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U S DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
WASHINGTON, D. C.

THE EFFECT ON TELEVISION SERVICE OF TRANSMITTING ANTENNA HEIGHT, RADIATED POWER, THE USE OF OFF-SET OR SYNCHRONIZED CO-CHANNEL CARRIERS, AND OF CORRELATION AMONG THE RADIO FIELDS RECEIVED FROM SEVERAL TRANSMITTERS

By
Harold Staras

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SUMMARY

Calculations have been made which provide useful information for consideration in the efficient allocation of frequencies to television stations. These calculations show that: (1) increasing, for all stations, either the transmitting antenna height or the effective radiated power or both, substantially improves the total service which can be provided, particularly in those regions where service is provided by only one or two stations, (2) synchronizing or "off-setting" co-channel carriers almost doubles the efficiency of service which can be provided to stations allocated in a triangular lattice network, and (3) the assumption of no correlation among the desired and undesired fields leads to results concerning efficiency of service which are quite accurate.

I INTRODUCTION

Data additional to those presented in a recent report[1/] prepared at the Central Radio Propagation Laboratory of the National Bureau of Standards are given herein. The computational methods and formulas used in this paper have, for the most part, been developed in the above-mentioned report and, in addition, the symbols and the assumed triangular network of stations (see Fig. 6) also remain the same.

It should also be pointed out that the words "off-set" and "synchronized" have been used interchangeably in this paper. Although these two systems are different, their effect on television service is assumed to be identical, i.e., to correspond to an acceptance ratio[2/] A = 28 db rather than the value A ≅ 40 db assumed for the purpose of this report for unsynchronized operation.

II SERVICE AS LIMITED BY NOISE AND INTERFERENCE FROM ONE OTHER STATION ONLY

Computations have been made yielding the Grade "A", Grade "B" and Grade "C" <u>effective</u> service radii and <u>effective</u> service areas of a desired station for different antenna heights when service is limited by noise and interference from a single co-channel undesired station with synchronized or off-set carrier (A = 28 db) or a single adjacent channel undesired station (A = 6 db). These data are shown graphically in Figs. 1 through 5 for an adjacent channel station

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1/ K. A. Norton and H. Fine, "A Study of Methods for the Efficient Allocation of Radio Frequencies to Broadcasting Services Operating in the Range Above 50 Mc," Report CRPL 4-5, August 1, 1949.

2/ A, the acceptance ratio, represents the minimum ratio between the desired and undesired fields permissible for an acceptable television service.

separation of 100 miles and a co-channel station separation of 200 miles. The effective service radius is defined (by (47) in the Norton-Fine report[1/]) to be the mean value of the range multiplied by the value of the probability of receiving the indicated grade of service at the range in question. It is important to remember in studying the illustrations in this paper that many televiewers receive the indicated grade of service beyond the distance corresponding to the effective service radius and furthermore that many televiewers within that distance do not receive this indicated grade of service; this point is illustrated by Figs. 20, 21, 22, 29 and 30 in the Norton-Fine report[1/]. Consequently, the value of these diagrams arises largely from the fact that the area within a particular contour is a direct measure of the total number of receiving locations at which the indicated grade of service is expected.

An examination of Fig. 1 shows that the higher grades of service suffer "percentagewise" the greatest reduction in service because of the operation of a nearby adjacent channel station, but suffer the least in terms of a reduction measured in square miles. Fig. 3 compares the effective Grade B service radius of a desired station when it is faced with interference from an adjacent channel station at a distance of 100 miles or from a co-channel station with synchronized or "off-set" carrier at a distance of 200 miles. From this figure, it is evident that the effective service radii are only slightly different when a co-channel interfering station is at a distance of 200 miles than when an adjacent channel station is at a distance of 100 miles. In the former case, a somewhat larger effective service radius is obtained in the direction toward the interfering station and a somewhat shorter effective service radius is obtained in the direction away from the interfering station. In Figs. 4 and 5 are shown the total effective service areas provided by two adjacent channel transmitters and by two co-channel transmitters. These effective service areas are given as a function of grade of service, antenna height, and radiated power.

III THE EFFECT OF TRANSMITTING ANTENNA HEIGHT AND RADIATED POWER ON SERVICE

It is apparent from these graphs, particularly Figs. 2 and 5, that the effective service radius and the total service area in rural regions, where service is provided by only one or two stations, is increased appreciably by increases in antenna height and radiated power. It is interesting to note, at this point, that the efficiency of service is improved when the transmitting antenna height is raised also for stations allocated on a triangular network (see Figs. 42, 43 and 44 in the Norton-Fine report[1/]). In the present case, however, involving only two stations, the increase in service with increase in transmitting antenna height or power becomes very marked.

IV SYNCHRONIZATION AND NON-SYNCHRONIZATION OF CO-CHANNEL STATIONS

A comparison of the efficiency of service[3/] and of the optimum station separation when co-channel carriers are synchronized or "off-set" and when they are not synchronized proves very significant. In the Norton-Fine report[1/] and in the results presented in the preceding portion of the present paper,

3/ The concept of the efficiency of service is derived in Section VIII of the Norton-Fine report[1/].

the calculations were all based on the assumption that an acceptance ratio, A, of only 28 db between desired and undesired co-channel fields will provide an acceptable television service; such a ratio is approximately applicable for co-channel stations with off-set or synchronized carriers. However, with unsynchronized stations, an acceptance ratio of at least 40 db between desired and undesired co-channel fields is necessary to provide an acceptable service. A comparison of the efficiency of service under these two conditions is provided by the graphical presentation shown in Fig. 7 for stations allocated in the triangular lattice network of Fig. 6. An examination of this graph reveals that, for the same effective radiated power, the station separation corresponding to a maximum efficiency is decreased by about 40 to 60 miles when co-channel carriers are "off-set". But, more important, when the co-channel station separation is in the neighborhood of 200 miles, the efficiency of service is approximately doubled by the off-setting of co-channel carriers, i.e., nearly twice as many potential receiving locations are provided with a Grade B service or better.

Figs. 8 and 9 compare the effective service radii and total service area provided with Grade B service by only two co-channel stations with a station separation of 200 miles under conditions of synchronization and non-synchronization. Here, the improvement of service due to off-setting the carriers becomes more pronounced as the radiated power is increased. For example, for an effective radiated power of 10 kw and a transmitting antenna height of 500 feet, off-setting the carriers of the two co-channel stations increases the total Grade B service area from 8,000 square miles to 9,400 square miles, an increase of 17.5 per cent. On the other hand, for an effective radiated power of 1,000 kw, off-setting the carriers increases the total service area from 12,000 square miles to 18,400 square miles, an increase of 53.3 per cent.

V CORRELATION OF FIELDS RECEIVED FROM SEVERAL TRANSMITTERS

In the Norton-Fine report[1/] all calculations were predicated on the assumption that the desired and undesired fields were uncorrelated with respect to either time or receiving location. However, the authors of that report realized at the time that the desired and undesired fields were probably to some extent positively correlated. It was, therefore, felt that it would be desirable to compute the effects of assuming perfect positive correlation on the efficiency of service.

For this paper, three separate assumptions were made to test the importance of correlation among the desired and undesired signals: (1) that the time variations of all the signals were perfectly correlated ($\rho_T = +1$) while the receiving location variations of the signals were completely uncorrelated ($\rho_L = 0$); (2) that the receiving location variations of all the signals were perfectly correlated ($\rho_L = +1$) while the time variations of the signals were completely uncorrelated ($\rho_T = 0$); and (3) that all the signals were perfectly correlated with respect to both time and receiving location ($\rho_T = \rho_L = +1$). Assumption (1) implies that tropospheric conditions, which are the predominant factors responsible for time variations of radio signals, have the same effect on all stations in the lattice network, but, at the same time, implying that a good receiving location for signals from one transmitter is in no way determined by whether it is a good or bad receiving location for signals from any other transmitter. Assumption (2) implies that a good receiving location for signals from one transmitter is a good receiving location for signals from any other transmitter and vice versa for a poor receiving location; however, the effects of tropospheric conditions are assumed to differ among the various transmitters and the receiver such that, if, at any one time, a high field is received from any transmitter, one cannot determine whether a high or low field will be received from another transmitter at that time. Assumption (3) implies that the effects of tropospheric conditions on the receiver are identical for all transmitters and that the merit of a receiving location for the fields from one transmitter is the same as its merit for the reception of the fields from any other transmitter.

Figs. 10 and 11 compare the efficiency of Grades A and B service[4] for a co-channel station separation of 200 miles and a transmitting antenna height of 500 feet for all transmitters under the following assumptions: (1) $\rho_T = \rho_L = 0$; (2) $\rho_T = +1$, $\rho_L = 0$; (3) $\rho_T = 0$, $\rho_L = +1$; and (4) $\rho_T = \rho_L = +1$. For Grade C service no simple method was developed for calculating efficiency of service for conditions (2) and (3) above. In this case, therefore, only conditions (1) and (4) were compared (see Fig. 12). It is quite obvious from an examination of Fig. 12 that the change in efficiency of Grade C service is fairly small in going from the assumption of no correlation with respect to either time or receiving location to the other extreme of assuming perfect correlation with respect to both time and receiving locations.

Inspection of Figs. 10 and 11 reveals that the efficiency of service is somewhat improved by assuming perfect time correlation. But, at medium and high radiated powers, the efficiency of service is changed only slightly by an assumption of perfect receiving location correlation. From the little actual data concerning time correlation that is available, it is believed that the time correlation among the fields received from several transmitters is quite small; so, no matter what the receiving location correlation is, the assumption of no correlation whatsoever among the fields approximates the actual situation very closely when the radiated power is above approximately 10 kw.

