Ka-Band Mobile Experiments[1]

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Introduction

The National Aeronautics and Space Administration (NASA) through the Jet Propulsion Laboratory (JPL) has been involved in the development of mobile satcom technologies for more than ten years. The initial work was performed at L-band (1.5 -1.6 GHz), and included system studies and analysis, subsystem and full terminal development, and culminated in numerous field experiments and demonstrations under the Mobile Satellite Experiments (MSAT-X) program.

With the ultimate transfer of these L-band technologies to the commercial sector, NASA and JPL have now turned their resources to a new frequency spectra, namely K- (20 GHz) and Ka-band (30 GHz). This is being achieved through the Advanced Communications Technology Satellite (ACTS) program. ACTS, which was built by Martin Marietta Astro Space (MMAS) under contract to NASA Lewis Research Center (LeRC), was launched on September 12, 1993. Currently, the satellite resides in geostationary orbit at 100° W longitude. Amongst the many different types of ground terminals that have been developed to operate with ACTS, JPL is under contract to design and build two separate mobile terminals. The first terminal, the ACTS Mobile Terminal (AMT), was completed during the summer of 1993, and can provide low (2,4/4 .8/9,6 kbps) and medium (64/128 kbps) data rate capabilities between a mobile terminal and fixed station via ACTS. The second terminal, the Broadband ACTS Mobile Terminal (BBAMT) is still under design, and is schedule to be completed during the first half of 1995. This terminal will be able to provide broadband capabilities (at least 384 kbps) between a mobile terminal and a fixed station.

One of the key aspects of this program is the presence of direct industrial participation in the form of experimentation with the various ground terminal equipment and the satellite. As part of the ACTS Experiments Program, JPL has been given the task of seeking out useful applications for mobile satcom and demonstrating these capabilities through ACTS and the AMT (and the BBAMT). To date, fourteen different experiments involving several different government agencies, U.S. industrial interests, and academia have been officially approved to experiment with ACTS and the AMT. In addition, five more experiments involving the BBAMT have been proposed, with one of these experiments already being approved.

[1] The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

The remainder of this paper will provide a brief technical description of both the satellite and the two mobile terminals. The potential of mobile satellite services will be explored followed by a description of the mobile experiments program. A particular emphasis on possible application to mariitime services is put forth in this paper.

The Potential for Mobile Satellite Services

Mobile satellite communications, while still in its relative infancy, is already beginning to have major impacts on our everyday lives. From its use in the trucking and maritime shipping industries, to satellite radio broadcasts while airborne, this technology is truly exciting. The extent with which this technology is used will only continue to grow. This section will provide a brief overview into the areas and services where mobile satcom should play/is playing a most eminent role. They include such diverse areas as personal communications, disaster relief communications, telemedicine communications, emergency medical communications, military communications, broadband aeronautical communications, and finally broadband maritime communications.

The 90's and beyond will be an era of explosive growth in the demand for personal information exchange. This includes such fields as voice communications, data communications, information services, position location services, and interactive communications to name but a few. Today's terrestrial networks are well on their way to supporting these services with the advent of universal personal/portable communications. The ultimate version of terrestrial-based Personal Communications System (PCS) would allow a customer to go wherever there were radio ports - probably in areas with fairly dense populations - and place and receive calls while moving freely throughout an extended area. Satellite interconnection into these terrestrial systems could provide a complementary service by providing access for rural, isolated users while augmenting the existing systems with a seamless network providing access for all users. Such a reconfiguration would increase the coverage capability and capacity of cellular telephone systems, terrestrial paging systems, and certain types of computer systems to name just a few.

Readily available, accurate information about the extent of a disaster is essential to planning and conducting an effective disaster relief operation. Immediately after a disaster's occurrence, it is necessary to know the boundaries of a disaster, the nature of the damage, the characteristics of the affected area, and the conditions of roads and utilities. This assessment information also assists with the verification of needs of victims and assists appropriate government agencies in determining the need for additional government aid. In light of several of the more recent disaster occurrences (Hurricane Andrew, Hurricane Iniki, Los Angeles fires, Northridge earthquake, etc.), the communication systems used for such relief assistance should be immune to these hazards. In addition, the communications should be distance-insensitive to cover the whole United States, and should be highly portable/mobile; once again making space-based mobile satellite communications a highly logical choice.

