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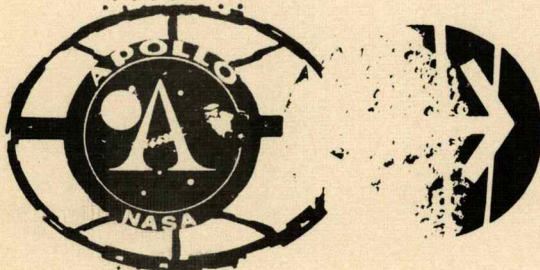
**APOLLO COMMUNICATION SYSTEMS
PERFORMANCE AND
COVERAGE ANALYSIS
FOR MISSION AS-204/LM-1**

By Communications Systems Section

TRW Systems Group

MSC Task Monitor

G.D. Arndt



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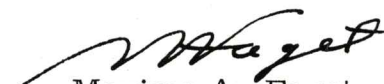
FROM : Director of Engineering & Development

SUBJECT: AS-204/LM-1 Communication Systems Performance
and Coverage Analysis

The attached document represents the communication systems performance and coverage analysis for Apollo Mission AS-204/LM-1. The data presented is based on the AS-206 (Mission AS-204/LM-1 was formerly Mission AS-206) Operational Trajectory with a launch date of April 1, 1967.

Little change is anticipated in the results presented due to a different launch date. The data presented here utilized measured antenna patterns and worst case specified parameters. Addendums to this report, utilizing an updated trajectory and measured parameters, if available, will be published when the revised trajectory is available. Predictions for a January launch date will be available by late December.

Questions concerning the contents of this report should be directed to T. W. Eggleston (EB2).


Maxime A. Faget

Enclosure

APOLLO COMMUNICATION SYSTEMS
TASK E-9D
TECHNICAL REPORT

APOLLO COMMUNICATION SYSTEMS PERFORMANCE
AND COVERAGE ANALYSIS FOR MISSION AS-204/LM-1

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Contract No. NAS 9-4810

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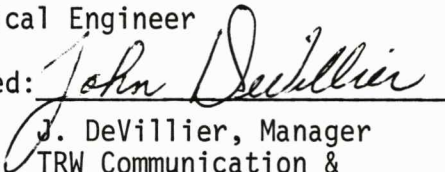
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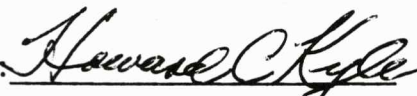
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TRW SYSTEMS

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SYMBOLS AND ABBREVIATIONS

A, B	-	Noise Spectral Density Constants
APS	-	Ascent Propulsion System
B_{IF}	-	IF Noise Bandwidth
$B_{2\beta 10}$	-	Carrier Loop Threshold Noise Bandwidth
BW_R	-	Telemetry Subcarrier Predetection Noise Bandwidth
DFI	-	Developmental Flight Instrumentation
DPS	-	Descent Propulsion System
f	-	Transmitted Frequency
FITH	-	Fire-In-The-Hole
GCS	-	Guidance and Control System
G_{GR}	-	Gain of MSFN Antenna
G_R	-	Gain of Receiving Antenna
G_{TR}	-	Gain of Transmitting Antenna
G_{SC}	-	Gain of Spacecraft Antenna
K	-	Isotropic Level of Radiation Distribution Plots
LOS	-	Line-of-Sight
LOX	-	Liquid Oxygen
LM	-	Lunar Module
L_{SC}	-	Spacecraft Circuit Loss
L_{PZ}	-	Polarization Loss
L_P	-	Pointing Loss
L_S	-	Space Loss
L_T	-	Transmitter Losses
L_R	-	Receiver Losses
L_{MIC}	-	Carrier Loss due to Modulation

M_V	-	Voice Modulation Index
M_{TM}, M_{TLM}	-	Telemetry Modulation Index
PRN	-	Pseudo-Random Noise
P_R	-	Total Received Power
P_{TR}	-	Transmitted Power
P_C	-	Carrier Power
RCS	-	Reaction Control System
R_{NM}	-	Range in Nautical Miles
RDP	-	Radiation Distribution Plot
SLA	-	Spacecraft LM Adaptor
SNR_{req}	-	Required Signal to Noise Ratio
TRC	-	Transponder Ranging Gain Constant
WRE	-	Weapons Research Establishment
ϕ_R	-	PRN Phase Deviation
θ, ϕ	-	Spacecraft Attitude Angles with Respect to Ground Station

MSFN STATIONS*

Manned Space Flight Network stations used on this mission, in orbital order, follow.

CNV	-	Cape Kennedy (DOD)
MIL	-	Merritt Island (NASA)
MLA	-	Merritt Island (DOD)
PAT	-	Patrick Air Force Base (DOD)
GBM	-	Grand Bahamas (NASA)
GBI	-	Grand Bahamas (DOD)
BDA	-	Bermuda (NASA)
ANT	-	Antigua (DOD)
VAN	-	USNS Vanguard (DOD)
CYI	-	Canary Island (NASA)
ACN	-	Ascension Island (NASA)
ASC	-	Ascension Island (DOD)
PRE	-	Pretoria (DOD)
TAN	-	Tananarive (NASA)
RKV	-	USNS Rose Knot (DOD)
CRO	-	Carnarvon (WRE)
GWM	-	Guam (NASA)
HAW	-	Hawaii (NASA)
CSQ	-	USNS Coastal Sentry (DOD)
CAL	-	South Vandenberg, California (DOD)
GYM	-	Guaymas (NASA)
GDS	-	Goldstone (NASA)
WHS	-	White Sands (DOD)
TEX	-	Corpus Christi, Texas (NASA)

*From References 5 and 6

1.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

As a result of the analysis performed in this report, the following conclusions and recommendations are made:

1. (a) The S-band signal strength plots show that neither the front (+Z) nor the aft (-Z) antenna, when used alone, will provide complete coverage for the mission. The -Z antenna is preferable since it will provide good signal margins on all burns and major events.
(b) The uplink modulation which is turned around in the spacecraft transponder decreases the downlink carrier power by 0.69 dB maximum. Therefore turning off the uplink modulation, which sacrifices the PRN ranging capability, will slightly improve downlink signal strengths.
2. C-band signal margins will be positive for both uplink and downlink throughout the mission with a few exceptions of short duration.
3. VHF telemetry plots show positive signal margins during all phases of the mission except for a few short periods. VHF telemetry coverage is considered satisfactory for the mission.
4. UHF signal margins will be positive throughout the mission.
5. The analysis presented in this report uses an operational trajectory which assumes April 1, 1967, as the nominal launch date. A change in launch date will have little effect on the performance results shown in this report if the spacecraft attitudes are constrained to lie within the region of acceptable S-band antenna gain. The S-band antenna patterns with the region of acceptable gain at a range of 1000 nautical miles are shown at the end of Section 5. Consequently the spacecraft attitude constraints are important when considering a new trajectory with a later launch date.
6. The S-band telemetry power can be increased by 4 dB by in-

creasing the telemetry modulation index to 1.3 radians. This recommendation is presently being implemented for LM-1. The S-band telemetry circuit margins will therefore be improved by four dB from those shown in this report; the 204/LM-1 addendums will reflect this new telemetry modulation index.

2.0 INTRODUCTION

The purpose of this report is to predict communications coverage for Mission AS-204/LM-1*. This mission will be the first spaceflight test of the Lunar Module and will be unmanned.

A specific objective of this report is to determine which S-band antenna should be used for the mission. Only one of the two antennas comprising the full S-band omnidirectional LM antenna system will be utilized and coverage will be limited to approximately a hemisphere. These two antennas are mounted on the front and rear of the spacecraft and are designated as the +Z and -Z antennas. For mission planning purposes the -Z antenna has been assumed to be used, pending publication of this report.

The mission consists of four low earth orbits by the LM vehicle for the primary purpose of flight testing the spacecraft. During this period, communications data will be obtained as a secondary objective for the purpose of evaluating the Unified S-band system. After the primary mission is completed, communications testing will continue until the spacecraft coolant becomes exhausted and communications fail. This report analyzes coverage only for the first four orbits.

The report consists principally of a series of signal strength plots versus elapsed mission time for the MSFN network. These plots include Unified S-band, C-band, VHF, and UHF communications. The signal strength plots were obtained from a computer program which combined the spacecraft trajectory and measured antenna patterns to make a simulation of the spaceflight. The results are shown in detail in Sections 5 through 8 of this report.

*Mission AS-204/LM-1 was formerly Mission AS-206

In obtaining trajectory information for this report, two sets of computer data were used. These consisted of one set for the launch trajectory which was used until orbit insertion, and one set for the operational trajectory which was used for the remainder of the mission. The trajectory from which data were taken assumed a launch date of 1 April 1967. Change of the launch date will have little effect on the results shown in this report if the spacecraft attitudes or the trajectory are not changed appreciably.

Antenna patterns used to obtain data for this report were from scaled down models except for the S-band system. The S-band antenna patterns were obtained from a full scale mockup of the spacecraft and were made at the test facilities of the Instrumentation and Electronic Systems Division at the Manned Spacecraft Center (Reference 15).

3.0 MISSION COMMUNICATION CONFIGURATIONS

The communications objective consists of a single secondary objective which is to verify, prior to manned LM operations, the LM S-band communications subsystem performance and MSFN compatibility. The approximate time of objective performance will be from the time that the LM S-band transmitter is turned on at four seconds before LM/SIV-B separation until the end of the mission, whenever MSFN and/or A/RIA coverage is available, and line-of-sight exists with the LM spacecraft.

The launch vehicle for AS-204/LM-1 consists of a Saturn I-B first stage and a Saturn IV-B second stage. The spacecraft consists of a spacecraft LM adapter, a nose cone in lieu of a CSM, and Spacecraft LM-1.

From a communications configuration standpoint, LM-1 is a standard Lunar Module with the following exceptions:

1. Added Equipment
 - a. LM Mission Programmer
 - b. Development Flight Equipment
 - 1) UHF Updata Receiver
 - 2) Two (2) C-Band Transponders
 - 3) Developmental Flight Instrumentation
 - a) Four (4) VHF FM/FM Transmitters
 - b) One (1) VHF PCM/FM Transmitter
 - c) Two (2) UHF/VHF SLA Mounted Antennas (fed in parallel)
 - d) Two (2) UHF/VHF LM Mounted Antennas (fed in parallel)
 - e) Four (4) C-Band LM Mounted Antennas (opposite antennas fed in parallel)
2. Removed Operational Communications Equipment
 - a. S-Band Erectable Antenna
 - b. EVA VHF LM Mounted Antenna
 - c. VHF AM Transceivers
 - d. Television
 - e. Data Storage Electronics Assembly
3. Inoperative Equipment
 - a. Audio Centers
 - b. One (1) Omnidirectional S-Band Antenna

- c. Two (2) VHF Omnidirectional In-Flight Antennas
- d. S-Band Steerable Antenna

Figure 3-1 shows all LM mounted communications antennas.

On an unmanned mission it is impossible to verify all LM/MSFN communications services that are utilized during a manned mission. However, the following S-band functions can and will be verified by a series of tests followed by postflight evaluations. The S-band uplink will exercise all signal combinations containing the S-band carrier, PRN ranging, simulated up-voice (1000 Hz tone on 30 kHz subcarrier), and the unmodulated 70 kHz subcarrier which will be utilized for updata on later missions.

The downlink S-band signal combinations will consist of the S-band carrier, PRN ranging code containing turned-around uplink subcarriers, and 51.2 kbps PCM telemetry. For additional information pertaining to verification of the S-band system refer to the Unified S-Band System Flight Verification Test Program Plan For Mission AS-204/LM-1 (Reference 19).

The UHF updata link provides the command capabilities for controlling the communication systems during the mission. A list of commands controlled by the UHF system can be found at the end of this section. A brief explanation of the S-band commands will clarify the list, i.e., the other systems work similarly. Before the S-band system can be utilized, command 212 (S-band enable) must be given. If the primary system is utilized command 31A (primary S-band enable) must be given. To transfer from the primary S-band transceiver to the secondary, command 30A (primary S-band off) must be given followed by 20A (secondary S-band on). Similarly, if switching from the secondary to the primary transceiver, command 21A (secondary S-band off) must be given followed by command 31A (primary S-band enable). If command 212 (S-band enable) had not been given switching from one transceiver to the other would have been accomplished but the S-band system would be off. The following list is given in numerical order.

UHF Updata Link Commands:

1. 20A - Secondary S-Band On
2. 21A - Secondary S-Band Off
3. 30A - Primary S-Band Off

4. 31A - Primary S-Band Enable
5. 52A - C-Band Off
6. 53A - C-Band On
7. 54B - DFI Calibration On
8. 55B - DFI Calibration Off

LM Guidance Computer Commands

1. 042 - S-Band Ranging On
2. 043 - S-Band Ranging Off
3. 152 - C-Band On
4. 153 - C-Band Off
5. 212 - S-Band Enable
6. 213 - S-Band Off

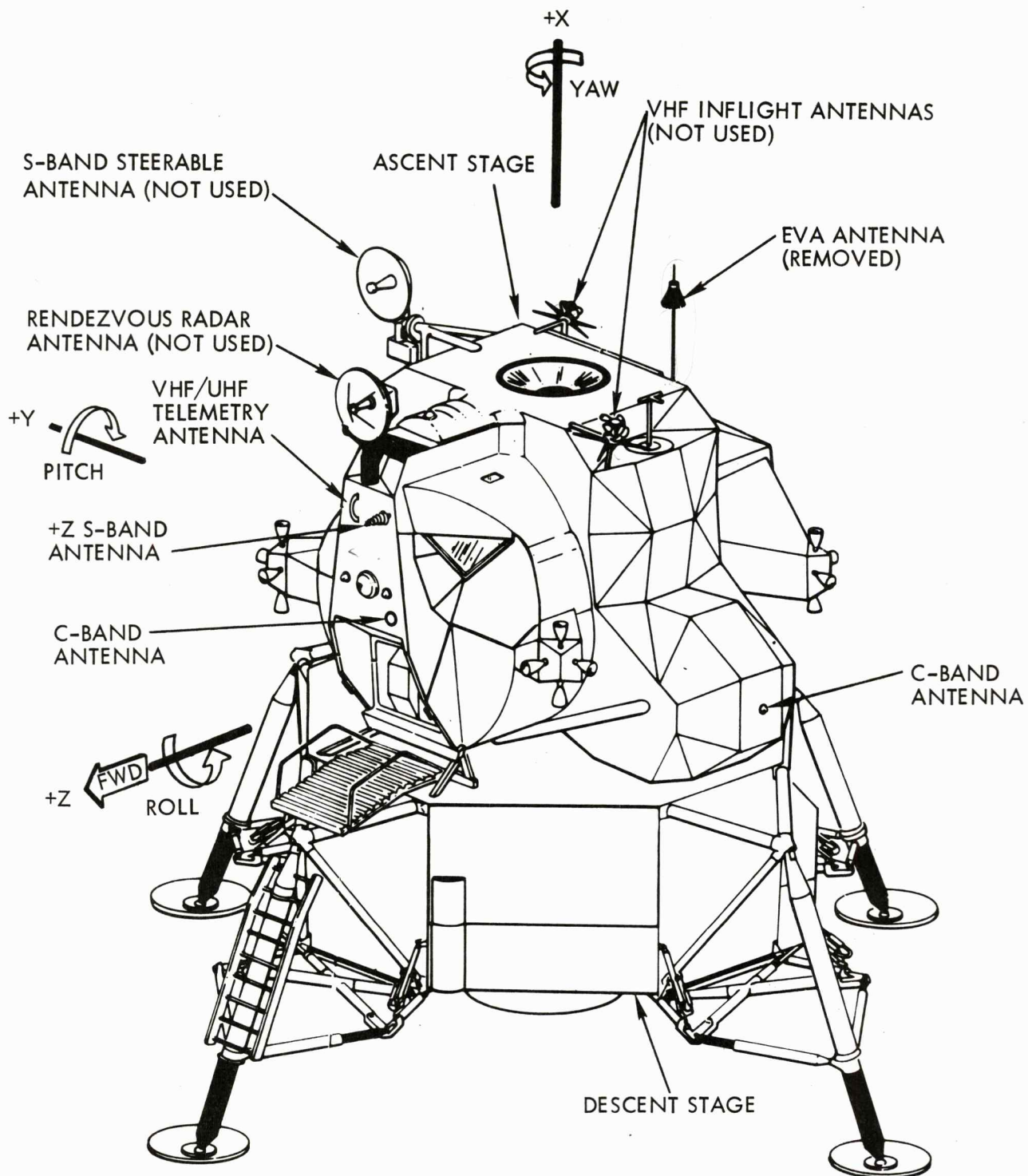


Figure 3-1. AS-204/LM-1 Antenna

4.0 MISSION SUMMARY

4.1 MISSION TRAJECTORY

The mission trajectory consists primarily of four low-earth orbits with apogees ranging up to approximately 185 nautical miles. The analysis described in this report is based on "05952-H130-R0-00, APOLLO Mission AS-206 Spacecraft Operational Trajectory, Volume 1," dated 10 February 1967. The major mission events are given in Table 4-1. These events occur during the first four revolutions of the mission. Since the LM will remain in orbit, certain testing, including communications, may continue for additional orbits if the various subsystems are functioning.

4.2 COMMUNICATION COVERAGE SUMMARY

A brief summary of communication coverage during the mission follows:

The Development Flight Instrumentation, consisting of C-band, UHF, VHF FM/FM telemetry, VHF PCM/FM telemetry, and associated instrumentation, will be activated prior to liftoff. During the launch phase and prior to SLA panel deployment, the following LM/MSFN telecommunication capabilities will exist:

1. Telemetry transmission via the VHF PCM/FM and PAM/FM/FM links which utilize the SLA mounted UHF/VHF antennas.
2. Updating via the UHF link which also uses the SLA mounted UHF/VHF antennas.

Tracking information to MSFN during the launch phase will be supplied by launch vehicle C-band since there are no exposed C-band antennas for transmission via LM C-band.

After SLA panel deployment and prior to LM separation, a limited LM C-band tracking capability will exist in addition to the above. The limitation is due to the antennas being partially shielded by the opened SLA panels. At LM separation all systems on board the LM will be fully operational. S-band equipment will be turned on four seconds prior to separation. For the remainder of the mission all LM telecommunications will be used when MSFN capability exists. C-band tracking and VHF PCM telemetry will be primary for obtaining data. S-band will be backup for obtaining data. UHF will be used for updata and command.

MSFN ground station support for Mission AS-204/LM-1 is shown in Table 4-2. Table 4-3 gives the signal acquisition and loss times based on a tracking elevation angle of five degrees above the local horizon. These times embrace the first four low-earth orbits of the mission. Figure 4-1 is a plot of the spacecraft altitude versus elapsed time from liftoff. Shown on the chart are the principle items of interest such as MSFN line-of-sight coverages and major events.

Table 4-1. Summary Flight Plan

<u>EVENT</u>	<u>TIME</u>
Saturn IB Lift-Off	00:00:00.0
S-IVB Shutdown/GCS + 10.2 secs/ Continue Venting	00:10:02.3
End S-IVB LOX Venting/ Maintain Inertial Attitude	00:10:32.7
Jettison Nose Cap/ Maintain Inertial Attitude	00:10:37.5
Orient LM/S-IVB to Local Horizontal	00:11:22.5
Deploy SLA Panels/ Maintain Local Horizontal	00:19:52.5
End S-IVB LH2 Venting/ Maintain Local Horizontal	00:30:53.3
Begin Inertial Attitude Hold S-IVB/LM	00:50:05.000
RCS Ignition with S-IVB Attached/Attitude Hold	00:53:54.999
LM S-Band Equipment Turned On	00:53:56.000
LM Separation/Sever Restraining Straps	00:54:00.000
RCS Shutdown	00:54:04.999
RCS Ignition	00:54:10.000
RCS Shutdown/Verification of LM Separation	00:54:14.999
Begin Orientation to DPS Cold-Soak Attitude	00:55:52.000
End Orientation to DPS Cold-Soak Attitude	00:57:51.999
Begin Revolution Two/ Maintain Cold-Soak Attitude	01:38:47.970
Begin Revolution Three/ Maintain Cold-Soak Attitude	03:11:56.490

Table 4-1. Summary Flight Plan (Continued)

<u>EVENT</u>	<u>TIME</u>
Acquisition of Rose Knot Victor Tracking	03:55:18.630
Begin Orientation for First DPS Burn	03:55:28.630
RCS Ullage	03:59:54.104
First DPS Burn	04:00:01.605
Change Throttle Setting to 94 Percent	04:00:27.605
Steady State Thrust	04:00:27.945
First DPS Thrust Tailoff	04:00:40.015
End First DPS Burn/ Coast to Second DPS Burn	04:00:40.425
Set Maximum Deadband in DAP	04:01:10.425
Acquisition of Coastal Sentry Quebec	04:33:02.381
Second DPS Burn	04:36:53.2
Switchover to Higate Target	04:39:46.000
Approach Phase	04:44:44.139
Begin Random Throttling	04:48:02.327
FITH Staging/First APS Burn	04:48:54.327
Coast to Second APS Burn	04:48:59.579
Acquisition of Coastal Sentry Quebec Tracking	06:09:11.913
Begin Re-Orientation for Second APS Burn	06:09:31.913
RCS Ullage Settling Maneuver	06:13:31.913

Table 4-1. Summary Flight Plan (Continued)

<u>EVENT</u>	<u>TIME</u>
Second APS Burn	06:13:35.413
End of APS Tailoff/Coast to End of Mission	06:20:42.754
Begin Fifth Revolution	06:22:19.039
Begin Sixth Revolution	07:57:33.237
End of Sixth Revolution	09:33:19.327

Table 4-2. MSFN Support for Mission AS-204/LM-1

<u>MSFN Station</u>	<u>S-Band</u>	<u>C-Band</u>	<u>VHF</u>	<u>UHF</u>
*CNV		X		X
MIL	X		X	
MLA		X		
PAT		X		
GBM	X			
GBI		X	X	X
BDA	X	X	X	X
ANT		X	X	X
VAN	X	X	X	X
CYI		X	X	
ACN	X		X	
ASC		X	X	
PRE		X	X	
**TAN		X	X	
RKV			X	X
CRO	X	X	X	X
GWM	X		X	
HAW	X	X	X	X
CSQ			X	X
CAL		X		
GYM	X		X	
GDS	X			
WHS		X		
TEX	X		X	X

*CNV C-Band will be used during launch only for SIV-B.

**Tan C-Band will track the S-IVB.

Table 4-3. MSFN Coverage Summary for Mission AS-204/LM-1*

<u>Station</u>	<u>Signal Acquisition Time</u>	<u>Signal Loss Time</u>	<u>**Coverage Duration</u>
MLA	0:00:00	0:07:30(est)	07:30(est)
PAT	0:00:09	0:07:30(est)	07:21(est)
GBI	0:02:30(est)	0:07:50(est)	05:20(est)
EGL	0:03:00(est)	0:06:00(est)	03:00(est)
BDA	0:05:50(est)	0:11:29.9	0:05:40(est)
***VAN1	0:12:06	0:15:15	0:03:09
VAN2	0:12:22	0:16:38	0:04:16
CYI	0:17:51.3	0:22:23.0	0:04:31.7
TAN	0:37:43.9	0:41:47.9	0:04:04.9
RKV	0:48:33.3	0:53:55.6	0:05:22.3
CRO	0:53:13.0	0:57:31.8	0:04:18.8
CSQ	1:28:36.0	1:30:30.6	0:01:44.6
GYM	1:29:44.0	1:34:18.6	0:04:34.6
WHS	1:31:15.4	1:35:19.0	0:04:03.6
TEX	1:32:42.8	1:37:09.3	0:04:26.5
MLA	1:36:36.9	1:40:54.1	0:04:17.2

* Some MSFN sites have both C-band and S-band stations, which are separated and have different call letter designations. Data tabulated above were available only for the station shown. Coverage times of companion stations ordinarily will be within one second of each other.

** Based on MSFN elevation look angle limitation of 5°.

*** VAN has two alternate locations.

Table 4-3. MSFN Coverage Summary for Mission AS-204/LM-1
(Continued)

<u>Station</u>	<u>Signal Acquisition Time</u>	<u>Signal Loss Time</u>	<u>*Coverage Duration</u>
PAT	1:36:38.9	1:40:53.6	0:04:14.7
GBI	1:37:23.8	1:41:09.2	0:03:45.4
BDA	1:39:57.9	1:44:37.1	0:04:39.2
VAN1	1:44:43	1:49:17	0:04:34
VAN2	1:45:20	1:49:58	0:04:38
TAN	2:10:12.8	2:15:39.7	0:05:26.9
RKV	2:22:08.9	2:27:27.2	0:05:18.4
CRO	2:26:22.4	2:31:51.6	0:05:29.2
HAW	2:52:10.4	2:55:47.6	0:03:37.2
CSQ	3:00:06.4	3:04:43.2	0:04:36.8
CAL	3:01:19.0	3:05:20.4	0:04:01.4
GDS	3:02:09.8	3:06:05.1	0:03:55.3
GYM	3:03:02.8	3:07:22.6	0:04:19.8
WHS	3:03:59.0	3:08:36.8	0:04:37.8
TEX	3:06:10.5	3:10:17.7	0:04:07.2
MLA	3:09:42.3	3:14:20.4	0:04:38.1
PAT	3:09:44.7	3:14:21.3	0:04:36.4
GBI	3:10:27.5	3:14:50.7	0:04:23.2
BDA	3:13:18.9	3:17:56.8	0:04:37.9
ANT	3:15:54.7	3:18:23.8	0:02:29.1
VAN1	3:18:10	3:21:49	0:03:39
ASC	3:29:00.9	3:33:41.7	0:04:40.8
PRE	3:39:44.0	3:45:35.7	0:05:51.7

Table 4-3. MSFN Coverage Summary for Mission AS-204/LM-1
(Continued)

<u>Station</u>	<u>Signal Acquisition Time</u>	<u>Signal Loss Time</u>	<u>*Coverage Duration</u>
TAN	3:45:51.7	3:46:32.6	0:00:40.9
RKV	3:55:18.5	4:00:46.4	0:05:27.9
CRO	3:59:27.5	4:04:51.8	0:05:24.3
HAW	4:24:12.8	4:30:33.5	0:06:20.7
CSQ	4:33:02.4	4:39:34.4	0:06:32.0
CAL	4:33:44.6	4:40:20.4	0:06:35.8
GDS	4:34:36.5	4:41:06.5	0:06:30.0
GYM	4:36:07.5	4:42:32.4	0:06:24.9
WHS	4:36:53.1	4:43:36.3	0:06:43.2
TEX	4:39:10.3	4:45:39.0	0:06:28.7
MLA	4:42:55.1	4:49:38.6	0:06:43.5
PAT	4:42:56.6	4:49:39.9	0:06:43.3
GBI	4:43:34.4	4:50:08.6	0:06:34.2
BDA	4:46:50.4	4:52:34.5	0:05:44.1
ANT	4:48:43.7	4:54:08.8	0:05:25.1
VAN1	4:51:16	4:57:38	0:06:22
VAN2	4:52:37	4:57:23	0:04:46
ASC	5:03:45.9	5:07:58.9	0:04:13.0
PRE	5:14:42.8	5:20:42.8	0:06:00.0
TAN	5:18:46.6	5:24:25.2	0:05:38.6
RKV	5:30:21.2	5:37:03.3	0:06:42.1
CRO	5:34:30.8	5:41:13.5	0:06:42.7

Table 4-3. MSFN Coverage Summary for Mission AS-204/LM-1
(Continued)

<u>Station</u>	<u>Signal Acquisition Time</u>	<u>Signal Loss Time</u>	<u>*Coverage Duration</u>
HAW	6:00:12.1	6:06:55.7	0:06:43.6
CSQ	6:09:11.9	6:15:35.3	0:06:23.4
CAL	6:10:11.9	6:16:11.7	0:05:59.8
GDS	6:11:07.4	6:16:57.8	0:05:50.4
GYM	6:12:03.0	6:18:43.8	0:06:40.8
WHS	6:13:08.3	6:19:42.6	0:06:34.3
TEX	6:15:11.2	6:21:53.5	0:06:42.3
MLA	6:19:06.2	6:25:53.4	0:06:47.2
PAT	6:19:07.4	6:25:54.3	0:06:46.9
GBI	6:19:43.5	6:26:27.4	0:06:43.9

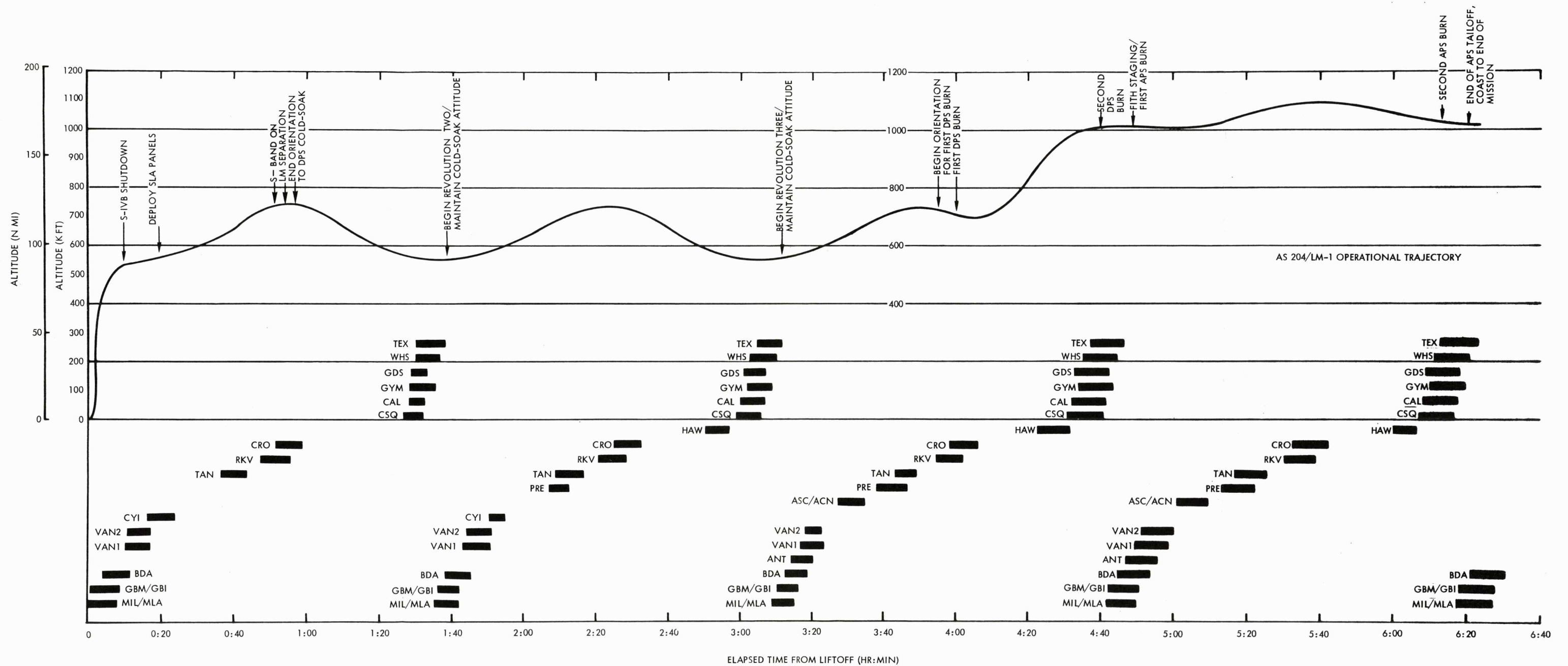


Figure 4-1. Altitude, Major Events, and Line-of-Sight Coverage for MSFN Stations

5.0 S-BAND SYSTEM COVERAGE

The Unified S-Band System on the LM-1 will be used as a backup for C-band and VHF communications. Verification of the S-band communication system is a secondary objective of the mission.

