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U S DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
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# A STUDY OF METHODS FOR THE EFFICIENT ALLOCATION OF RADIO FREQUENCIES TO BROADCASTING SERVICES OPERATING IN THE RANGE ABOVE 50 MC

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The report enclosed herewith, "A Study Of Methods For The Efficient Allocation Of Radio Frequencies To Broadcasting Services Operating In The Range Above 50 Mc," by Kenneth A. Norton and Harry Fine is being sent to you in response to a request received from the Federal Communications Commission. It is expected that the information contained in this report will be of interest to you in connection with the Further Proposed Rule Making Proceedings announced by the FCC in Mimeo. No. 37460.

This report was prepared in connection with the work of the Ad Hoc Committee of the Federal Communications Commission For The Evaluation Of The Radio Propagation Factors Concerning The Television And Frequency Modulation Broadcasting Services In The Frequency Range Between 50 and 250 Mc. Part of the work was done while the authors were members of the Sub-Committee on Evaluating Interference from Multiple Signals under the chairmanship of R. M. Wilmotte. However, neither the Sub-Committee nor the Ad Hoc Committee has yet had time to consider the enclosed report in its present form. It is being given general distribution at this time, prior to any formal action by the Ad Hoc Committee, at the specific request of the FCC because of the brief time available before the beginning of the Further Proposed Rule Making Proceedings. Sections I through IV of this report and the associated Figures 1 - 17, inclusive, are the same, except for minor editorial revisions, as the corresponding sections of Reference E to the Ad Hoc Committee report, file copies of which are available in the Docket Section of the FCC. The remaining Sections of Reference E are considered by the authors of the enclosed report to be obsolete, these earlier considerations being replaced by the more comprehensive material in the enclosed report.

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# A STUDY OF METHODS FOR THE EFFICIENT ALLOCATION OF RADIO FREQUENCIES TO BROADCASTING SERVICES OPERATING IN THE RANGE ABOVE 50 MC

by Kenneth A. Norton and Harry Fine

## Contents

SUMMARY

Methods are developed for describing the service provided by a television broadcasting system. It is shown how the service range of a clear channel television broadcasting station is limited by receiver and cosmic radio noise and formulas are presented for determining the field intensity required to provide a satisfactory television service in this case. Considering the statistical fluctuations of the field intensity of a television station with variations in receiving location and time, the effective service area for the clear channel case may be uniquely expressed by means of an integral, with respect to distance, of distance multiplied by the probability of receiving service at this distance. Three grades of service are defined in terms of the minimum percentage of the time, $T_a$, that a satisfactory television signal is required to be available at any particular receiving location; thus, Grades A, B and C service correspond to $T_a$ = 99%, 90% and 0, respectively.

Methods are next developed for determining the mutual interference to be expected between the television signals from two stations operating on the same or on adjacent radio frequency channels. This interference is conveniently measured by the ratio of the desired-to-undesired field intensity and it is found that the correlations with respect to time and receiving location between the desired and the undesired fields are important factors for determining the expected distribution of the interference with distance. The distributions used in this report were obtained by assuming zero correlation since adequate experimentally determined values of the correlation coefficients are not now available; although this assumption may lead to predicted distributions of service with distance considerably at variance from the true values, it is expected that the predicted service areas will be influenced to a smaller extent. Consequently, conclusions reached in this report relative to efficient methods of allocation are probably reliable in spite of the necessity for this assumption of zero correlation.

Methods are next developed for determining the combined interference to be expected when several television stations are operated within interfering range of each other. In this case, because the expected service will vary with direction from the desired stations, the determination of the total effective service area of such stations involves the integration throughout the entire area of the probability of receiving service within a differential element of the area. It is concluded that a maximum total coverage of area can be obtained with a limited number of television channels by locating them geographically in a triangular lattice with a co-channel separation of the order of 100-300 miles, the optimum spacing being dependent upon the effective radiated power, transmitting antenna height, grade of service, whether or not the co-channel stations are synchronized, etc.

The analysis shows that the use of high transmitting antennas and high transmitter power will provide television service throughout the greatest possible area.

## I INTRODUCTION

In several recent reports1/,2/,3/, one of the authors has outlined methods suitable for the efficient allocation of radio frequencies to broadcasting services operating on frequencies above 50 Mc. In those reports use was made of a theoretical study1/ of the expected ground wave and tropospheric wave field intensities. Since then two reports have become available4/5/ which provide a better basis for estimating broadcast field intensities in the frequency range 50-250 Mc and it is the purpose of the present report to use these latter data in a further study of this broadcast allocation problem.

## II THE BASIC DATA AVAILABLE AND THE ADDITIONAL ASSUMPTIONS NECESSARY FOR A SOLUTION OF THE ALLOCATION PROBLEM

The fields received near the ground from radio stations broadcasting in the frequency range above 50 Mc are affected primarily by the irregularities in the terrain at distances well within the line of sight but are affected at distances larger than this both by the irregularities in the terrain and the

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1/ Kenneth A. Norton, "Propagation in the FM Broadcast Band," Advances in Electronics, Vol. I, pp. 381-421, Academic Press, Inc., Publishers, New York, N. Y., 1948.

2/ Statement of Kenneth A. Norton, Chief of the Frequency Utilization Research Section of the Central Radio Propagation Laboratory of the National Bureau of Standards, relative to the efficient allocation of frequencies to television broadcast stations, July 27, 1948.

3/ Statement of Kenneth A. Norton, Chief of the Frequency Utilization Research Section of the Central Radio Propagation Laboratory of the National Bureau of Standards, at the September 20, 1948 Television Hearing before the Federal Communications Commission relative to the comparative coverage to be expected from television broadcasting stations operating in the 50 to 1000 Mc range.

4/ Kenneth A. Norton, Morris Schulkin and Robert S. Kirby, "Ground-Wave Propagation Over Irregular Terrain at Frequencies Above 50 Mc," Reference C to Report of the Ad Hoc Committee, FCC Dockets 8736, 8975, 9175, June 6, 1949.

5/ Edward W. Allen, Jr., William C. Boese and Harry Fine, "Summary of Tropospheric Propagation Measurements and Development of VHF Propagation Charts," Reference D to Report of the Ad Hoc Committee, FCC Dockets 8736, 8975, 9175, May 26, 1949.

inhomogeneities in the atmosphere. The irregular terrain report[4] deals with the expected distribution of field intensity with receiving antenna location while the tropospheric propagation report[5] provides curves suitable for predicting the expected distribution of field intensity with time. It will be convenient to express the field intensities, F', in decibels above one microvolt per meter for an effective radiated power, P', in decibels above one kilowatt radiated from a half-wave dipole, and the various ratios of desired-to-undesired field in decibels above unity. Furthermore, let $L \equiv 100q$ denote the percentage of receiving locations and $T \equiv 100p$ denote the percentage of the time; thus q denotes the probability of fields greater than some specified value with respect to receiving location and p denotes this same probability with respect to time. In the irregular terrain report[4] it was shown that the following formula can be used for estimating the field intensity, $F'(L)$, exceeded at L percent of the receiving locations at a fixed height, $H_r$, above the local terrain and at a fixed distance, d, from a transmitting antenna at a height, $H_t$:

$$F'(L) = P' + S(d, H_r, H_t, f) + M(d,f) + 19.26\ k(L) \qquad (1)$$

$$\text{For } 50 < f < 250 \text{ Mc; } 8' < H_r < 30'; \ d > d_o$$

In the above S, which depends upon d, $H_r$, $H_t$ and the radio frequency, f, denotes the theoretical field intensity expected[6] over a smooth spherical earth with a radius equal to 4/3 of its actual value; S is expressed in decibels above one microvolt per meter and is to be calculated for a power of one kilowatt radiated from a horizontal half-wave dipole. The transmitting antenna height, $H_t$, to be used in these calculations is the height of the center of the actual radiating system above the average level of the terrain 2 to 10 miles from the transmitting antenna location. The effective radiated power, P', may be expressed:

$$P' = 10 \log_{10} P - P'' + G \qquad (2)$$

In the above P denotes the actual transmitter power delivered to the transmission line expressed in kilowatts, P" denotes the loss of power in the transmission line and antenna expressed in decibels and G denotes the gain of the antenna array expressed in decibels relative to that of a half-wave dipole. $M(d,f)$ is the terrain factor shown as a function of frequency and distance in Figs. 9 and 10 in the irregular terrain report[4] while $k(L)$ is the normal distribution function given in Table V and defined by (3) and (4) in the same report[4]. $k(X)$, where X may be L, T, p, or q, is also given graphically in Fig. 1 of this report. Thus, we see by (1) that the field is log-normally distributed with respect to receiving location. Although the above expression (1) for $F'(L)$ is strictly applicable only for $d > d_o$, where $d_o$ is defined in the irregular terrain report[4] to be the distance beyond which the theoretical smooth-earth field is always less than the free-space field, theoretical considerations led to an extrapolation for $M(d,f)$ shown

6/ Kenneth A. Norton, "The Calculation of Ground Wave Field Intensity Over A Finitely Conducting Spherical Earth," Proc. I.R.E., Vol. 29, December 1941, pp. 623-639.

in Fig. 10 of the irregular terrain report[4] which may be used in (1) for $d < d_o$ simply by replacing S by the free-space field. An alternative, and probably more reliable, approach to the problem of estimating $F'(L)$ for $d < d_o$ is the use of the theory presented by Norton and Kirby as an appendix to one of the allocation statements to the FCC already cited[3]; an elaboration of this theory is also presented in the appendix to Reference C[4]. However, for the frequency range 50-250 Mc the problem of estimating $F'(L)$ for $d < d_o$ is probably of little practical importance and the above described simpler, although possibly less exact, methods of the irregular terrain report[4] have been used for obtaining the numerical results shown in this report.

Most of the measurements studied in connection with the irregular terrain report[4] were made out to distances only a little beyond the line of sight so that time variations of the field at fixed locations were relatively minor. Thus, if we let $F'(L,T)$ denote the field expected to be exceeded for T percent of the time at L percent of the receiving locations we may write:

$$F'(L,50) = P' + F(50,50) + R_L(L) \tag{3}$$

$$R_L(L) \equiv 19.26\ k(L) \tag{4}$$

$$F(50,50) = 20 \log_{10}(137,600/d) + M(d,f) \tag{5}$$

where $d < d_o$

$$\text{or } F(50,50) = S(d,H_r,H_t,f) + M(d,f) \tag{6}$$

where $d_o < d < 2\left(\sqrt{2H_t} + \sqrt{2H_r}\right)$

In the above d is expressed in miles, and $H_t$ and $H_r$ in feet and $R_L(L)$ is given graphically in Fig. 1.

On the other hand, most of the measurements studied in connection with the tropospheric propagation report[5] were made at larger distances where the importance of fading was predominant and the effects of terrain were averaged out by the methods used in the analysis. Thus, values of $F(50,T)$ were presented in the tropospheric report[5] covering the range of distances from 15 to 400 miles, transmitting antenna heights from 100' to 5000' and for the specific frequencies 63, 82, 98, and 195 Mc. The results of the tropospheric propagation report may be expressed by the following log-normal distribution of the field intensity with respect to time:

$$F'(50,T) = P' + F(50,50) + R(T) \tag{7}$$

$$R(T) \equiv \left[F(50,1) - F(50,50)\right]\ k(T) \equiv R(1)k(T) \tag{8}$$

where $F(50,50)$ denotes the median field (for $P' = 0$) shown in the tropospheric propagation report[5] or (at distances less than twice the distance to the line of sight) given by (5) or (6) since the analysis of the data available in both reports[4/5] indicated agreement in this range of distances. The function $k(T)$ is shown graphically in Fig. 1 and is identical to $k(L)$ except that the percentage of time variable T is used instead of the percentage of receiving locations L. $R(1) \equiv [F(50,1) - F(50,50)]$ is expressed in decibels and denotes the ratio between the fields exceeded for 1% and for 50% of the time, respectively, as received at a particular receiving location from a particular transmitting station. R(1) is shown in Figs. 24, 25, 26 and 27 of the tropospheric propagation report[5] as a function of distance, frequency and transmitting antenna height.

A limited amount of data (Fig. 15 in the tropospheric propagation report[5]) recorded for long periods of time at a fairly large number of different receiving locations at distances less than 2.5 times the distance to the line of sight indicate that (3) represents satisfactorily the distribution $F(L,50)$ for $T = 50\%$ of the time. For allocation purposes, however, it is desirable to be able to estimate $F(L,T)$ for all values of L and T; in the absence of adequate experimental data, which would obviously be most difficult to obtain, the results (3) of the irregular terrain study[4] will be combined with the results (7) of the tropospheric propagation study[5] by

(A) Assuming that the distribution (3) of the fields with receiving antenna location is the same at all distances, and

(B) Assuming that the distribution (3) of the fields with receiving antenna location is independent of their distribution with time, i.e., that quantitatively similar variations of the fields with time will occur at good and at bad receiving locations.

By making these two assumptions we may write our final general formula for the field expected at any distance:

$$F'(L,T) = P' + F(50,50) + R_L(L) + R(T) \qquad (9)$$

$F(50,50)$ may be obtained from (5) or (6) at short distances or at larger distances from Figs. 19, 20, 21, 22 and 23 of the tropospheric propagation report[5]. Although the above two assumptions (A) and (B) appear to be quite reasonable, it should be emphasized that neither have been adequately checked experimentally.

In order to use (9) for determining the ratio, $r(L,T)$, between the fields from a desired and an undesired station which is expected to be exceeded at L percent of the receiving locations for T percent of the time, the following two additional assumptions may be made:

(C) Assume that the distribution with receiving antenna location (3) of the desired field is independent of that for the undesired field, i.e., that good receiving locations for the desired station may be either good or bad for the undesired station, and

(D) Assume that the distribution (7) of the desired field with time is independent of that for the undesired field, i.e., that times of strong fields for the desired station may be times at which either strong or weak fields will be received from the undesired station.

By making these two additional assumptions, we may write the following expression for the ratio between the fields of the desired and undesired stations:

$$r(L,T) = P'_d - P'_u + F_d(50,50) - F_u(50,50) + r_L(L) + r(T) \qquad (10)$$

$$r_L(L) \equiv \sqrt{2}\, R_L(L) = 27.24\ k(L) \qquad (11)$$

$$r(T) \equiv \sqrt{R_d^2(T) + R_u^2(T)} = k(T)\sqrt{R_d^2(1) + R_u^2(1)} \qquad (12)$$

The above formulas for $r_L(L)$ and $r(T)$ follow from the fact[7] that the mean value of the difference of two normally distributed variables is simply the difference of their means and, when the variations of the two variables occur independently, the variance of the difference is simply the sum of the two variances. The function $r_L(L)$ is shown graphically in Fig. 1. It is recognized that neither of the assumptions (C) and (D) are likely to be borne out exactly in further experimental investigations; in fact, it is believed that the desired and undesired fields are probably characterized by positive coefficients of correlation, $\rho_T$ with respect to time and $\rho_L$ with respect to receiving antenna location. To the extent that this is true the coefficient of k(L) in (11) should be replaced by $27.24\sqrt{1 - \rho_L}$ and the coefficient of k(T) in (12) should be replaced by $\sqrt{R_d^2(1) + R_u^2(1) - 2\rho_T R_d(1)\, R_u(1)}$. In the tropospheric propagation report[5] a study of the correlation with respect to time indicated values as large as $\rho_T = +0.5$; however, the conclusion was reached in that report that $\rho_T$ should be set equal to zero in calculating the mutual interference between two stations.

Since adequate experimental determinations of $\rho_L$ and $\rho_T$ are not now available, their effects will be neglected in our present study; since $\rho_L$ and $\rho_T$ are probably always positive, their neglect will be an over-estimation of the mutual interference to be expected between stations for large values of L and T.

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7/ Harald Cramér, "Mathematical Methods of Statistics," Pages 188 and 212, Princeton University Press, 1946, Princeton, N. J.

## III THE FIELD INTENSITY REQUIRED TO PROVIDE SATISFACTORY TELEVISION BROADCAST RECEPTION

In the allocation of broadcast facilities, figures for the field intensity required for satisfactory reception are needed in two connections: (a) to determine the field intensities which should be protected from further degradation by undesired signals from other stations on the same or adjacent channels, or (b) to determine the number of televiewers provided by a given station with a satisfactory service.

It is important to distinguish between these two applications since the required fields applicable to (a) above may be substantially less than for (b). Thus, useful signals from the desired station are subject to interference from the undesired station only in an annular ring at the outer edge of the desired station's service area and within this annular ring the population will be predominantly rural in character. In fact, although there may be some large towns or even cities within this annular ring, well over half of its area will always consist of widely dispersed homes where television reception will be free from interference from man-made noise for nearly 100% of the time. Thus, it seems fair to conclude that the field required for satisfactory reception by these rural and suburban televiewers will not be substantially influenced by man-made noise. Furthermore, these televiewers will, of necessity, have provided themselves with good television receivers and may conveniently use directive receiving antennas since many of the stations they wish to receive will lie in the same general direction.

Figs. 2 and 3 give the results of applying the above considerations to the determination of the field intensities which should be protected from further degradation by other undesired signals. These results were obtained as follows. By definition of effective noise figure, NF'[8/], the available noise power at the input to the second detector of the receiver, referred to the terminals of the receiving antenna, may be written:

$$P_n = NF' \, kTB \text{ watts} \tag{13}$$

$$NF' = EN - 1 + L \cdot NF \tag{14}$$

where $kTB = 16.44 \cdot 10^{-15}$ watts for a 4000 kc television receiver bandwidth and $T = 300^\circ$ Kelvin.

EN = External cosmic radio noise factor as reported by J. W. Herbstreit[9/].

L = Transmission line and antenna power loss factor.

NF = Receiver noise figure as measured at the receiver terminals with a dummy antenna at room temperature ($T = 300^\circ$ Kelvin).

8/ Kenneth A. Norton and Arthur C. Omberg, "The Maximum Range of a Radar Set," Proc. I.R.E., Vol. 35, pp. 4-24, January 1947.

9/ J. W. Herbstreit, "Cosmic Radio Noise," Advances in Electronics, Vol. I, pp. 347-380, Academic Press, Inc., Publishers, New York, N. Y., 1948.

Fig. 2 shows as a function of frequency the values of EN and L together with two assumed values of NF and the resulting values of NF' determined by (14). The curves of NF and NF' indicated as applicable to a typical good television receiver are probably representative of only the best television receivers now on the market while the lower values of NF and NF' indicated as applicable to a television receiver designed for weak signal reception can be achieved only by using special care in the design, alignment and maintenance of the receiver.

The power received from the visual transmitter during the synchronization pulse that is available at the receiving antenna terminals is equal to:

$$P_s = \frac{(E \cdot 10^6)^2 \; A_r}{Z} \text{ watts} \tag{15}$$

where E is the received field intensity (i.e., the rms field intensity during the synchronization pulse which is the value reported in field intensity measurements and is a direct measure of the visual transmitter power) expressed in microvolts per meter, $Z = 376.7$ ohms, the impedance of free space, and $A_r$ is the absorbing area of the receiving antenna. $A_r = g\lambda^2/4\pi$ where g is the antenna gain relative to an isotropic antenna and $\lambda$ is the wavelength in meters. $g = 1.641$ for a half-wave dipole.

The intermediate frequency band-pass characteristics of the television receiver are so designed that the video carrier is reduced in intensity at the input to the second detector to just half of its value at mid-band and, since most of the composite video signal energy is contained in a range of frequencies very near to the carrier, the composite video signal voltage is also reduced to very nearly one-half of the value it would have if the carrier were (improperly) tuned to mid-band. As a consequence of this the peak-video-signal to noise-power ratio $(S_p/N)$ at the input to the second detector will be only one-fourth as large when the receiver is properly tuned as it would be when the receiver is improperly tuned with the picture carrier in the middle of the intermediate frequency band as would be the case, for example, in a measurement of the television receiver noise figure. In the output of the television receiver second detector the d.c. synchronization pulse voltage, $V_s$, will be equal to the peak value of the intermediate frequency pulse voltage (i.e., $\sqrt{2}$ times the intermediate frequency rms voltage during the pulse) but the detected rms video noise voltage, $V_n$, will (for large signal-to-noise ratios)[10/] be equal to the intermediate frequency rms noise voltage. Thus, the square of the synchronization-pulse-voltage to rms-video-noise ratio $(V_s/V_n)$ in the <u>output</u> of the second detector will be 2 times the value of $(S_p/N)$ at the <u>input</u>.

Since, in our present problem we are dealing with fluctuation noise which will completely degrade the picture before spoiling the synchronization, it

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10/ S. O. Rice, "Properties of a Sine Wave Plus Random Noise," Bell System Technical Journal, Vol. 27, pp. 109-157, January, 1948.

would seem that the peak-to-peak-picture-signal to rms-video-noise ratio ($V_p/V_n$) might be an even better index of performance than the synchronization-pulse-voltage to rms-video-noise ratio ($V_s/V_n$). Since the black level picture signal voltage is set at 0.75 times the synchronization pulse voltage and since the white level is preferably held to a value not less than 0.15 times the synchronization pulse voltage*, it follows that the peak-to-peak-picture-signal to rms-video-noise ratio ($V_p/V_n$) will be about 0.6 times (4.4 db below) the synchronization-pulse-voltage to rms-video-noise ratio ($V_s/V_n$).

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*The FCC Standards of Good Engineering Practice state that the maximum white level shall be 15 percent or less of the peak carrier amplitude but it seems to the authors that the advantage gained by complete modulation is surely very small compared to the danger from occasional over-modulation. Thus, over-modulation may be expected with a frequency of occurrence in direct proportion to the smallness of the maximum white level and, when over-modulated, the signals received by all televiewers throughout the entire service area will be degraded. This should be weighed against the fact that the use of an average maximum white level of 5 percent, for example, rather than 15 percent will increase the effectiveness of the picture signal with respect to fluctuation noise (there will be no effect on synchronization) by (0.7/0.6) i.e., 1.3 db. Thus, referring to the $R_L(L)$ distribution on Fig. 1 we may estimate the effect of operating consistently at 5 percent rather than 15 percent. Suppose we are at the distance from the transmitter at which 90 percent of the receiving locations have a signal ($R_L(90) = -10.7$ db) satisfactory with respect to fluctuation noise when the transmitter is operated with a maximum white level of 15 percent. If the maximum white level is now changed to 5 percent, $R_L(L) = -10.7 - 1.3 = -12$ db, and we see by Fig. 1 that L = 92.6 percent. Thus, at this distance we have increased the number of receiving locations with satisfactory signals from 90 percent to 92.6 percent. However, at shorter distances the percentage improvement is even less so that the net increase in televiewers with a detectably improved picture-signal to video-noise ratio will undoubtedly be found to be much less than one percent when allowance is made for the fact that most of the televiewers live within a very few miles of the station.

Thus, after allowing for the above factors, we may write:

$$(P_s/P_n) = 4(S_p/N) = 2(V_s/V_n)^2 = \frac{2}{0.36}(V_p/V_n)^2 \tag{16}$$

Substituting (13) and (15) in (16) and solving for E, we obtain:

$$E_n = 0.0588\sqrt{(S_p/N)\ NF'/g}\ f_{mc} \text{ microvolts per meter} \tag{17}$$

Thus, with reception on a half-wave dipole a peak-video-signal to noise-power ratio of 24 db, $(S_p/N) = 250$, will be provided at the second detector input when:

$$E_r = 0.727\sqrt{NF'}\ f_{mc} \text{ microvolts per meter} \tag{18}$$

The subscript r refers to the field required with a half-wave dipole. According to (16) the field intensity given by (18) will also provide at the second detector output a synchronization-pulse-voltage to rms-video-noise ratio, $(V_s/V_n) = 22.36$, and a peak-to-peak-picture-signal to rms-video-noise ratio, $(V_p/V_n) = 13.42$, since these values correspond to a value of $(S_p/N) = 250$.

It should be noted that the value finally adopted as an FCC standard for $(S_p/N)$ should correspond to a level at which the desired picture signal degradation due to noise is about equal to the corresponding degradation due to an undesired unsynchronized signal at the FCC standard level, i.e., 40 db weaker than the desired signal. By attempting to equalize these two degradations it should be possible to determine more accurately the minimum separation between co-channel stations which is permissible without further degradation from co-channel interference in areas in which the service is not already degraded by noise. It is not now known whether a peak-video-signal to noise-power ratio of 24 db as used in (18) and in Fig. 3 is appropriate in the sense defined above and laboratory tests are now being undertaken at CRPL to determine the reaction of groups of observers to typical television pictures viewed at various levels relative to the first circuit plus cosmic radio noise. If these laboratory tests indicate that a value different from the 24 db assumed in this report should be adopted, then the required fields as determined by (18) and shown on Fig. 3 should be corrected accordingly. Fig. 3 gives the values determined by (18) for the two receivers with noise figures as shown on Fig. 2. The two lower curves shown on Fig. 3 correspond to the use of a receiving antenna with a gain of 6 db relative to that of a half-wave dipole; these latter curves were obtained by assuming that the required field will be less than that given by (18) very nearly in direct proportion to the signal gain of the antenna used relative to that of a half-wave dipole. The support for this assumption follows from the fact that the cosmic radio noise arrives at the antenna more or less uniformly from all directions and its intensity will thus be affected very little by the receiving antenna directivity.

In the remainder of this report the values of required field intensity given by the upper curve on Fig. 3 are used as an indication of the values of field intensity which should be protected in rural receiving locations from further degradation by other undesired signals. In order to determine the actual number of televiewers with satisfactory reception throughout the service area of the station, it is necessary to consider, in addition to the above minimum values of required field intensity, the additional intensity necessary to overcome the effects of various man-made noises such as auto ignition, electric razors, oil burners, etc. Such noise sources become increasingly important more or less in proportion to the population density and those televiewers with homes immediately adjacent to well-traveled highways will require comparatively strong television signal fields in order to overcome the effects of the auto ignition which might otherwise limit their reception for a fairly large percentage of the time. This latter problem has been studied by R. W. George[11]. However, since this latter problem, for the reasons mentioned, is probably of secondary importance in connection with the present allocation problem, no further analysis will be made here of what this actual distribution of service may be expected to be.

## IV THE SOLUTION OF TYPICAL ALLOCATION PROBLEMS

The preceding discussion has provided the data necessary for a solution of typical allocation problems and the following equations and tables provide examples of the procedure to be followed in obtaining the answers to particular problems.

In general, it is believed that a reasonably accurate solution of any allocation problem can be obtained when it is possible to determine the percentage, L, of receiving locations at any distance, d, from a station which will have a specified grade of service: for example, the percentage of receiving locations which will have a field intensity greater, for a specified percentage of time, T, than the value required to overcome the effects of first circuit noise or at which the desired-to-undesired ratio will exceed some specified value for a percentage of time, T. In the examples which follow, T will be taken to be 90%, 99% and 99.9% of the time, the field intensity required for satisfactory service will be taken from the upper curve on Fig. 3: i.e., for 63 Mc, $F_r$ = 46.9 db above one

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11/ R. W. George, "Field Strength of Motorcar Ignition Between 40 and 450 Megacycles," Proc. I.R.E., Vol. 28, pp. 409-412, Sept. 1940.

microvolt per meter and for 195 Mc, $F_r$ = 57.7 db above one microvolt per meter; and the following ratios of desired-to-undesired field intensities are assumed to be required for freedom from inter-station interference: for co-channel unsynchronized operation, A = 40 db, for co-channel synchronized operation, A = 28 db, and for adjacent channel operation, A = 6 db. These values are not based on tests made at CRPL but merely represent values which have been chosen to illustrate the problem.

The percentage of receiving locations, L, at which the desired field for a television station operating on 63 Mc is greater than $F_r$ for a percentage of time, T, may be determined simply by setting the right hand side of (9) equal to $F_r$ and then solving for L:

$$P' + F(50,50) + R_L(L) + R(T) = F_r = 46.9 \ (f = 63 \text{ Mc}) \tag{19}$$

$$\therefore R_L(L) = 46.9 - P' - F(50,50) - R(1)\, k(T) \tag{20}$$

From Fig. 1, k(T) = -1.33 for T = 99.9%, k(T) = -1 for T = 99% and k(T) = -0.55 for T = 90%.

Table I gives a sample of the calculations needed to determine L from (20) at various distances from a station with transmitting antenna height of 500 feet. The values of F(50,50) and of R(1) are taken from Figs. 19 and 24, respectively, of Reference D[5].

The percentage of receiving locations, L, at which the field from a desired station (represented by the subscript d) is acceptable for a percentage of time, T, in the presence of interference from an undesired station (represented by the subscript u) may be determined simply by setting the right hand side of (10) equal to the acceptable ratio, A, and then solving for L:

$$P'_d - P'_u + F_d(50,50) - F_u(50,50) + r_L(L) + r(T) = A \tag{21}$$

$$r_L(L) = A + P'_u - P'_d - F_d(50,50) + F_u(50,50) - k(T)\sqrt{R_d^2(1) + R_u^2(1)} \tag{22}$$

TABLE I

SAMPLE CALCULATIONS OF THE PERCENTAGE OF RECEIVING LOCATIONS, L, AT WHICH THE DESIRED FIELD EXCEEDS FOR T PERCENT OF THE TIME THE FIELD, $F_r$ = 46.9 db ABOVE ONE MICROVOLT PER METER, WHICH IS REQUIRED ON 63 MC FOR SATISFACTORY RECEPTION IN RURAL AREAS

($H_t$ = 500'; $H_r$ = 30'; f = 63 Mc)

| | | T = 99% | | | | | T = 90% | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | P' = 0 | | P' = 10 | | | P' = 0 | | P' = 10 | |
| d miles | F(50,50) db | R(99) db | $R_L(L)$ db | L % | $R_L(L)$ db | L % | R(90) db | $R_L(L)$ db | L % | $R_L(L)$ db | L % |
| 5 | 78.0 | -0.65 | -30.45 | 99.988 | -40.45 | 100 | -0.36 | -30.74 | 99.99 | -40.74 | 100 |
| 10 | 66.6 | -1.3 | -18.4 | 98.7 | -28.4 | 99.97 | -0.7 | -19.0 | 98.93 | -29.0 | 99.977 |
| 15 | 59.4 | -1.95 | -10.55 | 89.6 | -20.55 | 99.37 | -1.05 | -11.45 | 91.6 | -21.45 | 99.52 |
| 20 | 54.1 | -2.6 | -4.6 | 71.5 | -14.6 | 96.2 | -1.4 | -5.8 | 76 | -15.8 | 97.2 |
| 30 | 46.1 | -3.9 | 4.7 | 28.5 | -5.3 | 74.3 | -2.1 | 2.9 | 36 | -7.1 | 80.6 |
| 40 | 38.9 | -5.7 | 13.7 | 4.9 | 3.7 | 32.5 | -3.1 | 11.1 | 9 | 1.1 | 44 |
| 50 | 31.9 | -8.6 | 23.6 | 0.22 | 13.6 | 5 | -4.7 | 19.7 | 0.85 | 9.7 | 11.8 |
| 60 | 25.1 | -12.3 | 34.1 | 0 | 24.1 | 0.18 | -6.8 | 28.6 | 0.03 | 18.6 | 1.2 |
| 70 | 18.6 | -16.0 | 44.3 | | 34.3 | 0 | -8.8 | 37.1 | 0 | 27.1 | 0.05 |

Table II gives a sample of the calculations needed to determine L from (22) at various distances, d, from a desired station along a line in the direction of an undesired station; the desired and undesired stations both operate on 63 Mc with a transmitting antenna height of 500'. The values of $F_d(50,50)$ and of $F_u(50,50)$ are taken from Fig. 19 of Reference D5/ for distances d and (D - d), respectively, while the values of $R_d(1)$ and $R_u(1)$ are similarly taken from Fig. 24 of Reference D5/ for the same two distances d and (D - d).

TABLE II

SAMPLE CALCULATIONS OF THE PERCENTAGE OF RECEIVING LOCATIONS, L, ALONG A LINE BETWEEN THE TWO STATIONS AT WHICH THE DESIRED FIELD IS A db GREATER FOR A PERCENTAGE OF TIME, T, THAN THE UNDESIRED FIELD WHEN THE STATIONS ARE SEPARATED BY A DISTANCE D

($H_t$ = 500'; $H_r$ = 8' to 100'; f = 63 Mc; D = 300 miles; T = 99%; $R_u(1)$ = 22.9 db)

| | | | | | $A + P'_u - P'_d$ = 6 db | | $A + P'_u - P'_d$ = 28 db | | $A + P'_u - P'_d$ = 40 db | |
|---|---|---|---|---|---|---|---|---|---|---|
| D - d miles | $F_d(50,50)$ db | $F_u(50,50)$ db | $R_d(1)$ db | r(99) db | $r_L(L)$ db | L % | $r_L(L)$ db | L % | $r_L(L)$ db | L % |
| 285 | 59.4 | -28.0 | 1.95 | -23.0 | -58.4 | 100 | -36.4 | 99.90 | -24.4 | 98.2 |
| 280 | 54.0 | -27.2 | 2.6 | -23.05 | -52.15 | 100 | -30.15 | 99.5 | -18.15 | 94.0 |
| 270 | 46.1 | -25.7 | 3.9 | -23.2 | -42.6 | 99.99 | -20.6 | 96.1 | -8.6 | 77.0 |
| 260 | 38.9 | -24.0 | 5.7 | -23.6 | -33.3 | 99.77 | -11.3 | 83.2 | 0.7 | 47.6 |
| 250 | 31.9 | -22.2 | 8.6 | -24.5 | -23.6 | 97.8 | -1.6 | 55.8 | 10.4 | 18.6 |
| 240 | 25.1 | -20.7 | 12.3 | -26.0 | -13.8 | 88.1 | 8.2 | 24.0 | 20.2 | 4.3 |
| 230 | 18.6 | -19.0 | 16.0 | -27.9 | -3.7 | 62.6 | 18.3 | 6.0 | 30.3 | 0.49 |
| 220 | 12.2 | -17.4 | 19.3 | -29.9 | 6.3 | 29.6 | 28.3 | 0.79 | 40.3 | 0.03 |
| 210 | 6.9 | -15.9 | 21.8 | -31.6 | 14.8 | 10.2 | 36.8 | 0.09 | 48.8 | 0 |
| 200 | 3.0 | -14.2 | 22.8 | -32.3 | 21.1 | 3.7 | 43.1 | 0 | | |
| 190 | 1.2 | -12.5 | 22.9 | -32.4 | 24.7 | 1.75 | | | | |
| 180 | -0.7 | -10.8 | 22.9 | -32.4 | 28.3 | 0.79 | | | | |
| 170 | -2.4 | -9.1 | 22.9 | -32.4 | 31.7 | 0:34 | | | | |
| 160 | -4.2 | -7.5 | 22.9 | -32.4 | 35.1 | 0.14 | | | | |
| 150 | -5.8 | -5.8 | 22.9 | -32.4 | 38.4 | 0.11 | | | | |

Other examples of the service and interference ranges are presented in Figs. 4-17 which illustrate the effects to be expected with a wide variety of variables. It is interesting to note that, as a consequence of the conclusion that the theoretical receiving antenna height-gain relation for horizontal polarization is applicable on the average up to a height of at least 30' and possibly as high as 100', irrespective of terrain[4] or tropospheric[2] effects, the distance at which a given interference condition may be expected will also be independent of the receiving antenna height since the median desired and the median undesired fields will be affected the same by any changes in this height. This may be seen most readily by noting, in (21), that any change in $F_d(50,50)$ to allow for receiving antenna height will be exactly balanced (for $d > d_o$[4]) by a corresponding change in $F_u(50,50)$. Thus, all of the interference curves shown in this report may be considered reasonably applicable for random receiving antenna heights throughout the range most often encountered in practice, i.e., up to say 100'.

It should be noted that the service curves, which are obtained from (19) or (20), are not independent of receiving antenna height, and, in fact, the use of a 100' receiving antenna will, on the average, increase the received field by about 10 db above the values for $H_r = 30'$ used in this report and this is equivalent to a 10 to 1 increase in the transmitter power. Thus, to determine, of the receiving locations at which 100' rather than 30' antennas are used, the percentage at which a specified grade of service is available, the curve for 1000 kw radiated power should be read for estimating the service expected from a station with 100 kw power and the curve for 100 kw used to determine the service expected from a 10 kw station.

