COMMUNICATIONS AND PROPAGATION EXPERIMENTS FOR THE OLYMPUS AND ACTS SATELLITES

C.W. Bostian, W.L. Stutzman, T. Pratt, J.C. McKeeman, and T.S. Rappaport

Satellite Communications Group
Bradley Department of Electrical Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

ABSTRACT

The ESA satellite OLYMPUS and the NASA satellite ACTS both provide opportunities for 12, 20, and 30 GHz propagation and communications experiments. OLYMPUS is scheduled for launch in 1989 and ACTS in 1992. Measurements are particularly needed on short-term signal behavior and on real-time frequency scaling of attenuation to support uplink power control and adaptive FEC techniques. The VA Tech Satellite Communications Group is now assembling equipment and will conduct OLYMPUS experiments that will include attenuation and fade slope measurements, uplink power control modeling, rain scatter interference measurements, and small-scale site-diversity operation. These will serve as prototypes for later ACTS experiments.

1. Introduction

This paper describes a set of propagation and communications experiments that the Virginia Polytechnic Institute and State University (VA Tech) Bradley Department of Electrical Engineering's Satellite Communications Group will perform with the OLYMPUS and the Advanced Communications Technology (ACTS) spacecraft. OLYMPUS is a European Space Agency (ESA) satellite offering coherent (derived from a common master oscillator) beacons at nominal frequencies of 12, 20, and 30 GHz and 30/20 GHz transponders. It is scheduled for launch in 1989. ACTS is a NASA satellite which will be launched in 1992, carrying beacons at nominal frequencies of 20 and 30 GHz and advanced 30/20 GHz transponders.

OLYMPUS provides an opportunity to investigate techniques and verify equipment that will be important in the ACTS program before ACTS is launched. For example, OLYMPUS measurements will provide propagation information for the adaptive forward error correction (FEC) to be used with ACTS. Prototype ACTS-program equipment tested and optimized with OLYMPUS can be duplicated and distributed to measurement sites around the U.S. This will provide the sites with equipment and data collection techniques that have already been field tested and will avoid problems that arise when untested hardware and software fail to meet expectations. In addition, the availability of both OLYMPUS and ACTS provides the opportunity to share equipment and do two experiments for less than twice the cost of one.

We assume that the general capabilities of ACTS and OLYMPUS are known to the reader, and will not discuss them in great detail here. Tables 1 and 2 list the key features of their beacons that are important to our experiments. Please note that the EIRP values given are edge of CONUS coverage unless otherwise stated.

Table 1. ACTS Beacon Information

<table>
<thead>
<tr>
<th>Frequency</th>
<th>20.185 GHz</th>
<th>20.195 GHz</th>
<th>27.505 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0.177 W</td>
<td>0.177 W</td>
<td>0.079 W</td>
</tr>
<tr>
<td>EIRP</td>
<td>17.5 dBW</td>
<td>17.5 dBW</td>
<td>14.25 dBW</td>
</tr>
<tr>
<td>Modulation</td>
<td>yes*</td>
<td>yes*</td>
<td>none</td>
</tr>
<tr>
<td>Polarization</td>
<td>Vertical</td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td>Coverage</td>
<td>CONUS</td>
<td>CONUS</td>
<td>CONUS</td>
</tr>
</tbody>
</table>

* Both of the ACTS 20 GHz beacons are modulated with 32 kHz and 64 kHz subcarriers carrying PCM telemetry. These beacons are also used for spacecraft ranging. During ranging, there is a 19 kHz subcarrier on which tones are frequency modulated.

Table 2. OLYMPUS Beacon Information

<table>
<thead>
<tr>
<th>Frequency</th>
<th>12.501866 GHz</th>
<th>19.770393 GHz</th>
<th>29.655589 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>European EIRP</td>
<td>14 dBW</td>
<td>24 dBW</td>
<td>24 dBW</td>
</tr>
<tr>
<td>Blacksburg EIRP</td>
<td>10 dBW</td>
<td>16 dBW</td>
<td>16 dBW</td>
</tr>
<tr>
<td>Polarization</td>
<td>Y or X</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

For convenience, in the discussions which follow we will refer to the operating frequencies of the ACTS and OLYMPUS beacons as nominally 12, 20, or 30 GHz, as appropriate. The exact frequencies are those in Tables 1 and 2.

