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Measurements at 38 GHz of Low-angle Fading Along Satellite-earth Paths in the Canadian Arctic

by
I. Lam

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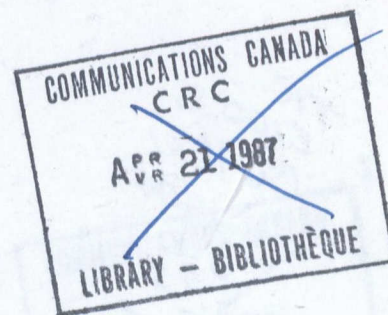
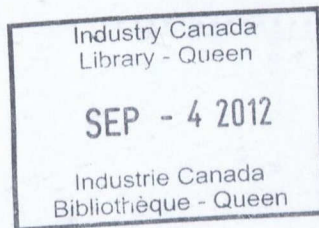
Ottawa, June 1986



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ABSTRACT

In 1984 a microwave propagation experiment was conducted in Alert, NWT, to study the characteristics of low angle fading at a frequency of 38 GHz. By monitoring the CW signal transmitted from the orbiting LES-8 satellite, propagation data were gathered over a range of elevation angles from 1 to 21 degrees. A total of three sets of measurements were made in the spring, summer and winter. These allowed comparisons to be made of the seasonal characteristics of low angle fading in the arctic.

The experimental data are examined with respect to the atmospheric conditions observed at Alert. Other results presented in this report include the variation of the median signal level with the elevation angle, cumulative distributions of the received signal level and fade rate statistics. The amount of signal fading increased rapidly as the elevation angle decreased. Fading was most severe in the summer which also had the highest fade rates. Very little fading was observed in winter.

1. INTRODUCTION

As the elevation angle of the satellite-earth path decreases the effects of tropospheric fading become increasingly severe. However, the use of these low angle propagation paths is necessary when providing communications coverage to high latitude locations via geostationary satellites. Low angle fading at 4 and 6 GHz has been studied from Eureka (latitude 80°N, elevation angle 1 degree) using the Anik A satellite [1]. Measurements have also been made in Resolute (75°N) and Ottawa (45°N) at a frequency of 7.3 GHz [2]-[4]. These measurements indicate that there is less fading in the arctic than at mid-latitude locations, and that the fading is more severe in the summer than in the winter.

Recent advances in high frequency solid state receiver components have improved the feasibility of millimetre wave satellite communications systems. The small antenna size required by these systems make them especially attractive for arctic applications. Measurements of low angle fading at 30 GHz have been made in Newfoundland [5] and Texas [6] using the ATS-6 satellite but none have been reported for arctic locations.

During 1984 a series of measurements were made of the strength of a 38 GHz signal that was transmitted from the Lincoln Experimental Satellite (LES-8) and received at Alert, NWT. This report summarizes the results of that experiment.

2. DESCRIPTION OF EXPERIMENT

A left-hand circularly polarized 38 GHz CW signal is transmitted from LES-8. The satellite follows an orbit which is inclined at 23 degrees relative to the earth's equatorial plane and the orbital period is 24 hours. When observed from earth the path of the satellite forms a figure eight pattern in the sky.

The measurements were made with a receiver at Alert ($82^{\circ}30'N$, $62^{\circ}20'W$) on the northern tip of Ellesmere Island as shown in Figure 1. At a latitude of $82^{\circ}N$ the satellite is accessible for approximately 11 hours per day since only the upper half of its figure eight path is visible. Figure 2 shows a set of look angles to LES-8 calculated for May 31, 1984. During each pass the satellite rises from below the horizon to a maximum elevation angle of 21 degrees and then sets back below the horizon. While the satellite is above the horizon its azimuth angle varies over a range of 6 degrees. The path profile drawn along the direction to LES-8 is shown in Figure 3. Because of blockage by hills (point A) along the path the physical horizon for the receiver is at an elevation angle of about 1 degree.

The receiving system was equipped with a 0.45 m diameter Cassegrain antenna which had a gain of 42 dB and a 3 dB beamwidth of 1.2 degrees. The antenna was mounted on a special steerable pedestal that was constructed at CRC. The pedestal had a pointing resolution of better than 0.05 degrees which was achieved through the use of microprocessor controlled stepping motors and precision optical shaft position encoders. A pre-programmed tracking method was used to point the receiving antenna towards the satellite. For each day the elevation and azimuth angles at 10 minute intervals were calculated from the satellite orbital elements and stored on magnetic tape. To control the antenna pointing, these values were used every few seconds by a computer to calculate the look angles by linear interpolation. Finally, accurate pointing was ensured by entering fine adjustments into the computer to maximize the received signal.

A steerable spot-beam antenna was used on the satellite to transmit the 38 GHz signal towards earth. Although pointing errors of this antenna caused undesirable variations in the received signal, time series plots of the data indicated that they were minor.

The satellite signal received by the antenna was down converted twice to an intermediate frequency of 245 MHz and this was monitored by a phase-locked-loop receiver. The receiver bandwidth was 1 kHz which resulted in a margin of better than 30 dB. The signal level was recorded digitally by sampling the receiver AGC voltage once every 0.42 sec.

All equipment was housed in a heated equipment shelter of dimensions 2.7 x 1.8 x 2.4 m (L x W x H). Most of one wall of the shelter was made of styrofoam insulation covered with a radome material (both practically lossless at 38 GHz) and this provided a window in the direction towards the satellite.

3. EXPERIMENTAL OBSERVATIONS

3.1 Measurement Periods

Three sets of measurements were made at Alert during 1984 under distinctly different atmospheric conditions. The equipment was transported to Alert by military aircrafts during early May. After the initial site preparation and equipment installation, the first set of measurements was made from May 27 to June 6. A second set of observations was then recorded from August 1 to August 8. These periods belong to the spring and summer seasons, respectively, when the sun was above the horizon for 24 hours every day. The third set of data was collected under winter conditions from November 30 to December 7. There was no daylight during this period as the sun remained below the horizon for the whole time.

3.2 Signal Characteristics

To facilitate the analysis the data for each pass of the satellite was normalized so that 0 dB corresponds to the median signal level at an elevation angle of 20 degrees. The signal level typically observed when there was little fading is illustrated in Figure 4. As the satellite rose above the horizon the signal was picked up and in a time of less than 1 minute it reached an average value close to -10 dB. Two other effects were observed as the satellite rose. The first was a gradual increase in the average signal level with the elevation angle. This was due to the reduced absorption associated with a shorter path through the atmosphere at the higher angles. The second effect was the decrease in the amount of fading as the elevation angle increased. There was virtually no signal fading for angles above 5 degrees and a stable signal was received throughout most of the day until the satellite set. At that time a gradual increase in fading activities and a decrease in the average signal level were observed. The average surface temperature on this December day was -30°C and the atmosphere was clear and calm.

Figure 4 also illustrates the effects of periodic adjustments to the pointing of the satellite antenna. During the experiment the antenna spot beam position was updated once every 15 minutes. This limited updating resulted in minor variations in the received signal strength such as those observed at around 0800 UT. Since these variations are of the order of 1 dB they do not significantly affect the signal statistics, especially at large fade depths.

The signal levels observed on December 1 and August 7 are compared in Figures 5a and b. On December 1 the peak-to-peak fading amplitude was about 10 dB when the satellite was between 1 and 2 degrees. This decreased rapidly to less than 3 dB for angles above 3 degrees. In comparison, the very rapid fading observed on August 7 had a peak-to-peak amplitude of larger than 25 dB. Furthermore, the median signal levels at low elevation angles were much lower in August than in December. This is explained by the increased atmospheric absorption associated with the warmer and more humid summer atmosphere.

Although low angle fading was severe on August 7, a stable signal was received for elevation angles above about 4 degrees. On this day the atmosphere was mostly clear with isolated high clouds and the average surface temperature was 0°C. The low angle fading on this day is typical of that observed during both June and August.

