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ACTS and OLYMPUS Propagation Experiments

Charles W. Bostian
Kenneth R. Baker

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

Abstract - The OLYMPUS and ACTS satellites both provide opportunities for 10-30 GHz propagation measurements. The spacecraft are sufficiently alike that OLYMPUS can be used to test some prototype ACTS equipment and experiments. Data are particularly needed on short term signal behavior and in support of uplink power control and adaptive FEC techniques. The VA Tech Satellite Communications Group has proposed a set of OLYMPUS experiments including attenuation and fade rate measurements, data communications, uplink power control, rain scatter interference, and small-scale site diversity operation. We are also developing a digital signal processing receiver for the OLYMPUS and ACTS beacon signals.

1. Introduction

This paper describes a set of experiments that our group has proposed for OLYMPUS and ACTS. The spacecraft are similar in that both both support communications and propagation research in the 10-30 GHz band. In describing our proposed experiments we invite comments from the NAPEX community and hope to interest other groups in similar studies.

OLYMPUS provides an opportunity to test techniques and equipment that will be important in the ACTS program before ACTS is launched. For example, OLYMPUS measurements will provide propagation information needed by the ACTS adaptive FEC system. Prototype ACTS-program equipment debugged with OLYMPUS can be duplicated and distributed to measurement sites around the U.S. Planning experiments with both satellites insures against launch delays on either one.

2. The Satellites

2.1 OLYMPUS

OLYMPUS is an ESA satellite offering coherent beacons at nominal frequencies of 12, 20, and 30 GHz and 30/20 GHz transponders. After a January 1989 launch it will be located at 19 deg. W, and we will see it at 14 deg. elevation. This relatively low angle will create interesting propagation effects without being unrepresentative of commercial links.

The propagation package includes beacons at 12.5 GHz (12501.866 MHz), 20 GHz (19770.393 MHz) and 30 GHz (29655.589 MHz) derived from a common oscillator. See Fig. 1. Experimenters may lock all receivers to the 12.5 GHz beacon and extend their 20 and 30 GHz dynamic range.

The 12.5 GHz earth coverage beacon will provide a +6 dBW EIRP toward our site with Y polarization (normal to the equator). The 20 and 30 GHz European coverage beacons will radiate +16 dBW toward Blacksburg. The 30 GHz beacon will transmit Y polarization and the 20 GHz beacon may be switched between X or Y polarization at 1866 Hz. ESA plans to operate the spacecraft predominantly in the switched mode for cross polarization discrimination (XPD) measurements. The U.S. is too far from boresight for reliable XPD measurements.

2.2 ACTS

ACTS is a NASA satellite intended to develop and prove advanced 30/20 GHz communications technology and to offer an opportunity for propagation experiments. It will provide a 30/20 GHz communication package to test hardware and operating procedures for a TDMA (time division multiple access)/DAMA(demand access multiple access) system for commercial satellites. Its adaptive FEC will make ACTS the first satellite to compensate for propagation effects in real time.

The ACTS beacon package consists of two beacons at 20 GHz which also transmit telemetry information and a 30 GHz CW beacon which will be useful for detecting uplink fades. The 20 GHz beacons are not optimum for propagation work because of their modulation. In addition, since the ACTS beacons are not derived from a common source, they offer less fade margin than OLYMPUS. The ACTS beacons have much better polarization purity than OLYMPUS for U.S. sites; ACTS is suitable for depolarization measurements.

3. Proposed VA Tech Experiments for OLYMPUS and ACTS

3.1 Background: Why Experiments are Needed

The reader may legitimately ask "After ATS-5, ATS-6, CTS, COMSTAR, and SIRIO, what could we still need to know about 30/20 GHz propagation ? If there is something, why can't we get it from further analysis of the old data ?" There are several reasons why more work is needed.

Virtually all of the 20/30 GHz and most of the 14/11 GHz propagation data available from U.S. sites were collected at high angles to determine worst-month and annual attenuation and depolarization statistics. They were not recorded with a time resolution suitable for analyzing fade rates and durations. While valuable for their intended purposes, these data cannot tell us much about short-term signal phenomena that are important to digital links or about real-time attenuation scaling for uplink power control or adaptive FEC. This is reflected in Science Review of the NASA Radio Propagation Program, Science and Technology Corporation Report STC-2127, February 1987, where a 1986 NASA review panel makes a cogent case for further work in 10-30 GHz propagation, emphasizing studies of fade rates and fade durations and such intersystem questions as rain scatter interference.

In a further attempt to assess the need for additional 20/30 GHz propagation, our group surveyed 19 people representing both satellite users and propagation researchers. Their replies indicated three important needs:

(a) Data that would be useful for developing some kind of adaptive control to mitigate the effects of rain fades on 20/30 GHz satellite links.

(b) Fade statistics for a broad range of climates.

(c) Simultaneous multiple and higher frequency measurements.

In summary, we feel that the greatest operational need is for short-term fade prediction for uplink power control and adaptive FEC. These processes both involve short-term prediction of signal behavior at one frequency and scaling this prediction to a (higher) uplink frequency.