The following S-band signal combinations will be used on Mission AS-204/LM-1.

UPLINK

All PM modes containing combinations of the following information

- A. Voice simulation - 1000 Hz tone on 30 kHz subcarrier
- B. Unmodulated 70 kHz subcarrier
- C. PRN ranging
- D. Carrier (2101.8 MHz)

DOWNLINK

One PM mode containing

- A. 51.2 kbps telemetry
- B. PRN ranging together with turned around uplink subcarriers
- C. Carrier (2282.5 MHz)

The S-band system coverage study in this report consists of using the above signal combinations in a simulated spaceflight to obtain predicted signal strengths for each MSFN station as a function of mission time.

S-band data were obtained from a computer program which combined the spacecraft trajectory data, spacecraft full scale antenna gain patterns, transmitted power, circuit and space losses, and receiver performance characteristics to give plots of Received Carrier Power versus Elapsed Time from Liftoff. Computer calculations were made at 2 second intervals during burns and orientation phases, and at 20 second intervals during coast phases. These data are shown in Figures 5-1 through 5-11.

Downlink data only are shown in this report for S-band. Since the MSFN transmitters have considerably more power than the spacecraft transmitter, uplink carrier signal strengths are much greater than downlink carrier signal strengths. Thus the downlink is by far the more critical path

and plotting the uplink data was considered unnecessary.

Worst case specified parameters were used for all calculations. Values used are shown in Appendix A. MSFN required signal levels were calculated for uncooled parametric amplifiers and a quiet sky, except for Ascension, Carnarvon, and Goldstone which have cooled parametric amplifiers. A full downlink (PRN and 51.2 Kbps telemetry) and a full uplink (PRN, 30 KHz and 70 KHz subcarriers) are used in the calculations for figures 5-1 through 5-15. Required signal levels were calculated from equations obtained from a mathematical model of the MSFN receivers (Reference 2).

Thresholds for telemetry are shown on the plots as the value of received carrier power which will produce a Bit Error Probability of 10^{-6} in the PCM telemetry output data. Thresholds for downlink PRN ranging and the carrier were 21.30 dB and 25.66 dB lower, respectively, than the telemetry thresholds, and are not shown on the graphs.

The S-band system will be activated four seconds before the LM/S-IVB separation command. No shadowing or flame effects will be present which will degrade the communications coverage during the LM/S-IVB separation event. Shadowing occurs when the ground station to spacecraft line of sight falls within seven degrees of the spacecraft body coordinate system. The flame effect is due to attenuation of the radio signal by the ionization produced in the rocket exhaust. However, rapid signal strength fluctuations may occur for a few seconds after separation due to reflections from the S-IVB.

Only one antenna will be used on the mission, i.e., either the +Z antenna or the -Z antenna. Data are shown on the graphs for both the +Z and -Z antennas as Received Carrier Power versus Elapsed Time from Liftoff. The received carrier power is the total received power less the modulation loss (sideband power). The modulation loss for the modulation indices used for this mission amounts to 1.79 dB.

Data are plotted whenever the spacecraft is within line of sight of a ground station, i.e., whenever the elevation look angle of the ground station is above 0° . Also indicated on the graphs are the times when the MSFN elevation look angles are 5° , and when major events and keyholes occur.

Keyholes are no coverage zones due to mechanical constraints on MSFN S-band antennas which, for 30' antennas, are semi-cones having angular radii of 14 degrees centered about the North and South axes. For 85' antennas the keyholes have East and West directions.

Since only one S-band spacecraft antenna is to be used on this mission, good coverage would be expected only when the spacecraft attitude is such that the antenna is on the station side of the spacecraft. This was confirmed by correlating the plots with spacecraft attitudes from trajectory data. When the antenna is on the far side, or shadowed by the spacecraft, some doubt exists that the signal strengths will be as high as indicated. The background level of the antenna patterns was noted to be around 30 dB lower than the isotropic level. This background level could possibly be much less in space than was present when the antenna patterns were obtained. However, no question exists as to the validity of the patterns when the antenna is directly visible.

The spacecraft antenna patterns for the ascent and descent configurations with the region of acceptable gain at a range of 1000 nautical miles are shown in Figures 5-12 through 5-15. The region of acceptable antenna gain is defined as any area of the antenna pattern which will provide adequate gain for 0 dB or greater circuit margin at a specified range. The spacecraft has two antennas but the two spacecraft configurations varies the antenna patterns. Hence two patterns are shown for each antenna. The descent configuration antenna patterns are used for the first three orbits. The ascent configuration antenna patterns are used during the fourth orbit. A plot of the spacecraft attitude relative to the Texas MSFN station is shown on each antenna pattern. The Texas MSFN station was selected because its communication coverage performance is generally inferior to that of the other MSFN stations. The elapsed time from liftoff and slant range for the points shown on each pattern are compiled in Table 5-1. The fluctuation of the spacecraft attitude relative to the region of acceptable gain can be correlated to the plots of received carrier power.

The following conclusions are made from analysis of the S-band system and plots.

1. The signal strength plots for S-band show that neither the +Z nor the -Z antenna, when used alone, will provide complete cover-

age for the mission. The -Z antenna is preferable since it will provide good signal margins on all burns and major events.

2. The uplink modulation, which is turned around in the spacecraft receiver, degrades the downlink carrier and telemetry power by 0.69 dB maximum. Therefore turning off this modulation would slightly improve the downlink signal strengths at the expense of sacrificing the PRN ranging capability.
3. If a new trajectory is considered for the mission special emphasis should be placed on constraining the spacecraft attitudes relative to the acceptable regions of antenna gain. This will insure adequate performance of the S-band system for a revised launch date.

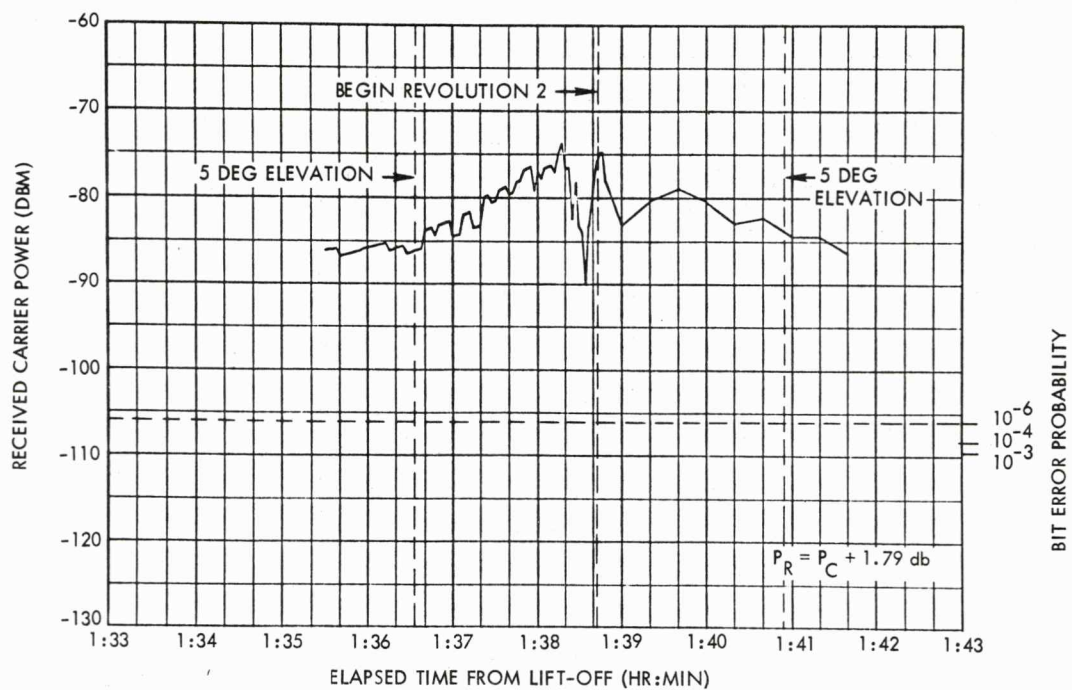


Figure 5-1a. MIL S-Band Received Carrier Power Versus Elapsed Time From Lift-Off, +Z Antenna, Orbit 1-2