There is one other point that might be inferred from Figs. 7, 10 and 11. Since the greatest increase in the efficiency of service due to correlation (Figs. 10 and 11) is smaller than the increase of service due to off-setting co-channel carriers (Fig. 7), we may probably safely infer that the optimum co-channel station separation on the lattice network of Fig. 6 will be changed very little even if correlation among the fields is significant.

4/ The methods for computing the efficiency of service, under the assumption that correlation exists among the signals, is discussed in the Appendix.

APPENDIX

CALCULATING EFFICIENCY OF SERVICE UNDER THE ASSUMPTION THAT CORRELATION EXISTS AMONG THE FIELDS RECEIVED FROM THE DIFFERENT TRANSMITTERS

The only description that is necessary here pertains to the method of obtaining the probability of service at any one distance from the desired station since, from that point on, the methods for obtaining the efficiency of service are identical with those described in the previous report[1/].

Consider first the assumption of zero time correlation and +1 receiving location correlation for Grades A and B service. Here the distributions of the interfering and desired stations are obtained and plotted as already described in Section VII of the Norton-Fine report[1/]. Such a plot is shown in Fig. 13. This graph is identical with Fig. 34 of the Norton-Fine report[1/] except that the distribution of the combined field from all interfering stations under the assumption of +1 receiving location correlation is also included.

To obtain the distribution of the combined field from all interfering stations (referred to in the Norton-Fine report[1/] as the desired field required to override the undesired fields) under the assumption of +1 receiving location correlation, the approximation given by (59) of the Norton-Fine report[1/]

$$q'_{dr}\left(\sum_i E_{ir}^2 < E^2,\ p_a\right) \cong \prod_i q'_{ir}(E_{ir} < E,\ p_a) \tag{1}$$

is no longer required. Instead, the following procedure is used. At any probability, q_{ir}, (see Fig. 13) the root-sum-square $\left(\sqrt{\Sigma E_{ir}^2}\right)$ of the individual field intensities (in microvolts per meter) is obtained. This value is then plotted in decibels above one microvolt per meter at the probability q_{ir}. This is done because +1 receiving location correlation means that a receiving location which receives a signal from one station corresponding to the probability, q_{ir}, receives signals from all other stations corresponding to the same probability, q_{ir}. In order to include the effect of noise, the noise level in microvolts per meter is added in quadrature to the combined field of all the interfering stations. In the final step of determining the probability of service for any one distance, the probability, q, where $F_d'(q, 0.5)$ intersects $F_{ir}'(\rho_L = +1)$ is read. This probability value determines the probability of service at this distance because this value represents the fraction of the receiving locations where the desired field exceeds the combined field from all undesired stations for 100 p_a% of the time. In the example shown on Fig. 13, this probability, q, is .89 when the radiated power is 20 db above one kw and 1.0 when the radiated power is infinite, i.e., when noise is neglected. As already stated, once the probability of service is determined at each distance, d, from the desired station, the efficiency of service is computed in the way described in the Norton-Fine report[1/].

Consider next the assumption of +1 time correlation existing among all the signals received at all receiving locations. In this case, the median value with respect to time of the desired field required to override the undesired field from station i is given by:

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

$$- k(p'_i)\sqrt{R_d^2(1) + R_L^2(1) - 2\,\rho_T\, R_d(1)\, R_i(1)} \qquad (2)$$

This equation is a modification of (56) of the Norton-Fine report[1] using the standard statistical technique of replacing $\sqrt{R_d^2(1) + R_i^2(1)}$ by the more general expression $\sqrt{R_d^2(1) + R_i^2(1) - 2\,\rho_T\, R_d(1)\, R_i(1)}$. This second expression reduces to the first one if time correlation is zero ($\rho_T = 0$). From here on the procedure for $\rho_L = 0$ is as described in the Norton-Fine report[1]. A distribution of the desired and undesired field intensities is plotted as in Fig. 13 remembering that the F'_{ir} of (2) above is used in place of the F'_{ir} of (56) in the Norton-Fine report[1]. Finally, if a receiving location correlation of +1 is assumed ($\rho_L = +1$), as well as $\rho_T = +1$, the root-sum-square method described in the preceding paragraphs is used, but now using the distribution F'_{ir} of (2).

For Grade C service the procedure is analogous to that described above. First a plot is made of the distribution of the desired and undesired fields as described in the Norton-Fine report[1] for Grade C service (see Fig. 14 -- identical with Fig. 25 of the Norton-Fine report[1]). If no correlation with either time or receiving location is assumed, the procedure is as developed in that report. If $\rho_T = +1$ <u>and</u> $\rho_L = +1$ is assumed, then the root-sum-square method described above is used.

It is interesting to point out that, in comparing the probability of service as a function of distance when $\rho_L = +1$ and when $\rho_L = 0$ (ρ_T being kept fixed), we get quite different curves (see Fig. 15). But, the total service area and, therefore, the efficiency of service are nearly the same as indicated by the curves of Figs. 10, 11 and 12.

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THE GRADES A, B AND C EFFECTIVE SERVICE RADII OF A TELEVISION STATION AS LIMITED BY NOISE AND INTERFERENCE FROM A SINGLE ADJACENT CHANNEL STATION

THE INTERFERING STATIONS ARE IN THE DIRECTION OF $\phi = 0$ AND AT A DISTANCE OF 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

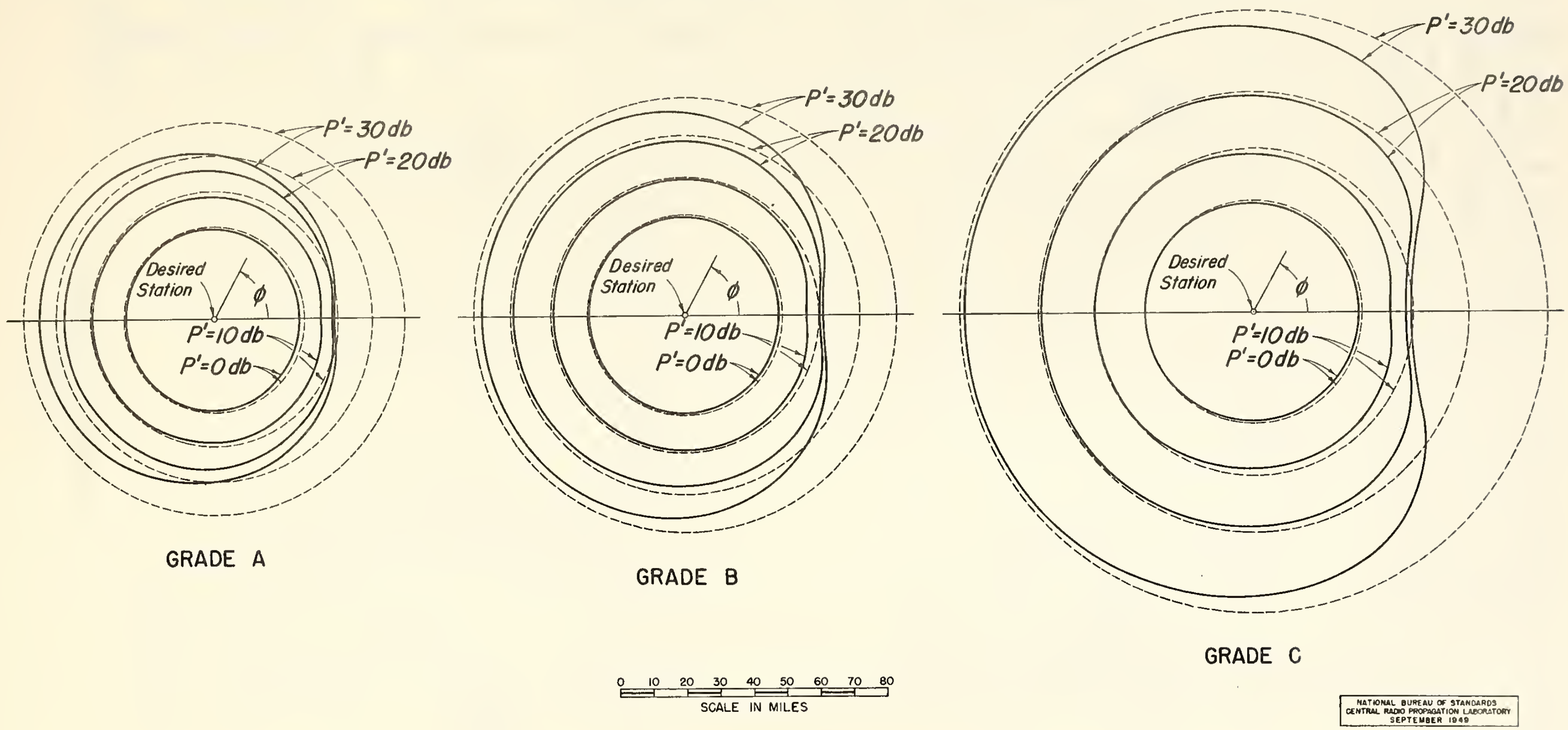

Figure 1

VARIATION WITH ANTENNA HEIGHT OF THE GRADE B EFFECTIVE SERVICE RADIUS OF A TELEVISION STATION AS LIMITED BY NOISE AND INTERFERENCE FROM A SINGLE ADJACENT CHANNEL STATION