As the White House's ideas for a countrywide health plan gets analyzed, there will be many logistical problems that will ultimately need to be overcome. One of these problems, that has already been hotly debated, is how to provide proper medical coverage to rural America. These areas, while usually having access to a general practitioner, rarely have more specialized medical personnel and equipment available. Providing full health coverage to this part of the country could potentially become unmanageable, both from a health care and cost standpoint. One possible solution to this problem is to remotely link rural areas with the state-of-the art medical centers that tend to be located in metropolitan areas. Providing mobile medical units roaming the countryside with trained technicians operating specialized medical equipment could provide much needed aid. The way that these medical units would be linked to the medical centers - mobile satellite communications.

The communication needs for paramedical and other emergency medical services far exceed the current capabilities. Specifically in geographically rugged areas characterized by hills, mountains, forestation, etc., terrestrial-based communications between the paramedic in the field and the end-destination hospital is categorized as intermittent at best. Even in areas where the terrestrial communication is not geographically challenged, the system's capabilities are still limited to voice only communications. Space-base mobile satellite communications could provide the answer to improving this situation. Mobile satellite communications is immune to localized geographical situations (i.e. mountains, forests, etc.). Furthermore, such a system could easily provide a combination of voice communications, along with real-time medical and GPS-provided positional information. This system would allow the awaiting doctor at the hospital to be better informed and prepared for the incoming patient, and would ultimately end up saving many lives.

As demonstrated by the recent Persian Gulf conflict, the communications requirements of a highly mobile Army can rapidly exceed the capabilities of existing terrestrial and space-based systems. In addition, the Army's new AirLand Operations Doctrine places a great dependence on improved mobility in order to cope with non-linear and highly dispersed battlefields. The supporting communications infrastructure must be highly responsive. The specific requirements for Army mobile communications systems have traditionally been difficult to quantify and qualify. At a minimum, terminals should be mobile, small, low cost, and capable of providing secure voice and data. Such terminals should also be distance-insensitive, meaning that a space-based mobile satellite communications system solution is a feasible one.

A fully captivated commercial audience at 40,000 feet is another logical application for mobile satellite communications. Limited mobile satellite services already exist today such as single channel voice (up to 9.6 kbps) and direct broadcast radio (SKY RADIO). The demands for even these limited, low data rate services is growing at an exponential rate. As these technological capabilities improve, and more bandwidth is made available, an explosion in aeronautical mobile satellite communications is expected. The general public would no longer be subjected to the outdated newsreel, sports clip, and year old movie provided via videotape. Live broadcast television would be provided directly to the passenger cabin. Full service voice, data, FAX, and even video teleconferencing would also provide the business traveler with the ultimate "office-in-the-sky."

The pleasure cruise ship industry should also be highly interested in mobile satcom services. These services that could be provided would be identical to those provided for broadband aeronautical communications (television broadcasts, voice, data, FAX, video teleconferencing, etc.). However, there would be several distinct differences. Due to the size and the type of motion that ships experience (as opposed to aircraft), larger antennas could be utilized. Thus, shipboard mobile satellite systems would have a much larger capacity than their aeronautical counterparts. Secondly, the passengers onboard a pleasure cruise are a more captivated audience. Quite often these people are aboard a ship for up to a week at a time (as opposed to several hours per flight for aeronautical passengers). That makes the potential for this market even more lucrative than that for the airline industry.

ACTS Characteristics

In order to accommodate the projected increases in worldwide telecommunications demand for the 1990's and beyond, technology innovations are needed that permit more cost-effective satellite communication systems. ACTS accomplishes this by furnishing the advanced technology necessary for developing future satellite operational networks. The specific key technologies of this satellite are as follows: (1) a multibeam antenna (MBA) scheme providing a rapidly reconfigurable pattern of hopping beams and fixed spot beams for predetermined locations as shown in Figure 1, (2) on-board baseband processor (BBP) providing high-speed digital processing for efficient use of transponder capacity by routing individual, circuit-switched messages to provide single-hop connectivity in a full-mesh network, and (3) a microwave switch matrix (MSM) providing dynamically reconfigurable, microwave, intermediate-frequency switch capable of routing low- or high-volume point-to-point traffic and point-to-multi-point traffic over 900 MHz channels.