Samples of detailed time series plots of the signal observed at various elevation angles while the satellite rose on May 31 are shown in Figure 6. The elevation angle corresponding to the start of each time series is indicated and each set of data spans a range of about 1/2 degree. At an elevation angle of 1 degree the fading is deep and fast with many fades per minute. This type of fading is rather similar to that observed on terrestrial line-of-sight paths. At 3 degrees the fading amplitude was reduced to less than 10 dB and there was a significant decrease in the number of fades per minute. As the angle increased further, both the fade depth and frequency decreased rapidly. There was very little signal level variation above 10 degrees.

3.3 Anomalous Propagation

Except for the amount of fading, the signal characteristics observed during each day are generally similar to those illustrated in Figure 4. However, on one occasion, August 3, the anomalous behaviour that is shown in Figure 7 was observed. The automatic data recording and antenna tracking system started the data logging operation at about 0850 before the satellite signal was available. At 0855 the satellite transmitter was turned on. Although the satellite was at an elevation angle of -2 degrees the signal was immediately received with a level of about -25 dB. This relatively stable but depressed signal was maintained until the satellite reached an elevation angle of 1 degree when the signal began to fluctuate rapidly. The normal signal level, however, was not observed until the satellite rose to an elevation angle of approximately 2 degrees.

It is interesting to examine the weather conditions associated with the above observations. On the afternoon of August 2 there were clear skies. The average surface temperature was 0°C and the relative humidity was close to 100%. On the morning of August 3, a sharp change in conditions occurred with the temperature increasing to 7°C and the humidity falling to below 60%. At the same time there was an increase in wind speed to about 40 km/h and a reversal in the wind direction. It is not clear how these conditions contributed to the signal behaviour described above. However, it appears that a kind of ducting or wave trapping mechanism associated with atmosphere layers may have been involved.

4. RESULTS

4.1 Analysis Method

For purposes of analysis the data were grouped into 1 degree intervals in elevation angle. The data collected on August 3 is considered a unique occurrence and, therefore, are not included.

4.2 Median Signal Level

The variation of median signal level with elevation angle for all the data is shown in Figure 8. Each point represents the median level, during one pass of the satellite, for the corresponding 1 degree interval in elevation angle. As the angle decreased, the spread in the median level increased from a value of about 3 dB for the 10-11 degree interval to more than 7 dB for the 1-2 degree interval.

The dashed line in Figure 8 shows the median level computed from the combined data for all days. The median signal level was also calculated for the data from each of the measurement periods. These show good agreement except at angles below 2 degrees where the median level for the August data is approximately 2.5 dB below those of the June and December values.

The effect of atmospheric absorption due to oxygen and water vapour is illustrated by the solid line in Figure 8. This theoretical curve was calculated for a surface water vapour density of 5 g m^{-3} and includes the effect of regular refraction. The comparison with experimental results indicates that absorption alone cannot fully account for the low median signal levels at small elevation angles.

4.3 Signal Level Distributions

Cumulative distributions of the received signal level are computed separately from the spring, summer and winter data sets. Figures 9 and 10 show the results for the spring and summer data, respectively, both plotted on Rayleigh coordinates. The signal distributions for the two data sets are consistent with each other except for the lower median (50%) level and slightly higher occurrences of low angle fading during the summer in the 1-2 degree interval.

The above observations may be examined with respect to the seasonal variations in atmospheric conditions at Alert. During early spring the average surface temperature varies between -10 and 0°C . There are occasional snow flurries and the ground is snow covered. The weather during this period is highly variable and, owing to the nearness of the ocean, clear sky conditions are frequently replaced by heavy fog in less than one hour. Although the same variability in atmospheric conditions occurs in August, the ground is not snow covered. Furthermore, the average surface temperature in August is between 0 and 10°C which is about 10 degrees higher than in the spring. This allows for an increase in the atmospheric water vapour content and accounts for the lower signal medians. During both of these periods the sun is always above the horizon, thus there is no significant variation in diurnal ground heating.

The signal distributions for the winter measurements are presented in Figure 11. Compared to the spring and summer results there was very little fading at all elevation angles. For example, the fade depth corresponding to 99% of the observation time, measured relative to the median (50%) level, is 5.6 dB for the 1-2 degree interval; this is less than half the value of 14.5 dB for both the spring and the summer. There were clear and calm days as well as those with gusty winds and blowing snow during December. The average temperature was -35°C and the sun stayed below the horizon during the entire period.

The signal distributions on the day with the least fading, December 1, and the most fading, June 5, are compared in Figure 12. The selection of these days was based on a visual inspection of the time series plots of the received signal level. In the 1-2 degree interval signal fading more than 17 dB below the median (50%) level were observed on June 5; this is about three times higher than the value of 5.6 dB observed on December 1. The signal distribution for the 1-2 degree interval on this day corresponds to that of a Rayleigh distribution with the same median.

4.4 Fade Rate Distributions

The fade rate is defined as the time rate of change of the received signal level. For this report the value was calculated by taking the difference between the signal level of consecutive data points and dividing by the data sampling interval of 0.42 sec.

Cumulative distributions of the fade rates were computed for the three lowest 1-degree intervals and these are presented in Figure 13. For each set of data, the fade rate is highest at low angles and it decreases rapidly with increasing elevation angle. For a given interval in elevation angle, the highest fade rates were observed in August and the lowest in December. Compared with the values reported by Webber et al [5] for the 30 GHz ATS measurements made from the east coast of Canada the fade rates observed at Alert are generally lower. For example, at an elevation angle of 1.24 degree, the fade rate exceeded for 1% of the time in the ATS measurements is 17.5 dB/s. The corresponding value observed during August at Alert is 7 dB/s for the 1-2 degree interval.

5. CONCLUSIONS

A series of measurements have been made at Alert, NWT, of the low angle fading characteristics of a 38 GHz signal. It was found that the amount of signal fading increases rapidly as the elevation angle of the satellite-earth path decreases. Furthermore, the fade depth, the frequency of fades and the fade rate all increase with decreasing elevation angle. The fading at angles below 2 to 3 degrees has characteristics similar to those occurring on terrestrial line-of-sight paths.

Partly because of a warmer and more humid atmosphere, low angle fading is most severe in the summer. The highest fade rates and the lowest median signal levels occur in the summer. There is little fading in December.

In agreement with previous experimental findings at SHF, the signal fading at EHF is less severe at Alert than at more southern locations. Furthermore, the lack of heavy rain storms in the arctic eliminates another major cause of signal fading at these higher frequencies. Based on these considerations, it is expected that EHF satellite systems will be capable of providing reliable communications to regions in the high arctic.

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The author wishes to acknowledge the support received from the MIT Lincoln Laboratory in providing the use of the LES-8 satellite during the experiment. Much assistance was provided by personnel in the Canadian Armed Forces and the Atmospheric Environment Service. The advice and help of colleagues and support staff at CRC are also much appreciated.

REFERENCES

1. J.I. Strickland, R.L. Olsen and H.L. Werstiuk, "Measurements of low angle fading in the Canadian arctic", *Annales des Télécom.*, vol.32, no.11-12, pp.530-535, Nov-Dec 1977.
2. K.S. McCormick, R.L. Olsen and L.A. Maynard, "Amplitude fading of satellite communications signals at SHF", *NATO/AGARD Conf. Proc.*, no.197, pp.18/1-8, 1972.
3. K.S. McCormick and L.A. Maynard, "Low angle tropospheric fading in relation to satellite communications and broadcasting", *Proc. IEEE., Intern. Conf. on Commun.*, Montreal, 1971.
4. K.S. McCormick and L.A. Maynard, "Measurements of SHF tropospheric fading along earth-space paths at low elevation angles", *Electron. Lett.*, vol.8, no.10, pp.274-276, May 1972.
5. R.V. Webber and K.S. McCormick, "Low elevation angle measurements of the ATS-6 beacons at 4 and 30 GHz", *Annales des Télécom.*, vol.35, no.11-12, pp.494-500, Nov-Dec 1980.
6. W.J. Vogel, A.W. Straiton and B.M. Fannin, "ATS-6 ascending: Near horizon measurements over water at 30 GHz", *Radio Sci.*, vol.12, no.5, pp.757-765, Sept-Oct 1977.

