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A STUDY OF WAVELENGTH DEPENDENCE OF TRANSHORIZON RADIO PROPAGATION

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ABSTRACT

The investigations of uhf and microwave transhorizon radio propagation carried out under this contract are summarized briefly. These include studies of fading, of wavelength dependence, of median diversity effect, or anomalous propagation over irregular terrain, and of information theoretic analysis of troposcatter circuits. The greater portion of this report is devoted to those experiments most recently completed, which were aimed specifically at the determination of wavelength dependence in the 1-10 Gc/s range, of the variability of this dependence, and of its relation, if any, to large-scale weather patterns.

It is concluded that, for the path involved, the wavelength dependence of excess propagation loss does vary, in a seemingly erratic manner from day to day and week to week and in a more consistent way seasonally. On the average, the higher frequencies are more favored in summer. Unfortunately, the meteorological data with which the radio results have been correlated are not of fine enough resolution, spatially or temporally, to provide much insight into the connection between air mass structure and the propagation mechanism.

It is also concluded that the short-term median signal levels on adjacent paths of a space diversity system may vary in an uncorrelated manner, but that this variation is considerably less than that between circuits widely separated in frequency on the same path.

Finally, two recommendations are made. One pertains to further studies directed principally at the communication problem. The other proposes continued investigations for geophysical purposes.

A. Introduction

This project has focussed on two general objectives: (i) to increase our knowledge of the characteristics of uhf and microwave radio signals propagated beyond the horizon, and (ii) to study the microscale meteorology of the troposphere and its relation to synoptic meteorology. Our approach to the first of these objectives has involved transmission of known signals over representative transhorizon paths and analysis of the signals arriving at the receiving terminals. In particular, the dependence of propagation loss (in excess of the free-space value) on frequency, time, and position (relative receiver location) has been investigated experimentally, and the problem of the communication capacity of such a stochastically variable channel has been studied theoretically. The second objective has been achieved, through the same experimental work, using the beams of radio waves as probes with which to explore the fine structure of the atmosphere (by interference techniques). Subsequently a search has been made for evidence of some relation between this measured atmospheric structure and large-scale weather features, as determined by conventional meteorological sounding techniques.

Theoretical and experimental investigation of the fading character of transhorizon signals and of the manner in which these rapid fluctuations are influenced by winds along the path was detailed in Scientific Report No. 1. Initial theoretical study and analysis as to wavelength dependence was presented in Scientific Report No. 2. This led to further experimentation aimed specifically at the determination of mean wavelength dependence and the variability of this dependence. Report No. 2 had indicated trends that might be expected. As well as collecting valuable empirical results, it was intended that this further experimentation should test these predictions. The present report is concerned with the conduct and results of these more recent measurements.

In carrying out this work it has been possible, and indeed necessary, to investigate several related phenomena. One of these, the so-called median diversity effect, pertains to variations in the shortterm mean signal received on a single frequency at spaced antennas. An account of this work is contained in the present report. Intense diurnal variation of mean received signal observed during summer days has also been studied. The associated anomalous propagation of radio waves over irregular terrain has been analysed extensively and related to local meteorological processes in Scientific Report No. 4. Scientific Report No. 3 gave details of the development and application of an amplitude distribution analyser that was used in this work. The problem of information transmission via a scatter channel was considered at some length. The (stochastic) transfer function for such a circuit was investigated theoretically in Scientific Report No. 5.

In the sections that follow the theoretical basis for these more recent measurements is reviewed, the experimental and calibration equipments and the field installations employed are described, performance of the actual experiments is detailed, and the resulting data are presented, analysed, and compared with meteorological records.

B. Theoretical Basis

In transhorizon radio propagation, when the effects of mean refraction have been accounted for (by a modification of earth-curvature), the average power received, relative to a free-space path, is given by (Wheelon, 1959)

$$\frac{P_R}{P_{FS}} = \frac{C_o d^2}{\lambda^4} \int \frac{g_T g_R}{R_1^2 R_2^2} \Phi_N(\underset{\sim}{k})\, dv. \qquad (1)$$

In this expression C_o is a constant, d is the path length, λ is the wavelength, g_T and g_R are the normalized transmitter and receiver antenna gain functions (including ground reflection effects), R_1 and R_2 are the ranges from transmitter and receiver to the element of volume dv, Φ_N is the spectral description of mean-square refractive index deviations at dv, and the wave number $\underset{\sim}{k}$, at which Φ_N is to be evaluated, is determined by the geometry and λ. The magnitude of $\underset{\sim}{k}$ is given by

$$k = \frac{4\pi}{\lambda} \sin \frac{\theta}{2}, \qquad (2)$$

where θ is the angle between incident and scattered propagation vectors, and the direction of $\underset{\sim}{k}$ is determined by the exterior bisector of those two propagation vectors. The integration extends over all space, although the principal contribution is made by the so-called common volume, the intersection of the transmitting and receiving antenna beams (above the horizon rays).

In the derivation of (1) it is assumed that multiple scattering plays a secondary role in this mode of propagation. This certainly is not always the case; but, under most circumstances, for most portions of the troposphere, primary scattering is itself so minute that higher order effects may safely be neglected.

Since the refractive index spectrum Φ_N is not only a function of $\underset{\sim}{k}$, and thus of wavelength, but also varies in intensity from one part of space to another, and with time, it is important, if one is to study the wavelength dependence of transhorizon propagation by analysis of signals on several frequencies, that measurements be made simultaneously and that the antenna patterns g_T and g_R be closely alike on the various frequencies. The latter requirement may be realized by using similar antennas, scaled to the wavelength, thus insuring identical free-space patterns, and by scaling the heights of the antennas above uniform foregrounds for which the reflection coefficients are the same at all frequencies. This would provide an identical weighting function for every elemental volume dv, independent of frequency, leaving λ the only variable in (1).

In practice it may not be convenient to scale the heights of the antennas. Failing to do this is not so serious as may at first be presumed. It leads to different fine structure in the weighting functions but does not disturb the overall envelopes. If average results only are sought, transport of the medium, and thus of regions of more or less intense Φ_N, through the antenna patterns by prevailing winds will tend to "smear" the contributions and equalize the results.

The experiment here reported has, therefore, consisted of the simultaneous transmission from a single site of signals of unvarying intensity on three frequencies spanning a 10:1 range (840 mc/s, 2800 mc/s, and 9100 mc/s). Both transmitting and receiving antennas have been scaled to wavelength, thus producing approximately equal beamwidths so that all channels "look" at the same portion of the atmosphere. Variations of mean received power on one wavelength relative to another are, consequently, indicative of variations in scattered energy alone and therefore of variations in the structure of the refractive index. Measurements necessary to the accurate determination of differences in the excess propagation loss have been made and this has been done reliably and consistently over a sufficiently long period of time to experience wide variations in large-scale weather conditions.

Excess propagation loss (L_p) is here defined as the ratio of power density (Wr_{fs}) that would exist in the aperture of a receiving antenna, were the entire experiment conducted in free space, to the power density actually observed (Wr_o), expressed in db. Predictions as to the form of Φ_N indicate differences in L_p of only 10db, or so. Considerable effort has had to be expended, therefore, in order to insure that experimental and calibration errors not overshadow the effects being sought.

C. The Experimental System

These experiments have been conducted over irregular terrain in central New York.

1. The Path

The map of Figure 1 shows the location of the path and its terminals in the Finger Lakes region. The path length is approximately 108 km with the transmitters placed at Hathaway Hill, near Rochester, and the receivers at the Tompkins County Airport, near Ithaca. The true transhorizon nature of this path is depicted by the profile, shown in Figure 2, which has been drawn to a 4/3 earth radius to account for standard refraction. The deep lake valleys crossing the path, as well as the rather steep intervening hills, produce considerable effect on radio propagation, especially on clear summer nights.

This phenomenon has been studied and reported separately in Scientific Report No. 4. It is mentioned here only for the reason that, as a consequence of these effects, it has been necessary to restrict observations for the experiments discussed in this report to the hours between 1000 and 1600, thus insuring that the principal mechanism responsible for the received signals was the irregular refractive index structure in the common volume, not diffraction or some anomalous process.

2. The Overall System

Figure 3 is a block diagram of the entire experimental system. It shows not only the transmitters and receivers for each of the three wavelengths (35.7 cm, 10.7 cm, and 3.3 cm), but also the second set of receivers on S-and X-band, for the study of median diversity, and the field strength meter that was employed for overall transmitter calibrations.

3. The Antennas

The transmitting and receiving antenna installations are shown in Figures 4 and 5 respectively. The fact that the transmitting antenna heights were inverse to wavelength was, in fact, a consequence of structural considerations. Nonetheless, the nature of the foreground (very irregular) and of the horizon (a distant ridge) suggest that, in order to equalize illumination in the region beyond the horizon and beneath the horizon plane, the shortest wavelength system should radiate from the highest point.

At both ends of the system 28 ft fiberglas (copper coated) parabolic dishes were employed at 840 mc/s, 10 ft aluminum dishes at 2800 mc/s, and 4 ft aluminum dishes at 9100 mc/s. On the two longer wavelengths the measured beamwidths were very nearly identical at 2.3°. However, on X-band it was necessary to defocus the feeds in the 4 ft dishes in order to achieve this beamwidth. All of the X-band antennas were operated in this defocused condition during these experiments.

The antennas were aligned with the aid of the field strength meter (at the transmitter site) and of auxiliary sources (at the receiver site). These instruments were placed on-path in the foreground (but definitely in the far-field) of the antennas. The test locations were carefully surveyed to insure accuracy of alignment. In elevation all antennas were normally operated with their boresights on the horizon.

4. System Calibration

Since the primary purpose of these experiments was the determination of excess propagation loss (L_p), and its variation with time and with wavelength, there was no need to measure absolute r-f power levels, either transmitted or received. It was necessary only to measure received power density on each frequency relative to the same standard in terms of which radiated power from the corresponding transmitter was determined. This was accomplished by using a standard signal generator as the reference on each band.

The appropriate generator was set-up in the far-field foreground of a given receiving antenna so that, when connected to a simple test antenna of carefully measured gain, the power density in the aperture of the receiving antenna could be accurately calculated. In this way the receivers were calibrated for operation as relative power density meters.

A highly stable field strength meter was calibrated (on each band) against these same standard signal generators and was then placed in the far-field foreground of the transmitting antennas (on the first ridge in front of the transmitter site, noted by a † on the path profile). The same test antennas were employed as those used at the receiver site. In this way, on what constituted a line-of-sight path with negligible ground reflections, it was possible to determine the radiated power on each frequency relative to that same reference source against which the corresponding "power density meter" at the receiver site was calibrated.

5. The Transmitters

The transmitters were operated and maintained by the Stromberg-Carlson Division of General Dynamics/Electronics, under subcontract. Figure 6a shows the UHF transmitter, the video portion of an RCA TTU-1B television transmitter, operated in a tone-modulated (2kc/s, 25%) mode at 500 w average carrier power. The frequency of this transmitter was, of course, crystal controlled. The S-and X-band transmitter shown in Figure 6b was part of a Gilfillan AN/MPN-1 GCA radar system. Magnetrons provided the r-f power, nominally 70w and 35w average at 2800 mc/s and 9100 mc/s respectively. These outputs were pulse modulated at a crystal-controlled prf of 2040 c/s with a measured pulse duration of 0.7 μs. Both transmitters were Conelrad protected to insure their immediate removal from the air in the event of a defense alert.

The level of r-f output to the antenna transmission line (wave-guide) was checked at least twice a day on each frequency. No attempt was made to attach absolute significance to these measurements. They were used only for daily correction of the radiated power measurements made by means of the field strength meter (described at the end of the preceding section). A built-in output power meter in the TTU-1B was used to make these daily calibrations on UHF. On S-and X-bands directional couplers and an hp 430 C microwave power meter, with an hp 477 B wide-band thermistor, were used. Except when tubes were replaced or when specific changes were made in supply voltages, or the like, these daily calibrations showed negligible variation in r-f power output on all bands throughout the course of these experiments.

6. The Receivers

The UHF signal was received on a superheterodyne receiver consisting of a diode mixer and crystal controlled local oscillator, a narrow-band cascode i-f preamplifier-filter (200 kc/s bandwidth), a logarithmic i-f amplifier, and an integrating d-c vacuum tube bridge driving the recorder. The dynamic range of the logarithmic amplifier, one of several built specifically for this work, was in excess of 60db.

The S-band and X-band signals were received using portions of the Gilfillan AN/MPN-1 radar equipment as shown in Figure 7. The full MPN-1 receivers were employed, one for each antenna on each frequency. Between the mixer--i-f preamplifier and the main i-f amplifier a switch-type coaxial attenuator was inserted, which was used as an accurately calibrated gain control. The level of video output (2040 c/s pulse trains) from each MPN-1 receiver was measured by an integrating a-c vacuum tube voltmeter, preceded by a narrowband 2040 c/s filter (15 c/s bandwidth). In addition the signals from one S-band and one X-band antenna were fed, following the mixer--i-f preamplifiers, to logarithmic i-f amplifiers. These units drove integrating, peak-reading a-c vacuum tube voltmeters.

Integration time constants of 30 seconds on X-band and 2 minutes on S-band and UHF were used to remove most of the rapid fading of the signals. Inasmuch as average values of propagation loss only were sought in these experiments, such electronic integration was considered suitable.

The response characteristic of each complete receiving system (mixer input to Esterline Angus graphic milliameter) was checked periodically and determined anew after each equipment change or tube replacement. Each day that the receivers were used a calibration was made of overall gain. This was accomplished by supplying a test signal at the mixer input, via a directional coupler, and determining the intensity required to produce a reference output indication. The signal generators employed for this purpose (GR-1021AU on UHF, Navy LAG on S-band, and hp 624 C on X-band) were semi-permanently installed, together with the necessary cables (waveguides), and were modulated so as to reproduce as nearly as possible the characteristics of the transmitted signals. In this way changes of system gain from day to day, as a consequence of tube aging, voltage variations, or other changes, were accounted for. Such daily calibrations were used to correct the calibration, as a relative power density meter, of each overall receiving system. Once again, no attempt was made to achieve absolute calibrations.

D. The Measurements

Some preliminary data were collected in the fall of 1959 and in the spring of 1960 on X-and S-band. The principal experiment, however, was conducted from August, 1960, through July, 1961.

1. Periods of Data Collection

Throughout this twelve-month period the entire system was operated continuously for two-day intervals each week, from approximately 0830 Thursday to 1530 Friday, except during the month of December, and in early January, when equipment malfunction necessitated shut-down. Unfortunately, in the winter months (December through March) the excess propagation loss (L_p) on X-band was so great that only occasionally did the received signal exceed the noise. Consequently, the data for this portion of the year are biased in favor of those (meteorological) situations conductive to somewhat enhanced (relatively) X-band propagation.

