Technology Issues for Mobile Ka-band Communications

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1. INTRODUCTION

The key to success of any future telecommunications system is its ability to provide many users with a diversity of services in a cost-effective manner. An important consideration is system (bandwidth) capacity which is required to support a large pool of users and their varied demands. Ka-band not only provides very large bandwidth capacity but has the potential of supporting user equipment which is significantly smaller than that for the lower frequency communication bands. Ka-band is therefore a good candidate for users seeking large capacities, diverse services and convenience.

To this end, NASA has established the Advanced Communications Technologies Satellite (ACTS) program to demonstrate the feasibility of the Ka-band spectrum for satellite communications. The success of the ACTS program depends on how well Ka-band propagation characteristics of the atmosphere will be understood and compensated for, particularly for terminals with a small propagation margin. The major perturbing elements in low-margin satellite links affecting space-to-Earth propagation are shown in "Table 1. From this table it is evident that rain attenuation and scintillation pose a threat for low margin communications, and therefore needs to be investigated.

Preparations for ACTS propagation experiments started in 1988 when the NASA Propagation Program began its participation in the European Space Agency's Olympus Experiment. Planning for" the ACTS experiments was initiated at the first ACTS Propagation Studies Workshop (APSW), November 28-29, 1989. Since then, the plan for the ACTS propagation experiments has continued to evolve through the efforts of APSW 2 and 3. lessons learned from the Olympus experiment also had a strong influence on preparation for the ACTS propagation campaign. The workshop participants have also provided guidelines regarding measurement parameters and requirements. These guidelines specify how the terminal should be configured so that it can record the following propagation and meteorological parameters:

- 20- and 27-GHz beacon receive signal level
- 20- and 27-GHz sky noise temperature
- Point rain rate near the terminal
- Atmospheric temperature and humidity at the Earth's surface

In response to the recommendations concerning propagation terminals, a two-phase plan has been devised. In Phase 1, the terminal prototype was completed, August 1992., and in Phase 2, seven terminals will be manufactured for distribution to ACTS experimenters. It is expected that the ACTS data collection will commence in July 1993, shortly after the Satellite's scheduled launch (mid-July, 1993).

in addition to the propagation impairments listed in 'Table 1, Ka-band poses significant technological challenges. In particular, it is a young technology that has lossy RF

Phenomenon	Effect	Remedy
Gaseous attenuation	Noticeable	Built-in margin
Hydrometeor attenuation:		
Cloud	Measurable	Built-in margin
Rain	Severe	Adaptive compensation
Snow	Negligible	N/A
Fog	Negligible	N/A
Depolarization	Interference and loss of power	Built-in margin for small levels of the effect
Scintillation	Rapid fluctuation of signal; dependence on frequency, site, time of day, season, and elevation angle	Not easy to circumvent; generally small for elevation angles above 10°
Excess noise emission	Signal absorption gives rise to broadband noise emission; significant for low-noise systems, i.e., deep space ground receivers	Not a serious concern for most commercial satellite ground receivers

Table 1, Space-to-Earth Wave Propagation Perturbing Elements at K-band.

components, potentially large frequency uncertainties and large Doppler shifts in mobile applications as well as a requirement for more accurate satellite-tracking to accommodate the higher antenna gains achievable at Ka-band.

To overcome the propagation and technological challenges, JPL is currently developing a proof-of-concept breadboard mobile terminal system to operate in conjunction with ACTS. As depicted in Figure 1, this system comprises a bent pipe propagation link connecting terminals at ground and mobile sites. As discussed in Section 11, the terminals are identical although only a single pilot signal, from the ground to the mobile station, is used to aid in Doppler compensation. Furthermore, ACTS possesses the high-gain spot-beam antennas required to support small mobile and personal terminals. The resulting ACTS Mobile Terminal (AMT) breadboard system will support both voice and data links and will be demonstrated in typical mobile and stationary environments. Basic technologies that enable Ka-band communications will be demonstrated first, followed by various enhancements to achieve improved system performance and efficiency.

