Chapter 8

Technology Assessment and Experimentation Plan

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8.1 Introduction

This chapter gives an assessment of the critical and enhancing technologies necessary to build the basic personal terminal (BPT), the supplier and the Network Management Center (NMC). The experimentation plan for testing PASS utilizing ACTS is detailed. The experimentation plan gives a list of candidate experiments and describes the proposed experimental set-up. ACTS will be used in the Microwave Switch Matrix (MSM) mode. The Microwave Switch Matrix - Link Evaluation Terminal (MSM-LET) at NASA Lewis Research Center (LeRC) will serve as the microwave front-end for the PASS supplier and the NMC. Link budgets are given for both the forward and return links between the supplier and the basic personal terminal. Finally the equipment required for the experiments is identified.

8.2 Identification of Critical and Enhancing Technologies

Table 8.1 lists the technologies whose development is important to the PASS project due to their role as critical/enabling or enhancing technologies for this project. The table lists the maturity level assigned to each technology based on definitions by the NASA Office of Aeronautics and Space Technology. The definitions for these maturity levels are listed in Table 8.2.

Table 8.1: Relevant Technologies - Space, Ground and Link Segments

Technologies	Importance	Maturity
Space Segment:		
Multibeam antenna and beam forming network	C	2-3
Large deployable antenna (offset-fed)	E	2-3
On-board switching (100s-1000s circuits)	E	3
On-board processing (up to 1000s carriers)	E	3
Efficient solid-state power amplifier (SSPA)	C	3
Efficient high power TWTA	C	4
Low noise receiver	C	4
Reconfigurable multibeam antenna	E	4
Dynamic interbeam power/bandwidth allocation	E	2
Ground Segment		
Low-cost, compact, tracking antenna	C	1-2
Low-cost, accurate frequency source	C	4
High-gain, low noise MMIC receiver	C	3
MMIC transmitter	C	3
Efficient SSPA	C	3
VLSI-based integrated vocoder/modem	C	5
Variable rate modem	E	4
Link Technologies:		
Rain compensation techniques	C	2-4
Efficient multiple access techniques	C	3-4
ISDN compatible networking technology	E	4
Power efficient modulation & coding	C	6
Robust modulation & coding to mitigate multipath, freq. error, and phase error	C	3
LPC voice coding (2.4 Kbps)	E	6

Legends:

C = Critical/enabling technologies
E = Enhancing technologies

Table 8.2: NASA Technology Maturity Levels

Technology Maturity Level	Technology Development Stage
1	Basic principles observed and reported.
2	Conceptual design formulated.
3	Conceptual design tested analytically or experimentally.
4	Critical function/characteristic demonstrated.
5	Component brassboard tested in relevant environment.
6	Prototype/engineering model tested in relevant environment.
7	Engineering model space qualified.

8.3 Experimentation Plan Using ACTS

8.3.1 Candidate Experiments

Three main tests will be performed. First, the communication link between supplier and basic personal terminal will be evaluated. Second, the performance of the variable rate modem and its effectiveness in combatting rain attenuation will be assessed. Third, the impact of the uplink power control schemes implemented at the supplier will be tested and evaluated.

Communication Link Tests

The communication link will be tested to confirm the calculated link budget, to assess terminal EIRP and G/T, and to check the performance of the satellite transponder on the transmitted signal.

The terminal's operational procedures will be verified under various SNR conditions. Specifically the following four features of the terminal will be tested: (1) antenna acquisition, pointing and tracking; (2) time and frequency acquisition of the BPT from the pilot signal generated by the supplier; (3) time for signal acquisition; and (4) call set-up.

The use of a low cost frequency standard in the BPT to set the frequency of the BPT's microwave local oscillators will be quantified in order to verify the noise performance and frequency stability of these local oscillators.

The modem performance will be evaluated according to the following parameters: (1) bit error rate vs. received signal-to-noise; (2) cumulative bit errors vs. time; and (3) Doppler tracking capability.

Finally, the vocoder's performance and sound quality will be assessed. The PASS 4.8

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kbps vocoder will utilize the same algorithm as the MSAT-X vocoder but will implemented with VLSI circuits.

Variable Rate Modem Test

The variable rate modem will be used in the BPT and in the supplier station. The supplier station will command a data rate change in the forward link if it is notified by the BPT that rain exists in the BPT's downlink beam. The data rate from the BPT will be decreased if rain attenuation is found in either the BPT's uplink beam or in the downlink beam to the supplier. 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 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.

Once these variable rate modem has been built, it will be tested to assess (1) response time, optimum setting of threshold levels and number of data rate steps; and (2) achieved system availability. These algorithms that control the data rate of the modulator and the vocoder will be implemented in software so that they can be refined in accordance with experimental results and retested.

Uplink Power Control

Uplink power control will be used by the supplier station alone to compensate for rain in the supplier's beam. Power control schemes frequently depend on the reception of a pilot from which fade information is calculated in order to adjust the power in the uplink beam accordingly. Either the beacon is at the identical frequency as the transmit signal, in which case a one for one adjustment of power for beacon fade attenuation may be performed, or the beacon is at a different frequency than the uplink signal, in which case frequency scaling techniques are used to predict the rain attenuation at the uplink frequency.