Both the AMT and BBAMT operate using the MBA with the MSM mode of operation of the satellite. The BBP mode of operation is utilized by the fixed ground terminals (TI VSAT's). Further technical details of ACTS' design are provided in [1].

AMT Description

A block diagram of the AMT is shown in Figure 2. Complete technical details about this terminal are provided in [2]. The figure identifies the different subsystems as elements of the two broad divisions of the AMT; namely, the baseband and microwave processors. The baseband processor consists of a speech codec (SC), a modem, and a terminal controller (TC). Attached to it also is a data acquisition system (DAS). The elements of the microwave processor are: the IF up/down converter (IFC) (the first stage of up-conversion, and the second stage of down-conversion), the RF up/down converter (the second stage of up-conversion, and the first stage of down-conversion), the antenna controller, and the antenna. The primary reason for the split into IF and RF modules is to enable the interface to the RF equipment to the ground station at the fixed site. The block diagram for the fixed terminal is shown in Figure 3. The baseband processor is identical to that of the mobile terminal, but the RF equipment of the ground station is used instead of the mobile terminal's RF converter and vehicle antenna system.

The TC is the brain of the terminal. It contains the algorithms that translate the communications protocol into the operational procedures and interfaces among the terminal subsystems. The TC also contains the rain compensation algorithm (RCA) routines and is responsible for executing them. The SC converts input analog speech signals to a compressed digital representation at data rates of 2.4, 4.8, and 9.6 kbps, with monotonically improving voice quality. Data rate switching is controlled by the TC, and is performed "on-the-fly" to have minimal impact on the continuity of the link. For the speech codec located with the fixed terminal, an interface into the Public Switched Telephone Network (PSTN) is also provided. Through this connection, a mobile user located within the continental United States (CONUS) may place a telephone call anywhere in the world. The baseband modem implements a simple, but robust Differential Binary Phase Shift Keying (DPSK) scheme with rate 1/2 convolutional coding and interleaving. This modem also has a novel Doppler estimation and correction algorithm built in as part of its design. With this algorithm, frequency offsets many times larger than the actual operation data rate may be corrected. Higher rate capabilities (64/1 28 kbps) can be provided as well. Finally the DAS performs continuous measurement and recording of a wide array of propagation, communications link, and terminal parameters (e.g., pilot and data signal conditions, noise levels, antenna direction, vehicle velocity, and heading, etc.). The DAS also provides real-time displays of these parameters to aid the experimenters in the field.

The critical K/Ka-band technology development associated with this terminal is the antenna design. This design incorporates an elliptical reflector antenna used in conjunction with a separate High Power Amplifier (H PA) for transmissions, and a Low Noise Amplifier (LNA) for receive purposes. This antenna can provide a peak Effective Isotropic Radiated Power (EIRP) of 32 dBW and a G/T of -5 dB/°K, over a 300 MHz bandwidth. The antenna controller, monitoring a received unmodulated data signal through the two RF subsections. Elevation tracking is manually set for a particular region. The RFC provides up (down) conversion from (to) the IFC output frequency of 3.373 GHz to (from) 30 GHz (20 GHz) for transmit (receive) purposes. The IFC translates between the 3.373 GHz IF and the lower 70 MHz IF at the input/output of the modem. A key function of the IFC is the pilot tracking and Doppler pre-compensation circuitry.

BBAMT Description

The block diagram design of the BBAMT is quite similar to that of the AMT, and actually builds off the experience that was gained during this initial terminal development. Complete technical details about this terminal are provided in [3]. This terminal is initially being designed for integration into general aviation and commercial aircraft. This terminal, providing minimum data rate capabilities up to 384 kbps, also consists of a microwave and baseband processor. An identical dual RF design scheme (IFC and RFC) provides the up/down conversion between the modems 70 MHz output/input and the K- and Ka-band antenna design. The BBAMT antenna design is a new technological development that is being accomplished by Electromagnetic Sciences, Incorporated (EMS) under contract to JPL. A mechanically steerable arraying scheme has been chosen as the basic antenna design. A conceptual design of this antenna is provided in Figure 4. In order to provide sufficient link margin to support these higher data rates, this antenna design has been enhanced over the AMT's antenna design. The specifications for this antenna include a minimum EIRP of 39 dBW and a G/T of O dB/°K. This particular antenna design will also provide elevation tracking, as well as azimuth tracking.