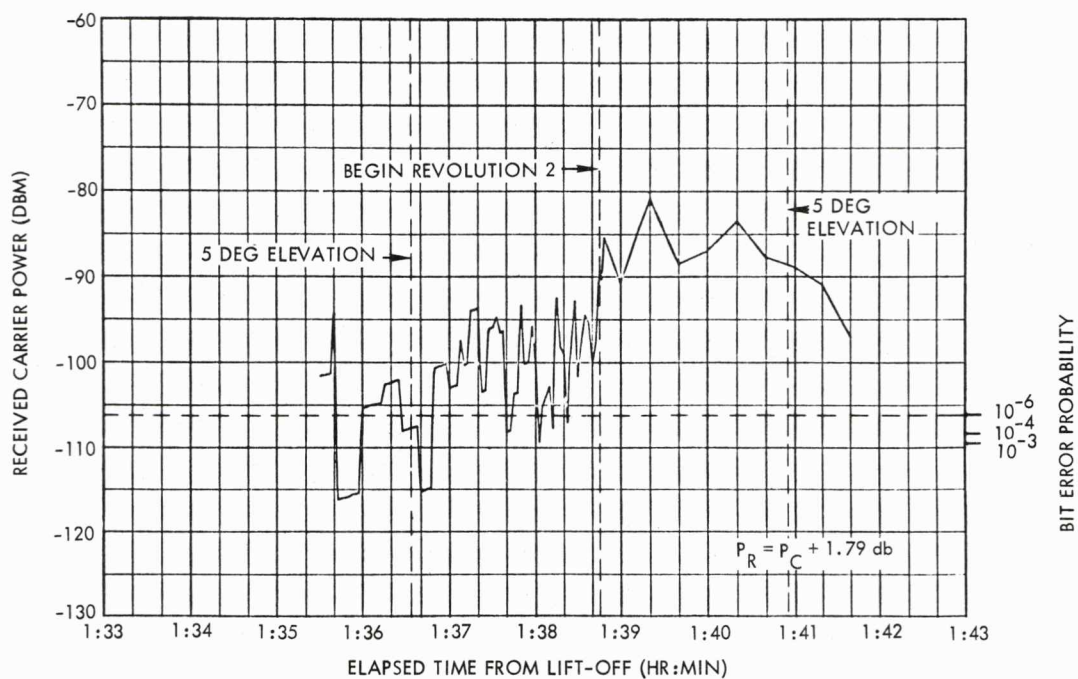


Figure 5-1b. MIL, -Z Antenna, Orbit 1-2

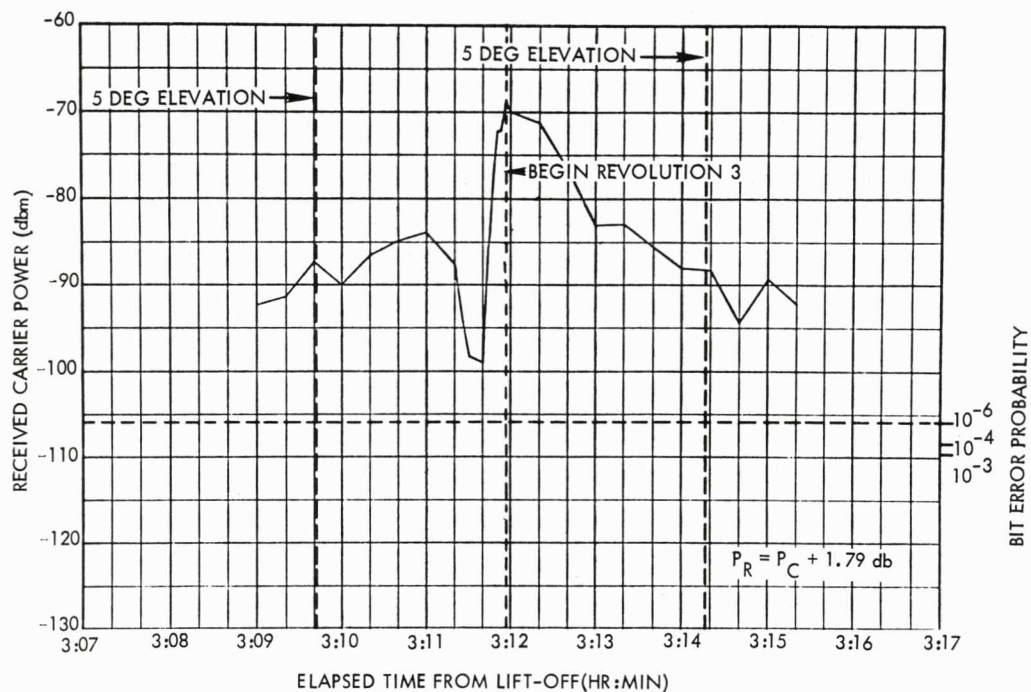


Figure 5-1c. MIL, +Z Antenna, Orbit 2-3

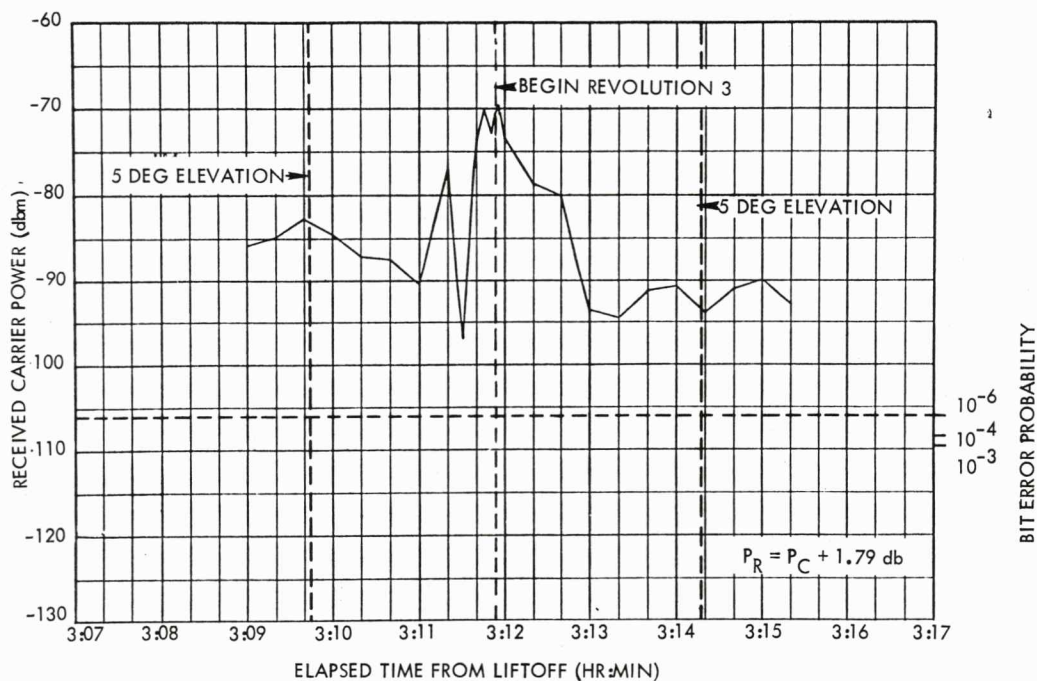


Figure 5-1d. MIL, -Z Antenna, Orbit 2-3

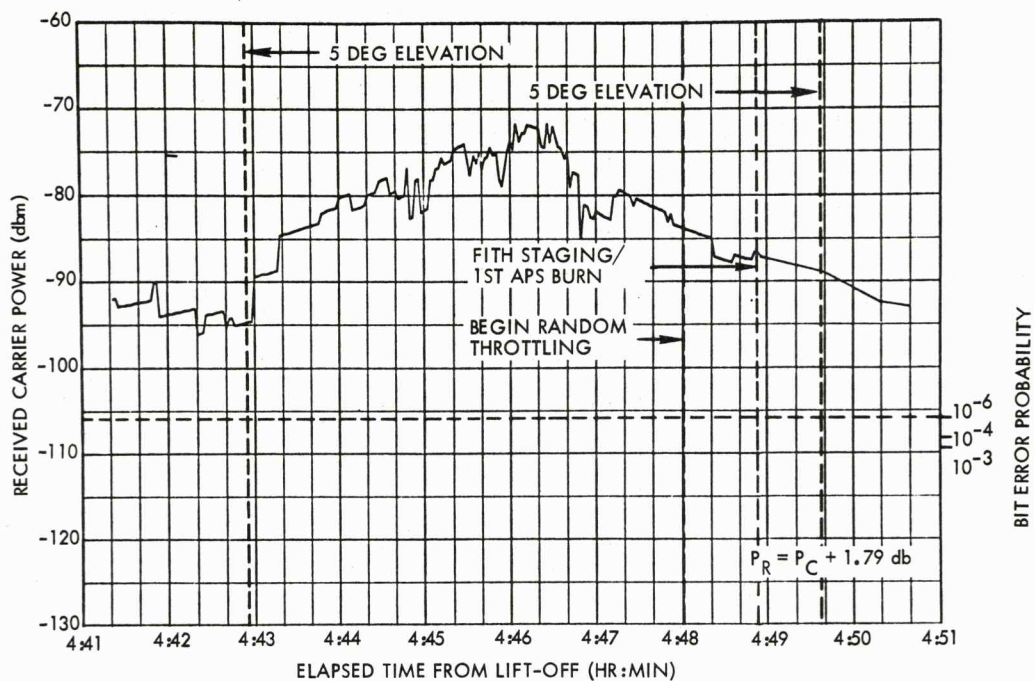


Figure 5-1e. MIL, +Z Antenna, Orbit 3-4

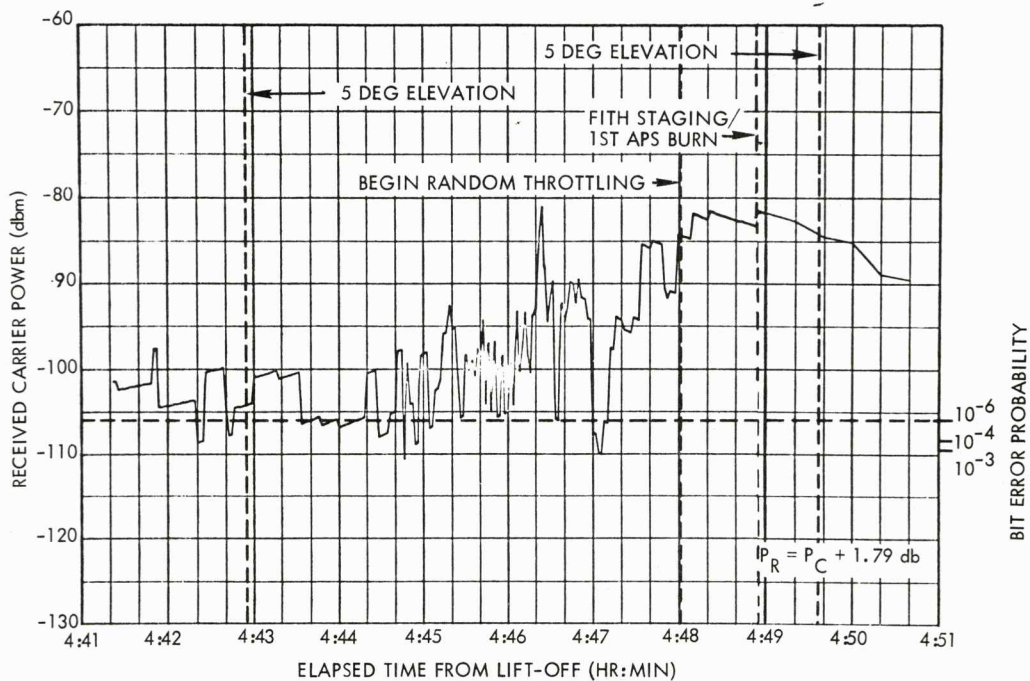


Figure 5-1f. MIL, -Z Antenna, Orbit 3-4

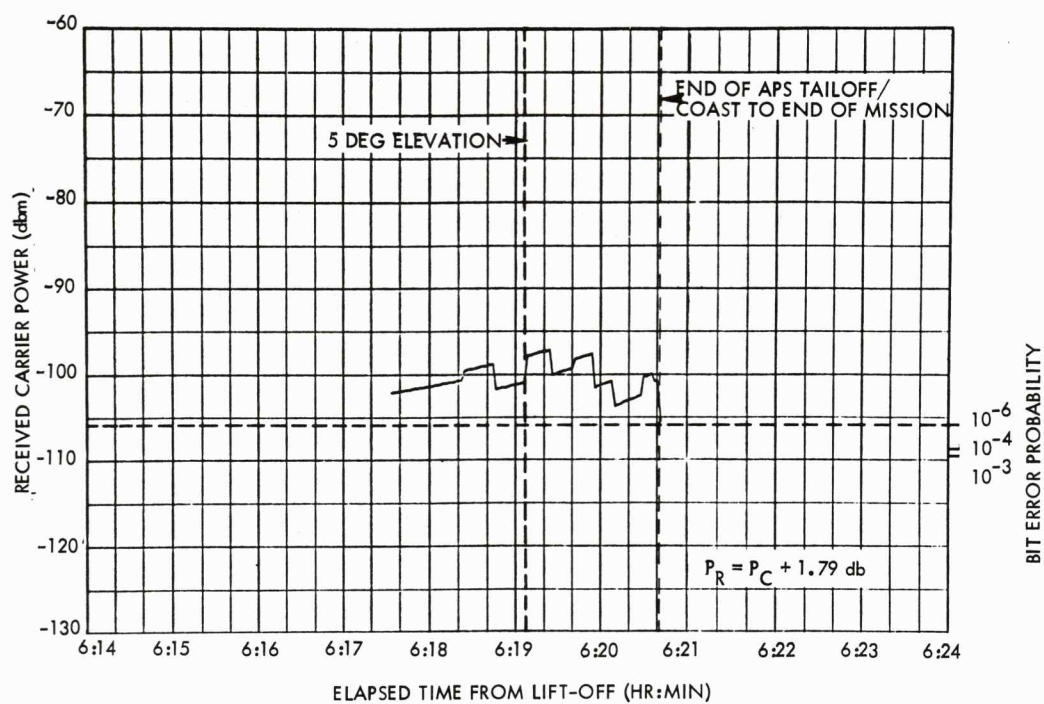


Figure 5-1g. MIL, +Z Antenna, Orbit 4

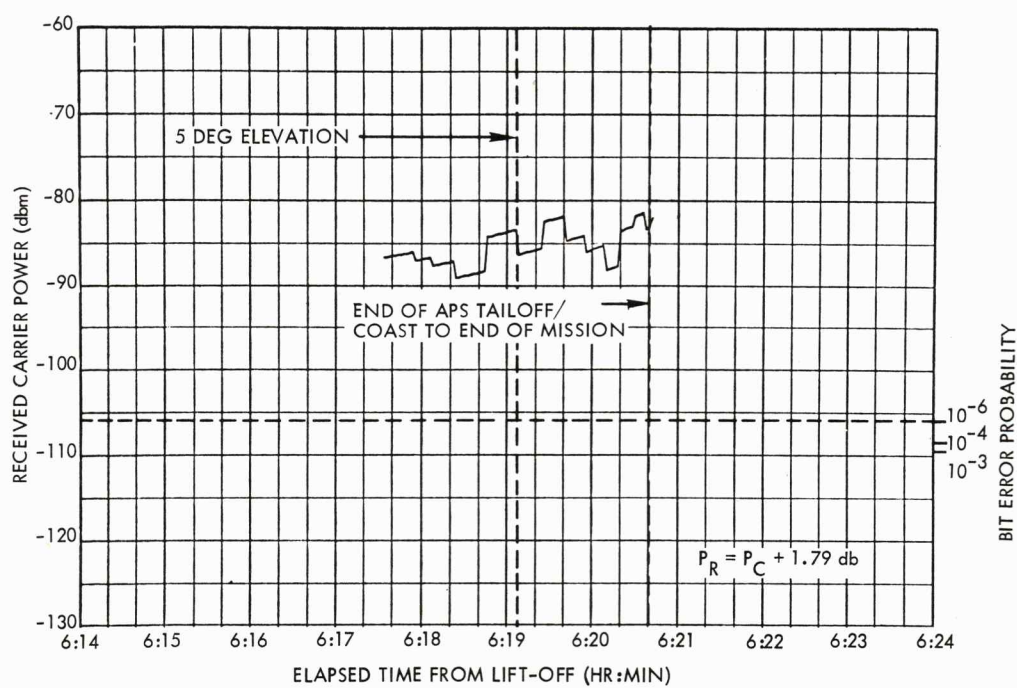


Figure 5-1h. MIL, -Z Antenna, Orbit 4

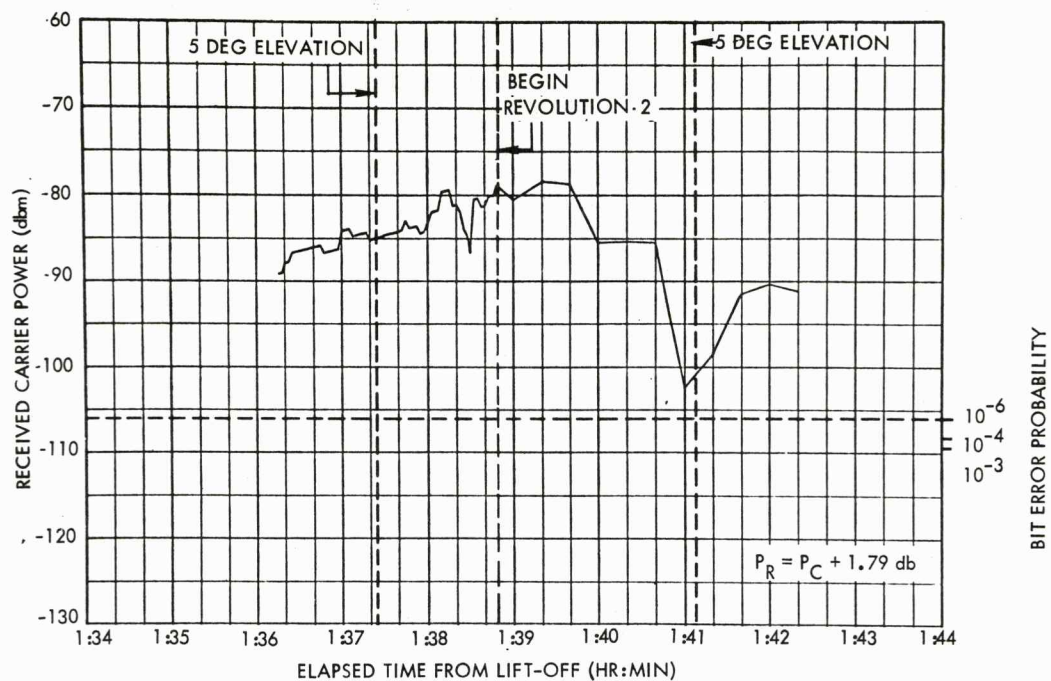


Figure 5-2a. GBI S-Band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 1-2

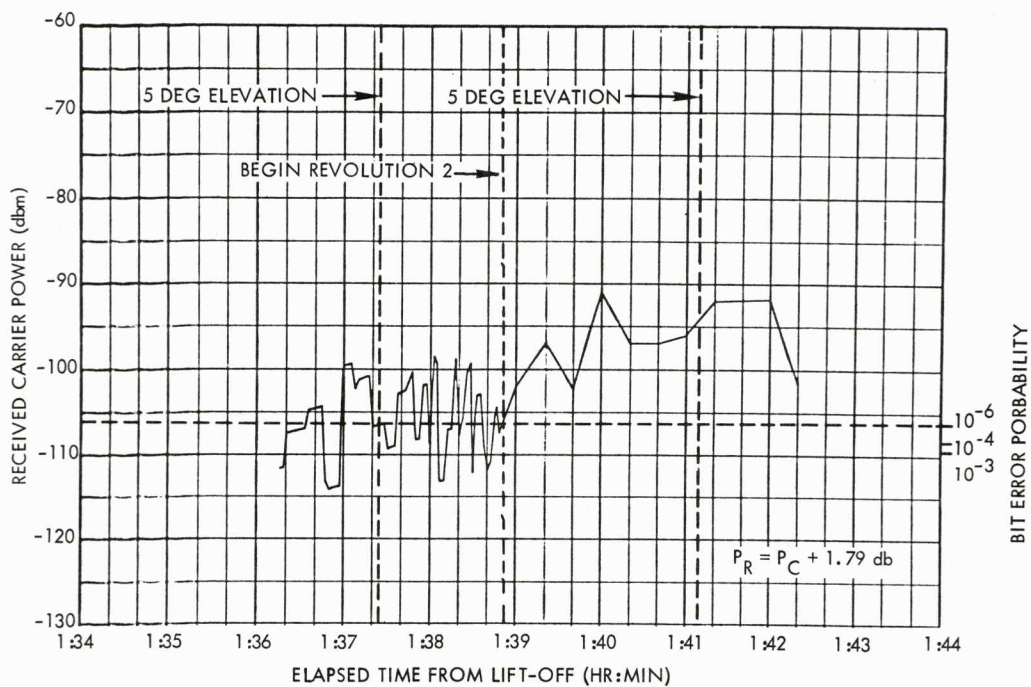


Figure 5-2b. GBI, -Z Antenna, Orbit 1-2

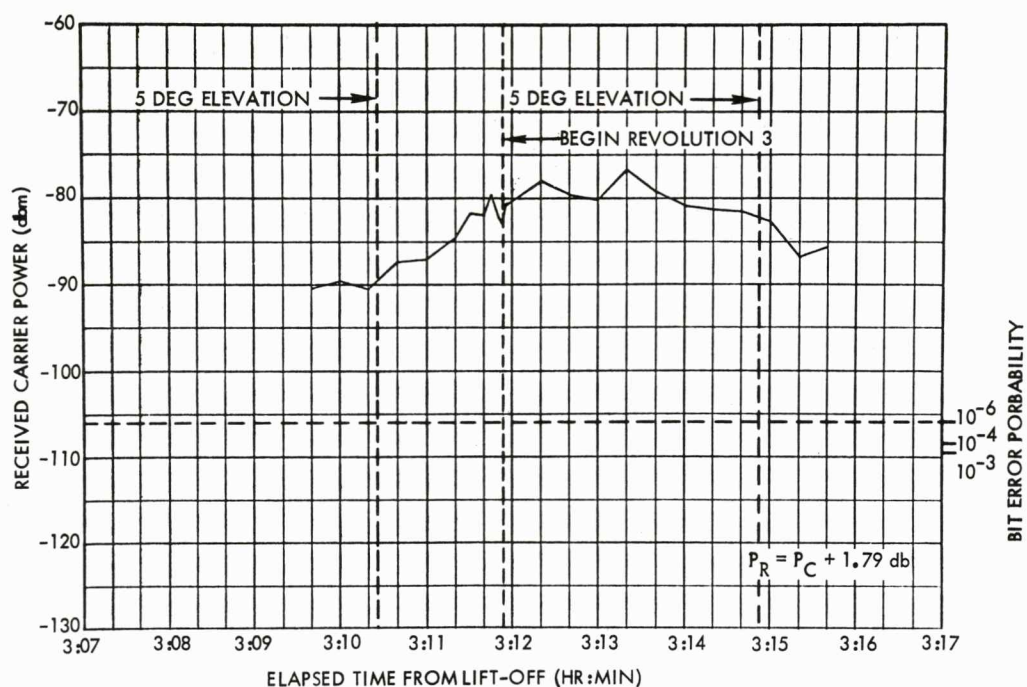


Figure 5-2c. GBI, +Z Antenna, Orbit 2-3

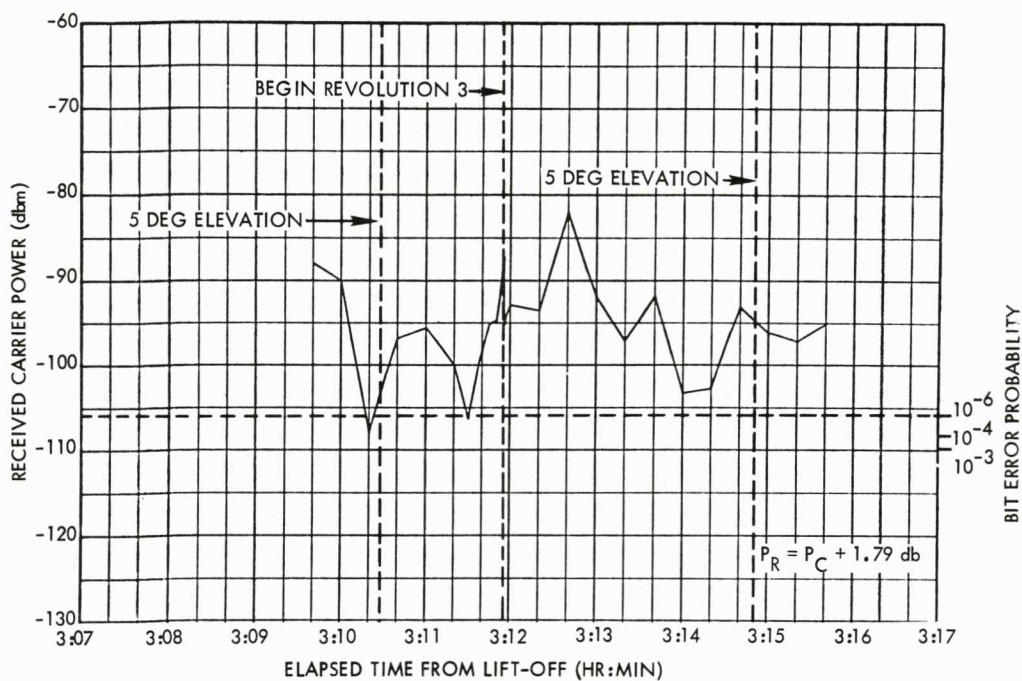


Figure 5-2d. GBI, -Z Antenna, Orbit 2-3

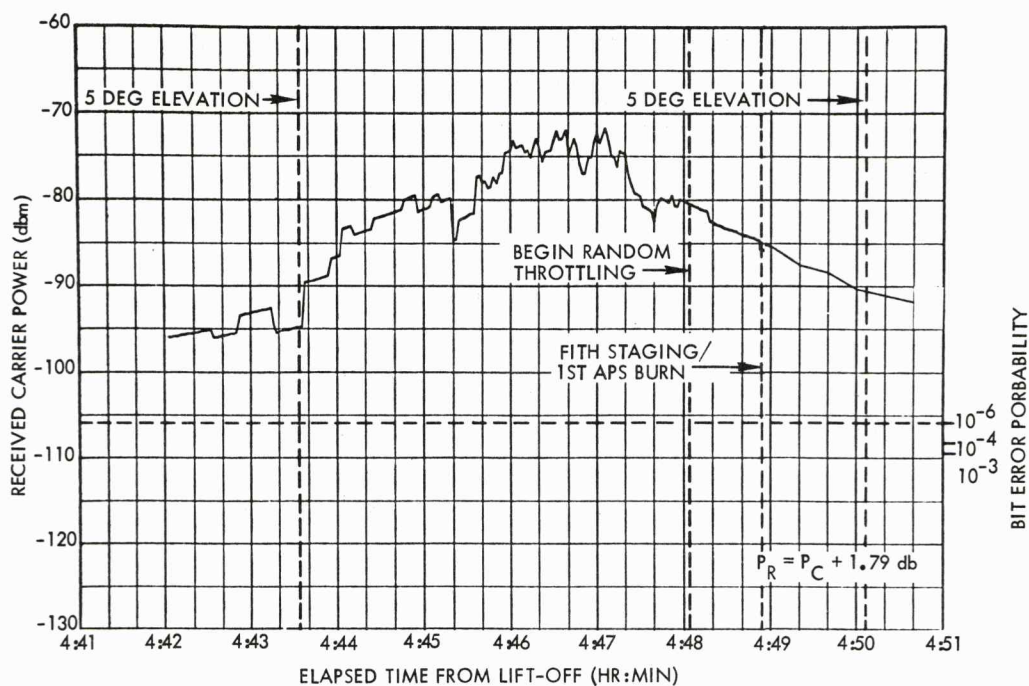


Figure 5-2e. GBI, +Z Antenna, Orbit 3-4

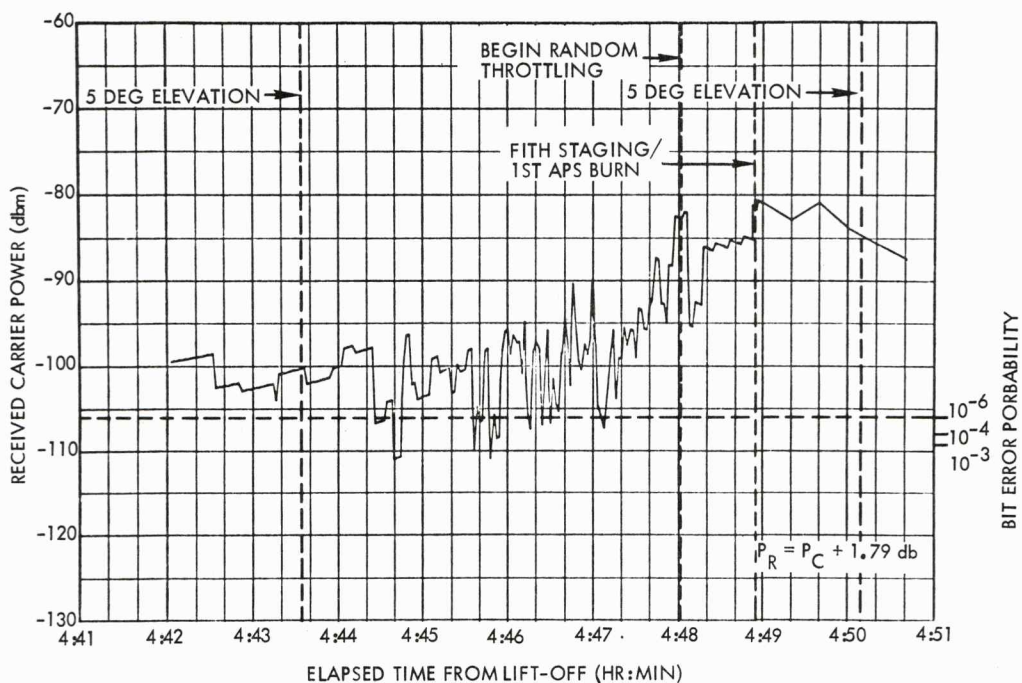


Figure 5-2f. GBI, -Z Antenna, Orbit 3-4

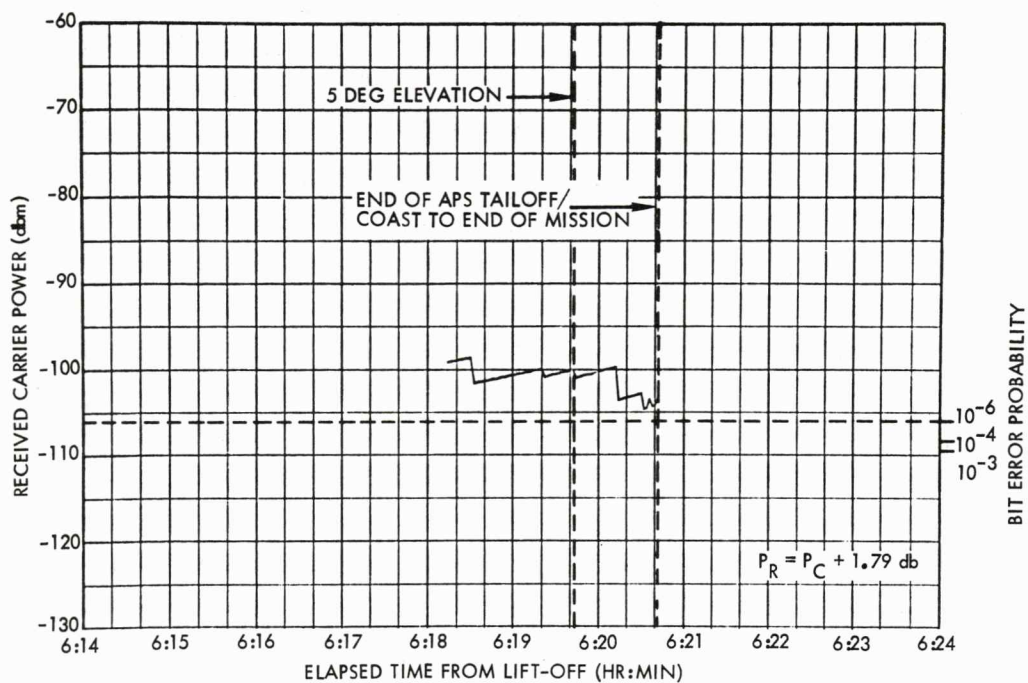


Figure 5-2g. GBI, +Z Antenna, Orbit 4

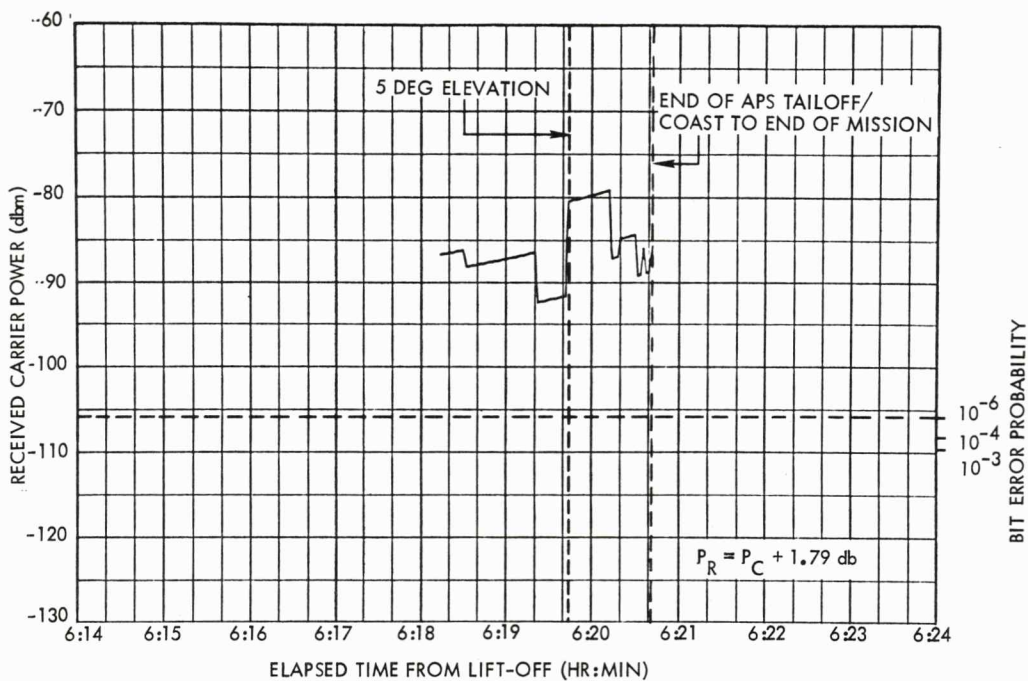


Figure 5-2h. GBI, -Z Antenna, Orbit 4

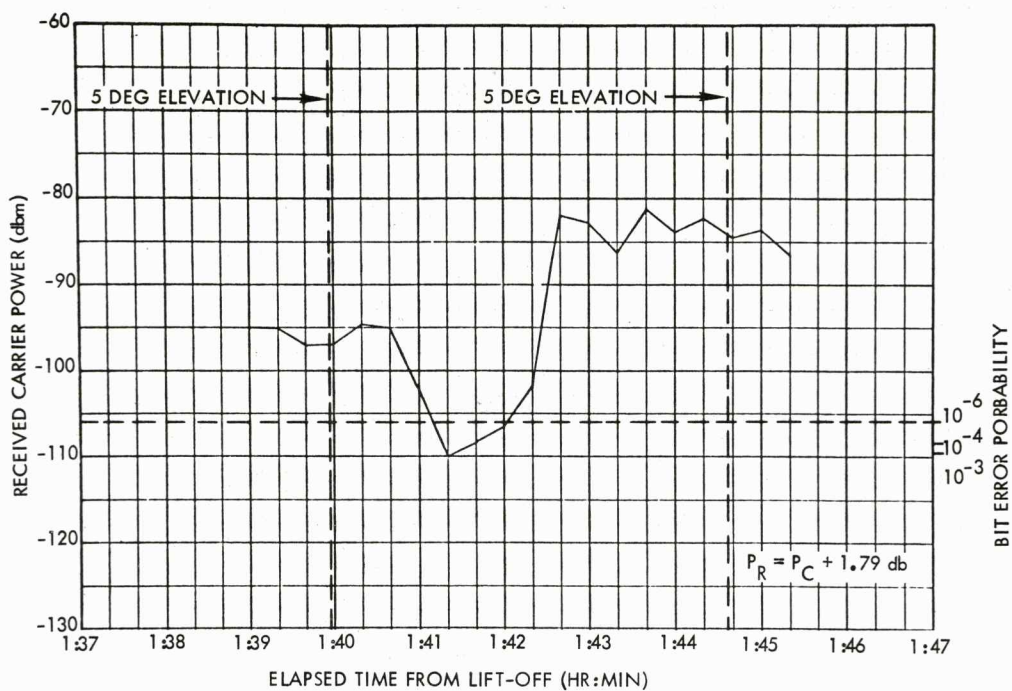


Figure 5-3a. BDA S-Band Received Carrier Power Versus Elapsed Time From Lift-Off, +Z Antenna, Orbit 2

