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PATH LOSS MEASUREMENTS VERSUS PREDICTION FOR LONG DISTANCE TROPOSPHERIC SCATTER CIRCUITS

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U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS REPORT

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ABSTRACT

Tropospheric forward scatter circuits have established their place in the world-wide communications network of the military and it is the intent of this paper to illustrate by a specific example how the performance of a circuit of this type may be predicted with adequate accuracy without making costly transmission loss measurements over the intended path.

PATH LOSS MEASUREMENTS VERSUS PREDICTION FOR LONG DISTANCE TROPOSPHERIC SCATTER CIRCUITS

by

A. F. Barghausen and C. F. Peterson

SUMMARY

Before any communications circuit can be established between two points, whether it be by wire lines, or by tropospheric or ionospheric radio propagation, a thorough knowledge of the intended path should be obtained so that an efficient and economical installation can be made. Each system should have as high a reliability as is required for its intended use. Tropospheric forward scatter circuits have established their place in the world wide communications network of the military and it is the intent of this paper to illustrate by a specific example how the performance of a circuit of this type may be predicted with adequate accuracy without making costly transmission loss measurements over the intended path.

1. INTRODUCTION

The basic objective of all path loss measurements is to obtain propagation information for the establishment of an efficient communication link between two or more geographical points.

It is the intent of this paper to show by means of an actual example that a prediction method is available which precludes the necessity, except in extreme cases, for transmission loss measurements over the intended tropospheric scatter path.

On the average, total expenditures for a two week accurate measurement program is of the order of \$100,000, even with compact equipment and at accessable sites. On the other hand, the prediction method for any path performance involves a total expenditure of the order of only \$5,000, not including the great savings in time so often important in the establishment of a military communications link.

Therefore, in order to emphasize the validity of the prediction process as opposed to extensive field tests at the actual location, calculations and path loss measurements were performed concurrently by completely separate groups within CRPL. Two separate reports were prepared, one submitted while the measurements were in progress, and the second at a much later date with a comparison between the observed and calculated values.

2. THE PREDICTION FORMULA

The prediction of the long-term median transmission loss utilizes methods [Rice, Longley and Norton, 1959], which make use of available information about terrain profiles and surface meteorological data. In this connection the CRPL radio standard atmospheres are used in which the radio refractive index decreases linearly with height for the first kilometer above ground and then decreases exponentially with height [Bean and Thayer, 1959a]. Figure 1 illustrates for typical rough terrain conditions the geometry of a forward scatter link in a linear gradient atmosphere. The most important parameters which enter into the prediction formula are the path distance d, and the elevation angles of the radio horizons, α_o and β_o.

Thus, for a particular path one should plot a complete terrain profile between the transmitting and receiving terminals and obtain in logical order the radio horizons, the angular distance and the effective antenna heights. To calculate the angular distance it is necessary to determine, in addition to the total distance d, the heights h_{ts} and h_{rs} of the antennas above sea level, the heights h_{Lt} and h_{Lr} of the radio horizons above sea level and the distances d_{Lt} and d_{Lr} to these horizon points from the transmitter and receiver, respectively.

Long term variations in climatological conditions cause the field strengths to be higher in summer than in winter on the average. Diurnal trends are usually most pronounced between May and October in the Northern hemisphere with minimum fields occurring in the afternoon. Therefore, the predictions are usually made of the cumulative distributions expected for eight specified time blocks, each covering a certain number of hours during the day for the winter and summer months [Rice, Longley and Norton, 1959].

The median basic transmission loss, L_{bms}, due to forward scatter is calculated by the following formula:

$$L_{bms} = F(d\theta) + 30 \log_{10} f_{mc} - 20 \log_{10} d_{mi} + H_o + A_a \qquad (1)^*$$

where $F(d\theta)$ is the attenuation function, which depends on the product of distance and angular distance; H_o is the frequency gain function, important for short distances and antennas only a few wavelengths above ground; and A_a is the atmospheric absorption, important for frequencies above 1000 megacycles.

To make some allowance for wide variations in meteorological conditions throughout the world, use is made of maps of the surface radio refractive index, N_s, [Bean and Horn, 1959b]. Tables are available in the prediction reference, [Rice, Longley and Norton, 1959], giving the standard exponential atmospheres for various values of surface refractivity as may be encountered throughout the world and the predictions are made in terms of the average value of the surface refractivity, N_s, expected at the average height h_s of the two radio horizons above sea level.

The two parts of the path terrain profile required by the prediction process are shown in Fig. 2 for the particular path on which our

*The formulas used here are somewhat simplified relative to those in the paper by Rice, Longley and Norton [1959]. $F(d\theta) = G(\eta) - F_o - F_s - F(h_{eg}, N_s)$, as explained in an unpublished report "Predicting the Performance of Communications Circuits," by P. L. Rice, A. P. Barsis, A. G. Longley, H. T. Dougherty and R. S. Kirby.

transmission loss measurements were made. Using this path profile, which was obtained from the best available topographical maps for the area, the various parameters required for the prediction formula are determined. These are N_s, the average surface refractivity expected at the average height $h_s = 0.5\ (h_{Lt} + h_{Lr})$, equivalent earth's radius, a, angular distance θ, and the path asymmetry factor $s = \alpha_o/\beta_o$.

Referring to (1), the single most important term is the attenuation function $F(d\theta)$ which gives the decibel attenuation of field strength as a function of the product of the distance and the angular distance for the particular path. The value of $F(d\theta)$ is also dependent upon the surface refractivity, N_s, and the path asymmetry, s. The unpublished paper by Rice, et. al., contains graphs of $F(d\theta)$ plotted as functions of the above parameters for each of the four standard reference atmospheres. The value of surface refractivity, N_s, for this path was obtained from world-wide maps compiled by the Radio-Meteorology Section of CRPL [Bean and Horn, 1959b]. The value used was 343 N-units and represents a mean surface value for the winter month of February at the midpoint of the path. The value of $F(d\theta)$ for this path is 207.1 db.

The remaining terms in the prediction formula were then determined for this particular path and found to be 2.4 db for H_o, and 0.9 db for A_a.

Substituting these values into (1), for the carrier frequency of 409.9 Mc, the resulting predicted basic transmission loss is:

$$L_{bms} = 207.1 + 78.4 - 54 + 2.4 + 0.9 = 234.8 \text{ db} \tag{2}$$

This value is the median of all hourly medians during time block 2 (November-April, 1300-1800 local time).

The entire cumulative distribution of the actual transmission loss L(p) expected to be observed over this transmission path for all hours or during the winter months from November to April is given by:

$$L(p) = L_{bms} - G_p - V(p, \theta) \quad (3)$$

The term G_p is defined as the path antenna gain and $V(p, \theta)$ is the particular long-term variability of hourly medians expected for all hours during the winter months. Values of $V(p, \theta)$ plotted as functions of the angular distance, are obtained from empirical curves for all hours during the winter months or for any other specified time block or combinations thereof and are contained in the paper by Rice, Longley and Norton [1959].