3.2 Proposed VA Tech Experiments

Fig. 2 illustrates our proposed experiments. These are described in the sections which follow.

3.2.1 Basic OLYMPUS Propagation Measurements

We will construct a receive-only terminal to collect 12, 20, and 30 GHz attenuation data with OLYMPUS and a build prototype data acquisition system for use with both OLYMPUS and ACTS. We intend to measure fade duration with a time resolution of 100 ms. Data on short-term OLYMPUS signal behavior will fill gaps in the current understanding of 10-30 GHz propagation and support the ACTS communications experiments.

3.2.2 The OLYMPUS CODE Experiment.

CODE, an acronym for COoperative Data Exchange, refers to a system that provides high speed data (up to 2 Mbps) into a remote earth station and low speed data (9.6 kbps)out to a hub station. The CODE system requires only 150 mW of transmitter power into a 0.9 m antenna at 29 GHz. We propose to build a CODE terminal to communicate with the European experimenters and to use it to operate a "live" uplink power control experiment with OLYMPUS. Our system will obtain an extra 8 dB of margin by using a 600 mW transmitter and a 1.2 m antenna.

3.2.3 Uplink Power Control Experiment.

We propose to develop hardware and software for a simulated uplink power controller. This device will make real time predictions of 30 GHz fading from 12 GHz and/or 20 GHz fade measurements. This unit, a self contained and independent addition to the OLYMPUS experiment, will operate under microprocessor control. This will allow immediate testing and optimization of uplink power control algorithms.

A 29 GHz waveguide attenuator, fitted with a stepper motor and controlled by a microprocessor, will be our uplink power control device. This should provide about 7 dB of control range, which is as large as most systems can handle. The algorithms developed from the propagation experiment will be used in the microprocessor during CODE experiment transmissions, and the bit error rate (BER) of the link will be monitored.

The availability of the OLYMPUS 20 and 30 GHz steerable spot beams provides a unique opportunity to test the ACTS baseband processor under operational conditions. We propose to use a double-hop configuration and our CODE equipment to transmit data through OLYMPUS to a receiving earth station connected to an ACTS baseband processor. The earth station will format the received CODE data into a TDM frame compatible with ACTS, send them through the baseband processor, and reformat the data back to a CODE format and retransmit them back through OLYMPUS. The general configuration for this experiment is shown in Figs.3 and 4.

The ACTS TDMA system is designed around data frames with 64 bit bursts at 110 Mbps. A data reformat operation will be required before data can be passed to the ACTS processor. Additional words can be added to the TDM frame to indicate the measured BER on the uplink and to provide a new sequence for downlink BER measurement. Control signals for the uplink power control, uplink FEC, and downlink FEC also need to be added into the data frame. The transmission from our earth station will be at the CODE 9.6 kbps rate. We propose to use a BER test set to generate a pseudo-random bit sequence so that the uplink BER can be measured by the receiving earth station. We understand that the Canadians plan a similar experiment using a double hop through a laboratory baseband processor.

3.2.4 Rain-Scatter Interference at 30 GHz

This experiment and the small-scale diversity experiment which follows are semi-independent measurements that will fill gaps in current knowledge of 10-30 GHz propagation as identified by the NASA Review Panel. Tests with OLYMPUS will determine whether these should be replicated on a large scale with ACTS.

A potential interference problem exists if an earth terminal illuminates a satellite in an adjacent orbital slot via rain scattering of the uplink signal. The probability of this happening increases if the earth station increases its uplink power to compensate for the attenuation due to the rain. The geometry of this problem is illustrated by Fig. 5(a). We propose to investigate this by placing a second 30 GHz antenna pointed 2 degrees off axis from the primary antenna. This inverted geometry is shown in Fig. 5(b). We will observe the common volume containing the rain using our 2.8 GHz multiple polarization radar and simultaneously measure power scattered into the second antenna.

3.2.5 A Small-Scale Diversity Experiment

There is some evidence for 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. Such antenna spacings would permit 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 costs.

We propose to test this hypothesis at 20 GHz by simply erecting a second receiving antenna approximately 50 m away from the primary receiving antenna. By comparing the fading characteristics of the two receivers, it should be possible to evaluate the quality and quantity of diversity gain such a system would enjoy.

3.2.6 ACTS Propagation Experiments

The results of the experiments described above will determine which OLYMPUS propagation measurements should be continued with ACTS. We anticipate that those which are continued will be replicated at a number of sites.

For a widespread propagation experiment like that envisioned for ACTS to be meaningful, the receivers and data collection systems at each site should be made as alike as is possible, and the data from the various sites should be processed in exactly the same way using the same software and the same data format. For these reasons we have proposed to develop prototype receivers and data acquisition systems for distribution to participating ACTS sites.Digital receivers in particular should offer consistent performance and immunity to thermal effects.

4. Summary of Work Accomplished in Support of Proposed Experiments

4.1 Introduction

During the current fiscal year our group was asked by JPL to look at the fade rate question as it affects the ACTS program and to design a prototype receiver for OLYMPUS and ACTS. In the sections that follow, we will report briefly on these two activities.

