Channel Characterisation for Future Ka-band Mobile Satellite Systems and Preliminary Results

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Abstract

Mobile Satellite Systems (MSS) are presently designed or planned to operate, with the exception of OMNITRACKS, in the lower part of the frequency spectrum (UHF to S-bands). The decisions taken at the last World Administrative Radio Conference in 1992 to increase the allocated L- and S-bands for MSS services will only partly alleviate the problem of system capacity. In addition the use of L- and S-band frequencies generally requires large antenna apertures on board the satellite terminal side. The idea of exploiting the large spectrum resources available at higher frequencies (20-30 GHz) and the perspective of reducing user terminal size (and possibly price too) have spurred the interest of systems designers and planners ([1]-[3]). On the other hand, Ka-band frequencies suffer from increased slant path losses due to atmospheric attenuation phenomena.

The European Space Agency (ESA) has recently embarked on a number of activities aimed at studying the effect of the typical mobile propagation impairments at Ka-band. This paper briefly summarizes ESA efforts in this field of research and presents preliminary experimental results.

1   Introduction

The advantages of Ka-band for future Land Mobile (LMS) and Personal Access Satellite Systems (PASS) can be summarized as follows:

- large spectrum resources (more than 1 GHz at Ka-band, downlink) would dramatically relax the requirements on frequency reuse and efficient on-board channel routing and processing, currently envisaged for L-band LMS systems;

- mobile terminal and spacecraft antenna sizes could be considerably reduced hence increasing market potential and lowering payload mass, respectively;

- share of the on-board resources of Fixed Satellite Services (FSS) (e.g. EUTELSAT with its EUTELTRACKS system) could be of great benefit for the satellite operators.

The price to pay, at least from the channel viewpoint, is an increased attenuation effect due to tropospheric phenomena such as rain, clouds, water vapour, and to blockage. In order to compensate for these propagation impairments, link margins higher than at L- or S-bands should be budgeted for. Unlike for UHF to S-bands ([4]-[5]), the typical mobile propagation phenomena, blockage and multipath, have not been thoroughly studied so far in the Ku-/Ka-band frequency range.

The lack of comprehensive and consistent information on the mobile propagation channel was one of the reasons which led ESA to fund two activities: the design and development of a multifrequency narrowband mobile receiver, and the first extended Ka-band LMS experimental campaign, in different European locations and environments. The identification of an empirical law linking RF signals and optical images was the second objective of these two research activities; at these high frequencies, in fact, the terminal antenna radiation pattern is highly directive (in our test case, we had a beamwidth of 2.4 degrees, [6]) and rather insensitive to multipath effects. An empirical law could be therefore found which uniquely associates RF shadowing to optical shadowing (see [7] for previous experiences) hence information on blockage effects can be obtained from passive rather than active experimental campaigns. In order to achieve these objectives ESA placed two contracts, the first on 1992 with the Danish company RESCOM to design and build a mobile Ka-band beacon receiver, and the second one in 1993 with the Joanneum Research Institute, Austria, to run a narrowband experimental campaign in different European locations. This paper shortly reports on the main features of the mobile beacon receiver and also presents preliminary results of the narrowband measurement campaign.

2 The Ka-band Land Mobile Beacon Terminal (LMBT)

The Ka-band LMBT is a narrowband receiver installed in a van, conceived and built to carry out LMS experimental measurements. It is currently equipped with a Ka-band antenna but has been designed as a multifrequency receiver so that experimental propagation data can be recorded and stored at up to three different frequency bands, simultaneously. This feature could allow for the possibility of frequency scaling empirical fade laws in a more rigorous way.

The Ka-band LMBT was originally designed to operate with the Olympus polarization-switched B1 beacon, at 19.8 GHz; on a later stage of the contract and due to the premature demise of Olympus, the LMBT RF front-end was eventually modified and it presently operates with the Italsat F1 18.7 GHz beacon. Italsat is an Italian telecommunication satellite which in addition to a number of communication payloads also carries on board three beacons for propagation experiments. The 18.7 GHz beacon has a reduced coverage in comparison with Olympus (Italy and the alpine region with its main beam) and offers a slightly less dynamic range at the receive mobile terminal.

Fast signal acquisition and tracking combined with stringent operational constraints (van speed and resulting Doppler, medium to long fade durations and related re-acquisition performance) were indoubtely the driving factors in the design of the Ka-band LMBT. Particular attention was also given to the data acquisition and video subsystems which had to handle a considerable amount of data, in real-time. Finally the whole receiver needed to be built and integrated in the van to insure robustness and sturdiness in mobile operational scenarios. The final LMBT configuration resulting from this set of requirements presently consists of the following subsystems:

1. Antenna: Cassegrain antenna with rotatable feed and radome;

2. Pointing: gyro-stabilized elevation-over-azimuth platform;

3. Receiver: RF units mounted on the platform and a rack-mounted detector unit, inside the van;

4. Data Acquisition System: a high capacity tape streamer for data recording and a computer for acquisition and handling of measurements data;

5. Central Control System: the operator PC and the interfacing network;

6. Video System: two colour CCD cameras and a video mixer;

7. Power System: a motor/generator unit and a 24V battery pack;

8. Van: a Mercedes-Benz 208D passenger van with heater and air-conditioning units.

The rotating platform is mounted on a metallic chassis and can be lowered down through the chassis inside the van to ease maintenance and house-keeping operations. Vibration dampers connect the chassis and the two 19" racks to the passenger van to filter out the effects of vibrations produced by the movement of the vehicle, and by the engine and generator. A functional block diagram of the LMBT and the layout of its physical configuration are given in Figs. 1 and 2, respectively. A short description of the performance and features of the LMBT subsystems is hereafter presented.
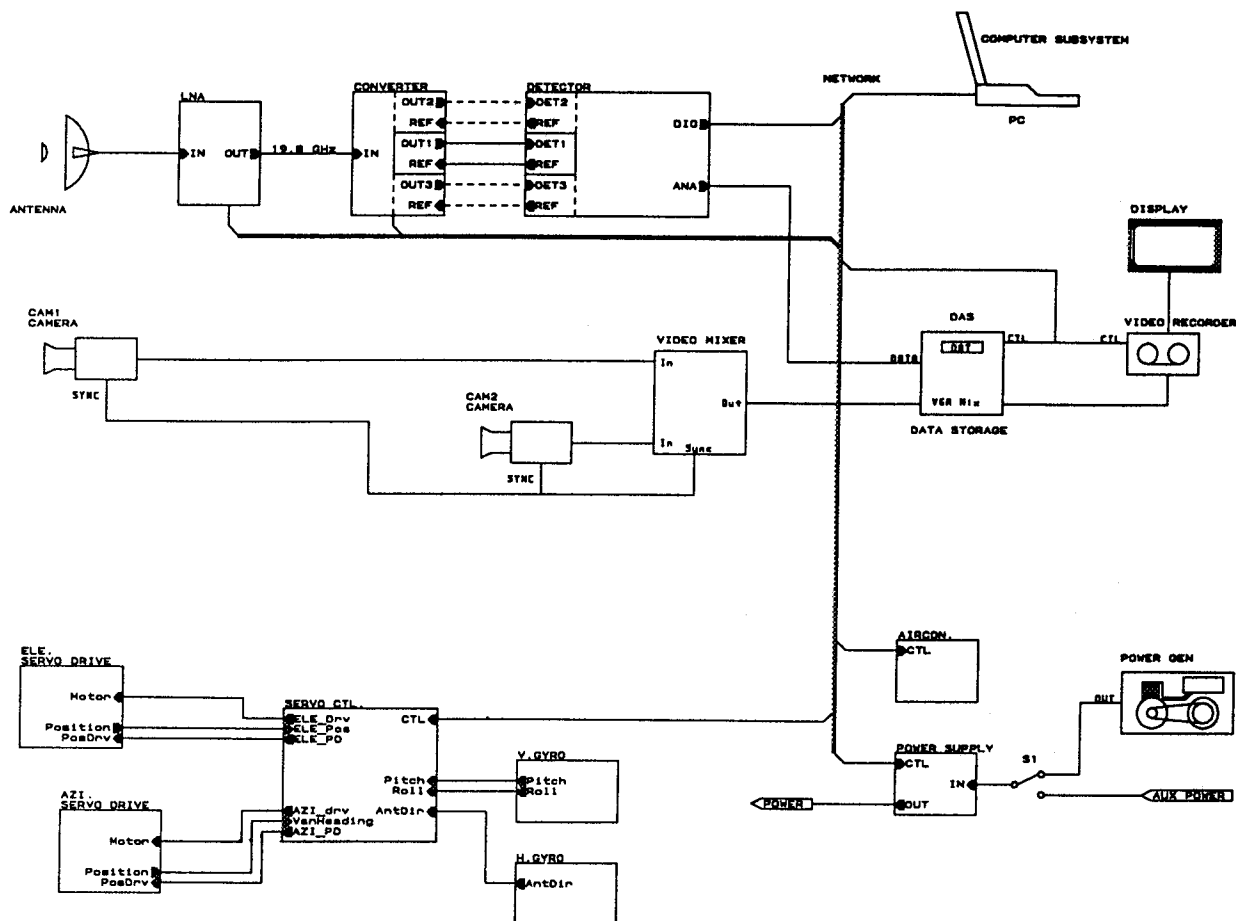

Figure 1: LMBT functional block diagram

2.1 The antenna subsystem

The antenna was designed to provide a gain able to ensure a minimum dynamic range of 30 dB (with a 50 Hz PLL bandwith, locked mode) in all experimental scenarios and to achieve a good pointing accuracy. The trade-off between gain and beamwidth led to the design of an antenna with the following characteristics (measured):

Antenna type	Cassegrain
Main reflector diameter	50 cm
Subreflector diameter	9.5 cm
Gain at 18.7 GHz	35.8 dBi
Beamwidth, 3 dB	2.4°
Return loss at 18.7 GHz	35.0 dB

