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A STUDY OF 46 MC/S TRANSMISSIONS BEYOND THE HORIZON IN EASTERN ONTARIO

by

L.A. MAYNARD

COMMUNICATIONS LABORATORY

OTTAWA CANADA

DRTE REPORT NO. 1021

JULY, 1959

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A STUDY OF 46 MC/S TRANSMISSIONS BEYOND THE HORIZON IN EASTERN ONTARIO

by

L.A. Maynard

ABSTRACT -- This report concerns 46 Mc/s transmissions over a 185 mile path between North Bay and Ottawa. Continuous recordings of received signal amplitude were made from February 10, 1956 to February 2, 1958. In addition, synoptic weather information was obtained from Killaloe, about 25 miles south of the centre of the transmission path and from Maniwaki, about 90 miles north of Ottawa. The signal transmission loss showed a strong seasonal dependence in both monthly median level and in the extent of the diurnal variation. The summertime transmission loss coincided approximately with the amount reported by Bullington(1)*, but transmission loss in winter approached a value some 13 db greater than this. Regular intervals of high signal fading rate observed during winter months were attributed to signal transmission by an ionospheric mode of ground back-scatter. Intervals of high fading rate and large transmission loss were found to be associated with regions of strong airstream convergence.*

1. INTRODUCTION

Commencing in February, 1956, a 46 Mc/s radio link was operated continuously for the next two years between North Bay and Ottawa as part of the D.R.T.E. study programme on radio propagation through the troposphere. During this period, information was obtained on signal transmission loss and on rate of signal fluctuation. The signal data was supplemented by synoptic weather information obtained from weather stations located near the transmission path. Information derived from an analysis of this data will be discussed under three separate headings: signal transmission loss, disturbances in signal transmission, and correlation between signal characteristics and selected weather structures.

The experimental facilities will be described in Section 2. Statistics on signal transmission loss will be given in Section 3, and details on special signal disturbances are discussed in Section 4. A study on the correlation between signal characteristics and special weather system features is presented in Section 5.

2. EXPERIMENTAL FACILITIES

The 46 Mc/s experimental scatter link extended for 185 miles between North Bay and Ottawa. The transmitter was located approximately 8 miles north of North Bay, while the receiver was situated near D.R.T.E., Shirley Bay, about 10 miles west of Ottawa, as shown in Fig. 1. Surface weather stations are operated by the Department of Transport at North Bay, Killaloe and Ottawa, and a radiosonde weather station is located at Maniwaki, some 90 miles north-east of the path centre. It may be seen that the Killaloe surface weather station is close (about 25 miles south) to the mid-point of the signal path.

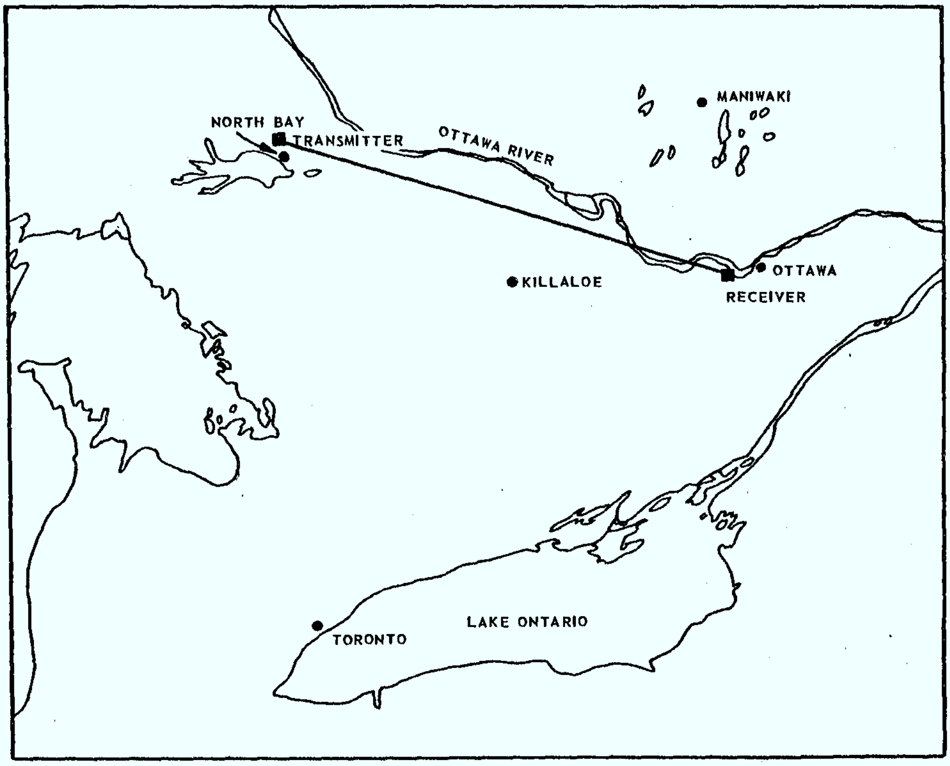


Fig. 1 - 46 Mc/s Transmission Path

The earth profile along the transmission path (Fig. 2) is over wooded, rolling terrain whose elevation above sea level gently increases towards North Bay. The land contour becomes quite irregular in the vicinity of the transmitter site. The tangential horizon intersection is about 5,000 feet above the earth's surface, slightly offset from mid-path toward the transmitter.

The transmitter was housed in an R.C.A.F. remote transmitter site near North Bay. The transmitting antenna was a four-bay Yagi array whose centre was 60 feet above the ground. The ground elevation at the base of the tower is 1100 feet above sea level and approximately 30 feet above the surrounding terrain in the direction of the receiver. The important features of the transmitter are summarized in Table I.

TABLE I - 46 MC/S TRANSMITTER

Model - Sinclair Radio Laboratories, VHF	
Operating Frequency	45.86 Mc/s
Frequency Deviation	5.6 kc/s
Type Modulation	FM at 4 kc/s
Output Power	1.5 kw
Antenna Height	60 feet above ground
Antenna Gain (relative to isotropic radiator)	16 db (design estimate)
Terrain elevation	1100 feet above m.s.l.
Antenna Cable Loss	0.5 db