THE INTERFERING STATIONS ARE IN THE DIRECTION OF $\phi = 0$ AND AT A DISTANCE OF 100 MILES;
$f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db; $G_d = G_l = 0$

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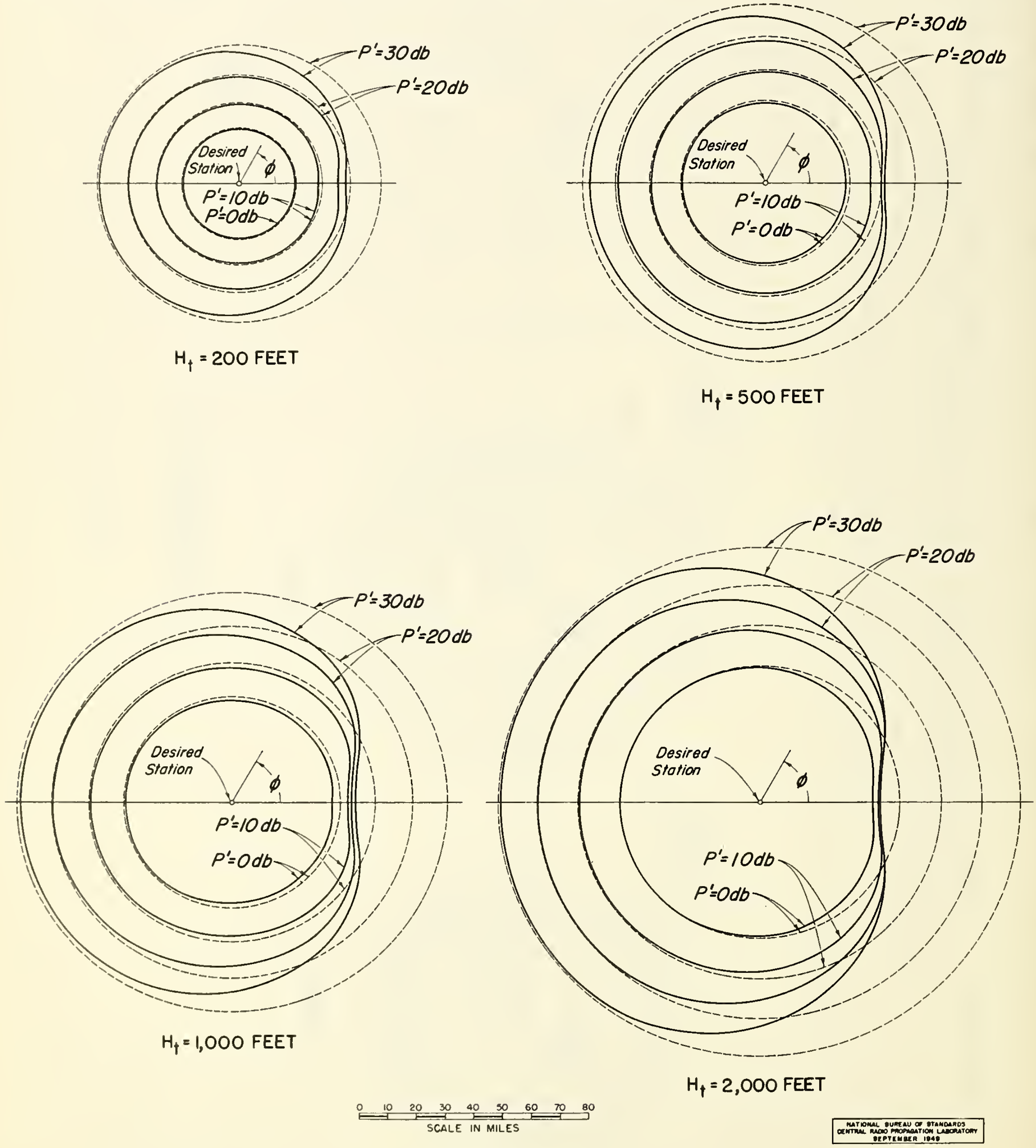


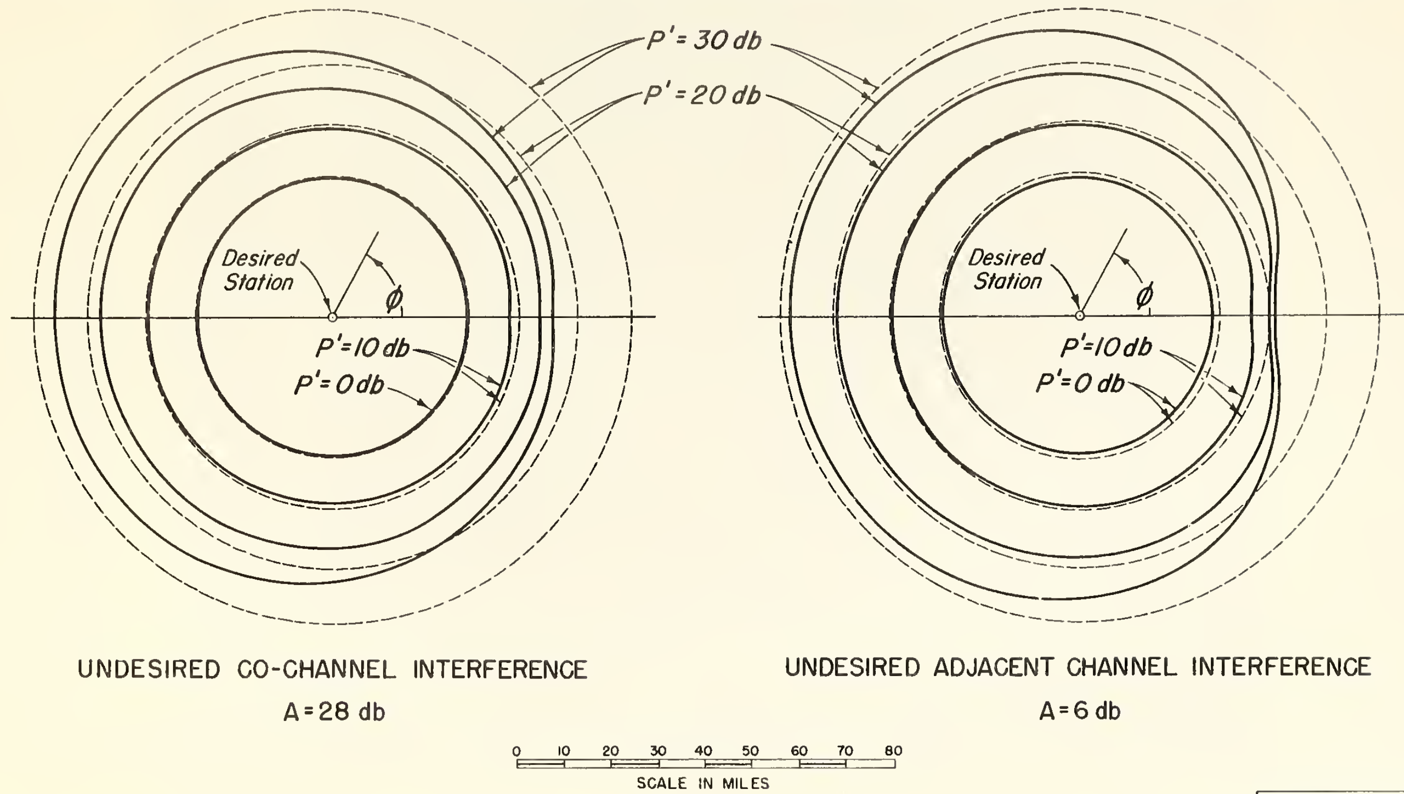
Figure 2

THE GRADE B EFFECTIVE SERVICE RADIUS OF A TELEVISION STATION AS LIMITED BY NOISE AND INTERFERENCE FROM A SINGLE ADJACENT CHANNEL STATION OR A SINGLE CO-CHANNEL STATION

THE UNDESIRED STATIONS ARE IN THE DIRECTION OF $\phi = 0$ AND AT A DISTANCE OF 100 MILES FOR THE ADJACENT CHANNEL STATION OR D = 200 MILES FOR THE CO-CHANNEL STATION;

$f = 63$ 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



UNDESIRED CO-CHANNEL INTERFERENCE

A = 28 db

UNDESIRED ADJACENT CHANNEL INTERFERENCE

A = 6 db

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Figure 3

COMPARISON OF GRADES A, B AND C EFFECTIVE SERVICE AREAS
FOR TWO ADJACENT CHANNEL OR TWO CO-CHANNEL TELEVISION STATIONS

CO-CHANNEL CARRIERS ARE ASSUMED SYNCHRONIZED OR OFFSET; A = 28 db

D = 200 MILES FOR CO-CHANNEL STATIONS; D = 100 MILES FOR ADJACENT CHANNEL STATIONS
f = 63 Mc; H_t = 500 FEET; H_r = 30 FEET; F_r = 46.9 db; $G_d = G_i = 0$