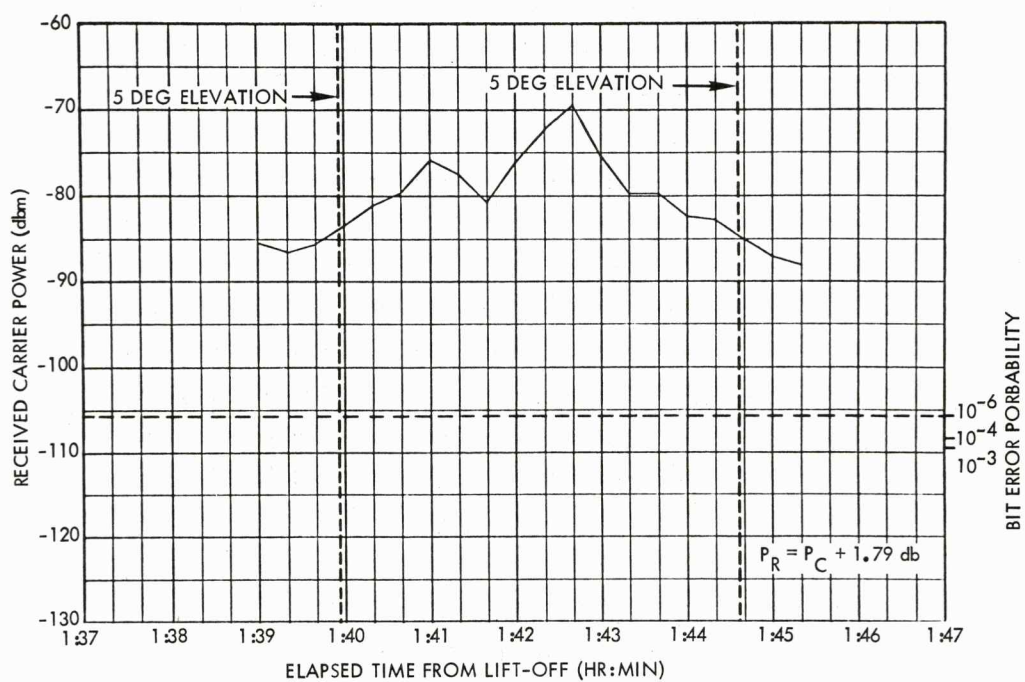


Figure 5-3b. BDA, -Z Antenna, Orbit 2

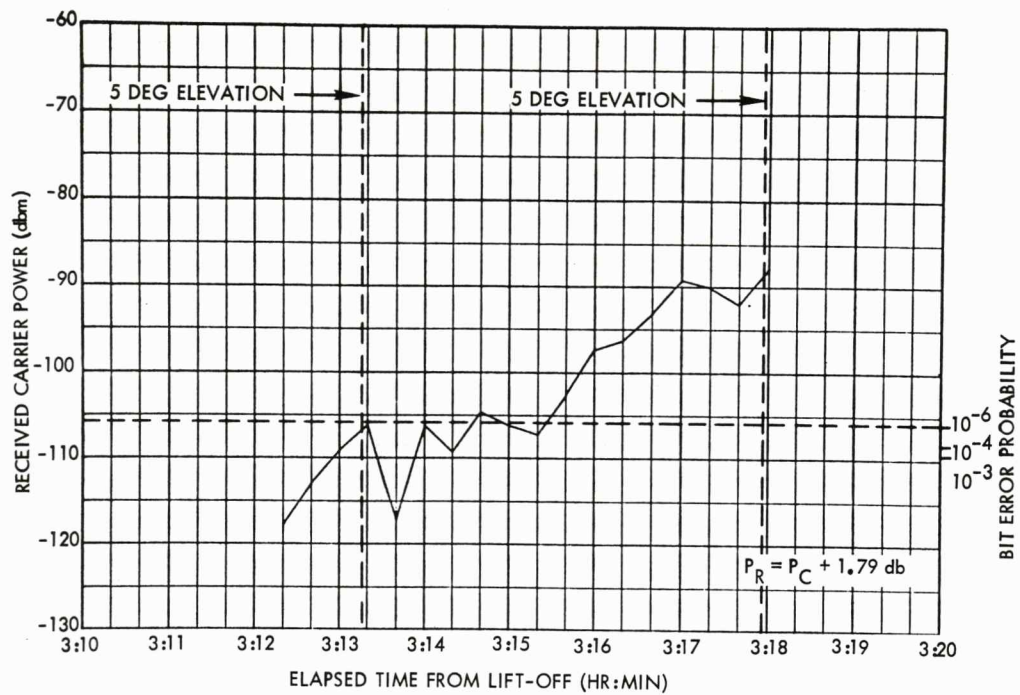


Figure 5-3c. BDA, +Z Antenna, Orbit 3

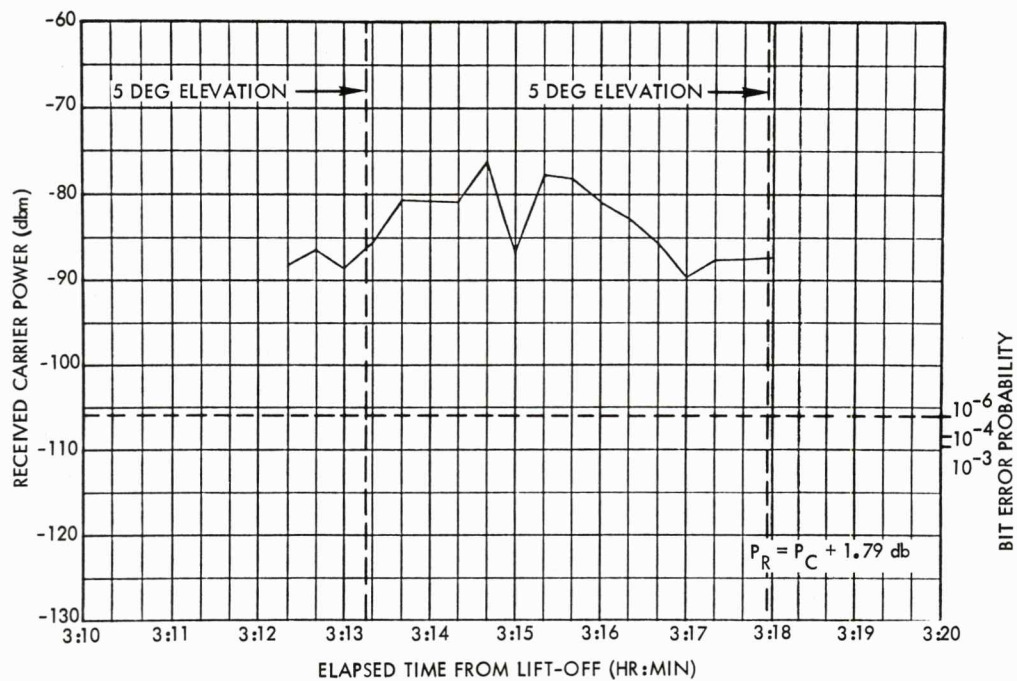


Figure 5-3d. BDA, -Z Antenna, Orbit 3

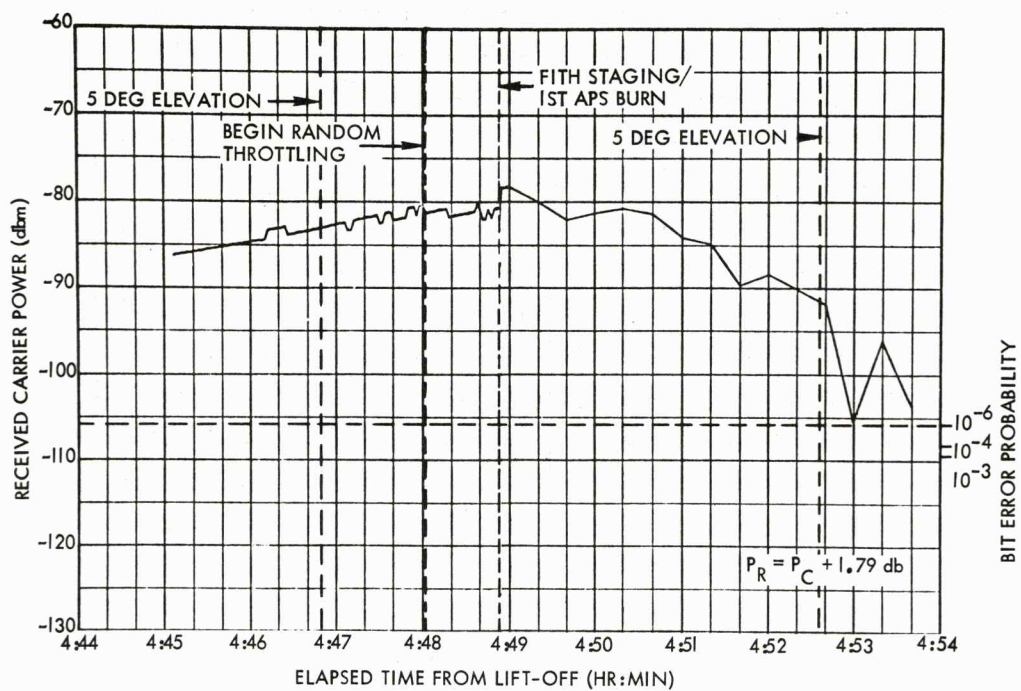


Figure 5-3e. BDA, +Z Antenna, Orbit 4

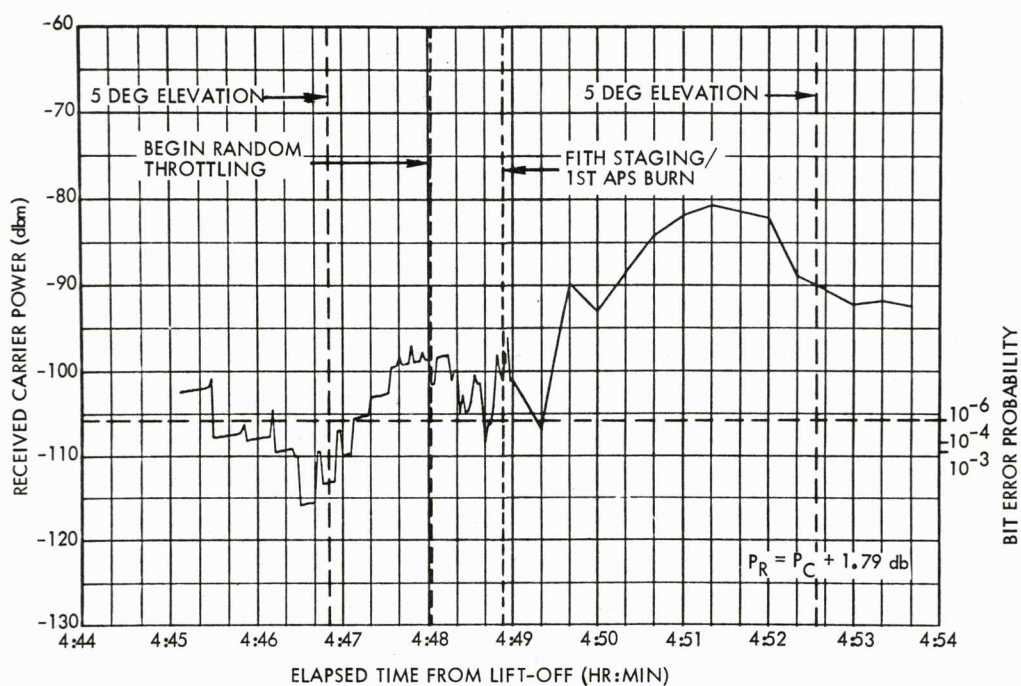


Figure 5-3f. BDA, -Z Antenna, Orbit 4

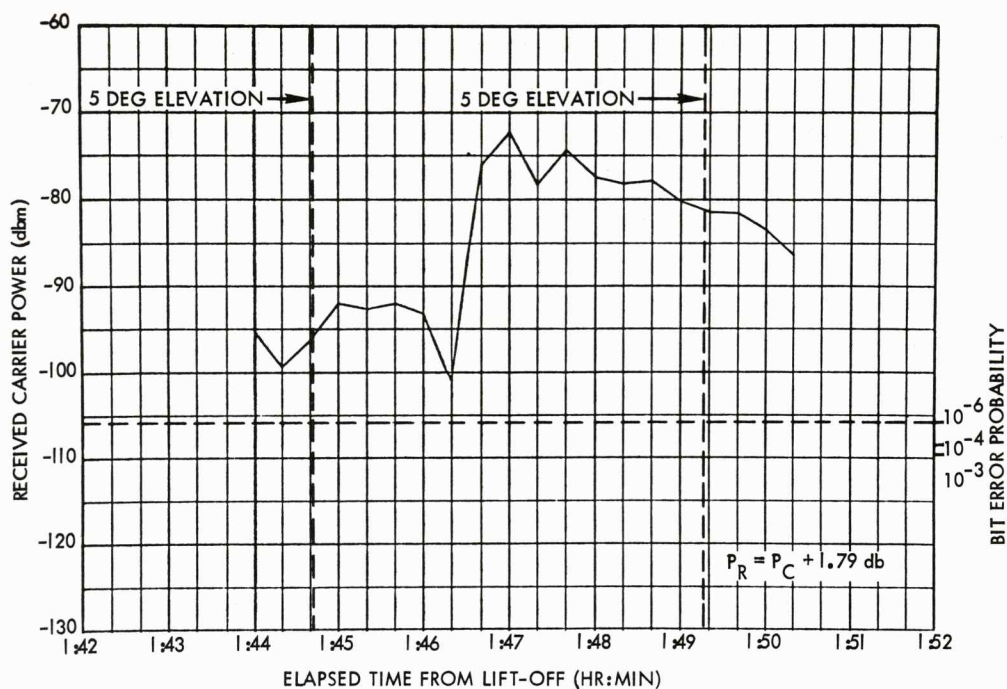


Figure 5-4a. VAN1 S-Band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 2

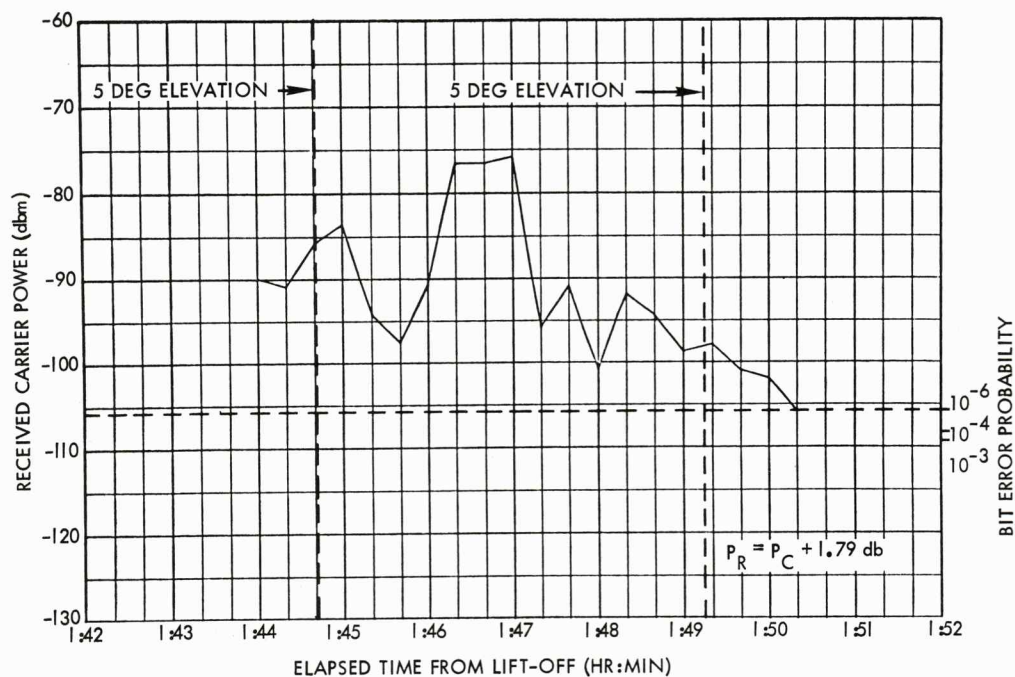


Figure 5-4b. VAN1, -Z Antenna, Orbit 2

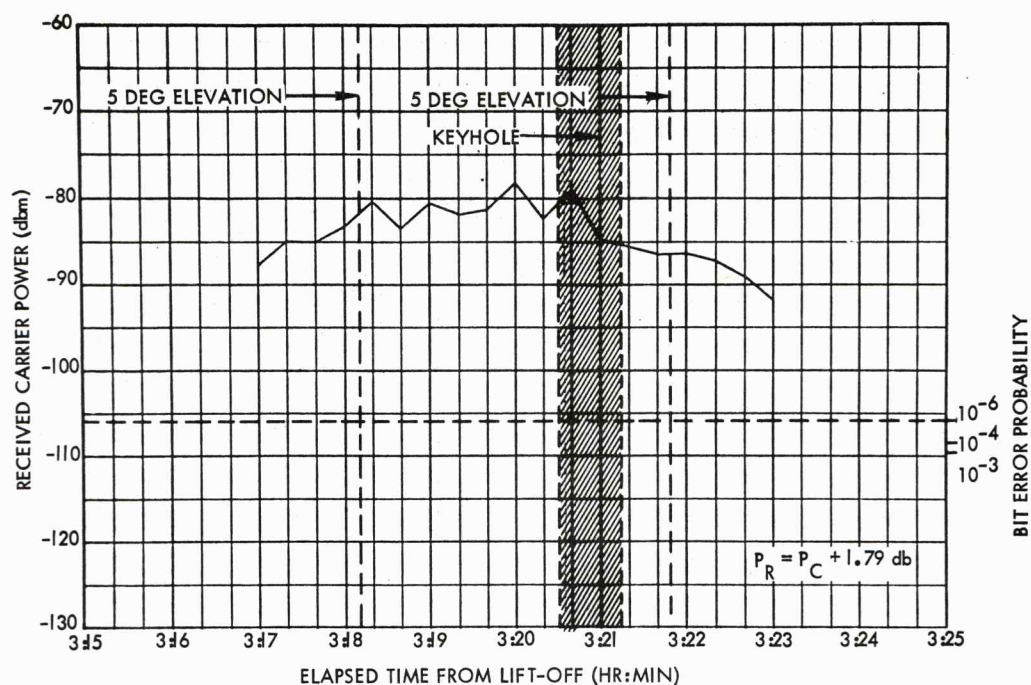


Figure 5-4c. VAN1, +Z Antenna, Orbit 3

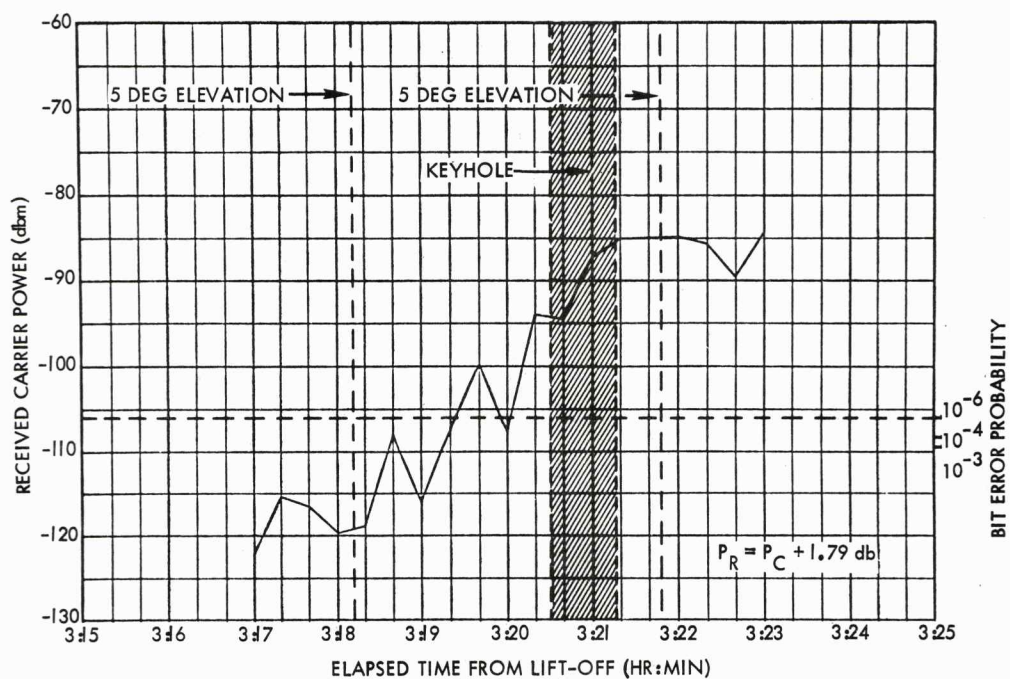


Figure 5-4d. VAN1, -Z Antenna, Orbit 3

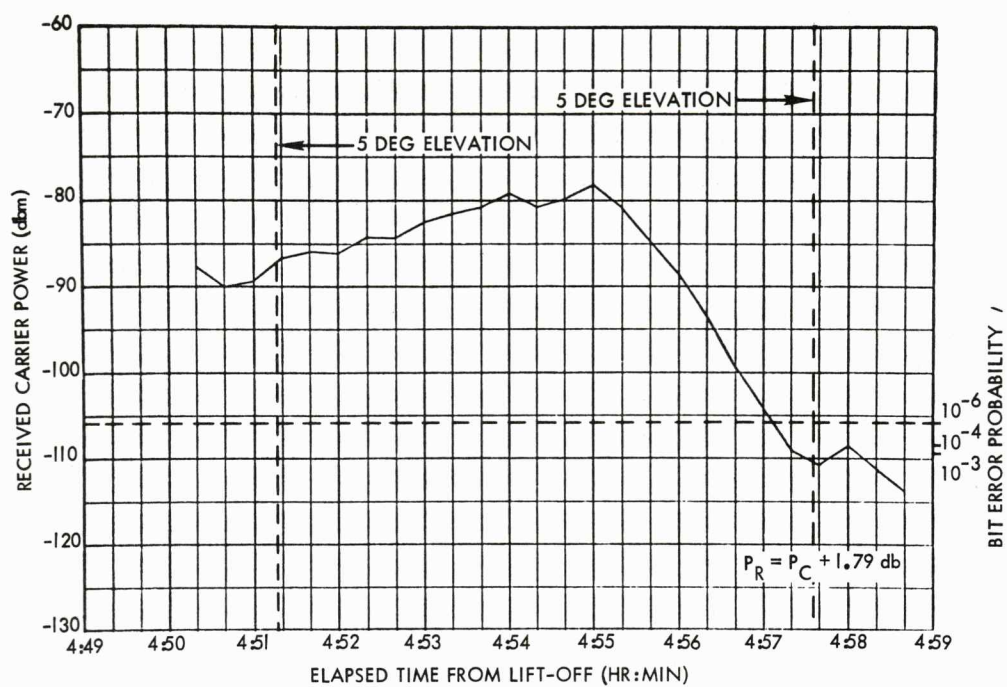


Figure 5-4e. VAN1, +Z Antenna, Orbit 4

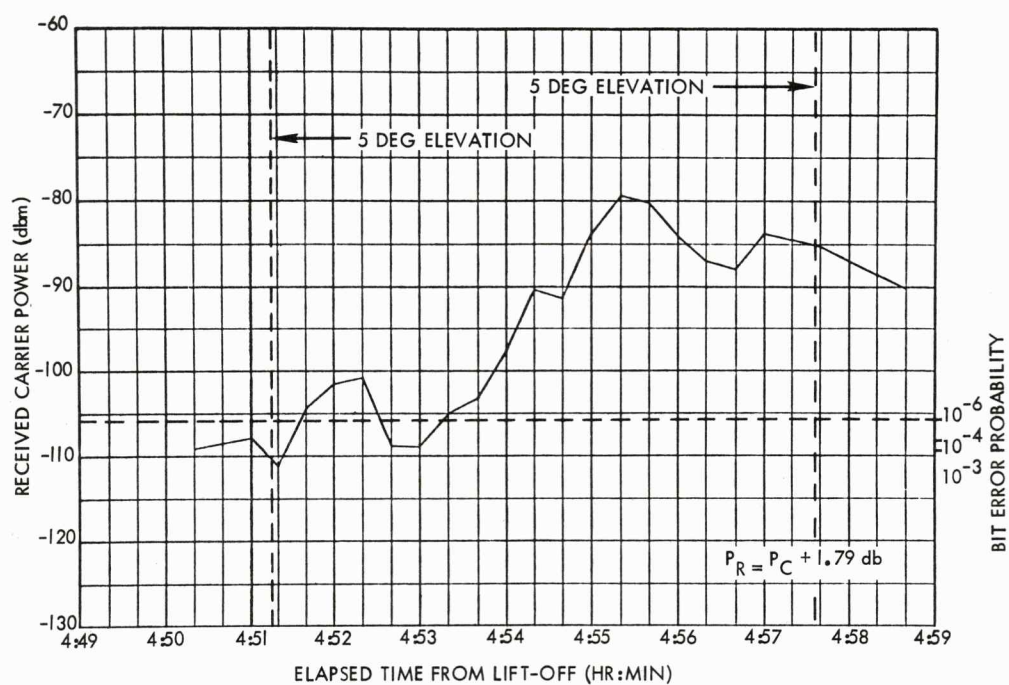


Figure 5-4f. VAN1, -Z Antenna, Orbit 4

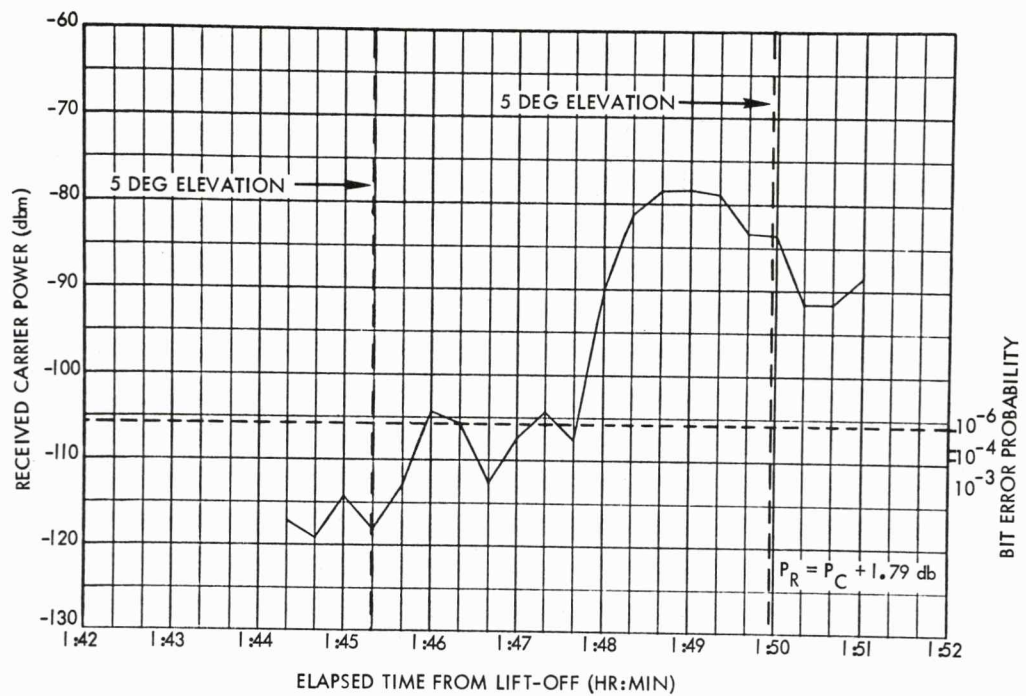


Figure 5-5a. VAN2 S-Band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 2

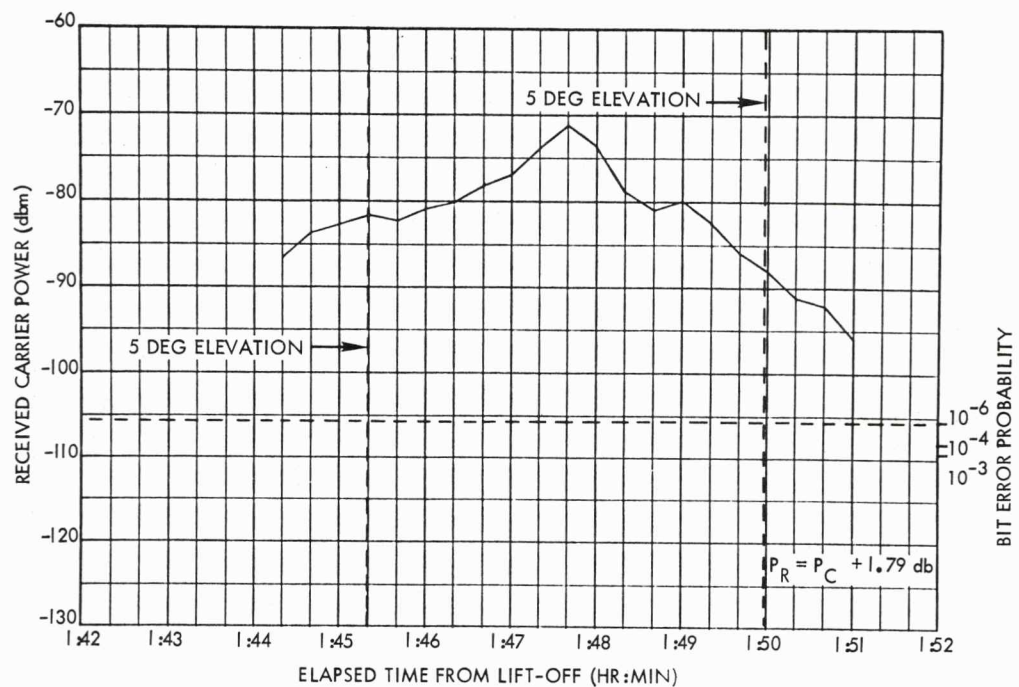


Figure 5-5b. VAN2, -Z Antenna, Orbit 2

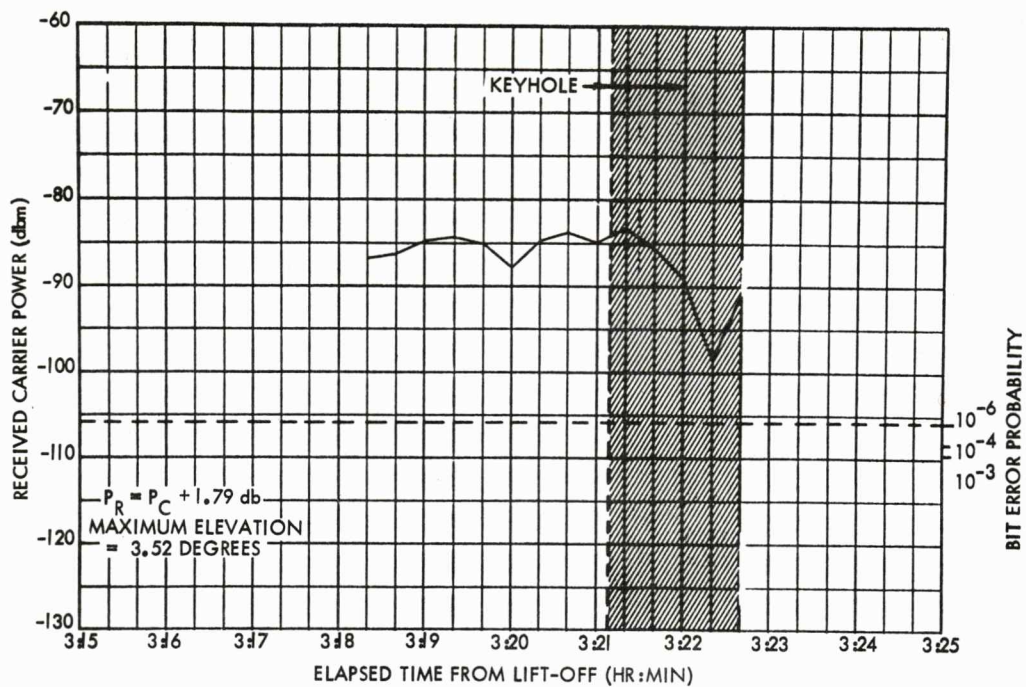


Figure 5-5c. VAN2, +Z Antenna, Orbit 3

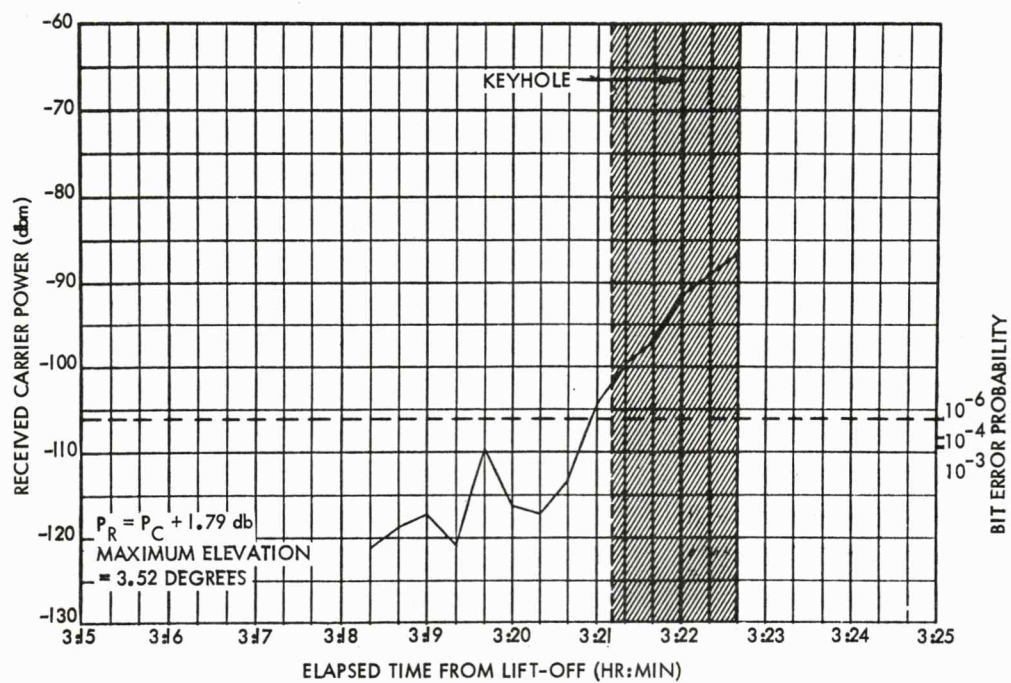


Figure 5-5d. VAN2, -Z Antenna, Orbit 3

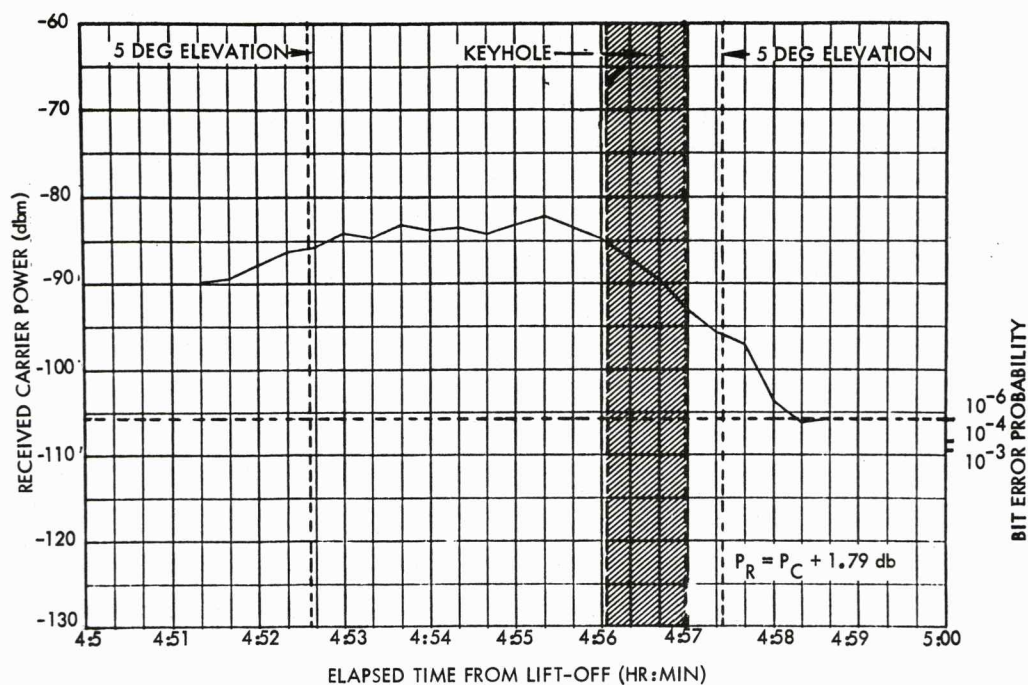


Figure 5-5e. VAN2, +Z Antenna, Orbit 4

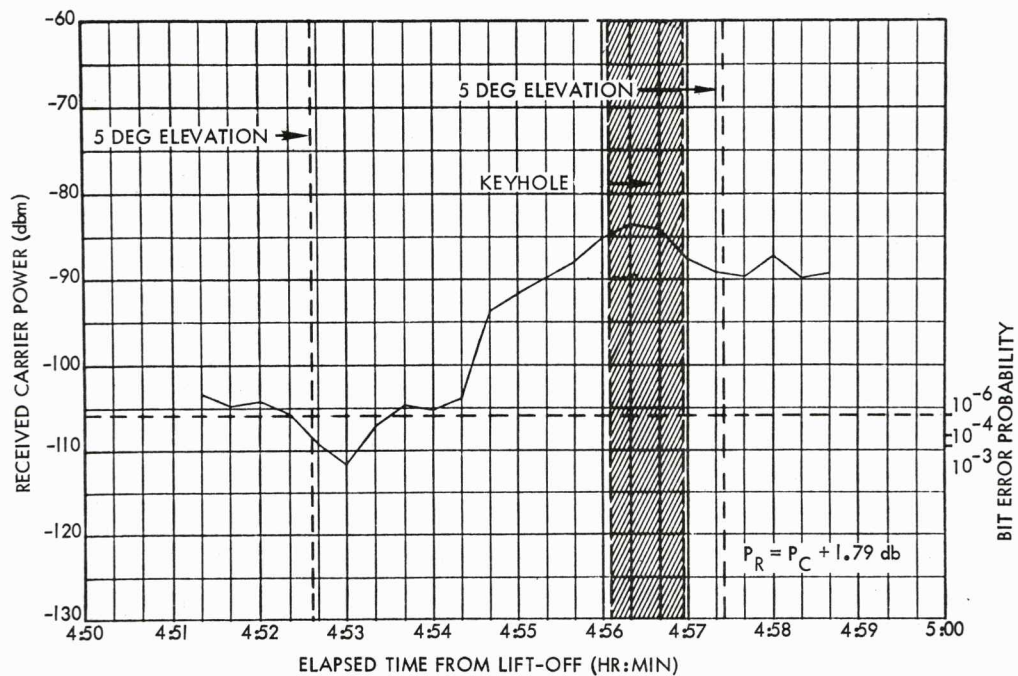


Figure 5-5f. VAN2, -Z Antenna, Orbit 4

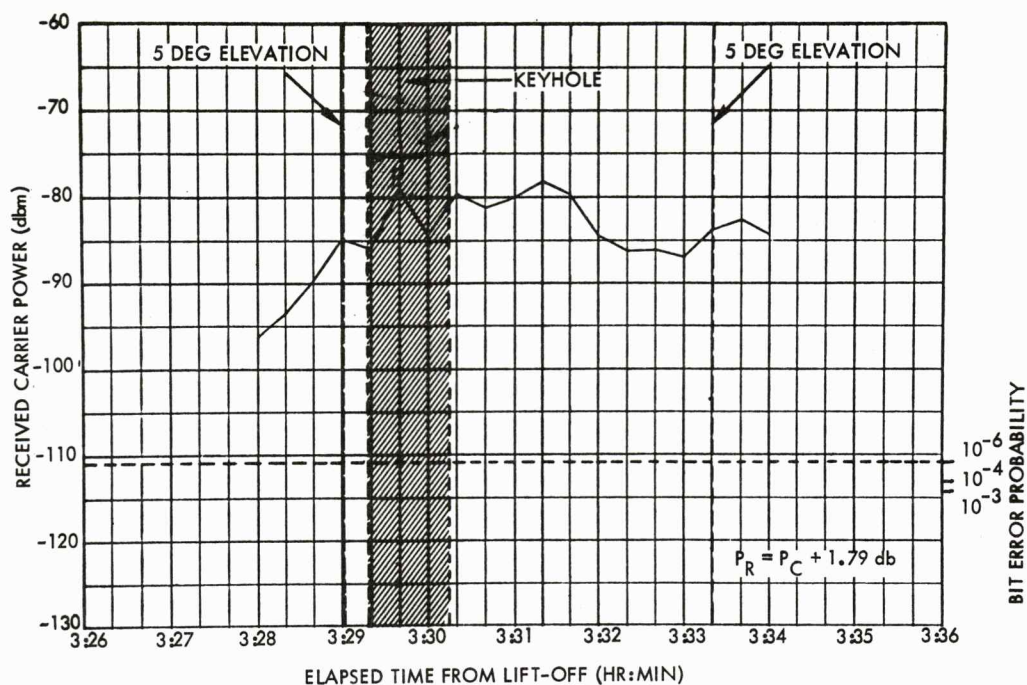


Figure 5-6a. ACN S-Band Received Carrier Power Versus Elapsed Time From Lift-Off, +Z Antenna, Orbit 3