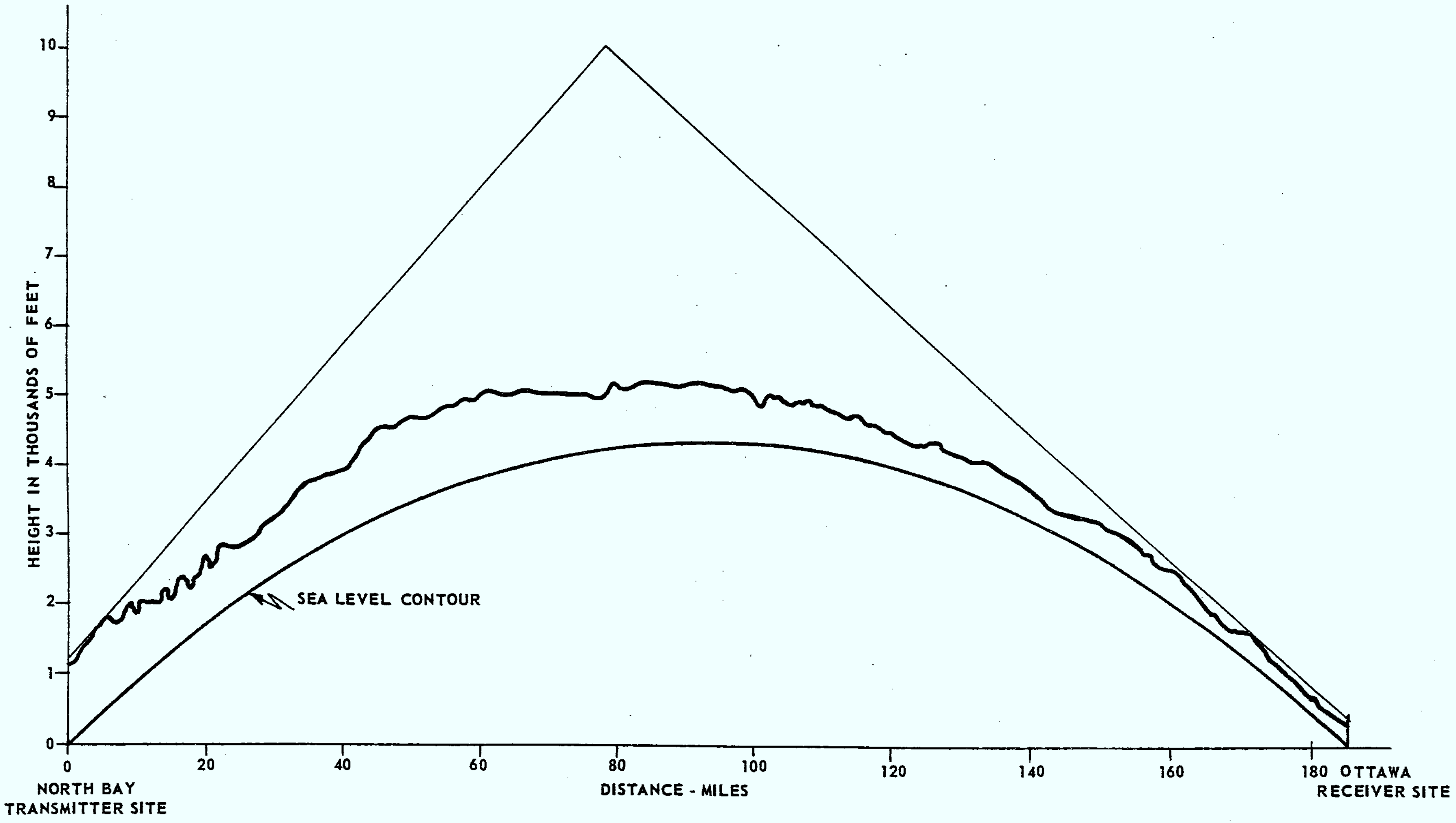


Fig. 2 - Earth Profile for 46 Mc/s Transmission Path (4/3 Earth Radius)

The antenna for the receiver at Shirley Bay is similar to the one used at the transmitter.

The terrain at the receiving station, in the direction of North Bay, is relatively flat for the first five miles. In the experimental work, the audio signal from the Hammerlund type SP 600 receiver, with a crystal controlled local oscillator, was amplified further by a Browning TAA16B audio amplifier. The dc component of the rectified audio signal was then recorded on an Esterline-Angus recording galvanometer, at a chart speed of one foot per hour. The important features of the receiver are summarized in Table II.

TABLE II - 46 MC/S RECEIVER

Model - Hammerlund SP 600

RF Bandwidth	8 kc/s
Audio Frequency Amplifier	Browning Labs TAA16B
AF Bandwidth	200 cps
Chart Recorder Time Constant	0.4 sec.
Antenna Height	60 Ft. above ground
Antenna Gain Relative to Iostropic Radiator	16 db (design estimate)
Antenna Cable Loss	Approximately 0.5 db
Terrain Elevation above m.s.l.	250 feet

3. SIGNAL TRANSMISSION LOSS

The variation in monthly median transmission loss for the 46 Mc/s signal is shown in Fig. 3, where the system parameters listed in Tables I and II have been assumed. It will be noted that the loss reached a maximum of 78 db in February, 1957, and a minimum of about 63 db in July, 1957; this is

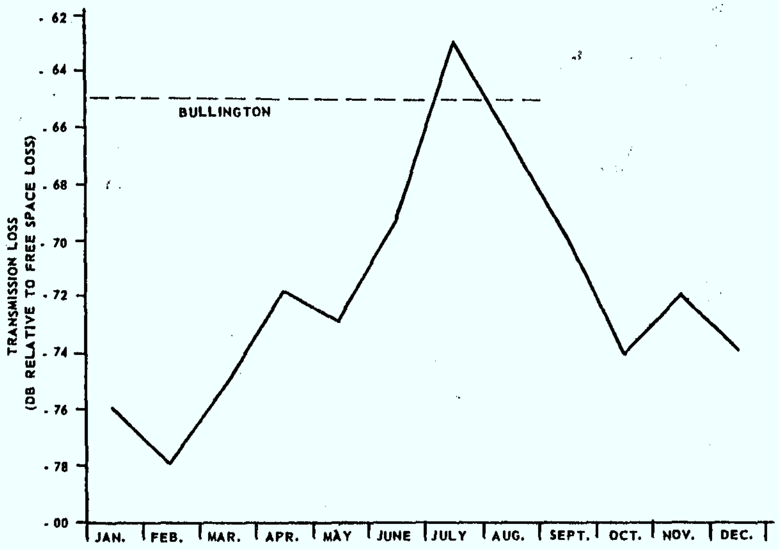


Fig. 3 - Seasonal Variation in Monthly Median Transmission Loss (1957)

