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TEST REPORT: LOW COST ACCESS AND EFFICIENT USE OF TDRSS

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SECTION I - INTRODUCTION

I.1 TEST BACKGROUND DEVELOPMENT

In order to develop new ways to increase the number of users taking advantage of NASA's Space Network for space-to-ground communications links, researchers at New Mexico State University (NMSU) developed a technique for using non-gimballed antennas for accessing a Tracking and Data Relay Satellite (TDRS) within the Space Network [1]. This concept would allow spin-stabilized satellites to access one of the TDRS spacecraft in the SN constellation as the user satellite sweeps past the TDRS position as the satellite approaches either its ascending or descending node if this node is relatively close to the TDRS subsatellite point. The research team from NMSU developing this concept proposed to NASA the use of the Extreme Ultra Violet Explorer (EUVE) to test this concept on orbit. EUVE differs from the desired satellite configuration in that EUVE has a relatively high-gain parabolic antenna and, most importantly, EUVE has an inertially-stabilized attitude control system while the concept to be tested was for a spin-stabilized satellite. We believed that these limitations would not affect the basic proof-of-concept test we were trying to achieve. With the approval and coordination of NASA, a total of six satellite passes through the West TDRS were requested and the necessary equipment configured for data collection at the Second TDRS Ground Terminal (STGT), also known as *Danzante*, at the White Sands Complex (WSC).

I.2 TEST OBJECTIVE

The objective of this test is to demonstrate that large quantities of telemetry data can be transmitted from the EUVE spacecraft via TDRS using a fixed, zenith-pointed spacecraft antenna. To emulate the action of a fixed, zenith-pointing spacecraft, the FDF at GSFC suggested pointing the EUVE antenna to the correct position to directly point to TDRS as the EUVE passed directly under the TDRS. This antenna pointing would be maintained during the duration of each pass and then changed appropriately for each pass.

I.3 TEST DESCRIPTION

The test was run at the times indicated in Table I.1

Table I.1 Test Times		
Date	**DOY**	**Hours (U.T.)**
13 May 1996	134	12:09 - 16:02
14 May 1996	135	11:47 - 15:41

During the experiment data collection times, the EUVE POCC commanded the spacecraft to point at zenith and then transmitted a test data pattern at DG1 Mode 2 dual-channel configuration. The I Channel data rate was 1 kbps and the Q Channel data rate was 32 kbps. Data captured at the WSC was sent from the LRBC to the GSC NMSU computer for storage. After the test pass, data was sent from the NMSU computer to the NMSU campus over a telephone line. After each test event, the connection from the Demux to the NMSU computer was disconnected.

I.4 TEST CONFIGURATION

As developed in [2], the test configuration would be as follows for the ground equipment:

a. EUVE data would be returned to the WSC via the MA return data stream.
b. Data would be demodulated using one of the available Integrated Receivers and both the I and Q Channel would be received.
c. The baseband data would be routed through the Low Rate Black Switch to the Multiplexer for packaging in 4800-bit blocks and time-tagging of the data.
d. The output of the Multiplexer would be transmitted to the EUVE POCC via NASCOM
e. The Multiplexer output would also be routed to the Demultiplexer where the EUVE Q Channel data would be removed.
f. The Q Channel data would be transmitted over a RS-422 link to a NASCOM Interface Board resident on a PC supplied by NMSU.
g. The PC would be used as a data collection PC for the Q Channel data. This PC would also have access to a telephone line so the data could be transmitted to the NMSU campus.

Additional test equipment used during the tests was an oscilloscope to monitor data connections at the WSC during each pass.

I.5 EXPECTED RESULTS

Based on the simulations and analysis developed in [1] and confirmed in [2], it is expected that the following results should occur with this set of tests:

a. Each EUVE pass will last for approximately five minutes centered on the time when the EUVE passes directly under the TDRS; this will be a function of the dynamic range of the receivers based on their pre-pass estimated best settings with a few minutes longer being possible if conditions act favorably.
b. The signal should fall off quickly outside of this time because the EUVE antenna system has a relatively high gain compared with the situation this concept was designed for.
c. We should be able to determine how quickly the receivers can lock onto the signal as it sweeps in view of the TDRS.

While this is not an exact analog of the spin-stabilized platform that the concept was designed for, it should exhibit behavior close enough to validate the concept.

The criteria for a successful test are then:

a. Was the link established at the predicted time and was lock maintained for the predicted duration?
b. Was the link performance (bit error rate) within predicted values?
c. Did all interfaces work as desired?
d. Was the total data received consistent with simulation results?

SECTION II - TEST TEAM

Table II.1 lists the members of the test team plus their status during the test. Not listed are members of the GSFC FDF and EUVE offices who gave support in the process.