The baseband processor consists of a modem, a video codec, and a DAS. A new modem design specification has been completed, and will be developed under contract for JPL. This basic design includes a coded (rate 1/2, constraint length 7 convolution coding) BPSK modulation scheme with interleaving. Several different commercially available video codecs will be tested as part of this terminal.” This terminal will be able to provide data rate capabilities up to a minimum of 384 kbps, suitable for compressed video transmissions. The DAS used as part of this terminal development will be of the same basic design as that used as part of the AMT.

Mobile Experiments Program

The basic objectives of the Mobile Experiments Program are: (1) to conduct a complete set of technological verification experiments that evaluate and verify the satellite’s and mobile ground terminal’s technologies, and (2) to conduct in conjunction with U.S. industry, NASA, and other interested non-NASA U.S. groups a balanced set of experiments and demonstrations that evaluate the potential telecommunications service applications of these technologies. official experimentation with the AMT began on December 6, 1993, and will continue through the end of 1995 with the BBAMT experiments. A summary of the AMT and BBAMT experiments is provided in Table 1. This list includes 21 different experiments, 16 involving the AMT and 5 involving the BBAMT. These experiments range in application (medical needs, emergency/disaster, military communications, personal communications, general communications, etc.) and platforms of use (a variety of land-mobile vehicles as well as aircraft).

One type of experiment that no U.S. industrial partner has yet to be identifed, is for a maritime-mobile experiment. An experiment of this type could be an extremely interesting proposition for non-critical communications, such as the pleasure cruise industry. One of the major drawbacks to land-mobile K- and Ka-band mobile satcom, should not be a major consideration - rain attenuation effects. Because of the non-critical nature of communications for the pleasure cruise industry, plus the fact that the routes that these ships follow rarely have significant rain events, K- and Ka-band satcom should be able to close the link for a large percentage of the time.

Utilizing the basic terminal design of the BBAMT, and adapting it to maximize its capabilities for mariitime purposes, this setup could potentially provide upwards of 45.0 Mbps of capacity for full-duplex services. Such a setup would be sufficient to provide multiple channels of digital television to a ship, and still be able to provide multiple full-duplex T1 data rate services. The key terminal modification for maritime purposes would lie in the antenna design. Whereas for the aeronautical setup a reasonably small antenna and accompanying electronics (HPA) is used, a shipboard terminal design would not have to be as restrictive. A parabolic reflector antenna design and a large HPA (on the order of 100 Watts RF output power) could be used to provide an order of magnitude more capacity than its aeronautical counterpart.

A sample forward and return link budget is presented in Tables 2 and 3, respectively, for this case. Some of the basic assumptions for this analysis is as follows: (1) a 1.2 meter parabolic antenna gimbled providing an on-pointing gain of 49.0 dBi for 29.63 GHz dB, (2) a HPA providing 100 Watts of RF output power, (3) a BPSK modem design similar to the one previously described (except for the data rate) in the BBAMT description section, and (4) operation of this setup in the waters offshore of the United States utilizing the ACTS' mechanically steerable antenna. For a data rate of 45.0 Mbps in the forward direction (T-3 data rate) and return direction, the respective link margins are 3.31 dB and 0.84 dB, respectively, with a 3 dB fade allowance included.

Summary

JPL has developed two mobile terminals that operate with ACTS, and is currently conducting a series of mobile experiments to explore the potential of K- and Ka-band to evaluate and meet the needs of future mobile satellite services. While numerous land-mobile and aeronautical-based experiments have been planned, no group has come forth to develop a maritime-mobile experiment. Such an experiment could potentially prove to be highly lucrative to the pleasure cruise industry amongst other groups. Participation by these external groups in the ACTS Experiments Program will help to expedite the transfer of these advanced technologies to the commercial sector.

References

[1] Gargione, F., "The ACTS Spacecraft," 14th AIAA International Communications Satellite Systems Conference, March 1992, Washington, D.C.