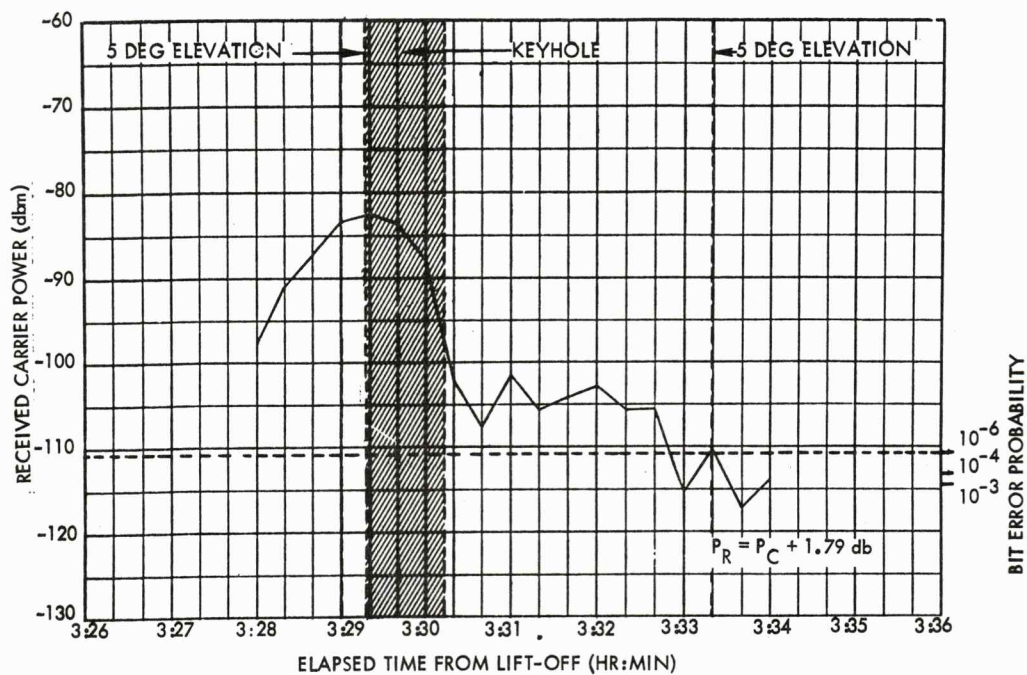


Figure 5-6b. ACN, -Z Antenna, Orbit 3

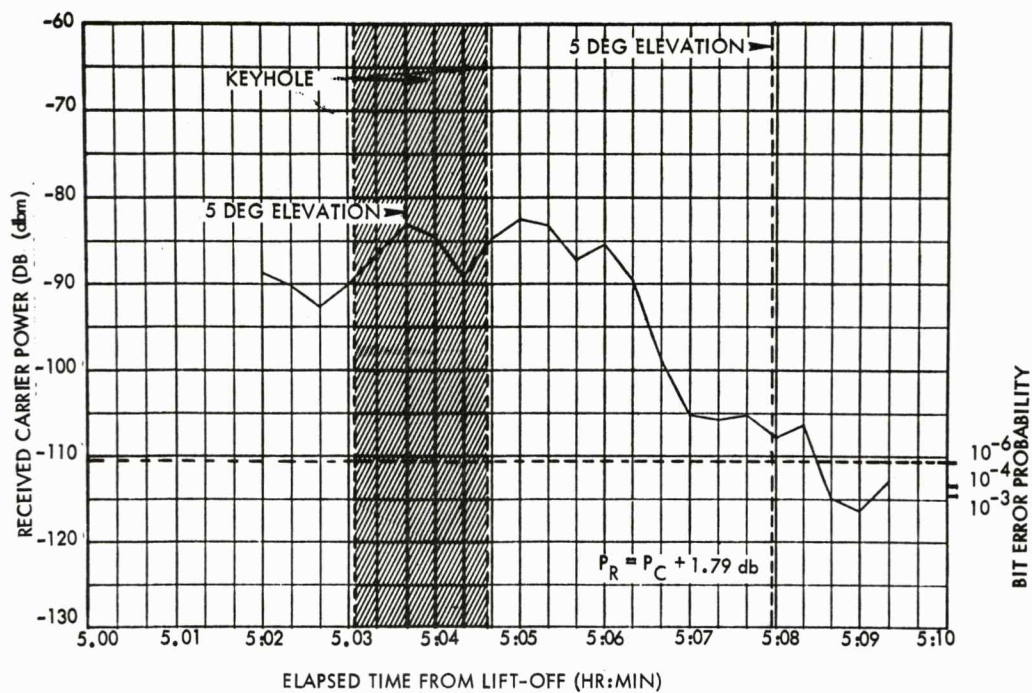


Figure 5-6c. ACN, +Z Antenna, Orbit 4

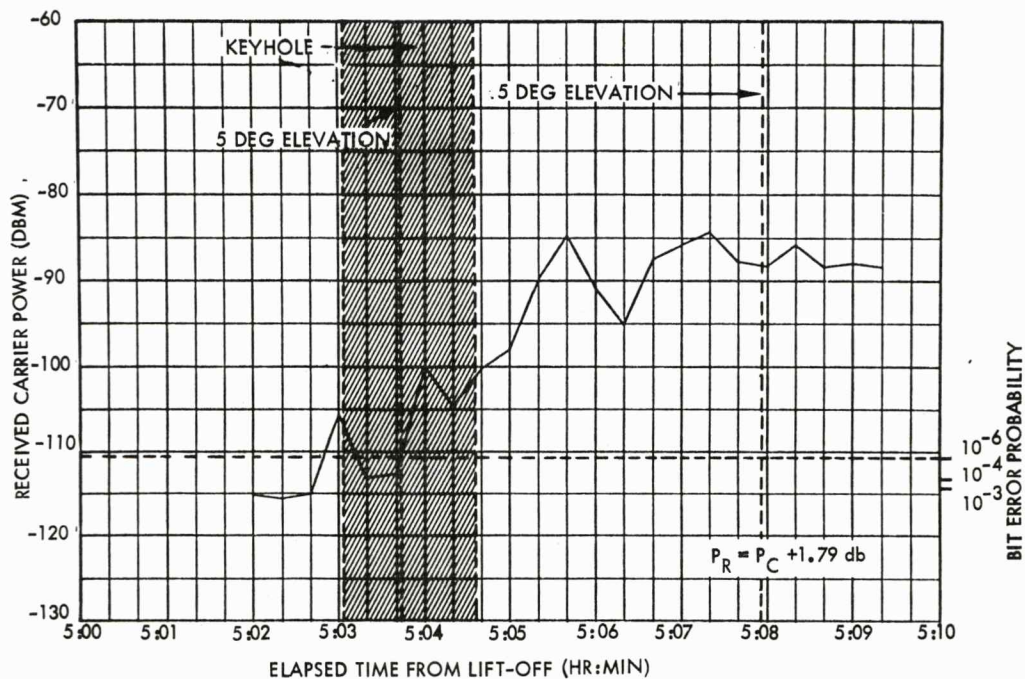


Figure 5-6d. ACN, -Z Antenna, Orbit 4

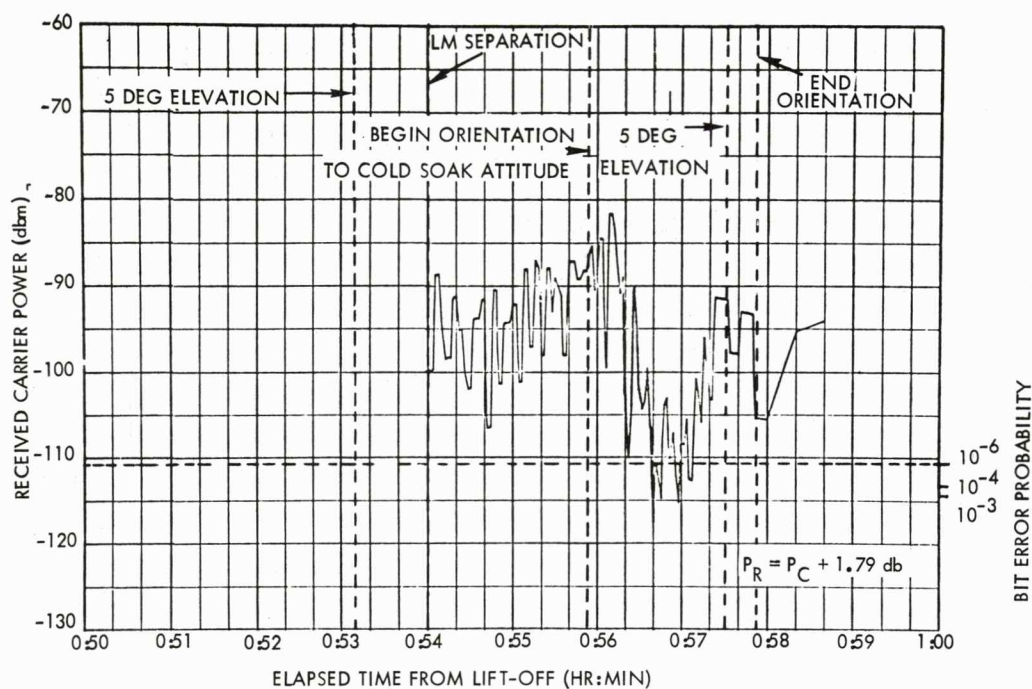


Figure 5-7a. CRO S-Band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 1

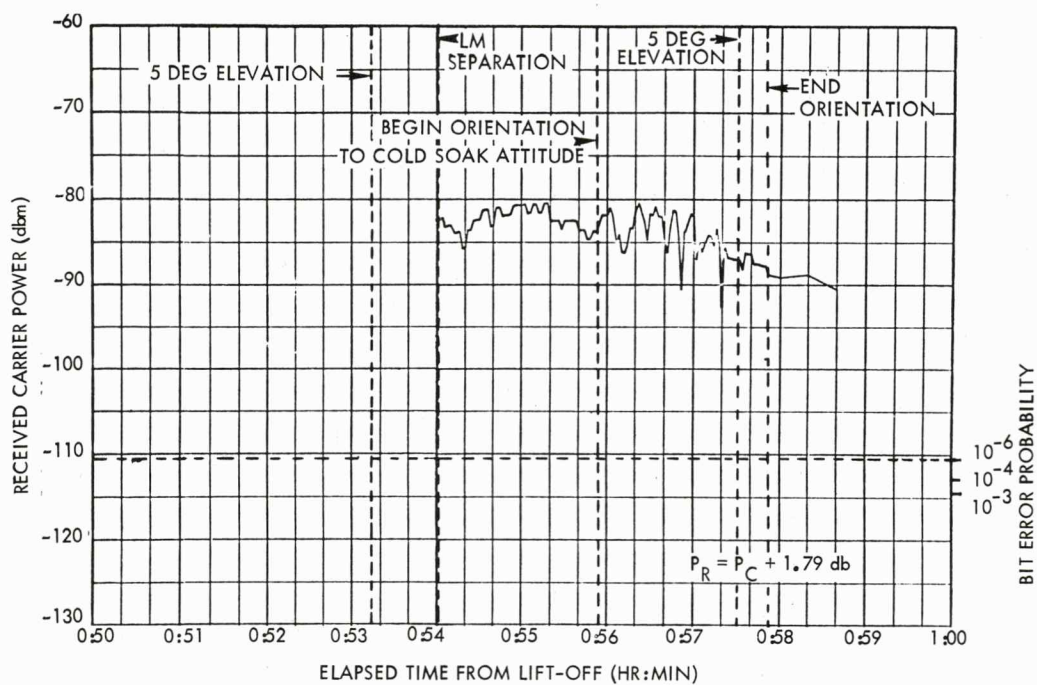


Figure 5-7b. CRO, -Z Antenna, Orbit 1

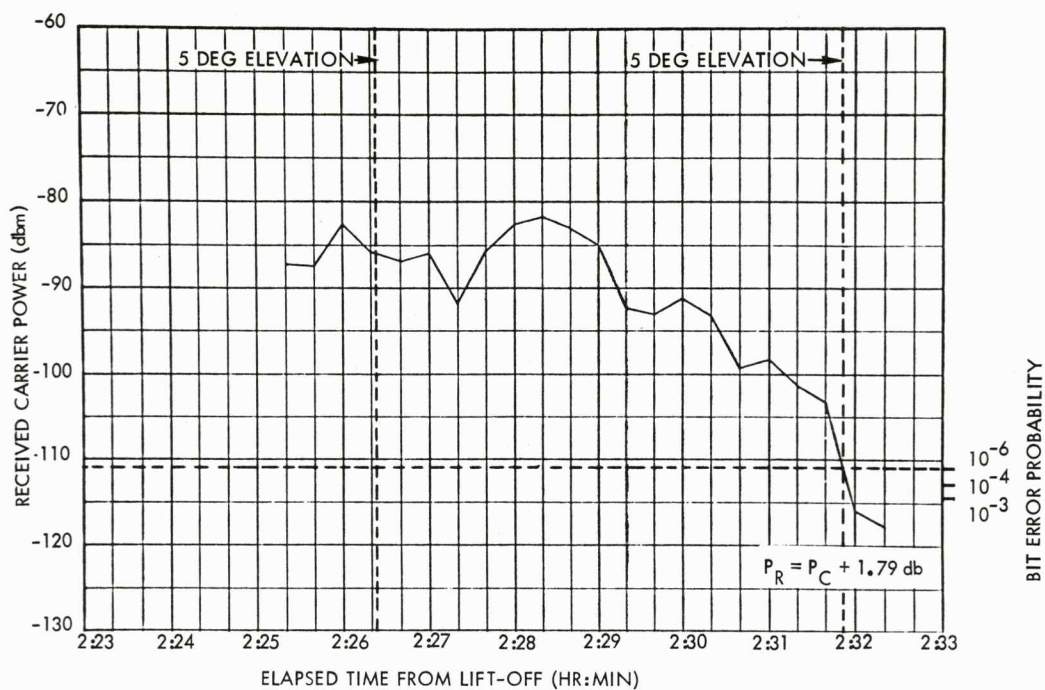


Figure 5-7c. CR0, +Z Antenna, Orbit 2

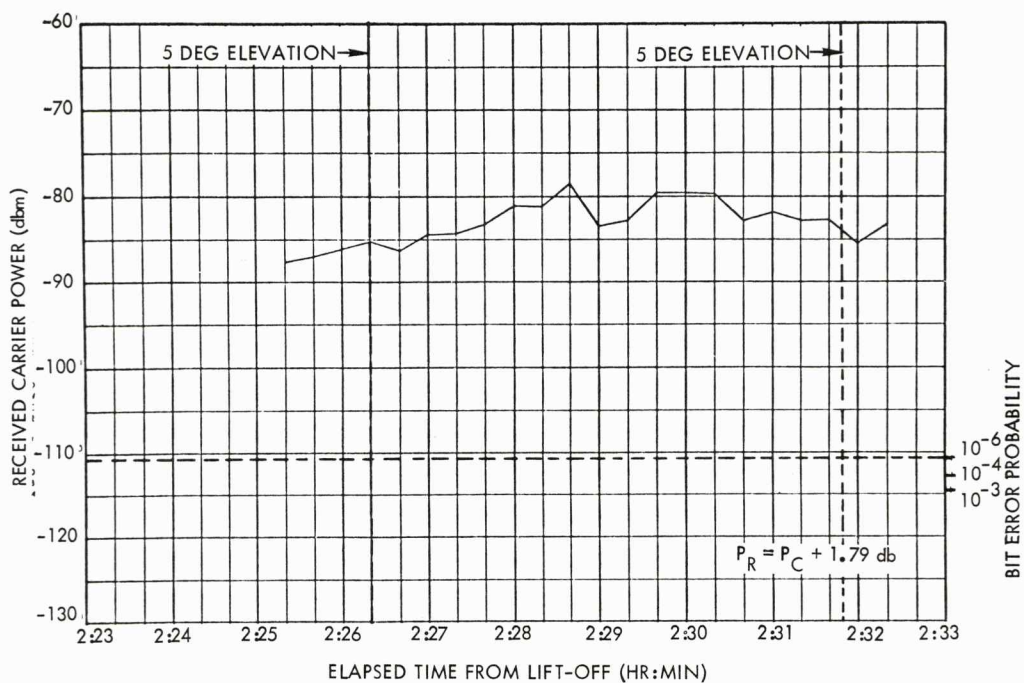


Figure 5-7d. CR0, -Z Antenna, Orbit 2

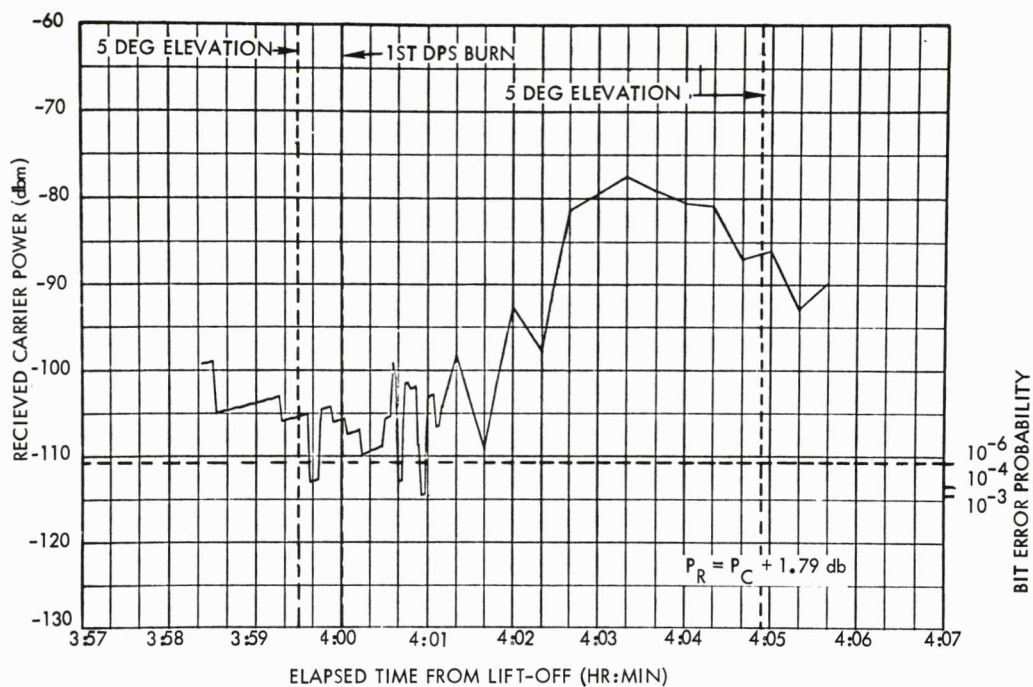


Figure 5-7e. CR0, +Z Antenna, Orbit 3

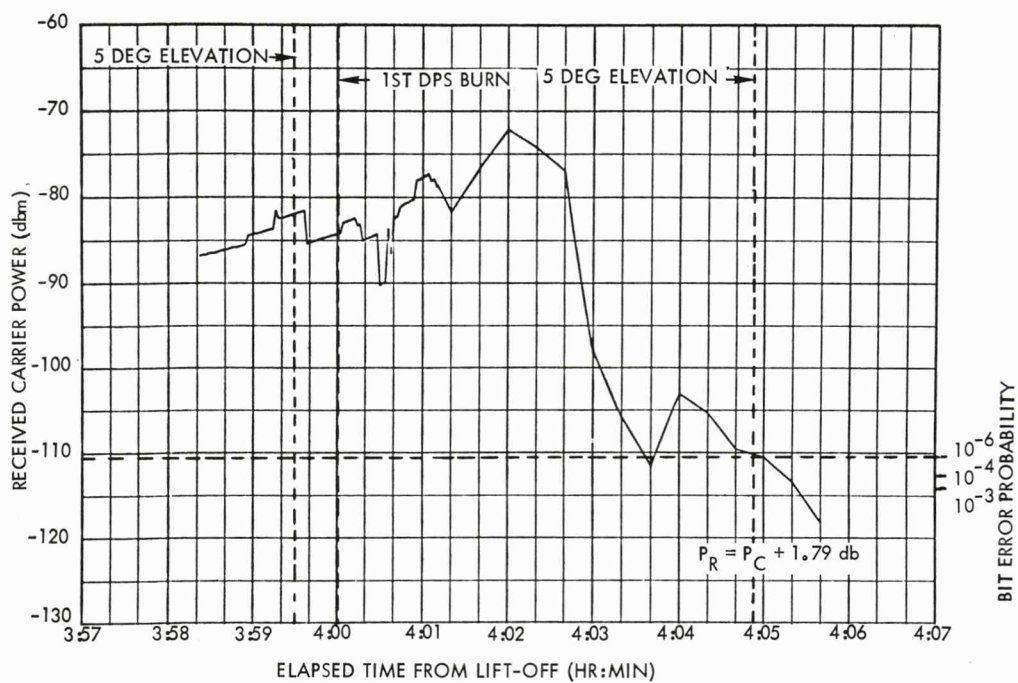


Figure 5-7f. CR0, -Z Antenna, Orbit 3

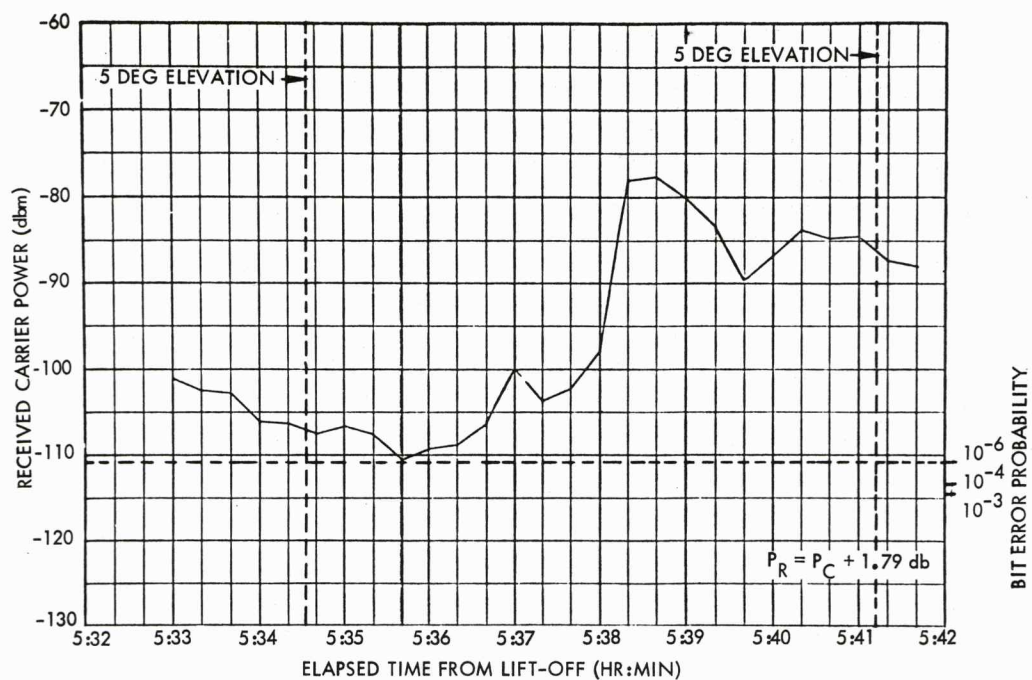


Figure 5-7g. CR0, +Z Antenna, Orbit 4

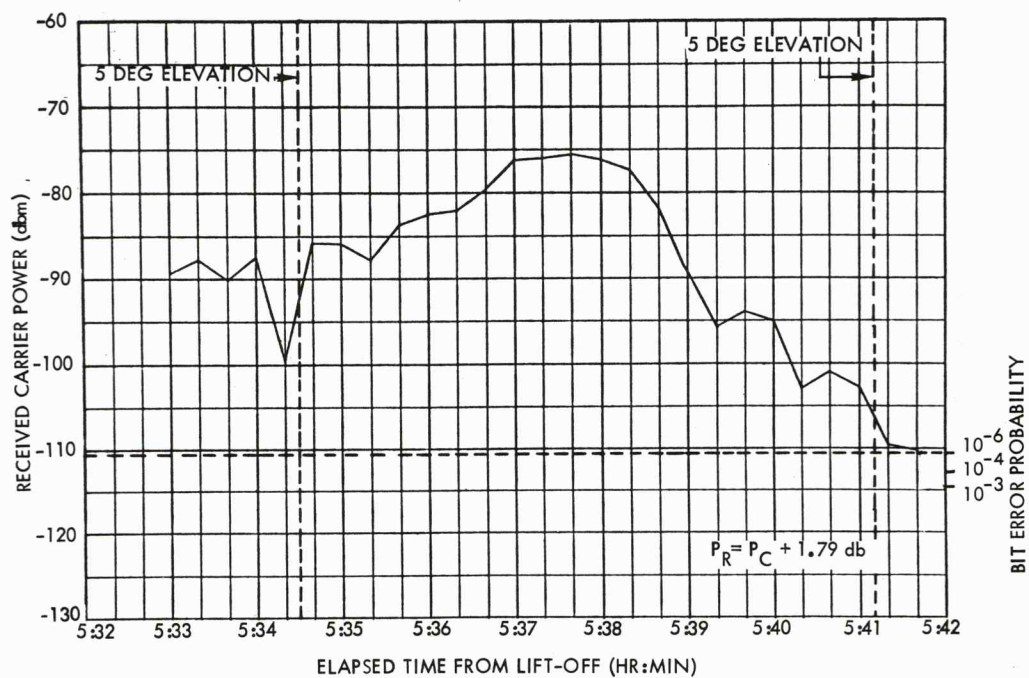


Figure 5-7h. CR0, -Z Antenna, Orbit 4

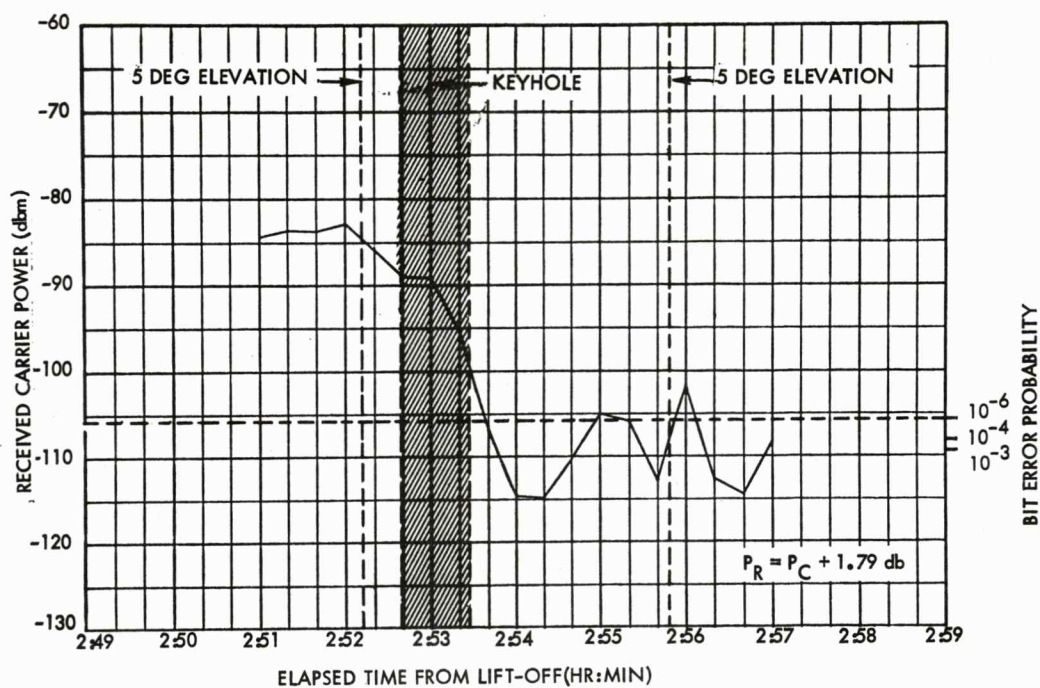


Figure 5-8a. HAW S-Band Received Carrier Power Versus Elapsed Time From Lift-Off, +Z Antenna, Orbit 2