4.2 Fade Rates

The question of how fast a 10 - 30 GHz signal can fade during rain has had a long and somewhat checkered history. Measurements reported in the literature differ significantly. These differences seem to be related both to the bandwidth and the dynamic characteristics of the measuring equipment and to the sampling rate, filter characteristics, and other details of the data acquisition and processing systems. One group argues on theoretical grounds that measured fade rates will always be limited by the dynamic response of the receiver, while older work on terrestrial paths indicates that the maximum fade rate is determined by how fast falling rain can fill the radio path. Since fade rate is very important to uplink power control and adaptive FEC systems, we have been investigating both its theoretical and experimental aspects with the idea of making definitive fade rate measurements on the OLYMPUS beacons. Our effort has included collecting and trying to rationalize all of the published literature on the subject.

Dennis Sweeney of our group has completed a preliminary evaluation of Ruthroff's (Ruthroff, 1970) expression for fade rate on a terrestrial link. To do this he used a hypothetical path 1.5 km long and modeled the rain as a step function of equal sized drops all falling at the same velocity. By step function we mean that the leading edge of the falling rain can be represented as a plane surface with rain above the plane and no rain below it. He evaluated the integral over the first Fresnel zone which represents the fade rate for frequencies of 30, 20, 15, and 10 GHz and rain rates of 10, 50 and 100 mm/hr. The following table is a sample of the results for 30 GHz.

Table 1. Predicted fade rates for a 1.5 km 30 GHz terrestrial path for step functions of rain at the rain rates shown.

Percent of volume intersected by rain	Fade rates in dB/s for step rate of		
	10 mm/hr	50 mm/hr	100 mm/hr
10%	0.146	0.730	1.461
30	0.622	3.110	6.219
50	0.934	4.670	9.340
70	0.622	3.109	6.219
90	0.146	0.730	1.460

The analysis produces a fade rate which is directly proportional to rain rate and symmetrical with respect to the center of the volume. This happens because after the rain reaches the center of the volume represented by the first Fresnel zone, rain is falling out of the volume as well as falling into it. When the volume is completely full of rain an equal amount falls out of the volume as falls into it and the net fade rate becomes zero.

While the values tabulated above seem reasonable, we have not yet been able to check them against the static attenuation values predicted by the aR^b relation for specific attenuation with coefficients published by Olsen, Rogers, and Hodge (1978).

4.3 Plans for ACTS and OLYMPUS Receivers

The section describes the fundamental OLYMPUS/ACTS receiver for propagation measurements. It will initially be configured to receive the OLYMPUS beacons; later it will become the heart of our ACTS receiver.

As Fig. 6 indicates, we plan a double conversion design with an 1120 MHz first IF and a 70 MHz second IF. The first frequency was chosen to facilitate coherent detection. The output of the second IF will feed either a quadrature detector or a digital signal processing (DSP) detector described below. The entire system is referenced to a single 70 MHz crystal. We plan to include an automatic calibration system and to achieve an overall measurement of plus or minus 0.1 dB.

Since the OLYMPUS beacons are coherent, the receivers will be linked by a common LO system that locks the 20 GHz and 30 GHz receivers to the 12 GHz beacon under normal operating conditions. The receivers may be switched to independent operation if a beacon fails or to permit testing of the digital detector to be developed for ACTS. During ACTS operation, all beacon receivers will operate independently.

By taking advantage of the coherent OLYMPUS beacons we will be able to measure 20 and 30 GHz fades down to the noise floor, providing a dynamic range of approximately 45 dB. Since the 12 GHz beacon is less susceptible to fading, the 20 and 30 GHz receivers will not lose lock during severe fades at those frequencies. This will lessen the inherent problem of most phase locked receivers -i.e. the inability to reacquire the carrier at the same fade depth as when lock was lost.

The link budgets for the three beacons are shown in Table 2. These calculations assume:

- system lock on the 12 GHz beacon
- 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 conditions
- antenna aperture efficiency factor of .65
- LNA and mixer noise temperature of 440K for 12 GHz
- LNA and mixer noise temperature of 1540K for 20/30 GHz

Table 2. OLYMPUS Link Budget for Coherent Receiver

Quantity	Units	12.5 GHz	20 GHz	30 GHz
satellite EIRP	dBW	6	16	16
free space loss	dB	206.5	210.5	214.0
atmos. loss	dB	.2	.95	.78
other losses	dB	1	2	2
antenna gain	dB	51.7	46.2	49.6
receiver NF	dB	4	8	8
system noise temp	dBK	28.6	32.6	32.6
G/T	dB/K	23.1	13.6	17.0
C/No	dBHz	50.0	44.8	44.8
C/N in 10 Hz BW	dB	30.0	-	-
C/N @ PLL thresh.	dB	10.0	-	-
Fade margin	dB	20.0	43.7	44.8

Note that the fade margin calculated for the 20 GHz and 30 GHz beacon is derived from the fade margin of the 12 GHz beacon. This was done by frequency scaling the 12 GHz fade margin to 20 GHz and to 30 GHz using the CCIR formula.