Key features of the AMT system include an adaptive fade compensation algorithm to help overcome Ka-band propagation impairments (i.e., rain attenuation). in addition, adaptive power control is being used between the ground station and ACTS to compensate for uplink propagation path attenuation. AMT utilizes Differential Binary Phase Shift

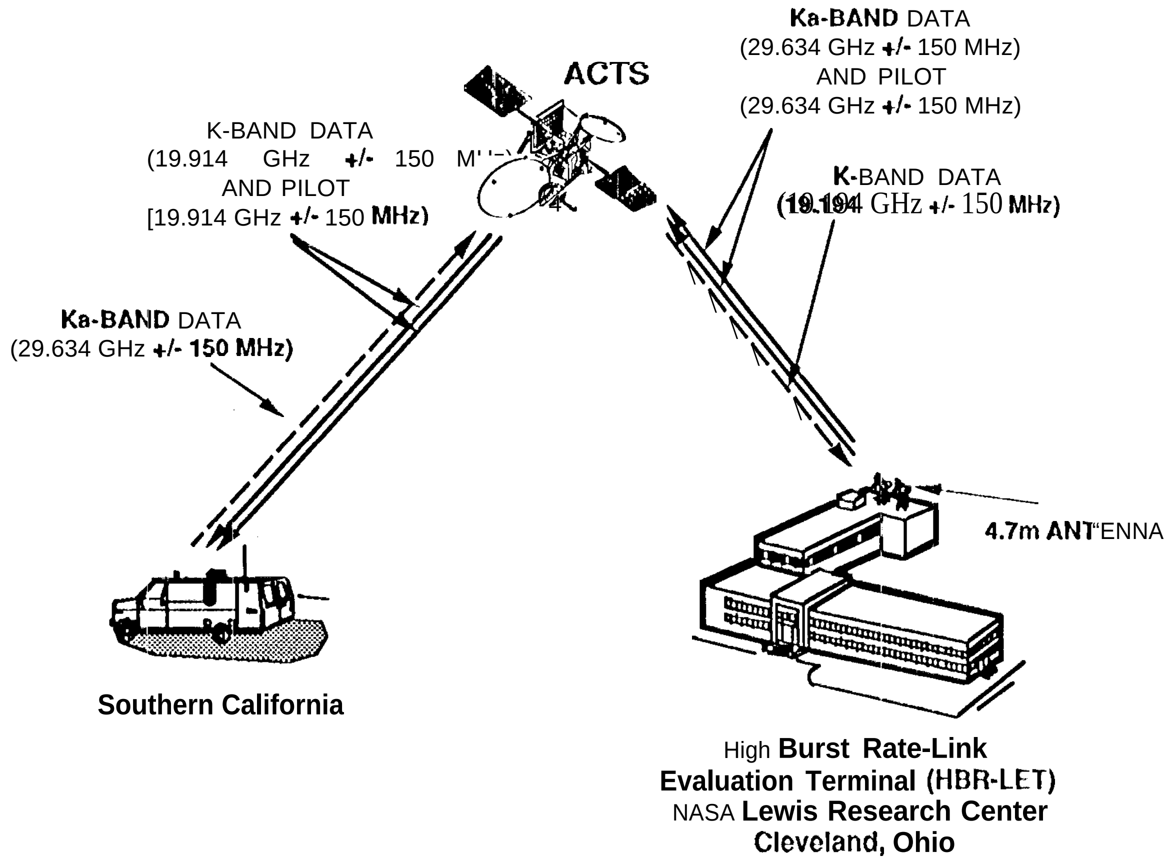

Figure 1. Proof-of-concept demonstration system for mobile Ka-band communications.

Keying (DBPSK) modulation with rectangular pulse shaping to provide resistance against the ACTS' phase noise. To accommodate the large Doppler shifts, which can especially degrade system performance at the lower data rates, an innovative, Doppler estimation and correction algorithm has been developed for the AMT. This algorithm is based on an open-loop, (delay-and-multiply architecture and can accommodate Doppler shifts well in excess of the symbol rate. Finally, the high-gain AMT antenna system is being designed to provide for accurate satellite-tracking as well as good cross-polarization isolation. In this way, AMT will demonstrate a viable Ka-band communication system that realizes the advantages higher frequency communication bands can offer.

In the remainder of this paper, we first describe the basic AMT system architecture in Section II. A description of the AMT adaptive fade compensation algorithm is then provided in Section III followed by descriptions of the AMT terminal design in Section IV and the high-gain AMT antenna system in Section V.

II. SYSTEM ARCHITECTURE AND OPERATION

Studies focusing on K-/Ka-band have explored system architectures and multiple-access schemes that can form the basis for a viable mobile and personal satellite communication system [1-4]. It has been shown that for CONUS coverage a geosynchronous satellite would be most practical, with the system typically taking the form depicted above in

Figure 1, i.e., the AMT experimental setup. A fixed station communicates through the satellite with a large number of mobile or personal access users scattered over CONUS.