The expected path antenna gain, G_p, may be estimated from a paper by Hartman and Wilkerson [1959] in which it is considered to be a function of the free space gains of the transmitting and receiving antennas as well as the ratio of the angular distance, θ, to the half-power beamwidth, Ω, of each antenna, and to the parameters s and η_s. Here η_s is the normalized height of the horizon ray crossover and may be determined from the paper by Rice, Longly and Norton [1959].

The predicted cumulative distribution of the transmission loss shown by dashed lines on Fig. 4 was calculated by using the following system parameters:

Path angular distance	$\theta = 89.05$ milliradians
Mean surface value of refractivity	$N = 343$
Free-space antenna gain	$G_t = G = 26.8$ db
Loss of antenna gain	$G_L = 1.4$ M
Path antenna gain	$G_p = G_t + G_r - G_L = 52.2$ db

Transmission Line Losses	$L_t = 3.9$ db
Transmitter power	$P_t = 33.0$ db w

The dashed curves labeled probable error limits and 0.05 and 0.95 limits were obtained from values of prediction uncertainty, expressed as standard deviations, versus percentage of time for all-hours, all-year medians.* These values are a result of extensive comparisons between predictions and measurements. The standard deviation of the medians amounts to 3.57 db with an additional standard deviation of 2 db taken for possible variations in equipment performance parameters and calibration errors; since these errors are independent the net uncertainty of the medians is $\sqrt{(3.57)^2 + (2)^2} = 4.09$ db. This prediction uncertainty arises from the fact that if a number of tropospheric scatter paths having identical geometrical and meteorological parameters are considered, an extensive long-term measurements program of transmission loss would result in a range of all-day, all-year distributions, as well as a range in long-term overall medians rather than a single result. However, using the prediction formula for these same paths the predicted all-day, all-year distribution of hourly medians would be identical.

The probable error limits and the 0.05 and 0.95 confidence limits shown are based on the assumption that the prediction errors, expressed in decibels, are normally distributed. Thus the probable errors, i.e. (0.25 and 0.75 confidence limits) are taken as 0.6745 times the expected standard deviation. The standard normal deviate for a 0.95 probability (1 out of 20 chances of a larger actual loss than that predicted) is 1.645 times the prediction uncertainty and is the outer curve labeled 0.95 limits, [Bennett and Franklin, 1954].

*A. P. Barsis, K. A. Norton, and P. L. Rice, "Predicting the Performance of Long Distance Communications Circuits," paper presented at the 1959 IRE National Convention, to be published in IRE Transactions on Communications Systems.

3. PATH LOSS MEASUREMENTS

The path loss test equipment which was used to obtain the measurements reported herein consisted of a 2 kw, continuous wave, 409.9 Mc transmitter, narrow band receivers having bandwidths of 2 kc and 50 cps, 28 foot parabolic antennas, and magnetic tape and automatic distribution analyzers for rapid data reduction in the field.

The recording period started on March 24, 1959 and ended on April 11, 1959, which amounts to 17 days of continuous records.

A plot of the hourly medians of transmission loss versus hour of the day and the hourly surface refractivity values are shown in Fig. 3. The solid line is drawn through the average value for each hour and each N_s value is the average of half hourly readings at both ends of the path. The predicted value of surface refractivity for this path, 343 N-units, [Bean and Horn 1959b], is 15 N-units higher than the average value measured during the 17 day test period.

A direct comparison between the measured cumulative distribution of all hourly medians and the predicted cumulative distribution is shown in Fig. 4. It is quite evident that excellent agreement is obtained for those percentages above 50% of all hours, which are within 1 db of the predicted transmission loss. At lower percentages, where high fields are experienced, the measured distribution departs significantly from the predicted transmission loss. However, such departures would be important only in the study of interference fields, and our main concern here is a high reliability of service fields where only those values at the higher percentages of the time are important.

4. EXPECTED PATH PERFORMANCE ESTIMATES

A prediction of the expected performance of a communications circuit over this particular path can now be made utilizing the predicted transmission loss as well as an improved prediction determined from an appropriate combination of both the predicted and the measured transmission loss.

The concept of service probability is used in estimating the performance of a communications circuit and is defined as the probability of obtaining a specified grade of service or better during a given percentage of the hours in a specified period of time, usually taken to be all hours of the year. The specified grade of service is predetermined in terms of an hourly median carrier-to-RMS-noise ratio R which takes into account the short-term signal fading and the modulation capabilities of the circuit.

This service probability concept uses the prediction uncertainty as discussed above for the prediction of the expected transmission loss as well as uncertainties in estimating equipment characteristics such as noise figures and the carrier-to-noise ratio R required for a specified grade of service.

Values of prediction uncertainty may be represented in graphical form as shown in Fig. 5, as a function of the percentage of all hours of the year. The curve labeled $\sigma_{rc}(p)$ represents the prediction uncertainty expressed in terms of a normal distribution having the indicated standard deviation values in db for the particular percentage of all hours of the year. This standard deviation, $\sigma_{rc}(p)$, combines the errors in estimating the transmission loss and the uncertainties in estimating the equipment characteristics.

It has been shown by a separate study* that these values of $\sigma_{rc}(p)$ may be reduced by taking into account the results of transmission loss measurements over the intended communications path. Basically, this method involves the use of weighted averages for the measured values as a function of the number of measurement days as well as the computed values and combining these in statistical form to represent

*A. P. Barsis, K. A. Norton and P. L. Rice, "Predicting the Performance of Long Distance Communications Circuits," to be published in IRE Transactions on Communications Systems.

an improved prediction uncertainty shown by the standard deviation values on the curve labeled σ_{rt} in Fig. 5. Analogous to the prediction uncertainty which is used for calculated values of field strength, a standard deviation may also be used for measured field strength values and is the curve labeled $\sigma_{or}(p)$.

Thus by use of the prediction uncertainty values from Fig. 5, curves of weighted cumulative distributions of hourly transmission loss may be computed and are shown in Fig. 6 for calculated values, L_{bc}, observed values, L_{bo}, and improved prediction values, L_{bt}, adjusted to all-day, all-year.

For the predictions of service probability the specified grade of service is given as not more than 1 in 10,000 character errors for standard FSK teletype, 60 WPM, 5 unit start-stop code. Estimates are based on a 12 voice channel FM system using quadruple diversity with parametric amplifiers having a noise figure of 2 db at the specified carrier frequency. Considering only 60 foot and 120 foot parabolic antennas, values of transmitter power versus frequency may be computed using the following simple relationship as given by Norton [1956, 1959].

$$P_t = L_b - G_p + F + L_t + R + B - 204 \tag{4}$$

where P_t = transmitter power in decibels relative to one watt

L_b = transmission loss for the operating frequency and propagation path in question

G_p = path antenna gain in decibels as defined earlier

F = effective noise figure of receiver in decibels

L_t = transmission line and associated losses, in decibels

R = pre-detection RMS carrier to RMS noise ratio for the bandwidth, type of modulation, and order of diversity used

$B = 10 \log_{10} b$, where b is the total bandwidth in cycles per second (including the effect of drift between transmitter and receiver oscillators).