Table II.1 EUVE Test Team Members		
Name	**Organization**	**Activity**
Leslie Ambrose	GSFC/532.3	Network Test Manager
Jeffrey Drake	GSFC	STGT Engineering
Stephen Horan	NMSU	Principal Investigator
Peter Hughes	GSFC	EUVE
James Pawloski	GSFC	EUVE POCC
Tri Thai	GSFC	GTD
Bob Gonzales	GTE	WSC Test Conductor
Ken Arakaki	NMSU	Engineering

SECTION III - DATA COLLECTION ACTIVITIES

III.1 DATA ACQUIRED

Of the six data passes available during the test time, measured E_b/N_0 from the MA receivers at the WSC was captured in addition to the Q-Channel spacecraft data. The start and stop times for the data collection are indicated in Table III.1. In the table, the times for the start of the pass and the end of the pass as predicted by the GSFC FDF are indicated. The time over which data was gathered is listed in the Measurement columns. The measurement time is based upon the times at which the receivers were locked onto the signal and were intended to be 15 minutes on either side of pass center time as predicted by the FDF. The Q-Channel data was not found to be necessary in the subsequent analysis and was primarily used to keep the receivers locked onto the EUVE transmission.

Table III.1 EUVE-to-TDRS Pass Log

		Predicted (U.T.)		Measurement (U.T.)		
Day	**Pass**	**Start of Pass**	**End of Pass**	**AOS**	**LOS**	**Channels**
134	1	11:58:00	12:48:00	12:09:10	12:39:10	I
	2	13:39:00	14:29:00	no data gathered this pass		
	3	15:20:00	16:11:00	15:32:30	16:01:40	I
135	1	11:37:00	12:27:00	11:47:30	12:16:40	I & Q
	2	13:18:00	13:55:00	13:15:37	13:36:35	I
	3	14:59:00	15:50:00	15:07:05	15:40:50	I

The measured Eb/No from the MA receivers are plotted on the six charts on the following page. As can be seen, the receivers were able to lock onto the transmitted signal virtually immediately at the start of the pass. This is in direct contradiction to the expected results. Based on the conceptual model being used, the total duration of good-quality data was expected to be five to seven minutes. Each pass was scheduled for 30 minutes to allow the test team to see the system capture the signal and acquire lock. Essentially, the system acquired lock to the signal immediately upon the start of data acquisition and held lock for the duration of the data acquisition. The Analysis section below will show how the conceptual model needed to be revised. The Implications section will discuss how these results may be used in spacecraft design and operations.

III.2 COMPARISON WITH CRITERIA FOR SUCCESS

The criteria for a successful test were given earlier in Section I.5. The criteria and the results with the actual experiment are as follows:

a. Was the link established at the predicted time and was lock maintained for the predicted duration?

The link was established at the start of the scheduled service time and not at the predicted start of the pass. The scheduled service was started and stopped fifteen minutes from predicted mid-event. The scheduled time was 30 minutes for an estimated 5 to 7 minute pass event. Therefore, the event lasted considerably longer than anticipated.

b. Was the link performance (bit error rate) within predicted values?

The link BER measurement could not be obtained based on the data because no a priori knowledge of the data pattern was available. Post-event analysis was able to clearly find the telemetry frames and other markers thereby indicating a first-order data integrity. The measured Eb/No at the WSC indicated that a good BER (better than 10^{-6}) should have been possible.

c. Did all interfaces work as desired?

Yes. No interfacing problems.

d. Was the total data received consistent with simulation results?

Because of the long event duration, considerably more data was acquired than predicted.

Therefore, the test was successful. However, it did point out problems with the simulation analysis performed before the event.