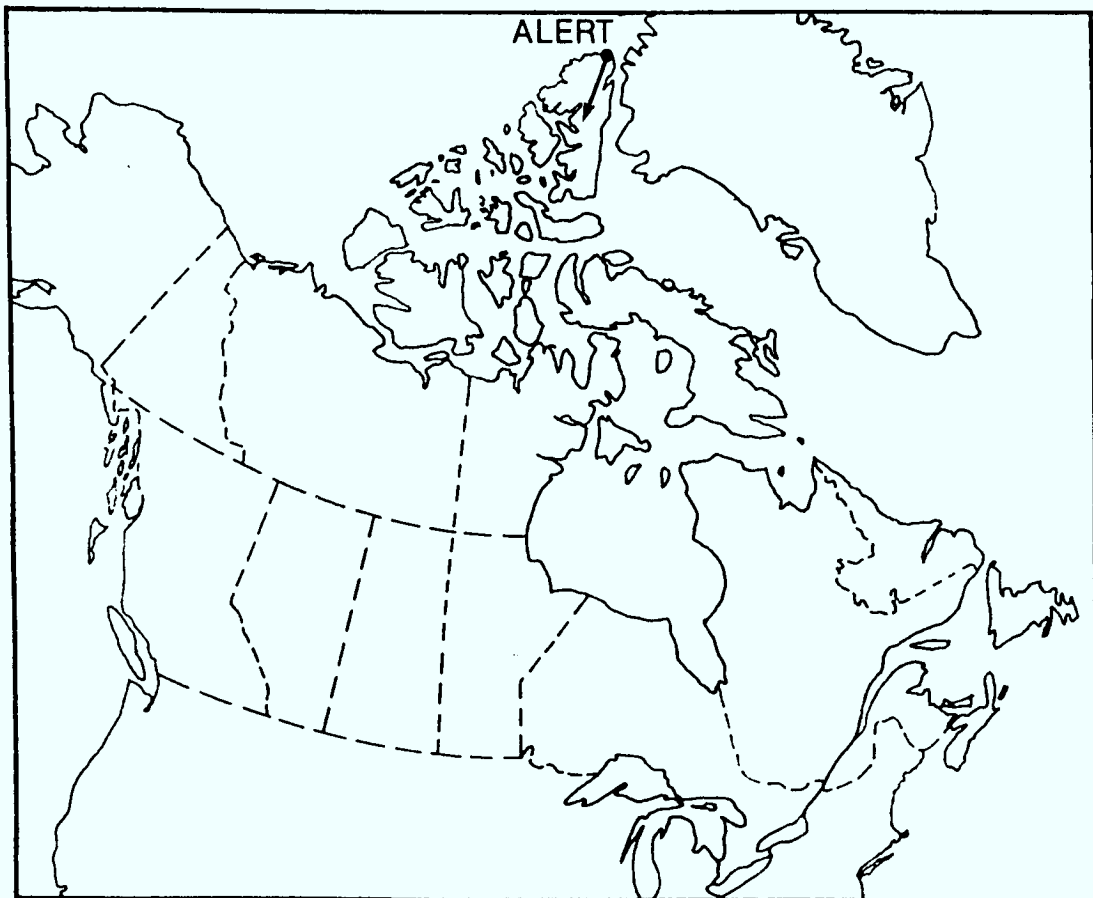


Figure 1. Map of Canada showing the location of Alert. The direction towards the LES-8 satellite is indicated by the arrow.

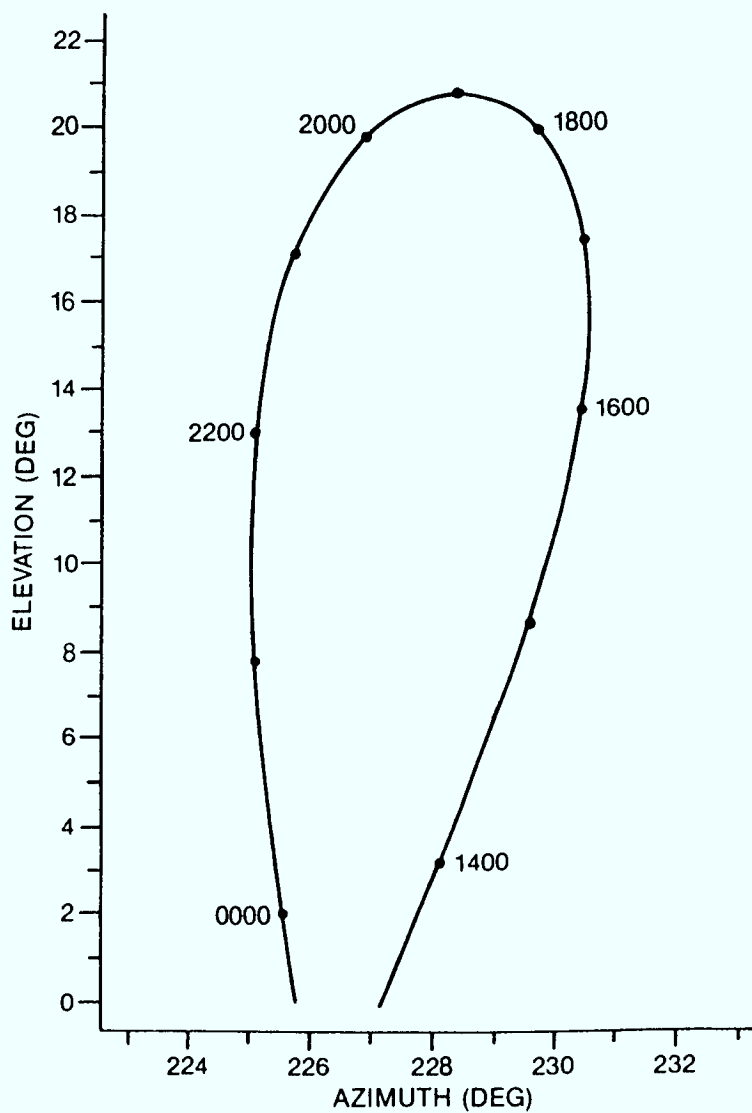


Figure 2. Typical look angles to LES-8 from Alert for May 31, 1984. The time of day in UT is indicated.