## V A UNIQUE DEFINITION OF THE SERVICE OF AN ACCEPTABLE GRADE, $T_a$, AVAILABLE AT A DISTANCE, d, FROM AN ASSUMED CLEAR CHANNEL TELEVISION BROADCASTING STATION

In this section, a definition will be developed for the probability, $Q_o(d,p_a)$, with respect to both time and receiving location of receiving an acceptable signal for a percentage of time, $T_a \equiv 100\ p_a$, or greater at a distance, d, from a television station which is assumed to be located sufficiently far away from other stations and other sources of man-made interference so that the only limitation to service is that arising from cosmic radio noise and the radio noise in the television receiver, as discussed in Section III above. Under these circumstances (19) provides a relation between the probability, $p \equiv T/100$ with respect to time and the probability, $q \equiv L/100$ with respect to receiving location of receiving a field equal to or greater than the required value, $F_r$, at the distance, d, from a television station which has a radiated power, P', and for which the median field at this distance is expected to be F(50,50). An example of this relation between p and q is given by the curve on Fig. 18 for a distance, d = 60 miles, from a television station on Channel 3 (f = 63 Mc) transmitting from an antenna at a height of 500 feet with an effective radiated power of 100 kilowatts; the assumed value of field required for an acceptable service in this example was 46.9 db above one microvolt per meter. We see by this curve that the field at the best 10% of the receiving locations at a distance of 60 miles may be expected to be acceptable for 96% or more of the time. Similarly the field at the best 41% of the receiving locations at 60 miles may be expected to be acceptable for 50% or more of the time. However, considering the fact that a televiewer who has a service available for less than some percentage of time, $T_a$, will not bother to tune his receiver to this channel, it is clear from Fig. 18 that there will be a percentage of receiving locations, $100\left[1 - q(p_a)\right]$, at the distance, d, at which the probability of service is essentially zero. This minimum acceptable value, $T_a = 100\ p_a$, will probably depend to some extent on the number of other satisfactory radio and television signals available to the televiewers, but it seems most unlikely that many people would attempt to use a signal available for a percentage of the time less than say $T_a$ 50% even if this were their only available radio or television signal. It would seem to be desirable that a study be made of the attitudes of rural televiewers towards signals available for various percentages of the time from one or more sources with the object of determining the appropriate value of $T_a$ to be used in particular circumstances. In the absence of quantitative data of this kind, the following three grades of broadcast service will be <u>arbitrarily</u> adopted for illustrating this problem: Grade A corresponding to $T_a = 99\%$, Grade B corresponding to $T_a = 90\%$ and Grade C corresponding to $T_a = 0$. The lowest grade of service, Grade C, should probably correspond to some value of $T_a$ other than 0% (perhaps 50%), but there are no simple means for calculating $Q_o\ (d,\ 0.5)$ whereas a simple formula is available for calculating $Q_o(d,\ 0)$. */

We now see by Fig. 18 that the probability with respect to both time and receiving location of receiving a service of grade $p_a$ or better may be determined by the integral:

$$Q_o(d,p_a) = \int_o^{q(p_a)} p\,dq \tag{23}$$

where $q(p_a)$ = value of q corresponding to $p = p_a = T_a/100$. Thus $Q_o(d,p_a)$ is, in the example shown for $p_a = 0.5$ on Fig. 18, simply the cross-hatched area under the curve; i.e., $Q_o(60,0.5) = 0.33$ for $T_a = 50\%$. Unfortunately no simple methods have been developed for calculating the value of this probability exactly except for the case $p_a = 0$. In this case the probability, $Q_o(d,0)$, may be determined by noting that, since the field has been assumed to vary independently with respect to time and receiving location, (19) becomes:

$$P' + F(50,50) + k\left[Q_o(d,0)\right]\sqrt{R_L^2(1) + R^2(1)} = F_r \tag{24}$$

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*/ Another approach to the problem of illustrating television service, using grades of service based on minimum percentage of time of acceptable service, and evaluating the service of stations not on the basis of field intensity contours but on the basis of total area or total population receiving each grade of service, is presented in Reference H to the Report of the Ad Hoc Committee, FCC Dockets 8736, 8975, 9175, "Deterioration of Service with Increasing Distance," R. M. Wilmotte and Harry Fine, May 26, 1949.

and this may be solved for $k\left[Q_o(d,0)\right]$:

$$k\left[Q_o(d,0)\right] = \frac{F_r - P' - F(50,50)}{\sqrt{R_L^2(1) + R^2(1)}} \tag{25}$$

The value of $Q_o(d,0)$ may now be determined from (25) by reference to the upper probability scale on Fig. 1 which gives $k(X)$ as a function of the probability $X$, i.e., in the present case $X = Q_o(d,0)$. For other values of $p_a$ the following considerations provide a method for estimating $Q_o(d,p_a)$ which will be increasingly accurate the nearer $p_a$ is to unity, i.e., for the better grades of service. Thus, we see by a careful examination of the example on Fig. 18, that $Q_o(d,p_a)$ must be less than $q(p_a)$ but greater than $p_a q(p_a)$:

$$p_a q(p_a) < Q_o(d,p_a) < q(p_a) \tag{26}$$

This suggests that we may use the following approximations for $T_a$ = 99% and 90%:

$$Q_o(d,0.99) \cong q_o(d,0.99) \tag{27}$$

$$Q_o(d,0.9) \cong q_o(d,0.9) \tag{28}$$

The values of $q_o(d,0.99)$ and $q_o(d,0.9)$ may be determined simply by setting $T$ = 99% or 90%, respectively, in (19) and noting, in that equation, that $L = 100\ q_o$. The use of these approximations will always slightly over-estimate the probability $Q_o(d,p_a)$ with respect to both time and receiving location of receiving a service of grade $p_a$ or better; in fact $q(p_a)$ is simply the probability, with respect to receiving location only, of receiving a service of grade $p_a$ or better. Consequently, we may consider that Grades A and B service are defined in terms of the probability of service of a given grade or better with respect to receiving location only, recognizing that the influence of the time variable on the probability of service with respect to both time and receiving location is negligible in the case of these particular grades of service. Thus, Grades A, B and C service will be defined by the probabilities $q_o(d,0.99)$, $q_o(d,0.9)$ and $Q_o(d,0)$, respectively. The subscript zero on these probabilities refers to the fact that the service measured by these probabilities is limited by noise only and thus corresponds to the special case where the television station is at a sufficiently great distance from any other station that no mutual interference is to be expected.

Before giving examples showing the variation with distance of the probabilities of receiving these three grades of service, one additional probability distribution will be discussed. This is the variation, with respect to receiving location, of the field intensity, $F_n$, required for satisfactory reception; $F_n \equiv 20 \log_{10} E_n \equiv F_r - 10 \log_{10} g_d'$ where $g_d'$ denotes the receiving antenna gain relative to that of a half-wave dipole. Thus, the variation in required field arises from the differences in television receiver noise figures and the differences in receiving antenna gain to be expected at various receiving locations. It has been estimated that the best 5% of the television receivers may be expected to have a noise figure of the order of 8 db or better at 63 Mc while the poorest 5% may be expected to have a noise figure greater than 25 db at 63 Mc; in estimating this value of 25 db for the poorest 5% of the receivers an allowance of 10 db has been added to allow for a deterioration in the sensitivity of some of the receivers due to tube aging and drift in alignment. The corresponding noise figures at 195 Mc have been estimated to be 8 db for the best 5% and 30 db for the poorest 5% of the receivers. These values may be combined with cosmic radio noise and antenna gain in accordance with the method given in Section III to determine the required field; the following results are based on the further assumption that a half-wave dipole receiving antenna will be used in the receiving installations corresponding to the poorest 5% of the receivers while a receiving antenna with a gain of 6 db over a half-wave dipole will be used at the installations corresponding to the best 5% of the receivers. On the above assumptions, the required field for 63 Mc will exceed a value of $F_n = 60$ db for the poorest 5% of the receiving installations but will be less than $F_n = 40.9$ db for the best 5% of the installations; the corresponding values for 195 Mc are $F_n = 74.5$ db and $F_n = 46.5$ db for the poorest and best 5% of the receiving installations. The above values of $F_n$ correspond to an assumed value of $(S_p/N)$ of 24 db although preliminary measurements made at CRPL indicate that this ratio may need to be increased by as much as 6 db; if later, more comprehensive, tests confirm that $(S_p/N)$ should be 30 db, then the above values of required field intensity should also be increased by 6 db. If, for convenience, we assume that the required field is log-normally distributed with respect to the above estimated values, then the difference, $R_r(1)$, between the 1% and 50% values of required field is equal to 13.5 db at 63 Mc and is equal to 19.8 db at 195 Mc. It might be supposed that these values should be added in quadrature to the corresponding value for the terrain effects, i.e., $R_L(1) = 19.26$ db in order to determine the relation between the median value of the required field intensity and that required at a given percentage of receiving locations. However, such an addition would only be appropriate if there were no correlation between the receiving location and the type of receiving installation. Actually, however, it seems that these two variables are likely to be closely correlated on the average and that particularly good installations will, in general, be found in those receiving locations where reception would otherwise be unacceptable. Thus, it would appear that the best index to the probable television station coverage will be obtained by assuming that the field intensity required for acceptable reception is the constant minimum value, say $F_r = 46.9$ db on 63 Mc, which may readily be achieved in a practicable receiving installation. This constant value will be used throughout this report for estimating the effects of receiver and cosmic radio noise on reception at 63 Mc.

Fig. 19 gives, as a function of distance from the television station, the above defined probabilities. The values of $Q_o(d,0.99)$ and $q_o(d,0.99)$ differed too little to be shown as separate curves. The values $Q_o(d,0.9)$ and $Q_o(d,0.5)$ were obtained by determining with a planimeter the area under curves of the type shown on Fig. 18. $Q_o(d,0)$ was determined by (25).

Since $Q_o(d,p_a)$ is the probability of satisfactory reception at the distance, d, and since this will be the same in all directions from the station, it also represents the probability of service within a differential annulus of radius, $r = d$ and area $2\pi\, rdr$. Thus, the effective service area, $A_{so}$, and effective service radius, $d_{so}$, of a hypothetical clear channel television station may be defined by the integral:12/

$$\text{Effective Service Area} = A_{so}(p_a, P') \equiv 2\pi \int_0^{\infty} Q_o(r, p_a)\, rdr \equiv \pi d_{so}^2(p_a, P') \qquad (29)$$

Fig. 20 gives $r \cdot q_o(r,0.99)$ as a function of r for the effective radiated powers $P' = 0$, 10, 20 and 30 db above one kilowatt. We see by (29) that $r \cdot q_o(r,0.99)$ is a measure of the Grade A service, the Grade A service area being proportional to the area under the curve defined by this function of r; this area may be obtained by means of a planimeter. It may also be shown that the effective service radius, $d_{so}$, defined in (29) may be obtained in each case simply by determining the area within the particular triangle (defined by the distance $d_{so}$) on Fig. 20 which is equal to that under the curve. Figs. 21 and 22 give data similar to that on Fig. 20 but corresponding to Grade B and Grade C service, respectively. Fig. 22 also gives a graphical comparison between the three grades of service for the case of an effective radiated power of 100 kw ($P' = 20$). The following table gives the values of $A_{so}(p_a, P')$ and of $d_{so}(p_a, P')$ as determined by the use of a planimeter from the curves on Figs. 20, 21 and 22.

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12/ This measure of television broadcast service was developed in a paper, "A Study of Efficient Methods for the Allocation of Frequencies to Television Broadcasting Stations," presented by K. A. Norton on May 20, 1949 as a part of a Symposium on Statistical Methods in Electrical Engineering at the University of Illinois.

TABLE III

THE EFFECTIVE SERVICE RADIUS AND EFFECTIVE SERVICE AREA EXPECTED FOR A CLEAR CHANNEL TELEVISION BROADCASTING STATION

$f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = 1$

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | |
|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | |
| Grade of Service | $d_{so}$ miles | $A_{so}$ sq. miles | $d_{so}$ miles | $A_{so}$ sq. miles | $d_{so}$ miles | $A_{so}$ sq. miles | $d_{so}$ miles | $A_{so}$ sq. miles |
| A | 26.9 | 2273 | 37.0 | 4301 | 47.2 | 6999 | 57.1 | 10243 |
| B | 28.9 | 2624 | 40.0 | 5027 | 51.8 | 8430 | 63.1 | 12509 |
| C | 32.3 | 3278 | 47.2 | 6999 | 63.8 | 12788 | 87.1 | 23833 |

The values in the above table correspond to reception on a half-wave dipole and to a peak-video-signal to noise-power ratio of 24 db, i.e., $(S_p/N) = 250$; by using an equivalent power, $P_e = P' + 10 \log_{10}(S_p/N) - 24 - 10 \log_{10} g'_d$, the values given in the above table may be considered applicable to other assumed values of $(S_p/N)$ or $g'_d$.

## VI METHODS FOR CALCULATING THE INTERFERENCE TO BE EXPECTED FROM MORE THAN ONE SOURCE

In Section V above, definitions were given for the service to be expected for the case where no other interfering signals are present and the only limitation to service was assumed to be the fluctuation noise in the radio frequency circuits of the receiver plus the cosmic radio noise picked up by the antenna. Since these sources of noise have practically identical characteristics and have random relative phases, it has been found convenient (Eq. (14) and Ref. 8) to refer each of these noises to the terminals of the receiving antenna and then add the effective noise powers at that point from all of these contributing sources. Finally, this combined noise power is used with an appropriate signal-to-noise ratio to determine the field intensity, $E_n$, (Eq. 17), which must be available from the desired station in order to provide a satisfactory clear-channel television broadcasting service. In view of the fact that the interfering signals from other television stations will also arrive at the receiving antenna with random relative phase, it would appear reasonable to assume that the following formula is appropriate for estimating the field intensity, $E_{dr}$, which must be available from the desired station in order to provide a satisfactory television service not only in the presence of noise alone but also in the presence of other interfering signals:

$$g_d' E_{dr}^2 = E_r^2 + \sum_{i=1}^{u} g_i'(100\, E_i)^2 + \sum_{i=u+1}^{u+s} g_i'(25\, E_i)^2 + \sum_{i=u+s+1}^{u+s+a} g_i'(2\, E_i)^2 \equiv$$

$$E_r^2 + g_d' \sum_{i=1}^{u+s+a} E_{ir}^2 \tag{30}$$

In the above, $g_d'$ denotes the receiving antenna gain for the desired signal relative to that of a half-wave dipole while the $g_i'$ are corresponding values of receiving antenna gain for the directions corresponding to each of the undesired signals. $E_r^2 \equiv g_d' E_n^2$ where $E_n$ is defined by (17). $E_i$(for $i = 1$ to $u$) denotes the field intensity of one of the u unsynchronized co-channel interfering stations so that $E_{ir} \equiv (100\, E_i)\sqrt{g_i'/g_d'}$ denotes the field intensity which would have to be available from the desired station to provide satisfactory service in the presence of this single source of interference only; similarly, $E_i$(for $i = u+1$ to $u+s$) denotes the field intensity of one of the s synchronized or "off-set" co-channel interfering stations while $E_i$($i = u+s+1$ to $u+s+a$) corresponds to the field intensity of one of the a adjacent channel interfering stations. The factors 100(A = 40 db), 25(A = 28 db) and 2(A = 6 db) are considered to represent with reasonable accuracy the required ratios of desired-to-undesired field intensities necessary in the presence of these three kinds of interfering signals to provide similar qualities of acceptable television service. It should, of course, be noted that the resultant annoyance arising from several sources of interfering signals will not necessarily be directly proportional to their independently added signal energies, as is implied by (30), and it is probable that, in their ultimate effect on the picture, these interfering signals will actually combine in some complicated fashion in the eye of the televiewer to produce either more or less annoyance than is indicated by (30). For example, the presence of one undesired signal may either enhance or mask the annoying effects of others. However, the exact mechanism for the addition of interfering signals is of secondary importance since each of the interfering signals will vary more or less independently with respect to both time and receiving location over very wide ranges so that the probability for the simultaneous occurrence of two or more signals of comparable intensity is small; the validity of this conclusion will be understood better at a later stage of our argument.

In order to make our problem of combining interfering signals concrete, reference will be made to the idealized triangular lattice allocation of television broadcast stations shown on Figs. 23 and 24. The reason for this particular arrangement of stations will be discussed in Section VIII. The desired station, for which the service is being assessed, is located at the center of the lattice on Fig. 24. Consider a particular television receiving location at a distance, d, from the desired station along the line between it and the undesired co-channel station No. 1 on Fig. 24. At such a receiving location there may be as many as 14 non-negligible interfering fields in addition to noise. Thus, the stations numbered 1 - 6, inclusive, are assumed to operate on the same channel and each are within interfering range of the receiving location. In addition, the adjacent channel stations 7-14, inclusive, may also cause interference. Some discussion of the possible effects of stations 15 - 38, inclusive, is presented in a later part of this report. The distances, $d_i$, from the receiving location to each of these interfering stations may be determined from the following equations in which D represents the separation between adjacent co-channel stations:

$$d_1 = D - d \tag{31}$$

$$d_2 = D + d \tag{32}$$

$$d_3^2 = d_4^2 = D^2 - d\,D + d^2 \tag{33}$$

$$d_5^2 = d_6^2 = D^2 + d\,D + d^2 \tag{34}$$

$$d_7 = \tfrac{1}{2}D - d \tag{35}$$

$$d_8 = \tfrac{1}{2}D + d \tag{36}$$

$$d_9^2 = d_{10}^2 = \frac{3}{4}D^2 + d^2 \tag{37}$$

$$d_{11}^2 = \tfrac{1}{4}D^2 - \tfrac{1}{2}dD + d^2 \tag{38}$$

$$d_{12}^2 = \tfrac{1}{4}D^2 + \tfrac{1}{2}dD + d^2 \tag{39}$$

$$d_{13}^2 = \frac{3}{4}D^2 - \frac{3}{2}dD + d^2 \tag{40}$$

$$d_{14}^2 = \frac{3}{4}D^2 + \frac{3}{2}dD + d^2 \tag{41}$$

Using the above distances, it is possible to determine the simultaneous distribution with respect to both time and receiving location of the desired field $F_d'$ and for each of the required values of the undesired fields; thus, $F_{ir}' = A_i + 20\log_{10} E_i + 10\log_{10} g_i' - 10\log_{10} g_d'$. These distributions are shown on Fig. 25 for the case where f = 63 Mc for the co-channel stations which are considered to be either synchronized or "off-set" so that A = 28 db; the transmitting antennas are at 500 feet for all stations in the lattice and all stations are assumed to have the same effective radiated power: P' = 20 db, i.e., 100 kilowatts; the distance from the desired station to the receiving location is d = 35 miles while the separation between adjacent co-channel stations is D = 200 miles. The formulas for these distributions may be expressed as follows:

$$F_d' = P' + F_d(50,50) + k\left[Q_d(d)\right]\sqrt{R_L^2(1) + R_d^2(1)} \tag{42}$$

where $Q_d(d)$ denotes the probability with respect to both time and receiving location that the desired field $F_d'$ will be exceeded; the values of $F_d(50,50)$ and of $R_d(1)$ are to be determined at the distance d. Similarly for the value of the desired field required to over-ride the individual undesired fields:

$$F_{ir}' = A_i + P' + F_i(50,50) + 10 \log_{10} g_i' - 10 \log_{10} g_d' + k\left[Q_{ir}(d_i)\right]\sqrt{R_L^2(1) + R_i^2(1)} \quad (43)$$

where $Q_{ir}(d_i)$ denotes the probability with respect to both time and receiving location that the required value of the undesired field, $F_{ir}'$, corresponding to undesired station i will be exceeded; the values of $F_i(50,50)$ and of $R_i(1)$ are to be determined at the distance $d_i$. The values of $F_{ir}'$ shown on Fig. 25 and throughout this report are based on the assumption that the receiving antenna is non-directional, i.e., $g_d' = g_i' = 1$.

Also shown on Fig. 25 is the expected distribution with respect to time and receiving location of $F_{dr}' \equiv 20 \log_{10} E_{dr}$ where $E_{dr}$ is defined by (30) to be the value of the desired field required to provide satisfactory television service in the presence of all of these interfering signals plus noise. The method of determining this distribution of $F_{dr}'$ will now be explained. Figs. 26, 27 and 28 give an example illustrating two methods for determining the probability distribution of $E_{ir}^2 + E_{jr}^2$ when the distributions of $E_{ir}$ and $E_{jr}$ are known and $E_{ir}$ and $E_{jr}$ are assumed to be uncorrelated. In this example $E_{ir} \equiv 25\ E_1$ and $E_{jr} \equiv 2\ E_7$ for the problem demonstrated on Fig. 25, i.e., for 63 Mc, $H_t$ = 500 feet, $P'$ = 20 db, d = 35 miles and D = 200 miles; thus, $E_{ir} = 25\ E_1$ represents the field required with co-channel station No. 1 operating alone and $E_{jr} = 2\ E_7$ represents the field required with adjacent channel station No. 7 operating alone. The first step in the method illustrated on Fig. 26 involves the substitution of a step function for the continuous distribution of $E_{ir}^2$; thus, it is assumed that the distribution of $E_{ir}^2$ may be approximately represented by ten constant levels, each of which are maintained for one-tenth of the receiving-location-time. These 10 levels are chosen so that they coincide with the $Q_i$ = 0.05, 0.15, ...0.95 values of $E_{ir}^2$. The highest eight of these constant levels are shown on Fig. 26. It is now a simple matter to determine the distribution of $E_{jr}^2$ plus each of these constant levels; these ten distributions are shown as dashed lines on Fig. 26. Finally, the circled points represent the required distribution of $E_{ir}^2 + E_{jr}^2$ as determined by this approximate method and these circled points are obtained simply by averaging, at the field intensity levels indicated, the ten values of $Q'$ for the ten dashed curves; for example, for $E^2$ = 200,000, $Q_{ij}' = (0+0+0.63+0.67+0.69+0.695+0.695+0.695+0.695+0.695)/10 = 0.546$. These circled points may be compared with the distribution determined by the product $Q_{ir}'(E_{ir}<E)\cdot Q_{jr}'(E_{jr}<E)$ and we see that in every case this product is a fair approximation to, although always somewhat larger than the true value, $Q_{ij}'$; thus:

$$Q_{ij}'(E_{ir}^2 + E_{jr}^2 < E^2) \cong Q_i'(E_{ir} < E) \cdot Q_j'\ (E_{jr} < E) \quad (44)$$

Before discussing (44) further its validity will be established in another way on Figs. 27 and 28.

On Fig. 27, $E^2_{ir}$ is plotted on a logarithmic scale along the abscissa while $E^2_{jr}$ is plotted on a logarithmic scale along the ordinate. The curved lines represent various levels of $E^2_{ir} + E^2_{jr}$. The 24 light vertical lines are plotted at the levels at which $E^2_{ir}$ is less than $E^2$ with a probability $Q'_{ir} = 0.04, 0.08, 0.12, \ldots, 0.96$ while the 24 light horizontal lines are plotted at the levels at which $E^2_{jr}$ is less than $E^2$ with a probability $Q'_{jr} = 0.04, 0.08, 0.12, \ldots, 0.96$ so that each rectangle bounded by these intersecting lines represents a differential probability $\Delta Q_{ij} = \frac{1}{(25)^2} = 0.0016$ that $E^2_{ir}$ and $E^2_{jr}$ lie within the corresponding indicated ranges simultaneously; the entire diagram is based on the assumption that $E_{ir}$ and $E_{jr}$ are not correlated. Finally, the probability $Q'_{ij}\left[E^2_{ir} + E^2_{jr} < E^2\right]$ is equal to the product $n \cdot \Delta Q_{ij}$ where n is the number of rectangles under the curve corresponding to the desired value of $E^2 = E^2_{ir} + E^2_{jr}$; e.g., for $E^2 = 10{,}000$ $Q'_{ij} = \frac{57.5}{625} = 0.092$, while the approximate value $Q'_{ir} \cdot Q'_{jr} = (0.51)(0.22) = 0.112$. Fig. 28 is a re-plot of the data on Fig. 27 using linear probability scales; comparing Figs. 27 and 28, it is evident that $Q'_{ij}\left[E^2_{ir} + E^2_{jr} < E^2\right]$ is simply the area under the curve corresponding to the desired value of $E^2$. The line on Fig. 26 labelled $Q'_{ij}\left[E^2_{ir} + E^2_{jr} < E^2\right]$ represents the value of this probability determined in this manner from Fig. 28; a planimeter was used in determining the area under each curve.

It will be noted that the two graphical methods just described for determining this distribution give essentially the same results and both indicate that (44) provides a fair approximation to $Q_{ij}$; thus we see by Fig. 26 that, the difference (expressed in decibels) between the approximate $Q'_{ir} \cdot Q'_{jr}$ curve and the accurate $Q'_{ij}$ curve is smaller the larger the value of $Q'_{ij}$ and, in this example, never exceeds 1.5 db. The approximation in using $Q'_{ir} \cdot Q'_{jr}$ for estimating $Q'_{ij}$ may best be appreciated by noting that $Q'_{ir} \cdot Q'_{jr}$ is simply the area below the line $E^2_{jr} = E^2$ and to the left of the line $E^2_{ir} = E^2$; e.g., for $E^2 = 10{,}000$ below and to the left of the dashed lines on Fig. 28. It can be shown that the error made in using (44) for determining the probability distribution of the sum of two signal energies will, in general, be somewhat greater the smaller the slopes of the two distributions but the maximum error will never be greater than 3 db. In particular, when the undesired signal i does not vary with time or receiving location, an error of 3 db will be made in using (44) at the value of $Q'_{jr}$ at which $E_{ir} = E_{jr}$, i.e., at which the two distributions cross; this situation arises in the case of noise but this 3 db error may be avoided by adding the effects of noise separately. It should be noted that the above derivations were all based on the assumption that the two undesired signals are uncorrelated. If these signals were correlated to some degree, there would tend to be a reduction in the expected interference and this would be in the direction of compensating for the small error made when the approximation (44) is used.

Equation (44) may, of course, be extended to more than two interfering signals; thus:

$$Q'_{dr}\left(\sum_i E_{ir}^2 < E^2\right) \cong \prod_i Q'_{ir}(E_{ir} < E) \tag{45}$$

where $\Pi$ denotes the product of the separate values of $Q'_{ir}$ for the several interfering signals determined at the particular value of E for which $Q'_{dr}$ is desired. Thus, the curve labelled $F'_{dr}$ (neglecting noise) shown on Fig. 25 was obtained by means of (45). For example, at the 50 db level:

$$Q'_{dr}\left(\sum E_{ir}^2 < 100,000\right) \cong (0.999)(0.996)(0.996)(0.988)(0.983)(0.973)(0.955)(0.932)$$
$$(0.932)(0.903)(0.86)(0.86)(0.79)(0.58) = 0.238$$

Finally, the effects of noise were included by adding to the above described distribution the constant field $F_n = F_r - 10 \log_{10} g'_d = 46.9$ db required to over-ride the receiver and cosmic radio noise. The resulting distribution of the required undesired field $Q'_{dr}(E_n^2 + \sum E_{ir}^2 < E^2)$ is labelled $F'_{dr}(P' = 20$ db) on Fig. 25. The next step in the calculations involves the determination of the probability with respect to receiving-location-time, Q(d,0), that the desired field, represented by $F'_d$ on Fig. 25, exceeds the required value of the undesired field represented by $F_{dr}$. This may be determined most readily by replacing the distribution $Q'_{dr}$ by a step function represented by the 18 constant levels of $F'_{dr}$ shown as dashed lines on Fig. 25 and corresponding to the 18 values of $Q'_{dr} = 0.99$, 0.97, 0.95, 0.93, 0.91, 0.85, 0.75, 0.65, 0.55, 0.45, 0.35, 0.25, 0.15, 0.09, 0.07, 0.05, 0.03, and 0.01. Thus, the required value of the undesired field may be expected to occupy each of the highest five and lowest five of these levels for $\frac{1}{50}$ of the receiving-location-time and may be expected to occupy each of the eight intermediate levels for $\frac{1}{10}$ of the receiving-location-time. Consequently, the probability Q(d,0) that the desired field will be acceptable at the distance d in the direction of station No. 1 will be approximately equal to the weighted sum of the 18 probabilities that the desired field exceeds these particular levels of $F'_{dr}$ arising from noise and 14 undesired stations; thus, for the example shown on Fig. 25:

$$\begin{aligned} Q(d,0) \cong\ & \tfrac{1}{50}(0.073 + 0.17 + 0.24 + 0.30 + 0.35) \\ & + \tfrac{1}{10}(0.47 + 0.60 + 0.70 + 0.765 + 0.82 + 0.86 + 0.895 + 0.92) \\ & + \tfrac{1}{50}(0.939 + 0.942 + 0.947 + 0.953 + 0.96) = 0.720 \end{aligned} \tag{46}$$

In this way $Q(d,0)$ may be determined as a function of d for the receiving locations located along the line in the direction of undesired station No. 1. An inspection of Fig. 24 shows that exactly the same deterioration of service may be expected for receiving locations along a line in the directions of stations 2, 3 and 6. Table IV has been prepared to show that only small differences are to be expected in the direction of station 5 (which is the same as for the direction of station 4), in the direction of station 9 (which is the same as for the directions of stations 10, 13 or 14), and in the direction of station 15 (which is the same as for the direction of station 20). This table also shows, for the particular distances $d = 35$ miles and $D = 200$ miles, the relative importance of undesired stations 15 - 38 inclusive. It will be noted that some of the undesired stations for $i > 14$ are of more importance at this particular distance than some of the undesired stations for $i < 15$. However, for other values of d the relative importance of particular stations changes; consequently, since none of the stations for $i > 14$ were large enough to cause more than a very minor change in the over-all results, these stations were always neglected in calculating $Q(d,0)$.

The effective service area, $A_s$, and effective service radius, $d_s$, of a station located in a lattice like that shown on Fig. 24 may now be defined:

$$A_s(p_a, D, P') \equiv \int_0^{2\pi} \int_0^{\infty} Q(\phi, r, p_a, D)\, r\,dr\,d\phi \equiv \pi d_s^2(p_a, D, P') \qquad (47)$$

In the above, $\phi$ denotes the direction from the desired station. A convenient method of evaluating (47) is to obtain a value of $\overline{Q(\phi, r, p_a, D)}$ averaged for several equally spaced values of $\phi$ at several different values of r; then $r \cdot \overline{Q(\phi, r, p_a, D)}$ is plotted as a function of r and the area under the resulting curve determined with a planimeter in the same manner used for determining the clear channel service area $A_{so}(p_a, P')$; thus:

$$A_s(p_a, D, P') = 2\pi \int_0^{\infty} \overline{Q(\phi, r, p_a, D)}\, r\,dr \qquad (48)$$

The four solid curves on Fig. 29 show $r \cdot Q(\phi, r, 0, 200)$ as a function of r for $P' = 20$ db in the twelve directions $\phi$ corresponding to stations (1, 2, 3 or 6), (4 or 5), (9, 10, 13 or 14) and (15 or 20). The dashed curve for $P' = 20$ db corresponds to the average value of $r \cdot Q(\phi, r, 0, 200)$ for these 12 directions; the dashed curves for other values of P' were obtained in a similar manner. Fig. 30 shows $r \cdot Q(1, r, 0, 200)$ for various values of P' as a function of r in the direction $\phi$ corresponding to station No. 1. A comparison of the dashed curves on Fig. 29 with the corresponding solid curves on Fig. 30 indicates that the deterioration of service is slightly greater in the direction of station No. 1 than when averaged for all 12 directions. This difference in deterioration of service with distance in various directions has been neglected in many of the following calculations and the assumption made that the deterioration of service

TABLE IV

TABULATION OF MEDIAN FIELD INTENSITIES $F'_{ir}(50,50)$ REQUIRED IN THE DIRECTIONS INDICATED IN THE PRESENCE OF 38 INTERFERING TELEVISION STATIONS TAKEN ONE AT A TIME

($f$ = 63 Mc, $H_t$ = 500 feet, $10 < H_r < 100$ feet, A = 28 db for synchronized co-channel and A = 6 db for adjacent channel stations; d = 35 miles, D = 200 miles)

| Path $T_1$ | | | Path $T_5$ | | | Path $T_9$ | | | Path $T_{15}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| i | $F'_{ir}$ | $d_i$ | i | $F'_{ir}$ | $d_i$ | i | $F'_{ir}$ | $d_i$ | i | $F'_{ir}$ | $d_i$ |
| 7 | 48.0 | 65.0 | 5 | 39.8 | 165.0 | 11 | 43.6 | 71.8 | 7 | 43.6 | 71.8 |
| 1 | 39.8 | 165.0 | 2 | 36.2 | 185.0 | 3 | 38.8 | 170.6 | 11 | 43.6 | 71.8 |
| 3 | 36.2 | 185.0 | 3 | 36.2 | 185.0 | 5 | 38.8 | 170.6 | 1 | 38.8 | 170.6 |
| 4 | 36.2 | 185.0 | 8 | 34.0 | 87.9 | 1 | 33.1 | 203.0 | 3 | 38.8 | 170.6 |
| 11 | 34.0 | 87.9 | 11 | 34.0 | 87.9 | 2 | 33.1 | 203.0 | 4 | 33.1 | 203.0 |
| 5 | 30.7 | 219.6 | 1 | 30.7 | 219.6 | 4 | 28.8 | 231.0 | 5 | 33.1 | 203.0 |
| 6 | 30.7 | 219.6 | 6 | 30.7 | 219.6 | 6 | 28.8 | 231.0 | 2 | 28.8 | 231.0 |
| 2 | 28.1 | 235.0 | 4 | 28.1 | 235.0 | 7 | 28.0 | 106.0 | 6 | 28.8 | 231.0 |
| 12 | 25.2 | 121.3 | 7 | 25.2 | 121.3 | 8 | 28.0 | 106.0 | 8 | 23.2 | 131.5 |
| 8 | 22.8 | 135.0 | 12 | 25.2 | 121.3 | 12 | 23.2 | 131.5 | 12 | 23.2 | 131.5 |
| 13 | 21.2 | 143.9 | 9 | 21.2 | 143.9 | 9 | 22.1 | 138.2 | 9 | 18.8 | 158.6 |
| 9 | 15.8 | 176.7 | 14 | 21.2 | 143.9 | 14 | 18.8 | 158.6 | 13 | 18.8 | 158.6 |
| 10 | 15.8 | 176.7 | 19 | 15.2 | 316.6 | 23 | 16.0 | 311.4 | 15 | 16.0 | 311.4 |
| 15 | 15.2 | 316.6 | 23 | 15.2 | 316.6 | 15 | 13.0 | 330.3 | 16 | 13.0 | 330.3 |
| 16 | 15.2 | 316.6 | 10 | 11.0 | 204.3 | 19 | 13.0 | 330.3 | 23 | 13.0 | 330.3 |
| 14 | 11.0 | 204.3 | 13 | 11.0 | 204.3 | 13 | 12.9 | 193.1 | 10 | 12.9 | 193.1 |
| 23 | 10.2 | 348.2 | 15 | 10.2 | 348.2 | 10 | 10.4 | 208.2 | 14 | 12.9 | 193.1 |
| 24 | 10.2 | 348.2 | 20 | 10.2 | 348.2 | 16 | 7.5 | 365.2 | 19 | 7.5 | 365.2 |
| 17 | 7.6 | 365.0 | 25 | 7.6 | 365.0 | 20 | 7.5 | 365.2 | 24 | 7.5 | 365.2 |
| 35 | 6.6 | 231.8 | 31 | 6.6 | 231.8 | 21 | 6.8 | 370.1 | 17 | 6.8 | 370.1 |
| 19 | 5.7 | 377.1 | 33 | 6.6 | 231.8 | 25 | 6.8 | 370.1 | 21 | 6.8 | 370.1 |
| 20 | 5.7 | 377.1 | 16 | 5.7 | 377.1 | 33 | 6.8 | 230.3 | 27 | 6.8 | 230.3 |
| 27 | 5.5 | 239.2 | 24 | 5.7 | 377.1 | 24 | 5.1 | 381.4 | 35 | 6.8 | 230.3 |
| 28 | 5.5 | 239.2 | 18 | 4.8 | 383.7 | 27 | 4.9 | 243.1 | 20 | 5.1 | 381.4 |
| 21 | 4.8 | 383.7 | 21 | 4.8 | 383.7 | 31 | 4.9 | 243.1 | 31 | 3.8 | 250.2 |
| 22 | 4.8 | 383.7 | 27 | 2.2 | 260.2 | 38 | 3.8 | 250.2 | 36 | 3.8 | 250.2 |
| 36 | 2.2 | 260.2 | 38 | 2.2 | 260.2 | 17 | 2.1 | 401.5 | 22 | 2.1 | 401.5 |
| 29 | 1.4 | 265.0 | 32 | 0.1 | 273.4 | 18 | 2.1 | 401.5 | 25 | 2.1 | 401.5 |
| 33 | 0.1 | 273.4 | 35 | 0.1 | 273.4 | 34 | 0.6 | 270.2 | 29 | 0.6 | 270.2 |
| 25 | -0.5 | 418.6 | 17 | -0.5 | 418.6 | 22 | -2.3 | 430.7 | 34 | 0.6 | 270.2 |
| 26 | -0.5 | 418.6 | 26 | -0.5 | 418.6 | 26 | -2.3 | 430.7 | 18 | -2.3 | 430.7 |
| 34 | -1.6 | 284.1 | 30 | -1.6 | 284.1 | 28 | -2.4 | 288.7 | 26 | -2.3 | 430.7 |
| 18 | -2.9 | 435.0 | 34 | -1.6 | 284.1 | 32 | -2.4 | 288.7 | 32 | -4.1 | 299.0 |
| 31 | -2.9 | 291.9 | 22 | -2.9 | 435.0 | 36 | -4.1 | 299.0 | 38 | -4.1 | 299.0 |
| 32 | -2.9 | 291.9 | 28 | -3.9 | 297.9 | 29 | -4.5 | 302.0 | 30 | -9.1 | 330.8 |
| 38 | -3.9 | 297.9 | 36 | -3.9 | 297.9 | 30 | -4.5 | 302.0 | 37 | -9.1 | 330.8 |
| 37 | -7.1 | 318.9 | 29 | -7.1 | 318.9 | 37 | -9.1 | 330.8 | 28 | -10.0 | 336.2 |
| 30 | -9.7 | 335.0 | 37 | -7.1 | 318.9 | 35 | -10.0 | 336.2 | 33 | -10.0 | 336.2 |

in the direction of station No. 1 provides an adequate measure of the effective service area. Thus, the following table gives the values of $A_s(0, D, P')$ and $d_s(0, D, P')$ as obtained simply by using $Q(1, r, 0, D)$ in (48) as a measure of $\overline{Q(\emptyset, r, 0, D)}$.

