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FIELD MEASUREMENTS IN MSAT-X

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Abstract

Results from the two most recent MSAT-X field experiments, the Tower-3 Experiment and the JPL/FAA/INMARSAT MARECS-B2 Satellite Experiment, are presented. Results that distinguish the unique propagation environment of the tower set-up are given and explained. The configuration and flight variables of the aeronautical experiment which used an FAA aircraft and an INMARSAT satellite are described. Results that highlight the disturbances on the aeronautical satellite channel are presented. The roles of satellite-induced signal variations and of multipath are identified and their impact on the link is discussed.

1. Introduction

Field experiments have played a major role in validating the technologies developed under MSAT-X and in evaluating the end-to-end system performance. This article summarizes results obtained in the two most recent field experiments with emphasis on propagation-related results.

The first experiment addressed is the Tower-3 (T3) Experiment conducted near Boulder, Colorado, in July and August of 1988. It was the first end-to-end mobile field experiment in MSAT-X [1]. A 1000-ft tower operated by NOAA was used as a platform to simulate a satellite transponder. As such, T3 offered only a simulated land-mobile environment, nevertheless, it served as an invaluable end-to-end system checkout.

The second, and more recent experiment, is the Joint JPL/FAA/ INMARSAT MARECS-B2 Satellite Experiment. This was a complete aeronautical mobile experiment and demonstration. The MSAT-X mobile terminal was flown on board a Boeing 727 and was successfully demonstrated during flight. Due to damage sustained by the aircraft in a windstorm immediately prior to the scheduled start of the experiment in January 1989, only a ground check-out part was conducted in January. The flight segment was postponed and successfully completed in March 1989.

In what follows, the Tower-3 experiment set-up is described first. Typical results from its unique propagation environment are then summarized. This is followed by a brief description of the FAA experiment configuration and some of its results.

2. Tower-3 Experiment and Results

2.1. The Tower Set-Up

The physical layout for the experiment is shown in Figure 1. The fixed station was set up inside the trailer located as identified in the figure. The fixed station antenna was a dual helibowl with approximately 12 dB of gain and a 28^{o} 3-dB beamwidth in elevation. (A refined version of this antenna was used in the Marecs B2 Satellite Experiment.) The dual helibowl was placed on the roof of the trailer. To simulate a satellite, an L-band translator [1] was placed atop the tower and a patch antenna was placed facing downwards on a boom extending horizontally from the top of the tower. The patch antenna by itself, i.e., in the absence of the tower in its radiation field, is omni-directional with -7 dB of gain.

Mobile tests were performed with the mobile laboratory van travelling along the North-South (N-S) and East-West (E-W) roads (Figure 1). The quantitative link performance tests were performed at and between the calibrated points A through E, and F through H, as shown the figure. Limiting the testing to these regions was required to reduce the problem of excessive signal variation due to the change in range-- a problem that does not exist in a satellite link.

2.2. Tower Propagation Environment

Preliminary pilot strength measurement runs along the N-S and E-W roads revealed large signal fluctuations (up to 5 dB peak-to-peak). It was determined that this could be significantly reduced by minimizing reflections off the tower structure. Consequently, absorbing material was placed on the antenna mounting platform between the patch antenna and the tower. This indeed resulted in a reduction of the observed fluctuations, but also resulted in a sharp signal drop-off north of point E and immediately west of point F. The complete elimination of tower antenna pattern ripples (which cause these spatial signal fluctuations) is known to be a very difficult problem. Hence, no attempt was made to eliminate these ripples.

The pilot signal was received at the van through JPL's mechanically steered medium gain antenna. The received pilot power is shown in Figure 2 for the N-S road. Three signal variation phenomena can be seen. The fastest variation is due to multipath, which is minimal for the tower environment as will be discussed shortly. The relatively wide ripples of about 1.5 dB peak-to-peak magnitude signal variations are due to the tower antenna pattern. The deep, sharp fades correspond to the telephone poles on the west edge of the N-S road. It is worth noting that the poles do not show up on the signal strength plots taken with the van traveling along the east side of the road away from the poles. This is because the poles are no longer in the line-of-sight between the vehicle antenna and the top of the tower.