2. Information Needed from OLYMPUS and ACTS Experiments

Virtually all of the 20/30 GHz propagation data available from U.S. sites, and most of what is available for 14/11 GHz were collected at high elevation angles for the purpose of determining long-term (worst-month and annual) attenuation and depolarization statistics. Most of the experimental sites were in the Mid Atlantic region, Florida, or Texas. These data were not collected with a time resolution suitable for analyzing fade depths and durations. In addition, the earlier experiments were planned when satellite users expected the future to bring networks of large regional earth terminals carrying trunk voice traffic, not digital very small aperture terminals (VSATs). Stringent reliability requirements were anticipated; hence attenuation measurements emphasized small percentages of time and large fade margins, and diversity experiments used long baselines. Thus, there are a number of reasons why existing
propagation data cannot tell us much about the short-term signal phenomena that will be important to the satellite networks of the 1990's. For the successful design of future satellite systems, which are expected to place emphasis on VSATs (low-cost terminals) and sophisticated digital modulations, new propagation measurements must be made.

Our own informal survey of the satellite communications user community indicates a strong need in particular for measurements that will be useful for developing some kind of adaptive control to mitigate the effects of rain-induced fades on 20/30 GHz links. From the downlink signal behavior, a controlling earth station must determine whether to call for a power increase or a code rate increase at the end of a fade. These actions involve predicting short-term signal behavior as well as uplink and downlink frequencies. A related problem is the prediction of fade durations and interfade intervals. Satellite users and propagation researchers are also interested in fade statistics for a broad range of climate zones and in simultaneous measurements at multiple and higher frequencies. Another concern is potential rain scatter interference between VSAT users and satellites in 2 degree orbital spacings.

In summary, the objectives of our OLYMPUS and ACTS experiments are: (1) measure short term signal behavior, (2) investigate other ways for small terminals to provide acceptable fade margins, for example, through the use of small scale diversity, and (3) develop and test uplink power control techniques. We are also interested in assessing the level of rain scatter interference in VSATs. The following sections describe the experiments we plan to do with OLYMPUS and ACTS to achieve these objectives.

3. Planned Experiments

3.1 Attenuation Measurements.

We plan to measure general attenuation statistics, including fade duration distributions, at 12, 20, and 30 GHz with OLYMPUS and at 20 and 30 GHz with ACTS. As indicated above, in the past most 10 - 30 GHz propagation experiments were largely directed toward long-term signal behavior (i.e., annual statistics) and thus collected data at typically one-minute intervals. Our experiments are concerned with short-term effects, and we feel that to represent this with some margin of safety requires that we routinely measure received signal levels at 0.1 second intervals (10 Hz sample rate) with a provision for going to shorter intervals (faster sample rates) during selected fades. We are confident that the short-term behavior of attenuation will be sufficiently well described by these measurements for all practical applications.

3.2 Uplink Power Control

We intend to use our OLYMPUS attenuation measurements to develop a model and an algorithm for uplink power control. This will be pursued through off-line modeling and testing using sampled data taken at both 10 Hz and 100 Hz rates. This technology will then be directly applicable to developing uplink power control systems for ACTS.

As part of the development of a prototype controller, we will sample and record the complex (amplitude and phase) co-polarized signals from all three OLYMPUS beacons at a sufficiently high sample rate during a number of significant fading events. These data will provide realistic time histories of downlink and expected uplink signal behavior that will permit us to test uplink power control algorithms off-line. We will also provide these time histories to other ACTS experimenters so that they may test prototype ACTS power control and adaptive FEC systems on the ground. These tests will provide data on the effectiveness of uplink power control and the adaptive FEC systems used on ACTS several years before launch.

3.3 A Small Scale Diversity Experiment

There is meteorological evidence of fine scale structure in heavy rain. We believe that it may be possible to derive diversity gain from antenna spacings on the order of 50 m. If this is true, a 50 m antenna spacing would permit the use of diversity reception by one site with two antennas. Since two complete and widely separated sites are presently required to take advantage of diversity gain, this would result in a considerable savings in earth terminal construction.

