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A Study of Satellite Motion-Induced Multipath Phenomena

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Abstract

Experiments have been undertaken at COMSAT Laboratories to determine some of the propagation effects likely to be encountered by handheld satellite communications devices. L-band pilot tones aboard geosynchronous satellites at 15° and 40° elevations were used to examine diurnal signal variations measured by using a hemispherical antenna. It was found that the receiver with a hemispherical antenna suffered daily peak-to-peak signal level variations of up to 12 dB compared to only 2 to 3 dB for a receiver equipped with a directional antenna. These results were highly repeatable, and extensive tests were conducted to confirm the accuracy of the data. The results suggest that the diurnal variations were due to multipath effects caused by the motion of the satellite with respect to the receive antenna. Noting that the orbit inclinations of the satellites used in the experiment were only on the order of 2 to 3°, the results also suggest a potentially serious signal variation problem for low-gain antenna-based communications systems using low earth orbit satellites, since the satellite elevation angles relative to earth change far more rapidly.

Introduction

With the current and projected rise in the use of mobile communications systems, significant efforts are being invested in propagation studies at the frequencies concerned, particularly L-band. Many of these studies have involved taking signal propagation data from fast moving vehicles [1],[2]. However, little consideration has been given to signal propagation for stationary or slow-moving communications systems, principally the handheld variety. Handheld personal communications systems will be power-limited and restricted to small operating margins. Only limited blockage and multipath experiments have been used to develop preliminary fade margins and performance specifications. So far, effects induced by the satellite movement have been ignored. A few experiments have been conducted at COMSAT Laboratories to identify propagation phenomena that handheld satellite communications systems are likely to encounter.

This paper discusses one particular set of experiments which involved the diurnal variation of an L-band satellite signal received by an omnidirectional antenna. The results reported herein indicate that diurnal motion of the satellite, or its corollary, physical movement of the antenna, can cause signal variations in excess of 9 dB peak-to-peak for low-gain antennas under certain conditions. A preliminary finding is that close-in multipath effects may be the cause of the variations.

System Description

Two receivers were set up, one employing a 16-dB-gain dish antenna with a 25° half power beamwidth, and the other using a 3-dB-gain hemispherical Global Positioning System (GPS) antenna. A computer-controlled frequency tracking system was used to keep the receivers locked on the signal. The GPS-based receiver was slaved to the frequency of the dish-based system to avoid potential discrepancies during frequency tracking. The receivers were coupled to a 10-MHz crystal reference source for coherency, and their down-converters shared a common local oscillator to further maintain system coherency. The signal power was measured by a detector within a 65-Hz bandwidth to allow sufficient measurement range. The high resolution and linear outputs of the receivers were sampled at 100 Hz, but since storage space was limited, the data were recorded at a rate of 10 Hz. The receivers were automatically calibrated and re-centered on the signal after each minute of recording, as the signal center frequency drifted diurnally due to the Doppler effect. Concurrently,1 second averaging of the noise level at a frequency 1-kHz below the pilot's center frequency was made, and a record of the noise level was stored to allow accurate assesment of potential gain fluctuations along the receive chains. For more information on the receivers, see Reference 3.

Long-Term Signal Variations

The two antennas were positioned on a flat roof at the Laboratories, with the rest of the equipment in an air-conditioned room directly below the antennas. The signal source was a 1.537525-GHz pilot tone re-broadcast via a global coverage antenna on the INMARSAT-II F-4 satellite in geosynchronous orbit at 55.5° west with an elevation angle of 40°. The pilot EIRP at the satellite was about 10 dBW.

Figure 1 shows the variation in signal power over 24 hours obtained with the GPS antenna directed at zenith, and with the high-gain antenna lined up on the satellite. Both antennas had clear paths to the satellite, as they were mounted on a flat rooftop, about 2.5 m apart and 1.5 m above the surface. There are significant differences in the signatures of the two signal levels shown in Figure 1. The peak-to-peak signal variation experienced by the GPS-based receiver is nearly twice that observed for the high-gain antenna system. To obtain the results shown in in Figure. 2, the GPS antenna was lined up along the satellite look angle; the high-gain antenna was left unchanged. In this case the GPS antenna system experienced as much as 4 times greater peak-to-peak variations. Of equal significance is the rapidity signal variation measured by the GPS antenna; the signal changed by up to 7 dB within 1.5 hr, compared to less than 1 dB of change over the same time interval when measured by the high-gain antenna.

