CHANNEL AND TERMINAL DESCRIPTION OF THE ACTS MOBILE TERMINAL

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ABSTRACT

The Advanced Communications Technology Satellite (ACTS) Mobile Terminal (AMT) is a proof-of-concept K/Ka-band mobile satellite communications terminal under development by NASA at the Jet Propulsion Laboratory. Currently the AMT is undergoing system integration and test in preparation for a July 1993 ACTS launch and the subsequent commencement of mobile experiments in the fall of 1993. The AMT objectives are presented, followed by a discussion of the AMT communications channel, and mobile terminal design and performance.

AMT OBJECTIVES

The AMT is a part of a larger ACTS program which has as it goal to pave the way for the next generation of communications satellite technology and services. The ACTS program is developing high risk technologies so as to reduce risk and thus stimulate commercial use by U.S. companies. The AMT is a mobile digital communications terminal that is being developed by the Jet Propulsion Laboratory (JPL) for NASA in an effort to advance the technology and system concepts necessary for a commercially viable mobile satellite communications system at K/Ka-band frequencies.

The AMT, as depicted in Figure 1, will demonstrate speech and data transmissions in the Ka-band mobile satellite communications channel. Ka-band is particularly promising for mobile communications because of the large amount of available spectrum and the amenability to small high gain antennas. The AMT is being developed as a mobile satellite communications platform by NASA to aide the development of aeronautical mobile, maritime mobile, land mobile, micro-terminal, and personal communications. Additionally, the AMT will be used to characterize the Ka-band mobile communications channel through a series of propagation experiments.

AMT SYSTEM ARCHITECTURE

The AMT will utilize the geosynchronous ACTS satellite in bent-pipe mode. The key ACTS technologies that the AMT will exploit include high gain spot-beam antennas and a 30 GHz uplink and a 20 GHz downlink. ACTS is scheduled to be launched into geosynchronous equatorial orbit at 100° W in July 1993. It will carry a four year supply of expendables, and has been approved for a two-year experiment cycle starting in September 1993. Funding for two additional years of experiments is pending.

The AMT uses a frequency division multiple access (FDMA) architecture. The fixed station transmits an unmodulated pilot which is used by the mobile terminal for antenna tracking, as a frequency reference for Doppler precompensation and in measuring rain attenuation, The system can run at data rates of 2.4, 4.8, 9.6 and 64 kbps.

AMT COMMUNICATIONS CHANNEL

Rain Attenuation

One of the challenges of operating at 20 and 30 GHz is that these frequencies are susceptible to rain attenuation. In preparation for ACTS launch some propagation experiments at these frequencies have been performed by Virginia Polytechnic Institute and State University (VPI) using the European Space Agencies (ESA) Olympus satellite. The experience gained with Olympus has resulted in a valuable data base of 20/30 GHz propagation data,

VPI built fixed site ground-based terminals to receive the 12, 20 and 30 GHz Olympus beacons. Due to the respective locations of Olympus (19° West) and the ground-based receivers (VA), the beacons were visible at a 14° path elevation angle, VPI conducted measurement campaigns in 1990, 1991, and 1992, and has established statistics on signal attenuation, including rain attenuation, The statistics published to date are for the period January-May 1991 [2], Yearly statistics are not available yet,

A comparison of the VPI empirical rain attenuation data has been made with the rain attenuation predicted by theory [3]. A statistical rain attenuation model (Manning's model) using the parameters of the Olympus satellite and the Blacksburg ground location was used to generate the theoretical attenuation statistics. The predicted statistics based on Manning's model are for an average year.

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Although the comparison of both the predicted and empirical data sets can only be indicative, mainly because the statistics have been established for different lengths of time, the comparison is still a valuable attempt to validate Manning's model with actual data, as it is the only experimental data available to date.

Both sets of data, predicted and empirical data sets, are analyzed in detail in [2] and [3]. The worst month case statistics derived by VPI were obtained for March and May 1991. The data demonstrates that for 94% of a month time (worst month case), the rain attenuation did not exceed 3 dB at 30 GHz and 1dB at 20 GHz. 970/. of the time the rain attenuation did not exceed 5 dB at 30 GHz and 2.5 dB at 20 GHz. 98% of the time the rain attenuation did not exceed 8 dB at 30 GHz and 3,6 dB at 20 GHz. These data points indicate how rapidly the attenuation level increases with the link availability. Manning's yearly model predicts attenuations that are lower by 3.5 dB and 1.6 dB respectively, for a link availability of 980A.

