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Global Positioning System Performance During FAA Helicopter Test on Rotor Effects

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January 1985

DOT/FAA/CT-TN84/47

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Technical Report Documentation Page

1. Report No. DOT/FAA/CT-TN84/47	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle GLOBAL POSITIONING SYSTEM PERFORMANCE DURING FAA HELICOPTER TEST ON ROTOR EFFECTS		5. Report Date January 1985
		6. Performing Organization Code ACT-140
7. Author(s) Jerome T. Connor and George Paolacci		8. Performing Organization Report No. DOT/FAA/CT-TN84/47
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 10704A
12. Sponsoring Agency Name and Address Federal Aviation Administration Programming Engineering and Maintenance Service Washington, D.C. 20590		13. Type of Report and Period Covered Technical Note June - September 1984
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report covers the 1984 Federal Aviation Administration (FAA) tests using a single channel Global Positioning System (GPS) receiver under the turning rotor blades of a Sikorsky twin-turbine 4-composite bladed S-76 Helicopter and an Army 2-metal bladed UH-1H helicopter. The report cites the performance of the Magnavox Z-Set GPS receiver during acquisition and operation at various rotor speeds on the ground.

17. Key Words NAVSTAR GPS Z-Set Helicopter/GPS		18. Distribution Statement Document is on file at the Technical Center Library, Atlantic City Airport, New Jersey 08405	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

The Navigation Satellite Timing and Ranging (NAVSTAR)/Global Positioning System (GPS) provides extremely accurate position, velocity, and time information to suitably equipped users. In 1984, the Federal Aviation Administration (FAA) conducted tests using the GPS Z-set receiver under the turning rotor blades of a Sikorsky twin-turbine, 4-composite bladed S-76 helicopter and an Army 2-metal bladed UH-1H helicopter.

The objective of the test was to determine if the helicopter rotor motion significantly affected the performance of a GPS receiver during acquisition and operation at various rotor speeds on the ground.

The GPS receiver was a Magnavox Z-set which sequentially processes coarse acquisition (C/A) signals on 1575.42 megahertz (MHz) from four satellites. It was designed as a relatively low cost, low dynamics, but fairly sophisticated first generation navigator. The Z-set consists of the antenna assembly, low noise preamplifier, receiver/processor, and control display unit (CDU).

The Z-set receiver, CDU, and preamplifier were mounted with instrumentation equipment in a rack and moved next to the helicopter. The equipment was connected to the helicopter's electrical system to satisfy its complete power requirements. The helicopter was located at the Technical Center away from buildings and large objects to maintain line of sight with the satellites. The antenna was connected to the 80-foot RG-214 cable and moved to various positions, i.e., (a) next to the helicopter and 3 feet below the rotor path, (b) 3 feet below the center of the rotor path, (c) 3 feet below the edge of the rotor path, and (d) 60 feet outside the rotor path.

The test results showed:

1. The time to acquire satellites with the antenna at various locations beneath the rotor path was in the same range as previously measured in tests with fixed wing aircraft.

2. The GPS receiver derived position was not affected by the various rotor speeds.

3. The amount of attenuation required to prevent the GPS receiver from tracking satellite signals was the same regardless of the position of the antenna.

4. The safety margin of attenuation before the satellites were affected was approximately 21 decibels (dB) with the present satellite power, and using the Z-set receiver with an antenna at ground level at the FAA Technical Center.

The effect of helicopter rotor motion on GPS performance in the UH-1H and the S-76 helicopter on the ground is negligible.

INTRODUCTION

OBJECTIVE.

The objective of the test was to determine if helicopter rotor rotation significantly affected the performance of a Global Positioning System (GPS) receiver during acquisition and operation at various rotor speeds on the ground.

BACKGROUND.

The current world-wide civil short-range air navigation system, very high frequency omnidirectional range (VOR)/distance measuring equipment (DME), transmits fixed radial course information from the VOR ground stations; the DME station responds to airborne interrogations. The VOR/DME ground station provides readily usable aircraft navigation information of bearing and distance within its coverage area. However, not all geographic regions permit effective VOR/DME service. For long-range navigation, aircraft utilize Loran, Omega, and inertial navigation systems, with each system having its advantages and disadvantages. The Navigation Satellite Timing and Ranging (NAVSTAR)/ Global Positioning System (GPS) is a candidate replacement for these systems.

This satellite-based navigation and positioning system provides accurate position, velocity, and time information. When the GPS is fully operational, a receiver/processor will select signals from several satellites, decode and process those signals to determine three-dimensional user position in any weather, 24 hours a day, anywhere on or near the surface of the earth. Unlike the DME system, the GPS system is totally passive and a high number of users will not saturate the system.

A complement of seven satellites presently permit three-dimensional, four-satellite navigation (4-hour interval when all satellites are in a healthy operational status) over selected geographical areas. Full operational capability is scheduled for the late 1980's.

The Federal Aviation Administration (FAA) implemented an extensive program in 1979 to define and determine the potential role of GPS as a civil navigation system. In preparation for the NAVSTAR/GPS project, the FAA requested early in 1981 that Magnavox incorporate the latest version of the software, version 10, in the Z-set and deliver the modified receiver to the Technical Center for test. In 1981 the Technical Center flight-tested the Z-set in a Grumman G-159 Gulfstream and in a Sikorsky twin-turbine CH-53 helicopter. Results of these tests are contained in documents 4 and 5 cited in the section "Related Documentation/Projects."

