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NATIONAL BUREAU OF STANDARDS REPORT

2494

PROPAGATION OF RADIO WAVES OVER LAND AT 1046 MC

(Report for the Air Navigation Development Board)

By

A. P. Barsis, B. R. Bean, J. W. Herbstreit,
K. O. Hornberg, and K. A. Norton

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NATIONAL BUREAU OF STANDARDS REPORT

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1406-30-6800 — May 1, 1953 — 2494

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Tropospheric Propagation Research Section
Central Radio Propagation Laboratory

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PROPAGATION OF RADIO WAVES OVER LAND AT 1046 MC

(Report for the Air Navigation Development Board)

1. INTRODUCTION AND SCOPE

1.1 Background

The Air Navigation Development Board in discharge of its duties as expressed in its Charter, initiated an investigation of radio wave propagation in the 960-1600-Mc frequency band and placed the supervision of such a project under the Central Radio Propagation Laboratory of the National Bureau of Standards.

The most important aspect of this study of radio wave propagation is its bearing on the problem of assessing the reliability of air-to-ground communications or radio navigation. Most of the following report deals either directly or indirectly with this important problem.

Furthermore, inasmuch as the frequencies to be used within this band must necessarily be recurrent to conserve the frequency spectrum, the distance between co-channel facilities must be determined by the interference within the service area of one station by transmissions from another station or stations on the same frequency. In view of the fact that evidence existed wherein transmissions at these frequencies did not behave strictly as line-of-sight but that interference fields existed well beyond line-of-sight, the National Bureau of Standards originated the Cheyenne Mountain Field Station in Colorado Springs, Colorado to investigate the propagation phenomena associated with simulated air-to-ground transmissions, not only at distances within line-of-sight where the question of service reliability is involved but also at points far beyond the radio horizon which may be involved in the solution of mutual interference problems.

The experiments conducted along these lines were to be the first phase of a long range program and were to be of a continuous nature for a period of at least one year to determine adequately the nature of the diurnal and seasonal variations of the radio field intensity.

In view of the realization that climatological conditions vary greatly throughout this country and the world and that the propagation data assembled over the Cheyenne Mountain path would have to be very carefully interpreted for extension to other areas, a radio meteorological program was considered advisable in conjunction with the Cheyenne Mountain experiments. The meteorological phase of the program is designed to test the accuracy of recent developments in radio meteorology analysis and to improve these methods on a climatological basis.

The technical supervision of the ANDB project within CRPL was assigned to Mr. J. H. Chisholm from the beginning of the project until November, 1951 when he resigned from the National Bureau of Standards. Mr. G. R. Chambers was then assigned the supervision of the ANDB project in addition to the 100-1000-Mc program operating concurrently. Upon the resignation of Mr. Chambers in June, 1952, Mr. K. O. Hornberg was assigned the duties held by his predecessor and is currently in charge.

1.2 Scope of this Report

The purpose of this report is to present the experimental data on 1046 Mc obtained at the Cheyenne Mountain Field Station for the period February 1, 1952 through January 31, 1953. Continuous recordings were not made prior to this period and consequently any previous data are not considered. In addition, this report includes the analysis of diurnal and seasonal variations in hourly median signal levels, the analysis of variations in instantaneous signal levels and the analysis of prolonged space-wave fade-outs within the radio horizon for the period investigated, an analysis of the effects of irregular terrain at points within the radio horizon, an analysis of the scattered signals at points far beyond the radio horizon, including estimates of the expected effective gains of large antenna arrays, the required spacing for diversity arrays and the effective intelligence bearing bandwidths of the propagation paths. Finally, as a result of a recent investigation of propagation over high mountain ridges, an analysis is presented of the "obstacle gains" expected on 1000 Mc in mountainous terrain.

2. DESCRIPTION OF FACILITIES

2.1 Transmission Paths

The 1046-Mc Cheyenne Mountain project is shown pictorially in Fig. 1 with the transmitting site located on Cheyenne Mountain at an elevation of 8800 feet above mean sea level and several fixed and semi-mobile recording sites in eastern Colorado, Kansas and Arkansas. Figs. 2a, b and c show the terrain profiles along the transmission paths from the transmitter to each of the three fixed recording sites located at Kendrick, Colorado (49.3 mi), Karval, Colorado (70.2 mi), and Haswell, Colorado (96.6 mi). Fig. 2d shows the terrain profile out to Garden City and Anthony, Kansas. The definition is given on Fig. 2d of an angle, θ, which we have used throughout this report to characterize a particular transmission path. This is simply the angle between the radio horizon lines in the great circle plane. Transmission paths within the line-of-sight will be characterized by negative values of θ while positive values of θ correspond to non-optical paths. The usefulness of the parameter θ in tropospheric propagation lies in the fact that it can be used (largely independently of the antenna height h provided h is sufficiently great) to describe fading characteristics and transmission loss relative to free space, while at the same time it can be used to extrapolate the results of propagation measurements to a terminal at an arbitrarily high elevation. Fig. 2e demonstrates how the same angle θ can characterize various transmitting heights h_{t1}, h_{t2}, and h_{t3}, while Figs. 11c and 12e show how the experimental data can be described in terms of the parameter θ, being largely independent of the heights of the terminals. This principle is of great importance in engineering air-to-ground communication and navigation systems. The method of calculating θ for transmission paths over irregular terrain is discussed in Appendix I and the value of θ for our 1046-Mc transmission paths are given in Table I, based on an assumed effective radius of the earth equal to four-thirds of its actual value to allow for standard air refraction. The terrain profiles of Figs. 2a, b, c, and d are based on standard atmospheric refraction and show that the Kendrick and Karval sites are within line-of-sight, while the Haswell site is just beyond line-of-sight and in the diffraction zone and the Garden City location is well beyond line-of-sight and considered out of the diffraction zone and in the scattering region for reception. An examination of these terrain profiles in the light of Rayleigh's criterion of roughness indicates that the actual terrain is quite rough compared to the wavelength of transmissions, although the transmission path appears visually to be as level as one is likely to find in siting VHF ground terminals. The practical significance of this roughness is discussed in detail in a later section of this report.

The soil condition along the transmission path in eastern Colorado and western Kansas is quite arid, being utilized for cattle grazing and dry farming. In central Kansas, in the vicinity of Garden City, the land becomes less arid and wheat farming predominates.

The prevailing wind conditions are usually from the northwest with turbulence at all levels extending from the mountain region to the Colorado-Kansas border. Wind velocities in the Colorado Springs and Haswell, Colorado areas are generally in excess of 15 mi per hr with gusts exceeding 50 mi per hr quite frequently. The area is one of conflict between the settled conditions of mountain induced subsidence and solar induced turbulence. The area is under intensive study by meteorologists as the birthplace of tornadoes and the Geophysical Research Directorate is planning an intensive turbulence study to be conducted in this area next summer. Although the site for these propagation measurments was chosen primarily for a high mountain site, subsequent investigation has revealed the area to be an ideal location for radio-meteorological studies due to the heterogeneous meteorology available.

2.2 Transmitting Facilities

The 1046-Mc 4-kilowatt CW transmitter is located on Cheyenne Mountain near Colorado Springs, Colorado with the transmitting antenna at an elevation of 8760 feet above mean sea level or approximately 3000 feet above the average elevation of the plains at the base of the mountain. Figs. 3a and 3b are photographs of the transmitter site and a close-up of the antenna. Fig. 3c is a photograph of the Klystron transmitter. A block diagram of the 1046-Mc transmitting facility is shown in Fig. 3d. A more detailed description of the Klystron transmitter can be found in NBS Report 1826.[1/]

The horizontally polarized transmitting antenna is of the slot-fed-horn type and has a gain of 26 db with respect to an isotropic radiator. This gain is obtained through the use of half-power horizontal and vertical beam widths of 18 and 6 degrees, respectively.

2.3 Recording Facilities

The 1046-Mc transmissions are recorded continuously 24 hours per day, seven days a week, at four fixed locations namely Kendrick, Colorado; Karval, Colorado; Haswell, Colorado and Garden City, Kansas. Short term continuous recordings are made during mid-summer and mid-winter at Anthony, Kansas and Fayetteville, Arkansas. Inasmuch as the Anthony and Fayetteville sites are far beyond the radio horizon, less emphasis has been placed on this part of the program.

Pertinent Recording site data are given in Table I.

TABLE I

Site	Miles from Transmitter	θ	True Bearing from Trans.	Elevation Above MSL-Feet	Antenna	Antenna Height Above Ground-Feet
Kendrick	49.3	-0.221°	105.569°	5260	Dipole	42.7
Karval	70.2	-0.130°	97.059°	5060	Dipole	42.7
Haswell	96.6	0.102°	105.255°	4315	Dipole	42.7
Garden City	226.5	1.532°	105.247°	2855	Dipole	42.7
Anthony	393.5	3.422°	103.352°	1335	Parabolic Reflector	10.0
Fayetteville	616.3	5.638°	103.670°	1325	Parabolic Reflector	38.0

Figs. 4a and 4b are photographs of typical fixed and mobile recording sites, respectively. A block diagram of a recording site is shown in Fig. 4c. Fig. 4d is a photograph of the recording equipment including receiver, calibrating signal generator, frequency standard, chart recorder and time totalizing recorder.

A block diagram of the Brooklyn Polytechnic Research and Development Co. Inc. type 856-X narrow-band receiver is shown in Fig. 4e.

Further details of the recording facilities are given in NBS Report 1826.1/

3. RESULTS OF MEASUREMENTS

3.1 General Discussion

Results of continuous measurements on 1046 Mc for all transmission paths are available in the form of Esterline-Angus graphical records for all fixed receiving sites while additional microfilm records of time totalizer data are available for the Garden City and Anthony sites. Figs. 5a to 5d are samples of Esterline-Angus charts showing representative recordings for typical night and afternoon periods during winter and summer at each of the four fixed sites. Fig. 5e shows the only data available out of a period of several weeks recordings at Fayetteville, Arkansas. Although it has not been possible as yet to undertake a detailed numerical study of fading rates at the various sites, inspection of the chart samples indicates an increase in the fading rate with distance from the transmitter beyond the radio horizon. The rapid fading at Garden City makes analysis of the Esterline-Angus charts quite difficult, and time totalizers are used for this reason as they provide means for interpretation of rapidly fading signals. At Haswell, which is some 20 miles beyond the radio horizon, the amount and rate of fading has been found to vary with the time of the day and the season, and is undoubtedly strongly influenced by prevailing atmospheric conditions. Execution of the meteorological program planned will provide a basis for a detailed study of the correlation between the character of the received signal, and the status of the lower atmosphere.

Significant signal variations at the two sites within the radio horizon appear to be irregular in nature, and, in general, are not characterized by single fading rate for this range. Observed prolonged space wave fade-outs will be discussed in a subsequent portion of this report.

3.2 Hourly Medians

For purpose of data analysis and presentation, the hourly median value expressed in decibels below free space value was used. This constitutes a measure of the field or power available for 50% of each hour for which recordings are available. Hourly median values are determined from the Esterline-Angus and time totalizer records, and are tabulated for each receiving site. In order to determine diurnal variations of the received power, the hourly median values for each month at each receiving site are separated into eight three-hour periods (midnight to 3 a.m., 3 a.m. to 6 a.m., etc.) and data for each of the three hour periods have been investigated separately.

Figs. 6a to 6j show over-all distributions of hourly medians for each month for which data were available. These distributions are plotted on probability graph paper, and show the number of hours of recordings which serve as a basis for each of the curves shown. It is seen from the graphs that the curves approach lines representing normal distributions with varying slopes. For each month and each site, therefore, an over-all monthly median, and the observed range of hourly median values may be determined, and these serve as a basis for characterizing the seasonal variations of these values at each site, and of the measured dependence of the signal on the distance from the transmitter. The ratio of hourly median values exceeded for 10% and for 90% of all hours is used as a measure of the variance of the monthly signal.

Fig. 6k shows distributions of hourly medians for each site for all hours of the entire year for which recordings were available.

Fig. 6l shows the distribution of hourly medians recorded at the Anthony site during August, 1952.

Typical distributions for nighttime and afternoon diurnal periods are shown in Figs. 7a to 7d. Distributions of hourly medians during the months of February, June and September are shown for the periods 3 a.m. to 6 a.m., and noon to 3.p.m. It is believed that the larger variance of the transmission loss during the early morning hours at Kendrick and Karval, particularly in September, is largely due to the occurrence of prolonged space wave fade-outs at these locations. A monthly median for each three-hour period, and a corresponding measure of its variance may be determined from these distributions, and equivalent graphs (not shown) drawn for all three-hour periods for all months form the basis for Figs. 8 and 9.

Figs. 8a and b use the monthly medians for each three-hour period to depict the diurnal change in the hourly median values. Each set of curves shows the diurnal signal change at the four sites for each month, and thus permit observation of diurnal changes with distance, and over the season. Diurnal changes were not shown in cases where sufficient data for individual three-hour periods were not available for a particular site at a certain month. Similarly, Figs. 9a and b show the diurnal changes of the variance of hourly medians as obtained from the monthly distributions.

Fig. 10a shows the seasonal variation of median signal levels comparing the over-all monthly values to the typical night and afternoon periods. In studying this graph one should bear in mind that no data at all were available for March, November and December, and incomplete data for some of the other months at several of the receiving sites.

Fig. 10b shows the seasonal trend of the variances drawn for the same period as Fig. 10a. The same restrictions with regard to the incompleteness of the data apply.

Finally, Figs. 11a and b show the over-all monthly medians and their variances versus distance. The points shown for each site are taken from the monthly distributions (Figs. 6a to j). The line on graph connects points taken from the aggregate yearly distributions for each site (Fig. 6k).

Fig. 11c shows the variation of the median attenuation for the month of August relative to the free space value as a function of the angular distance, θ. This illustrates, in the case of the 100-Mc data, how attenuations measured at different antenna heights varying from 30' to 7800' above local terrain all lie on a single curve when plotted as a function of θ.

3.3 Distributions of Signal Levels Within the Hour

The material discussed so far is based on the hourly median of the received signal as its unit of evaluation; however, signal variations occurring within the hour are important as well. They may be described by fading range and fading rate. As detailed studies of the fading rate are not yet available, the following discussion will be restricted to fading range problems. It has been found convenient to define fading range within each hour as the ratio of power levels (expressed in decibels) exceeded for 90% and 10% of each hour.

The month of August, 1952, has been selected for detailed studies of fading range. For all sites beyond the radio horizon (Haswell, Garden City, and Anthony), distributions of signal levels were obtained for each individual hour. These distributions were tabulated with reference to the median value of signal observed for each hour, and the distribution of deviations from the median was averaged over the entire month for each hour, i.e. the 30 percentages of time for each deviation level corresponding to the 30 days of the month were averaged to determine a percentage typical of that month and deviation level. These average distributions were then plotted on Rayleigh graph paper. Samples of these average distributions are shown on Fig. 12a, together with a straight line representing the ideal Rayleigh distribution. From each distribution the fading range is read off as the ratio (in decibels) exceeded for 90% and 10% of each hour, and compared with the range for an ideal Rayleigh distributed signal (13.4 db). Figs. 12b, c, and d show the diurnal variation of the hourly medians and of the fading range for the three sites beyond the radio horizon. Fig. 12e shows the variation of fading range with the angular distance, θ.

4. PROLONGED SPACE-WAVE FADE-OUTS

A phenomenon of considerable significance in assessing the reliability of communication and navigation systems which are usually designed to operate out to line-of-sight distances ($\theta = 0$), is the prolonged space-wave fade-out which has been found to occur on transmission paths with angular distances, θ, near zero. It has been found that the 1046 Mc signal at Kendrick ($\theta = -0.221^{\circ}$) and Karval ($\theta = -0.130^{\circ}$) exhibit prolonged fade-outs amounting up to 20 db and more from the monthly median signals, and lasting from a minute up to several hours.

Fig. 13a shows a sample of the recording chart for the time a fade-out of this kind occurred. The sample shows the 1046 Mc recorded fields at both of the above sites and, in addition, the signal recorded simultaneously on 100 and 192.8 Mc. These records illustrate the significant fact that this phenomenon is of importance only at the higher frequencies; consequently, our extensive experience with the reliability of communication systems operating at the lower VHF frequencies is not applicable, at least as regards this phenomenon, to a 1000 Mc system. For the purpose of detailed study, we have adopted the following precise definition of a fade-out: <u>A prolonged space-wave fade-out is said to occur whenever the field at Karval on 1046 Mc drops 5 db or more below the monthly median level for one minute or more.</u> The 5 db level was chosen to make the phenomenon operationally significant while the mininum of one minute was chosen to rule out the rapid phase interference types of fading including those due to passing aircraft. Table I of Appendix II catalogs the time of occurrence and intensity of these prolonged space-wave fade-outs which, by definition, occur at Karval (near the radio horizon), while Table II of Appendix II catalogs the fields at Kendrick (within the radio horizon), and Haswell (beyond the radio horizon, $\theta = 0.102$) only for those times that fade-outs occurred at Karval. The median fields for Kendrick in Table II of Appendix II are referred to the over-all monthly median level since no appreciable diurnal cycle exists there, while the effect of the normal diurnal cycle is removed from the Haswell data of Table II of Appendix II by referring the field strength during the time of a fade-out to the pertinent monthly median 3-hourly field. The relative monthly frequency of the fade-outs is shown in Fig. 13b, and the diurnal distributions of the time of onset of these fade-outs is shown in Fig. 13c. These figures show an apparent tendency for estival and nocturnal occurrence of the fade-outs. Indeed, 81% of the fade-outs occur in the months of May through September while 92% of the fade-outs occur between two hours before sunset and two hours following sunrise. Fig. 13d shows the percent of total recording time that the fade-outs produced fields at least 5 db below the monthly median. May is the maximum with 10.5% while the occurrence in all of the summer months is in excess of 4.9% of the time; however, since the occurrence for the lowest month, October, is 2.8%, all months have occurrences which are operationally significant for systems designed to operate out to line-of-sight.

Fig. 13e shows the cumulative distribution of the length of time of fade-outs in excess of 5, 10, and 15 db. The operational significance of the fade-outs can be seen from the observation that 90% of the fade-outs of at least 5 db depth are at least 6 min. long, while 50% are of at least 24 min. duration.

An example of the dependence of these fade-outs on meteorological conditions is presented in Figs. 13f and g. Fig. 13f shows the received 1046 Mc fields for Kendrick, Karval and Haswell, Colorado, for the night of June 21-22, 1952. Starting at 10 p.m., June 21, fade-outs of 5 to 15 db are observed at Kendrick and Karval while the 1046 Mc field at Haswell shows a spectacular rise at 11:30 p.m. Meanwhile, detailed low level wiresonde measurements were made at Haswell and are shown on Fig. 13g. Fig. 13g illustrates the diurnal nature 2/ of the refractive index-height distribution, showing a linear afternoon gradient of 0.0125 N units/meter (0.03918 N units/meter being equivalent to a standard 4/3 atmosphere), an increasing surface gradient due to nocturnal radiation of the ground as the night goes on (the 2320 and 0250 profiles have ducting gradients, i.e., a gradient greater than 0.157 N units/meter which is sufficient to trap the energy provided it extends over a sufficient height interval, which for 1046 Mc is only 49 meters), and finally, after sunrise the steep surface gradients are lifted aloft by convection to produce profiles similar to those at 0554 or 0945.

With the above information as background, an analysis was made of the La Junta, Colorado, radiosonde soundings of the U.S. Air Force's Tornado project. These soundings were taken at 0800 and 2000 MST from July 19, 1952 to September 26, 1952. During this period there were 43 nights of concurrent radio and meteorological observations of which only four nights of record, or 9%, were without fade-outs. The La Junta refractive index profiles were then classified as (1) linear provided the refractive index gradients were (a) normal for the period of record, i.e. 0.025 N units/meter, (b) less than normal, or (c) not in excess of 60% greater than normal, i.e., 0.040 N units/meter and possessed no departures from this degree of linearity within 500 meters of the surface, or (2) ground modified if either the surface gradient was more than 0.040 N units/meter or if the base of the surface gradient had been lifted no more than 500 meters above the surface. The profiles for 1612 and 2035 of Fig. 13g meet the definition for linearity while the profiles 2320, 0250, 0554 or 0945 of Fig. 13f meet the definition of a ground modified profile. Of the 39 nights with prolonged space-wave fade-outs, 31 or 79.5% had ground modified pro-files. If a fade-out occurred prior to the evening sounding or subsequent to the morning sounding, then that particular sounding was considered typical of the time of fade-out. Conversely, the evening sounding was considered typical of evening-no-fade-out-conditions if none occurred in the first half of the night while the morning sounding was considered typical of morning-no-fade-out-conditions if none occurred in the last half of the night. Table II summarizes this analysis and shows that 74.1% of the refractive index profiles are ground modified during fade-outs while 63.2% of the profiles are linear in the absence of fade-outs, indicating a favorable order of magnitude dependence upon the above defined characteristics of the refractive index profile for those times fade-outs occurred and during times of no fade-outs. Presumably this agreement could be improved by modifying the above definitions and this will be done as time permits.

TABLE II

Dependence of Prolonged Space-Wave
Fade-Outs on the Refractive Index Profile
at La Junta
For the Period July 19, 1952 to September 26, 1952

	Number of Observations	Linear Refractive Index Profile	Ground Modified Refractive Index Profile
Fade-Outs	27	25.9%	74.1%
No Fade-Outs	19	63.2%	36.8%

Although the above analysis needs to be carried much further by means of the more detailed meteorological measurements soon to be available directly on our Cheyenne Mountain paths, cursory examination of meteorological data at 15 widely scattered stations throughout the United States makes it appear likely that these fade-outs will be observed everywhere in the United States and in all seasons, the maximum occurrence being dependent upon the climatic area. Consequently, the transmitter power used on 1000 Mc communication and navigation systems should be increased enough to allow for these fade-outs if reliable operation is to be insured through the 24 hours at all seasons of the year.

5. CALCULATIONS OF EXPECTED FIELDS AND EFFECTS OF ROUGH TERRAIN

Methods of computing fields within and beyond the radio horizon have been discussed in various publications. The problem, in general, consists in replacing the actual terrain and actual atmosphere by a simplified model for which it is possible to calculate the field. One such model is a smooth spherical earth surrounded by an atmosphere in which the refractive index decreases linearly with height above the surface, and the received field at any point is calculated using procedures established by space-wave theory in case of within line-of-sight paths[3/], and diffraction theory for paths extending beyond the radio horizon [4/]. Atmospheric refraction is taken into account by multiplying the radius of the earth by a factor k which is a measure of the gradient of the refractive index of the atmosphere.

Deviations between measured and computed values will depend on errors introduced by (a) replacement of actual rough terrain by a smooth spherical earth, (b) magnitude and linearity of the refractive index gradient, and (c) components of field due to other modes of transmission.

At distances far beyond the radio horizon the field is much stronger than expected from the diffraction theory, and is thought to be largely due to scattering from tropospheric discontinuities. This aspect is discussed in the following section of this report.

The effect of scattering on the field received within the radio horizon is probably too small to be detected by the equipment installed and operating now. At Haswell, a certain amount of field due to scattering appears to be present in addition to the steady component due to the diffracted field (see Fig. 12 and pertinent discussion, above).

In accordance with methods outlined in the reference cited above [3/], the actual terrain profile between the transmitter site and the receiving sites at Kendrick and Karval was replaced by second-degree curves extending from each receiving site to somewhat beyond its horizon. This was done by the method of least squares, and Figs. 2a and b show the resulting curves together with the profiles, and the space-wave geometry involved. Inspection of the profiles shows that the terrain between the receiver horizon and the transmitter would not contribute reflected components to the field appearing at the receiving antenna because none of it, except a small portion in the vicinity of the transmitter, is illuminated by the receiving antenna. The directivity of the transmitting antenna is such that no appreciable reflection would occur along the steep slope near the transmitting antenna. Based on terrain curvature associated with the best fitting curves shown, and effective radius of the earth values for various assumptions of a (linear) gradient of refractive index, various values of the expected field at Kendrick and Karval were computed. Fig. 14a shows a graph of the field (in decibels below free space) versus k for three frequencies at Kendrick and Karval. The k corresponding to "standard atmosphere" or the "four-thirds earth" is indicated. The curves provide an indication of expected changes in field for a change in atmospheric condition, but do not take into account non-linearity of the refractive index gradient, or the effect of terrain roughness.

Similarly, a least-square terrain fit was used to compute the diffraction field at Haswell. The terrain profile and the curve are shown in Fig. 2c.

As a result of computations outlined above, the following values of received field at the first three sites were obtained and are compared with measured data (expressed in decibels below free space).

Site	Computed Field		Measured Field*
	Winter k = 1.261	Summer k = 1.333	
Kendrick	-5.3	-5.5	0
Karval	-5.7	-6.6	+0.4
Haswell	+22.7	+17.5	+28.8

* Median taken from yearly distribution of hourly medians (Fig. 6k)

In all cases the measured field appears to be less than the computed field, which may be attributed largely to the effect of terrain roughness. It therefore is desirable to develop a correction value which may be applied to the smooth-earth figures to take into account the additional loss due to terrain roughness.

For points within the radio horizon the quantity $4\pi \Delta h \sin \psi / \lambda$, designated here as Rayleigh's criterion of roughness, offers a convenient measure of the effect of terrain departure from a smooth spherical earth.[3] It evaluates terrain roughness in terms of actual departure of height in relation to the wavelength of the signal to be transmitted, and the grazing angle, and is a measure of the phase shift the waves undergo on reflection from rough terrain instead of a smooth earth. Since the reflected energy comes from a much larger region of the ground, under rough terrain conditions, than the single Fresnel zone characteristic of a regular reflection, there may be either an increase or a decrease of the received field, depending upon the phase relation of the direct and the multiple components of the ground reflected wave.

In order to determine an empirical relationship between Rayleigh's criterion, and the expected deviations from the smooth earth field, a program for additional measurements within the radio horizon has been started. Short period measurements are being made on a number of points about 30 miles from the transmitter, and extending in an arc about 45 degrees to the north and to the south of the center line of the antenna beam. Measurements on 1046 Mc at these additional points are not yet available; however, a sufficient amount of data on 92, 100 and 192.8 Mc have been evaluated, and the available Kendrick and Karval results on 1046 Mc compared to them in the following way.

For each point the field expected on the various frequencies was computed using the same method as was outlined above for Kendrick and Karval. The value of Rayleigh's criterion for each condition was computed and compared with the deviation of the measured from the computed field. The value of Δ h used in Rayleigh's criterion is the root-mean-square deviation of the terrain from the second degree curve. In addition to the 30-mile points, computed and measured fields on 100, 192.8 and 1046 Mc at Kendrick and Karval were treated in the same way.

Fig. 14b shows a graph of the field deviations obtained in the above manner versus Rayleigh's criterion using all available measurements within the radio horizon. In this graph the deviations are shown taking into account their sign, namely positive values for measured fields higher than the computed fields, and negative values for measured fields lower than the computed fields. In Fig. 14c the deviations have been plotted on log-log graph paper versus Rayleigh's criterion, but in this case regardless of their sign. An empirical straight-line least-square fit was then computed to determine a linear relation between Rayleigh's criterion and the expected deviation of the measured from the computed field.

It is seen from inspection of Figs. 14b and c that the two points denoting 1046-Mc measurement fit well within the general trend of the data. The straight-line fit on Fig. 14c indicates that Rayleigh's criterion has to be less than 0.007 in order to keep the deviations less than 1 db, and less than 0.0001 in order to keep the deviations below 0.2 db. Such low magnitudes of Rayleigh's criterion imply the necessity for extremely smooth terrain (especially at higher frequencies such as 1046 Mc), together with low grazing angles in order to obtain agreement between measured fields and the values computed by the use of a smooth earth theory. Since these required values of smoothness are based on an extrapolation of empirical data by means of an empirical formula, they are of questionable validity. However, it does appear from an examination of the data on Figure 14c, that an accuracy of the order of 1 db required a value of Rayleigh's criterion at least as small as 0.1, a value much smaller than had heretofore been considered necessary.

6. RADIO WAVE SCATTERING AT 1000 MC

As a result of the availability of a system with a large margin of detectability even at large ranges (due to the use of narrow bandwidths and high transmitter power), it has been possible to investigate the field received on 1046 Mc at very large distances. Thus measurable fields have always been available at Anthony, Kansas, a distance of 393.5 miles, and were even available for a few hours (see Fig. 5e) at Fayetteville, Arkansas, a distance of 617.7 miles. These fields are many orders of magnitude stronger than would be estimated from the theory of propagation over a smooth earth in a standard atmosphere (e.g. 412 db above that level at Anthony, Kansas) and were tentatively explained in our preliminary report 1/ in terms of a theory of partial reflection. As a result of further measurements and theoretical investigation, we now believe that the Booker-Gordon theory 5/ of scattering, as elaborated by Staras 6/, provides the correct explanation of these intense fields. Some of the analysis leading to this conclusion is given in the paper, "Radio Wave Scattering in Tropospheric Propagation" by J. W. Herbstreit, K. A. Norton, P. L. Rice and G. E. Schafer 7/.

It is important to emphasize that these scattered signals are of importance not only at large distances beyond the horizon where they constitute the dominant component of the received field but are also important at all shorter distances since they combine with the diffracted field at points near the radio horizon and with the space wave field at points within the radio horizon to cause the rapid fading of the received field. A recent paper by Gordon 8/ attempts an extension of the scattering theory to points within the radio horizon.

The reduced fading range at the shorter distances (i.e. for negative and small positive values of θ) shown on Figs. 12a and b, may undoubtedly be explained in terms of the combination of a small scattered Rayleigh-distributed component plus a relatively constant diffracted component. The magnitude of this scattered random component in relation to the constant component of the received field may be estimated by means of the theoretical relation shown on Fig. 15a, in connection with our measured values of the within-the-hour fading range, Figs. 12 a, b, c, d, e. This theoretical relation was derived from results in two papers by Norton 9/10/.

In addition to a knowledge of the magnitude of this scattered component, which may be obtained from our present results in the manner described above, we need to know the expected distortion of signals which is likely to arise from the resulting fading.

The progress so far made on this latter problem will be described below. Although much further work is required, we now have estimated values for the parameters involved and are in a position to make useful engineering estimates of the restriction in effective intelligence bearing bandwidths resulting from the presence of this scattered component.

Fig. 15b shows the results of measurements of the correlation of Cheyenne Mountain transmissions as received on spaced antennas at Garden City, Kansas. The measurements on 1046 Mc were quite complete, being made not only normal to the great circle plane but also vertically and along the path in the great circle plane.

The significance of these measurements in terms of antenna design is more or less obvious at least in a qualitative way. In order to realize full gain from a receiving antenna, it is necessary that the phase of the received signals be coherent over its entire aperture. Thus we see that the apertures of broadside arrays will be limited to only a few square wavelengths whereas the Yagi or rhombic types of array may be many wavelengths long without a substantial loss in effective gain. It should be noted that an increase in antenna aperture will, in any case, always result in some increase in gain since more power will be absorbed, but this gain will be less than that expected in free space for large aperture arrays because of the incoherence of the received fields over the large apertures. This same conclusion was reached in the scattering paper[7/] referred to above, and a method was given there for calculating the loss in gain to be expected for a given size of antenna array. Using that method of calculation, the expected total loss in antenna gain has been determined and is shown as a function of the free space gains of the transmitting and receiving antennas and the angular distance, θ, on Fig. 15c.

Before discussing the correlation measurements further it will be instructive to consider the question of antenna height-gain in the scattering region. Fig. 15d gives some measurements of height-gain together with the theoretical curves obtained by the method outlined in our scattering paper.[7/] A portion of this height-gain may be explained simply by noting that the higher receiving antennas can "see" a lower portion of the atmosphere where the scattering parameter $[C(0)/\ell]$ has a larger value; however, some of the height-gain may be explained by the usual mechanism for explaining height-gain when dealing with completely coherent waves, i.e., that the fields received after ground reflection are nearly out of phase with the fields received directly from the scattering medium. The following approximate theoretical discussion of this latter height-gain effect will help in understanding the mechanism involved and will indicate as well the role that correlation plays in the phenomenon.

Let E_d and E_r represent the instantaneous magnitudes of the incident and ground-reflected components of the fields received from the scattering medium. The first approximation will be the assumption that the scattered field may be assumed to arrive at the receiving location from the single elevation angle, ψ_r'', corresponding to the center of gravity of the scattering medium. The resultant field at the receiving antenna may then be approximated by the expression:

$$E = E_d \exp\left[-j\, 2\pi \frac{h_r}{\lambda} \sin \psi_r''\right] - E_r \exp\left[+j\, 2\pi \frac{h_r}{\lambda} \sin \psi_r''\right]$$

$$= (E_d - E_r) \cos \left[2\pi \frac{h_r}{\lambda} \sin \psi_r''\right] - j(E_d + E_r)\sin\left[2\pi \frac{h_r}{\lambda} \sin\psi_r''\right]$$

The negative sign associated with E_r arises from the 180° phase reversal characteristic of waves received near grazing incidence after reflection from the ground. The instantaneous received power is thus proportional to:-

$$P \sim E \cdot E^* = (E_d - E_r)^2 \cos^2\left[2\pi \frac{h_r}{\lambda} \sin \psi_r''\right]$$

$$+ (E_d + E_r)^2 \sin^2 \left[2\pi \frac{h_r}{\lambda} \sin \psi_r''\right]$$

In the above E^* denotes the conjugate complex value of E. In determining the average power from the above, it should be remembered that the mean value $\overline{E}_r^2$ is equal to $\overline{E}_d^2$ and that the average of $E_d \cdot E_r$ is simply $\rho \cdot \overline{E}_d^2$ where ρ is the correlation coefficient between the direct and ground-reflected wave fields.

Thus we obtain for the mean received power:-

$$\bar{P} \sim 2\overline{E}_d^2 \left[1 - \rho \left\{\cos^2\left[2\pi \frac{h_r}{\lambda} \sin \psi_r''\right] - \sin^2\left[2\pi \frac{h_r}{\lambda} \sin \psi_r''\right]\right\}\right]$$

In order to evaluate the above it is necessary to be able to estimate the value of ρ. An estimate of ρ may be obtained by measuring the correlation of the fields on two antennas, both of which are a large number of wavelengths above the earth, and spaced vertically by an amount $\Delta h = 2\, h_r$. Thus we may evidently use the results shown on Fig. 15b for 1046 Mc to estimate ρ.

Consider first the case $\left[(\Delta h/\lambda) < 1 \text{ at this distance} \right]$ where we see by Fig. 15b that the correlation ρ is approximately equal to unity. In this case the above reduces to:-

$$\bar{P} \sim 4\, \bar{E}_d^{\,2} \sin^2 \left[2\pi \frac{h_r}{\lambda} \sin \psi_r' \right] \qquad (\rho = 1)$$

and we see that the received power will increase (since $2\pi \frac{h_r}{\lambda} \sin \psi_r'$ is small) as the square of the height in wavelengths.

Next consider the case $\left[(\Delta h/\lambda) > 10 \text{ at this distance} \right]$ where the correlation ρ is approximately zero. In this case:-

$$\bar{P} \sim 2\, \bar{E}_d^{\,2}$$

and there is no further height gain due to this phase interference phenomenon, the effect of the ground merely doubling the available scattered power at the receiving antenna.

If we set $\Delta h = 2h_r$ in the above we see that phase interference would be expected to play no further part in the height-gain phenomenon when $(h_r/\lambda) > 5$ at this receiving location. Reference to the measurements shown on Fig. 15d indicates that this result is roughly substantiated by the data. The height-gain above that height increases at a slower rate and is largely due to the fact that the higher antennas "see" lower portions of the atmosphere. Better agreement would scarecely be expected in view of the very approximate nature of the above theoretical derivation. The theoretical height-gain curves compared on Fig. 15d with the data were derived from the more accurate methods of the scattering paper 7/ and appear to be in fair agreement with the data when consideration is given to the short periods of time involved in these measurements.

One additional qualification to be placed on the experimental height-gain measurements of Fig. 15d needs to be mentioned. Since the two antennas used for the measurements were mounted on the same vertical mast, they may have interacted to some extent when they were near the same height. This is particularly evident on the 100 Mc data as would be expected since the separation expressed in wavelengths for a given vertical spacing is less at this frequency. This effect probably influenced the 1046 Mc data to a more limited extent although there appears to be some evidence of such an effect when (h_r/λ) is near 50.

We turn now to the problem of calculating the correlation coefficient of the fields received on spaced antennas and of the fields received on the same antenna on spaced radio frequencies. The latter problem has a direct bearing on the intelligence bearing capacity of the transmission medium. Thus, for example, we would expect distortion of a 5 kc voice communication if the correlation coefficient for frequencies spaced by 5 kc were near zero. Actually we will find that the transmission medium is expected to be capable of supporting undistorted transmissions over bands of the order of 100 kc in width even at the distance of 226 miles, where our spaced receiver correlation studies were made, and over still wider bands at shorter distances.

We have been able to obtain accurate formal expressions for the correlation coefficient as a function of antenna spacing but have not been able to evaluate the resulting integral expressions in closed form. We are now in the process of evaluating these integrals by numerical methods. In the meantime, although we recognize that the assumed model does not fit the physical situation very well, we have been using the results obtained by Rice[11] for evaluating ρ. Rice assumed that the magnitude of the contributions to the scattered field were normally distributed in all three dimensions with respect to a mean value at the center of gravity. If we let $(Z/\lambda)_\rho$ denote the separation normal to the path at which the correlation coefficient of the fields for antennas spaced by this distance is ρ, then we may use Rice's equations (5) and (9) to determine the frequency separation Δf (in cycles per second) for which the received fields will have this same correlation coefficient ρ:-

$$\Delta f = (Z/\lambda)_\rho \, C/r \, 2 \sin (\psi''_r /2)$$

In the above C is the velocity of light, r the distance and ψ''_r the angular elevation in radians of the center of gravity of the scattering volume from the receiving location. If we neglect the variation of $[C(0)/\mathcal{L}]$ with height, it may be shown that $\psi''_r = \theta$ where θ is defined in Fig. 2e; if the variations of $[C(0)/\mathcal{L}]$ are allowed for, then $\psi''_r < \theta$. Consequently if we use θ as an estimate of ψ''_r we will underestimate Δf. For the Garden City path $\theta = 0.027$ radians, $r \cong 100$ miles and we obtain:-

$$\Delta f > (Z/\lambda)_\rho \frac{186000}{100 \cdot 0.027} = 69{,}500 \, (Z/\lambda)_\rho$$

If we take $(Z/\lambda)_\rho = 1.5$ corresponding to $\rho \cong 1$ as may be seen on Fig. 15b we find that $\Delta f > 100$ kc. This effective bandwidth may be expected to increase rapidly with decreasing distance since $(Z/\lambda)_\rho$ will increase while θ will decrease.

It should be noted that the above is based on a very approximate theoretical analysis of this problem, and it should be verified by further theoretical work as outlined above and also experimentally.

7. LARGE REDUCTIONS OF TRANSMISSION LOSS AND FADING BY THE PRESENCE OF A MOUNTAIN OBSTACLE IN BEYOND-LINE-OF-SIGHT PATHS*

Very successful VHF communications have been reported with essentially no fading over very long paths across mountainous terrain. A detailed examination of these reports has just been completed by Frederic H. Dickson, Office of the Chief Signal Officer; John J. Egli, Signal Corps Engineering Laboratories; Jack W. Herbstreit, National Bureau of Standards; and Gilbert S. Wickizer, RCA Laboratories. This group visited engineers and scientists of the Mutual Telephone Company of Hawaii; the Electrical Communication Laboratory, Ministry of Communications, Tokyo, Japan (similar to the Bell Telephone Laboratories in the U.S.A.); the Radio Research Laboratories, Ministry of Postal Services, Tokyo, Japan (similar to CRPL in U.S.A.); and the Civil Aeronautics Administration in Alaska.