In the PASS experiment where NASA LeRC's MSM-LET will be used as the supplier, both methods may be tested as the MSM-LET will receive information about the beacons generated from the satellite at 20.185 GHz, 20.195 GHz, and 27.505 GHz. This will be discussed in greater depth in Section 8.3.2.

8.3.2 Proposed Experiment Set-Up

Use of ACTS and ACTS Ground Station

ACTS will be used in the microwave switch matrix (MSM) mode to connect the supplier and the BPT. In the forward link, ACTS will be commanded from the NASA Ground Station at LeRC to connect the Cleveland fixed beam to receiver #1 and IF module #1; the MSM matrix will connect the input from IF module #1 to HPA #1; and the output of this HPA will be connected to the Eastern scan sector hopping beam.[1] This beam will be kept stationary over the LA/San Diego area for the duration of the test. The forward link is shown in Fig. 8.1.

In the return link, ACTS will be commanded from the NASA Ground Station at LeRC to connect the LA/San Diego hopping beam to receiver #2 and IF module #2; the MSM matrix will the input from IF module #2 to HPA #2; and the output of this HPA will be connected to the Cleveland fixed beam for the duration of the test. Thus two of ACTS' possible three wide band transponders will be used for this experiment.[2] The return link is shown in Fig. 8.2.

As mentioned earlier, the NASA LeRC Microwave Switch Matrix - Link Evaluation Terminal (MSM-LET) will be used as the PASS supplier. This terminal is collocated with the NASA Ground Station (NGS) at LeRC. It is one of three terminals intended for use by experimenters - the other two being intended for use with the Baseband Processor (BBP) mode of ACTS, i.e., the BBP Low Burst Rate - 1 terminal and the BBP Low Burst Rate - 2 terminal. The specifications for the NGS, the MSM-LET, and the other two experimental stations are shown in Table 8.3 (taken from [1]).

The NASA Ground Station will be receiving the ACTS generated beacons at 20.185 GHz, 20.195 GHz, and 27.505 GHz. The first two beacons are fade and unified telemetry beacons; 20.185 GHz is a vertical beacon and 20.195 GHz is a horizontal beacon. These beacons are used for spacecraft telemetry using a constant modulation, to point ground terminal antenna, and to measure rain fade. The 27.505 GHz vertical pilot is a rain fade beacon only. The strength of the 27.505 GHz beacon will be monitored by the supplier to determine the necessary uplink power control. Rain fades strength on both the 20 GHz and 30 GHz beacons will be monitored and sent to the BPT so that, upon reception of the supplier generated pilot, it can differentiate between rain in the uplink and downlink beams.

To remain compatible with MSM-LET terminal, the supplier will transmit in the channel centered at 29.634 GHz $\pm$ 166 MHz and receive in the channel centered at 19.914 GHz $\pm$ 166 MHz. The ACTS frequency plan is shown in Fig. 8.3 (taken from [2]).

[1]ACTS is put into the MSM or BBP mode by a 29.975 GHz horizontal command autotrack signal which is transmitted from the NGS.

[2]ACTS possesses four wideband transponders; however, one is used for redundancy so that only three can operate at any one time.