204 db is a constant equal to $(-10 \log_{10} kT)$, where k is Boltzmann's constant, and the reference temperature T is taken to be 288° K.

For this particular path, values of $F + L_t$ were assumed to vary from 2.3 db to 10 db for the frequency range 200 megacycles to 2000 megacycles and the value of R from 10.3 db to 9.3 db based on the work by Watt, Coon, Maxwell and Plush [1958]. For 12 voice channels, the bandwidth term B is taken to be equal to 60 db, and will vary with the type of modulation and special circuit techniques that might be employed. Substituting these values in (4) and using computed values of the path antenna gain, G_p, as a function of frequency for this particular path, Fig. 7 is obtained which indicates the transmitter power required to provide the specified grade of service. In order to provide a comparison of frequencies, the basic transmission loss L_b in (4) is taken as the time block 2 median [Rice, Longley and Norton, 1959]. Thus, the optimum frequency for these antenna sizes, this particular path, the given equipment characteristics and the specified grade of service is indicated by the minimum relative transmitter power value in each case.

5. EFFECTS OF DEVIATIONS FROM EXPECTED PATH PERFORMANCE

Using the weighted cumulative distribution curves of hourly transmission loss for both the calculated values and improved prediction values shown in Fig. 6, and the minimum transmitter power P_t, for each antenna size and frequency as obtained from Fig. 7, a plot of transmitter power expected to provide the specified grade of service or better for the indicated percentage of hours is shown in

Fig. 8. The use of these curves may be interpreted in the following manner: A 10 Kw (40 dbw) transmitter, operating with 60 foot parabolic antennas in the 500 - 600 megacycle range would be expected to provide the specified grade of service or better during 97.2% of all hours for the improved prediction values as opposed to the estimated 98.6% of all hours with the same transmitter power based on the calculated values alone.

In order to allow appropriately for the effects of any errors which are inevitably present in predictions of the future, it is desirable to express the final predictions by making use of the concept of service probabilities. Since the prediction uncertainties are defined in terms of the probability of obtaining a specified grade of service or better for a given percentage of time, the values of service probability are obtained by combining the all-day, all-year distribution of expected transmitter power values of Fig. 8 with the standard deviation values $\sigma_{rt}(p)$ and $\sigma_{rc}(p)$ of Fig. 5.

The service probability curves for this particular path are shown for both the predictions alone and the improved predictions taking into account the extensive measurement program conducted at the actual locations.

The service probability, $F(t)$, is obtained for each case by considering the system power $P[F(t), p]$ required to provide the specified grade of service or better during p percent of all hours with the probability $F(t)$ related to the expected value of system power $P(0.5, p)$ by:

$$P[F(t), p] = P(0.5, p) + t \cdot \sigma_{rc}(p), \tag{5}$$

where

$$F(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp(-z^2/2)\, dz \qquad (6)$$

t is a standard normal deviate, and $\sigma_{rc}(p)$ (or $\sigma_{rt}(p)$) has been defined above. Values of t for various service probabilities F(t), may be found in probability tables, [Bennett and Franklin, 1954]. To obtain the service probability for fixed values of transmitter power P_o, the term $P[F(t), p]$ in (5) may be replaced with various values of P_o and (5) solved for t:

$$t = \frac{P_o - P(0.5, p)}{\sigma_{rc}(p)} \qquad (7)$$

Thus the curves of Fig. 9 are obtained by reading the appropriate values of P (0.5, p) from Fig. 8 and the appropriate values of $\sigma_{rc}(p)$ or $\sigma_{rt}(p)$ from Fig. 5 for the particular value of time availability p, in percent of all hours.

As an example of the use of the curves in Fig. 9, let it be required to determine the probability of obtaining the specified grade of service for 98% of all hours using 120 foot parabolic antennas, and 10 Kw transmitters operating in the optimum frequency range for the antenna size, namely between 200 and 300 megacycles for a 12 voice channel, quadruple diversity FM system. From the appropriately labeled curve of Fig. 9, the service probability F(t) is found to be 0.95. This means that out of 100 randomly chosen predictions all based on the same parameters, 95 would be expected to provide the specified grade of service or better and 5 would be expected to fail to do so.

Comparison of the curves in the lower and upper portions of Fig. 9 indicates relatively small differences in the probability of success with and without, respectively, utilizing the path loss measurements.

The following table tabulates these probabilities.

TABLE I

Probabilities that the designated equipment components will provide for 99% of the hours, a grade of service corresponding to an 0.01% error rate or better.

	60 foot antenna (500-600 Mc)		120 foot antenna (200-300 Mc)	
	10 kw	40 kw	10 kw	40 kw
Based on Calculations alone	0.50	0.82	0.94	0.993
Based on measurements plus calculations	0.45	0.92	0.993	> 0.9999
Change in risk achieved by making the measurements	-0.05	0.10	0.053	<0.007

Thus we see that the change in the risk achieved by making the measurements in this particular case is essentially negligible.

Note that both sets of predictions, those based on the calculations alone and those based on the short term measured values combined with the calculated values, are subject to a large degree of uncertainty. This uncertainty could be substantially reduced only by making measurements over a very long period of time; in fact several years' observations would be required to produce predictions with negligible uncertainty, i.e., corresponding to nearly horizontal lines on Fig. 9.

This paper has presented only one comparison between prediction and measurements and, while excellent agreement is shown for this particular path, others may not agree as well. However, it is recommended that if path loss measurements are made, they should be taken at sampled intervals throughout the day for a period extending over many months. This may not be economically feasible and the prediction formula can generally be expected to give at least as good an estimate of the expected communications system performance as a two or three week measurement program.