Detailed data analysis was performed on the data gathered during the experiment [2]. One of the experiment objectives was to characterize the multipath channel present at the tower site. Least squares fitting techniques were applied to a host of multipath data gathered on the N-S and E-W roads using the JPL mechanically steered, medium gain antenna. This revealed that a Rician probability density function with a k factor (ratio of direct to scattered signal powers) of 20 to 21 dB fits well the multipath environment experienced at the tower site. This is shown in Figure 3. It was found that the fit could be further enhanced if a running average is used to smooth the ripples due to the tower antenna [2]. Also of interest is the effect of the bin size on the fit obtained. This is illustrated in Figure 4. The high values of k obtained clearly indicates that the barren, flat tower site creates very little multipath. The channel behaves much like an additive white gaussian noise channel.

3. The Joint JPL/FAA/INMARSAT MARECS-B2 Satellite Experiment

The basic objective of the experiment was to demonstrate the voice and data link performance in a typical aeronautical environment. Of particular importance was the demonstration to the FAA of the quality and robustness of the MSAT-X speech codecs. To support the objectives of the experiment, data to fully characterize the link and the disturbances on the channel was gathered.

3.1 Experiment Configuration

Figure 5 depicts the experiment set-up. The configurations of the ground segment (1/89) and the flight segment (3/89) are quite similar. The primary difference is that the Aircraft Terminal (ACT) was placed on the roof of the FAA hangar during the ground segment (and was referred to as the Ground Aircraft Terminal [GACT] [3,4]). With one exception, the ACT components are identical to those in the GACT. The exception is the aircraft antenna assembly used in the aircraft to mount the antenna to the inside of a passenger window [5]. For logistical simplicity during flight tests a separate antenna and assembly were used for each side of the fuselage. The ACT or GACT served as one end of the MSAT-X link. Another MSAT-X mobile terminal was located at INMARSAT's Coast Earth Station (CEST) in Southbury, CT. The mobile terminal was interfaced at IF to COMSAT's hardware chain [3,4]. One and two-way data and voice links were established through the MARECS-B2 satellite [4,6] located at 26^{o} west longitude.

3.2 Flight Paths

Selection of the flight paths for the flight segment proved to be one of the more intriguing aspects of the experiment. Factors relating to angle to satellite, doppler, path length, air traffic and weather conditions had to be taken into account [5]. Originally, three flights were planned, one each for the evenings of March 29, 30 and 31. Unseasonable weather patterns with severe thunderstorms interfered however. The first flight took the straight-line path shown in Figure 6 between Salisbury, MD, and Boston, MA. The middle flight scheduled for 3/30 had to be cancelled due to very severe weather and lightning at the FAA center which made fueling the plane hazardous. To avoid dangerous weather and increase the experiment duration as much as possible on the last (or second) flight, the southerly path from Atlantic City, NJ, to Charleston, SC, was taken on 3/31. Both flights were flown entirely at a cruising altitude between eight and nine thousand feet. This was to enable an airspeed in the 200 to 250 knot range. Unfortunately, that altitude placed the plane in the middle of the thunderstorms, thereby creating a very rough experiment environment replete with periods of intense turbulence.

3.3 Results

During the ground segment of the experiment both pilot and data channel signal power were recorded at the GACT and the CES. The most salient observation made for this additive white Gaussian noise (AWGN) channel (both ends are stationary) is signal power fluctuation due to variations in satellite loading. This is evident in the data collected from the digital readings of the power meter connected to the IF of the MSAT-X receiver. As seen from a typical plot shown in Figure 7, the variation in the signal power of the forward link is within +/- 0.8 dB. Smaller variation was generally observed at the CES on the return link. This is attributed to the fact that the automatic gain control on the return transponder (the high gain channel used) is normally off.

During flight, turbulence and minor course corrections added to the fluctuations in the received signal at the aircraft. From Figure 8 it is seen that the data channel signal power varies within +/- 1.5 dB. A plot of the received pilot during the same test period is given in Figure 9. It shows the general correlation and agreement between the signals received on the pilot and data channels (which are separated by 20 kHz in this experiment).