The empirical VPI data obtained for the five month period, January-May 1991, which intuitively shows less attenuation than the worst-month data, matches the yearly Manning model better. At lower attenuation levels (less than 5 dB) the empirically derived rain attenuation is more severe than predicted, and at larger attenuation levels, it is less severe.

ACTS is located at 100° West longitude; its ground-based terminals will operate at an elevation angle of at least 30°. Rain attenuation will therefore be less severe than for Olympus, due to the shorter propagation path through the atmosphere. The simulation based on Manning's model has been run for ACTS, at various locations representing the different climates and rain conditions in the US. The data demonstrates that, for a link availability of 98% of an average year, the attenuation will theoretically not exceed 1.2 dB at 30 GHz, and 1 dB at 20 GHz.

Shadowing

A mobile satellite system like the AMT is affected by shadowing and multipath propagation due to roadside obstacles and terrain conditions. The degree of shadowing depends on the intersecting path length with roadside obstacles. Many parameters affect the intersecting path, like path elevation angle, azimuth direction to the satellite, nature and geometry of the obstacle (tree, utility pole), obstacles setback from the road, lane and direction driven, size and type of road driven (rolling/flat, straight/road bends), etc. Also, the antenna pattern, the environment, rural/suburban, the season, and the frequency, affect the degree of shadowing,

No data is currently available on Ka-band shadowing effects. However, research and experiments on shadowing have been conducted at UHF(870 GHz) and L-band (1.5 GHz)[4]. These measurements have been used to quantify the influence of the system variables on the degree of shadowing and to assess the statistics of shadowing as a function of these variables.

Although the measurements have not been carried out at Ka-band, a few important conclusions can be drawn from the L-band data that are of importance for the AMT experiment, The statistics presented here were obtained at L-band, and as such, define the lower shadowing limit at Ka-band.

1) An increase/decrease of 20° in the path elevation angle (40" - 600), will significantly reduce/increase respectively the degree of shadowing, by 7.5 dB at the 2% link outage probability level [4].

2) Driving on the lane which is the farther away from the roadside obstacle can reduce shadowing significantly. The farther away the vehicle is from the obstacle, the shorter will be the intersecting path with the obstacle, thereby reducing the degree of shadowing. Also, the wider the road is, the larger will be the improvement. The data analyzed here demonstrated at the 1% probability level, a 2.5 dB reduction on a wide road with trees, and a 4 dB reduction on a narrow road with utility poles [3].

3) Fades Were calculated up to 10 to 15 dB and 1 to 8 dB at the 1% and 10% probability its, respectively [4]. These results were obtained with a low-gain antenna system using ETS-V (elevation angle 51 "). Fades for the "high gain antenna mode", were calculated up to 25 dB at the 1% probability level.

Doppler, frequency offset, and Doppler rate

A significant impairment to AMT communications is the frequency offset introduced by the various oscillator instabilities throughout the link and the Doppler and Doppler rate introduced by vehicle motion. Typical vehicular induced Doppler frequency offsets and Doppler rates can approach 3 kHz and 370 Hz/sec respectively if they are not compensated for. Oscillator instabilities can raise the total frequency offset to 10 kHz or greater depending on how often the system oscillators are calibrated.

Phase Noise

The phase noise of the AMT communications channel, though not an inherent problem of Ka-band communications, is a serious impairment that the AMT must overcome. The ACTS communication payload, having been designed for high rate transmissions, possesses very low phase noise (-108 dBc/Hz) at frequency offsets of 1 MHz, It has, however, a high phase noise specification closer to the carrier (-52 dBc/Hz at 1 kHz) which is problematic for low bit rate communications like the AMT. The AMT modulation scheme must be designed such to minimize the degradation due to this phase noise.

AMT DESIGN AND PERFORMANCE

A block diagram of the AMT is presented in Figure 2. Descriptions of each of the subsystems follows. A key feature of the AMT that is interwoven among several of the subsystems is the rain compensation algorithm (RCA) [6]. The basic premise of the RCA is that by lowering the data rate from 9.6 kbps to 4.8 or 2.4 kbps in the advent of a rain event, the link margin can bc increased by approximately 3 dB and 6 dB, respectively. The RCA is a novel algorithm by which the AMT is able to dynamically adjust the data rate to help mitigate the effects of rain attenuation. The RCA utilizes pilot power measurements at the mobile terminal and satellite beacon power measurements at the fixed terminal to determine rain attenuation, The rain attenuation information is communicated to both terminals through the AMT communications protocol [7] and a conflict free decision as to whether the data rate should bc lowered or raised is made.