[2] Dessouky, K. and Jedrey, T., "The ACTS Mobile Terminal (AMT), " 14th AIAA International Communications Satellite Systems Conference, March 1992, Washington, D.C.

[3] Abbe, B. S., Jedrey, T. C., Estabrook, P., and Agan, M. J., "ACTS Broadband Aeronautical Experiment, " International Mobile Satellite Conference '93, June 1993, Pasadena, California.

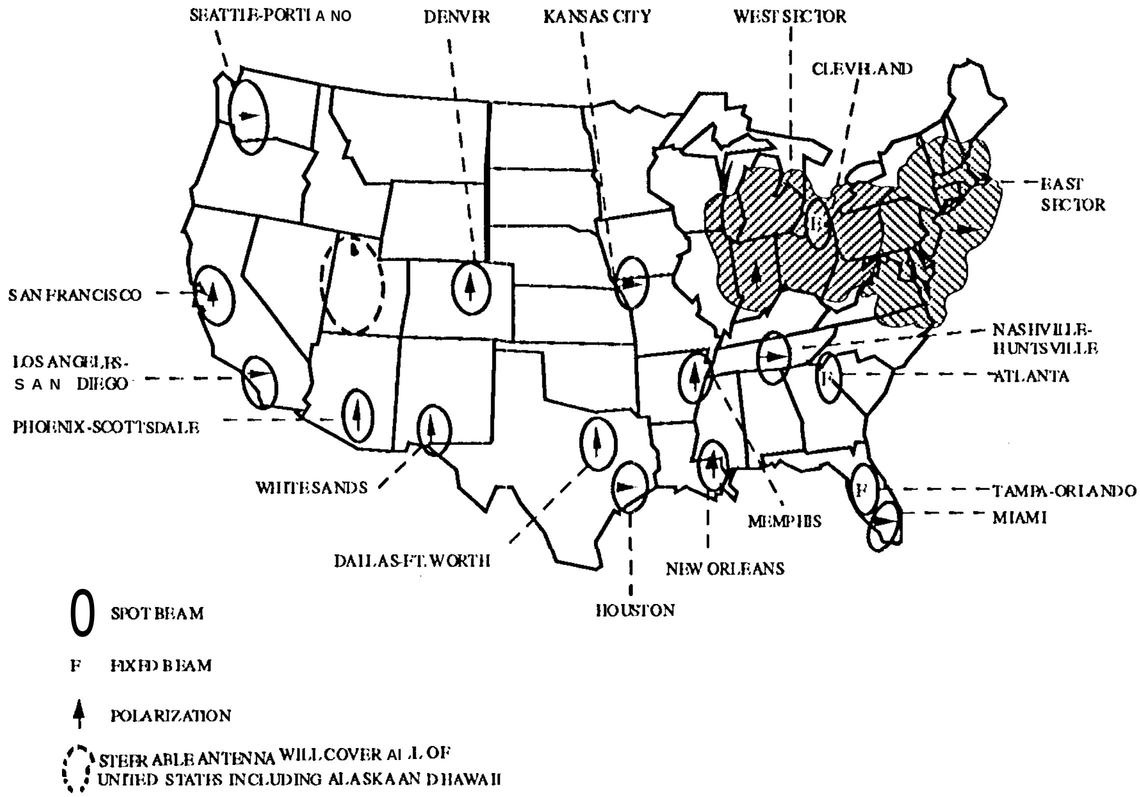

Figure 1 ACTS MBA Coverage

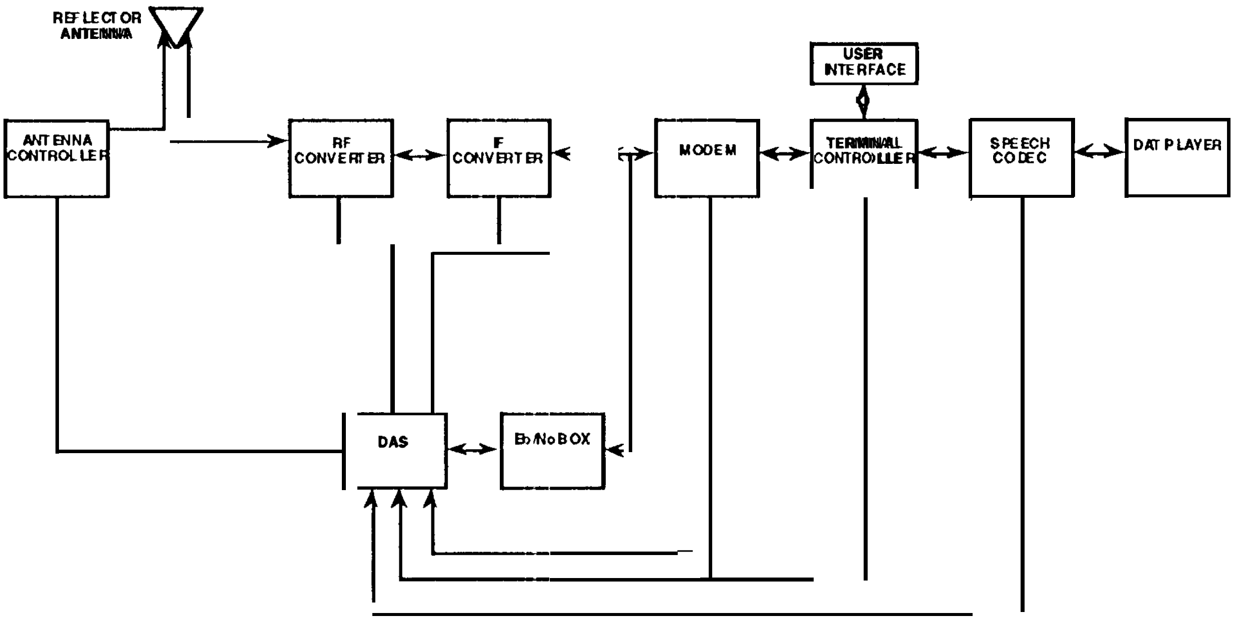

Figure 2 AMT Mobile Terminal Block Diagram

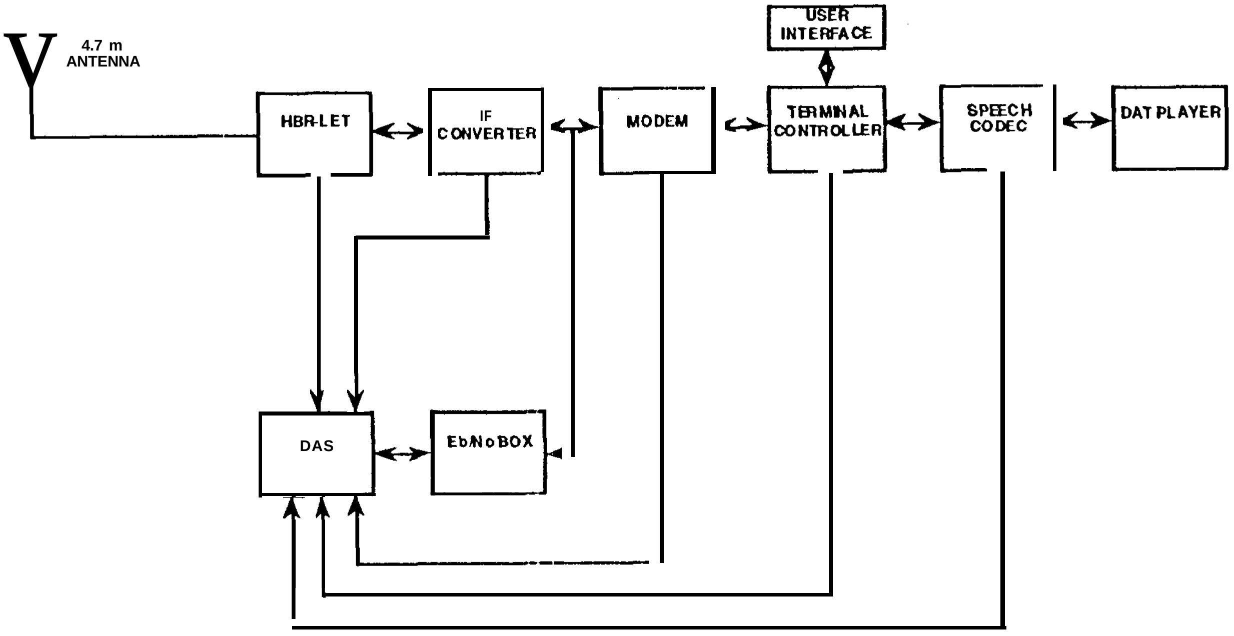

Figure 3 AMT Fixed Terminal Block Diagram

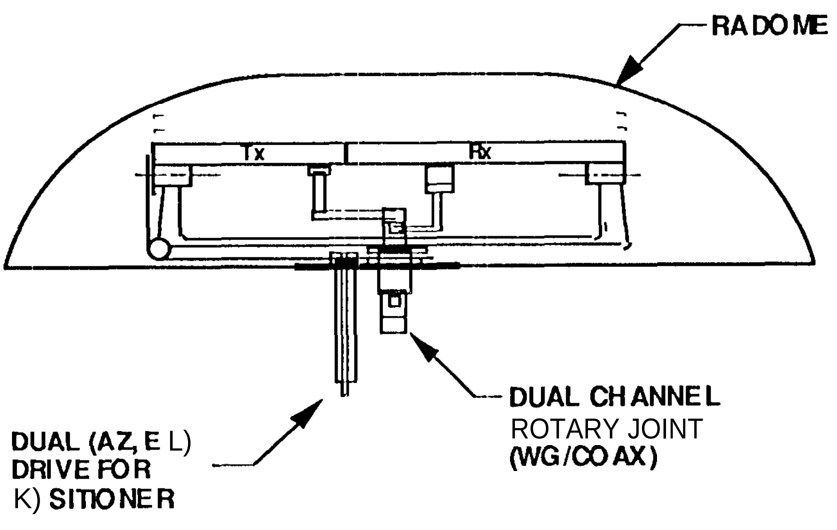

Figure 4 Conceptual Design of BBAMT Antenna

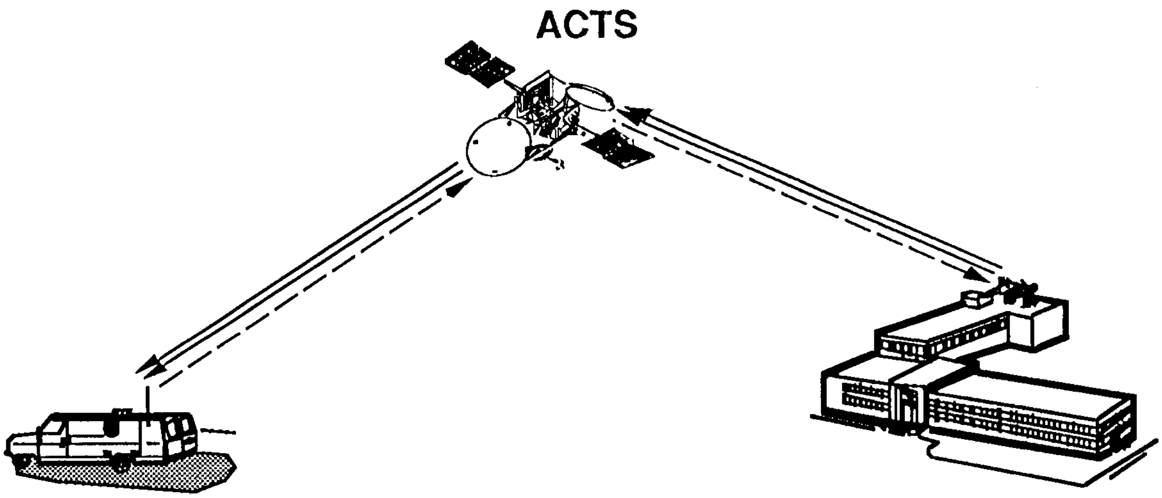

Figure 5 Baseline ACTS Mobile Experiments Configuration

Table 1 **ACTS** Mobile Experiments Summary

Experiment	Terminal	Principal Investigator
Land-Mobile, Phase I	AMT	JPL
Emergency Medical	AMT	EMSAT Corporation
Secure Land-Mobile, Phase I	AMT	NCS