Table 1: LMBT antenna characteristics
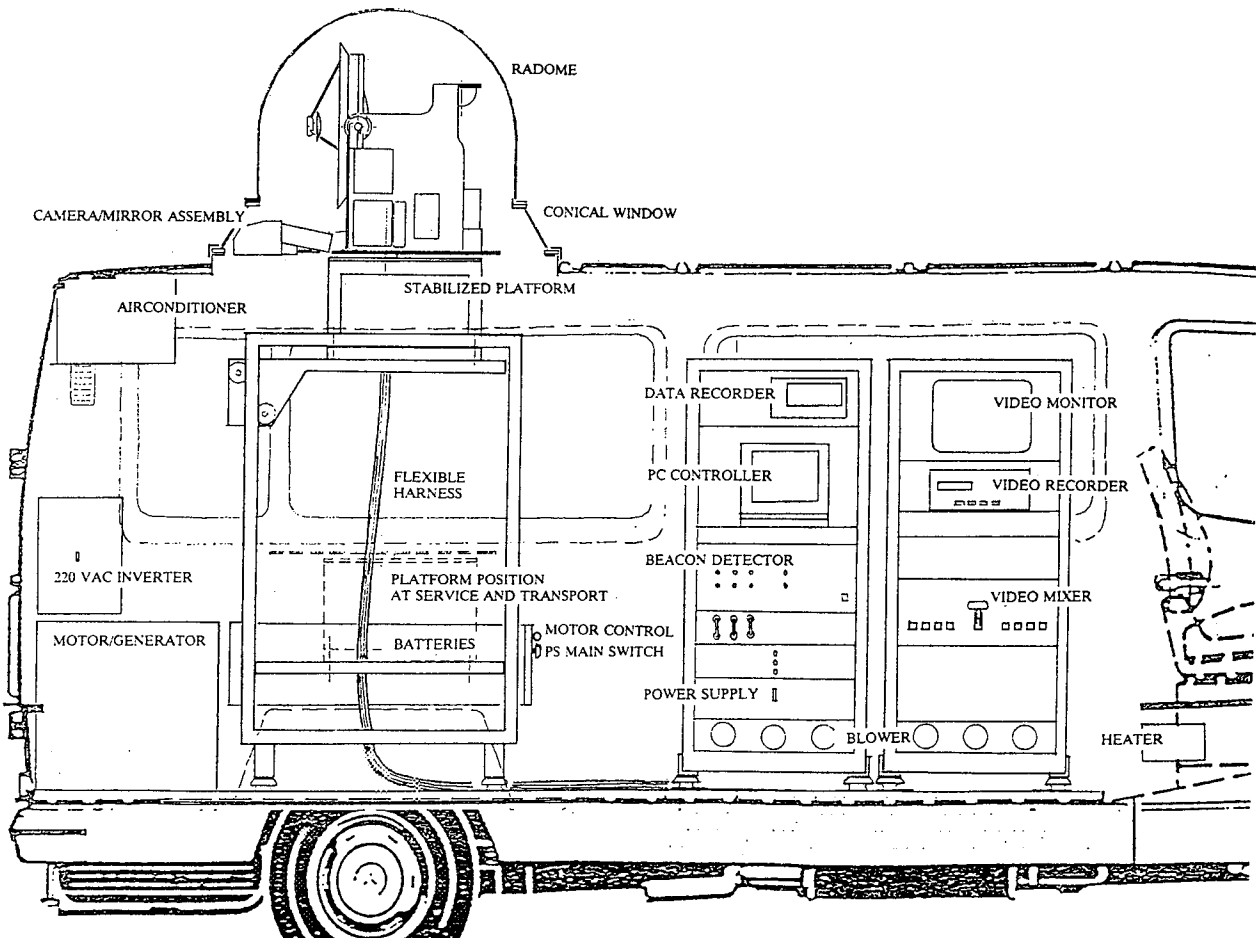
Figure 2: LMBT layout

The antenna is mounted on the elevation gimbal of the stabilization system. The glass-fibre radome has an insertion loss of less than 0.5 dB and it is screwed down on a truncated cone made of a light-transparent material such as to provide full optical visibility to the antenna-slaved video camera.

2.2 The platform subsystem

The platform is the most complicated and demanding amongst all the LMBT subsystems. Correct pointing towards the satellite has to be granted in all operational conditions and for a period of time equivalent to the duration of a measurement run, originally fixed in 15 minutes. A figure of 1 dB of maximum pointing loss, i.e. a pointing error of less than 0.7° at 18.7 GHz, was the baseline objective. In its final experimental configuration, the LMBT platform showed pointing losses of less than 0.4-0.6 dB throughout the acceptance tests.

The servo-controlled stabilized platform is a gyro based system with sensors designed to be as insensitive as possible to horizontal and vertical accelerations in order to stabilize the platform and the units mounted on it on all three axis. The solution selected for the design of our Ka-band LMBT was to use two gyroscopes, a vertical one providing information on the pitch and roll angles, and a directional one (gyro-compass) giving read-outs of the North angle, i.e. heading. Both vertical and directional gyros, which are standard avionic equipment, are mounted on the azimuth turntable, controlled to maintain a constant heading. The major drawback of this solution is that the directional gyro has an in-built circuit slaved to a flux valve magnetic sensor providing the gyro a fixed heading reference. This magnetic sensor (compass) is unfortunately strongly influenced by all sorts of magnetic fields generated by the van metallic structure and instrumentation, and by nearby buildings, cars, power lines and so forth. So only at the platform start-up the compass is used to give an initial reference; in mobile measurements, the directional gyro is operated in unslaved mode.

Particular attention was also given in the inital design and later in the fine tuning of the system to the mechanical construction and balancing of the stabilization platform, which also hosts the antenna-slaved video camera and some RF units. The servo control electronics circuits are implemented on five PCBs.

2.3 The receiver subsystem

The principal requirements at the receiver level were basically low noise figure, low phase noise and high medium term stability. An overall noise figure of 2 dB, referenced to the antenna output port, has been achieved thus providing a satisfactory C/N_o level during the measurements. The phase noise of the receiver mainly due to the reference oscillator was kept within that one of the satellite signal itself. Finally a gain variation of ±0.2 dB was measured; this low figure is considered not to contribute significantly to the overall uncertainty of each measurement run. The receiver consists of two major subsystems, the Front End and the Detector.

The Front End, schematically drawn in Fig. 3, is made of a Low Noise Amplifier (LNA), a downcoverter, and microwave and reference oscillator units. The LNA is mounted directly on the antenna feed horn to reduce losses whereas the remaining units are placed on the platform turntable. The measured LNA gain and bandwidth at 18.7 GHz are 28.0 dB and 1 GHz, respectively; the corresponding noise figure is 1.4 dB.

The Detector unit processes the 70 MHz signal from the downconverter and provides in digital form the signal I and Q components to the Data Acquisition subsystem and to the operator PC. There are three identical detector chains to allow for simultaneous multifrequency measurements although only one is used in the current LMBT configuration. The basic functions of the detector subsystem are to establish a phase-locked acquisition to the correct transmitted satellite signal, to compensate for potential large Doppler shifts and to perform a fast and efficient reacquisition after long fades exceeding the maximum LMBT dynamic range. Signal acquisition, tracking and recapture functions
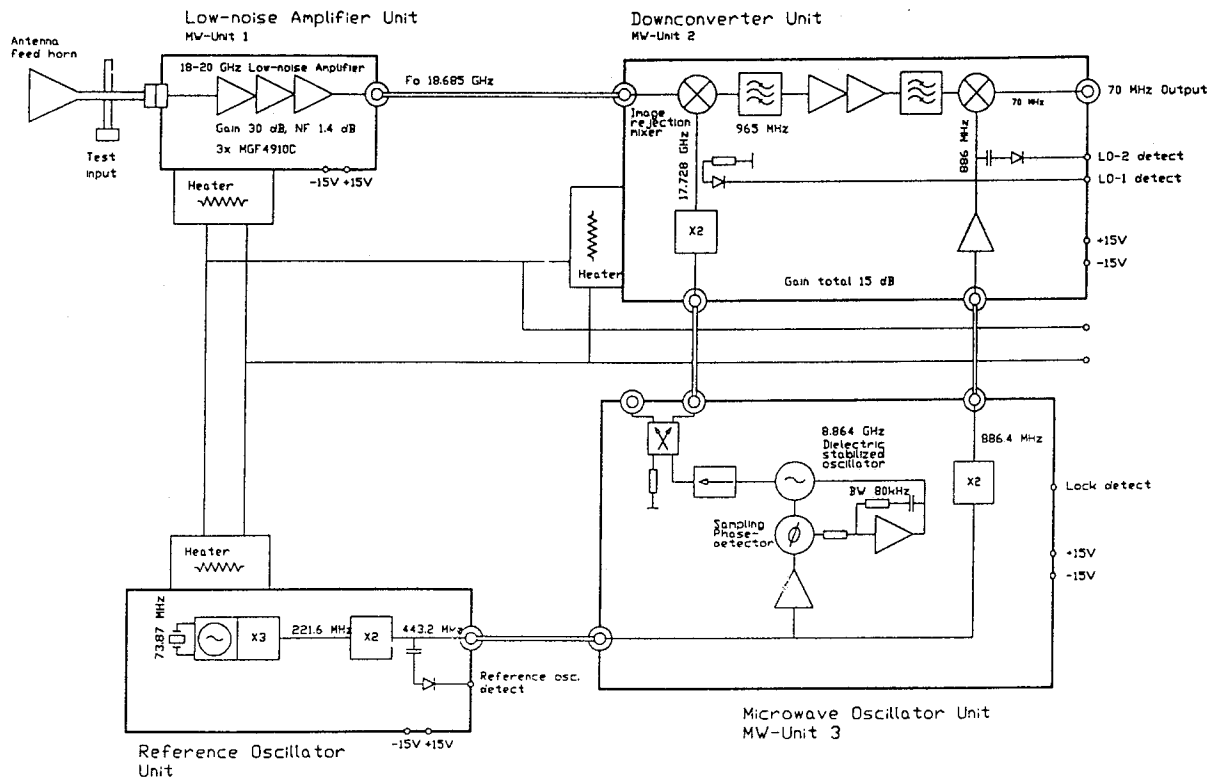
Figure 3: LMBT Front-End functional block diagram

are of course essential in the design of any receiver designed to operate in mobile scenarios; these requirements are even more stringent at Ka-band and with such narrow antenna beamwidth. The solution adopted was a rather conventional one, a Phase Lock Loop (PLL) with four bandwidths (50, 100, 200 and 400 Hz), but proved to be simple and suitable for the specified system requirements. A substantial number of measurements was carried out at RESCOM premises during the acceptance tests at different vehicle speeds, headings and PLL bandwidths, and in acceleration and constant speed modes; in all these tests a recapture time of less than 0.1 s was found.