In a preliminary study prepared in the Office of the Chief Signal Officer, Lt. Col. H. V. Cottony, USAR, on military leave of absence from the National Bureau of Standards, pointed out that a considerable increase in received field strength would result when a large knife-edge obstacle is located at the mid-point of an 85-Mc 100-mile path. Japanese scientists have made similar theoretical investigations and have substantiated their findings by experiments.[12]

Figs. 16a and b show the results of using the four-ray method of Schelleng, Burrows and Ferrell[13] for computing diffraction across a knife edge at radio frequencies. These figures show the expected basic transmission loss[14] at 100 and 1000 Mc over transmission path distances of 50 and 150 miles. The basic transmission loss is defined to be the ratio, expressed in decibels, between the power delivered to an isotropic transmitting antenna divided by the received signal power available from an isotropic receiving antenna. The actual transmission loss on a circuit may thus be obtained simply by subtracting the effective transmitting and receiving antenna gains, expressed in decibels relative to an isotropic antenna, from the basic transmission loss shown on Figs. 16a and b. On 1000 Mc it was not convenient to show in detail how the transmission loss varied with obstacle height because of the resultant large number of maxima and minima. However, the position of the maxima and the average energy levels are indicated. The average energy level indicated on the graph refers to an average with respect to obstacle height. The calculated minima

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* A paper embodying some of the results of this section was read before the URSI-IRE meeting in Washington, April 1953.

on 1000 Mc were not as deep as those on 100 Mc; however, the deep minima calculated on 100 Mc are due to the symmetry assumed for the geometry and would not be expected to occur in practice. To simplify the calculations, the ground reflection coefficient for horizontal polarization has been assumed to be (-1), thus neglecting the small phase and amplitude changes expected for an actual earth as well as the divergence of the energy reflected from the curved earth's surface. With this approximation the height of the obstruction must be greater than the elevation of the common horizon to have an obstacle gain as the computed transmission loss is impotent at this point, e.g., 1850 feet for the 150-mile path. It may be seen from these figures that for particular combinations of antenna heights, obstacle heights, and frequency, tremendous "obstacle gains" in received field strength are to be expected. The "obstacle gain" is defined, as may be seen by reference to Figs. 16a and b, to be the ratio of the received signal power expected with and without the obstacle. Experimental evidence has been obtained of the existence of these very large predicted "obstacle gains" in field strength. These hitherto unexpected gains are being used in obtaining very satisfactory VHF radio communication over severely obstructed transmission paths in mountainous regions.

One of the examples of the use of "obstacle gain" examined in detail was for the 38-Mc 160-mile transmission circuit operated by the Civil Aeronautics Administration between Yakutat and Gustavous, Alaska. This path passes over the 8000-foot level of Mt. Fairweather from two low terminals (approximately 200 feet) at the transmitting and receiving locations. The profile of this path together with a typical sample signal strength recording made by the Civil Aeronautics Administration on this circuit is shown in Fig. 16c. On the basis of smooth earth diffraction theory with the mountain removed, the calculated transmission loss for this 38-Mc circuit would have been 207 db; however, on the assumption that Mt. Fairweather acts as a single 8775-foot knife-edge ridge, calculations using the four-ray diffraction theory indicate that only 127-db transmission loss would be expected. The observed transmission loss was approximately 134 db, within 7 db of the value indicated by the knife-edge diffraction calculations. These values correspond to a calculated "obstacle gain" of 80 db and a measured "obstacle gain" of 73 db greater than the field strength to be expected over a smooth spherical earth. Thus it appears that the mountain behaves effectively like a knife edge. Effective transmitting and receiving antenna heights of 50 feet and gains of 8 db over an isotropic antenna have been assumed in the above calculations together with an allowance of 4 db for transmission line losses.

Over a smooth spherical earth, signals arrive well below the radio horizon not only by the normal diffraction process around the curved surface of the earth, but by scattering from the turbulent atmosphere. This turbulence is greatest near the surface of the earth. It is the turbulence of the higher atmosphere which is within line-of-sight of both transmitting and receiving antennas that is considered[7] responsible for the relatively weak, scattered, fading signal normally observed at distances beyond the horizon. An estimate of the scattered signal basic transmission loss exceeded for 1 percent and 50 percent of the time for a distance of 150 miles at 100 Mc over a smooth spherical earth is also shown on Fig. 16a; this estimate was obtained by extrapolating the NBS Cheyenne Mountain data[7] so as to correspond to the 100-foot transmitting and receiving antenna heights of this example. It may be noted that the calculated "obstacle gain" of the properly situated knife-edge ridge reduces the transmission loss to such an extent that the received signal strength will far exceed the signal received by way of the atmospheric scattering process and will thus effectively eliminate the fading arising from this scattering.

In addition, when an obstruction is situated at the proper location and extending well above the horizon of both the transmitting and receiving antennas, the radio transmissions travel through the most turbulent and disturbing region of the atmosphere close to the surface of the earth at a relatively large grazing angle. This large grazing angle reduces the possibility of the existence of numerous additional variable transmission paths from the highly turbulent lower portions of the atmosphere. In this way the principal cause of tropospheric fading is effectively eliminated. The absence of severe tropospheric fading on a long obstructed VHF transmission circuit is strikingly illustrated by the typical recording shown in Fig. 16c. Over a period of 30 days' recordings on this path, the instantaneous transmission loss was found to vary from its mean value by less than $\pm$ 2 db.

Detailed experimental evidence of the existence of the above described "obstacle gains" and reduction in fading has not as yet been obtained at 1000 Mc; however, the theoretical study illustrated in Fig. 16b indicates that even greater "obstacle gains" may result at 1000 Mc than have been observed at the lower frequencies. The same reasoning with regard to reduction in fading would also be expected to apply at 1000 Mc.

The possibility of the existence of these large "obstable gains" should be recognized in siting 1000-Mc systems in mountainous regions both from the standpoint of undesired interference that may result behind a large obstacle and, in the case of point-to-point communication, from the standpoint of providing a desired service over a large mountain ridge which would have been heretofore considered virtually impossible propagationwise.

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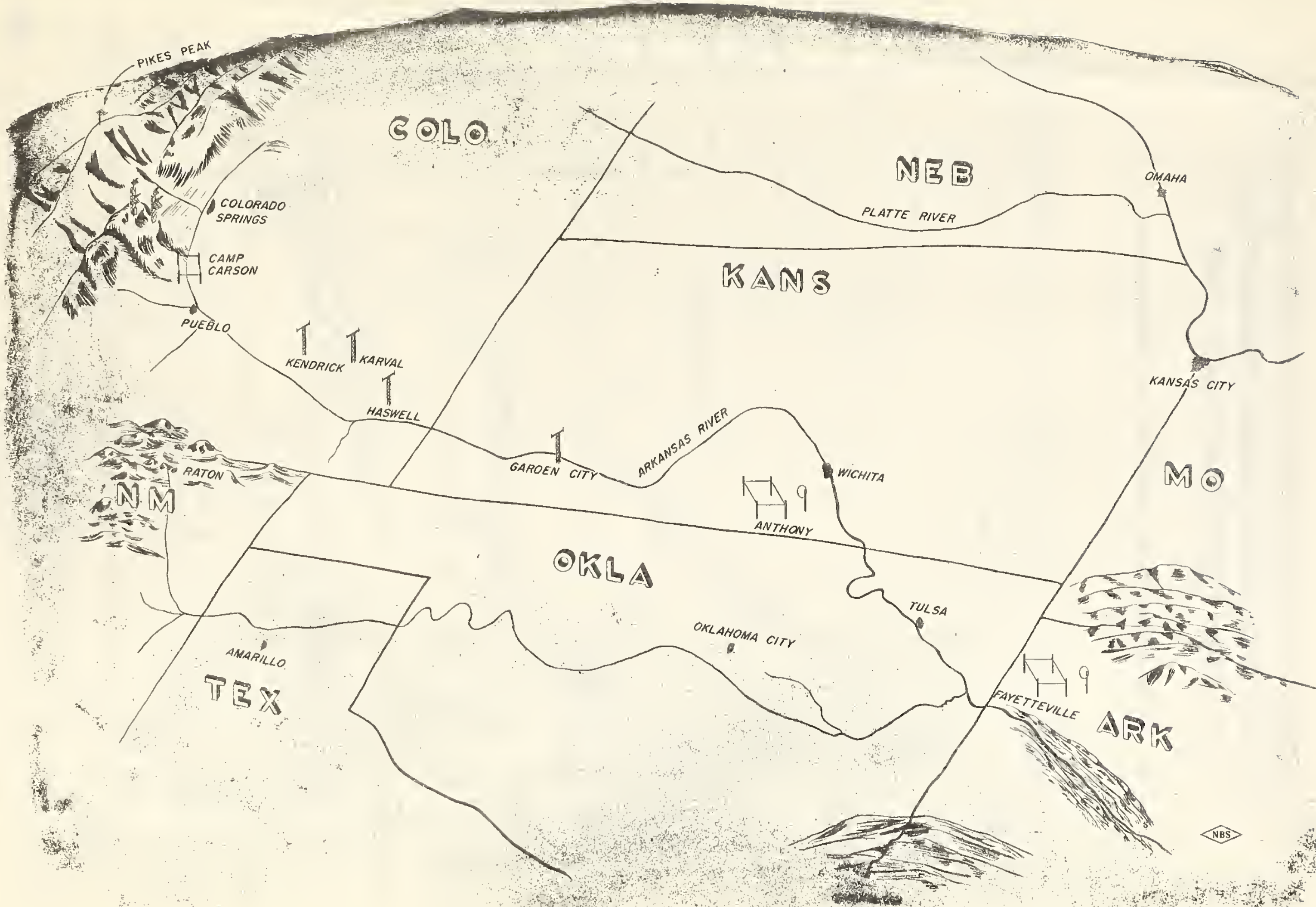

PIKES PEAK
COLO
NEB
OMAHA
PLATTE RIVER
COLORADO SPRINGS
CAMP CARSON
KANS
PUEBLO
KENDRICK
KARVAL
HASWELL
KANSAS CITY
ARKANSAS RIVER
GARDEN CITY
WICHITA
RATON
NM
MO
ANTHONY
OKLA
TULSA
OKLAHOMA CITY
AMARILLO
TEX
FAYETTEVILLE
ARK
NBS

FIG. I

GEOMETRY FOR SPACE WAVE CALCULATIONS FOR PATH BETWEEN SUMMIT TRANSMITTER SITE AND KENDRICK RECEIVING SITE

RAY PATHS SHOWN ARE FOR 1046 Mc TRANSMISSIONS

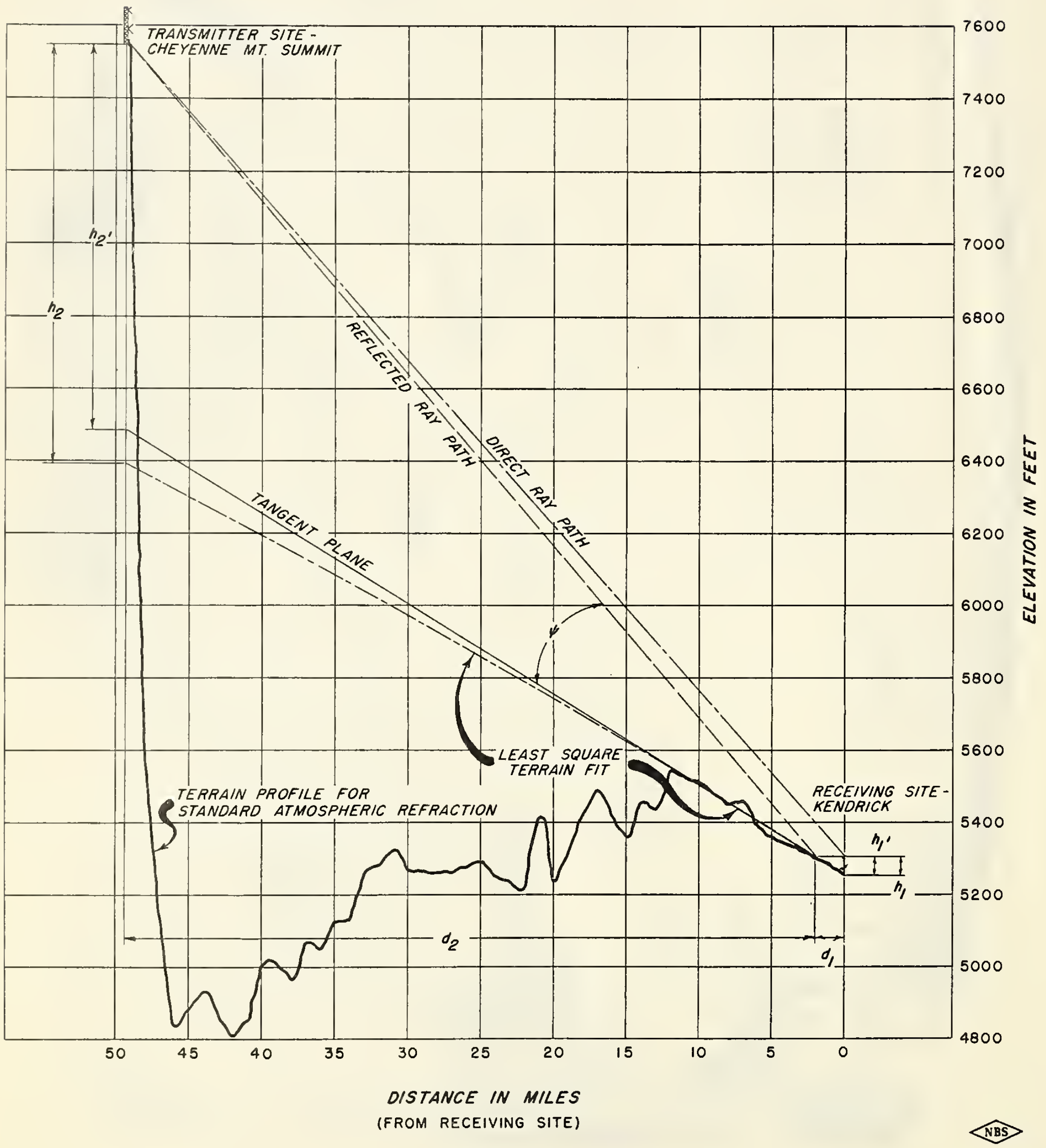


FIG. 2a

NBS

GEOMETRY FOR SPACE WAVE CALCULATIONS FOR PATH BETWEEN SUMMIT TRANSMITTER SITE AND KARVAL RECEIVING SITE

(RAY PATHS SHOWN ARE FOR 1046 Mc TRANSMISSIONS)