Multipath is known to have a minor effect in the aeronautical satellite link. A Rician density with k (ratio of direct to scattered powers) of 15 dB is well accepted. This small amount of multipath is embedded in the short term signal fluctuations exhibited in Figure 9. System performance is measured in terms of bit error rate versus signal to noise ratio. Preliminary analysis [5] has shown that despite flight dynamics only a small degradation of about 0.5 dB is present relative to the AWGN channel observed in the ground segment. This confirms that multipath fading does not play a significant role in the satellite aeronautical satellite link at hand.

4. Upcoming Field Measurements

The first true land mobile satellite experiment using the MSAT-X equipment will take place in July 1989 in Australia. The MSAT-X mobile laboratory will be driven between Sydney and Brisbane and in the vicinity of both cities. A wealth of propagation and system performance data will be gathered and subsequently analyzed. Future articles will report on both the propagation and system performance measurements to be made, and will aim to elucidate the effects of the propagation environment on observed system performance.

REFERENCES

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6. da Silva Curiel, A., "The First Generation INMARSAT System," Proceedings of the Third International Conference on Satellite Systems for Mobile Communications and Navigation, IEE Publication 222, London, U.K., June 1983.

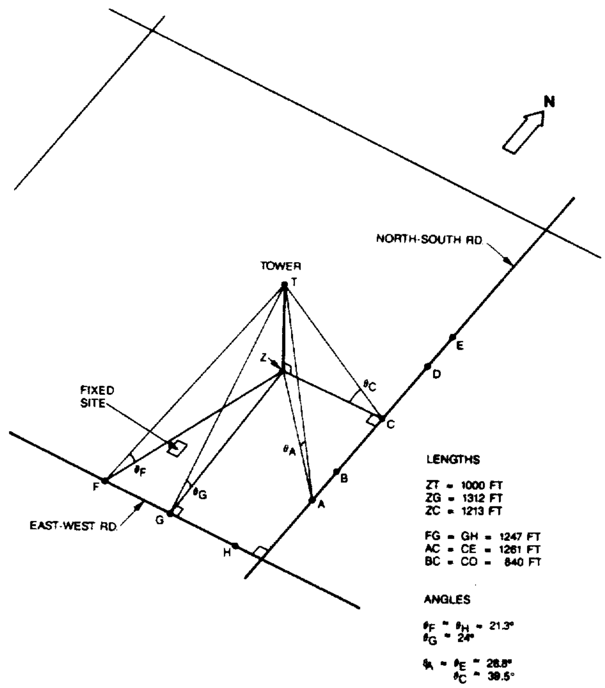

Figure 1. Layout of the Tower-3 Experiment

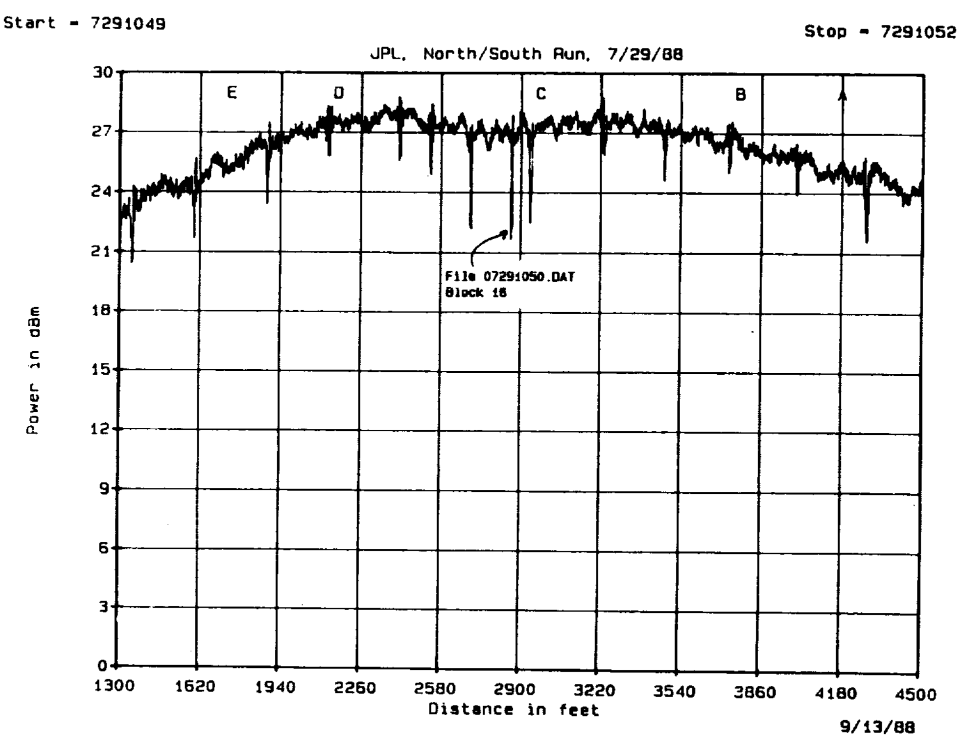

Figure 2. Pilot Signal Power Received at Van on North-South Road

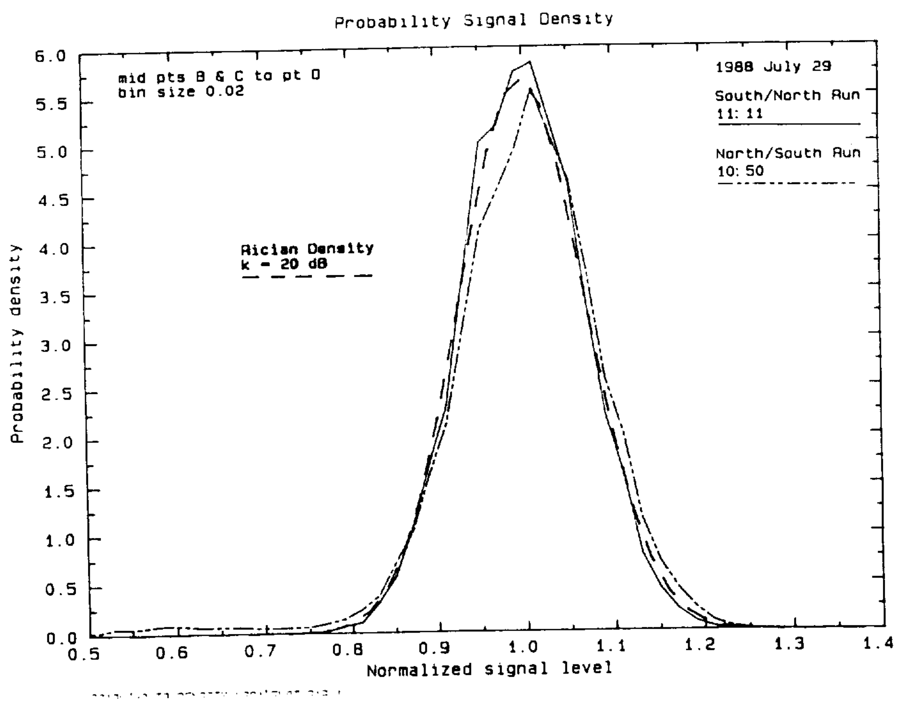

Figure 3. Rician Densities to Fit Received Pilot

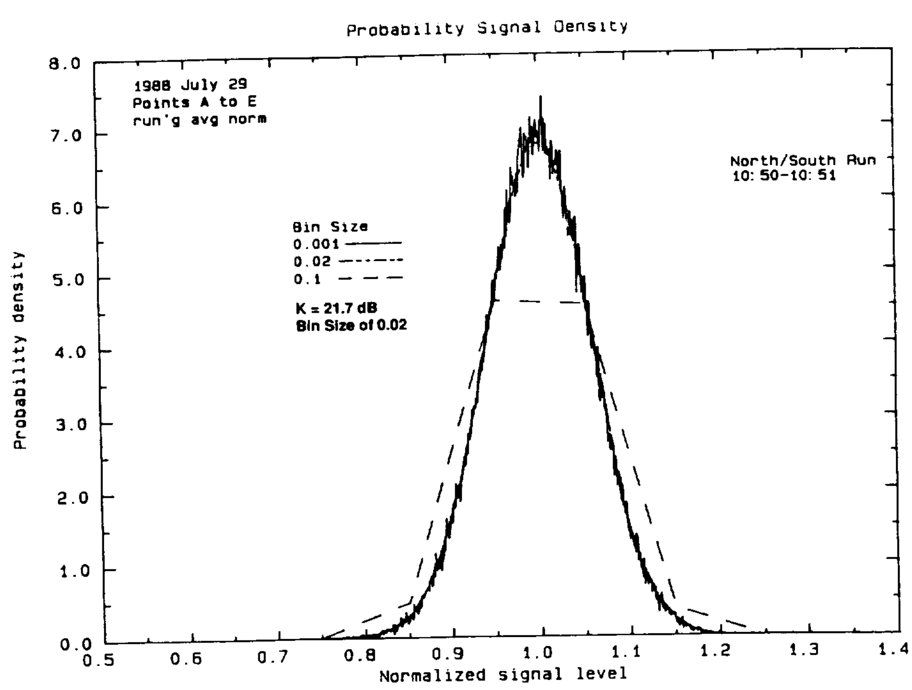

Figure 4. Effects of Bin Size Choice and Running Average Smoothing on Data Fitting

