N91-11961

# EXPERIMENTS FOR KA-BAND MOBILE APPLICATIONS — THE ACTS MOBILE TERMINAL

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## Abstract

To explore the potential of Ka-band to support mobile satellite services, JPL has initiated the design and development of a Ka-band land-mobile terminal to be used with the Advanced Communications Technology Satellite (ACTS). The planned experimental setup with ACTS is described. Brief functional descriptions of the mobile and fixed terminals are provided. The inputs required from the propagation community to support the design activities and the planned experiments are also discussed.

## 1 Introduction

JPL is embarking on the design of a mobile terminal to be used in conjunction with the Advanced Communications Technology Satellite (ACTS) to explore the potential of Ka-band to meet the needs of future mobile satellite services. Mobile service providers have the desire to provide a greater number of services to mobile users and to support a larger user base. In view of the congestion and small bandwidth available at L-band, and of the existence of prior allocations at C- and Ku-band, Ka-band may be the next band available to the mobile community, whether for land, aeronautical or maritime mobile users. The goals of the ACTS Mobile Terminal (AMT) project are to develop link technologies necessary for operation in Ka-band and the characterization of the land-mobile channel in that band. Thus, the key system and technology challenges confronting mobile communications at Ka- band will be identified and solutions proposed. Once the experiments have been carried out and the data analyzed, issues such as the differences between operation in L-band and Ka-band, the need for and performance of various channel compensation techniques, and the tradeoffs of system availability versus terminal complexity will be better understood.

## 2 Overview of AMT Project

The AMT project began in May 1990 and will continue through the various phases of analysis, design, development, test and subsequent data analysis until late 1993. The following tasks will be performed in support of this project. First, the system challenges arising from mobile operation in the Ka-band channel: rain attenuation, shadowing, Doppler, and multipath, will be identified, quantified as best as possible, and algorithms will be designed to compensate for the channel. Second, the mobile terminal will be designed to develop the enabling technologies for a land-mobile satellite demonstration and will incorporate the channel compensation algorithms. The terminal will have a modular architecture to support future hardware developments and future experiments and demonstrations. It will also possess extensive recording and analysis equipment to permit real-time and post-experiment analysis of the mobile channel. The individual terminal components will be built by July 1992; they will be integrated into the mobile and fixed terminals and undergo system tests from July until December 1992. Third, a series of experiments, beginning in January 1993 and lasting through June 1993, will be carried out to characterize the land-mobile channel and to verify the terminal performance. Fourth, the data obtained from these experiments will be analyzed in order to improve understanding of the Ka-band channel impairments, to identify the performance of the