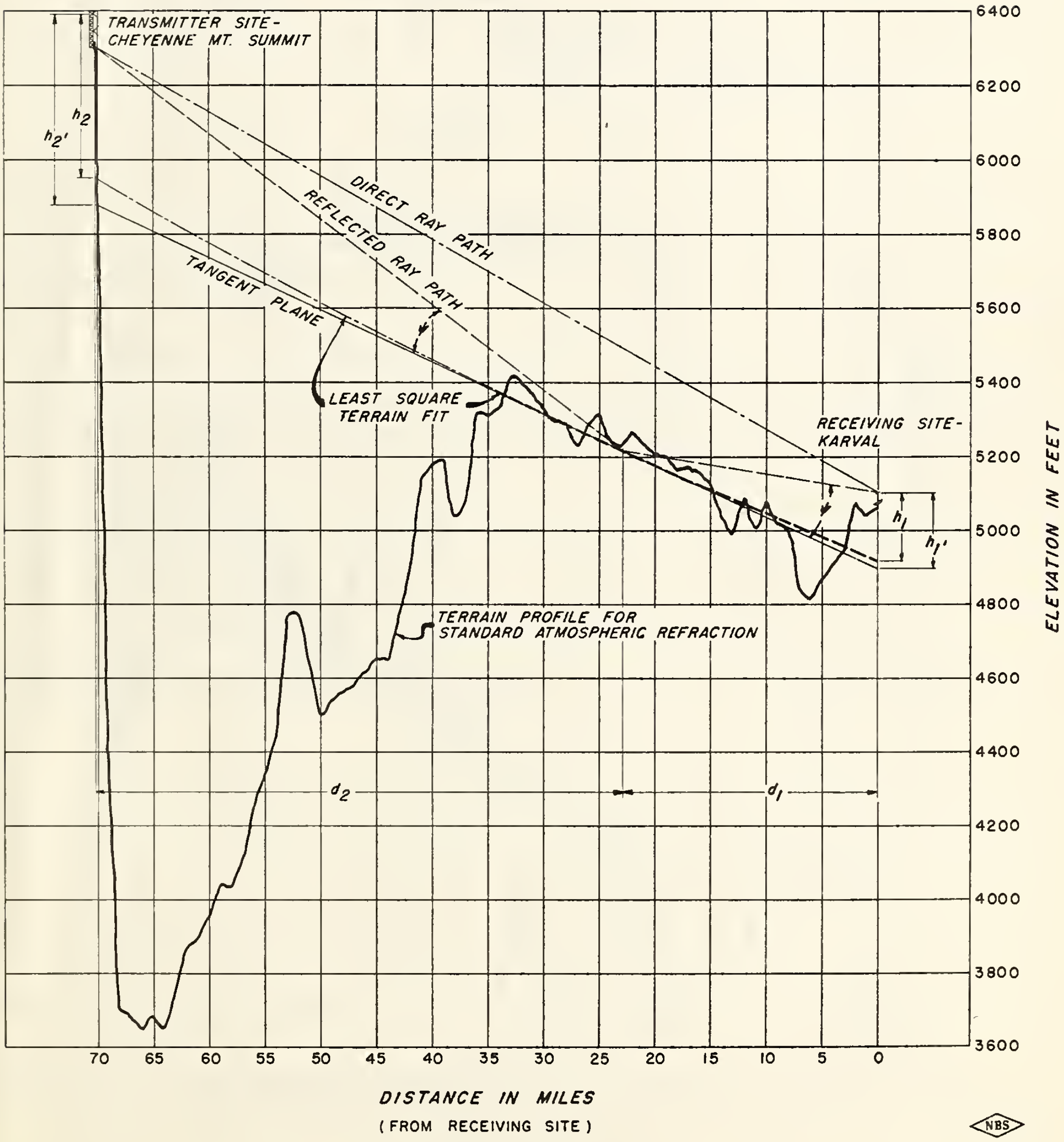


FIG. 2b

GEOMETRY FOR DIFFRACTION CALCULATIONS FOR PATH BETWEEN SUMMIT TRANSMITTER SITE AND HASWELL RECEIVING SITE

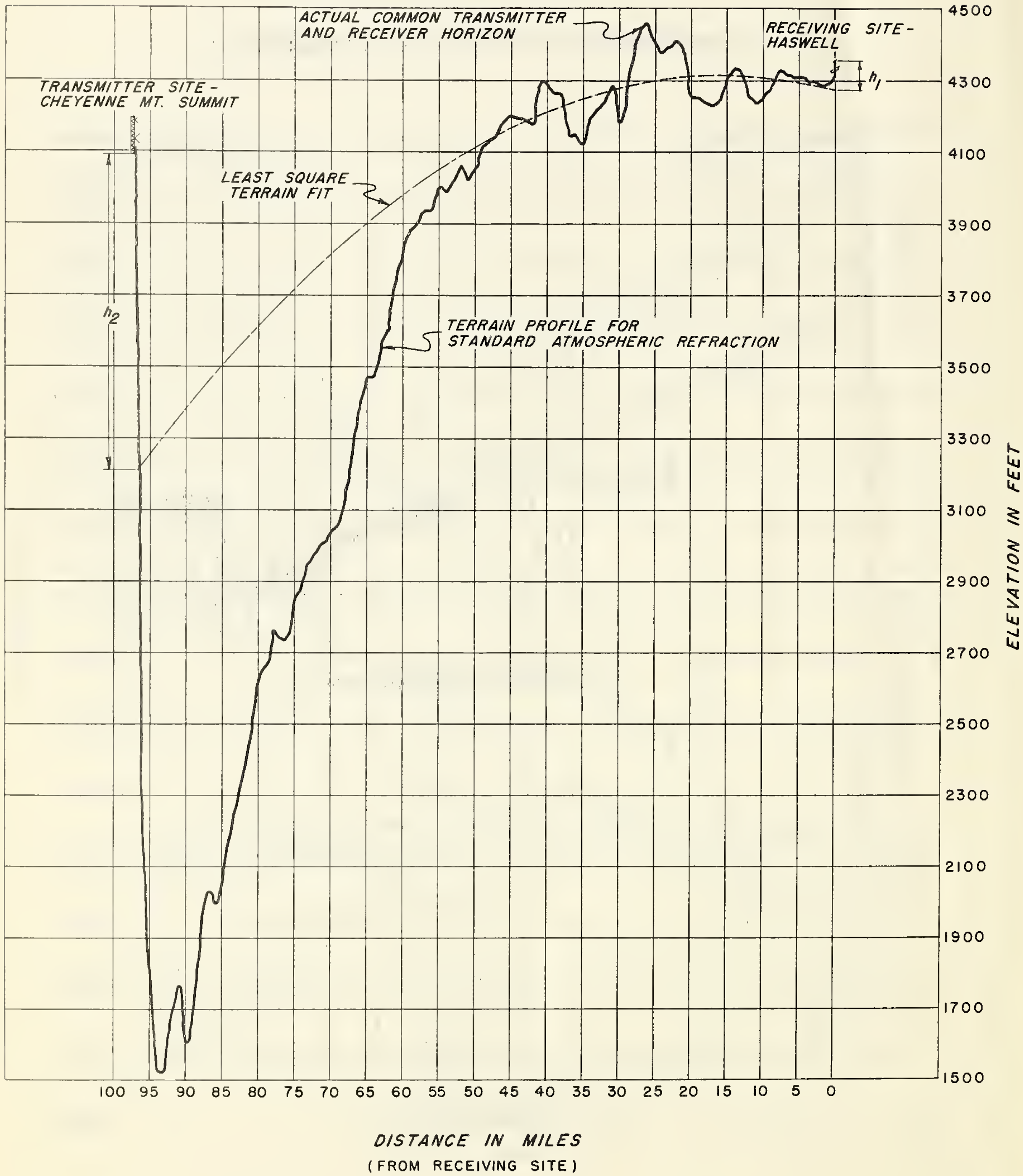


FIG. 2c

TERRAIN PROFILE OF COLORADO-KANSAS PATHS

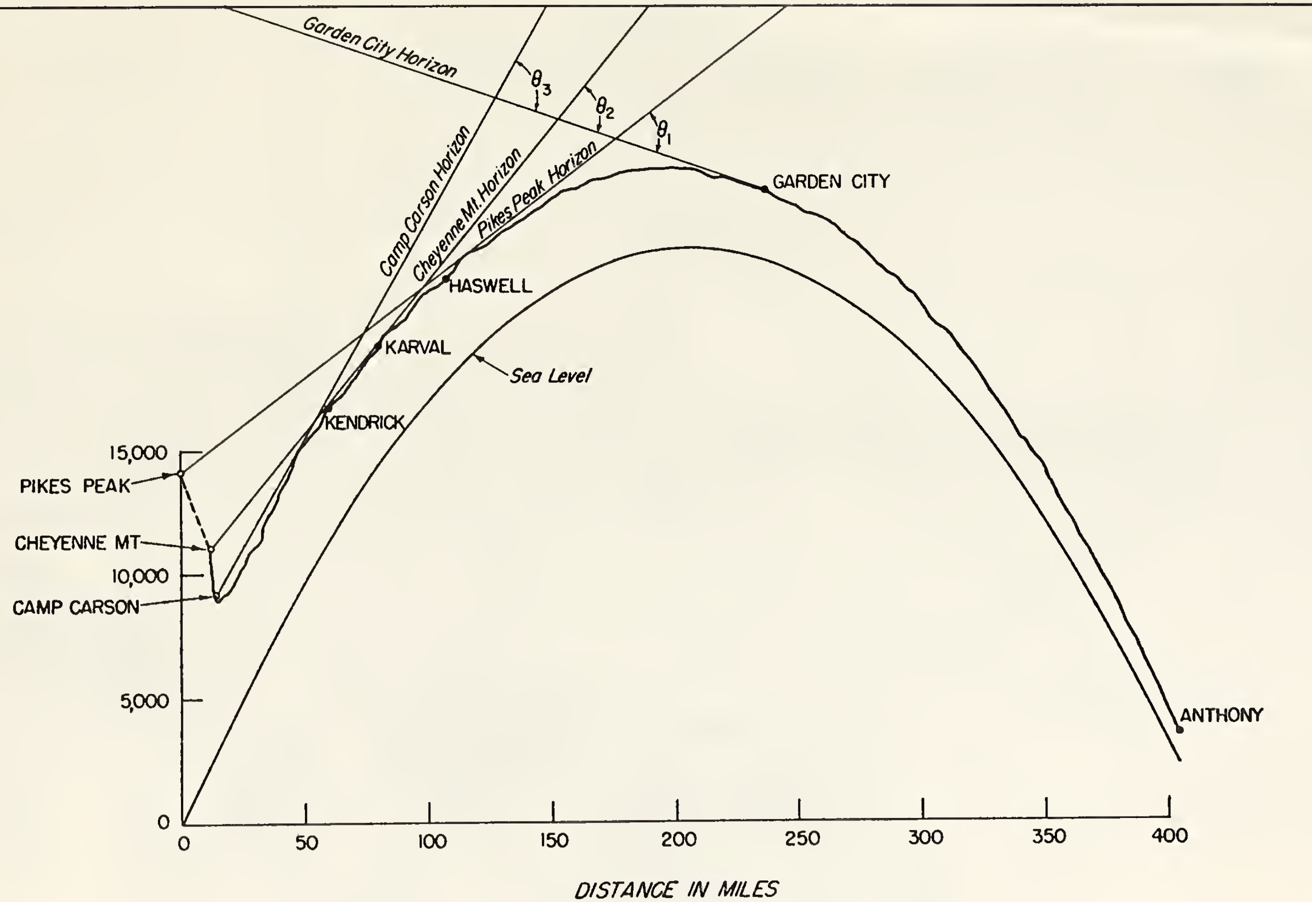


Figure 2d

THE PARAMETER θ IN TROPOSPHERIC WAVE PROPAGATION

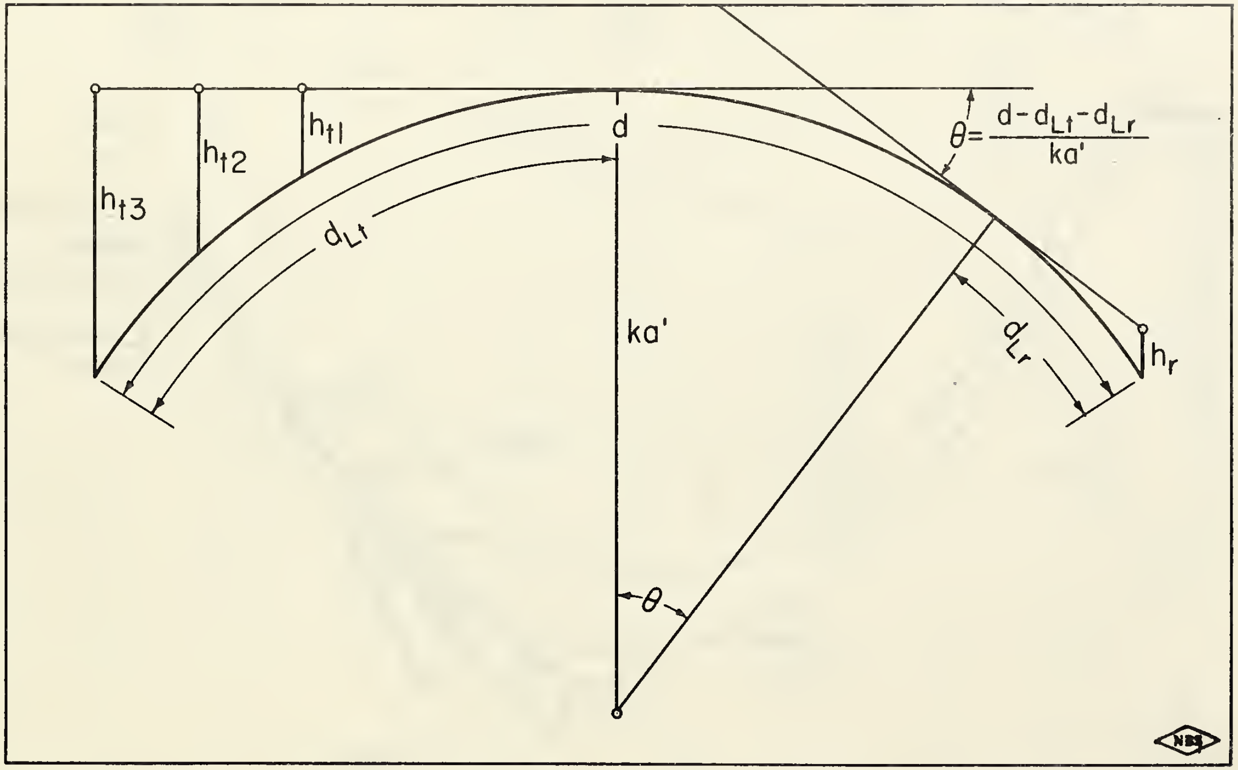


Figure 2e

FIG. 3a

FIG. 3b

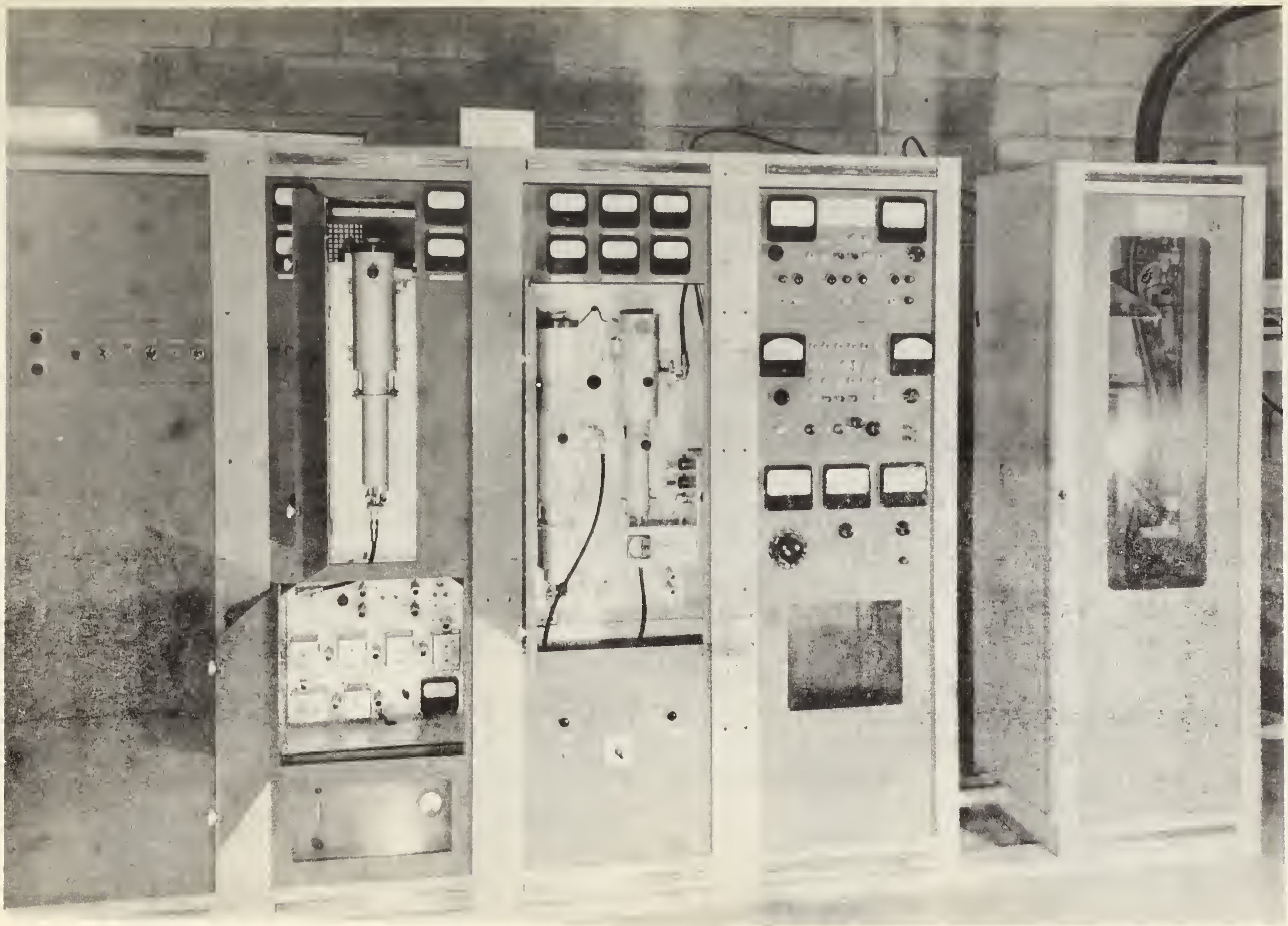


FIG. 3c

BLOCK DIAGRAM OF 5 KW 1046 MC TRANSMITTER

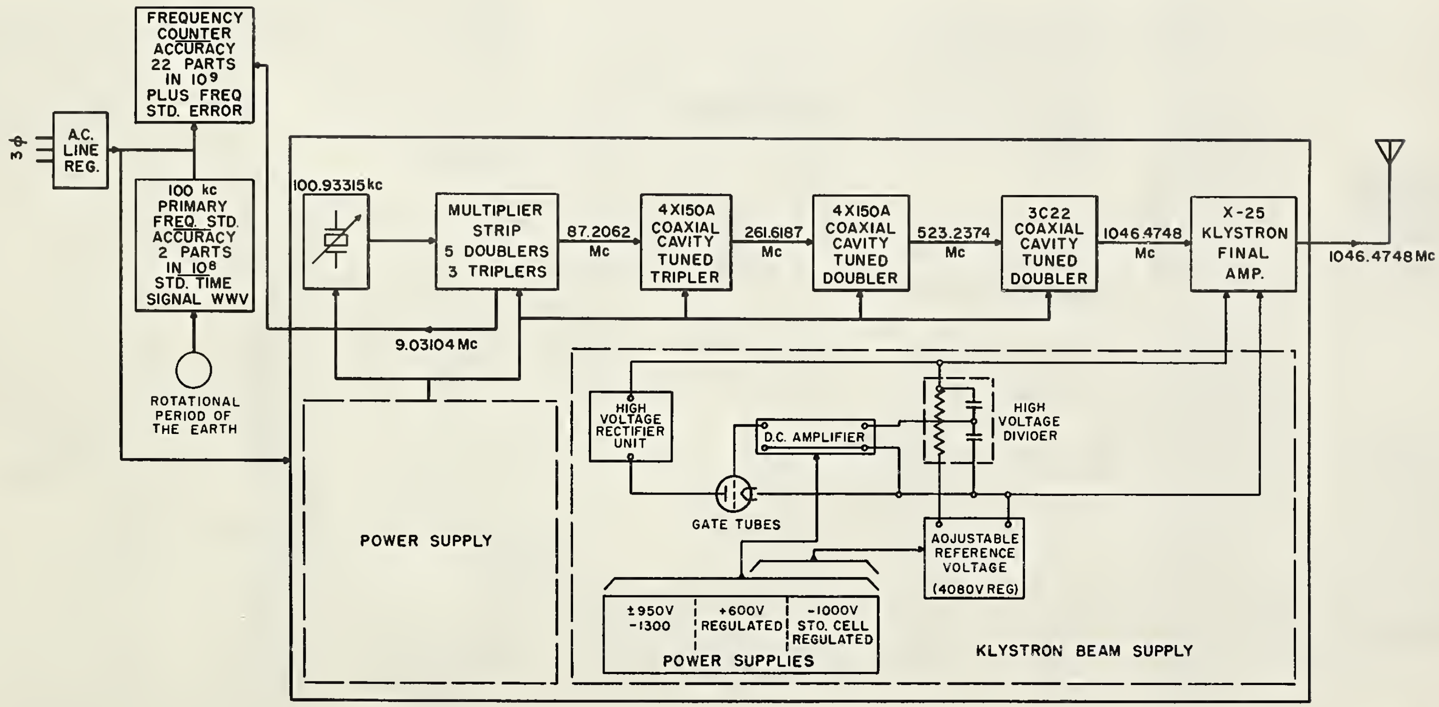


FIG. 3d

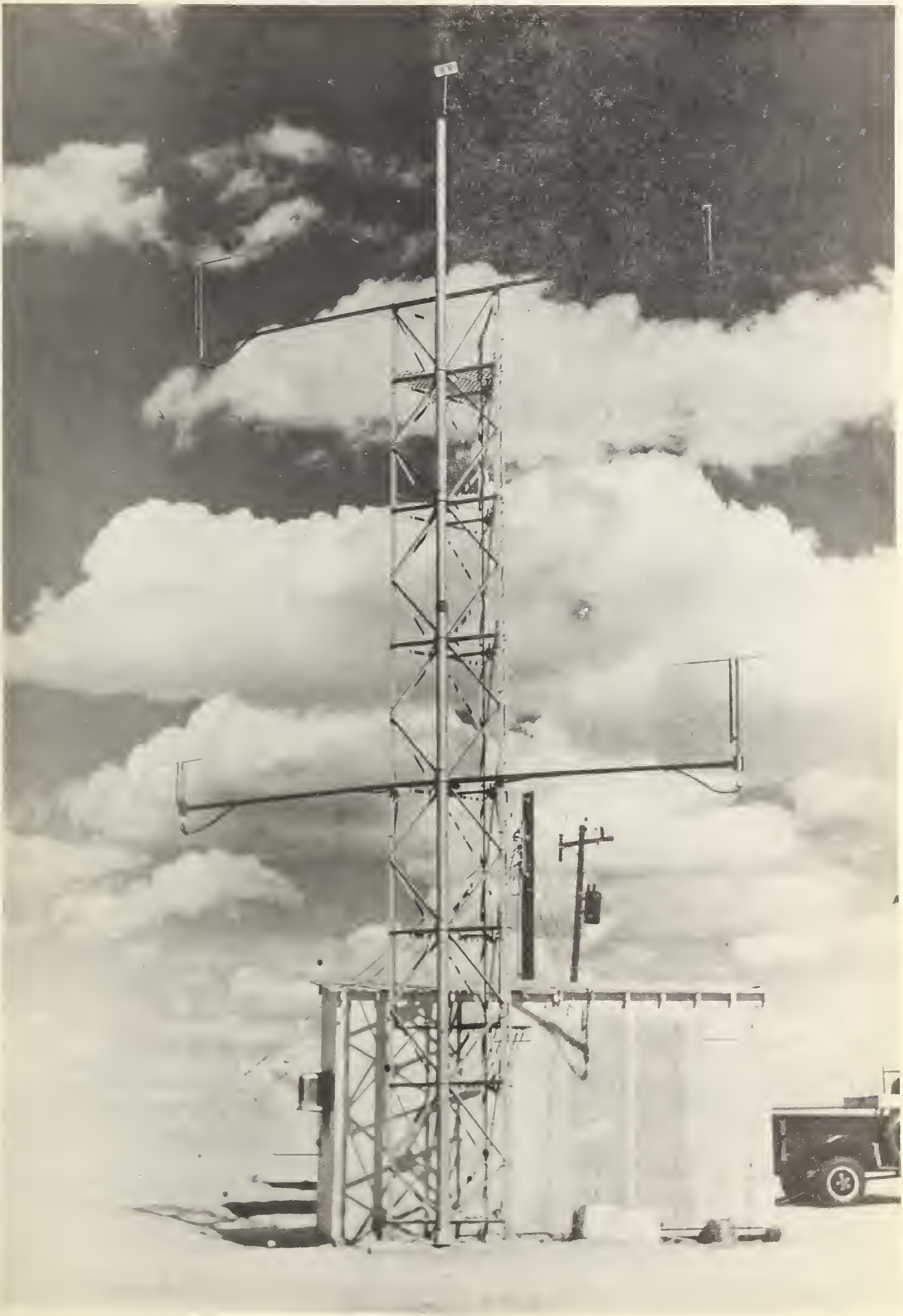


FIG. 4a

FIG. 4b

BLOCK DIAGRAM OF TYPICAL 1046 Mc RECORDING SITE

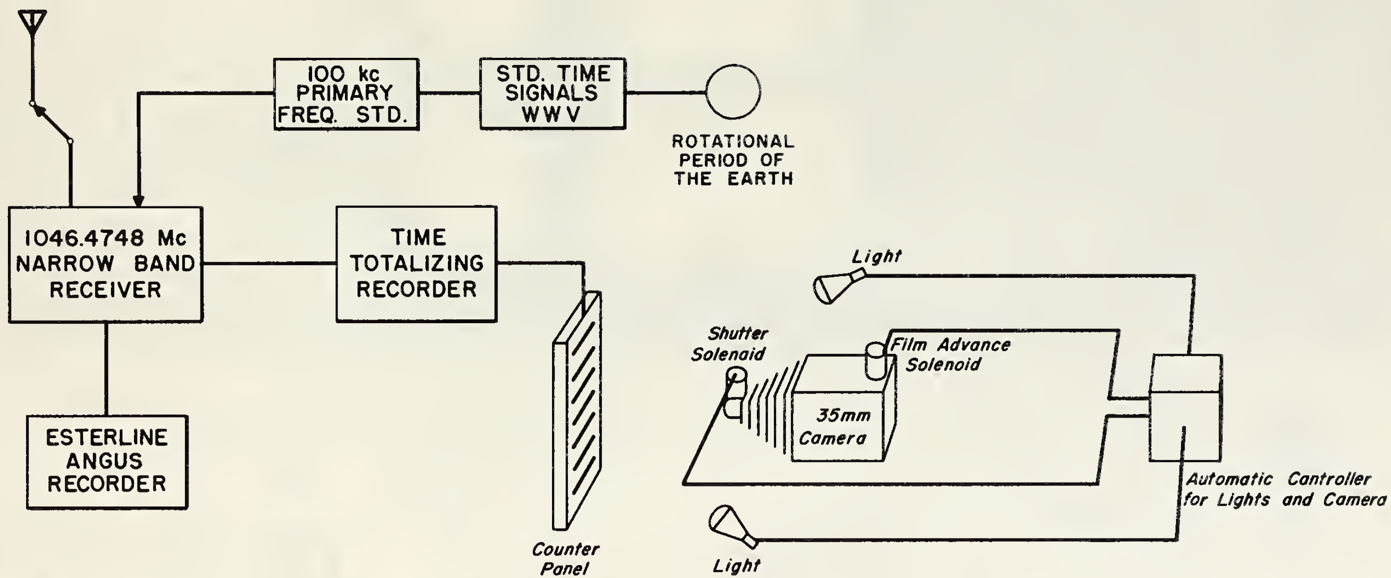


FIG. 4c

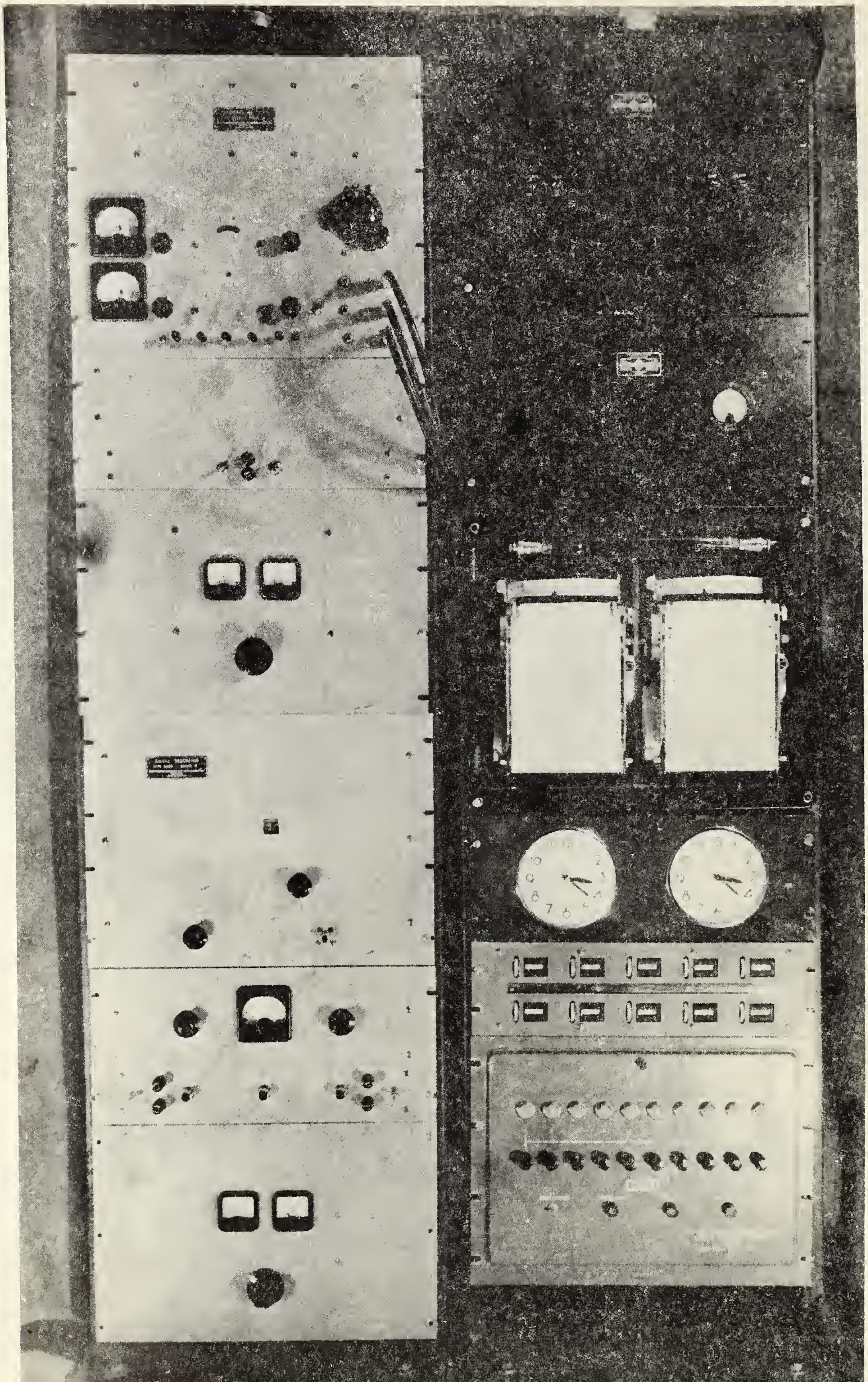


FIG. 4d

BLOCK DIAGRAM OF 1046.475 Mc NARROW BAND RECORDING RECEIVER PRD TYPE 856-X

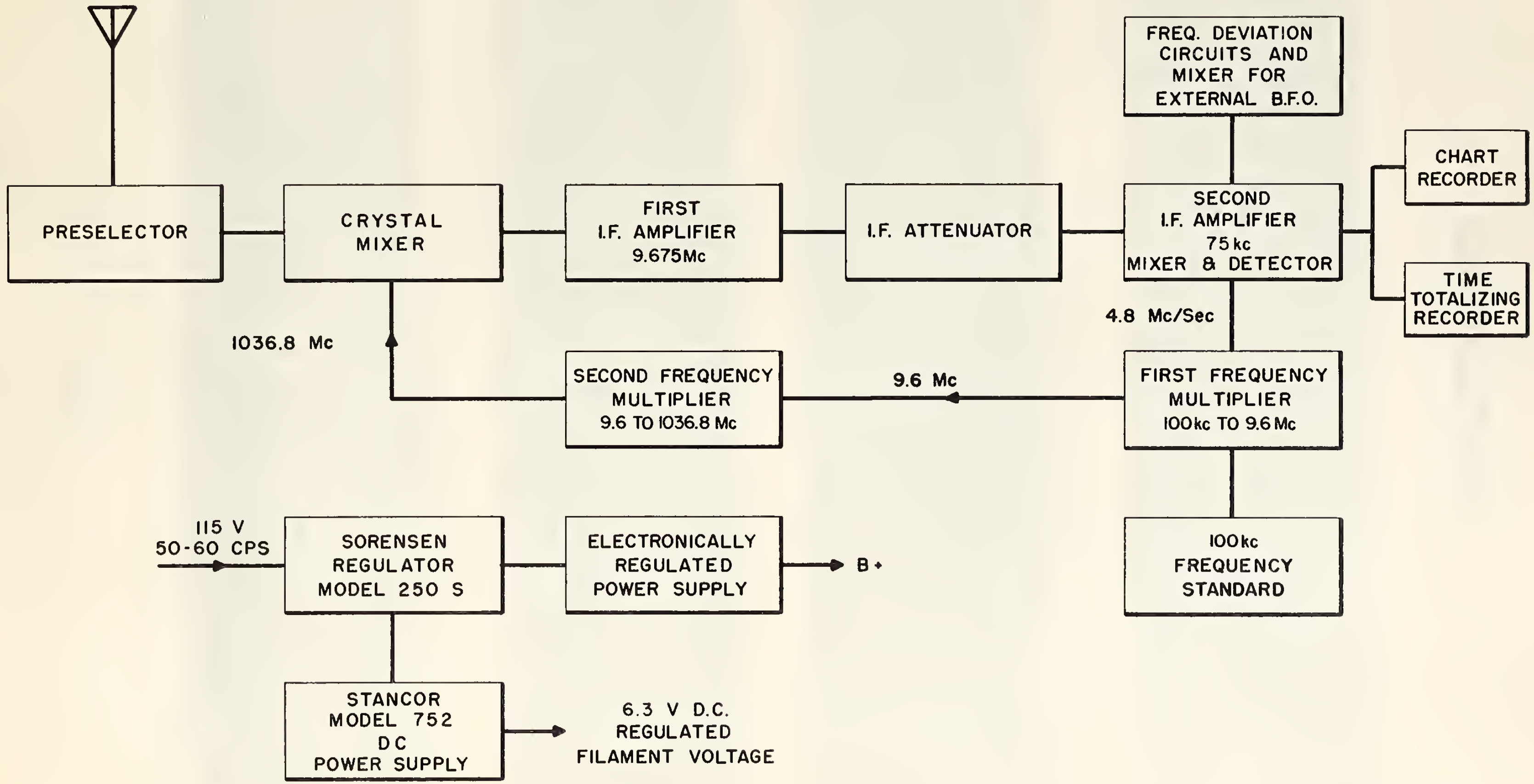


FIG. 4e

SAMPLE 1046 Mc RECORDINGS
MDNT - 6AM, FEBRUARY 23, 1952

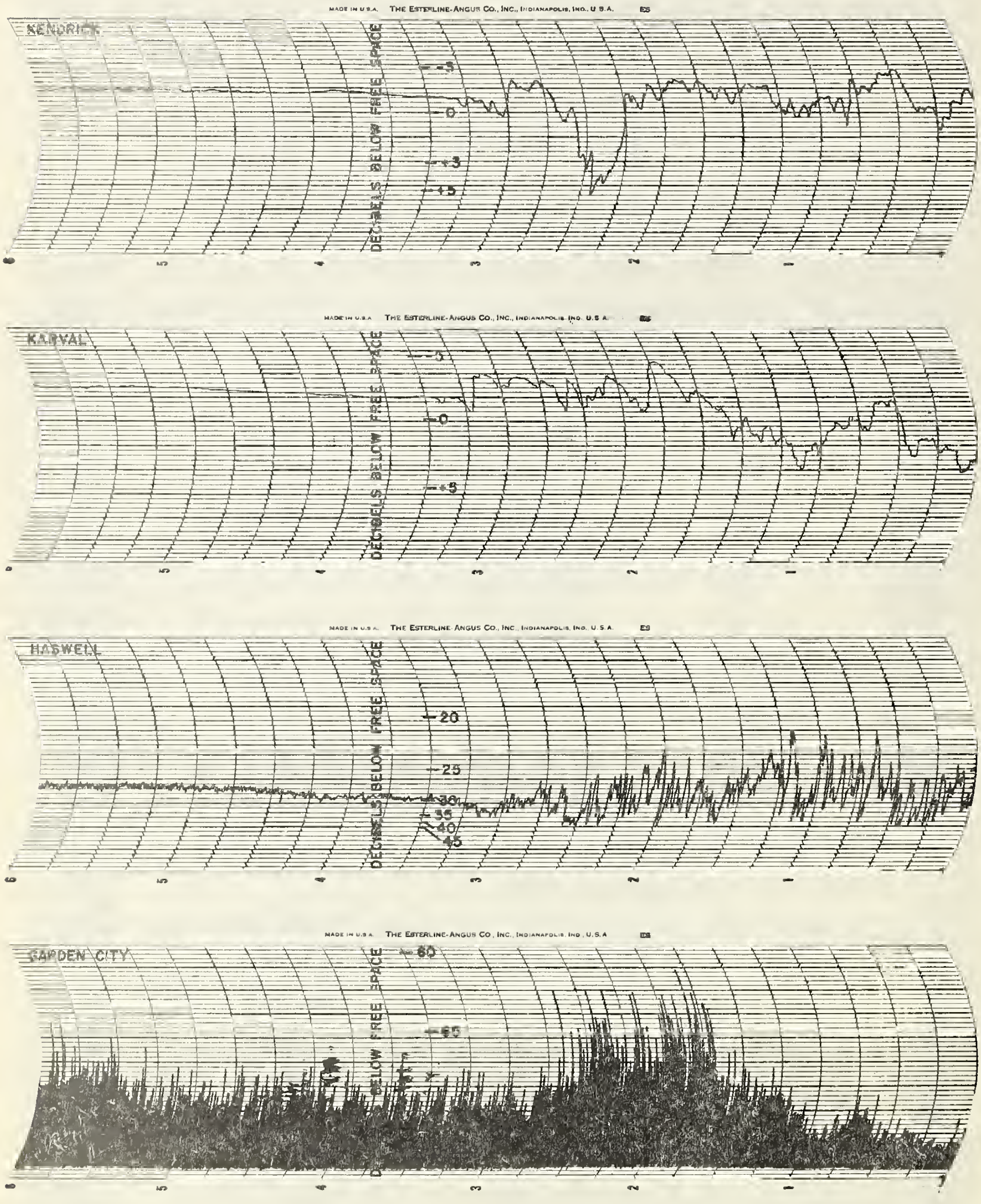


FIG. 5a

SAMPLE 1046 Mc RECORDINGS
NOON - 6PM, FEBRUARY 23, 1952

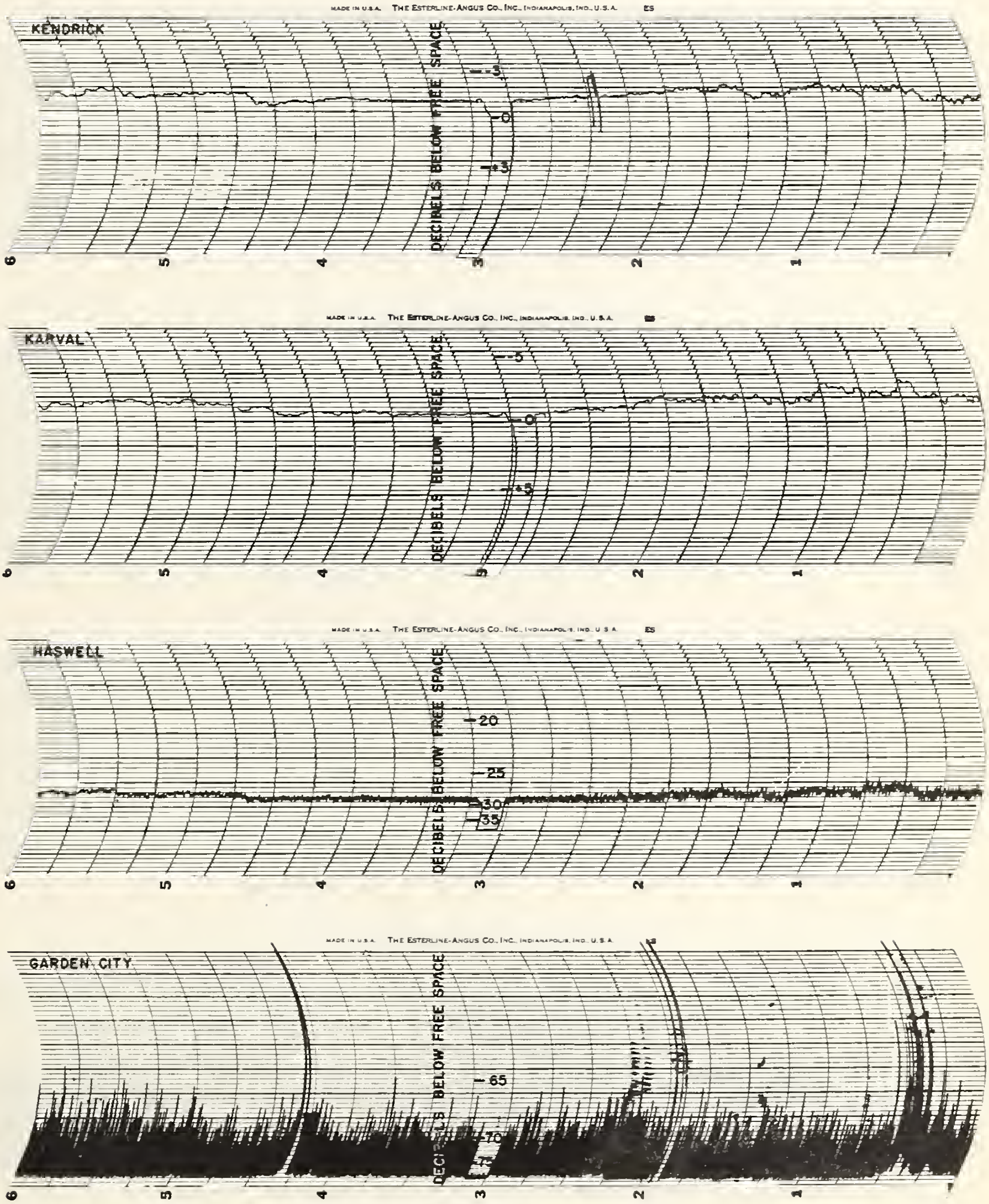


FIG. 5b

SAMPLE 1046 Mc RECORDINGS
MDNT - 6AM, JULY 9, 1952

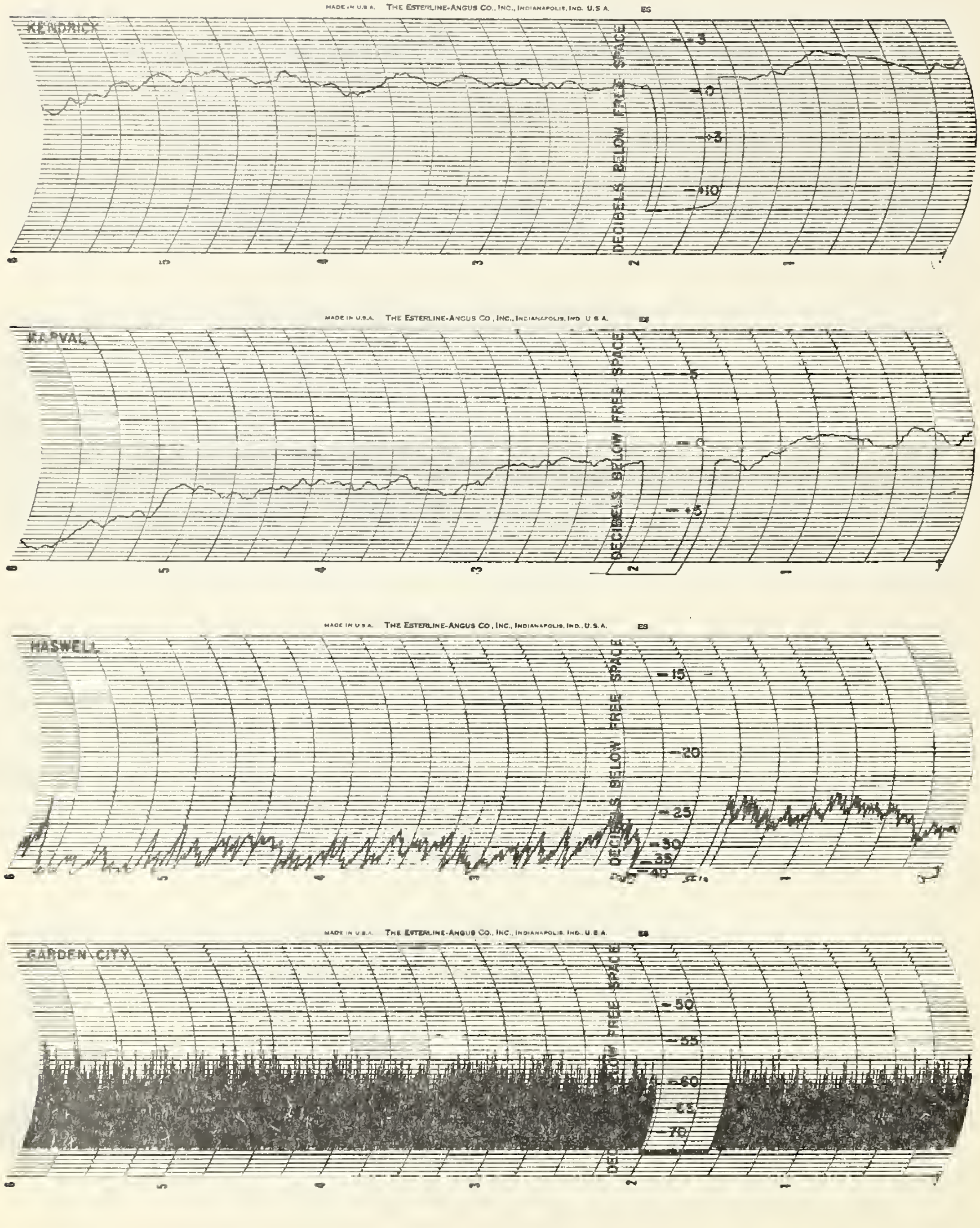


FIG. 5c

SAMPLE 1046 Mc RECORDINGS
NOON - 6PM, JULY 9, 1952

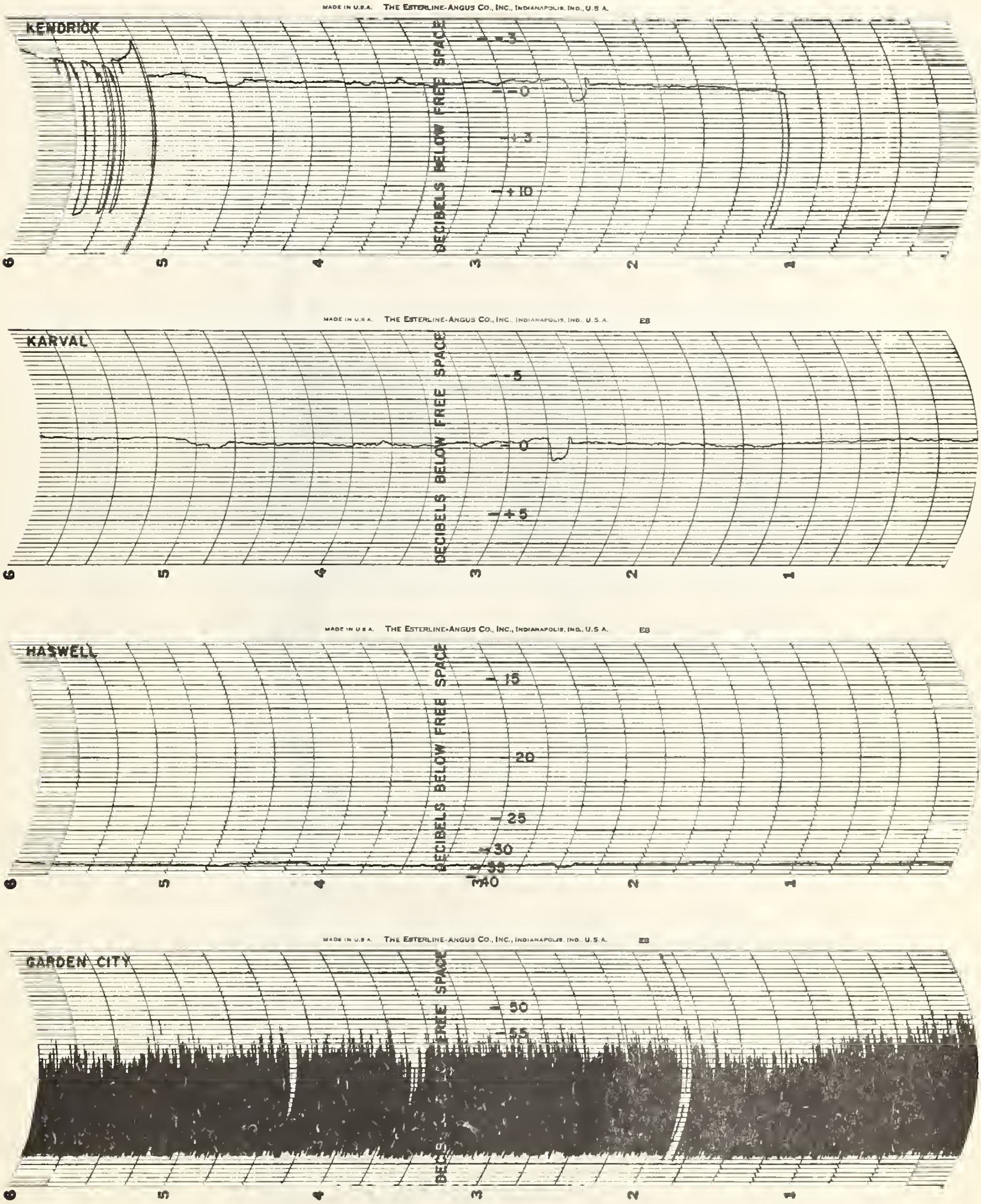


FIG. 5d

SAMPLE OF 1046 Mc RECORDING
FAYETTEVILLE, ARKANSAS

EXCEPTIONALLY HIGH FIELD 0230 TO 0500, AUG. 16, 1952

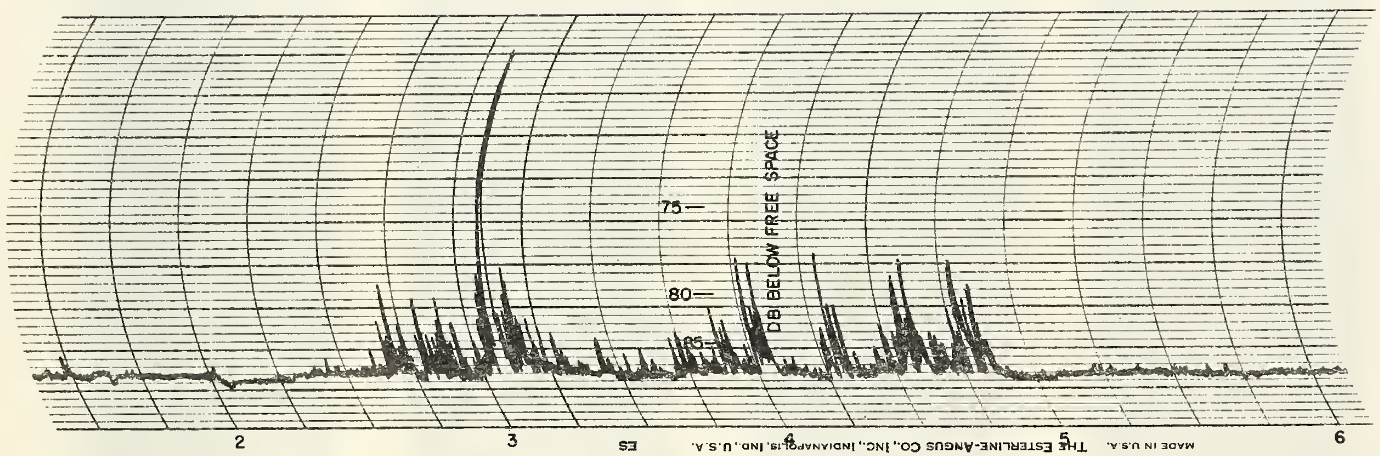
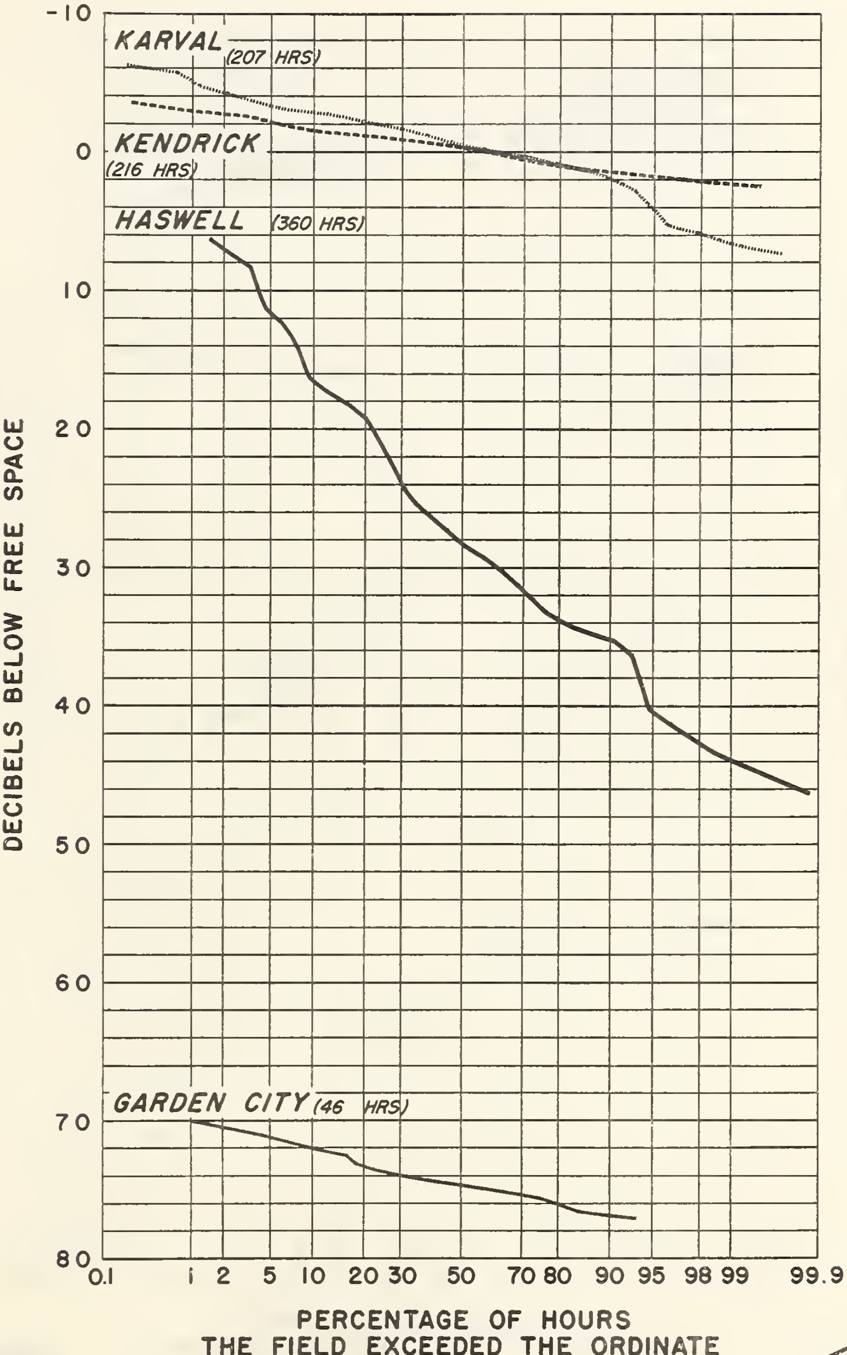


FIG. 5e

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS RECORDED ON 1046 Mc DURING FEBRUARY, 1952