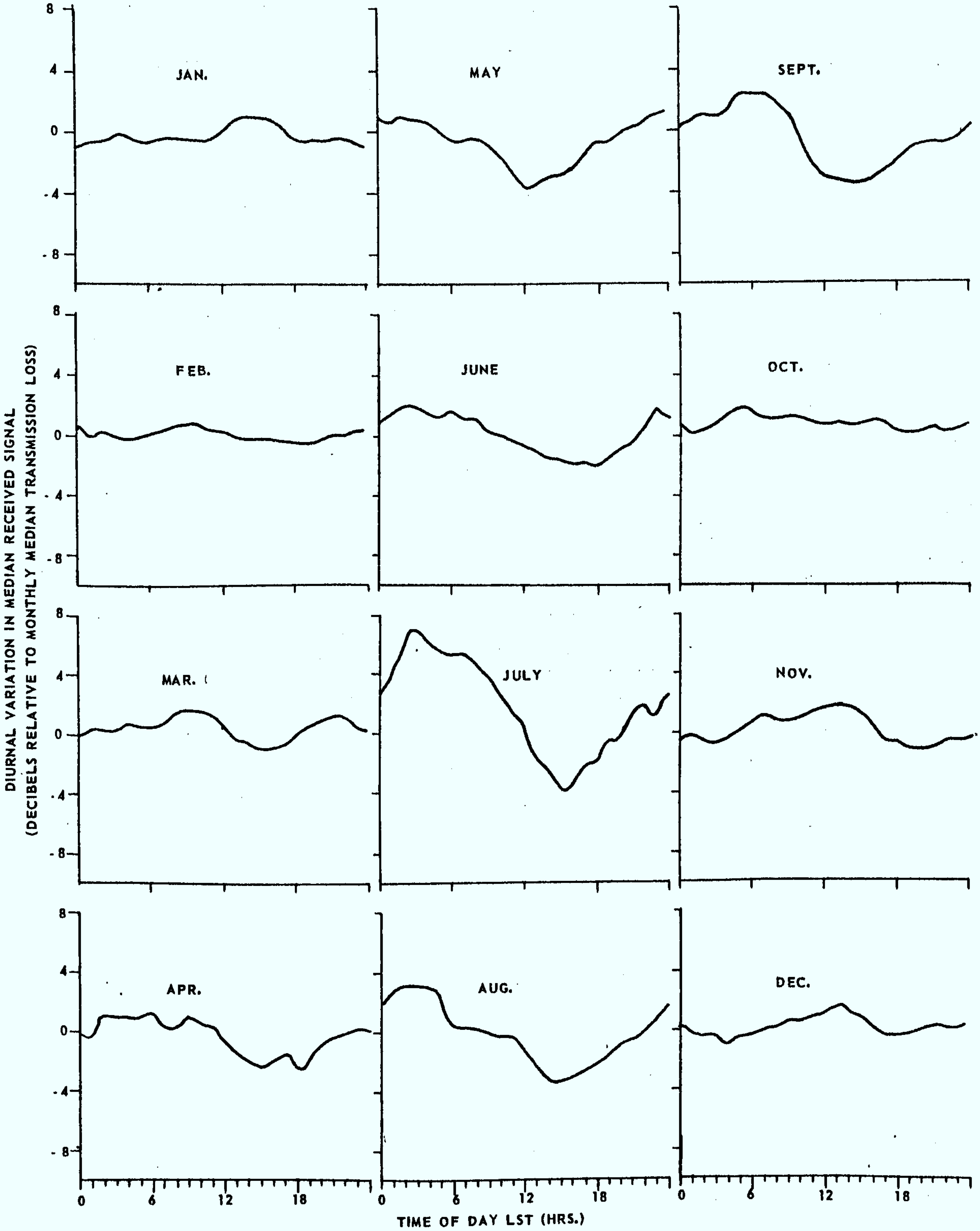


Fig. 4 - Diurnal Variation of Hourly Median Transmission Loss

a difference of 15 db between mid-summer and mid-winter. The transmission loss indicated by Bullington(1) for this path length is about 65 db below free space. This figure is close to the minimum transmission loss found in mid-summer.

Fig. 4 shows the diurnal variation in median received signal. Here, it will be seen that the extent of the diurnal transmission loss change reached a maximum during July and a minimum around mid-winter. It may be noted further that the diurnal variation in signal amplitude in winter was of the order of 2 db or less, but this change increased to a maximum of 10 db during July. Minimum transmission loss occurred around 03:00 hours and maximum around 15:00 hours, L.S.T.

A small decrease in transmission loss was found between 08:00 and 14:00 hours for the winter months. This decrease is readily seen in the diurnal curves for November, December and January shown in Fig. 4. Further examination of signal records for these periods showed the existence of marked signal interference at these hours. A study of this interference will be described in the next section.

In Fig. 5 histograms of hourly median signal levels are given for each month of 1957.

REMARKS

In this experiment, a marked seasonal variation in transmission loss has been observed. Monthly median loss was seen to vary from 63 db below free space values in mid-summer to 78 db below free space values in mid-winter. The period of minimum loss observed in mid-summer agreed with that reported by Bullington(1). Diurnal variation also showed a marked seasonal dependence, reached a maximum of 10 db in mid-summer and decreasing to a minimum of about 2 db in mid-winter. Histograms of hourly median transmission loss showed a tendency to broaden in the summer. The spread was about twice as great in summer as in winter, (indicating a more stable transmission loss in winter).

4. PRONOUNCED WINTER TRANSMISSION DISTURBANCES

During the winter intervals of extremely high fading rate were observed frequently. These occurred between November, 1956, and February, 1957, and again during the same months of 1957-58. The signal fading rate and median level varied markedly from those normally observed at other times. A typical record illustrating the transition from normal to irregular signal is shown in Fig. 6. Over a period of 30 minutes, the signal fading rate increased by a factor of more than fifty. In general, the median signal level increased by several decibels during each of these intervals. Attempts were made to correlate these periods of high fading rate with meteorological data received from local weather stations and with radio-sonde data received from the Maniwaki weather station. No relationship was apparent between these intervals and the presence of weather fronts, inversion layers, or any other meteorological parameters considered. Because of the regularity in daily occurrence of the phenomenon and also because the effect was not observed during ionospheric blackouts, ionospheric back-scatter was suspected as the cause of this phenomenon. As a test of the suspected mode of propagation, a rotating antenna system was set up at a new receiver site near Ottawa. The yagi antenna used had a front to back ratio of about 16 db. When this yagi was rotated during a suspected back-scatter period, the 46 Mc/s signal that arrived from the back direction rose to as much as 10 db above the tropospheric signal that arrived from the direction of the transmitters.

Sample records showing received signal as a function of antenna direction are shown in Fig. 7. The record in Fig. 7(A) was taken in February 9, 1958, at 07:40 hours. It shows the 46 Mc/s signal arriving only from the direction of the North Bay transmitter and at a level of about 1 μ.v. The record in Fig. 7(B) was taken 16 minutes later. Here, a signal is arriving not only from the direction of the transmitter but also from the opposite direction. The amplitudes of these two signals are approximately equal. However, this new signal is seen to differ from the North Bay signal in that it fluctuates in amplitude much faster than the North Bay signal.