Considerable effort was expended in the development of a post-detection correlation reception technique to combat this signal-to-noise limitation and preliminary tests in the fall of

1961 showed promise of success. However, the contract was terminated before the system could be perfected. As a result, no useful data were collected by this means.

As noted previously nighttime signals were often appreciably enhanced, especially during the summer. This has been attributed (see Scientific Report No. 4) to locally peculiar anomalous propagation conditions. For this reason only those portions of the data deriving from mid-day operation (1000 to 1600) have been included as part of the experiments that are the subject of this report.

2. Operating Procedure

At least twice each day of operation the generated power levels at the transmitters were measured and recorded in the station log. Similarly, before and after each two-day run the gain of each receiver was checked as described in Section C.6. These calibrations, together with periodic time marks and the settings of the receiver switch attenuators (gain controls) were recorded directly on the charts of the graphic milliammeters. The X-and S-band receivers were also checked periodically for tuning of their local (klystron) oscillators and for on-scale deflection of their output recorders.

In several specific instances, with all receivers carefully aligned and calibrated, the short-time average power density was observed to decrease at one of the receiving antennas, on a given frequency, at the same time that it was increasing at the other antenna. Such diverging trends continued for 10 minutes to a half-hour at a time and occasionally resulted in as much as 5 db difference between the mean (or median) levels. The operating personnel were on the lookout for cases of this nature and made special note of them on the recorder charts, when such instances were observed and verified by checks to insure proper alignment of all components.

Other than for tuning and gain adjustments the system ran without attention, all pertinent information being recorded directly on the graphic milliammeter charts. The only additional information required for the calculation of L_p values was the receiver response characteristics, the transmitter power levels, and the far-field calibrations of both the receivers and the transmitters.

3. Calibrations

As mentioned in Section C.6, the receiver response characteristics were checked regularly. Test signals, the levels of which were varied in 2 db steps, were supplied to the receivers and the output levels recorded. This was repeated for various settings of the gain controls (switch attenuators). These response curves were subsequently plotted and used in the reduction of the data.

Far-field calibrations were performed approximately every two months, although weather conditions in winter prevented access to the field test site at the transmitter during December, January, and February. In making transmitter calibrations the field strength meter, with its antennas of known gain mounted atop the portable tower (see Figure 8), was placed directly on-path, under the main beams of the transmitting antennas, and within clear line-of-sight thereof. Received signals were recorded on all three bands for several adjacent locations along the line-of-sight in order to detect ground reflections, if any. This appeared to be a problem at UHF only. Ultimately it was found to be related to the tone modulation of the UHF signal. From the received signal levels and from the known distance between the field test site and the transmitters, it was possible to calculate correction factors to be applied to the measured power densities at the receiver site in order to determine values of L_p. Once, near the beginning of the twelve-month experiment, and again near the end, the antennas at both ends of the system were checked for directional alignment. On these occasions the transmitting antennas were lowered in elevation until the signals at the field test site maximized, so that a true calibration of radiated power could be made.

E. Analysis of the Data

It must be recalled that the primary purpose of these experiments was the investigation of mean (or median) propagation phenomena (over periods of the order of a day) and the identification, if possible, of characteristics of these phenomena with specific meteorological situations.

1. Sampling of the Data

In view of these objectives no attempt was made to determine, or to analyse, the rapid variations in the excess propagation loss. On the contrary, in addition to the electronic integration included in the receiving equipment a further smoothing was effected by visually averaging the signal records on the recorder charts over five-minute periods. Inasmuch as the fluctuations in these records during such an interval rarely exceeded 1 db, this operation was readily accomplished. One of these five-minute means (at the half-hour) was then taken as representative of each hour.

By means of an appropriate receiver response characteristic, together with its calibration as a relative power density meter (by the far-field tests) and any necessary correction thereof, as determined by the daily calibrations, these samples from the records were converted to values of observed power density at the receiver site, Wr_o. These values of Wr_o were then subtracted from the calculated free-space power density at the receiver site, Wr_{fs}, derived from the transmitter far-field calibrations (corrected if necessary for daily fluctuations in transmitter output) and modified by the ratio of the squares of the distance between transmitters and the transmitter field test site (2.77 km) and the path length (108 km). The hourly sample values of mean excess propagation loss L_p thus determined were tabulated for each receiving system. Altogether seven entries were made for each hour:

a) AN/MPN-1 receiver on X-band, lefthand antenna

b) AN/MPN-1 receiver on X-band, righthand antenna

c) Logarithmic receiver on X-band, righthand antenna

d) AN/MPN-1 receiver on S-band, lefthand antenna

e) AN/MPN-1 receiver on S-band, righthand antenna

f) Logarithmic receiver on S-band, righthand antenna

g) UHF (logarithmic) receiver, central antenna,

All succeeding analyses have employed values of L_p taken from this tabulation (See Appendix, Table II).

2. Median Diversity Experiment

As noted previously, if the observed differences in L_p between different frequency bands are to be attributed to the change in wavelength (indirectly to the refractive index spectral structure $\Phi_N(\underset{\sim}{k})$ and changes therein), evidence is required that the slight differences in receiving antenna locations (space diversity effect) is not the basic factor responsible for the variations in the data. Since five-minute average samples only are analysed in this report, one would anticipate that the normal space diversity effect would be largely suppressed. Nonetheless, there was evidence in preliminary work that some residual (median) diversity effect persisted. It was for this reason that dual receiving systems were installed on X-and S-band.

Although this co-frequency median diversity effect is not so pronounced as that evidenced between different frequency bands, it is nonetheless a real phenomenon deserving of a satisfactory explanation. The measurements here reported are clear evidence, on the one hand, of its occurrence and, at the same time, provide adequate demonstration that this effect alone cannot be credited with major responsibility for the day-to-day variations in the difference of L_p values observed on the several bands.

When allowance is made for those instances that must be laid to shifts in calibrations (from one period to another), the distributions of hourly samples for each of several months, as presented in Figure 9, show a standard deviation of ΔL between left-and right-hand receiving systems of 215 db. The roughly 2 db rms random deviation in hourly five-minute samples (for a single system) implied by these data is too great to be accounted for entirely in terms of equipment performance fluctuations. This result, together with the specific observations referred to earlier, in which one receiver output was noted to decrease at the same time that the output of the other receiver on that channel increased, cannot be dismissed as mere aberations. That in a space diversity system there is some uncorrelated variation between hourly samples is now an established fact. The cause, on the other hand, of this seemingly anomalous state of affairs remains ambiguous.

3. Wavelength Dependence Study

In analysing the data to determine the frequency dependence of the propagation mechanism and, more specifically, variations in this dependence with changes in meteorological conditions, two further steps were taken to suppress any influence of the median diversity effect discussed above.

First, daily average values of L_p were employed (averages of the six midday hourly samples). Second, the mean of the two X-band systems was used to represent that wavelength, and a similar mean was used for S-band. The standard deviation of the difference between X-and S-values of L_p attributable to median diversity and system uncertainty would thus be expected to be less than 1.8 db.

Figure 10 shows the distribution of these differences (ΔL_{X-S}), as well as those between X-band and UHF (ΔL_{X-U}) and between S-band and UHF (ΔL_{S-U}), for the entire year from August 1960 through July 1961. Figure 11 presents the same date separately by season: summer months (June through September) versus the rest of the year. The considerably increased variances indicate that additional factors are involved. The pronounced seasonal differences, both in median value and in variance, suggest that meteorological effects may well be responsible.

However, before an attempt is made to identify any such meteorological influence, it is important to note the strong evidence here offered in support of the day-to-day variability of wavelength dependence. Figure 12 is a chronological plot of the differences in daily-average excess propagation loss between the various pairs of frequencies. The fact that these ΔL values change significantly from one day, or one week, to the next, and that in some instances they change by as much as 15 db within a month, is clearly indicative of variations in the wavelength dependence of the propagation phenomenon. Further, the fact that ΔL_{X-S} and ΔL_{S-U} are not equal (within experimental uncertainty) at all times, and that ΔL_{X-U} differs from twice ΔL_{X-S}, indicates the extreme complexity of the mechanism(s) responsible for the received signals. One can only conclude that the processes involved in propagation over this short transhorizon path in hilly terrain are intricate and variable.

4. Meteorological Factors

An attempt has been made to correlate the variations in ΔL (as indicative of variations in the refractive index structure $\Phi_N(\underline{k})$, and in the closely related temperature and humidity structure) with various meteorological parameters. Surface and upper air soundings (radiosonde data) have been supplied by the U. S. Weather Bureau for those weather stations nearest to the radio path. Unfortunately the data of primary interest (upper air temperature, humidity, and winds) are available only from 0700 and 1900 soundings and these only for the stations at Buffalo and Albany, approximately 150 miles west and east of the path. No detailed information whatever is available for the important common volume, the region 500 to 3000 feet above the immediate vicinity of Geneva, New York.

As a consequence it would be surprising indeed to find strong correlation between the radio propagation measurements and the available meteorological data. This is particularly true in the present case in which the portion of the atmosphere principally involved in the propagation is close to the surface and therefore subject to strong surface influence, so that remotely collected weather data con, at best, give a poor estimate of conditions in the region of prime importance.

Nonetheless, various temperature, wind, and stability factors have been deduced from the soundings for a sample set of days throughout the year. Approximately thirty days were selected, in groups of two or more such that the ΔL value (averaged over the 10:1 frequency range) was reasonably consistant within each group yet covered a representative range for the set as a whole. Temperature and wind speed values within the common volume (at 2000 feet) have been taken directly from the 190C radiosonde and from the 1300 and 1900 raob soundings. In nearly every instance data from several surrounding weather stations have been averaged so as better to represent conditions over Geneva. Values of the Richardson number*, based on the 1000-4000 foot interval, have been calculated from similarly averaged data.

The results are shown in the form of scatter plots in Figure 13. There is little or no evidence of correlation between difference in excess propagation loss and wind speed or Richardson

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*Richardson number, R_i, is the ratio of static stability to the square of wind shear and as such is indicative of the ratio of the stabilizing influence of the density gradient as opposed to the turbulence-producing effect of the wind field.

number. On the other hand there appears to be fairly strong inverse correlation between ΔL and temperature. Closer inspection of the tabulated results (Appendix, Table I) shows that this is more a seasonal dependence of both parameters than a direct relation. From this there follows the suggestion that $\Phi_N(\underset{\sim}{k})$ tends toward one structure in the colder, less moist months and toward a different, and more variable, structure during the warmer, humid months.

Another possible explanation is that this effect is a consequence of variable mean refraction (generally less in winter than in summer), which in turn raises the common volume in winter as well as increasing the magnitude of the wave number $\underset{\sim}{k}$ at which Φ_N is sampled by a particular frequency. These shifts in altitude and in wave number magnitudes could be responsible for a consistent change in the form of the refractive index spectral structure, on which the propagation depends. That, in turn, would account for the observed change in dependence of excess propagation loss on wavelength of the radio signal.

F. Conclusions and Recommendations

The investigations carried on under this contract have shed light on a number of facets of tropospheric propagation and on several tropospheric phenomena as well. Not all of these results have direct or immediate implications of an engineering nature. They are interesting, nonetheless, and may provide valuable insight in other areas of research.

1. Summary of Results

The results of the various investigations may be summarized as follows:

a. The primary cause of signal fading over troposcatter circuits is horizontal drift perpendicular to the path as opposed to turbulent motions in the atmosphere, the role of which appears to have been overemphasized by numerous investigators. This conclusion stems from the discovery that the fading spectrum induced by such horizontal drift does not fall-off as rapidly as the Gaussian model assumed in previous analyses. (Scientific Report No. 1.)

b. The wavelength dependence of transhorizon tropospheric propagation, at uhf and microwave frequencies, varies from day-to-day and from season-to-season. These variations reflect changes in the refractive index structure, and there is evidence that these changes in structure are related to other, larger scale meteorological factors, specifically the dynamic stability of the troposphere. (Scientific Report No. 2 and Section E above.)

c. Independent variation of median propagation loss over adjacent, co-frequency channels for periods of from tens of minutes to several hours does, in fact, occur. This variation is not so great as that between widely separated frequencies, but it is real and is, as yet, not satisfactorily explained. Section E above.)

d. Greatly enhanced propagation may occur over irregular terrain, expecially on summer nights. This reflects locally peculiar meteorological patterns that may be attributed to radiation cooling and highly moist valley bottmes (lakes). (Scientific Report No. 4.)

e. Information theoretic analysis of a troposcatter circuit is presently limited by the mathematical difficulty of expressing, in tractible form, the necessary joint probability distribution function for the time-variable transfer function of the channel. On the other hand, with knowledge of the time and spectral structure of the refractive index variations it is possible to calculate the coherence time and coherence bandwidth of a given circuit. (Scientific Report No. 5.)

f. Standard Weather Bureau upper-air data, as gathered by radiosonde techniques, are helpful in analysing radio propagation results when the path geometry places the common volume a kilometer or more above level terrain. However, the geographical, altitude, and time resolution of these data is too coarse to be able to gain from them much insight into the influence of meteorological effects when the common volume is below one-half kilometer, especially if the terrain is highly irregular. (Scientific Report No. 2 and Section E above.)

2. Implications and Recommendations

There are consequences implied by these results that may be of considerable significance. One of these is the fact that, particularly on shorter paths, higher frequency circuits can exhibit markedly superior performance under temperate-zone summer conditions. It has customarily been assumed that the propagation loss would be less at lower frequencies. Another is the possible degradation of performance in diversity systems due to the independent variation of median levels. Usual analysis assumes equal median levels, and a difference of 3-6 db will introduce appreciable error in the reliability calculations. A third important implication regards the use of radio propagation experiments for geophysical exploration. The possibilities for studying refractive index and related meteorological structures by radio "sounding" techniques, both monostatic and bistatic, are demonstrated in the investigations that have been carried out. The opportunities in this vein have barely been tapped.

On the basis of the studies here reported two specific recommendations are made.

Recommendation 1. Detailed analyses should be made of wide-band signals received over transhorizon tropospheric circuits. Such studies will lead to a fuller understanding of the nature and stochastic character of the time-variable transfer function by which this propagation mechanism may be described and will, therefore, make possible more effective utilization of the radio spectrum. The transmissions analysed should be of 200 mc/s bandwidth, at a minimum, and preferably of 1000 mc/s bandwidth. As a byproduct this type investigation may also yield valuable information as to the nature of the propagation mechanism itself, whether it is at any given time primarily volume or layer scattering.

