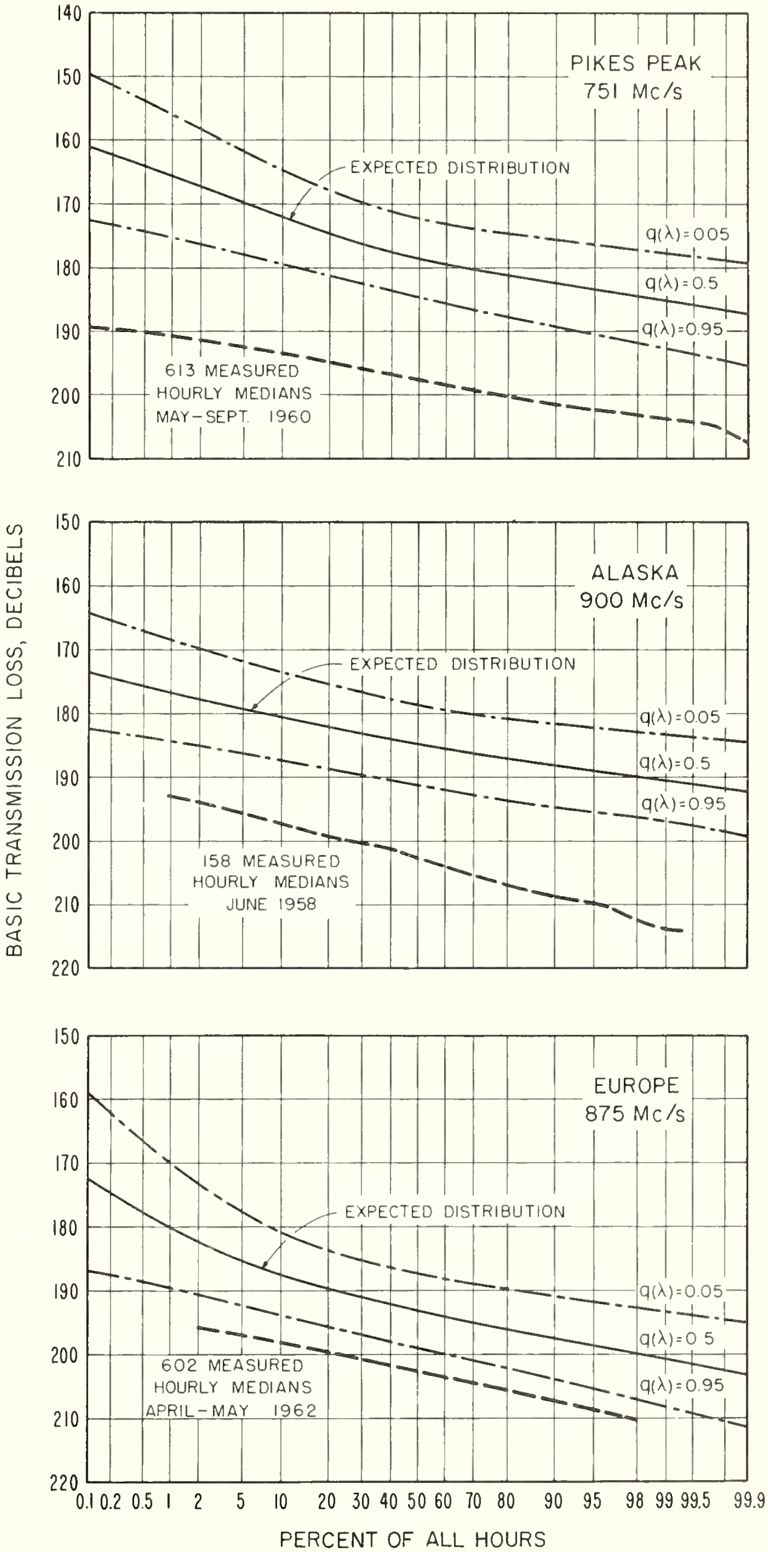


FIGURE 6

B- 37876

COMPARISON OF CALCULATED AND MEASURED HOURLY MEDIAN DISTRIBUTIONS FOR THREE KNIFE-EDGE DIFFRACTION PATHS



Note - the calculated distributions for this path should be raised by 7.3 db

Figure 7

B- 37877

COMPARISON OF CALCULATED AND MEASURED RANGE OF HOURLY MEDIANS FOR THREE KNIFE-EDGE DIFFRACTION PATHS (MEASURED DISTRIBUTIONS ADJUSTED TO CALCULATED OVERALL MEDIANS)