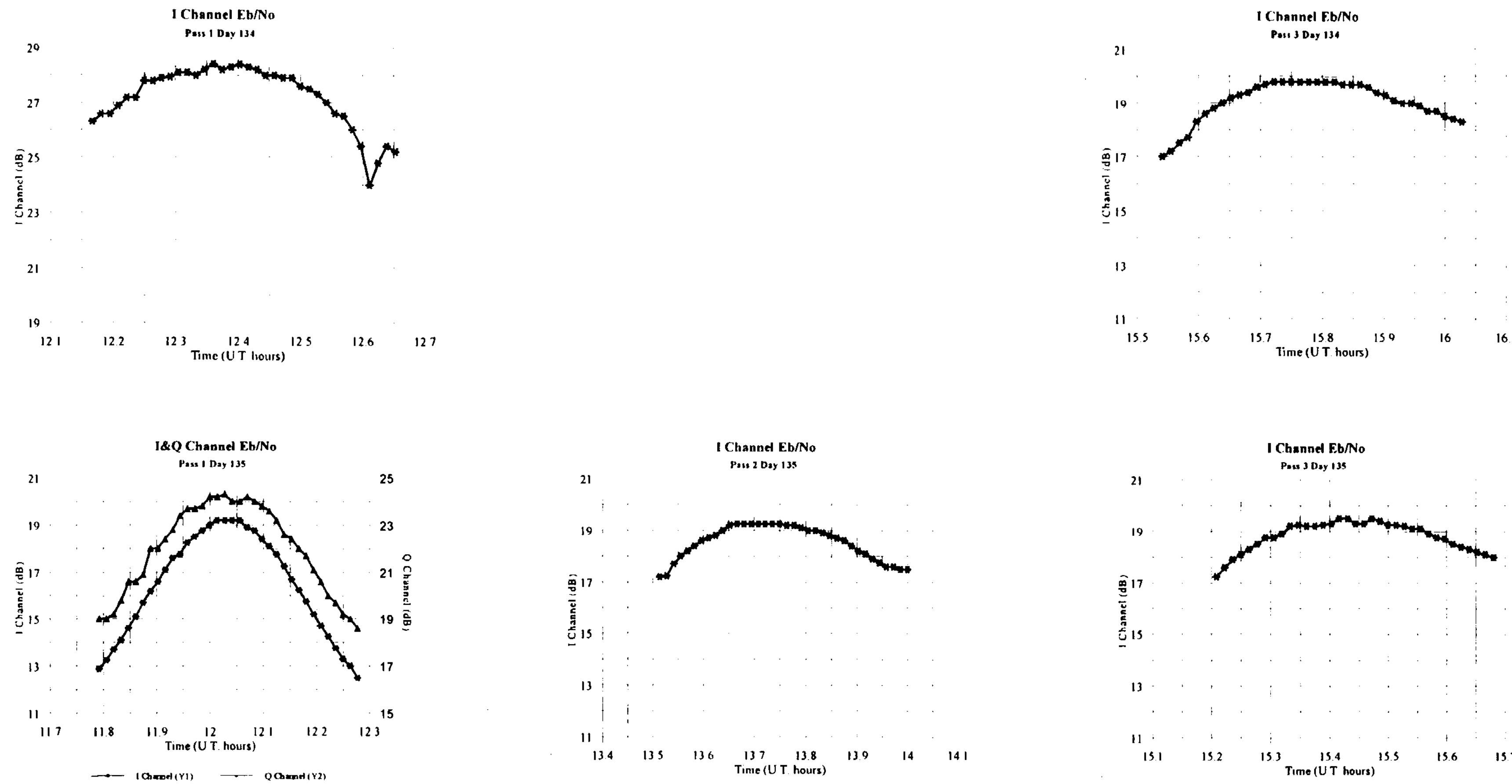

Figure III.1 - Eb/No measurements made at the WSC for each EUVE pass through TDRS West

SECTION IV - ANALYSIS

IV.1 EXPLANATION OF RESULTS

The performance of the system did not explicitly validate the concept of an antenna being swept past TDRS because the duration of good-quality data was much longer than that expected based upon simulation analysis. In subsequent discussions with the FDF, the reason for the unexpected results became clear. The initial conceptual model for the test assumed that the EUVE would act in a sweeping motion with respect to the EUVE antenna and the TDRS MA antenna. To accomplish this, the EUVE antenna was positioned properly to point directly at TDRS West as the EUVE swept under the TDRS. During the test pass, the antenna would not be moved to track the apparent TDRS position. However, this model neglects the effects of having an inertially-stabilized attitude control system in the EUVE. This type of attitude control tries to maintain the pointing of the spacecraft with respect to the inertial coordinate system. For all intentions, the spacecraft will point at the same location on the sky unless it is perturbed from this pointing. While the TDRS is still in earth orbit, its orbital altitude of 42,164 km with respect to the center of the earth and in excess of 35,000 km from the EUVE, places it effectively at a distance of infinity with respect to the EUVE's antenna pointing. Therefore, the inertial attitude control system maintains antenna pointing during a whole TDRS visibility period. With this type of spacecraft, the sweeping motion of a spinning satellite cannot be replicated without actively pointing the antenna during the pass.

IV.2 SIMULATED EVENTS

In order to better understand the results, a series of simulations using the package Satellite Tool Kit [3] were performed. The simulation was configured for TDRS West and the EUVE using the orbital elements given in Table IV.1 which were obtained from the Air Force Institute of Technology reflector site [4]. The simulation used an inertial attitude control model for the EUVE spacecraft. The EUVE parabolic and TDRS MA antennas were modeled as sensor-objects within the simulation. The EUVE "sensor" would accept input over an angle of 13.2 degrees from boresight. The TDRS MA antenna system was modeled as a "sensor" having the capability to accept input over an angle of 26 degrees from boresight. For the simulation, a contact was defined as the time when both sensors were mutually in view of each other. The times of the contacts based on the simulations is given in Table IV.2. In this table, the contact times as predicted by the GSFC FDF are also listed to show that they compare quite well. Ground tracks for EUVE (light and heavy sinusoidal lines), TDRS West (dot at the equator at -174° longitude), and TDRS 6 (wavy line to the east of TDRS West) for the first three simulations of the passes on day 134 are shown in Figures IV.1 through IV.3 with similar results being obtained for the other three passes for day 135. The heavy-lined section of the ground track for the EUVE indicates the portion of a pass with a contact through TDRS West. The AOS and LOS points along the ground track are indicated. The difference between the three sets of ground tracks are the azimuthal angle for pointing the EUVE antenna used in the STK simulations.