Recommendation 2. A second-generation version of the scaled, multiple frequency experiment described in the earlier sections of this report should be carried out. It should involve at least three frequencies covering a span in excess of 10:1. The path length should exceed 300 km so as to insure that the critical portion of the troposphere is sufficiently above the surface to be free of immediate terrain influence. More local (both geographically and in time) meteorological data should be collected as part of the experiment so that the relation of propagation results to weather structure can be clearly established. Finally, the experimental system should permit measurements at off-path angles (and the antenna beamwidths should be narrow enough to permit resolution of 1-2° shifts in direction). This will make possible exploration of anisotropy in the refractive index structure. Recent preliminary measurements have indicated such non-uniform structure occurs, and an experimental technique by which it may be studied in remote parts of the atmosphere will be of considerable value to the dynamical meteorologists.

G. Personnel

The following individuals contributed to the scientific work carried on under this contract:

Professor W. E. Gordon

Professor N. H. Bryant

Professor R. Bolgianc, Jr.

Research Associate S. M. Colbert

Fellow T. Laaspere

Research Assistant R. P. Cassam

Research Assistant H. E. Hardebeck

In addition a number of students (both graduate and under-graduate) were employed from time to time as technicians. Of these Mr. J. O. Moore must be noted for the extended and valuable assistance he supplied on a number of the projects.

H. Previous Publications

In addition to a series of status reports, five scientific reports and a number of pape s have been published during the period covered by this contract.

Scientific Report No. 1. "An Analysis and Re-evaluation of the Role of Horizontal Drift in Producing Fading in Tropospheric Scatter Propagation," by T. Laaspere, 31 August 1958.

Scientific Report No. 2. "A Meteorological Interpretation of Wavelength Dependence in Transhorizon Propagation," by R. Bolgiano, Jr., 15 September 1958.

Scientific Report No. 3. "An Amplitude Distribution Function Analyzer," by E. E. Austein, 1 August 1959.

Scientific Report No. 4. "An Investigation of Anomalous Transhorizon Radio Wave Propagation over Irregular Terrain," by R. Cassam, 15 February 1962.

Scientific Report No. 5. "On the Transfer Function for a Radio Scatter Channel," by H. E. Hardebeck, 15 March 1962.

"On the Role of Convective Transfer in Turbulent Mixing," by R. Bolgiano, Jr., J. Geophys. Res., vol. 63, pp. 851-853 (1958).

"Wavelength Dependence in Transhorizon Propagation," by R. Bolgiano, Jr., Proc. I.R.E., vol. 47, pp. 331-332 (1959).

"Turbulent Spectra in a Stably Stratified Atmosphere," by R. Bolgiano, Jr., J. Geophys. Res., vol. 64, pp. 2226-2229 (1959).

"A Theory of Wavelength Dependence in Ultrahigh Frequency Transhorizon Propagation Based on Meteorological Considerations," by R. Bolgiano, Jr., J. Res. N.B.S., vol, 64D, pp. 231-237 (1960).

I. Related Contracts

The list below gives a number of contracts the work of which was related to that of this contract. They are identified by the institution under which the work was performed.

Cornell University: AF 33(616)-442
AF 33(616)-3236
AF 30(602)-682
AF 30(602)-1408
AF 30(602)-1717

University of Michigan: AF 30(602)-1982
General Electric Company: AF 19(604)-1723
Syracuse University: AF 19(604)-1179
University of Texas: AF 19(604)-2249
Stanford University: DA 36(039)SC-73151
Navy Electronics Laboratory: SR 05401, NE 120000-819F.6

J. Reference

Wheelon, A. D., "Radio wave scattering by tropospheric irregularities," J. Res. N.B.S. 63D, 205-233 (Sept.-Oct. 1959).

APPENDIX

Tabulated Data

Table I.

Daily Averages-ΔL and Meteorological Factors 2/24/64

Date 1960	X_L-X_R	S_L-S_R	X-S	S-UHF	X-UHF	ΔL	$T_{1000'}$, °C	$U_{2000'}$, m/s	Ri
8/4	-3.0	3.0	-1.6	-4.6	-5.6	-3.1	22.5	3.5	5.2
8/5	-0.4	-1.0	-3.9	-7.5	-11.4	-5.7	16.5	10.0	1.5
8/11	-2.8	-1.2	-3.9			-3.9		12.0	
8/12	-1.9	-1.7	-3.2			-3.2	21.8	13.0	3.1
8/18	-1.9	-0.8	-2.3	-4.2	-6.5	-3.2	24.5	9.0	6.7
8/19	-2.6	4.9	-2.7	-6.5	-9.2	-4.6	22.8	19.0	4.9
8/25	0.0	-0.1	-5.6	-6.0	-11.6	-5.8	19.5	8.0	3.6
8/26	-2.3	0.4	-4.5	-7.5	-12.0	-6.0	23.5	25.0	0.9
9/1	0.0	1.2	-6.8	2.2	-5.3	-4.5			
9/2	1.3	2.4	-6.3	-5.0	-11.3	-5.7			
9/8	1.7	-1.3	-6.2	-2.1	-8.4	-4.2			
9/9	0.0	-0.8	-5.5	-2.9	-8.4	-4.2			
9/15		0.0		-9.0		-9.0			
9/16		2.7		-7.0		-7.0			
9/22		-0.8		-4.2		-4.2			
9/23		-3.3		0.4		0.4			
9/29	-0.5	-2.4	5.3	-8.0	-3.0	-1.3	17.5	11.0	7.1
9/30	-3.3	-3.1	4.3	-7.0	-2.7	-1.3	12.0	28.0	0.4
10/6	-3.1		12.9			12.9			
10/7	-1.7	-11.8	13.2	-8.7	4.5	2.3			
10/13	3.3	0.9	21.5	-24.6	-3.1	-1.5			
10/14	-6.7	-2.4	20.8	-24.9	-5.1	-2.0			
10/20	-0.8	-2.8	7.5			7.5			
10/21	-1.3	-0.1	6.2	6.2	12.4	6.2	4.5	16.0	4.6
10/27	-5.4	-4.7	7.9	5.7	13.6	6.8	11.4	17.0	3.0
10/28	-6.8	-3.6	8.2	6.3	14.6	7.2	10.0	17.0	10.9
11/3		-0.9							
11/4	-8.1	0.9	13.1	0.2	19.8	6.7			
11/10	-2.0	0.0	8.8	-1.5	6.9	3.7	2.5	42.0	1.3
11/11	-1.8	2.6	9.9	0.2	9.9	5.0	3.0	15.0	1.2
11/17	0.4	1.2	7.6	9.6	17.3	8.6			
11/18	0.8	0.3	11.1			11.1			

Daily Averages-ΔL (con't) 2/24/64

Date 1961	X_L-X_R	S_L-S_R	$\overline{X}-\overline{S}$	$\overline{S}$-UHF	$\overline{X}$-UHF	$\overline{\Delta L}$	$T_{1000'}$, °C	$U_{2000'}$, m/s	Ri
1/12		4.2							
1/13		-1.3							
1/19				3.7		3.7			
1/20		7.8		4.2		4.2			
1/26				6.6		6.6			
1/27				7.4		7.4	-11.0	45.0	1.0
2/2		3.7		1.2		1.2			
2/3		7.4		3.0		3.0			
2/9		8.7		3.9		3.9			
2/10		8.2		-1.8		-1.8			
2/16	-14.5(1hr)	3.3	19.0	-2.3	12.9	8.4	-6.8	12.0	6.4
2/17	-12.3	0.2	12.9	-1.9	11.0	5.5	3.5	45.0	0.7
2/23		3.2		0.5		0.5			
2/24		-1.1		3.7		3.7			
3/2		1.4(1hr)							
3/3		2.9	9.2			9.2	7.5	32.0	0.9
3/9		-1.2		0.5		0.5			
3/10		0.3		-1.0		-1.0			
3/16		-1.3		2.1		2.1			
3/17		-1.1		2.3		2.3			
3/23		-4.1		7.3		7.3			
3/24		-4.4		7.1		7.1	1.0	23.0	4.5
3/30									
3/31				1.4		1.4			
4/20		-0.4		0.3		0.3			
4/21		0.4		-0.1		-0.1			
4/27		0.9		3.9		3.9			
4/28									
5/4	-2.4	-0.7	7.8	-1.1	6.6	3.3			
5/5	-3.8	1.0	5.3	-4.3	1.1	0.5			
5/11	-4.9	-0.2	4.6	-9.8	-5.2	-2.6	16.5	16.0	2.9
5/12		-5.8		-3.9		-3.9	22.0	35.0	0.2
5/18	-5.3	9.1	9.7	4.3	13.9	7.0	10.5	24.0	2.1
5/19	-4.9	7.5	11.1	5.9	15.6	8.5	8.5	9.0	6.9

Daily Averages-ΔL (con't) 2/28/64

Date 1961	$X_L - X_R$	$S_L - S_R$	$\overline{X}-\overline{S}$	$\overline{S}$-UHF	$\overline{X}$-UHF	$\overline{\Delta L}$	$T_{1000'}$, °C	$U_{2000'}$, m/s	Ri
5/25	-0.5	10.8	3.2	3.6	6.8	3.4			
5/26		6.6	4.7	9.4	14.5	7.0			
6/8		3.8		-0.7		-0.7			
6/9									
6/15	-0.7	7.8	0.0	5.7	5.6	2.8	14.2	22.0	0.4
6/16	-0.1	-0.5	1.0	0.6	2.0	0.8	16.5	21.0	4.0
6/22	-3.0	3.1	2.5	-3.1	-0.6	-0.3			
6/23	-4.5	6.1	1.7	-0.9	0.8	0.4			
6/29	-0.6	11.1	0.4	-4.6	-4.2	-2.1	23.5	25.0	3.1
6/30	0.0	6.6	-0.7	-4.8	-5.4	-2.7		24.0	
7/6									
7/7	9.9	-4.0	-4.8	7.1	2.4	1.1			
7/13	-1.0	0.4	0.4	4.6	4.2	2.1			
7/14	-0.3	12.6	-0.8	5.4	4.5	2.3			
7/20		2.6	-1.9	2.9	1.0	0.5			
7/21		0.9	-1.1	1.8	0.6	0.3			
7/27	-3.7	-0.5	-3.5	12.1	8.5	4.3			
7/28	-1.9	-1.0	-2.7	14.0	11.3	5.6			

Table II

Hourly Sample Values of Mean Excess Propagation Loss, L_p

AN/MPN-1 X-band Lefthand Antenna (X-L)

Date/Hour 1960	1030	1130	1230	1330	1430	1530
8/4	56.5	54.5	53.5	56.5	60.5	62.5
8/5	52.0	49.5	51.0	53.5	54.5	--
8/11	51.0	51.0	52.5	61.5	62.0	62.0
8/12	57.0	59.0	61.5	62.5	63.0	--
8/18	--	51.5	51.5	53.5	54.0	56.5
8/19	53.0	52.5	50.5	47.5	45.5	--
8/25	54.0	55.5	53.5	54.0	54.0	56.0
8/26	53.5	50.5	57.5	57.5	58.0	--
9/1	--	--	--	--	--	50.5
9/2	54.0	54.0	53.5	53.5	54.5	--
9/8	59.0	55.5	53.5	50.5	53.5	56.0
9/9	56.5	53.5	57.5	57.5	55.5	--
9/15	64.5	60.5	58.0	59.5	59.5	61.0
9/16	47.0	47.0	47.5	48.0	49.5	--
9/22	56.5	59.0	61.0	63.0	61.0	62.5
9/23	68.0	67.5	66.5	66.5	67.0	--
9/29	--	59.0	59.5	63.5	63.0	63.0
9/30	68.5	69.0	68.0	63.0	61.0	--
10/6	58.0	64.0	68.5	68.0	68.0	69.0
10/7	68.0	66.5	63.5	64.0	65.0	--
10/13	61.0	66.5	>67.5	>67.5	>67.5	70.5
10/14	60.5	61.5	62.5	63.0	67.0	--
10/20	65.0	64.0	65.5	67.0	67.5	67.5
10/21	64.5	68.0	66.0	61.5	65.0	--
10/27	59.0	56.0	58.0	60.0	58.5	62.0
10/28	65.5	64.0	60.5	62.5	65.5	--
11/3		SIGNAL MASKED BY NOISE				
11/4	66.5	70.0	69.5	69.5	69.5	70.0
11/10	--	--	67.0	68.5	69.0	70.0
11/11	73.5	74.0	73.5	73.5	74.0	73.5
11/17	67.0	68.0	69.0	71.0	71.5	71.5
11/18	68.0	68.5	69.5	73.0	73.5	73.0
1961						
1/12						
1/13						
1/19						
1/20						
1/26						
1/27						
2/2						
2/3						
2/9						
2/10						

AN/MPN-1 X-band Lefthand Antenna (X-L)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/16	--	67.5	71.5	73.5	75.5	--
2/17	62.5	66.5	59.5	65.5	73.5	65.5
2/23						
2/24						
3/2						
3/3	65.5	66.5	68.5	71.5	71.0	71.5
3/9						
3/10						
3/16						
3/17						
3/23						
3/24						
3/30						
3/31						
4/6 }						
4/7 }	System Inoperative					
4/13 }						
4/14 }						
4/20						
4/21						
4/27						
4/28						
5/4	70.7	67.7	69.7	68.7	69.2	70.7
5/5	--	--	66.2	67.2	--	--
5/11	53.2	52.7	55.2	54.2	--	--
5/12						
5/18	64.2	65.7	66.7	65.2	67.2	64.7
5/19	67.2	66.7	66.7	69.2	70.2	--
5/25	61.3	Tx off	62.8	63.8	64.3	63.3
5/26	70.8	70.3	70.3	69.3	68.8	--
6/1 }	System Inoperative					
6/2 }						
6/8						
6/9						
6/15	62.1	63.1	65.1	57.6	66.1	66.1
6/16	60.1	63.6	65.6	60.6	62.5	--
6/22	59.5	57.5	56.5	57.0	58.0	58.0
6/23	61.5	61.5	60.5	58.5	60.5	--
6/29	61.5	61.5	60.5	61.0	61.0	61.5
6/30	63.5	63.0	58.5	65.5	59.5	59.5
7/1	60.0	59.0	57.5	62.0	66.5	--
7/6						
7/7	63.5	65.5	59.5	64.5	71.0	--
7/13	50.8	53.8	56.8	59.3	58.3	60.3
7/14	58.8	60.8	60.3	60.3	59.8	--
7/20						
7/21						

AN/MPN-1 X-band Lefthand Antenna (Y-L)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
7/27	48.0	52.0	51.5	52.0	58.0	60.0
7/28	52.0	57.0	57.5	61.0	62.0	--
8/3	55.9	55.9	57.4	57.9	59.9	63.9
8/4	54.9	59.9	60.4	64.4	67.9	--

AN/MPN-1 X-band Righthand Antenna (X-R)