The link budgets for both the forward and return links are presented in Table 1, and include actual measured subsystem performance to the extent possible. A photograph of the mobile terminal is shown in Figure 3.

Speech Codec

The speech codec 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. The 2.4 kbps compression algorithm is the government standard LPC-1 O, the 4.8 kbps algorithm is the proposed CELP government standard, and at 9.6 kbps an MRELP algorithm is adopted. Data rate switches are performed upon command from the TC based on RCA information or upon user command. Data rate switching is performed with no user intervention and "on-the-fly" to have minimal impact on the continuity of the link. Finally, the codec is capable of interfacing to the Public Switched Telephone Network (PSTN). For example, the user at the mobile terminal can place a call to a telephone anywhere in CONUS.

Terminal Cent roller

The terminal controller 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. For example, it executes the timing and handshake procedures for the interaction among the speech coder, modcm, user interface, and any external device (data source or sink) during link setup, relinquishment, or data rate change. The TC also contains the RCA routines and is responsible for executing them. The TC also has control over the operation of the IF and RF electronics and maintains high-level control over the antenna platform. The TC in addition is responsible for providing the user with a system monitoring capability and supports an interface to the data acquisition system (DAS). Finally, the TC will support the test functions required during experimentation, such as bit stream generation, correlation and bit error counting.

Modem

The baseline AMT modcm will implement a simple but robust DPSK scheme with rate 1/2 convolutional coding and interleaving. The driver here is to minimize the impact of the phase noise of ACTS on the performance of the modulation scheme . The performance of the modem at a data rate of 9.6 kbps is a bit error rate (BER) of 10^{-3} at an E_b/N_o of 6.6 dB in AWGN with frequency offsets and including modcm implementation losses. The modcm has been designed to handle frequency offsets of +/- 10.0 kHz without additional degradation. Simulations have determined that up to 1.0 dB of degradation duc to ACTS phase noise could bc experienced. Alternate pseudo-cohcrcnt BPSK modulation schemes wherein link synchronization information is imbedded into the data channel were explored for possible Eb/No performance gains, but the performance was found to bc seriously degraded in the presence of phase noise. In addition to the 2.4, 4.8 and 9.6 kbps rates the modcm will be designed to handle up to 64 kbps for the demonstration of high quality digital audio and slow scan compressed video on the forward link. Essential to the modcm design is a built-in robustness to deep, short-term shadowing. The modcm will "free-wheel", i.e., not loose synchronization through a signal outage caused by road-side trees and will reacquire the data as rapidly after such a drop-out,

IF Converter

The IF up/down converter translates between 3.373 and a lower 70 MHz IF at the output/input of the modem. A kcy function of the IF converter is pilot tracking and Doppler pre-compensation. The down-converted pilot is tracked in a phase-locked loop and used as a frequency reference in the mobile terminal. The tracked pilot is also processed in analog hardware and mixed with the up-converted data signal from the modcm to pre-shift it to offset the Doppler on the return link, The IF converter provides the TC and antenna subsystem with pilot signal strength for RCA and antenna pointing operation respectively. Finally the pilot in-phase and quadrature components arc provided to the DAS for link characterization.

RF Converter

Preceding (or following) the antenna the RF up (down) converter will convert an IF around 3.373 GHz to (from) 30 (20) GHz for transmit (receive) purposes. The choice of the 3.373 GHz IF band is dictated by compatibility with the fixed station RF hardware to bc used at NASA LcRC during demonstration. For the passive reflector antenna, the RF up-converter will also provide the antenna with sufficient power on the transmit signal through the usc of a TWTA.

Antennas

The vehicle antenna is a critical Ka-band technology item in the AMT. Two types of antennas are being developed, The first is a "passive" elliptical reflector-type antenna to be used in conjunction with a separate TWTA or a solid state power amplifier (SSPA), and the second is an "active" array antenna with MMIC HPA's and LNA's integrated onto the array. Both antennas have their distinct advantages. The reflector is simpler and less risky and when a transmit power of 1.5 W or less is required does not need the somewhat bulky TWTA. For higher data rate applications when a higher transmit power is required the reflector can be used with the TWTA. The active array, despite being more complex and risky to develop, exploits MMIC technology to overcome some of the losses in the Ka-band hardware. The integration of the amplifiers also leads to a smaller more conformal antenna assembly. The antenna will have a minimum EIRP of 22 dBW, G/T of -8 dB/K, and bandwidth of 300 MHz. Testing of the reflector antenna has found the actual minimum G/T to be -6 dB/K. The reflector will reside inside an ellipsoidal water-repelling radome of outside diameter 9" (at the base) and maximum height 3.5".