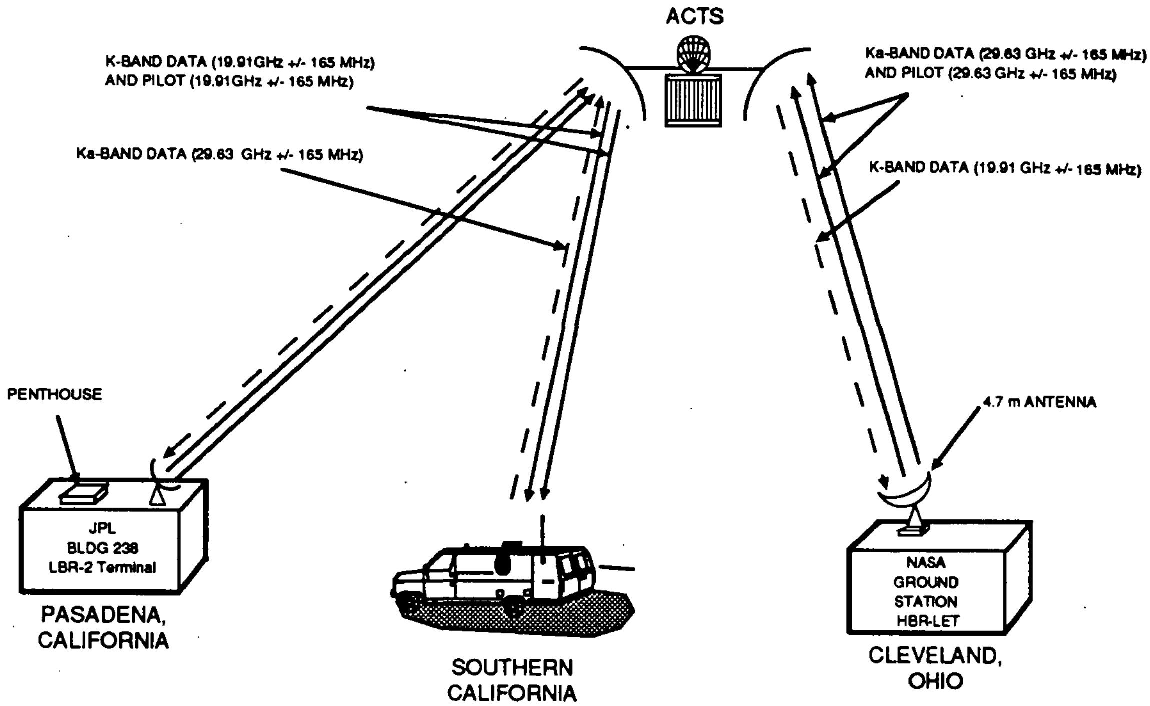


Figure 1: The AMT experimental setup using ACTS.

proposed compensation schemes, and to assess the measure of terminal performance improvement versus ensuing terminal complexity. Last, a series of recommendations for mobile service operation in this band will be released.

# 3 Experimental Setup

Figure 1 shows the experimental setup for the AMT testing using ACTS. ACTS will be used in the microwave switch matrix (MSM) mode to connect the mobile hub station with the mobile unit. The NASA ground station known as the High Burst Rate - Link Evaluation Terminal (HBR-LET) will be used to simulate a mobile hub station. This terminal is located at the NASA Lewis Research Center (LeRC) in Cleveland, Ohio. In the AMT experiment, only the 4.7 meter antenna and up- and down-conversion electronics of the HBR-LET will be utilized. Baseband equipment specific to the AMT will be designed to interface to the HBR-LET at an IF of 3.373 GHz. This terminal has a $G/T \approx 27$ dB/K and transmits at an EIRP varying from 68 dBW to 76 dBW, depending on the drive level to the travelling wave tube amplifier (TWTA).

The mobile terminal will be located in Southern California; this allows access to the satellite via its Los Angeles/San Diego uplink and downlink beams. Block diagrams for the fixed and mobile equipment will be given in Section 4. To facilitate debugging of the mobile to hub station communication link, the possibility of obtaining a second fixed terminal for installation at JPL is being investigated. This 'JPL' terminal would have three uses: (1) as a testbed for the mobile terminal hardware being developed at JPL; (2) as a local hub station in lieu of the HBR-LET for initial system operation; and (3) as a second 'mobile' terminal for network tests should network protocols be tested rather than simulated.

The forward link is depicted by the solid lines in Figure 1. Two signals are transmitted from the HBR-LET terminal: one is the data stream that would be sent from the hub station; the other is the pilot signal that would be sent from the Network Management Control center of the network. The data stream is currently modelled as being a 96 kbps time domain multiplexed signal containing information for users in the Los Angeles/San Diego beam from the hub station. The pilot signal will be used by the mobile terminal for antenna acquisition and tracking, as a frequency reference to permit time and frequency acquisition, and finally to acquire rain fade information about the Cleveland beam.

This information for the Cleveland beam is generated in Cleveland by the HBR-LET and by the NASA ground station (NGS), which is collocated with the HBR-LET. The NGS receives three ACTS generated beacons: a vertically polarized beacon at 20.185 GHz, a horizontally polarized beacon at 20.195 GHz, and a vertically polarized beacon at 27.505 GHz. The first two beacons are fade and unified telemetry beacons. The latter is a rain fade beacon only. Rain fade information at both 20 GHz and 27 GHz is received by the NGS and passed along to the HBR-LET. In addition the HBR-LET possesses its own 20 GHz beacon receivers. This rain fade information will be communicated to the mobile terminal, possibly by modulating the pilot, and thus notifying it of the rain attenuation in the Cleveland beam. This data is necessary so that the mobile terminal, upon reception of the Cleveland transmitted pilot, can distinguish between rain fades in the uplink beam and those in the downlink beam.

