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OLYMPUS PROPAGATION STUDIES IN THE U.S. - Propagation Terminal Hardware and Experiments

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Abstract - Virginia Tech is performing a comprehensive set of propagation measurements using the OLYMPUS satellite beacons at 12.5, 20, and 30 GHz. These data will be used to characterize propagation conditions on VSAT - type networks for next generation small aperture Ka-band systems.

1. Introduction

The European Space Agency (ESA) satellite OLYMPUS was launched July 12, 1989. The spacecraft contains a sophisticated package of propagation beacons operating at 12.5, 19.77, and 29.66 GHz (referred to as 12.5, 20, and 30 beacons). These beacons cover the east coast of the United States with sufficient power for attenuation measurements. The Virginia Satellite Communications Group is completing the hardware construction phase and will begin formal data collection in June.

As satellite communication systems move toward the 20/30 GHz frequency range for wider bandwidth and reduced interference, the role of small earth terminals (VSATs) becomes increasingly important. Previous satellite communications systems used large earth terminals with wide fade margins to achieve high reliability. Past propagation experiments were aimed at accumulating data for these wide margin systems. VSATs, however, with their modest propagation reliability requirements coupled with fade compensation techniques and low margins have now become practical. Propagation research must now shift to the measurement and modelling of low margin systems. This requires accurate measurement of fade statistics and fade dynamics for low to moderate fading, 3 to 5 dB. Fade dynamics are also important to the design of compensation schemes. The objective of our experiment is to investigate propagation effects on future Ku- and Ka- band communications systems. The Advanced Communications Technology Satellite (ACTS), scheduled for launch in 1992, will provide another opportunity for Ka-band propagation studies throughout North America.

The experiment program at Virginia Tech offers some unique opportunities. The collection of simultaneous data at three frequencies spanning the 12 to 30 GHz region is extremely useful in frequency scaling studies. This is possible because all links have the same path (14° elevation, 108° azimuth). The 14° elevation angle is relatively low and data in this region is also very useful in its own right because this is at the lower limit for CONUS coverage with domestic satellites. Our experiment was designed to record low-fade events accurately. This is valuable in amassing a data base for low margin operational satellite links such as VSAT systems. Another feature of our OLYMPUS program is that it provides a test bed for ACTS due to the similarity of frequencies (ACTS beacons are at 20.2 and 27.5 GHz). In particular, we have designed and built a beacon receiver for OLYMPUS which can be used for ACTS.

2. The Measurement System

The propagation experiment system at Virginia Tech will continuously measure the 12.5, 20, and 30 GHz OLYMPUS beacons for one year. The east coast of the United States is far off boresight of the OLYMPUS 20 and 30 GHz antennas; however, there is sufficient EIRP from the beacons in our direction for good propagation measurements using moderate sized antennas. Cross-polarization measurements are not possible as the satellite antennas have low XPD well away from boresight.

Four separate receiving systems are used; one each for 12.5, 20, and 30 GHz, as well as a 20 GHz diversity terminal. The receiving antennas are 12, 5, and 4 feet in diameter at 12.5, 20 and 30 GHz, respectively. Thus, the 20/30 GHz portions of the experiment employ VSAT class terminals. The second 20 GHz terminal will be used to determine the advantages of small scale site diversity reception using VSAT terminals.

A unique feature of the OLYMPUS beacon package is that the three spacecraft beacons are coherent since they are derived from a common oscillator. The Virginia Tech OLYMPUS receivers take advantage of their coherence by deriving frequency locking information from the 12.5 receiver. This information is used to maintain lock for all four receivers. In effect, this widens the dynamic range of the 20 and 30 GHz receivers, which experience more fading during a rain event than does the 12.5 GHz receiver.

The receivers at all three frequencies are very similar. Each receiver has a low noise amplifier followed by a mixer-preamp whose output IF frequency is 1120 MHz. A motorized attenuator is included in the RF section to aid in system calibration. The 1120 MHz IF is subsequently mixed down to produce lower IF frequencies of 70 MHz and 10 kHz. The 10 kHz signal is then used in detection and tracking.

A hybrid analog/digital receiver is used in our detection scheme for the 12.5 GHz system. The analog portion of the receiver tracks the carrier frequency and maintains the signal within a 3 Hz window. Simultaneously, the 10 kHz carrier is sampled at a 40 kHz rate by a 12 bit A/D converter. Each sample is then filtered by a digital FIR filter and the resulting 16 bit I and Q values are recorded by the data acquisition system.