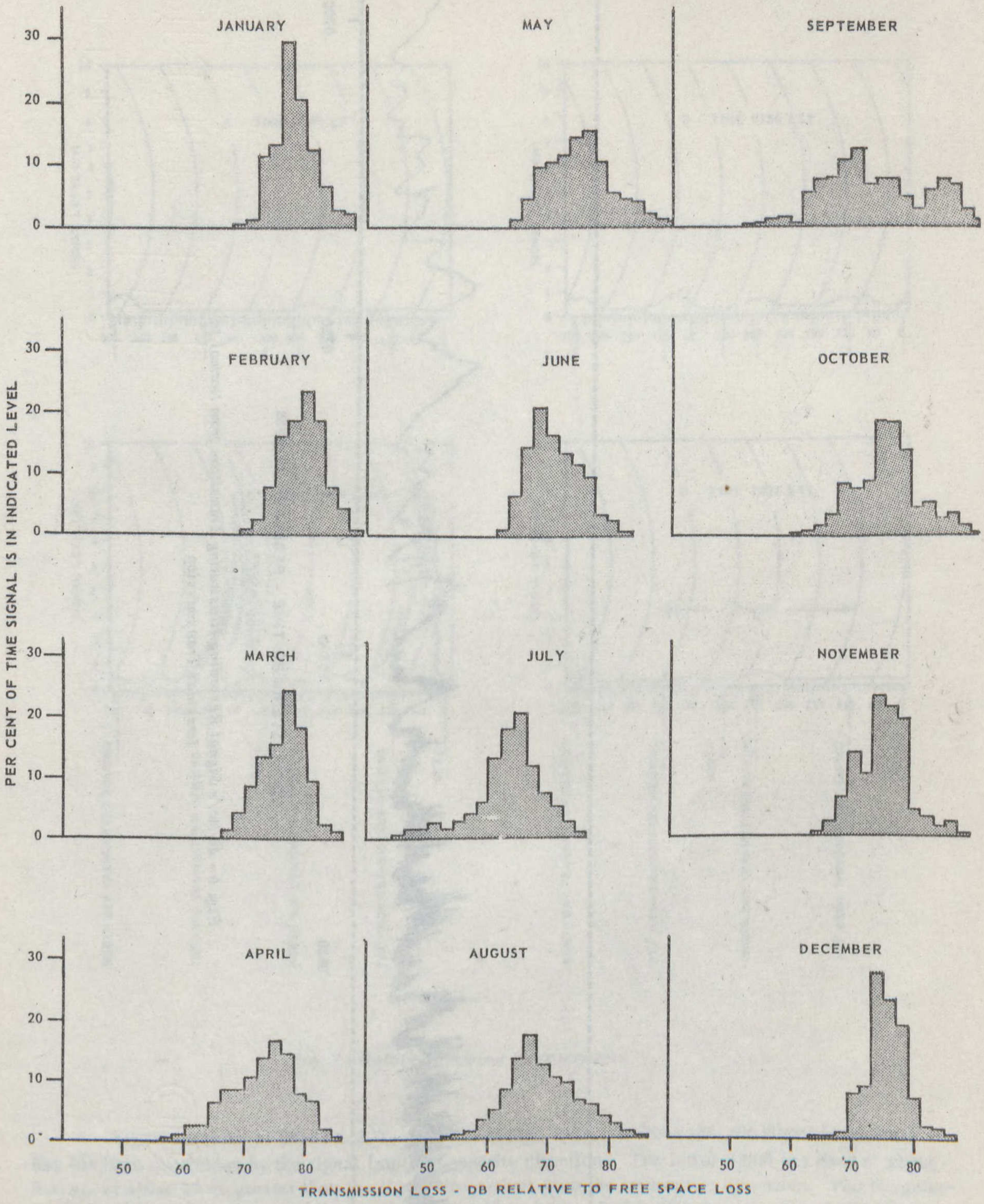


Fig. 5 - Histograms of Hourly Median Levels - 1957

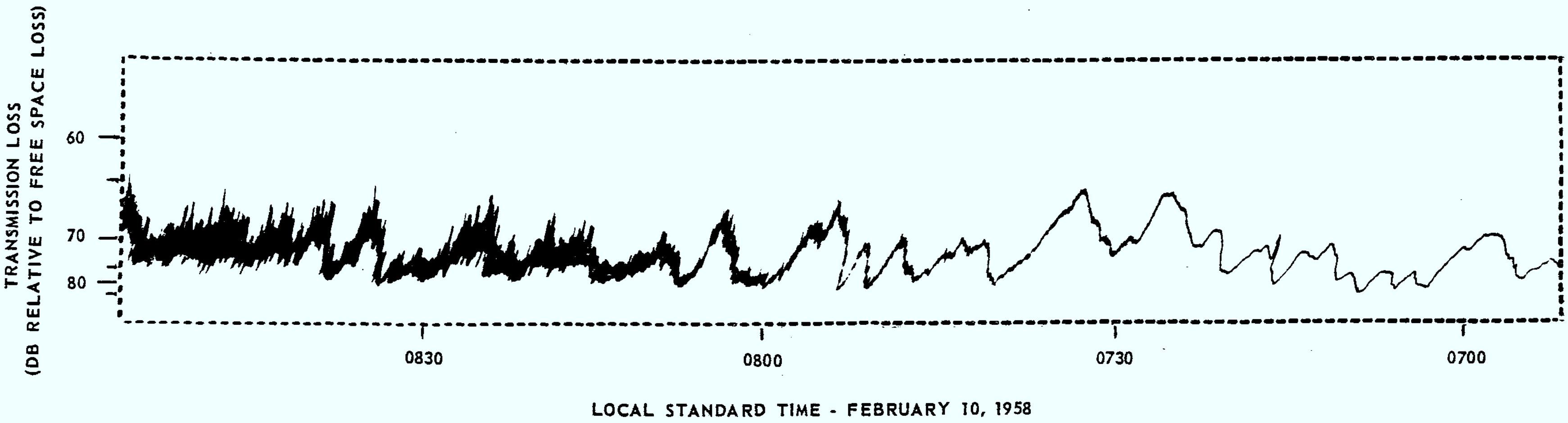


Fig. 6 - 46 Mc/s Signal Recording Illustrating Transition from Normal to Irregular Transmission

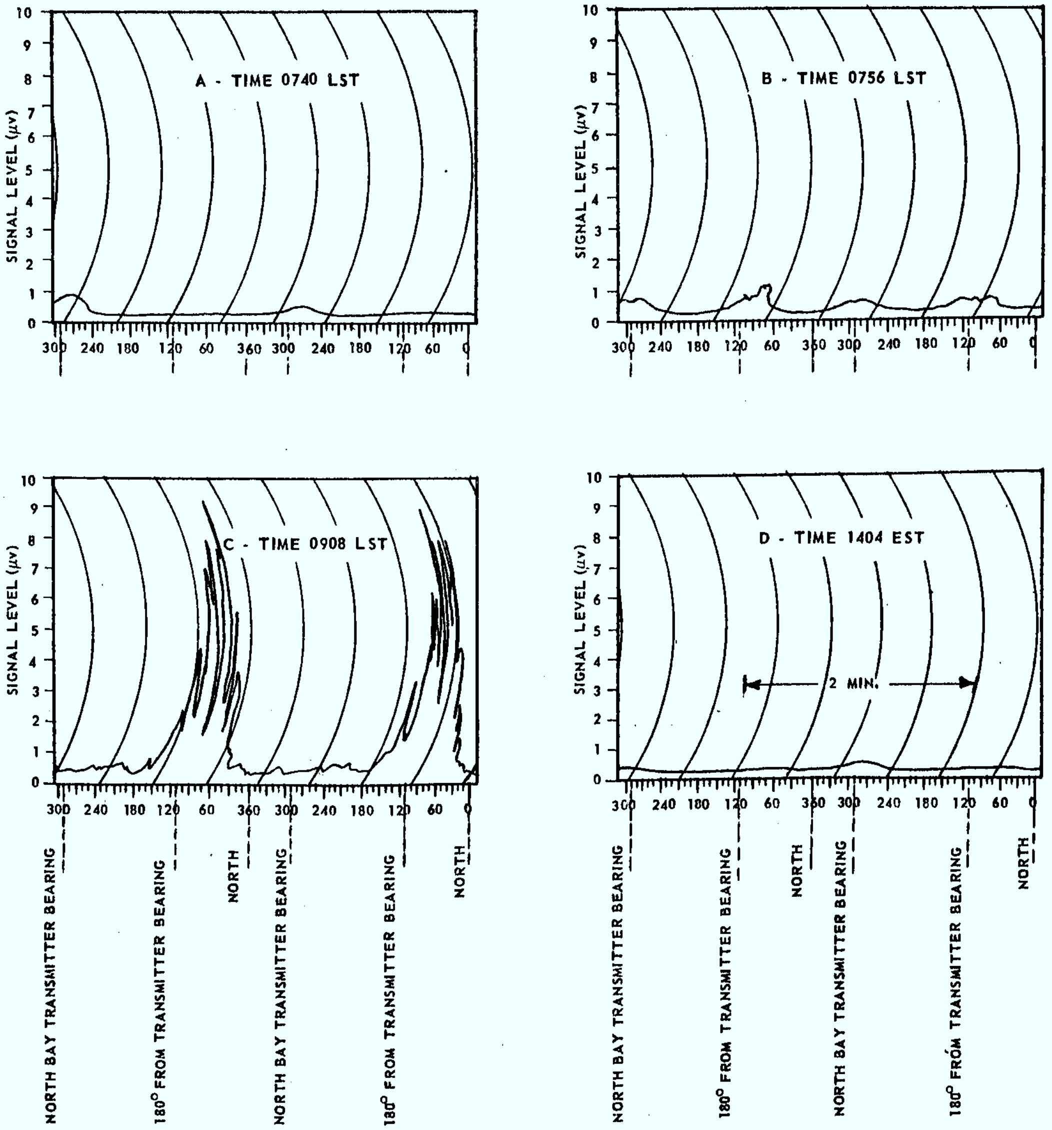


Fig. 7 - Rotating Antenna Measurements

Signal recorded at 09:08 L.S.T. is shown in Fig. 7(C). It shows that the signal from North Bay has been overridden by the signal from the opposite direction. The latter signal has risen to about 8 μ.v., or about 12 db greater than the signal that arrives from the transmitter direction. The irregularity in amplitude of the new signal is particularly evident here. By 14:04 hours, the new signal has disappeared, and the transmission again comes only from North Bay, at a level between 1 and 2 μ.v., as the record in Fig. 7(D) shows.