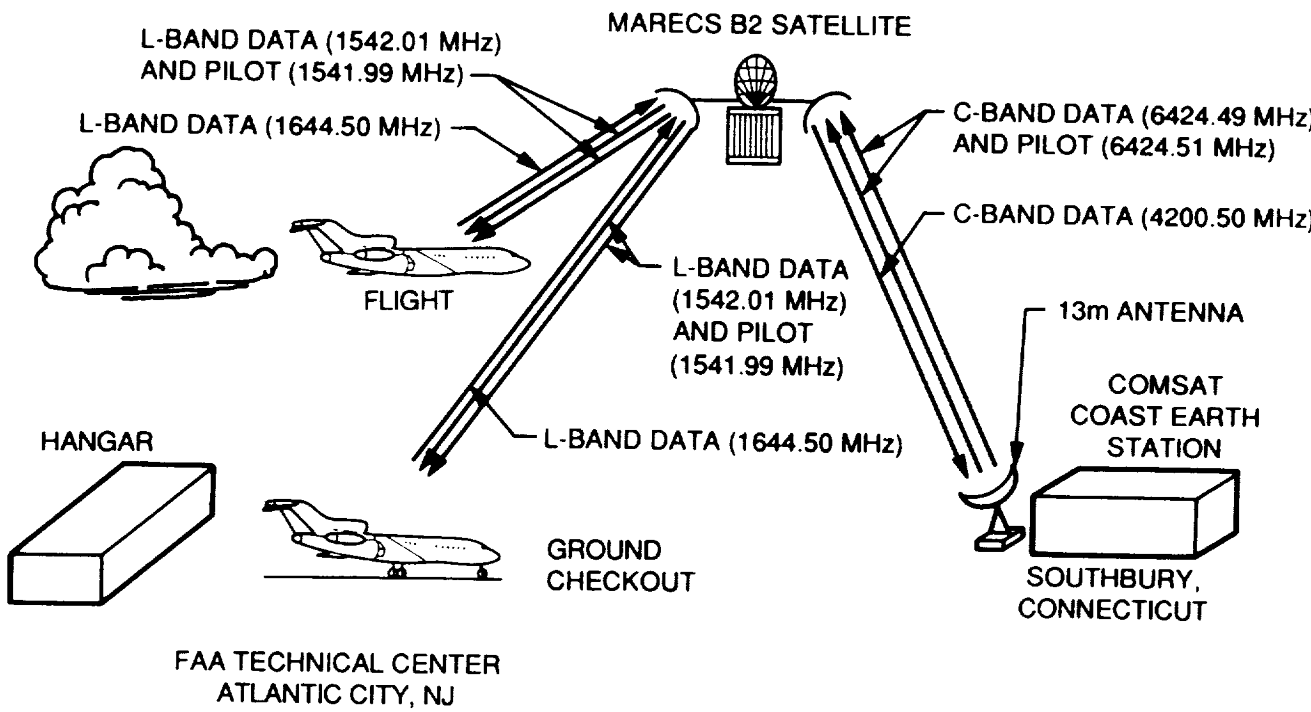

Figure 5. Configuration of JPL/FAA/INMARSAT Satellite Experiment

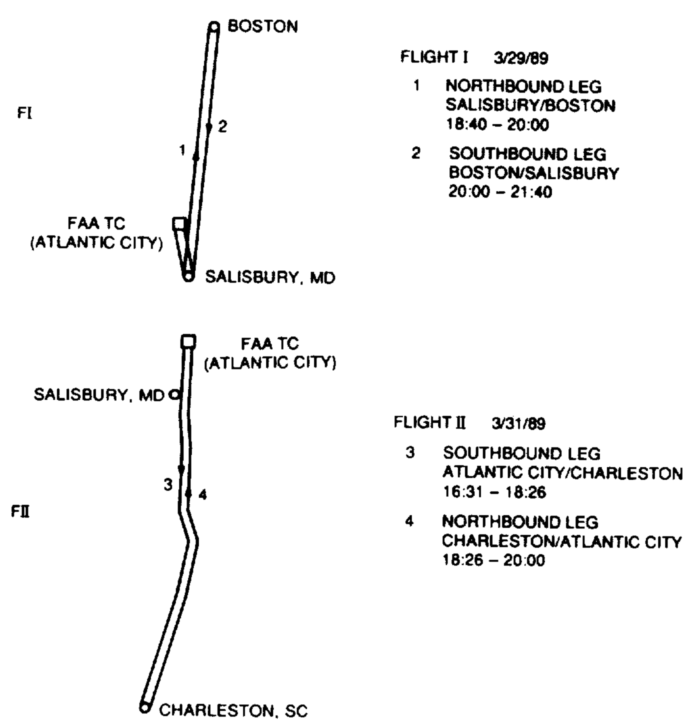