Clouds and scintillation can produce up to 3 dB of attenuation at 30 GHz on a 14° elevation-angle path and may be present for a large percentage of the time. Therefore, it is important in a slant-path propagation experiment to be able to set the clear air reference level accurately. Radiometers operate at each beacon frequency in our receiving system to aid in setting this clear air reference level. The radiometers are of the total power design; the RF and IF sections are housed in a temperature controlled environment to keep gain constant. The radiometer design is unique in that it uses the same RF chain as the beacon receiver.

The output of the receivers and radiometers are continuously monitored by the data acquisition system (DAS), which is discussed in a companion paper.

3. The Experiment Program

The objectives of the experiment are summarized in Table 2. Attenuation data will be collected from the 12.5, 20 and 30 GHz OLYMPUS beacons for a one year period. Radiometric data will be collected to assist in setting reference levels to improve low level attenuation measurement accuracies. However, such data may be useful in its own right.

To examine small-scale diversity, we will operate a second 20 GHz receiver which will be located near the main 20 GHz terminal. Although widely spaced diversity terminals have been studied for deep fades, short baseline diversity for low/moderate fading has not. Attenuation data at the diversity station will be compared to that of the main terminal during the same sub-year time interval. Diversity gain will be examined for each station as a function of baseline distance.

For the fade slope portion of the experiment, statistics on the rate at which individual fades begin and end (in dB per second) will be accumulated and correlated with the physics of propagation. Fade slope data are useful in studies of various modulation schemes for Ka-band VSAT systems.

Attenuation data at 30 GHz will be used to test various algorithms to predict how fading can be relieved using uplink power control.

4. Receiver Development

The 12.5 GHz signal suffers much less fading than the 30 GHz signal. Attenuation in rain increases approximately as the square of the frequency, so a 10 dB fade at 12.5 GHz is accompanied by a 57 dB fade at 30 GHz and a 25 dB fade at 20 GHz. Locking the receiver to the 12.5 GHz signal means that it will stay in lock when the higher frequencies are below the minimum measurement level of the receiver, and there will be no hysteresis effect when the fade ends and the signal levels rise to the point where measurements can continue. The dynamic range of our 12.5 GHz receiver is 30 dB. We might expect to experience one event a year in which attenuation exceeds 30 dB at 12.5 GHz on our 14° slant path from OLYMPUS. A fade of this severity will cause loss of lock in the receiver, but we expect the outage to be very brief.

The heart of our receiver is a frequency lock loop (FLL) operating at a 10 kHz IF frequency with a bandwidth of less than 20 Hz. We are using a FLL in preference to a phase lock loop (PLL) for two reasons. We can achieve a narrower locking bandwidth with the FLL, and hysteresis effects when the FLL loses lock and must reacquire on a weak signal are less severe than with the PLL. Our FLL locks the three beacon signals into a 3 Hz bandwidth, providing a dynamic measurement range in excess of 40 dB in the 20 and 30 GHz receiver channels. The 12.5 GHz receiver has been bench tested giving over 30 dB dynamic range. It also has been tested with the spacecraft beacon for several weeks demonstrating excellent performance in clear air and in fading.

5. Initial Results

An intense rain cell moved across the Virginia Tech Tracking Station on April 21. At the time we were monitoring the 12.5 GHz beacon signal for stability by strip chart recording. The results of the beacon fade are shown in Fig. 1. A large fade of over 20 dB occurred first, followed by a second fade of a few dB; the system was not calibrated for use with a strip chart recorder. During the second fade 12.5 GHz radiometer data were recorded by hand and later plotted as shown in Fig. 2. The agreement to the beacon signal is very good, indicating the value of the radiometer for low fades.

Table 1

Characteristics of OLYMPUS Receivers at Virginia Tech

Terminal	12	20 & 20D	30
Frequency (GHz)	12.5	19.77	29.65
Polarization	V	Switched V,H	V
Switching loss (dB)	-	4	-
EIRP toward Blacksburg (dBW)	9.1	19.7	19.7
Antenna Size (m)	4.0	1.5	1.2
Power available from antenna (dBW)	-147.0	-145.0	-146.8
C/N in 3 Hz BW (dB)	49.9	48.5	45.3