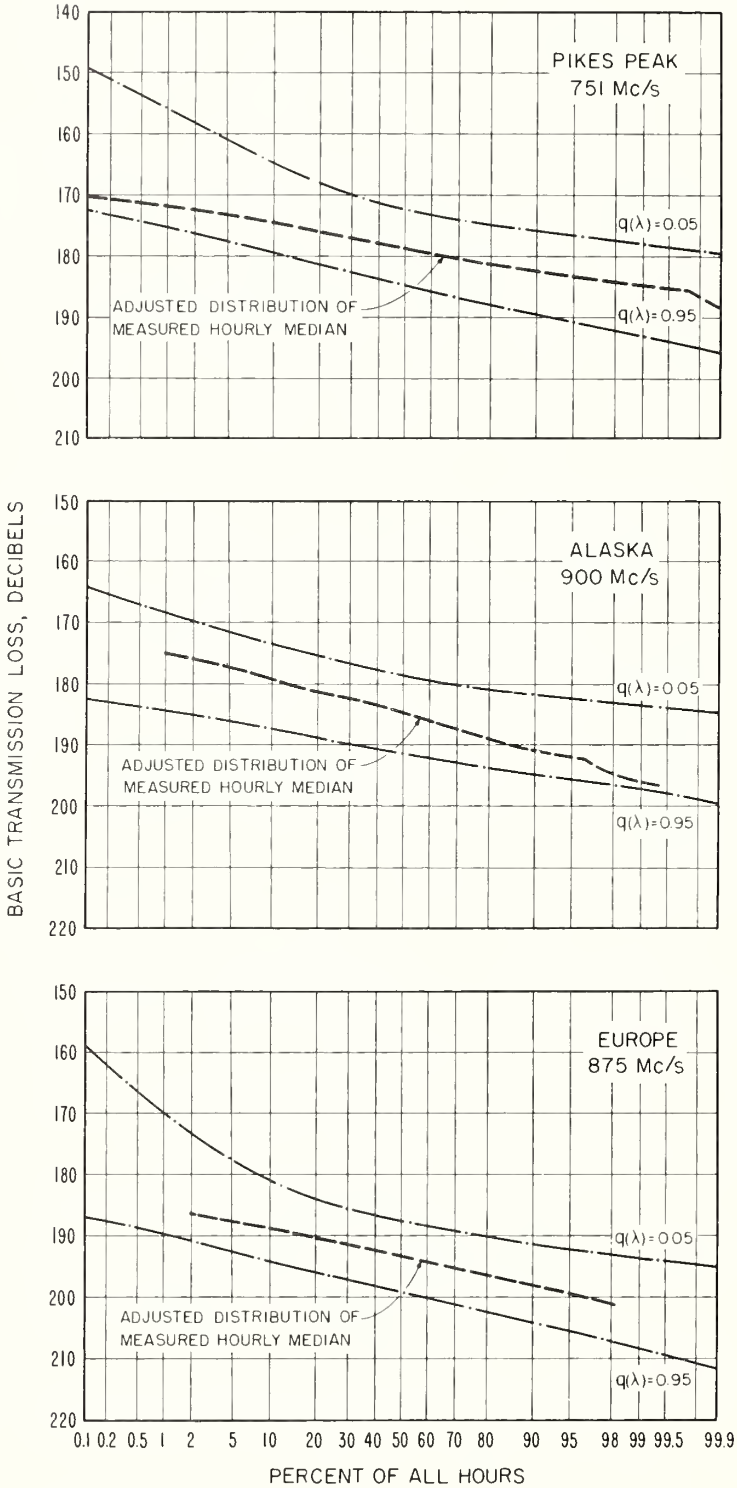


Figure 8

B-37878

CUMULATIVE DISTRIBUTIONS OF FADEOUT DURATIONS, SUMMER

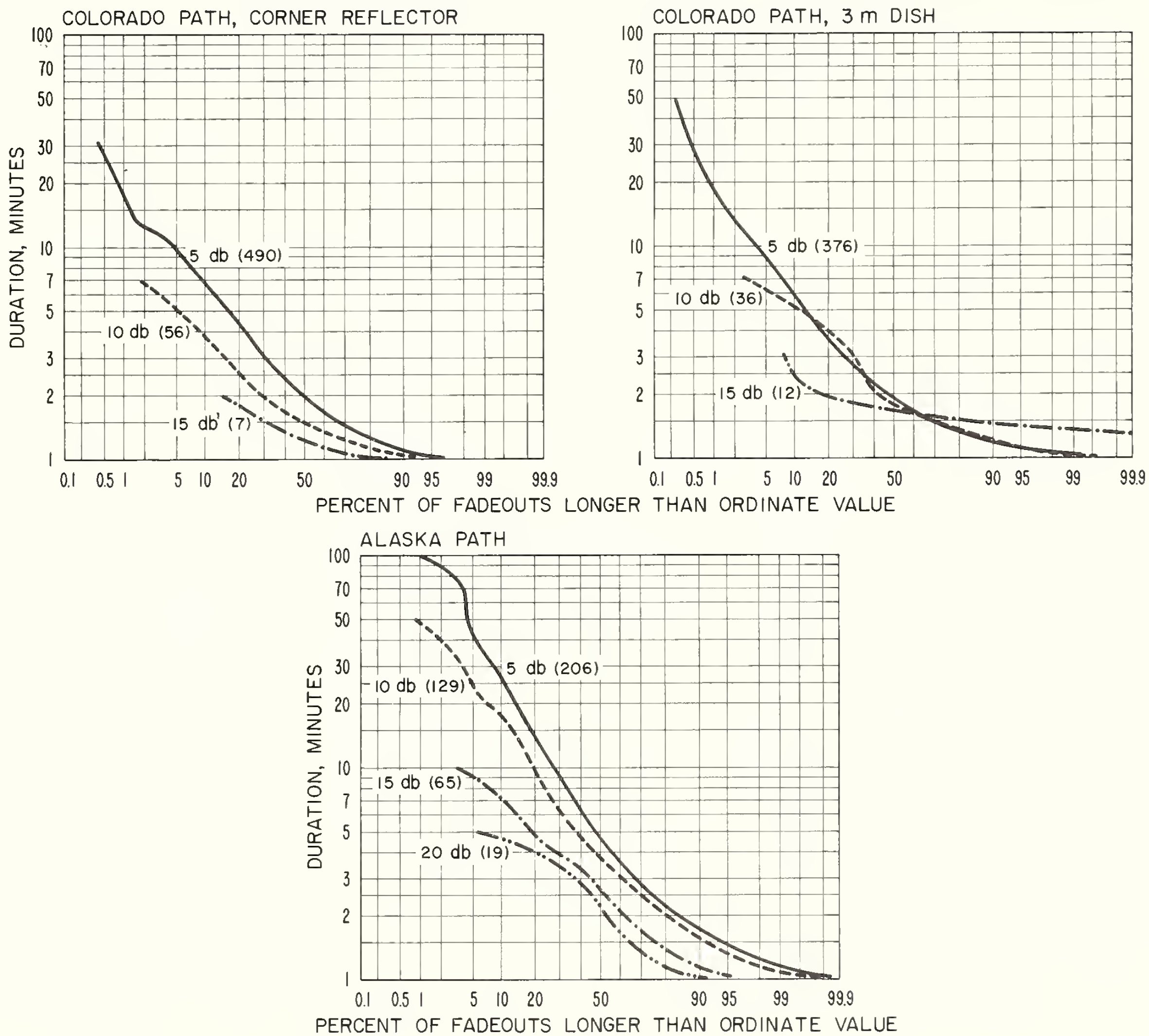


Figure 9

B- 37880

CALCULATED HEIGHT GAIN CURVE FOR ALASKA KNIFE-EDGE DIFFRACTION PATH