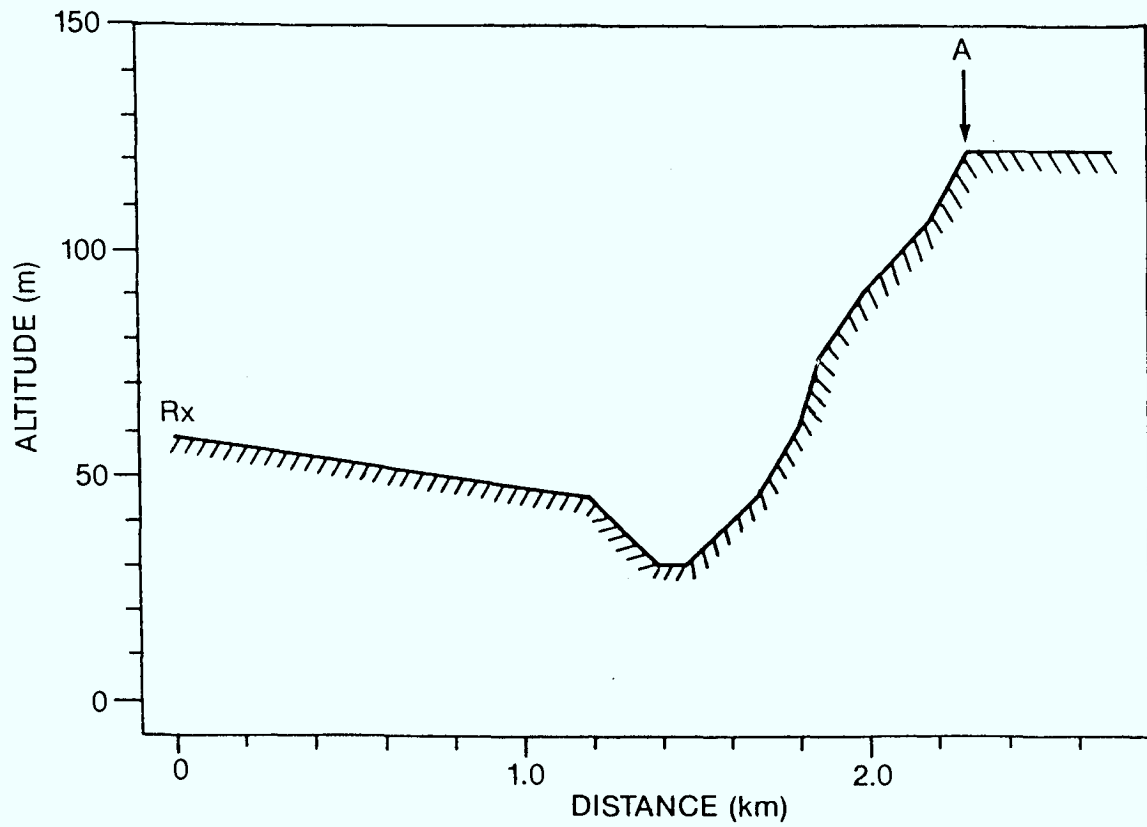


Figure 3. Path profile drawn from Alert in the direction to LES-8.

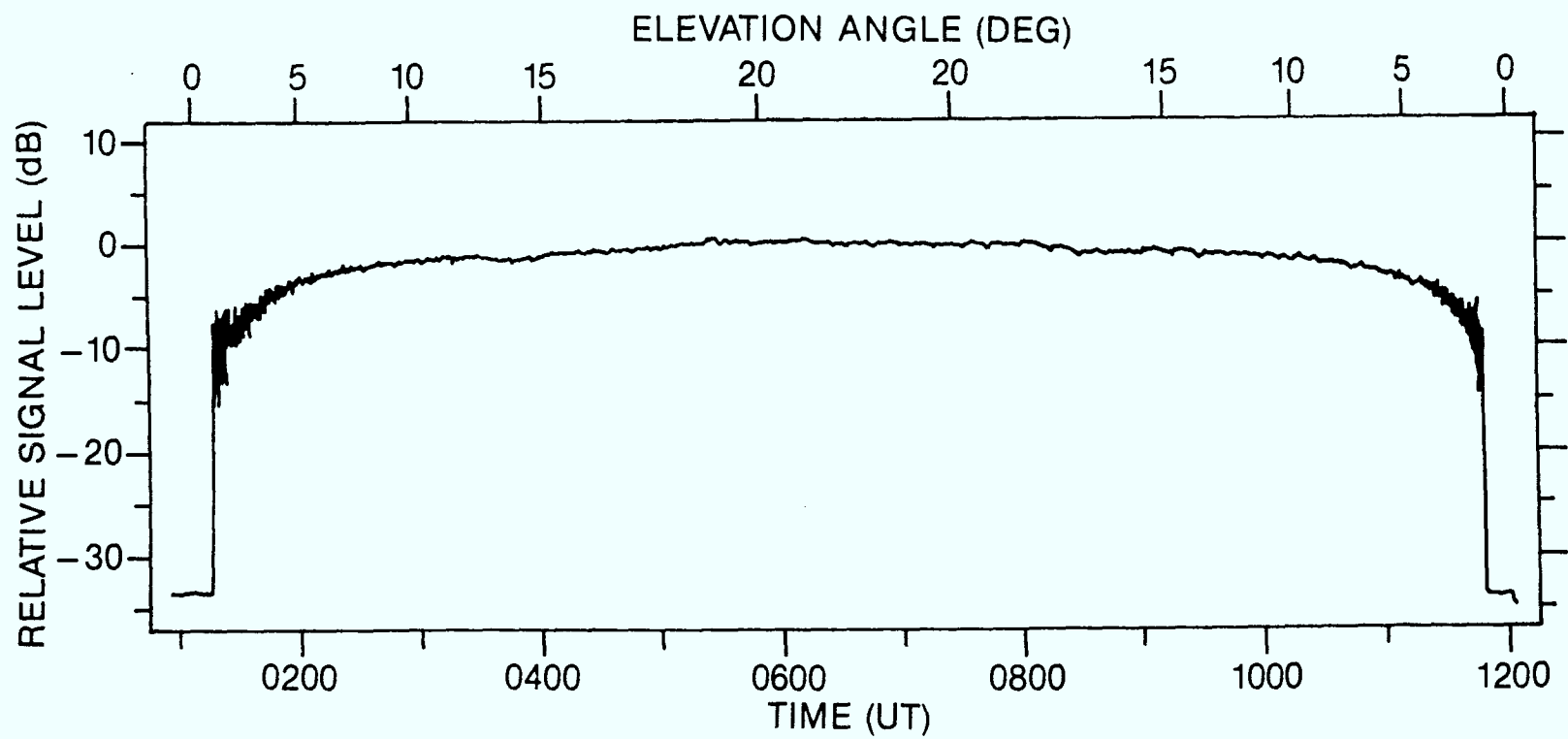


Figure 4. Signal level observed on a day with little fading.