Table 2

Objectives of the Virginia Tech OLYMPUS Experiment

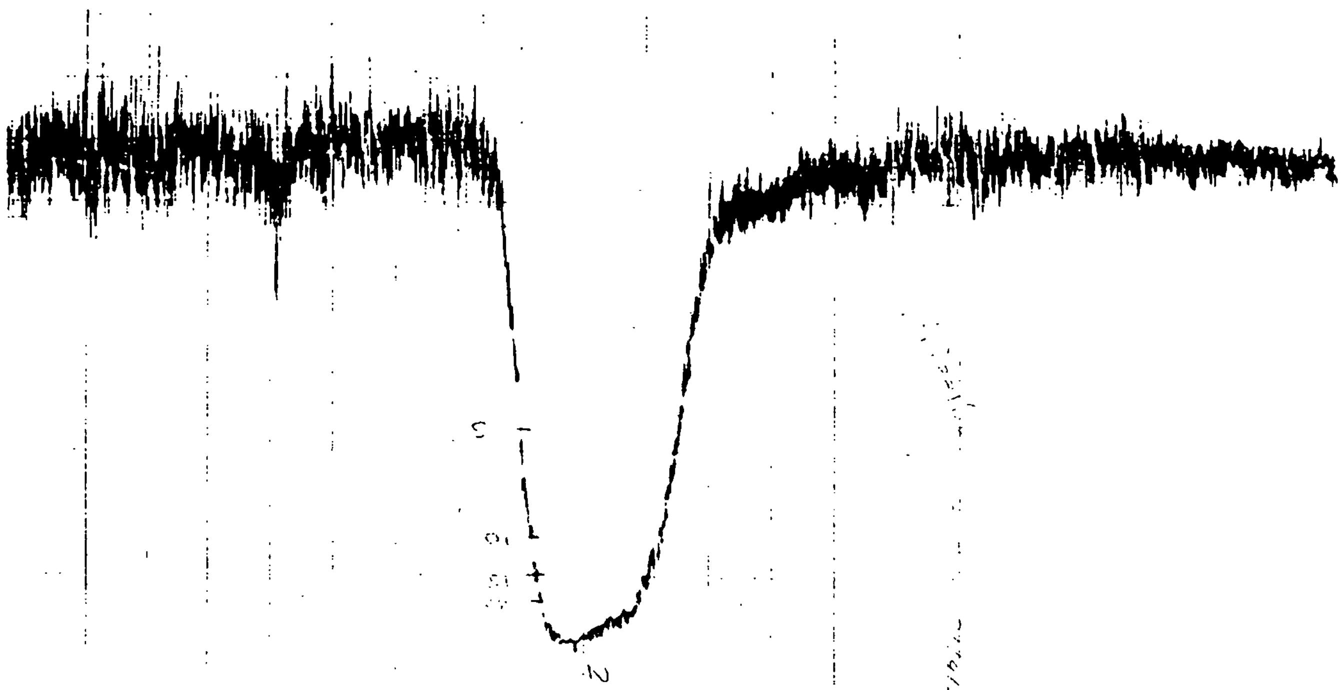
Attenuation Measurements:

- Fade statistics
- Frequency scaling of attenuation
- Fade duration
- Fade interval
- Fade slope

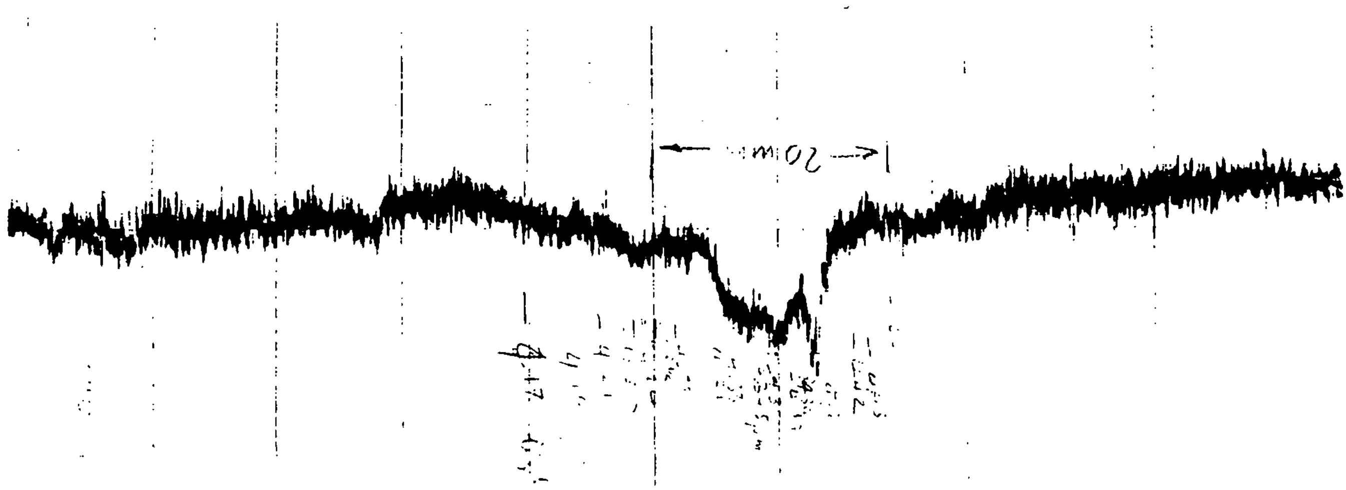
Radiometric Measurements

Small Scale Diversity

Uplink Power Control



a) A fade of more than 20 dB.



b) A subsequent fade of a few dB.