The antenna pointing system enables the antenna to track the satellite for all practical vehicle maneuvers. Either of the two 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 compliment the inertial information derived from a simple turn rate sensor, The combination will maintain the antenna aimed at the satellite even if the satellite is shadowed for up to ten seconds. 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 make the mechanical dithering scheme feasible and obviate the need for additional RF components to support electronic pointing. The necessary processing will reside in the antenna controller.

Data Acquisition System

The DAS performs continuous measurement and recording of a wide array of propagation, communication 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.

CONCLUSIONS

The ACTS mobile terminal is a proof-of-concept K/Ka-band mobile satellite communications terminal that has been developed by JPL for NASA. The terminal has been designed and the technology developed to explore the potential of a future commercial satellite system at these frequencies. They key technical challenges are to: 1) develop tracking, high-gain vehicular antennas, 2) design power efficient communications schemes, 3) compensate for high rain attenuation, 4) overcome high Doppler shifts and frequency uncertainties.

The AMT is currently undergoing system integration and test in preparation for a two year experimentation period starting in September 1993. U.S. industry has expressed significant interest in experimenting with the AMT as evidenced by the many planned experiments which are detailed in [8]. In addition a smaller derivative system is planned for broadband aeronautical experiments [9]. The goal of stimulating commercial use of K/Ka-band for mobile satellite communications is being achieved and hopefully the end result will be a commercial satellite system at these frequencies.

REFERENCES

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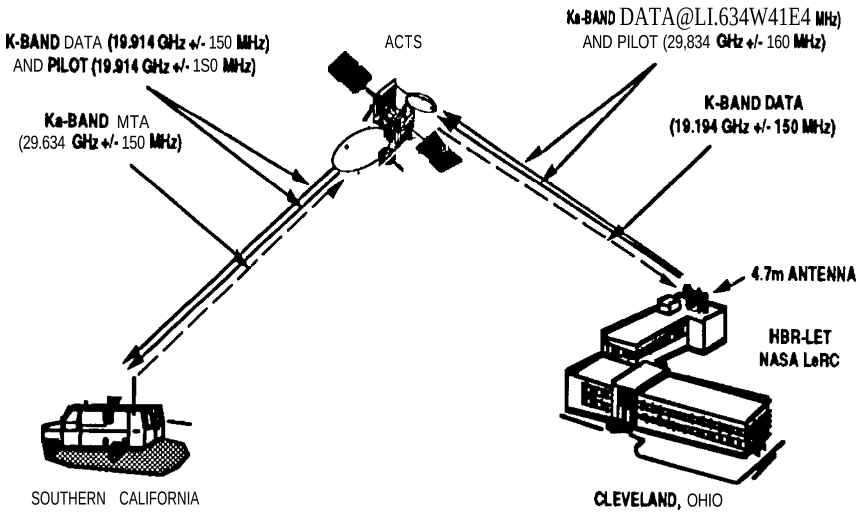

Figure 1 The AMT Experimental Setup

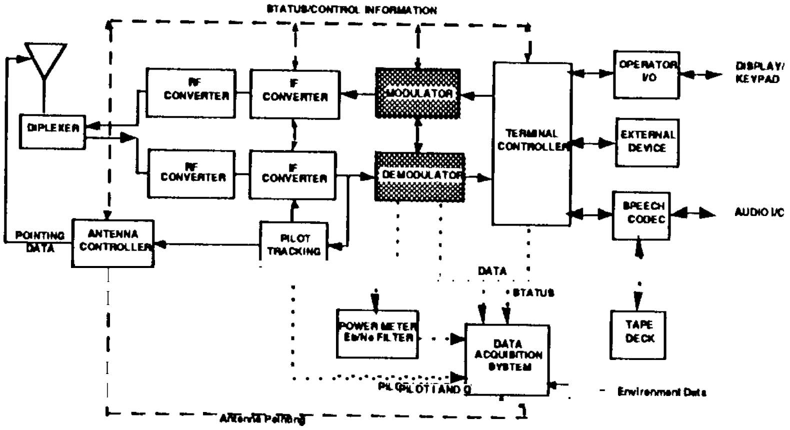

Figure 2 Block Diagram of the ACTS Mobile Terminal

Figure 3 ACTS Mobile Terminal Photograph (Mobile Terminal)