6. ACKNOWLEDGEMENTS

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GEOMETRY FOR A LINEAR GRADIENT ATMOSPHERE

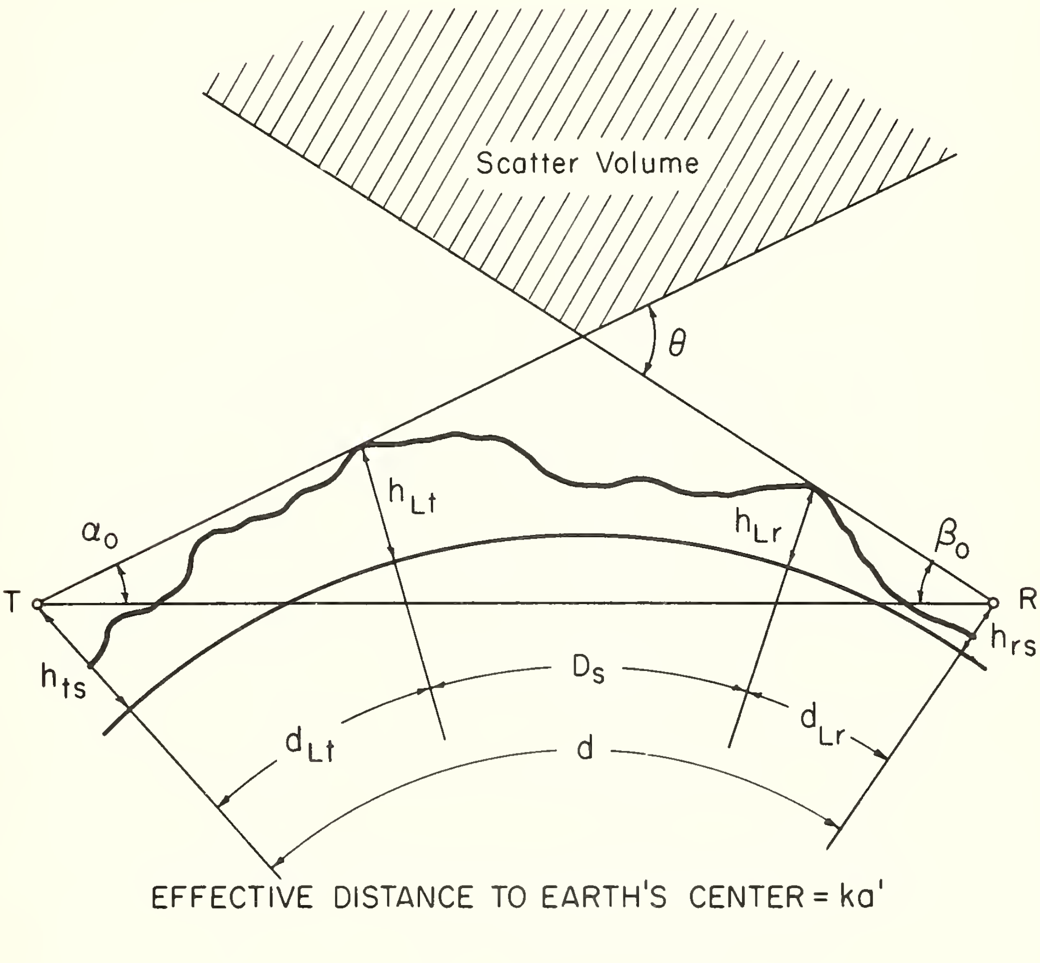

Figure 1

PROFILE OF A TROPICAL MARITIME PATH
FOR WHICH ESTIMATES AND MEASUREMENTS HAVE BEEN MADE

FREQUENCY 409.9 Mc; ANTENNAS 8.6 METER PARABOLAS (28 FEET)