Measurements made over several days indicated that the signal level variations obtained were highly repeatable from day to day. Figure 3 shows data from 4 consecutive days. The time series for each day of data is progressively shifted by the difference between a sidereal day and a calendar day (approximately 4 min.). The correlation over 4 days on a sidereal basis is evident in the figure.

Extensive receiver checks were performed to eliminate the possibility of equipment effects which could contaminate the results. A stable signal source, offset a few Kilohertz from the satellite's pilot tone, was set up on the roof, and the response of the GPS-based system was tested over 12hours. The received signal remained within 0.5 Hz of the transmit frequency and experienced less than 0.1 dB power level variation. Noise level checks that were conducted over many days indicated the same order of stability. Investigations into weather patterns showed that even though there had been significant changes in the daily temperature cycles, no such changes were detected in the received signal levels from either antenna. It was also determined that there were no extraneous interfering signals. It became clear from these intensive investigations that the major variations in the observed signal-to-noise ratios were soley the result of changes in the received carrier level.

After ruling out all local effects, interfering signals, and equipment problems, the signal level variations were determined to be due to diurnal variations in the satellite position, satellite mutation effects and, to a lesser extent, changes in Doppler frequency. In an attempt to settle the location dependency of the effects, the GPS antenna was moved to atop a 10-ft pole at the very edge of the roof and directed toward the satellite. Figure 4 presents almost 24 hr. of measurement data. From this figure, it is evident that the signal variations are different from the previous ones and also greatly reduced; the total daily peak- to-peak variation recorded from the dish antenna and the GPS antenna are similar. Also, the effects were not diurnally repetitive. This could be attributed to the fact that there was a large car parking lot 40 ft directly below the GPS antenna. Some of the data were recorded over a weekend, when there were comparatively few cars were moving around. On regular working days the distribution and number of cars varies. This indicates that a constant reflective surface may not have existed during the measurement period, which could explain the dissimilarity in the daily signal traces. Therefore, it can be argued that the recorded signal level was fairly dependent on the reflective quality of its surrounding; hence, the signal level is probably location-dependent. This suggests that the daily observable variations in signal level recorded by the hemispherical antenna are due to multipath effects, which change over the course of a day because of the motion of the satellite with respect to the receive antenna.

To support the above argument, a similar experiment was conducted at yet another location. The receivers were moved to a flat, open grassy area on COMSAT grounds bordering a highway. Data could only be recorded during working hours, since the equipment could not be left unattended outside overnight. Approximately 6 hours of data were taken and as can be seen in Figure 5, the recorded data bears little resemblance to that measured on the roof. The changes in signal level at the GPS antenna were much smaller and smoother at the new location, but as before, the peak-to-peak variations were always greater than those measured by the dish antenna.

To independently confirm the validity of the results obtained using the INMARSAT-II F-4 , another pilot tone from a different satellite (INMARSAT-II at 15°W) was tested. The tone frequency was at 1.537528- GHz, with an elevation of approximately 15° and an azimuth of 110°. Measurements were made on the roof, and data were taken over several days (see Figure 6). While the long-term tre of the signal traces recorded by the dish and GPS antenna receivers were very similar, the peak-to-peak variations over the course of a day were significantly different; 4 dB for the dish and over 10 dB for the GPS antenna. As noted before, changes in signal levels were again highly repeatable from day to day. Having almost identical signal behavior when using a second satellite source may again suggest that the signal level variations are due to changes in multipath characteristics caused by motion of the satellite relative to the earth stations. It was evident that the dish receiver was more affected than in previous measurement campaigns, possibly because of a partial interception of its lobe with the roof surface. This might suggest that the multipath was produced from an area directly in front of the antennas, probably the roof surface.

These independent sets of measurements, bearing remarkable similarity in terms of diurnal variation to the data sets made using the INMARSAT-II F-4 satellite, seem to support that there is a much larger diurnal variation in signal level received by a hemispherical antenna than by a narrowbeam antenna. It also could imply that the variation may be the result of closein multipath effects.

Another pilot tone at 1.5415 GHz aboard the MARECS B-2 at 15° west has also been measured, and showed variations similar in shape to those for the 15° elevation satellite discussed previously. Preliminary investigations of diurnal signal variations measured through a glass window from inside an office at COMSAT Laboratories have also shown similar results.