To alleviate the EIRP burden on the user terminal, satellite spot beams are used in covering CONUS. in principle, the satellite could be of the bent-pipe or processing type. However, since the technology for onboard processing to support a large mobile user base is still in its infancy, such technology could not be advocated without a complex tradeoff study. It has also been shown [1,3] that a nonprocessing, geosynchronous satellite in the bent-pipe mode could be utilized effectively with a combination of multiple-access schemes, Combining FDMA or CDMA with TDMA, capacities of 30,000 4.8 kbps channels have been predicted for a 6000-lb-class satellite. The bandwidth required is approximately 300 MHz.

Consistent with ACTS, AMT uplinks will be at 30 GHz and downlinks at 20 GHz as shown in Figure 1. To be compatible. with a planned mid- 1993 satellite experiment, FDMA was selected for the base technology demonstration because of its lower risk. CDMA and TDMA techniques will be utilized in the follow-on enhancements.

in the FDMA architecture utilized for the AMT, an unmodulated pilot is transmitted from the fixed station to each user spot beam. The mobile terminal uses this pilot to aid antenna tracking and to measure rain attenuation, and as a frequency reference for Doppler correction and precompensation. For system efficiency, a pilot is transmitted only in the forward direction, i.e., from the fixed to the mobile terminal, Hence, for the AMT, there will be two signals in the forward direction: the pilot and the information (voice or data) link. In the return direction (mobile to fixed), only the information channel is transmitted. The data rate is automatically selected (2..4, 4.8 or 9.6 kbps) depending on channel conditions. A separate higher rate of 64 kbps will also be supported, but only under certain link conditions.

The absence of a pilot on the return link necessitates a creative solution to the problem of Doppler compensation on that link, The return link Doppler due to car motion can be as high as 3 kHz, with a rate up to 250 Hz/sec. In addition, uncertainties in the various oscillators along the links can accumulate about 2 kHz of frequency offset. Thus, the Doppler and frequency uncertainties can be a large fraction of the data rates. In the AMT demonstration, the Doppler shift present on the pilot will be tracked at the mobile terminal, translated in frequency and used to precompensate (appropriately preshift) the data channel on the return link, This will result in a significant performance enhancement at the fixed terminal and a reduction in the guard bands that would otherwise be required.

III. AMT FADE COMPENSATION AND THE COMMUNICATION PROTOCOL

The communication protocols developed for the AMT are consistent with the networking framework developed for MSAT-X [5,6] and were designed specifically to be efficient in the mobile satellite environment. The AMT links are classified as open-ended for voice or long data transfers such as fax, or close-ended for short data transfers such as messages. Data transmission in either link type will be subject to acknowledgment and retransmission, as required, to ensure data integrity. The protocol constructs extend the generic L-band concepts to accommodate. the additional requirements at Ka-band.

operation at 20 and 30 GHz -- particularly at 30 GHz -- is susceptible to significant atmospheric attenuation (especially rain). To increase link availability and service continuity, the data rate on the AMT links can be reduced to compensate for fade impairments. Recent studies [7] have indicated that under worst-month conditions, system availability can be improved from as low as 90% to above, 99% by simply reducing the data rate from 9.6 to 2..4 kbps.

The AMT fade-compensation algorithm (termed RCA in [7]) and communication protocol [8] have. undergone parallel development for maximum compatibility y and efficiency in system operation. The RCA and the communication protocol enable proper initial selection of data rates as well as data-rate change “on the fly” (i.e., with about a quarter second of silence.) during an existing link.

The RCA relies on channel-attenuation measurements on both link ends. The pilot is used at the mobile terminal and the satellite beacon(s) at the fixed terminal, with rain attenuation measured at each terminal. This is performed either in the IF downconverter's pilot receiver module in the case of the mobile terminal or in the beacon receiver at the fixed station. This information is then fed to the terminal controller, where it is processed by the RCA software. The RCA is used to perform data rate selection or change indication both at link setup and during an existing call (voice or data). Evaluations of tradeoffs have established that the most dependable and efficient data rate control scheme is the one wherein a joint, conflict-free procedure for rate determination is used. Basically, the terminal that indicates a call, or that senses the onset of fading during an existing call, transmits a request (appropriate packet) containing its information to the other terminal. The latter uses its own local information and the information it received to determine the final data rate; it then relays that information to the first terminal. During an existing voice call, the control packets exchanged are appropriately embedded in the compressed voice in a manner that virtually eliminates any impact on the users [8]. The challenges in the design of the protocol have been to maintain sufficient robustness of the data control procedure despite the possible presence of vegetative shadowing and to achieve responsiveness to fade dynamics while minimizing overhead, delay and implementation complexity [8].