TABLE V

THE EFFECTIVE GRADE C SERVICE RADIUS AND EFFECTIVE GRADE C SERVICE AREA EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

(Co-channel stations are either synchronized or "off-set"; all stations have the same power and antenna height; $f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g_d' = g_i' = 1$; this table may be used for other values of $F_n$ by replacing the indicated values of P' by $P'_{Fn} = F_n - 46.9 + P'$; service determined from the probabilities in the direction of station No. 1 only)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | | ∞ | |
|---|---|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | | ∞ | |
| D miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles |
| 75 | 14.0 | 616 | 14.1 | 625 | 14.1 | 625 | 14.1 | 625 | 14.1 | 625 |
| 100 | 19.7 | 1219 | 20.2 | 1282 | 20.4 | 1307 | 20.4 | 1307 | 20.4 | 1307 |
| 150 | 27.4 | 2359 | 31.3 | 3078 | 32.0 | 3217 | 32.0 | 3217 | 32.0 | 3217 |
| 200 | 30.9 | 3000 | 39.7 | 4951 | 42.7 | 5728 | 43.3 | 5890 | 43.3 | 5890 |
| 250 | 31.4 | 3097 | 43.6 | 5972 | 51.7 | 8397 | 53.9 | 9127 | 54.4 | 9297 |
| 300 | 31.5 | 3117 | 45.2 | 6418 | 57.2 | 10279 | 63.5 | 12668 | 65.5 | 13478 |
| 400 | 31.9 | 3197 | 46.4 | 6764 | 61.7 | 11960 | 76.1 | 18194 | 87.6 | 24108 |
| ∞ | 32.3 | 3278 | 47.2 | 6999 | 63.8 | 12788 | 87.1 | 23833 | ∞ | ∞ |

The values of $d_s$ obtained from the dashed curves on Fig. 29 are 31.0, 40.6, 45.3, 46.6, and 46.8 miles, corresponding to D = 200 miles and P' = 0, 10, 20, 30 and $\infty$; these values differ from the corresponding values in Table V by only a few percent and it is considered that the approximation involved in estimating the service area by taking into account only the deterioration of service in the single direction $T_1$ is warranted in view of the extensive additional calculations which would have been required if allowance had been made for the differences in the three other significant directions $T_5$, $T_9$ and $T_{15}$.

The effective service radius, $d_s(\phi)$, for a particular direction may be defined by the equation:

$$\pi d_s^2(\phi) = 2\pi \int_0^{\infty} Q(\phi, r, p_a, D)\, r dr \tag{49}$$

Fig. 31 illustrates the directional characteristics of the service of a station in a lattice like that of Fig. 24. The effective service radii shown for the various directions were obtained from (49) by determining the area under curves of $r \cdot Q(\phi, r, 0, 200)$ such as those shown as solid curves on Fig. 29 for P' = 20 db. It is interesting to note that the service area becomes more nearly circular for the lower values of radiated power; this occurs because of the fact that receiver noise is more nearly the controlling factor with low power.

## VII METHODS FOR DETERMINING GRADES A AND B SERVICE IN THE PRESENCE OF MORE THAN ONE SOURCE OF INTERFERENCE

The problem of determining the Grade A or Grade B service in the presence of multiple interfering stations is similar to, although slightly more complicated than, the corresponding Grade C service computations described in the preceding section. An example will first be presented illustrating for Grade A or Grade B service the method of combining the interference from two stations and, as in the preceding Grade C case, this method may then be extended to any number of interfering sources by induction. The example chosen will be identical to that described for Grade C service on Figs. 26, 27 and 28, but now it becomes necessary to determine the probability, $q'_{ij}(E_{ir}^2 + E_{jr}^2 < E^2)$, <u>with respect to receiving location only</u> that the value of the desired field required to provide satisfactory television service is less than E with a probability, $p_a$, or better with respect to time in the presence of two undesired television stations i and j.

Consider first the nature of the interfering fields at some <u>particular</u> receiving location. In general, the median value with respect to time of the desired field required to over-ride the undesired field from station i may be expressed:

$$F'_{ir} = A_i + P'_i + F_i(50,50) + G_i - G_d + k(q_{ir})\, R_L(1) + k(p_i)\sqrt{R_d^2(1) + R_i^2(1)} \qquad (50)$$

In the above, $G_i$ and $G_d$ denote the receiving antenna gain (expressed in db above that expected for a half-wave dipole) in the directions of station i and the desired station, respectively. Thus, at some particular receiving location the median values with respect to time of the desired field required to over-ride the undesired fields from stations i and j may be expressed:

$$F'_{ir} = F'_{im} + k(p_i)\sqrt{R_d^2(1) + R_i^2(1)} \qquad (51)$$

$$F'_{jr} = F'_{jm} + k(p_j)\sqrt{R_d^2(1) + R_j^2(1)} \qquad (52)$$

In the above $F'_{im}$ and $F'_{jm}$ denote median values with respect to time at the particular receiving location in question. Identifying $p_i$ and $p_j$ with $Q_{ir}$ we see that (51) and (52) are of the same form as (43). Thus, by an argument identical to that used in the preceding section, we conclude that:

$$p'_{ij}(E^2_{ir} + E^2_{jr} < E^2) \cong p'_i(E_{ir} < E)\cdot p'_j(E_{jr} < E) \qquad (53)$$

The above equation is the counterpart of (44) and represents an approximate value for the probability with respect to time only, at a particular receiving location, of a median value with respect to time of the desired field required to over-ride the fields from both undesired stations i and j. As in the preceding section the primes represent probabilities of values less than E while the unprimed probabilities are the complementary values corresponding to probabilities of values greater than E. As in the corresponding Grade C problem, the derivation of (53) depends on the assumption that $E_{ir}$ and $E_{jr}$ are not correlated with respect to time. In the present case, however, some correlation with time is necessarily present between $E_{ir}$ and $E_{jr}$ as defined by (51) and (52) by virtue of the fact that the time variations of the common desired station have been included with those of the two undesired stations by adding $R_d(1)$ in quadrature with $R_i(1)$ and $R_j(1)$. This correlation is necessarily small, however, since $R_d(1)$ is always smaller than $R_i(1)$; furthermore, since the correlation will be positive, it will actually tend to compensate for the approximation involved in using (53).

A service of grade $p_a$ or better may now be defined by noting that $p_a$ is simply equal to the probability $p'_{ij}$ of having a root-sum-square value of the two median required desired fields less than E. Since (51), (52) and (53) are applicable at any arbitrarily chosen receiving location, the following relation between $p'_i$ and $p'_j$ must therefore apply, for a service of grade $p_a$ or better, at all receiving locations:

$$p'_i(E_{ir} < E) \cdot p'_j(E_{jr} < E) \cong p_a \tag{54}$$

The above equation, together with the two equations obtained by setting i = i and j in (50), provide a relation between the probability $q'_i \equiv (1 - q_i)$ and $q'_j \equiv (1 - q_j)$ which may be integrated over all receiving locations with a grade of service $p_a$ or better to determine the probability, $q'_{ij}(E^2_{ir} + E^2_{jr} < E^2)$; thus:

$$q'_{ij}(E^2_{ir} + E^2_{jr} < E^2,\ p_a) = \int_0^{q'_{ir}(p'_i = p_a)} q'_{jr}\, dq'_{ir} \tag{55}$$

$$20 \log_{10} E = A_i + P'_i + F_i(50,50) + G_i - G_d - k(q'_{ir})\, R_L(1)$$

$$-k(p'_i)\sqrt{R^2_d(1) + R^2_i(1)} \tag{56}$$

$$20 \log_{10} E = A_j + P'_j + F_j(50,50) + G_j - G_d - k(q'_{jr})\, R_L(1)$$

$$-k(p'_j)\sqrt{R^2_d(1) + R^2_j(1)} \tag{57}$$

The above two equations were obtained by noting that $k(p') = k(1 - p) = -k(p)$. Effects of correlation among the undesired field intensities with respect to receiving location could be included by an appropriate modification of (56) and (57) but the magnitude of this correlation is not known at the present time and its effect has been neglected throughout this report. Consider, as an example, Grade B service so that $p_a = 0.9$; the following table gives values of $p_i'$, $p_j'$, $q_i'$ and $q_j'$ as determined for a value of $E = 500$ µv/m from (54), (56) and (57) for the particular case $i = 1$ and $j = 7$ previously illustrated for Grade C service in Figs. 26, 27 and 28.

TABLE VI

SAMPLE CALCULATIONS OF THE RELATION BETWEEN $q_i'$ AND $q_j'$ FOR A GRADE B SERVICE

($p_a = 0.9$ or better; $f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $P' = 20$ db; $d = 35$ miles; $D = 200$ miles; $i = 1$; $j = 7$; $G_i = G_j = G_d = 0$; $20 \log_{10} E = 54$ db)

| $p_i'$ | $p_j'$ | $k(p_i')$ | $k(q_{ir}')$ | $q_{ir}'$ | $k(p_j')$ | $k(q_{jr}')$ | $q_{jr}'$ |
|---|---|---|---|---|---|---|---|
| 0.9 | 1 | -0.551 | -0.0678 | 0.565 | $-\infty$ | $\infty$ | 0 |
| 0.9091 | 0.99 | -0.5740 | -0.0401 | 0.54 | -1 | 0.4647 | 0.138 |
| 0.9186 | 0.9797 | -0.6 | -0.0085 | 0.51 | -0.8806 | 0.3721 | 0.194 |
| 0.9483 | 0.9491 | -0.7 | 0.1128 | 0.40 | -0.7033 | 0.2347 | 0.295 |
| 0.9686 | 0.9291 | -0.8 | 0.2341 | 0.297 | -0.6316 | 0.1791 | 0.339 |
| 0.9819 | 0.9166 | -0.9 | 0.3554 | 0.205 | -0.5944 | 0.1503 | 0.362 |
| 0.99 | 0.9091 | -1 | 0.4766 | 0.134 | -0.5740 | 0.1344 | 0.38 |
| 1 | 0.9 | $-\infty$ | $\infty$ | 0 | -0.5511 | 0.1167 | 0.398 |

Fig. 32 gives $q_{jr}'$ as a function of $q_{ir}'$ for $E = 200$, 500, 1000 and 2000 µv/m as determined in the manner described above and as illustrated in Table VI for the case $E = 500$ µv/m. The area under each of these curves provides an approximate measure of the probability of Grade B service available at these levels of desired field intensity in the presence of these two undesired stations, the approximation arising from the neglect of correlation and from the fact that the approximate expression (54) was used in establishing the relation between $q_{ir}'$ and $q_{jr}'$. In order to avoid the difficulty of determining the areas under curves of the type shown on Fig. 32, a further approximation will be made by noting that this area is approximately equal to the rectangular area bounded by the vertical and horizontal lines defined by the probabilities $q_{ir}'(E_{ir} < E, 0.9)$ and $q_{jr}'(E_{jr} < E, 0.9)$, e.g., as shown by the dashed lines on Fig. 32 for the value of $E = 500$ µv/m; thus:

$$q_{ij}'(E_{ir}^2 + E_{jr}^2 < E^2, 0.9) \cong q_{ir}'(E_{ir} < E, 0.9) \cdot q_{jr}'(E_{jr} < E, 0.9) \qquad (58)$$

Fig. 33 shows the distributions of $F'_{ir}(q, 0.1)$, $F'_{jr}(q, 0.1)$, and of $F'_{dr}(q'_{ij}, 0.9)$, the latter distribution being shown for three cases: (a) as determined by (58), (b) by the more accurate expression (55), and (c) for +1 receiving location correlation between i and j. The distribution defined by (55) was evaluated by determining the areas under the curves on Fig. 32 by means of a planimeter. It should be noted that (58) provides a better approximation to (55) for the larger values of E. If, as seems likely, the correlation between the undesired fields with respect to receiving location is positive, then this will change $q'_{ij}$ in the same direction as the change involved by the use of the approximation (58) and thus may compensate to some extent for the error arising from the use of (58). The effect of correlation is shown for the hypothetical case of +1 correlation by the dashed line on Fig. 33; in this case, the resultant value of $F'_{dr}(q'_{ij}, 0.9)$ was found simply by obtaining the root-sum-square value: $E^2_{ir} + E^2_{jr}$ at each value of q.

The above discussion provides the justification for the adoption of the following approximate formula for combining the effects of several interfering sources:

$$q'_{dr}\left(\sum_i E^2_{ir} < E^2, p_a\right) \cong \prod_i q'_{ir}(E_{ir} < E, p_a) \tag{59}$$

Fig. 34 provides an example of the use of (59) in establishing the probability, $q(d, p_a)$, of service of grade $p_a$ or better. In this example, $p_a = 0.9$ corresponding to Grade B service. The effects of noise have been included in this analysis by adding in quadrature to $E_{dr}$ the constant field represented by:

$$F_n(p_a) = F_r - G_d - k(p_a)\, R_d(1) \tag{60}$$

$F_n(p_a)$ is the median value with respect to time of the desired field which is required to over-ride the noise and provide a service of grade $p_a$ or better. In the example shown on Fig. 34, $G_d = 0$ and $k(p_a) = -0.5511$. The method of determining $q(d, p_a)$ involves averaging the appropriately weighted values of $q_d$ at the 18 levels indicated by the dashed lines on Fig. 34 in the same manner discussed in the example shown on Fig. 25 and illustrated by (46); thus, in the example on Fig. 34, $q(35, 0.9) = 0.544$.

In the above described manner, $q(d, p_a)$ has been determined for the receiving locations along the line in the direction of station No. 1 in a lattice of stations like that on Fig. 24 for $p_a = 0.99$ and 0.9 corresponding to Grade A and Grade B service, respectively. These data were then used for determining the Grade A and Grade B service areas by the same procedure followed in the previous section. Tables VII and VIII give the resulting values of $A_s(p_a, D, P')$ and $d_s(p_a, D, P')$ for $p_a = 0.99$ and 0.9, respectively, for several values of D and of P'.

Tables IX, X, and XI give Grade B service results similar to those in Table VIII but now for antenna heights of 200', 1000' and 2000'.

Fig. 35 shows the effective service radius, $d_s(\emptyset)$, as determined by (49) for the case of a station isolated from all except one adjacent channel interfering station at a distance D = 100 miles. The effective service area, $A_s(p_a, D, P')$ and effective service radius, $d_s(p_a, D, P')$, for this case were obtained by the use of (48); it was considered that an adequate measure of the expected service could be obtained by averaging $Q(\emptyset, r, p_a, D)$ in only six directions. Table XII gives these results for a Grade B service. Similar results are given in Table XIII for a single interfering synchronized or "off-set" co-channel station.

TABLE VII

THE EFFECTIVE GRADE A SERVICE RADIUS AND EFFECTIVE GRADE A SERVICE AREA EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

(Co-channel stations are either synchronized or "off-set"; all stations have the same power and antenna height; f = 63 Mc; H = 500 feet; H = 30 feet; $F_r$ = 46.9 db; $g_d' = g_i' = 1$; this table may be used for other values of $F_n$ by replacing the indicated values of P' by $P'_{F_n} = F_n - 46.9 + P'$; service determined from the probabilities in the direction of station No. 1 only)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | | ∞ | |
|---|---|---|---|---|---|---|---|---|---|---|
| P'(db above one kilowatt) | 0 | | 10 | | 20 | | 30 | | ∞ | |
| D miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles |
| 75 | 9.2 | 266 | 9.2 | 266 | 9.2 | 266 | 9.2 | 266 | 9.2 | 266 |
| 100 | 12.8 | 515 | 13.0 | 531 | 13.0 | 531 | 13.0 | 531 | 13.0 | 531 |
| 150 | 19.2 | 1158 | 20.5 | 1320 | 20.7 | 1346 | 20.7 | 1346 | 20.7 | 1346 |
| 200 | 23.8 | 1780 | 27.1 | 2307 | 28.2 | 2498 | 28.4 | 2534 | 28.4 | 2534 |
| 250 | 26.0 | 2124 | 32.5 | 3318 | 35.6 | 3982 | 36.2 | 4117 | 36.2 | 4117 |
| 300 | 26.7 | 2240 | 35.5 | 3959 | 40.9 | 5255 | 42.9 | 5782 | 43.9 | 6054 |
| 400 | 26.8 | 2256 | 36.3 | 4140 | 44.6 | 6249 | 50.8 | 8107 | 54.9 | 9469 |
| ∞ | 26.9 | 2273 | 37.0 | 4301 | 47.2 | 6999 | 57.1 | 10243 | ∞ | ∞ |

TABLE VIII

THE EFFECTIVE GRADE B SERVICE RADIUS AND EFFECTIVE GRADE B SERVICE AREA EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

(Co-Channel stations are either synchronized or "off-set"; all stations have the same power and antenna height; f = 63 Mc; $H_t$ = 500 feet; $H_r$ = 30 feet; $F_r$ = 46.9 db; $g'_d = g'_i = 1$; this table may be used for other values of $F_n$ by replacing the indicated values of $P'$ by $P'_{F_n} = F_n - 46.9 + P'$; service determined from the probabilities in the direction of station No. 1 only)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | | ∞ | |
|---|---|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | | ∞ | |
| D miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles |
| 75 | 12.4 | 483 | 12.4 | 483 | 12.4 | 483 | 12.4 | 483 | 12.4 | 483 |
| 100 | 17.3 | 940 | 17.5 | 962 | 17.5 | 962 | 17.5 | 962 | 17.5 | 962 |
| 150 | 24.6 | 1901 | 27.1 | 2307 | 27.6 | 2393 | 27.6 | 2393 | 27.6 | 2393 |
| 200 | 27.5 | 2376 | 34.5 | 3739 | 37.2 | 4347 | 37.7 | 4465 | 37.7 | 4465 |
| 250 | 28.3 | 2516 | 38.4 | 4632 | 45.0 | 6362 | 46.9 | 6910 | 47.3 | 7029 |
| 300 | 28.7 | 2588 | 39.3 | 4852 | 48.8 | 7482 | 53.4 | 8958 | 55.3 | 9607 |
| 400 | 28.9 | 2624 | 39.8 | 4976 | 51.1 | 8203 | 60.1 | 11347 | 67.8 | 14441 |
| ∞ | 28.9 | 2624 | 40.0 | 5027 | 51.8 | 8430 | 63.1 | 12509 | ∞ | ∞ |

TABLE IX

THE EFFECTIVE GRADE B SERVICE RADIUS AND EFFECTIVE GRADE B SERVICE AREA EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

(Co-channel stations are either synchronized or "off-set"; all stations have the same power and antenna height; $f = 63$ Mc; $H_t = 200$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g_d' = g_i' = 1$; this table may be used for other values of $F_n$ by replacing the indicated values of $P'$ by $P'_{F_n} = F_n - 46.9 + P'$; service determined from the probabilities in the direction of station No. 1 only)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | | ∞ | |
|---|---|---|---|---|---|---|---|---|---|---|
| P'(db above one kilowatt) | 0 | | 10 | | 20 | | 30 | | ∞ | |
| D miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles |
| 75 | 9.1 | 260 | 9.3 | 272 | 9.3 | 272 | 9.3 | 272 | 9.3 | 272 |
| 100 | 13.2 | 547 | 13.8 | 598 | 14.0 | 616 | 14.0 | 616 | 14.0 | 616 |
| 150 | 17.8 | 995 | 21.1 | 1399 | 22.2 | 1548 | 22.5 | 1590 | 22.5 | 1590 |
| 200 | 19.0 | 1134 | 25.7 | 2075 | 29.1 | 2660 | 30.7 | 2961 | 30.7 | 2961 |
| 250 | 19.1 | 1146 | 27.6 | 2393 | 34.2 | 3675 | 37.2 | 4347 | 37.9 | 4513 |
| 300 | 19.1 | 1146 | 28.4 | 2534 | 37.1 | 4324 | 42.5 | 5674 | 44.7 | 6277 |
| 400 | 19.1 | 1146 | 28.4 | 2534 | 39.0 | 4778 | 47.6 | 7118 | 57.0 | 10207 |
| ∞ | 19.1 | 1146 | 28.4 | 2534 | 39.0 | 4778 | 50.1 | 7885 | ∞ | ∞ |

TABLE X

THE EFFECTIVE GRADE B SERVICE RADIUS AND EFFECTIVE GRADE B SERVICE AREA EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

(Co-channel stations are either synchronized or "off-set"; all stations have the same power and antenna height; $f$ = 63 Mc; $H_t$ = 1000 feet; $H_r$ = 30 feet; $F_r$ = 46.9 db; $g_d' = g_i' = 1$; this table may be used for other values of $F_n$ by replacing the indicated values of $P'$ by $P'_{F_n} = F_n - 46.9 + P'$; service determined from the probabilities in the direction of station No. 1 only)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | | ∞ | |
|---|---|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | | ∞ | |
| D miles | $d_s$ miles | $A_s$ sq. miles | $d_s$ miles | $A_s$ sq. miles | $d_s$ miles | $A_s$ sq. miles | $d_s$ miles | $A_s$ sq. miles | $d_s$ miles | $A_s$ sq. miles |
| 75 | 12.3 | 475 | 12.3 | 475 | 12.3 | 475 | 12.3 | 475 | 12.3 | 475 |
| 100 | 17.9 | 1007 | 18.0 | 1018 | 18.0 | 1018 | 18.0 | 1018 | 18.0 | 1018 |
| 150 | 28.4 | 2534 | 29.5 | 2734 | 29.8 | 2790 | 29.8 | 2790 | 29.8 | 2790 |
| 200 | 34.4 | 3718 | 38.9 | 4754 | 40.2 | 5077 | 40.6 | 5178 | 40.6 | 5178 |
| 250 | 37.9 | 4513 | 45.2 | 6418 | 49.6 | 7729 | 50.6 | 8044 | 50.6 | 8044 |
| 300 | 39.8 | 4976 | 48.4 | 7359 | 56.4 | 9993 | 59.1 | 10973 | 59.4 | 11085 |
| 400 | 40.2 | 5077 | 49.5 | 7698 | 60.8 | 11613 | 71.3 | 15971 | 76.4 | 18337 |
| ∞ | 40.2 | 5077 | 49.5 | 7698 | 62.3 | 12193 | 75.0 | 17671 | ∞ | ∞ |

TABLE XI

THE EFFECTIVE GRADE B SERVICE RADIUS AND EFFECTIVE GRADE B SERVICE AREA EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

(Co-channel stations are either synchronized or "off-set"; all stations have the same power and antenna height; $f$ = 63 Mc; $H_t$ = 2000 feet; $H_r$ = 30 feet; $F_r$ = 46.9 db; $g_d' = g_i' = 1$; this table may be used for other values of $F_n$ by replacing the indicated values of $P'$ by $P'_{Fn} = F_n - 46.9 + P'$; service determined from the probabilities in the direction of station No. 1 only)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | | ∞ | |
|---|---|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | | ∞ | |
| D miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles | $d_s$ miles | $A_s$ sq.miles |
| 75 | 11.3 | 401 | 11.3 | 401 | 11.3 | 401 | 11.3 | 401 | 11.3 | 401 |
| 100 | 17.3 | 940 | 17.3 | 940 | 17.3 | 940 | 17.3 | 940 | 17.3 | 940 |
| 150 | 29.0 | 2642 | 29.5 | 2734 | 29.5 | 2734 | 29.5 | 2734 | 29.5 | 2734 |
| 200 | 39.0 | 4778 | 40.7 | 5204 | 41.3 | 5359 | 41.3 | 5359 | 41.3 | 5359 |
| 250 | 46.0 | 6648 | 51.2 | 8235 | 52.7 | 8725 | 52.7 | 8725 | 52.7 | 8725 |
| 300 | 48.4 | 7359 | 59.3 | 11047 | 62.0 | 12076 | 63.1 | 12509 | 63.1 | 12509 |
| 400 | 48.4 | 7359 | 63.0 | 12469 | 72.4 | 16467 | 81.2 | 20714 | 83.2 | 21747 |
| ∞ | 48.4 | 7359 | 63.0 | 12469 | 77.2 | 18723 | 91.3 | 26187 | ∞ | ∞ |

TABLE XII

THE EFFECTIVE GRADE B SERVICE RADIUS AND TOTAL SERVICE AREA EXPECTED FOR TWO ADJACENT CHANNEL STATIONS SEPARATED BY A DISTANCE D

(Both stations have the same power and antenna height; $f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $G_d = G_i = 0$; this table may be used for other values of $F_n$ by replacing the indicated values of P' by $P'_{Fn} = P' + F_n - 46.9$)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | |
|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | |
| D miles | $d_s$ miles | $2A_s$ sq.miles | $d_s$ miles | $2A_s$ sq.miles | $d_s$ miles | $2A_s$ sq.miles | $d_s$ miles | $2A_s$ sq.miles |
| 50 | 25.8 | 4182 | 33.9 | 7220 | 40.2 | 10154 | 45.6 | 13064 |
| 75 | 28.0 | 4926 | 37.4 | 8790 | 45.2 | 12836 | 51.6 | 16732 |
| 100 | 28.5 | 5104 | 38.8 | 9456 | 48.3 | 14658 | 56.0 | 19704 |
| 125 | 28.6 | 5140 | 39.3 | 9702 | 50.5 | 16022 | 59.2 | 22022 |
| 150 | 28.7 | 5176 | 39.5 | 9804 | 50.9 | 16280 | 61.1 | 23456 |
| 200 | 28.9 | 5248 | 39.6 | 9854 | 51.0 | 16342 | 61.8 | 23996 |
| ∞ | 28.9 | 5248 | 40.0 | 10054 | 51.8 | 16860 | 63.1 | 25018 |

TABLE XIII

THE EFFECTIVE GRADE B SERVICE RADIUS AND TOTAL SERVICE AREA EXPECTED FOR TWO CO-CHANNEL STATIONS WITH SYNCHRONIZED OR "OFF-SET" CARRIERS SEPARATED BY A DISTANCE D

(Both stations have the same power and antenna height; $f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $G_d = G_i = 0$; this table may be used for other values of $F_n$ by replacing the indicated values of P' by $P'_{Fn} = P' + F_n - 46.9$)

| Effective Radiated Power in Kilowatts | 1 | | 10 | | 100 | | 1000 | |
|---|---|---|---|---|---|---|---|---|
| P' (db above one kilowatt) | 0 | | 10 | | 20 | | 30 | |
| D miles | $d_s$ miles | $2A_s$ sq.miles | $d_s$ miles | $2A_s$ sq.miles | $d_s$ miles | $2A_s$ sq.miles | $d_s$ miles | $2A_s$ sq.miles |
| 100 | 25.7 | 2075 | 31.2 | 3058 | 34.0 | 3632 | 35.3 | 3915 |
| 150 | 27.7 | 4822 | 35.9 | 8098 | 42.0 | 11084 | 46.0 | 13296 |
| 200 | 28.4 | 5068 | 38.8 | 9456 | 47.6 | 14238 | 54.1 | 18390 |
| 250 | 28.8 | 5212 | 39.8 | 9952 | 50.3 | 15896 | 59.2 | 22022 |
| 300 | 28.8 | 5212 | 39.9 | 10002 | 50.7 | 16148 | 61.4 | 23688 |
| 400 | 28.9 | 5248 | 39.9 | 10002 | 50.8 | 16214 | 62.3 | 24386 |
| $\infty$ | 28.9 | 5248 | 40.0 | 10054 | 51.8 | 16860 | 63.1 | 25018 |

# VIII THE GEOGRAPHICAL SEPARATION REQUIRED BETWEEN TELEVISION BROADCAST STATIONS FOR THE EFFICIENT COVERAGE OF THE GREATEST AREA WITH INTERFERENCE-FREE SERVICE

One measure of the efficiency of an allocation of broadcasting stations is the size of the area provided with interference-free service. Suppose, for example, that only a few television channels are available and that it is desired to provide the maximum possible coverage of some large area (such as the area of the United States) with a satisfactory interference-free television service. It seems likely that the maximum number of stations can be packed into the area without causing mutual interference when they are arranged in a triangular lattice. Thus, we have seen in the preceding section that the service areas of stations in such a lattice are approximately circular and for this case the optimum arrangement is triangular; in particular, it can be shown that the triangular lattice provides 15% more coverage of area than a square lattice provided the individual service areas are circular. Consider the allocation of stations in a triangular lattice as shown on Figs. 23 and 24. Within any triangle defined by any three adjacent stations, the effective area provided with interference-free service is exactly equal to the area of a semi-circle of radius, $d_s(p_a, D, P')$, thus:

$$\text{Area served within each triangle} = \pi d_s^2/2 \qquad (61)$$

$$\text{Total area of each triangle} = \sqrt{3}\ D^2/4 \qquad (62)$$

$$\therefore \text{Percentage of total area provided with service} = \frac{200\pi}{\sqrt{3}}\left(\frac{d_s}{D}\right)^2 \qquad (63)$$

Figs. 36, 37 and 38 show this percentage of any large area which can be provided by means of a single television channel with Grade A, Grade B or Grade C service, respectively, as a function of the separation D between adjacent co-channel stations. It should be noted that, for each value of radiated power and grade of service, there is an optimum value of the separation D required between adjacent co-channel stations operating in a triangular lattice allocation such as that shown on Fig. 24.

Figs. 39, 40 and 41 give Grade B service results similar to those shown on Fig. 37 but now for transmitting antenna heights = 200 feet, 1000 feet and 2000 feet, respectively.

The dashed curves on Figs 36-41, inclusive, give values of the percentage of total area served on the hypothetical assumption that all interference, except that due to noise, has been eliminated. Thus, the difference between the dashed and solid curves, for any particular value of D, represents the loss in efficiency (directly proportional to the loss in coverage area) due to mutual station interference alone. The curves labelled $P' = \infty$ on Figs. 36-41 are of interest since the difference between these curves and the other solid curves, for any particular value of D, represents the loss in efficiency due to noise alone. The dashed curves were obtained by substituting $d_{so}$ in (63) rather than $d_s$.

Figs. 42, 43 and 44 show results similar to those in the preceding figures but in these latter figures the percentage of any large area which can be provided with service is shown as a function of power and antenna height for the fixed separation D = 200 miles.

Theresults given in Figs. 36-44, inclusive, were all obtained on the assumption that the stations are to be allocated in a triangular lattice like that shown on Fig. 24; it is considered that such results are likely to be reasonably representative of the kind of allocation problem to be expected in the congested Eastern part of the United States. In order to provide a basis for the allocation of stations in much less congested situations, the service area is shown in Figs. 45 and 46 for two stations isolated from all other interfering stations as a function of their separation D. Fig. 45 is for two co-channel stations while Fig. 46 is for two adjacent channel stations.

All of the results shown in Figs. 36-46 inclusive are applicable for other assumed values of the required field, $F_r$, for other receiving antenna gains, $G_d$, and for other receiving antenna heights, $H_r$ (up to 100'), provided the values of P' indicated on the curves are replaced by an equivalent power $P_e' = P' + F_r - 46.9 - G_d - 20 \log_{10}(H_r/30)$.

The results given on Figs. 36-46 inclusive show that the use of high transmitting antennas and high transmitter power will provide television service throughout the greatest possible area.

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## DEFINITIONS OF SYMBOLS

E denotes the field intensity of a television signal expressed in microvolts per meter.

$F = 20 \log_{10} E$ denotes the field intensity expressed in decibels above one microvolt per meter for a station with an effective radiated power of one kilowatt; F' denotes a corresponding field for an effective radiated power P'. P' is expressed in decibels above one kilowatt.

F(L,T) denotes a value of F exceeded at L percent of the receiving locations for T percent of the time.

F(50,50) is given graphically as a function of distance, antenna height, and frequency in Reference D.

$S(d, H_r, H_t, f)$ denotes the theoretical field intensity expected over a smooth spherical earth with a radius equal to 4/3 of its actual value, expressed in decibels above one microvolt per meter for an effective radiated power of one kilowatt.

M(d,f) is the terrain factor derived in Reference C.

The normal distribution function, k(X), is defined by means of the following two equations:

$$k(X) = 0.42986^{*}\, k'(X) = -k(1 - X)$$

$$X = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{k'(X)} e^{-y^2/2}\, dy$$

As defined above X is a probability and must be multiplied by 100 to represent a percentage; k(X) is defined in such a way that k(0.01) = 1 and k(0.99) = -1.

*Note that this factor was given erroneously as 0.42992 on page 14 of Reference C; also Table V in Reference C should be changed as follows: k(0.05) = 0.7071, k(0.1) = 0.5511, k(0.3) = 0.2254.

$L = 100q$ denotes the percentage of receiving locations at a given distance from the television station at which the received field is expected to exceed the field $F'(L,T)$.

$T = 100p$ denotes the percentage of the time at a given distance from the television station for which the received field is expected to exceed $F'(L,T)$.

$q$ and $p$ are probabilities with respect to receiving location and time, respectively, that the received field will exceed $F'(q,p) = F'(L,T)$.

$q' = 1 - q$ and $p' = 1 - p$ are probabilities that the received field will be less than $F'(q,p)$.

$T_a = 100\ p_a$ denotes the minimum percentage of the time that an acceptable television service is required to be available at those receiving locations with a service of grade $p_a$.

Grade A service corresponds to service of grade $T_a = 99\%$ or better.

Grade B service corresponds to service of grade $T_a = 90\%$ or better.

Grade C service corresponds to service of grade $T_a = 0$ or better.

$R_L(1) = F(1,T) - F(50,T) = 19.26$ db denotes a measure expressed in decibels of the variation of the field intensity with receiving location.

$R(1) = F(L,1) - F(L,50)$ denotes a measure expressed in decibels of the variation of the field intensity with time; $R(1)$ is given graphically as a function of distance, antenna height and frequency in Reference D.

$d$ = distance from the desired station expressed in miles.

$D$ = separation expressed in miles between adjacent co-channel stations.

$d_i$ = distance from the receiving location to an undesired station.

The subscript d is used to designate the desired station while the subscripts u, i or j are used to denote undesired stations.

$A$ = minimum ratio expressed in decibels between the desired and undesired receiver terminal signals required for an acceptable television service; for unsynchronized co-channel signals $A = 40$ db, for synchronized co-channel signals or for co-channel stations with "off-set" carriers $A = 28$ db and for adjacent channel signals $A = 6$ db.

$Q_o(d,p_a)$ denotes the probability with respect to time and receiving location of receiving a clear channel service of grade $p_a$ or better.

$q_o(d, p_a)$ denotes the probability with respect to receiving location of receiving a clear channel service of grade $p_a$ or better.

$G = 10 \log_{10} g'$ denotes the antenna gain expressed in decibels relative to that of a half-wave dipole.

$F_r$ = field required with a half-wave dipole receiving antenna in rural areas to provide an acceptable television service in the absence of sources of interference other than receiver and cosmic radio noise.

$F_n = F_r - G_d$ denotes the required field under the above conditions for a receiving antenna with a gain $G_d$ in the direction of the desired station.

$Q(\phi, r, p_a, D)$ denotes the probability with respect to time and receiving location of receiving a service of grade $p_a$ in the direction $\phi$ and at the distance r from a television station operating within interfering range of one or more other stations.

$A_s(p_a, D, P')$ denotes the effective service area of a television station operating within interfering range of one or more other stations; $d_s(p_a, D, P')$ is the corresponding effective service radius.

$d_s(\phi)$ is the effective service radius in the direction $\phi$ from a television station operating within interfering range of one or more other stations.

$A_{so}(p_a, P')$ and $d_{so}(p_a, P')$ are the effective service area and effective service radius, respectively, for a clear channel station, i.e., for $D = \infty$.