Conclusions

The satellite used for the measurements wasgeosynchronous orbit with an inclination of 2.2°. The elevation angle changes by less than ±2.2° over a sidereal day. The movement of the satellite with respect to earth is therefore slow, leading to correspondingly slow changes in multipath effects. By inference, if the signal had emanated from a low earth orbiting satellite, similar changes (but at a higher rate) would be experienced by the user, particularly when employing a low-gain antenna.

Increases in signal variations observed when a low-gain antenna was lined up along the satellite look angle suggest an increased contribution from reflected signal components of the antenna's surroundings, as a large part of the antenna pattern intercepted multipath-producing surfaces. The results from the measurements indicate a strong relationship between the physical orientation of the antenna, and the profile/texture of the surrounding surfaces, whether they were walls, flat areas, cement, or foliage.

It appears that the user of a handheld satellite communications terminal would have to be aware of its limitations in order to use it satisfactorily. Also, further propagation studies of the phenomena, including an investigation into the nature of the suspected multipath components, is prudent.

Acknowledgement

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References

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[3] ``Propagation Considerations on L-Band Handheld Communication Service Operations Via Satellite," R. M. Allnutt, A. W. Dissanayake, K. T. Lin, and C. Zaks, International Conference on Antennas and Propagation, Edinburgh, Scotland, April1993, Proc.

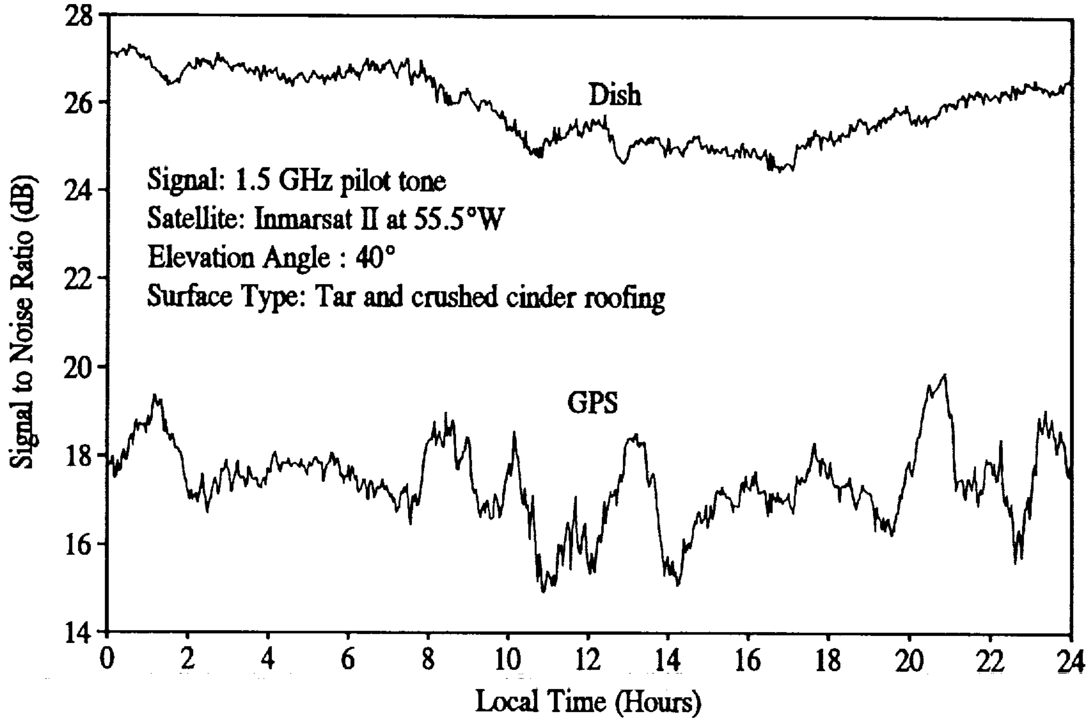

Figure 1. A Comparison of Received Satellite Signal Strength at 1.5 GHz Between Directional (Dish) and Hemispherical (GPS) antenna; 14 October 1992