NORAD Two-Line Elements	
Satellite	**Mean Orbital Elements**
EUVE	1 21987U 92031A 96133.75979634 .00000715 00000-0 23180-4 0 5418 2 21987 28.4307 61.1763 0008917 26.4215 333.6854 15.19769324218282
TDRS 3 East	1 19883U 89021B 96133.27792245 -.00000284 00000-0 10000-3 0 2137 2 19883 0.0462 87.0249 0002464 15.3180 187.0595 1.00273204198751
TDRS 4 West	1 21639U 91054B 96134.58492492 .00000067 00000-0 00000+0 0 326 2 21639 0.0894 72.6418 0004855 340.4259 214.7824 1.00274365111549
TDRS 6 Spare	1 23613U 95035B 96135.47274652 .00000092 00000-0 10000-3 0 1670 2 23613 0.6144 83.4531 0000719 113.7157 44.2074 1.00006658 3042

Table III.2 EUVE-to-TDRS Pass Log					
		Simulated (U.T.)		**Predicted (U.T.)**	
Day	**Pass**	**Start of Pass**	**End of Pass**	**AOS**	**LOS**
134	1	11:54:18	12:52:06	11:58:00	12:48:00
	2	13:34:46	14:33:04	13:39:00	14:29:00
	3	15:15:38	16:14:49	15:20:00	16:11:00
135	1	11:33:16	12:31:06	11:37:00	12:27:00
	2	13:13:45	14:12:08	13:18:00	14:08:00
	3	14:54:41	15:53:57	14:59:00	15:50:00

From these results, we can predict that the entire 58-minute pass should have been observable and not just the 30 minutes over which data was collected. This implies that non-active pointing for spacecraft antennas on inertially-stabilized satellites has some potentials for spacecraft design.

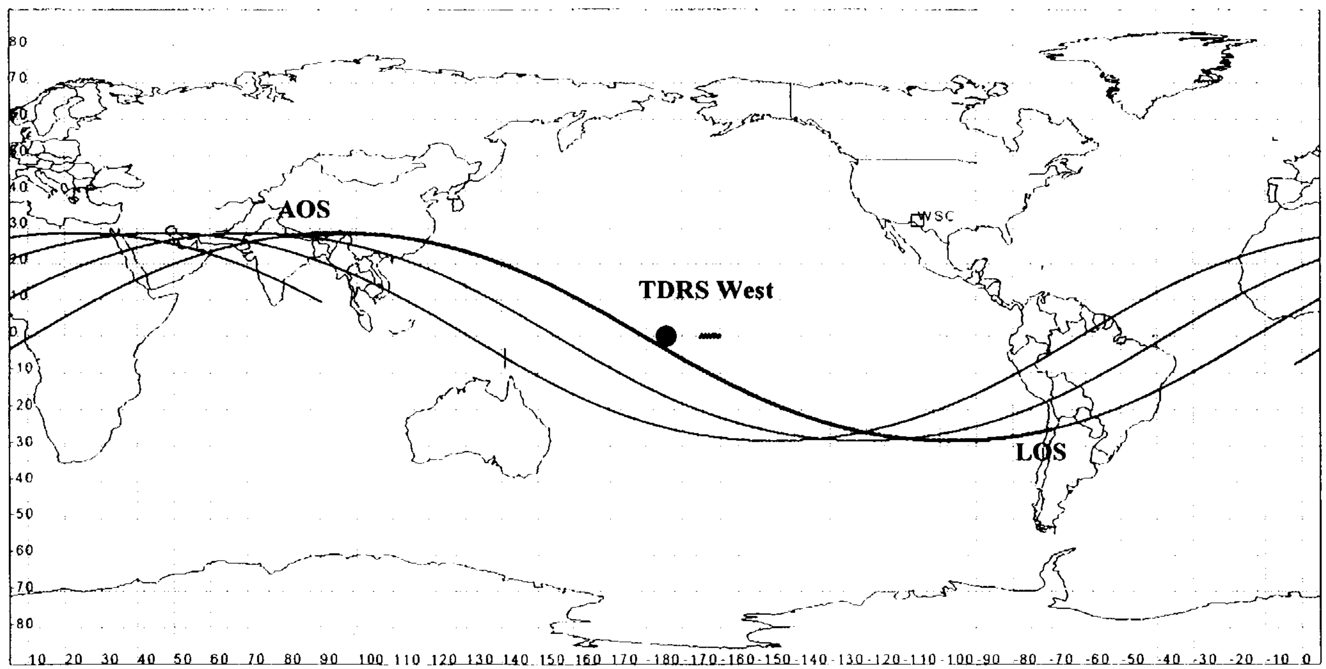

Figure IV.1 - First EUVE-to-TDRS Pass on Day 134.