THE LOG NORMAL DISTRIBUTIONS REQUIRED FOR THE STUDY OF BROADCAST ALLOCATIONS FOR FREQUENCIES BETWEEN 50 AND 250 Mc

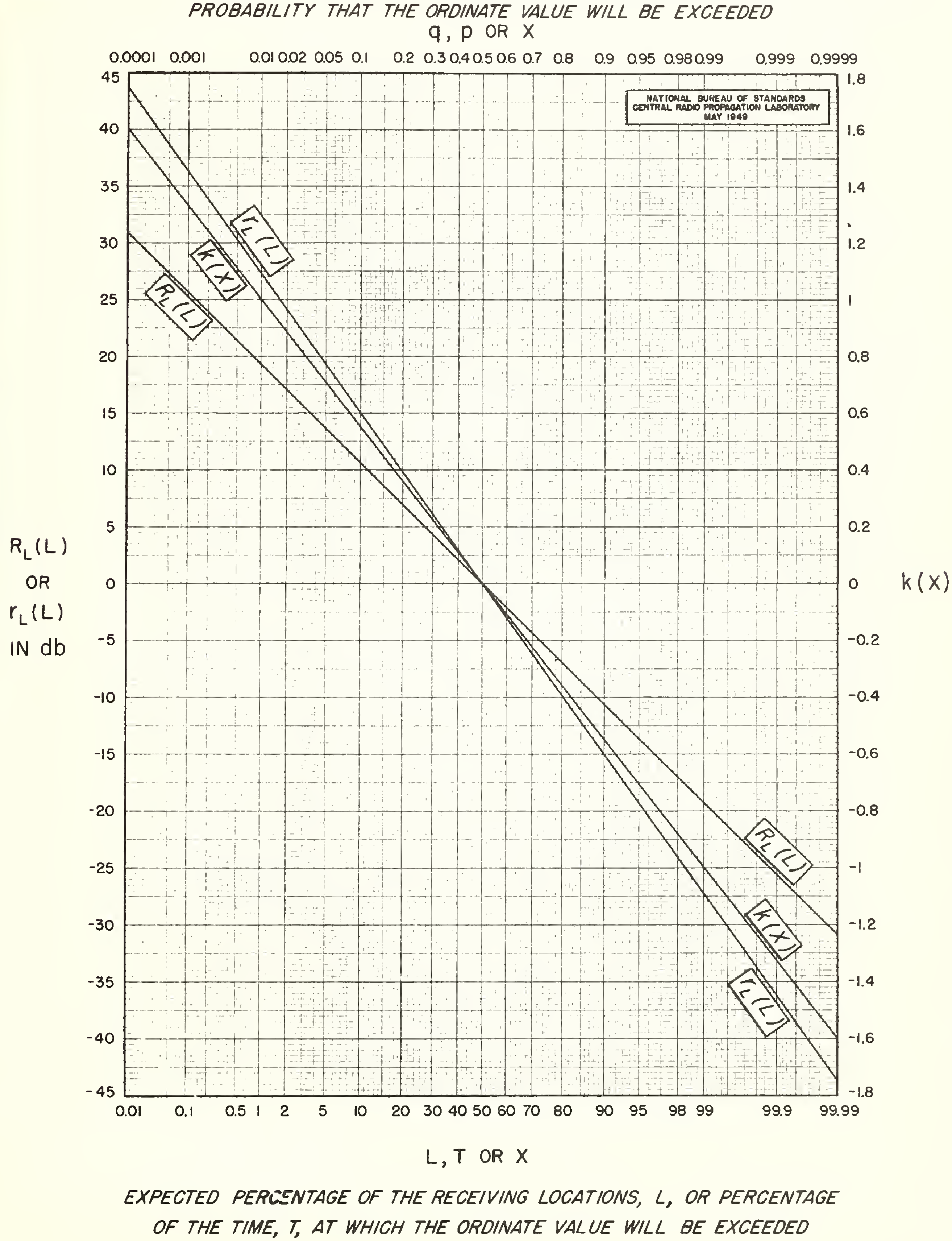


Figure 1

THE EFFECTIVE NOISE FIGURE NF' REFERRED TO THE ANTENNA TERMINALS SO AS TO INCLUDE THE TRANSMISSION LINE POWER LOSS L AND THE EXTERNAL COSMIC NOISE EN

( NF' = EN - 1 + L · NF WHERE NF DENOTES THE RECEIVER TERMINAL NOISE FIGURE AS MEASURED WITH A DUMMY ANTENNA)

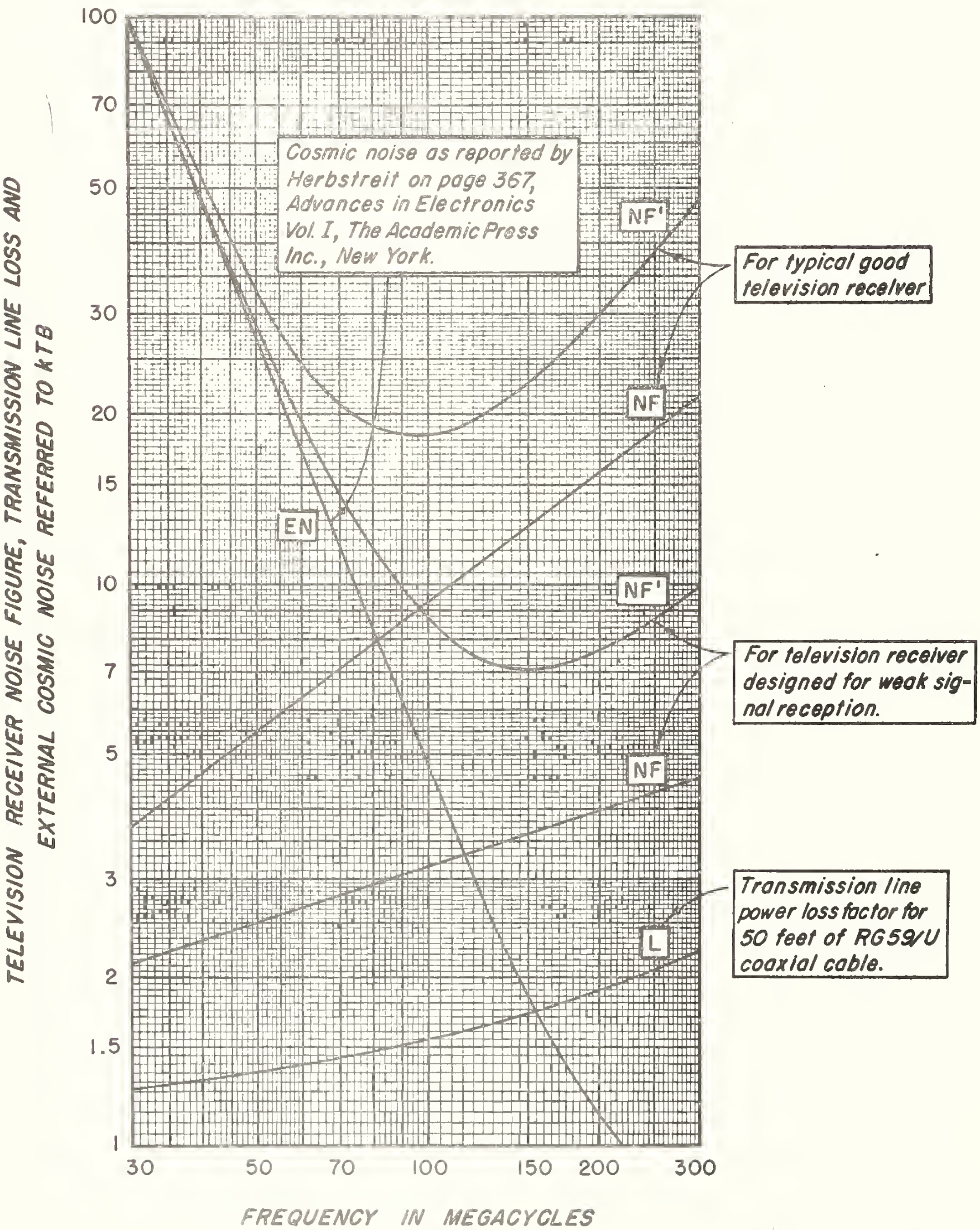


Figure 2

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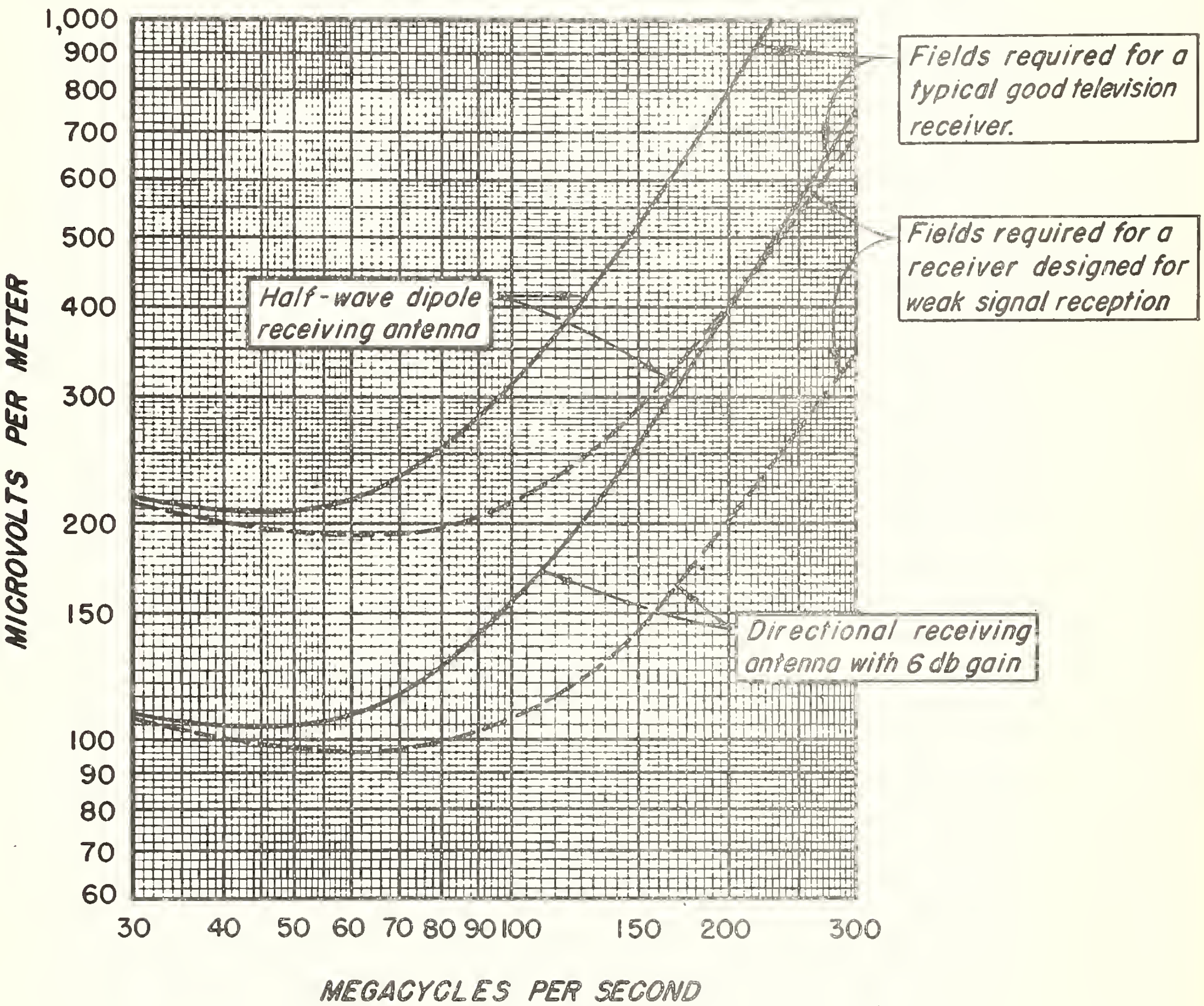
FEBRUARY 1949

FIELD INTENSITY REQUIRED IN THE ABSENCE OF MAN MADE NOISE FOR SATISFACTORY TELEVISION BROADCAST RECEPTION USING AN EXTERNAL ANTENNA CONNECTED TO THE RECEIVER BY MEANS OF 50 FEET OF RG 59/U COAXIAL CABLE

(PROVIDES AN INTERMEDIATE FREQUENCY RMS VIDEO PEAK SIGNAL-TO-NOISE RATIO OF 24 db WITH AN INTERMEDIATE FREQUENCY VIDEO BANDWIDTH OF 4000 KC)

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FEBRUARY 1949

Figure 3

DISTRIBUTION OF RECEIVING LOCATIONS WITH INTERFERENCE FREE RECEPTION FOR THE PERCENTAGES OF THE TIME INDICATED

$f = 63$ Mc ; $H_T = 500$ FEET ; SEPARATION BETWEEN DESIRED AND UNDESIRED STATIONS 250 MILES

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

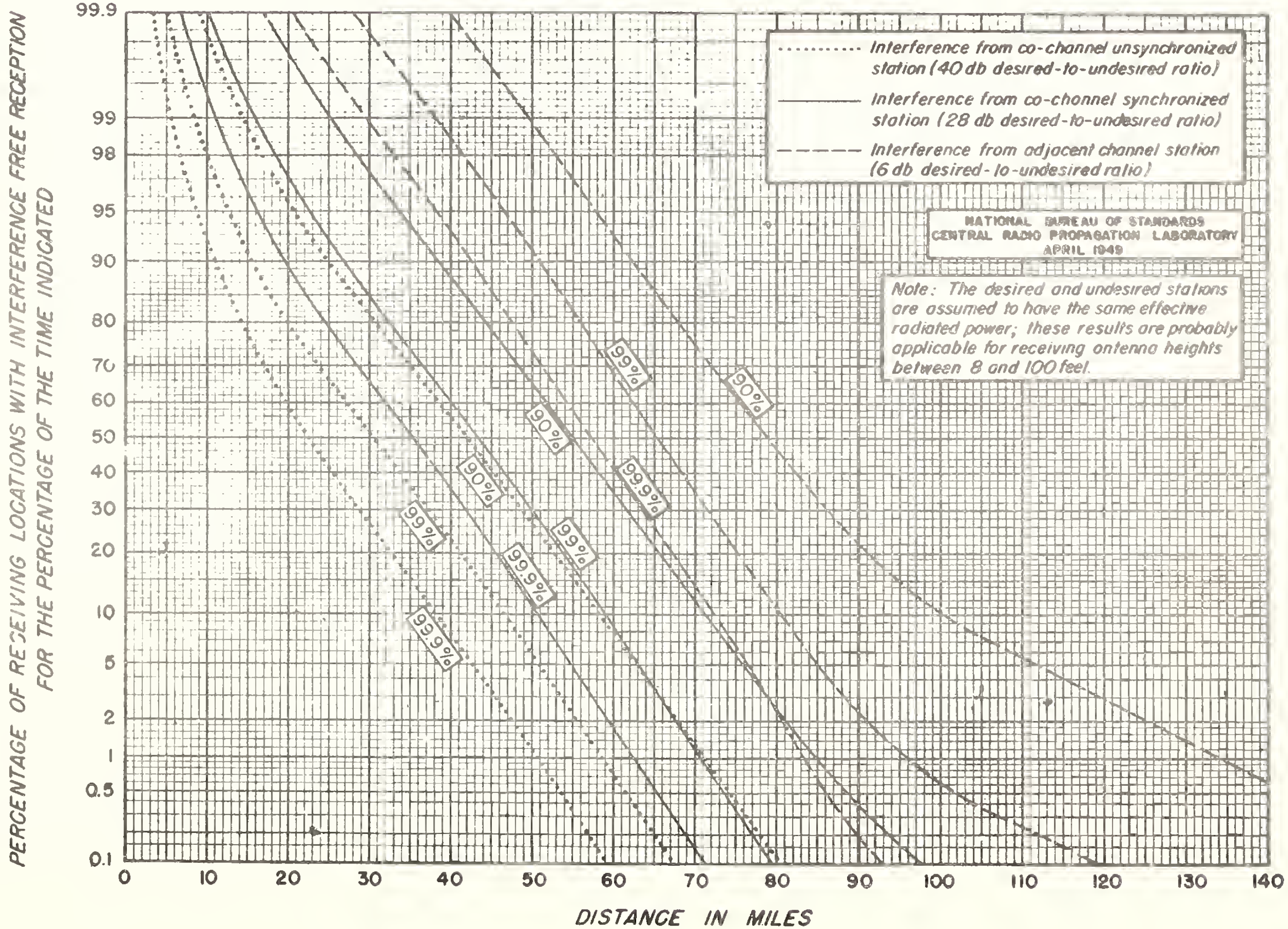



Figure 4

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 90% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL UNSYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 90% OF THE TIME, i.e. 221 $\mu$v/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

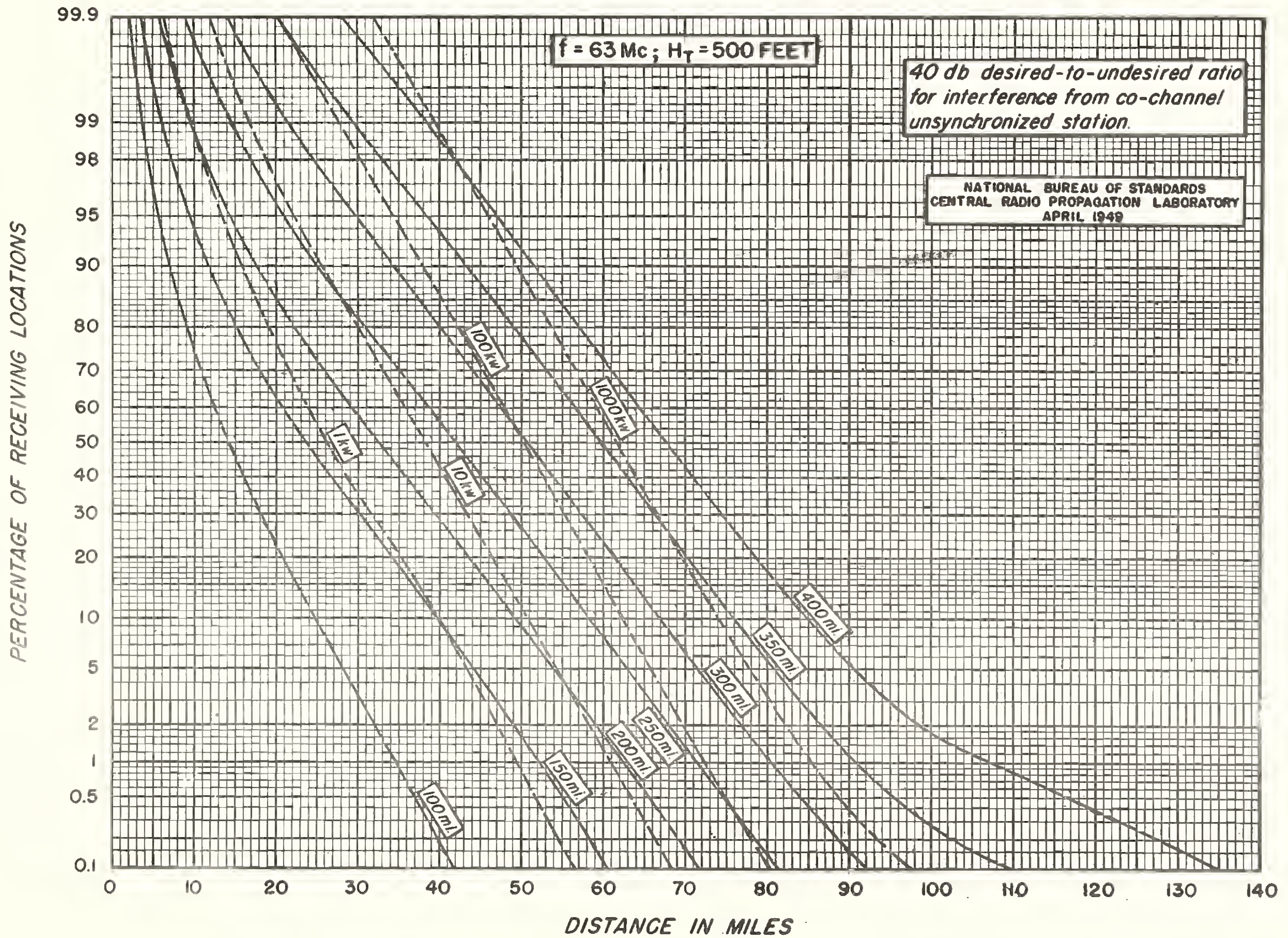



Figure 5

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 99% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL UNSYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME, i.e. 221 $\mu$v/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

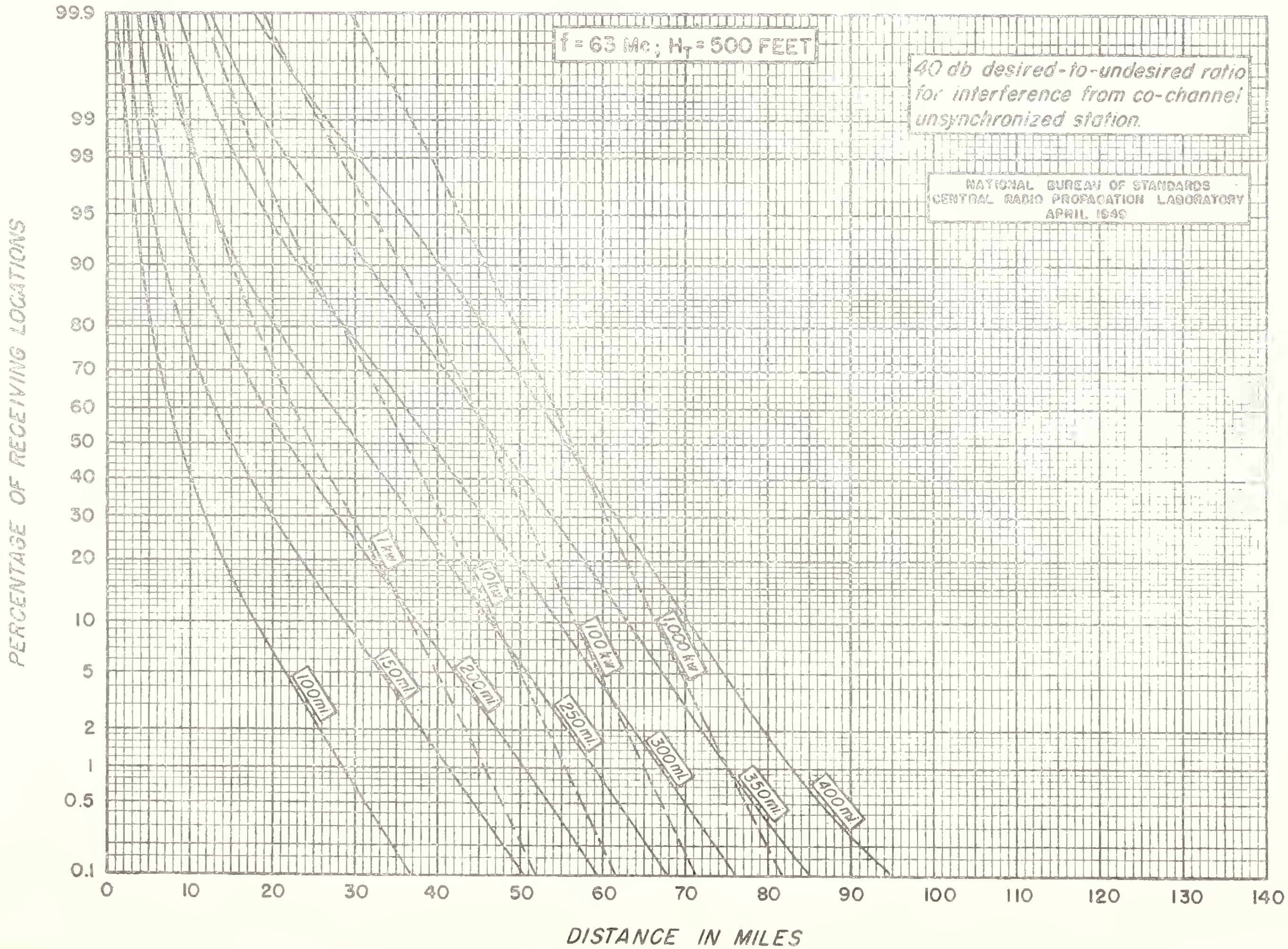



Figure 6

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 99.9% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL UNSYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99.9% OF THE TIME, i.e. 221 μv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

( BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION )

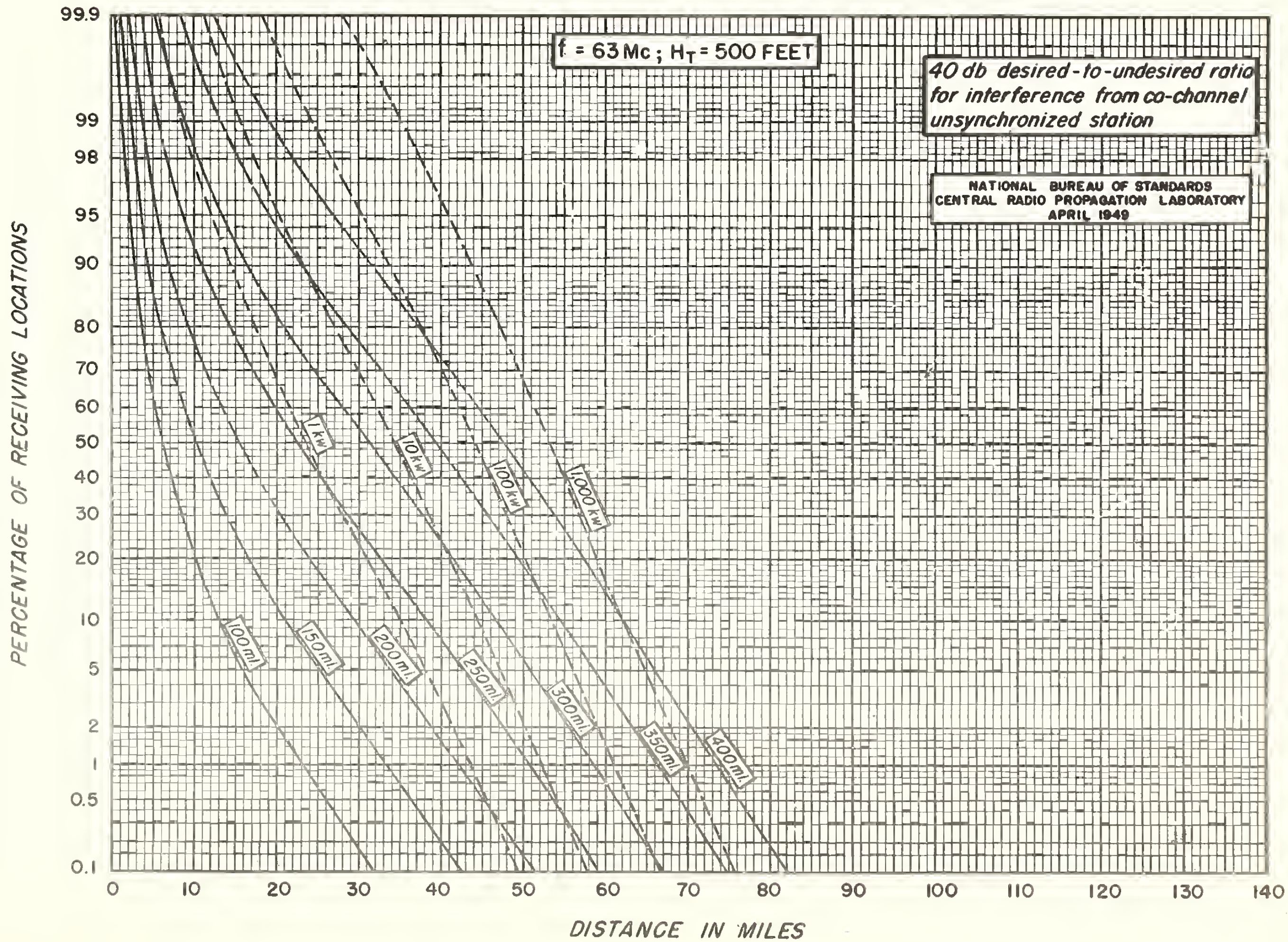



Figure 7

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 90% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL SYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 90% OF THE TIME, i.e. 221 μv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

( BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

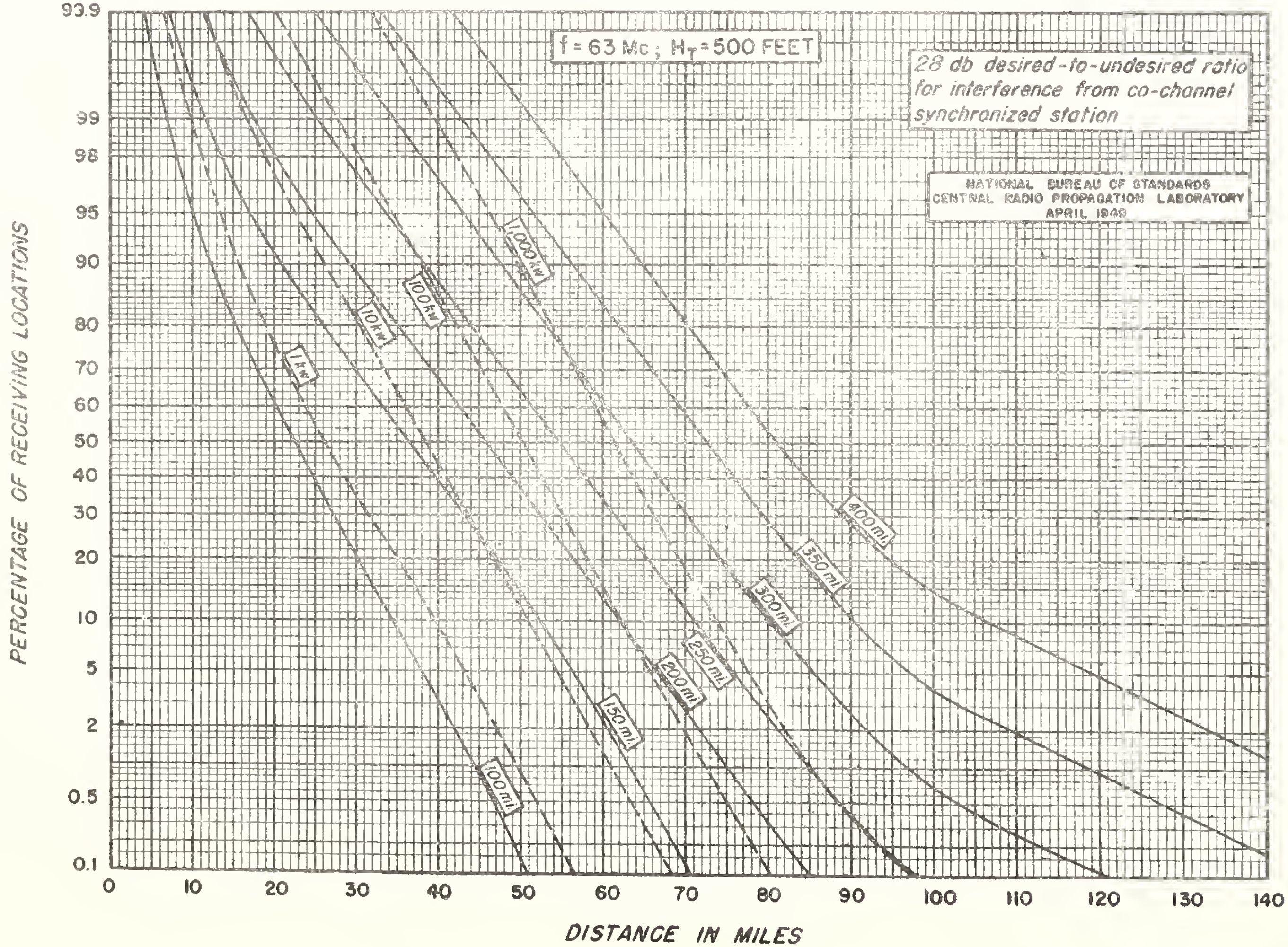
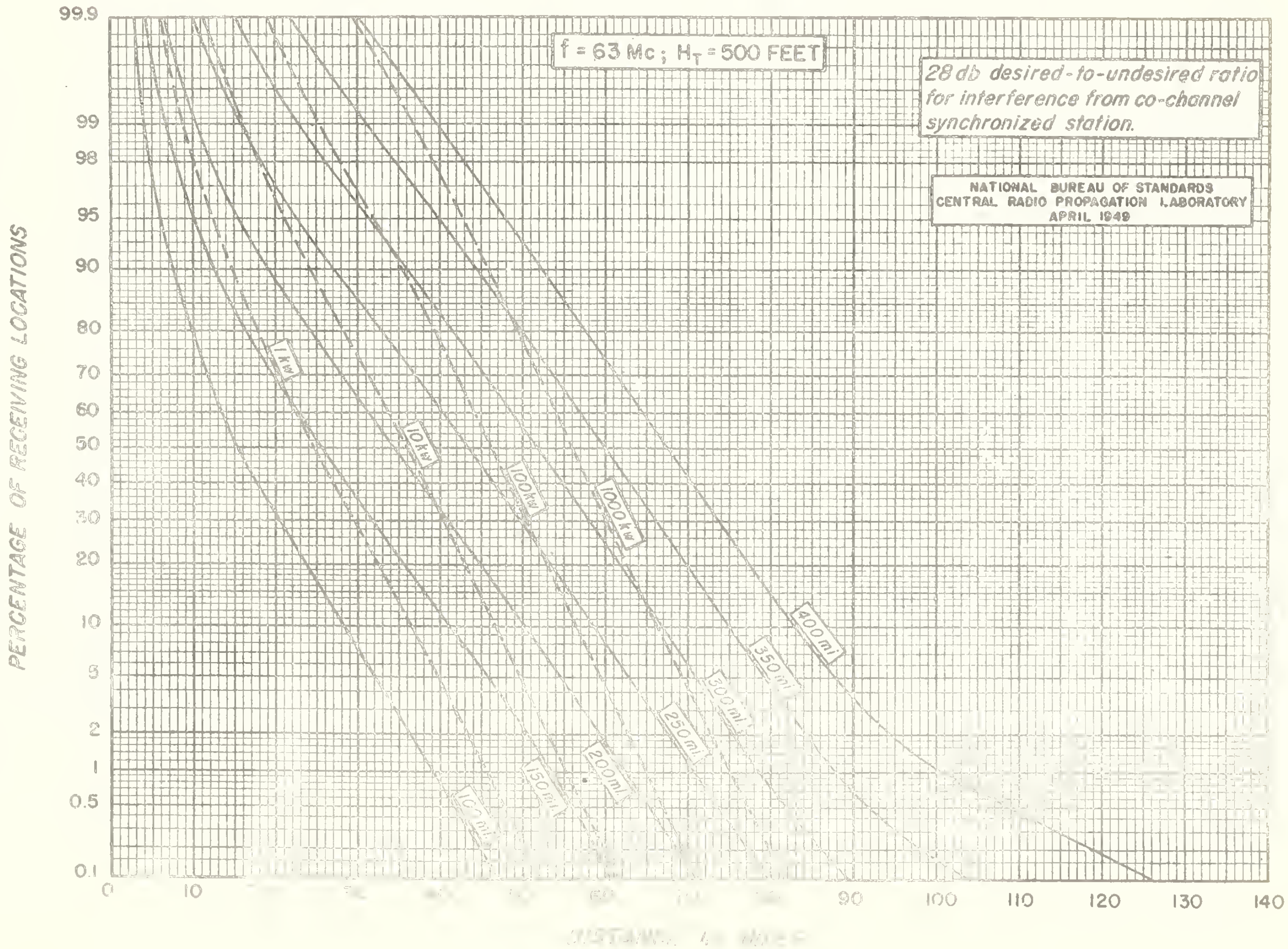



Figure 8

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 99% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL SYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME, i.e. 221 µv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)



DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 99.9% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL SYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99.9% OF THE TIME, i.e. 221 μv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

( BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION )

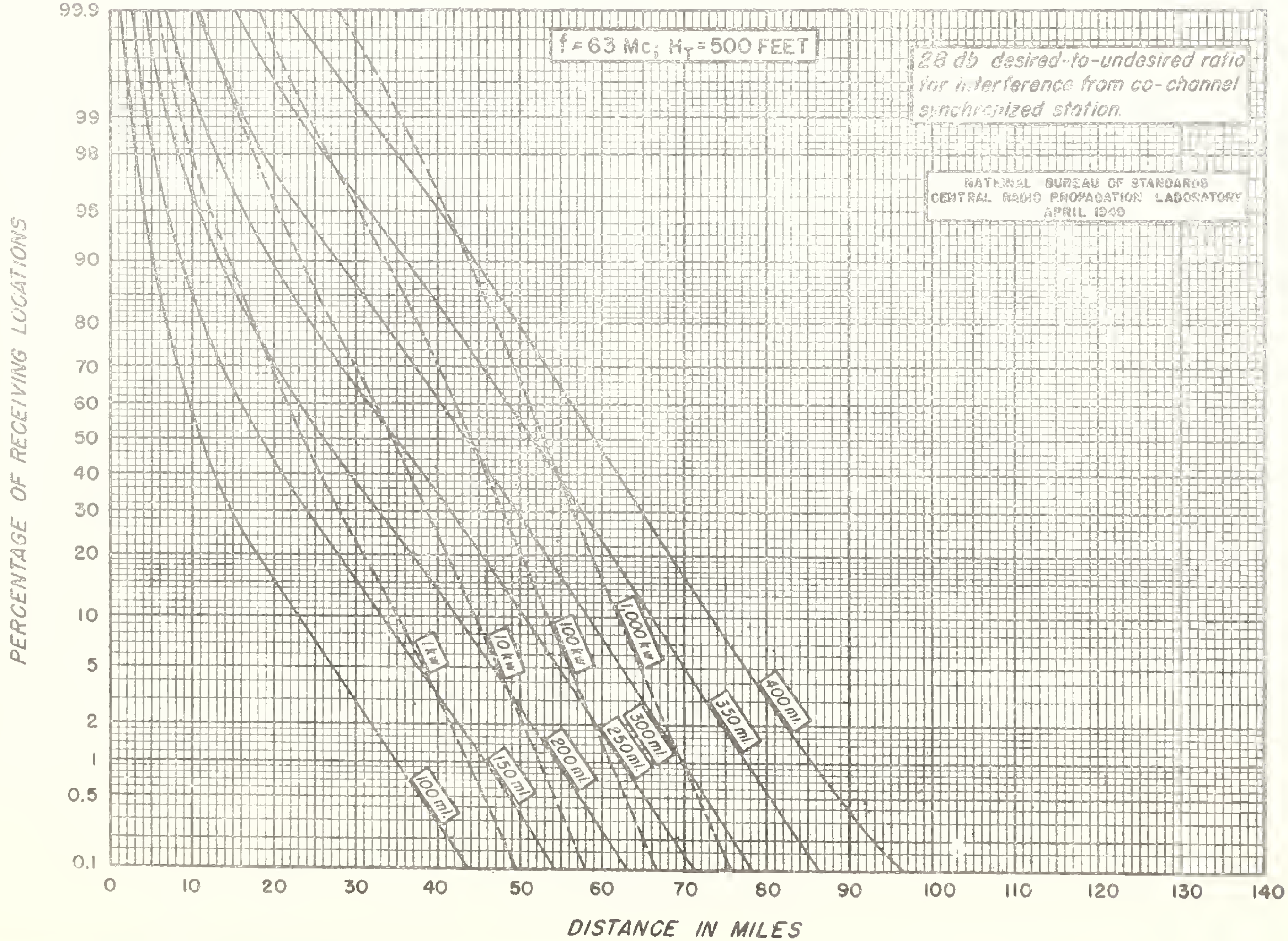



Figure 10

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 90% OF THE TIME OF INTERFERENCE ... STATION WITH THE SAME EFFECTIVE RADIATED POWER ...