2.4 The data acquisition subsystem

The Data Acquisition Subsystem (DAS) essentially collects and store information on the received beacon signal and on the status of the overall system. A functional block diagram is given in Fig. 4. The computer is equipped with an Intel 80386 CPU, 33 MHz clock and 2 Mbytes of RAM, and operates under MS-DOS environment. There are three boards connected to the computer: the A/D converter providing the signal from the detector, the video board which receives the pictures from the two video cameras properly combined in a video mixer, and the I/O board which collects all the environmental and system status data. The sampling rate can be selected from 1 up to 15 KHz, therefore a high capacity storage medium is required: an ExaByte EXB-8500 tape streamer with 8mm cartridges of 5 GBytes capacity. Amongst other functions, the DAS generates the time stamp which synchronizes the signals and images recording so that, during off-line analyses, signal fades can be uniquely associated to actual natural or man-made obstacles.
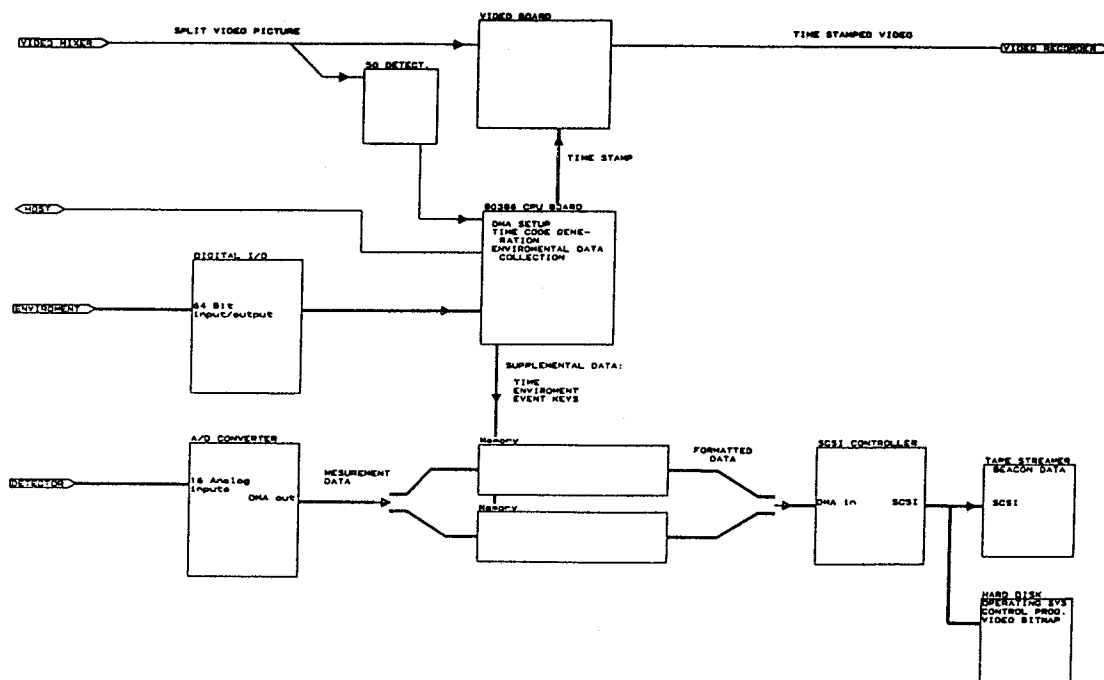
Figure 4: LMBT Data Acquisition System

2.5 The video subsystem

The main purpose of this subsystem is to provide the experimenter with real-time and synchronized optical information on environmental attributes and landscape. Two video cameras are used to achieve this objective: one antenna-slaved and the other, forward-looking and wide-angle. The former is placed on the platform turntable and is slaved to the antenna movements hence it allows the operator to closely watch and indentify any obstruction along the line-of-sight; the latter (with an opening angle of 107°) is placed behind the windshield of the van and provides a general description of the environmental scenarios. The video signals from both cameras are combined in a mixer and they are time synchronized with the DAS. In order to ensure full optical visibility to the side-looking antenna-slaved camera, an acryl truncated cone is assembled with the glass-fibre radome (the solution of a fully RF and light transparent radome was not viable); a two-mirrors arrangement, where one mirror is controlled by a servo loop slaved to the antenna one and the other is fixed, allows the video camera to point at the satellite direction with an error of ±0.5°.

2.6 The other LMBT subsystems

The remaining LMBT subsystems (Central Control, Power Supply, Racks and Passenger Van) are only briefly described. The Central Control Subsystem (CSS) is responsible for all the interfacing network of the LMBT; making use of the CSS features the operator is able to control and monitor all the LMBT functions. The CSS is executed from the operator PC while the actual interconnections between subsystems are dealt with by a network of locally intelligent nodes and a simple CAN (Controller Area Network) bus which is a serial communication protocol supporting distributed real-time control, originally developed for automotive applications. The operator PC is of a laptop type, with a 386 SX-20 MHz, 12 Mbytes of RAM and coprocessor; an 80 Mbytes hard disk is integrated in the PC.

From this PC, the operator controls data acquisition and presentation, the latter being displayed on the PC screen in several user-selectable menu pages.

As the whole receiver needs power in the order of 2 kW, a 24 V DC system has been implemented where the primary supply source is a pack of four 12 V truck batteries. The battery pack is charged by a gasoline generator, placed in the van inside a sound-insulated compartment. Two 19" racks are used; they are installed on the van floor through shock absorbers. Finally, the vehicle selected for this activity is a Mercedes-Benz 208/33 passenger van large enough to accomodate the Ka-band LMBT and possible future upgrade at other frequency bands, e.g. L- and S-bands. Air-conditioning and heating units are foreseen to keep the platform temperature correctly controlled and to ensure comfortable working conditions. The passenger van speed is measured by means of a proximity sensor mounted in the vicinity of the flange connecting the gear box and the drive shaft.

3   The experimental Ka-band LMS campaign

A contract was placed by ESA in late 1993 with the Joanneum Research, Institute for Applied System Technology (IAS) in Graz, Austria, to collect and analyse experimental data for the characterisation of the Ka-band LMS narrowband propagation channel. After a careful campaign planning phase needed to identify suitable European LMS scenarios, a large number of measurements was carried out in France, Germany and Austria in spring 1994; in all these countries a strong satellite signal was always experienced ensuring an optimum dynamic range. The experimental campaign was performed in open, wooded, suburban and urban areas at different speeds and azimuth angles. From an operational point of view, a reference level (0 dB) was measured and recorded in line-of-sight conditions, at the beginning and at the end of each experimental run; the average duration of each run was of 10-15 minutes. Video images were also recorded and will be intensively studied on a second stage of the data analyses to find an empirical law linking RF to optical signals, i.e. active to passive measurements. The following set of narrowband statistics will be produced for each of the environments and azimuth angles (where applicable):

- Probability Distribution Functions (PDF)

- Cumulative Distribution Functions (CDF)

- Average Fade Durations (AFD)

- Level Crossing Rates (LCR)

- Durations of Fades (DoF)

- Time Shares of Fades (TSoF)

- Durations of Connections (DoC) (or of Non-Fades)

- Time Shares of Connections (TSoC) (or of Non-Fades)

Few preliminary results are presented in the following figures. In Fig. 5 a sample of a time series recorded in a suburban area around the city of Munchen, Germany, is given; the corresponding Cumulative Distribution Function (CDF) is drawn in Fig. 6. The average van heading during this specific run was 65 degrees thus offering an almost orthogonal position with respect to the satellite signal (Italsat F1 is in a geostationary orbit at 13E). In Figs. 7 and 8 an example of time series and

corresponding CDF for an urban area in Munchen is presented, this time with an average van heading of 170 degrees; the van position during the entire run was therefore almost constantly parallel to the transmitted satellite signal hence with very few blockages. For all the runs, the average elevation angle was of 30 degrees.

Although the results presented in this paper represent a very small sample of the large amount of data recorded during the IAS Ka-band experimental campaign, few interesting considerations can be drawn from a preliminary analysis of these results. At Ka-band the signal received at the mobile terminal looks very much like an on-off (binary) signal; the temporary blockage offered by man-made or natural obstacles can most of the times drive the receiver out of its dynamic range. The propagation channel could be therefore characterised using state-models like the ones defined in previous works ([8]-[10]). In addition, we think that an empirical law relating RF to optical signals could well describe the propagation channel behaviour highlighted in Fig. 5 and 6. The importance of the latter consideration lies in the fact that passive measurements could be effectively envisaged to characterise the Ka-band LMS propagation channel, rather than the more expensive and time-consuming active ones. Whether this approach can be also applied to L- or S-band LMS channels is still to be seen; considerations of the radiation pattern of the mobile terminal antenna (vehicle-mounted or hand-held) hence of the overall impact of multipath shall be part of the modelling effort. Finally, the quite different results
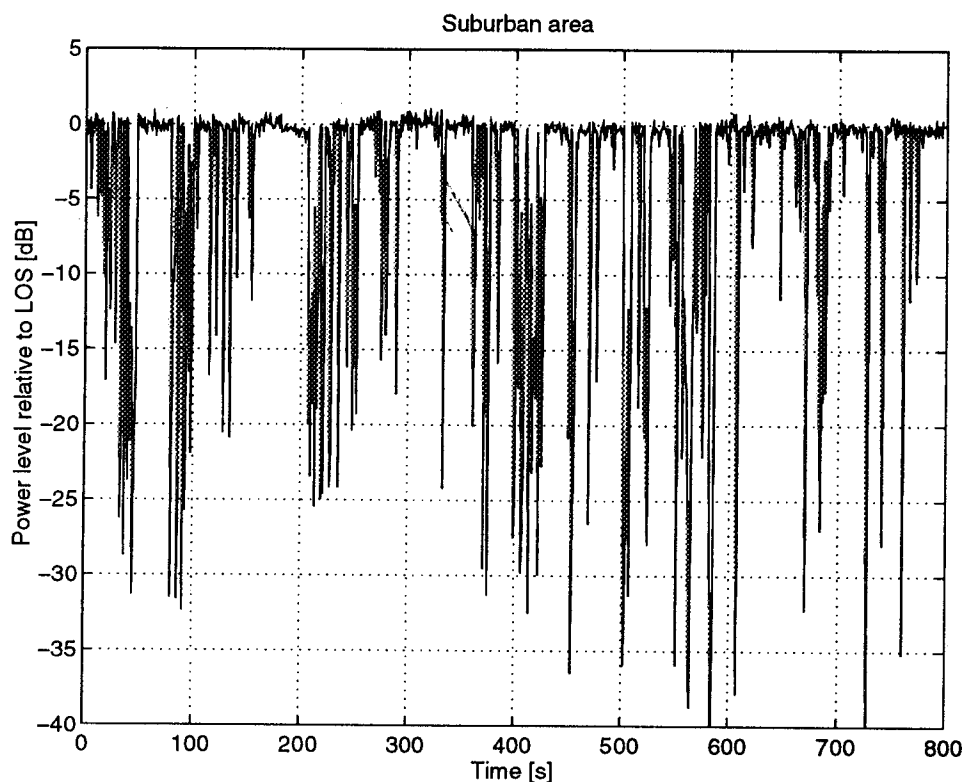