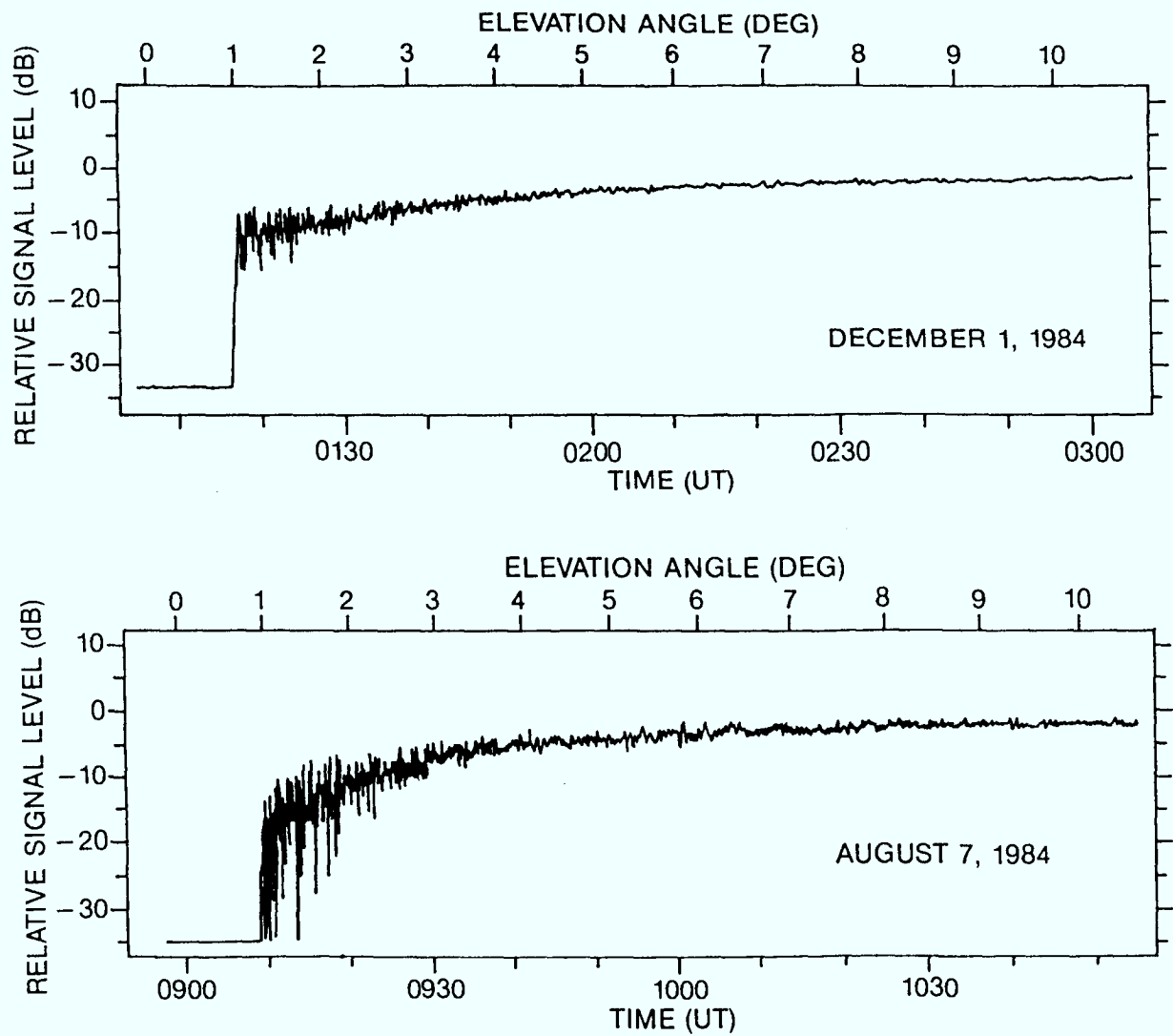


Figure 5. A comparison of the signal levels observed on:
(a) a day with little fading, and
(b) a day with severe low angle fading.

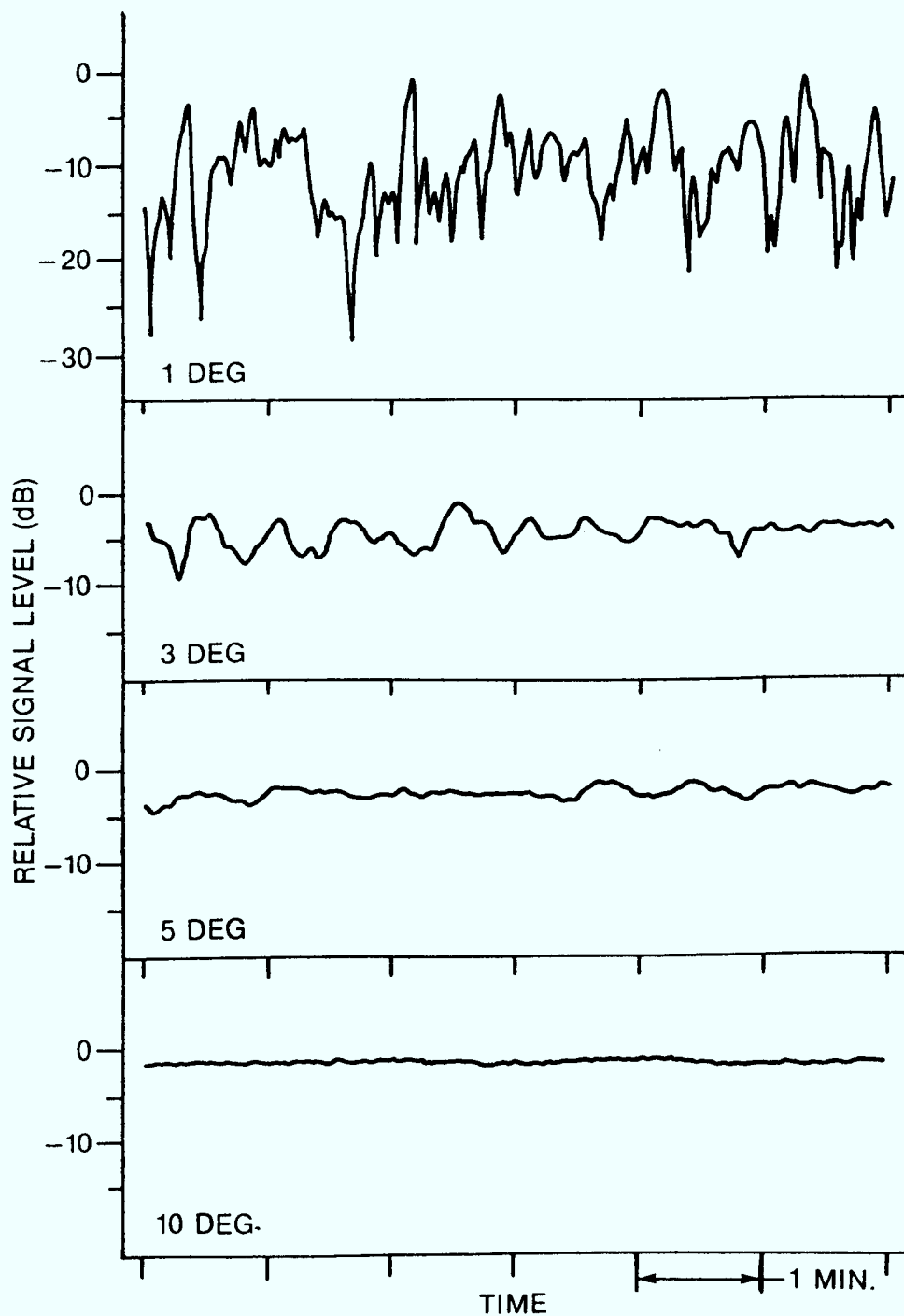


Figure 6. Detailed time series of signal levels recorded at various elevation angles on May 31, 1984.