SURFACE REFRACTIVITY $N_s = 320$

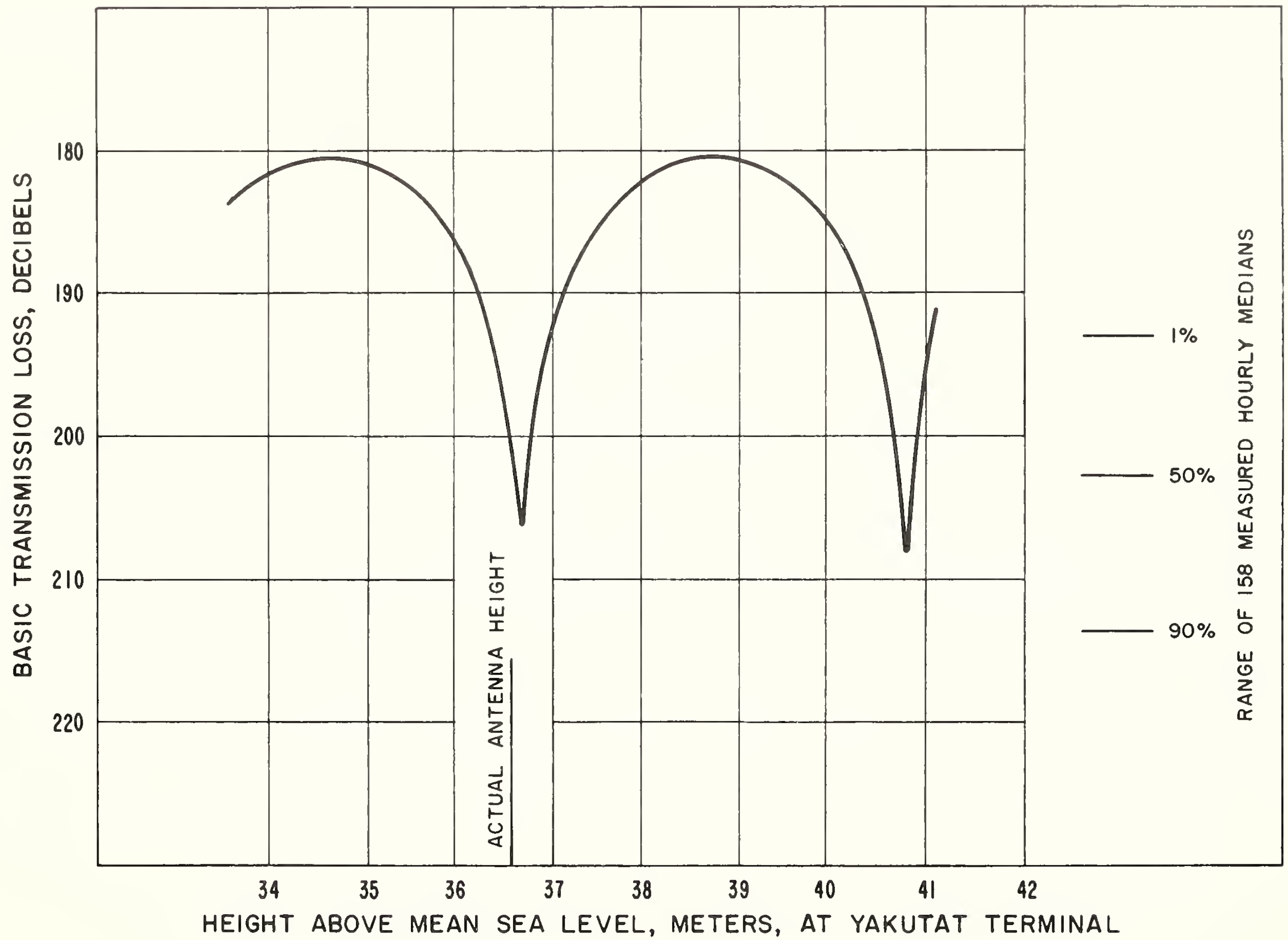


Figure 10

GPO 832707 B- 37873

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Luther H. Hodges, *Secretary*

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

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Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

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