Figure 6. Flight Paths Selected In Experiment

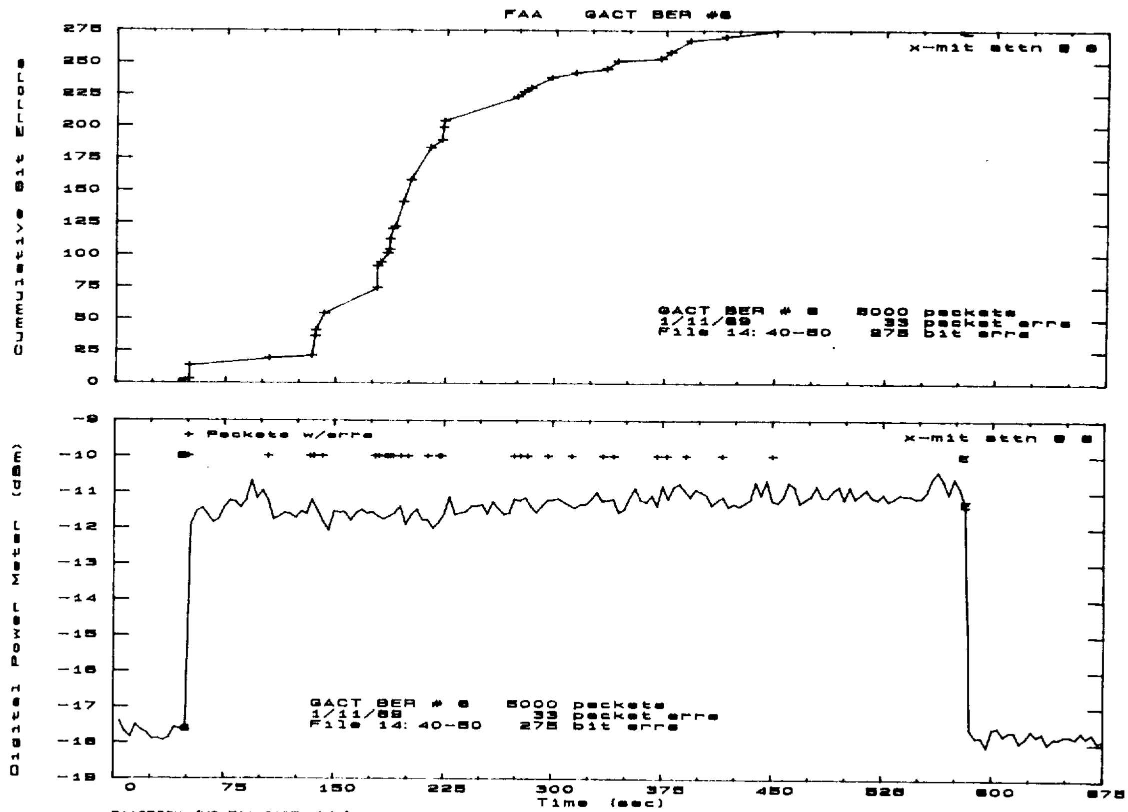

Figure 7. Data Channel Signal