NBS

FIG. 6a

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING APRIL, 1952

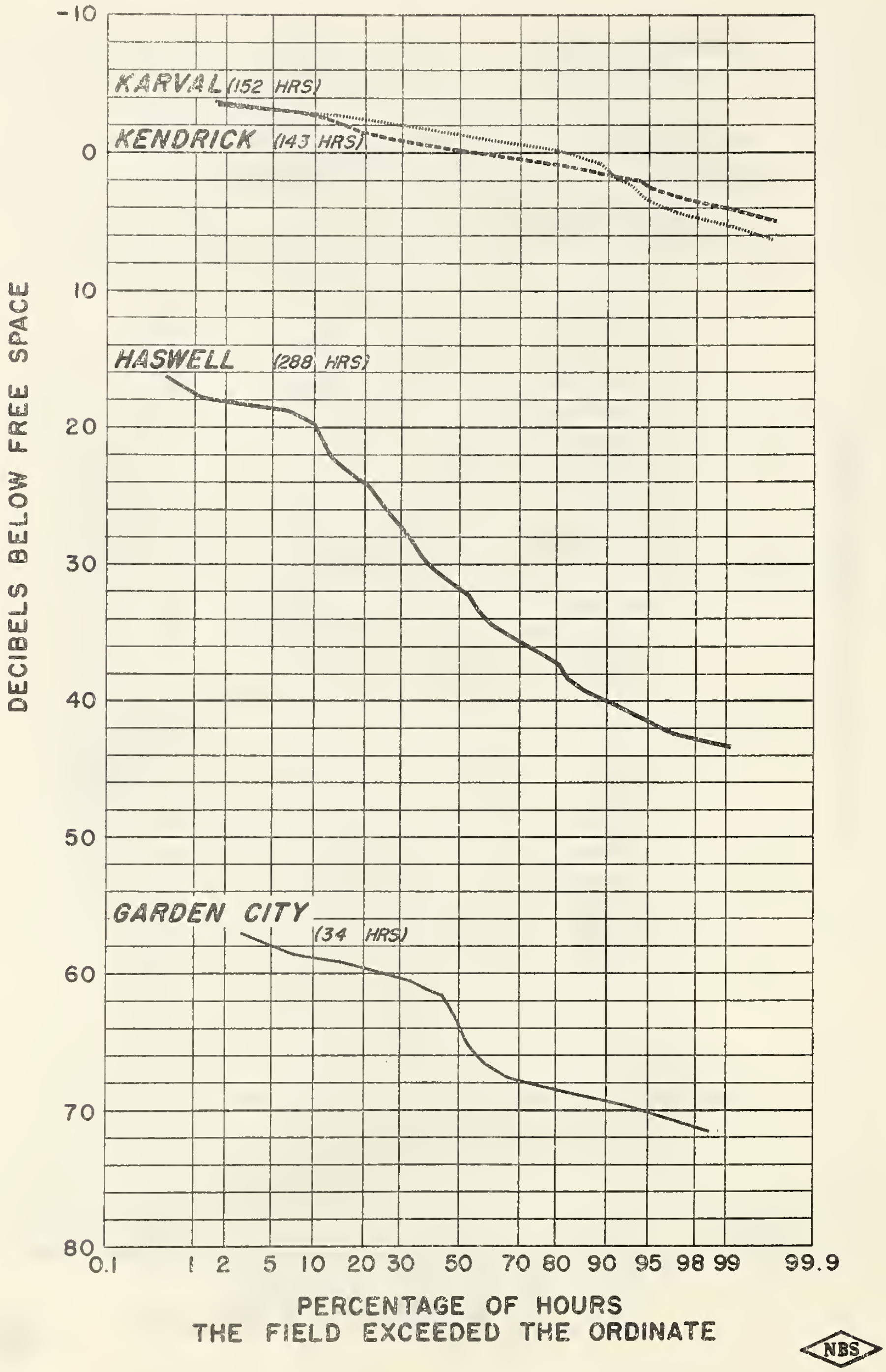


FIG. 6b

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING MAY, 1952

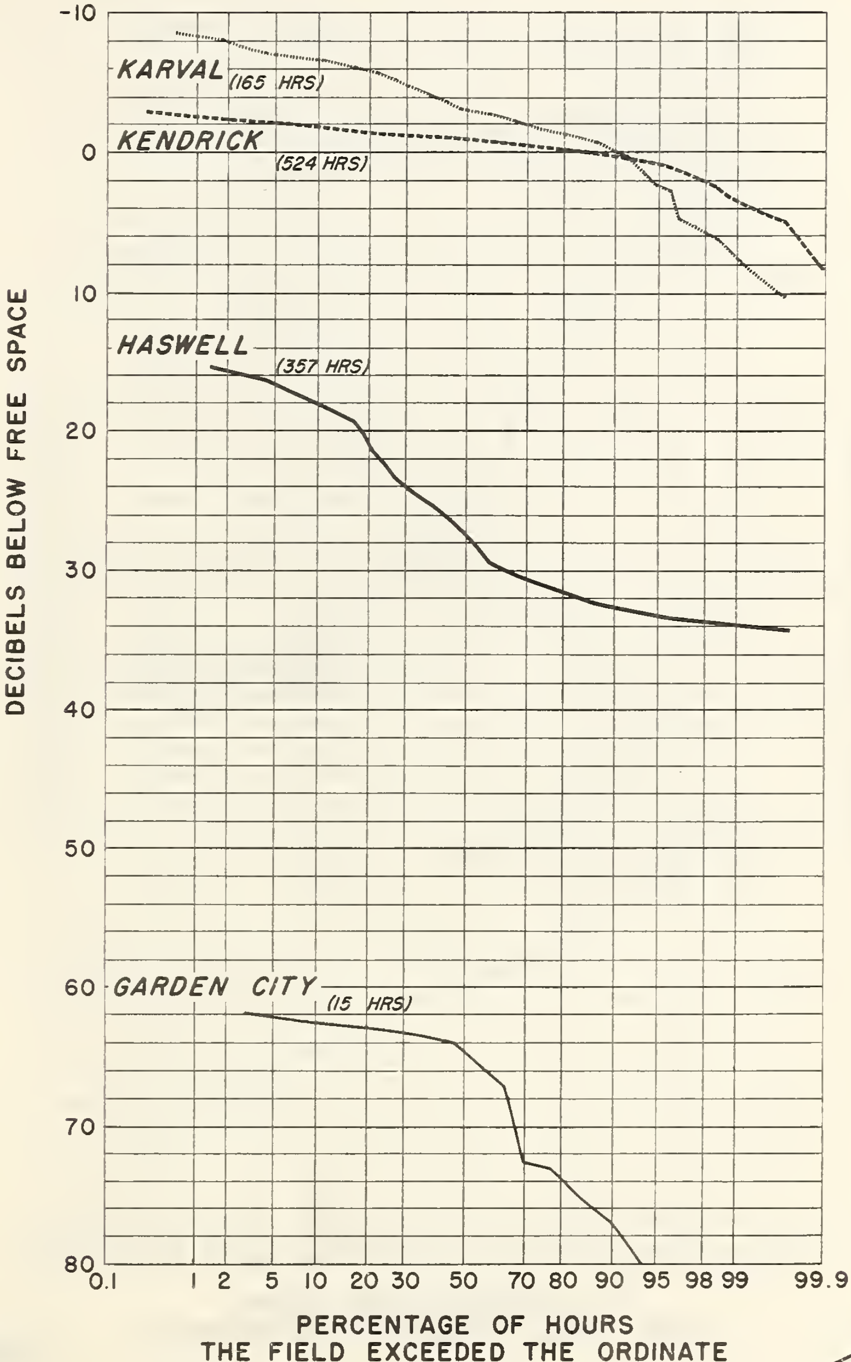


FIG. 6c

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING JUNE, 1952

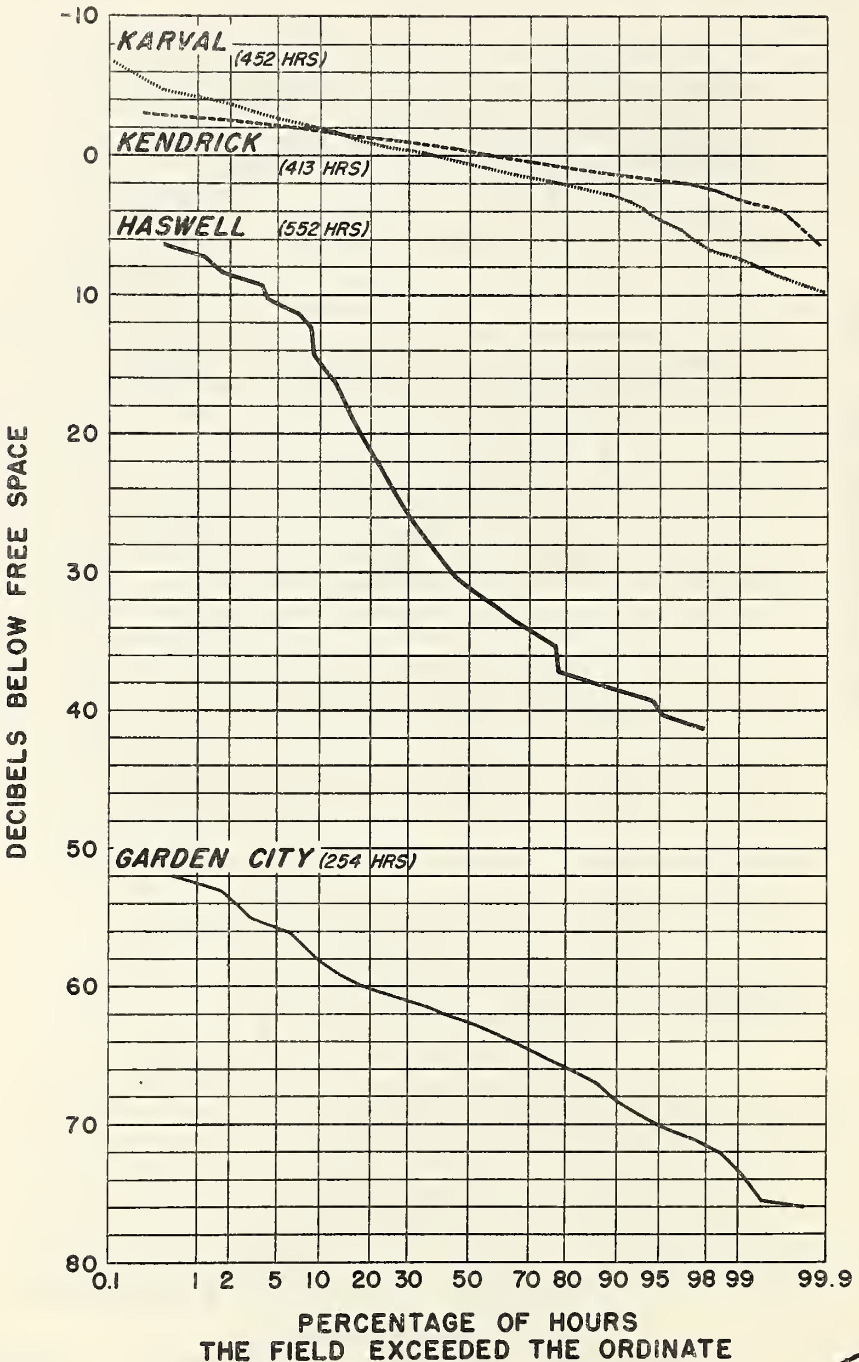
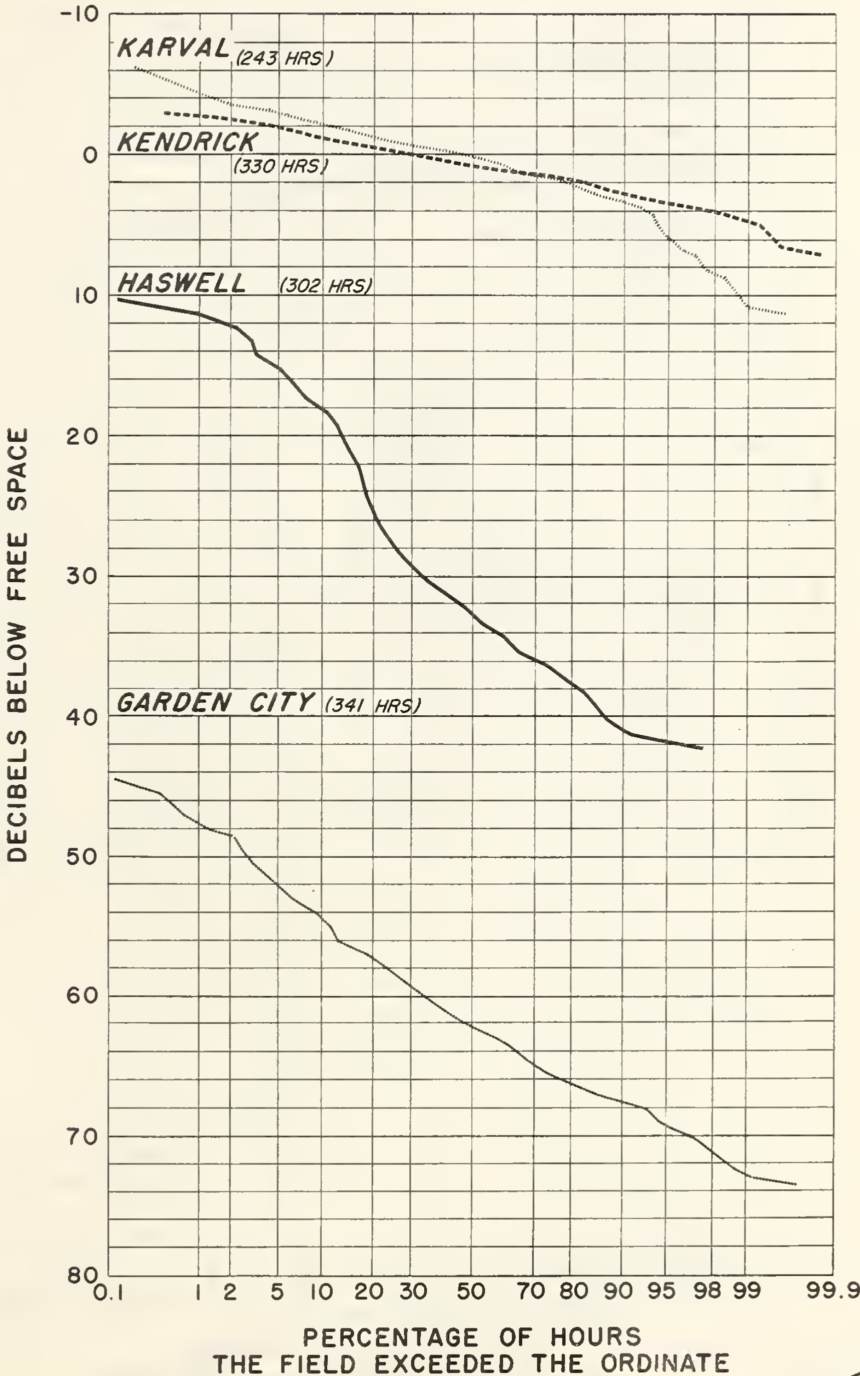


FIG. 6d

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS RECORDED ON 1046 Mc DURING JULY, 1952



NBS

FIG. 6e

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING AUGUST, 1952

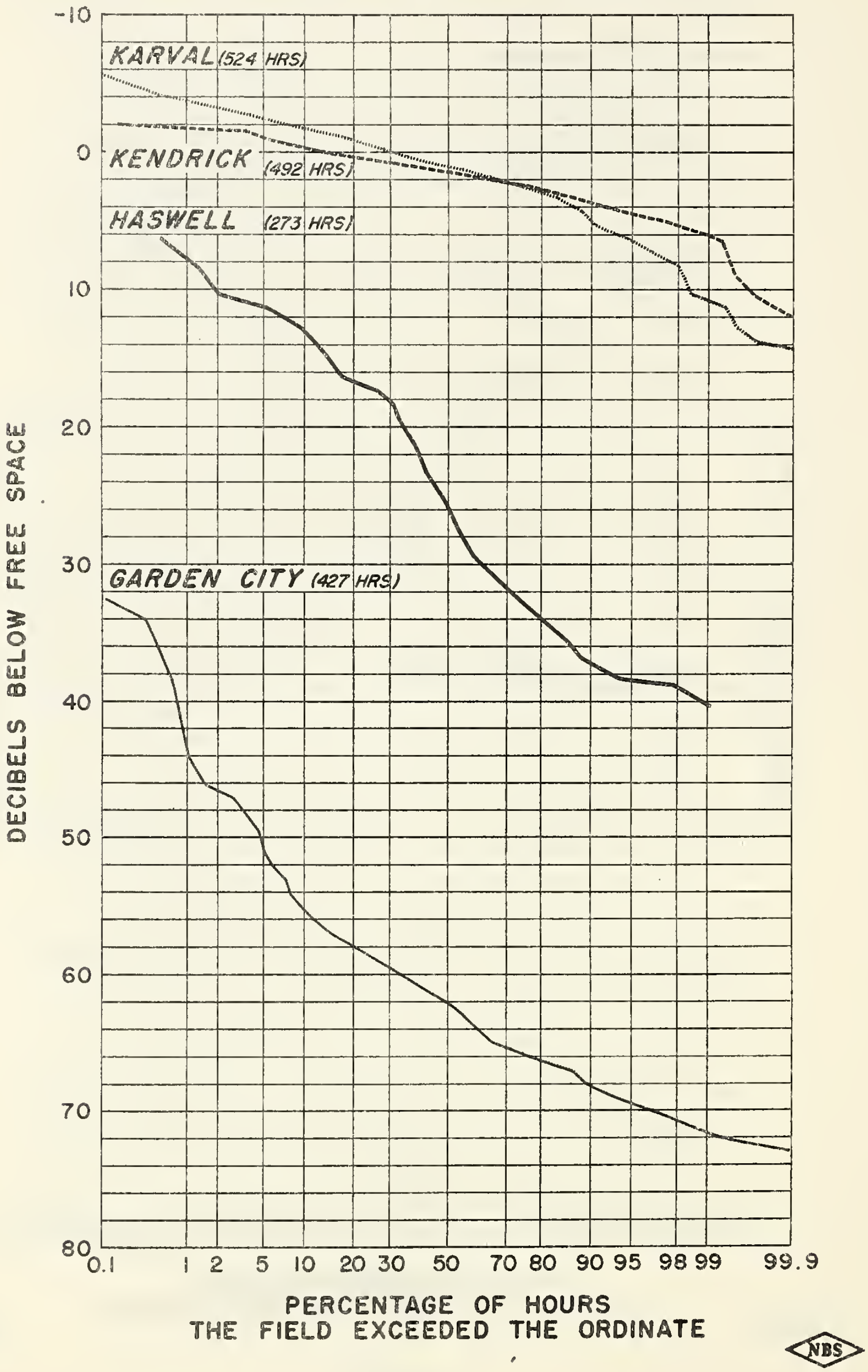


FIG. 6f

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING SEPTEMBER, 1952

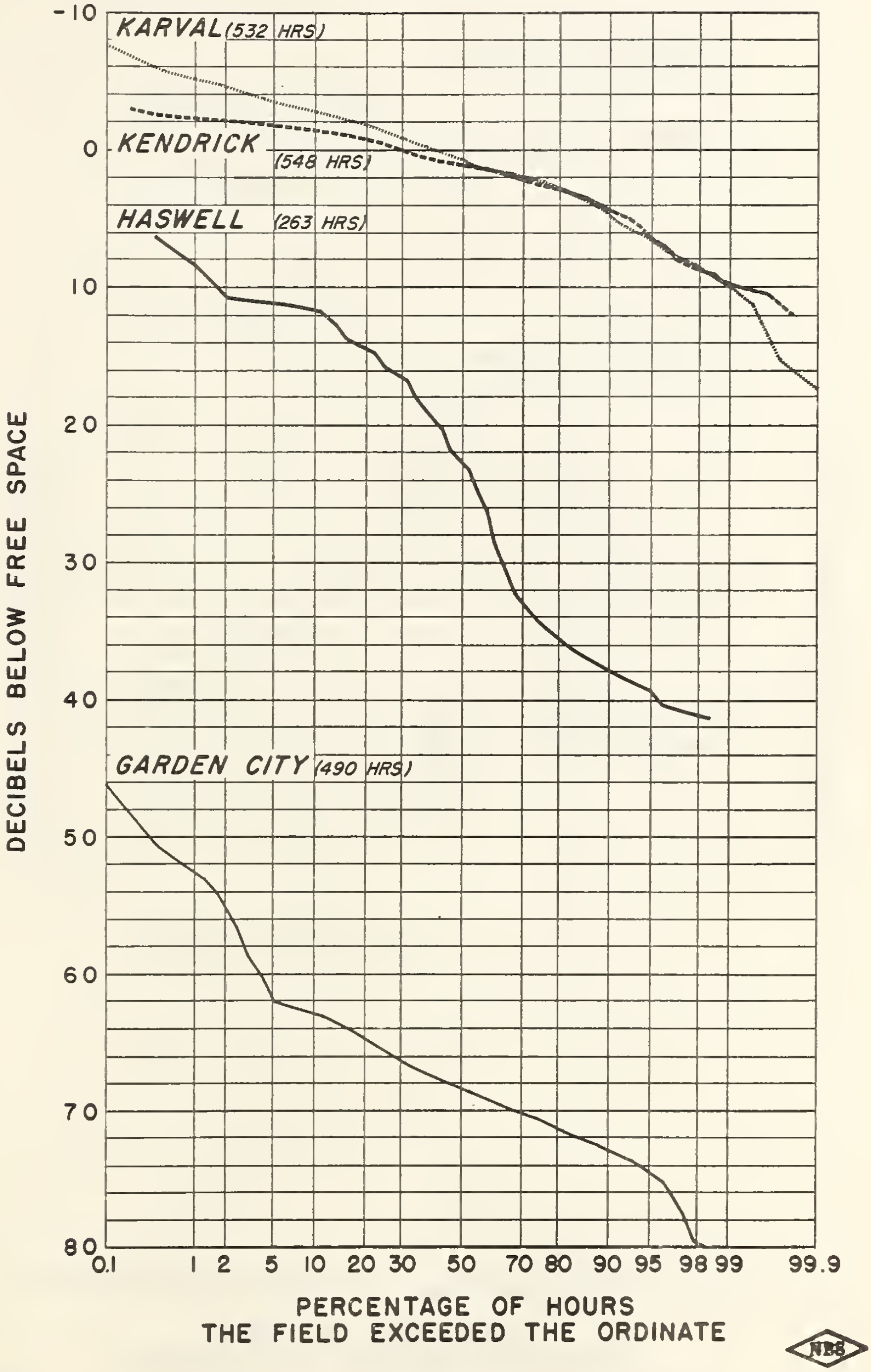


FIG. 6g

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING OCTOBER, 1952

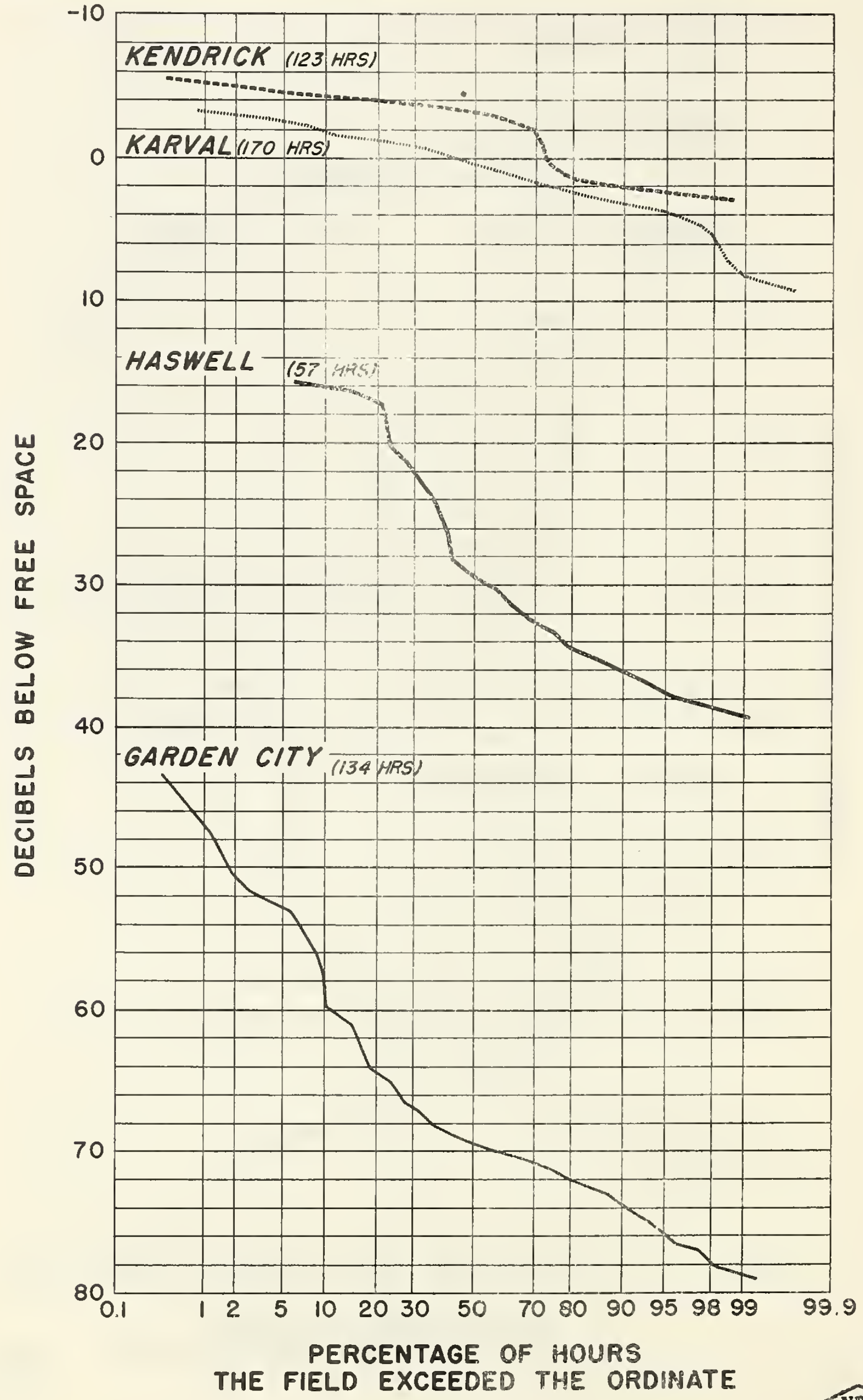
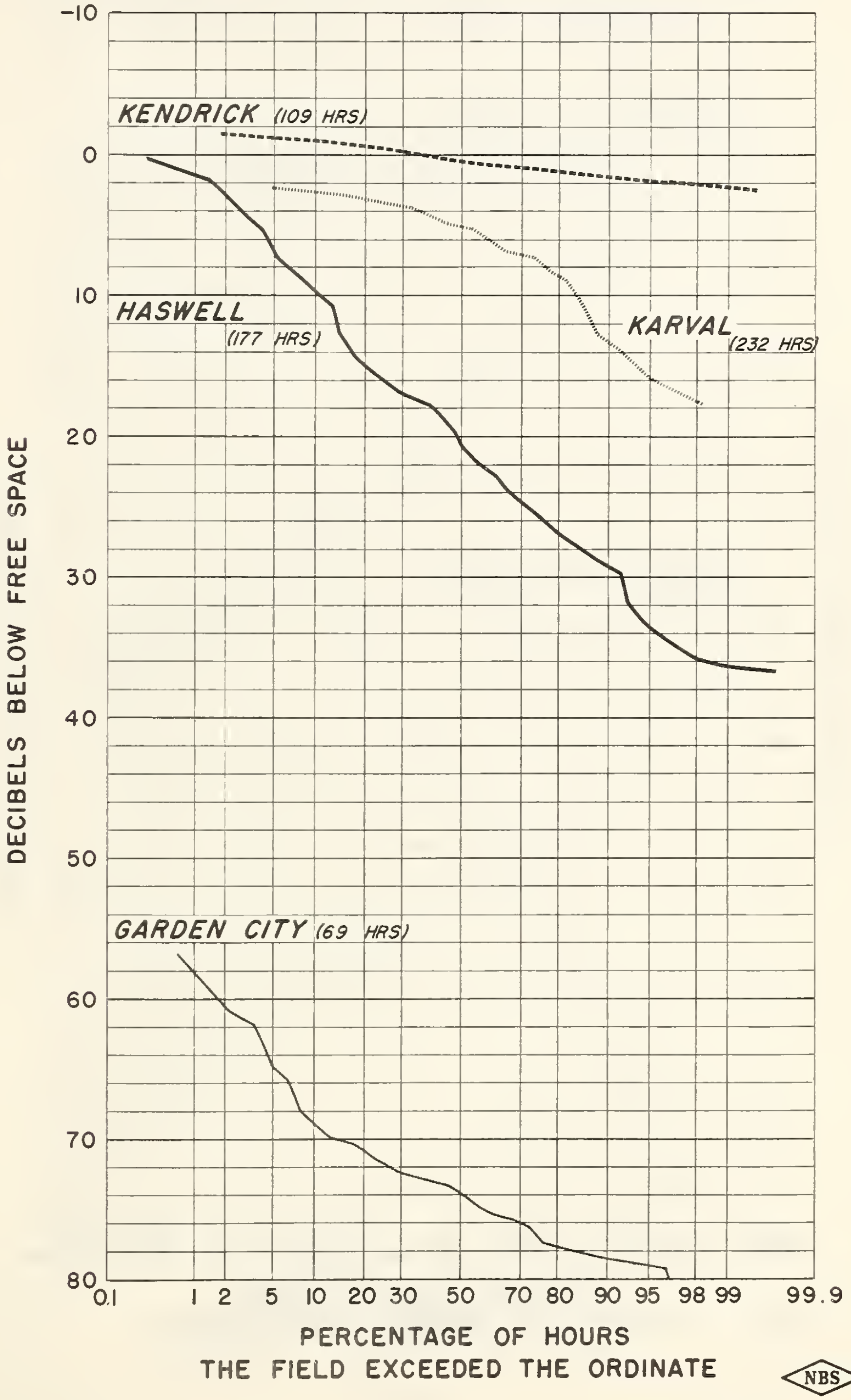


FIG. 6h

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc DURING JANUARY, 1953



NBS

FIG. 6j

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED ON 1046 Mc FEB. 1952 - JAN. 1953

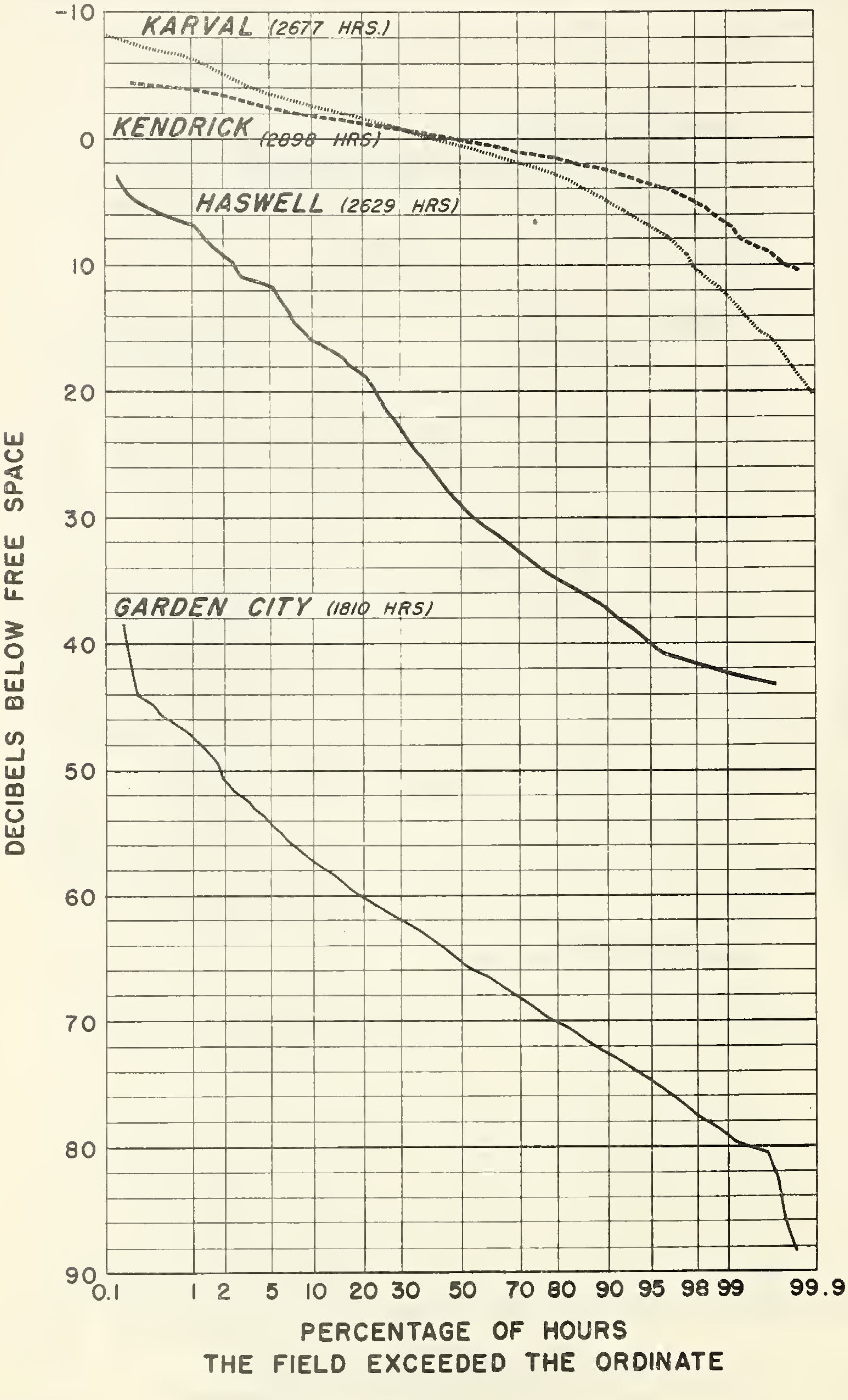
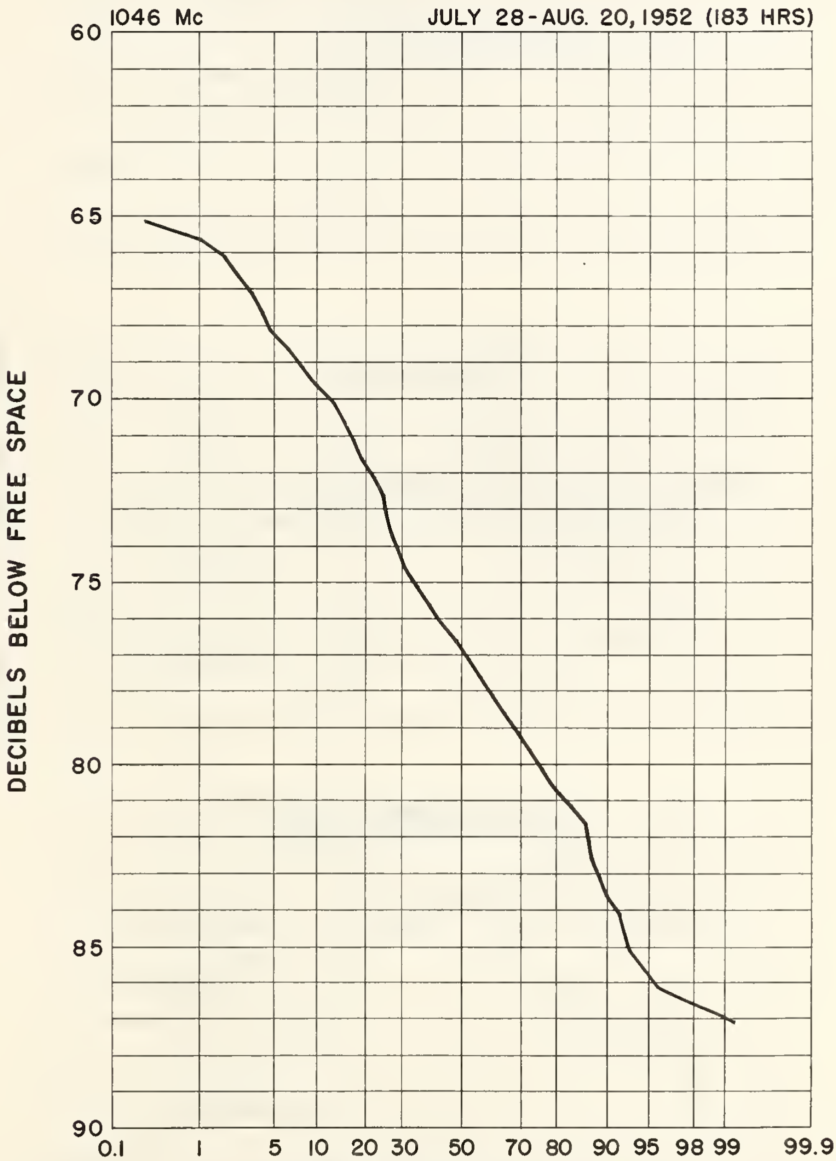


FIG. 6k

DISTRIBUTION OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED AT ANTHONY, KANSAS



PERCENTAGE OF HOURS
THE FIELD EXCEEDED THE ORDINATE

NBS

FIG. 61

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED DURING 3AM - 6AM AND NOON - 3PM

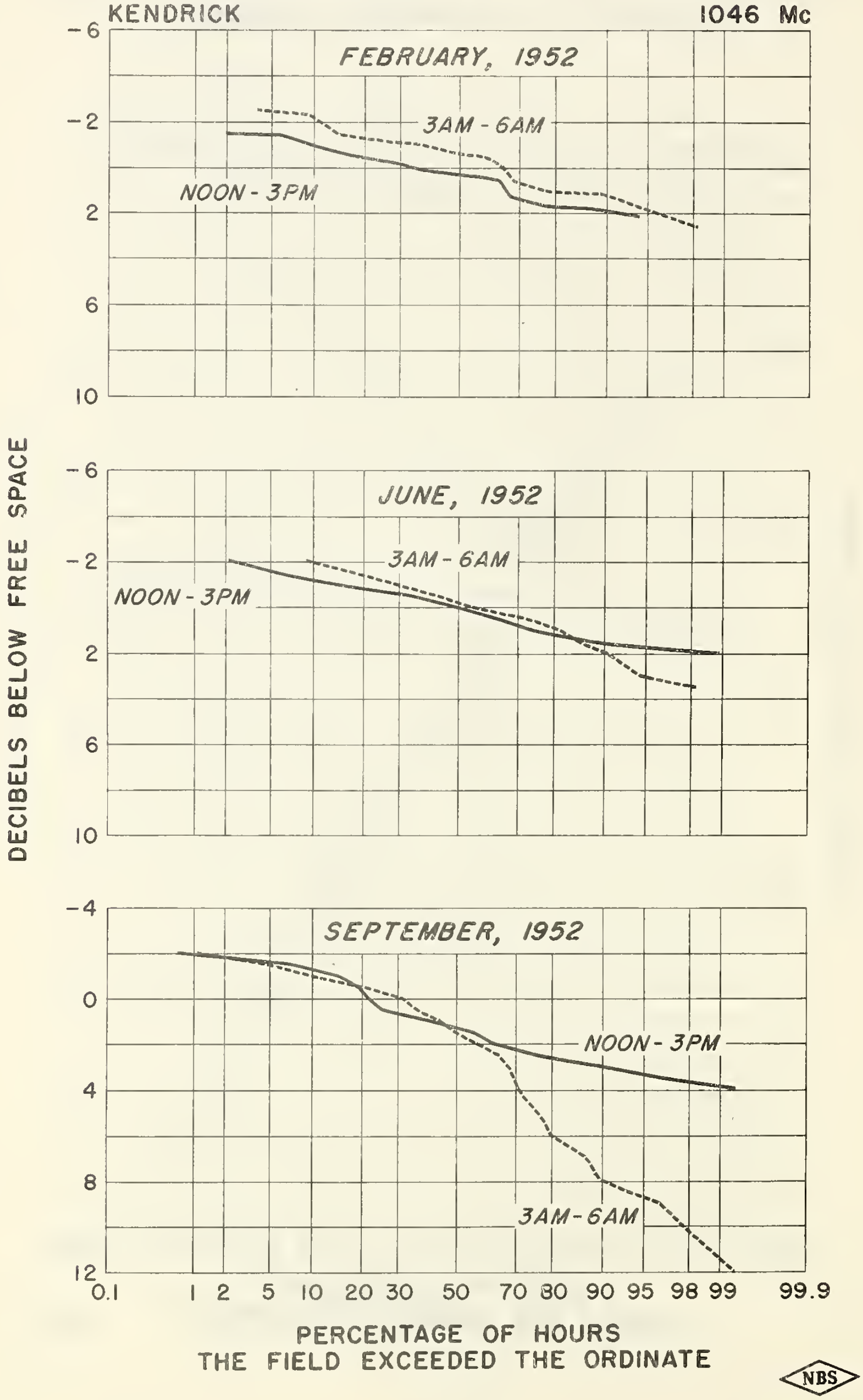


FIG. 7a

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED DURING 3AM - 6AM AND NOON - 3PM

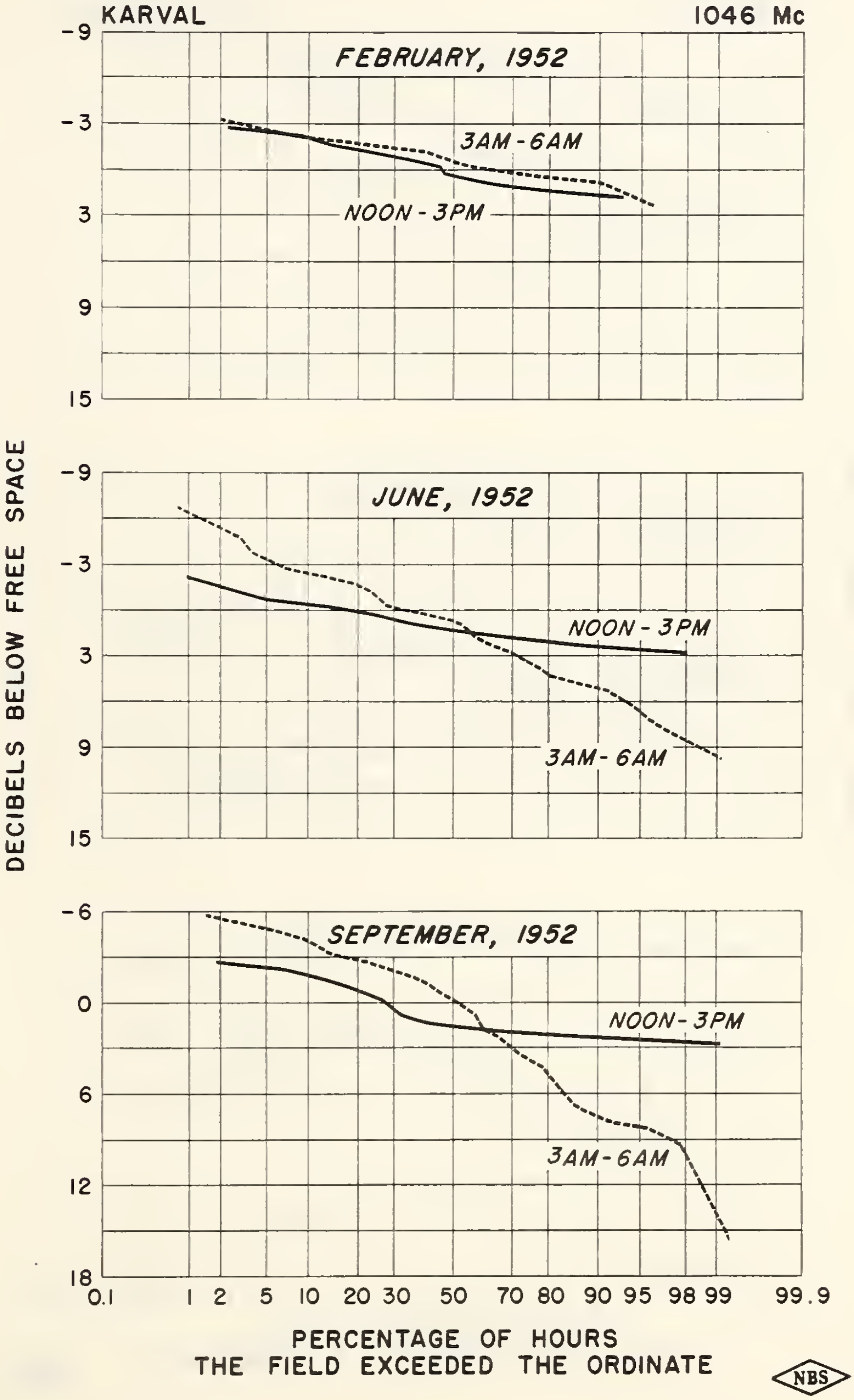


FIG. 7b

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED DURING 3AM - 6AM AND NOON - 3PM