In 1982 the FAA conducted a 50-hour fixed wing flight test program in an Aero Commander, a twin-engine general aviation type aircraft, using the GPS Z-set receiver with its positioning information filtered and interfaced to cockpit

instruments. Over 175 GPS and 40 VOR nonprecision approaches were made to the Technical Center runways using 15 pilots with varying degrees of experience. The results of this test are contained in document 6 cited in the section "Related Documentation/Projects."

In 1984, the FAA conducted tests using the GPS Z-set receiver under the turning rotor blades of a Sikorsky twin-turbine 4-composite bladed S-76 helicopter and an Army 2-metal bladed UH-1H helicopter. This report provides the results of these tests.

RELATED DOCUMENTATION/PROJECTS.

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2. Advisory Circular 90-45A, Approval of Area Navigation Systems for Use in the U.S. National Airspace System, February 1975.

3. Connor, Jerome T., Project Plan for NAVSTAR/GPS Fixed Wing Z-set Testing, DOT/FAA/CT-81/120, March 1982.

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9. Magnavox Government and Industrial Electronics Company, User's Manual (Computer Program) for User Equipment Z-Set of the NAVSTAR Global Positioning System, DCRL Item AOOX.

10. Luciani, V. J., NAFEC Range Instrumentation Systems, FAA-NA-79-32, February 1980.

TECHNICAL APPROACH

ACQUISITION TEST.

The GPS receiver was initialized with the antenna located 3 feet below the rotor path at each of four locations: (a) next to the helicopter rotor hub, (b) at the center of the rotor path, (c) at the edge of the rotor path, and (d) 60 feet outside the rotor path. Prior to each acquisition cycle, the Z-set was disconnected from power for at least 2 minutes. The time from initialization to the time when all the satellites in view were acquired (up to four) was recorded and compared to determine the effects of the helicopter rotor motion on signal acquisition. Table 1 provides detailed data for each helicopter pertaining to this test. A series of acquisition tests were conducted sequentially at different locations.

MONITOR TEST.

The performance of the Z-set was monitored at each of the locations previously cited at 100, 80, and 60 percent of maximum safe rotor revolutions per minute (rpm's). Any change in performance was analyzed to determine if it was caused by the turning of the rotor.

ATTENUATION TEST.

The labortory test configuration was varied to determine the effects of components inserted in series with the antenna, such as the 80-foot cable used with the helicopter.

During the helicopter test, the amount of attenuation was increased between the antenna and preamplifier until the GPS receiver was affected. The level of attenuation required to affect the receiver at each of the locations previously cited was recorded and compared to determine the effects of the helicopter rotor motion. A series of attenuation tests were conducted sequentially at different locations.

TEST ITEM DESCRIPTION

The Magnavox Z-set is a single channel receiver which sequentially processes coarse acquisition (C/A) signals on 1575.42 megahertz (MHz) from four satellites. It was designed as a relatively low cost, low dynamics, but fairly sophisticated first generation navigator for transport aircraft. The Z-set consists of the antenna assembly, low noise preamplifier, receiver/processor, and control display unit (CDU). Its main features are given in table 2. The CDU is used to initialize the set, enter waypoints to the nearest second, collect an almanac, and to monitor the receiver's navigation status.

The FAA performed tests on a Z-set, serial No. 6, with software version No. 10. Within the Z-set the resident eight-state Kalman filter computes user position, velocity, and time every 1.2 seconds (the normal sequence time per satellite). The processor updates the CDU position display every second based on the last navigation solution for aircraft position, speed, and ground track.

The Z-set periodically reviews its stored satellite almanac data, determines the optimum satellite constellation, and the time to change constellations. The algorithm for the latter function weighs the geometric dilution of precision (GDOP) value, satellite health status, tracking and data gathering history, and satellite visibility period. The satellite tracking program initiates track at a minimum elevation angle less than 10° above the horizon. An interface module to the Z-set accepts encoded barometric altimeter data (increments of 100 feet/30.5 meters) for processor controlled input to the navigation solution during periods when only two or three healthy satellites are available.

TEST CONFIGURATION

The Z-set receiver, CDU, and preamplifier were mounted with the Position Locating (PL) interface unit, Kennedy tape recorder, and IRIG-B time code generator in a rack and moved next to the helicopter. The equipment was connected to the helicopter electrical system to satisfy its power requirements. The helicopter was located at the Technical Center away from buildings and large objects to maintain line of sight with the satellites. The antenna was connected to the 80-foot RG-214 cable and moved to various positions beneath the rotor during the test.

The GPS receiver was connected in series with the preamplifier, various attenuators, and the GPS antenna. There were slight differences between laboratory, S-76, and UH-1H test configurations with respect to the amount of fixed cable lengths and connectors in series with the antenna. There was only one attenuator in the UH-1H test configuration and two attenuators plus associated connectors in the S-76 and laboratory test configurations. There was also a fixed 100-foot low loss radio frequency (RF) cable that connected the GPS roof antenna to the laboratory, which was unique and prevented duplicating the helicopter test configurations in the laboratory. Two signals from internal receiver test points were utilized to indicate when the receiver changed satellites and the satellites' relative signal strength. These signals were processed in a Technical Center designed relative signal strength monitor and were digitized, time-tagged, and recorded via the PL interface unit. Figure 1 shows the block diagram of the test configuration. Appendix A describes the relative signal strength monitor.

TEST RESULTS

ACQUISITION TEST.

On July 12, 1984, the Z-set was initialized both under the rotor path of the 4-composite bladed Sikorsky S-76 helicopter and 60 feet from the tip of the rotor path. The acquisition time varied between 4 and 9 minutes, except for the initial acquisition when it entered search the sky mode to collect an almanac. The mean acquisition time was 6.5 minutes for six acquisitions.