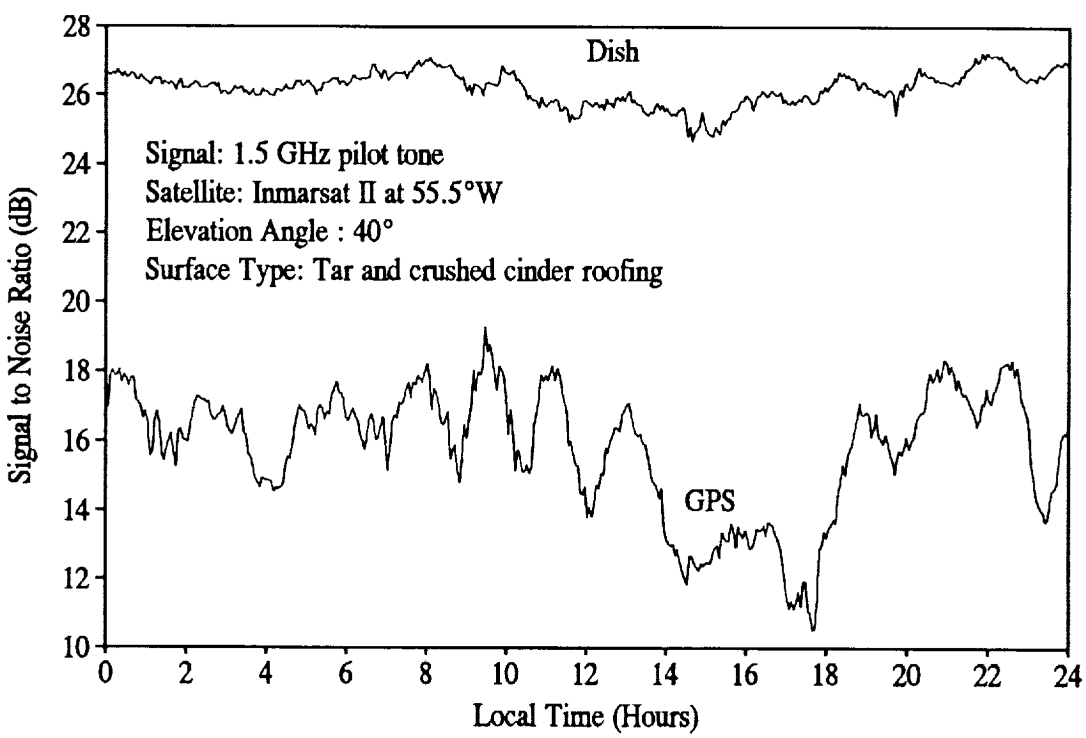

Figure 2. A Comparison of Received Satellite Signal Strength at 1.5 GHz Between Directional (Dish) and Hemispherical (GPS) antenna; 24 October 1992

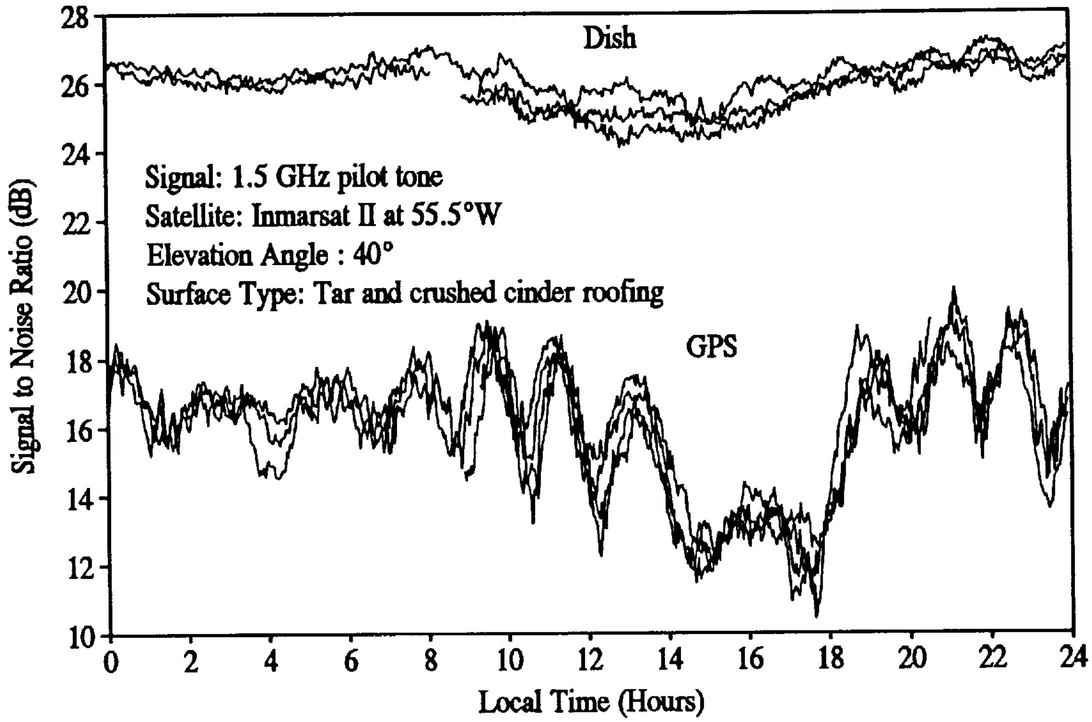

Figure 3. A Comparison of 4 Days of Satellite Signal Strength Data Measured (22 - 25 October 1992).