Table 3 shows link budgets for a system where the receivers are independent. That is, they lock individually to their respective carriers. The link budget for the 12 GHz beacon is the same as Table 1 and is not repeated here. Therefore Table 2 shows the link budgets for only the 20 GHz and 30 GHz receivers. Comparison of the two tables shows that phase locking the receivers achieves potentially 30 dB more dynamic range for the 20 GHz and 30 GHz systems.

Table 3. OLYMPUS Link Budget for Non-coherent Receiver

Quantity	Units	20 GHz	30 GHz
satellite EIRP	dBW	16	16
free space loss	dB	210.5	214.0
atmos. loss	dB	.95	.78
other losses	dB	2	2
antenna gain	dB	46.2	49.6
receiver NF	dB	8	8
system noise temp	dBK	32.6	32.6
G/T	dB/K	13.6	17.0
C/No	dBHz	44.8	44.8
C/N in 10 Hz BW	dB	24.8	24.8
C/N @ PLL thresh.	dB	10.0	10.0
Fade margin	dB	14.8	14.8

Figure 7 shows this receiver reconfigured for ACTS. The 20 and 30 GHz receivers individually acquire the incoming signals. The overall receiver design is not as complex as the coherent OLYMPUS receiver, but many major components are the same. Since the ACTS 20 GHz beacon is modulated, the receiver must be able to measure signal strength in the presence of this modulation.

Fig. 8 presents a block diagram of our ACTS digital signal processing (DSP) detector. Designed around one of the new DSP chips, the detector will feature (1) the ability to find and lock to the carrier rather than a sideband and (2) the ability to measure signal power in the presence of modulation. It works by downconverting the incoming 70 MHz IF signal to 67.5 kHz. The signal is then bandlimited to 135 kHz and sampled at 300 kHz and fed to the DSP portion of the receiver, here shown simply as a block. Using digital filtering and spectral estimation techniques the DSP block determines the carrier frequency, the type and depth of modulation, and the received power.

All of the various operations will be under the control of a microprocessor. As the signal drifts, it will be tracked by tuning the direct digital synthesis (DDS) LO used in the initial down conversion. The processor will also control the serial and parallel output ports. The first will deliver measurement data while the second will control the receiver and pass status information.

5. References

Olsen, R.L., D.V. Rogers, and D.B. Hodge, "The aR^b Relation in the Calculation of Rain Attenuation," IEEE Trans. AP-S, Vol. AP-26, pp. 318-329, March 1978.

Ruthroff, C.L., "Rain Attenuation and Radio Path Design," BSTJ, Vol. 49, pp. 121-135, January 1970.

6. Acknowledgments

This paper summarizes the ideas and work of many members of the VA Tech Satellite Communications Group who have worked on plans for ACTS and OLYMPUS experiments. In particular we would like to acknowledge the contributions of Warren Stutzman (propagation measurements), Tim Pratt (uplink power control and the CODE Experiment), John McKeeman (data collection), Robert Porter (data collection and processing), Dennis Sweeney (fade rates, receiver design), and Sandra Fitzhugh (receiver design). Cynthia Marshall prepared the manuscript for printing. Richard Campbell of Michigan Tech has served as a consultant on receiver design.

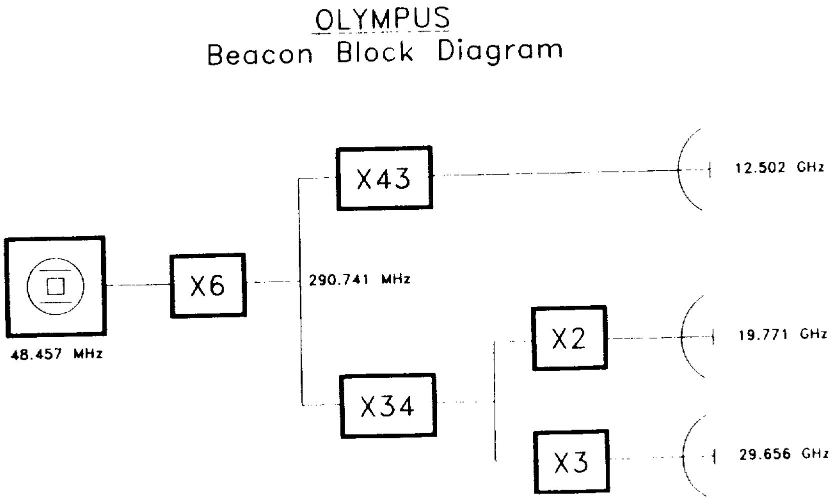


Figure 1. Derivation of the OLYMPUS beacon frequencies.