IV. MOBILE AND FIXED TERMINAL DESIGN

Figure 2, which shows a block diagram of the mobile terminal, identifies subsystems as elements of two broad divisions of the AMT: the baseband and microwave processors. The baseband processor consists of a speech codec; a modem and terminal controller, and a data acquisition system (DAS). The elements of the microwave processor are the IF up- and downconverters (the first stage of upconversion and the second stage of downconversion), the RF up- and downconverters (the second stage of upconversion and the first stage of downconversion), the antenna controller and the antenna, The primary reason for the split into IF and RF modules is to enable the interface to the ground station RF equipment at the fixed site,

Figure 3 shows a block diagram for the fixed terminal. The baseband processor is identical to that of the mobile terminal except that the ground station RF equipment is used insteadi of the mobile terminal’s RF converter and vehicle antenna system.

The terminal controller (TC) is the brain of the AMT. It contains the algorithms that translate the communications protocol into operational procedures and interfaces among the terminal subsystems; it also contains and executes the RCA routines. The TC has control over IF and RF electronics operation; maintains high-level control over the antenna platform, and provides the user with a system-monitoring capability. It also supports an interface to the DAS and will support test functions required during experimentation, such as bit-stream generation, correlation and bit-error counting.

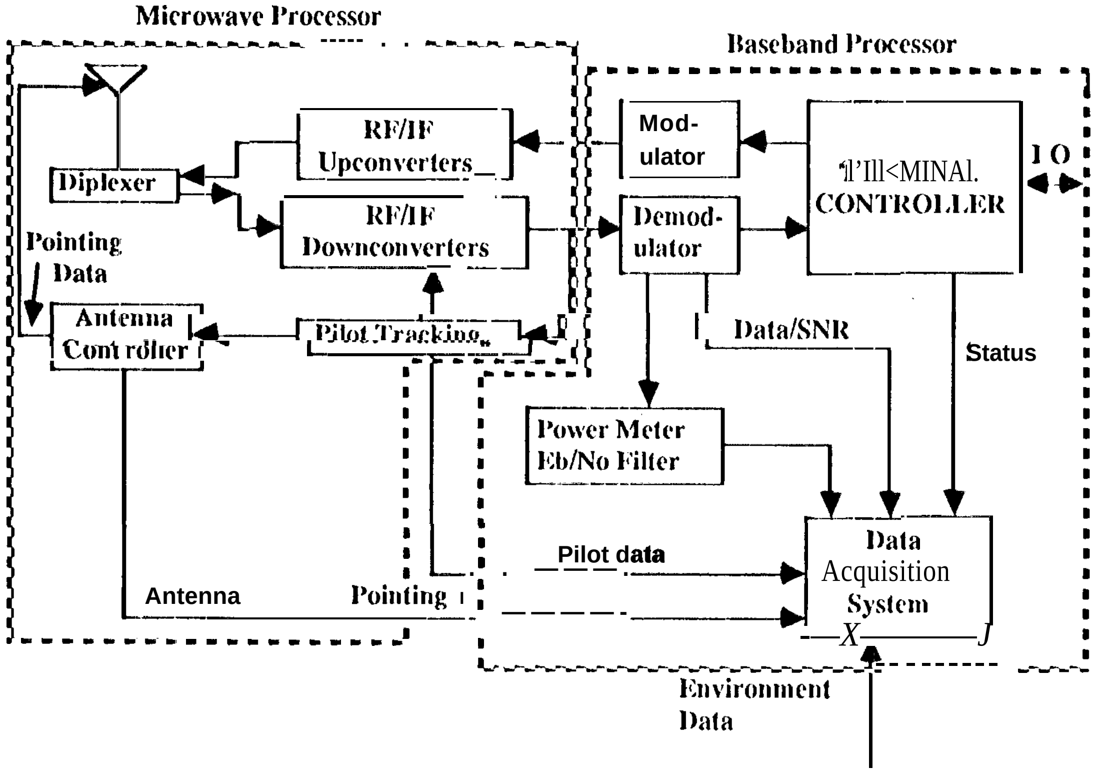

Figure 2. The mobile terminal.