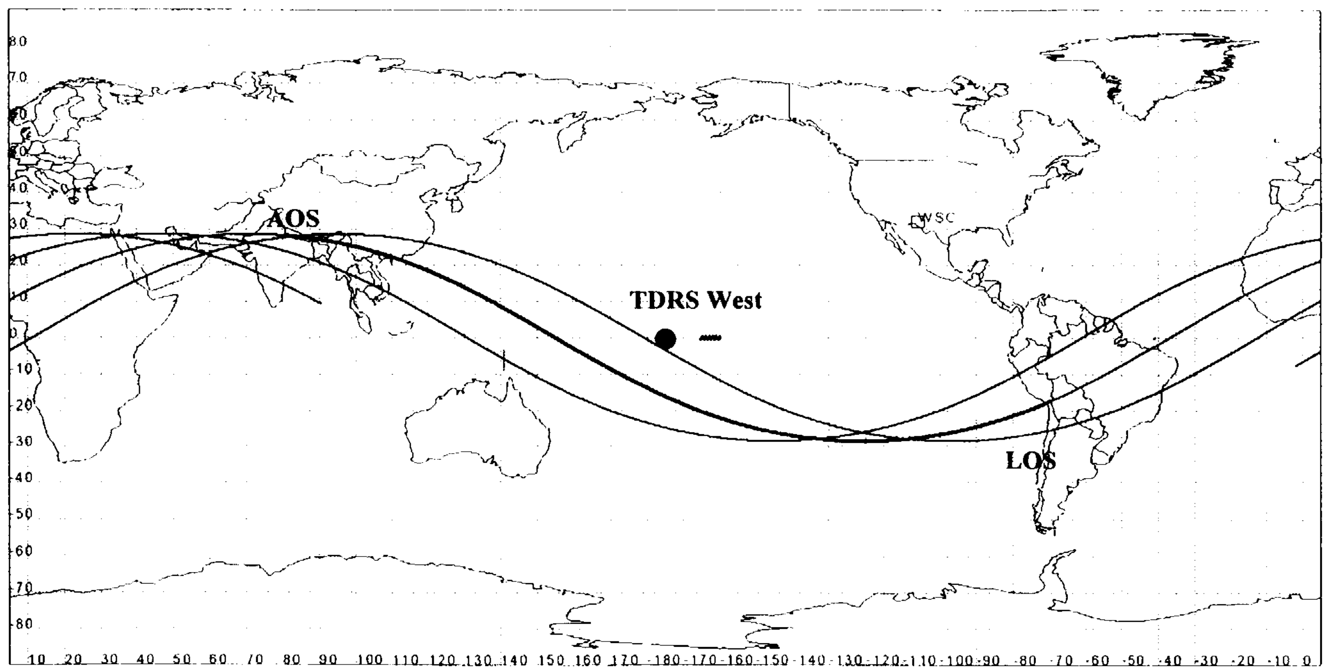

Figure IV.2 - Second EUVE-to-TDRS Pass on Day 134.

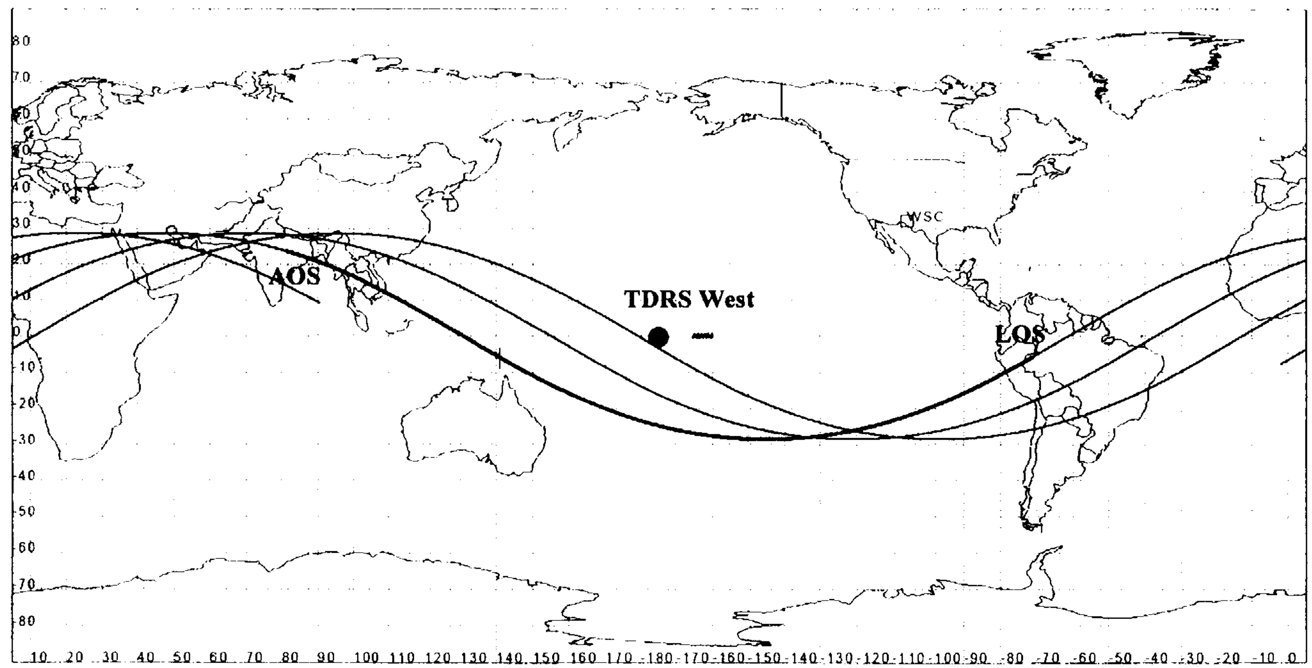

Figure IV.3 - Third EUVE-to-TDRS Pass on Day 134.

IV.3 SPACE LOSS CONTRIBUTION

In an effort to better understand the E_b/N_o results obtained at the WSC, it was decided to investigate the space loss contribution to the data collected. The normal definition for the space loss in a link is given by

$$L_s = 20 \log (4\pi R/\lambda)$$

where R is the link range and λ is the operating wavelength. Since we are concerned with the relative loss, we can define the relative space loss, L_{sr}, to that found at the minimum range, R_o, via

$$L_{sr} = 20 \log (R/R_o)$$

As can be seen from the charts in Figure IV.4, the space loss will amount to approximately 2 dB over the whole contact time. For the times during which data was gathered, the space loss accounts for approximately 1 dB but not the whole variation of approximately 2 dB. This implies that we are also observing the variation in the antenna gain during this period.