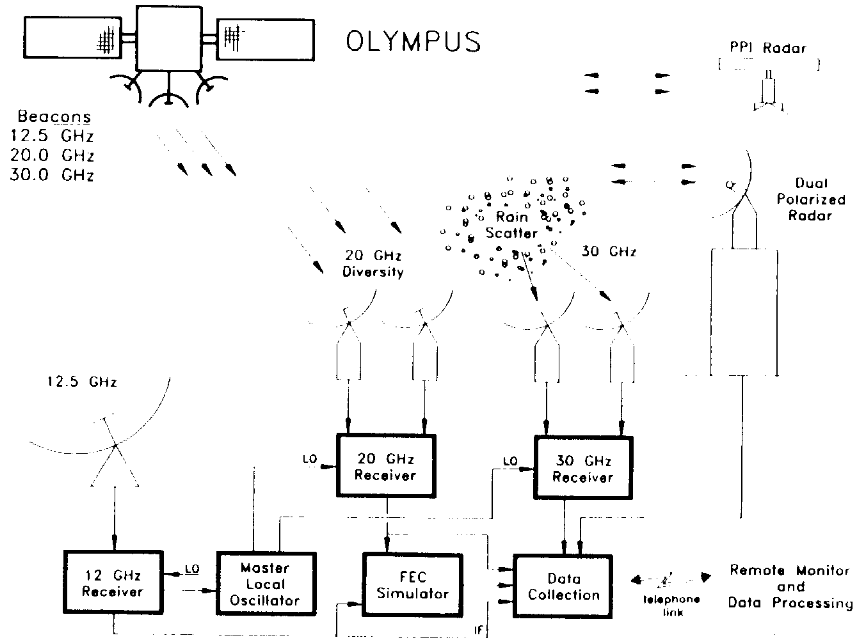


Figure 2. Schematic picture of the proposed experiments.

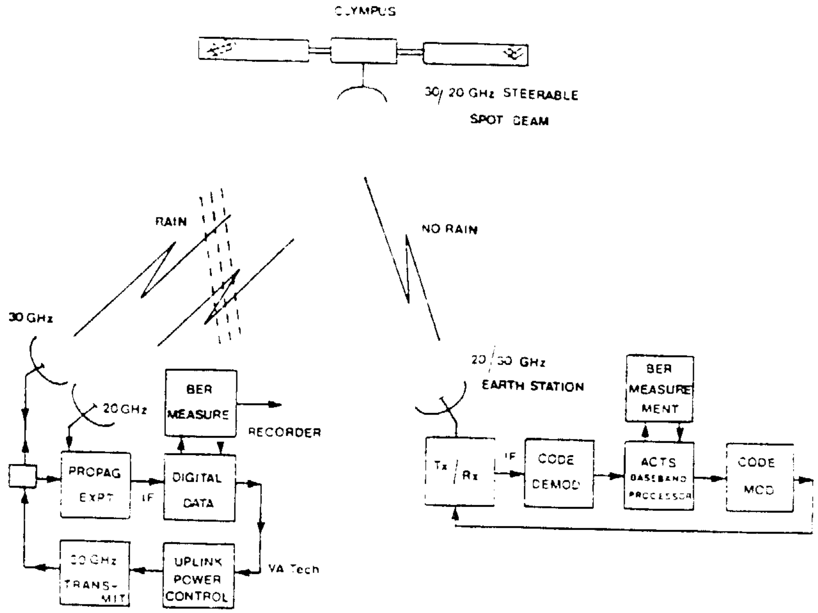


Figure 3. Uplink power control experiment using OLYMPUS.

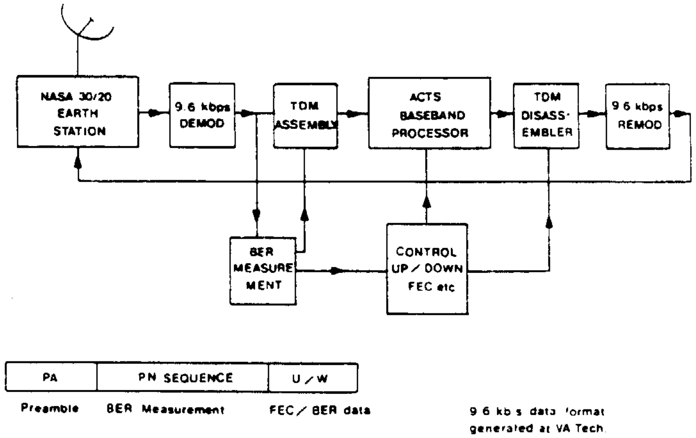


Figure 4. Data formatting in the uplink power control experiment.