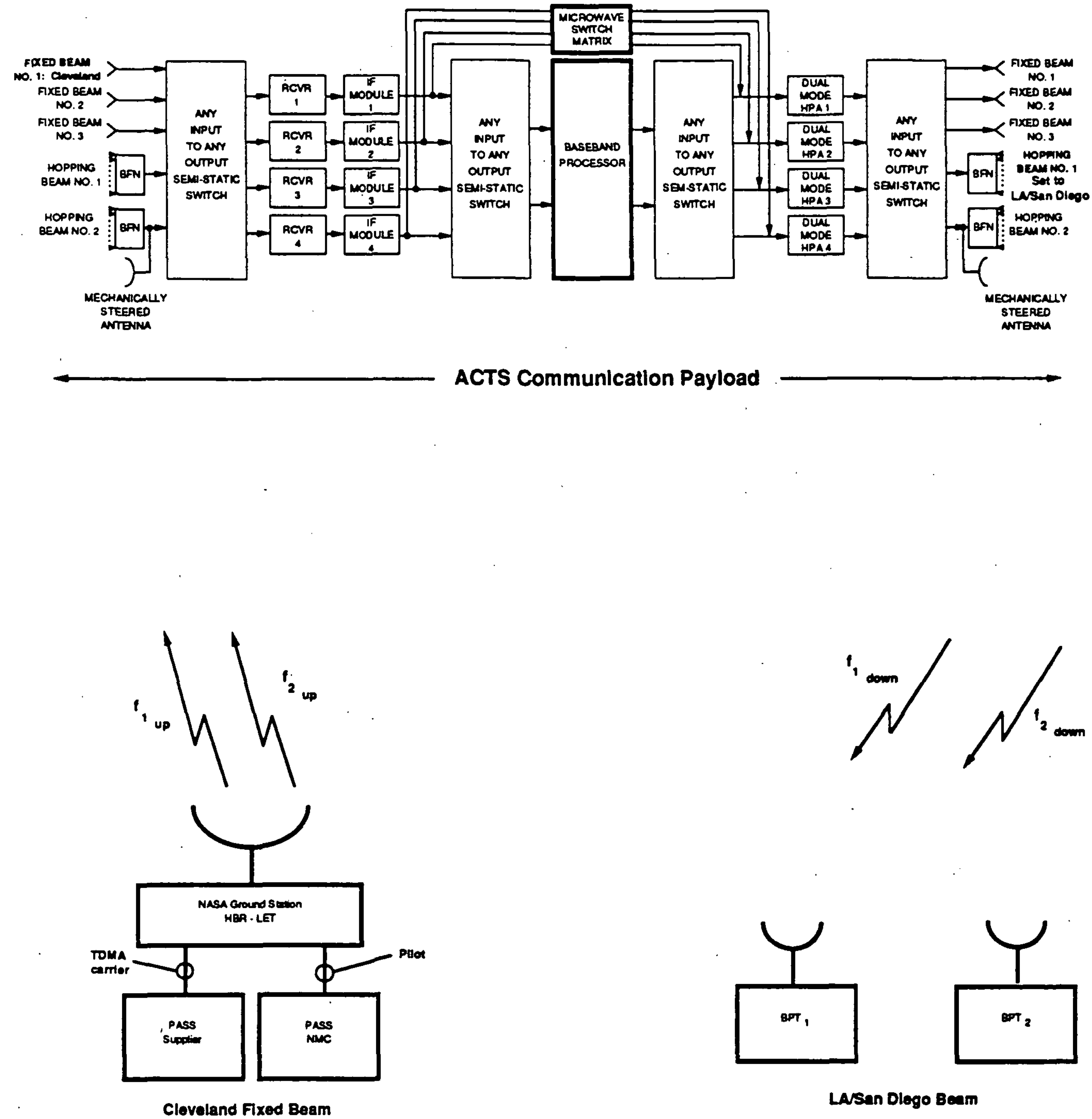

Figure 8.1: Forward link demonstration.

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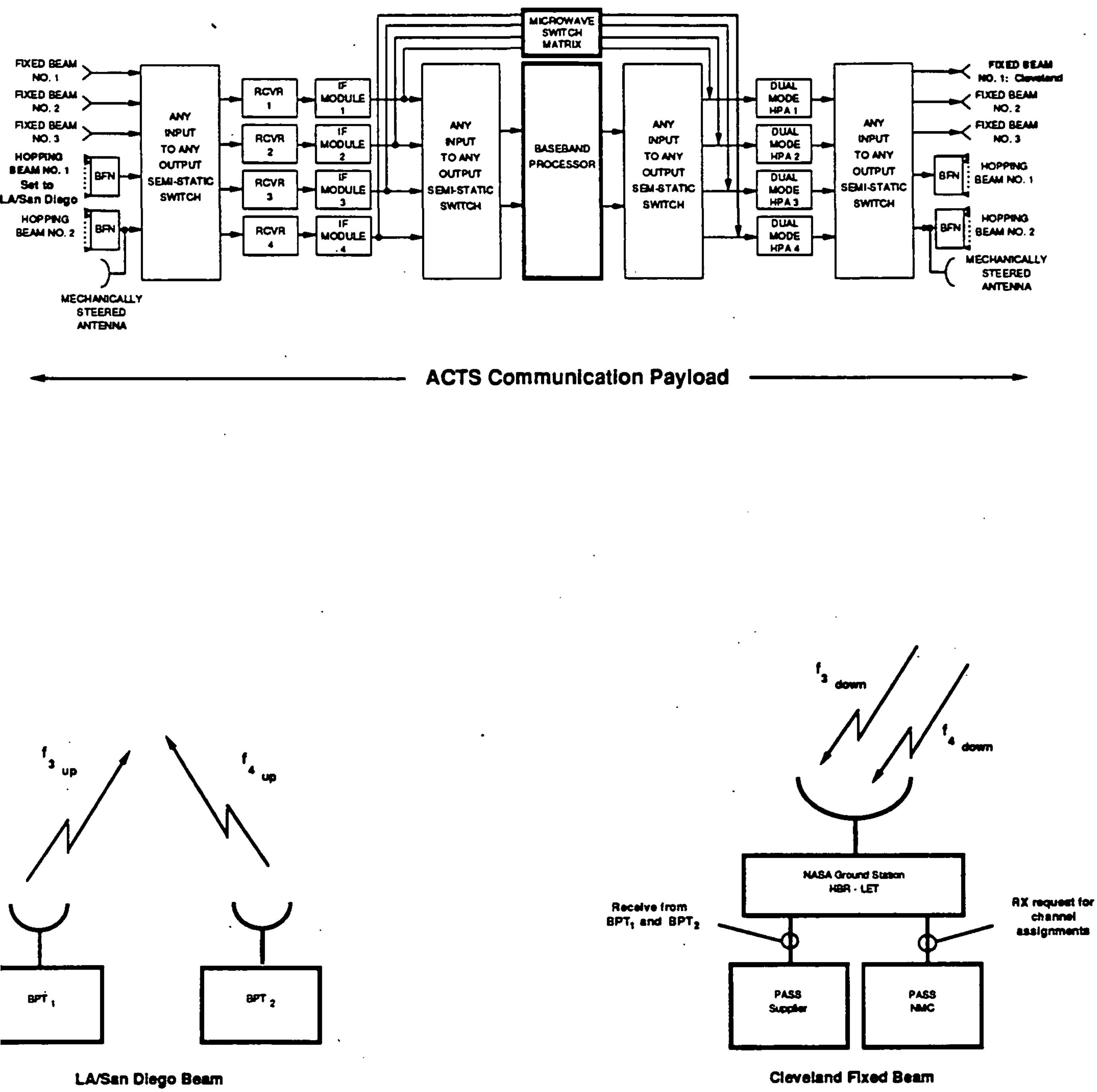