The speech codec converts input analog speech signals to a compressed digital representation at data rates of 2,4, 4,8 or 9.6 kbps, with monotonically improving voice quality. "The 2.4 kbps compression algorithm is the U. S. Government standard LPC- 10; the 4.8 kbps algorithm is the proposed CELP Government standard, and an MRELP algorithm has been adopted at 9.6 kbps. The latter may be changed to the digital cellular standard, Data rate switches will be performed on command from the TC based on RCA information or on user command. Data rate switching will normally occur "on the fly" with no user intervention and will have. minimal impact on the continuity of the link. The codec will also contain special design features to make its operation robust in the mobile satellite environment, with its shadowing-induced outages. Finally, the codec will be capable of interfacing with the Public Switched Telephone Network.

The baseline AMT modem will implement a simple but robust DBPSK scheme with rate 1/2 convolutional coding and interleaving so as to minimize the impact of ACTS' phase noise on the modulation scheme performance. The modem has a bit error rate of 10^{-3} at an Eb/No of 7 dB in additive white Gaussian noise (AWGN), including modem implementation losses, Half a dB of performance degradation due to ± 4.5 kHz combined frequency offsets on the links through ACTS could be encountered. Additionally, up to 1.5 dB of degradation due to ACTS' phase noise could be experienced. Alternate modulation schemes such as "pseudo-coherent" BPSK, wherein link synchronization information is embedded into the data channel, will be explored to investigate possible Eb/No performance gains.

in addition to the data rates of 2.4, 4.8 and 9.6 kbps, the modem will be designed to handle up to 64 kbps for a possible demonstration of slow scan (10 frames/sec)