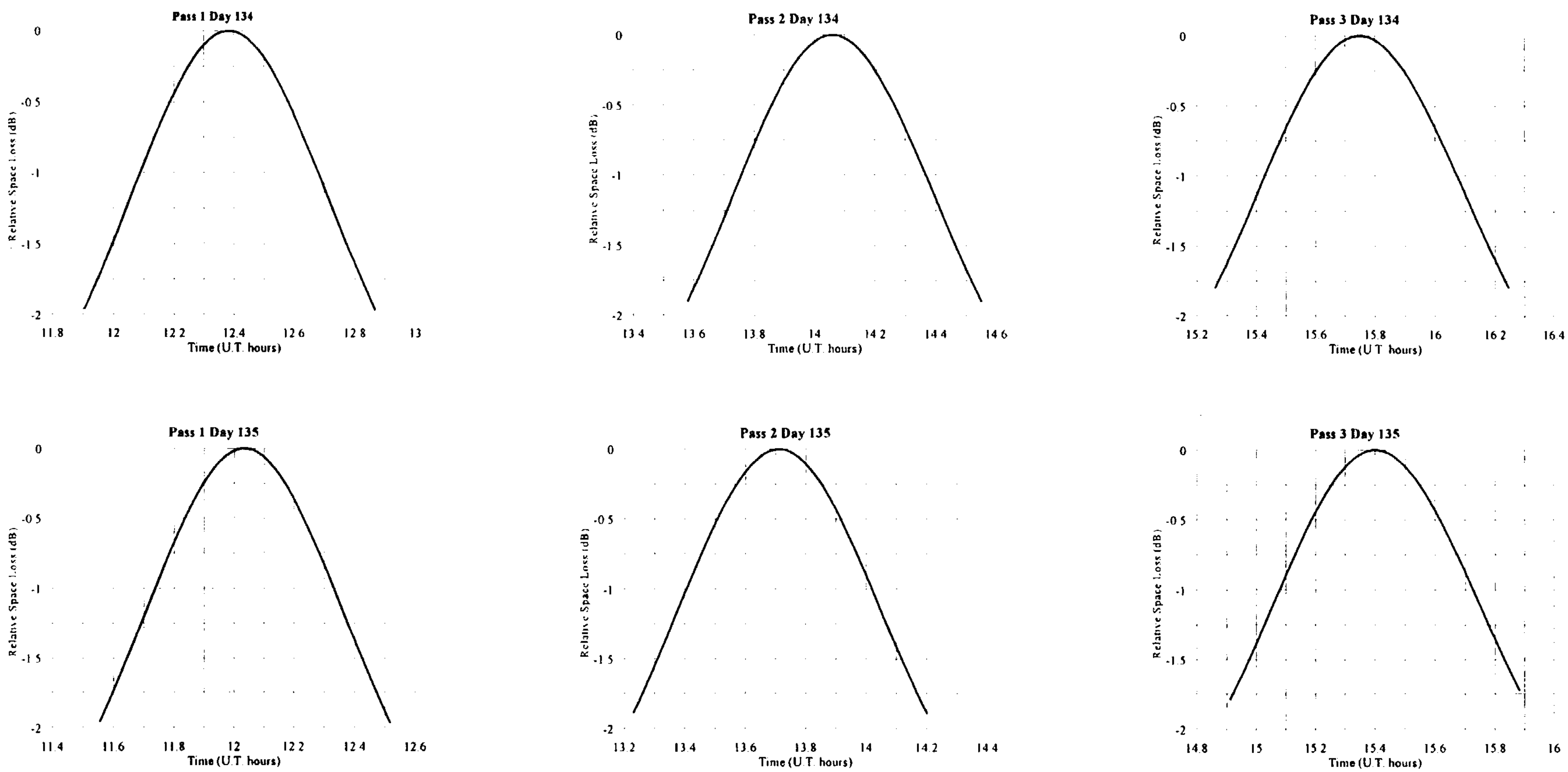

Figure IV.4 - Predicted Space Loss Contributions for Each Pass.

SECTION V - IMPLICATIONS

The test brought out a significant, unexpected result: inertially-stabilized spacecraft can achieve full-pass access to a given TDRS under the following conditions:

a. Based upon the simulation results, the antenna for the transmitting satellite needs to have a Half Power Beam Width (HPBW) exceeding 13.2 degrees
b. For narrow HPBW-antennas, the pointing angle needs to be exact from the transmitting satellite to the TDRS
c. If the HPBW is wider, the pointing does not need to be as exact and in fact can cover several orbits with one pointing angle if the HPBW is broad enough.

These conclusions are based on the simulation results but their agreement with the actual events is encouraging. The case of the mis-aligned antenna is illustrated in Figure V.1. Here, the azimuthal angle is offset by 5° from its optimal value. As can be seen, the full-pass coverage is not obtained. However, if the antenna cone angle (one half of the HPBW) is increased from 6.6° to 10°, the full pass is again achieved. This is illustrated in Figure V.2. If the cone angle is set to 32° (HPBW is 64°), then all three orbits are covered from one azimuthal position as shown in Figure V.3. This could be useful for low-gain antenna systems.