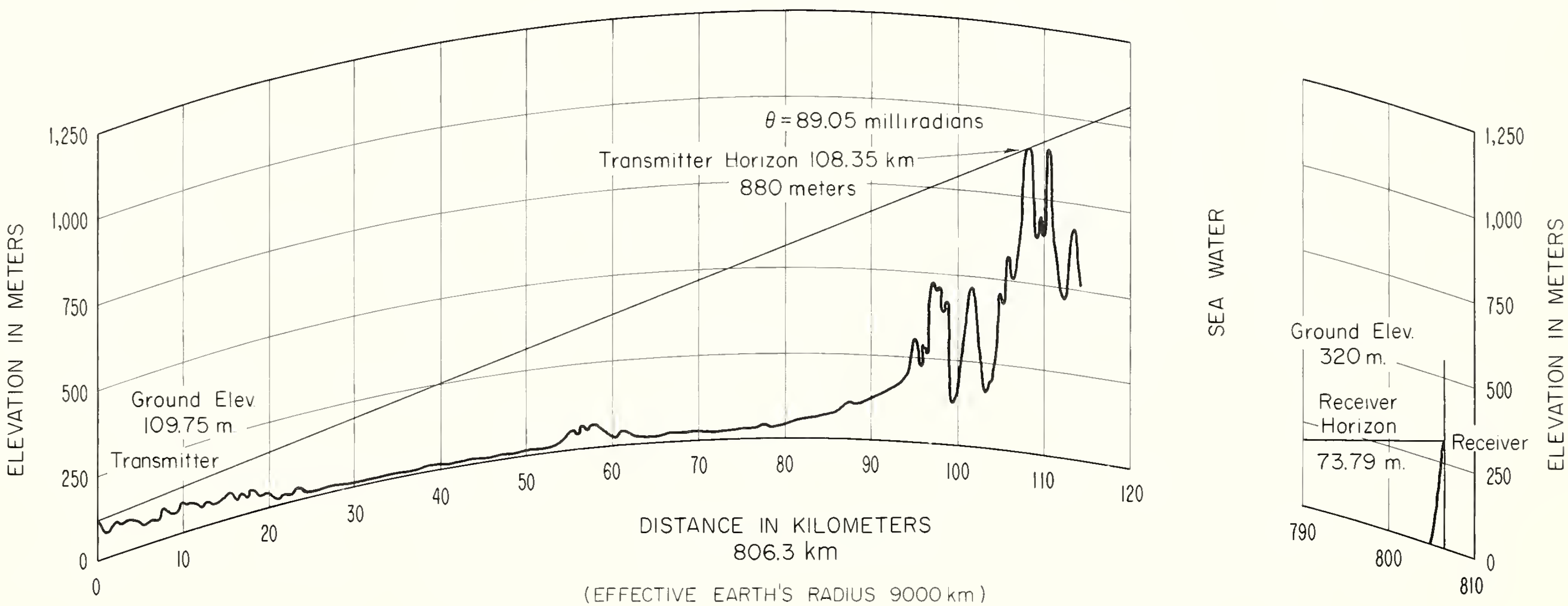

Figure 2

DIURNAL VARIATIONS OF MEASURED DATA
APRIL 2–18, 1959
366 HOURS

d = 806.3 km; θ = 89 mr; 8.6 m PARABOLIC ANTENNAS

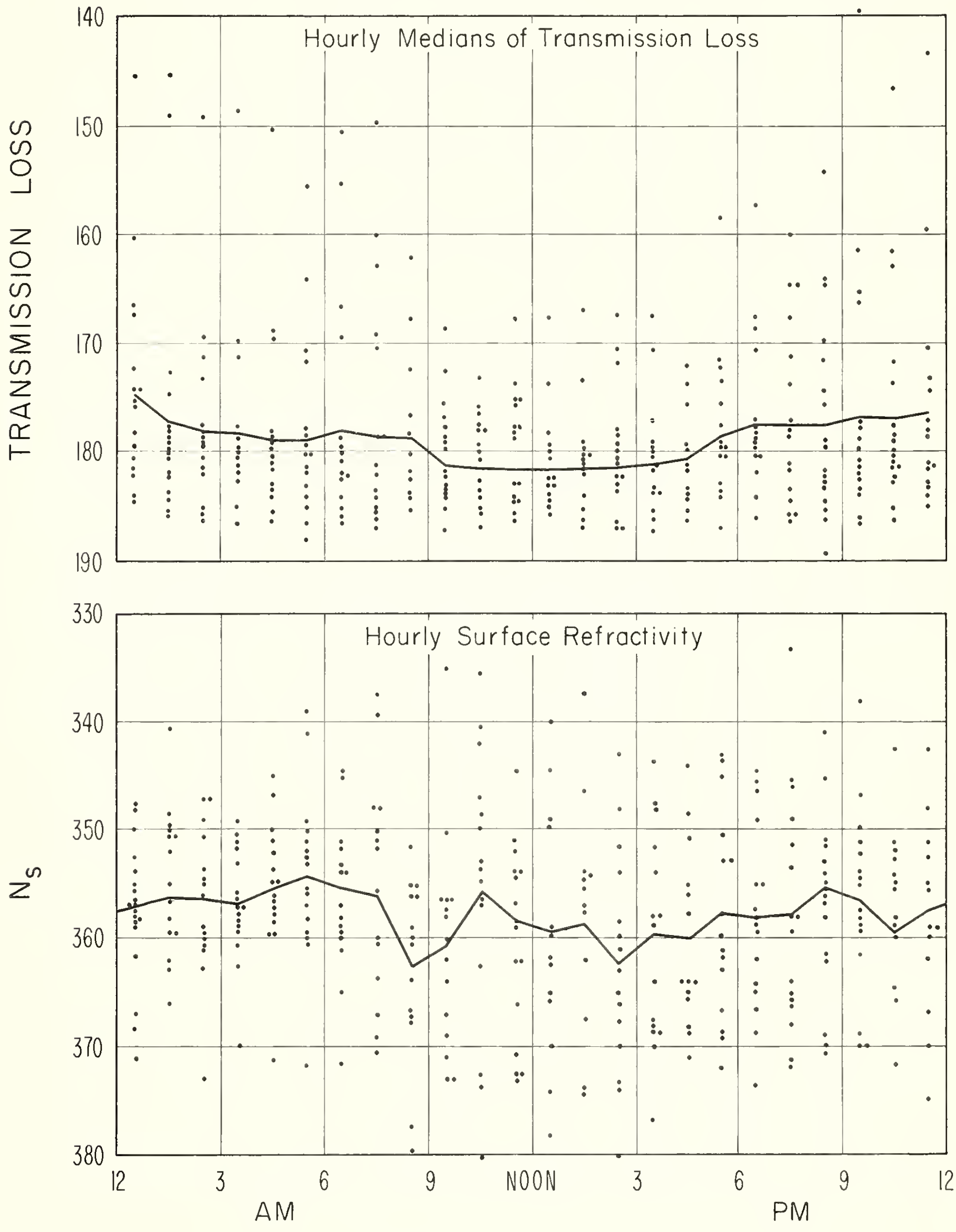

Figure 3

MEASURED AND EXPECTED DISTRIBUTION OF HOURLY MEDIAN TRANSMISSION LOSS