Figure 8.2: Return link demonstration.

Table 8.3: Types of ACTS Earth Stations

	NASA Ground Station	BBP/ LBR-1 (Portable)	BBP/ LBR-2	NASA MSM Link Evaluation Terminal
EIRP	74dBW/68dBW	72dBW/66dBW	66dBW/60dBW	76dBW/68dBW
G/T	>27 dB/K	≈22/16 dB/K	≈22/16 dB/K	>27 dB/K
Antenna Diameter	≈5.0 m	2.4 m	2.4 m/1.2 m	4.77 m
High Power Amplifier	54W/14W	≈65W/16W	≈16W	60W
Uplink Burst ‡ Rate	LBR-1/LBR-2	110/55 Mbps	27.5/13.8 Mbps	220/110 Mbps
Downlink Burst Rate	110/55 Mbps	110/55 Mbps	110/55 Mbps	220/110 Mbps

† Earth station requirements depend on location within the ACTS antenna coverage. 90% of expected experimenter locations can use the lower $EIRP$ and G/T values.
‡ Lower burst rate used to compensate for rain fade.

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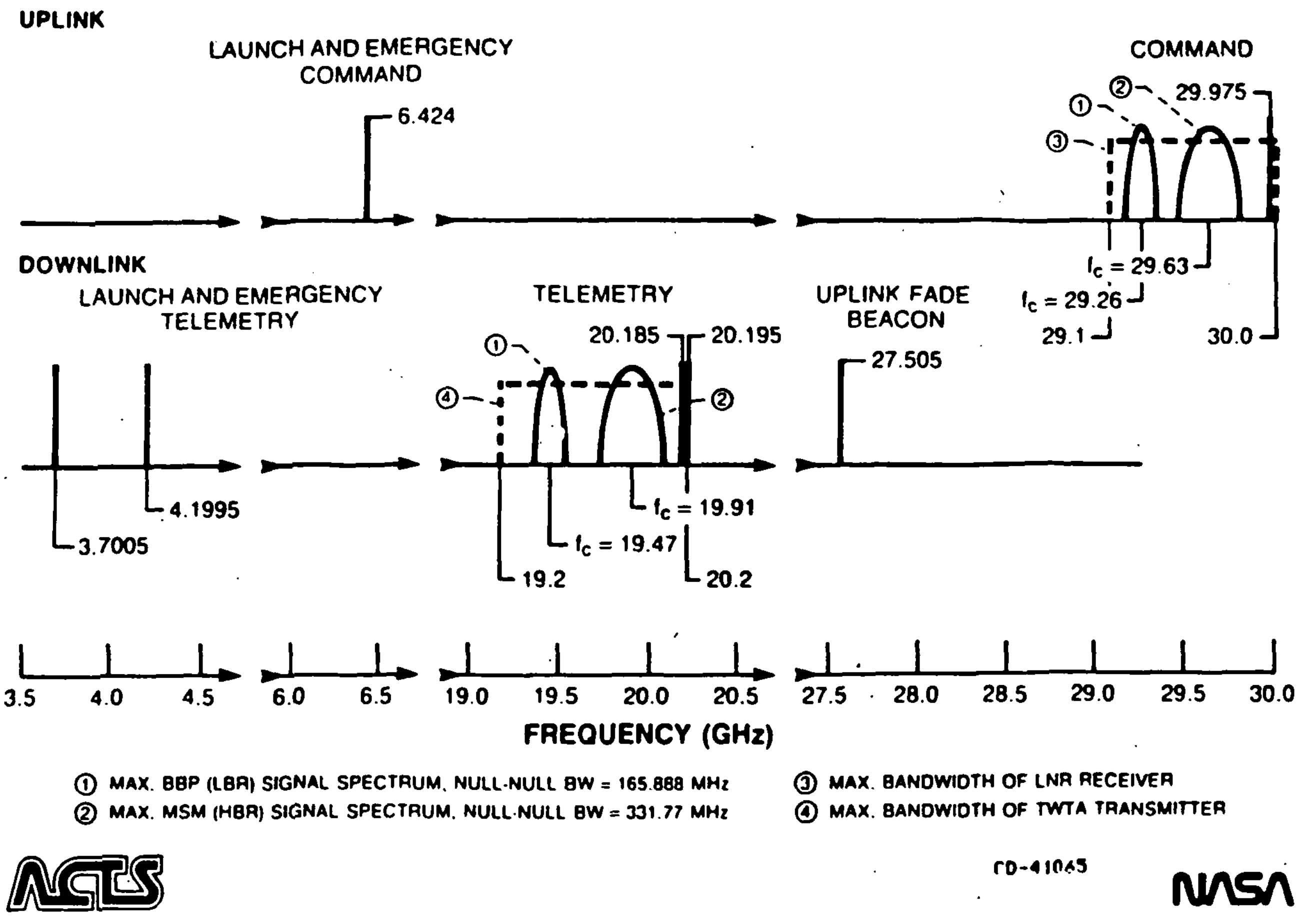