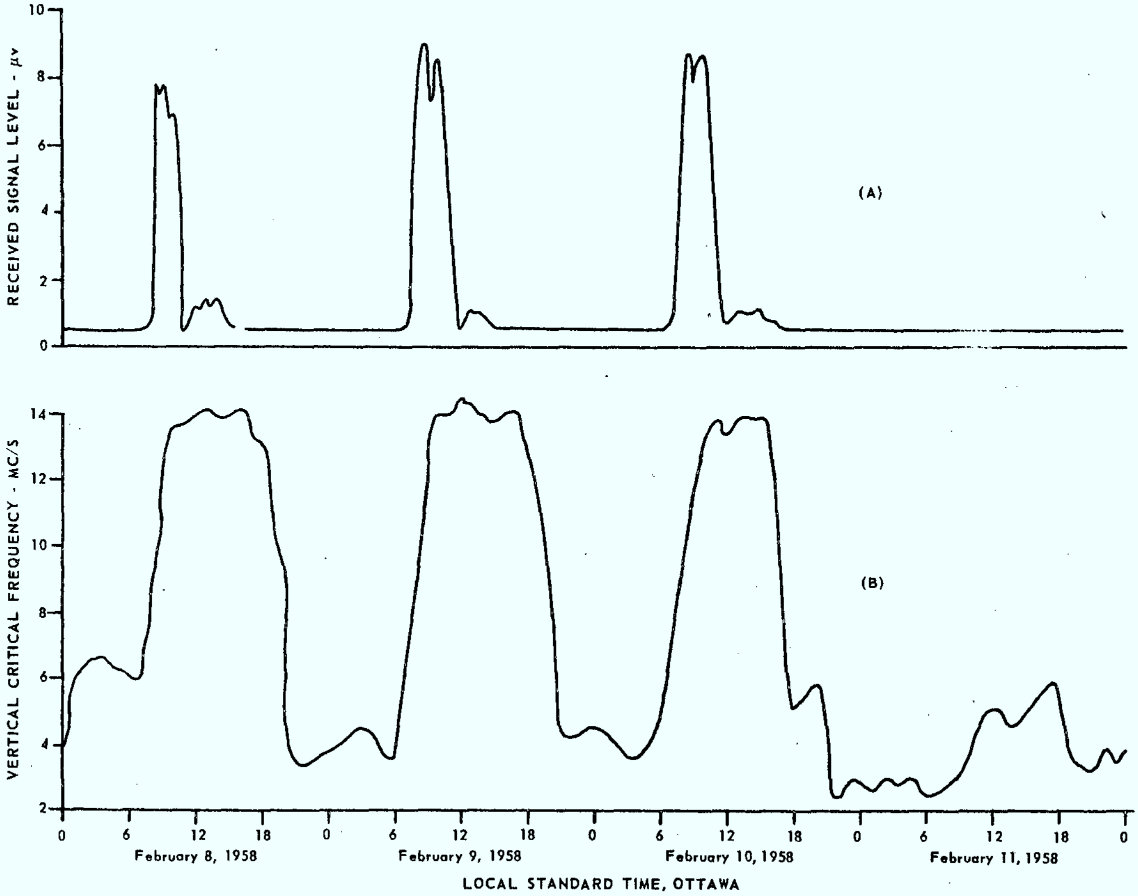


Fig. 8 - Diurnal Variation of Back-Scattering Signal

A four-day plot of the variation in amplitude of the new signal is illustrated in Fig. 8(A). This figure shows the variation in received signal for the interval between February 8, 1958 and February 11, 1958, with the antenna pointed 180° from the transmitter direction. For the first 3 days shown, the signal is seen to increase abruptly from noise level to between 7 and 9 μ.v. at about 07:30 hours L.S.T. on each day. A rapid drop in signal level was observed at about 11:00 hours L.S.T. on each of these days. Between 11:00 and 15:00 hours, the signal remained at a low level between noise level and 1 1/2 μ.v. Finally, the new signal disappeared at about 15:00 hours and did not return until the following day at about 07:30. This diurnal cycle was repeated for several days up until February 11, when no signal arrived from a direction 180° from the transmitter bearing.

The information obtained from the rotating antenna measurements, supplanted by information on the ionosphere, leaves little doubt that the 46 Mc/s signal interference results from ionospheric back-scatter. The vertical-incidence critical frequencies for the interval between February 8 and February 11 at Ottawa are shown in Fig. 8(B). It will be seen that the vertical critical frequency increases rapidly at the same time that the new signal is first observed. Further, the vertical critical frequency remains high during the whole of the time that the new signal is present. On February 11, when the vertical critical frequency remained low, no signal was observed from the direction 180° from the transmitter bearing.

This signal behaviour can be explained by the geometry of the radio path. Fig. 9 illustrates the geometry involved in ionospheric back-scatter of the nature suspected. Incident energy from the North Bay transmitter is reflected by the F_2 layer of the ionosphere back to the ground far beyond the

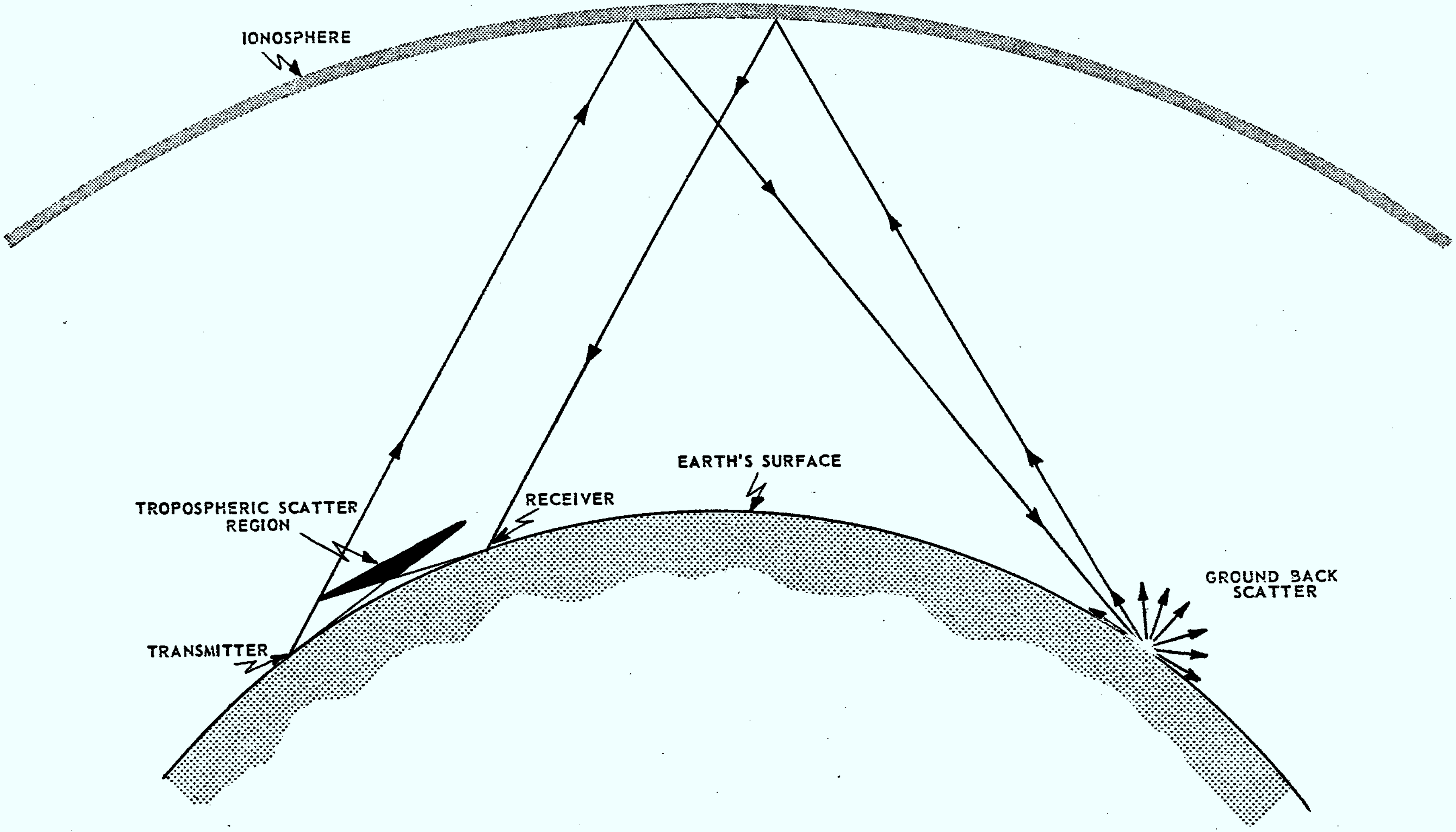


Fig. 9.- Geometry of the 46 Mc/s Transmission Path

receiver location. In this region the energy incident on the earth's surface is scattered in all directions and the fraction scattered in the back direction is propagated once more via ionospheric reflection back to the receiver.