Based on these simulations and the actual test results, this would indicate that some new possibilities for antenna pointing on inertially controlled platforms are possible with these concepts, for example,

a. Antenna sysems which have lost their tracking capability could be pre-pointed to obtain useful passes,
b. Emergency backup antennas could be made and permanently mounted on a satellite,
c. Antenna systems where minimizing the wear on gimbals or needing to operate in reduced-power mode is necessary for a time could take advantage of this method to point to TDRS for data services.

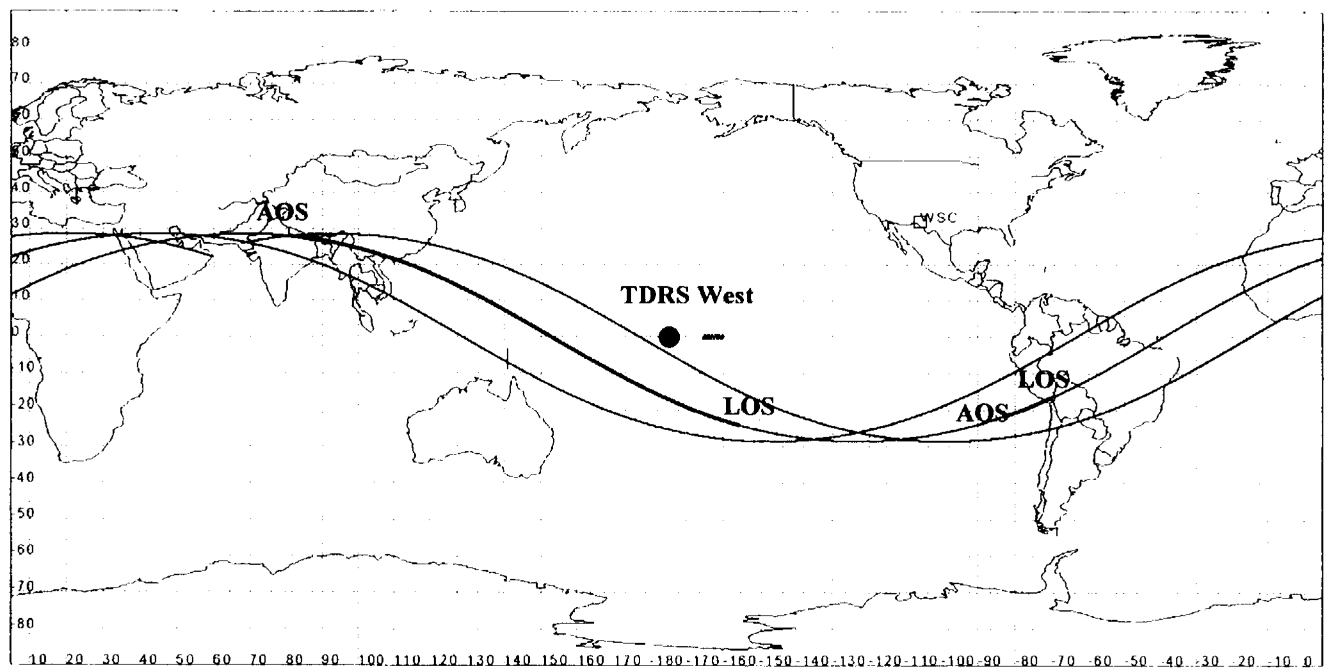

Figure V.1 - Azimuth angle offset by 5° from optimal and narrow HPBW antenna used.