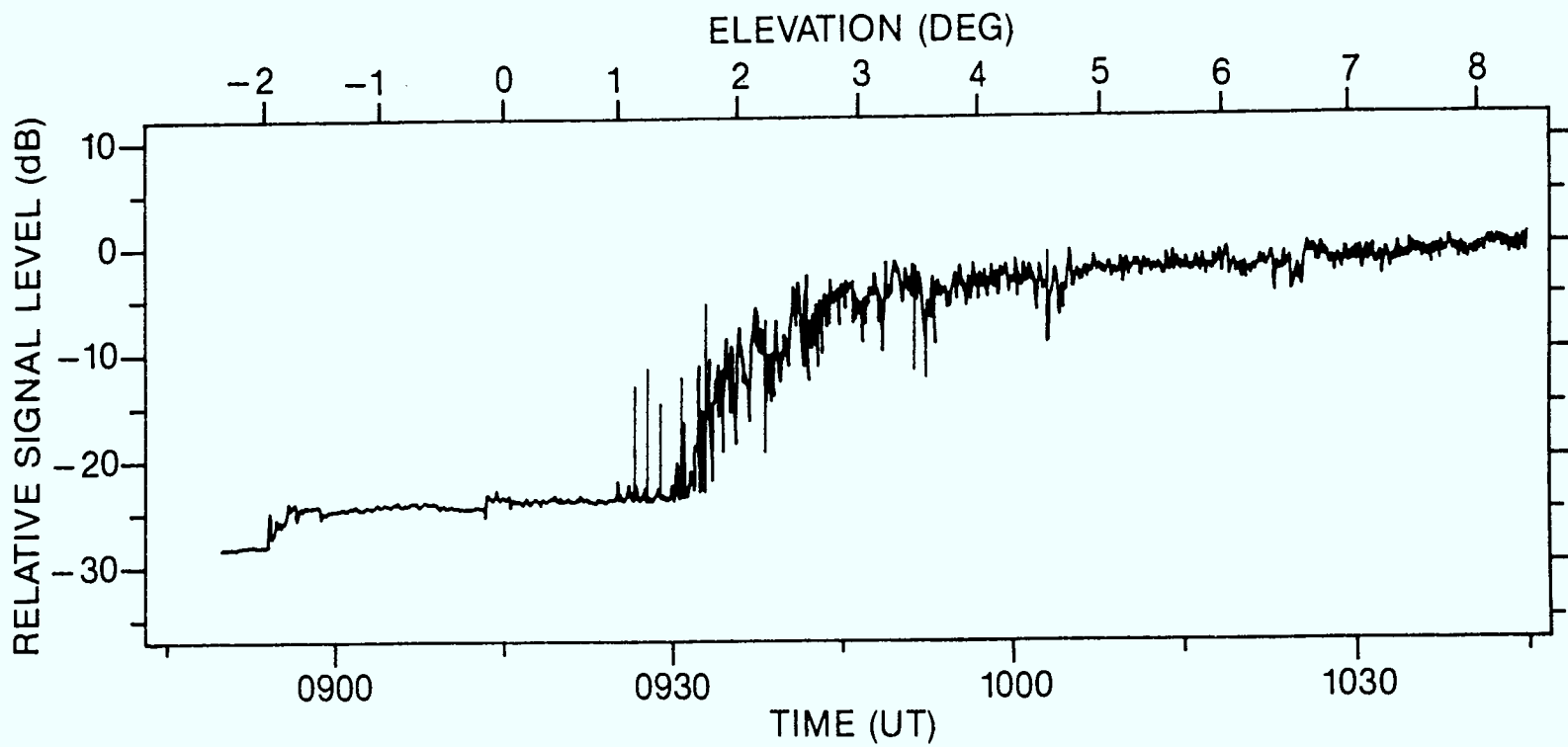


Figure 7. Anomalous signal behaviour observed on August 3, 1984.

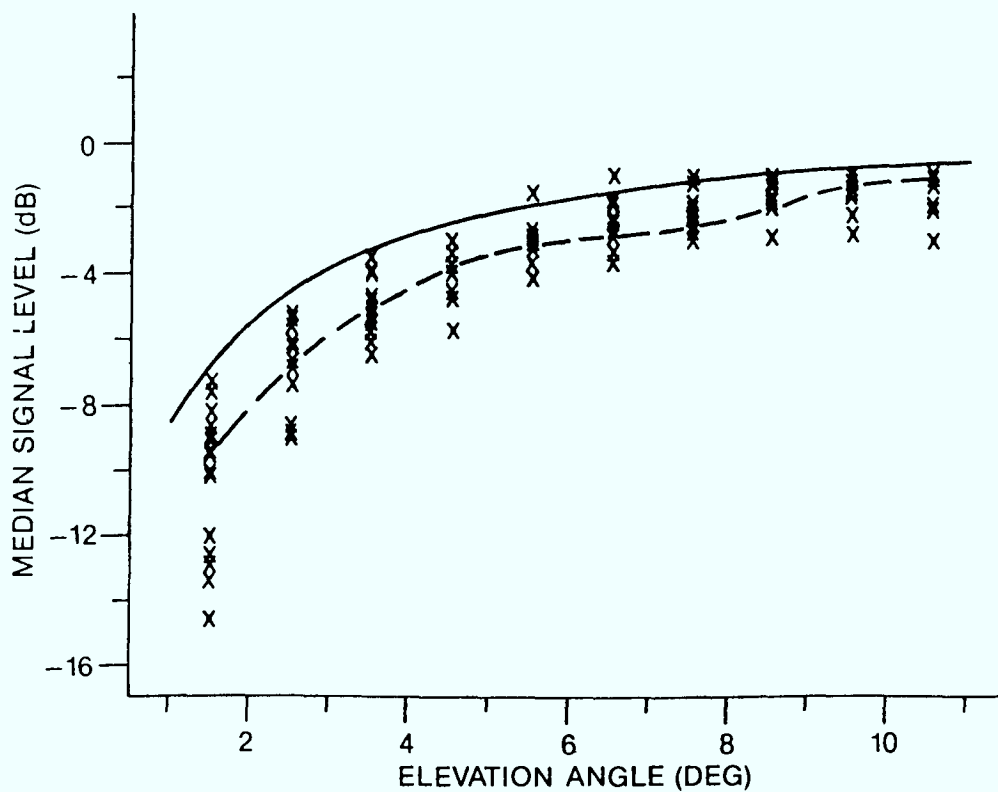


Figure 8. Variation of median signal level with elevation angle. Each point represents the median level observed during one pass of the satellite.

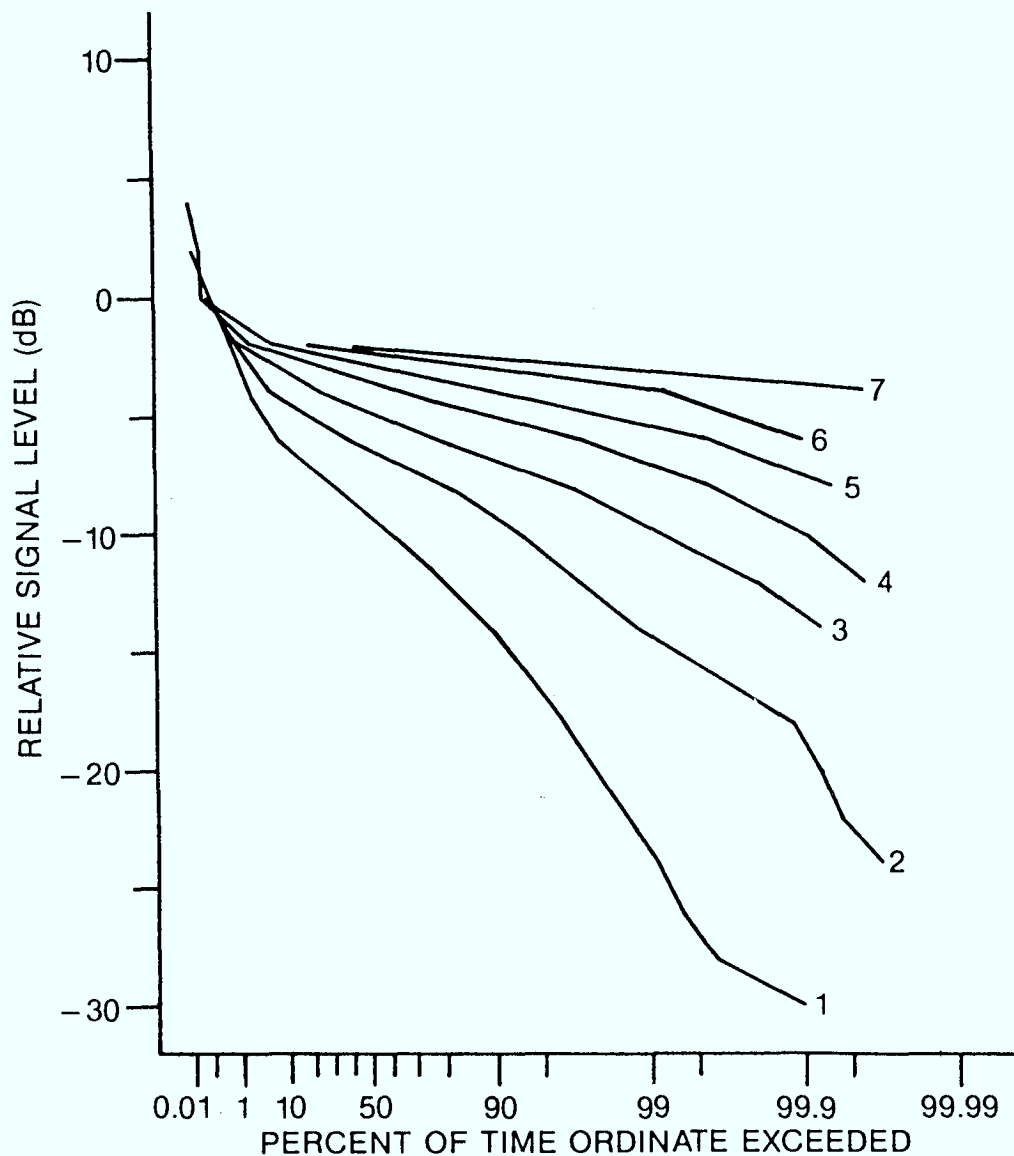


Figure 9. Distributions of the received signal level for the May-June measurements. Subscripts indicate the interval of elevation angle, 1 for 1-2 degree, etc.