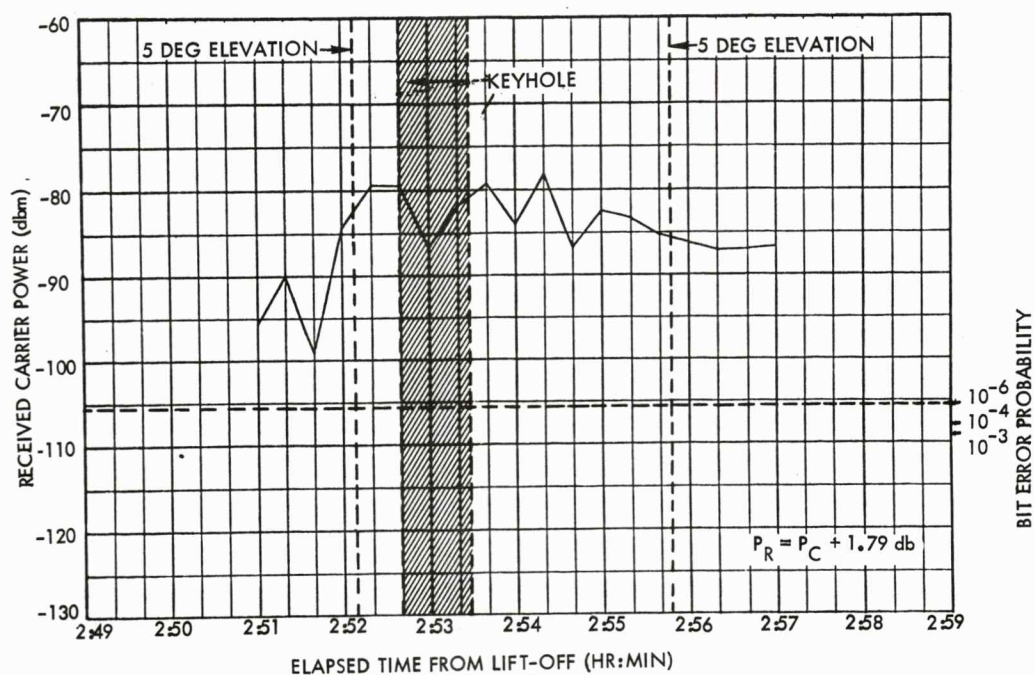


Figure 5-8b. HAW, -Z Antenna, Orbit 2

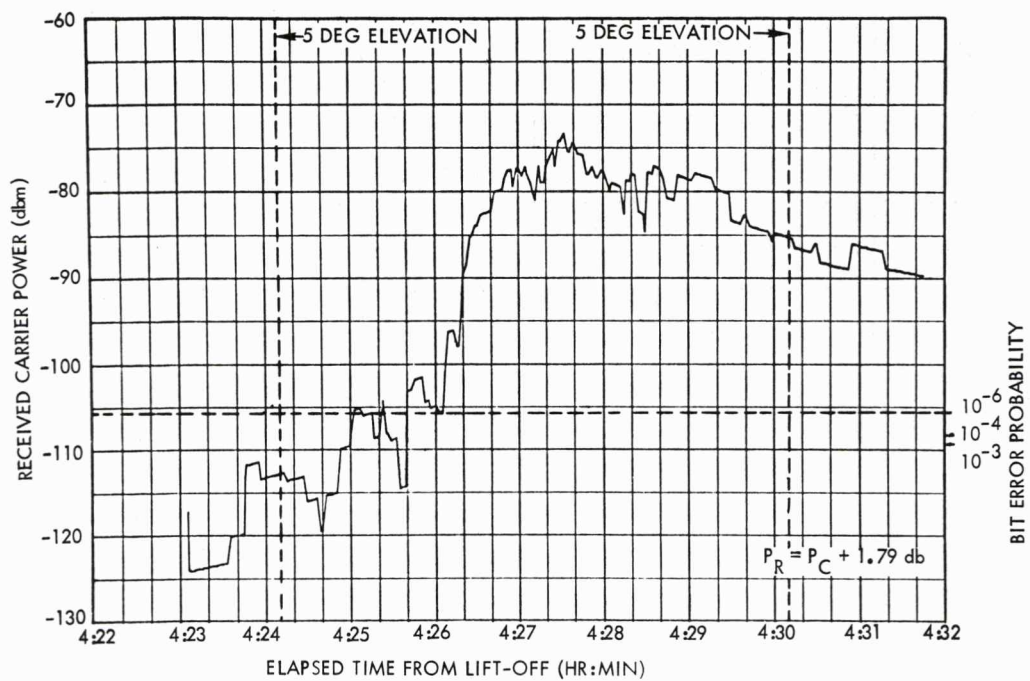


Figure 5-8c. HAW, +Z Antenna, Orbit 3

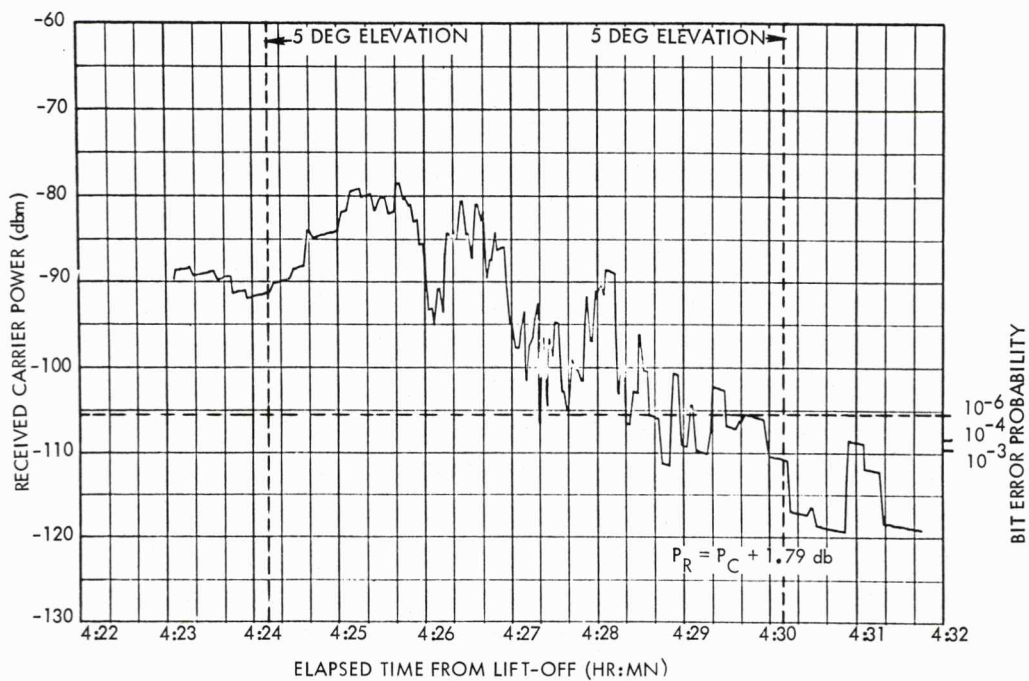


Figure 5-8d. HAW, -Z Antenna, Orbit 3

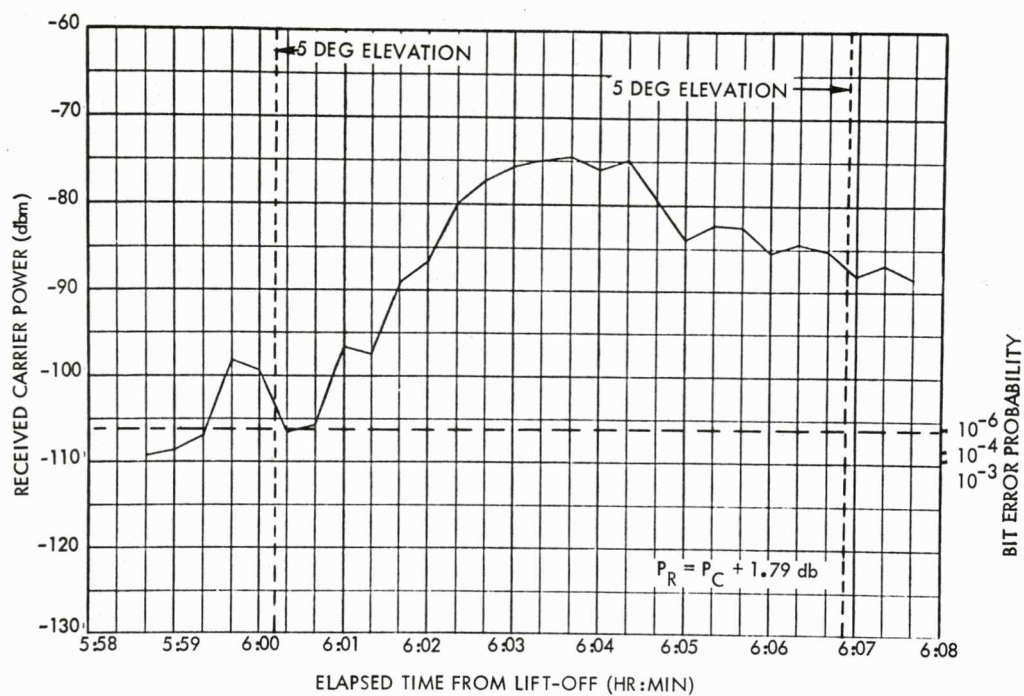


Figure 5-8e. HAW, +Z Antenna, Orbit 4

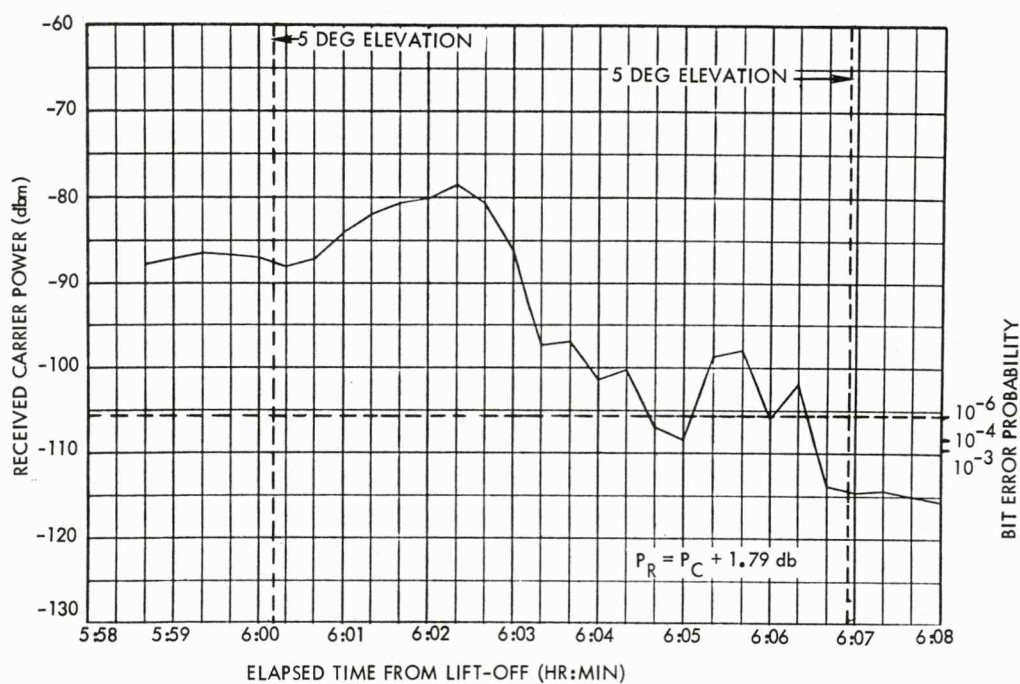


Figure 5-8f. HAW, -Z Antenna, Orbit 4

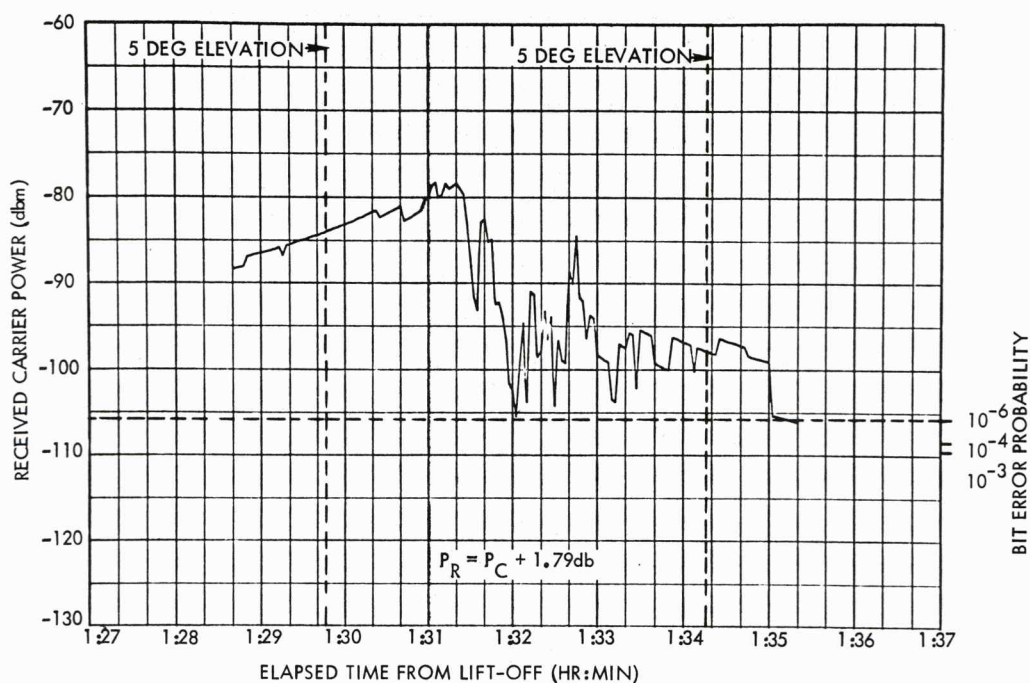


Figure 5-9a. GYM S-band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 1

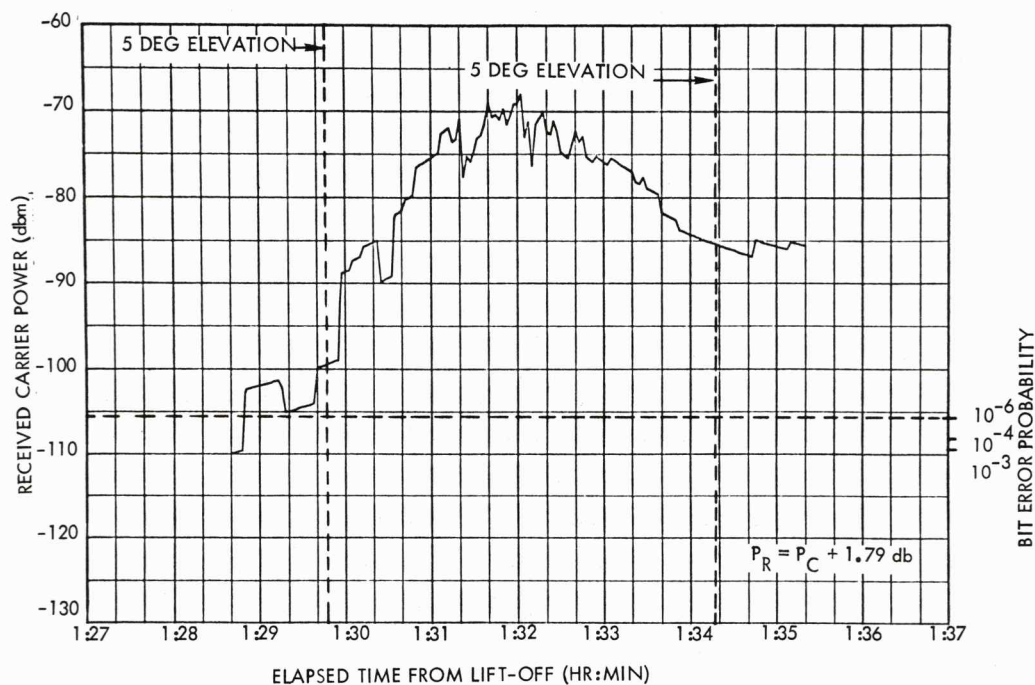


Figure 5-9b. GYM, -Z Antenna, Orbit 1

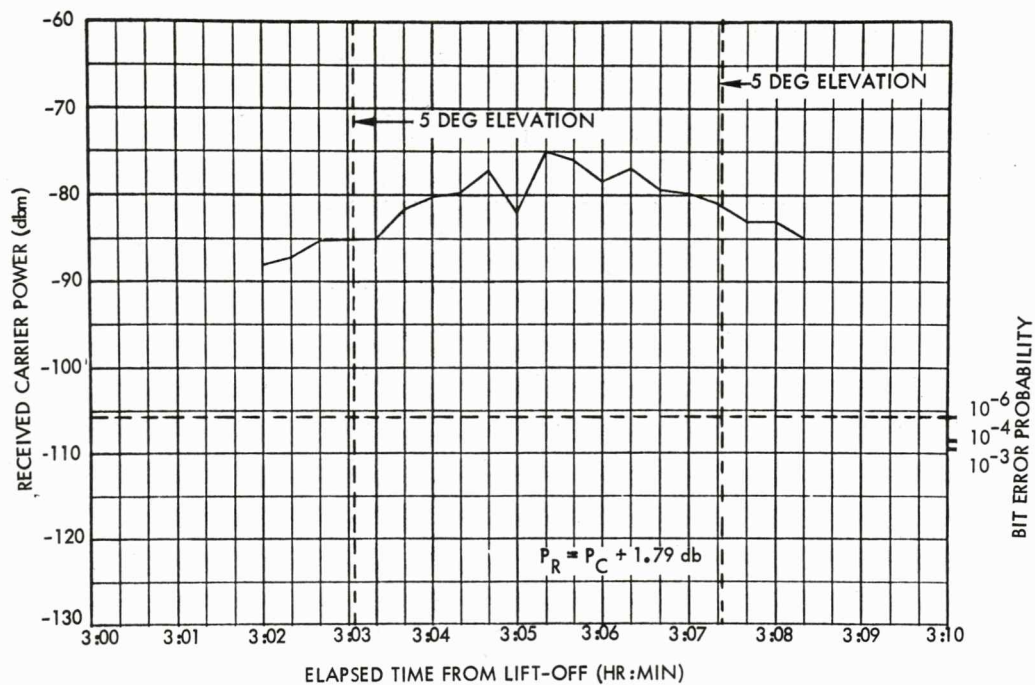


Figure 5-9c. GYM, +Z Antenna, Orbit 2

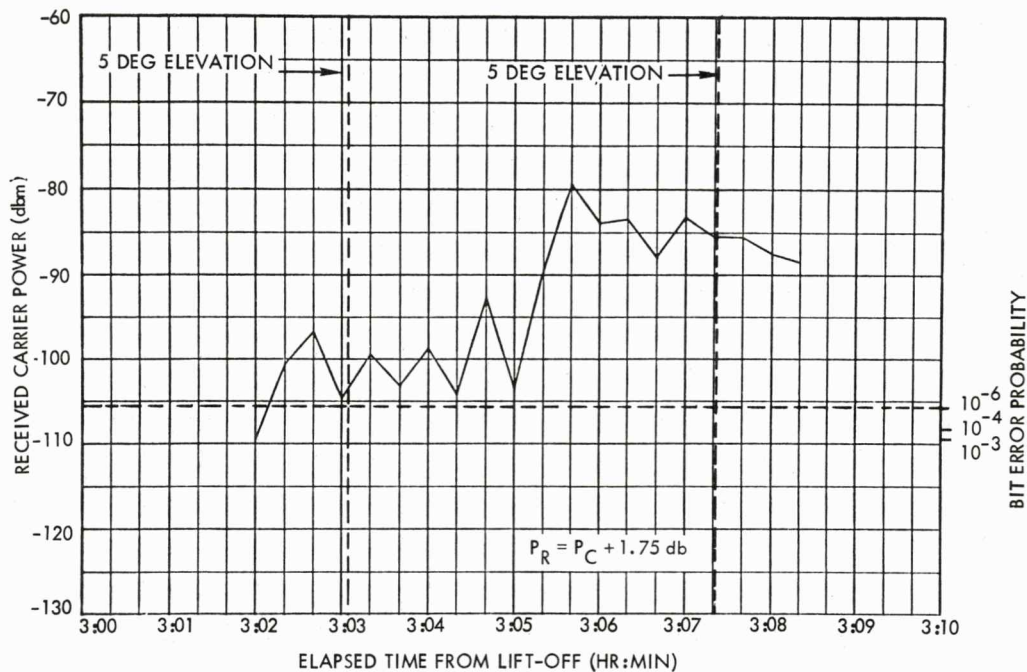


Figure 5-9d. GYM, -Z Antenna, Orbit 2

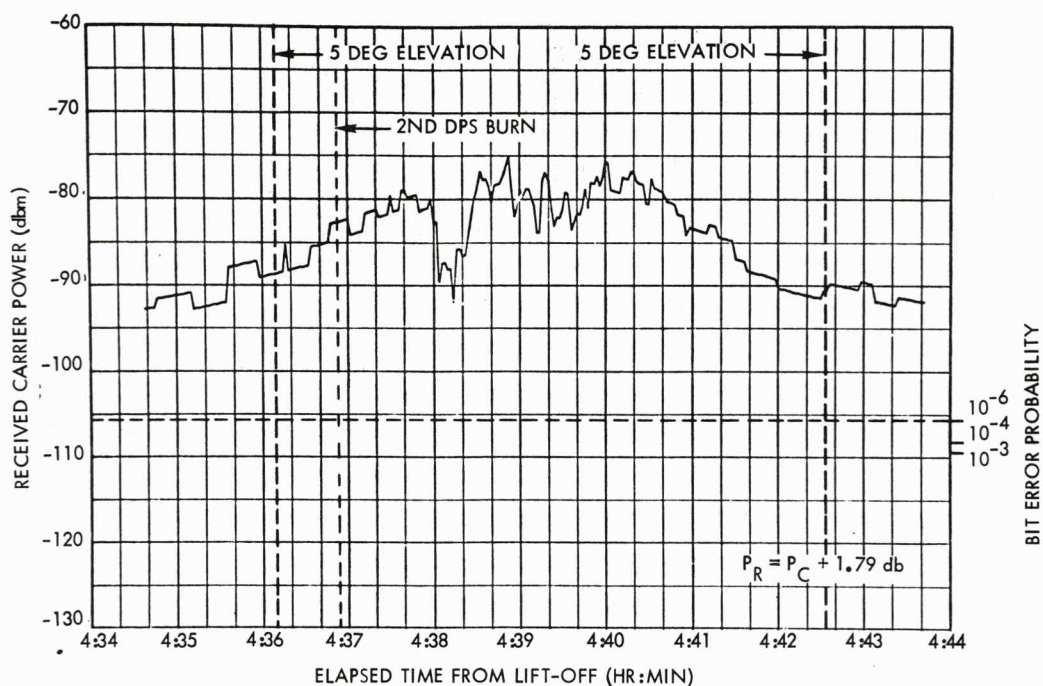


Figure 5-9e. GYM, +Z Antenna, Orbit 3

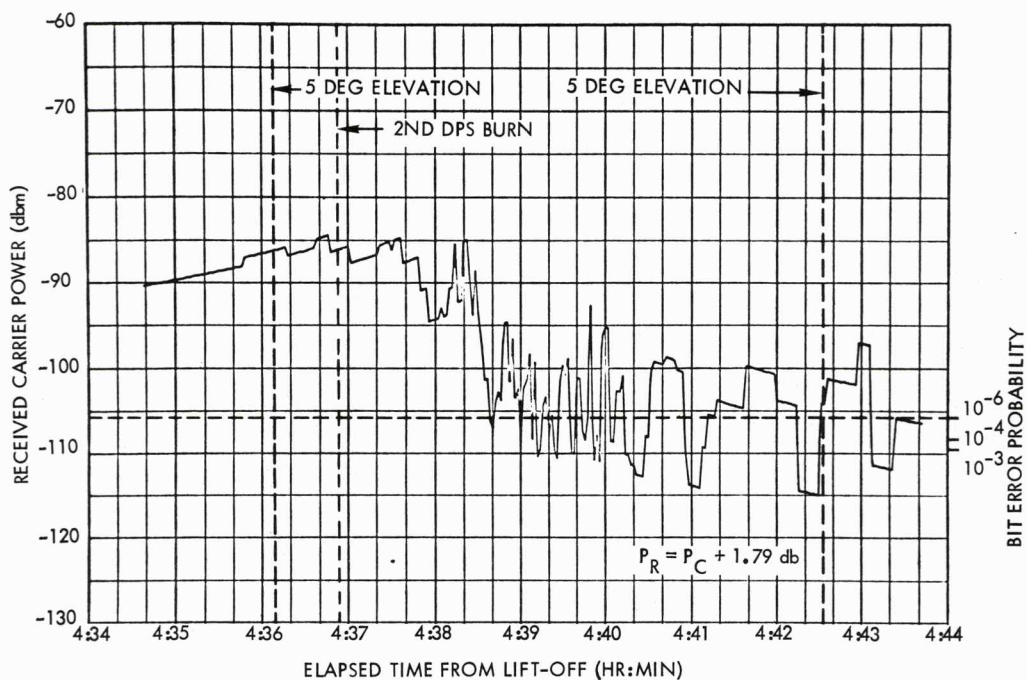


Figure 5-9f. GYM, -Z Antenna, Orbit 3

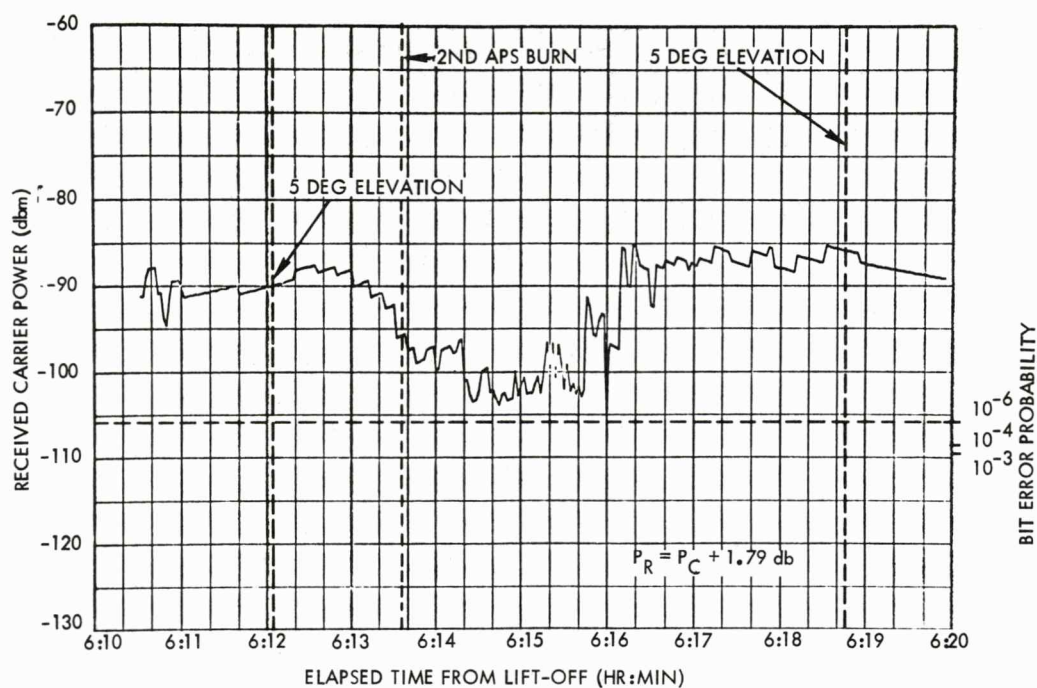