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 90% OF THE TIME OF INTERFERENCE FROM AN ADJACENT CHANNEL STATION WITH THE SAME EFFECTIVE RADIATED POWER, AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 90% OF THE TIME, i.e. 221 μv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

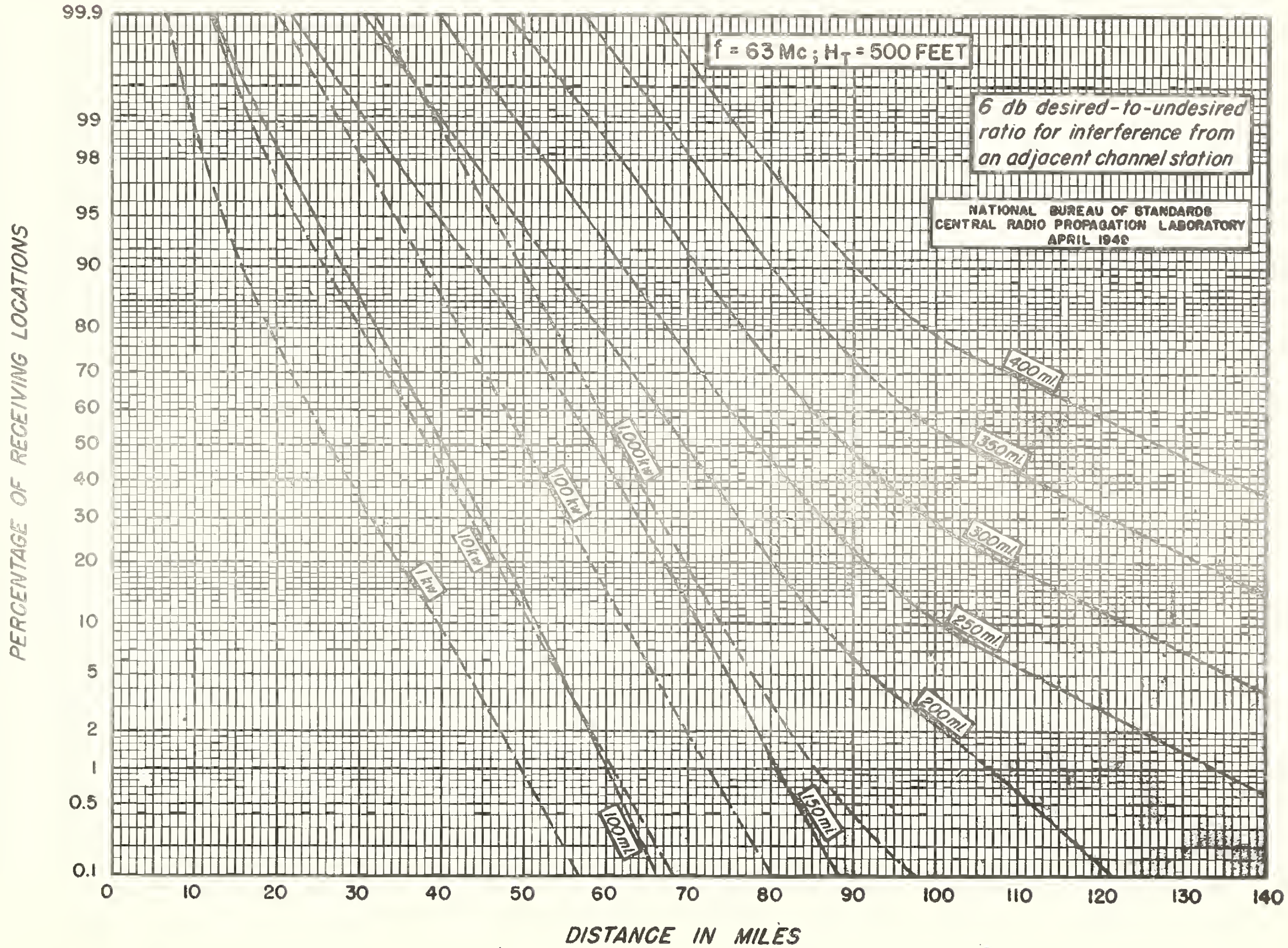



Figure 11

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 99% OF THE TIME OF INTERFERENCE FROM AN ADJACENT CHANNEL STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME, i.e. 221 μv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

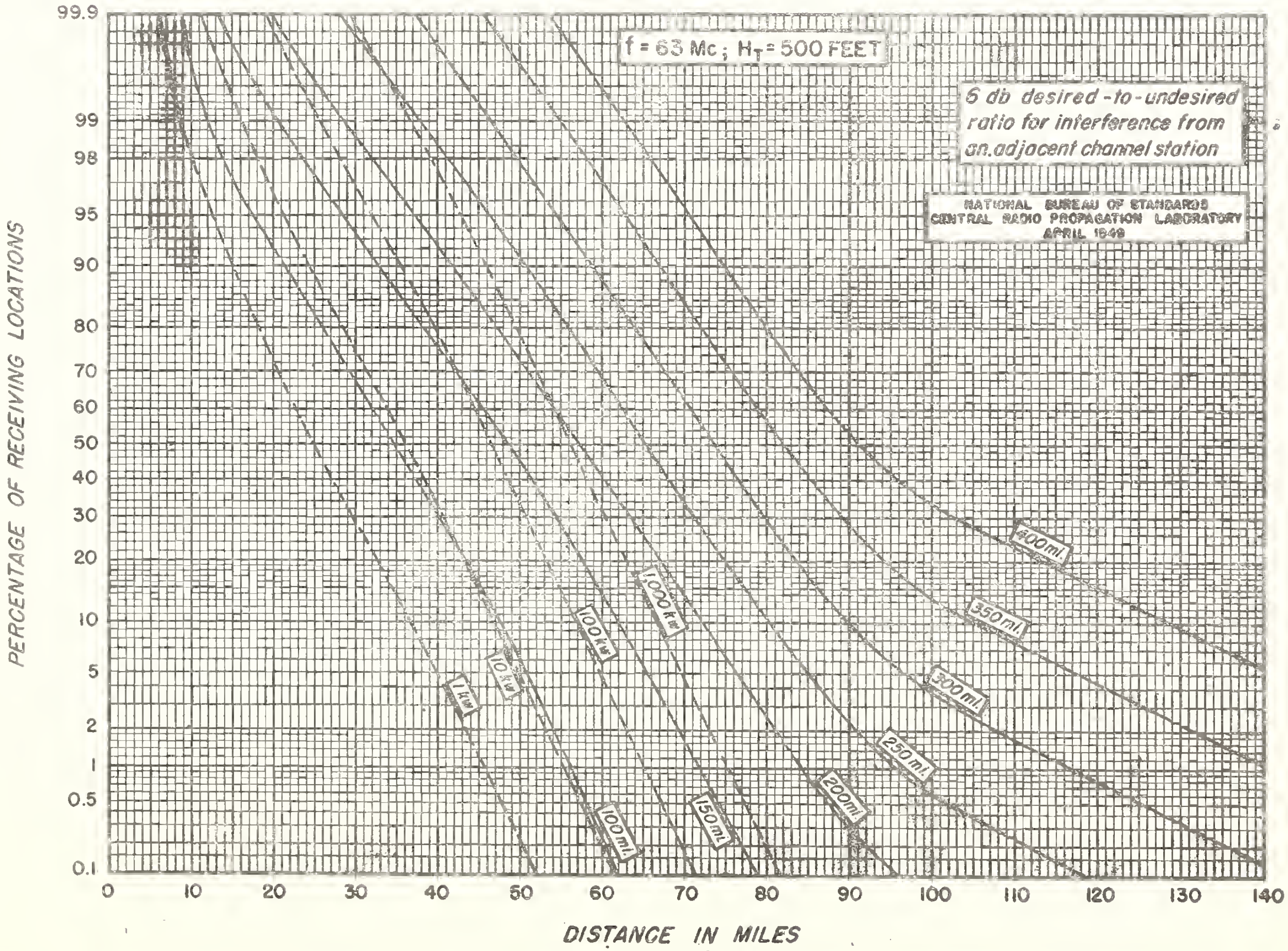



Figure 12

DISTRIBUTION OF THE RECEIVING LOCATIONS FREE FOR 99.9% OF THE TIME OF INTERFERENCE FROM AN ADJACENT CHANNEL STATION WITH THE SAME EFFECTIVE RADIATED POWER AND SEPARATED FROM THE DESIRED STATION BY THE DISTANCES INDICATED

THE DASHED CURVES GIVE THE DISTRIBUTION OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99.9% OF THE TIME, i.e. 221 μv/m FROM DESIRED STATIONS WITH THE EFFECTIVE RADIATED POWERS INDICATED ON THE CURVES

( BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION )

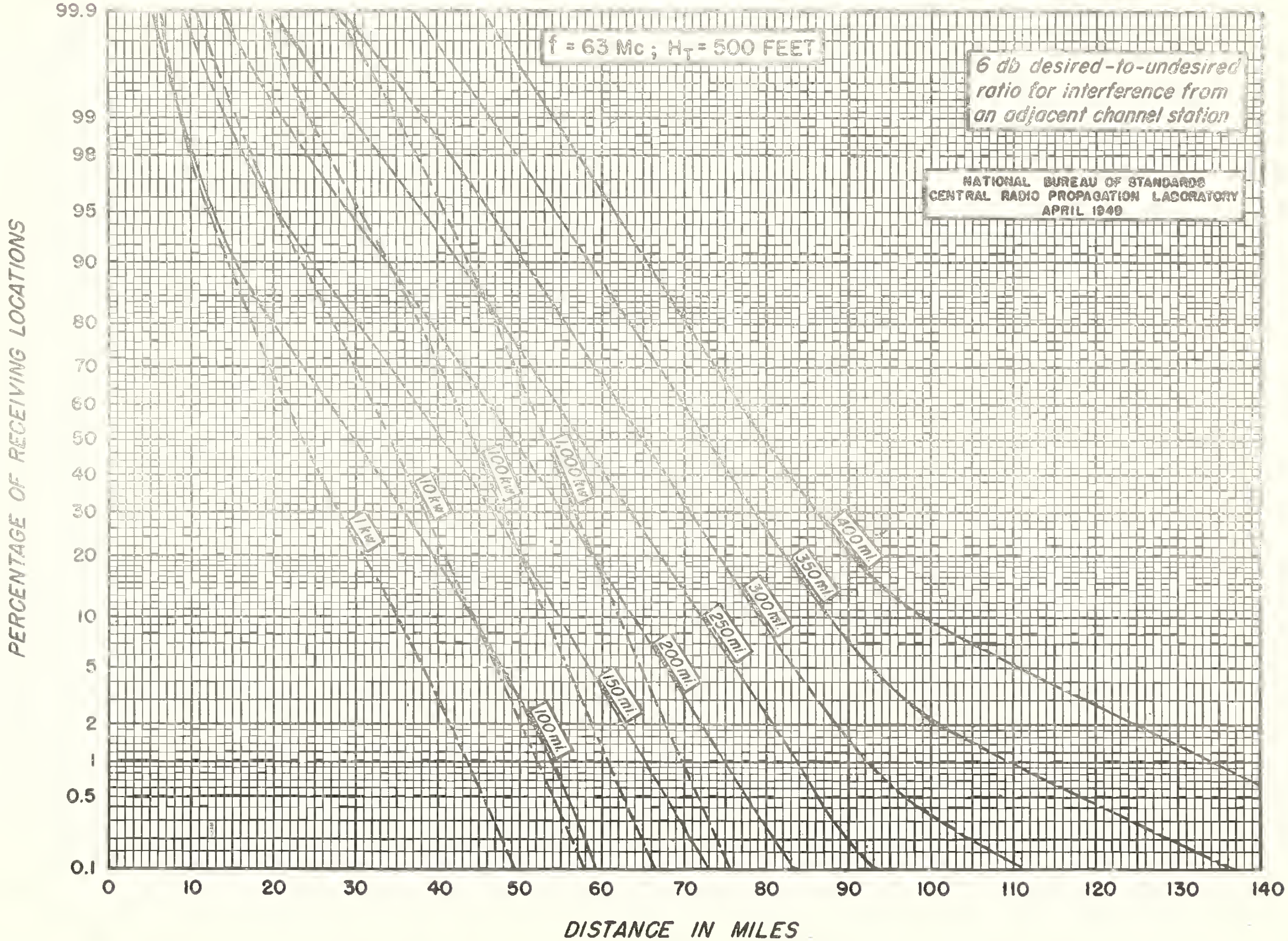



Figure 13

DISTRIBUTIONS, FOR THE ANTENNA HEIGHTS INDICATED, OF RECEIVING LOCATIONS FREE, FOR 99% OF THE TIME, OF INTERFERENCE FROM A CO-CHANNEL UNSYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER

THE DASHED CURVES ARE FOR STATIONS RADIATING AN EFFECTIVE POWER OF 100 KILOWATTS FROM ANTENNAS AT THE HEIGHTS INDICATED AND GIVE THE DISTRIBUTIONS OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME, i.e. A DESIRED FIELD OF 221 μv/m

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

f = 63 Mc; SEPARATION BETWEEN DESIRED AND UNDESIRED STATIONS: 300 MILES

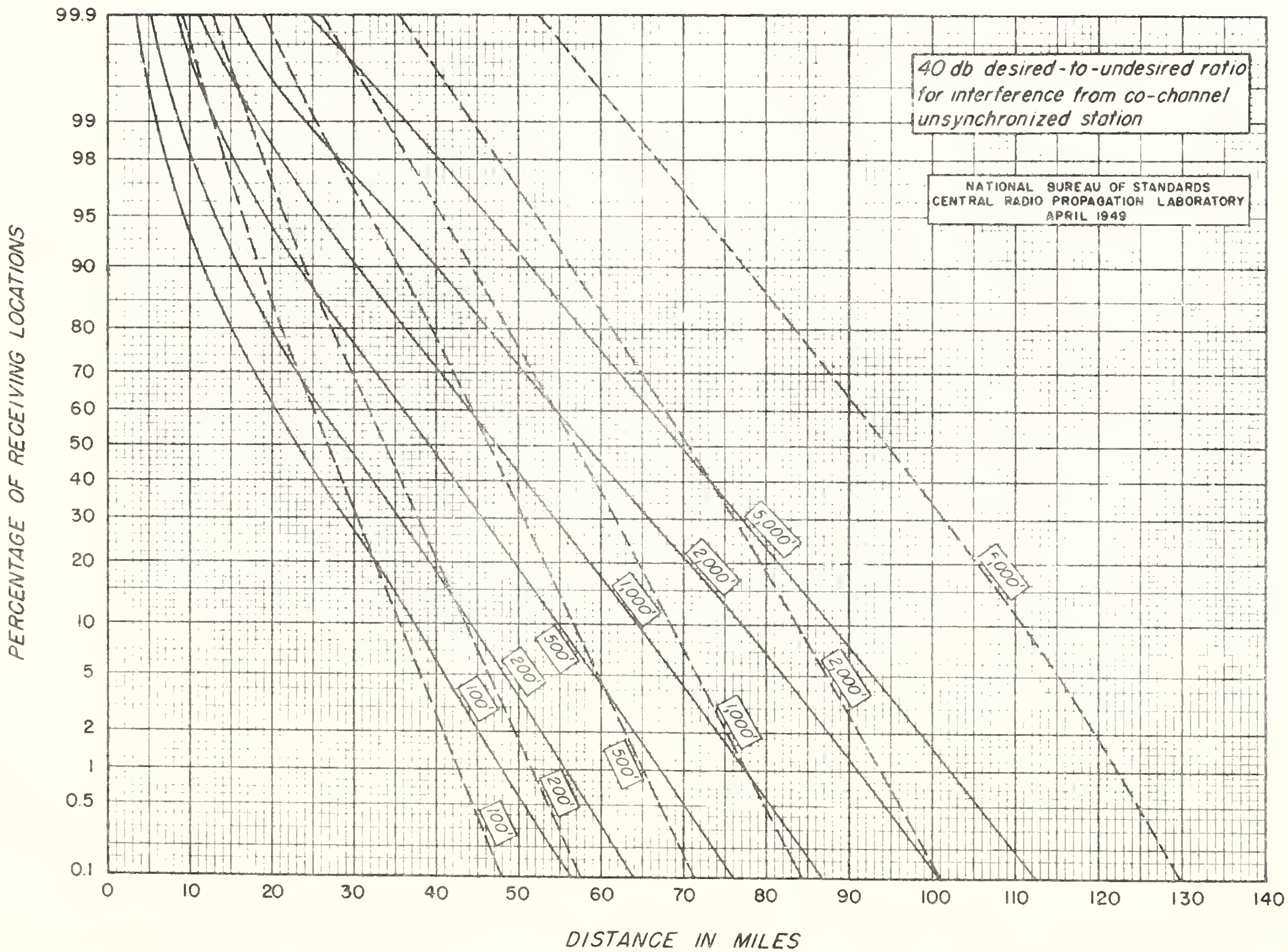



Figure 14

DISTRIBUTIONS, FOR THE ANTENNA HEIGHTS INDICATED, OF RECEIVING LOCATIONS FREE, FOR 99% OF THE TIME, OF INTERFERENCE FROM A CO-CHANNEL SYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER

THE DASHED CURVES ARE FOR STATIONS RADIATING AN EFFECTIVE POWER OF 100 KILOWATTS FROM ANTENNAS AT THE HEIGHTS INDICATED AND GIVE THE DISTRIBUTIONS OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME, i.e. A DESIRED FIELD OF 221 $\mu$v/m

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

f = 63 Mc; SEPARATION BETWEEN DESIRED AND UNDESIRED STATIONS: 225 MILES

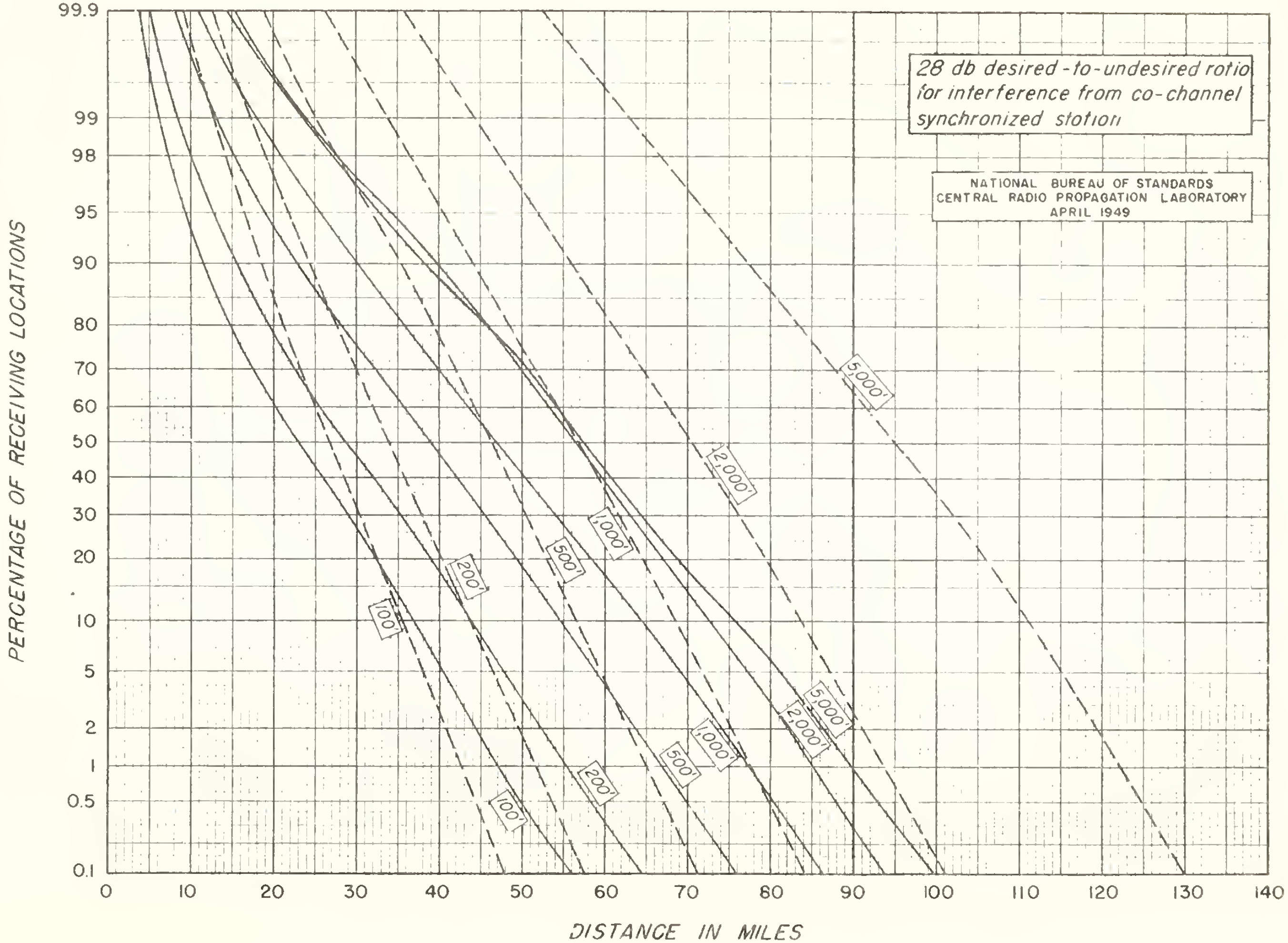



Figure 15

DISTRIBUTIONS, FOR THE ANTENNA HEIGHTS INDICATED, OF RECEIVING LOCATIONS FREE, FOR 99% OF THE TIME, OF INTERFERENCE FROM AN ADJACENT CHANNEL STATION WITH THE SAME EFFECTIVE RADIATED POWER

THE DASHED CURVES ARE FOR STATIONS RADIATING AN EFFECTIVE POWER OF 100 KILOWATTS FROM ANTENNAS AT THE HEIGHTS INDICATED AND GIVE THE DISTRIBUTIONS OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME, i.e. A DESIRED FIELD OF 221 μv/m

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

f = 63 Mc; SEPARATION BETWEEN DESIRED AND UNDESIRED STATIONS: 130 MILES

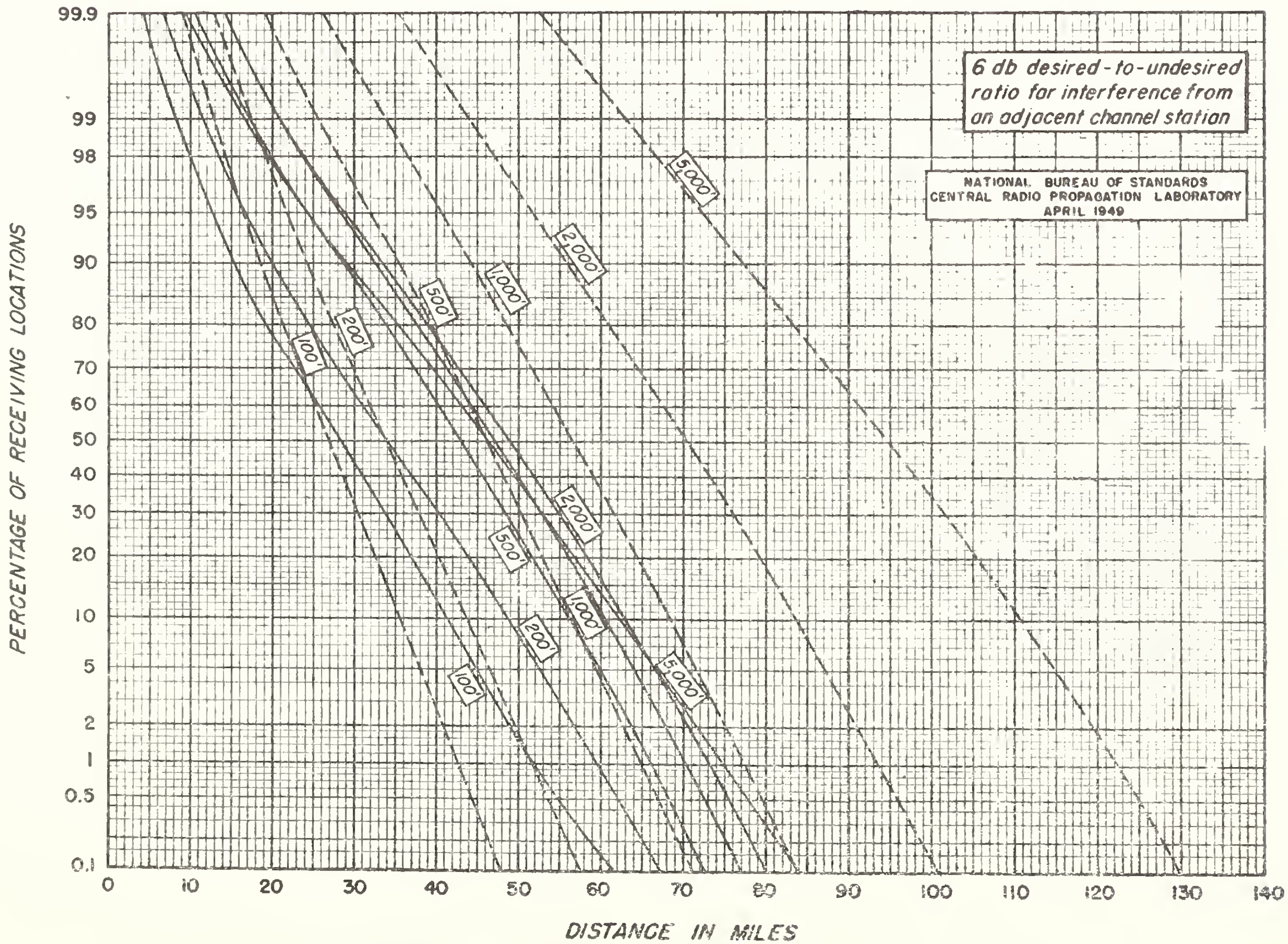



Figure 16

DISTRIBUTION, FOR FREQUENCIES OF 63 Mc AND 195 Mc, OF RECEIVING LOCATIONS FREE FOR 99% OF THE TIME OF INTERFERENCE FROM A CO-CHANNEL UNSYNCHRONIZED STATION WITH THE SAME EFFECTIVE RADIATED POWER

ALSO SHOWN, FOR STATIONS RADIATING THE EFFECTIVE POWERS INDICATED, ARE THE DISTRIBUTIONS OF RURAL RECEIVING LOCATIONS FREE FROM NOISE FOR 99% OF THE TIME FOR A FREQUENCY OF 63 Mc (i.e. A DESIRED FIELD OF 221 μv/m) AND FOR A FREQUENCY OF 195 Mc (i.e. A DESIRED FIELD OF 770 μv/m)

(BASED ON THE ASSUMPTION THAT THE DESIRED AND UNDESIRED FIELDS ARE UNCORRELATED WITH RESPECT TO EITHER TIME OR RECEIVING LOCATION)

$H_T$ = 500 FEET; SEPARATION BETWEEN DESIRED AND UNDESIRED STATIONS: 300 MILES

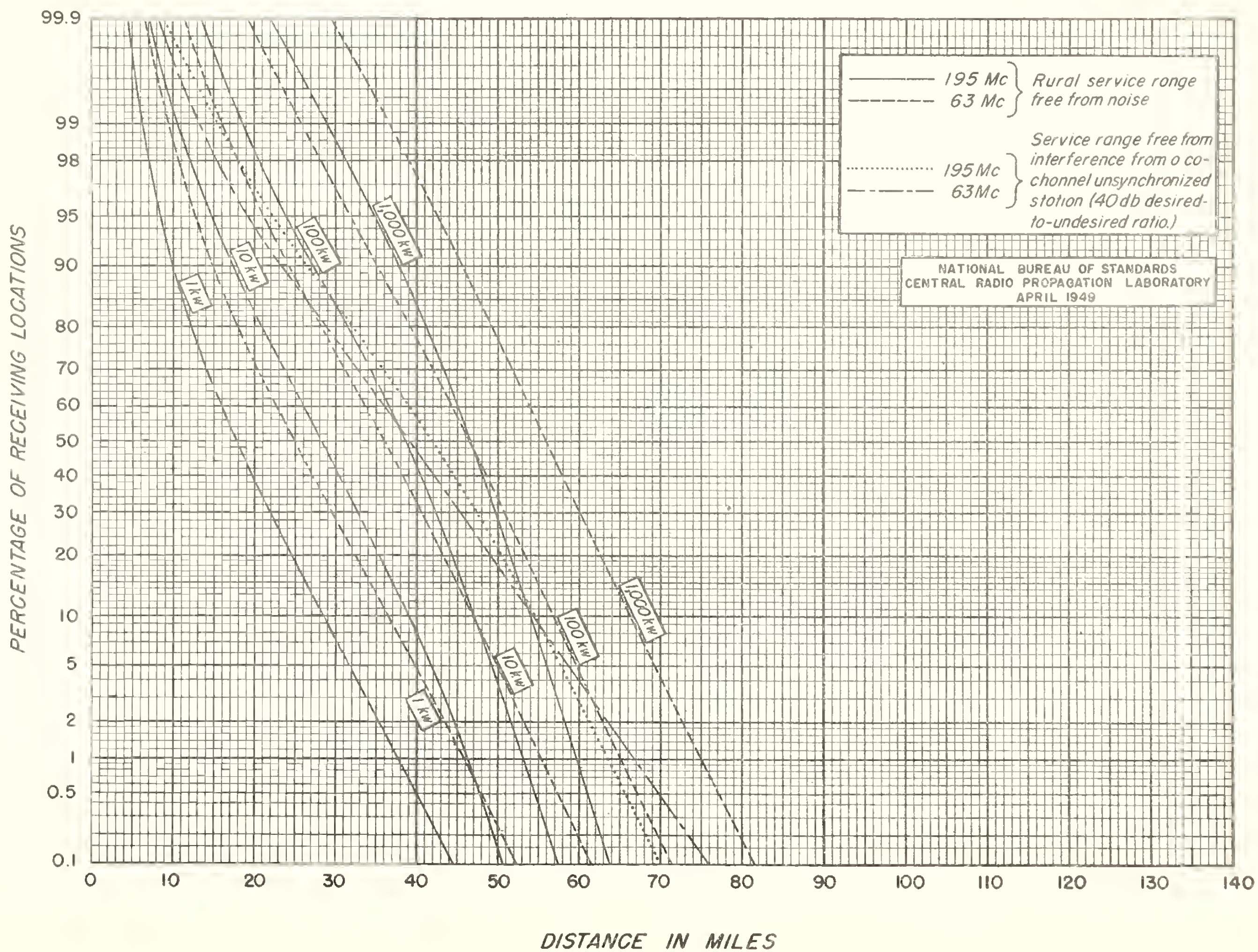



Figure 17

PROBABILITY $Q_0(d,p_a)$ OF TELEVISION SERVICE AT A DISTANCE d OF GRADE $p_a$ OR BETTER

$$Q_0(d,p_a) = \int_0^{q(p_a)} p\,dq$$

$q(p_a)$=VALUE OF q CORRESPONDING TO $p = p_a$

$f$ = 63 Mc; $H_t$ = 500 FEET; $P_r$ = 100 KW

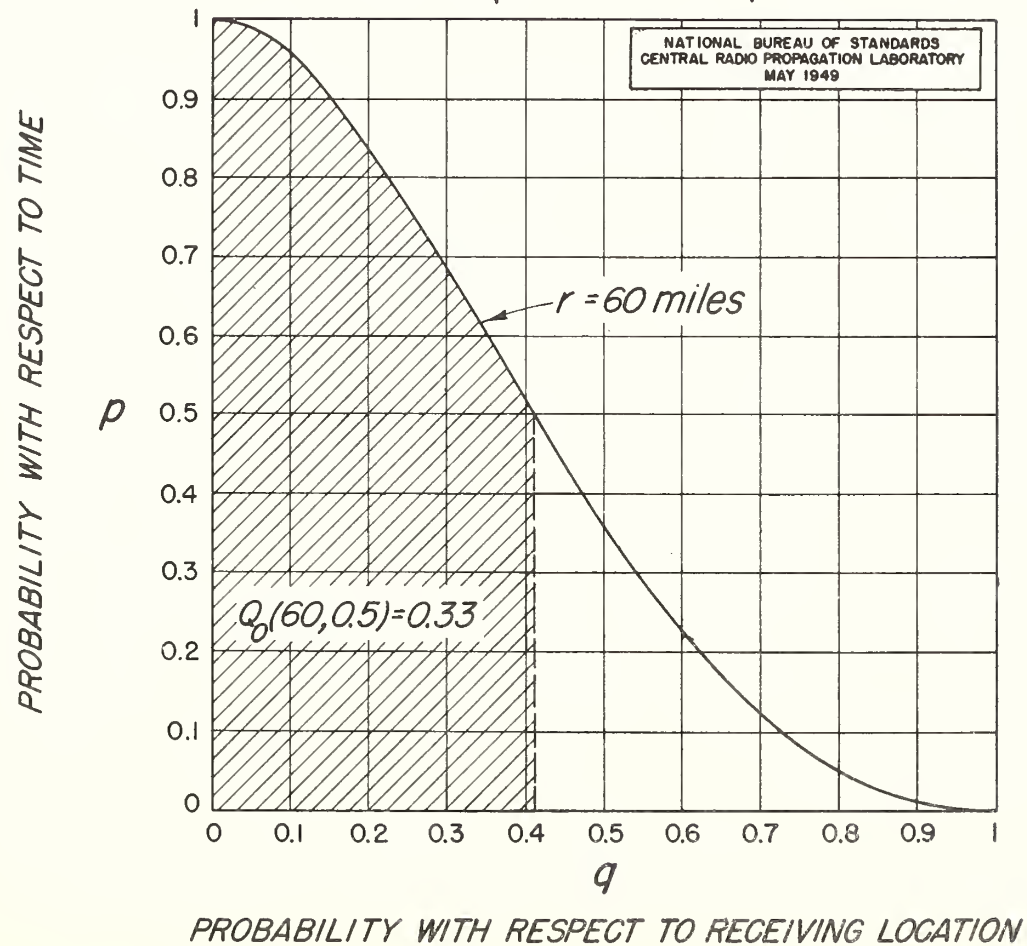



Figure 18

DISTRIBUTION OF TELEVISION SERVICE WITH TIME AND RECEIVING LOCATION

FREQUENCY 63 Mc; TRANSMITTING ANTENNA HEIGHT 500 FEET;
EFFECTIVE RADIATED POWER 100 KILOWATTS
RURAL SERVICE LIMITED BY NOISE