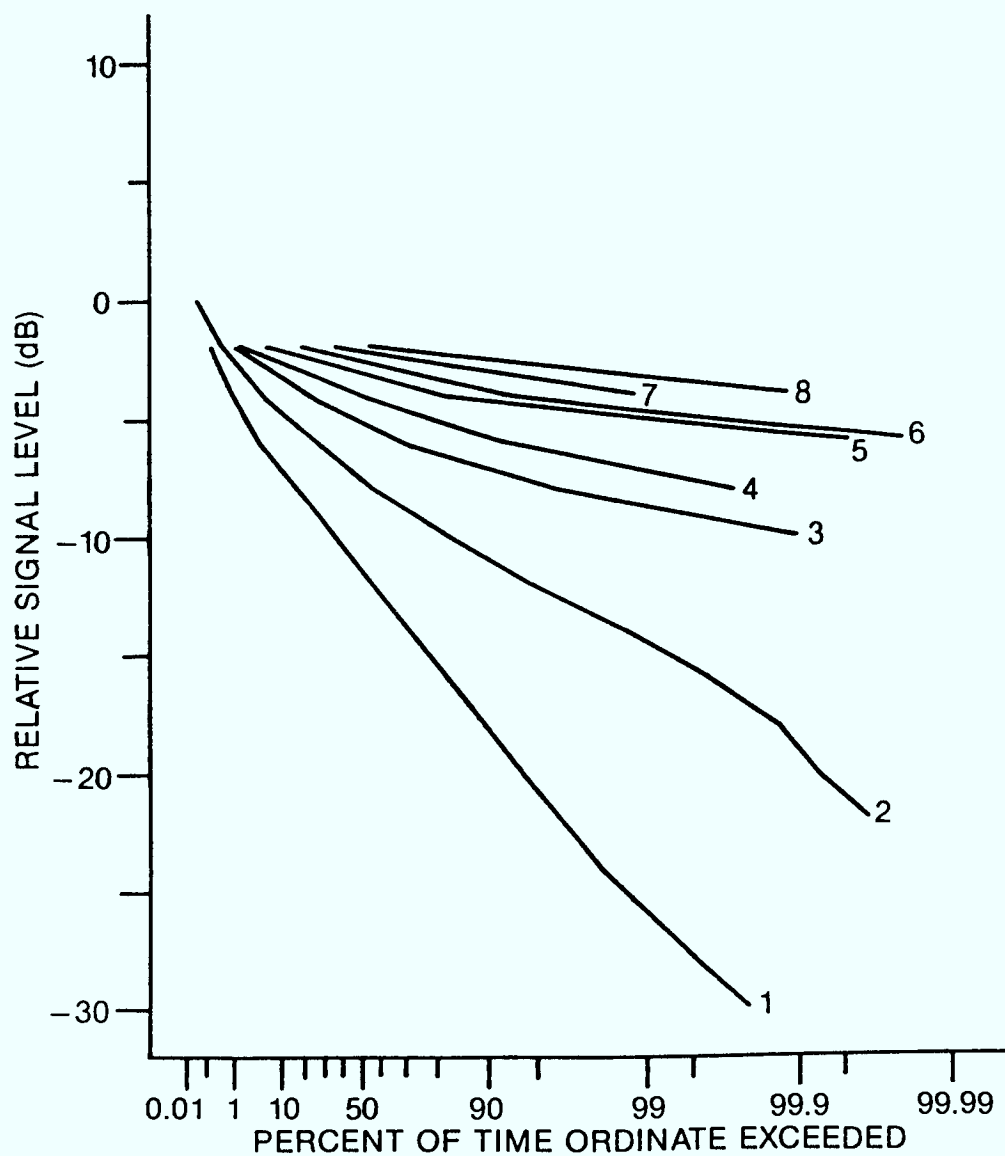


Figure 10. Distributions of the received signal level for the August measurements. Subscripts indicate the interval of elevation angle, 1 for 1-2 degree, etc.

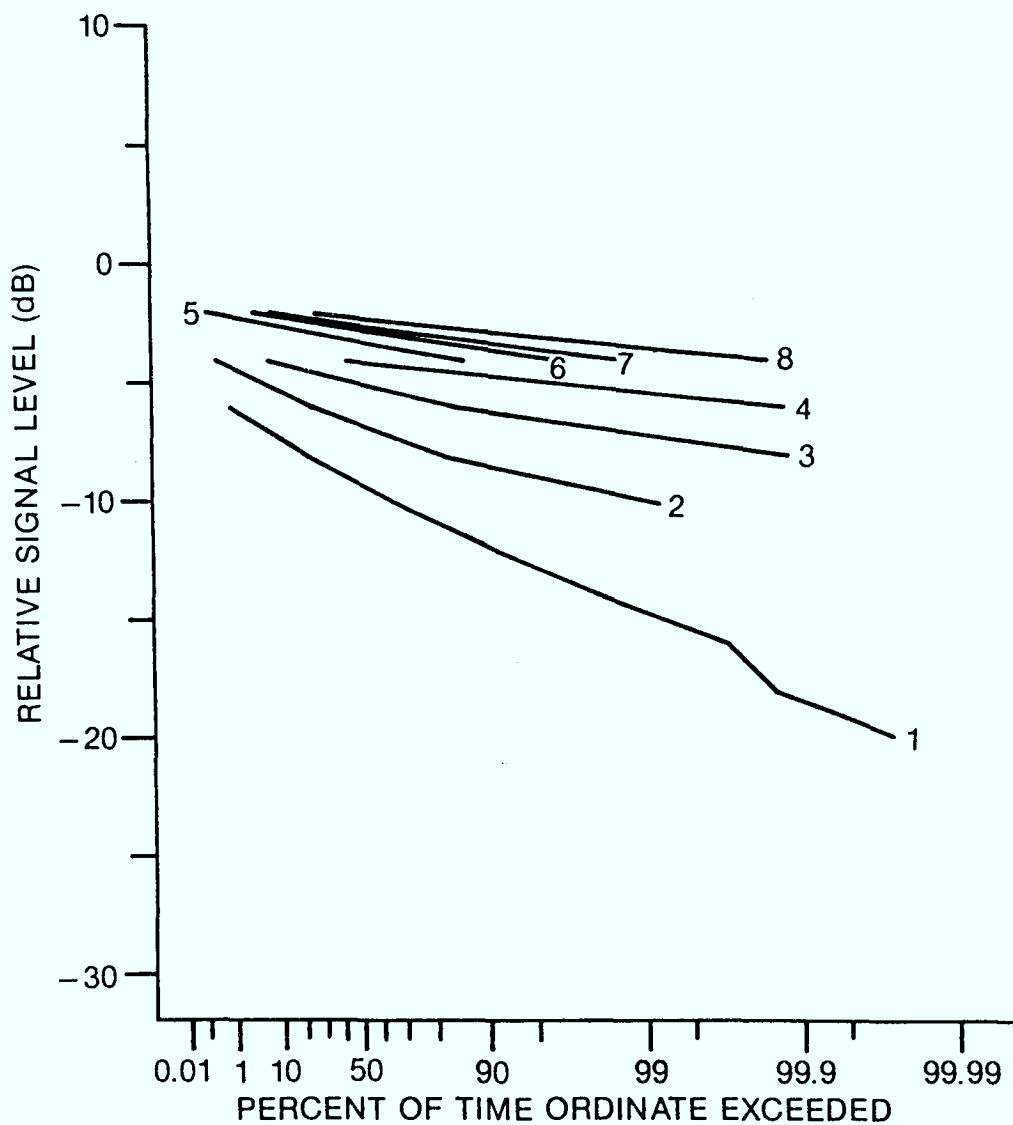


Figure 11. Distributions of the received signal level for the December measurements. Subscripts indicate the interval of elevation angle, 1 for 1-2 degree, etc.