The maximum usable frequency (MUF) for single hop ionospheric propagation is given by

$$\text{MUF} = F_c \sec \phi$$

where ϕ is the angle of incidence at the ionosphere and F_c is the vertical critical frequency at mid-path. The maximum usable frequency therefore is seen to be a function of F_c and of ionospheric height (since ϕ is a function of ionospheric height).

It may be concluded then, that F_c failed to rise high enough on February 11 to support propagation at 46 Mc/s. Insufficient data are available for determining ϕ between February 8 and 11, but variation in ionospheric height might explain the sudden drop in signal at 11:00 hours on February 8, 9, and 10.

REMARKS

Normal tropospheric propagation on the 46 Mc/s experimental radio link was disturbed during the winter months of 1956-57 and 1957-58.

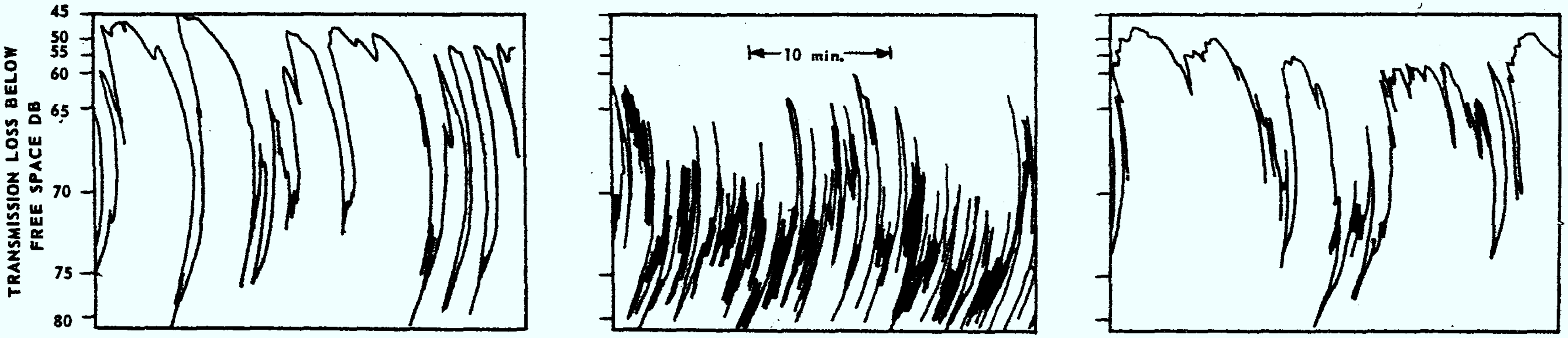
Antenna d-f experiments showed that this disturbance was due to the strong signal that entered the back lobe of the antenna array at 180° from the transmitter bearing. Further analysis of ionospheric conditions at this time left little doubt that the interfering signal arose from ground back-scatter via the ionosphere.

5. SPECIAL STUDIES ON SIGNAL FADING RATE AND TRANSMISSION LOSS

Special intervals of transmission on the 46 Mc/s path have been selected for detailed study. It has been shown in this report and elsewhere(2) that the signal fading rate and transmission loss undergo systematic changes with the time of day and the season. There are irregular intervals of short duration, however, during which the fading rate and the transmission loss increase considerably above the diurnal maximum. It is these irregular intervals which will be considered in this section.

It has been found in the 46 Mc/s transmissions that the irregular intervals of high fading rate occurred mainly during the warmer months of the year. (The periods of interference due to ionospheric back-scatter will not be considered here). During these intervals, the fading rate often changed in a few minutes from approximately 20 fades per hour to as much as 200 fades per hour, and the signal transmission loss often showed a coincidental increase. This feature of the signal is illustrated by the records shown in Fig. 10. The samples were obtained a few hours before, during, and a few hours after an interval of high fading rate. In (A) the signal is fluctuating slowly with an average transmission loss of about 55 db. In (B), the signal transmission loss and fading rate have increased. (C) shows the signal has returned to normal again after the disturbance has passed.

A preliminary study indicated that intervals of enhanced fading rate were usually associated with a weather disturbance occurring in an area of low pressure. Signal disturbances of this type, sometimes occurring as often as once or twice a week, have been observed for some time in VHF circuits. Pickard and Stetsen(3), using a radio link similar to the one studied here, found some statistical correlation to exist between the passage of weather fronts and the characteristic decrease in median signal commonly observed. Further investigation failed to show any consistent correlation between signal high fading rate intervals and characteristics of individual fronts such as height, position, velocity and direction. However,



(A)

(BEFORE)

(B)

(DURING)

(C)

(AFTER)

Fig. 10 - Sample of Received Signal Record taken Before, During and After Mild Thunderstorm Activity

initial studies(2) indicated that the more pronounced effects on signal characteristics were often associated with the presence in the transmission path of a low centre associated with a frontal system.

In attempting to discover the relationship between the low pressure area weather system and signal characteristics, it was noticed that on certain occasions an excellent correlation was obtained between rainfall intervals within a low pressure area at mid-path and signal median level and fading rate.

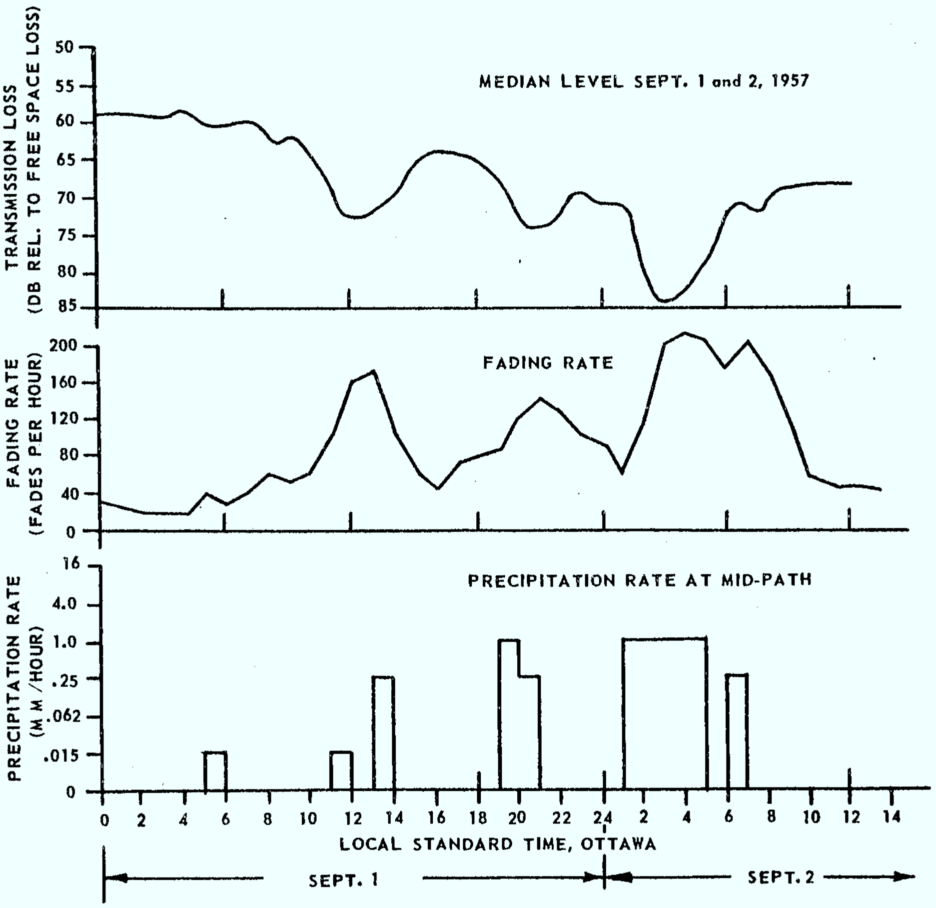


Fig. 11 - Effect of Precipitation on Signal Characteristics

Fig. 11 shows plots of transmission loss, signal fading rate and precipitation intervals at Killaloe weather station, situated near the centre of the transmission path for September 1, 00: 00 hours to September 2, 12: 00 hours, 1956. Observations on precipitation were recorded once each hour, and therefore the rate of precipitation that occurred on the hour was assumed to continue for the next hour.