On September 17, 1984, the Z-set was initialized under the rotor path of the 2-metal bladed helicopter and 60 feet from the edge of the rotor path. The

acquisition time varied between 3.5 to 7 minutes. The mean acquisition time was 5.5 minutes for seven acquisitions.

On two previous test programs the acquisition times averaged 6.5 and 4 minutes, respectively. These tests were conducted without the attenuation of the 80-foot cable and associated connectors used in the helicopter tests. The difference between acquisition times for these tests and previous tests is negligible. Data are summarized in table 3.

MONITOR TEST.

There was apparently no effect on the GPS receiver performance at the different antenna locations beneath the rotor path and at different rotor speeds. Several times during the test when the antenna was moved next to the helicopter or beneath the center of the rotor path, the GPS receiver indicated that the signals from one or two satellites were not being received. On one occasion, the antenna was raised a foot closer to the rotor path, a higher elevation with respect to the helicopter fuselage, and the remaining signals were acquired. Post-test analysis showed that the satellite signals that were not received when the antenna was in the lower position were physically on the other side of the helicopter fuselage. The only other time that the GPS receiver indicated a loss of one satellite signal was during a change in satellite receiver constellation selection, which is normal for this particular GPS receiver.

Figure 2 is a plot of satellite elevation and azimuth angles at the Technical Center on July 10, 1984, showing the position of the satellites and the occurrence of two constellation changes. Satellite pseudo-random noise (PRN) code numbers are utilized throughout this report to identify the satellites. Figure 3 shows satellite No. 8's unfiltered signal strength measurement taken from an internal receiver test point. Figure 4 is a plot of satellite Nos. 8 and 11 filtered signal strength measurements for July 10, 1984. The numeric filter, which is the running average of the 10 preceeding readings, is used for analysis and plot clarity. Figure 5 shows the effect of UH-1H rotor motion on signal strength. Although the signal strength level is not significantly affected, the number of signal dropouts and reinforcements increased slightly as the antenna was moved closer to the rotor hub.

ATTENUATION TEST.

The GPS receiver was affected by the increase in attenuation in a nonlinear manner. Small increases in attenuation had no effect on the receiver performance. A certain threshold level caused the GPS receiver to lose track of a satellite's signal and in several minutes, in most cases, to terminate the navigation mode. On several occasions, a 2 decibel (dB) difference in threshold attenuation was measured between one satellite signal and the remaining satellite signals. Normally, the lowest satellite in the sky had the lowest threshold attenuation level, especially when its elevation angle was below 15°.

In the laboratory the attenuation of the UH-1H helicopter test and the S-76 test configurations was measured. The attenuation of the test set configurations was 11 dB for the UH-1H and 13 dB for the S-76.

In the test of the 2-metal bladed UH-1H, the threshold attenuation level was 10 dB plus the 80-foot cable test configuration attenuation (11 dB) for a total attenuation of 21 dB. In the test of the 4-composite bladed S-76, the threshold attenuation level was 9 dB plus its 80-foot cable test configuration attenuation (13 dB) for a total attenuation of 22 dB. The threshold attenuation level remained the same regardless of antenna position under the rotor path or when the antenna was 80 feet away from the helicopter. Table 4 shows the results of the individual test. Figure 6 shows the effects of attenuation on a satellite signal.

The threshold attenuation level was approximately 21 dB. This is a considerable margin of safety.

TECHNICAL ANALYSIS/CONCLUSIONS

The test results showed:

1. The time to acquire satellites with the antenna at various locations beneath the rotor path was in the same range as measured in previous fixed wing aircraft tests.

2. The GPS receiver derived position was not affected by the various rotor speeds (60, 80, and 100 percent of maximum safe rpm's) of the 2-metal bladed UH-1H and the 4-composite bladed S-76.

3. The amount of attenuation required to prevent the GPS receiver from tracking satellite signals was the same regardless of the position of the antenna beneath the rotor blades or outside the rotor blades.

4. The Z-set GPS receiver, with its antenna at ground level at the FAA Technical Center, was able to track the satellites until the satellite signal was attenuated by 21 dB. However, in the future this safety margin may be considerably less when different receivers, antennas, production satellites radiated power levels, interference levels, and aircraft maneuvers are involved.

The effect of helicopter rotor motion on GPS performance in the UH-1H and the S-76 helicopter on the ground is negligible.