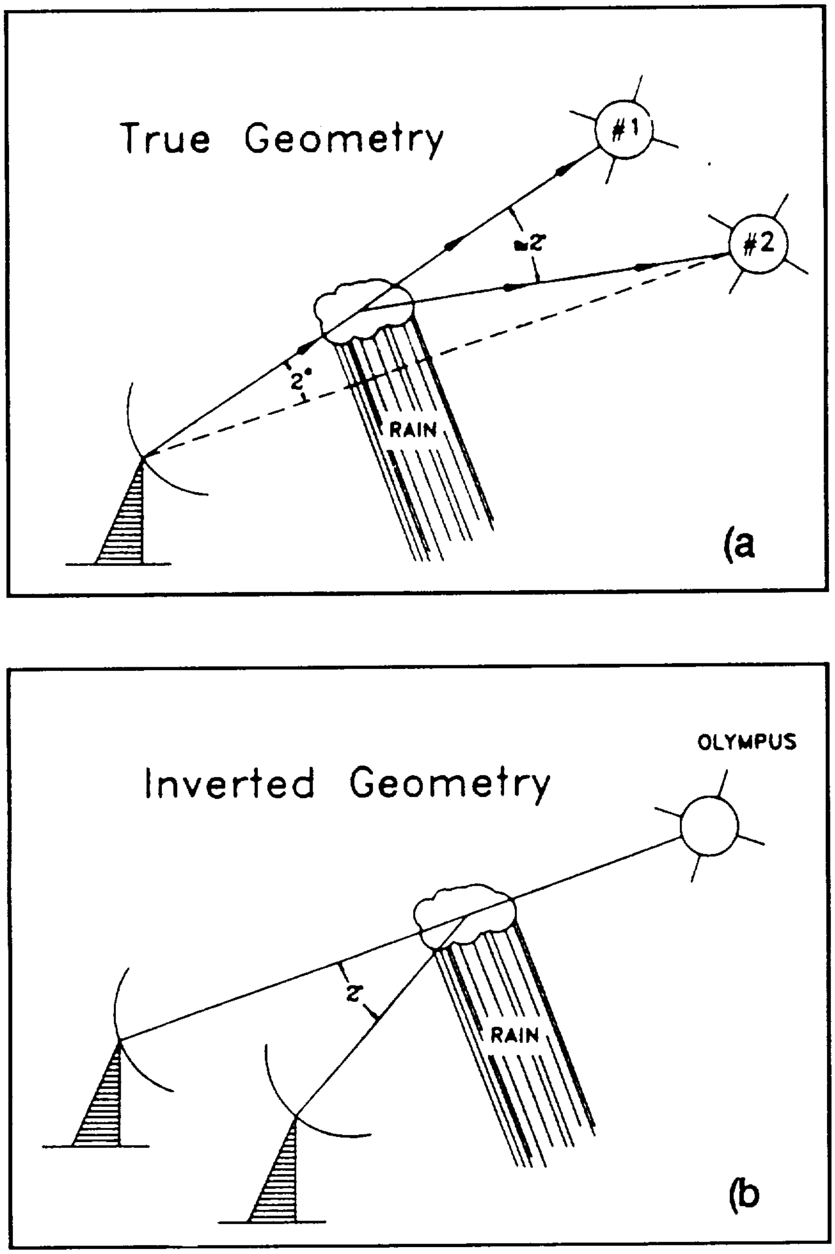


Figure 5. Rain scatter experiment.

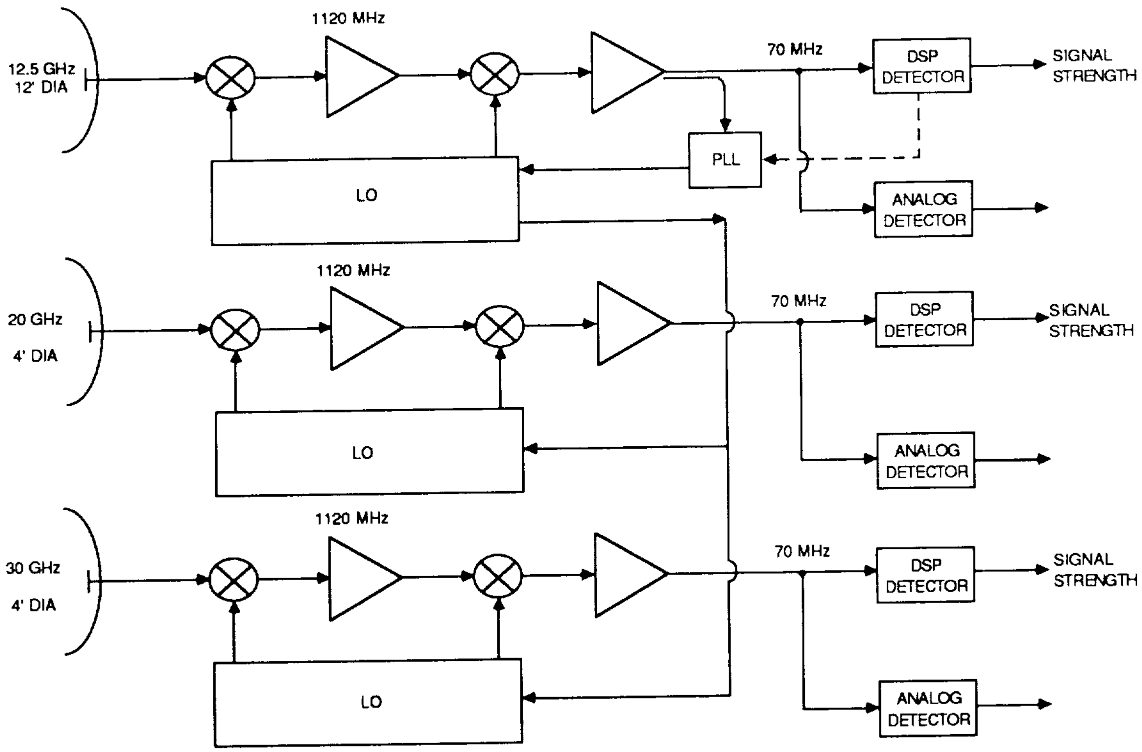


Figure 6. Overview of the OLYMPUS receiver.