Comm-on-the-Move	AMT	U.S. Army CECOM
Aero-X	AMT	NASA LeRC
Satellite/Terrestrial PCN	AMT	Bellcore
Satellite News Gathering I	AMT	IDB Communications, Inc.
Satellite News Gathering II	AMT	NBC
High Quality Audio Broadcast	AMT	CBS Radio, CCS
Enhanced Aero-X	AMT	NASA LeRC
Telemedicine I	AMT	University of Washington Medical Center
Telemedicine II	AMT	State Government of Hawaii
Land-Mobile, Phase II	AMT	JPL
Uplink Power Control	AMT	VPI
Secure Land-Mobile, Phase II	AMT	NCS
Aero Tracking& HDR	BBAMT	Rockwell International Corporation
Kuiper Airborne Observatory	BBAMT	NASA ARC
Weather Imagery Aero	BBAMT	Vigyan, NASA LaRC
Mobile ATM	BBAMT	COMSAT Laboratory
Infrared Imaging	BBAMT	NASA ARC
Army HDR	BBAMT	U.S. Army Special Forces

Table 2 Forward Link Budget for a Maritime-Mobile Experiment

Parameter	Value
UPLINK: LeRC Fixed Station-to-ACTS	
Transmit Parameters	
EIRP, dBW	71.00
Pointing Loss. dB	-0.80
Radome Loss, dB	-0.00
Path Parameters	