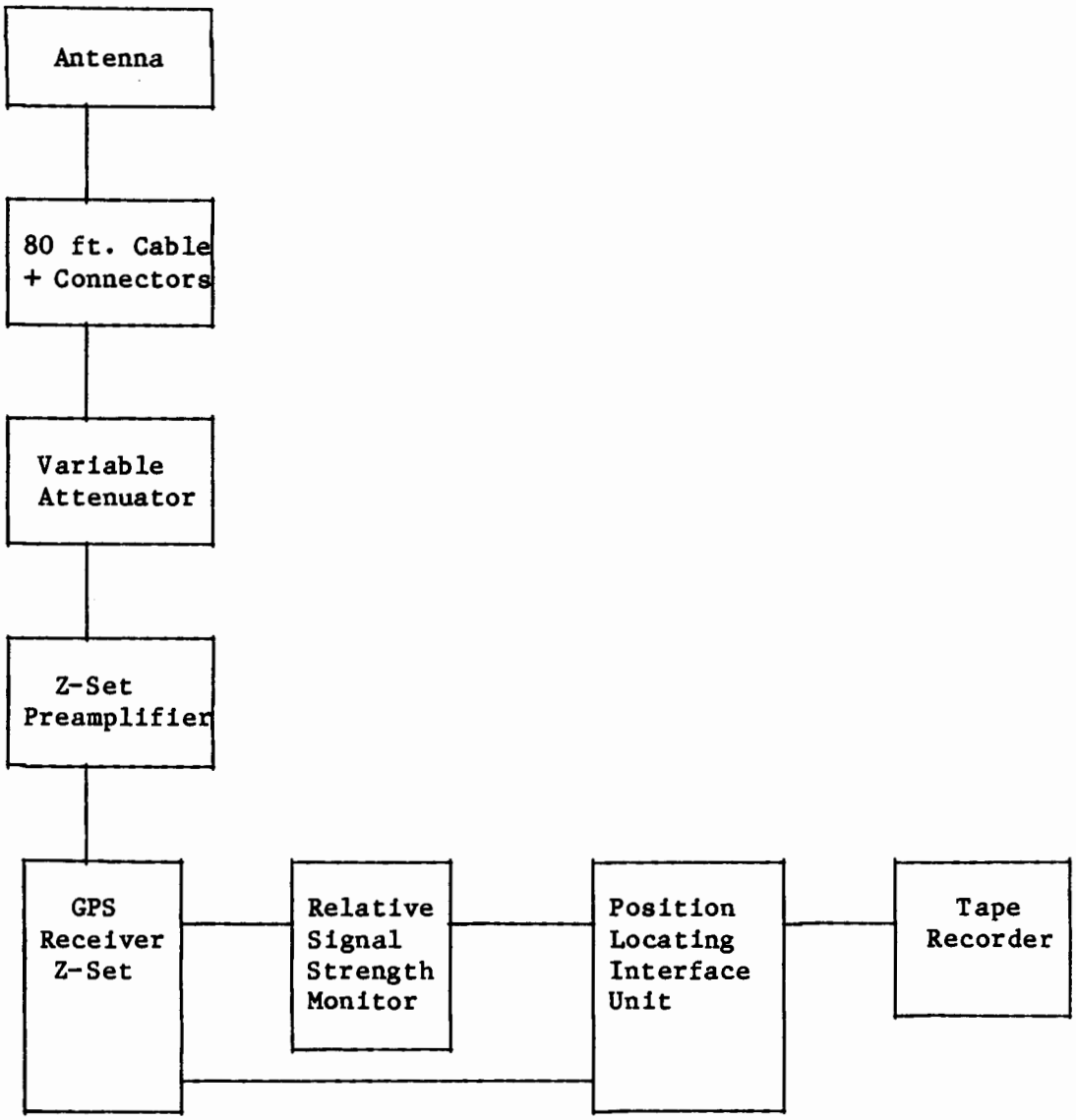
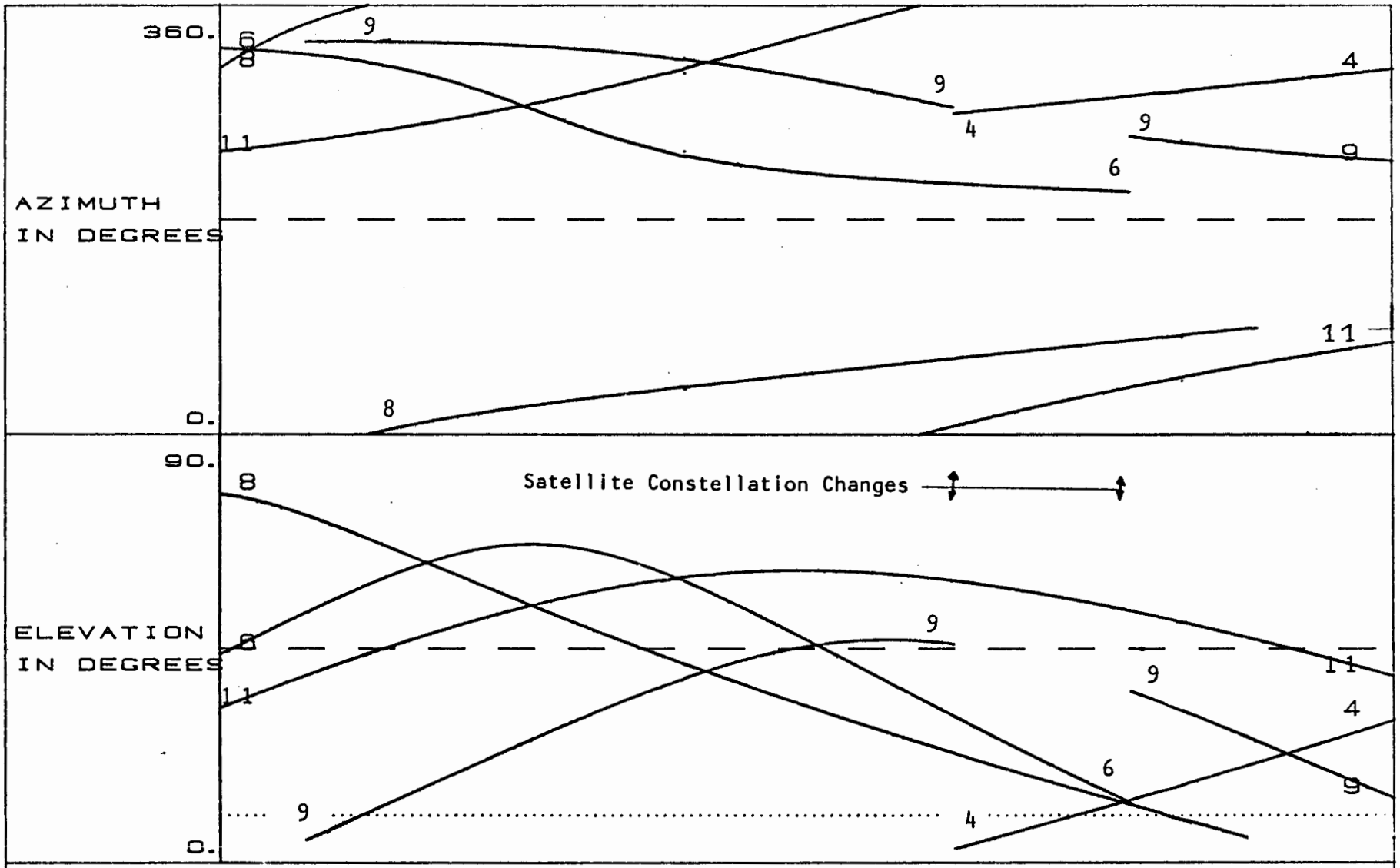