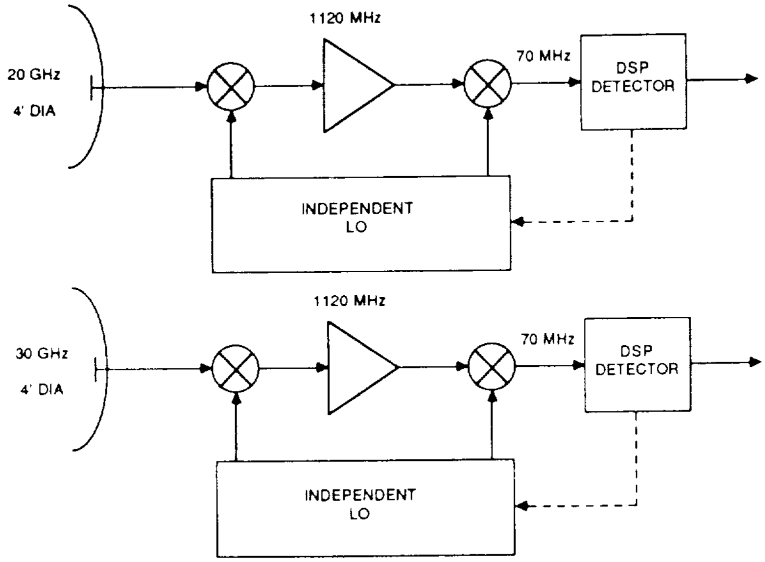


Figure 7. The ACTS receiver.

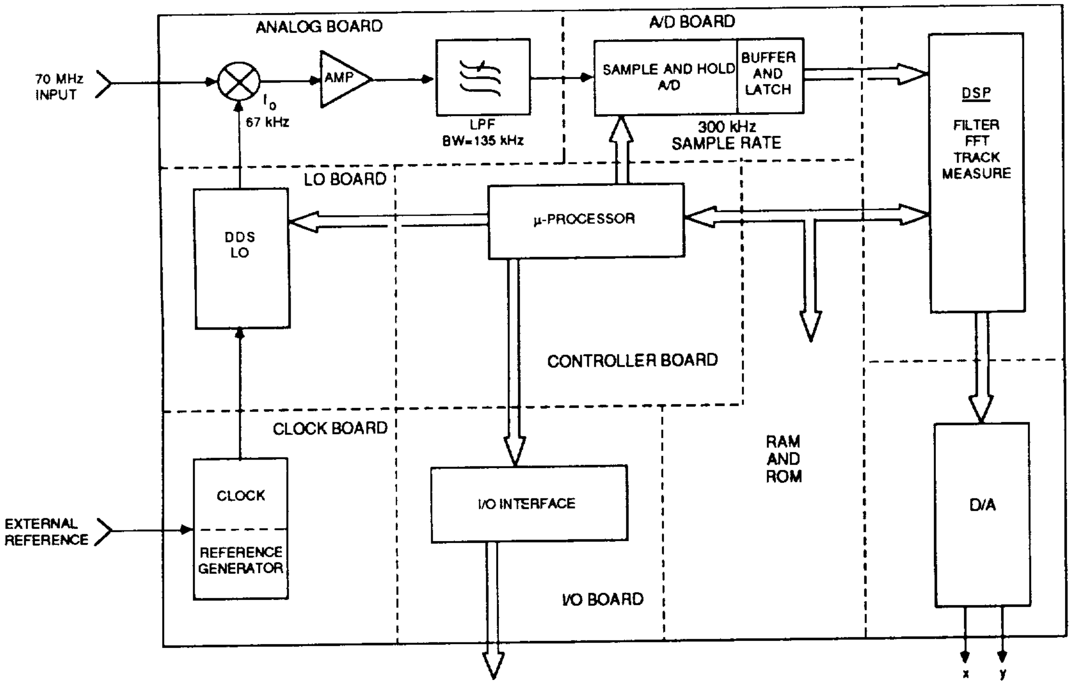
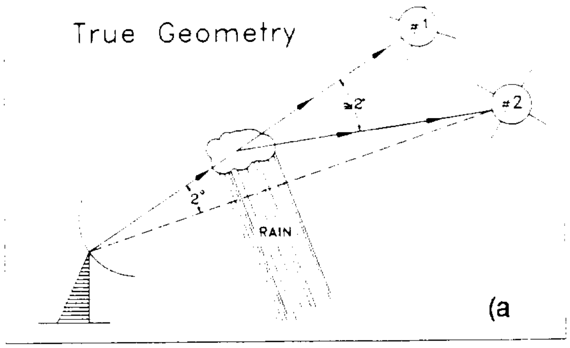