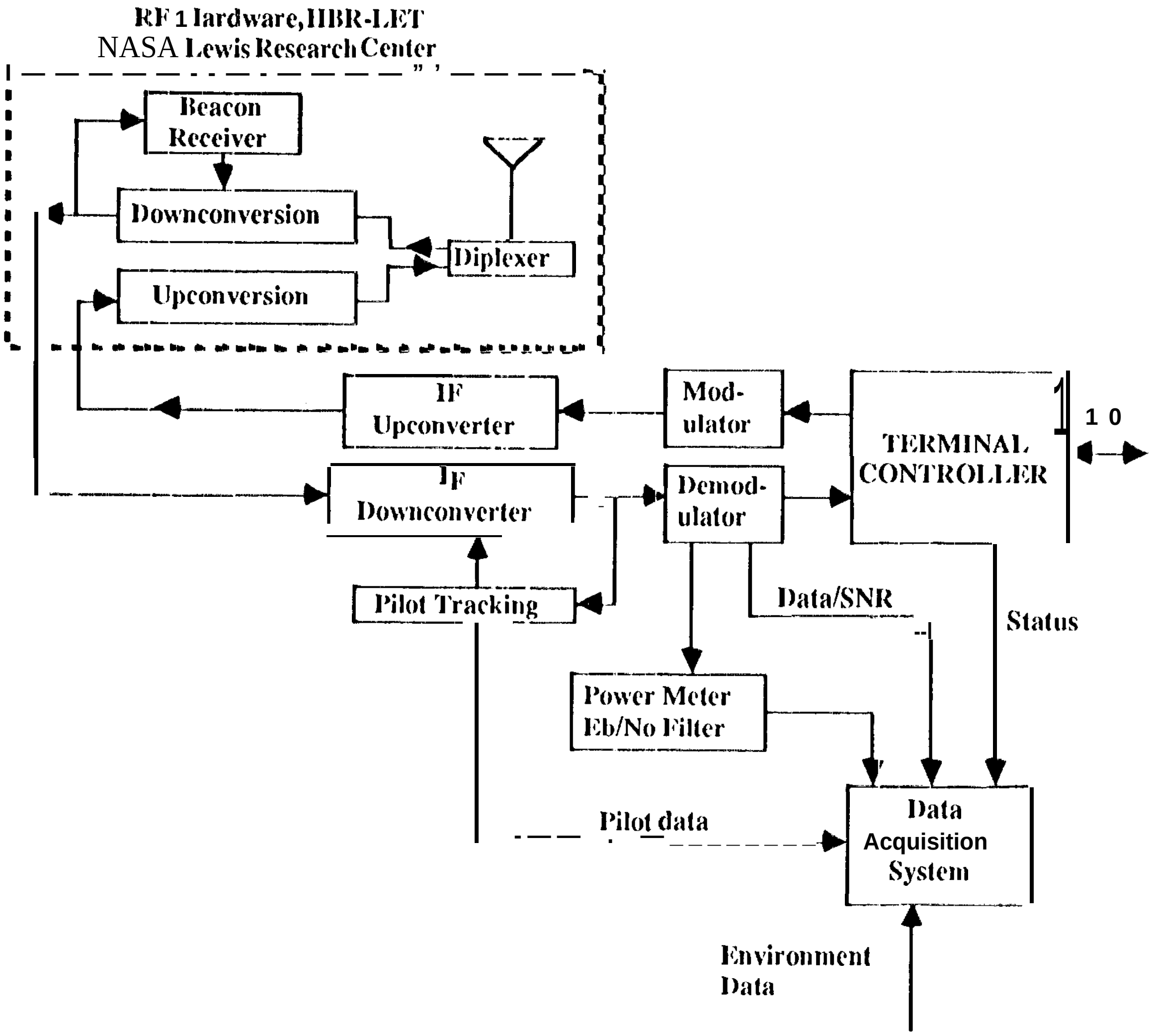

Figure 3. The fixed terminal,

compressed video on the forward link. Essential to the modem design is a built-in robustness to deep, short-term shadowing. The modem will “free-wheel”, i.e., it will not lose synchronization from signal outages caused by roadside trees. The modem is also being designed to handle the possible frequency offsets due to oscillator uncertainties and drifts along the link. Any residual Doppler at the mobile terminal that is not corrected through pilot tracking or at the fixed terminal (after precompensation) will be estimated and corrected by the modem’s Doppler estimation algorithm. This algorithm, which is based on an open-loop, delay-and-multiply architecture, can accommodate Doppler shifts well in excess of the symbol rate as shown in [9].

The DAS will perform continuous measurement and recording of a wide array of propagation, communication link and terminal parameters (e.g., pilot and data signal conditions, vehicle velocity and heading, noise levels and antenna direction). The DAS will also provide real-time displays of these parameters to aid experimenters in the field.

V. AMT MOBILE ANTENNA DESIGN

The critical Ka-band technology item in the microwave processor (Figure 2) is the vehicle antenna design. Two types of antennas are under development: a "passive" elliptical reflector to be used in conjunction with a separate high power amplifier (HPA), and an "active" array with integrated MMIC HPAs and low noise amplifiers (LNAs). Each type of antenna has distinct advantages. The reflector is simpler and less risky but requires a separate power amplifier, which could be an expensive or bulky item. The active array, despite being more complex and risky to develop, exploits MMIC technology to overcome the losses in the Ka-band hardware and obviates the need for a potentially expensive power amplifier. The integration of the amplifiers also leads to a smaller, more conformal antenna assembly. With the potential mass market that Ka-band can support, the active array holds the promise of high performance at low cost, It will have a minimum EIRP of 22 dBW, G/T of -8 dB/K and bandwidth of 300 MHz. The reflector will reside inside an elliptical water-repelling radome with a 9 in. outside diameter (at the base) and a maximum height of 3.5 in.

The antenna pointing system enables the antenna to track the satellite for all normal vehicle maneuvers. Both the antennas will be mated to a simple yet robust mechanical steering system, A scheme wherein the antenna will be smoothly dithered about its boresight by about a degree at a rate of 2 Hz will be used, The pilot signal strength measured through this dithering process will be used to complement the inertial information derived from a simple turn-rate sensor. The combination will maintain the antenna's gain at the satellite even if the satellite is shadowed for up to 10 sec. This mechanical pointing scheme is one of the benefits of migration to Ka-band. The considerably smaller mass and higher gain achievable relative to L-band makes the mechanical dithering scheme feasible and obviates the need for additional RF components to support electronic pointing. The necessary processing will reside in the antenna controller, which will later become part of the TC.

VI, CONCLUSIONS

JPL is developing a K-/Ka-band mobile terminal and is planning a series of mobile experiments to explore the potential of K-/Ka-band to meet the needs of future mobile satellite services. Two major technical challenges have been identified: maintaining the link in a demanding propagation environment and developing the enabling Ka-band technologies. The first challenge requires developing data rate and power control algorithms to compensate for atmospheric fading; designing a modem and transceiver capable of combating Doppler and frequency offsets while providing power efficiency and robustness to shadowing, and the development of high-performance, simple-to-implement pointing algorithms. The second technical challenge entails the development of low-cost, high-performance, reliable small antennas that will utilize Ka-band MMIC components and packaging techniques. It is hoped that AMT development and the availability of ACTS as an invaluable satellite of opportunity will lead to other experiments and demonstrations of advanced land mobile terminal hardware; maritime and aeronautical systems; hybrid satellite and land based networks, and, eventually, true personal microterminals.

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