ALL HOURLY MEDIANS; d = 806.3 km, θ = 89 MILLIRADIANS
8.6 m. PARABOLIC ANTENNAS

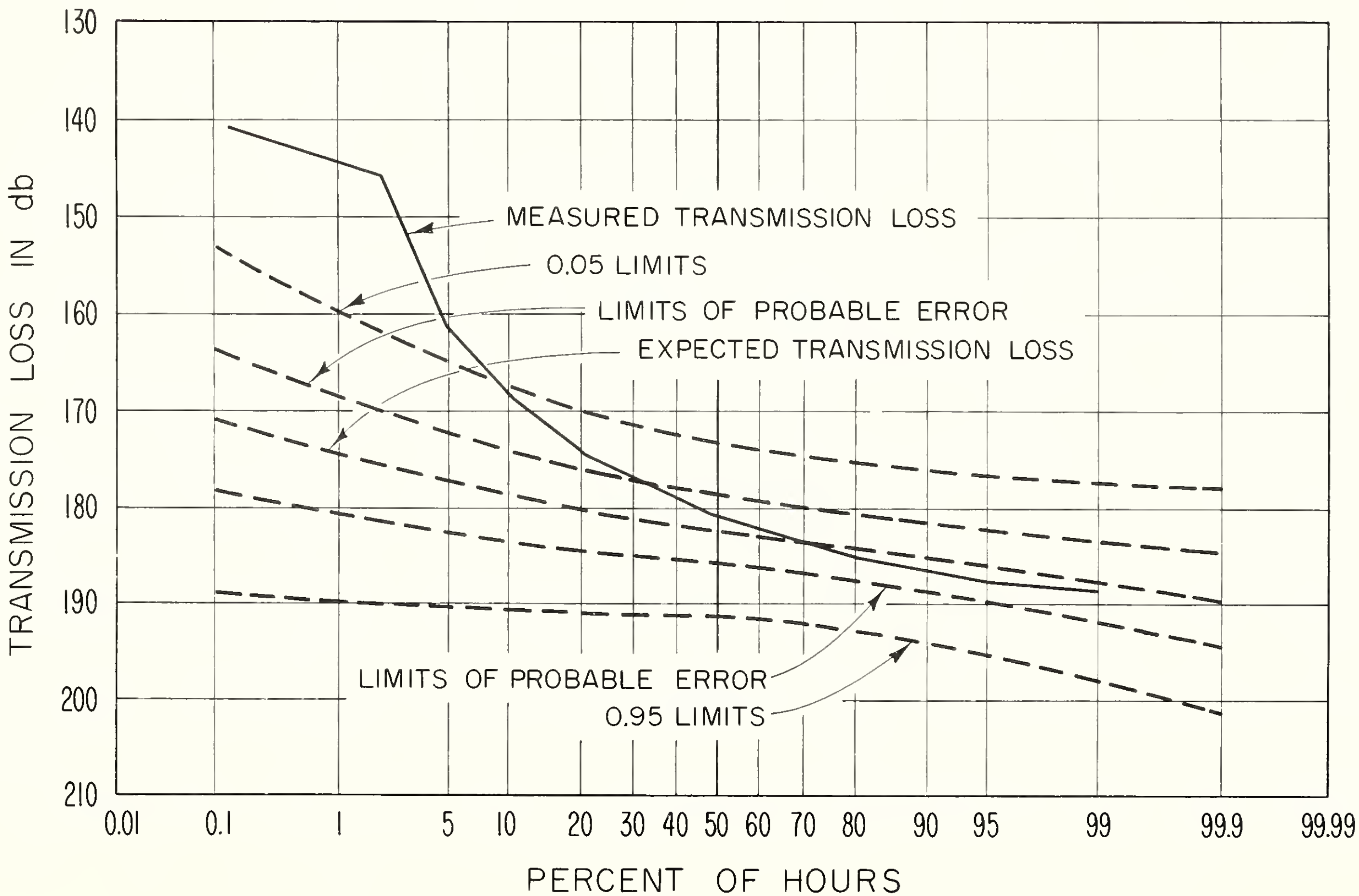

Figure 4

PREDICTION UNCERTAINTY

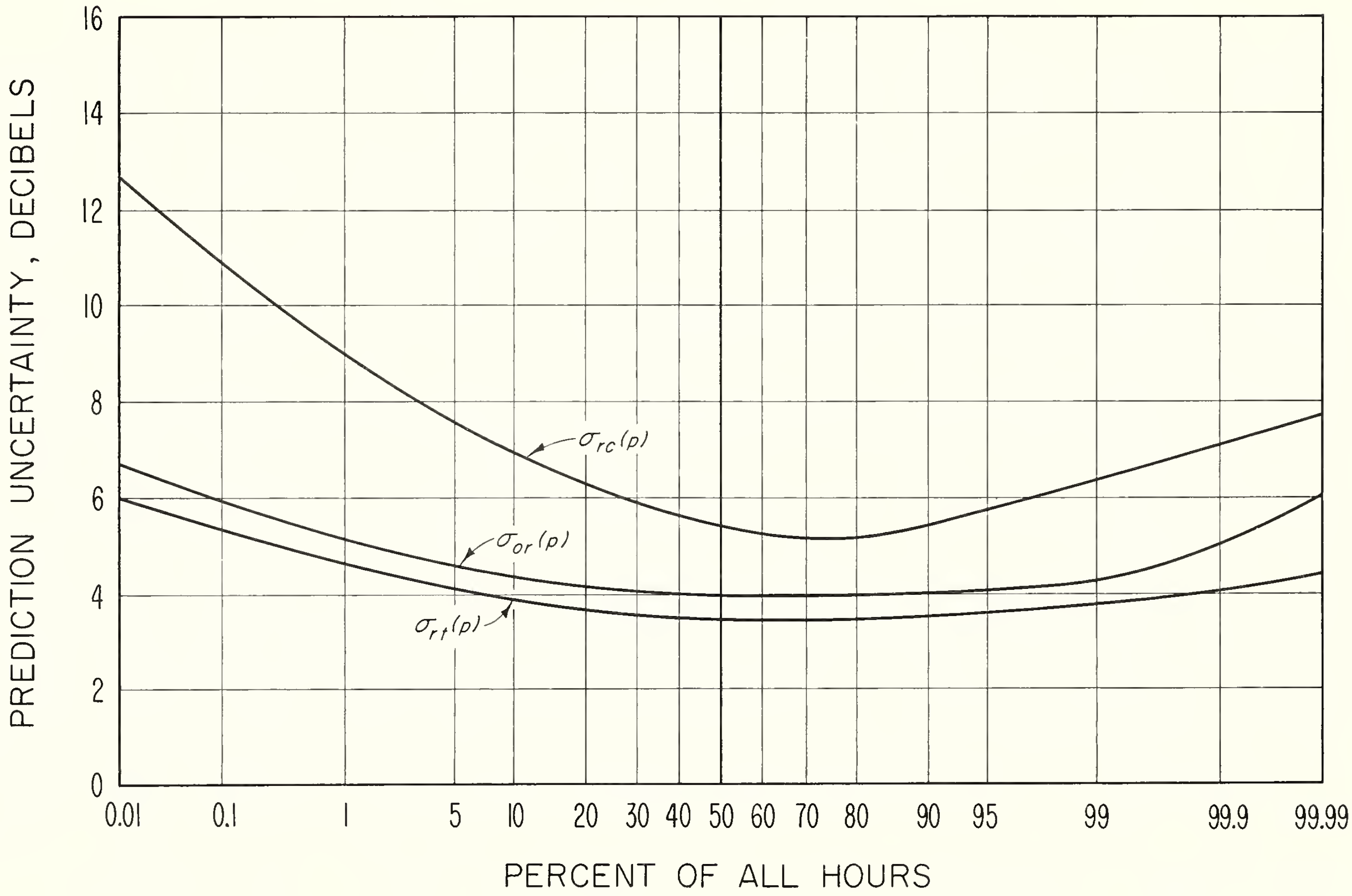

Figure 5

WEIGHTED CUMULATIVE DISTRIBUTIONS OF HOURLY TRANSMISSION LOSS
$d = 806.3$ km; $\theta = 89$ MILLIRADIANS; 8.6 m PARABOLIC ANTENNAS