Date/Hour 1960	1030	1130	1230	1330	1430	1530
8/4	61.5	59.5	57.5	60.5	61.0	62.0
8/5	51.5	49.5	52.0	55.0	54.5	--
8/11	54.0	58.5	60.5	61.5	61.5	61.0
8/12	57.5	61.0	65.0	65.0	64.0	--
8/18	61.0	54.0	53.5	55.5	55.5	58.0
8/19	55.0	54.5	53.5	51.0	48.0	--
8/25	--	--	--	52.5	54.5	57.0
8/26	54.5	53.5	59.5	60.0	61.0	--
9/1	--	--	--	53.5	54.5	50.5
9/2	52.0	52.5	52.5	52.5	53.5	--
9/8	57.0	54.5	54.0	48.0	50.5	54.0
9/9	57.0	54.0	57.0	57.5	55.0	--
9/15						
9/16						
9/22						
9/23						
9/29	--	--	--	--	65.0	62.0
9/30	69.5	72.0	69.0	70.0	68.5	--
10/6	59.5	67.5	71.5	71.5	71.0	73.0
10/7	69.0	68.0	65.0	66.0	67.5	--
10/13	>60.5	65.0	63.0	63.0	61.0	74.0
10/14	67.0	68.0	69.5	70.0	73.5	--
10/20	65.0	66.0	66.5	67.0	68.5	68.5
10/21	66.0	69.0	66.5	64.0	66.0	--
10/27	65.0	61.0	61.5	64.0	64.5	69.5
10/28	70.5	69.5	68.0	70.5	73.5	--
11/3		SIGNAL MASKED BY NOISE				
11/4	77.0	77.5	77.5	77.0	77.5	77.5
11/10	--	--	63.5	70.5	71.5	72.0
11/11	75.5	75.0	75.5	75.5	75.5	75.5
11/17	65.0	66.5	68.5	70.0	72.5	73.0
11/18	66.0	66.0	67.5	73.0	74.0	74.0
1961						
1/12						
1/13						
1/19						
1/20						
1/26						
1/27						
2/2						
2/3						
2/9						
2/10						
2/16	81.0	82.0	NOISE →			
2/17	77.5	78.0	79.5	80.0	82.0	80.0

AN/MPN-1 X-band Righthand Antenna (X-R)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/23						
2/24						
3/2						
3/3						
3/9						
3/10						
3/16						
3/17						
3/23						
3/24						
3/30						
3/31						
4/6						
4/7						
4/13						
4/14						
4/20						
4/21						
4/27						
4/28						
5/4	72.0	71.0	70.5	72.0	72.0	72.5
5/5	--	--	--	69.0	71.5	--
5/11	57.9	58.4	60.4	59.4	62.9	62.4
5/12						
5/18	68.6	69.1	71.1	71.1	73.1	72.1
5/19	72.1	71.6	71.6	73.1	75.6	--
5/25	60.5	--	63.5	65.5	66.0	64.0
5/26						
6/1						
6/2						
6/8						
6/9						
6/15	62.4	64.4	64.9	68.4	66.4	67.9
6/16	59.9	62.9	65.4	61.9	62.9	--
6/22	62.6	60.6	59.1	59.5	61.1	62.6
6/23	64.6	65.1	66.1	63.6	65.6	--
6/29	65.2	62.7	62.2	60.7	61.2	58.7
6/30	65.7	65.7	58.2	62.2	59.2	58.7
7/1	58.2	56.2	56.2	58.7	62.2	--
7/6						
7/7	55.4	57.4	51.4	54.9	55.4	--
7/13	54.0	56.0	59.0	59.5	57.0	60.0
7/14	60.5	60.5	60.0	61.0	59.5	--
7/20						
7/21						

AN/MPN-1 X-band Righthand Antenna (X-R)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
7/27	48.6	53.1	54.1	56.6	60.6	71.6
7/28	52.6	58.6	62.6	62.6	62.6	--
8/3	57.3	57.8	58.3	59.8	62.8	65.8
8/4	53.3	58.8	61.3	62.3	64.8	--

Logarithmic X-band Righthand Antenna

Date/Hour 1960	1030	1130	1230	1330	1430	1530
8/4	60.0	58.0	57.0	59.0	60.0	60.0
8/5	53.0	50.0	53.0	56.0	55.0	--
8/11	55.5	58.0	62.0	62.0	63.0	62.0
8/12	In excess of 63 db (signal in noise)					
8/18	--	54.0	53.0	56.0	56.0	58.0
8/19	56.0	56.0	54.0	50.0	50.0	--
8/25	--	--	--	54.0	55.5	55.5
8/26	56.0	54.5	60.5	60.5	63.5	--
9/1	--	--	--	56.0	54.5	52.5
9/2	52.5	54.0	54.0	54.0	54.5	--
9/8	56.5	55.5	54.5	50.0	52.0	54.0
9/9	56.0	53.5	56.5	59.5	55.5	--
9/15						
9/16						
9/22						
9/23						
9/29		SIGNAL MASKED BY NOISE				
9/30		SIGNAL MASKED BY NOISE				
10/6		SIGNAL MASKED BY NOISE				
10/7		SIGNAL MASKED BY NOISE				
10/13	63.0	69.5	>70.5	>70.5	>70.5	>70.5
10/14	63.5	63.5	66.5	65.5	69.5	--
10/20		SIGNAL MASKED BY NOISE				
10/21		SIGNAL MASKED BY NOISE				
10/27	65.5	61.5	63.0	65.5	65.5	70.5
10/28	70.0	70.0	68.5	>71.0	>71.0	--
11/3		SIGNAL MASKED BY NOISE				
11/4		SIGNAL MASKED BY NOISE				
11/10		SIGNAL MASKED BY NOISE				
11/11		SIGNAL MASKED BY NOISE				
11/17	66.0	66.0	69.0	--	--	--
11/18	66.0	65.5	66.5	65.0	--	--
1961						
1/12						
1/13						
1/19						
1/20						
1/26						
1/27						
2/2						
2/3						
2/9						
2/10						
2/16						
2/17						

Logarithmic X-band Righthand Antenna

Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/23						
2/24						
3/2						
3/3						
3/9						
3/10						
3/16						
3/17						
3/23						
3/24						
3/30						
3/31						
4/6						
4/7						
4/13						
4/14						
4/20						
4/21						
4/27						
4/28						
5/4						
5/5						
5/11						
5/12						
5/18						
5/19						
5/25						
5/26						
6/1						
6/2						
6/8						
6/9						
6/15	65.0	67.0	68.0	72.0	69.0	70.0
6/16	61.0	66.0	66.0	68.0	70.0	--
6/22	60.5	58.5	58.5	58.5	60.5	63.5
6/23	63.5	63.5	64.5	61.5	63.5	--
6/29	63.4	60.4	59.4	60.4	60.4	57.9
6/30	65.4	65.4	57.9	62.4	59.4	58.4
7/1	59.4	56.9	54.9	58.4	60.4	--
7/6						
7/7	63.6	67.6	61.6	64.6	65.6	--
7/13	56.0	58.0	61.0	61.0	59.0	62.0
7/14	61.0	61.0	61.0	62.0	60.0	--
7/18	--	--	--	--	62.3	61.3
7/19	56.3	59.3	--	60.3	63.3	62.3
7/20	58.3	60.3	61.3	61.3	63.3	61.3
7/21	57.3	58.3	57.3	58.3	60.3	61.3

Logarithmic X-band Righthand Antenna

Date/Hour 1961	1030	1130	1230	1330	1430	1530
7/23	--	--	--	--	62.3	68.3
7/24	--	58.3	56.3	54.3	58.3	55.3
7/25	58.3	--	59.3	--	--	--
7/27	49.3	54.3	55.3	58.3	61.3	63.3
7/28	55.3	60.3	61.3	62.3	62.3	--
8/3	56.5	56.5	58.5	59.5	65.5	66.5
8/4	52.5	57.5	60.5	65.5	66.5	--
8/8	--	--	--	--	--	57.5
8/9	--	56.5	61.5	57.5	--	52.5
8/10	58.5	56.5	52.5	53.5	53.5	54.5
8/11	58.5	59.5	57.5	56.5	56.5	--
8/17	55.5	59.5	57.5	59.5	58.5	60.5
8/18	--	56.5	58.5	--	--	--
8/21	--	--	--	--	--	64.5
8/22	68.5	70.5	--	69.5	67.5	64.5
8/23	--	65.5	61.5	60.5	60.5	57.5
8/24	62.5	59.5	60.5	59.5	59.5	59.5
8/25	59.5	54.5	53.5	56.5	55.5	--
8/28	--	--	--	--	56.0	60.5
8/29	60.5	58.5	58.0	58.0	53.5	58.0
8/30	60.0	58.0	55.0	55.5	58.5	57.0
8/31	65.5	63.5	58.5	60.5	60.5	61.5
9/1	57.5	57.5	58.5	62.5	62.5	--
9/7	55.5	56.0	59.5	60.5	61.5	61.5
9/8	50.0	51.0	54.5	58.0	61.0	61.5
9/9	54.5	53.5	59.5	60.5	60.5	61.0
9/10	52.5	56.5	59.5	59.5	59.0	59.5
9/11	62.5	60.5	61.5	61.5	61.0	61.0
9/12	67.5	66.5	64.5	66.0	66.5	65.5
9/13	57.5	56.5	58.0	58.0	59.5	60.0
9/14	58.5	59.5	60.0	58.0	60.0	60.5
9/15	62.0	63.0	63.5	63.0	63.5	63.5

Date/Hour 1960	AN/MPN-1 1030	S-band 1130	Lefthand 1230	Antenna 1330	(S-R) 1430	1530
8/4	60.0	59.5	58.0	60.5	63.5	63.5
8/5	54.5	53.5	55.5	57.5	57.5	--
8/11	57.0	61.0	62.0	64.0	64.0	63.5
8/12	61.0	62.5	65.0	64.5	67.0	--
8/18	54.5	57.0	58.0	59.5	56.5	59.0
8/19	57.0	57.5	56.5	55.5	55.5	--
8/25	59.5	60.0	59.0	58.5	61.5	62.5
8/26	58.0	58.0	63.0	63.5	63.5	--
9/1	60.0	62.5	65.5	64.5	63.0	58.5
9/2	60.0	60.5	60.0	61.0	62.0	--
9/8	62.5	60.0	59.0	57.0	59.0	59.5
9/9	62.0	60.0	62.5	62.5	59.0	--
9/15	60.5	58.0	59.5	61.5	62.5	61.0
9/16	49.5	49.0	49.0	51.0	54.0	--
9/22	57.0	59.0	60.0	61.0	60.0	61.0
9/23	63.5	63.0	64.5	62.5	66.0	--
9/29	--	54.5	55.0	56.5	56.5	55.5
9/30	61.5	62.5	62.5	62.0	61.5	--
10/6	51.0	55.0	56.0	55.5	55.5	56.0
10/7	60.0	59.5	58.5	58.5	58.5	--
10/13	38.5	48.0	45.5	>48.0	>48.0	46.5
10/14	42.5	43.5	43.5	45.0	47.0	--
10/20	57.0	57.0	58.0	57.0	58.5	58.0
10/21	59.0	60.0	--	--	59.5	--
10/27	50.0	50.0	52.0	53.0	53.0	54.0
10/28	55.5	57.5	55.5	57.5	59.5	--
11/3	60.5	60.5	57.0	59.0	56.0	58.0
11/4	59.0	61.0	61.0	61.5	60.5	60.5
11/10	--	--	60.0	61.5	61.0	61.5
11/11	65.0	65.5	66.0	67.0	67.0	67.0
11/17	61.5	62.0	62.5	62.5	64.0	63.0
11/18	57.5	58.0	59.0	61.5	61.5	59.5
1961						
1/12	62.9	61.4	61.9	61.9	61.9	62.4
1/13	56.4	57.4	57.9	57.9	57.4	56.9
1/19	63.2	63.2	62.2	60.2	63.2	63.2
1/20	66.2	66.2	66.2	66.2	65.2	65.2
1/26	--	61.3	61.8	61.8	61.8	61.8
1/27	62.8	63.8	63.8	63.3	62.8	62.8
2/2	58.7	60.7	--	--	--	63.2
2/3	60.7	60.7	61.7	61.2	61.7	61.7
2/9	66.7	68.2	69.7	70.2	69.7	67.7
2/10	67.2	66.2	67.2	67.2	69.2	69.2
2/16	58.2	59.7	61.2	61.7	64.2	64.7

AN/MPN-1 S-band Lefthand Antenna (S-R)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/17	58.7	60.2	61.2	62.2	61.2	60.7
2/23	62.7	65.7	65.2	65.7	63.2	63.2
2/24	61.2	62.7	64.7	63.7	63.2	62.2
3/2	--	--	--	--	--	62.7
3/3	60.7	60.7	61.7	62.2	61.7	61.7
3/9	62.7	63.7	64.7	64.7	63.7	63.2
3/10	61.7	62.2	62.2	61.7	60.7	60.2
3/16	61.2	61.2	61.2	62.2	62.7	62.2
3/17	61.2	61.2	60.7	61.2	61.2	61.2
3/23	--	--	--	--	62.2	62.2
3/24	61.7	62.2	62.2	61.2	61.7	62.2
3/30						
3/31	58.7	59.7	60.7	62.7	63.7	63.7
4/6						
4/7						
4/13						
4/14						
4/20	60.5	62.0	62.5	62.5	62.0	62.5
4/21	63.5	63.5	63.5	62.5	61.5	62.0
4/27	62.0	62.5	63.5	63.0	63.0	62.0
4/28						
5/4	63.5	63.5	63.5	63.5	64.0	60.0
5/5	--	63.5	63.5	63.5	64.5	--
5/11	52.2	52.2	53.7	53.2	54.7	54.7
5/12	63.2	62.2	62.2	61.7	61.7	--
5/18	62.3	64.3	64.8	63.8	63.8	59.8
5/19	63.3	64.3	64.8	64.8	64.8	--
5/25	64.4	--	66.4	66.9	67.4	66.4
5/26	69.9	68.9	68.9	67.9	67.4	--
6/1						
6/2						
6/8	67.1	66.6	67.1	65.6	67.1	64.6
6/9						
6/15	68.2	69.2	70.2	71.2	70.2	70.2
6/16	59.7	62.2	63.7	66.2	67.7	--
6/22	59.7	58.2	57.2	57.7	58.7	59.2
6/23	63.7	63.7	64.2	64.7	64.2	--
6/29	67.6	67.1	65.6	65.6	67.1	66.6
6/30	70.6	70.1	62.6	55.1	64.1	63.1
7/1	59.6	59	58.6	60.1	62.1	--
7/6						
7/7	62.2	65.7	60.2	61.2	64.2	--
7/13	55.5	56.5	56.5	59.0	58.5	58.5
7/14	61.0	60.5	59.5	61.0	--	--
7/18	68.3	66.8	66.3	66.8	64.8	65.8
7/19	58.3	59.8	62.8	62.8	63.8	62.8