Level Variations in Ground Segment of Experiment

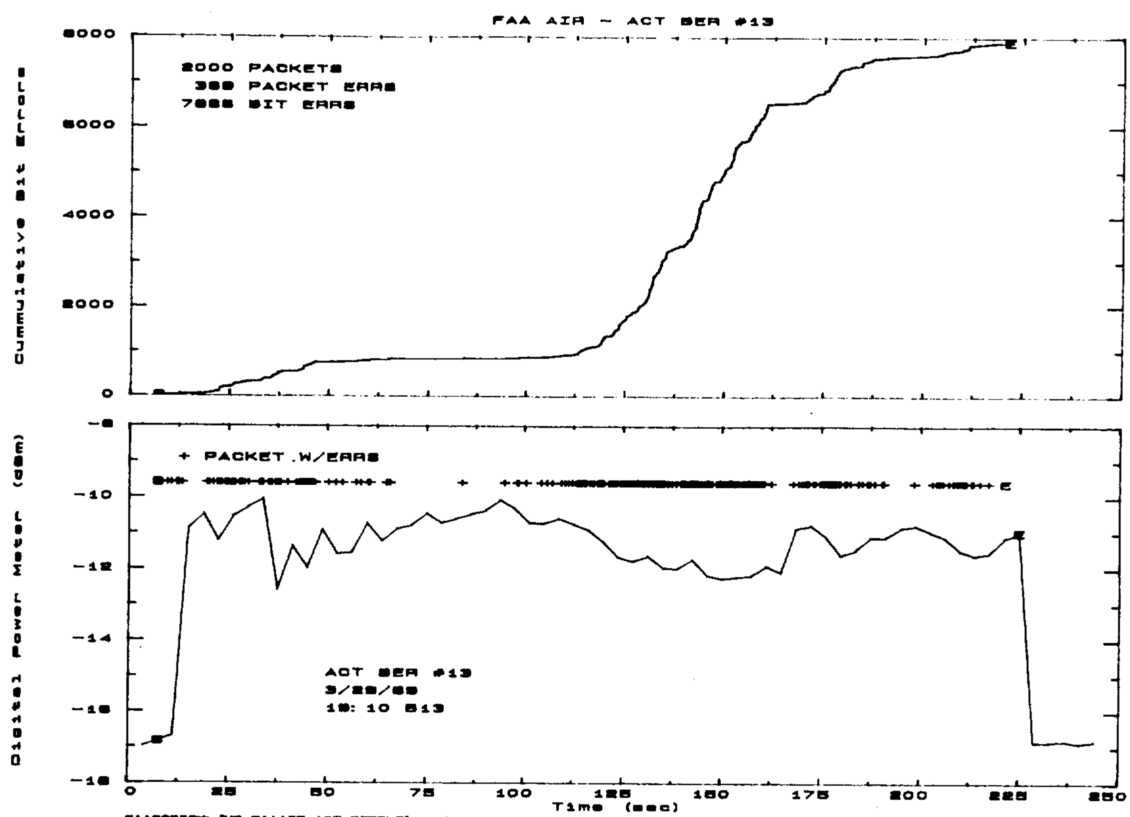

Figure 8. Data Channel Signal Level Variations