We will use a second 20 GHz terminal for this experiment. The terminal will be mounted on a movable platform and moved to various locations on the VA Tech SATCOM Tracking Station premises. This will permit us to investigate different diversity spacings during the course of the experiment. This information should then characterize small scale diversity effectiveness as a function of antenna separation.

3.4 Rain Scatter Interference at 20 GHz

The possibility of an earth terminal illuminating the satellite in an adjacent orbital slot via scattering of the uplink signal by rain is a potential cause of interference. This probability of this happening would be enhanced by an earth station's increasing its uplink power to compensate for the attenuation due to the rain. The geometry of this problem is illustrated by Fig. 1(a). We plan to investigate this by placing a second 20 GHz antenna pointed 2 degrees off axis from the primary antenna. This inverted geometry is shown in Fig. 1(b). We will observe the common volume containing the rain using our 2.8 GHz multiple polarization radar. We then observe the output of the second receiver and can correlate any rise in detected output with the occurrence of rain in the path. This measurement should also permit the determination of the magnitude of the phenomenon.

4. Receivers

4.1 Introduction

One of our goals for this research program is to develop prototype receivers for ACTS and to test them with OLYMPUS. We intend for the ACTS receivers to use sophisticated digital signal processing (DSP) components and techniques.

We hope that the ACTS experiment will involve several measurement sites around the country. By utilizing digital techniques in our design we intend to develop a propagation receiver whose performance will be easily repeatable from unit to unit. This repeatability means a closer correlation of data between the different receivers. Such a receiver is also more easily configured in the event that a change of receiver characteristics is necessary at some later date. Digital receiver techniques are particularly important for meaningful propagation experiments with ACTS because the ACTS beacons are modulated with telemetry and the format of the modulation will change with time.

4.2 Local Oscillators and Intermediate Frequencies

A functional block diagram of the intermediate frequency (IF) and local oscillator (LO) system that we plan to use for OLYMPUS is shown in Fig. 2. This system locks to the 12 GHz beacon. In doing so it produces a 48.457 MHz signal which is coherent with and is an integer submultiple of each of the three OLYMPUS beacons. This is the same frequency multiplication strategy used in the satellite. Once produced, this base frequency of 48.457 MHz can be used to demodulate each of the beacons. The system features a final IF of 70 MHz for which off-the-shelf components are abundant. The entire system is referenced to a single 70 MHz crystal oscillator.
The LO system works by comparing the 70 MHz output of the 12 GHz receiver with the 70 MHz reference. The comparison provides an error voltage which is used to adjust the frequency and the phase of the 48.457 MHz oscillator. The synchronization loop is completed when the 48.457 MHz signal is multiplied up to serve as the LO for the 12 GHz receiver. The 48.457 MHz signal is also multiplied up to provide the LO for the 20 and 30 GHz receivers. Each LO signal experiences the same multiplications as used in the satellite so that each LO signal has the same relative phase as that transmitted by the satellite.

4.3 Analog Receivers for OLYMPUS

The receivers to be used for OLYMPUS are double-conversion superheterodyne receivers. Each of the three receivers uses a common IF scheme. The first IF is 1120 MHz and the second IF is 70 MHz. The first IF was chosen to conform to the special needs of the planned coherent detection scheme. 1120 MHz is also close enough to commonly used radar and communications IF frequencies to make components readily available. The entire system is referenced to a single crystal oscillator to achieve the required coherence. Figure 3 is a block diagram of the RF and IF portions of the receiver.

4.4 Anticipated Link Performance

The coherence of the OLYMPUS beacons and the technique of phase locking the 20 GHz and 30 GHz receivers to the 12 GHz beacon will permit fade depths to be measured on these channels down to the C/No level. This results in a rain fade margin of approximately 45 dB. Since the 12 GHz beacon is less susceptible to fading, lock will not be lost during severe fade events at 20 GHz and 30 GHz. This also eliminates the reacquisition problem of conventional receivers (i.e., the inability to reacquire the carrier at the same fade depth as when lock was lost). The antennas used by this terminal will be a 12 foot prime focus reflector at 12 GHz and 4 foot prime focus reflectors at 20 and 30 GHz.