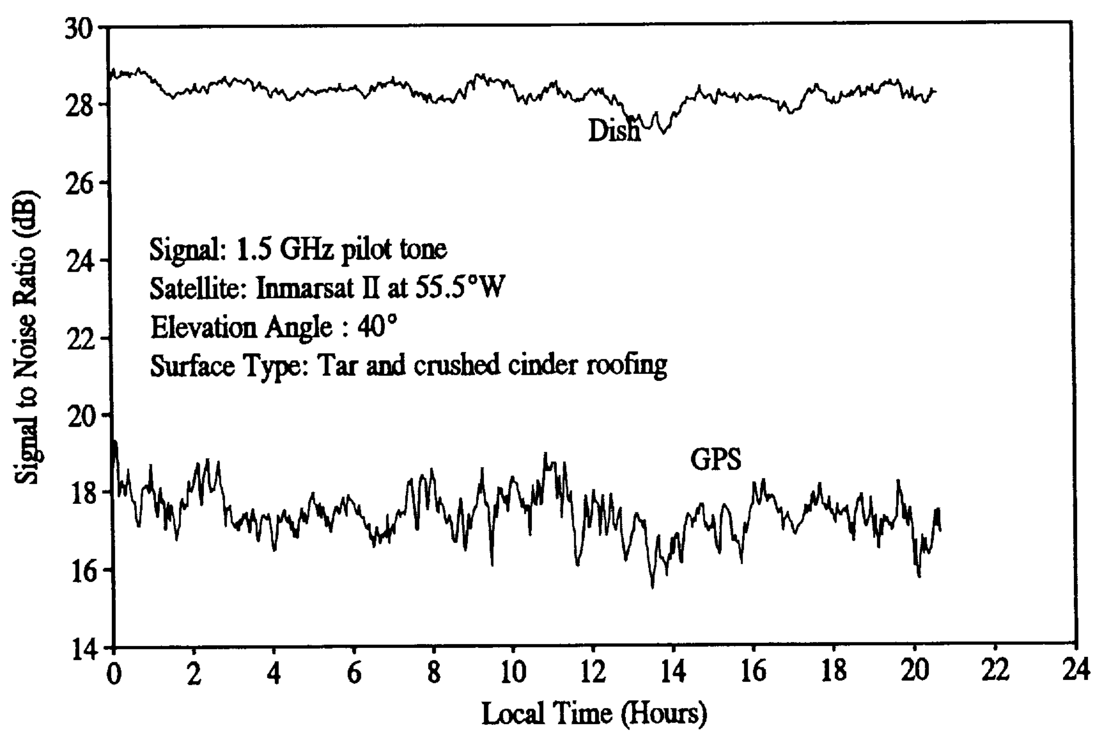

Figure 4. A Comparison of Received Satellite Signal Strength at 1.5 GHz Between Directional (Dish) and Hemispherical (GPS) antenna; 11 October 1992