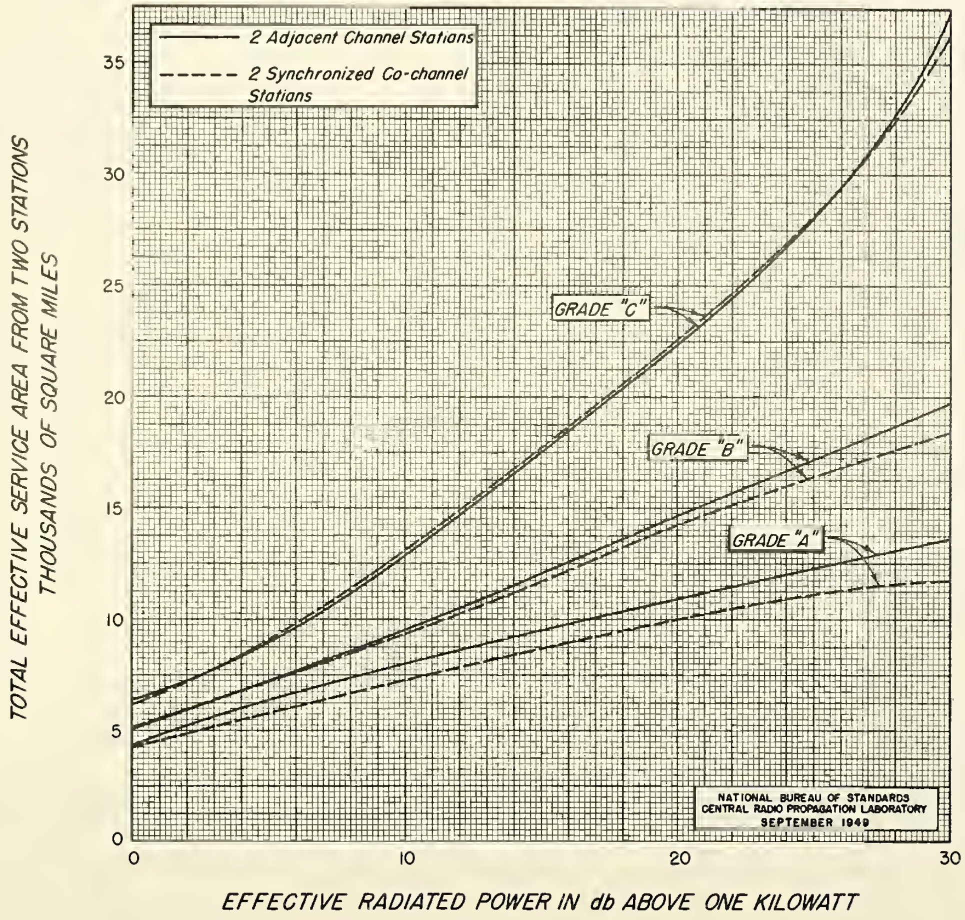

Figure 4

THE EFFECT OF TRANSMITTING ANTENNA HEIGHT ON THE TOTAL GRADE B EFFECTIVE SERVICE AREA FOR TWO ADJACENT CHANNEL OR TWO CO-CHANNEL TELEVISION STATIONS

CO-CHANNEL CARRIERS ARE ASSUMED SYNCHRONIZED OR OFFSET; $A = 28$ db

$D = 200$ MILES FOR CO-CHANNEL STATIONS; $D = 100$ MILES FOR ADJACENT CHANNEL STATIONS

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

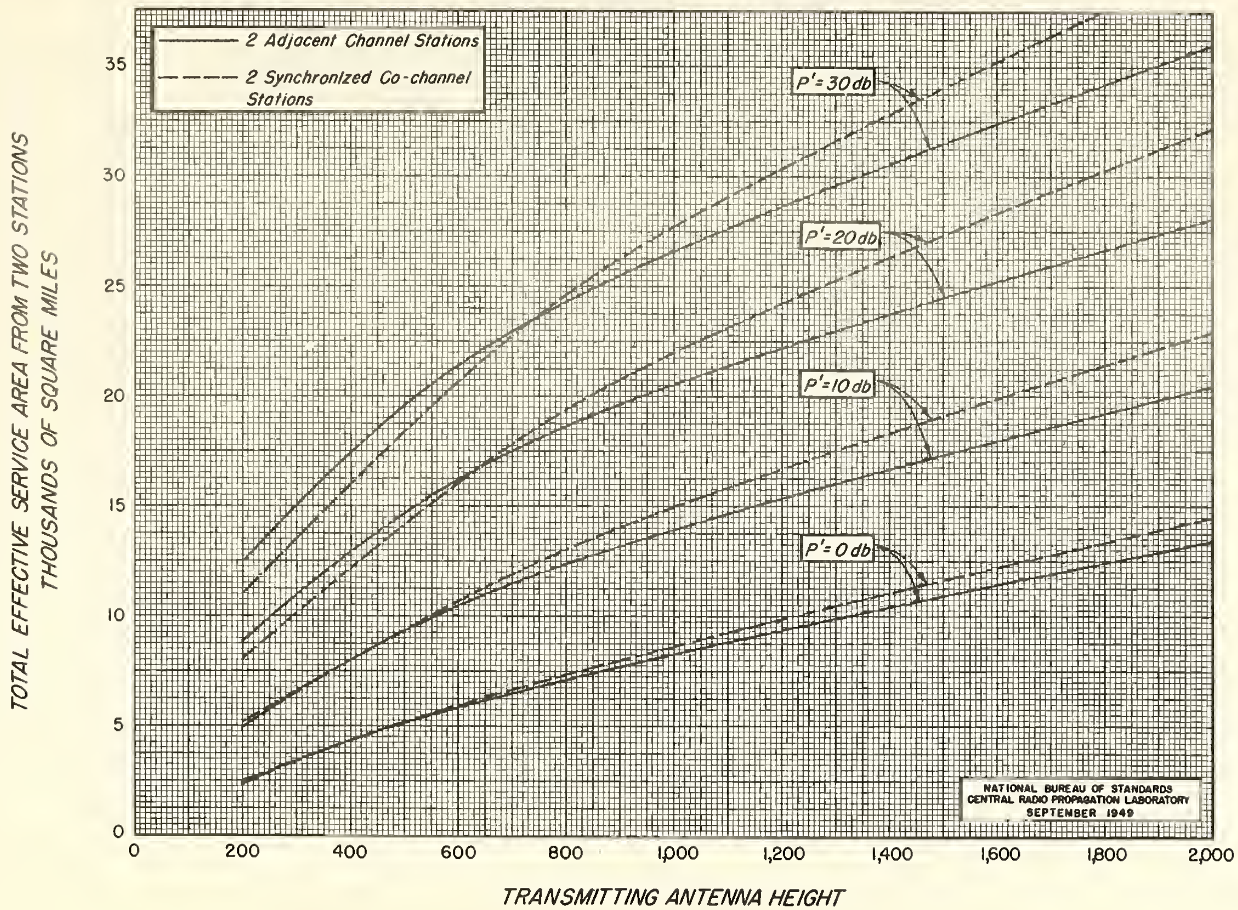

Figure 5

IDEALIZED ALLOCATION OF TELEVISION BROADCAST STATIONS ON A TRIANGULAR LATTICE

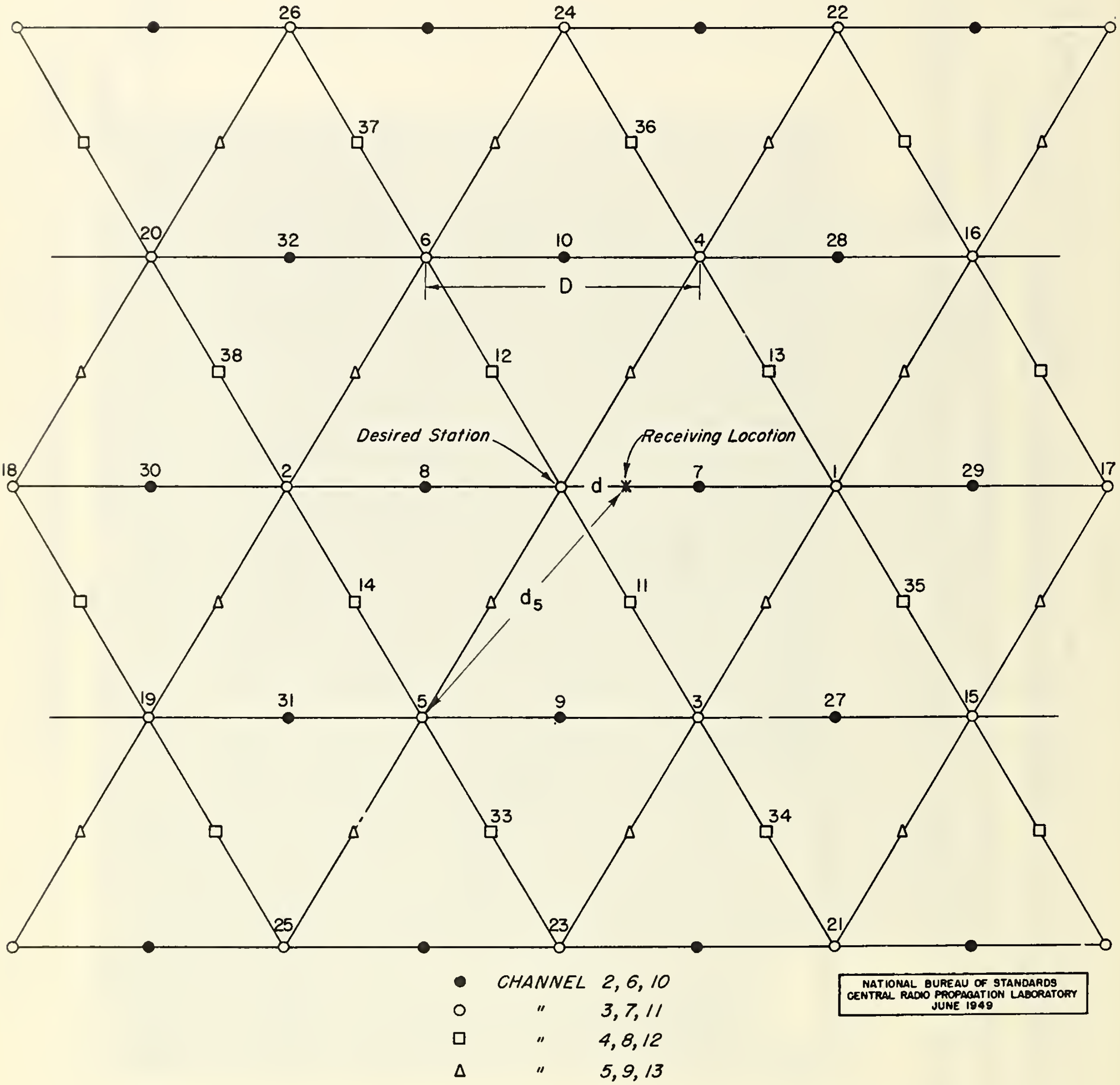

Figure 6

COMPARISON OF EFFICIENCY OF GRADE B SERVICE FOR SYNCHRONIZED AND UNSYNCHRONIZED CO-CHANNEL STATIONS

The stations are assumed to be allocated on a triangular lattice as shown on figure 8; $f = 63$ 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