In the forward link, ACTS is commanded by the NGS to receive signals on the fixed Cleveland beam and to translate these signals to one of four possible transponders, e.g. transponder #1.[1] The MSM will connect the output of receiver #1 to the high power amplifier #1 and to the Los Angeles/San Diego feed of the ACTS downlink scanning beam. The scanning beam will be kept fixed over the LA/San Diego area for the duration of the experiment. Two signals, namely the data and the pilot, will be received by the ACTS transponder. The effects of the limiter in the MSM ACTS transponder have be taken into account to obtain the correct link margins. A preliminary clear-weather link budget for the forward link from Cleveland to LA/San Diego is shown in Table 1. Conservative numbers have been used in conjunction with the transponder and the HBR-LET. The available $C/No_{overall}$ is 67.4 dB-Hz; the required $C/No$ for 96 Kbps operation is 58.3 dB-Hz. This corresponds to a required $E_b/N_o$ of 4 dB for differentially coherent BPSK in an AWGN channel at a BER of $10^{-3}$, a convolutional code with $r = 1/2$ and $K = 7$, a modem implementation loss of 1.5 dB, and an overall fade allowance for light vegetative shadowing of 3.0 dB. The clear weather forward link margin is 9.1 dB.

The return link is depicted in Figure 1 by the dotted lines. The mobile terminal transmits a single signal, the data channel signal (voice or data messages), to the hub station. Its data rate varies according to the rain fade conditions in the uplink beam (LA/San Diego) and the downlink beam (Cleveland). ACTS is commanded by the NGS to receive signals on the LA/San Diego beam feed of the ACTS uplink scanning beam and to translate these signals to one of four possible transponders, e.g. transponder #2. The microwave switch matrix will connect the output of receiver #2 to the high power amplifier #2 and hence to the Cleveland fixed beam feed. The uplink scanning beam will be kept fixed over the LA/San Diego area for the duration of the experiment.

A preliminary clear weather link budget for the return link from LA/San Diego to Cleveland is shown in Table 2. Again, conservative characteristics for the transponder and HBR-LET are assumed. The available $C/No_{overall}$ is calculated to be 50.87 dB-Hz; the required $C/No$ is 48.32 dB-Hz. The latter corresponds to requirements similar to those of the forward link with the exception of the data rate. The return link clear-weather margin is 2.55 dB.

When the 'JPL' terminal is used as the hub station in JPL to JPL tests, the two uplink signals from the 'JPL' terminal and the one uplink signal from the mobile terminal will be received by the uplink LA/San Diego beam feed and transmitted to the downlink LA/ San Diego beam feed via the same ACTS transponder. Thus signals with very different power levels will be present in the transponder; the effect of the limiter differs from that of the two previous cases. The clear weather forward link margin is then calculated to be 8.4 dB at 96 Kbps. The clear weather return link margin is calculated to be 1.6 dB at 4.8 Kbps. The return link can not support the full 9.6 Kbps link.

In later experiments, signals from both the mobile terminal and the 'JPL' terminal may be transmitted

[1] ACTS possesses four wideband transponders of which three can be used at any one time as one is saved for redundancy.