Space Loss, dB	-213.48
Frequency, GHz	29.63
Range, km	38000
Atmospheric Attenuation, dB	-0.36
Receive Parameters	
Polarization Loss, dB	-0.13
G/T, dB/°K	21.25
Pointing Loss, dB	-0.22
Bandwidth, MHz	900
Received C/N_o, dB-Hz	105.91
Transponder SNR_{IN}, dB	16.37
Limiter Suppression, dB	2.93
Hard Limiter Effective SNR_{OUT}, dB	19.30
DOWNLINK: **ACTS-to-BBAMT**	
Transmitter Parameters	
EIRP, dBW	62.35
Pointing Loss, dB	-0.32
Path Parameters	
Space Loss, dB	-209.89
Frequency, GHz	19.91
Range, km	37408
Atmospheric Attenuation, dB	-0.32
Receiver Parameters	
Polarization Loss, dB	-0.50
Radome Loss, dB	0.00
G/T, dB/°K	20.00
Pointing Loss, dB	-0.50
Downlink C/N_o, dB-Hz	99.28
Overall C/NO, dB-Hz	98.84
Modem Required E_b/N_o, dB	3.00
O B	
M	
N	
Link Margin, **dB**	3.31

Table 3 Return Link Budget for a Maritime-Mobile Experiment

Parameter	Value
UPLINK: BBAMT-to-ACTS	
Transmit **Parameters**	
EIRP, dBW	69.00
Pointing Loss, dB	-0.80
Radome Loss, dB	0.00