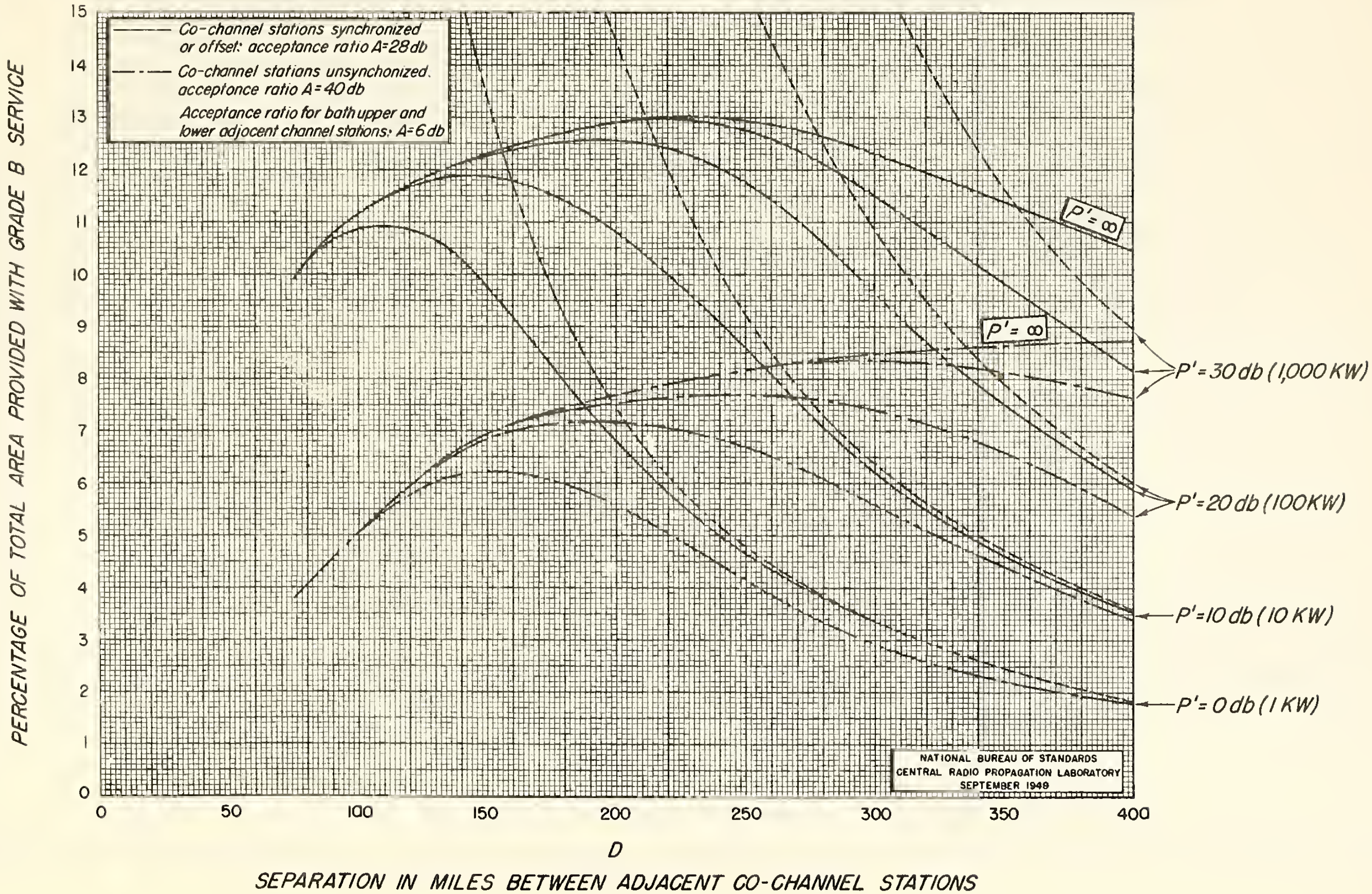

Figure 7

COMPARISONS WITH AND WITHOUT THE USE OF OFFSET CARRIERS OF THE GRADE B EFFECTIVE SERVICE RADII OF A TELEVISION STATION AS LIMITED BY NOISE AND INTERFERENCE FROM A SINGLE UNDESIRED CO-CHANNEL STATION

$D = 200$ 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

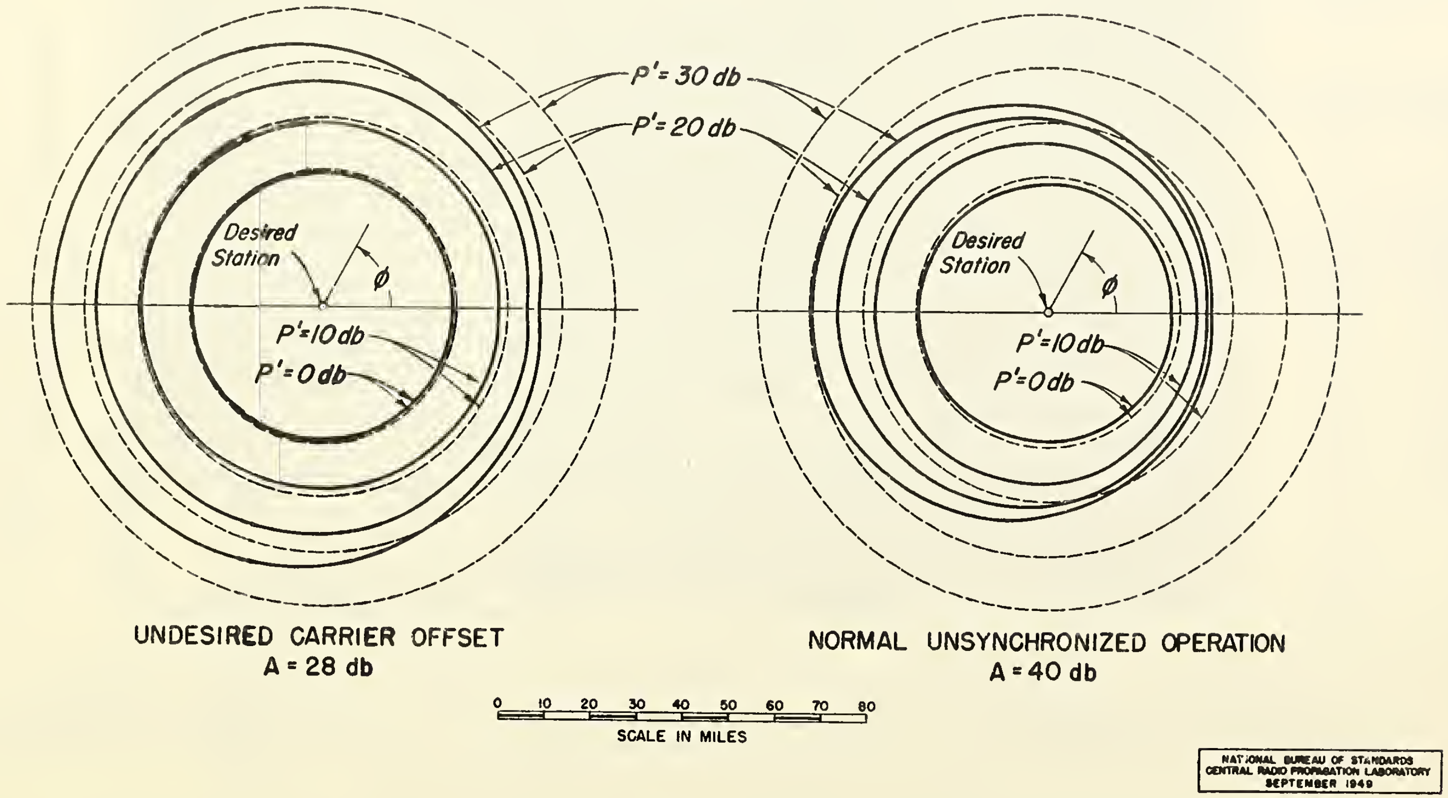

Figure 8

COMPARISON WITH AND WITHOUT OFFSET CARRIERS OF THE TOTAL GRADE B EFFECTIVE SERVICE AREA PROVIDED BY TWO CO-CHANNEL TELEVISION STATIONS