Figure 5-9g. GYM, +Z Antenna, Orbit 4

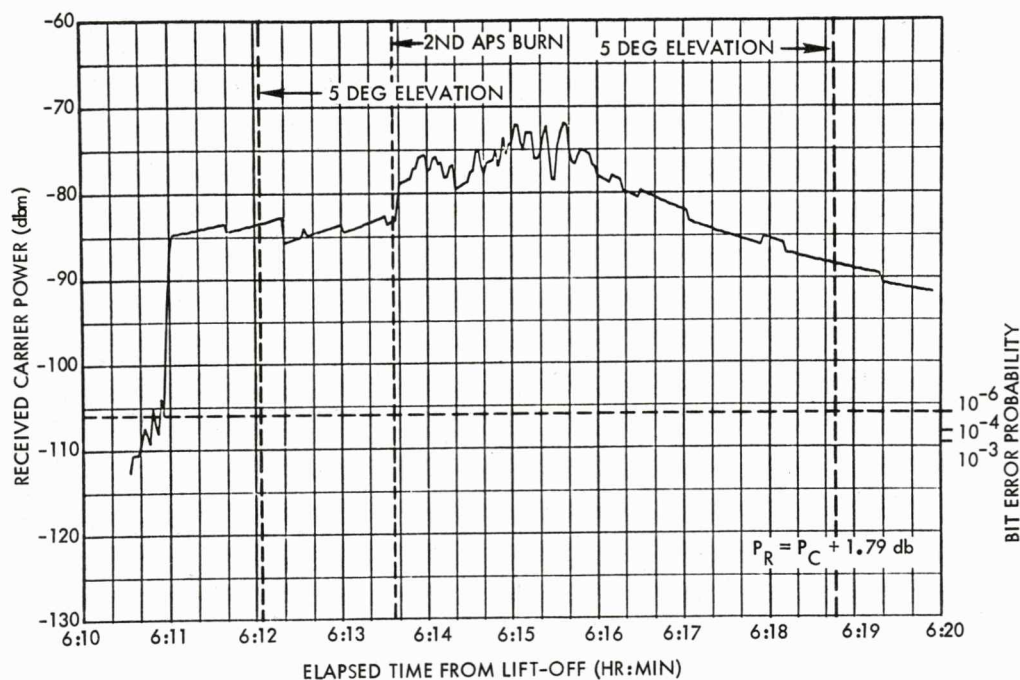


Figure 5-9h. GYM, -Z Antenna, Orbit 4

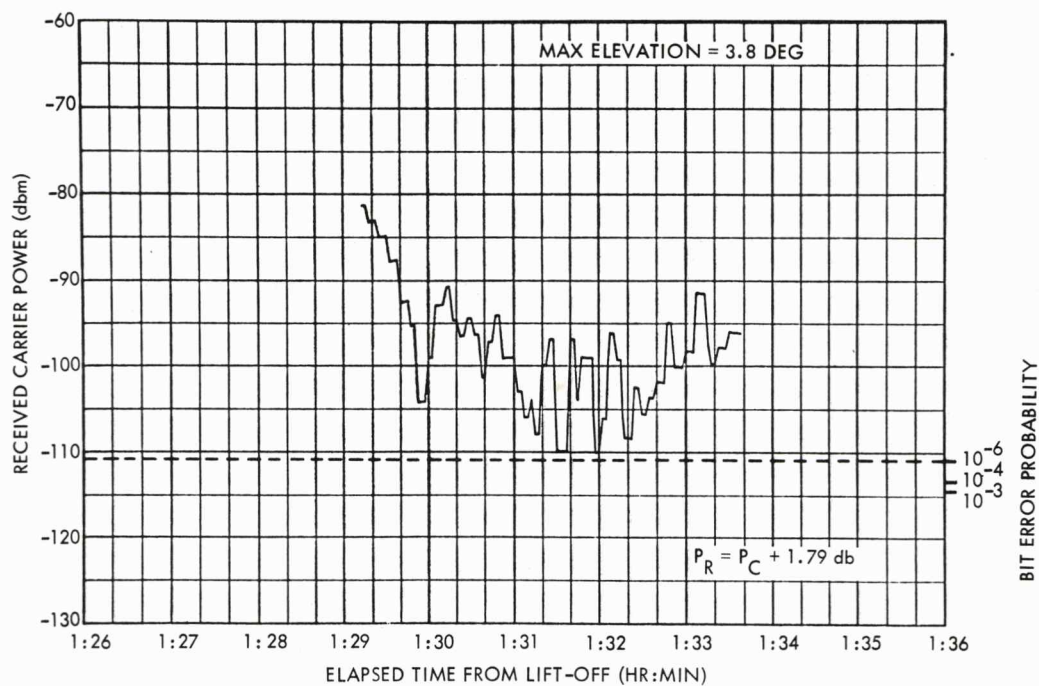


Figure 5-10a. GDS S-band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 1

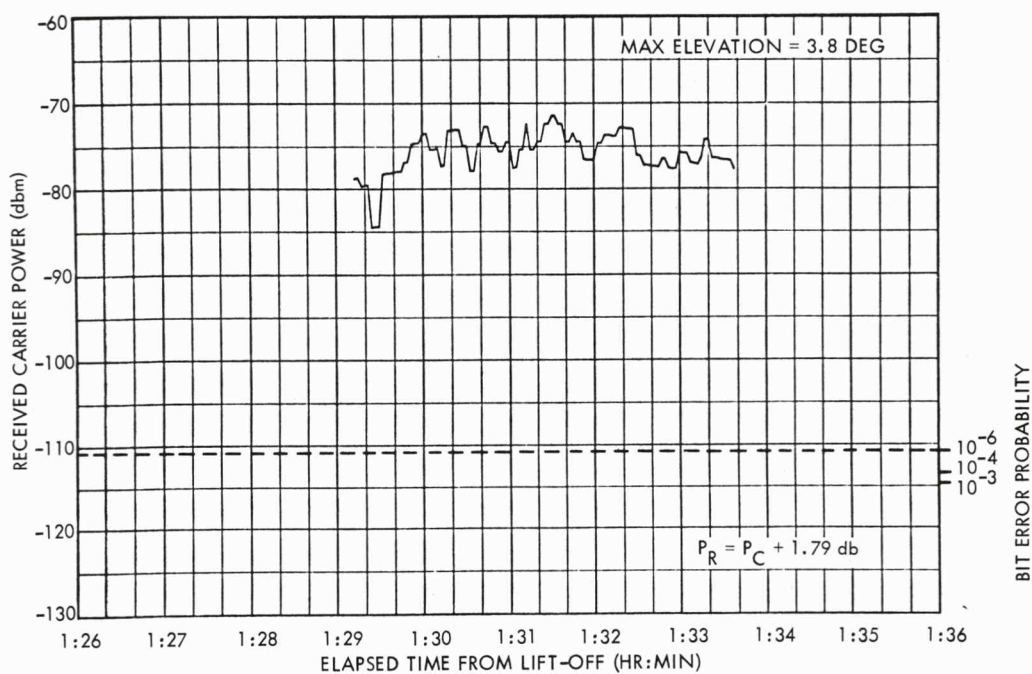


Figure 5-10b. GDS, -Z Antenna, Orbit 1

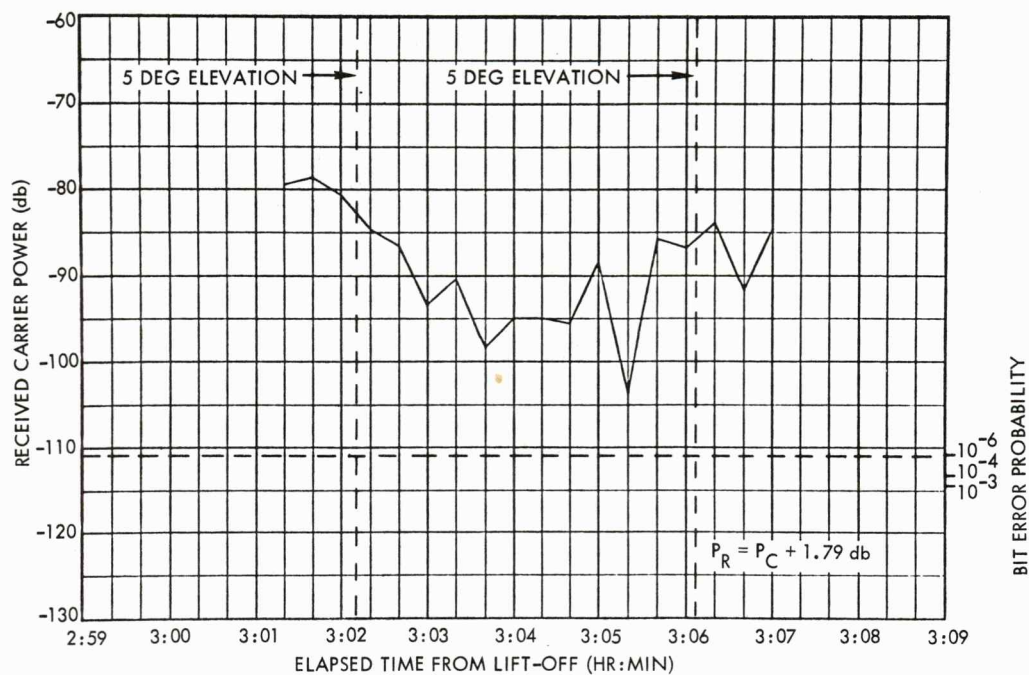


Figure 5-10c. GDS, +Z Antenna, Orbit 2

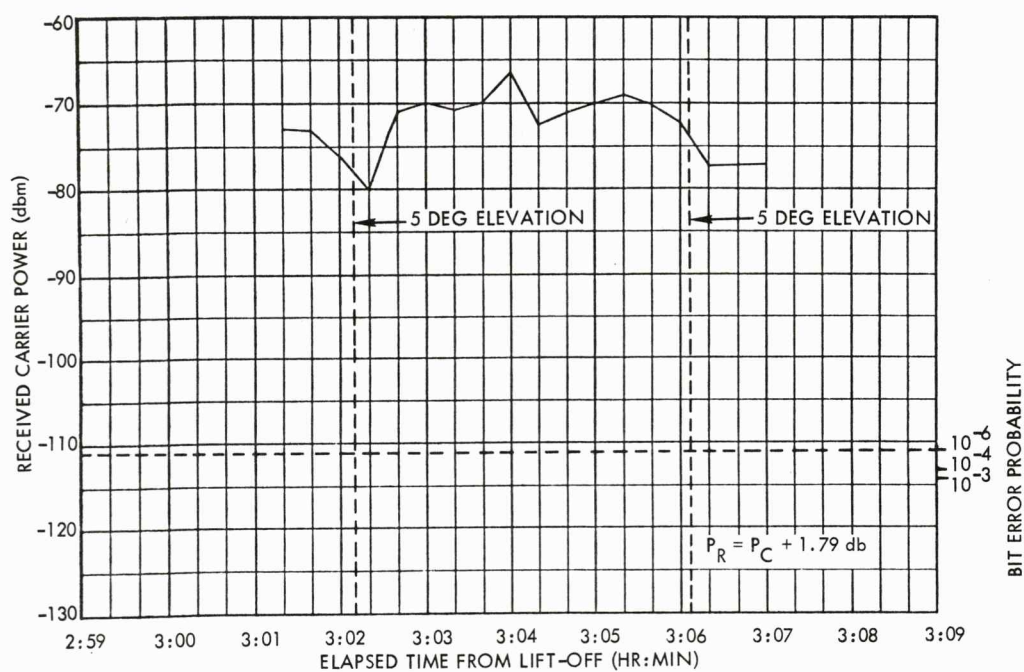


Figure 5-10d. GDS, -Z Antenna, Orbit 2

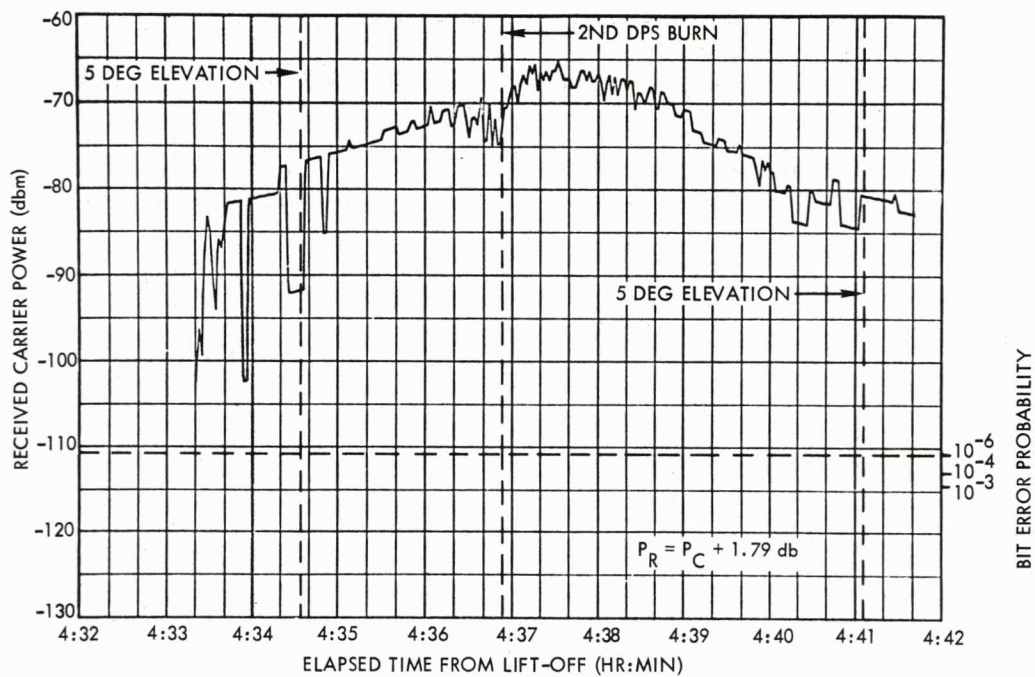


Figure 5-10e. GDS, +Z Antenna, Orbit 3

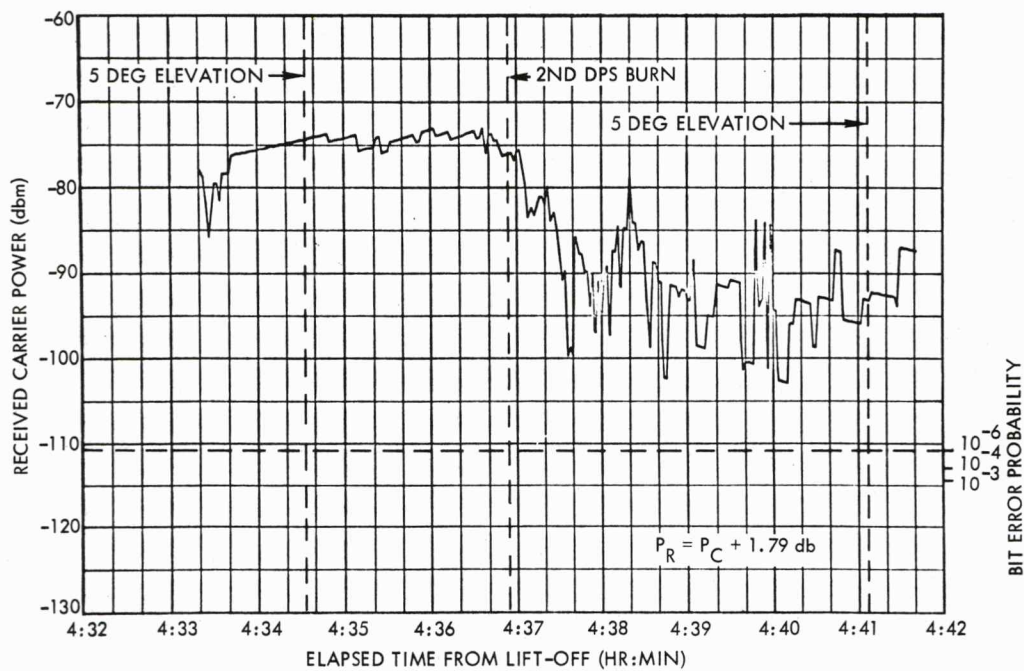


Figure 5-10f. GDS, -Z Antenna, Orbit 3

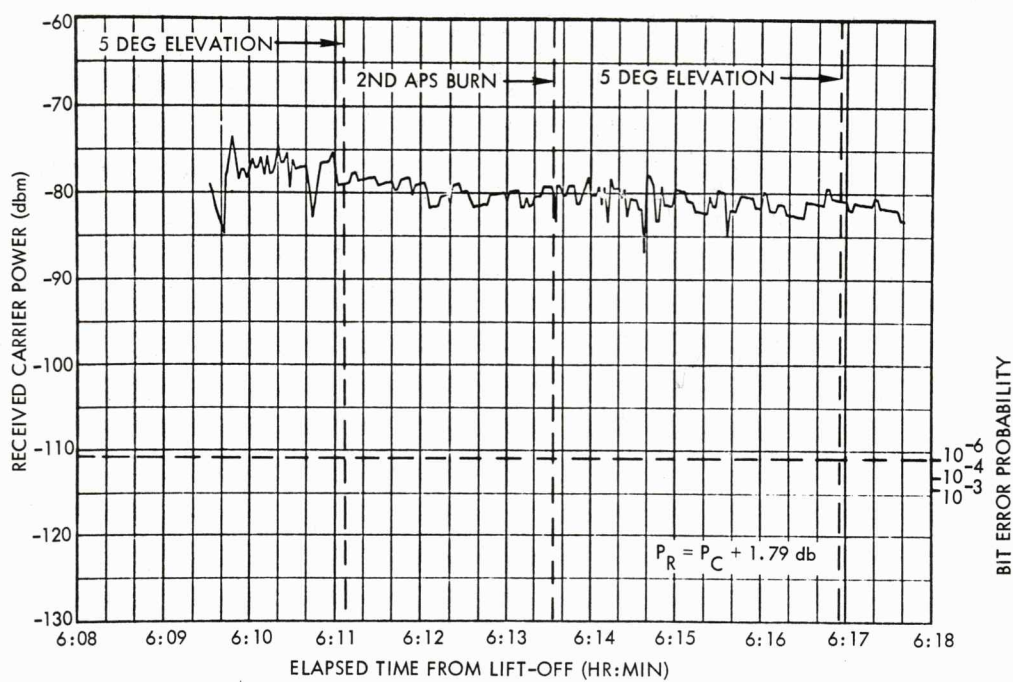


Figure 5-10g. GDS, +Z Antenna, Orbit 4

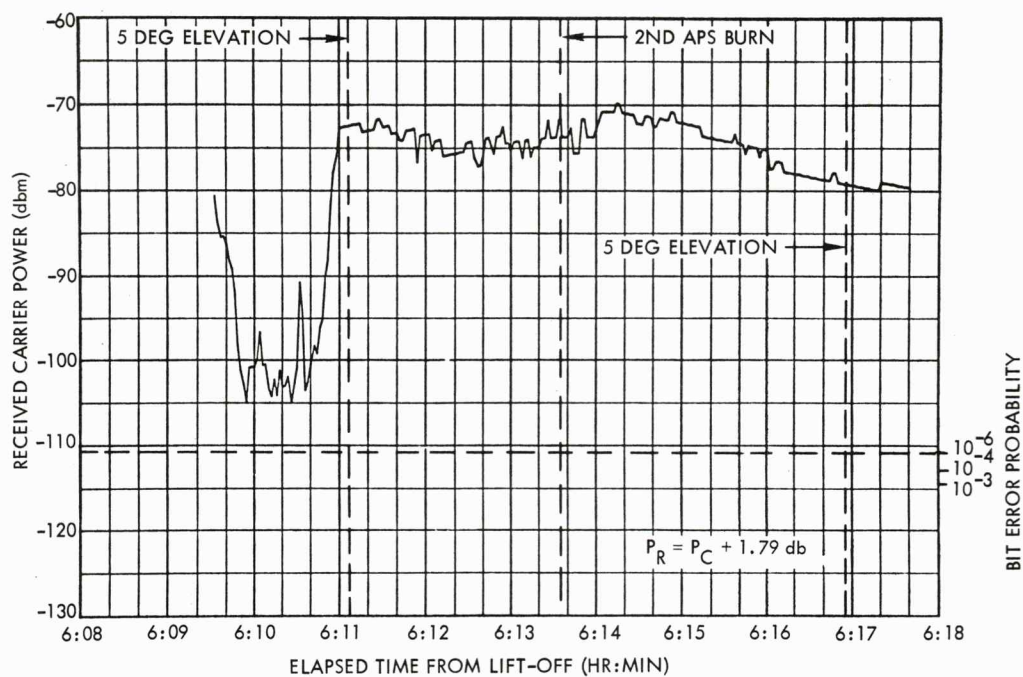


Figure 5-10h. GDS, -Z Antenna, Orbit 4

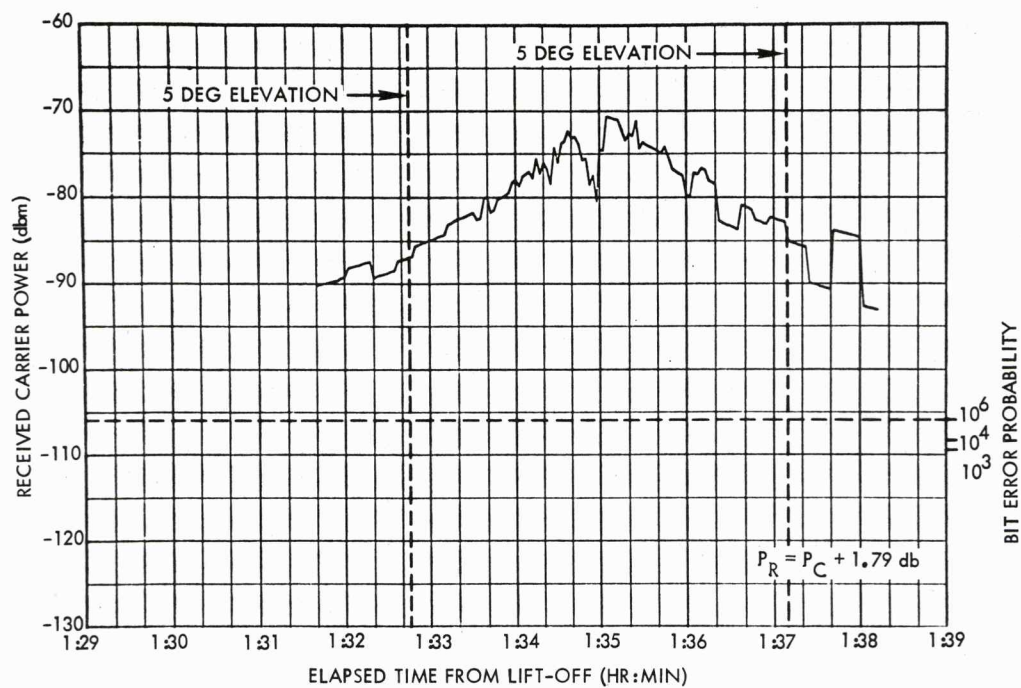


Figure 5-11a. TEX S-band Received Carrier Power Versus Elapsed Time from Lift-Off, +Z Antenna, Orbit 1