AN/MPN-1 S-band Lefthand Antenna (S-R)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
7/20	--	61.8	63.3	62.3	65.3	66.3
7/21	60.8	59.3	59.3	60.8	62.3	62.3
7/27	47.3	51.3	62.3	63.8	65.8	64.3
7/28	59.3	62.3	63.3	64.8	65.3	--
8/3	64.6	64.6	65.1	66.1	67.1	68.1
8/4	59.6	61.6	62.6	63.6	64.6	--

Date/Hour 1960	AN/MPN-1 1030	S-band 1130	Righthand 1230	Antenna 1330	(S-L) 1430	1530
8/4	57.5	57.0	56.5	59.5	62.0	63.5
8/5	55.5	54.5	56.0	58.5	59.0	--
8/11	57.0	61.0	63.0	66.0	66.0	65.5
8/12	62.0	64.5	67.0	66.5	68.5	--
8/18	54.0	57.0	57.0	59.0	60.5	62.0
8/19	52.5	53.5	53.5	51.0	47.0	--
8/25	61.0	62.0	60.5	58.0	60.0	60.0
8/26	58.0	57.0	63.0	63.0	63.0	--
9/1	56.5	60.0	65.0	64.5	63.0	55.5
9/2	57.5	58.0	57.5	58.5	59.0	--
9/8	64.0	61.0	60.0	57.5	60.5	61.5
9/9	63.0	60.5	64.0	64.0	58.5	--
9/15	64.5	60.5	58.0	59.5	59.5	61.0
9/16	47.0	47.0	47.5	48.0	49.5	--
9/22	56.5	59.0	61.0	63.0	61.0	62.5
9/23	68.0	67.5	66.5	66.5	67.0	--
9/29	--	55.5	56.5	59.0	60.5	58.5
9/30	60.0	61.5	68.5	68.0	[illegible]7.5	--
10/6						
10/7	49.0	47.5	45.5	47.0	47.0	--
10/13	37.0	43.0	>45.5	>45.5	>45.5	50.0
10/14	45.0	46.0	46.0	47.0	49.5	--
10/20	60.5	59.0	59.0	60.5	62.5	61.0
10/21	59.5	61.5	59.5	57.5	60.0	--
10/27	55.5	54.5	57.0	57.0	57.0	59.0
10/28	60.0	60.0	60.5	61.0	62.0	--
11/3	60.0	61.0	58.5	61.0	57.0	59.0
11/4	57.5	60.5	60.5	60.5	59.5	60.0
11/10	--	--	60.5	61.0	61.0	61.5
11/11	63.5	63.5	63.5	64.0	64.0	63.5
11/17	60.5	60.5	61.0	61.5	62.5	62.5
11/18	57.0	57.5	58.5	61.0	61.0	60.5
1961						
1/12	59.8	57.3	58.3	57.8	57.3	56.8
1/13	56.8	59.8	59.3	59.3	58.8	57.3
1/19						
1/20	57.8	58.3	58.3	58.3	58.3	57.8
1/26						
1/27						
2/2	58.3	59.3	--	--	--	53.8
2/3	52.3	52.3	53.8	55.3	55.3	54.8
2/9	59.3	59.8	60.3	60.3	60.3	59.8
2/10	59.3	59.3	59.3	58.8	60.8	60.8
2/16	54.5	57.0	58.0	59.0	60.0	60.0
2/17	56.5	59.5	61.0	62.0	62.0	60.5

	AN/MPN-1 S-band Righthand Antenna (S-L)					
Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/23	60.8	62.8	61.8	60.8	60.3	60.8
2/24	60.3	62.3	62.3	62.3	69.3	68.3
3/2	--	--	--	--	--	61.3
3/3	56.3	57.3	58.3	59.8	59.3	59.3
3/9	65.3	65.8	65.8	65.3	63.8	63.8
3/10	61.3	61.8	61.8	61.3	60.8	60.3
3/16	62.8	62.8	62.3	63.3	63.3	62.8
3/17	62.8	62.3	62.3	61.8	61.8	62.3
3/23	--	--	--	--	66.3	66.3
3/24	65.8	67.3	66.3	65.3	65.8	67.3
3/30						
3/31						
4/6						
4/7						
4/13						
4/14						
4/20	61.0	63.0	62.5	62.5	63.0	62.5
4/21	65.0	65.5	64.5	63.0	59.0	57.0
4/27	62.8	62.3	62.8	61.3	60.8	60.8
4/28						
5/4	62.7	63.2	64.2	64.2	65.2	61.7
5/5	--	62.7	62.7	62.7	63.7	--
5/11	51.2	51.2	54.2	53.7	55.2	56.7
5/12	65.7	70.2	69.2	67.7	67.2	--
5/18	54.7	55.7	55.7	52.7	53.2	51.7
5/19	55.2	56.2	56.7	57.7	58.2	--
5/25	53.2	--	55.7	56.2	56.2	53.2
5/26	62.7	61.2	61.7	61.7	61.7	--
6/1						
6/2						
6/8	64.2	63.7	66.7	60.2	60.2	60.7
6/9						
6/15	60.0	60.5	62.5	64.0	62.5	63.5
6/16	53.5	57.0	58.0	60.5	62.5	--
6/22	56.5	55.0	54.0	54.5	56.0	56.5
6/23	58.5	58.5	58.5	57.0	57.5	--
6/29	57.0	56.5	54.5	55.0	56.0	54.0
6/30	63.0	62.0	57.0	61.0	57.0	56.0
7/1	57.5	56.5	57.0	58.5	59.0	--
7/6						
7/7	68.4	69.4	63.4	65.4	65.9	--
7/13	54.6	54.1	54.1	59.6	58.6	61.1
7/14	48.1	48.1	47.6	48.1	--	--
7/18	63.6	62.6	59.1	58.1	59.1	60.1
7/19	56.1	56.1	60.6	59.6	60.6	58.1

AN/MPN-1 S-band Righthand Antenna (S-L)

Date/Hour 1961	1030	1130	1230	1330	1430	1530
7/20	59.1	61.1	61.1	60.1	63.1	62.6
7/21	58.1	57.1	59.1	60.6	63.1	61.6
7/27	51.0	53.0	58.0	61.5	63.0	71.0
7/28	54.0	64.5	66.0	67.5	68.0	--
8/3	60.2	61.2	62.2	63.2	64.2	66.7
8/4	54.2	57.2	58.7	61.7	62.2	--

Logarithmic S-band Righthand Antenna

Date/Hour 1960	1030	1130	1230	1330	1430	1530
8/4	56.0	56.0	55.0	58.0	60.0	62.0
8/5	55.0	52.0	54.0	56.0	57.0	--
8/11	58.0	63.0	65.0	65.0	65.0	66.0
8/12	63.0	65.0	68.0	68.0	67.0	--
8/18	53.0	56.0	56.0	58.0	58.0	60.0
8/19	50.0	53.0	51.0	49.0	48.0	--
8/25	59.5	60.0	57.0	56.5	59.5	60.5
8/26	57.5	55.5	62.5	63.5	63.0	--
9/1	54.5	58.5	63.0	59.0	56.5	57.5
9/2	57.5	57.5	57.0	58.5	59.5	--
9/8	65.0	61.5	59.0	56.5	60.0	61.5
9/9	62.5	58.5	62.5	62.5	54.5	--
9/15	63.0	56.0	56.5	58.0	58.5	60.5
9/16	47.5	46.0	46.5	48.5	51.0	--
9/22	55.5	57.5	60.5	63.5	61.5	62.5
9/23	69.0	68.0	67.0	66.5	68.0	--
9/29	55.5	54.5	56.5	59.5	60.5	59.0
9/30	59.5	60.5	59.0	58.5	58.0	--
10/6						
10/7						
10/13						
10/14						
10/20	60.0	58.5	59.0	60.5	62.0	60.5
10/21	59.5	61.5	60.0	58.5	59.0	--
10/27	57.5	56.5	57.0	57.5	57.0	58.5
10/28	--	--	61.5	62.5	65.0	--
11/3	60.0	61.0	59.0	61.0	56.5	59.0
11/4	55.5	59.0	58.5	58.0	57.5	58.0
11/10	61.5	61.0	59.5	61.0	61.5	61.5
11/11	64.0	64.0	64.0	64.0	64.5	64.0
11/17	60.5	61.0	61.5	62.0	63.0	62.5
11/18	57.0	57.5	59.0	61.0	61.5	59.0
1961						
1/12						
1/13	56.8	60.8	60.8	61.8	60.8	58.8
1/19						
1/20						
1/26	--	58.6	58.6	58.6	58.6	58.6
1/27	60.6	60.6	60.6	59.6	59.6	59.6
2/2						
2/3						
2/9						
2/10						
2/16						
2/17						

Logarithmic S-band Righthand Antenna

Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/23						
2/24						
3/2						
3/3						
3/9						
3/10						
3/16						
3/17						
3/23						
3/24						
3/30						
3/31						
4/6						
4/7						
4/13						
4/14						
4/20						
4/21						
4/27						
4/28						
5/4						
5/5						
5/11	54.6	54.6	59.6	57.6	60.6	59.6
5/12	--	--	69.6	70.6	69.6	--
5/18	58.2	58.2	58.2	55.2	56.2	52.2
5/19	56.2	57.2	58.2	59.2	60.2	--
5/25	54.3	--	58.3	55.3	56.3	51.3
5/26	66.3	65.3	63.3	62.3	62.3	--
6/1						
6/2						
6/8	66.5	66.5	66.5	58.5	60.0	64.5
6/9						
6/15	56.0	57.0	58.5	60.5	59.0	59.5
6/16	53.5	56.5	58.0	60.0	61.0	--
6/22	53.2	51.7	50.7	51.7	52.2	53.7
6/23	54.7	55.2	54.7	53.2	53.7	--
6/29	56.1	56.1	55.1	55.1	55.1	53.1
6/30	62.1	61.1	57.1	63.1	56.1	54.1
7/1	60.1	59.1	59.1	62.1	64.1	--
7/6						
7/7	59.5	62.5	54.5	57.5	58.5	--
7/13	56.7	54.7	54.7	60.7	60.7	62.7
7/14	62.7	61.7	60.7	60.7	59.7	--
7/18	63.3	63.3	61.3	60.3	58.3	58.3
7/19	56.3	57.3	61.3	61.3	60.3	56.3
7/20	59.3	62.3	61.3	61.3	63.3	62.3
7/21	57.3	58.3	58.3	60.3	62.3	62.3

Logarithmic S-band Righthand Antenna

Date/Hour 1961	1030	1130	1230	1330	1430	1530
7/24	62.3	59.3	55.3	54.3	55.3	54.3
7/25	59.3	60.3	55.3	--	--	--
7/27	53.0	56.0	61.0	64.0	66.0	66.0
7/28	53.0	61.0	61.0	63.0	63.0	68.0
8/3	55.8	56.8	59.8	60.8	61.8	63.8
8/4	52.8	55.8	56.8	58.8	60.8	--
8/10	51.9	51.9	49.9	53.9	50.9	51.9
8/11	54.9	58.9	58.9	55.9	54.9	--
8/17						
8/18						
8/22						
8/23						
8/28	--	--	--	--	63.5	68.5
8/29	65.5	63.5	64.5	63.5	64.5	64.5
8/30	67.5	68.5	67.5	67.5	64.5	63.5
8/31	68.5	68.5	66.5	66.5	65.5	65.5
9/1	66.7	66.7	67.7	--	--	--
9/7	72.4	73.4	--	--	--	73.4
9/8	62.9	65.4	71.4	--	--	73.4
9/9	68.4	68.4	71.4	73.4	72.4	72.4
9/10	66.5	68.5	69.5	69.5	69.5	69.5

Logarithmic UHF Center Antenna

Date/Hour 1960	1030	1130	1230	1330	1430	1530
8/4	63.5	64.0	64.0	65.0	68.0	64.5
8/5	63.0	63.0	63.5	63.5	--	--
8/11, 8/12	No Data--Equipment Inoperative					
8/18	63.0	66.0	67.0	64.0	64.0	60.0
8/19	62.0	63.0	64.0	59.0	55.0	--
8/25	64.0	66.5	66.0	67.5	66.5	66.5
8/26	65.0	70.0	69.5	69.0	69.5	--
9/1	58.5	60.0	57.5	57.5	55.0	63.0
9/2	63.5	65.0	55.0	64.0	65.5	--
9/8	64.0	65.0	66.0	63.5	61.5	61.5
9/9	68.0	65.0	66.0	64.5	60.0	--
9/15	66.0	72.0	73.0	74.0	72.0	67.5
9/16	48.0	51.0	58.0	61.0	63.5	--
9/22	58.5	63.0	66.5	67.5	67.0	65.5
9/23	61.5	63.5	67.5	67.5	65.5	--
9/29	--	--	--	67.0	66.5	65.0
9/30	71.5	71.5	71.5	71.0	67.5	--
10/6	--	--	--	--	--	--
10/7	59.5	61.0	63.0	62.5	63.5	--
10/13	65.5	68.5	70.0	69.5	71.5	73.0
10/14	69.0	70.5	71.0	71.0	70.0	--
10/20	--	--	--	--	--	--
10/21	53.5	52.5	53.5	53.0	53.5	--
10/27	47.0	48.0	50.5	50.0	49.5	49.0
10/28	50.0	52.5	51.5	53.5	54.5	--
11/3	--	--	--	--	--	--
11/4	60.0	60.0	60.5	60.5	59.5	59.5
11/10	60.5	61.5	63.0	64.5	62.5	63.0
11/11	64.5	64.5	65.0	65.0	65.0	64.0
11/17	52.0	52.5	52.5	53.0	52.0	51.5
11/18	--	--	--	--	--	--
1961						
1/12	--	--	--	--	--	--
1/13	--	--	--	--	--	--
1/19	59.5	58.5	58.5	58.5	59.5	59.5
1/20	58.5	59.5	57.5	57.5	56.5	57.5
1/26	56.5	56.5	55.5	55.5	54.5	53.5
1/27	53.5	55.5	56.5	55.5	56.5	57.5
2/2	57.5	59.5	61.5	59.5	59.5	56.5
2/3	52.5	54.5	54.5	55.5	55.5	55.5
2/9	59.5	60.5	61.5	60.5	60.5	59.5
2/10	63.5	66.5	67.5	65.5	64.5	65.5
2/16	59.5	63.5	62.5	63.5	61.5	62.5
2/17	59.5	61.5	63.5	64.5	63.5	61.5