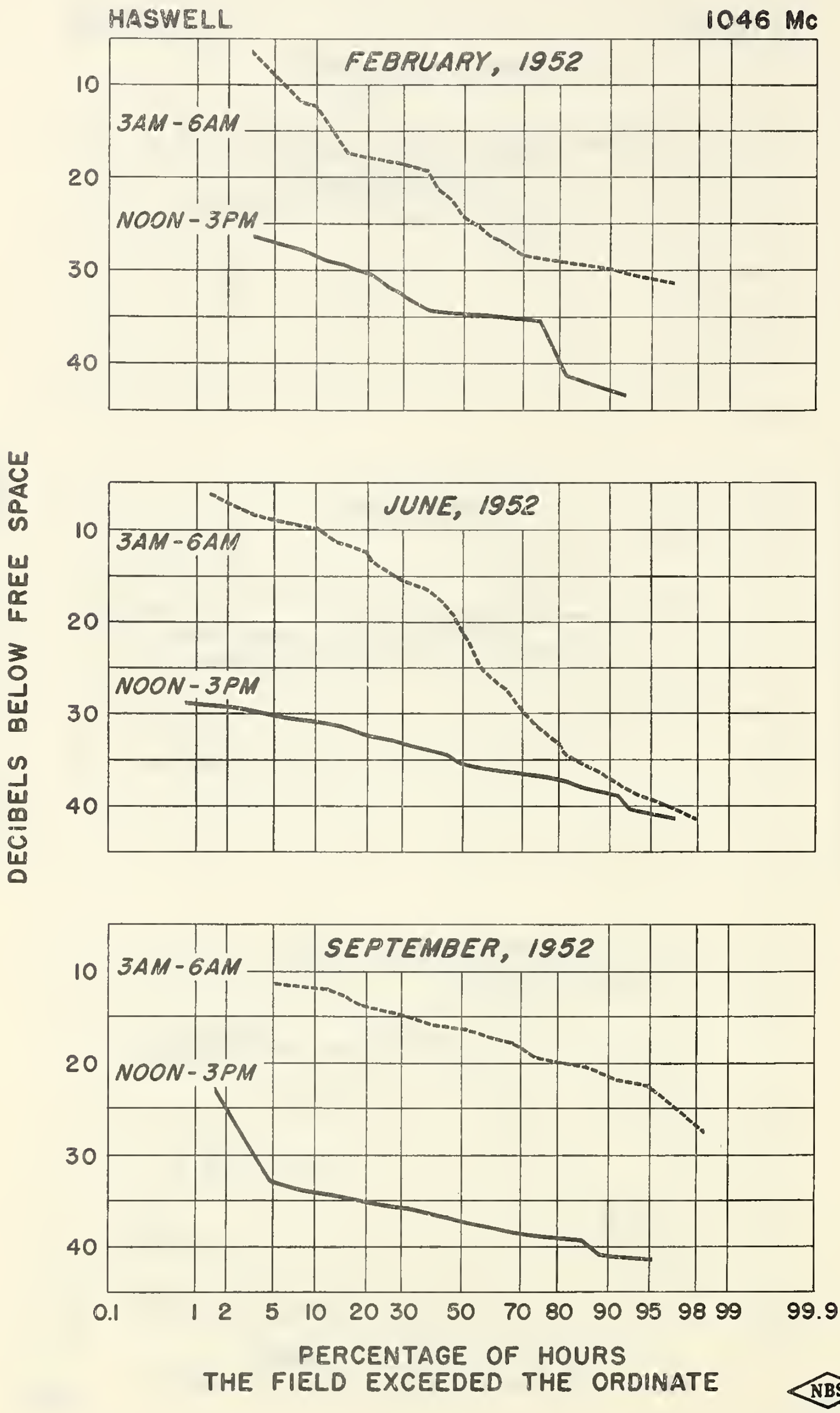


FIG. 7c

DISTRIBUTIONS OF HOURLY MEDIAN SIGNAL LEVELS
RECORDED DURING 3AM-6AM AND NOON-3PM

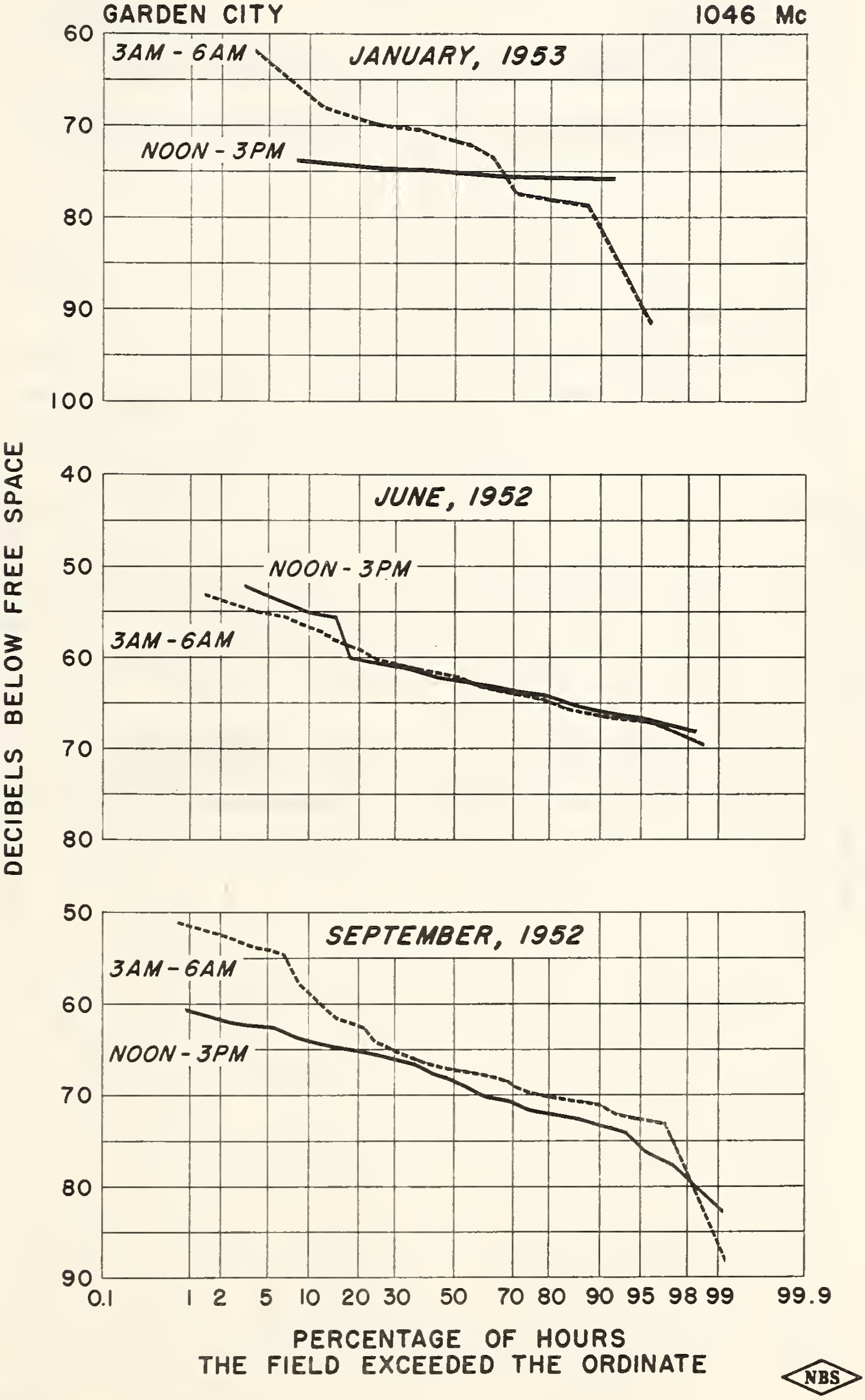


FIG. 7d

DIURNAL VARIATION OF MEDIAN SIGNAL LEVELS

1046 Mc

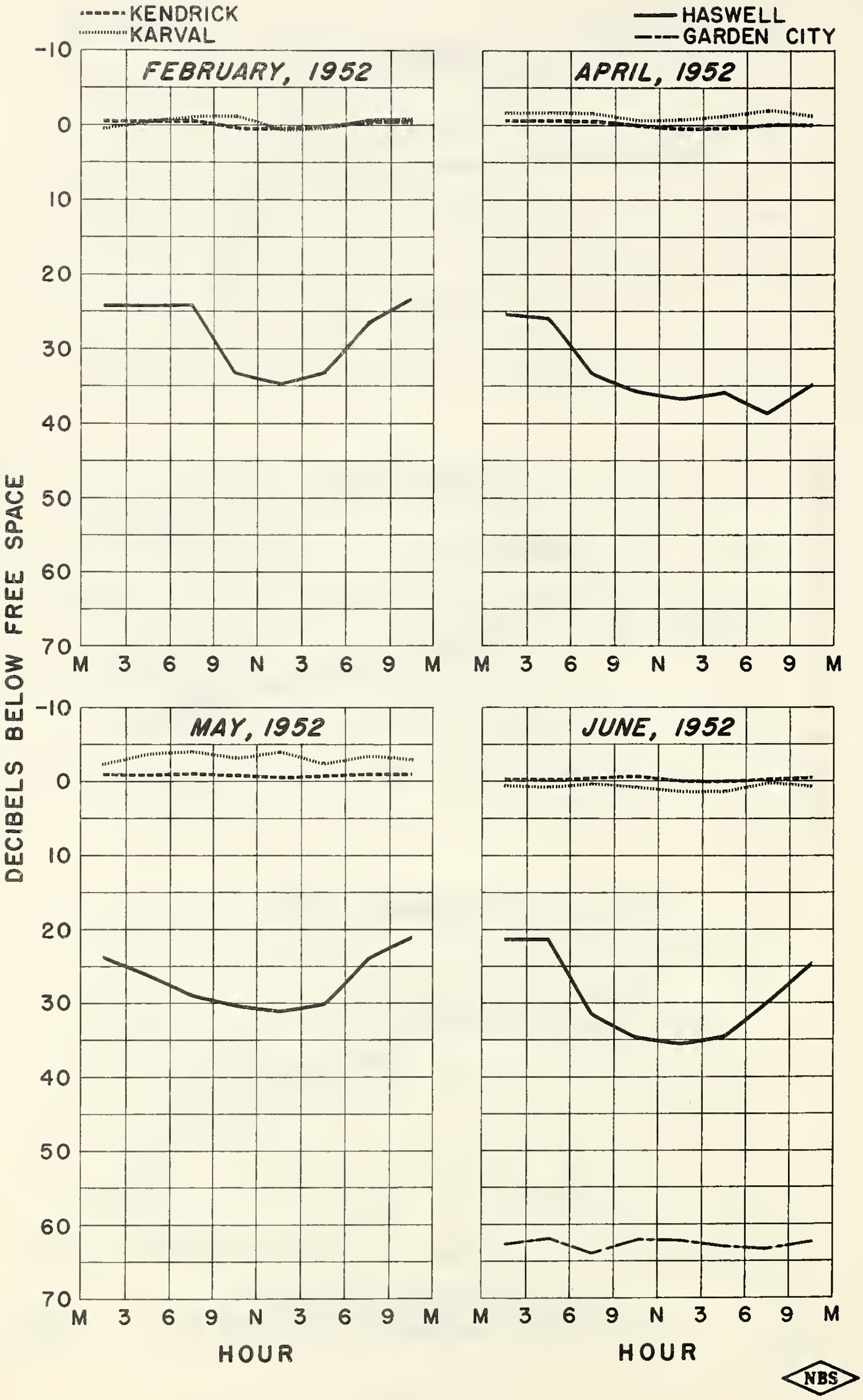


FIG. 8a

DIURNAL VARIATION OF MEDIAN SIGNAL LEVELS

1046 Mc

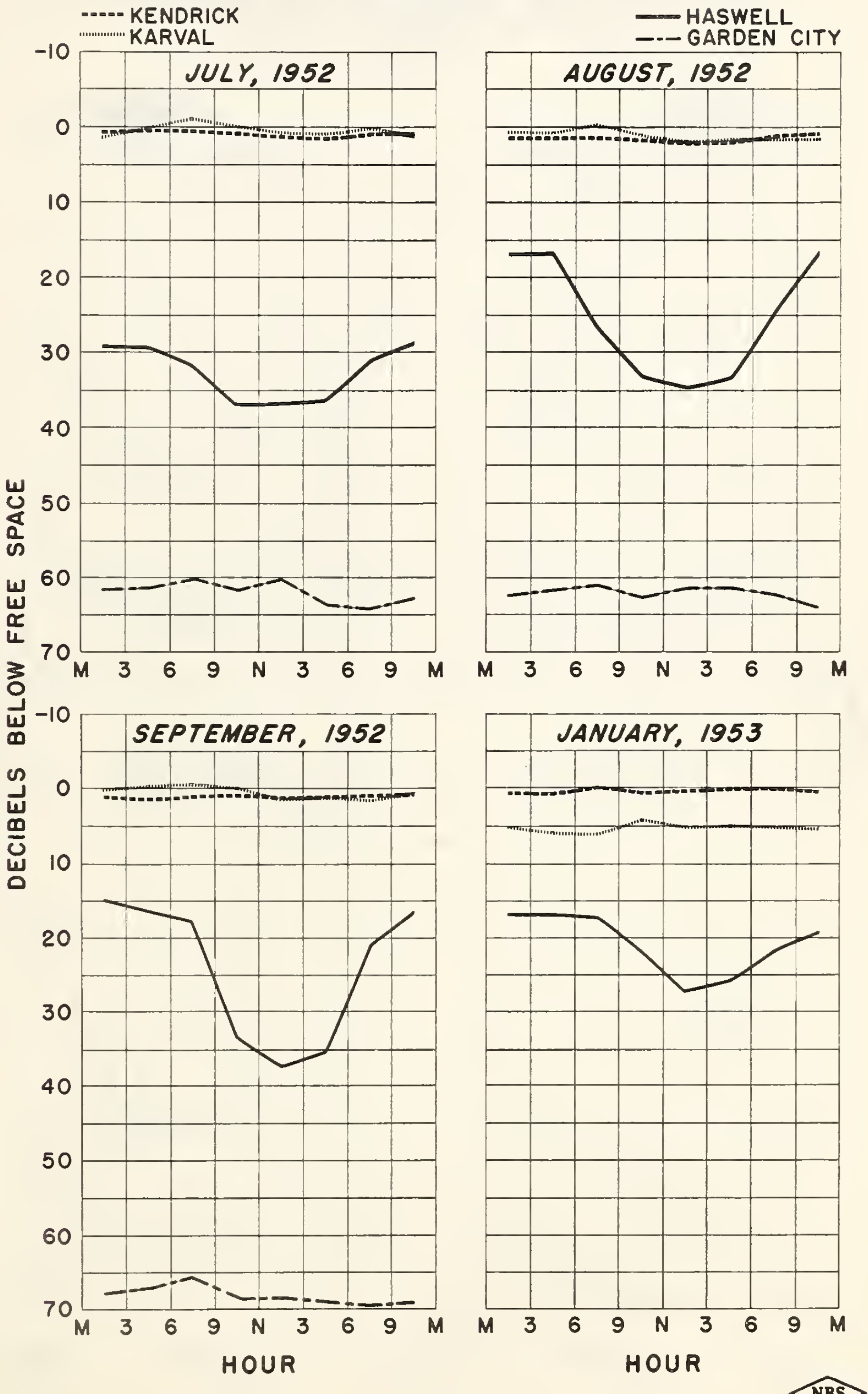


FIG. 8b

DIURNAL VARIATION OF DIFFERENCE IN DECIBELS
OF LEVELS EXCEEDED BY 10% AND 90%
OF ALL HOURLY MEDIANS

1046 Mc

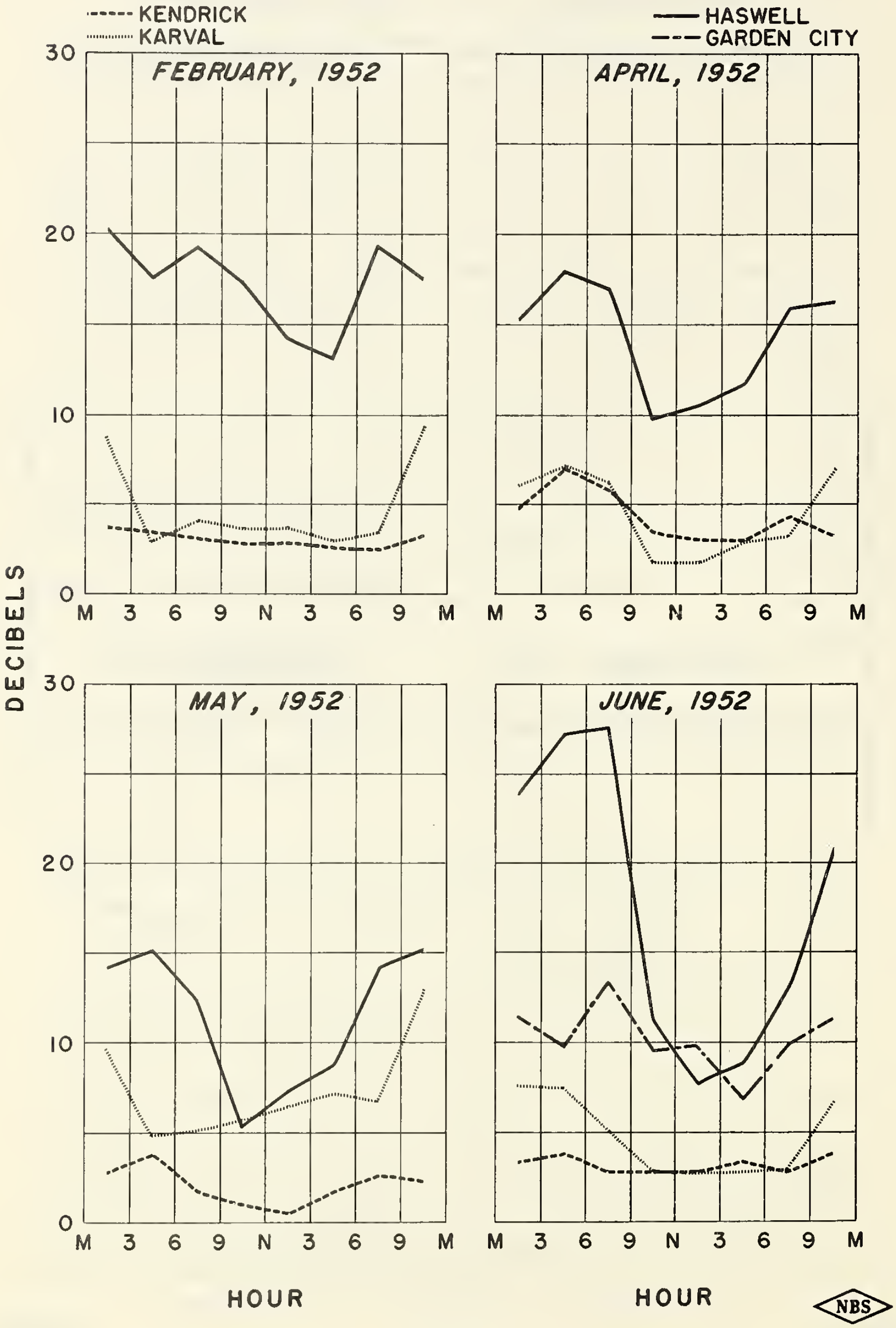


FIG. 9a

DIURNAL VARIATION OF DIFFERENCE IN DECIBELS OF LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS

1046 Mc

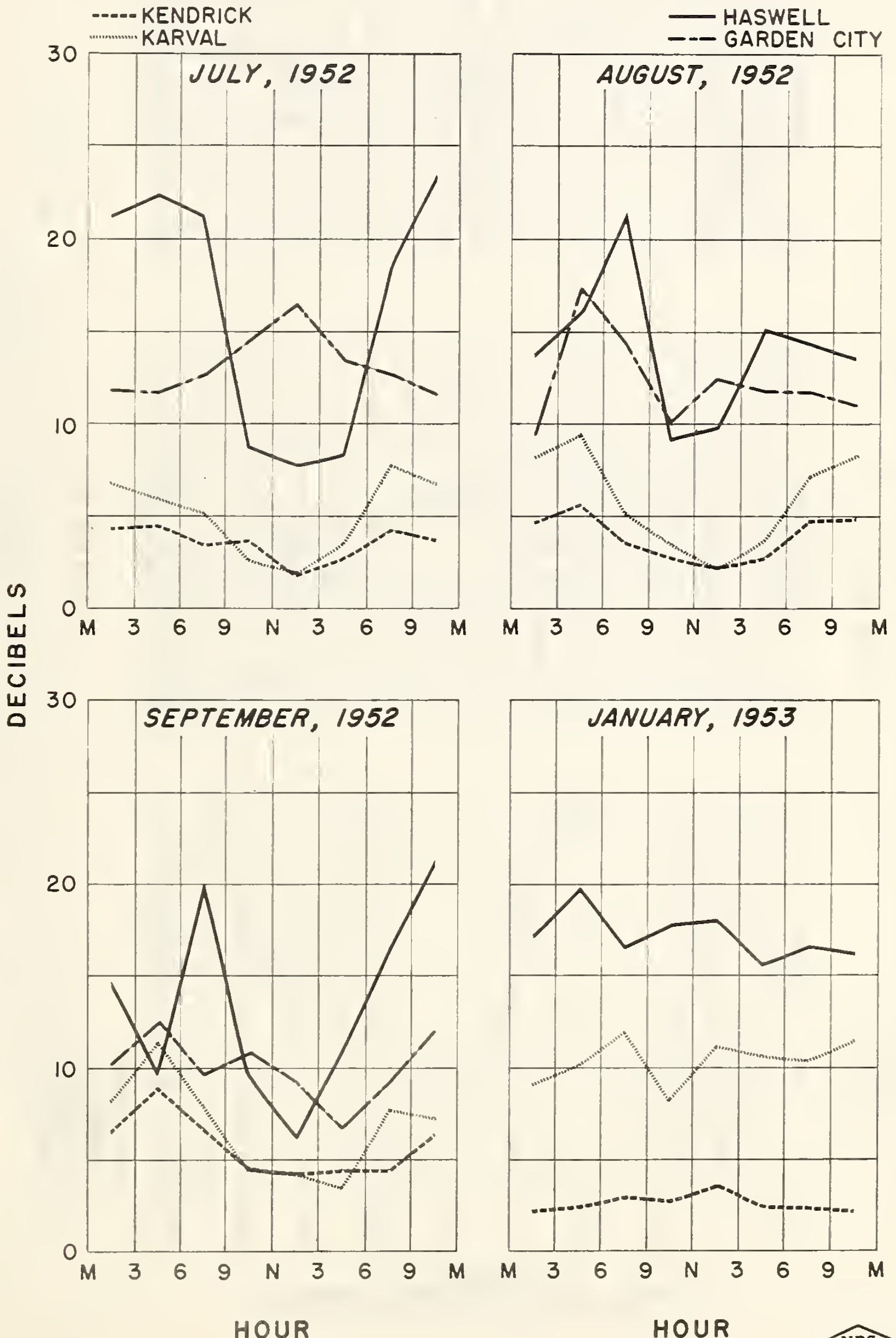


FIG. 9b

SEASONAL VARIATION OF MEDIAN SIGNAL LEVELS

1046 Mc

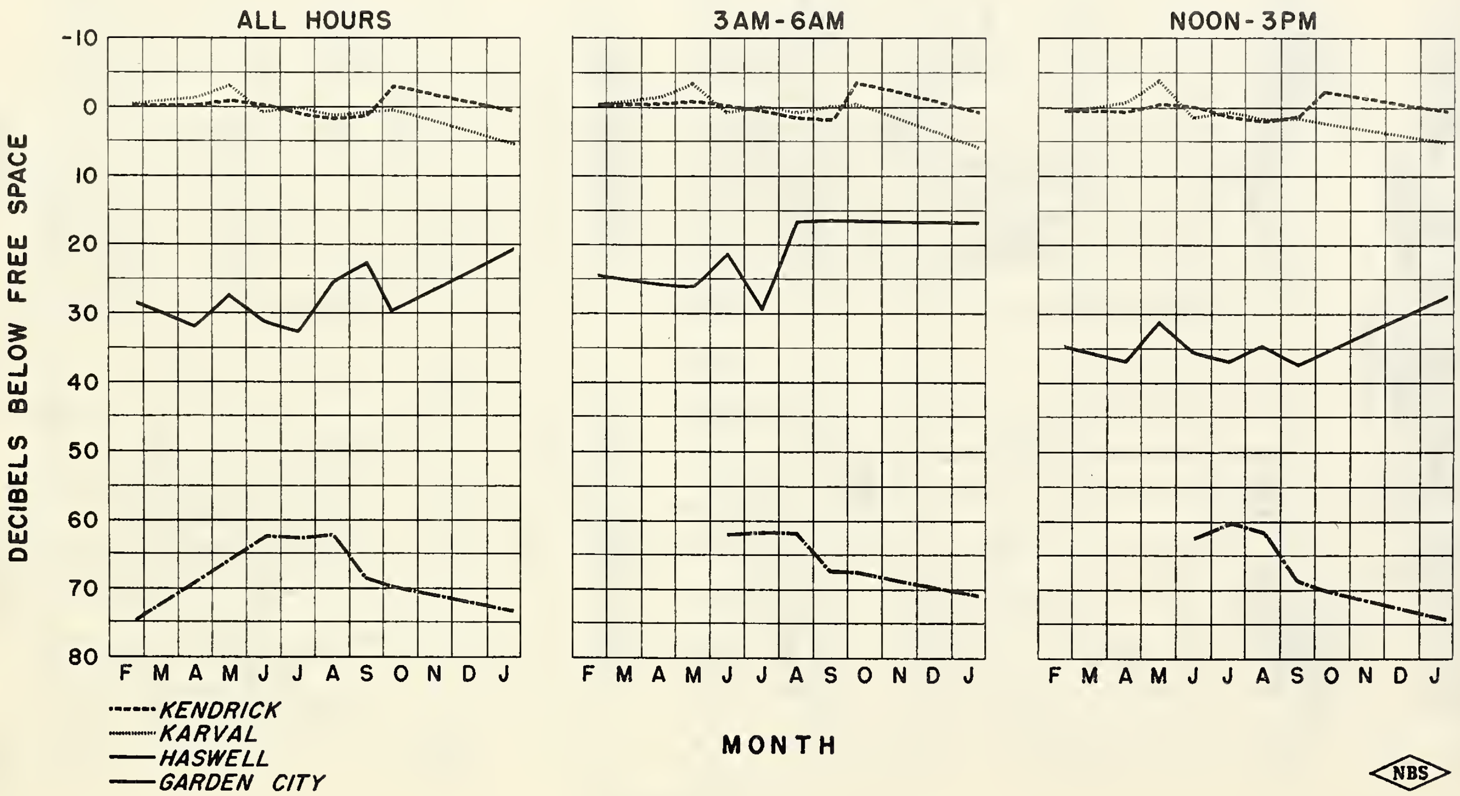


FIG. 10a

SEASONAL VARIATION OF DIFFERENCE IN DECIBELS
OF LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS

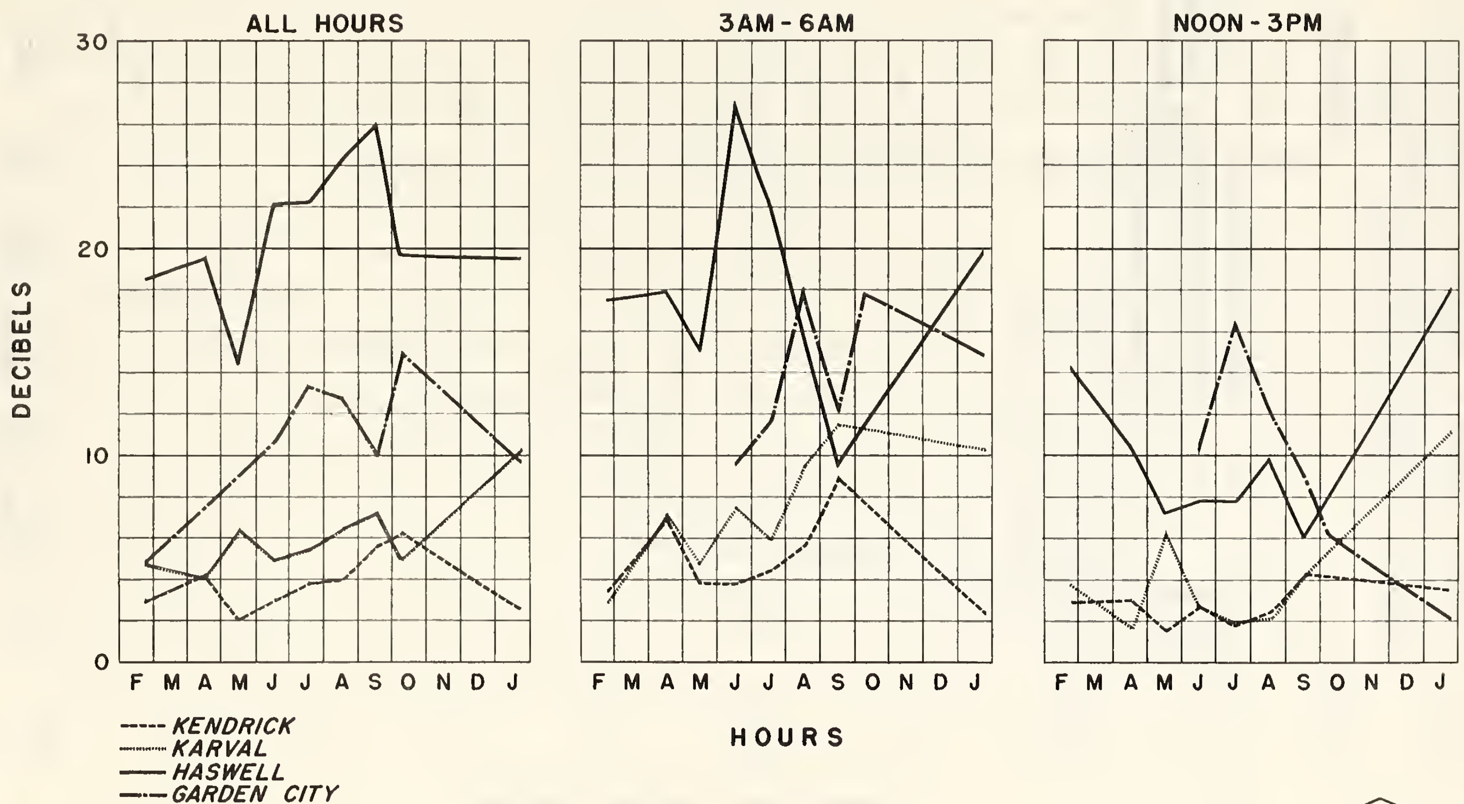


FIG. 10b

DISTRIBUTION OF MONTHLY MEDIAN SIGNAL LEVELS VERSUS DISTANCE

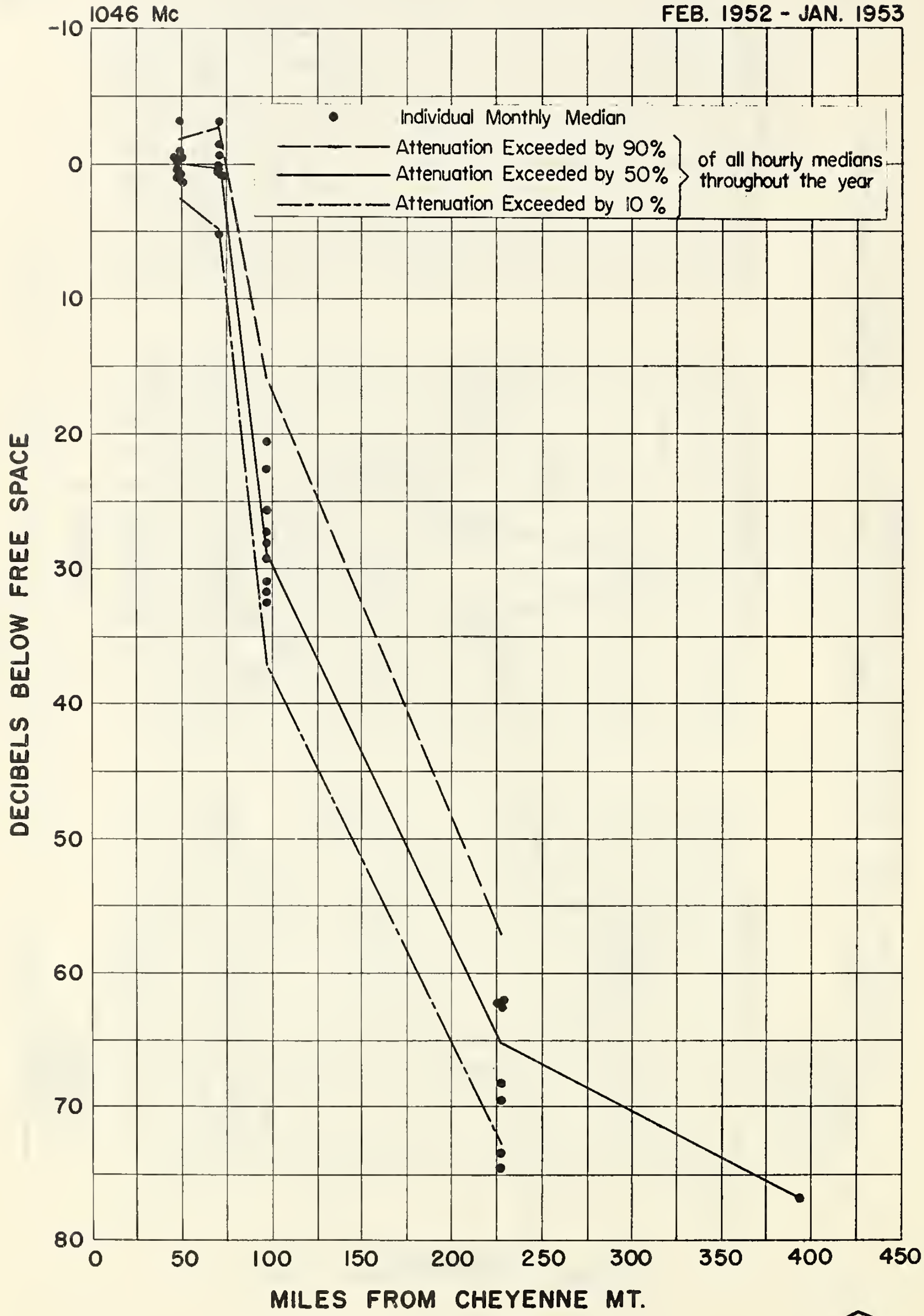


FIG. 11a

DISTRIBUTION OF MONTHLY RATIOS OF LEVELS EXCEEDED BY 10% AND 90% OF ALL HOURLY MEDIANS VERSUS DISTANCE

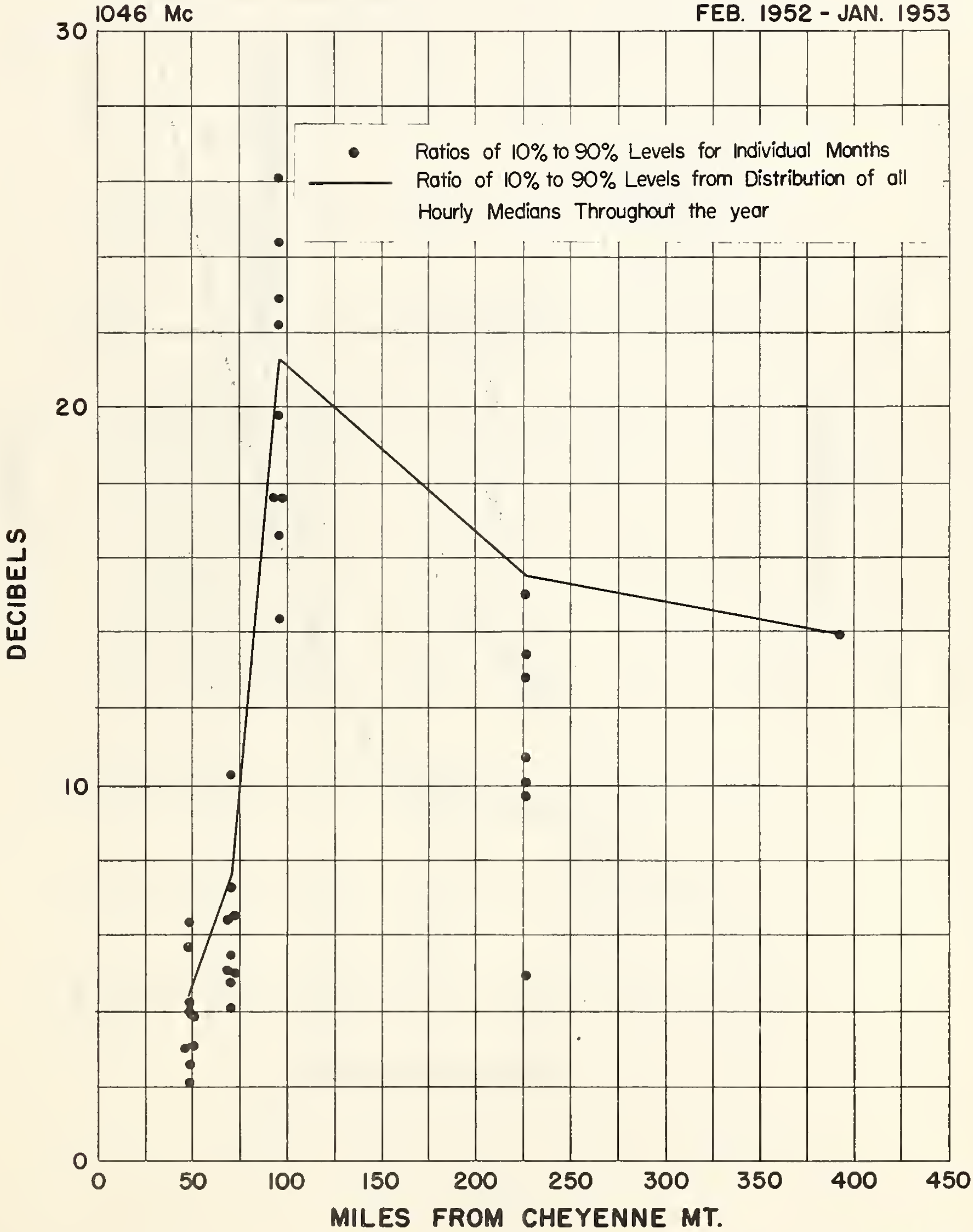


FIG. 11b

DEPENDENCE OF ATTENUATION RELATIVE TO FREE SPACE ON THE ANGULAR DISTANCE BELOW THE HORIZON

θ Calculated Assuming k = 4/3

August, 1952 Data

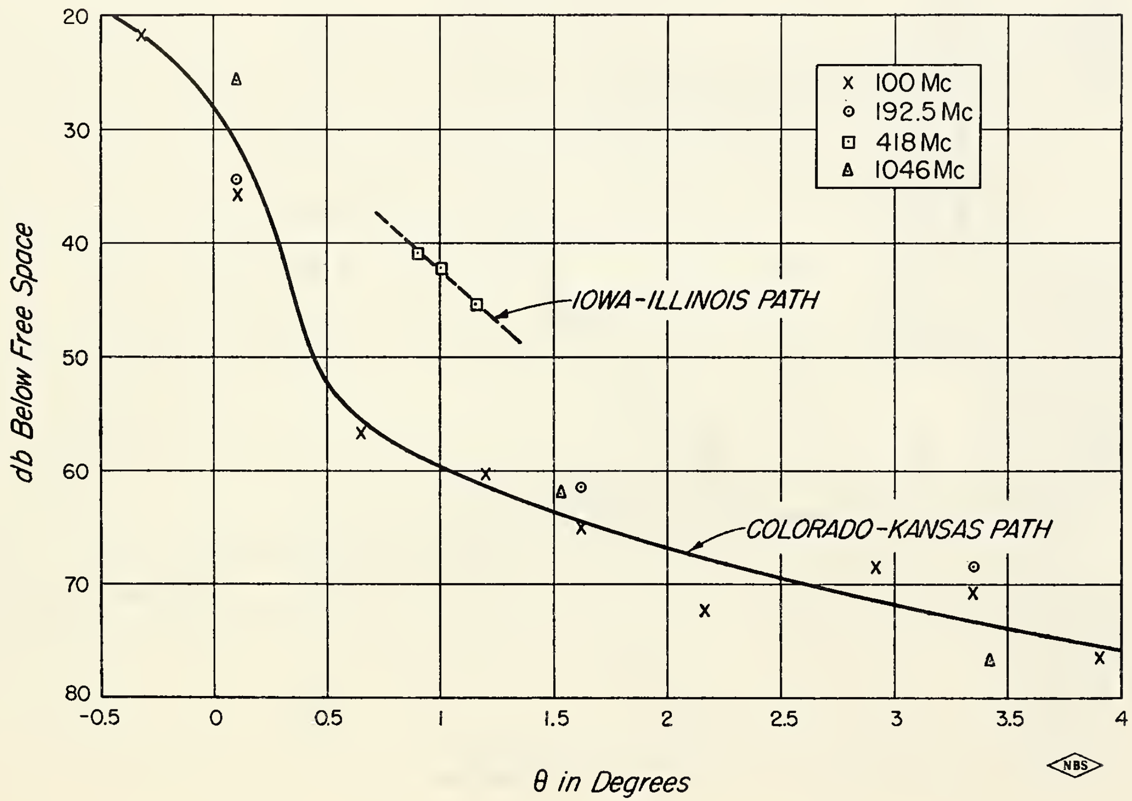


Figure 11c

AVERAGE DISTRIBUTIONS OF INSTANTANEOUS SIGNAL LEVELS

1046 Mc; August 1952

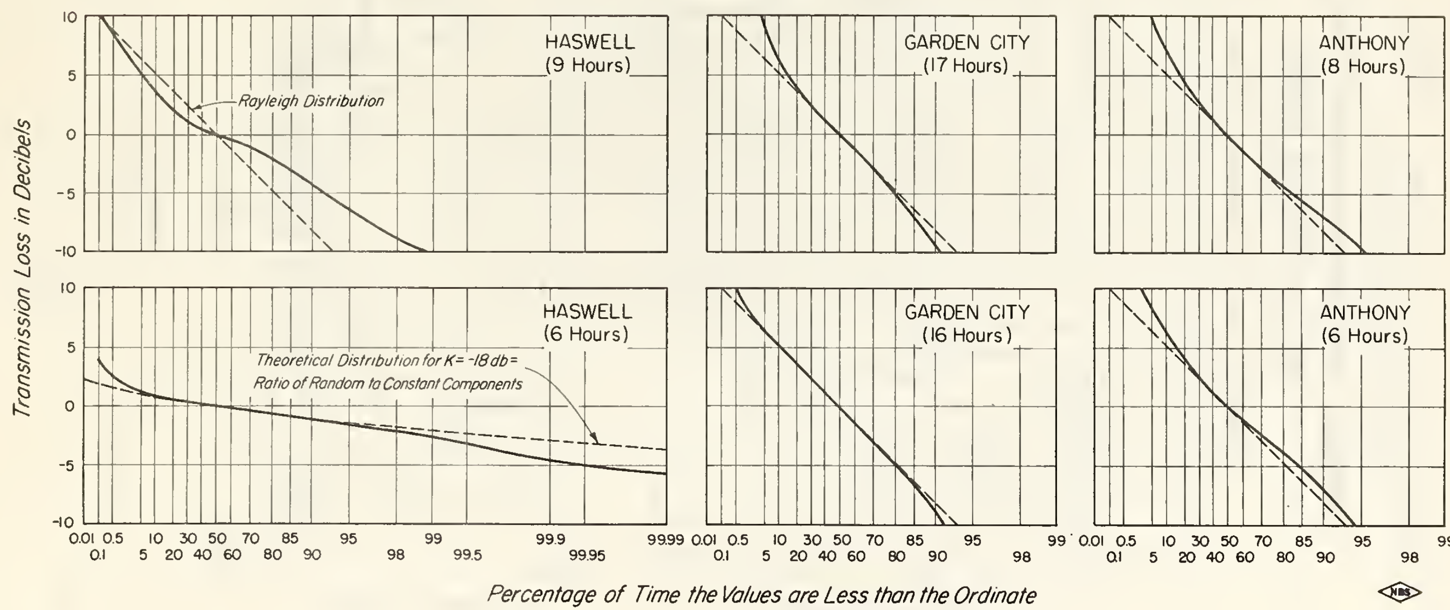


Figure 12a

DIURNAL VARIATION OF HOURLY MEDIANS AND OF FADING RANGE

1046 Mc; Haswell, Colorado; August 1952

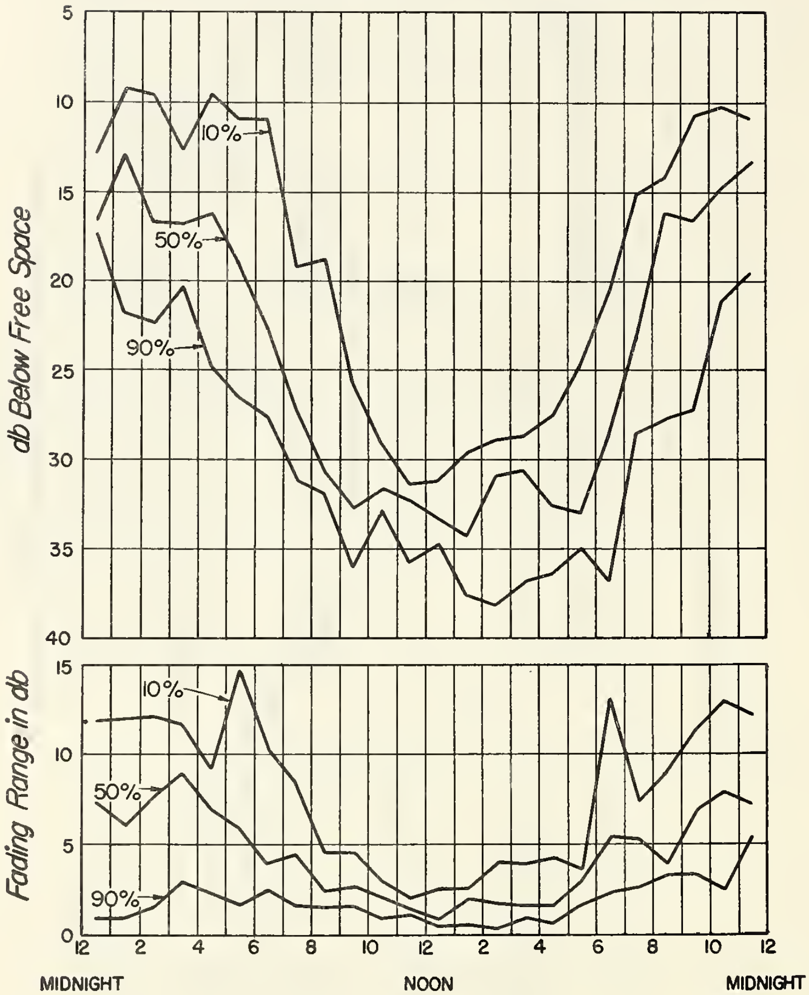
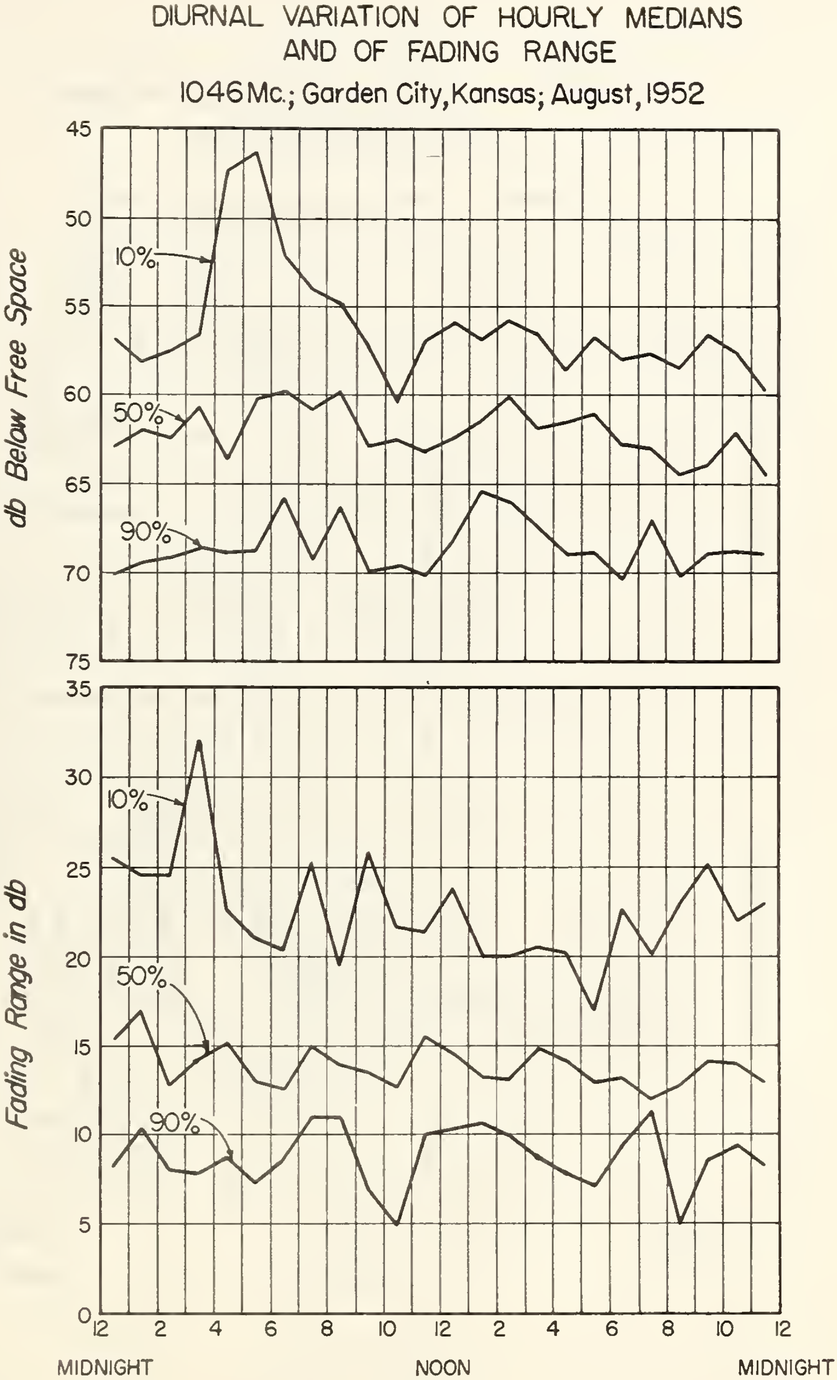