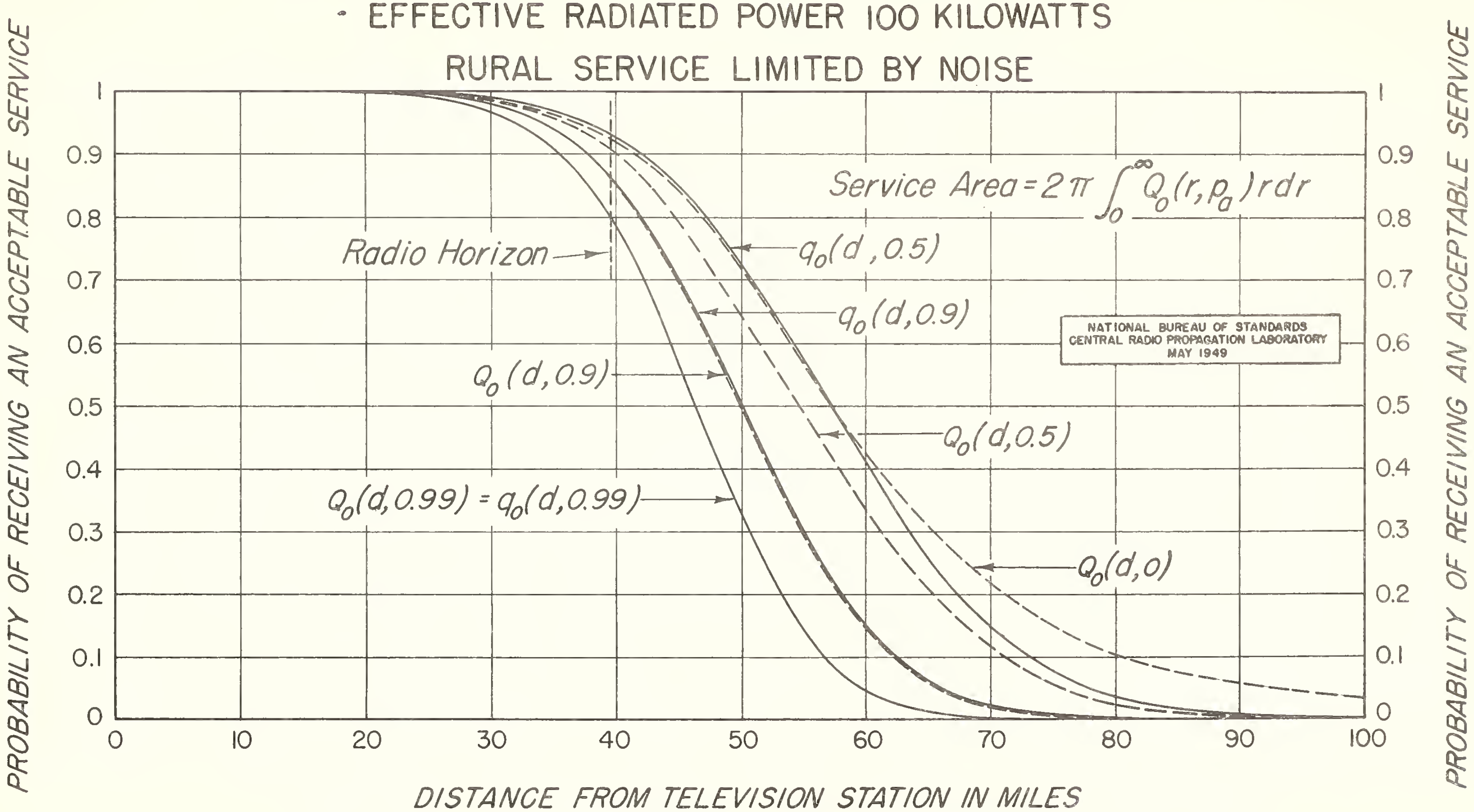



Figure 19

DISTRIBUTION OF GRADE A SERVICE EXPECTED FROM A CLEAR CHANNEL TELEVISION STATION

$f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db

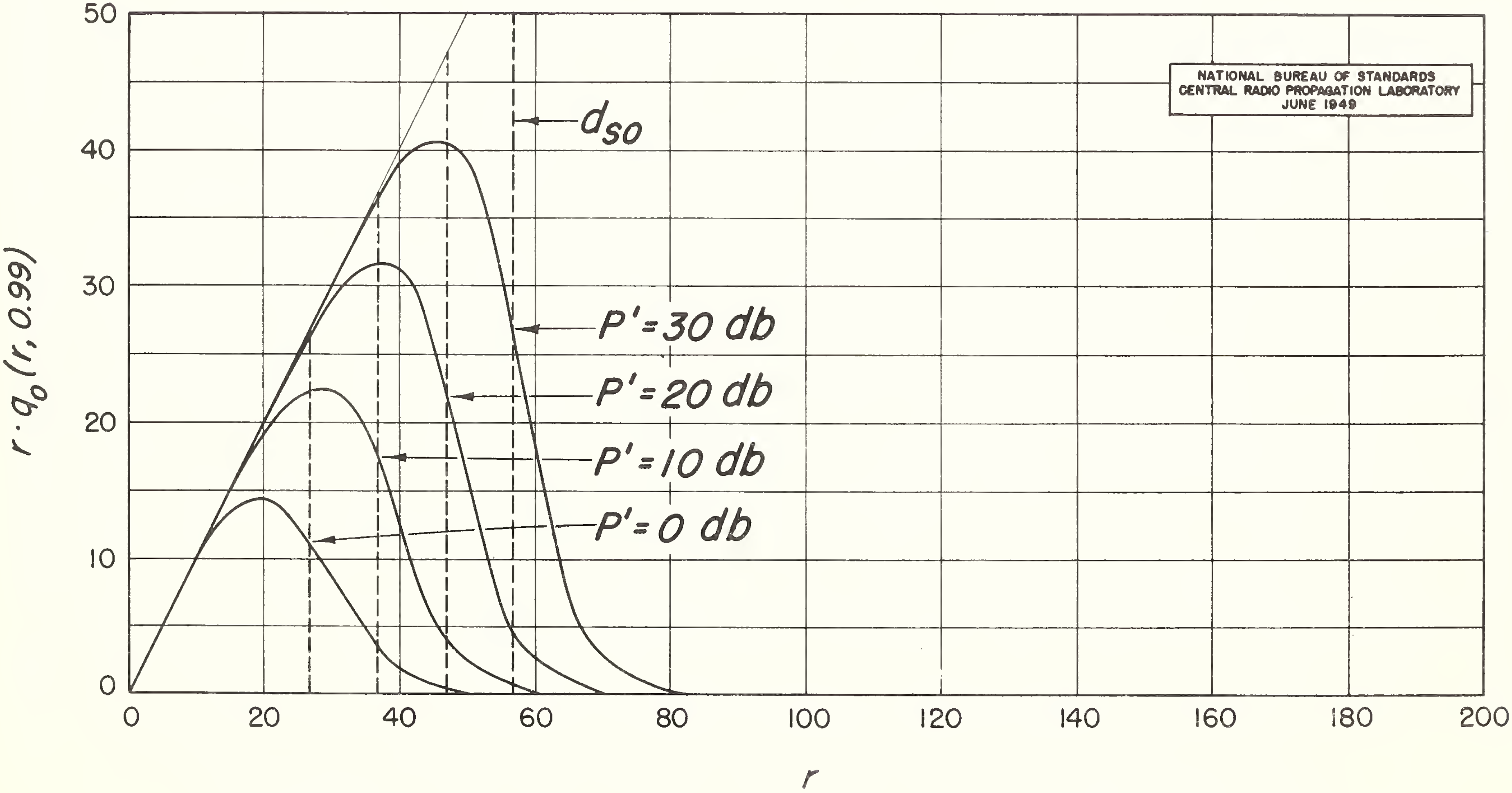



Figure 20

DISTRIBUTION OF GRADE B SERVICE EXPECTED FROM A CLEAR CHANNEL TELEVISION STATION

$f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db

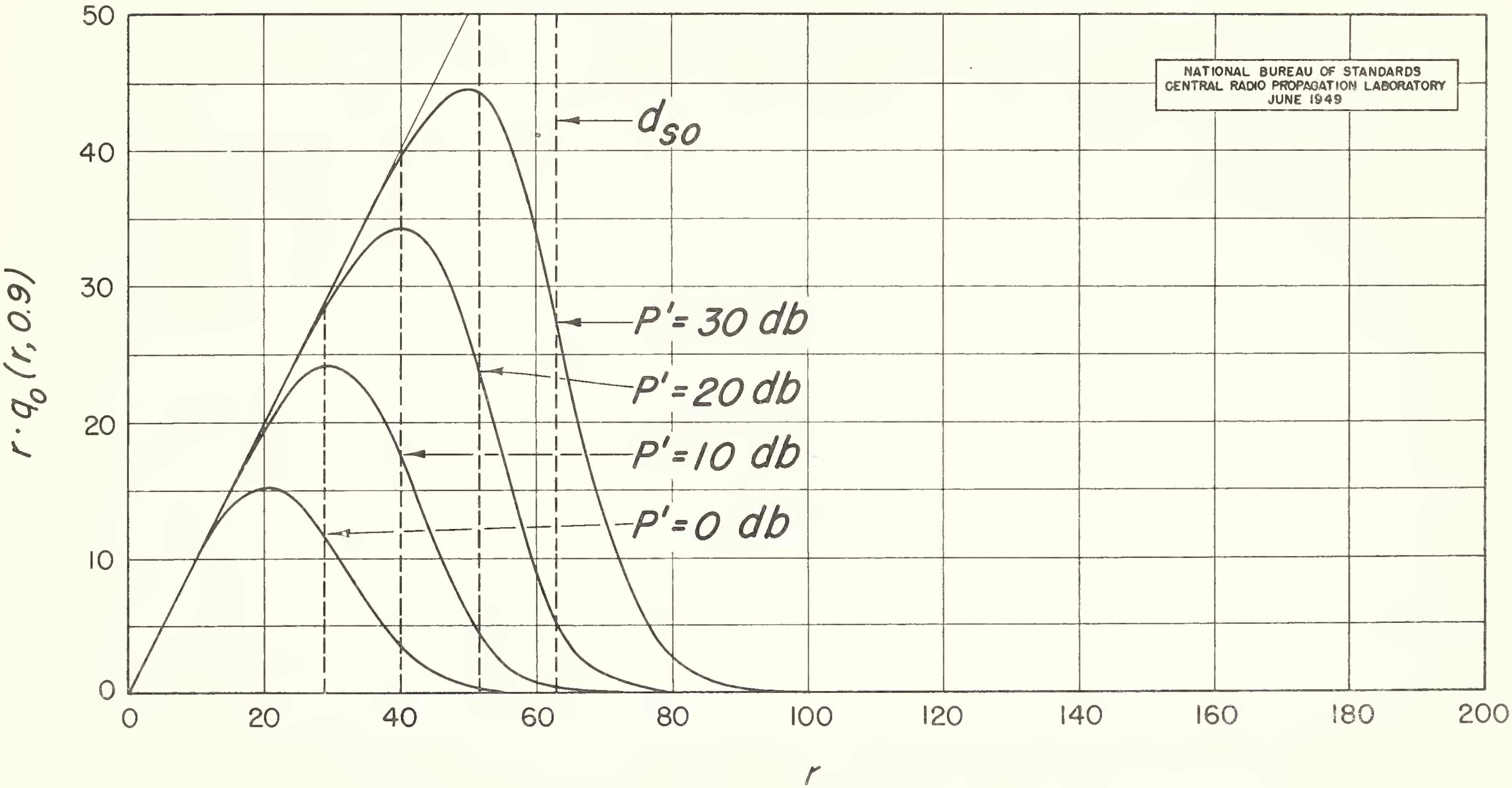



Figure 21

DISTRIBUTION OF GRADE C SERVICE EXPECTED FROM A CLEAR CHANNEL TELEVISION STATION

$f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db

The dashed and dotted curves also show Grade A and B service for $P' = 20$ for comparison with the Grade C service

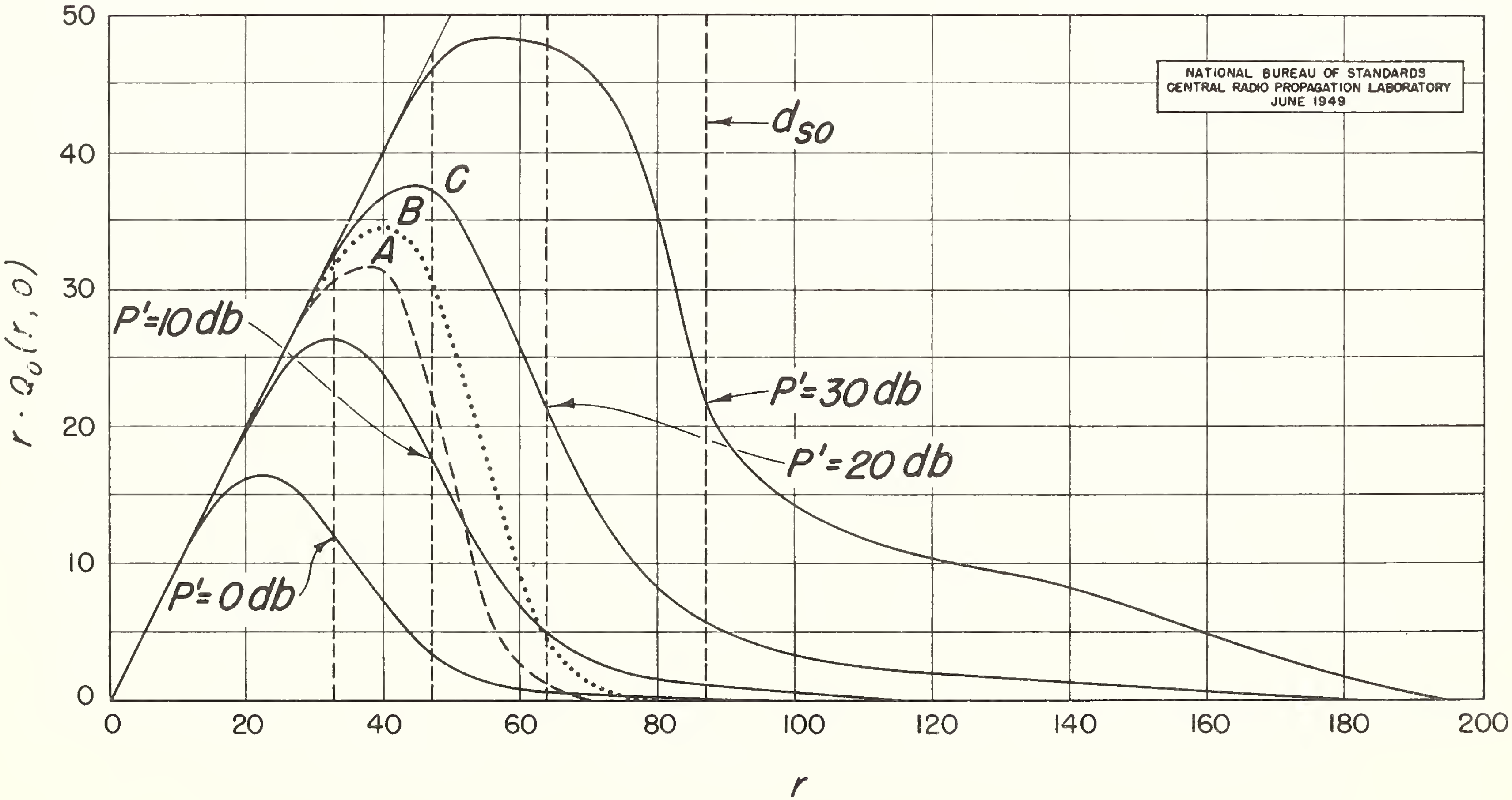



Figure 22

IDEALIZED ALLOCATION OF TELEVISION BROADCAST STATIONS ON A TRIANGULAR LATTICE

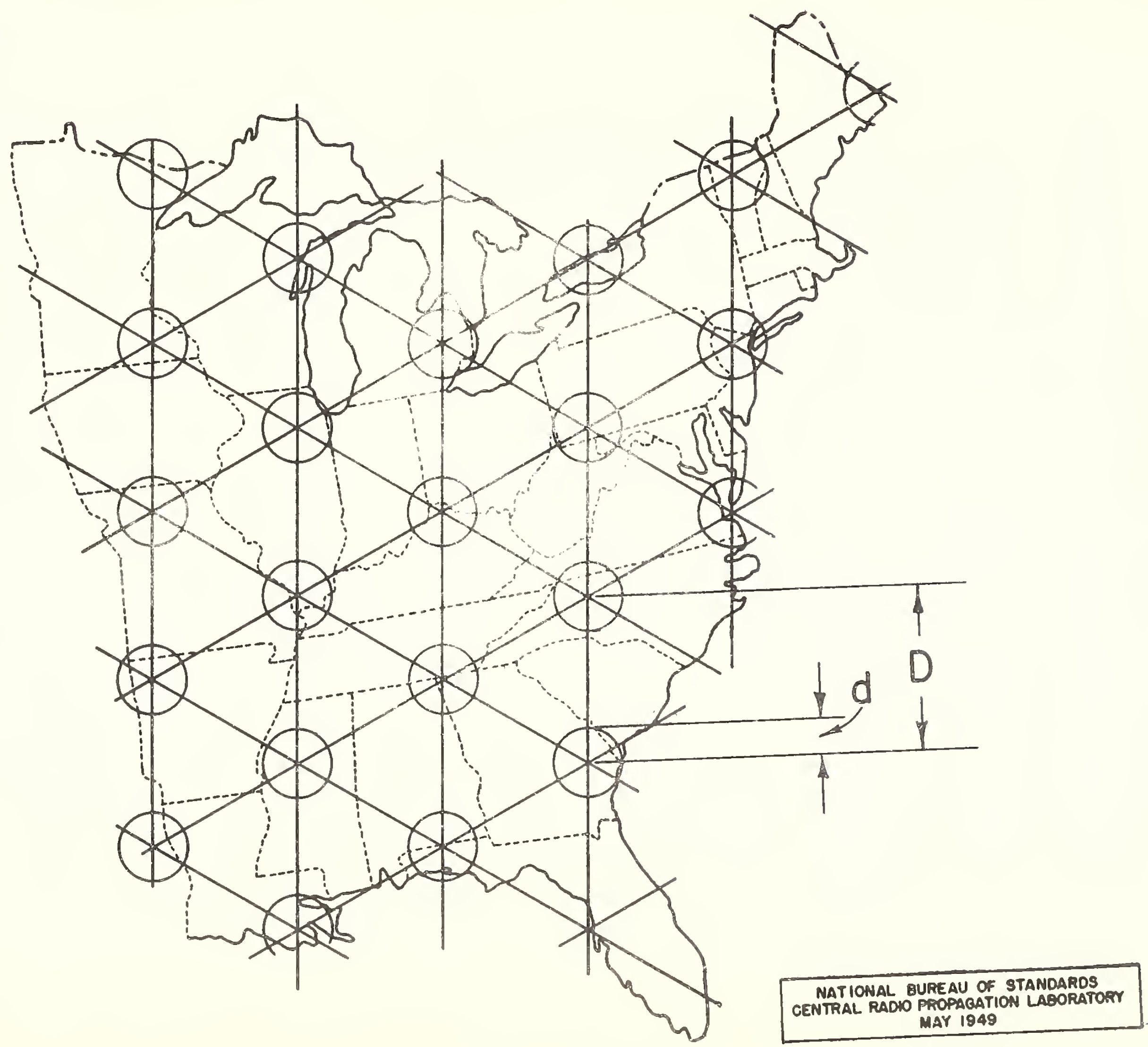
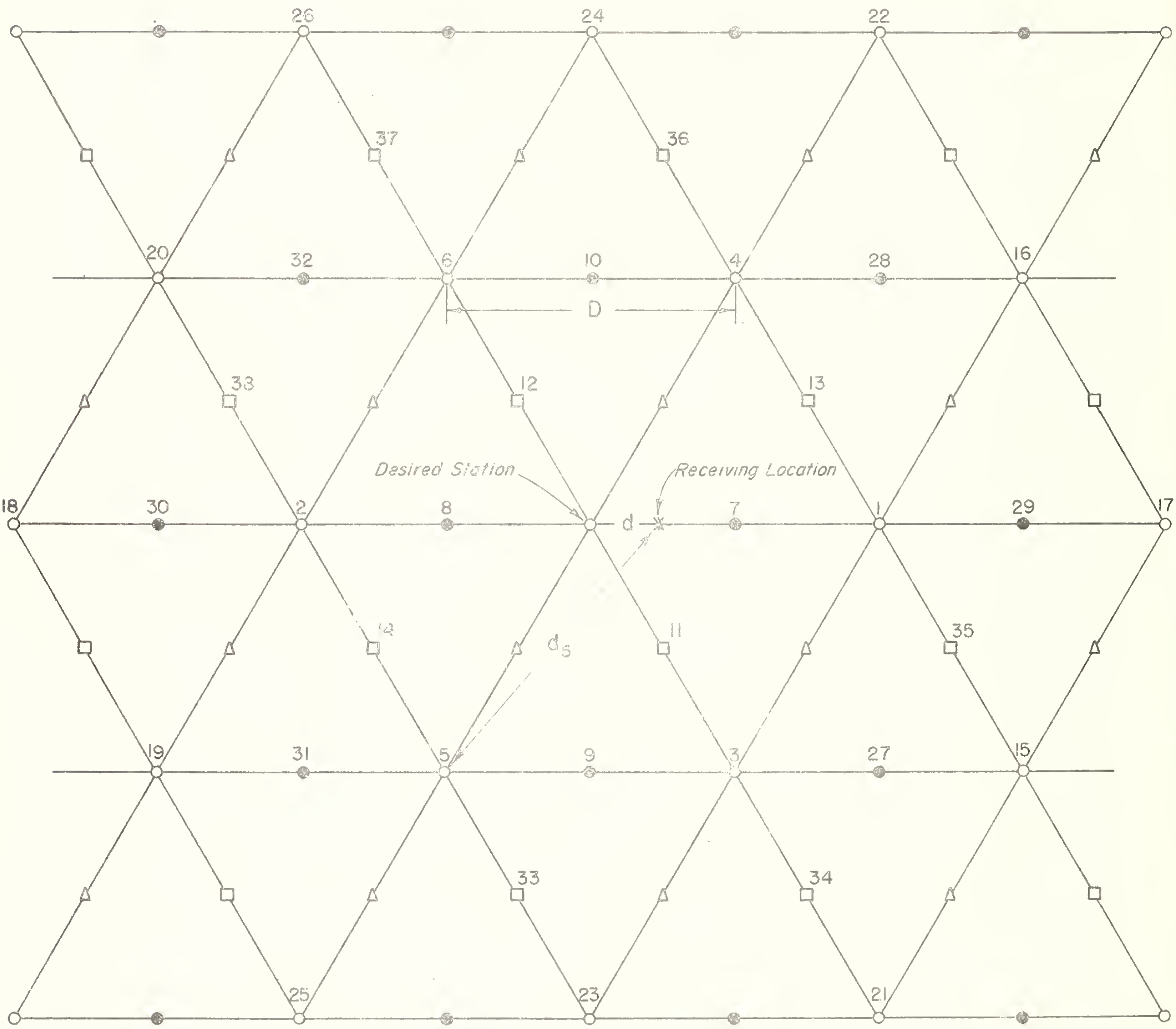



Figure 23

IDEALIZED ALLOCATION OF TELEVISION BROADCAST STATIONS ON A TRIANGULAR LATTICE




| | |
|---|---|
| ● | CHANNEL 2, 6, 10 |
| ○ | " 3, 7, 11 |
| □ | " 4, 8, 12 |
| Δ | " 5, 9, 13 |

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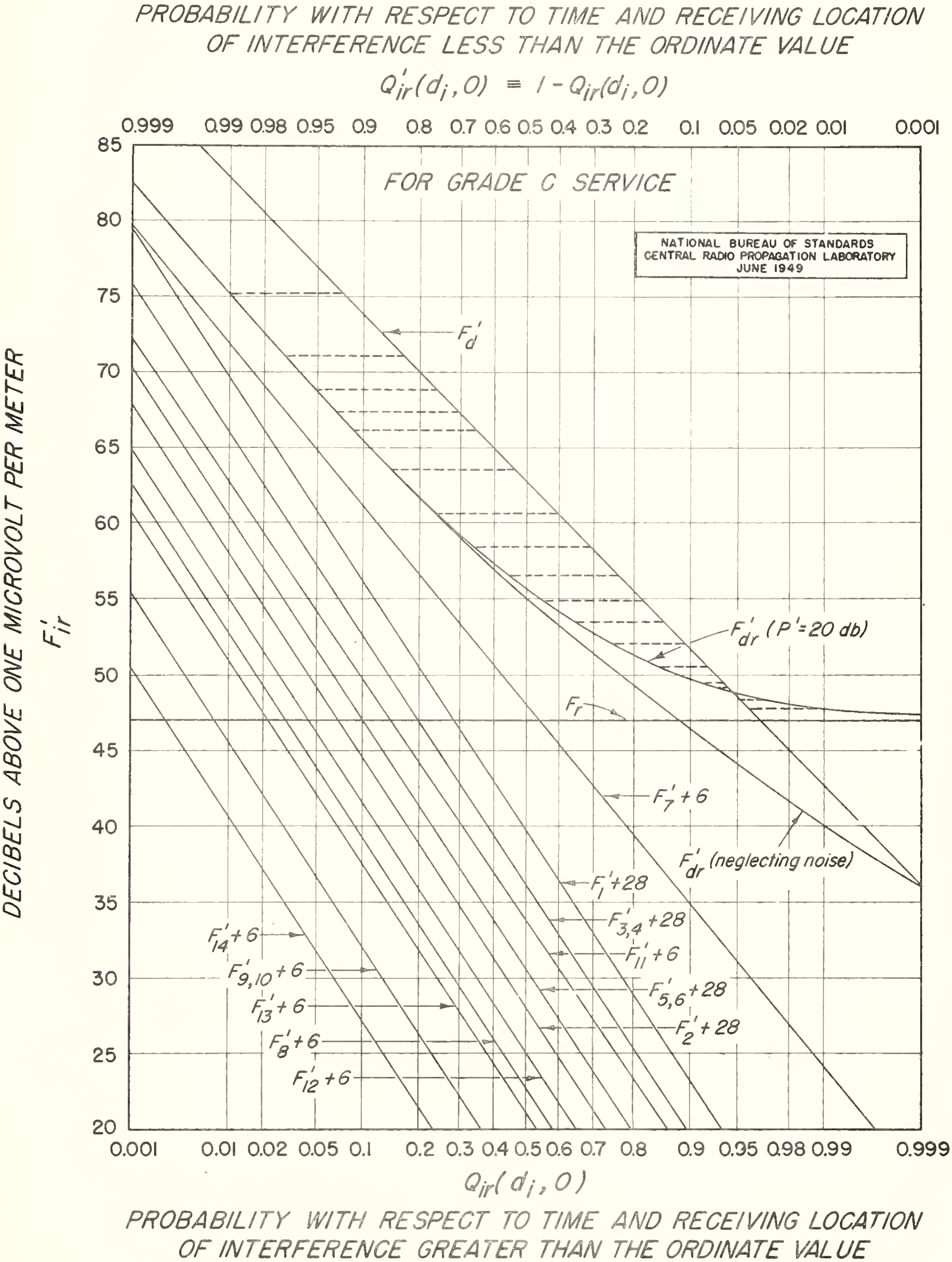
JUNE 1949

Figure 24

DISTRIBUTIONS OF THE INTERFERING AND DESIRED FIELD INTENSITY FOR THE RECEIVING LOCATIONS AT A DISTANCE d = 35 MILES AND FOR A CO-CHANNEL SEPARATION D = 200 MILES FOR THE ARRANGEMENT OF STATIONS SHOWN ON FIGURE 24

f = 63 Mc for the desired and the co-channel undesired stations; for all stations $H_t$ = 500 feet and P' = 20 db above one kilowatt; $H_r$ = 30 feet



EXAMPLE ILLUSTRATING A GRAPHICAL METHOD FOR DETERMINING THE PROBABILITY $Q'_{ij}(E_{ir}^2 + E_{jr}^2 < E^2)$ AND SHOWING THE DEGREE OF APPROXIMATION INVOLVED IN THE ASSUMPTION THAT $Q'_{ij} \cong Q'_{ir} \cdot Q'_{jr}$ WHEN $E_{ir}$ AND $E_{jr}$ ARE NOT CORRELATED

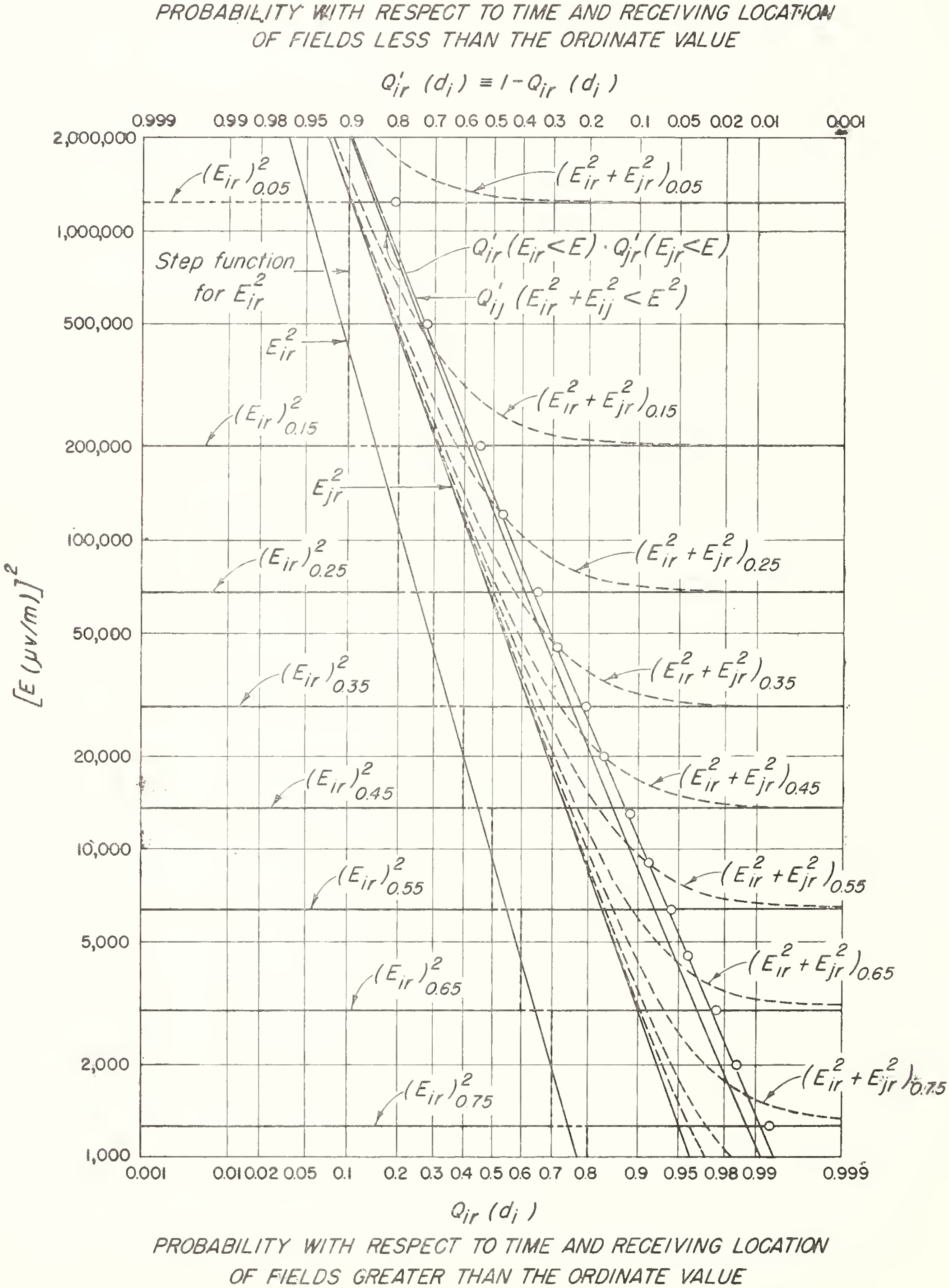



Figure 26

EXAMPLE ILLUSTRATING A GRAPHICAL METHOD FOR DETERMINING THE PROBABILITY

$Q'_{ij}(E^2_{ir}+E^2_{jr}<E^2)$ WHEN $Q'_{ir}(E_{ir}<E)$ AND $Q'_{jr}(E_{jr}<E)$ ARE KNOWN AND $E_{ir}$ AND $E_{jr}$ ARE NOT CORRELATED

(THE CURVED LINES REPRESENT CONSTANT VALUES OF $E^2_{ir}+E^2_{jr}$)

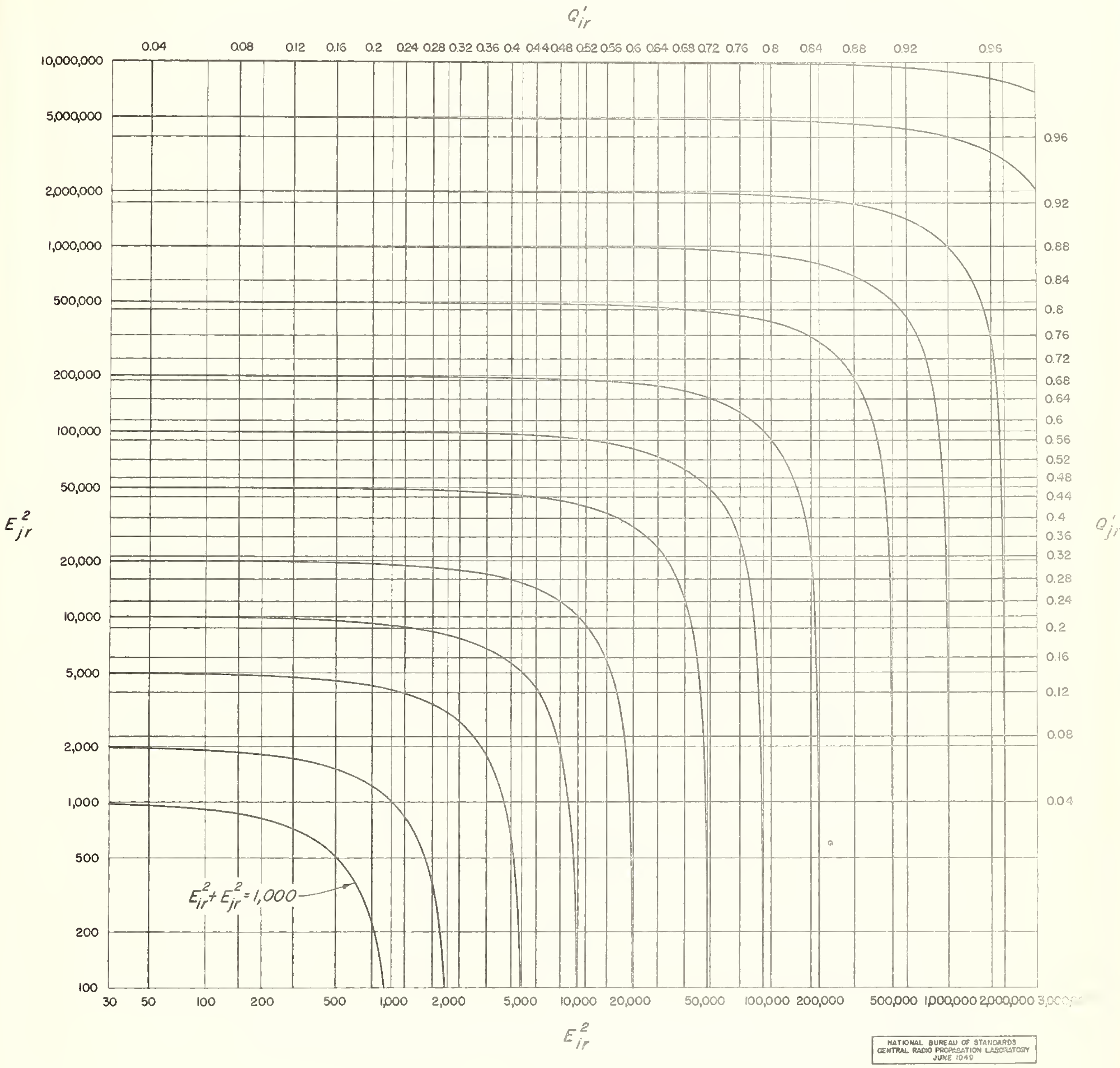



Figure 27

EXAMPLE ILLUSTRATING A GRAPHICAL METHOD FOR DETERMINING THE PROBABILITY $Q'_{ij}\,(E_{ir}^2 + E_{jr}^2 < E^2)$ WHEN $Q'_{ir}\,(E_{ir} < E)$ AND $Q'_{jr}\,(E_{jr} < E)$ ARE KNOWN AND $E_{ir}$ AND $E_{jr}$ ARE NOT CORRELATED

(THE CURVED LINES REPRESENT CONSTANT VALUES OF $E_{ir}^2 + E_{jr}^2$)