Logarithmic UHF Center Antenna

Date/Hour 1961	1030	1130	1230	1330	1430	1530
2/23	60.5	64.5	61.5	63.5	62.5	61.5
2/24	56.5	59.5	60.5	62.5	60.5	59.5
3/2	--	--	--	--	--	--
3/3	--	--	--	--	--	--
3/9	61.5	61.5	64.5	65.5	64.5	64.5
3/10	61.5	62.5	62.5	63.5	62.5	61.5
3/16	62.5	61.5	60.5	59.5	59.5	59.5
3/17	59.5	59.5	59.5	59.5	58.5	59.5
3/23	--	--	--	--	56.5	57.5
3/24	56.5	58.5	56.5	56.5	56.5	57.5
3/30	--	--	--	--	--	--
3/31	59.5	59.5	59.5	61.5	60.5	60.5
4/6	--	--	--	--	--	--
4/7	--	--	--	--	--	--
4/13	--	--	--	--	--	--
4/14	--	--	--	--	--	--
4/20	63.5	63.5	63.5	61.5	61.5	62.5
4/21	65.5	65.5	65.5	65.5	62.5	60.5
4/27	58.5	57.5	57.5	57.5	57.5	59.5
4/28	--	--	--	--	--	--
5/4	64.5	63.5	63.5	64.5	63.5	64.5
5/5	67.5	67.5	67.5	67.5	67.5	--
5/11	59.0	61.0	63.0	65.0	66.0	66.0
5/12	67.0	68.0	70.0	71.0	69.0	--
5/18	56.0	56.0	55.0	52.0	54.0	52.0
5/19	54.0	55.0	55.0	55.0	55.0	--
5/25	55.0	56.0	60.0	59.0	59.0	53.0
5/26	55.0	55.0	56.0	56.0	57.0	--
6/1	--	--	--	--	--	--
6/2	--	--	--	--	--	--
6/8	65.5	66.5	66.5	61.5	67.5	61.5
6/9	70.5	68.5	67.5	66.5	66.5	--
6/15	59.5	60.5	59.5	60.5	61.5	59.5
6/16	59.5	61.5	60.5	60.5	60.5	--
6/22	62.5	59.5	57.5	59.5	61.5	60.5
6/23	64.5	61.5	61.5	60.5	61.5	--
6/29	65.5	65.5	65.5	68.5	65.5	62.5
6/30	66.5	67.5	66.5	65.5	69.5	65.5
7/1	59.5	60.5	60.5	60.5	61.5	--
7/6	58.5	61.5	61.5	60.5	60.5	60.5
7/7	59.5	60.5	55.5	55.5	56.5	--
7/13	51.8	52.8	52.8	52.8	53.8	55.8
7/14	55.8	55.8	55.8	55.8	54.8	--
7/20	--	--	61.5	63.5	64.5	61.5
7/21	57.5	57.5	57.5	58.5	57.5	--
7/27	46.1	47.1	51.1	50.1	49.1	50.1
7/28	46.1	49.1	48.1	47.1	47.1	--

Logarithmic UHF Center Antenna

Date/Hour 1961	1030	1130	1230	1330	1430	1530
8/3	52.4	53.4	53.4	51.4	51.4	52.4
8/4	49.4	53.4	53.4	53.4	55.4	--
8/10	50.5	49.5	50.5	49.5	46.5	46.5
8/11	--	55.5	56.5	54.5	53.5	--
8/17	52.5	53.5	54.5	55.5	54.5	55.5
8/18	55.5	53.5	55.5	55.5	57.5	--

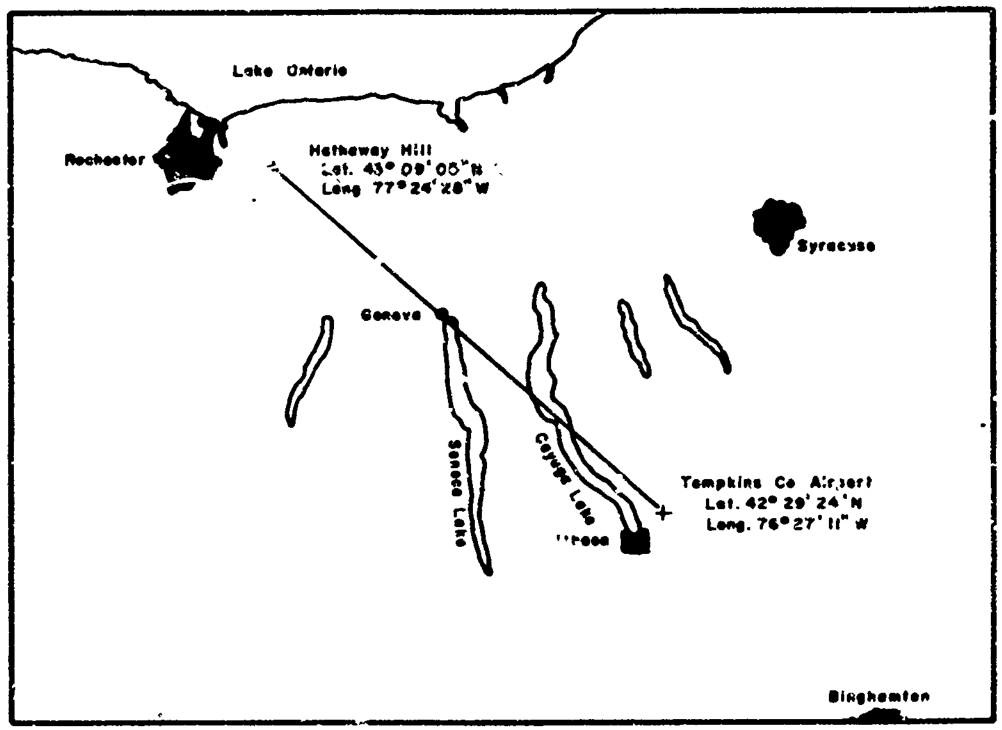


Figure 1. Map of Rochester-Ithaca Region.

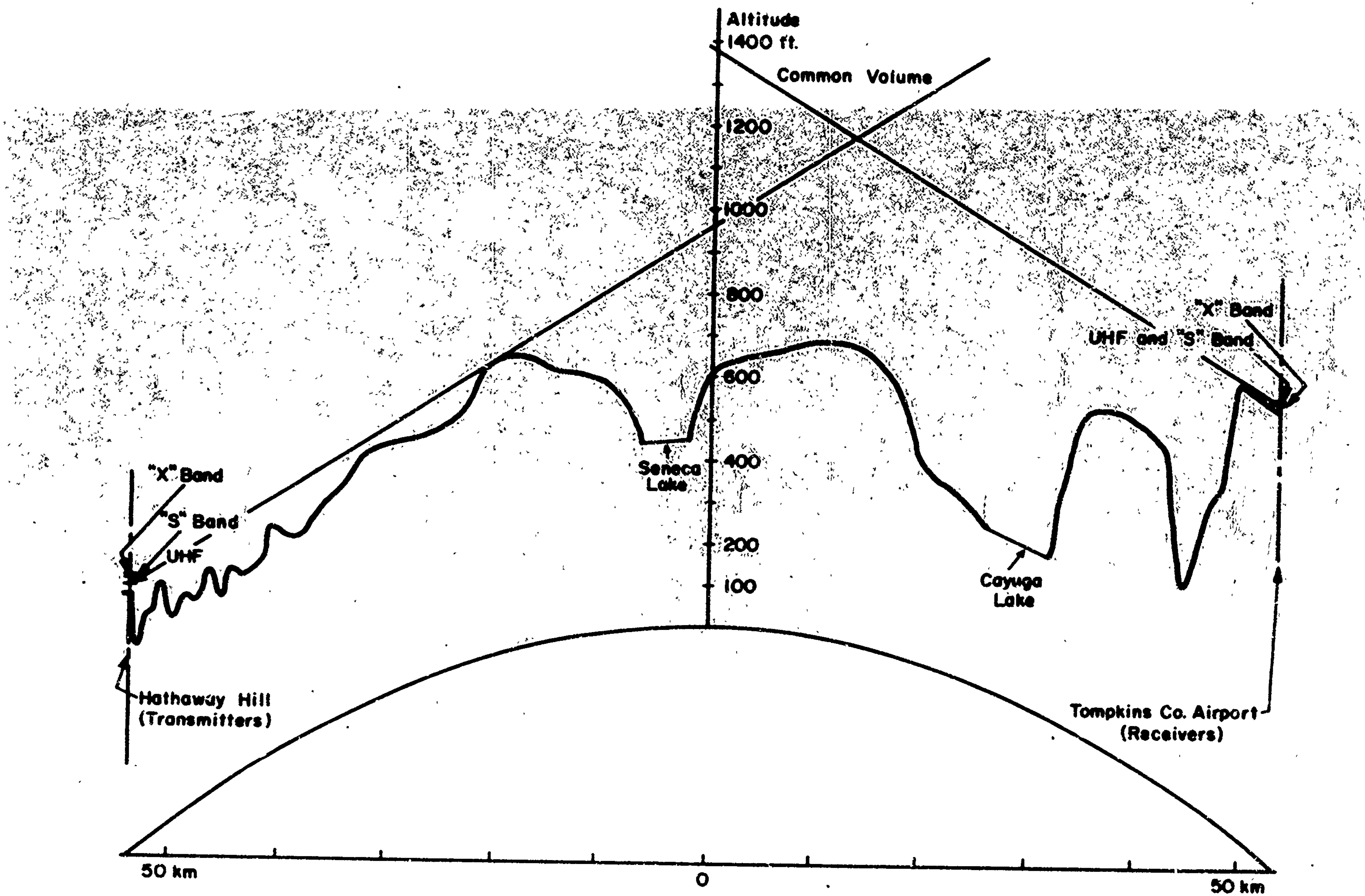
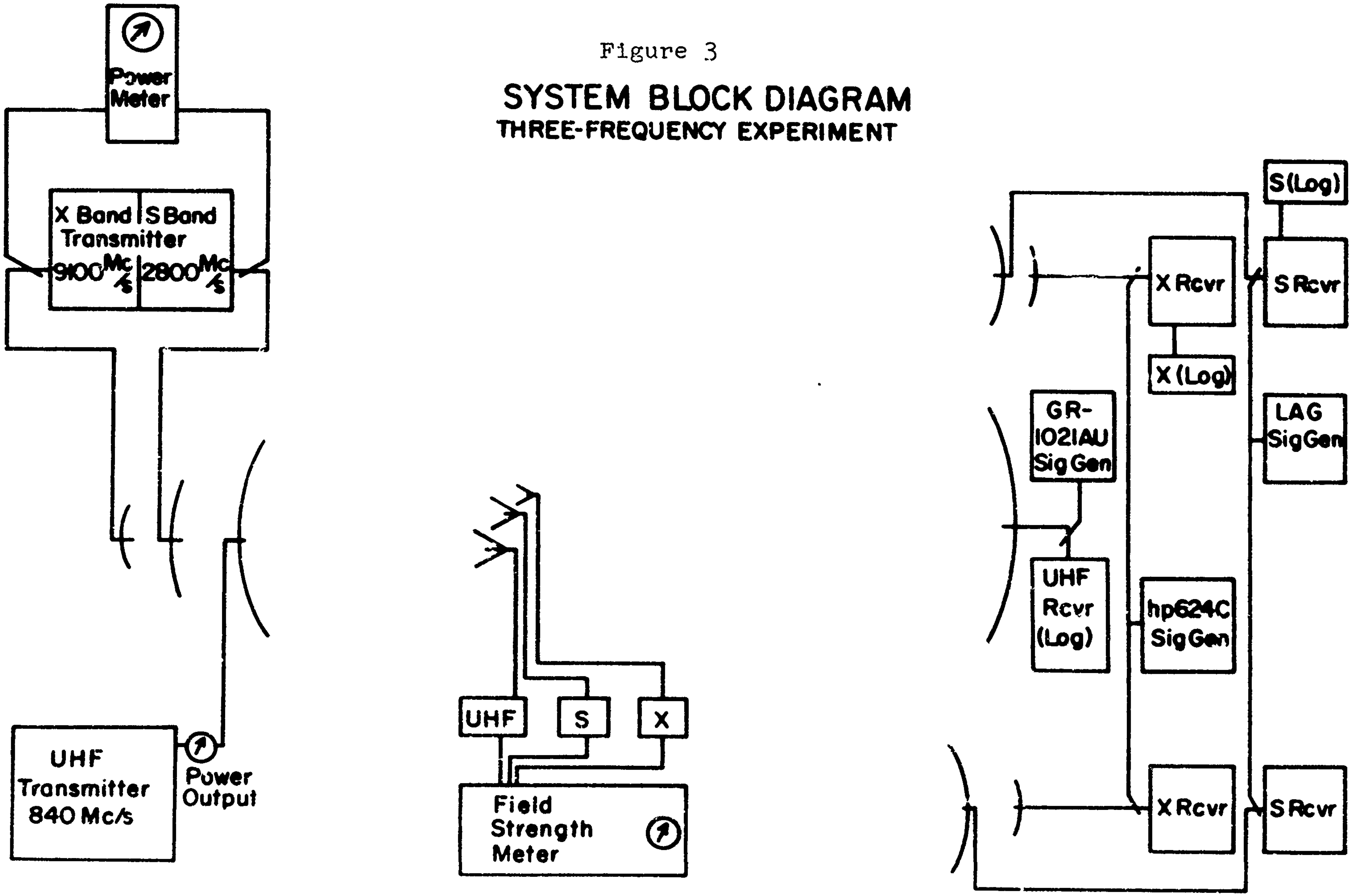


Figure 2. Elevation Profile of the Great Circle Path.