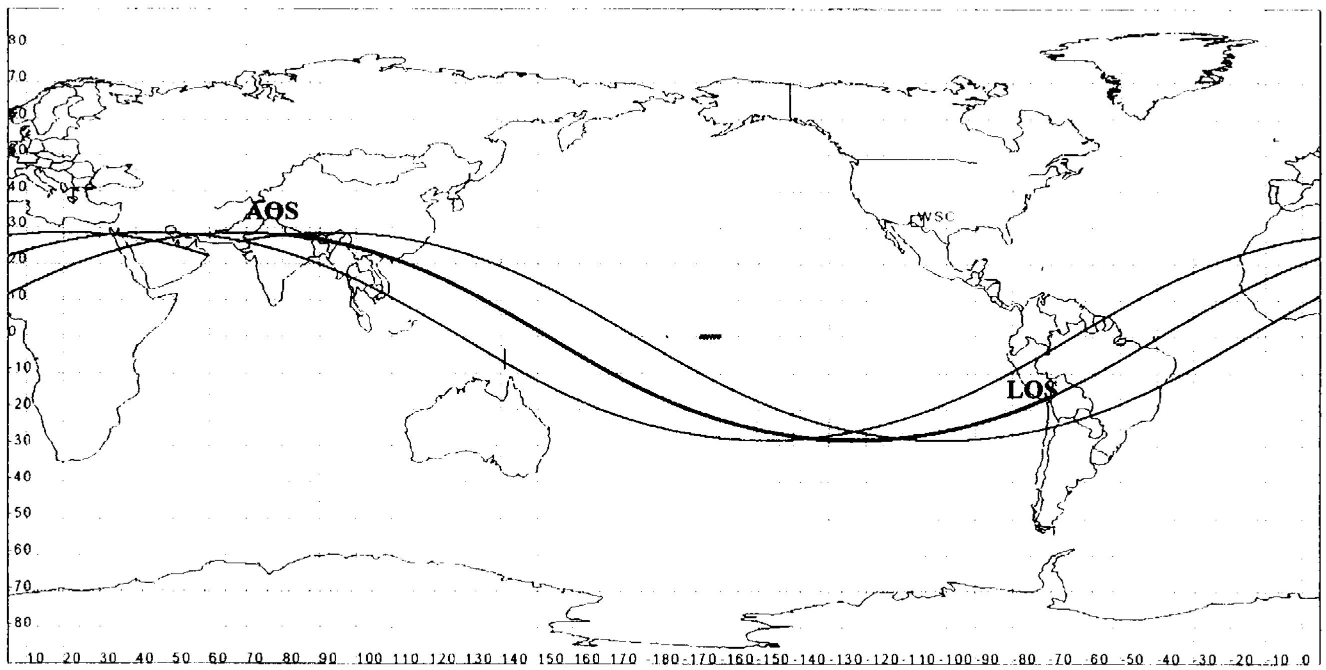

Figure V.2 - Azimuth angle offset by 5° from optimal and wide HPBW antenna used.

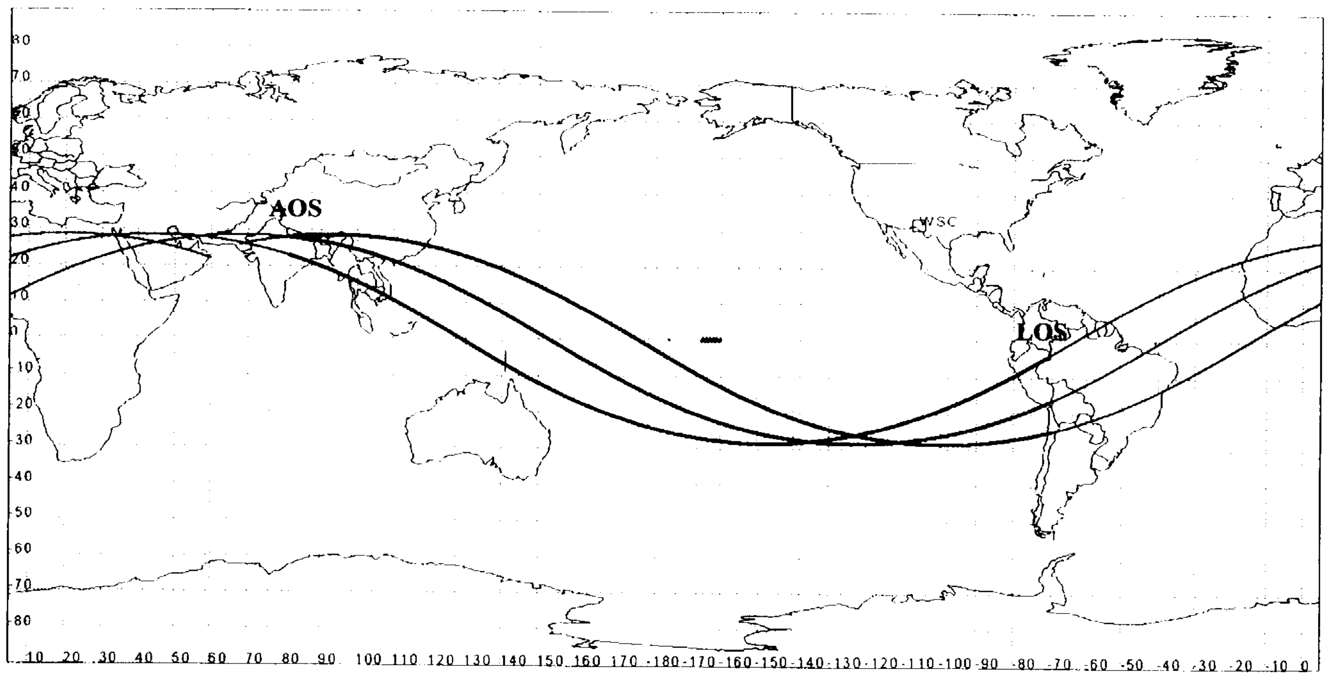

Figure V.3 - Three-orbit contact with a 32° cone angle for the antenna.

SECTION VI - ACKNOWLEDGMENTS

This research was supported by NASA Grant NAG 5-1491 to New Mexico State University. The members of the test team all contributed to the success of this effort.

SECTION VII - REFERENCES

[1] Horan, S., "Small Satellite Access of the Space Network," *Proc., 9th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, September 1995.

[2] Drake, J., "Experimental EUVE Data Collection and Link Simulation at the STGT," M.S.E.E Technical Report, New Mexico State University, April 1996.

[3] Analytical Graphics, "Satellite Tool Kit," version 2.1, 1995.

[4] Anonymous ftp of the file tle.812 from archive.afit.af.mil in directory pub/space.