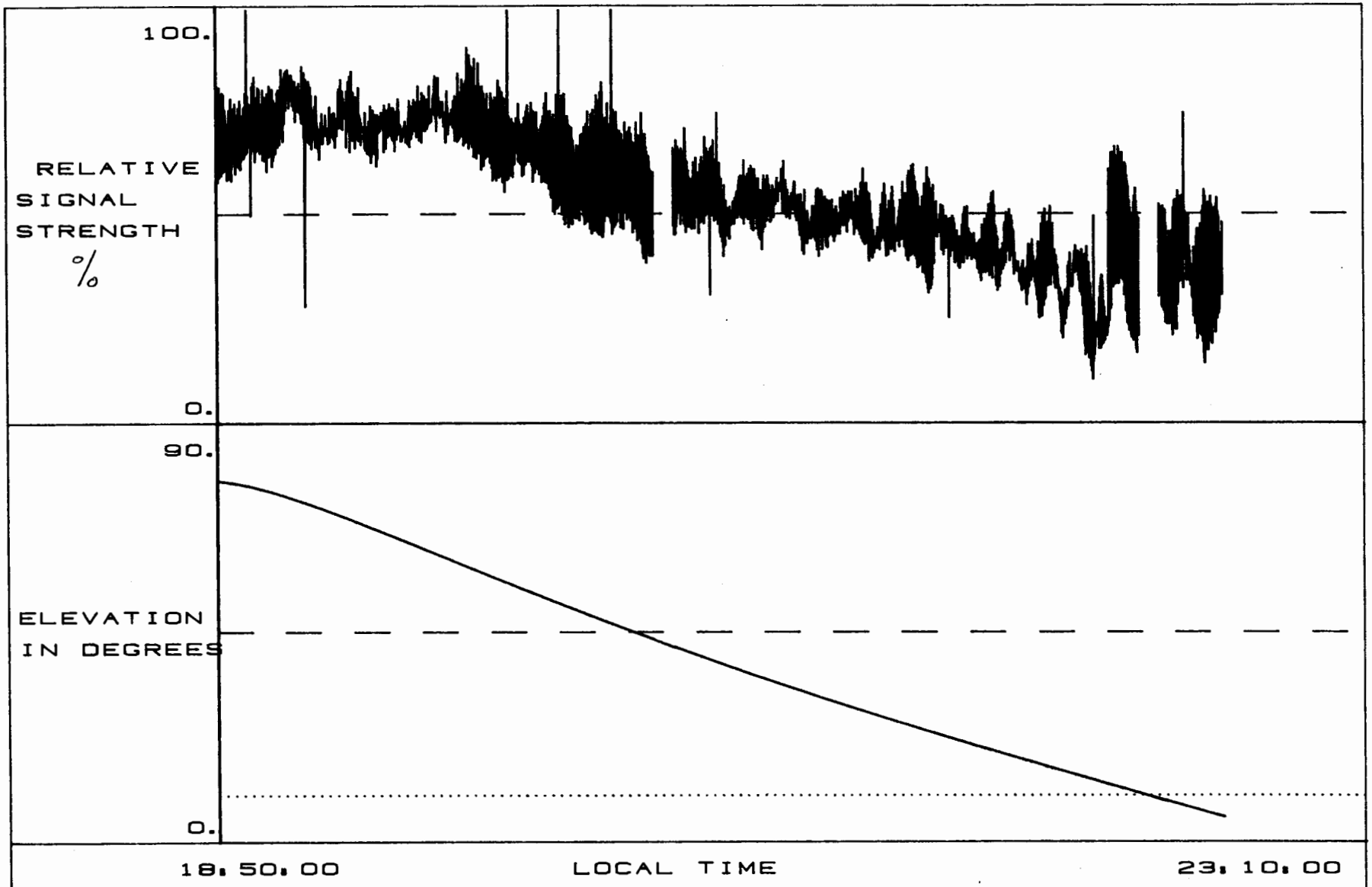