Table 1: Forward Link Calculation for the Cleveland to LA/San Diego beam

| Uplink<br>Supplier to Satellite<br>30 GHz | | Downlink<br>Satellite to AMT<br>20 GHz | |
|---|---|---|---|
| HBR-LET at LeRC: | | Satellite: | |
| $f_{center}$ (uplink) | 29.63 GHz | $f_{center}$ (downlink) | 19.91 GHz |
| Antenna Gain (4.7m) | 61 dBi | Antenna Gain (3.3m) | 48.1 dBi |
| TX Polarization | HP | TX Polarization | VP |
| EIRP | 65 dBW | EIRP (61.7 dBW max) | 56.22 dBW |
| $L_{pointing}$ | -0.39 dB | $L_{pointing}$ | 0 dB |
| Propagation Losses (Clear Weather): | | Propagation Losses (Clear Weather): | |
| $L_{Atmosphere}$ | -0.92 dB | $L_{Atmosphere}$ | -0.61 dB |
| $L_{Space}$ (Clev. to ACTS) | -213.48 dB | $L_{Space}$ (ACTS to LA) | -209.89 dB |
| $L_{Polarization}$ | -0.5 dB | $L_{Polarization}$ | -0.5 dB |
| Satellite: | | ACTS Mobile Terminal in LA: | |
| $L_{Pointing}$ | 0 dB | $L_{Pointing}$ | -0.5 dB |
| G/T (Clev. Fixed Beam) | 19.6 dB/K | G/T | -5.91 dB/K |
| C/T | -130.69 dBW/Hz | C/T | -161.19 dBW/Hz |
| $C/No_{up}$ | 97.91 dB-Hz | $C/No_{down}$ | 67.41 dB-Hz |
| $B_T$ (900 MHz) | 89.54 dB-Hz | | |
| $SNR_{in}$ | 8.37 dB | | |
| Limiter Suppression Factor, $\Gamma$ | 3.8 | | |
| Hard Lim. Eff. $SNR_{out}$ | 4.57 dB | | |
| Overall Link Performance: | | | |
| $C/No_{overall}$ | | 67.40 dB-Hz | |
| $C/No_{required}$ (for 96 kbps operation) | | 58.32 dB-Hz | |
| Link Margin | | 9.08 dB | |

Table 2: Return Link Calculation for the LA/San Diego to Cleveland Beam

| Uplink<br>AMT to Satellite<br>30 GHz | | Downlink<br>Satellite to Supplier<br>20 GHz | |
|---|---|---|---|
| ACTS Mobile Terminal in LA: | | Satellite: | |
| $f_{center}$ (uplink) | 29.63 GHz | $f_{center}$ (downlink) | 19.91 GHz |
| Antenna Gain | 24.7 dBi | Antenna Gain (3.3m) | 51.3 dBi |
| TX Polarization | HP | TX Polarization | VP |
| EIRP | 21.0 dBW | EIRP (64.8 dBW max) | 28.85 dBW |
| $L_{pointing}$ | -0.5 dB | $L_{pointing}$ | 0 dB |
| Propagation Losses (Clear Weather): | | Propagation Losses (Clear Weather): | |
| $L_{Atmosphere}$ | -0.61 dB | $L_{Atmosphere}$ | -0.92 dB |
| $L_{Space}$ (LA to ACTS) | -213.34 dB | $L_{Space}$ (ACTS to Clev.) | -210.03 dB |
| $L_{Polarization}$ | -0.5 dB | $L_{Polarization}$ | -0.5 dB |
| Satellite: | | HBR-LET at LeRC: | |
| $L_{Pointing}$ | 0 dB | $L_{Pointing}$ | -0.5 dB |
| G/T (LA/SD Spot Beam) | 17.3 dB/K | G/T | 27.3 dB/K |
| C/T | -176.65 dBW/Hz | C/T | -155.80 dBW/Hz |
| $C/No_{up}$ | 51.95 dB-Hz | $C/No_{down}$ | 72.80 dB-Hz |
| $B_T$ (900 MHz) | 89.54 dB-Hz | | |
| $SNR_{in}$ | -37.60 dB | | |
| Limiter Suppression Factor, $\Gamma$ | $\pi/4$ | | |
| Overall Link Performance: | | | |
| $C/No_{overall}$ | | 50.87 dB-Hz | |
| $C/No_{required}$ (for 9.6 kbps operation) | | 48.32 dB-Hz | |
| Link Margin | | 2.55 dB | |