Figure 3

SYSTEM BLOCK DIAGRAM
THREE-FREQUENCY EXPERIMENT



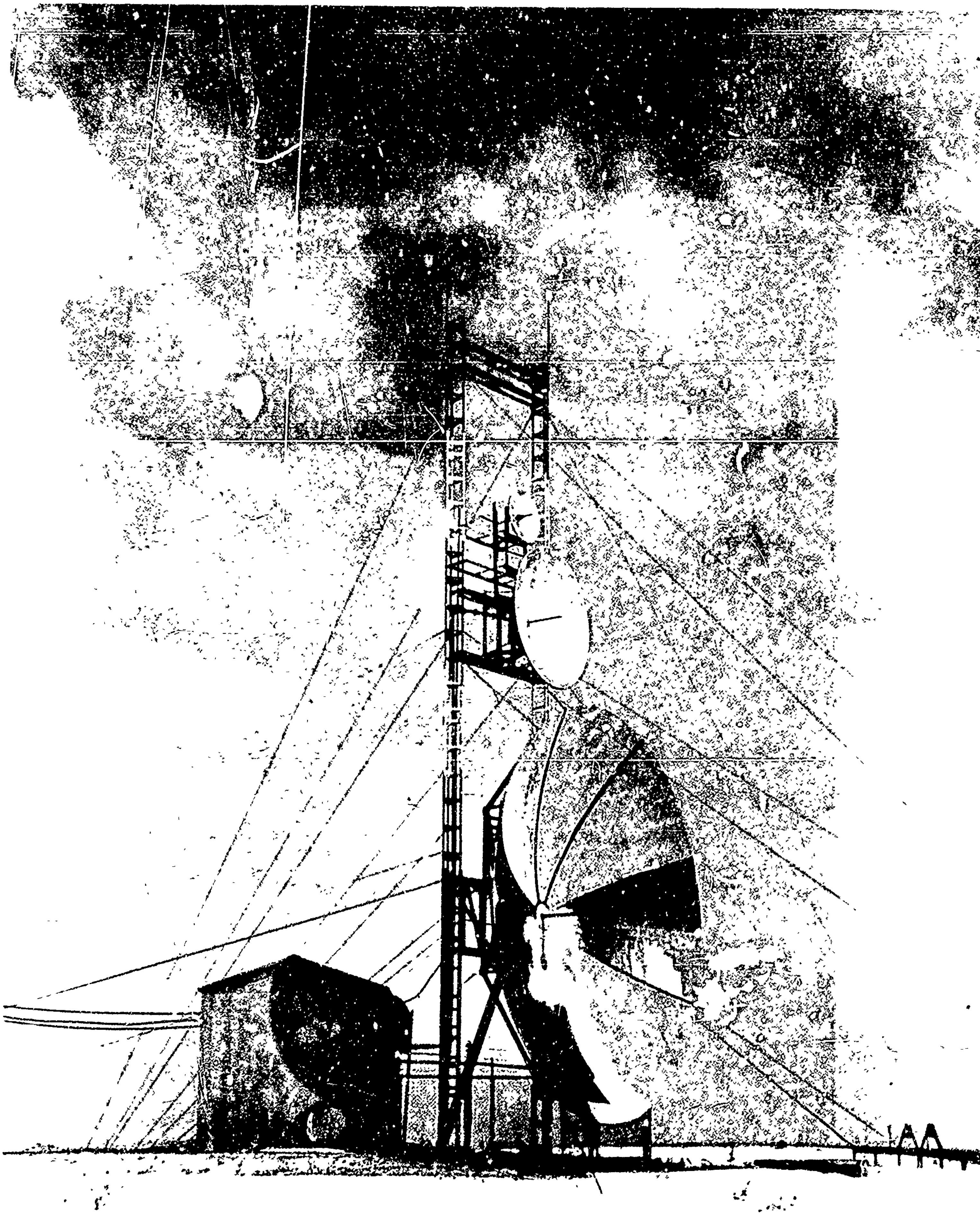


Figure 4.   Transmitting Antennas

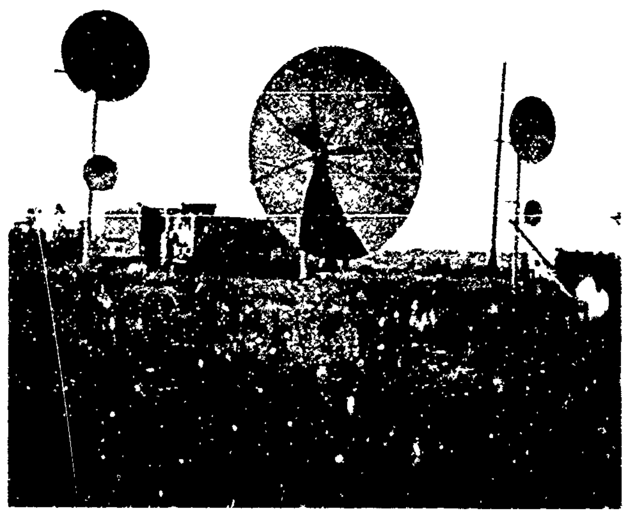


Figure 5. Receiving Antennas

Figure 6. Transmitters -- (a) TTU-1B UHF

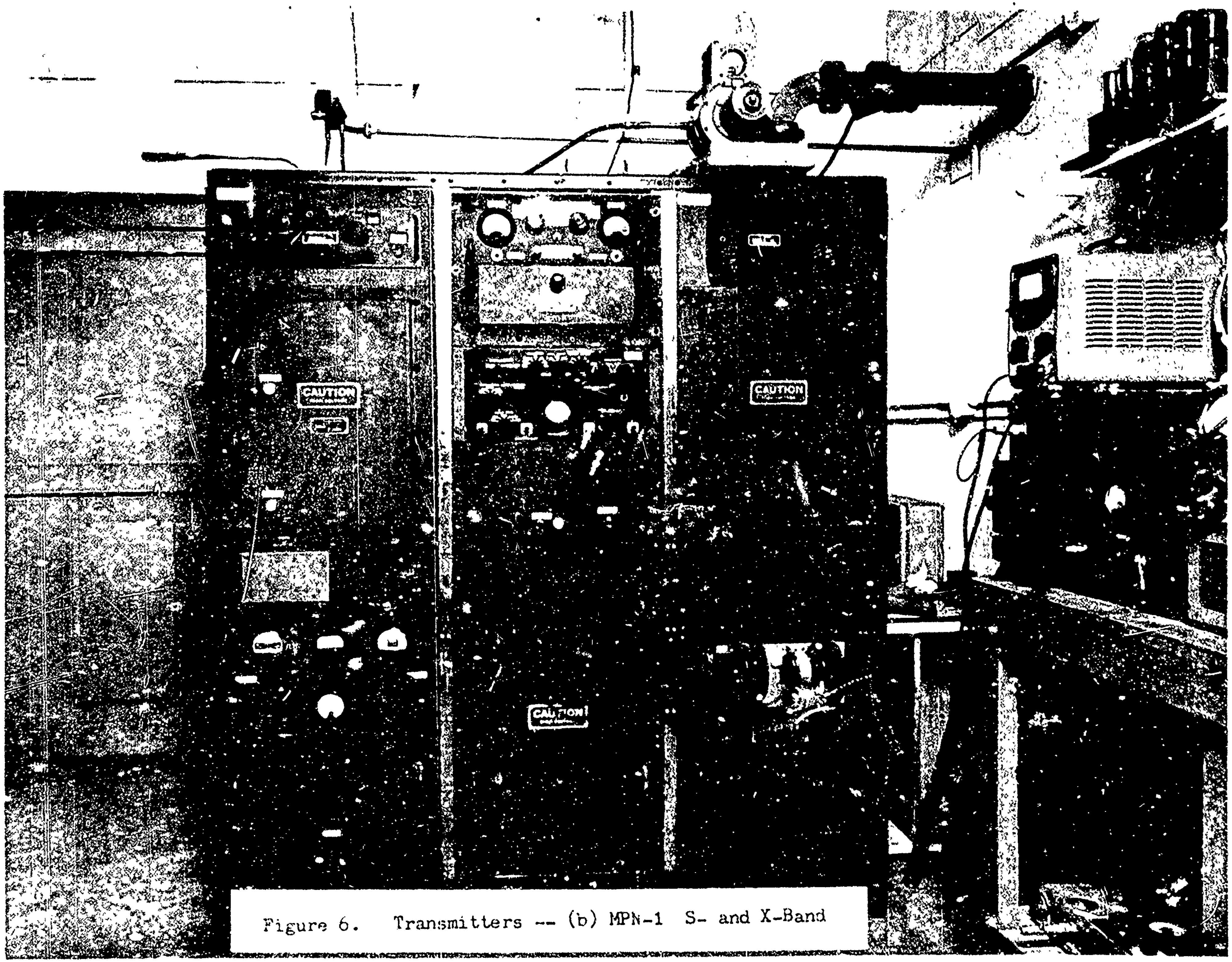


Figure 6. Transmitters -- (b) MPN-1 S- and X-Band

Figure 7. Receivers -- X-Band MPN-1 and Logarithmic

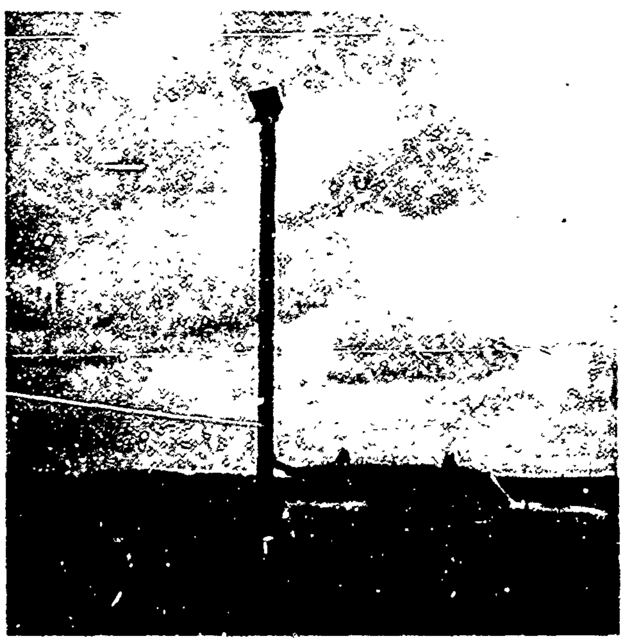


Figure 8. Far-Field Calibration Set-up

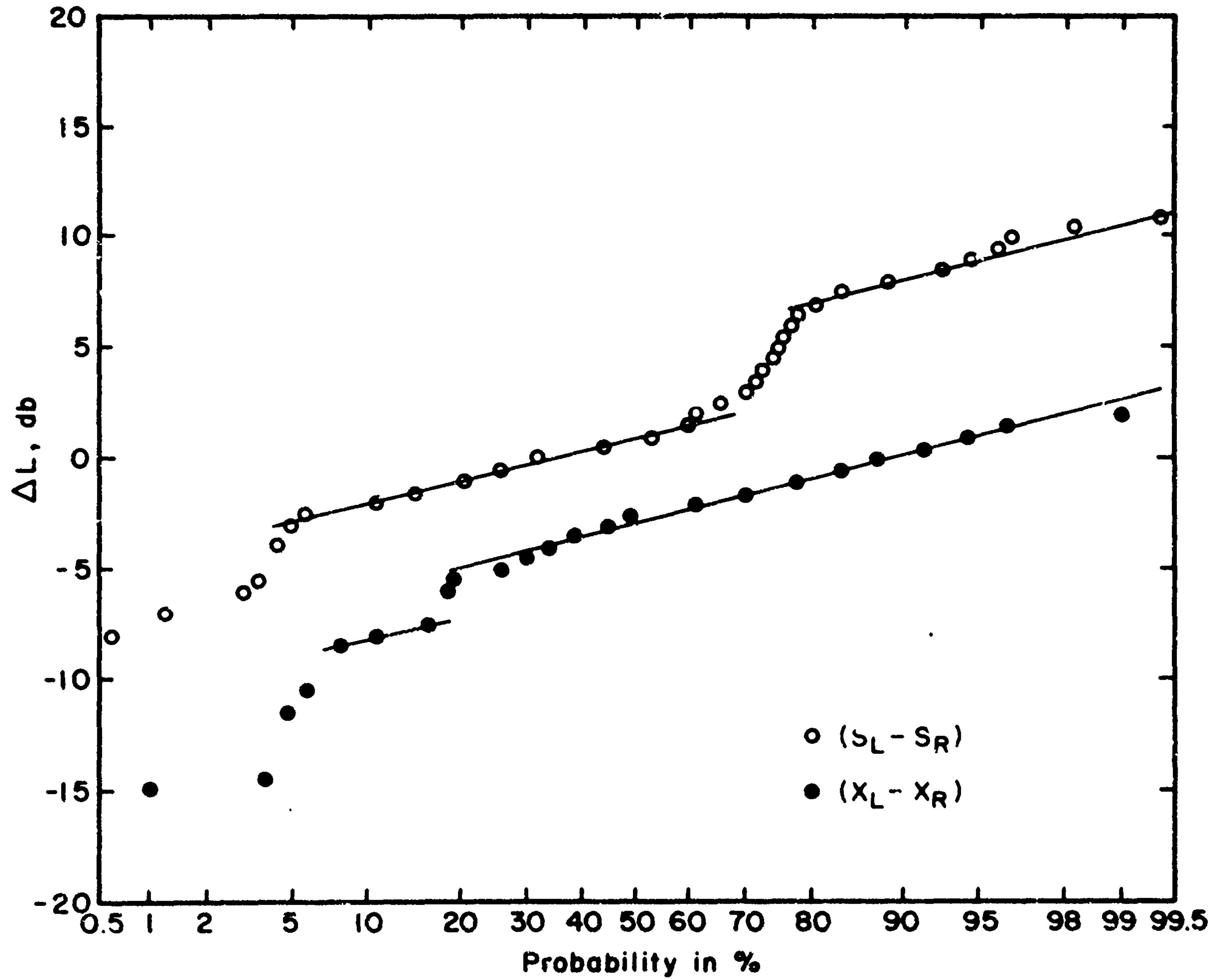


Figure 9. Median Diversity. Hourly Samples. (Aug., Nov., Feb., May 1960-61)