FIGURE 1. TEST CONFIGURATION BLOCK DIAGRAM



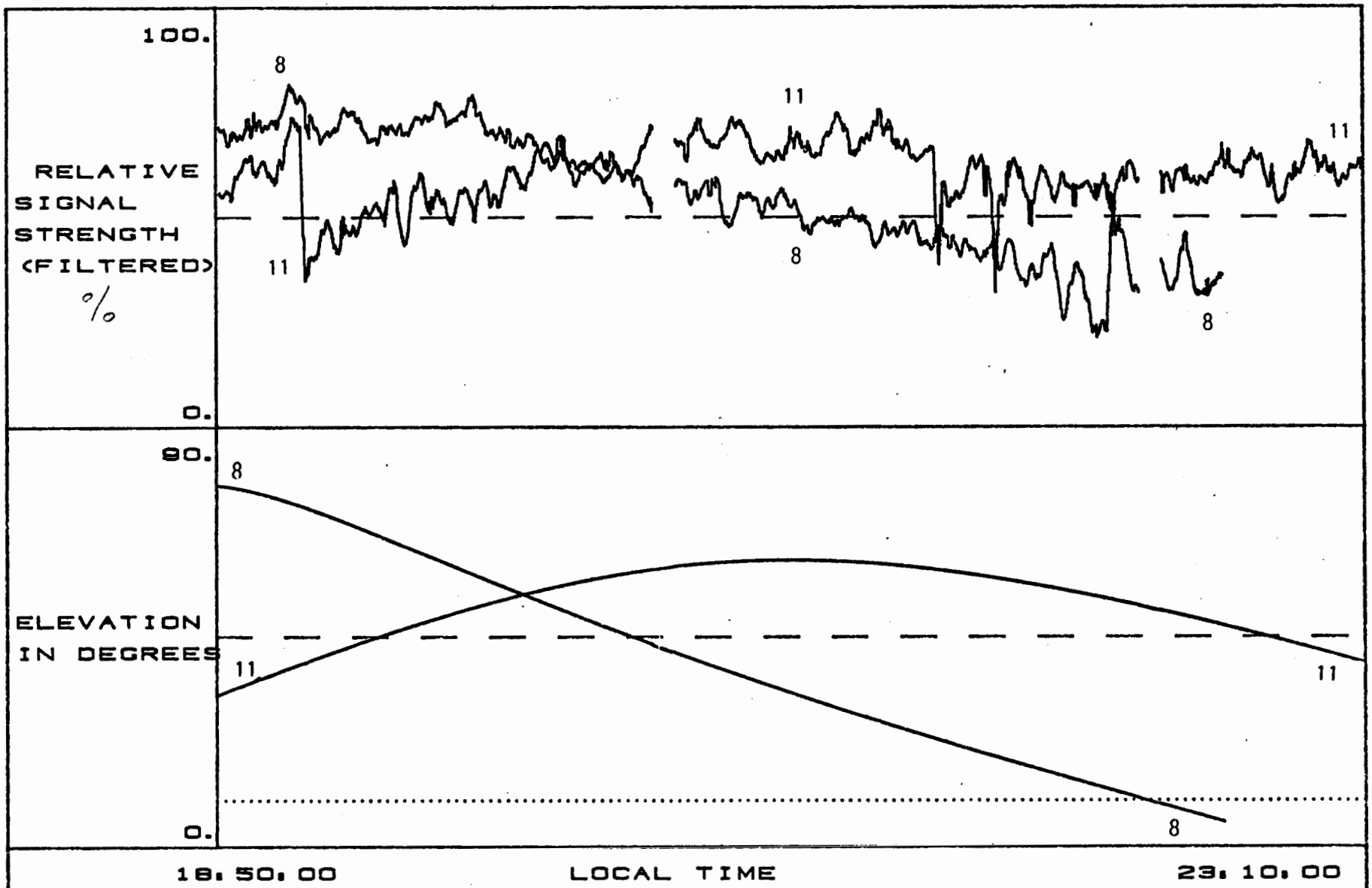
SATELLITE PATH PLOT FOR 10 JULY 1984

FIGURE 2



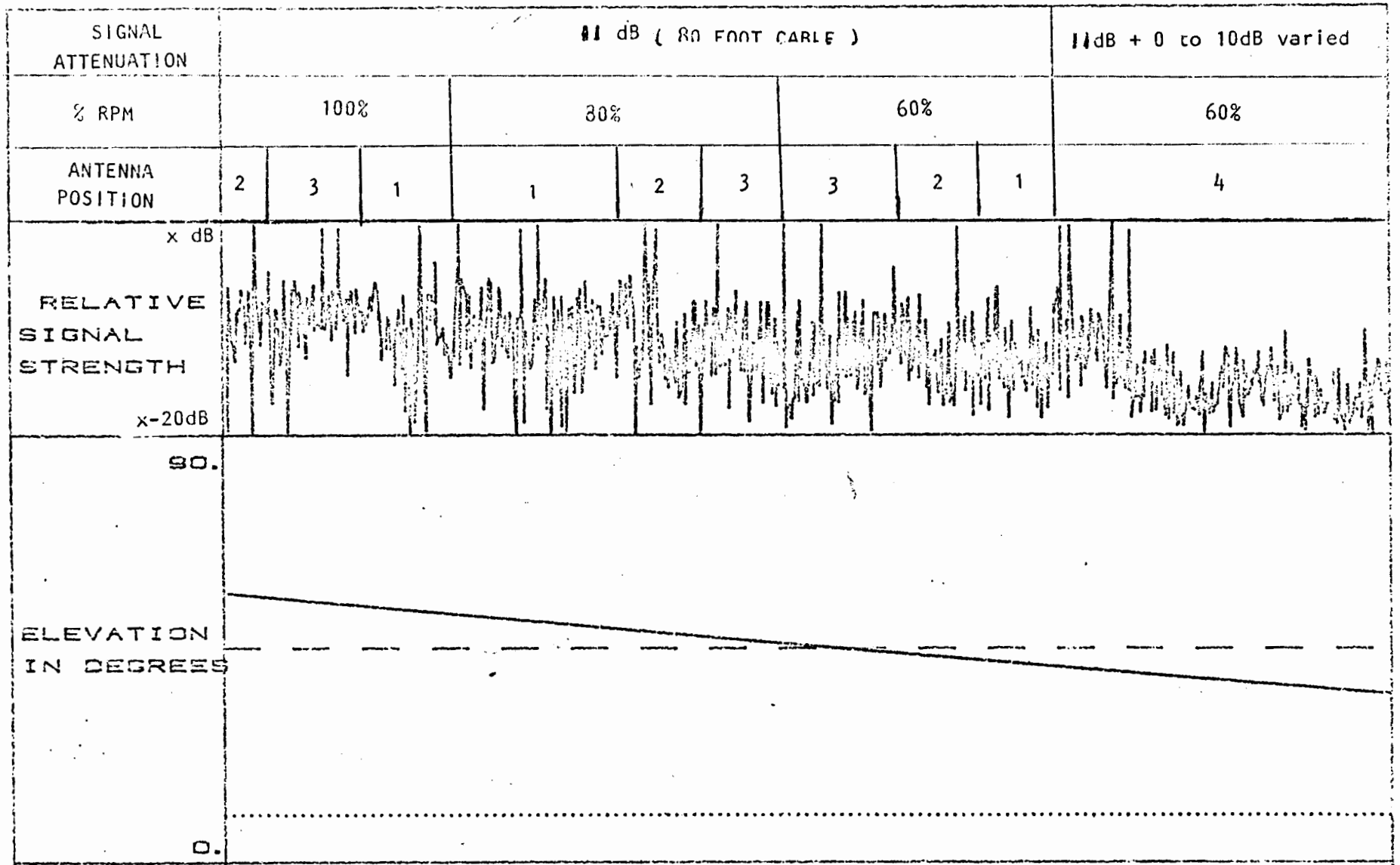
SATELLITE #8 - UNFILTERED SIGNAL STRENGTH PLOT FOR 10 JULY 1984