Figure 8.3: Frequency location of ACTS pilots.

Link Budget Assumed for Experiment

The link budget for the forward link is given in Table 8.4. Two equal power signals are assumed to be transmitted from the supplier in the forward link: the supplier generated pilot and the TDMA information signal, nominally set to 100 Kbps. In this plan, the pilot would be used as a beacon for the BPT's antenna to acquire and track the satellite signal, to set the frequency reference for the BPT, and for rain fade information. The performance of the MSM-LET terminal is taken from LeRC's link budgets: transmit losses are due to feed losses of 0.76 dB and waveguide losses of 3.43 dB. The transmit power varies from 10W to 65 W saturated. The $EIRP$ is taken to vary from 68 - 75 dBW depending on the drive level of the TWTA. Satellite multibeam edge of beam gain is taken from NASA's LET link calculation for 220 Mbps SMSK experiment using the Cleveland/Cleveland fixed beam mode. Satellite system temperature is calculated based on a receiver noise temperature of 3.4 dB and an antenna view temperature of 300 K as per the assumptions taken in the G/T calculation in the GE presentation at the ACTS Critical Design Review [2]. The downlink multibeam antenna gain and transmit losses are taken from [3] for the LA/San Diego beam. The effect of the limiter in the ACTS transponder is calculated as in [4]. First, limiter suppression factor, Γ, is calculated. Then, the transmit power is calculated from:

$$P_{TX} = P_{max}\left(\frac{SNR_{in}\,\Gamma}{SNR_{in}\,\Gamma + 1}\right)$$

where P_{max} is the maximum output of the satellite TWT - for two equal power signals transmitted on the uplink, the maximum power in each signal is $P_{max}/2$. The overall C/No is found from:

$$C/N_{overall} = \frac{1}{(C/N_{up}\,\Gamma)^{-1} + (C/N_{down})^{-1}}.$$

$C/No_{overall}$ for the forward link is 63.0 dB-Hz; the required C/No for 100 Kbps operation at a BER of 10^{-5} with a convolutional code with $r = 1/2$ and $K = 7$ is 54.5 dB-Hz. The forward link margin is therefore 8.5 dB.

The link budget for the return link is given in Table 8.5. Only one signal, an SCPC 4.8 Kbps signal, is transmitted from the BPT in the return link.[3] Again, the characteristics of the LA/San Diego beam are taken from [3] and system temperature assumes a receiver of 3.4 dB and an antenna view temperature of 300 K from [2]. To present a conservative link budget, the gain of the multibeam transmit antenna is taken from [3] to be 51.3 dB rather than the 53.1 dB in the LeRC's calculation for the 220 Mbps SMSK experiment. The transmit losses in the multibeam transmit antenna are taken from the above LeRC link calculation to be 4.1 dB rather than the lower 3.8 dB listed in [3]. $C/No_{overall}$ is calculated to be 44.4 dB-Hz as compared with the required C/No 41.3 dB-Hz for a BER of 10^{-5} with a convolutional code with $r = 1/2$ and $K = 7$. The return link margin is therefore 3.1 dB.

[3]This assumption translates into the use of one BPT in the LA/San Diego beam, in fact it may be interesting to simulate operation of a network with several BPT transmitting at once. The effect of several uplink signals upon the ACTS transponder limiter will then have to be taken into account.