Table 1 AMT Link Budgets

RETURN (AMT-TO-ACTS-TO-HUB) LINK BUDGET

UPLINK: AMT-TO-ACTS

TRANSMITTER PARAMETERS	
EIRP, DBW (NOMINAL)	22,00
POINTING LOSS, DB	-0.50
RADOME LOSS, DB	-0.40
PATH PARAMETERS	
SPACE LOSS, DB	-213.34
(FREQ., GHZ/MHZ	29.63
RANGE, KM)	37408.00
ATMOSPHERIC ATTN, DB	-0.44
RECEIVER PARAMETERS	
POLARIZATION LOSS, DB	-0.50
G/T, DB/K	19.56
POINTING LOSS, DB	-0.32
BANDWIDTH, MHZ	900.00
RECV'D C/NO, DB.HZ	54.66
TRANSPONDER SNR IN, DB	-34.88
LIM. SUPPRESSION	-1.0$
TRANSPONDER SNR IN, DB	-35.93

DOWNLINK: ACTS-TO- HUB

TRANSMITTER PARAMETERS	
EIRP, DBW	30.06
POINTING LOSS, DB	-0.22
PATH PARAMETERS	
SPACE LOSS, DB	-210.03
(FREQ., GHZ/MHZ	19.91
RANGE, KM)	38000.00
ATMOSPHERIC ATTN, DB	-0.50
RECEIVER PARAMETERS	
POLARIZATION LOSS, DB	-0.13
ANT. DIRECTIVITY (MIN.), DBI	
SYSTEM TEMP., K	
G/T, DB/K	27.00
POINTING LOSS, DB	-0.50
DOWNLINK C/N0, DB.HZ	74.78
OVERALL C/N0, DB.HZ	53.58
REQ'D EB/N0 (AWGN--SIMULATION), DB	6.00
MODEM IMPLEMENT. LOSS, DB	0.60
REQUIRED EB/N0, DB	6.60
LOSS DUE TO ACTS PHASE NOISE,DB	1.00
FADE ALLOWANCE (OVERALL), DB	3.00
DATA RATE, BPS	9600.00
REQ'D EFFECTIVE C/N0,DB.HZ	50.42
HARDWARE PERFORMANCE MARGIN, DB	3.16

FORWARD (HUB-TO-ACTS-TO-AMT) LINK BUDGET

UPLINK: HUB-TO-ACTS

TRANSMITTER PARAMETERS	
EIRP, DBW	37,00
POINTING LOSS,DB	-0.80
PATH PARAMETERS	
SPACE LOSS, DB	-213.48
(FREQ., GHZ/MHZ	29.63
RANGE, KM)	38000.00
ATMOSPHERIC ATTN, DB	-0.36
RECEIVER PARAMETERS	
POLARIZATION Loss, DB	-0.13
G/T, DB/K	21.25
POINTING LOSS, DB	-0.22
BANDWIDTH, MHZ	900.00
RECV'D C/NO, DB.HZ	71.86
TRANSPONDER SNR IN, DB	-17.68
EFF. LIM. SUPPRESSION, DB	-1.00
HARD LIM. EFF. SNR OUT, DB	-18,68

DOWNLINK: ACTS-TO-AMT

TRANSMITTER PARAMETERS	
EIRP, DBW	45.04
POINTING LOSS, DB	-0.32
PATH PARAMETERS	
SPACE LOSS, DB	-209.89
(FREQ., GHZ/MHZ	19.91
RANGE, KM)	37408.00
ATMOSPHERIC ATTN, DB	-0.32
RECEIVER PARAMETERS	
POLARIZATION LOSS, DB	-0.50
RADOME LOSS, DB	-0.20
ANT. DIRECTIVITY (MIN.] DBI	18.90
SYS. TEMP. (REF TO REFLECTOR), K @	320.00
G/T, DB/K	-6.15
POINTING LOSS, DB	-0.50
DOWNLINK C/N0, DB.HZ	55.76
OVERALL C/NO, DB.HZ	55.63
REQ'D EB/N0 (AWGN--SIMULATION), DB	6.00
MODEM IMPLEMENT. LOSS, DB	0.60
REQUIRED EB/N0, DB	6.60
LOSS DUE TO ACTS PHASE NOISE,DB	1.00
FADE ALLOWANCE (OVERALL), DB	3.00
DATA RATE, BPS	9600.00
REQ'D EFFECTIVE C/N0,DB.HZ	50.42
HARDWARE PERFORMANCE MARGIN. DB	5.21