FIGURE 3



SATELLITES #8 AND #11 FILTERED SIGNAL STRENGTH PLOT
FOR 10 JULY 1984

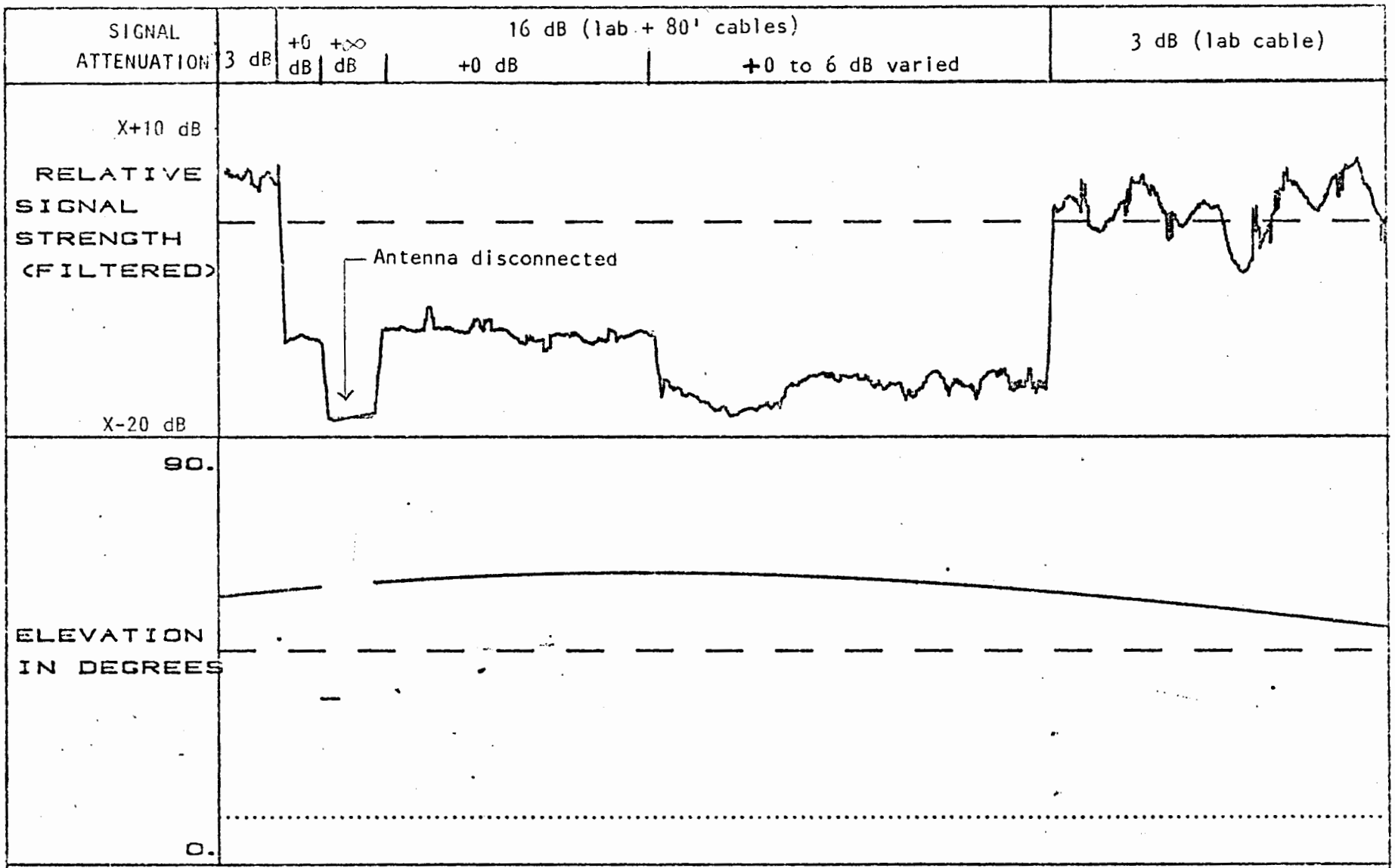
FIGURE 4



SIGNAL STRENGTH VS. ANTENNA POSITION

SAT 8

FIGURE 5



ATTENUATION EFFECTS PLOT ON 13 JULY 1984

FIGURE 6

TABLE 1. HELICOPTER ROTOR TEST DATA

Parameter		UH-1H	S-76
Main Rotor Dia.		48 ft.	44 ft.
Rotor Blade Width		21 in.	15.5 in.
RPMs at 100%		324	293
Antenna Positions (Ref. to rotor hub)	#1	4.5 ft.	3.5 ft.
	#2	12 ft.	11 ft.
	#3	24 ft.	22 ft.
	#4	80 ft.	80 ft.
Antenna Shading At Positions	#1	12%	23%
	#2	5%	7%
	#3	3%	4%
	#4	0%	0%

TABLE 2. Z-SET PARAMETERS

Operational Parameters	Characteristics
RF signal input level (to antenna)	-130 to -120 dBm
Frequency (L_1)	1575.42 $\pm$10 MHz
Polarization	Right hand circularly polarized
Antenna gain	0 dBic minimum from 30° to 90° (above the horizon) -1.5 dBic minimum from 5° to 30°
Antenna coverage	Hemispherical
Antenna axial ratio	<3 dB at 90° <5 dB at 45° <16 dB at 5°
Pseudorange measurement accuracy	$\leq$50 meters (2 sigma)
Vehicle velocity dynamics	$\leq$400 m/s
Vehicle acceleration dynamics	$\leq$5 m/s^2
Initial signal acquisition time	<300 seconds
Jamming to signal power ratio	25 dB