Figure 5: Time series in a suburban area around Munchen, Germany (f=18.7 GHz)

shown in Fig. 5 and 7 prove again that information on azimuth angle is essential in the data analysis and that considerations made for link availability estimation in multisatellite LMS systems can not be drawn without it.
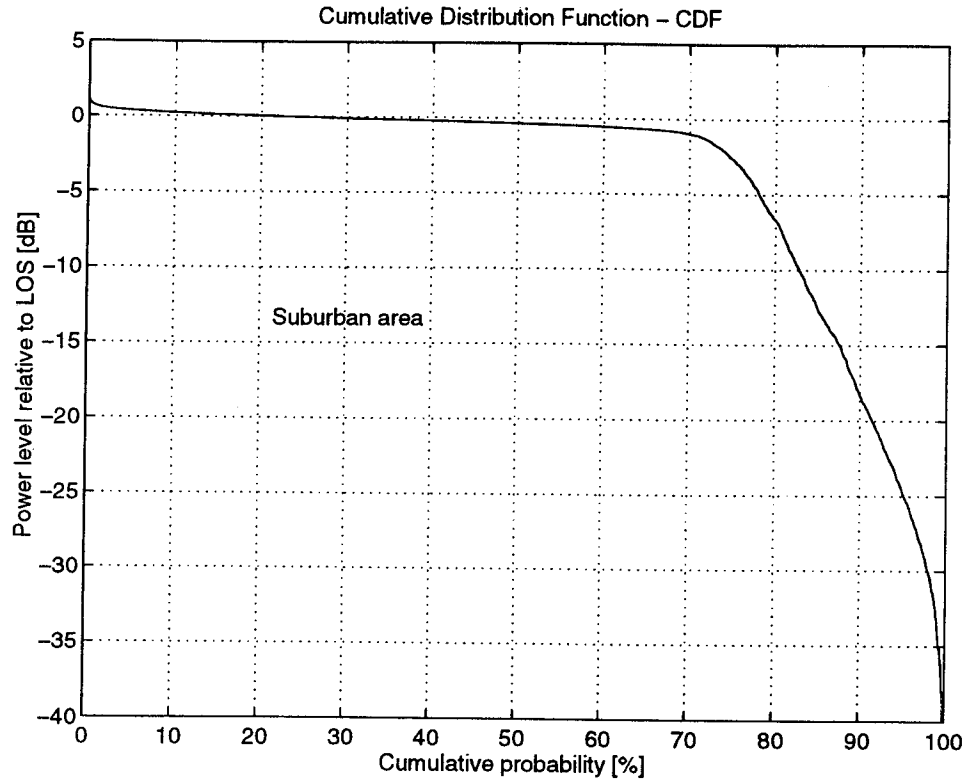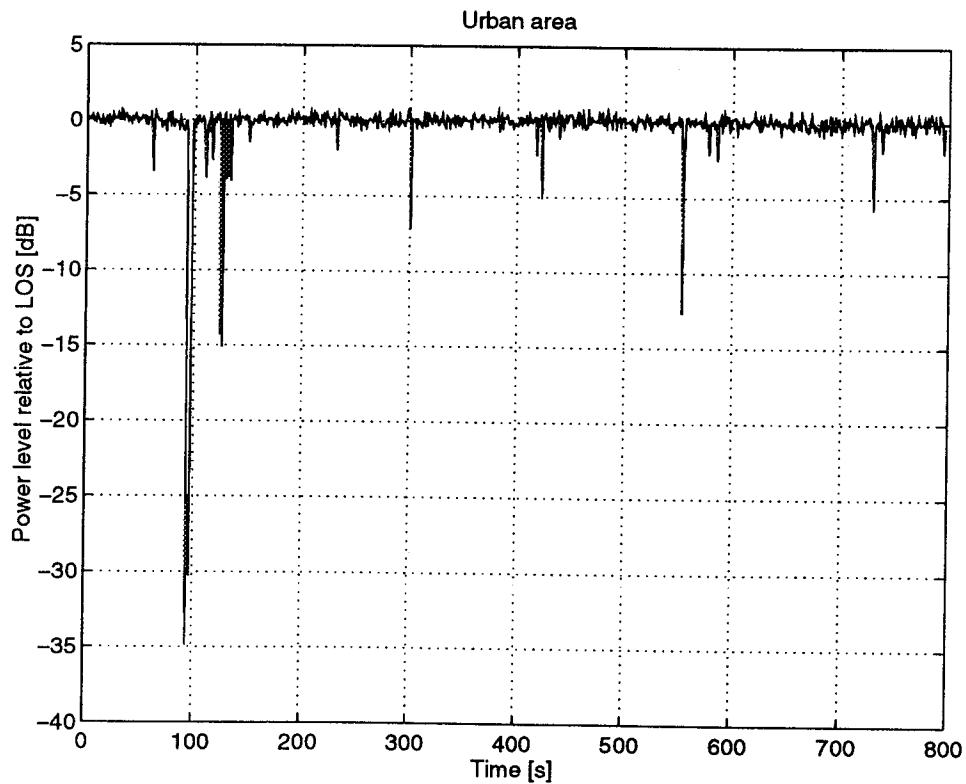
Figure 6: CDF, suburban area (f=18.7 GHz)

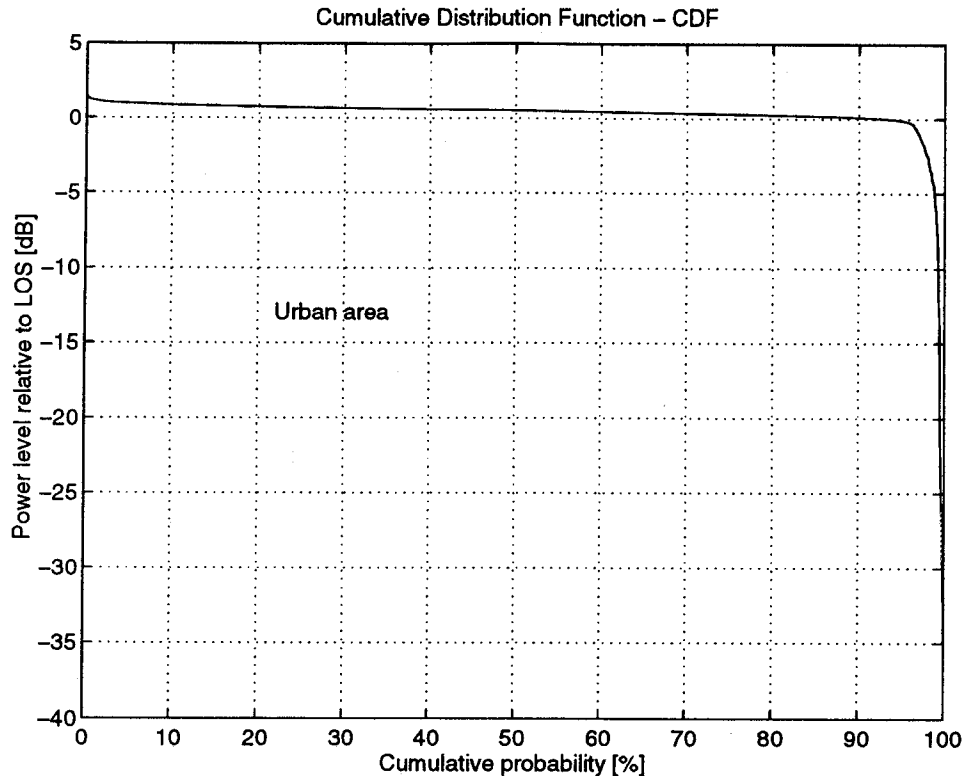Figure 7: Time series in an urban in Munchen, Germany (f=18.7 GHz)

Figure 8: CDF, urban area (f=18.7 GHz)

4   Conclusions

In this paper a Land Mobile Beacon Terminal designed to carry out LMS experimental narrowband campaigns at Ka-band has been presented and briefly described. The terminal presently operates with the Italsat 18.7 GHz propagation beacon but it is inherently capable to receive simultaneously three RF signals, just changing or upgrading the RF front-ends. A combined data and video acquisition system allows to uniquely link RF Ka-band to optical signals so that the propagation engineer can effectively derive information on channel blockage phenomena from passive optical measurements. The terminal installed in a passenger van has been already use to complete the first extended Ka-band LMS experimental campaign, in different European locations and operational scenarios; preliminary results have been also presented.

It is foreseen to upgrade the existing LMBT configuration with L- and S-band front-ends and to integrate it with wideband channel sounders presently under development. The final objective is to have a comprehensive experimental equipment to use intensively in narrow- and wideband multifrequency LMS and terrestrial measurements which should ensure an otpimum characterization and modelling of the propagation channel for mobile communication services of the next generation.

Acknowledgements

References

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[10] Vucetic B., Du J., *Channel model and simulation in Satellite Mobile Communication Systems*, IEEE Trans. Vehic. Techn., vol. , pag. 1209-1218, October 1992.
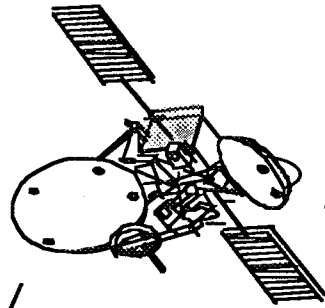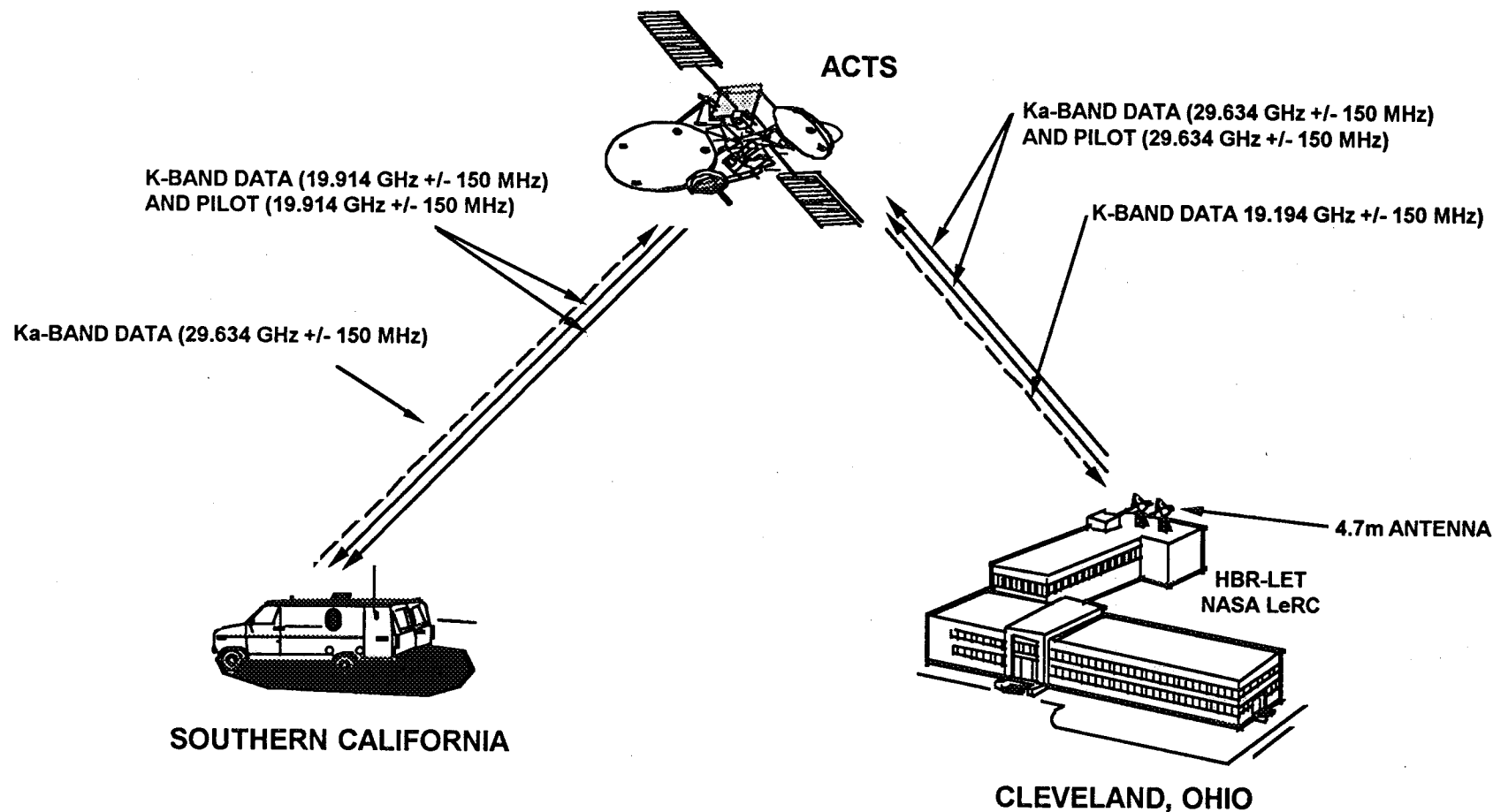
ACTS Mobile Experiments Summary
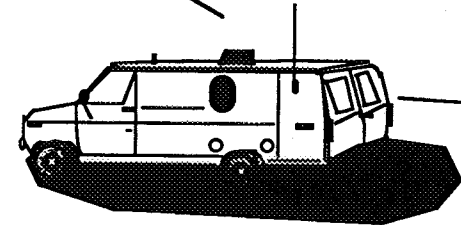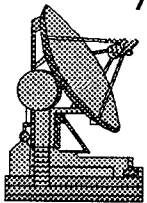
Deborah S. Pinck
ACTS Mobile Terminal Task
JPL- California Institute of Technology