Table 8.4: Forward Link Calculation with ACTS

Uplink Supplier to Satellite 30 GHz		Downlink Satellite to BPT 20 GHz	
MSM-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 Power	11.2 dBW/channel	TX Power (46W max)	13.5 dBW
TX Losses	-4.19 dB	TX Losses	-4.7 dB
TX Polarization	HP	TX Polarization	VP
EIRP	68 dBW	EIRP (61.7 dBW max)	56.9 dBW
$L_{pointing}$	-0.39 dB	$L_{pointing}$	-0.5 dB
Propagation Losses (Clear Weather):		Propagation Losses (Clear Weather):	
$L_{Atmosphere}$	-0.61 dB	$L_{Atmosphere}$	-0.92 dB
L_{Space} (Clev. to ACTS)	-213.46 dB	L_{Space} (ACTS to LA)	-209.88 dB
$L_{Polarization}$	-0.5 dB	$L_{Polarization}$	-0.5 dB
$L_{Co-channel\ Interference}$	-1.0 dB	$L_{Co-channel\ Interference}$	-1.0 dB
Satellite:		Basic Personal Terminal in LA:	
$L_{Pointing}$	-0.5 dB	$L_{Pointing}$	-0.7 dB
G/T (Clev. Fixed Beam)	19.6 dB/K	G/T	-9 dB/K
Antenna Gain (2.2m)	50.1 dBi	Antenna Gain	19.3 dBi
System Temperature	30.9 dBK	System Temperature	28.3 dBK
C/T	-128.85 dBW/Hz	C/T	-165.6 dBW/Hz
C/No_{up}	99.75 dB-Hz	C/No_{down}	63.0 dB-Hz
B_T (900 MHz)	89.54 dBHz		
SNR_{in}	10.21 dB		
Limiter Suppression Factor, Γ	2.0		
Overall Link Performance:			
$C/No_{overall}$		63.0 dB-Hz	
$C/No_{required}$ (for 100 kbps operation)		54.5 dB-Hz	
Link Margin		8.5 dB	

Table 8.5: Return Link Calculation with ACTS

Uplink BPT to Satellite 30 GHz		Downlink Satellite to Supplier 20 GHz	
Basic Personal Terminal in LA:		Satellite:	
f_{center} (uplink)	29.63 GHz	f_{center} (downlink)	19.91 GHz
Antenna Gain	22.8 dBi	Antenna Gain (3.3m)	51.3 dBi
TX Power	-5.5 dBW/channel	TX Power (46W max)	-28.4 dBW
TX Losses	-1.0 dB	TX Losses	-4.1 dB
TX Polarization	HP	TX Polarization	VP
EIRP	16.3 dBW	EIRP (64.8 dBW max)	18.78 dBW
$L_{pointing}$	-0.7 dB	$L_{pointing}$	-0.5 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.)	-210.0 dB
$L_{Polarization}$	-0.5 dB	$L_{Polarization}$	-0.5 dB
$L_{Co-channel\ Interference}$	-1.0 dB	$L_{Co-channel\ Interference}$	-1.0 dB
Satellite:		MSM-LET at LeRC:	
$L_{Pointing}$	-0.5 dB	$L_{Pointing}$	-0.39 dB
G/T (LA/SD Spot Beam)	17.3 dB/K	G/T	27 dB/K
Antenna Gain (2.2m)	49.2 dBi	Antenna Gain (4.7m)	57.5 dBi
System Temperature	30.9 dBK	System Temperature	30.5 dBK
C/T	-183.05 dBW/Hz	C/T	-167.52 dBW/Hz
C/No_{up}	45.55 dB-Hz	C/No_{down}	61.08 dB-Hz
B_T (900 MHz)	89.54 dBHz		
SNR_{in}	-43.99 dB		
Limiter Suppression Factor, Γ	$\pi/4$		
Overall Link Performance:			
$C/No_{overall}$		44.4 dB-Hz	
$C/No_{required}$ (for 4.8 kbps operation)		41.3 dB-Hz	
Link Margin		3.1 dB	

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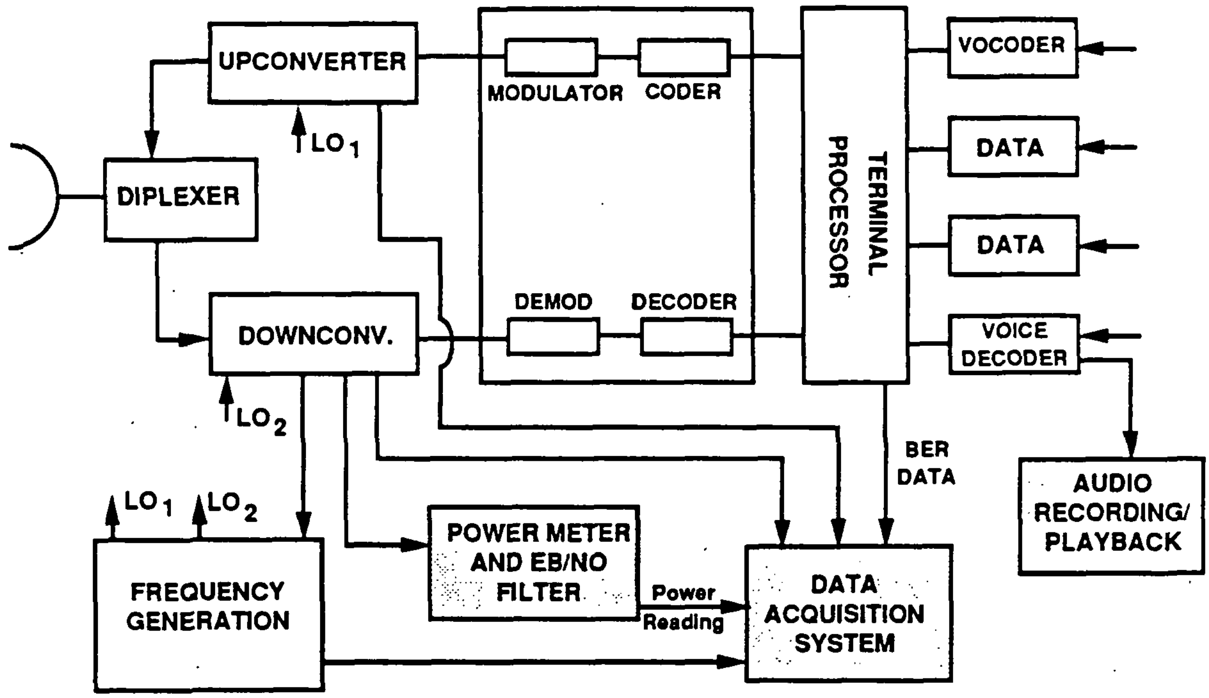