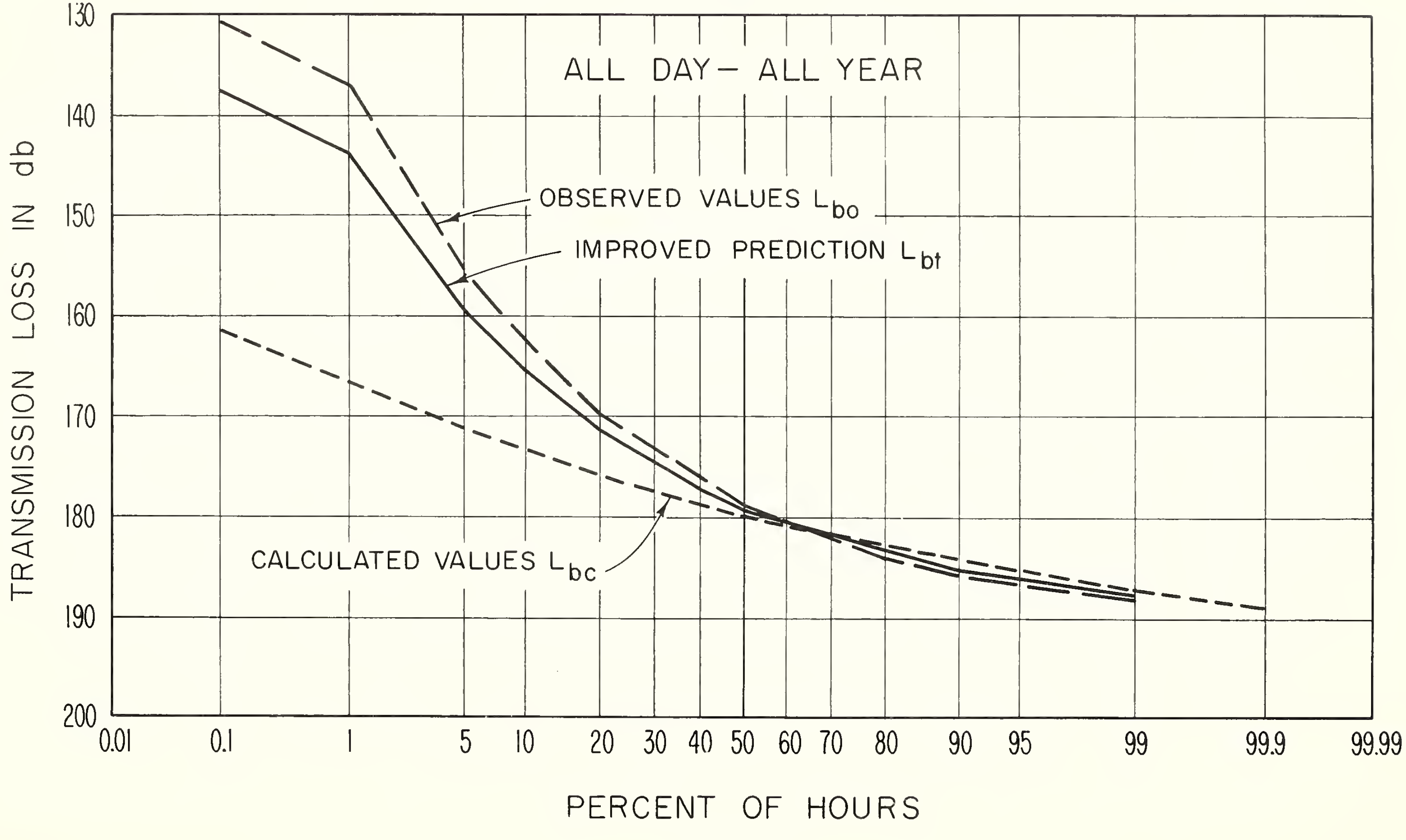

Figure 6

TRANSMITTER POWER VERSUS FREQUENCY FOR TIME BLOCK 2 MEDIAN
d = 806.3 km; θ = 89 MILLIRADIANS; 12 VOICE CHANNELS
QUADRUPLE DIVERSITY FM SYSTEMS