$D = 200$ MILES; $f = 63$ Mc; $H_t = 500$ FEET; $H_r = 30$ FEET; $F_r = 46.9$ db; $G_d = G_i = 0$

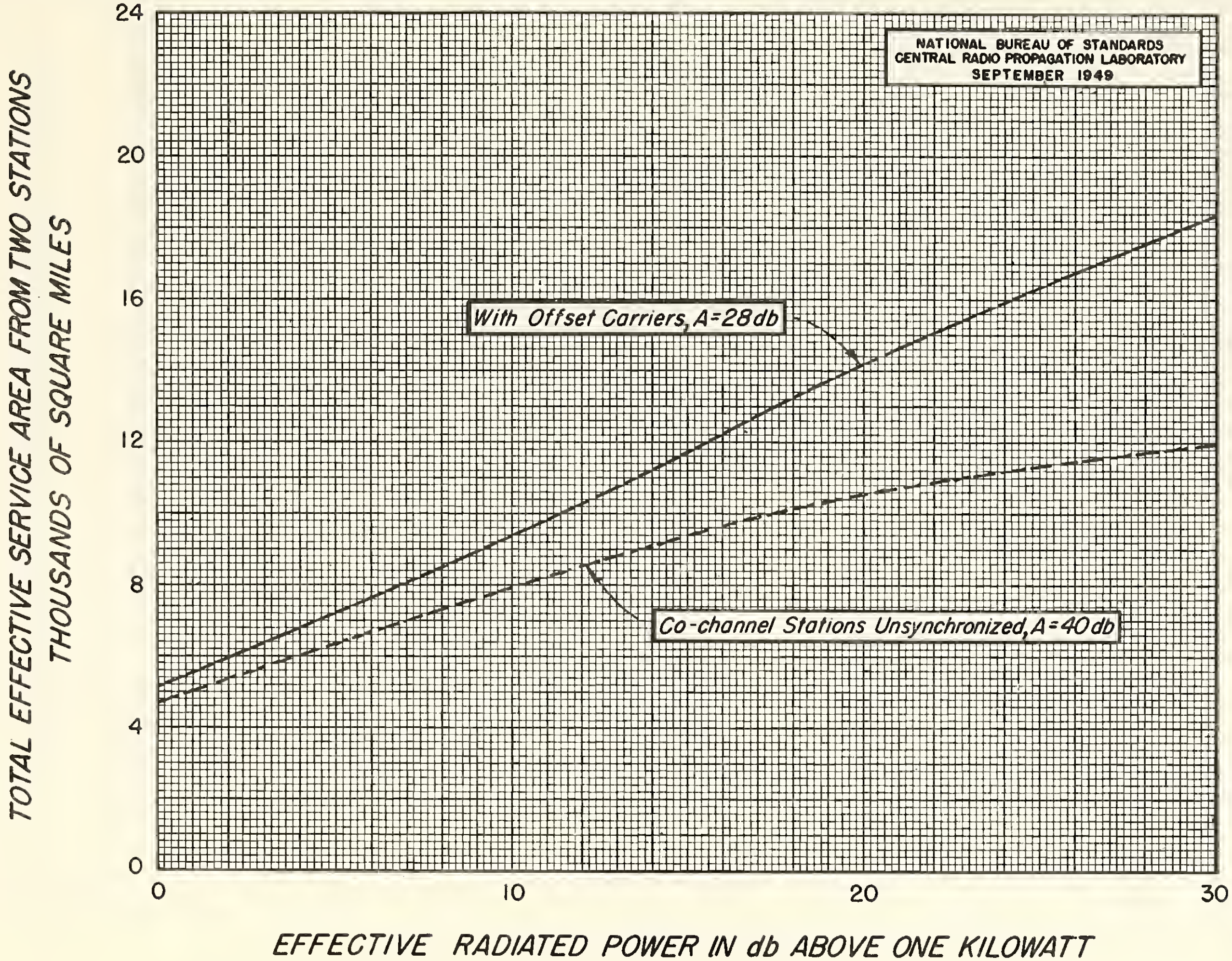

Figure 9

COMPARISON OF EFFICIENCY OF PROVIDING GRADE A SERVICE FOR CORRELATED AND UNCORRELATED FIELDS

The stations are assumed to be allocated on a triangular lattice as shown on figure 6; co-channel carriers are synchronized or "offset"; D=200 miles; f=63 Mc; H_t=500 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 long dash curve corresponds to the hypothetical assumption that all interference, except that due to noise, has been eliminated

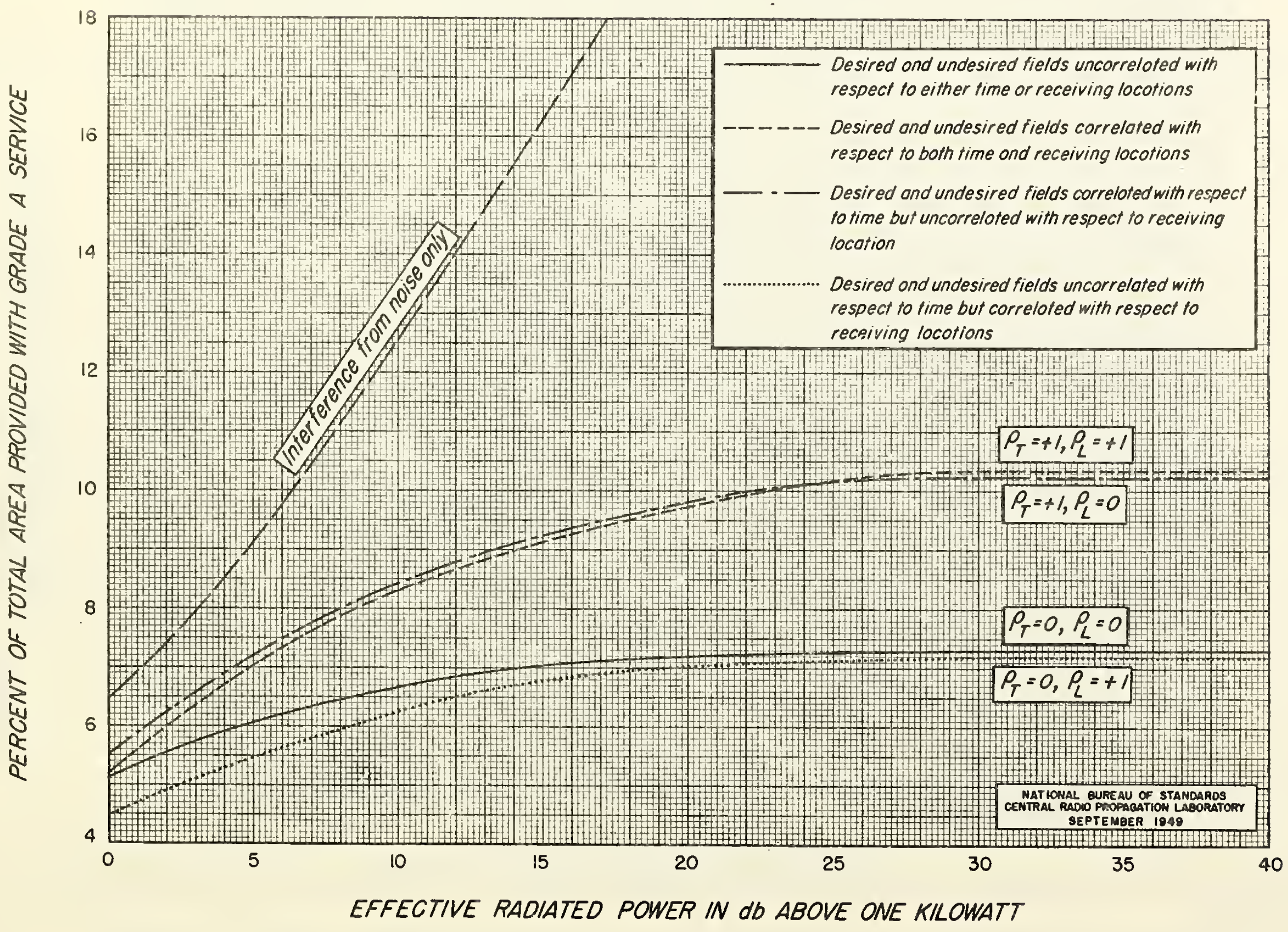

Figure 10

COMPARISON OF EFFICIENCY OF PROVIDING GRADE B SERVICE FOR CORRELATED AND UNCORRELATED FIELDS

The stations are assumed to be allocated on a triangular lattice as shown on figure 6; co-channel carriers are synchronized or "offset"; D=200 miles; f=63 Mc; H_t=500 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 long dash curve corresponds to the hypothetical assumption that all interference, except that due to noise, has been eliminated