Figure 8.4: Modified user terminal.

From Tables 8.4 and 8.5, it can be seen that the dynamic range required at the output of the BPT is 132 dB, as the BPT transmits a -5.5 dBW signal and receives a -137.3 dBW signal. The dynamic range required at the MSM-LET is greater, 148 dB, as it transmits an 11.2 dBW signal and receives a -137.0 dBW signal.

Equipment Required for ACTS Experiment

For these experiments, it will be necessary to modify the BPT from the prototype specified in the PASS study report [4]. These modifications depend upon the number of BPTs that will be transmitting simultaneously (due to the limiter in the ACTS transponder) and on the certain specifications of the MSM-LET. A block diagram of the modified user terminal is shown in Figure 8.4. The interface equipment to the MSM-LET, which simulates the PASS NMC and the supplier, is shown in Figure 8.5. The measurement and analysis equipment is shown in each figure.

The ACTS experiment will require the following equipment: (1) two BPTs, one for test and one for backup or, possibly, both used simultaneously for network demonstration; (2) a modified NMC station containing only baseband to IF equipment, the NMC's function is to generate the pilot for the LA/SD beam and to handle channel assignment requests from BPTs; and (3) a modified supplier station containing only baseband to IF equipment, it is simplified to transmit one TDM signal to the BPT and to receive one or more SCPC signals