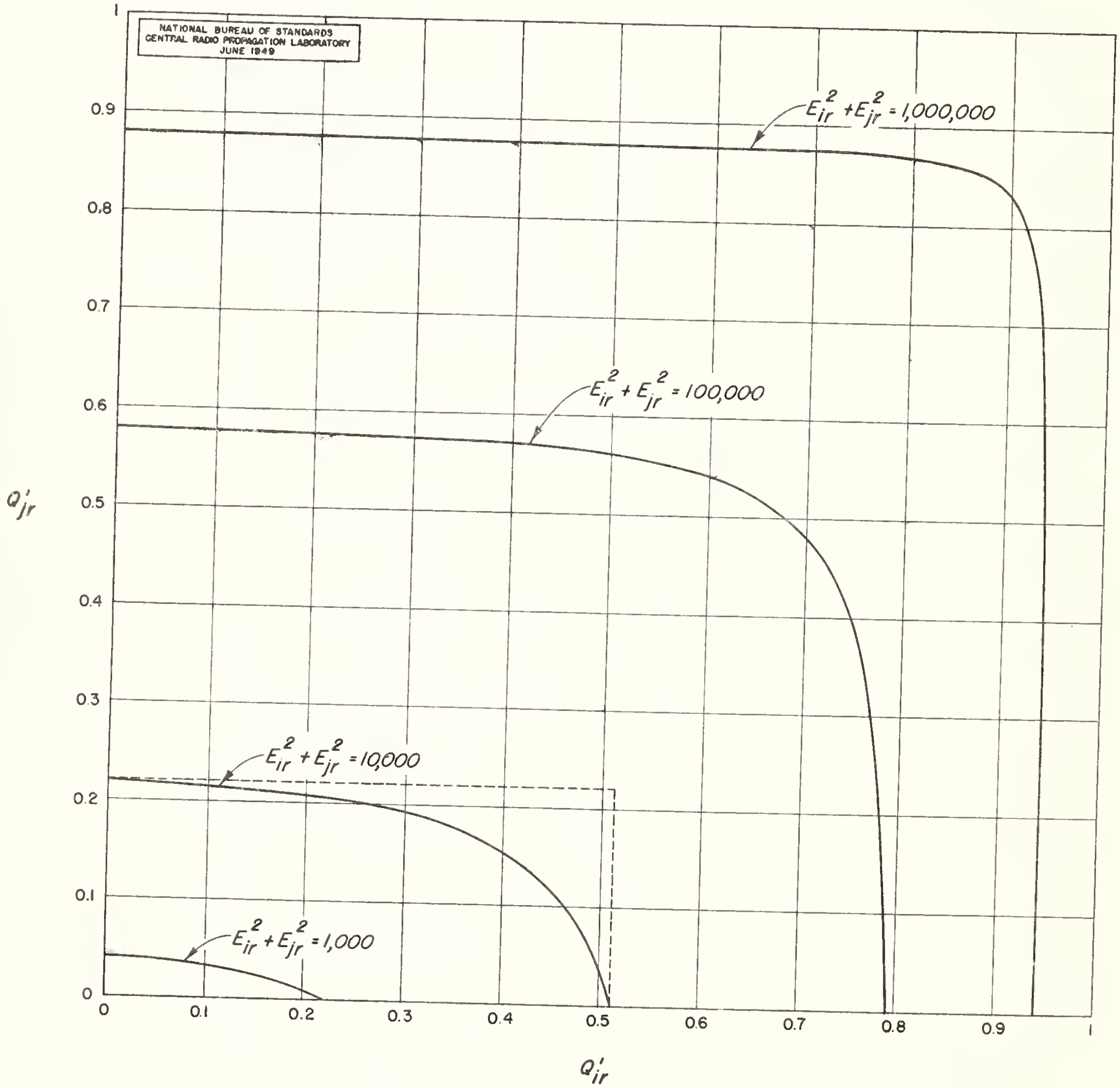



Figure 28

DISTRIBUTION OF GRADE C SERVICE EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

D = 200 MILES; f = 63 Mc; $H_t$ = 500 FEET; $H_r$ = 30 FEET; $F_r$ = 46.9 db

The dashed curves represent the average Q for 12 directions from the desired station

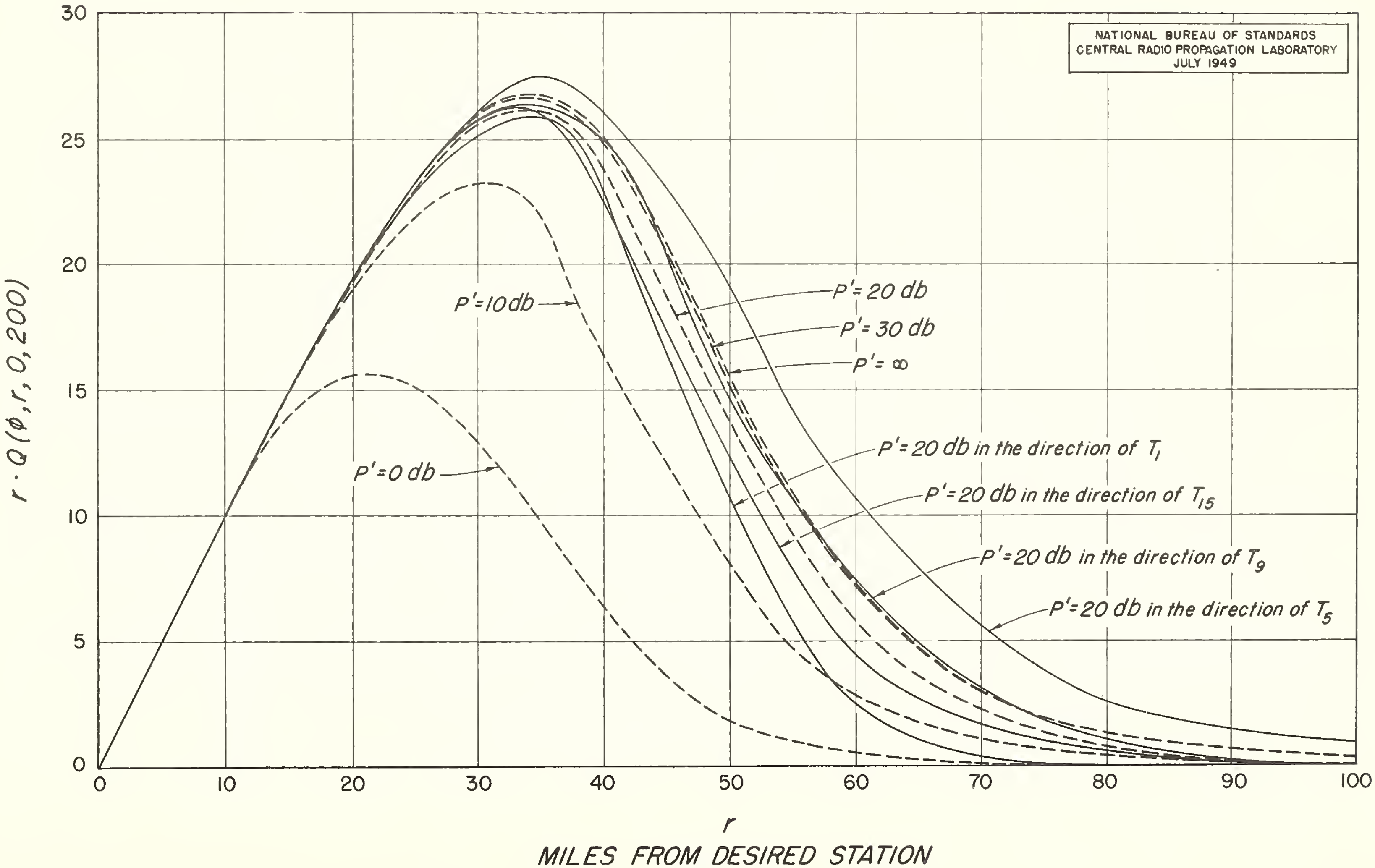



Figure 29

DISTRIBUTION OF GRADE C SERVICE EXPECTED FOR A TELEVISION STATION OPERATING IN THE LATTICE SHOWN ON FIGURE 24

$D = 200$ MILES; $f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db

The deterioration of service is shown as the distance is increased in the direction of station N° 1

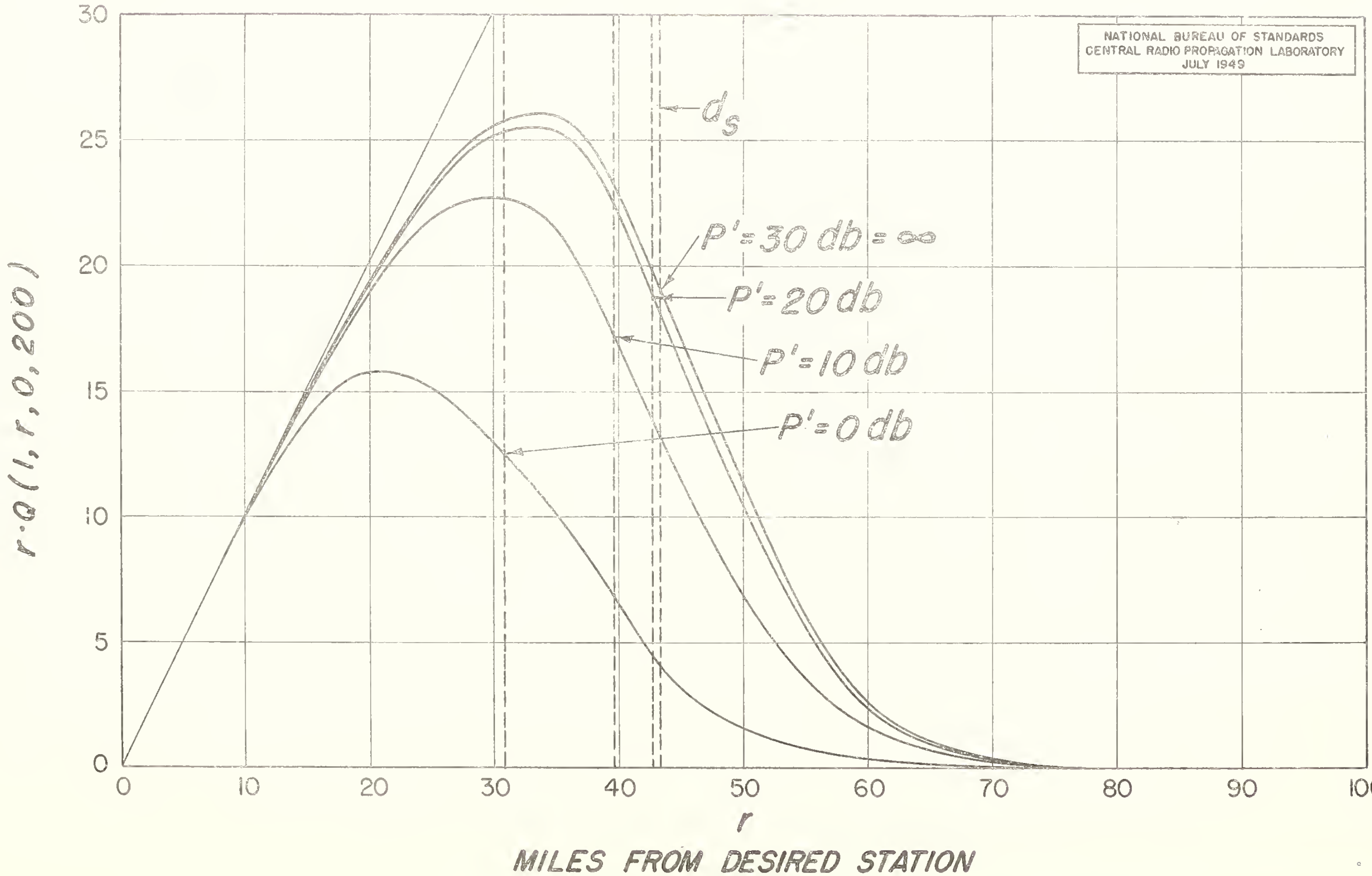



Figure 30

THE GRADE C SERVICE RADIUS SHOWN FOR 12 DIFFERENT DIRECTIONS FROM A STATION IN THE LATTICE SHOWN ON FIGURE 24

D = 200 MILES; f = 63 Mc; $H_t$ = 500 FEET; $H_r$ = 30 FEET; $F_r$ = 46.9 db; $g'_d = g'_i = 1$

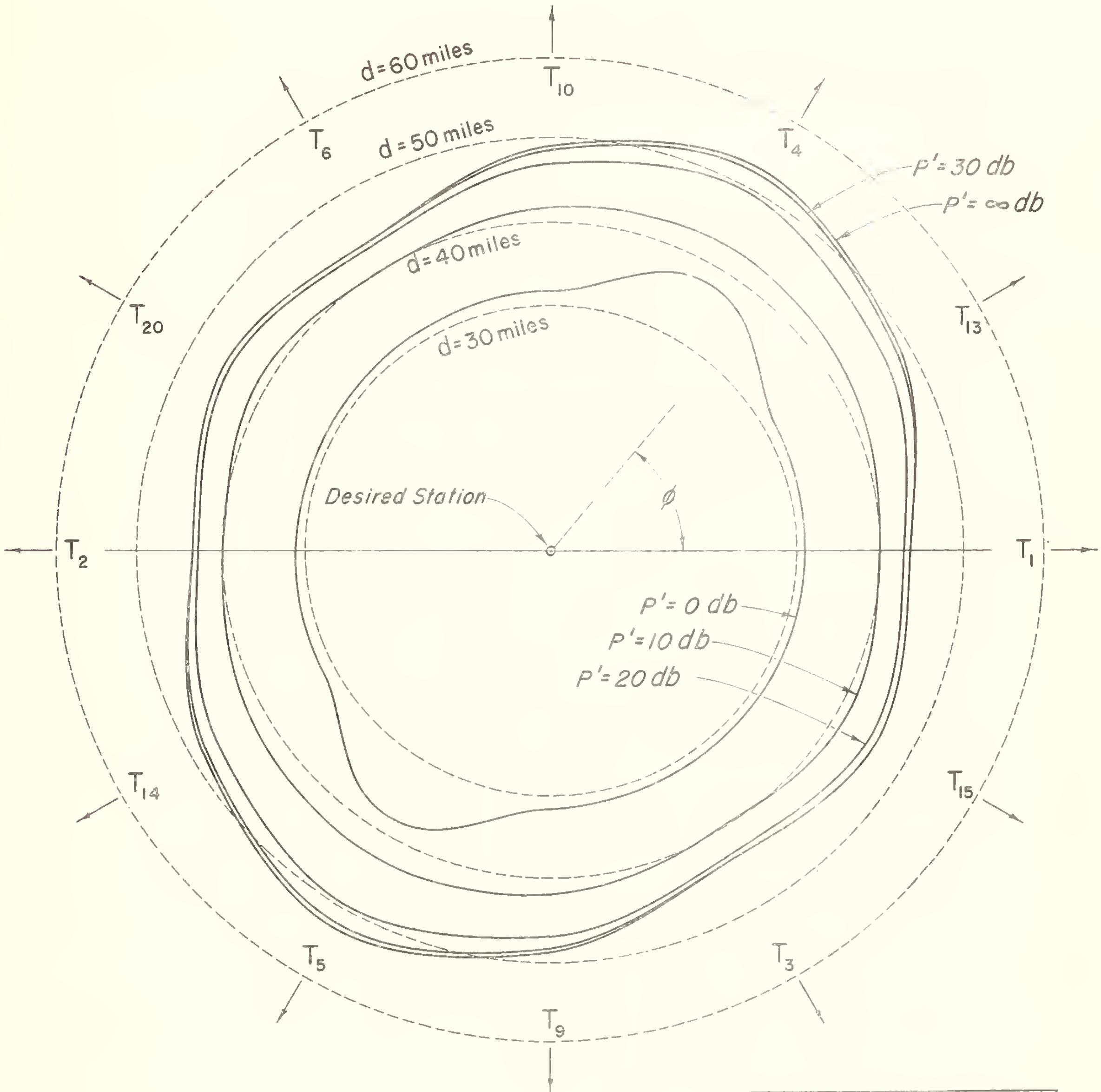



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Figure 31

GRAPHICAL METHOD FOR DETERMINING THE PROBABILITY OF GRADE B SERVICE INCLUDING THE EFFECTS OF TWO SOURCES OF INTERFERENCE

$$q_{ij}(E_{ir}^2 + E_{jr}^2 < E^2, 0.9) \cong \int_0^{q_{ir}(0.9)} q_{jr}\, d\, q_{ir} \cong q'_{jr}(E_{jr} < E, 0.9) \cdot q'_{ir}(E_{ir} < E, 0.9)$$

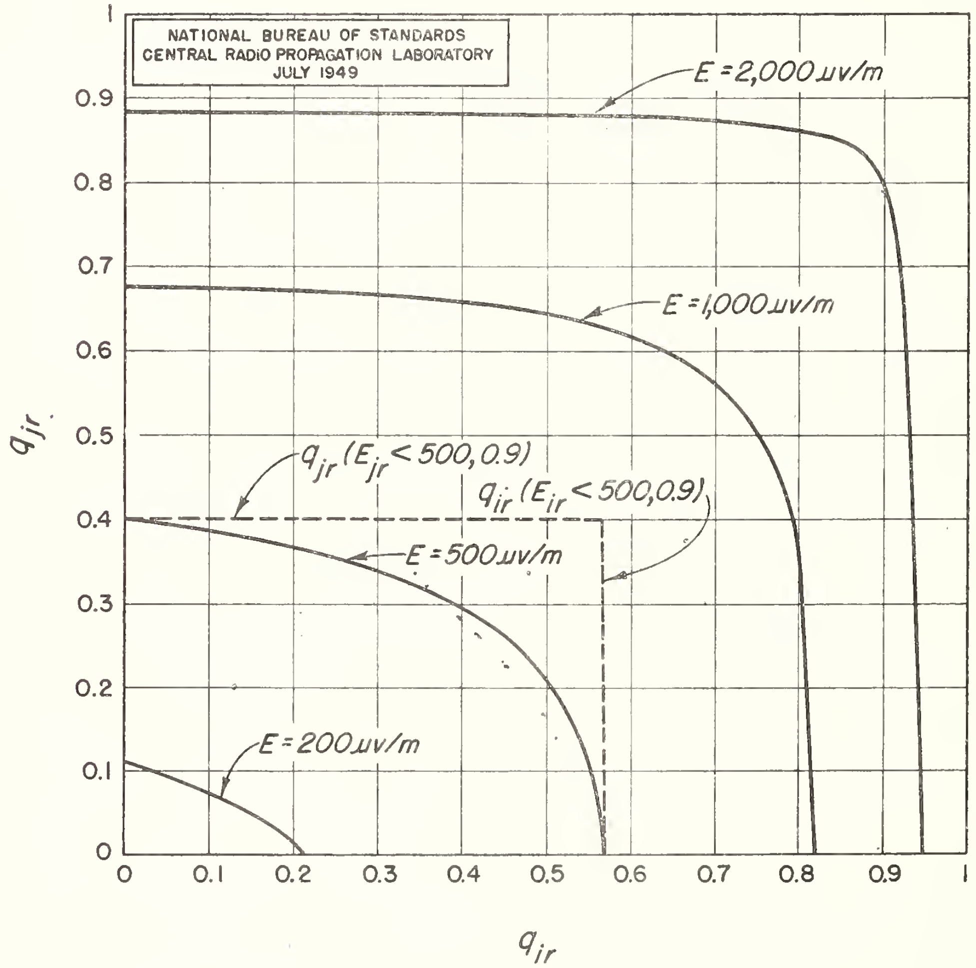



Figure 32

EXAMPLE SHOWING THE DEGREE OF APPROXIMATION INVOLVED IN THE USE OF $q'_{ij} = q'_{ir} \cdot q'_{jr}$

GRADE B SERVICE

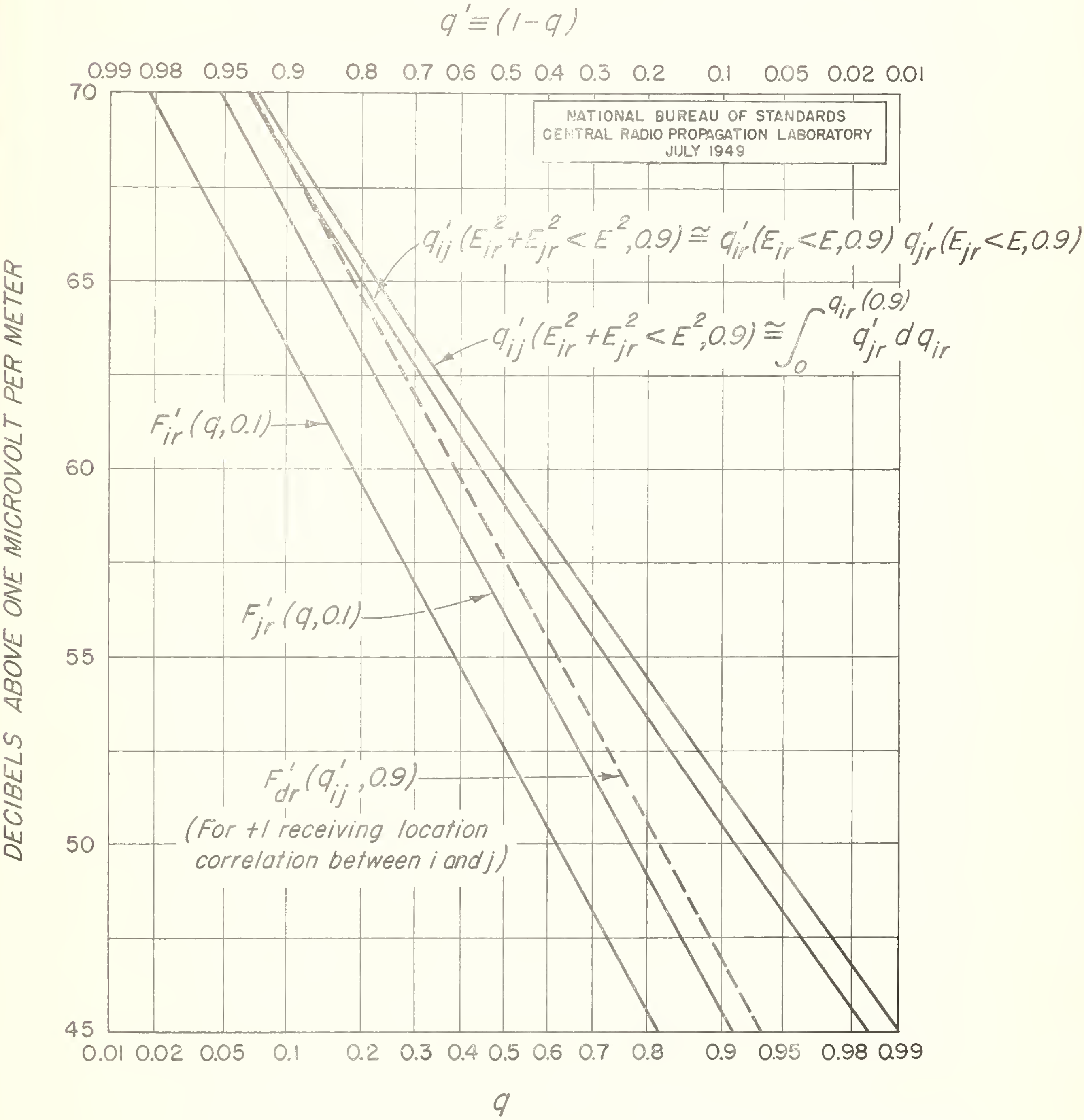



Figure 33

DISTRIBUTIONS OF THE INTERFERING AND DESIRED FIELD INTENSITY FOR THE RECEIVING LOCATIONS AT A DISTANCE d = 35 MILES AND FOR A CO-CHANNEL SEPARATION D = 200 MILES FOR THE ARRANGEMENT OF STATIONS SHOWN ON FIGURE 24

f = 63 Mc for the desired and the co-channel undesired stations; for all stations $H_t$ = 500 feet and P' = 20 db above one kilowatt; $H_r$ = 30 feet

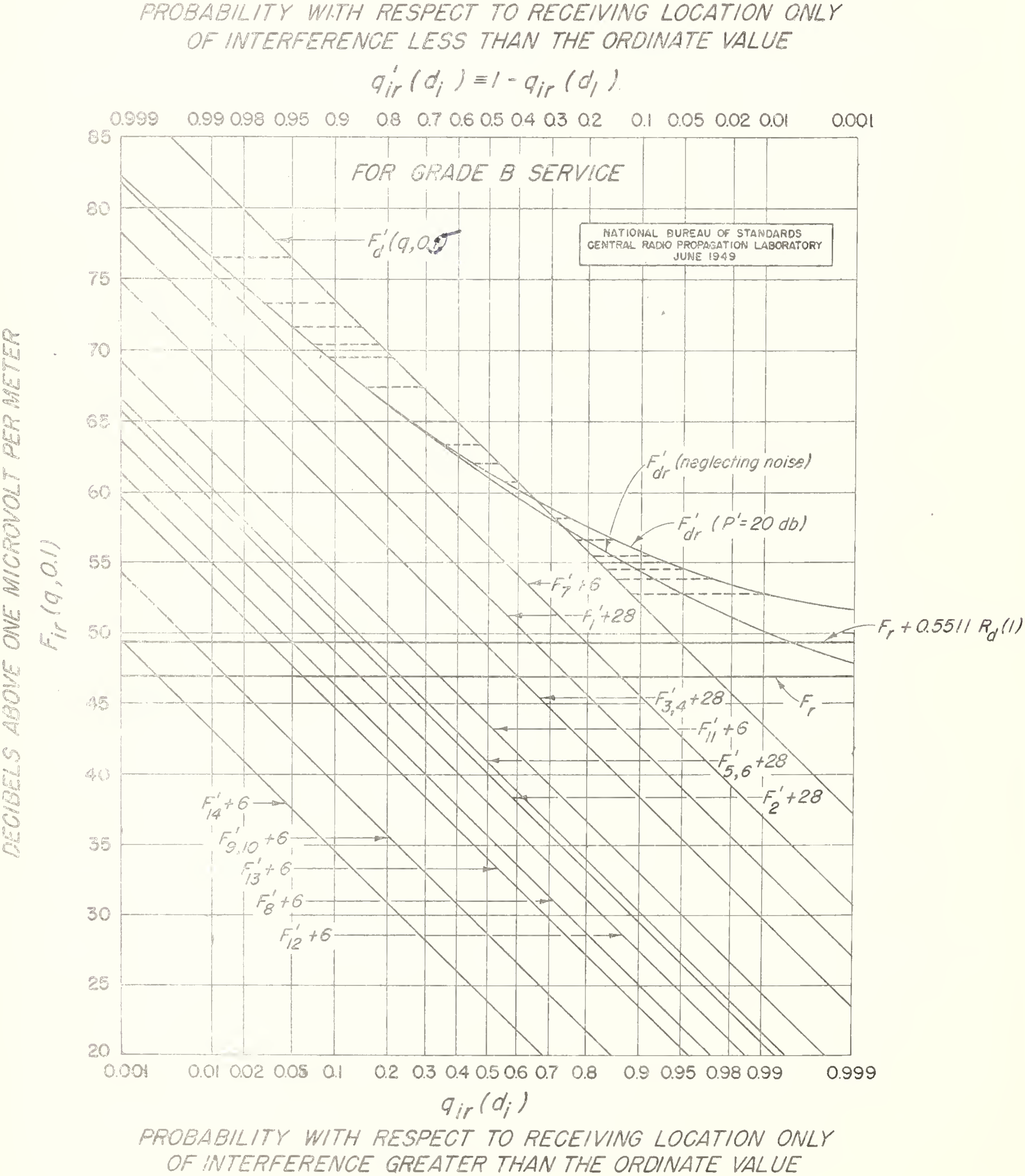
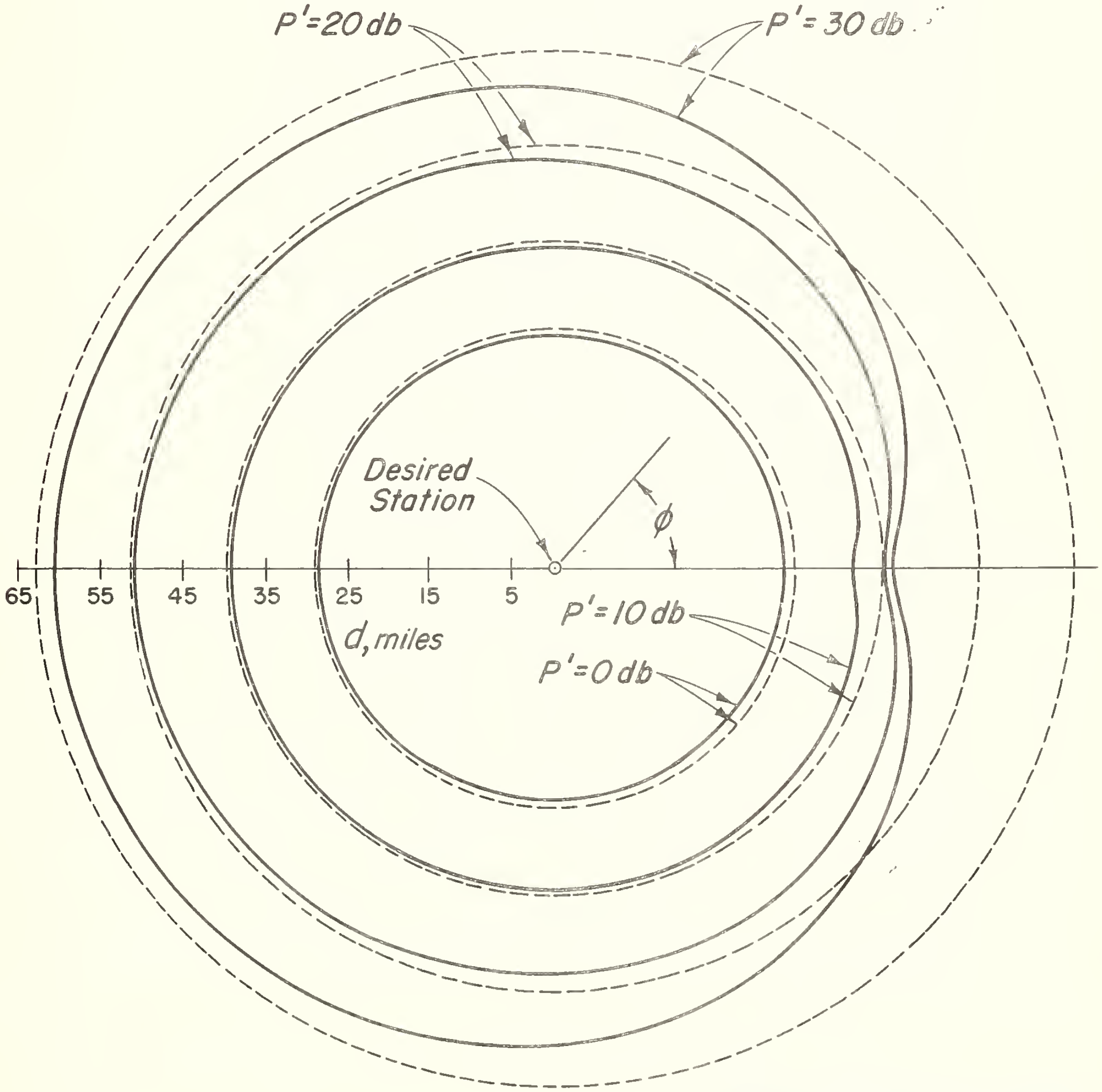



Figure 34

THE GRADE B EFFECTIVE SERVICE RADIUS OF A DESIRED STATION AS LIMITED BY INTERFERENCE FROM A SINGLE UNDESIRED ADJACENT CHANNEL STATION

D = 100 MILES; $f$ = 63 Mc; $H_t$ = 500 FEET; $H_r$ = 30 FEET; $F_r$ = 46.9 db; $G_d = G_i = 0$

The dashed curves correspond to the effective service area which would be available if the interfering station were not operating

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JULY 1949

Figure 35

## PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE A SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = g'_i = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

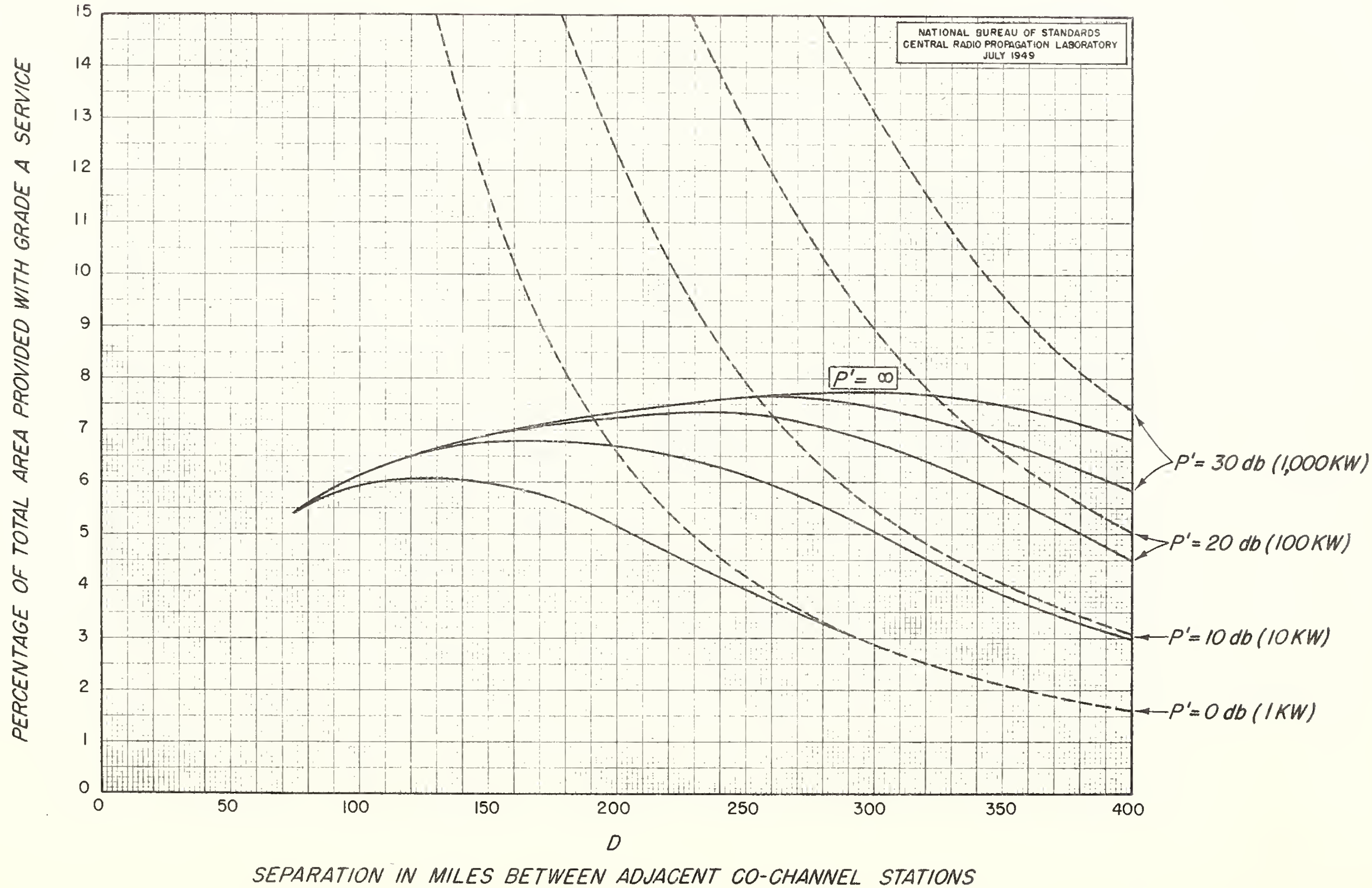


Figure 36

## PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE B SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f=63$ Mc; $H_t=500$ feet; $H_r=30$ feet; $F_r=46.9$ db; $g'_d=g'_i=1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

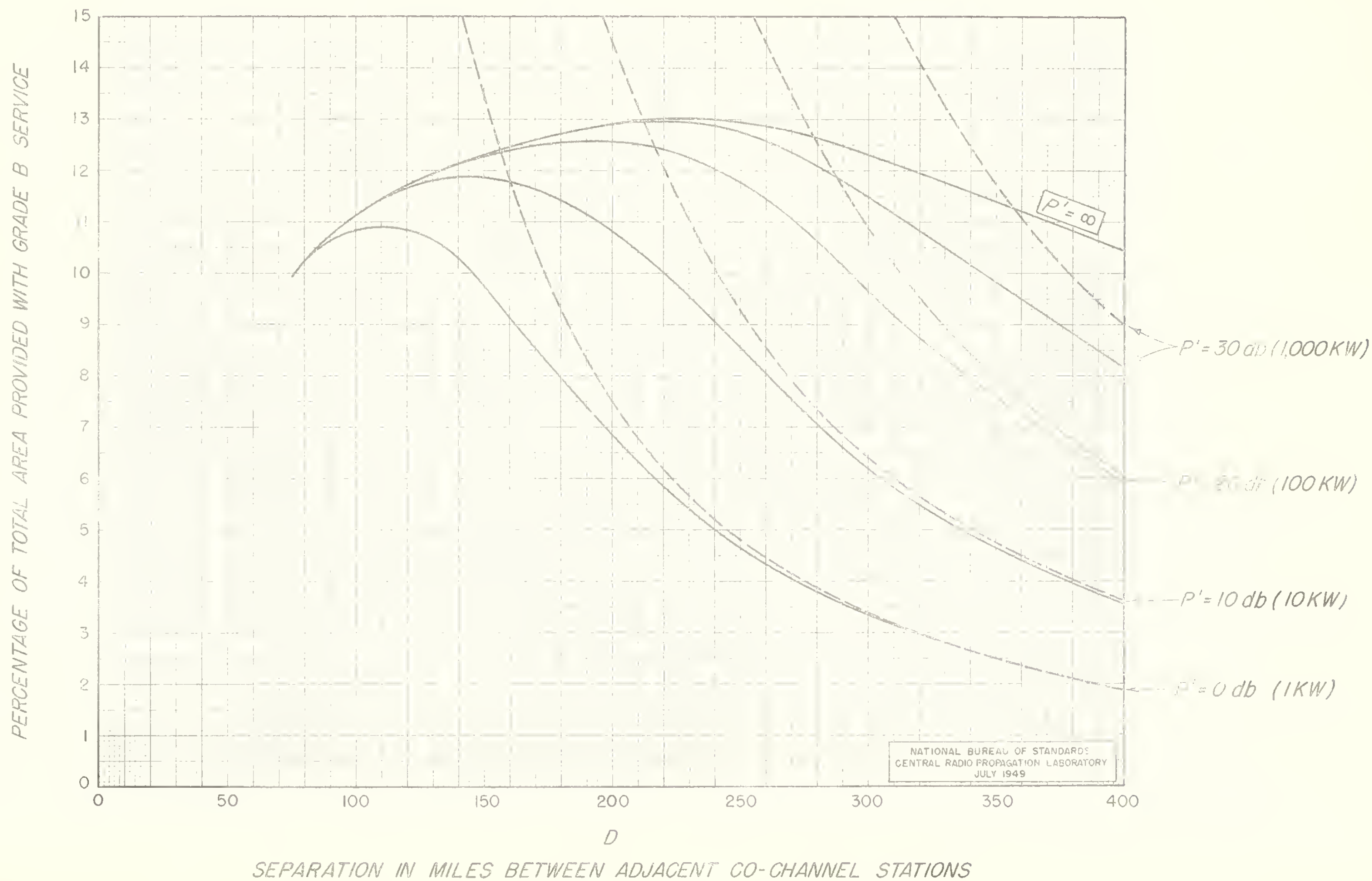


Figure 37

# PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE C SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_t = 500$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g_d' = g_i' = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