Figure 12 b



DIURNAL VARIATION OF HOURLY MEDIANS
AND OF FADING RANGE
1046 Mc.; Garden City, Kansas; August, 1952
db Below Free Space
45
50
55
60
65
70
75
10%
50%
90%
Fading Range in db
35
30
25
20
15
10
5
0
12
2
4
6
8
10
12
2
4
6
8
10
12
MIDNIGHT
NOON
MIDNIGHT

Figure 12 c

DIURNAL VARIATION OF HOURLY MEDIANS AND OF FADING RANGE

1046 Mc; Anthony, Kansas; August, 1952

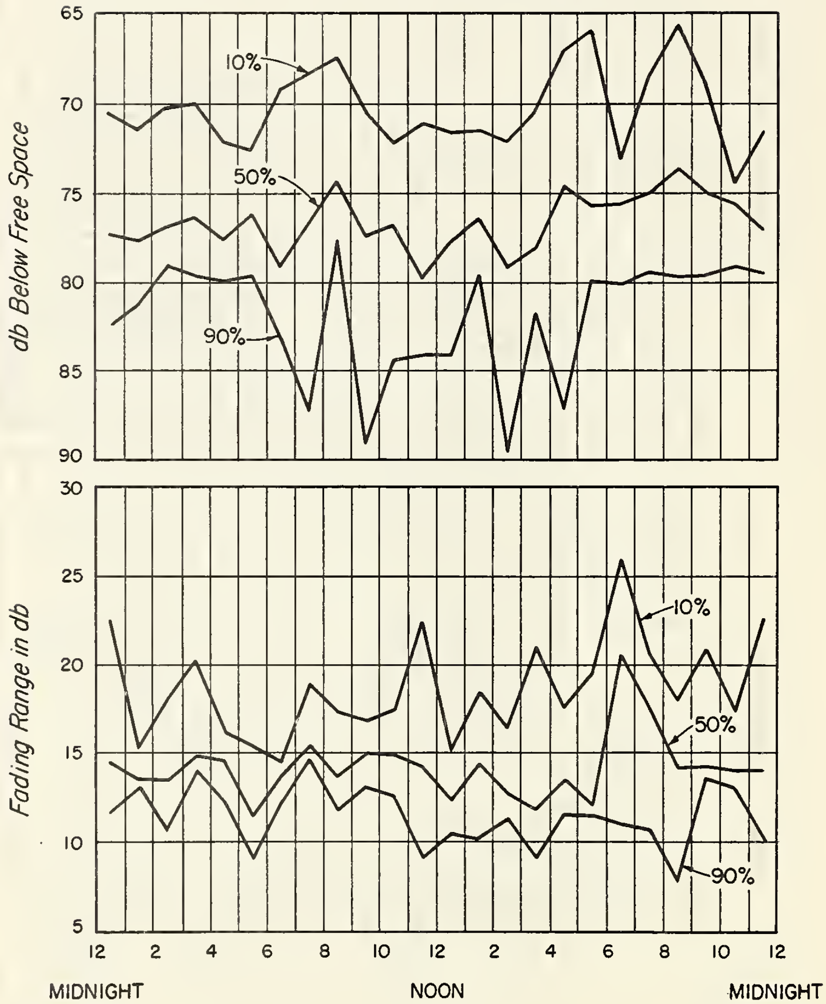


Figure 12d

DEPENDENCE OF FADING RANGE
ON THE ANGULAR DISTANCE BELOW THE HORIZON

θ Calculated Assuming k = 4/3
August, 1952 Data

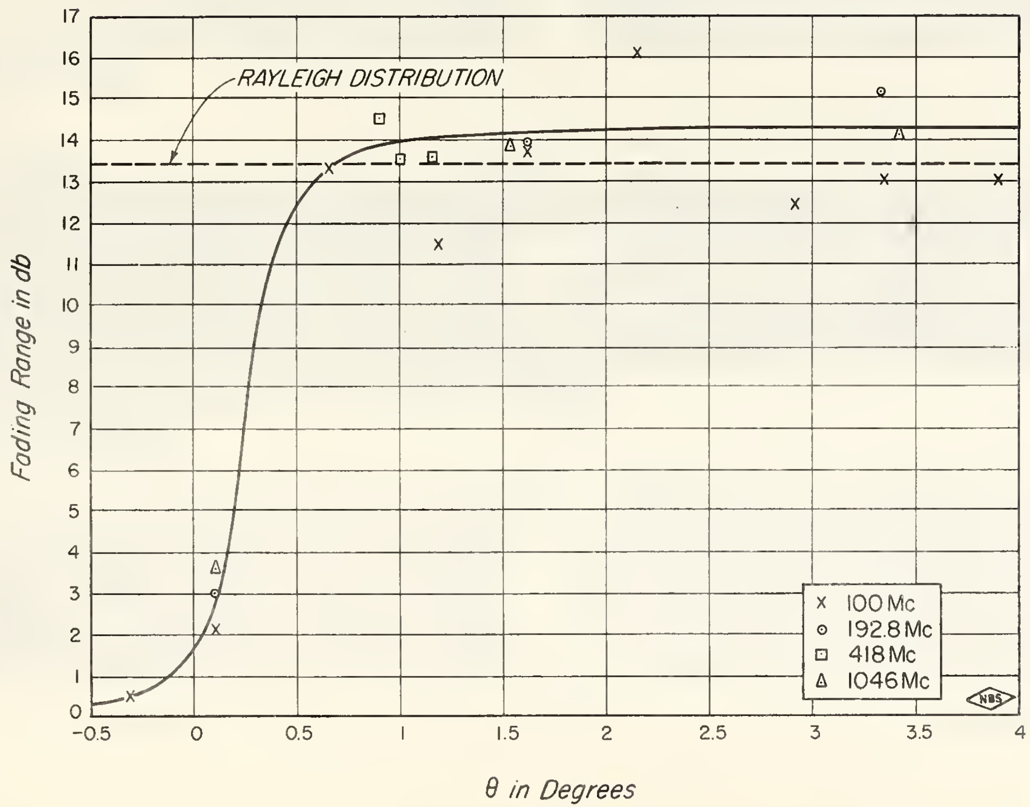


Figure 12 e

RECORDING CHART SAMPLES
CHEYENNE MT. OPTICAL PATHS

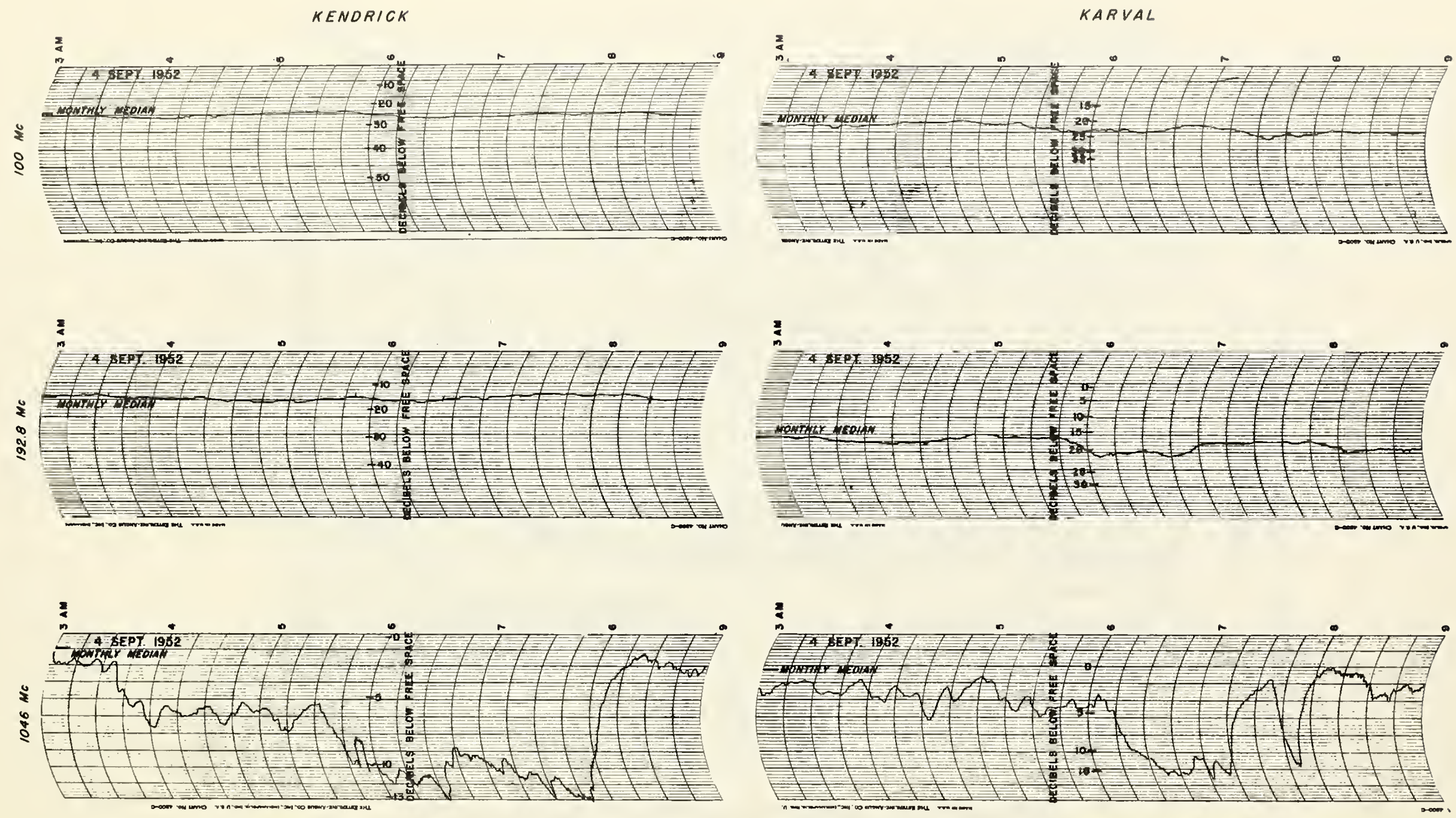


FIG. 13a

ANNUAL DISTRIBUTION OF NORMALIZED OCCURRENCES
OF PROLONGED SPACE WAVE FADE OUTS AT 1046 Mc
AT KARVAL, COLORADO

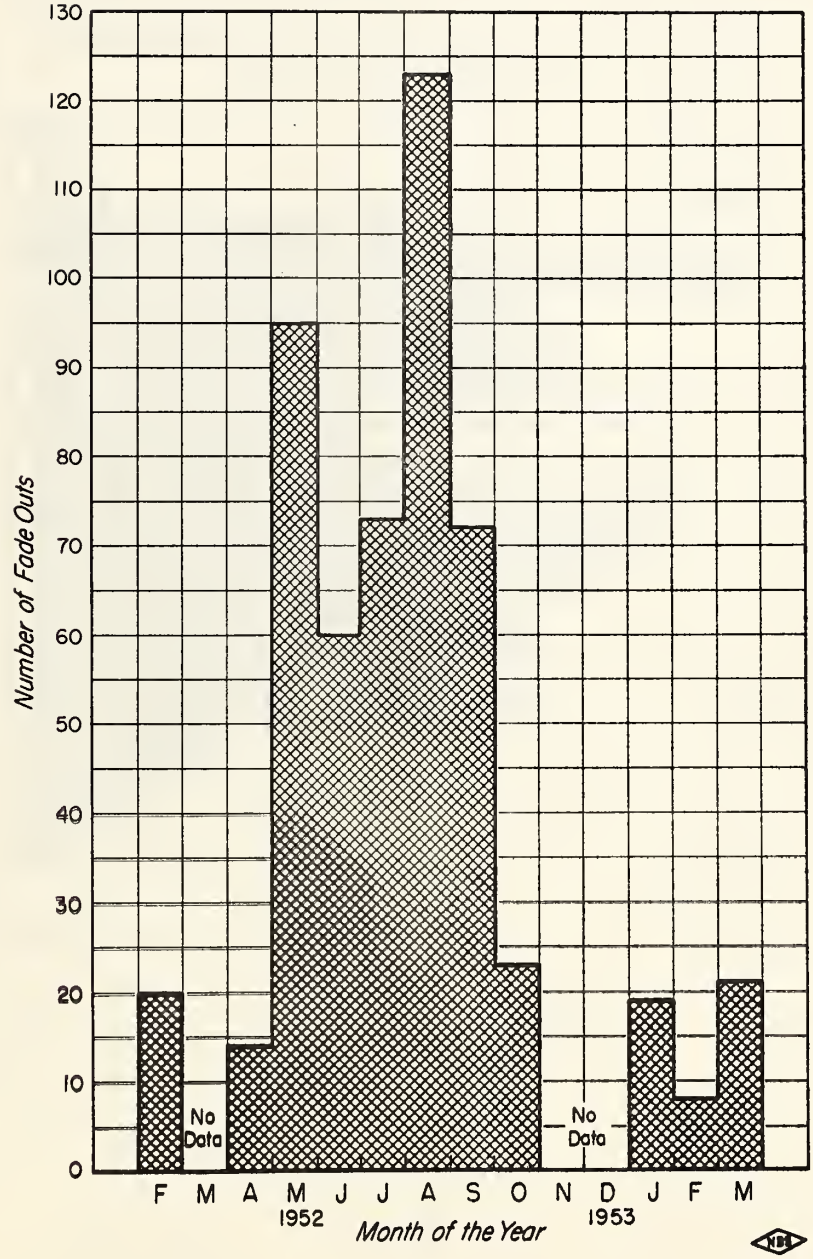


Figure 13b

DIURNAL DISTRIBUTION OF THE 248 PROLONGED SPACE WAVE FADE OUTS THAT OCCURRED AT 1046 Mc AT KARVAL, COLORADO FROM FEBRUARY, 1952 TO JANUARY, 1953

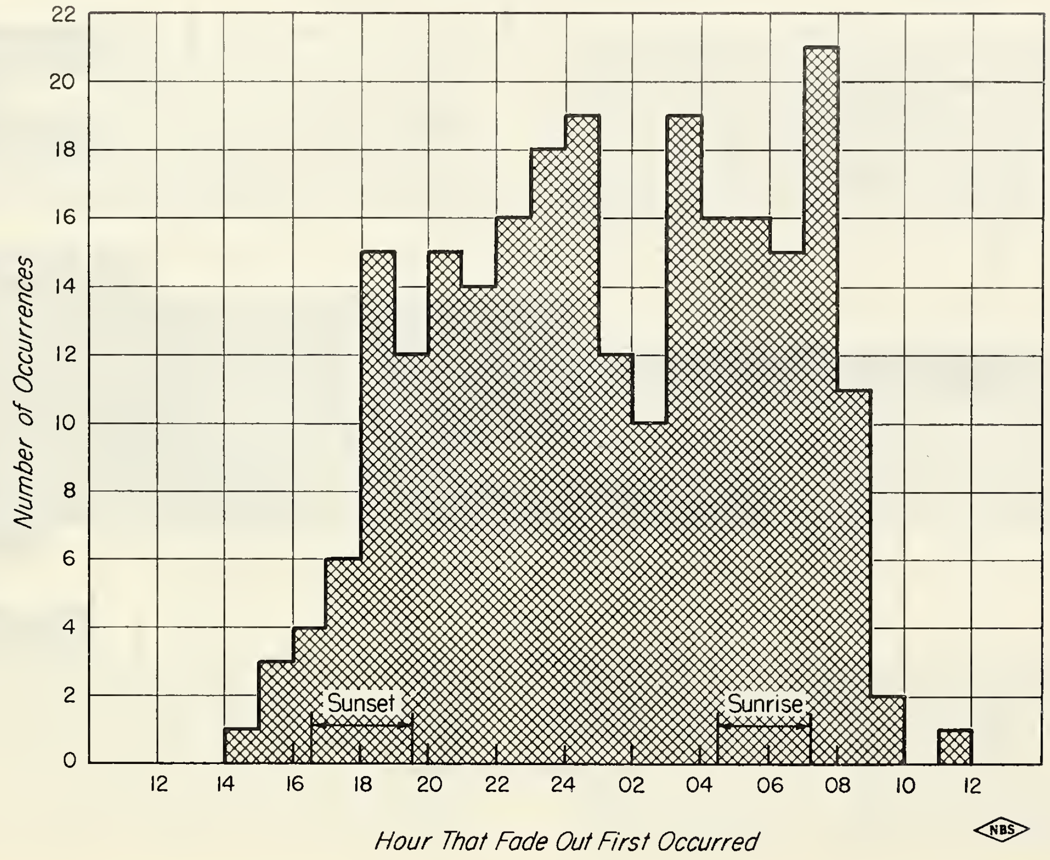


Figure 13c

PERCENT OF TOTAL TIME FOR EACH MONTH THAT THE 1046 Mc FIELD AT KARVAL, COLORADO IS AT LEAST 5, 7, 10, AND 15 DB BELOW THE MONTHLY MEDIAN FIELD DUE TO PROLONGED SPACE WAVE FADE OUTS

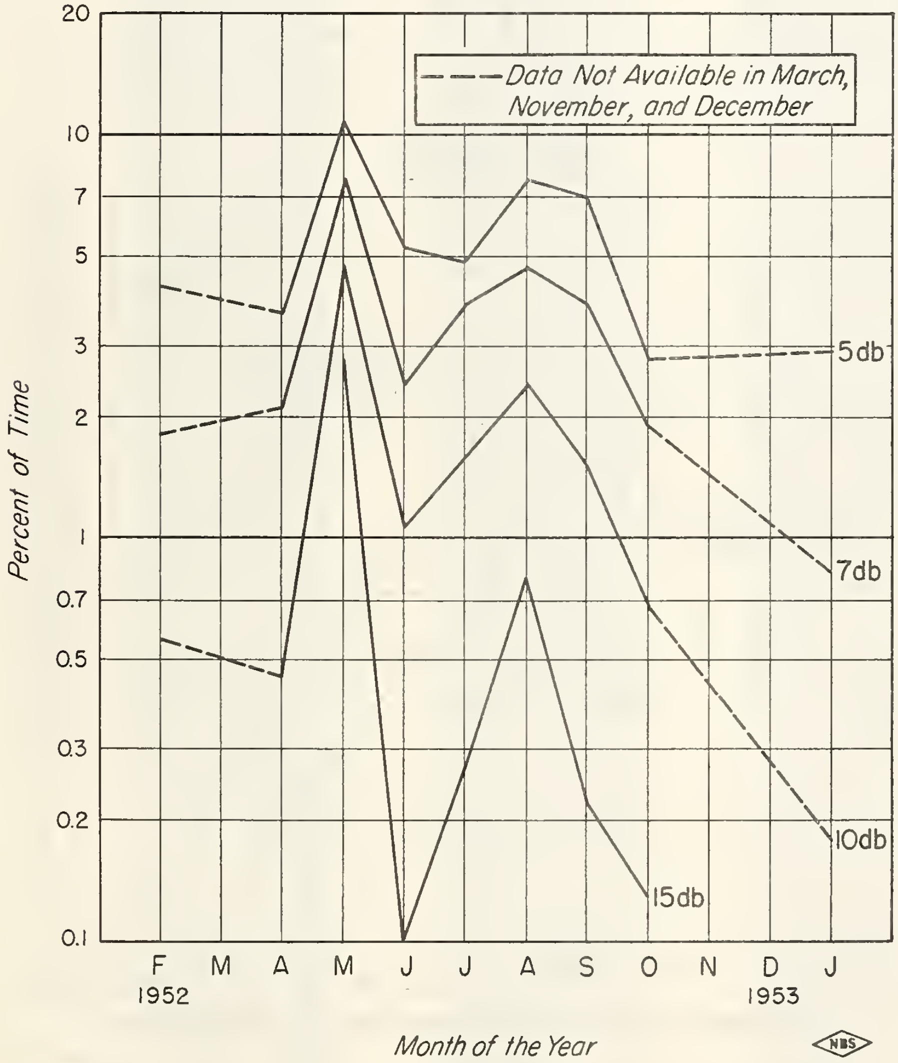


Figure 13d

CUMULATIVE DISTRIBUTION OF THE DURATION OF SPACE-WAVE FADE-OUTS

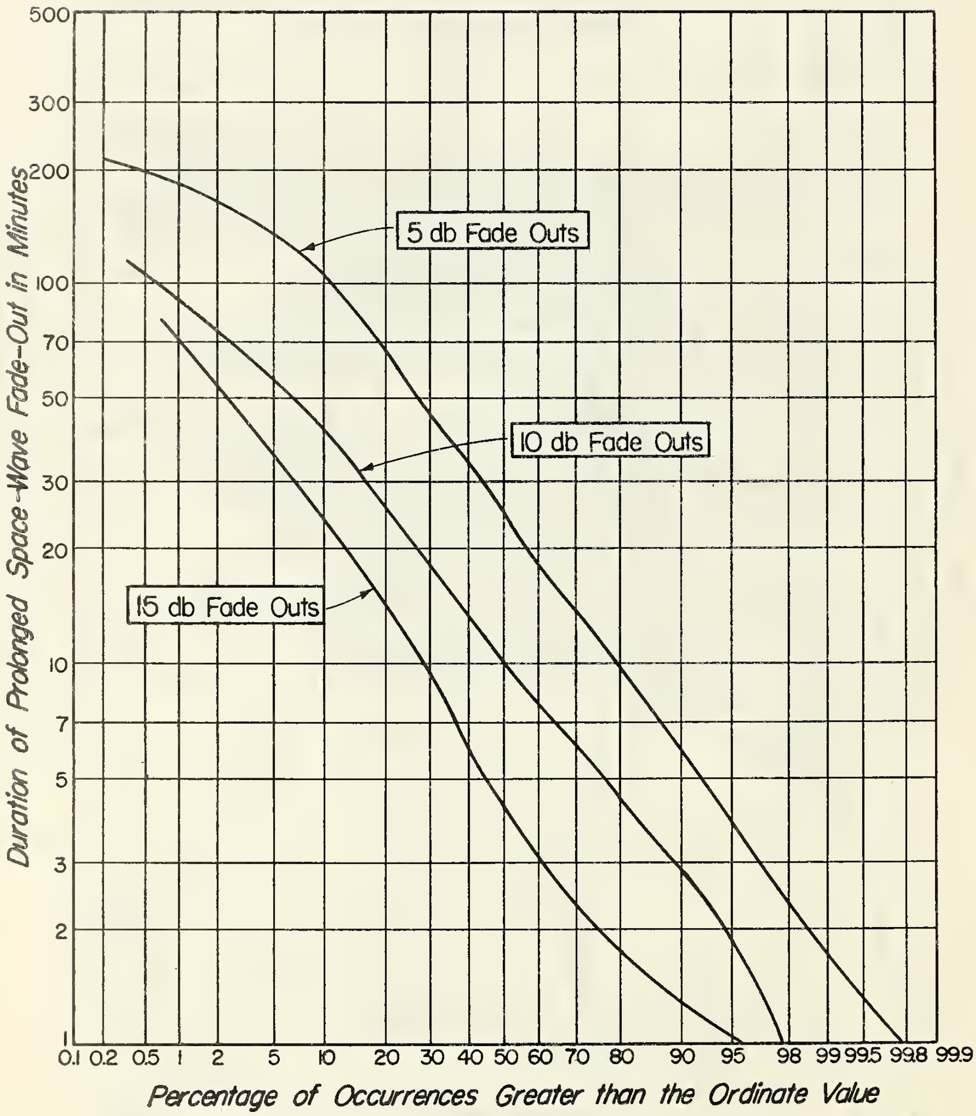


Figure 13 e

1046 Mc FIELDS FOR THE NIGHT OF JUNE 21-22, 1952
AT KENDRICK, KARVAL, AND HASWELL, COLORADO

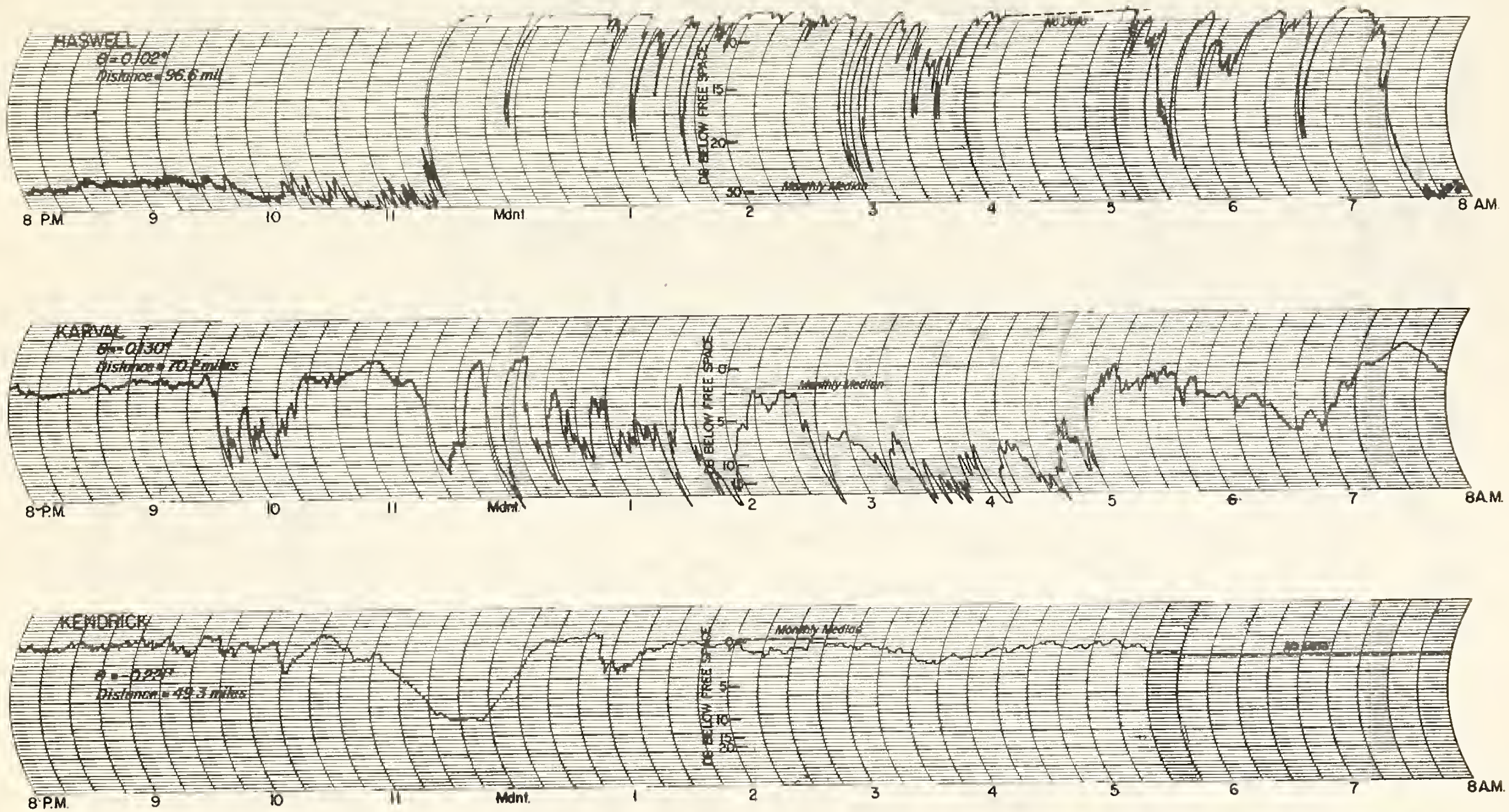


Figure 13 f

N. B. S. Low Level Wiresonde
Haswell, Colorado
June 21-22, 1952

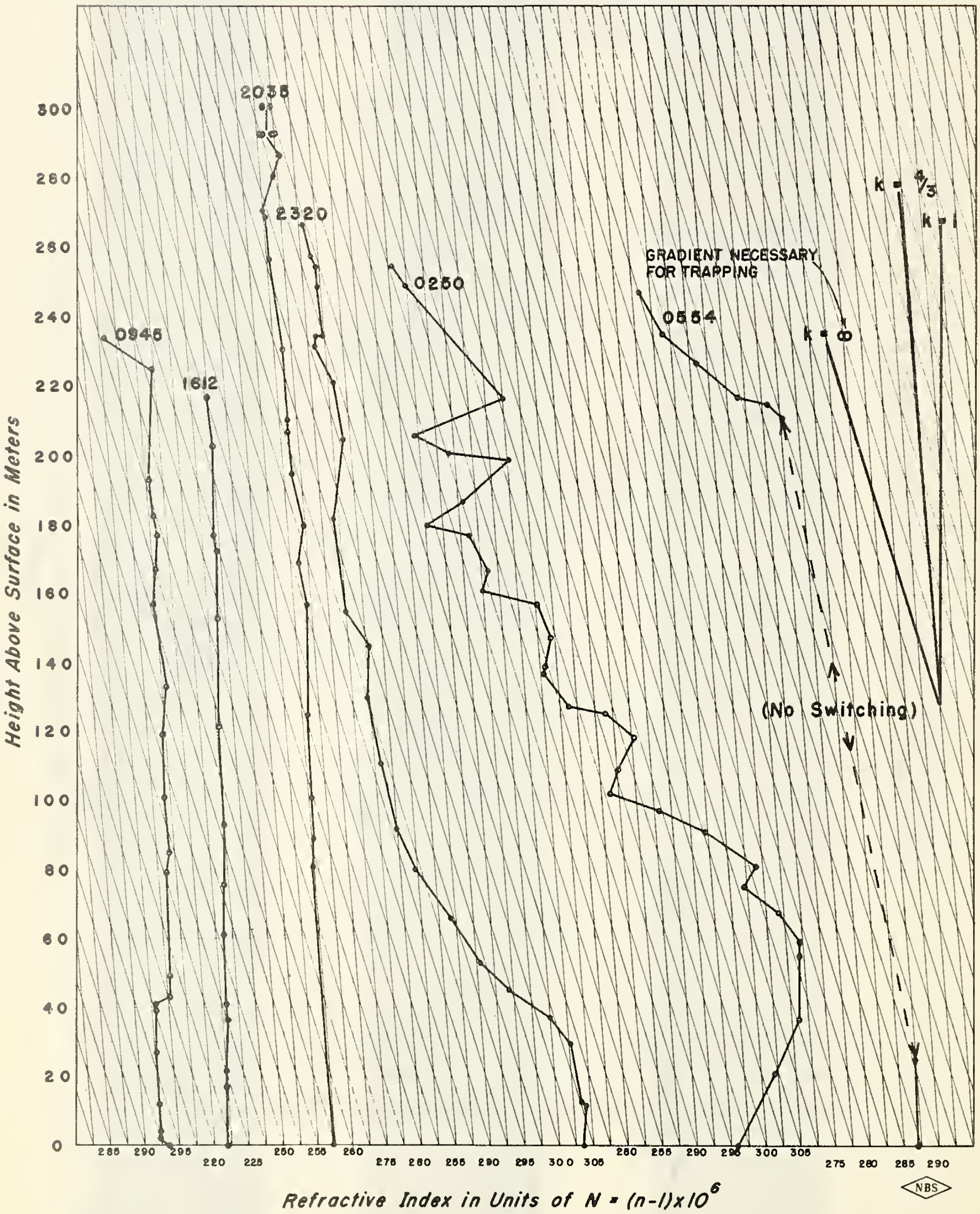
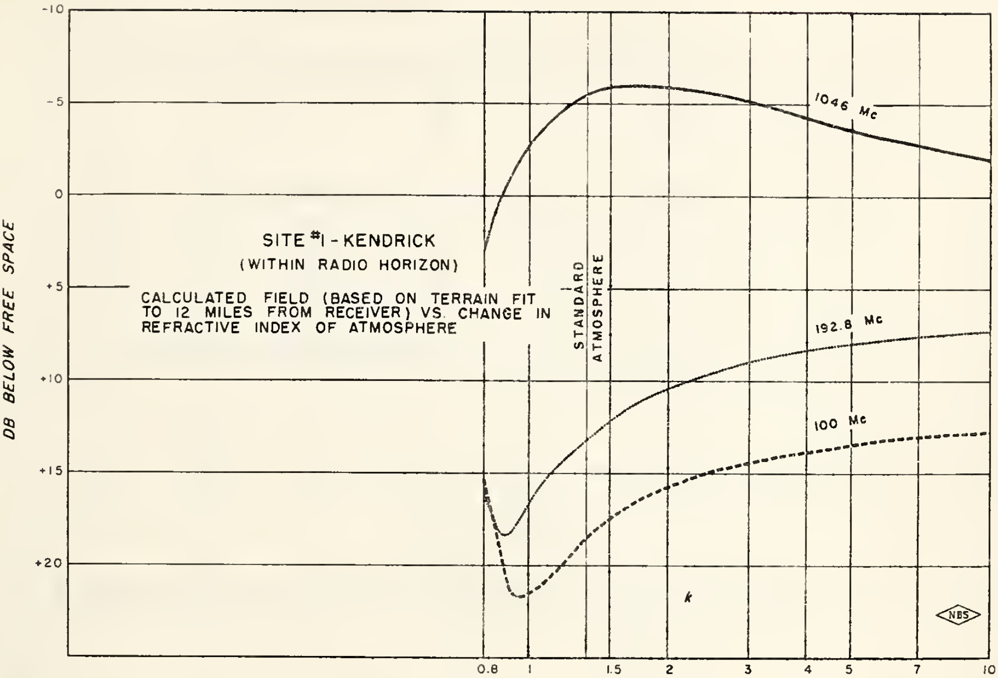