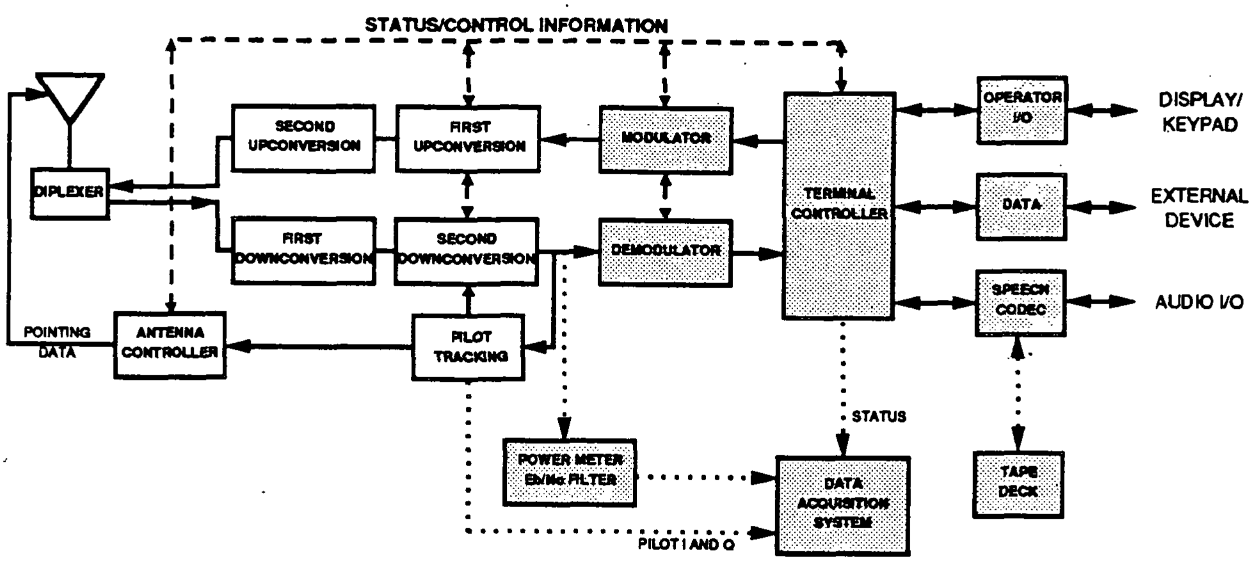


Figure 2: Block diagram of the mobile terminal.

simultaneously to the hub station in Cleveland to simulate network operation. The effect of several uplink signals sharing the limiting ACTS transponders will have to be taken into account in this case as well.

# 4 Mobile and Fixed Terminal Design

## 4.1 The Mobile Terminal

The block diagram for the mobile terminal is shown in Figure 2. The terminal is conveniently divided into a microwave and a baseband processor. The elements belonging to the baseband processor are shown shaded. They include auxiliary components required for experimentation.

The antenna under design is a low profile, high gain, mechanically steered array. The antenna controller will allow the antenna to acquire and track the HBR-LET generated pilot signal. The RF up- and down-converters will translate their respective input signals at 3.373 GHz and 19.91 GHz to output frequencies of 29.63 GHz and 3.373 GHz, 3.373 GHz being the specified IF for interfacing to the HBR-LET. The IF up- and down-converters will translate between the modem output IF, most likely 70 MHz, and 3.373 GHz. Pilot tracking, where needed, will be performed in the IF down-converter.

The modem must be power efficient and utilize robust modulation and demodulation schemes that allow it to freewheel through vegetative shadowing. It will operate at variable data rates - from 9.6 Kbps to 2.4 Kbps - to compensate for rain fading as will the speech codec. The latter will utilize different vocoder algorithms depending on the output symbol rate so as to maximize speech quality for a given data rate.

These variable rate modems and codecs will be used in both the mobile and fixed terminals. The hub station will command a data rate change in the forward link if it is notified by the mobile terminal that rain exists in the mobile terminal's downlink beam. The data rate from the mobile terminal will be decreased if rain attenuation is found in either the mobile terminal's uplink beam or in the downlink beam to the hub station. The algorithm for data rate change is envisioned as operating without network coordination. The modem, therefore, must be able to sense or command a data rate change without receiving information from the network or notifying it.