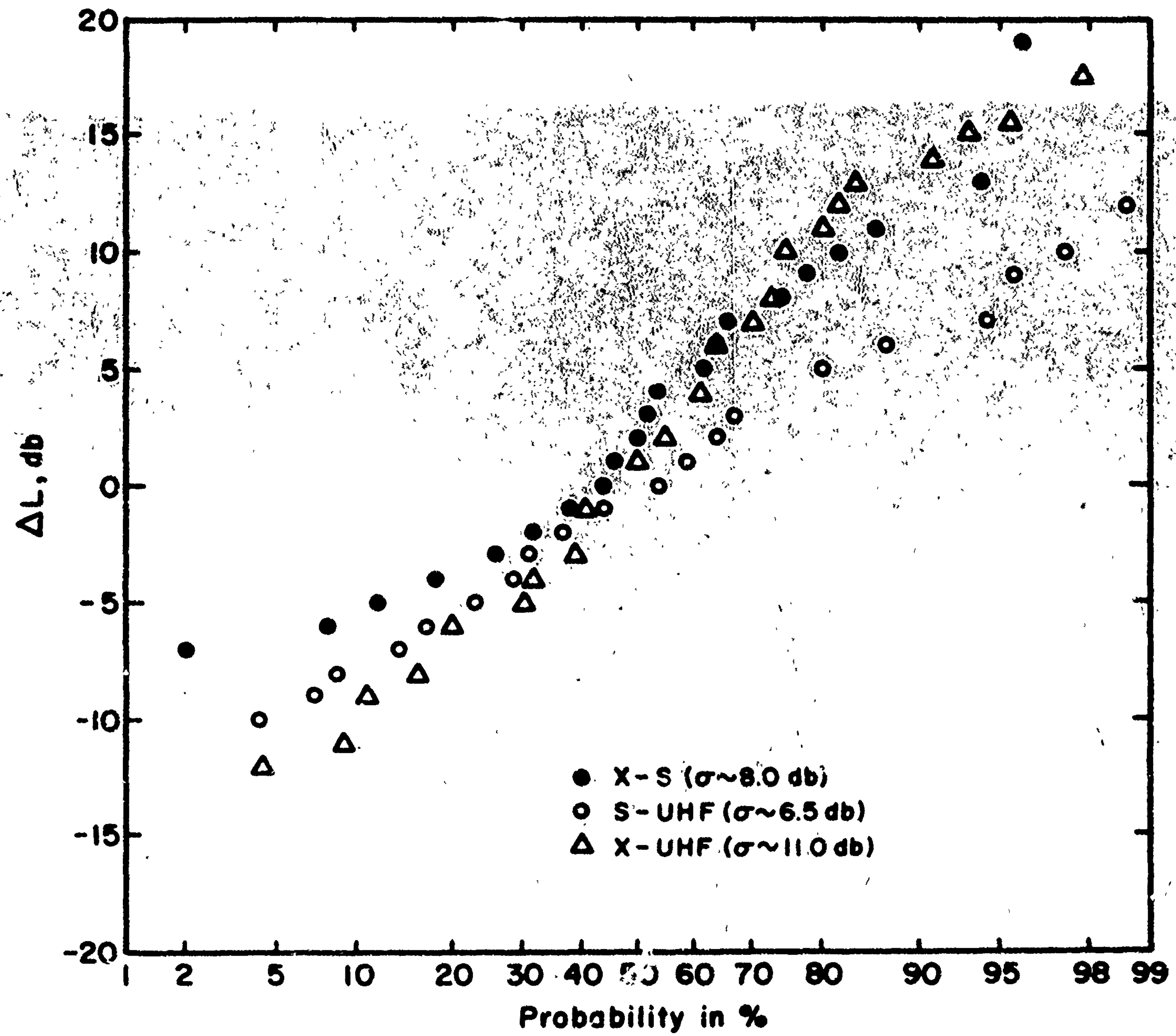


Figure 10. Differences in Daily Averages.
Aug. 1960 - July 1961

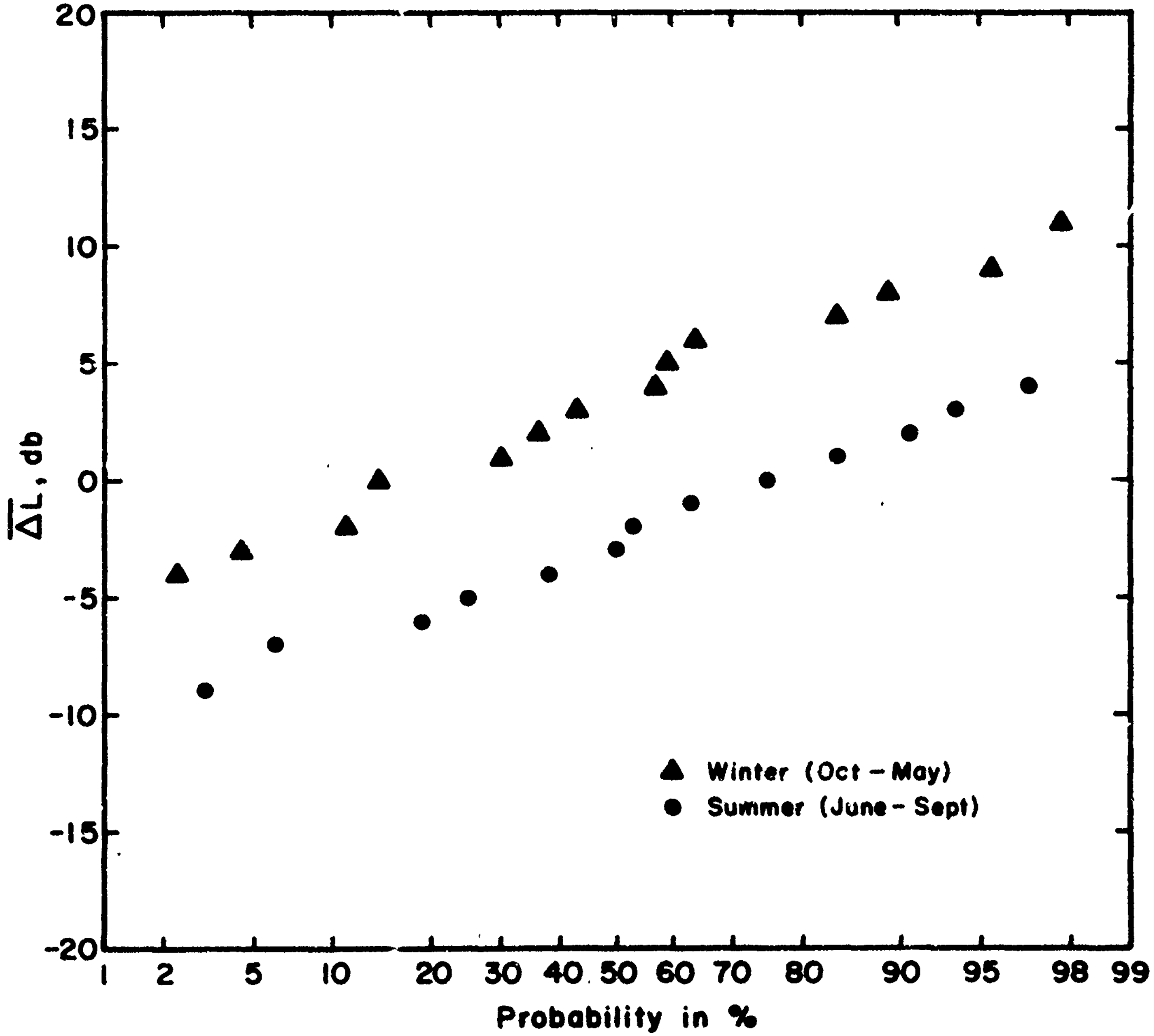


Figure 11. Average Differences in Daily Averages. By Seasons

$$\overline{\Delta L} = \frac{\Delta L_{X-S} + \Delta L_{S-U}}{2}$$

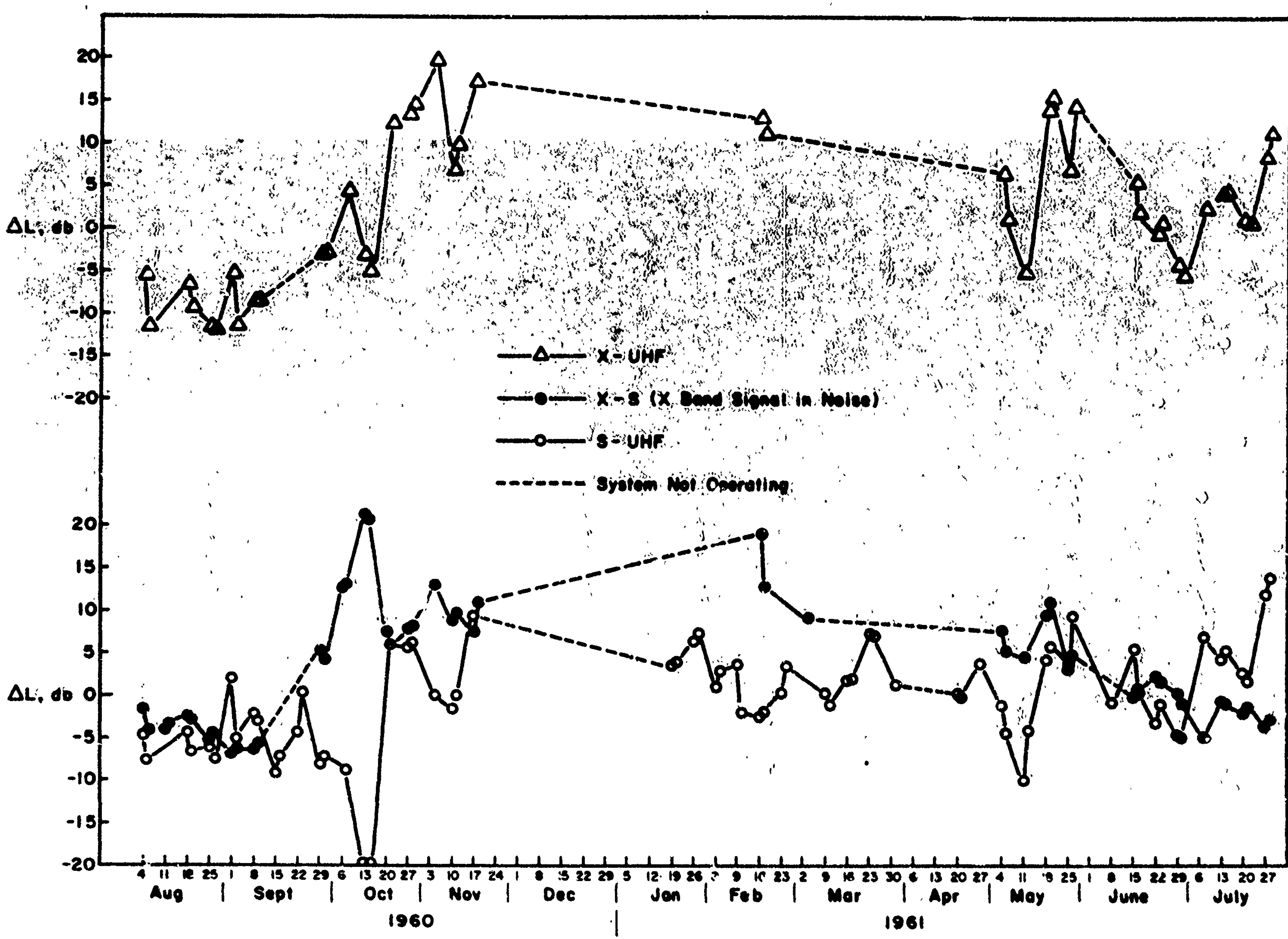


Figure 12. Chronological Record of Differences in Excess Propagation Loss.

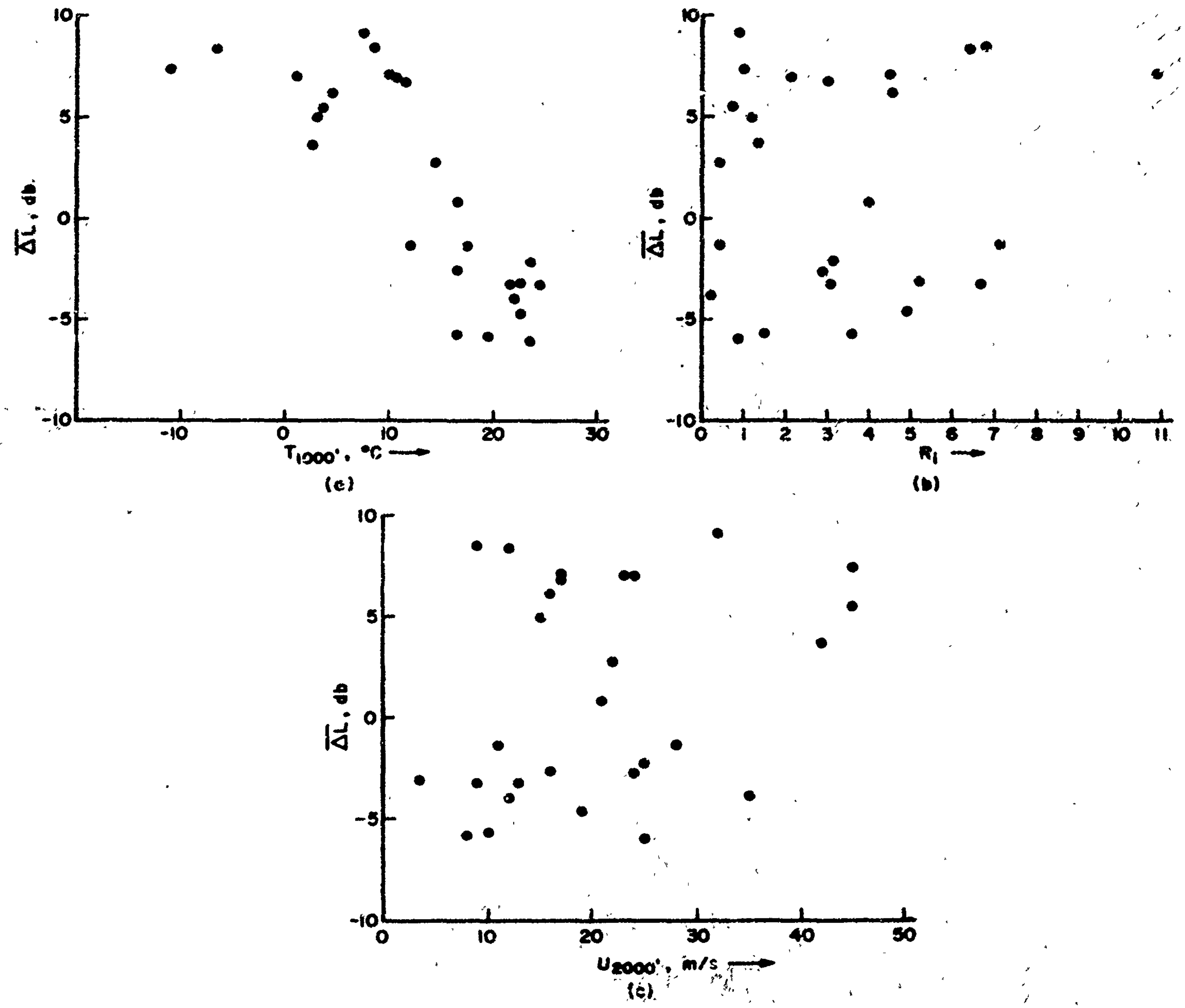


Figure 13. Correlation of Average Propagation Loss Differences with Meteorological Factors.

RCA Laboratories, Princeton, N.J., MAXIMIZING THE PERFORMANCE OF PHOTOCONDUCTORS by J. Dresner, et al. Air Force Cambridge Research Laboratories, Bedford, Mass. Scientific Report—Number AFCRL-64-145. 65 pages. April 1964. Unclassified Report

Backscattering from a monopole (linear scatterer) grounded in a cavity can be considerably diminished and almost suppressed by cavity-loading if the protruding length of the monopole does not exceed 0.45λ. The optimum depth of the cavity is about 0.25λ.

The good agreement between theory and experiment justifies the rather bold theoretical assumptions made to avoid involved mathematics and implies their usefulness in similar problems.

1. Backscattering from a loaded monopole
2. Reflection from a loaded monopole
3. Radar cross section of a loaded monopole

I. Project No. 5635 Task No. 563503
II. Contract AF19(604)-8353
III. J. Dresner, et al.
IV. In DDC collection

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SAMPLE REFERENCE SLIPS