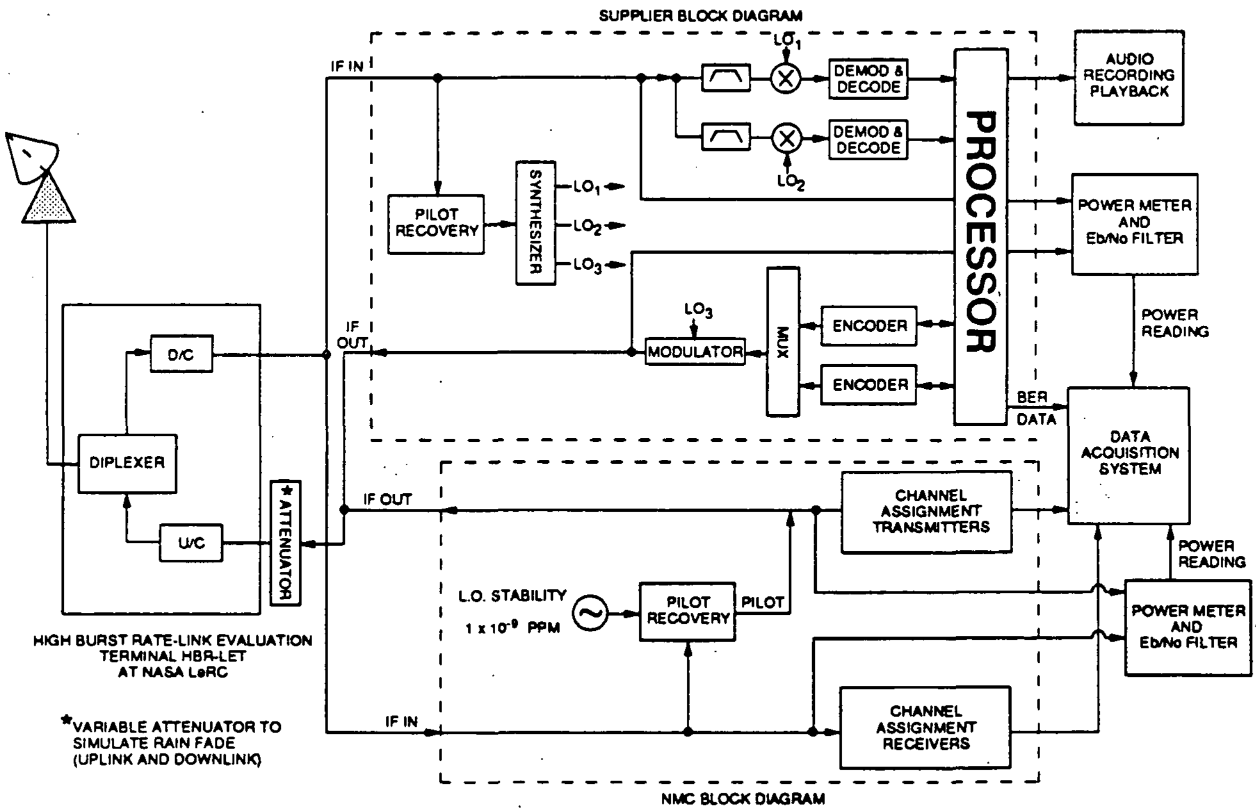

Figure 8.5: Interface equipment to Cleveland Master Station (MSM-LET).

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from the BPT(s). The NMC and supplier equipment will be located at NASA LeRC; they will utilize the RF up/downconverters and the 4.7m antenna of the MSM-LET terminal. The latter interfaces with the NGS terminal to obtain rain fade information about the 20.185 GHz, 20.195 GHz, and 27.505 GHz beacons.

The following measurement and analysis equipment will be necessary: (1) BER measurement set-ups: one for each BPT and one to be shared by the supplier and NMC; (2) signal-to-noise measurement set-ups: one for the BPTs and one to be shared by the supplier and NMC; (3) data acquisition systems: one for the BPTs and one to be shared by the supplier and NMC; and (4) voice recording/playback equipment: one for the BPTs and one to be shared by the supplier and NMC.

The specifications for the receive portion, the transmit portion and the antenna of the modified user terminal are given in Tables 8.6, 8.7 and 8.8, respectively. Table 8.7 lists the BPT's transmit power as varying from 0.28 Watts to 0.56 Watts - the higher power is necessary to overcome the effects of the limiter if two BPTs were to use the same ACTS transponder.

8.4 Conclusion

The components of a personal access satellite system, i.e., a BPT and the supplier and NMC equipment, can be built in time for a demonstration of PASS using ACTS; however, the construction of certain components will necessitate the development of key technologies. Testing the PASS system on ACTS is feasible. The satellite will be used in the Microwave Switch Matrix mode and the front-end and antenna of the LeRC MSM-LET will be employed for the PASS supplier and NMC stations. Link margins of 8.5 dB and 3.1 dB on the forward and return links, respectively, can be then be achieved. These clear weather margins guarantee that a reasonable test of PASS is possible with ACTS.

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Table 8.6: Preliminary Specifications for Modified BPT - Receive Side

Center Frequency	19.914 GHz		
RF Bandwidth	1000 MHz		
Max. No. of RX Subbands	9		
Subband Components:	Number/subband	Bit rate	BW
Pilot	1		5 KHz
BPT - TDMA Carrier	1 or more	100 Kbps	410 KHz
EPT - TDMA Carrier	1 or more	300 Kbps	1210 KHz
G/T	-9.0 dB/K		
Data Rates	96 Kbps (nominal) 48, 24 Kbps (fade)		
Modulation, Access	BPSK, TDMA		
Coding	r=1/2, K=7 convolutional code		
Received Signal Power	-137.3 dBW (nominal)		
C/No	63.0 dBHz		
C/No Required	54.5 dBHz (BER=10^{-5} at 100 Kbps)		
Link Margin	8.5 dB		
Noise Floor (kTB)	-144.2 dBW (@ 96 Kbps)		
Dynamic Range	TBD		
Received Pilot Power	-137.3 dBW (nominal)		
Frequency Acq. Time	500 ms (maximum)		
Modem Loss	1 dB		
LO Freq. and Phase Stab.	TBD		
Transponder Freq. Uncertainty	TBD		

Table 8.7: Preliminary Specifications for Modified BPT – Transmit Side

Center Frequency	29.634 GHz
RF Bandwidth	900 MHz
Max. No. of RX Subbands	9
Subband Components:	Number/subband BW
Demand Assigned 4.8 Kbps Channels	1 or more 24.2 KHz
Transmit Power	0.28 Watts (nominal) to 0.56 W
Link Margin	3.1 dB
EIRP	16.3 dBW (nominal)
Data Rates	4.8 Kbps (nominal) 2.4, 1.2 Kbps (fade)
Modulation, Access	BPSK, SCPC
Coding	r=1/2, K=7 convolutional code
Freq. Stability	TBD

Table 8.8: Preliminary Specifications for Modified BPT Antenna

Gain	22.8 dB @ 30 GHz 19.3 dB @ 20 GHz
Coverage	360° Azimuth 15-60° Elevation
Pointing Accuracy	TBD
Polarization	Linear*
Axial Ratio	2 dB (Design Goal)
Antenna Size	TBD
Acquisition Mode	Manual or Automatic
Acquisition Time	<2 sec under nominal conditions

* Linear polarization is assumed for link calculation. Transmit and receive signals from BPT are relayed by the ACTS satellite on orthogonal polarizations (horizontal and vertical).

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