Outline

- **AMT Experiments Configuration**
- **ACTS Mobile Terminal Configuration**
- **AMT Experiments**
- **Experiment Results**
  - Satellite Characterization - Linearity Tests
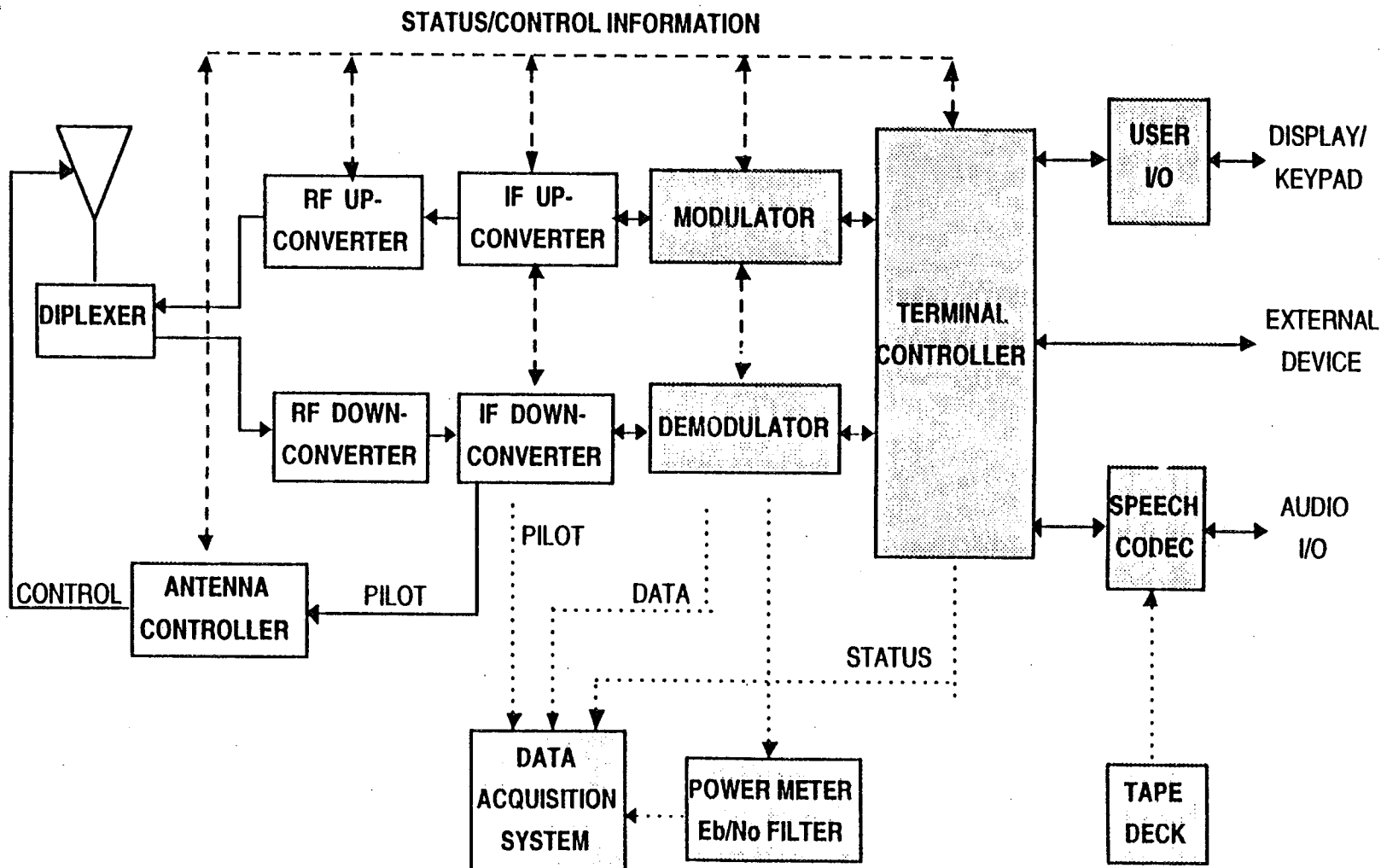 - AMT Baseline Performance - BERs
  - Shadowing Events
- **Conclusions**

AMT Experiments Configuration

ACTS

Ka-BAND DATA (29.634 GHz +/- 150 MHz)
AND PILOT (29.634 GHz +/- 150 MHz)

K-BAND DATA (19.914 GHz +/- 150 MHz)
AND PILOT (19.914 GHz +/- 150 MHz)

K-BAND DATA 19.194 GHz +/- 150 MHz)

Ka-BAND DATA (29.634 GHz +/- 150 MHz)

4.7m ANTENNA

HBR-LET
NASA LeRC

SOUTHERN CALIFORNIA

CLEVELAND, OHIO

ACTS GENERATED BEACONS AT 20.185,
20.195, AND 27.505 GHz ARE NOT SHOWN.
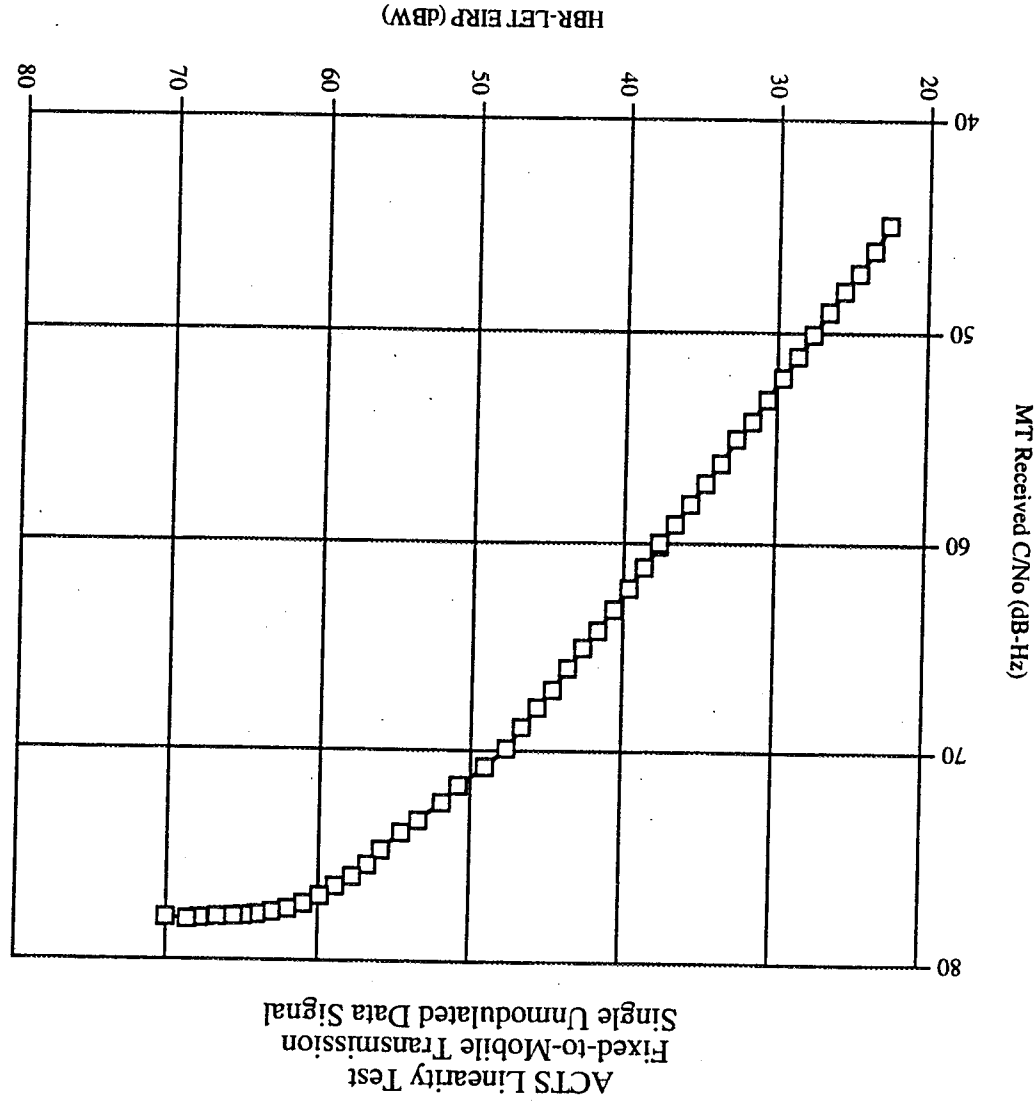
6/13/94