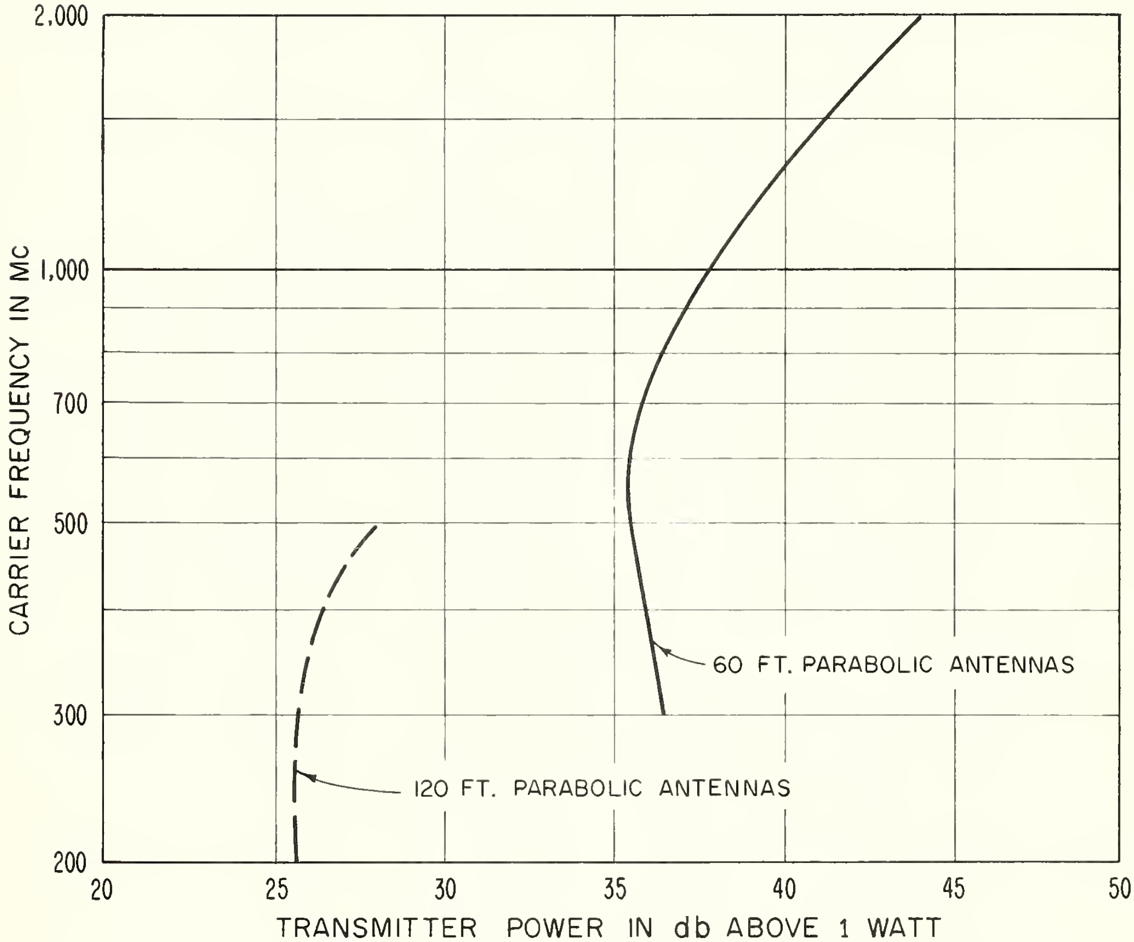

Figure 7

TRANSMITTER POWER EXPECTED TO PROVIDE
THE SPECIFIED GRADE OF SERVICE FOR
INDICATED PERCENTAGE OF HOURS

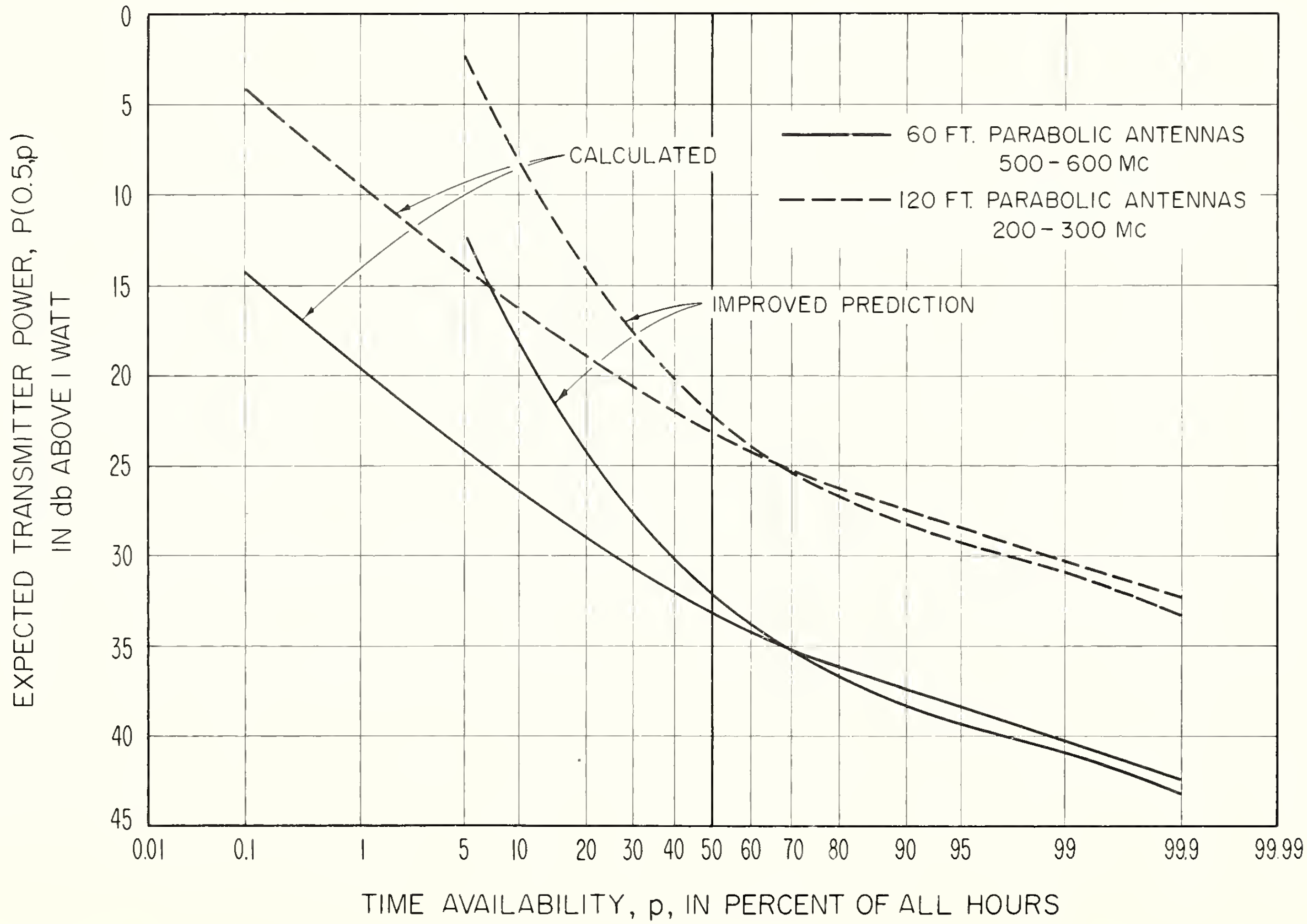

Figure 8

SERVICE PROBABILITY
12 VOICE CHANNELS, QUADRUPLE DIVERSITY FM SYSTEMS
$d = 806.3$ km, $\theta = 89$ MILLIRADIANS
BASED ON CALCULATED VALUES

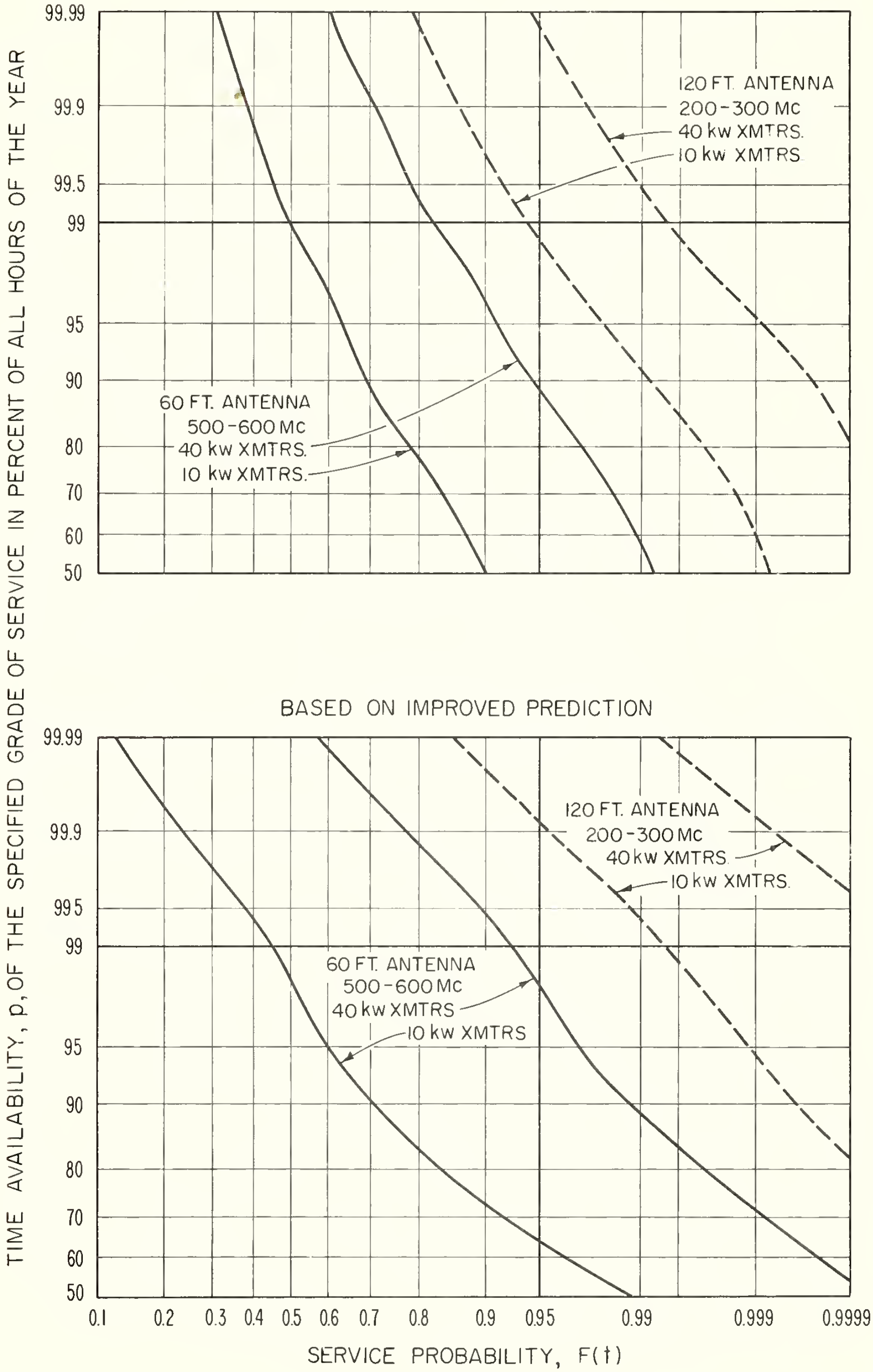

Figure 9

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A. V. Astin, *Director*

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WASHINGTON, D.C.

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

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

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

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

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Analytical Chemistry. Inorganic Chemistry.

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

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

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

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

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Solid State Physics. Electron Physics. Atomic Physics.

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

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry. Molecular Structure and Radiation Chemistry.

• Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

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

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

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

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

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

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