***Path* Parameters**	
Space Loss, dB	-213.34
Frequency, GHz	29.63
Range, km	37408
Atmospheric Attenuation, dB	-0.36
Receive Parameters	
Polarization Loss, dB	-0.13
G/T, dB/°K	14.50
Pointing Loss, dB	-0.22
Bandwidth, MHz	900
Received C/N., dB-Hz	97.30
Transponder SNR_{IN}, dB	**7.75**
Limiter Suppression, dB	**2.35**
Hard Limiter **Effective** SNR_{OUT}, dB	**10.10**
DOWNLINK: ACTS-to-LeRC Fixed Station	
Transmitter Parameters	
EIRP, dBW	62.00
Pointing Loss, dB	-0.32
Path Parameters	
Space Loss, dB	-210.03
Frequency, GHz	19.91
Range, km	38000
Atmospheric Attenuation, dB	-0.32
Receiver Parameters	
Polarization Loss, dB	-0.50
Radome Loss, dB	0.00
G/T, dB/°K	27.00
Pointing Loss, dB	-0.50
Downlink C/N_o, dB-Hz	96.40
Overall C/N_o, dB-Hz	96.37
Modem Required E_b/N_o, dB	3.00
Frequency Offset Degradation, dB	-1.00
ACTS Phase Noise Degradation, dB	-1.00
Fade Allowance, dB	3.00
Data Rate, Mbps	45.00
Effective C/N. Required, dB-Hz	95.53
Link Margin, dB	0.84