ACTS Mobile Terminal Configuration

STATUS/CONTROL INFORMATION

DIPLEXER

RF UP-CONVERTER

IF UP-CONVERTER

MODULATOR

TERMINAL CONTROLLER

USER I/O

DISPLAY/ KEYPAD

RF DOWN-CONVERTER

IF DOWN-CONVERTER

DEMODULATOR

EXTERNAL DEVICE

SPEECH CODEC

AUDIO I/O

CONTROL

ANTENNA CONTROLLER

PILOT

PILOT

DATA

STATUS

DATA ACQUISITION SYSTEM

POWER METER Eb/No FILTER

TAPE DECK
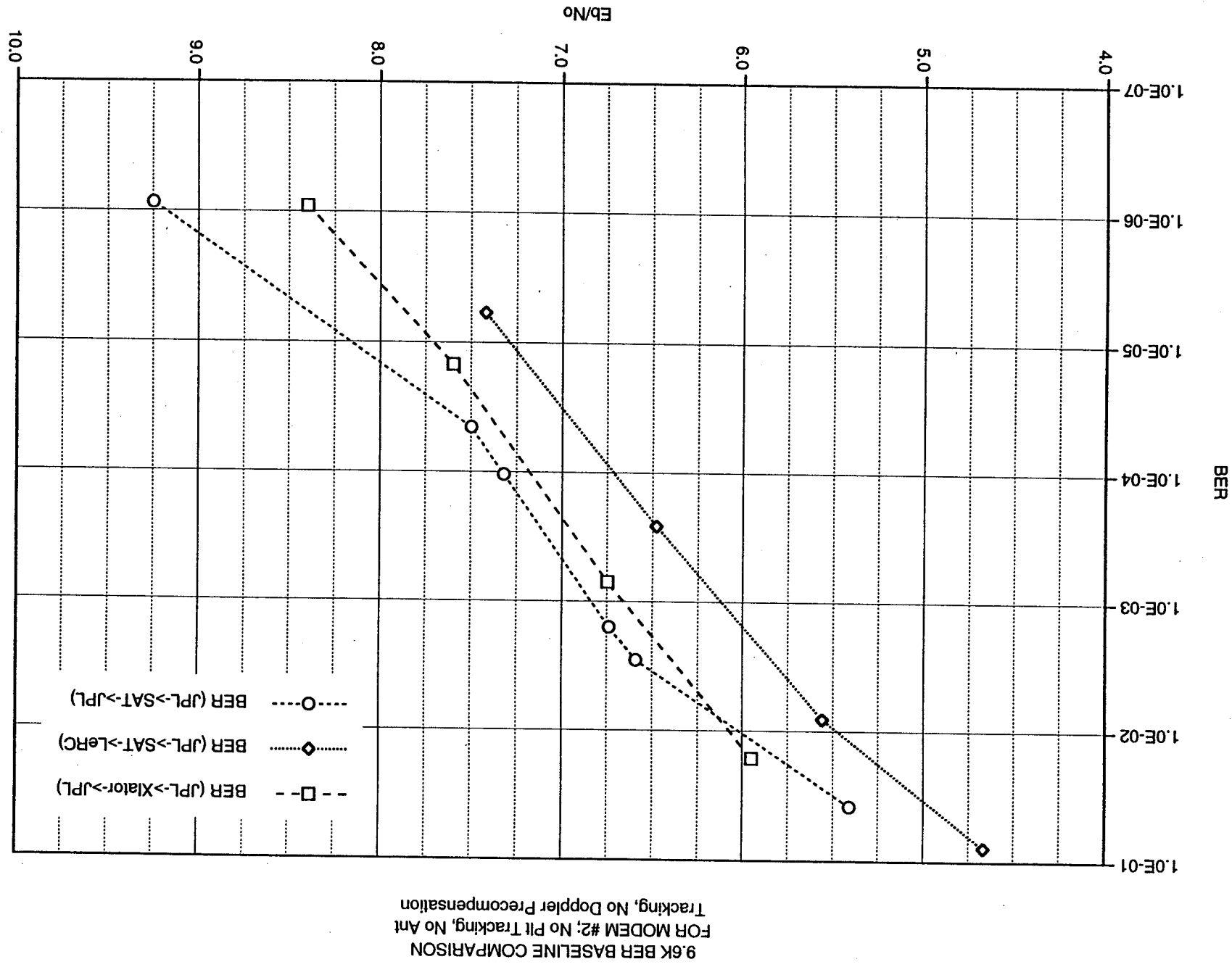
6/13/94

Satellite Characterization:

JPL

ACTS Linearity Test
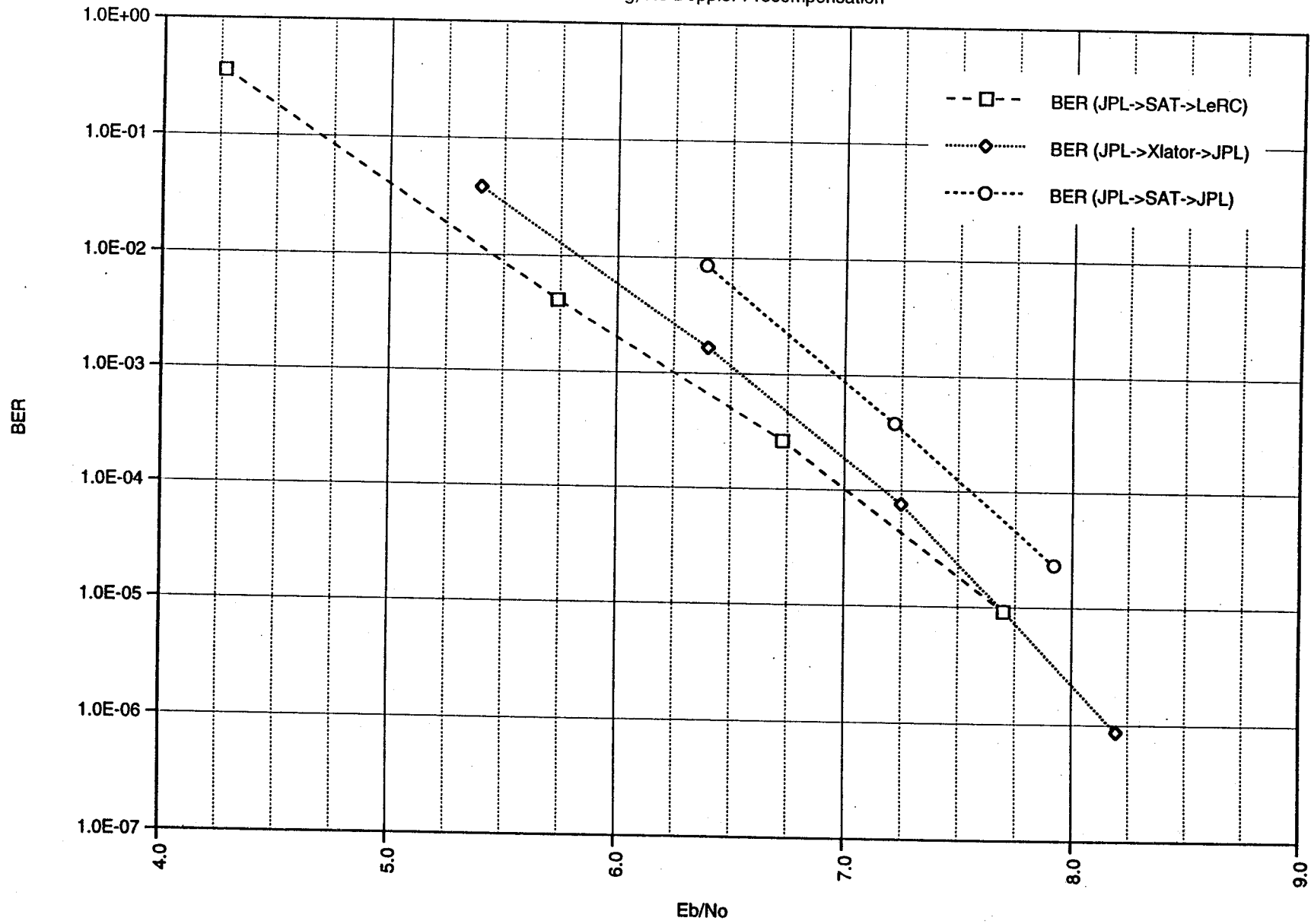Fixed-to-Mobile Transmission
Single Unmodulated Data Signal

HBR-LET EIRP (dBW)

MT Received C/No (dB-Hz)

122

JPL

Satellite Characterization:

ACTS Linearity Test
Mobile-to-Fixed Transmission
Single Unmodulated Data Signal

Mobile Terminal EIRP (dBW)

Fixed Terminal Received C/No (dB-Hz)