in Flight Segment of Experiment

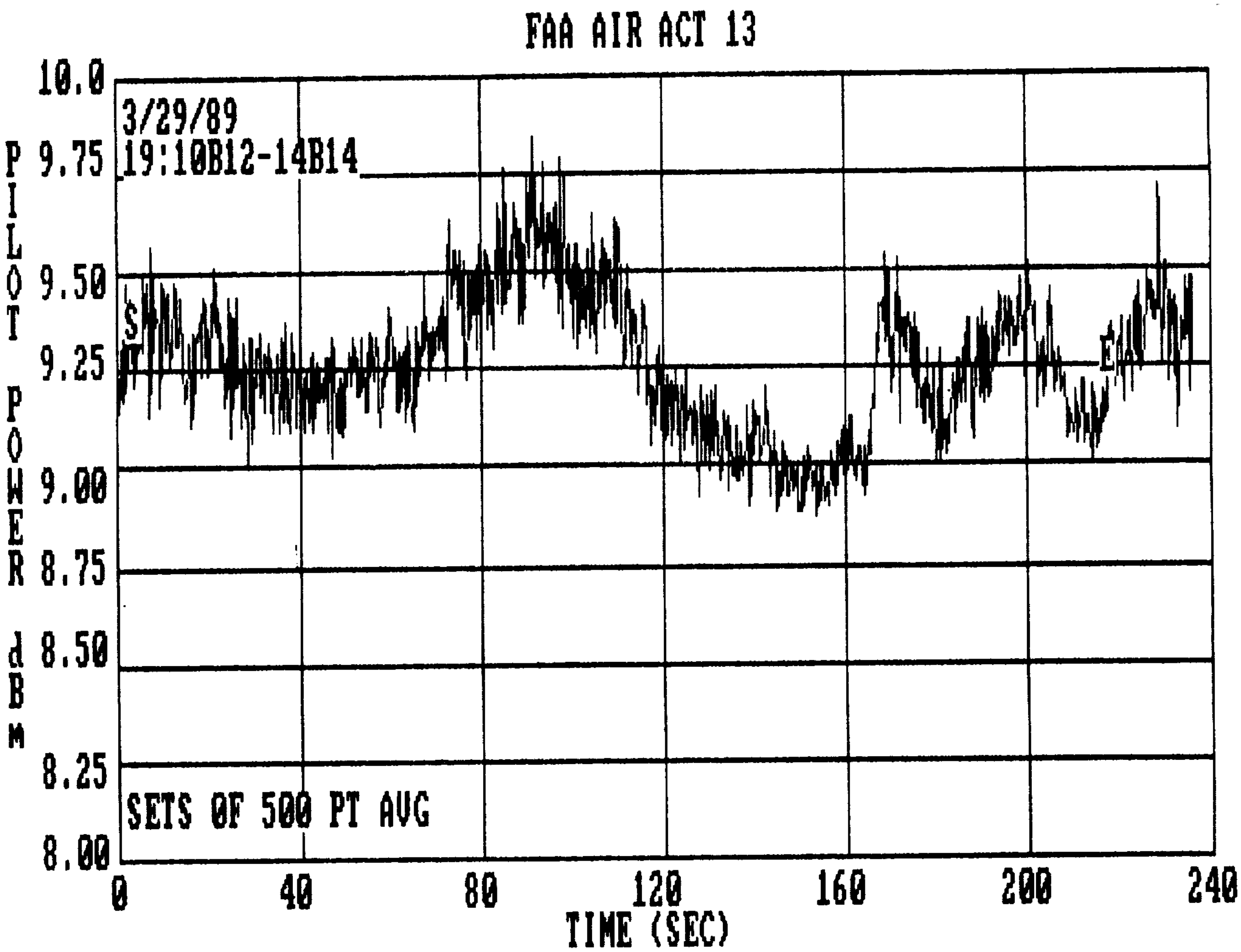

Figure 9. Pilot Signal Fluctuations During Flight Segment