In Fig. 11, it may be seen that each occurrence of precipitation was approximately coincident with two signal characteristics. First, an increase in fading rate accompanied each rainfall interval, and second, an increase in transmission loss coincided with the rainfall interval. A good correlation is apparent between the increase in fading rate and the increase in path transmission loss.

However, further investigation indicated that in the majority of cases where precipitation occurred, such pronounced correlation did not exist.

Since high fading rate and high transmission loss intervals are sometimes, but not always, associated with precipitation, it could be concluded that the phenomenon affecting the signal may be conducive to, but not necessarily associated with precipitation.

In an attempt to resolve the problem of why certain intervals of precipitation affected the signal characteristics while other intervals of precipitation showed no marked effect, attempts have been made to separate the precipitation intervals into classes relating to the type of weather structure associated with it.

Observations of received signal data suggested precipitation associated with thunderstorm activity might be of significance in this study. The thunderstorm was therefore chosen as the first class to be considered.

Between February, 1956 and December, 1957, intervals of thunderstorm activity at Killaloe were listed and the received signal characteristics were matched and compared with these occurrences. Although approximately 25 thunderstorms occurred during this period coincident power failures were frequent at both the transmitter and receiver sites due to lightning. As a result, only seven usable examples were available for the two year interval.

One of these occurred on August 11, 1956, between 13:30 and 14:00 hours. At this time, mild thunderstorm activity was observed in the vicinity of the Killaloe weather station, situated near the centre of the transmission path. The signal records for this occurrence are those shown in Fig. 10.

Near 05:00 hours L.S.T., several hours before the storm passage, the signal showed slow fading and was at a relatively high level, indicating a low transmission loss. During the storm interval (Fig. 10(B)) the signal fading rate increased significantly.

Later, as shown in Fig. 10(C), the signal returned to its normal, slowly fading characteristic and the median level returned to approximately the same value as that before the storm. This record sample was taken at about 20:00 hours on August 11, 1956, about 6 hours after the storm had passed through the transmission path.

A comparison of signal characteristics with precipitation and cloud structure during a typical thunderstorm passage is shown in Fig. 12. According to the Killaloe weather records, thunderstorm activity was centred about the precipitation interval (shown in Fig. 12(C)) near 13:00 hours on August 11, 1956. The two upper curves show that a maximum in both fading rate and transmission loss coincided with the thunderstorm interval.

A plot of the cloud structure over mid-path during the same interval is shown in Fig. 12(D). The width of each block shown represents the duration of cloud cover at the Killaloe weather station. The height of each of the blocks represents typical cloud layer thickness. Only clouds based between zero and 10,000 feet are plotted in Fig. 12 (D). It may be seen from Fig. 12(D) that Cumulonimbus (CB) and heavy Cumulus (CU+) clouds were present at mid-path during this interval, as would be expected since thunderstorm activity is usually associated with this type of cloud structure. Both CB and CU+ clouds are very turbulent clouds of great vertical development; their thickness may vary from 20,000 to 40,000 feet with bases as low as 1500 feet. In almost all the thunderstorm activity observed, these cloud types coincided with the storm interval.

In contrast to the effect of the precipitation interval at 14:00 hours, a two-hour interval of precipitation occurred on August 11, 1956 near 22:00 hours as seen in Fig. 12(C). At this time, two cloud layers were present, stratocumulus (SC) based at 5,000 feet and altocumulus (AC) (not plotted)

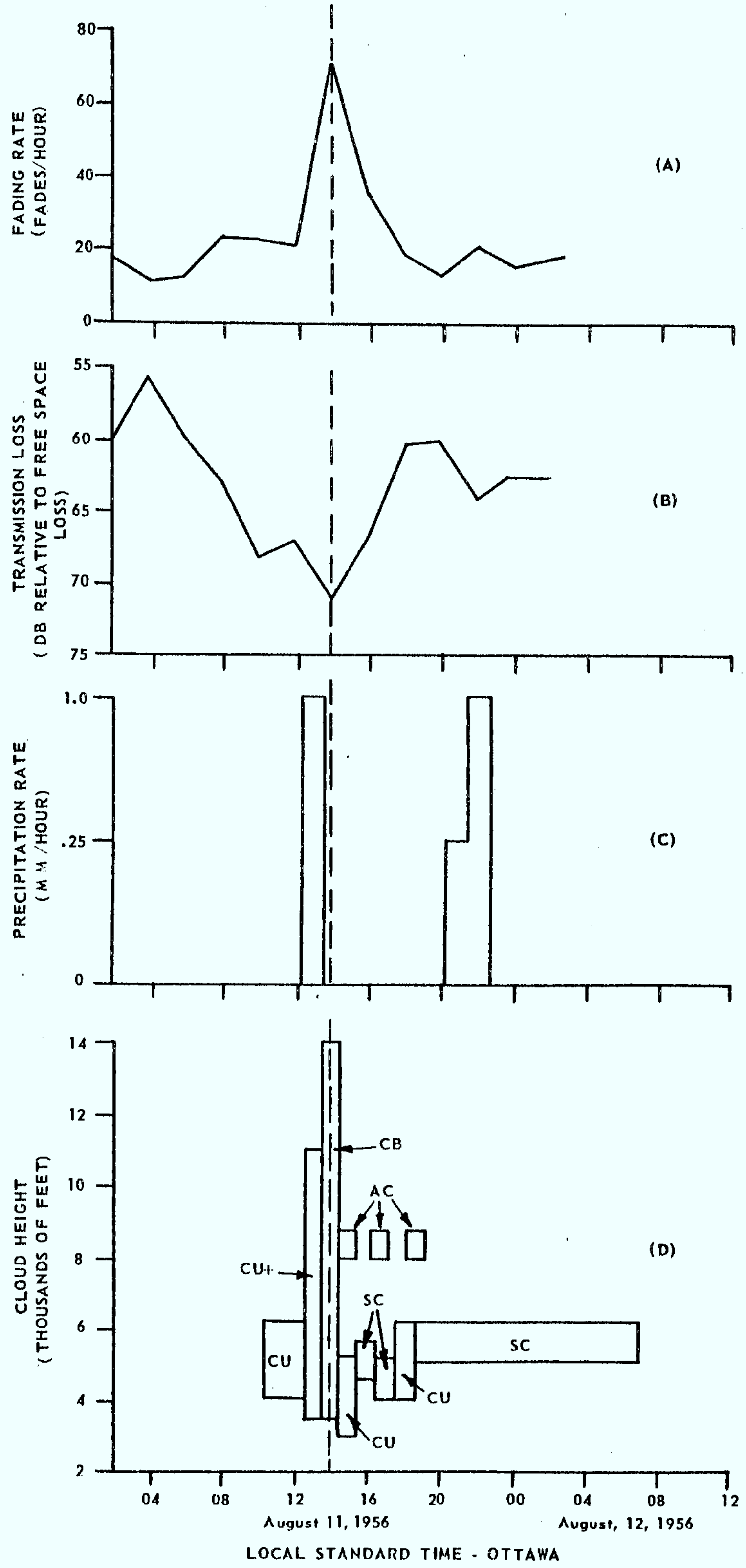


Fig. 12 - The Effects of Thunderstorm Activity on Signal Behaviour

based at 12,000 feet. During this interval no appreciable rise in either fading rate or transmission loss beyond the normal variation generally encountered was observed.