6/12/94

Eb/No

BER

10.0
9.0
8.0
7.0
6.0
5.0
4.0

1.0E-07 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01

----O---- BER (JPL->SAT->JPL)
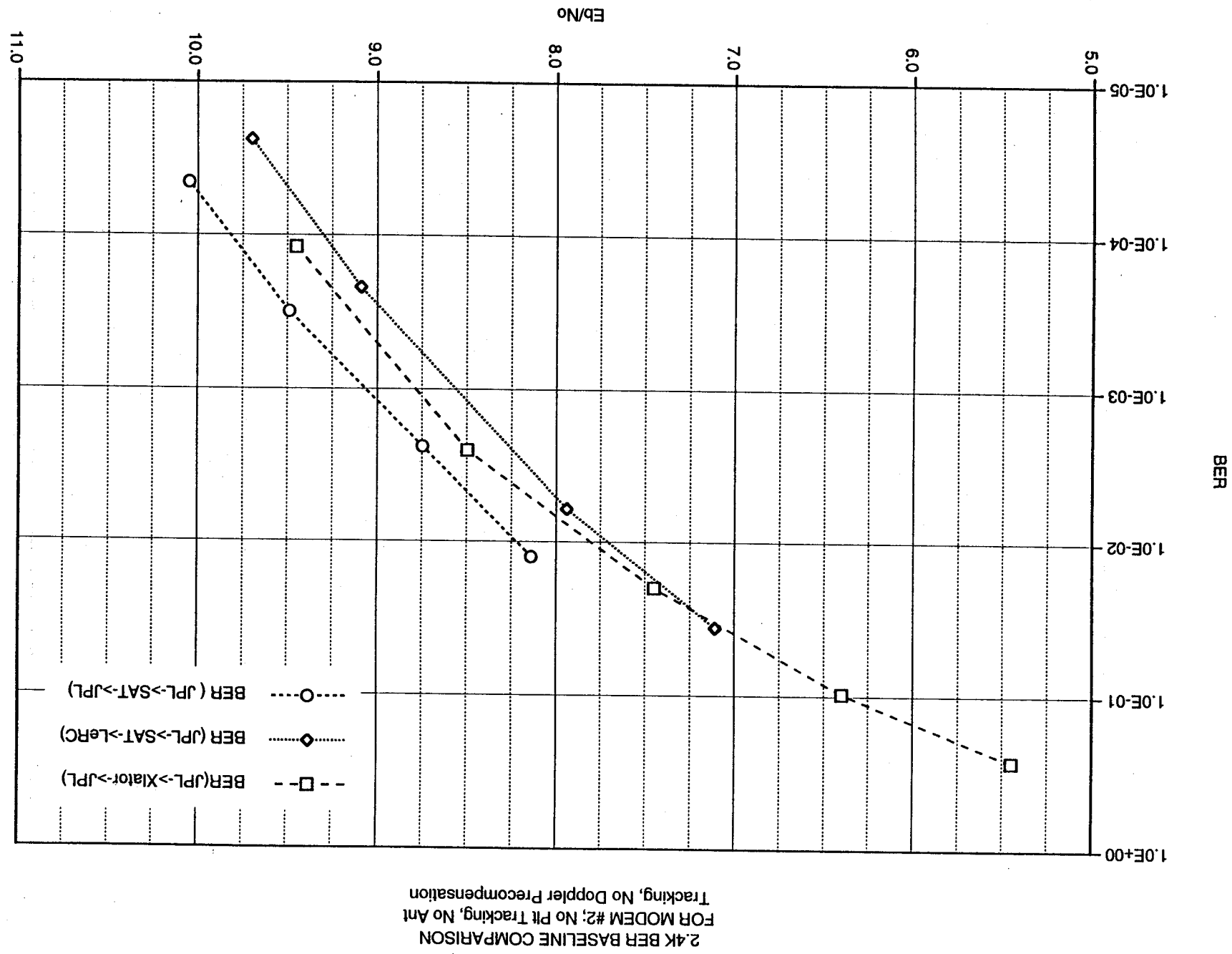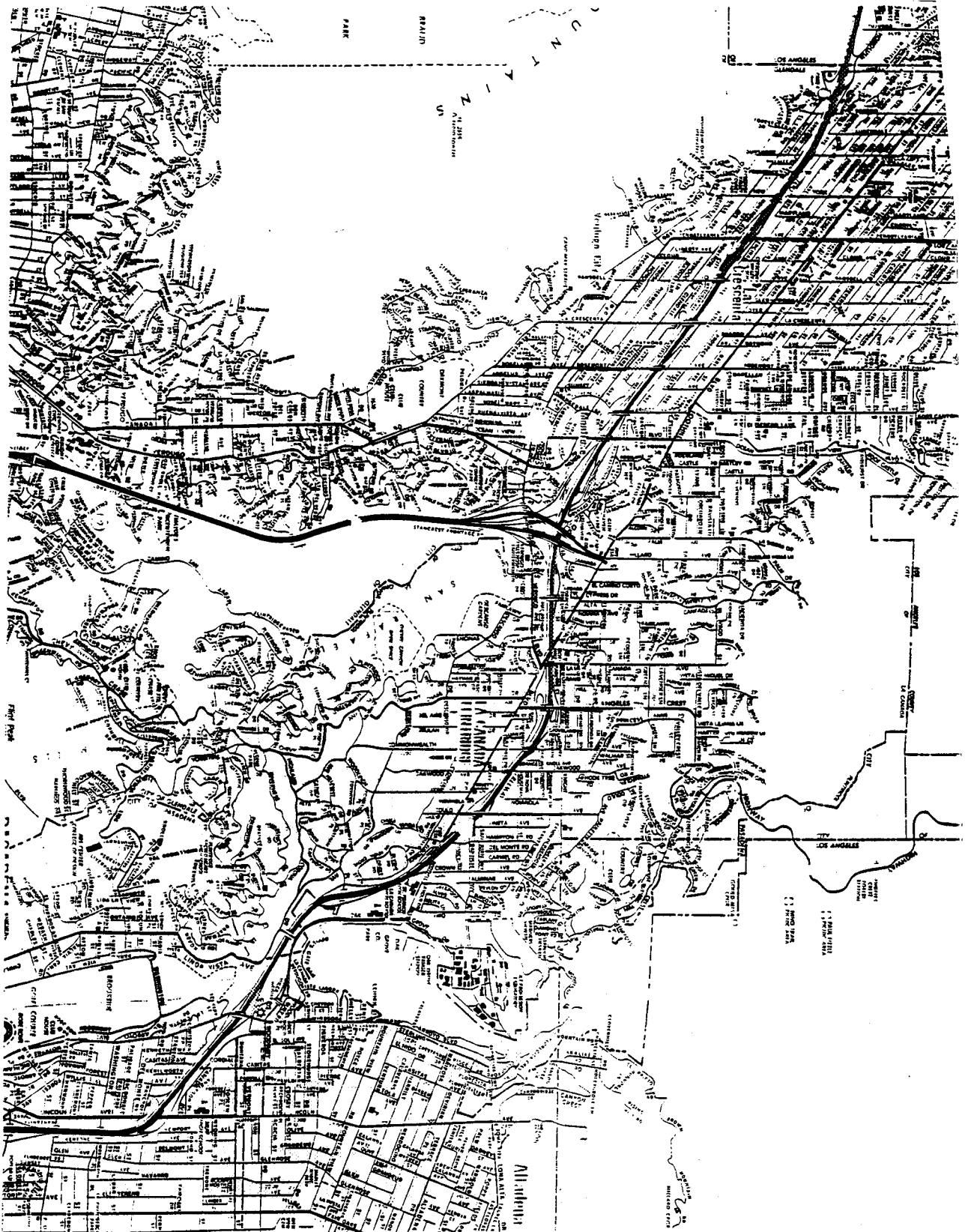
········◇········ BER (JPL->SAT->LeRC)

- -□- - BER (JPL->Xlator->JPL)

9.6K BER BASELINE COMPARISON
FOR MODEM #2: No Plt Tracking, No Ant
Tracking, No Doppler Precompensation

4.8K BER BASELINE COMPARISON
FOR MODEM #2; No Plt Tracking, No Ant
Tracking, No Doppler Precompensation

BER

Eb/No

- - □ - -   BER (JPL->SAT->LeRC)

·······◇·······   BER (JPL->Xlator->JPL)

- - O - -   BER (JPL->SAT->JPL)

Eb/No

BER

126

2.4K BER BASELINE COMPARISON
FOR MODEM #2; No Plt Tracking, No Ant
Tracking, No Doppler Precompensation

- - -O- - - BER (JPL<->SAT->JPL)
········◇········ BER (JPL<->SAT<->LeRC)
- -□- - BER(JPL->Xlator->JPL)

11.0
10.0
9.0
8.0
7.0
6.0
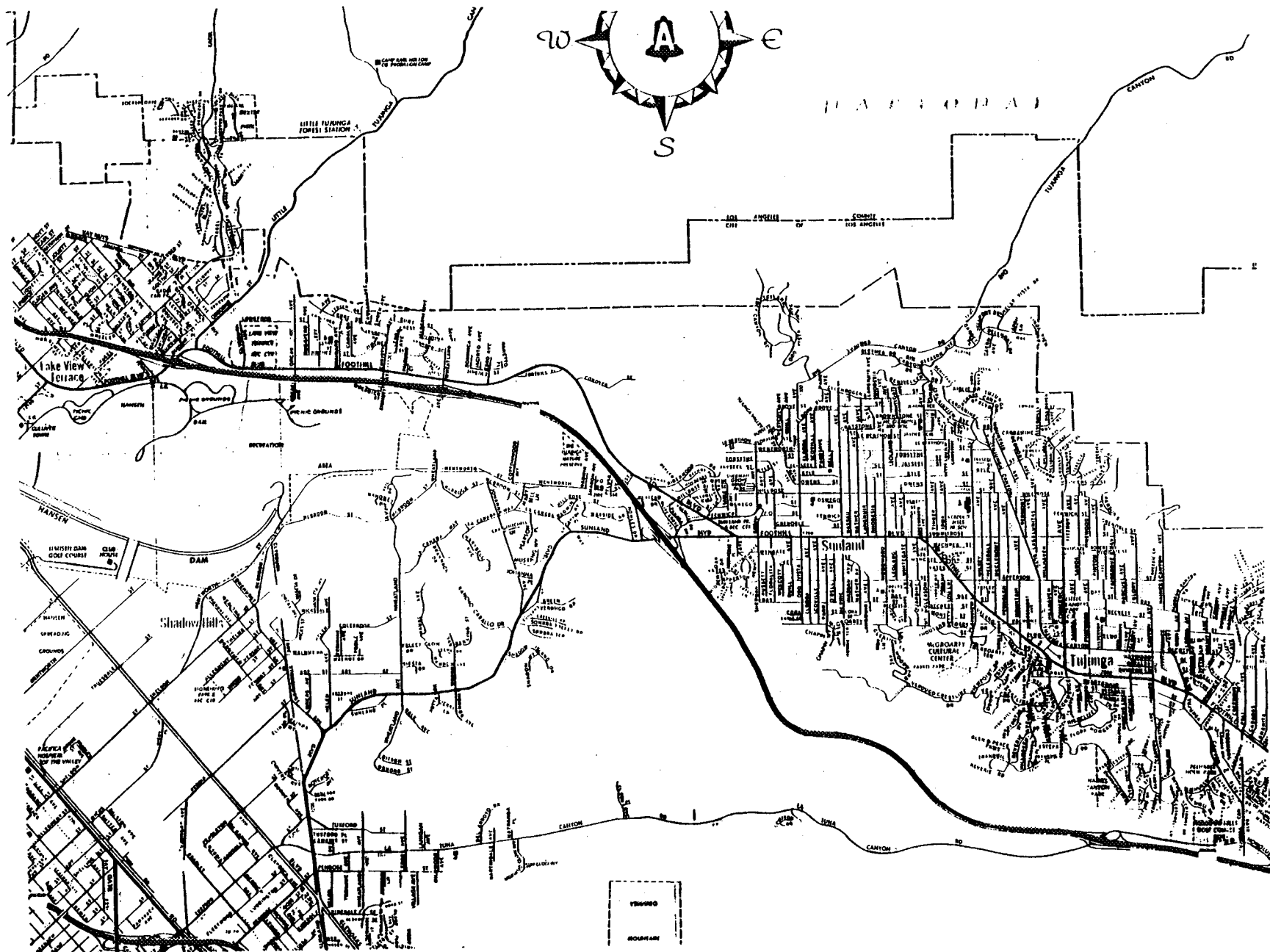5.0

1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00

I-210 Eastbound, overpasses west of Oak Grove Exit
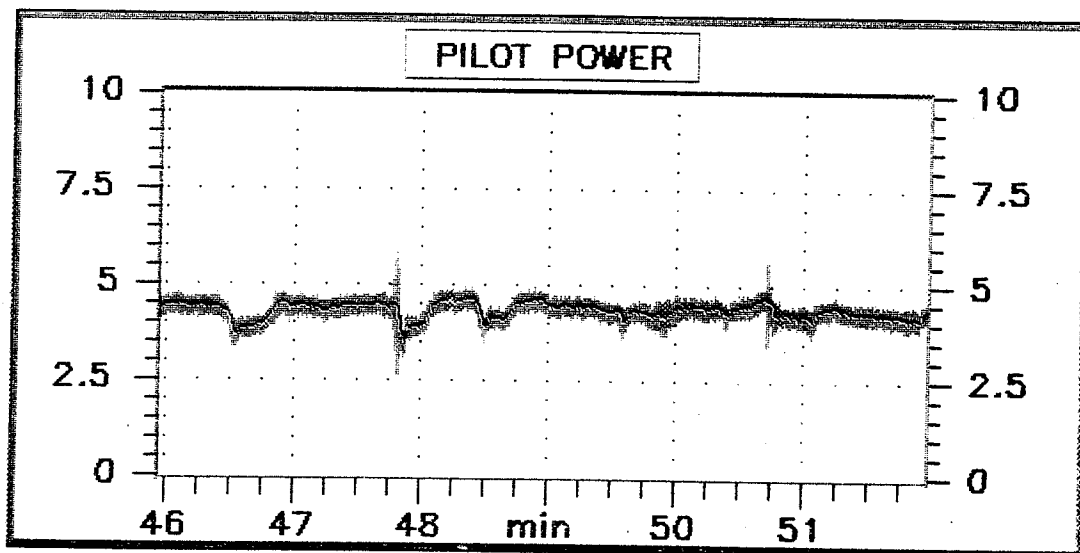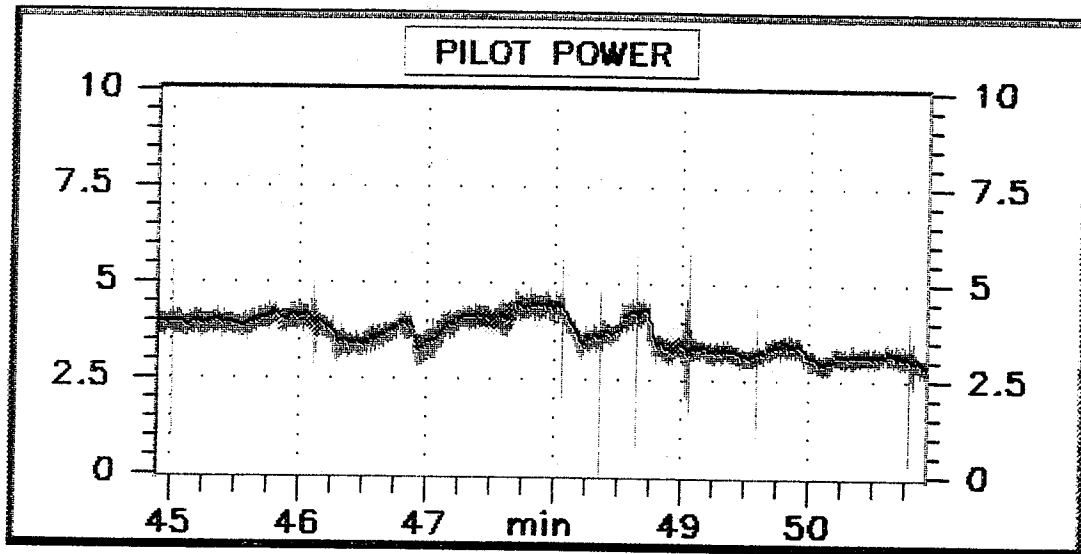NCS-1 MT, 2 February 1994