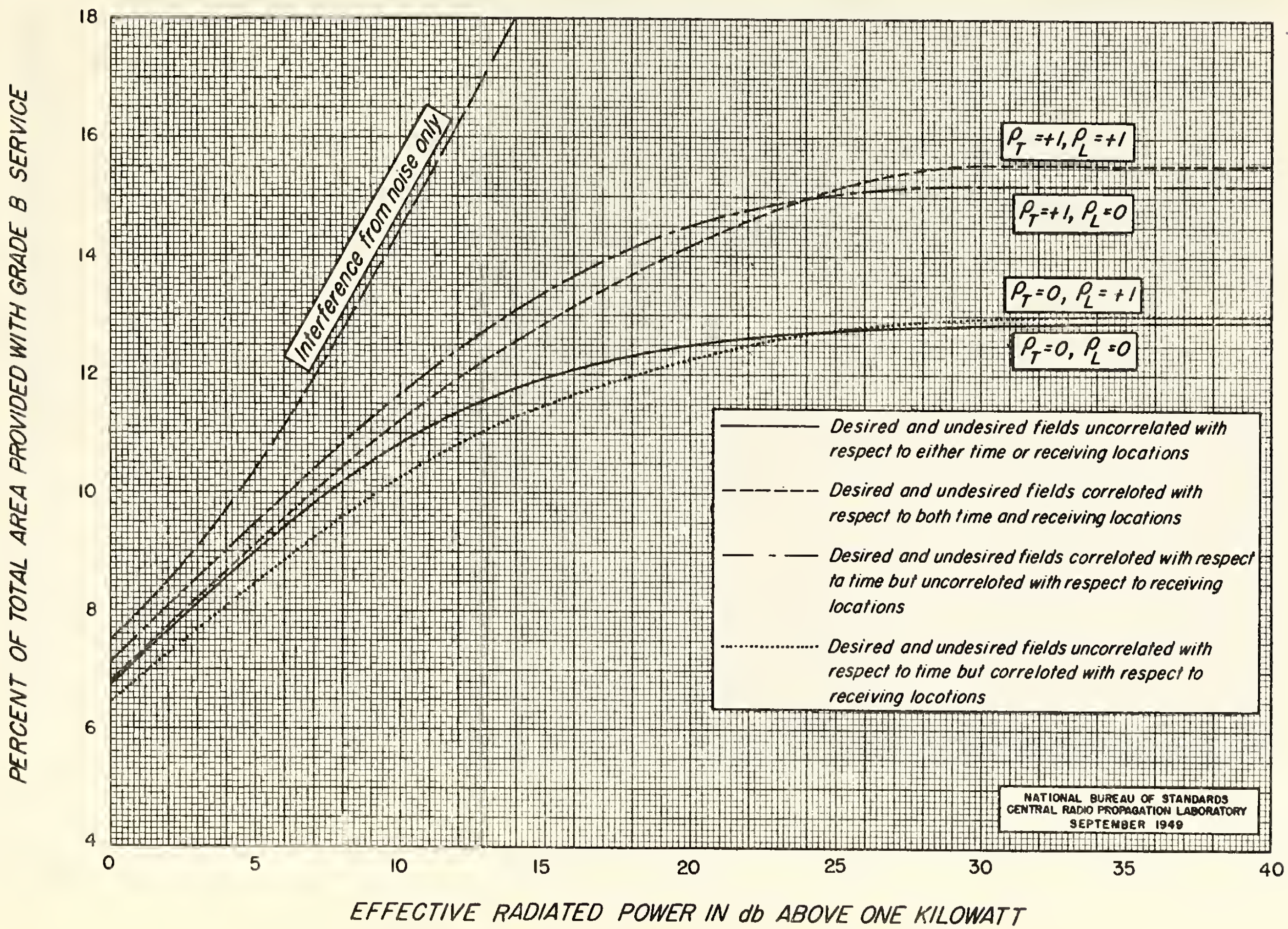

Figure 11

COMPARISON OF EFFICIENCY OF PROVIDING GRADE C SERVICE FOR CORRELATED AND UNCORRELATED FIELDS

The stations are assumed to be allocated on a triangular lattice as shown on figure 6; co-channel carriers are synchronized or "offset"; D=200 miles; f=63 Mc; H_t=500 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 long dash curve corresponds to the hypothetical assumption that all interference, except that due to noise, has been eliminated