The link budgets for the three beacons are shown in Table 3. These calculations assume:

System lock on the 12 GHz beacon
A 12 ft. dish for 12 GHz reception
4 ft. dishes for 20 GHz and 30 GHz reception
Antenna temperature 290 K as for deep fade condition
Antenna gain calculated with an efficiency factor of .65
LNA and mixer noise temperature of 440K for 12 GHz
Mixer noise temperature of 1540K for 20/30 GHz

Table 4 shows link budgets for a system where the receivers are independent (as will be the situation with ACTS). That is, they lock independently to their respective carriers. The link budget for the 12 GHz beacon is the same as Table 2 and is not repeated. Therefore Table 4 shows the link budgets for only the 20 GHz and 30 GHz receivers. Comparison of the two tables shows that coherently locking the receiver LO achieves 30 dB more dynamic range for the 20 GHz and 30 GHz systems.

5. Data Acquisition and Processing

A versatile, multichannel data acquisition system (DAS) is a requirement for radio wave propagation research. At the heart of this system must be a robust computing system capable of receiving and processing data from digital and analog receivers and from environmental instruments, while maintaining internal housekeeping functions. Further, to maintain accuracy this system must continuously sample all data inputs many times each second, store weeks of data, and operate unattended. Since the thrust of this research is measuring the effects of rain on propagation, lightning strikes pose additional hazards for computer systems, and the data acquisition system must be capable of autonomous recovery in the likely event of power interruption.

VA Tech is developing a DAS suitable for monitoring and processing the OLYMPUS and ACTS propagation measurements. The propagation data will be acquired from digital and analog receivers attached to each of the 12, 20, and 30 GHz antennas. Environmental data will be simultaneously logged from rain, wind and temperature gauges, and alarms from sensors within the DAS enclosure. The assortment of data types as well as their varying accuracy and timing requirements demand a highly flexible data acquisition system for OLYMPUS and ACTS. Past experience indicates that a sufficient sampling rate for the receiver data is 10 Hz, while rain rate, wind speed and temperature sensors can be sampled at a much slower rate. Sensor alarms from the enclosure are treated as interrupts, and all analog and digital data lines will be optically isolated between the collection computer system and the receivers. To protect against power outages, surges and brownouts, all components of the DAS will be powered by uninterruptable power supplies.

Other features required by our OLYMPUS/ACTS DAS include data display, data formatting, system self test, and remote system operation. Received data must be displayed as well as stored in real time at each collection site and the data must follow a standard format. The display system used in our DAS is icon driven and designed for maximum operator friendliness. The data will be stored in a format easily accessible by a standard database query language (SQL). Additionally, a program will be available to convert data files into an ESA defined data file for maximum transportability and exchange with other OLYMPUS experimenters. A significant feature of our DAS is a periodic self test and recalibration capability. The DAS will have the capability to switch the receiver between

Table 3. OLYMPUS LINK BUDGET w/ COHERENT LO

<table>
<thead>
<tr>
<th>Satellite EIRP</th>
<th>12.5 GHz</th>
<th>20 GHz</th>
<th>30 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>dBW</td>
<td>10.0</td>
<td>16.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Table 4. OLYMPUS LINK BUDGET w/o COHERENT LO

<table>
<thead>
<tr>
<th>Satellite EIRP</th>
<th>20 GHz</th>
<th>30 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>dBW</td>
<td>16.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path Loss</th>
<th>210.5</th>
<th>214.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/No</td>
<td>44.8</td>
<td>44.8</td>
</tr>
<tr>
<td>C/N (100 Hz)</td>
<td>44.8</td>
<td>44.8</td>
</tr>
<tr>
<td>Fade Margin</td>
<td>44.8</td>
<td>44.8</td>
</tr>
</tbody>
</table>

52.2.3.
generated test inputs and data inputs to allow system wide automatic diagnostics to be completed. The output from this test will allow the DAS to maintain accurate data files and keep latent data fault to a minimum. Finally, remote system operation will comprise remote testing of a DAS site from the VA Tech host site, remote data collection and remote set up and control.

6. Acknowledgments

The authors wish to acknowledge the contributions of their colleague Robert Porter and their graduate students Kenneth Baker, Sandra Fitzhugh, Fatim Haidara, George Ruhlmann, and Dennis Sweeney to this paper and to the OLYMPUS and ACTS experiments. Cynthia Marshall and Ken Baker assisted with the preparation of this manuscript.

The work described in this paper was sponsored by NASA and JPL under JPL Contract 956512.