The design of the algorithm used to control the data rate will depend on the time variation of the rain fade. These second order rain statistics will depend on the location in CONUS and on the time of year; they

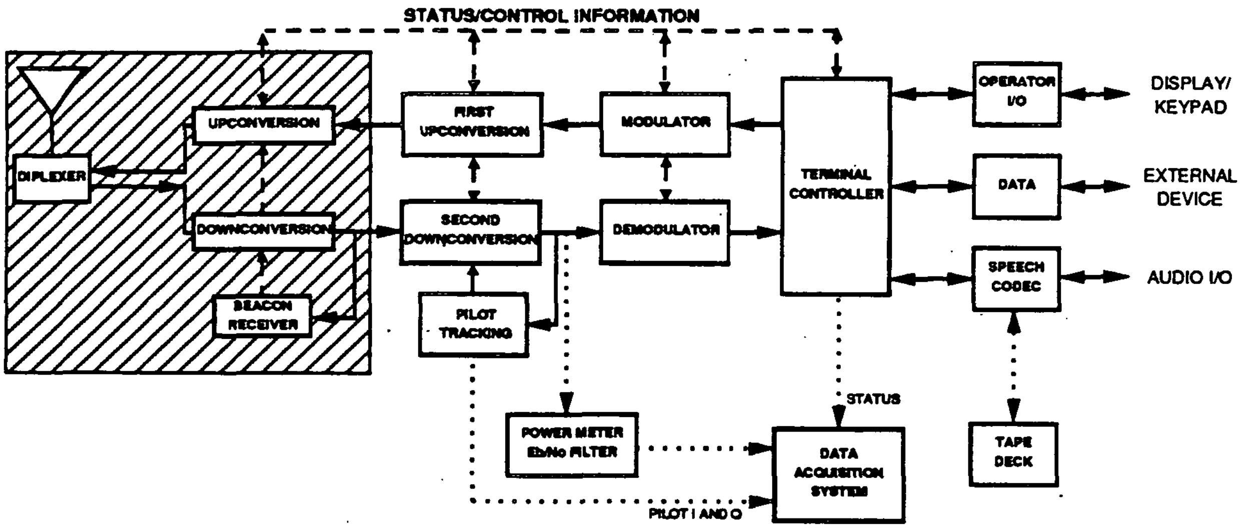


Figure 3: Block diagram of the fixed terminal.

will be obtained from the propagation community based on the results obtained from the OLYMPUS-1 and ACTS beacons. The data will be used to determine the thresholds at which the data rate should be changed and the number of data rate levels necessary to compensate for rain fades. It will also be used to determine whether changes in the data rate should be ordered apriori or aposteriori to the measurement of these rain fade threshold levels. The design of the algorithm and its implementation must also take into account the level of BER improvement expected, the increased signal delay, and the implementation cost in the modem. The ensuing system availability (for various data rates and voice qualities) will then be assessed.

The terminal controller governs the interface between the various types of inputs to the terminal, i.e. from the codec, the keyboard, or any other external device, and the modem. It monitors and controls the operation of all of the terminal's components and is responsible for executing the rate control algorithms. The terminal controller will also perform various diagnostic tests on the terminal and will pass status data on to the data acquisition system.

The data acquisition system will record the operation of many of the terminal's components. It will provide for real time display of various signal levels and bit-error-rate information. Channel characterization in terms of vegetative shadowing, rain fades, Doppler and multipath depend on accurately recording and time-tagging the performance of the link and on being able to correlate this with the correct mobile environment.

## 4.2 The Fixed Terminal

The block diagram for the fixed terminal is given in Figure 3. Shown is the equipment that will be necessary for the hub station whether it is located at NASA LeRC or at JPL. The equipment shown in the hatched box belongs to the HBR-LET terminal located at LeRC or to the loaned equipment for the 'JPL' terminal. The remaining equipment is identical to that used in the mobile terminal. It should be noted that the pilot tracking circuit is not necessary for the operation of the fixed terminal.