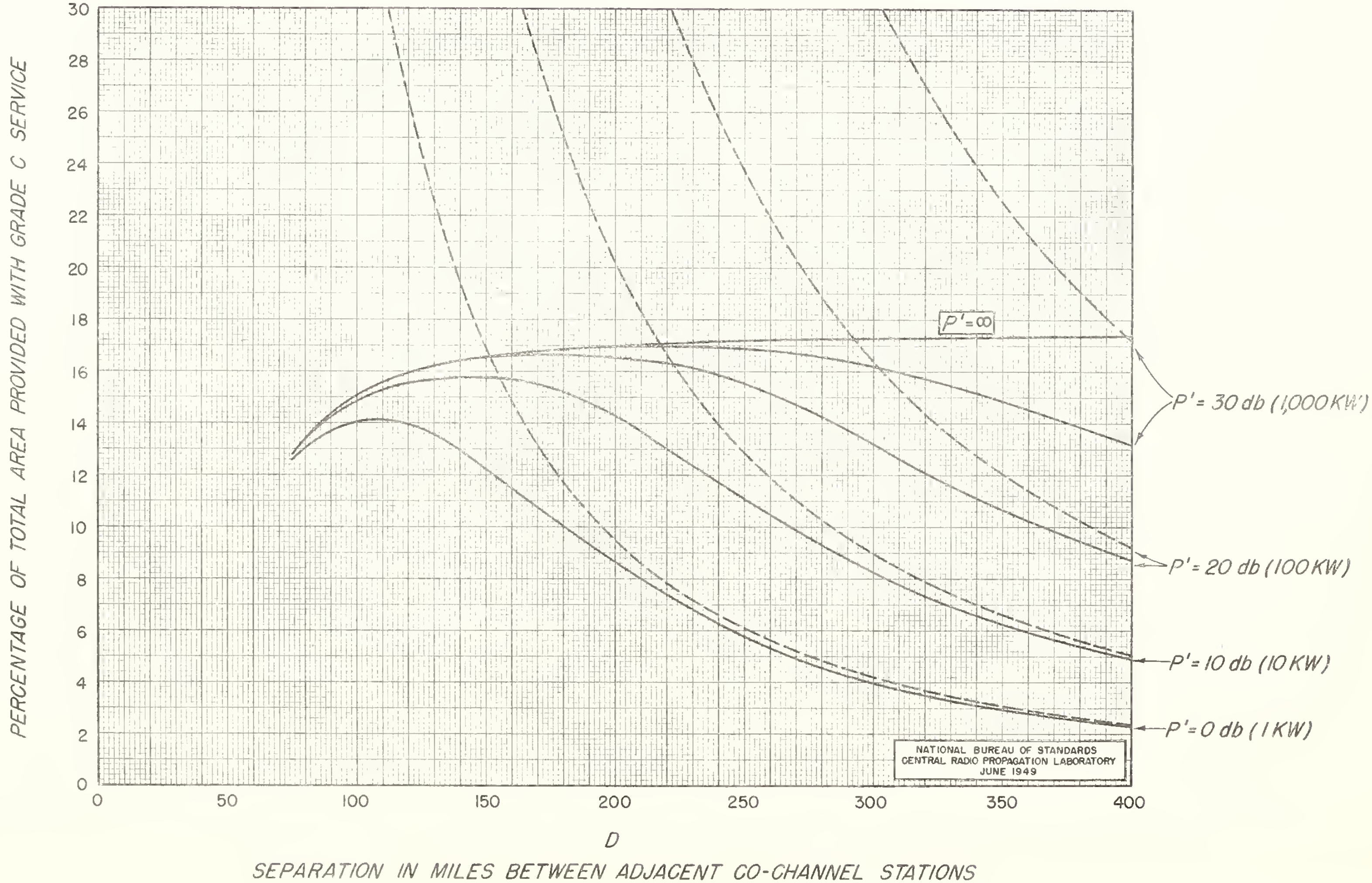


Figure 38

PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE B SERVICE
BY MEANS OF A SINGLE TELEVISION CHANNEL

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_t = 200$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = g'_i = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

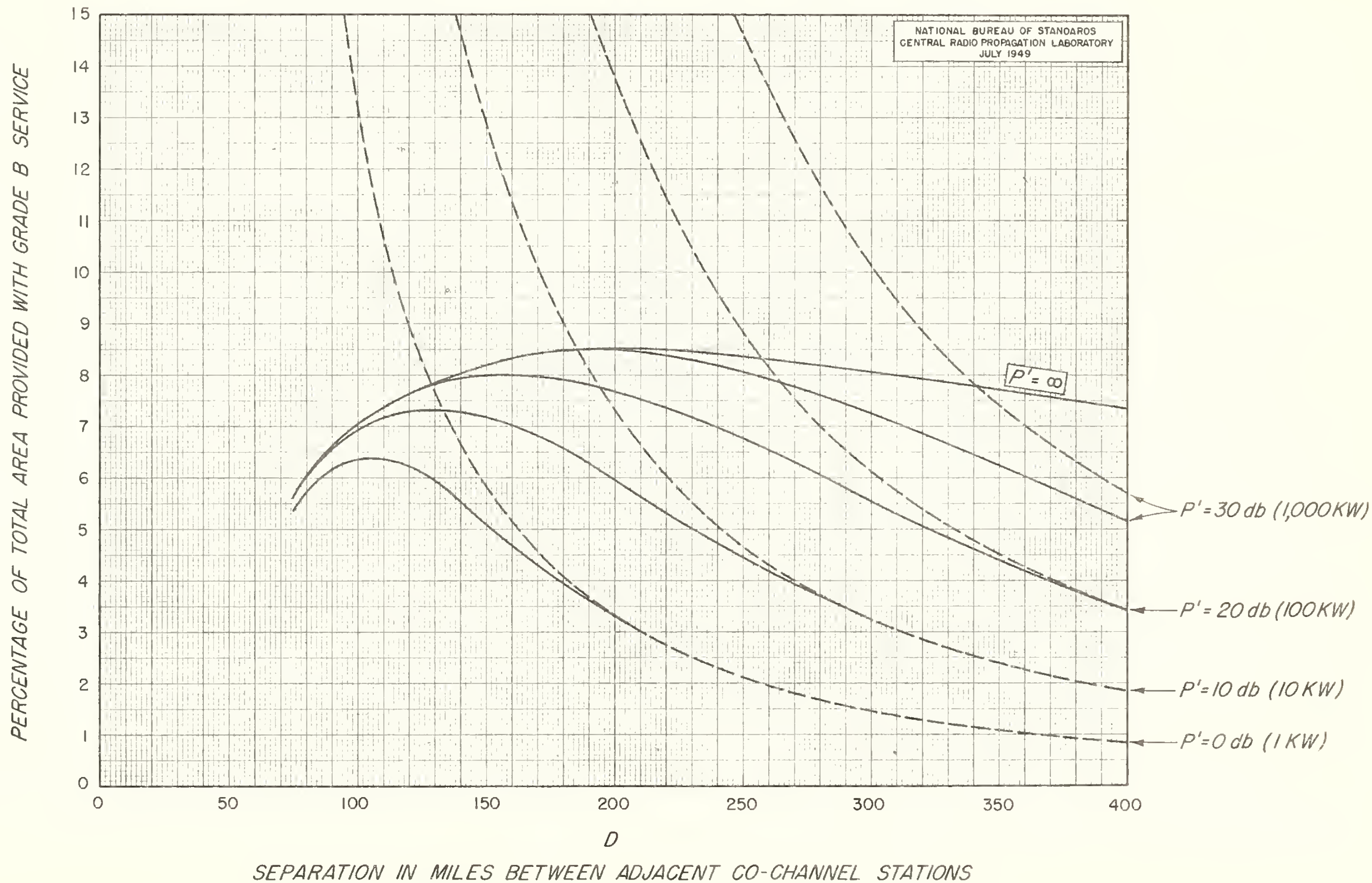


Figure 39

# PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE B SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_t = 1{,}000$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = g'_i = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

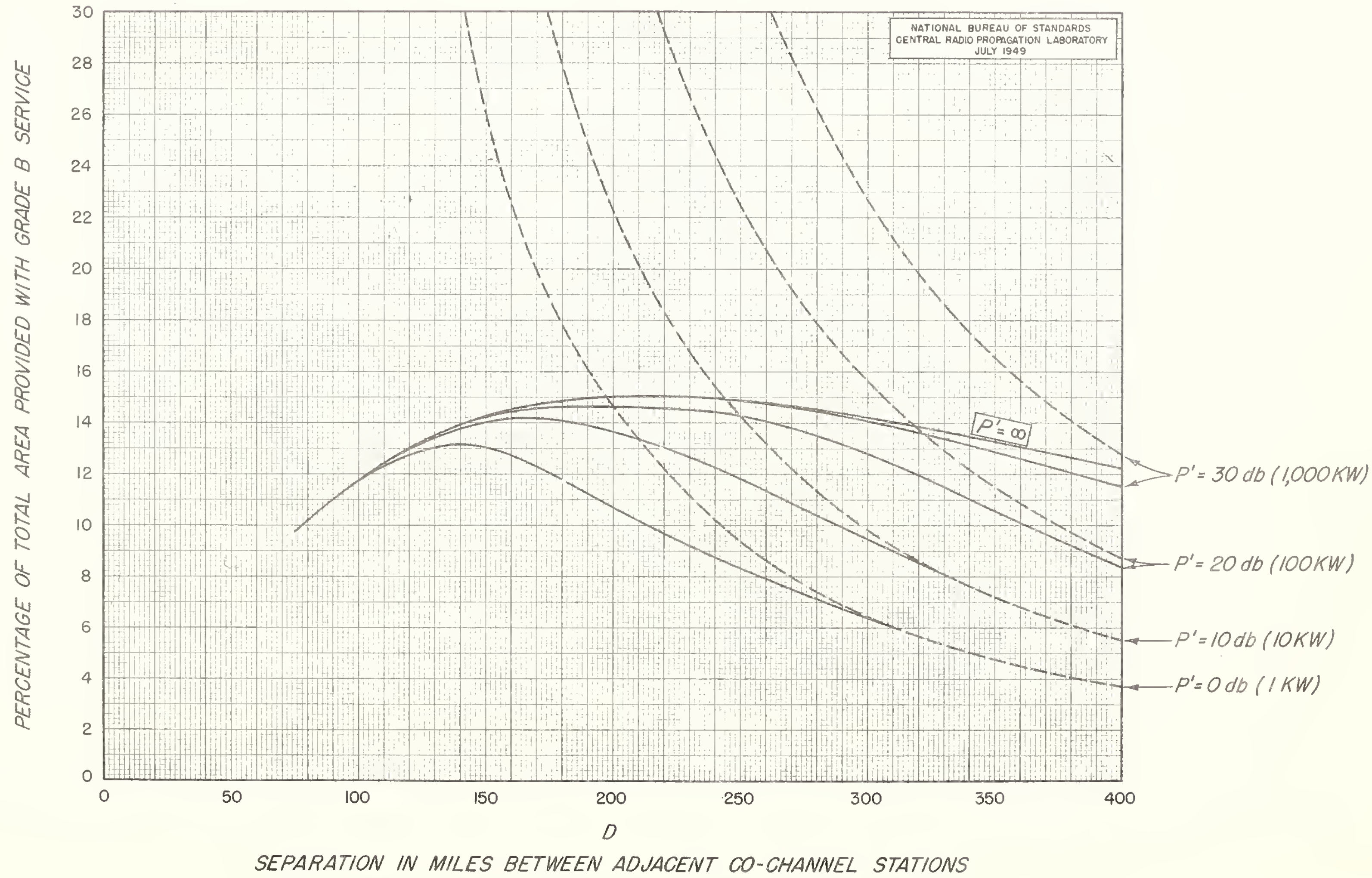


Figure 40

PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE B SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_t = 2{,}000$ feet; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = g'_i = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

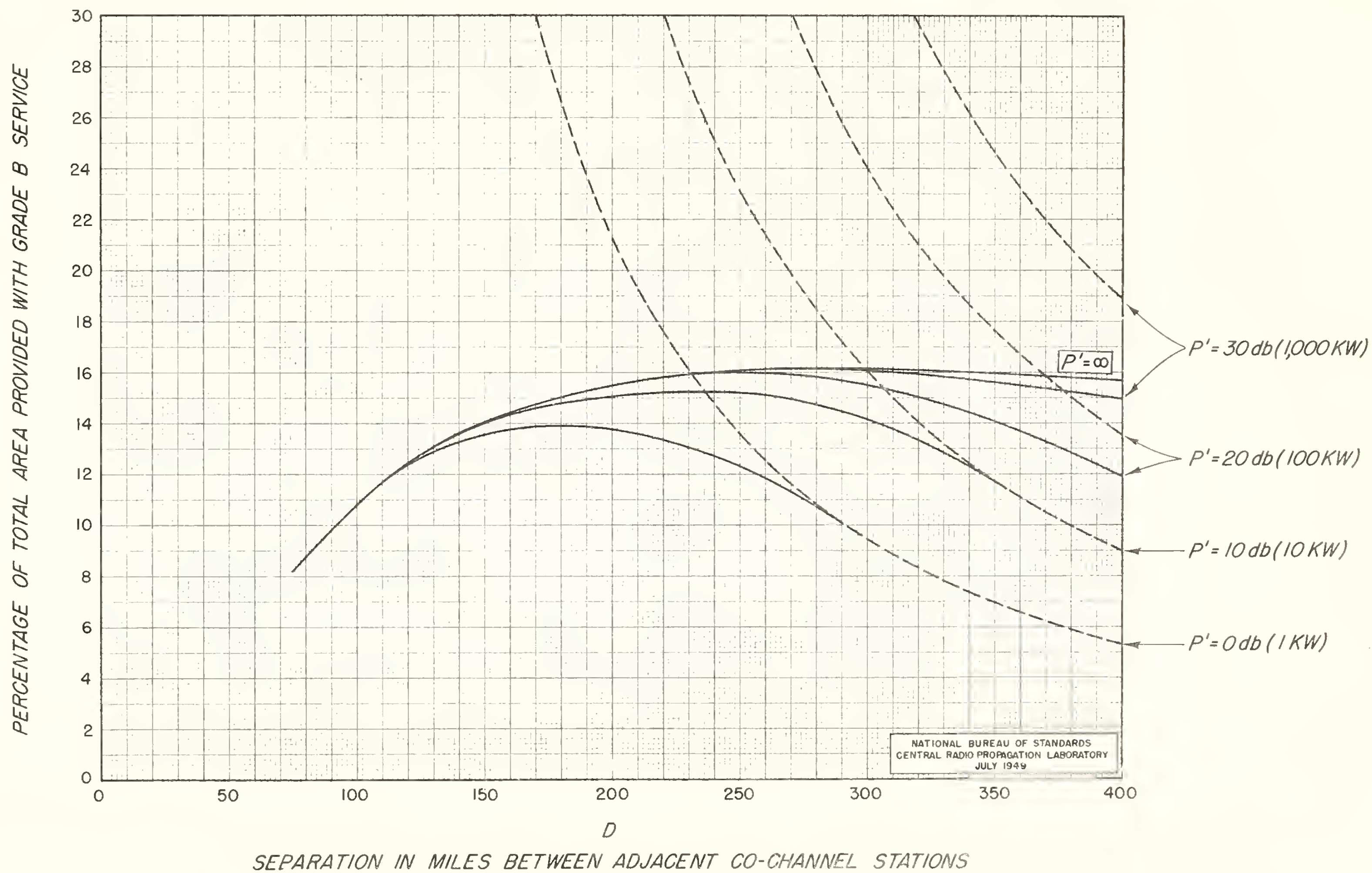


Figure 41

PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE A SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL FOR A CO-CHANNEL STATION SEPARATION D=200 MILES

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; f=63 Mc; $H_r$=30 feet; $F_r$=46.9 db; $g_d'=g_i'=1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

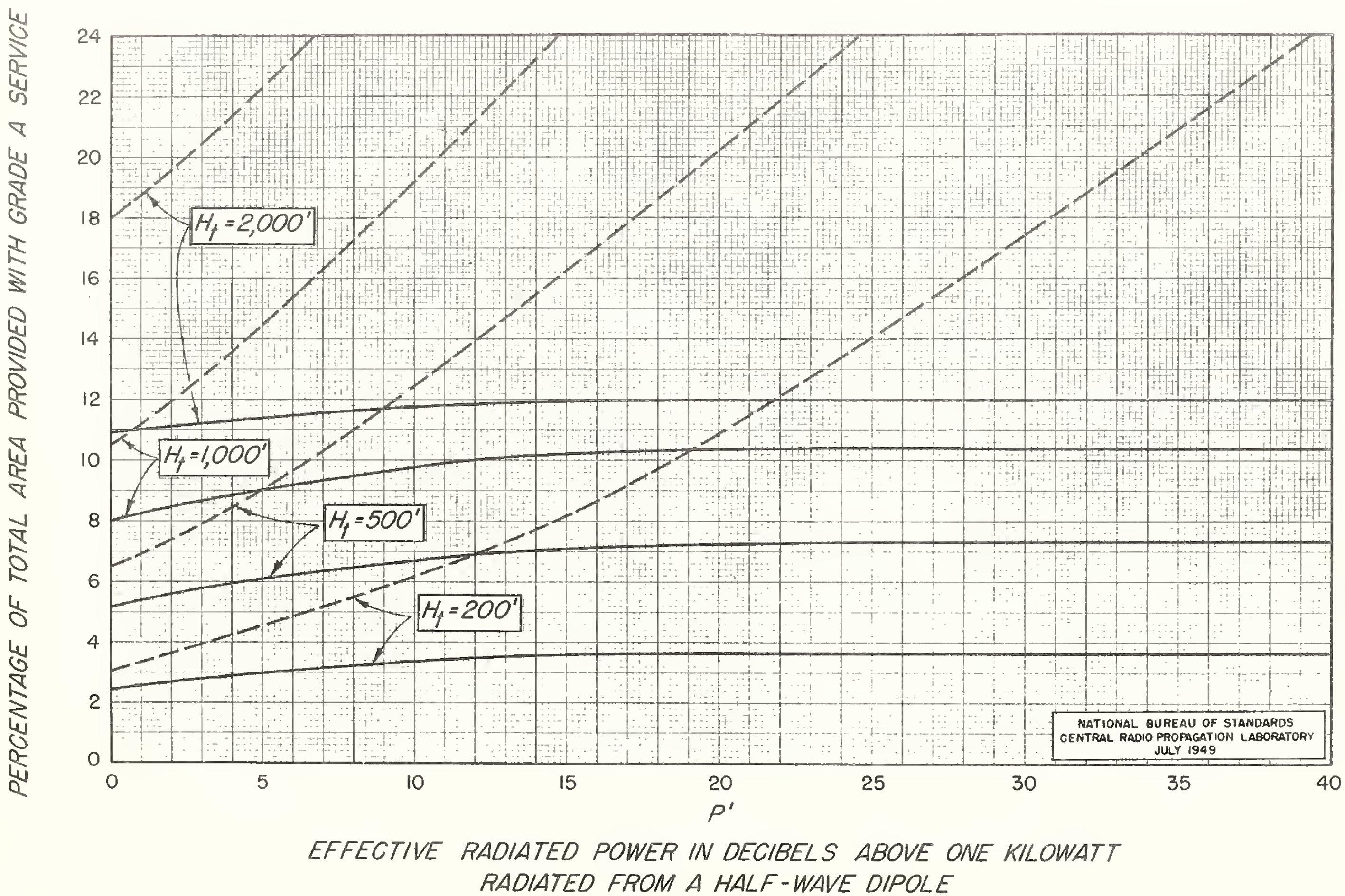


Figure 42

PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE B SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL FOR A CO-CHANNEL STATION SEPARATION D=200 MILES

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = g'_i = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

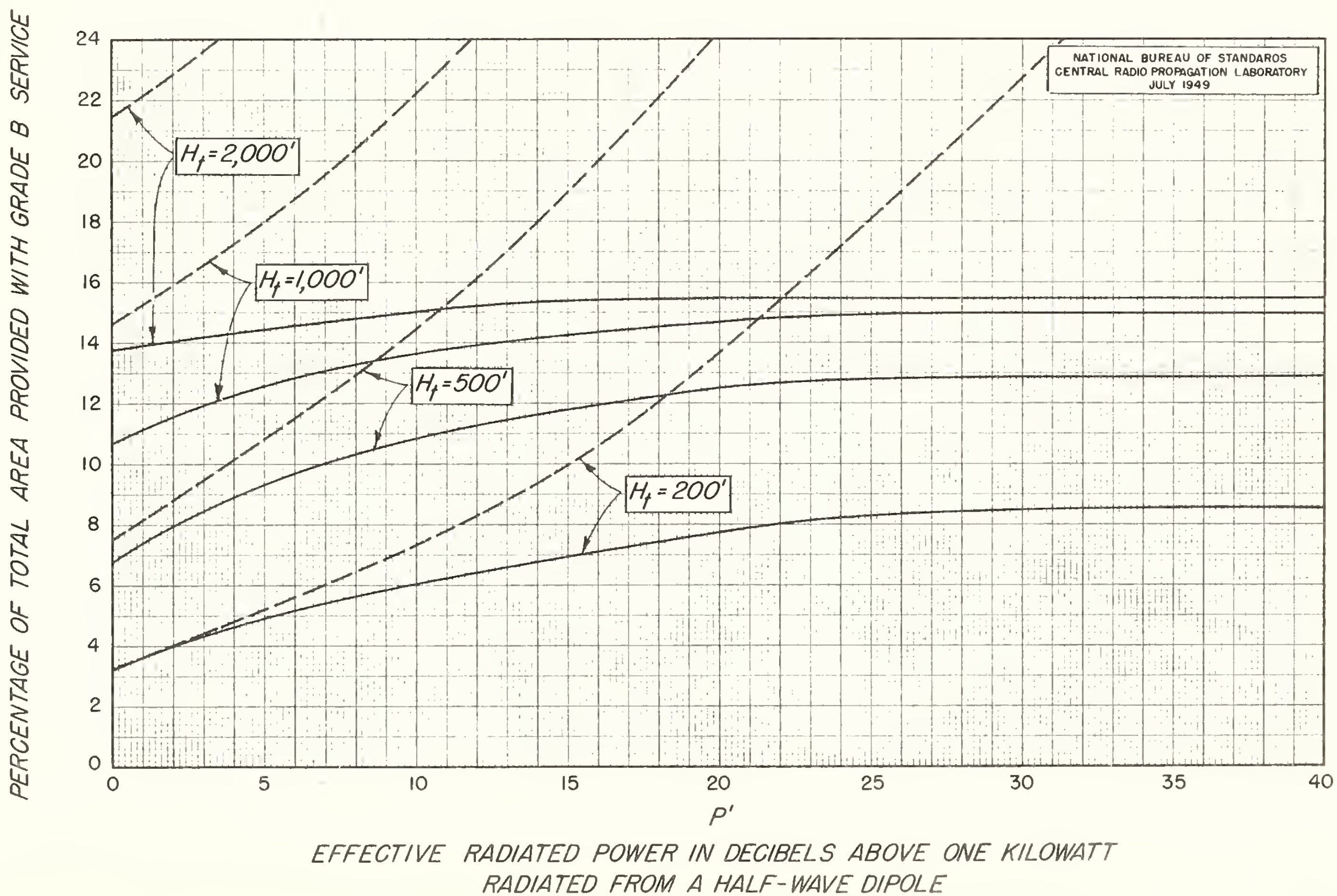


Figure 43

PERCENTAGE OF ANY LARGE AREA WHICH CAN BE PROVIDED WITH GRADE C SERVICE BY MEANS OF A SINGLE TELEVISION CHANNEL FOR A CO-CHANNEL STATION SEPARATION D=200 MILES

The stations are assumed to be allocated on a triangular lattice as shown on figure 24; co-channel carriers are either synchronized or "offset"; $f = 63$ Mc; $H_r = 30$ feet; $F_r = 46.9$ db; $g'_d = g'_i = 1$; all stations in the lattice are assumed to be using the same effective power and antenna height; the dashed curves correspond to the hypothetical assumption that all interference, except that due to noise, has been eliminated

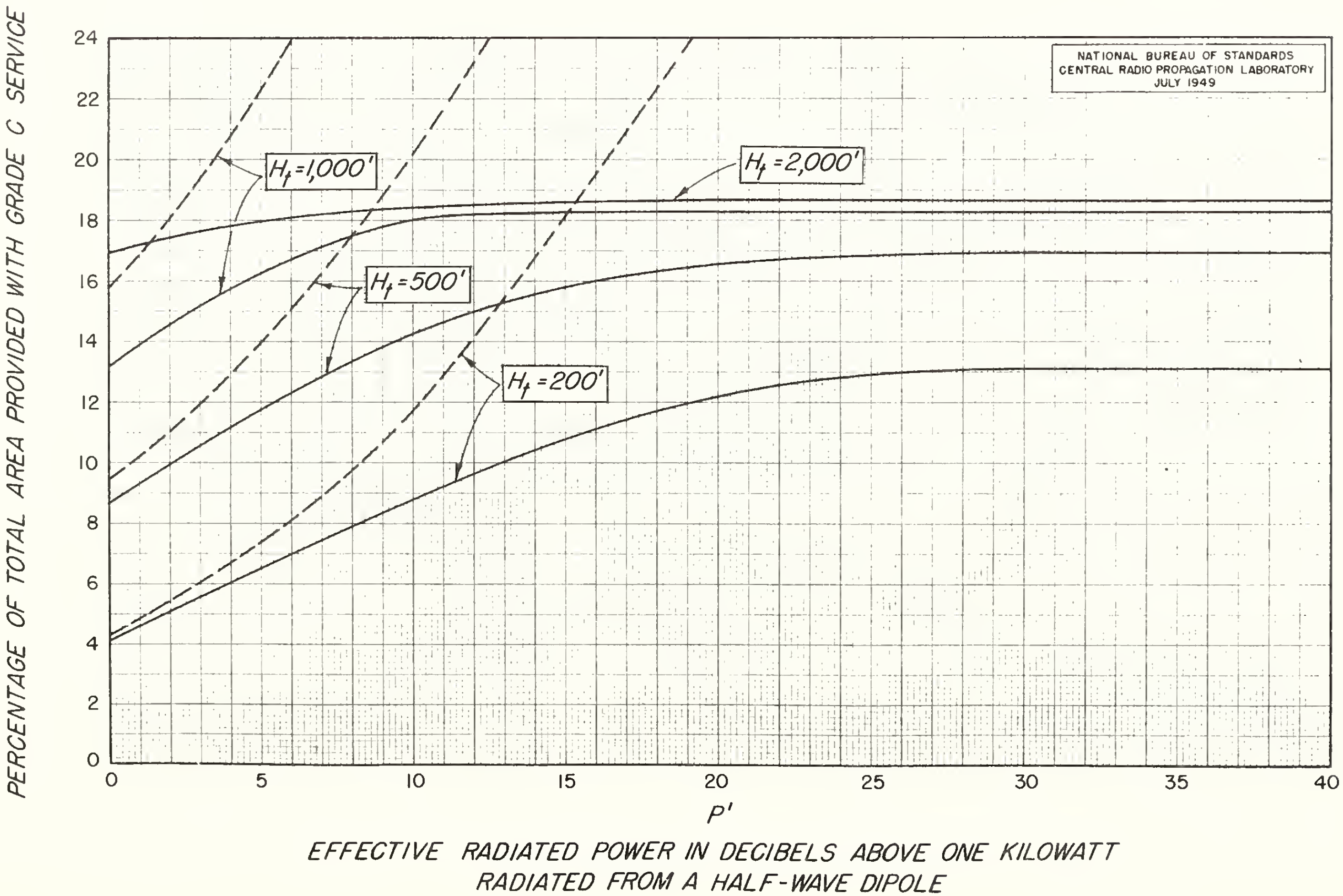


Figure 44

THE SUM OF THE TWO GRADE B SERVICE AREAS EXPECTED FOR TWO CO-CHANNEL TELEVISION STATIONS

$f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db; $G_d = G_i = 0$

The dashed lines are the limiting values for very large separations

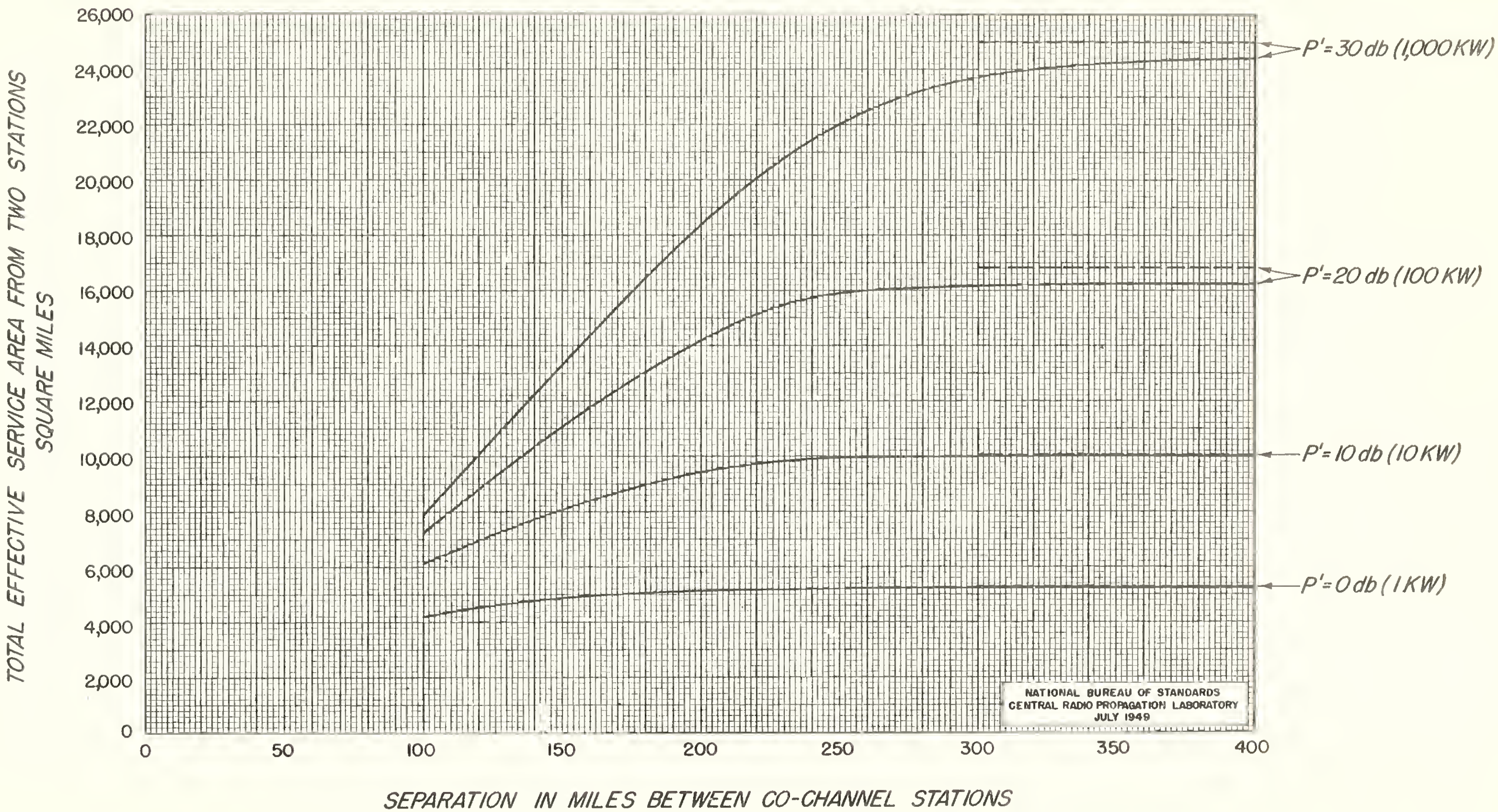


Figure 45

THE SUM OF THE TWO GRADE B SERVICE AREAS EXPECTED FOR TWO ADJACENT CHANNEL TELEVISION STATIONS

$f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db; $G_d = G_i = 0$

The dashed lines are the limiting values for very large separations

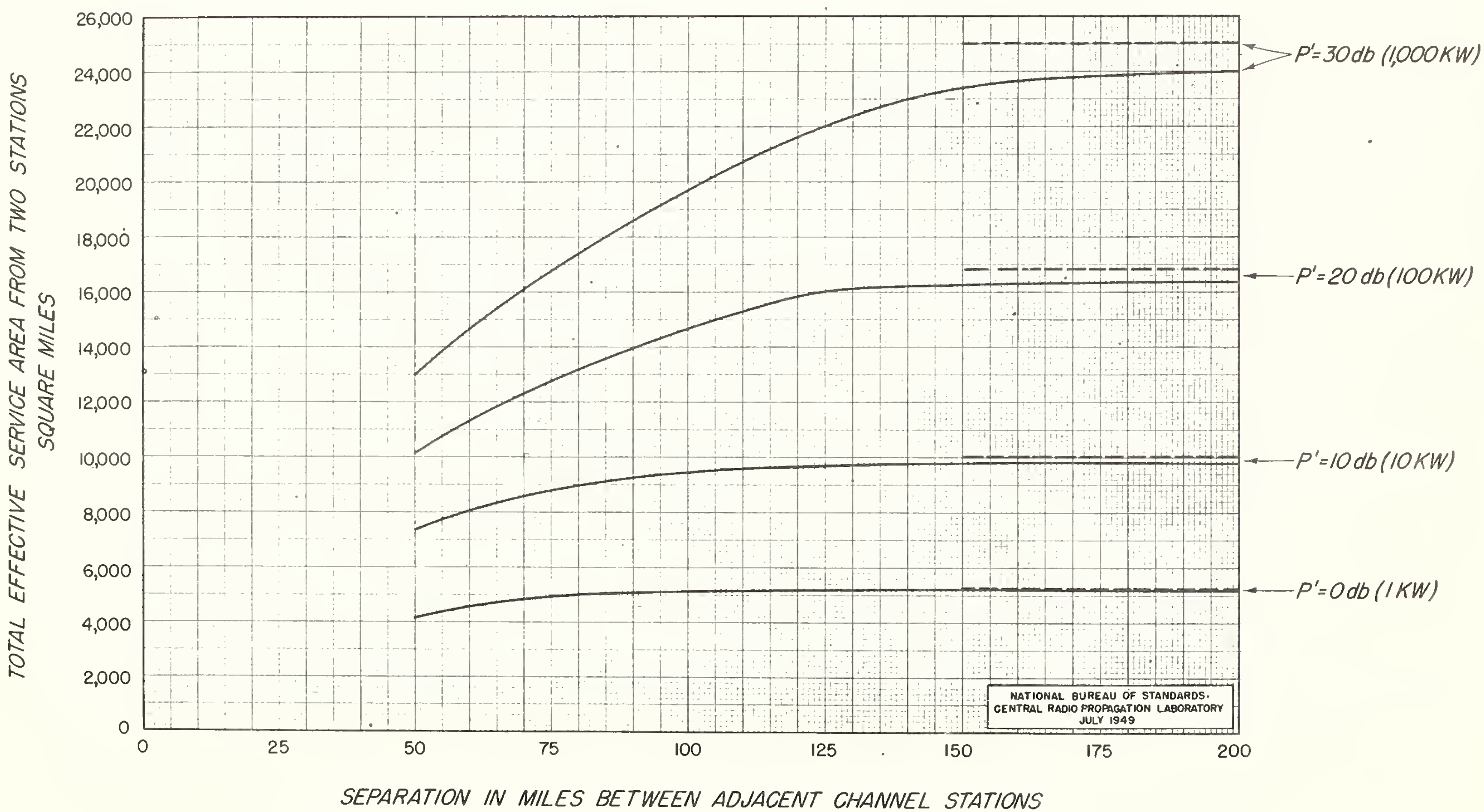


Figure 46