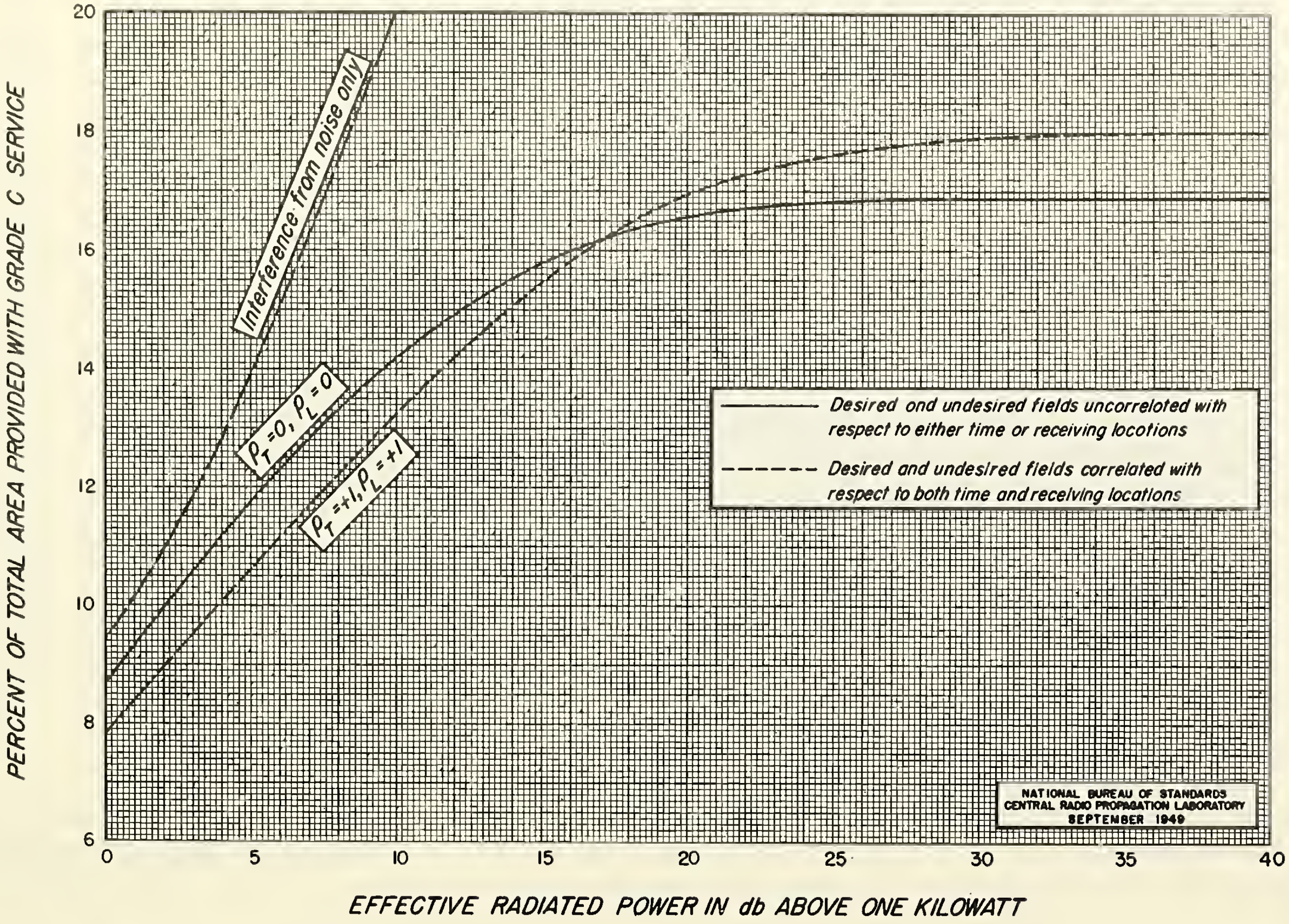

Figure 12

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 6

$f = 63$ 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

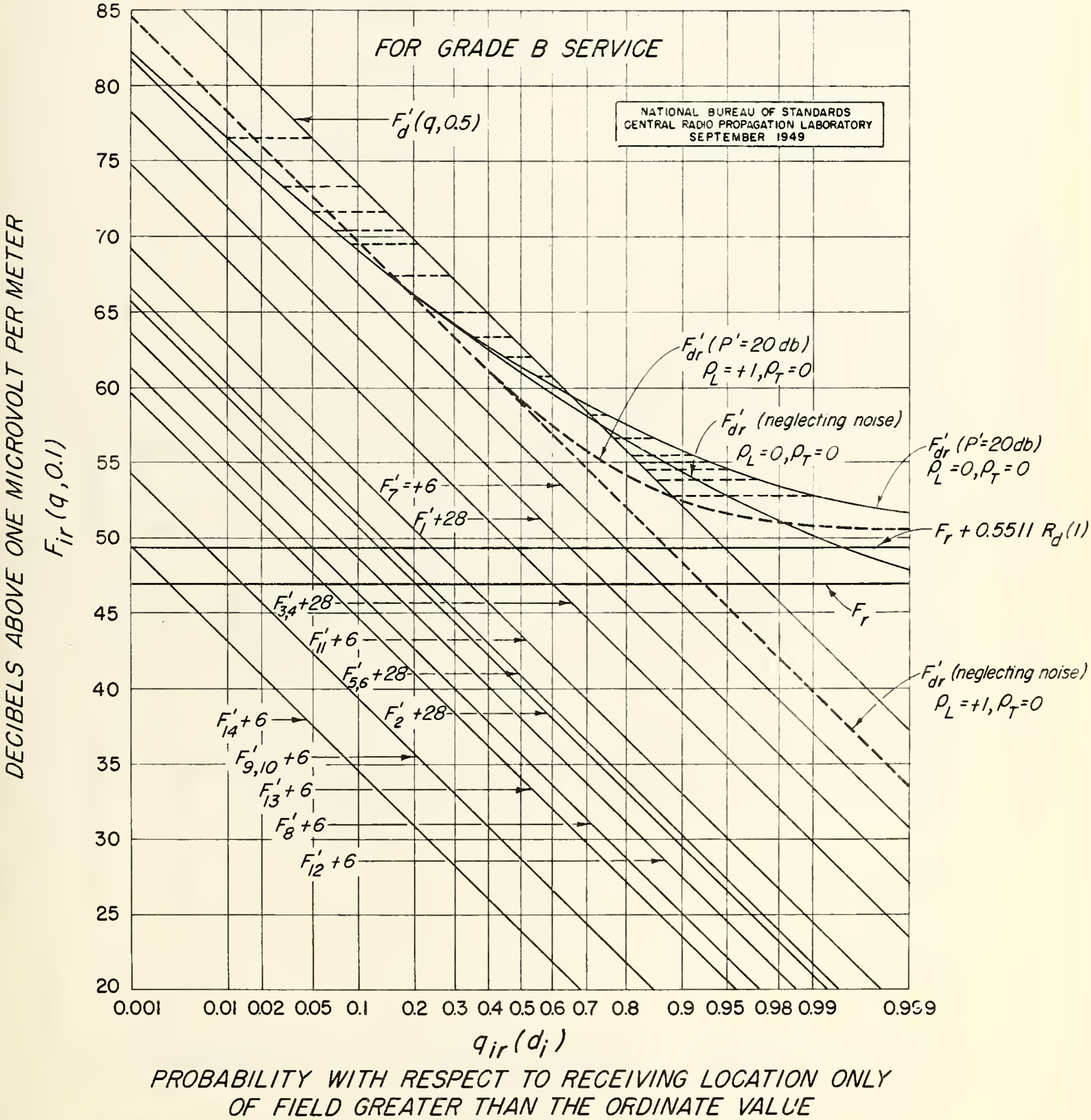

Figure 13

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 6

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

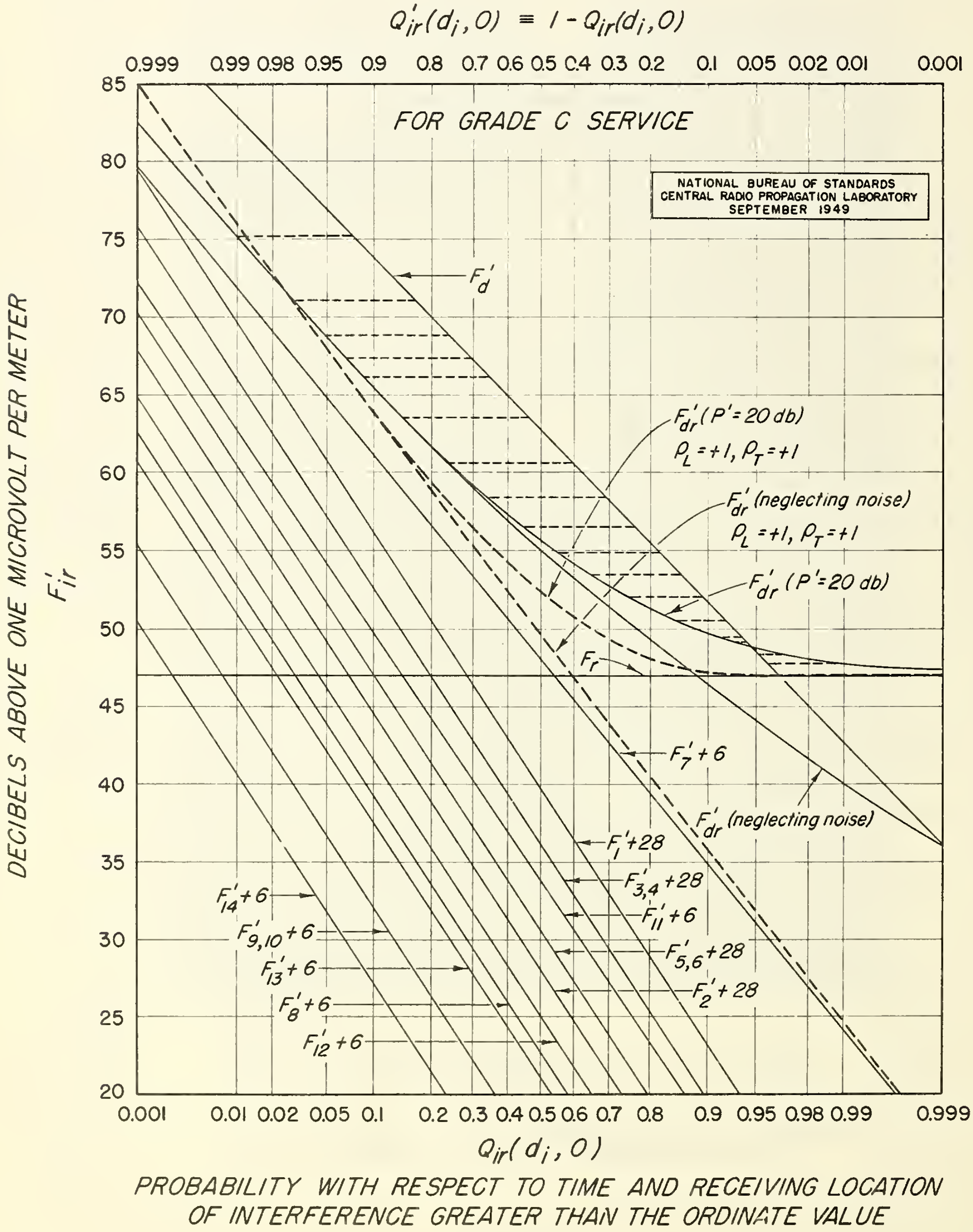

Figure 14

COMPARISON OF THE DISTRIBUTION OF GRADE B SERVICE FOR FIELDS CORRELATED WITH RESPECT TO RECEIVER LOCATION AND FOR FIELDS NOT SO CORRELATED

D = 200 MILES; f = 63 Mc; H_1 = 500 FEET; H = 30 FEET; F = 46.9 db; P' = 20 db

Correlation with respect to time is assumed to be zero

The deterioration of service is shown as distance is increased in the direction of station No. 1

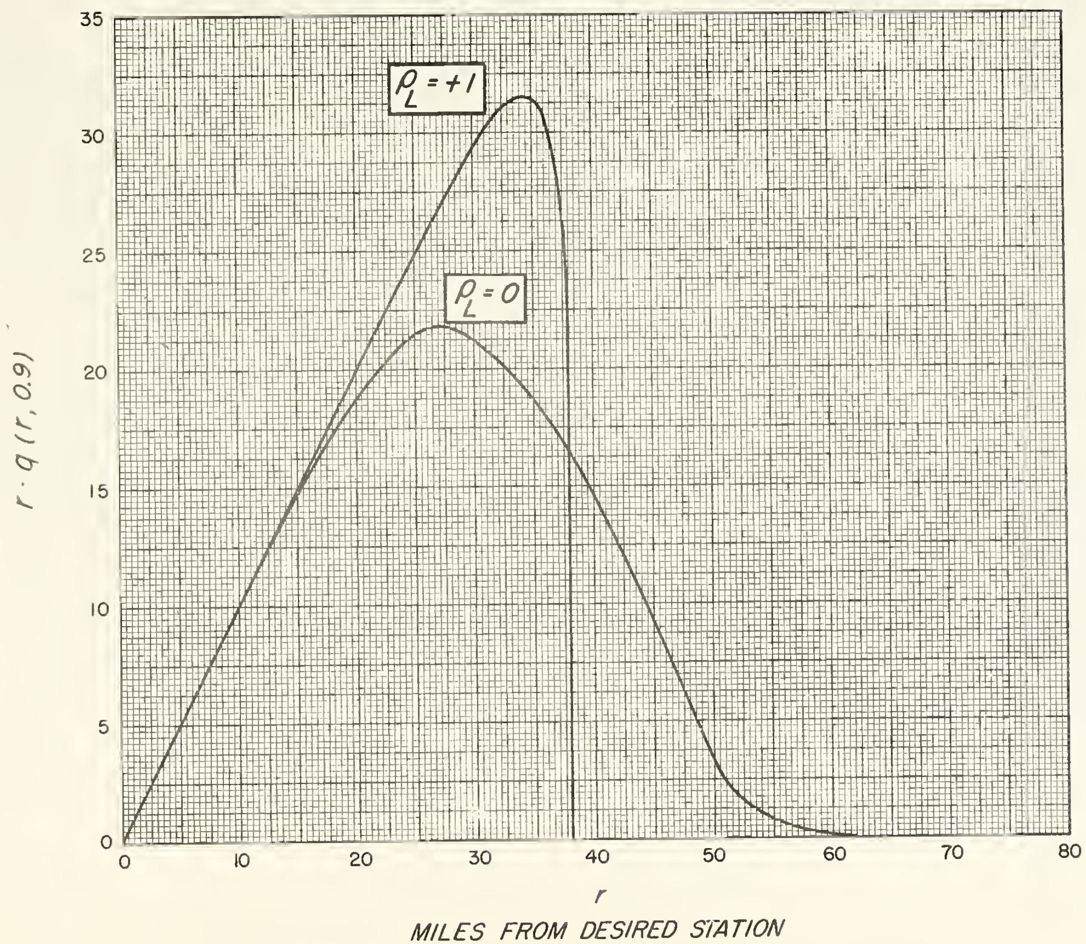

Figure 15