Preamplifier bandwidth selectivity at L_1	24 $\pm$8 MHz at 3 db point $\leq$50 MHz at 70 dB point
Preamplifier gain at L_1	30 to 39 dB

Note: dBm = decibels referenced 1 milliwatt
dBic = decibels referenced to isotropic antenna
m/s = meters per second

TABLE 3. ACQUISITION TIMES

Aircraft Type	Mean (Min)	Range (Min)	No. of Acquisitions
S-76	6.5	4 to 9	6
UH-1H	5.5	3 to 7	7
Previous	6.5	3 to 14	140+
Fixed Wing Aircraft Tests	4	3 to 7	25

TABLE 4. THRESHOLD ATTENUATION LEVELS

Location	Aircraft	
	UH-1H Sept 17	S-76 July 12
Next to Helicopter	21	--
Below Center of Rotor	21	23, 21, 22 22, 23
Below Edge of Rotor	21	--
60 Feet from Rotor	21	22
Average	21	22

Note: All Levels in dB

APPENDIX
RELATIVE SIGNAL STRENGTH MONITOR

As shown in figure A-1, "I" and "X" are signals originating from the baseband board of the Magnavox Z-set. The "I" signal is a 50 bps data signal. The "X" signal is a 400 μs pulse ocurring every 1.2 seconds and is used for the sampling trigger. The output of the Relative Signal Strength Monitor is sent to the existing PL interface where it is digitized, time-tagged, and sent to be recorded on the Kennedy Model 9832 magnetic tape recorder.

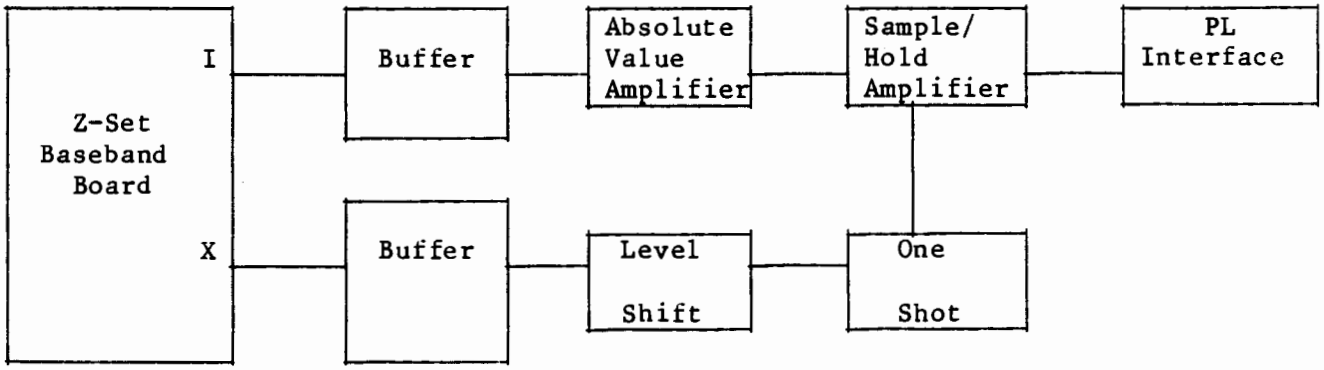


FIGURE A-1. RELATIVE SIGNAL STRENGTH CIRCUIT BLOCK DIAGRAM