PILOT POWER
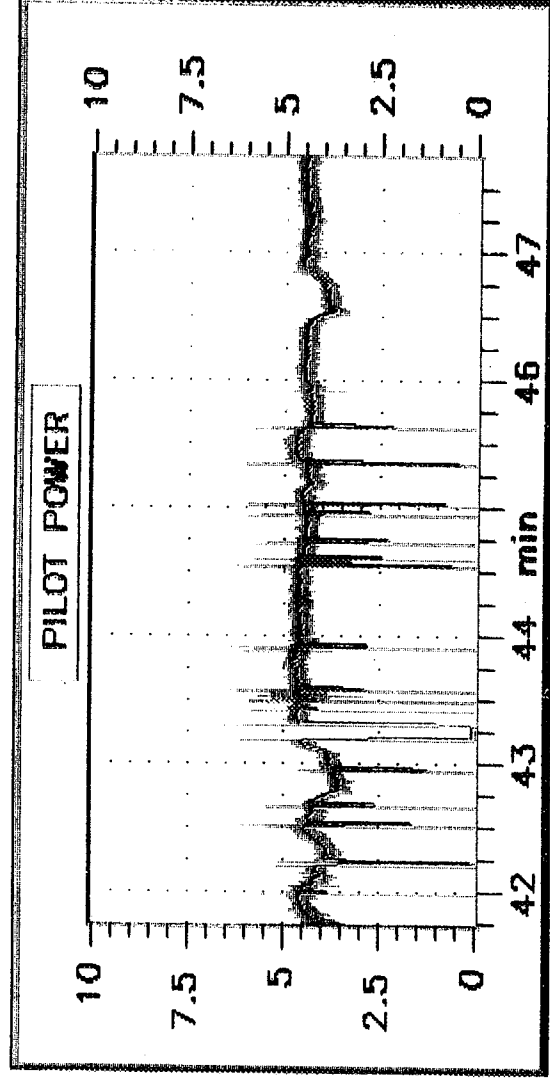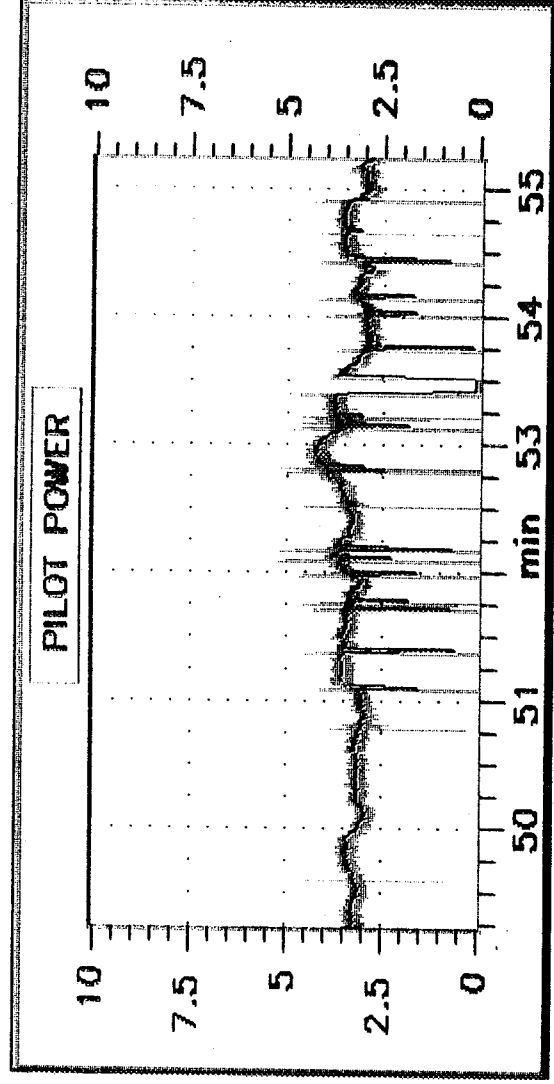
I-210 Westbound, overpasses west of Oak Grove Exit
NCS-1 MT, 2 February 1994

PILOT POWER

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I-210 Eastbound
Hilly terrain between La Crescenta and San Fernando Valleys
NCS-1 MT, 2 February 1994

I-210 Westbound
Hilly terrain between La Crescenta and San Fernando Valleys
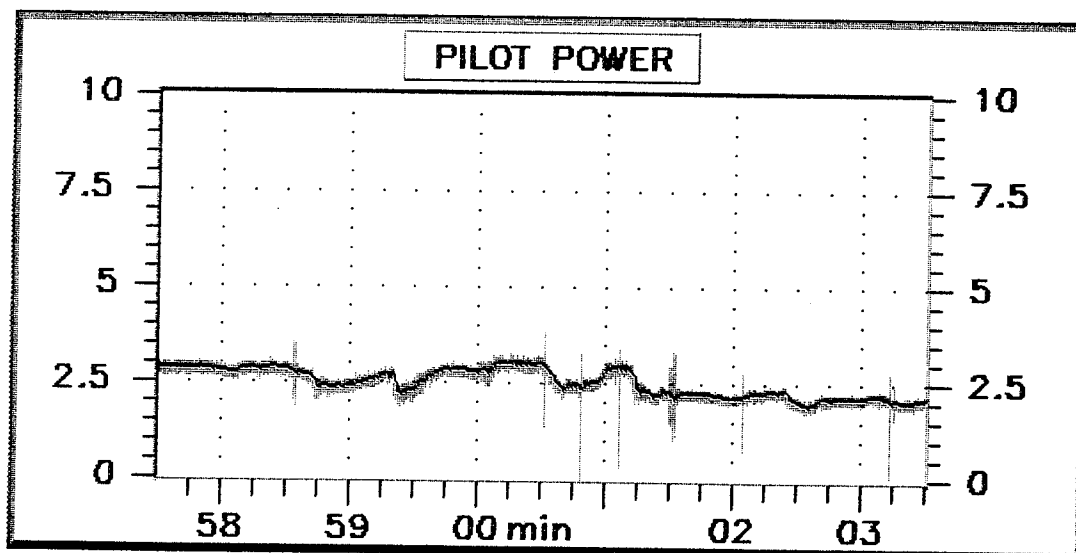**NCS-1 MT, 2 February 1994**

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I-210 Eastbound
Hilly terrain between La Crescenta and San Fernando Valleys
NCS-1 MT, 2 February 1994

I-210 Eastbound
Hilly terrain between La Crescenta and San Fernando Valleys
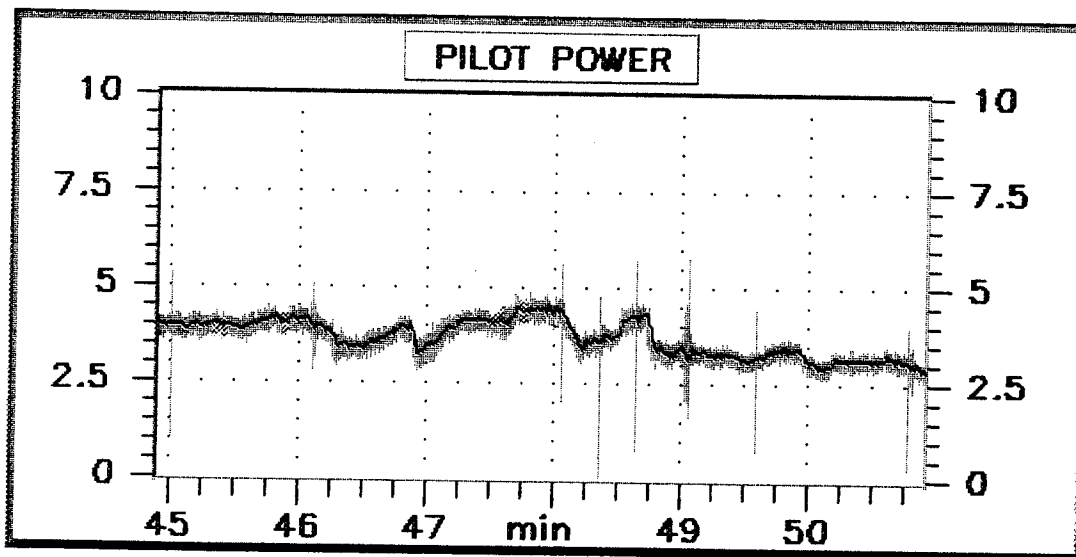**NCS-1 MT, 1 February 1994**

Conclusions

- ## Satellite Characterization:
  - MT to FT: linear for complete useful range of the MT's transmit EIRP
  - FT to MT: linear for transmit EIRPs less than 50 dBW
  - received C/N_0 of 78 dB-Hz, 28 dB higher than that required to operate the terminal at 9.6 kbps

- ## Baseline System Performance:
  - in agreement with satellite simulator tests
  - for a BER of 10^{-3} from FT to MT
    - » @ 9.6 kbps, $E_b/N_0 = 6.8$ dB
    - » @ 4.8 kbps, $E_b/N_0 = 6.7$ dB
    - » @ 2.4 kbps, $E_b/N_0 = 8.5$ dB

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Conclusions (cont.)

- **Baseline System Performance:**
  - **for a BER of 10^{-3} from MT to FT**
    - » **@ 9.6 kbps, $E_b/N_0 = 6.2$ dB**
    - » **@ 4.8 kbps, $E_b/N_0 = 6.3$ dB**
    - » **@ 2.4 kbps, $E_b/N_0 = 8.7$ dB**
- **Shadowing: tbd**
- **Near Toll Quality Voice**

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