Figure 8. The ACTS digital signal processing (DSP) detector.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#1
#2
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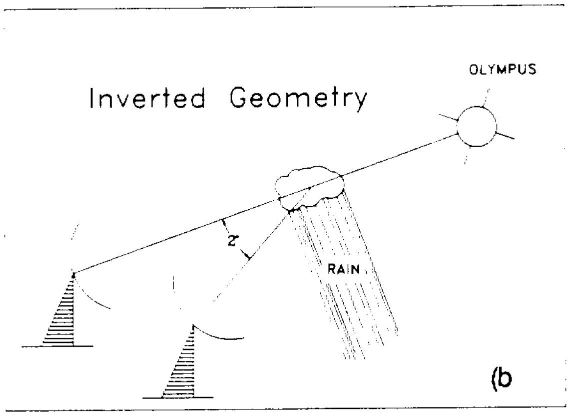
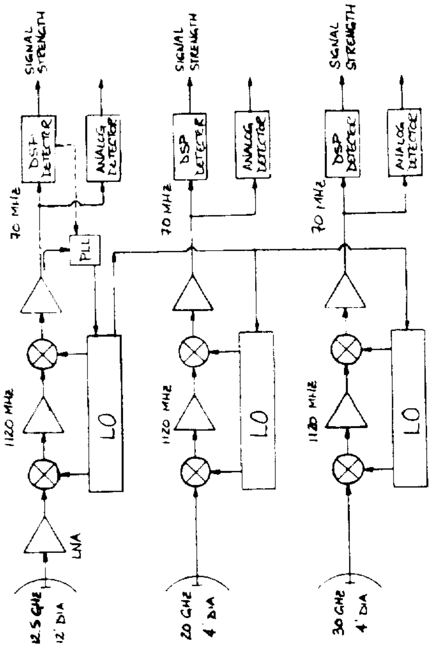
RAIN
(a


Inverted Geometry
OLYMPUS
2°
RAIN
(b


12.5 GHz
12' DIA
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ANALOG DETECTOR
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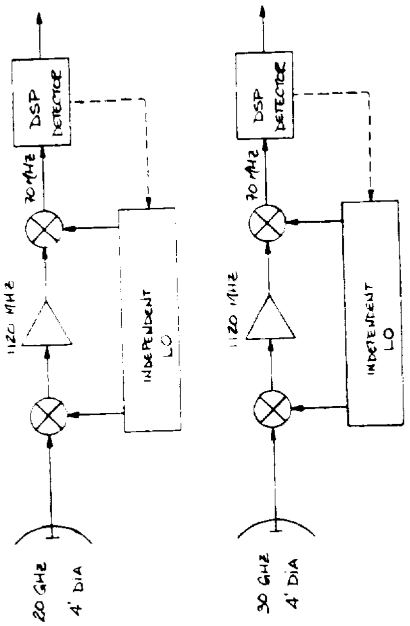
30 GHz
4' DIA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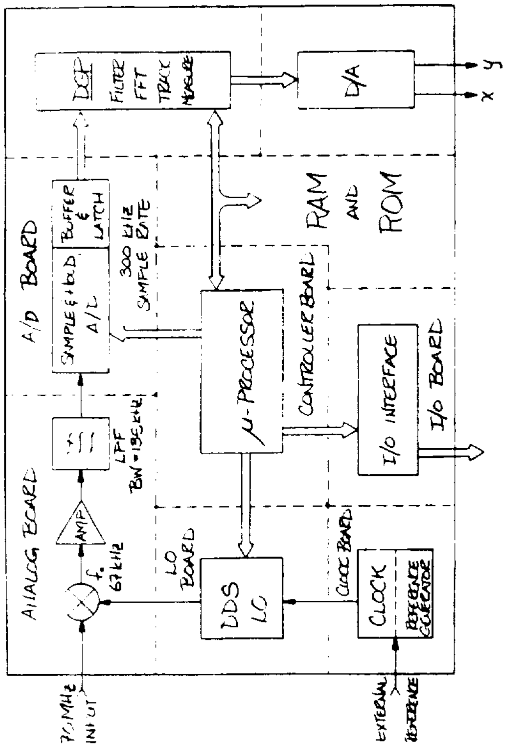
4' DIA
1120 MHz
70 MHz
DSP DETECTOR
INDEPENDENT LO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f₀ 67 kHz
AMP
LPF BW = 135 kHz
A/D BOARD
SAMPLE & HOLD A/D
BUFFER & LATCH
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D/A
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RAM AND ROM
μ-PROCESSOR
CONTROLLER BOARD
I/O INTERFACE
I/O BOARD
LO BOARD
DDS LO
CLOCK BOARD
CLOCK
REFERENCE GENERATOR
EXTERNAL REFERENCE