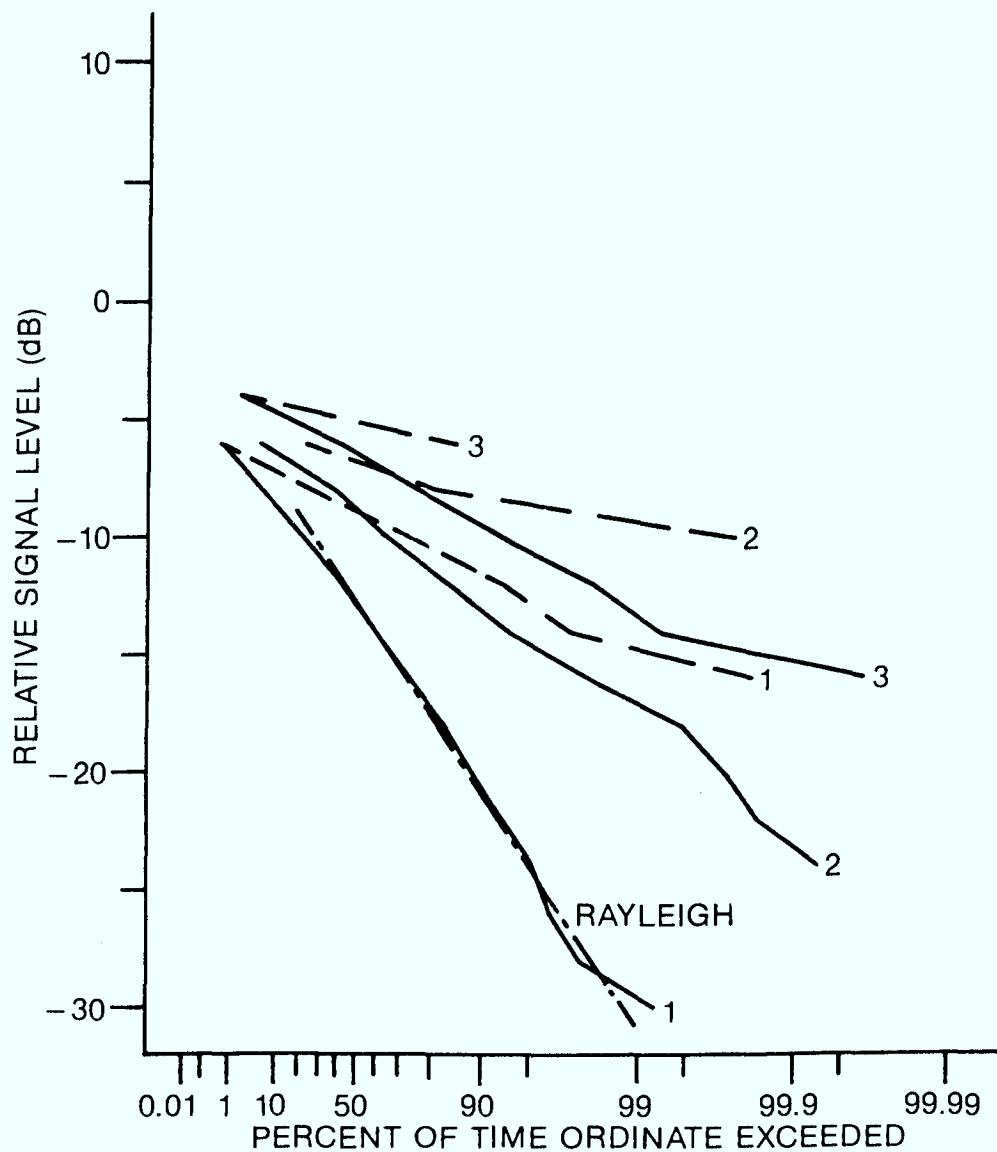


Figure 12. Signal level distributions for days with the least fading (dashed line) and the most fading (solid line). Subscripts indicate the interval of elevation angle, 1 for 1-2 degree, etc.

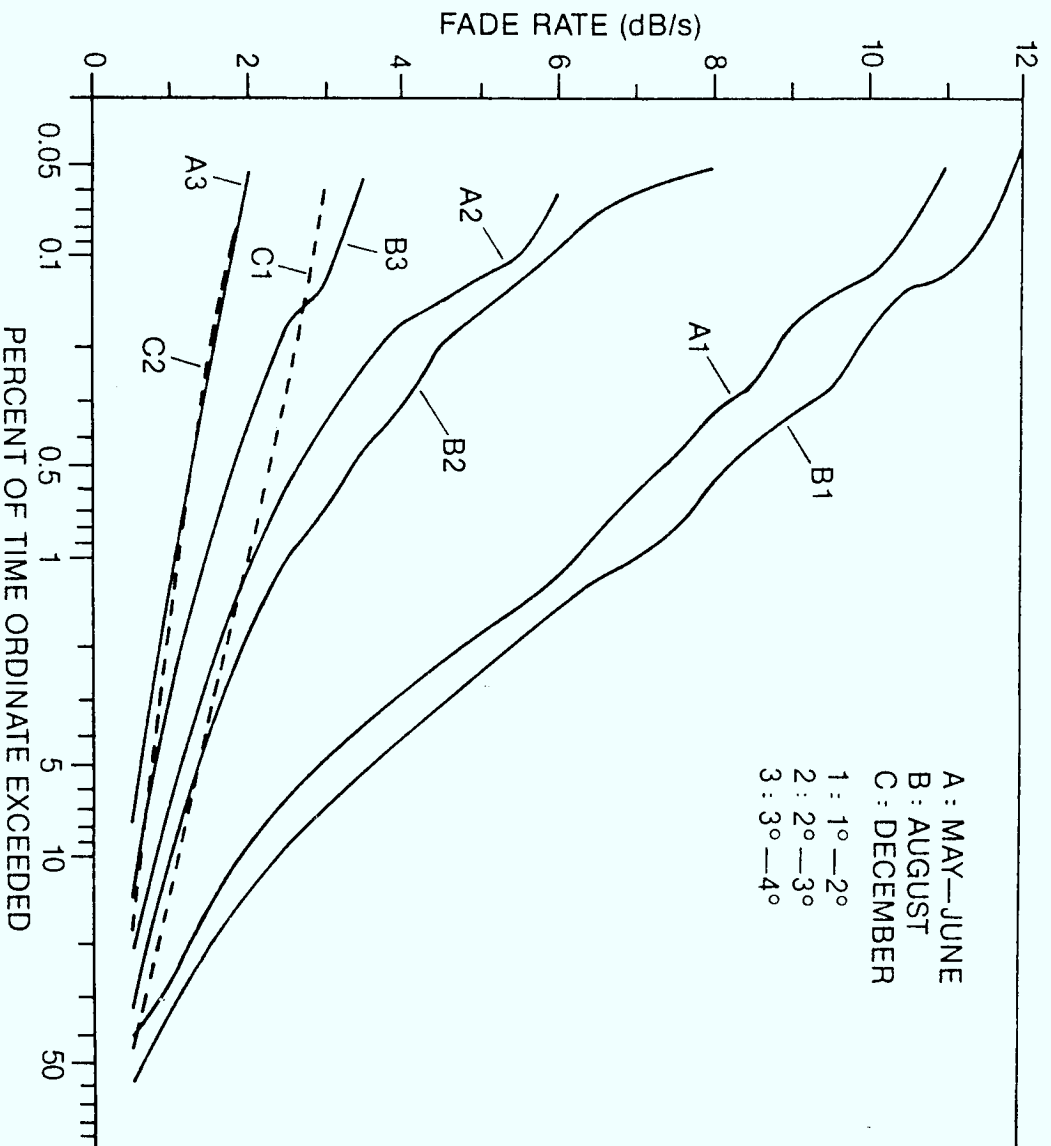


Figure 13. Distributions of the signal fade rate for the spring, summer and winter measurements.

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