All components function as in the mobile terminal with the exception of the terminal controller which performs an additional task. It monitors the rain fade condition at 27 GHz from the NGS's beacon receivers in order to control the drive level of the HBR-LET's TWTA. Algorithms for uplink power control will be developed for use only by the hub station to compensate for rain in its beam. Due to transmit power limitations, the mobile terminal cannot compensate for uplink rain fades in this manner.

## 5 Planned Experiments

Planned experiments include both stationary and mobile clear-weather link tests of the mobile terminal. The objectives for these tests will be to: (1) verify the analyses performed prior to terminal design; (2) permit the refinement of the Ka-band channel characterization; (3) determine system and subsystem performances under true field conditions; (4) support terminal design refinements and enhancements; and (5) demonstrate the technologies and system concepts to potential end-users and manufacturers.

Antenna acquisition and tracking functions will be demonstrated and quantified. Modem and codec performance will be ascertained at various data rates. Performance of the chosen modulation and coding schemes and modem and speech codec implementations will be evaluated in terms of compensating for Doppler and frequency offsets, minimizing any effects due to multipath, and permitting freewheeling through shadowing with quick recovery from voice outages.

The performance of the power and data rate control rain compensation algorithms will be measured, first, by simulating rain attenuation, and, then by testing during various rainy conditions. The variable rate modem will be tested to assess its response time, optimum setting of threshold levels, number of data rate steps, and to determine the achieved system availability. The data rate control algorithms for the modulator and the speech coder will be implemented in software so that they can be refined in accordance with experimental results and retested. The ensuing system availability will then be assessed in light of the increased terminal complexity required to implement these algorithms. The appropriate tradeoff analysis will be performed and conclusions will be derived.

This baseline experimentation plan will provide a foundation upon which other Ka-band mobile, aeronautical or maritime, and micro-terminal experiments can be based.

## 6 Inputs from the Propagation Community

Information about the Ka-band channel is necessary for the AMT project in order to guide the development of the rain compensation algorithms and to aid in the selection of the modulation and coding schemes. Second order rain statistics at Ka-band are required to determine how useful changing the data rate is in preserving the link. Investigations are under way to determine the most useful format for such statistics. Decisions have to be made on whether simply the time variations of the rain attenuation would be sufficient, or if the channel model requires conditional expectations or the autocorrelation of the rain fade process. Both rain statistics and inputs regarding channel modeling are required from the propagation community.

Channel characterization in terms of shadowing and multipath are also necessary. Issues such as the shadowing and scattering characteristics due to tree tops, the duration and depth of tree shadowing as a function of the mobile terminal elevation angle, and multipath as a function of elevation angle and beamwidth for high gain mobile antennas must be studied.

## 7 Conclusion

JPL is initiating the design of a mobile terminal and developing plans for a series of mobile communication link experiments at Ka-band in order to explore the potential of Ka-band to meet the needs of future mobile satellite services. The two main technical challenges foreseen are those of maintaining the link in a severe propagation environment and of developing the enabling Ka-band technologies. The first challenge consists of developing the power and data rate control algorithms to compensate for rain fade, the modulation and coding techniques to combat Doppler and multipath, a modem implementation that freewheels through shadowing events, and high performance antenna tracking algorithms. The second technical challenge involves developing of Ka-band components, packaging techniques and active antennas.

The land-mobile ACTS experiments are centered around the goal of providing a more accurate characterization of the Ka-band channel and its potential to support mobile communications. The planned baseline experimentation plan will serve as a starting point for other mobile and micro-terminal experiments at Ka-band. Although the experimental phase of the AMT project is currently scheduled to occur from January to June 1993, it is hoped that other experiments involving advanced land mobile terminal hardware, maritime or aeronautical applications, testing of hybrid satellite and land based networks, or demonstration of truly personal micro-terminals will occur throughout the lifetime of ACTS.

## Acknowledgement

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.