Figure 13g



$$\frac{1}{ka} = \frac{1}{a} + \frac{1}{n_0}\frac{dn}{dh}$$

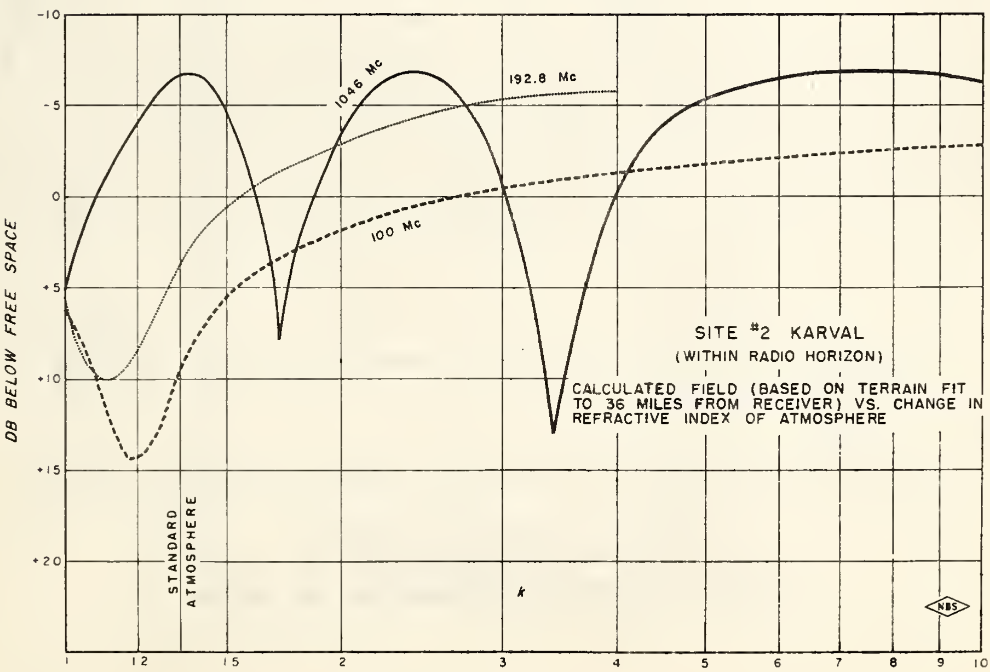


FIG 14a

CHEYENNE MOUNTAIN OPTICAL PATHS
PLOT OF FIELD DEVIATIONS VS. RAYLEIGH'S CRITERION

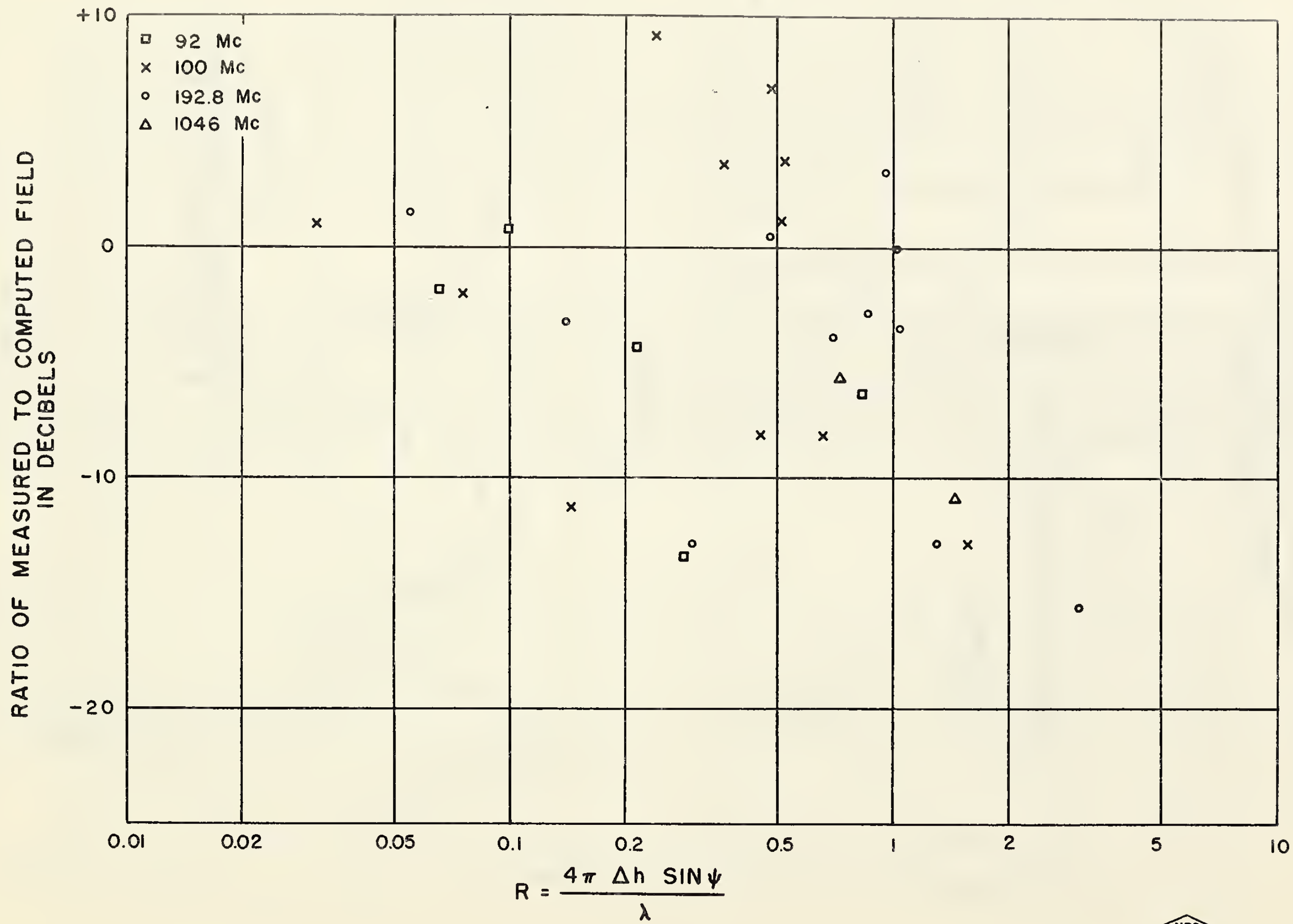


FIG. 14b

CHEYENNE MOUNTAIN OPTICAL PATHS

PLOT OF FIELD DEVIATIONS VS. RAYLEIGH'S CRITERION

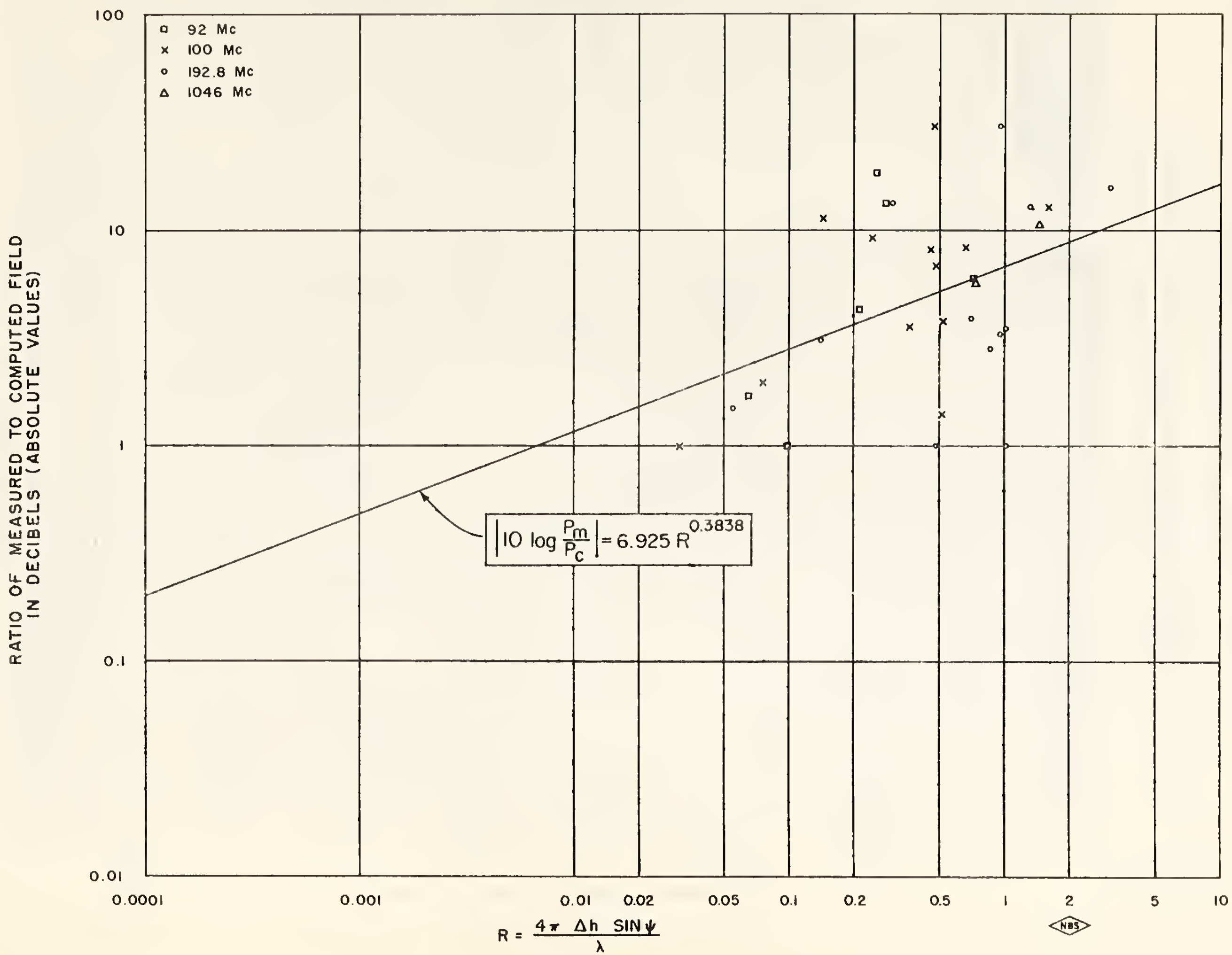


FIG. 14c

MEDIAN ($R_{0.5}$) AND RANGE ($R_{0.1}-R_{0.9}$) FROM THE CUMULATIVE DISTRIBUTION OF THE RESULTANT AMPLITUDE OF A CONSTANT VECTOR PLUS A RAYLEIGH DISTRIBUTED VECTOR

Power in Random Component is ($K-R_{0.5}$) Decibels Relative to the Median Level of the Cumulative Distribution

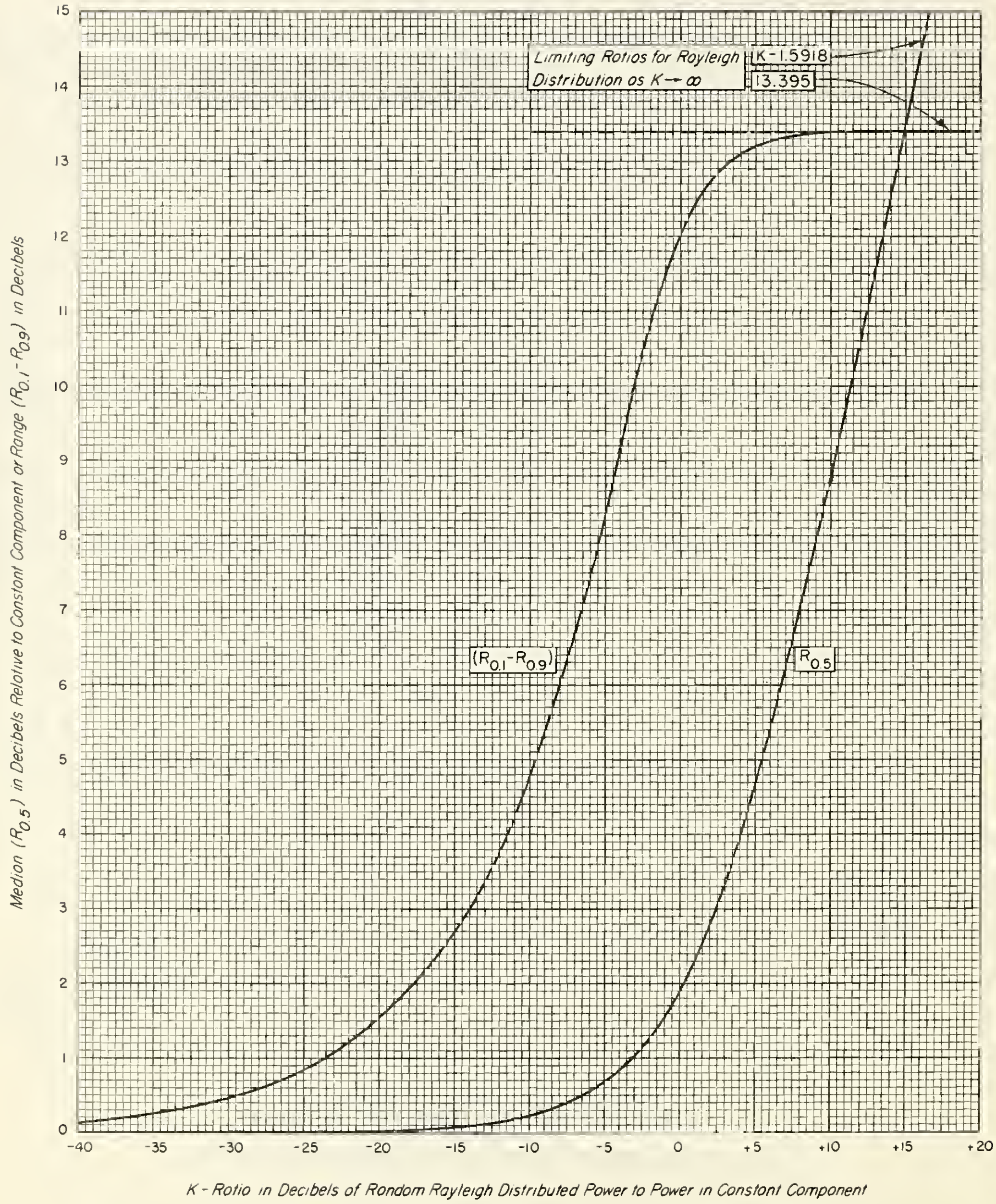


Figure 15a

CORRELATION OF CHEYENNE MOUNTAIN FIELD STRENGTHS RECEIVED ON SPACED ANTENNAS AT GARDEN CITY, KANSAS

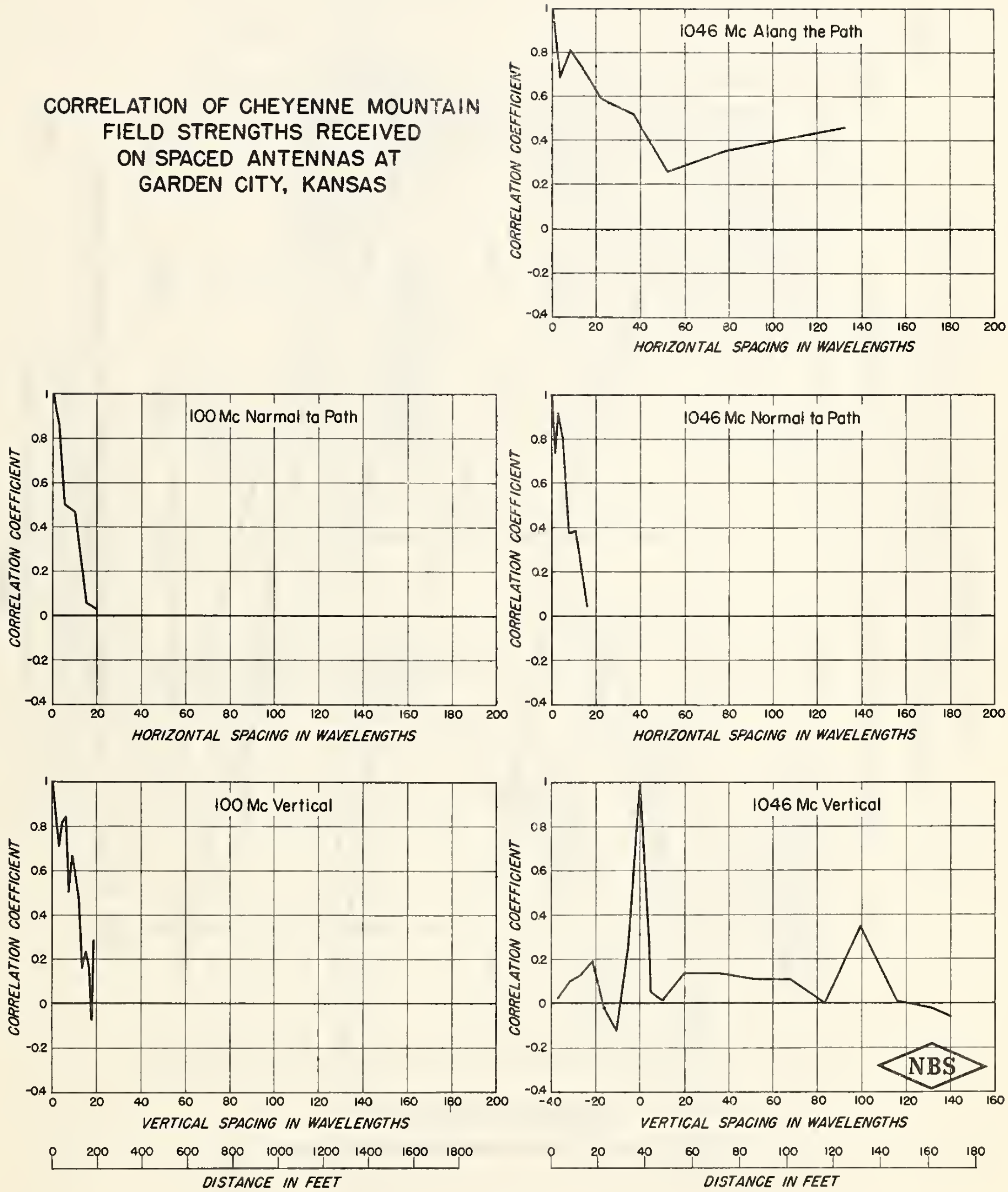


Figure 15b

TENTATIVE ESTIMATE OF LOSS OF ANTENNA GAIN
RELATIVE TO THE FREE SPACE GAIN

[Applicable when $(h_t/\lambda)\cdot\theta>1$ and $(h_r/\lambda)\cdot\theta>1$]

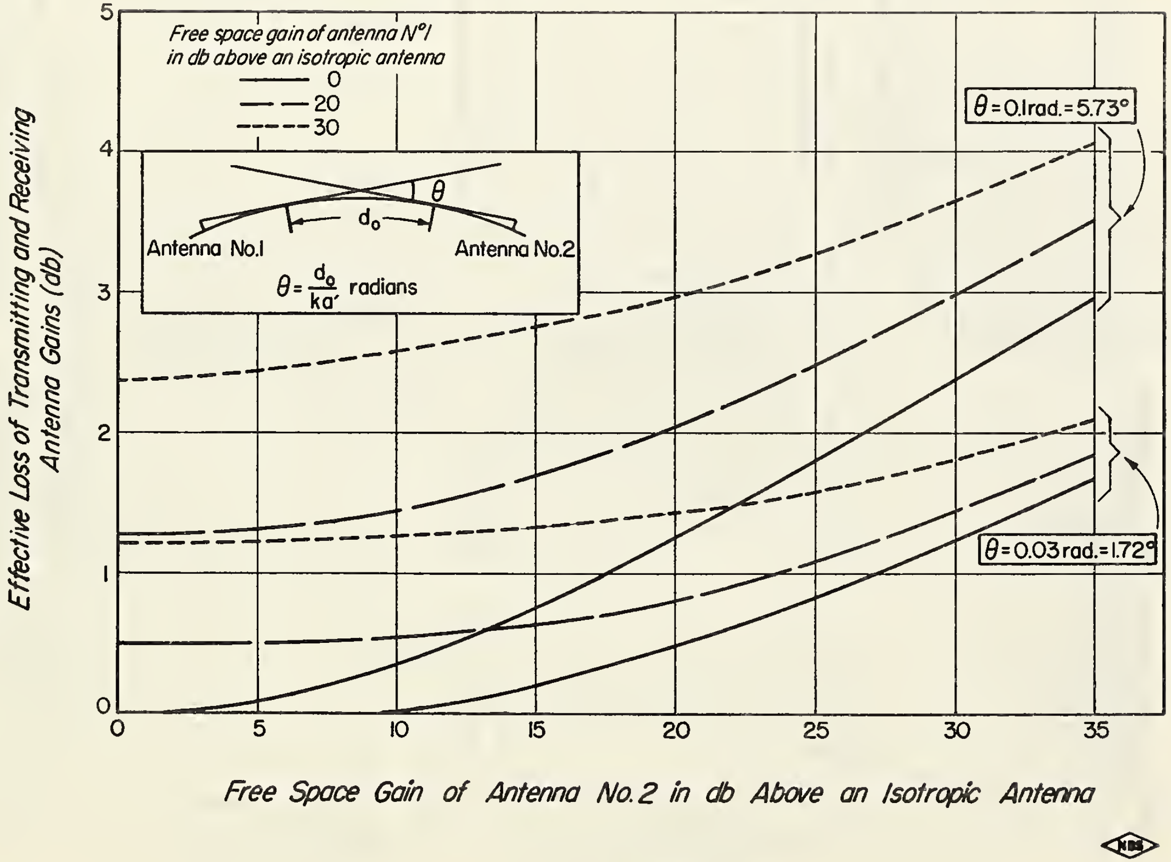


Figure 15 c

HEIGHT GAIN OBSERVATIONS AT GARDEN CITY, KANSAS

Rotios of Medion Fields Observed During 1 to 10 Minute Periods
On Vertically Spoced Antennas

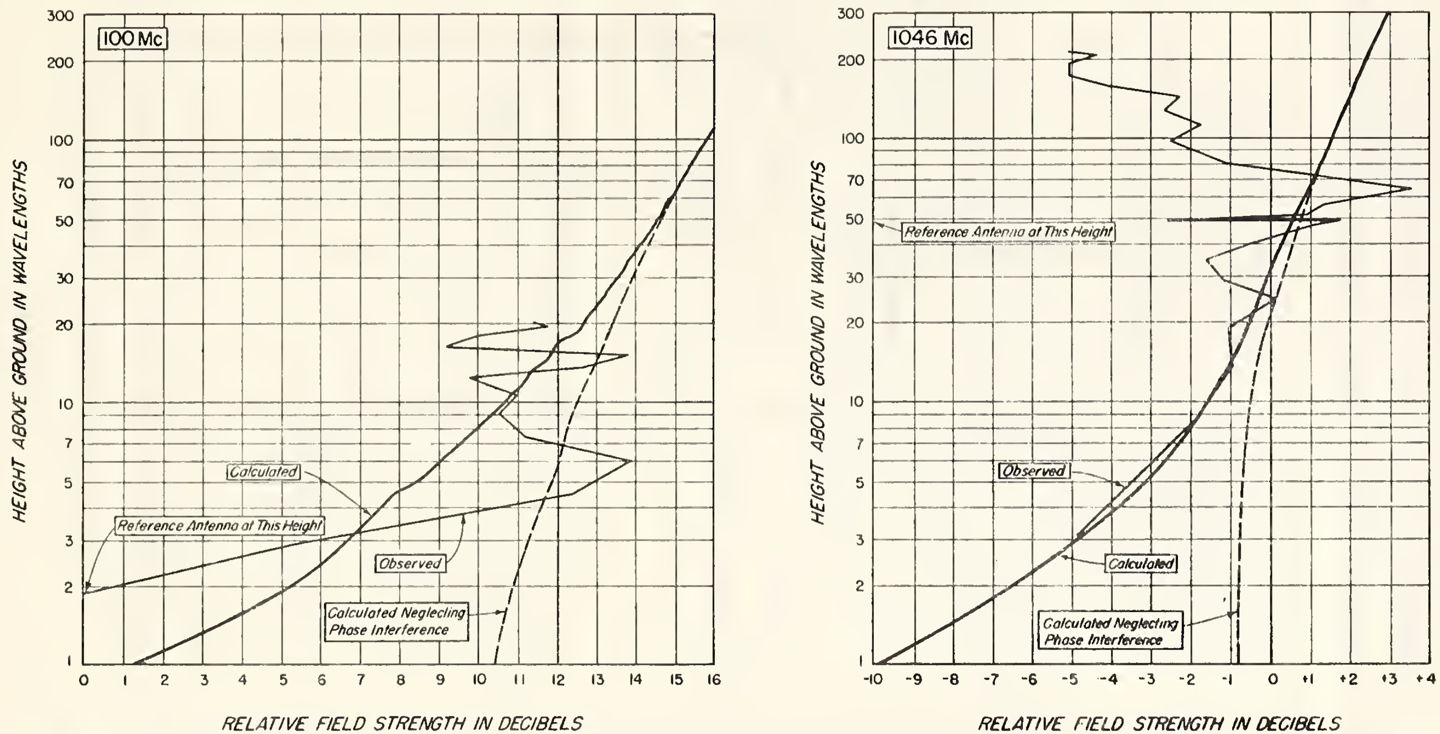


Figure 15d

THEORETICAL OBSTACLE GAINS AT 100 Mc
ASSUMING FOUR-RAY KNIFE-EDGE DIFFRACTION THEORY

Transmitting and Receiving Antenna Heights Each 100 Feet Above the Surface

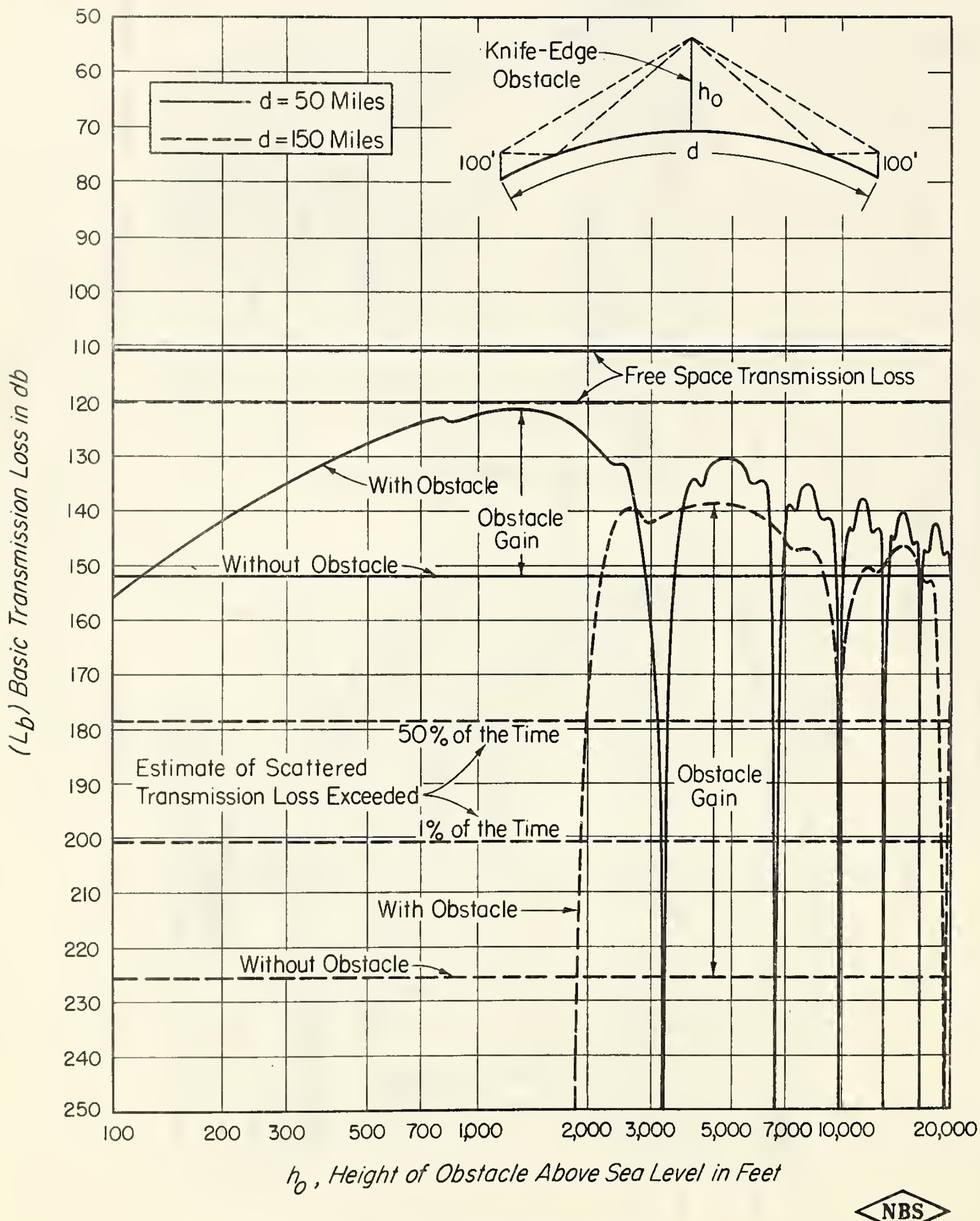


Figure 16a

THEORETICAL OBSTACLE GAINS AT 1,000 Mc
ASSUMING FOUR-RAY KNIFE-EDGE DIFFRACTION THEORY

Transmitting and Receiving Antenna Heights Each 100 Feet Above the Surface

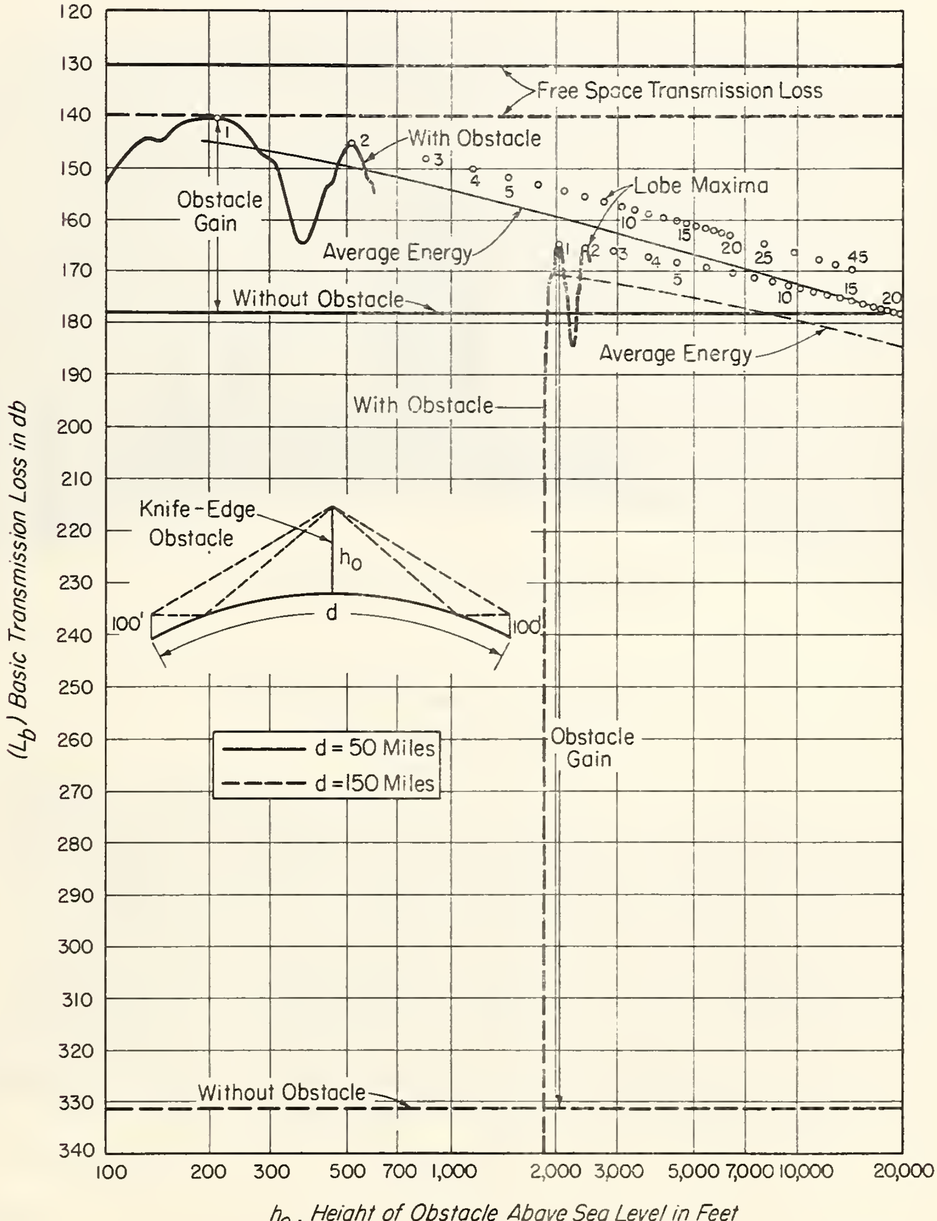
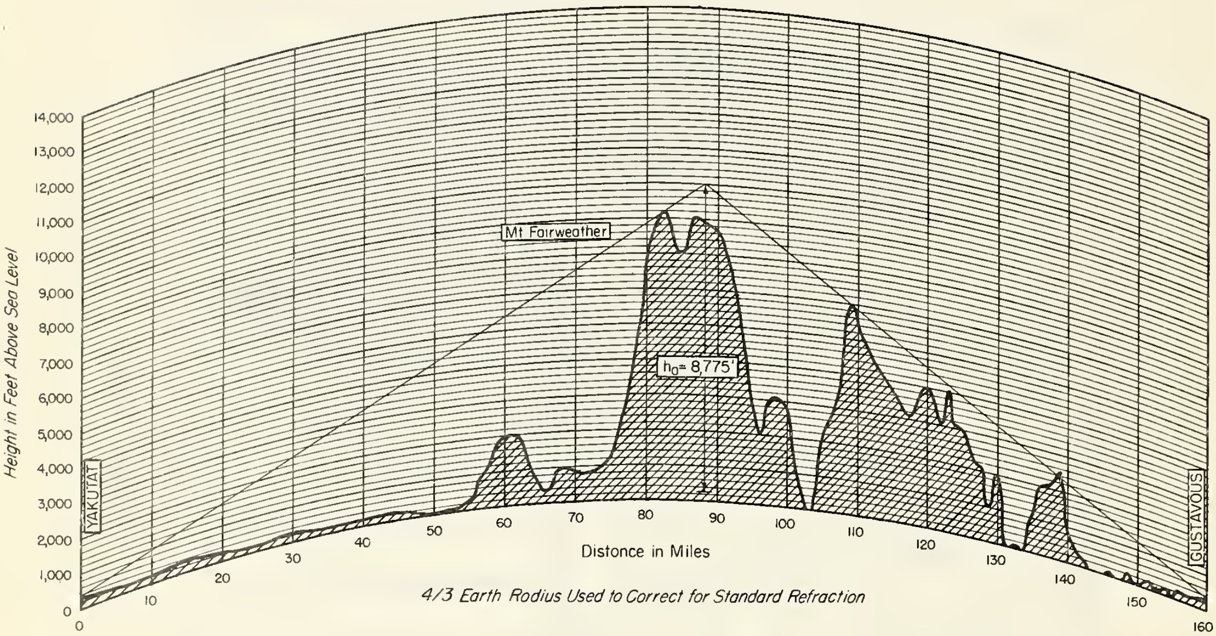


Figure 16b

NBS

PROFILE OF PATH FROM YAKUTAT TO GUSTAVOUS, ALASKA

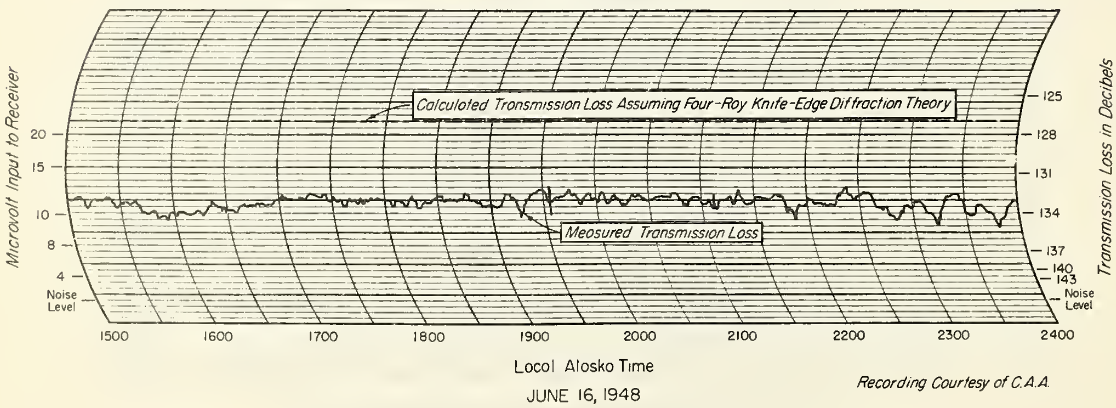
$h_t = h_r = 50$ feet; $f = 38$ Mc



TYPICAL SAMPLE RECORDING ON THE ABOVE PATH

50 Watt Transmitter Power

$h_t = h_r = 50$ Feet



Recording Courtesy of C.A.A.