Figure 1. Beacon fades at 12.5 GHz for a rain event of April 21, 1990.

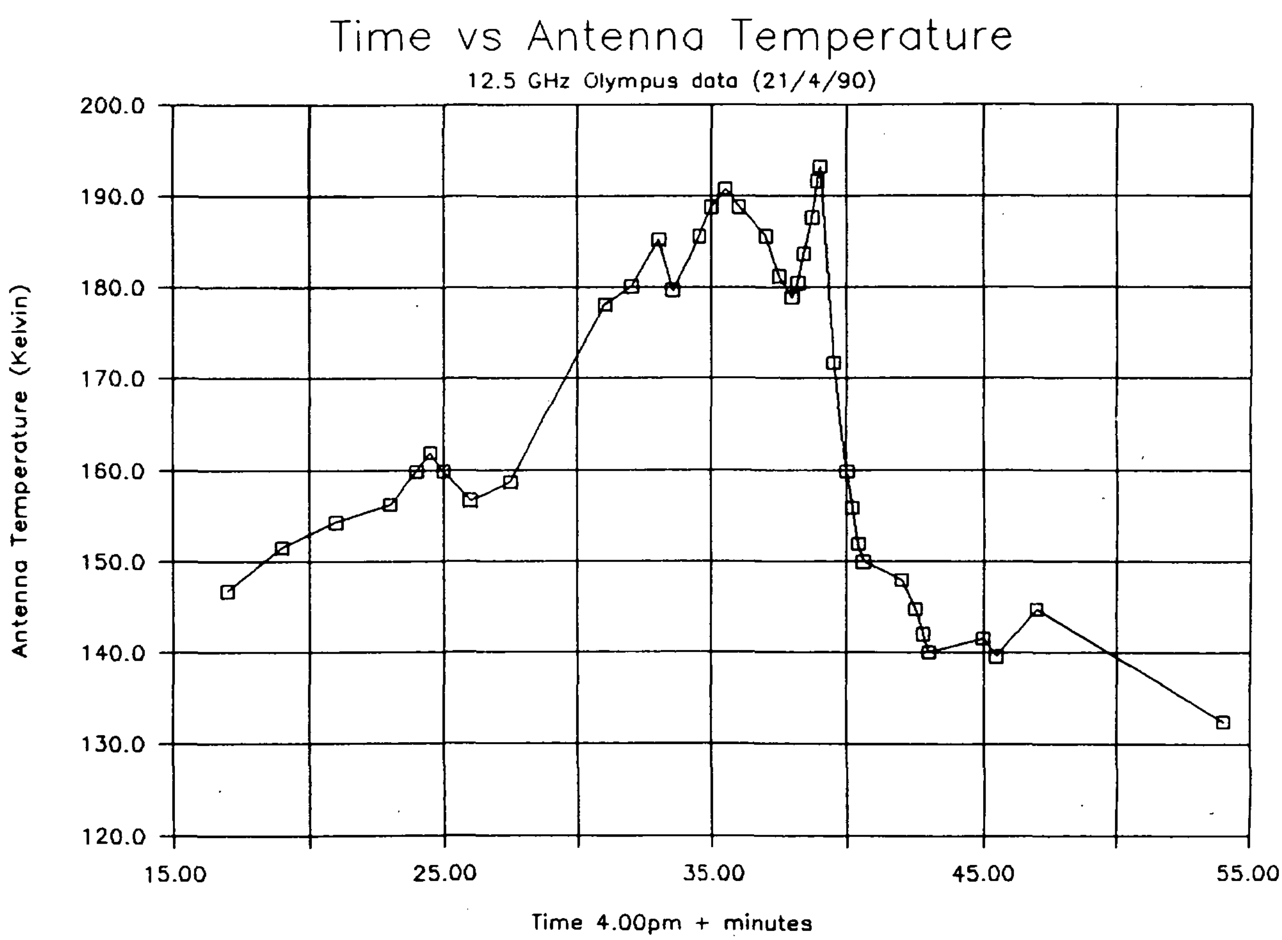


Figure 2. Radiometric temperature time history for the second event of Fig. 1.