An examination of the physical structure of these cloud types show them both to have thicknesses in the vicinity of about 1,000 feet and severe turbulence associated with CB and CU+ clouds is not present with AC and SC cloud types.

REMARKS

It has been found that periods of high fading rate and low median level are generally associated with disturbed weather conditions. In certain cases where a more pronounced signal disturbance has been observed, rainfall at mid-path accompanied the period of signal disturbance. Investigation showed that a marked signal disturbance invariably accompanied thunderstorm activity at mid-path. Furthermore, the peak in signal disturbance coincided with periods of precipitation that originated from clouds of large vertical development associated with the thunderstorm activity. However, precipitation associated with cloud types of a more statified and non-turbulent nature often failed to show appreciable effect on the signal fading rate and the transmission loss.

6. DISCUSSION

In the past few years, a large number of experiments have shown that electromagnetic waves in the centimeter and meter wavelength region are propagated via the troposphere to distances well beyond the horizon with field intensities many orders of magnitude above that predicted by conventional diffraction theory. In 1950, Booker and Gordon(4) proposed that short waves are propagated beyond the horizon by a process of scattering by isotropic dielectric fluctuations caused by the turbulent motion of the troposphere in a volume common to both the transmitting and receiving antennas. However, some investigators(6) feel that this and other theories(5) present some difficulties in explaining certain commonly observed signal characteristics.

The diurnal variation in transmission loss shown in Fig. 4 indicates that high field strength periods generally occur during the night and early morning whereas minimum field strength periods generally occur during mid-afternoon. Signal fading rate shows a similar diurnal variation(2), with maximum fading rate occurring in mid-afternoon.

It is well known to meteorologists that tropospheric turbulence is generally greatest during that period of the day when the median signal level is at a minimum, i.e., between noon and sunset. During this period, solar heating of the earth's surface tends to promote atmospheric convection with the production of increased turbulence in the lower troposphere.

During the night, absence of surface heating results in lower surface temperature, which increases the vertical stability and reduces turbulence. However, the night-time signals are generally stronger than the daytime signals, seemingly in contradition to turbulent scatter theory. The absence of wintertime diurnal variation may possibly be explained by the lower relative surface temperatures which are due to the reduced heat absorption by the snow covering. Partly on the basis of the above arguments, which seem to be substantiated in this experiment, Bauer(6) suggests that reflections from stratified elevated layers play a major role in the propagation of short radio waves to distances well beyond the horizon, rather than the turbulent scattering mechanism suggested by Booker and Gordon, at least in the VHF region.

An examination of the physical structure of the thunderstorm suggests an explanation of the cause of the associated signal disturbance.

Thunderstorms are shower clouds in which electrical discharges can be seen as lightning or heard as thunder. It has been long recognized that the thunderstorm represents an intense form of shower or an advanced stage in the development of convection in moist air. Strong updrafts that carry moisture to heights often beyond 30 - 40,000 feet occur in the development of the storm. Converging air feeds the updraft, not only from the ground, but also from the cloud environment at all levels penetrated by the cloud.

These strong vertical air currents cause severe turbulence and large scale mixing of the atmosphere, which tends to destroy any horizontal stratification of either temperature or humidity that may have previously existed; this causes a general decrease in the signal level previously supported by the presence of elevated reflecting layers.

As pointed out earlier in this report, Pickard and Stetson have found a general increase in transmission loss to be associated with the passage of a weather front through the transmission path. Similar results have been reported by Hay(7,8) in that a general increase in both fading rate and transmission loss are usually found to be associated with weather front passages. It has been observed that the frontal effect is often more pronounced if the low centre associated with the front passes close to the transmission path. Effects similar to this have been observed by Klinker(9) in Europe.

Surface winds associated with frontal motion tend to follow the isobars (lines of constant pressure) blowing slightly inwards towards a region of low pressure. This inward flow, known as convergence, depends mainly on wind speed and ground roughness. In most cases winds show strong converging effect in the vicinity of deep low centres. Since there can be no accumulation of air in this low pressure area, the excess air is forced aloft and causes vertical air motion. Convergence is often associated with the presence of a weather front, the degree of convergence increasing toward the low centre associated with the frontal system. However, it should be pointed out that a frontal system is not essential to the existance of a convergent air stream.

A similar explanation of effect of the thunderstorm on signal characteristics might suggest itself, in that vertical air currents caused by surface air stream convergence tend to destroy any pre-existing horizontal stratification in atmospheric refractive index.

An experiment which seems to substantiate this idea was described by Wagner(10) . An airborne refractometer measurement was carried out recently between Pittsburg, Pa. and Scott Air Force Base in Illinois at an altitude of about 4,000 feet, under the direction of Lt. H. Chapman. The flight passed from a large divergent air centred near Pittsburg into a region of convergence over Indiana. The divergent region was characterized by a reasonably steady refractive index trace with a maximum variation in the order of 0.6 N units. Upon passing into the convergent area, however, variations in refractive index in the order of 10 N units were observed over periods as short as several seconds. This was presumably caused by the forced ascent of air, which increased the moisture content at the flight altitude and obviously disturbed any horizontal stratification which may have existed.

It might appear then, that although the actual refractive index turbulence increases in intensity in regions of convergence, due to increased moisture carried aloft, radio frequency energy propagated beyond the horizon decreases due to the destruction of atmospheric stratification.

In conclusion it might be pointed out that both in this study and others, it has been shown that frontal weather systems, low pressure areas, thunderstorm activity, and weather disturbances that contain cloud systems of extensive vertical development all tend to cause an increase in both signal fading rate and transmission loss in beyond-the-horizon radio propagation. Vertical air motion due to convection or airstream convergence is a pheomenon common to all of these weather disturbances.

The results of the foregoing study suggest that a converging air stream with its associated vertical air motion and increased atmospheric turbulence tends to destroy any pre-existing atmospheric stratification. This causes a decrease in field strength in beyond-the-horizon VHF propagation.

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8. REFERENCES

(1) Bullington, K. Radio transmission beyond the horizon in 40-400 mc/s band. Proc. I.R.E., 41: 132. 1953.

(2) Almond, J. A preliminary note on 46 mc/s signal transmissions over a 185 mile path. RPL Project Report 22-0-11. 1956.

(3) Pickard, G.W. and H.T. Stetson. Tropospheric reception at 42.8 mc/s and meteorological conditions. Proc. I.R.E., 35: 1445. 1947.

(4) Booker, H.G. and W.E. Gordon. A theory of radio scattering in the troposphere. Proc. I.R.E., 38: 401. 1950.

(5) Carroll, T.J. and R.M. Ring. Propagation of short radio waves in a normally stratified troposphere. Proc. I.R.E., 43: 1384. 1955.

(6) Bauer, J.R. The suggested roll of stratified elevated layers in transhorizon short-wave radio propagation. M.I.T. Lincoln Laboratory Technical Report No. 124. 1956.

(7) Hay, D.R. , J.W.B. Day and L.A. Maynard. A note on the effect of weather fronts on vhf-uhf transmission beyond the horizon. Paper presented at URSI Meeting, Berkeley, California. 1956.

(8) Hay, D.R. and G.E. Poaps. A study of signal fading rate in 500 mc/s scatter transmissions. DRTE Project Report No. 1013. 1959.

(9) Van Klinker, L. Remote reception observations in the 3 meter broadcast band. Hockfrequenztechn, U. Electroak, 65: 77. 1956. (in German).

(10) Wagner, N.K. The occurrence of microwave index of refraction fluctuations in a converging air stream. Bulletin American Meteorological Society, No. 8, 38: 494. 1957.