NBS

Figure 16c

APPENDIX I

to

PROPAGATION OF RADIO WAVES OVER LAND AT 1046 MC

(Report for the Air Navigation Development Board)

* * *

CALCULATION OF THE ANGULAR DISTANCE, θ, OVER IRREGULAR TERRAIN

CALCULATION OF THE ANGULAR DISTANCE, θ, OVER IRREGULAR TERRAIN

We see by Fig. 2e (see also (16), (17) and (18) in Appendix II) that the angular distance, θ, (denoted by $(\alpha_o + \beta_o)$ in Appendix II) is simply equal, over a smooth spherical earth, to the distance between the horizons of the transmitting and receiving antennas divided by the effective radius of the earth, a:-*

$$\theta = \frac{d - d_{Lt} - d_{Lr}}{a} \tag{1}$$

Fig. I-1 shows the geometry involved to take into account the effect of irregular terrain on the determination of α_o; a similar geometry is involved in the determination of β_o.

From this geometry it may be shown that:-

$$\alpha_o = \frac{d}{2a} - \frac{d_{Lt}}{a} + \frac{(h_{ts} - h_{rs})}{d} - \delta_t \tag{2}$$

$$\beta_o = \frac{d}{2a} - \frac{d_{Lr}}{a} - \frac{(h_{ts} - h_{rs})}{d} - \delta_r \tag{3}$$

where

$$\delta_t = \frac{h_{ts} - h_{Lt} - \frac{d_{Lt}^2}{2a}}{d_{Lt}} \tag{4}$$

$$\delta_r = \frac{h_{rs} - h_{Lr} - \frac{d_{Lr}^2}{2a}}{d_{Lr}} \tag{5}$$

$$\theta \equiv \alpha_o + \beta_o = \frac{d - d_{Lt} - d_{Lr}}{a} - \delta_t - \delta_r \tag{6}$$

In the above d_{Lt} and d_{Lr} denote the actual distances to the radio horizons as determined from the terrain profiles plotted for the path, h_{Lt} and h_{Lr} denote the heights above sea level of the terrain at the respective horizons, and h_{Lt} and h_{Lr} denote the antenna heights above the same reference, sea level. The distance to the radio horizon, d_{Lt}, is determined by plotting on linear graph paper the heights, $h_T(x)$, above sea level of the actual terrain at the distances, x, corrected for the effects of the normal earth's curvature and of air refraction, $\left[h_T(x) - \frac{x^2}{2a}\right]$, versus the distance. The farthest unobstructed point on the terrain, as determined on this modified plot, is the radio horizon, and the distance to this point is denoted by d_{Lt}; this is the same procedure as that used by Norton 1/ in a recent paper.

*In Appendices I and II, the symbol a is used for simplicity to denote ka', where a' denotes the actual radius of the earth.

1/ Kenneth A. Norton, "Transmission Loss of Space Waves Propagated Over Irregular Terrain," Trans. of IRE Professional Group on Antennas and Propagation, No. PGAP-3, Aug. 1952; Also published as NBS Report 1737, June 16, 1952.

GEOMETRY FOR IRREGULAR TERRAIN CALCULATIONS

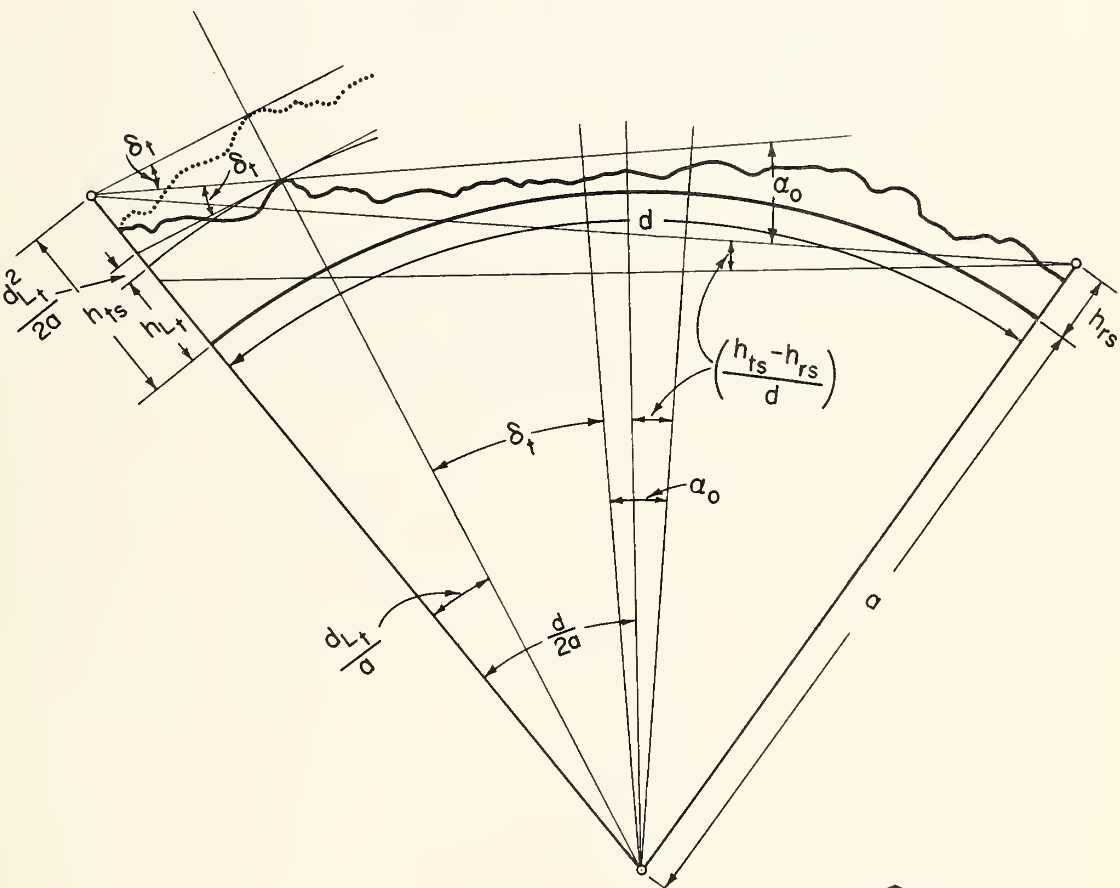


Figure I-1

APPENDIX II

to

PROPAGATION OF RADIO WAVES OVER LAND AT 1046 Mc

(Report for the Air Navigation Development Board)

* * *

TABLES OF PROLONGED SPACE-WAVE FADE-OUTS
OCCURRING ON CHEYENNE MOUNTAIN PATHS
AND
CONCURRENT MEDIAN FIELD STRENGTHS

TABLE I

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
2/1/52	0030-0220	115	25	5	0	0	0	11.3
	2055-2240	105	30	0	0	0	0	9.3
2/2 0900 to 2/20 1500			No Data					
2/21	0300-1000		No Data					
2/21 2200 to 2/22 1400			No Data					
2/25	0422-0553	91	78	65	25	0	0	13.8
2/26	0025-0125	60	30	0	0	0	0	8.4
	0900-1400		No Data					
	1855-1952	45	12	0	0	0	0	9.5
2/27	0047-0302	105	43	0	0	0	0	9.6
2/28	1100-1200		No Data					
	1500-1600		No Data					
	1700-1900		No Data					
2/29 0800 to 4/7 1500			No Data					
4/8	0100-1200		No Data					
4/9 0800-4/10 1000			No Data					
4/11	0350-0635	134	78	10	5	0	0	13.6
4/12	0700-1100		No Data					

TABLE I (Page 2)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
4/13	0700-0800		No Data					
4/14 0100 to 4/16 1500			No Data					
4/16 1700 to 4/18 1300			No Data					
4/18-19	2132-0035	165	100	31	7	0	0	12.3
4/19 0600 to 4/23 1300			No Data					
4/23	2212-2247	25	17	0	0	0	0	9.3
4/24	0000-0800		No Data					
4/24 2000 to 5/7 1400			No Data					
5/7 1800 to 5/12 1400			No Data					
5/12 1900 to 5/13 1500			No Data					
5/13 2100 to 5/22 1400			No Data					
*5/20	1943-2243	177	135	111	-	78	-	>15.5
	2313-2335	18	16	12	-	8	-	>15.5
*5/21	0150-0305	42	35	27	-	13	-	>15.5
	0427-0504	37	34	31.5	-	28	-	>15.5
	2132-2229	36	28	18	-	12	-	>15.5
	2348-0003	15	14	13	-	11	-	>15.5

TABLE I (Page 3)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
*5/22	0028-0101	23	17	7	-	5	-	>15.5
	0238-0349	71	69	64	-	60	-	>15.5
	0547-0629	39	32	28	-	22	-	>15.5
	1814-1858	42	36	28	-	18	10	25*
	2006-2020	8	0	0	-	0	0	7
5/22-23	2308-0123	128	83	49	-	21	13	30*
5/23	1100-1200		No Data					
5/24-25	2150-0210	192	121	42	-	1	0	15.5
5/25	0552-0614	7	0	0	0	0	0	6
	0715-0719	4	0	0	0	0	0	5.5
	1500-1700		No Data					
	1812-1818	5	0	0	0	0	0	5.7
	2225-2237	10	0	0	0	0	0	7
5/26	0150-0229	28	0	0	0	0	0	6
	0836-0857	8	6	3	1	0	0	14
	1200-1400		No Data					
	1647-1742	50	32	3	0	0	0	11
	1800-2300		No Data					

*These values or the values for these days are estimated.

TABLE I (Page 4)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
5/27	0700-0800		No Data					
	1200-1400		No Data					
	2054-2317	143	120	45	36	-	-	>13.5
5/28	1400-1700		No Data					
5/29 1300 to 6/4 1200			No Data					
6/5	0406-0413	7	0	0	0	0	0	5.7
	0648-0656	8	6	5	0	0	0	11.7
	1400-1600		No Data					
	2000-2200		No Data					
6/6	0543-0604	16	8	0	0	0	0	10
6/7	0605-0608	3	0	0	0	0	0	6.7
6/7 1500 to 6/9 1600			No Data					
6/9	2000-2100		No Data					
	2132-2205	33	30	20	-	12	-	>15
	2309-2348	14	9	5	-	4	-	>15
6/10	0007-0022	15	10	8	-	5	-	>15
	0152-0240	33	21	11	-	6	-	>15
	0440-0648	53	21	0	0	0	0	10

TABLE I (Page 5)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
6/10	0700-1300		No Data					
6/11	0216-0235	19	12	0	0	0	0	9.3
	0416-0546	90	3	0	0	0	0	7.9
	1000-1200		No Data					
6/12	0100-0300		No Data					
	0343-0403	17	8	0	0	0	0	10
	0518-0545	27	24	14	-	-	-	>10.7
	0710-0723	8	6	4	0	0	0	10.4
	1100-1700		No Data					
	2032-2306	127	65	8	-	-	-	>10.7
6/13	0050-0155	53	28	12	-	-	-	>10.7
	0312-0329	8	2	0	0	0	0	7.3
	0415-0536	55	36	25	-	-	-	>10.7
	1000-1200		No Data					
6/14	0017-0233	62	39	24	16	-	-	>13.7
	0604-0626	22	12	0	0	0	0	9.2
	0700-0710	10	9	4	-	-	-	13.7*
	2037-2110	20	0	0	0	0	0	6.5

*These values are estimated.

TABLE I (Page 6)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
6/15	0207-0247	20	0	0	0	0	0	6.2
6/15 2300 to 6/16 0200			No Data					
6/16 1200 to 6/17 1200			No Data					
6/17	2036-2045	6	0	0	0	0	0	6.5
	2210-2337	67	13	4	0	0	0	11
6/18	0119-0345	120	35	0	0	0	0	8.6
	0900-1000		No Data					
6/19	0000-0100		No Data					
	1700-2100		No Data					
6/20	0100-0200		No Data					
	0402-0416	14	9	2	0	0	0	12
	0603-0652	49	27	10	0	0	0	10.9
6/21	0600-0900		No Data					
	1100-1200		No Data					
6/21-22	2333-0204	59	36	16	14	0	0	13.2
6/22	0204-0242	Rapid and Deep Fading						
	0242-0501	115	73	46	38	-	-	> 13.7
	1000-2100		No Data					

TABLE I (Page 7)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in D
		5 db	7 db	10 db	12 db	15 db	20 db	
6/23	0149-0254	65	49	35	12	-	-	>13.7
	0900-1000		No Data					
	2200-2300		No Data					
6/24	1000-1500		No Data					
6/24 2100 to 6/26 1400			No Data					
6/26	1500-1700		No Data					
6/26-27	2322-0047	41	18	8	5	-	-	>13.7
6/27	0313-0334	14	1	0	0	0	0	7.4
	0720-0739	19	15	11	0	0	0	12
	0900-1600		No Data					
6/28	0100-0200		No Data					
	0428-0628	77	24	7	3	0	0	12.2
	0855-0909	14	0	0	0	0	0	7.0
6/30	1522-1610	25	13	8	3	0	0	13.7
6/30 2200 to 7/2 1400			No Data					
7/2	1500-1600		No Data					
7/3	0800-1100		No Data					
	1300-1400		No Data					

TABLE I (Page 8)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
7/3	1737-2028	109	76	27	20	–	–	>14
	2028-2301	Rapid and Deep Fading						
	2301-2351	16	13	2	1	–	–	>14
7/4	0104-0331	45	25	11	6	–	–	>14
7/4 0331 to 7/5 0300		Rapid and Deep Fading						
7/5	0300-0800	No Data						
	0800-2353	Rapid and Deep Fading						
7/5-6	2353-0018	16	12	0	0	0	0	9.1
7/6	0300-0500	No Data						
	0608-0706	18	7	0	0	0	0	8.1
	2157-2215	18	10	0	0	0	0	8.9
	2340-2350	7	0	0	0	0	0	6.8
7/7	0900-1700	No Data						
	1900-2100	No Data						
	2124-2202	38	30	2	0	0	0	10.6
7/8	0000-0300	No Data						
	0900-1800	No Data						
	2204-2325	68	27	20	12	–	–	>12
7/9	0100-0200	No Data						

TABLE I (Page 9)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
7/9	0513-0659	103	50	19	6	-	-	>12
7/10 1200 to 7/15 0200			No Data					
7/15 0800 to 7/17 1300			No Data					
7/17	1450-1528	27	16	1	0	0	0	10.6
	1625-1644	19	12	1	0	0	0	10.6
	1733-1807	34	24	0	0	0	0	9.3
	1931-2046	75	61	39	0	0	0	11.6*
7/18	0300-0500		No Data					
	1100-1600		No Data					
	2100-2200		No Data					
	2246-2322	36	31	22	18	7*	0	16*
7/19	0048-0140	50	46	36	25	14	0	16*
	0358-0416	18	7	0	0	0	0	8.1
7/19 1000 to 7/28 2200			No Data					
7/29	0900-1800		No Data					
7/30	0000-0100		No Data					
	0400-1600		No Data					
	1727-1737	10	8	3	2	0	0	13.6

*These values are estimated.

TABLE I (Page 10)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
7/30	1807-1820	13	11	7	6	3	0	18.5*
	1858-1948	23	11	8	7	2	0	17*
	1955-2245	39	31	20	16	10	0	18.5*
	2321-2350	11	8	3	0	0	0	12
7/31	0021-0115	33	20	7	6	4	0	18.5*
	*0332-0345	13	10	7	5	0	0	14.9
	0300-0400	Missing Data						
	0600-1000	Missing Data						
	2300-2400	Missing Data						
8/1	1906-2028	47	40	17	6	1	0	16.1
	2057-2313	104	100	85	72	59	35	25.2*
8/2	0055-0104	9	5	4	0	0	0	10.4
	0200-0400	Missing Data						
	0536-0554	18	12	8	6	3	0	20*
	0700-0800	Missing Data						
	*0744-0748	4	3	2	0	0	0	10.4
	1534-1724	64	44	27	10	2	0	18*
	2005-2143	73	62	57	24	4	0	17.2

*These values or the values for these times are estimated.

TABLE I (Page 11)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
8/3	0200-0300	Missing Data						
	0552-0651	13	10	9	4	2	-	20*
	0700-0800	Missing Data						
	1700-1800	Missing Data						
8/3 2000 to 8/7 1500		Missing Data						
8/7	1620-1810	54	24	2	0	0	0	13.1
	1800-1900	Missing Data						
8/8	0059-0235	37	23	12	10	8	-	>16*
	0357-0400	2.0	1.5	1	0.5	0.3	-	>16*
	1100-1200	Missing Data						
	1949-2036	41	28	8	0	0	0	11.7
8/8-9	2200-0047	142	31	0	0	0	0	8.2
8/9	1544-1947	154	87	43	22	19	-	>19*
	2131-2210	39	27	5	0	0	0	10.5
8/10	0032-0052	10	2	0	0	0	0	8.2
	0305-0607	153	124	65	40	29	0	16*
	1738-1806	28	25	18	14	11	0	20
	2054-2059	5	4	0	0	0	0	9.5

*These values are estimated.

TABLE I (Page 12)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
8/10	2155-2233	7	0	0	0	0	0	7
	2224-2228	4	3	2	1.5	1	0	20*
8/11	0012-0029	17	9	3	0	0	0	11.1
	0106-0209	38	24	8	4	1.5	0	15.2
	1300-1400	Missing Data						
	1600-2000	Missing Data						
8/12	0500-0504	4	2	1	0	0	0	10.4
	0828-0830	2	1	0	0	0	0	8.0
	0956-0959	3	0.2	0	0	0	0	7.6
	2225-2244	9	6	0.2	0	0	0	10.7
	2205-2230	20	16	11	8	5	-	>17*
8/13	0044-0114	30	26	16	12	8	-	>17
	0506-0558	41	26	3	0	0	0	11.2
	0736-0739	3	0	0	0	0	0	6.2
	1500-1600	Missing Data						
	2126-2204	37	21	6	1.5	0	0	12.2
8/15	0253-0345	52	37	15	7	2	0	16*
	0424-0436	10	8	6	1	0	0	13.2

*These values are estimated.

TABLE I (Page 13)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
8/15	0655-0705	10	6	4	2	1.5	0	16*
	1400-1500	Missing Data						
8/16	0728-0739	11	9	6	2	0	0	14.2
	1400-1700	Missing Data						
8/16 2300 to 8/17 0300		Missing Data						
8/17	0355-0442	23	14	9	5	2	-	>15.2
8/17 1500 to 8/20 1100		Missing Data						
8/20 1500 to 8/21 1500		Missing Data						
8/22	1200-1300	Missing Data						
	1400-1700	Missing Data						
	1900-2000	Missing Data						
8/23	0237-0239	2	0	0	0	0	0	5.8
	0300-0400	Missing Data						
	0344-0536	28	13	8	2	0	0	16.9
	0617-0627	10	6	4	3	1	0	16.9
	0653-0656	3	2	0	0	0	0	7.7
	0726-0755	20	14	3	1	0	0	12.4
	0839-0911	13	4	2	1	0	0	13.2
	0947-1046	27	15	8	0.5	0	0	12.7
	0345-1046	Rapid and Deep Fading						
	1300-1400	Missing Data						
	1900-2200	Missing Data						

*These values are estimated.

TABLE I (Page 14)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
8/23	2233-2253	20	17	15	12	8	2	>21
8/23-24	2331-0057	53	33	13	6	4	3	>21
8/24	0057-0150	Rapid and Deep Fading						
	0150-0225	14	3	0	0	0	0	10
	0340-0431	41	32	8	5	0.5	0	16.2
	0506-0528	11	3	0	0	0	0	8.5
	0858-0942	14	4	0	0	0	0	9.2
	1710-1830	53	29	12	8	5	3	>21
	1900-1936	26	6	0	0	0	0	8.7
	*2017-2200	87	36	15	4	2.5	0	16.7
	2100-2200	Missing Data						
8/25	0300-0428	41	5	0	0	0	0	8.2
	0509-0545	36	30	12	5	3	1	>21
	0814-0830	16	13	9	5	0	0	15
	1958-2010	12	0	0	0	0	0	6.4
	2143-2151	8	0	0	0	0	0	5.6
8/26	0628-0629	1	0	0	0	0	0	6.8
	0736-0743	7	0	0	0	0	0	6.8

TABLE I (Page 15)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
8/26	1300-1400	Missing Data						
	2017-2051	23	10	0	0	0	0	9.8
	2138-2213	27	14	8	5	0.5	0	15.4
8/27	0750-0757	7	6	0	0	0	0	9.5
	1841-1847	6	5	4	3	0	0	14.4
8/27-28	2225-0104	71	24	14	9	3	1	>21
8/28	0307-0324	16	11	7	5	3	0.5	>21
	0421-0448	14	11	6	4	3	2	>21
	0557-0600	3	2	0.5	0	0	0	10.7
	1758-1828	18	9	0	0	0	0	9.8
	1902-1914	12	0	0	0	0	0	6.9
	1949-2008	18	14	0.5	0	0	0	11.4
	2040-2042	2	0	0	0	0	0	5.7
	2105-2113	8	1.5	0	0	0	0	7.8
	2246-2249	3	0	0	0	0	0	6.0
8/28-29	1800-0400	Rapid and Deep Fading						
8/29	0316-0352	23	13	0	0	0	0	9.9
	0700-0800	Missing Data						

TABLE I (Page 16)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
8/29	1200-1400	Missing Data						
	1854-1902	8	7	6	5	3	0.5	20*
	1931-1951	20	14	5	3	1	0	16.8
	2012-2044	31	19	9	8	5	3	>21
	2116-2155	40	36	28	26	22	10	>21
	2244-2328	39	30	22	15	1.5	0	17.5
8/30	0017-0053	39	27	24	21	14	7	>21
	0236-0347	31	29	18	16	14	7	>21
	0707-0732	18	3	0	0	0	0	8.2
	0807-0811	4	2	0	0	0	0	8.4
	2208-2235	23	14	7	5	0	0	15
8/31	0415-0455	38	31	24	17	13	6	>21
	0725-0744	19	14	12	8	3	1	>21
9/2	0550-0615	10	0	0	0	0	0	7
	0654-0707	16	12	2	0	0	0	10.7
	1100-1300	Missing Data						
	1917-2003	42	32	5	0	0	0	12
9/3	0159-0353	108	68	37	24	7	0	17.9

*These values are estimated.

TABLE I (Page 17)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
9/3	0757-0802	5	4	3	2	1	1	>21.6
	2213-2240	25	14	7	3	0	0	13.3
9/3-4	2341-0007	24	10	0	0	0	0	8.4
9/4	0615-0754	76	67	55	35	2	0	15.7
	1200-1300	Missing Data						
	1700-1900	Missing Data						
	2059-2207	68	59	48	46	37	14	>21.6
9/5	0023-0034	11	9	6	5	4	2	>21.6
	1100-1300	Missing Data						
	1835-2055	88	50	14	11	5	0	16.2
9/5-6	2309-0010	48	26	6	2	0	0	13.1
9/6	0257-0313	7	0	0	0	0	0	6.9
	0348-0730	116	81	40	25	5	0	16.8
9/7	0300-0600	Missing Data						
	0706-0714	8	0	0	0	0	0	6.5
9/8	0125-0140	7	0	0	0	0	0	5.6
	0302-0410	58	21	3	0	0	0	11.6
	0521-0536	12	0	0	0	0	0	6.9
	0717-0752	34	8	0	0	0	0	8.3

TABLE I (Page 18)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
9/8	1300-1400	Missing Data						
9/8 2300 to 9/9 0200		Missing Data						
9/9	0255-0352	43	32	4	0	0	0	10.6
	0632-0646	12	5	0	0	0	0	8.4
	0751-0800	9	3	0	0	0	0	8.9
	1000-1600	Missing Data						
	1700-2400	Missing Data						
9/10	0130-0210	32	2	0	0	0	0	7.3
	1300-1500	Missing Data						
	2100-2300	Missing Data						
9/11	0000-0500	Missing Data						
	1100-1400	Missing Data						
9/12	0011-0014	3	1	0	0	0	0	7.4
	0238-0257	17	16	10	5	1	0	15.9
	0405-0413	8	5	3	0	0	0	11.6
	0711-0757	44	28	12	1	0	0	12.9
	1400-1500	Missing Data						
	1700-1800	Missing Data						

TABLE I (Page 19)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 KC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
9/12	2343-2351	5	3	0	0	0	0	10
9/13	0704-0716	4	0	0	0	0	0	6.6
	1851-1925	32	4	0	0	0	0	7.7
9/14	1600-2300	Missing Data						
9/15	0447-0451	4	0	0	0	0	0	6.7
	0641-0705	20	10	6	4	2	0	19.4
	1106-1149	35	23	3	0	0	0	11.2
	1200-1300	Missing Data						
	*1851-1915	23	17	-	-	-	-	Off Scale
	1900-2000	Missing Data						
	2040-2110	27	7	0	0	0	0	10
	2336-2349	14	8	0	0	0	0	10
9/16	0050-0223	70	27	0	0	0	0	9.4
	0305-0516	73	47	21	13	6	3	> 21.6
	0702-0713	11	10	6	4	3	2	> 21.6
	0818-0833	17	11	1	0	0	0	10.6
	1000-1100	Missing Data						
	1643-2318	120	46	33	15	2	0	18.1

*The values for these times are estimated.

TABLE I (Page 20)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
9/17	0422-0727	165	122	60	47	40	30	>26.6
	1900-2000	Missing Data						
	2225-2322	40	31	19	2	0	0	12.2
9/18	0528-0735	126	88	42	16	6	2	22.6
	1400-1500	Missing Data						
9/19	0140-0205	25	16	0	0	0	0	9.6
	0530-0543	11	1	0	0	0	0	7
	0754-0805	12	10	0	0	0	0	9.6
9/20 1000 to 9/22 1500		Missing Data						
9/23	1100-1200	Missing Data						
	1841-2120	37	0	0	0	0	0	6.9
9/24	0400-0600	Missing Data						
	0747-0800	14	8	0	0	0	0	9.6
	1954-2222	130	28	0	0	0	0	8.1
9/25	0807-0825	20	4	0	0	0	0	8.1
	1600-1700	Missing Data						
9/26	1300-1400	Missing Data						
	1858-2058	122	85	45	20	0	0	14.1

TABLE I (Page 21)

PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
9/26-27	2342-0152	69	36	0	0	0	0	10
9/27 0900 to 9/30 1300		Missing Data						
9/30	1800-1900	Missing Data						
10/1	1000-1100	Missing Data						
	1400-1600	Missing Data						
10/2	1200-1300	Missing Data						
10/3	0049-0154	65	53	13	0	0	0	11.6
	0432-0530	55	25	0	0	0	0	10
	0658-0738	43	31	20	15	10	-	>16.6
10/5	0800-1200	Missing Data						
10/6 0700 to 10/8 1700		Missing Data						
10/9	0440-0536	55	38	20	0	0	0	12
	0900-1300	Missing Data						
10/9 2200 to 10/10 0500		Missing Data						
10/10	1300-1400	Missing Data						
10/10 1800 to 10/13 1600		Missing Data						
10/14	0000-0400	Missing Data						
10/14 1000 to 1/13/53 1500		Missing Data						

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PROLONGED SPACE-WAVE FADE-OUTS FOR THE PERIOD
JANUARY 1, 1952 TO FEBRUARY 1, 1953
(OCCURRENCES OF DIPS IN FIELD ON 1046 MC AT KARVAL, COLORADO
THAT ARE AT LEAST 5 DB FOR ONE MINUTE OR MORE
BELOW THE MONTHLY MEDIAN FIELD)

Date	Time of Occurrence	Length of Time in Minutes Signal Was At Least the Indicated Level Below Monthly Median						Maximum Depth of Fade in Db
		5 db	7 db	10 db	12 db	15 db	20 db	
1/14 0500 to 1/15 1500		Missing Data						
1/15	1900-2200	Missing Data						
1/16	0400-0600	Missing Data						
	0900-1100	Missing Data						
	1200-1300	Missing Data						
1/17 1700 to 1/19 1400		Missing Data						
1/19 1900 to 1/20 0300		Missing Data						
1/20	0333-0842	203	80	15	9	0	0	15
	0900-2000	Missing Data						
	2100-2200	Missing Data						
1/20-21	2329-0155	97	23	10	4	0	0	15
1/21 1400 to 1/23 1500		Missing Data						
1/24	0633-0702	29	0	0	0	0	0	7
	0857-0952	30	2	0	0	0	0	9
1/25	2323-2335	12	3	0	0	0	0	9.5
1/26 0700 to 1/27 1300		Missing Data						
1/28	0637-0706	29	8	0	0	0	0	8
1/29 1300 to 1/30 1200		Missing Data						

TABLE II

Fields at Kendrick and Haswell
During Prlonged Space-Wave Fade-Outs at Karval

Date & Time at Karval		Kendrick	Haswell
		Db Above Monthly Median	Db Above Pertinent 3-Hourly Monthly Median
2/1	0030-0220	X	X
2/25	0442-0553	-3.7	X
2/26	0025-0125	X	+10.9
	1855-1952	X	+17.2
2/27	0047-0302	X	+5.3
4/11	0350-0635	X	X
4/18-19	2132-0035	X	-3.3
4/23	2212-2247	-2.8	-1.0
5/20	1943-2243	-0.7	X
	2313-2335	-1.4	X
5/21	0150-0305	0	X
	0427-0504	0	X
	2132-2229	0	X
	2348-0003	-0.3	X
5/22	0028-0101	-0.1	X
	0238-0349	-3.1	X
	0547-0629	+0.5	X
	1814-1858	+0.6	X
	2006-2020	+0.9	X
5/22-23	2308-0123	-0.6	> +3.8
5/24-25	2150-0210	+0.4	> +4.8
5/25	0552-0614	-1.6	> +8.8
	0715-0719	+0.9	+8.3
	1812-1818	+0.8	+6.5
	2225-2237	+0.8	+1.9

X Denotes No Data

TABLE II (Page 2)

Date & Time at Karval		Kendrick Db Above Monthly Median	Haswell Db Above Pertinent 3-Hourly Monthly Median
5/26	0150-0229	-1.8	+1.8
	0836-0857	+0.8	+2.7
5/27	2054-2317	-0.1	+6.3
6/5	0406-0413	+1.5	> +11.9
	0648-0656	+0.5	+21.6
6/6	0543-0604	-0.3	+5.1
6/7	0605-0608	+0.4	+19.8
6/9	2132-2205	0	+15.6
	2309-2348	+0.9	+10.4
6/10	0007-0022	+0.6	+5.0
	0152-0240	+0.2	+5.0
	0440-0648	+0.7	+6.9
6/11	0216-0235	-1.5	-4.3
	0416-0546	-0.2	+0.4
6/12	0343-0403	-2.1	+0.4
	0518-0545	-3.3	+6.1
	0710-0723	+0.7	+23.2
	2032-2306	+1.8	+3.6
6/13	0050-0155	-2.7	+4.5
	0312-0329	-5.1	+4.6
	0415-0536	-2.1	+4.6
6/14	0017-0233	X	X
	0604-0626	X	X
	0700-0710	X	X
	2037-2110	X	X
6/15	0207-0247	X	X
6/17	2036-2045	X	X
	2210-2337	X	X

X Denotes No Data

TABLE II (Page 3)

Date & Time at Karval		Kendrick Db Above Monthly Median	Haswell Db Above Pertinent 3-Hourly Monthly Median
6/18	0119-0345	X	X
6/20	0402-0416	X	> +14.9
	0603-0652	X	+24.7
6/21	2147-2214	-0.8	-5.1
6/21-22	2333-0204	-1.5	> +15.0
6/22	0242-0501	-1.1	X
6/23	0149-0254	X	X
6/26-27	2322-0047	-2.3	-9.0
6/27	0313-0334	+0.1	-3.5
	0720-0739	-1.3	+2.2
6/28	0428-0628	X	-3.6
	0855-0909	X	-1.7
6/30	1522-1610	X	+10.6
7/3	1737-2028	+0.8	+8.6
	2301-2351	-1.0	+7.3
7/4	0104-0331	0	+4.0
7/5-6	2353-0018	-0.4	+6.8
7/6	0608-0706	-0.3	+12.7
	2157-2215	X	+1.2
	2340-2350	X	-2.0
7/7	2124-2202	-1.4	+15.1
7/8	2204-2325	+1.0	+3.4
7/9	0513-0659	X	X

X Denotes No Data

TABLE II (Page 4)

Date & Time at Karval		Kendrick Db Above Monthly Median	Haswell Db Above Pertinent 3-Hourly Monthly Median
7/17	1450-1528	X	X
	1625-1644	X	X
	1733-1807	X	X
	1931-2046	X	X
7/18	2246-2322	-0.4	X
7/19	0048-0140	-2.2	X
	0358-0416	+0.8	X
7/30	1727-1737	+0.4	< -5
	1807-1820	+0.2	< -10.2
	1858-1948	-0.5	< -10.2
	1955-2245	+1.3	+3.8
	2321-2350	+0.5	-1.2
7/31	0021-0115	+1.0	+4.0
	0332-0345	+2.1	+1.7
8/1	1906-2028	X	+1.8
	2052-2313	X	> +10.2
8/2	0055-0104	X	-8.1
	0536-0554	X	> +10.2
	0744-0748	X	-4.0
	1534-1724	+0.1	X
	2005-2143	-1.1	X
8/3	0552-0651	+5.4	X
8/7	1620-1810	X	+7.8
8/8	0059-0235	X	> +2.6
	0357-0400	X	> +2.4
	1949-2036	-2.3	+6.9
8/8-9	2200-0047	+1.7	X
8/9	1544-1947	+0.8	X
	2131-2210	-0.8	X

X Denotes No Data

TABLE II (Page 5)

Date & Time at Karval		Kendrick Db Above Monthly Median	Haswell Db Above Pertinent 3-Hourly Monthly Median
8/10	0032-0052	+0.8	> +2.4
	0305-0607	> +2.9	-0.1
	1738-1806	-3.7	-0.9
	2054-2059	> +2.9	X
	2155-2233	> +2.9	+2.2
8/11	0012-0029	X	> +2.6
	0106-0209	X	> +2.6
8/12	0500-0504	X	X
	0828-0830	X	-5.9
	0956-0959	X	+0.5
	2025-2044	X	X
	2205-2230	X	X
8/13	0044-0114	X	X
	0506-0558	X	X
	0736-0739	X	X
	2126-2204	+1.0	-3.8
8/15	0253-0345	+0.9	-1.1
	0424-0436	+0.1	+1.4
	0655-0705	+2.1	+2.7
8/16	0728-0739	+1.6	X
8/17	0355-0442	+1.9	X
8/23	0237-0239	+1.4	X
	0344-0536	-0.1	X
	0617-0627	+0.6	X
	0653-0656	-1.0	X
	0726-0755	-1.8	X
	0839-0911	-0.6	X
	0947-1046	-1.5	X
	2233-2253	-0.2	X
8/23-24	2331-0057	-0.5	X

X Denotes No Data

TABLE II (Page 6)

Date & Time at Karval		Kendrick Db Above Monthly Median	Haswell Db Above Pertinent 3-Hourly Monthly Median
8/24	0150-0225	-0.8	X
	0340-0431	-1.3	X
	0506-0528	+1.4	X
	0858-0942	-1.1	X
	1710-1830	-1.1	X
	1900-1936	-2.3	X
	2017-2200	-2.1	X
8/25	0300-0428	-2.1	X
	0509-0545	-2.6	X
	0814-0830	0	X
	1958-2010	-0.1	X
	2143-2151	-1.7	X
8/26	0628-0629	+0.1	X
	0736-0743	-0.1	X
	2012-2051	+0.5	+4.8
	2138-2213	-0.8	+0.2
8/27	0750-0757	+0.3	X
	1841-1847	+0.8	X
8/27-28	2225-0104	+0.5	X
8/28	0307-0324	+0.3	X
	0421-0448	-0.4	X
	0557-0600	+0.3	X
	1758-1828	+0.1	X
	1902-1914	+1.8	X
	1949-2008	+1.0	X
	2040-2042	+0.4	X
	2105-2113	0	+7.2
	2246-2249	-1.1	0.0
8/29	0316-0352	+0.1	-5.6
	1854-1902	+0.8	+11.4
	1931-1951	+0.7	+7.6
	2012-2044	+0.5	+14.4
	2116-2155	-2.3	+6.2
	2244-2328	-2.1	+6.2

X Denotes No Data

TABLE II (Page 7)

Date & Time at Karval		Kendrick: Db Above Monthly Median	Haswell: Db Above Pertinent 3-Hourly Monthly Median
8/30	0017-0053	-2.2	+7.6
	0236-0347	-1.9	+6.4
	0707-0732	-1.1	+16.7
	0807-0811	-0.4	+16.0
	2208-2235	-3.4	X
8/31	0415-0455	-1.2	X
	0725-0744	0	X
9/2	0550-0615	-1.3	X
	0654-0707	-0.8	X
	1917-2003	-1.8	2.0
9/3	0159-0353	-3.0	-11.7
	0757-0802	> +1.3	-4.9
	2213-2240	-1.2	X
9/3-4	2341-0004	-3.3	X
9/4	0615-0754	-9.4	X
	2059-2207	-3.1	-16.5
9/5	0023-0034	-1.5	> +4.5
	1835-2055	-4.7	-3.7
9/5-6	2309-0010	+0.6	-2.6
9/6	0257-0313	+1.2	-3.5
	0348-0730	+0.1	-1.2
9/7	0706-0714	+0.5	X
9/8	0125-0140	+2.0	X
	0302-0410	+1.4	X
	0521-0536	0	X
	0717-0752	+1.9	X
9/9	0255-0352	-1.0	X
	0632-0646	-3.1	
	0751-0800	0	X

X Denotes No Data

TABLE II (Page 8)

Date & Time at Karval		Kendrick: Db Above Monthly Median	Haswell: Db Above Pertinent 3-Hourly Monthly Median
9/10	0131-0210	X.	X
9/12	0011-0014	X	X
	0238-0257	X	X
	0405-0413	X	X
	0711-0757	X	X
	2343-2351	X	X
9/13	0704-0716	X	X
	1851-1925	X	X
9/15	0447-0451	X	X
	0641-0705	X	X
	1106-1149	-3.3	X
	1851-1915	-8.8	X
	2040-2110	-4.6	X
	2336-2349	-6.2	X
9/16	0050-0223	-8.7	X
	0305-0516	-7.4	X
	0702-0713	-5.0	X
	0818-0833	-3.2	+1.0
	1643-2318	-1.4	-2.4
9/17	0422-0727	-3.3	-4.1
	2225-2322	-3.1	-6.5
9/18	0528-0735	-2.7	-2.5
9/19	0140-0205	+0.3	X
	0530-0543	+1.1	X
	0754-0805	+1.6	X
9/23	1841-2120	-2.7	-0.7
9/24	0747-0800	+0.9	+6.5
	1954-2222	+0.1	+1.2

X Denotes No Data

TABLE II (Page 9)

Date & Time at Karval		Kendrick Db Above Monthly Median	Haswell Db Above Pertinent 3-Hourly Monthly Median
9/25	0807-0825	+1.2	+7.3
9/26	1858-2058	+2.3	+9.3
9/26-27	2342-0152	+2.5	+4.3
10/3	0049-0154	-3.0	+13.6
	0432-0530	-2.2	+13.6
	0658-0738	-2.5	+12.6
10/9	0440-0536	X	X
1/20/53	0333-0842	X	X
	2329-0155	X	-0.5
1/24	0633-0702	X	X
	0857-0952	X	X
1/25	2323-2335	X	X
1/28	0637-0706	-1.5	<+0.5

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