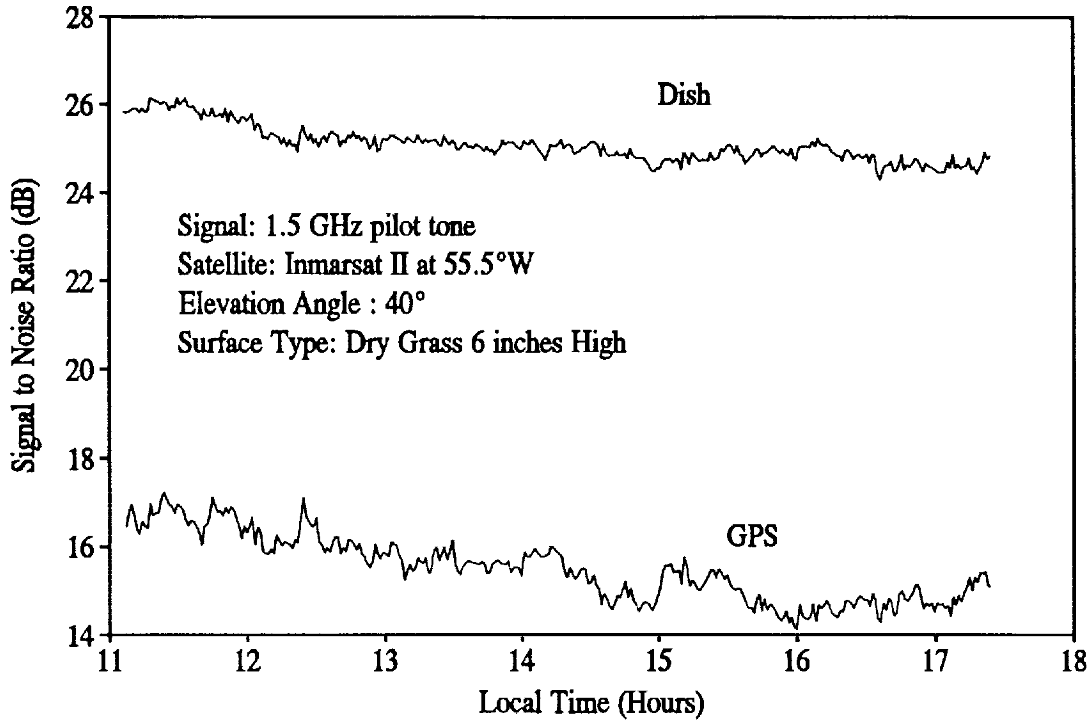

Figure 5. A Comparison of Received Satellite Signal Strength on a Grass Surface 28 October 1992

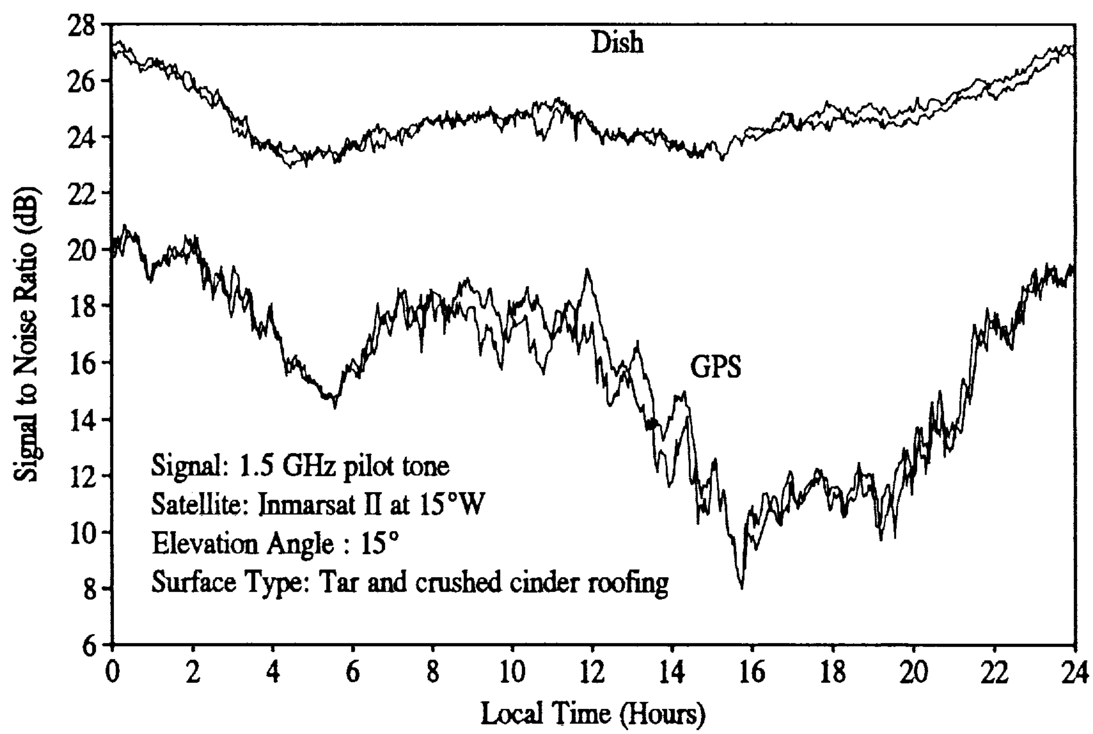

Figure 6. A Comparison of Received Signal Strength from a Second Satellite 7-9 December 1992