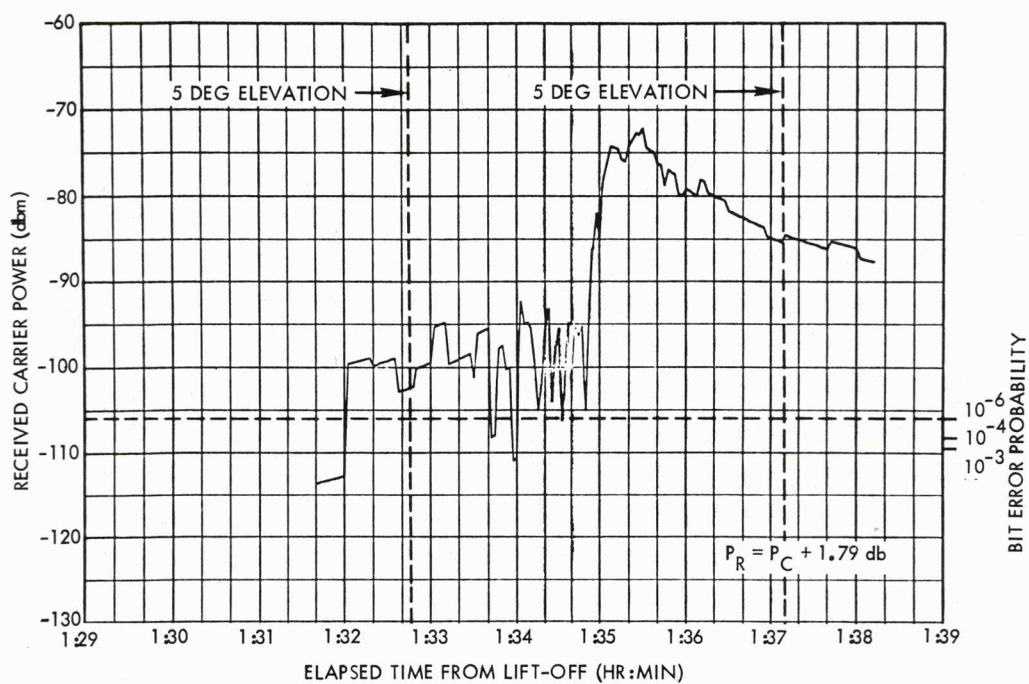


Figure 5-11b. TEX, -Z Antenna, Orbit 1

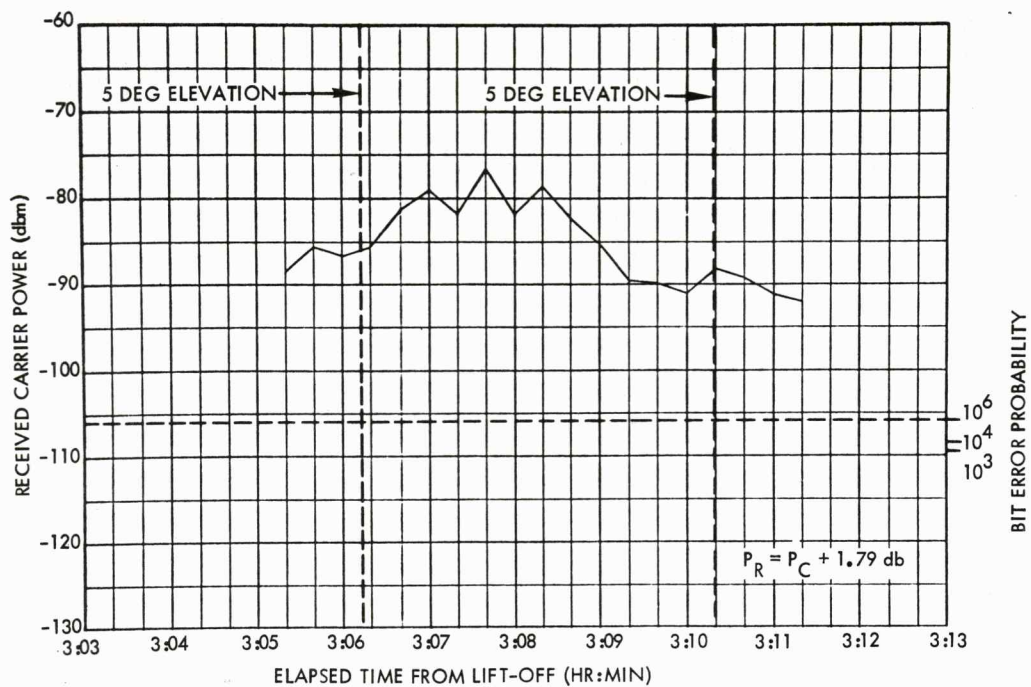


Figure 5-11c. TEX, +Z Antenna, Orbit 2

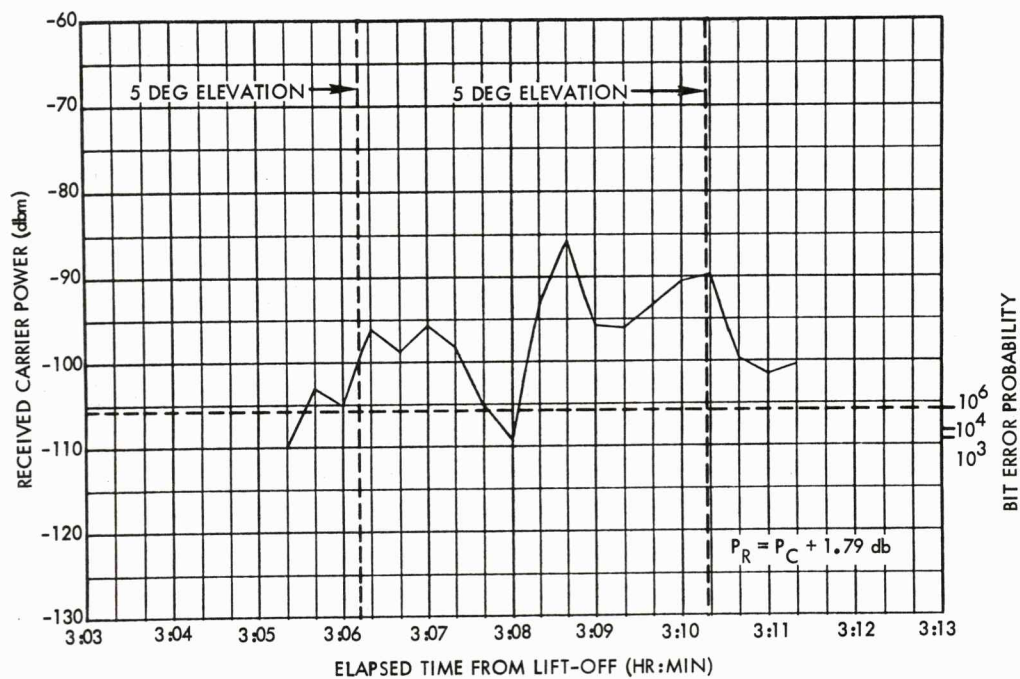


Figure 5-11d. TEX, -Z Antenna, Orbit 2

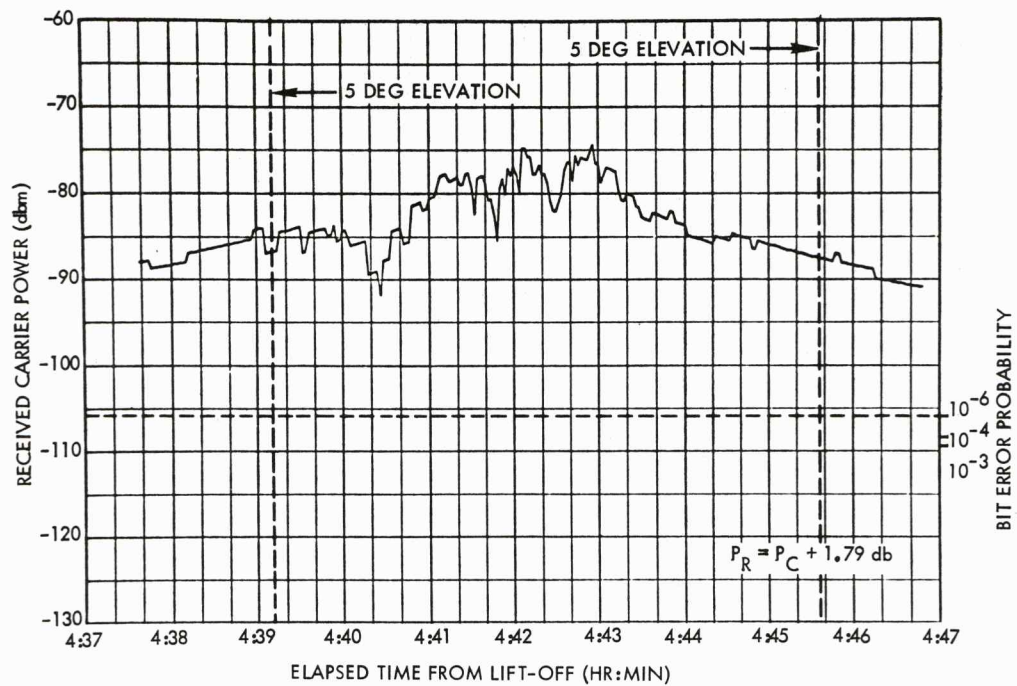


Figure 5-11e. TEX, +Z Antenna, Orbit 3

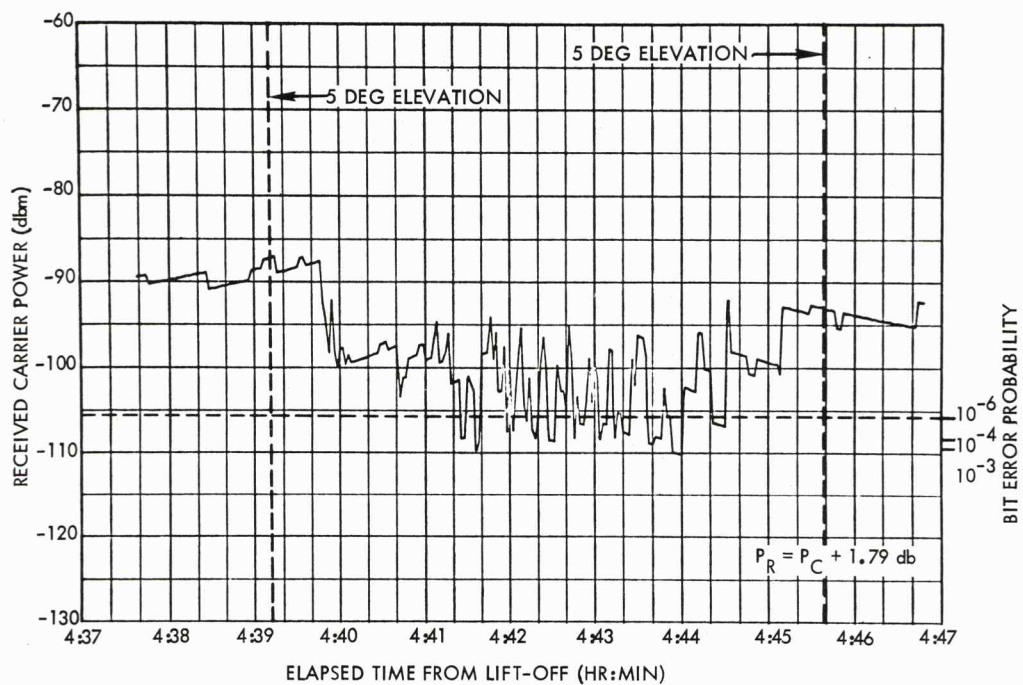


Figure 5-11f. TEX, -Z Antenna, Orbit 3

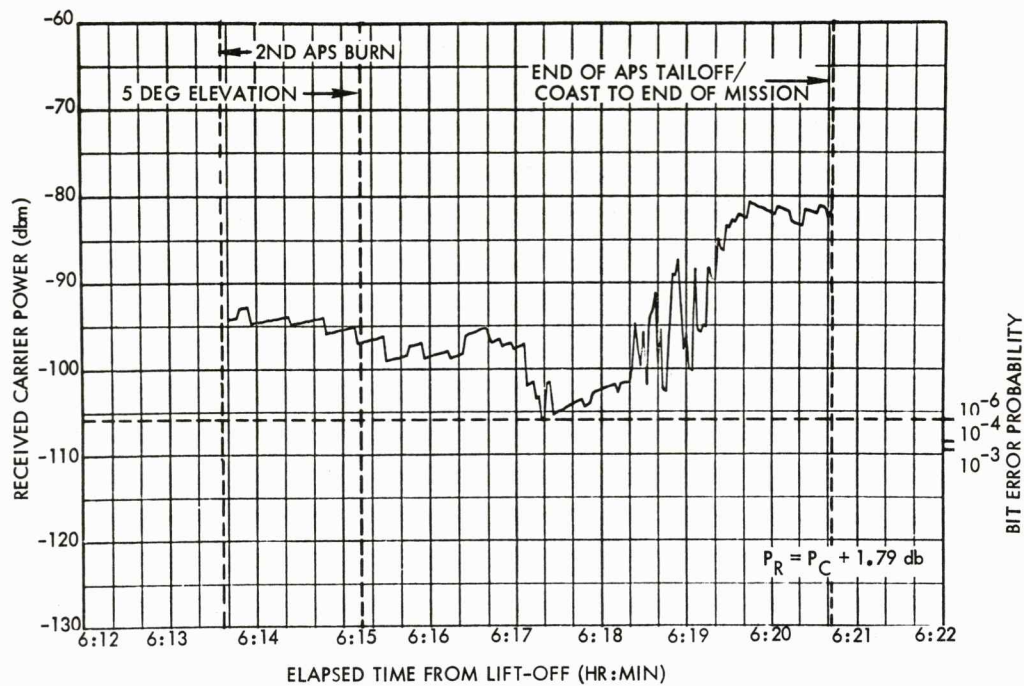


Figure 5-11g. TEX, +Z Antenna, Orbit 4

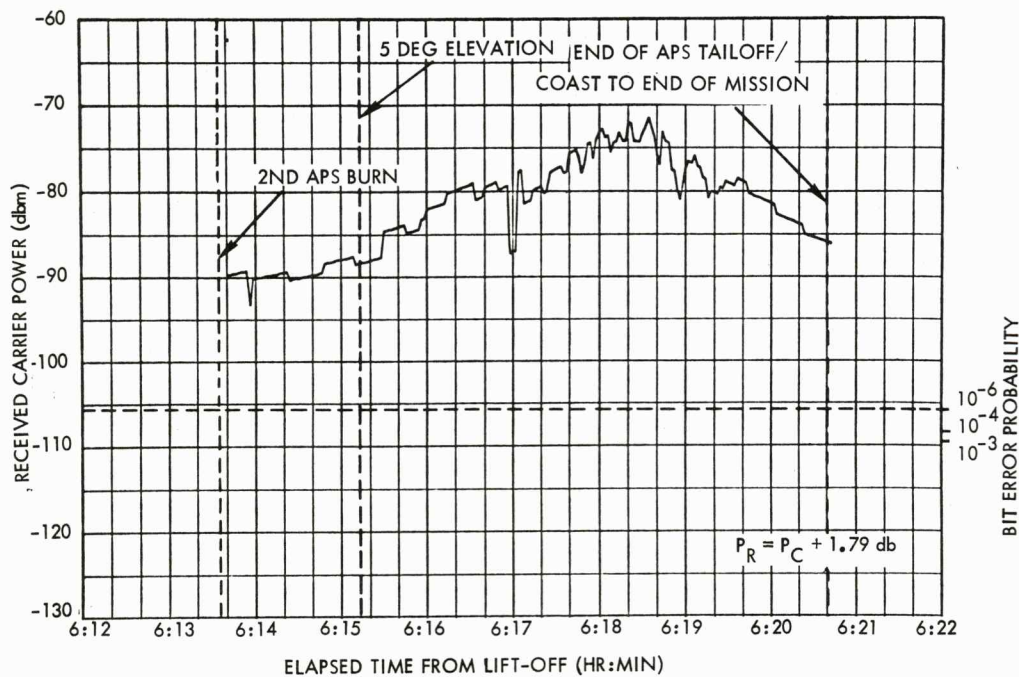


Figure 5-11h. TEX, -Z Antenna, Orbit 4

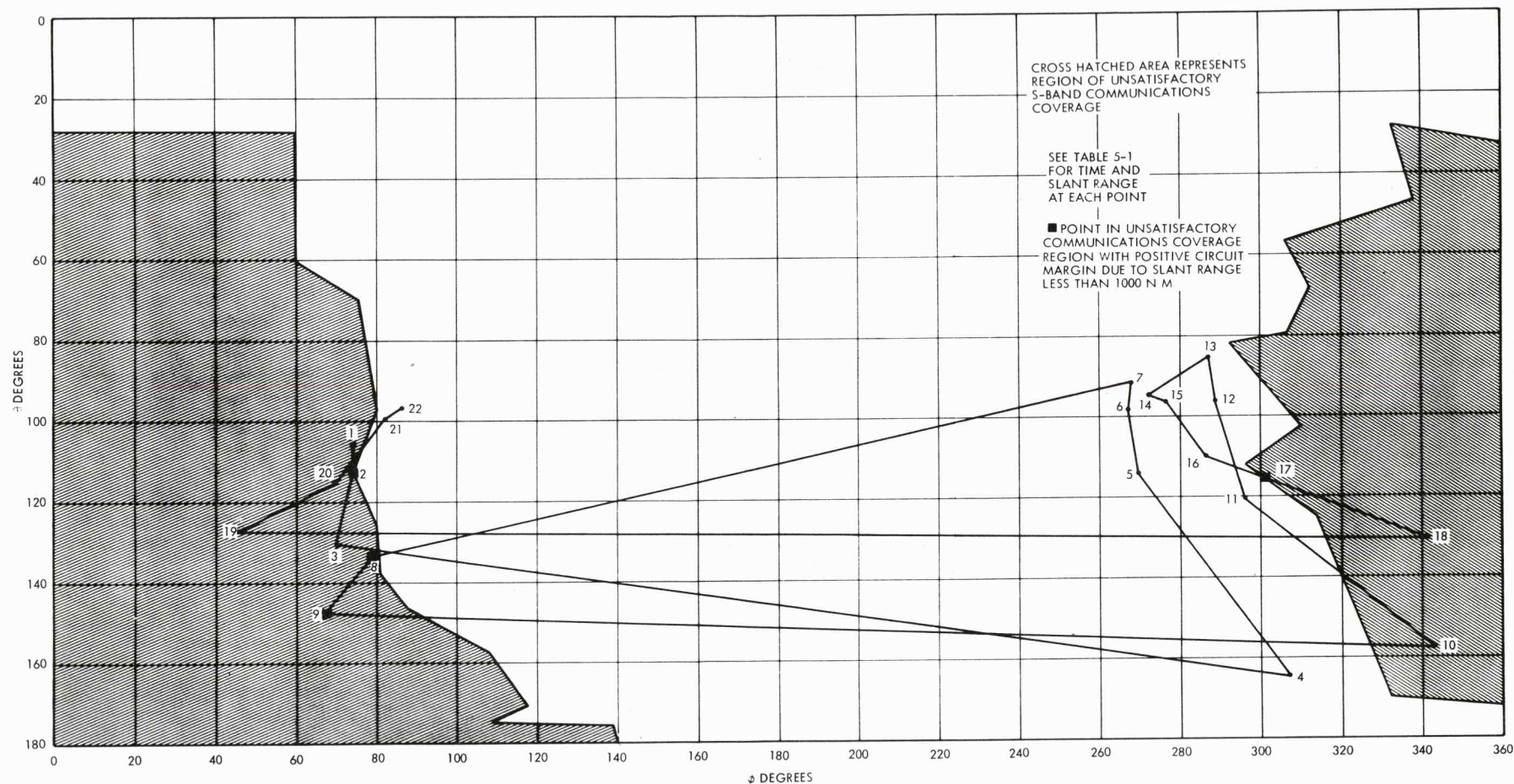


Figure 5-12. LM Descent Configuration -Z Antenna Pattern with Region of Unsatisfactory S-Band Communications Coverage at 1000 Nautical Miles

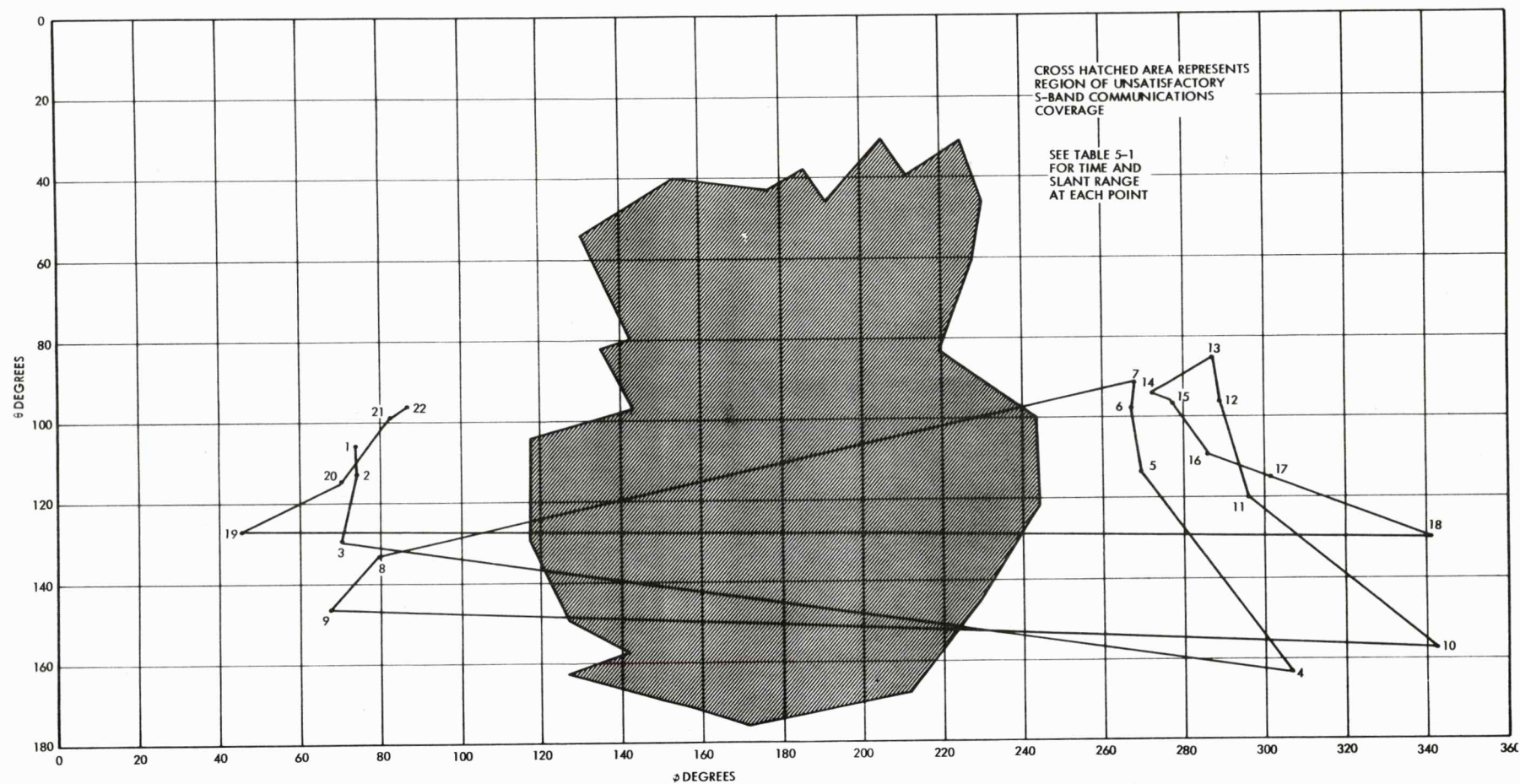


Figure 5-13. LM Descent Configuration +Z Antenna Pattern with Region of Unsatisfactory S-Band Communications Coverage at 1000 Nautical Miles

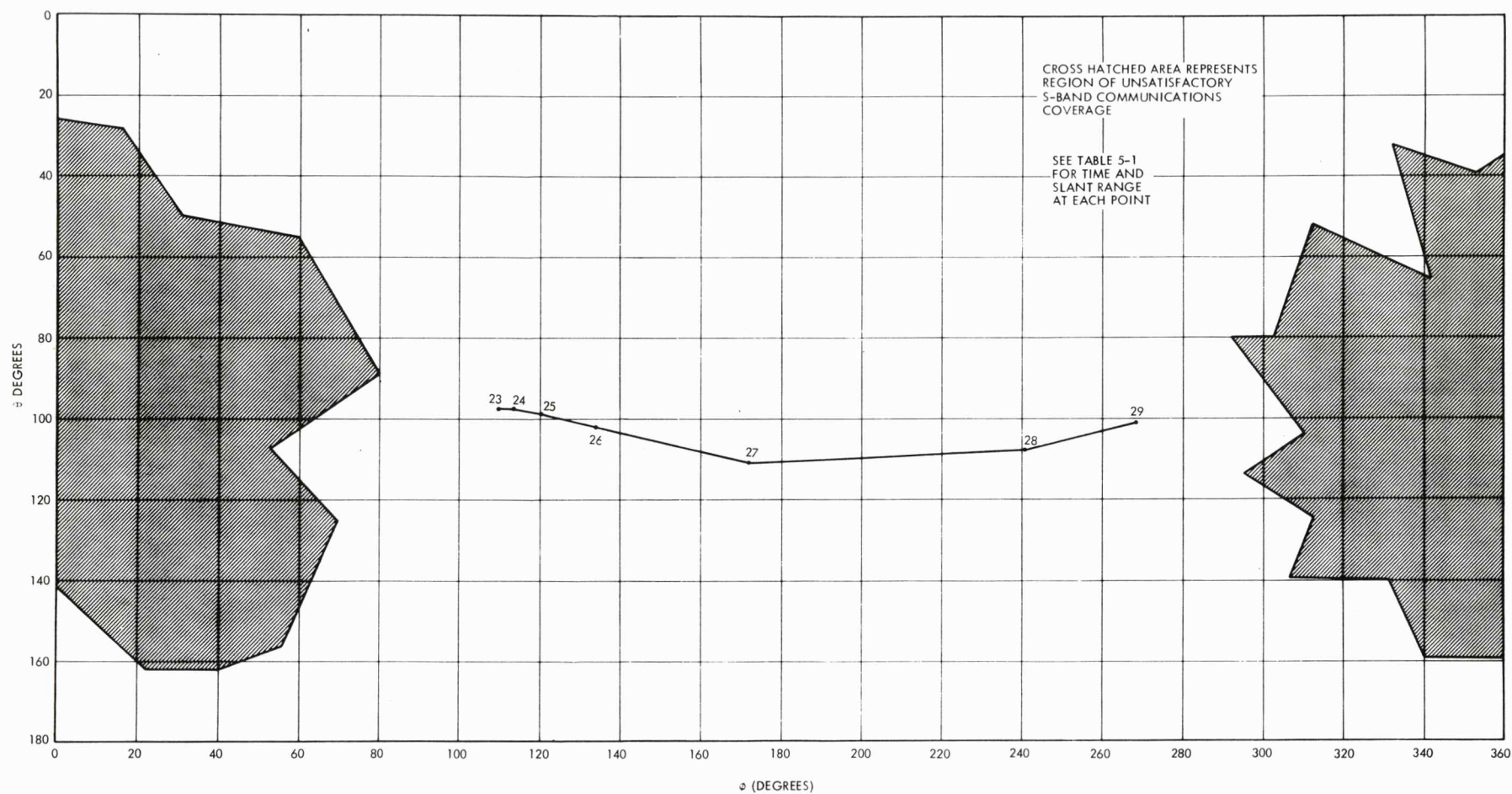


Figure 5-14. LM Ascent Configuration -Z Antenna Pattern with Region of Unsatisfactory S-Band Communications Coverage at 1000 Nautical Miles

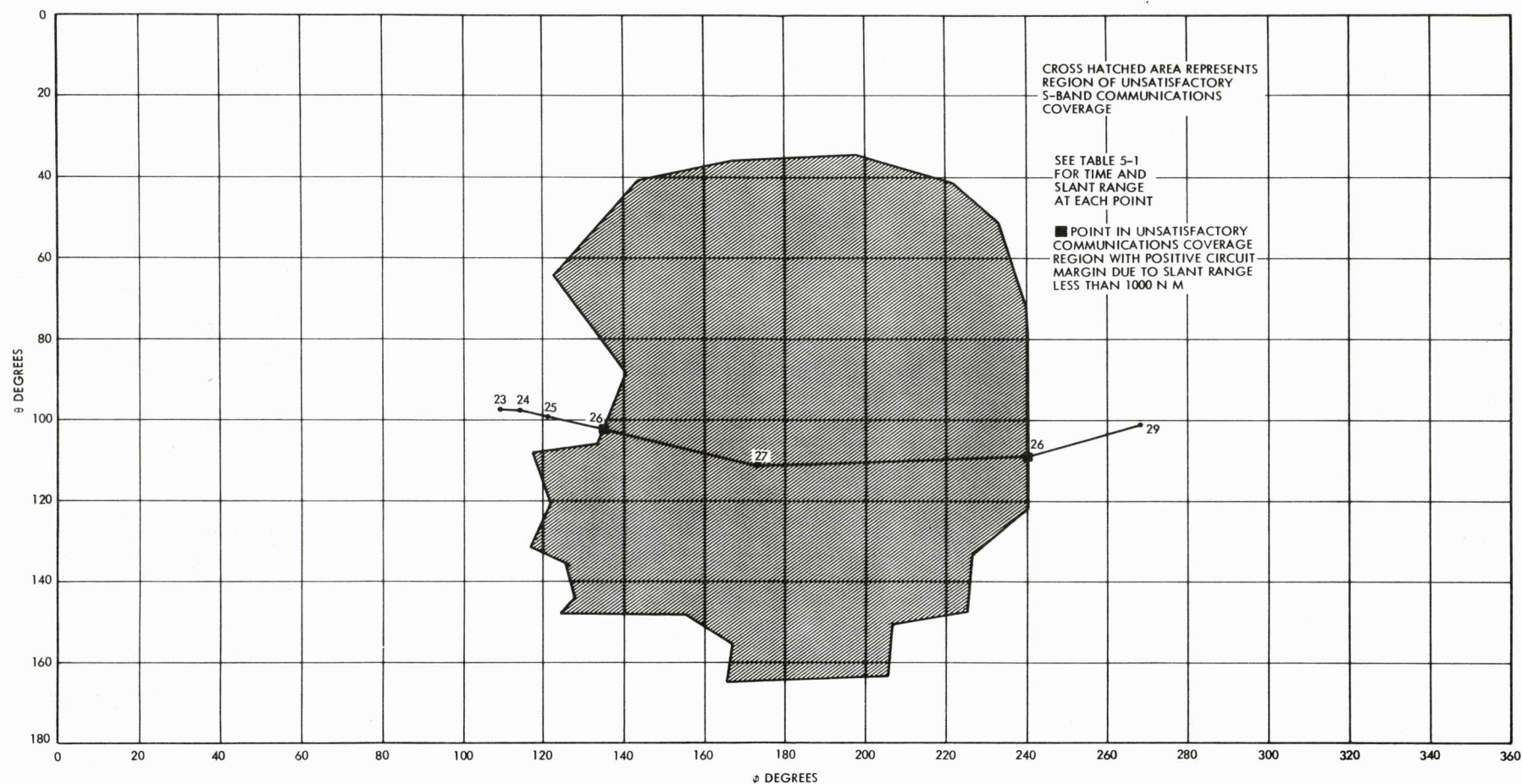


Figure 5-15. LM Ascent Configuration +Z Antenna Pattern with Region of Unsatisfactory S-Band Communications Coverage at 1000 Nautical Miles

Table 5-1 Description of Curves on Figures 5-12 through 5-15

TEXAS				
Point	Time (Hrs,Min)	Slant Range <u>Nautical Miles</u>	Spacecraft Attitude Angles with Respect to Texas Ground Station	
			θ	ϕ
Orbit 1				
1	1:32	715.2	104.99	73.84
2	1:33	488.46	112.78	73.83
3	1:34	277.23	130.50	70.43
4	1:35	164.48	163.50	307.25
5	1:36	299.04	114.20	269.58
6	1:37	513.49	98.35	267.82
7	1:38	740.95	91.08	268.15
Orbit 2				
8	3:06	306.00	132.74	78.55
9	3:07	394.91	147.26	66.40
10	3:08	308.00	157.87	342.93
11	3:09	271.00	119.64	296.08
12	3:10	561.16	96.38	289.03
13	3:11	703.49	85.17	287.41
Orbit 3				
14	4:38	1009.57	94.01	272.15
15	4:39	787.77	96.65	277.41
16	4:40	571.52	109.10	286.13
17	4:41	373.61	115.76	301.12
18	4:42	245.10	130.05	342.43
19	4:43	297.34	127.26	45.25
20	4:44	473.67	115.13	70.63
21	4:45	684.06	99.46	82.03
22	4:46	904.41	96.53	87.82

Table 5-1 Description of Curves on Figures 5-12 through 5-15 (cont)

Point	Time (Hrs,Min)	TEXAS		
		Slant Range Nautical Miles	Spacecraft Attitude Angles with Respect to Texas Ground Station	
			θ	ϕ
Orbit 4				
23	6:14	1015.58	97.50	109.34
24	6:15	791.31	97.82	114.12
25	6:16	570.57	99.14	121.08
26	6:17	360.43	102.68	134.19
27	6:18	199.39	111.69	172.04
28	6:19	235.10	108.85	241.68
29	6:20	420.36	101.50	268.29

6.0 C-BAND SYSTEM COVERAGE

The C-band system used on the AS-204/LM-1 consists of two beacons, one connected to the two Y axis antennas, and one connected to the two Z axis antennas, which respond when interrogated by MSFN C-band radars. Operating frequencies are 5690 MHz for uplink and 5765 MHz for downlink. MSFN equipment types are shown in Table 6-1. The C-band system is the primary tracking system for the mission.

A C-band beacon mounted in the S-IVB/IMU will be used for tracking until LM separation. Coverage for this beacon is not included in this report.

C-band data were obtained from a computer program which combined the spacecraft trajectory data, spacecraft one-third scale antenna gain patterns, transmitted power, circuit and space losses, and receiver performance characteristics to give plots of Total Received Power versus Elapsed Time from Liftoff. A flow chart of the computer program is shown in Figure D-1. Calculations were made at 2 second intervals during burns and orientation phases, and at 20 second intervals during coast phases. Worst case specified parameters were used for the calculations. These parameters are shown in Appendix A, and sample calculations are shown in Appendix B.

The computer plots are shown in Figures 6-1 through 6-14. Plots are shown for downlink only for the AN/FPQ-6 and AN/TPQ-18. Plots for both downlink and uplink are shown for the AN/FPS-16 and AN/MPS-25 since the uplink is the critical path for these stations. This may be seen from the following considerations. The AN/FPS-16 and AN/MPS-25 have 26.4 dB greater transmitted power than the spacecraft, which is to the advantage of the uplink. The required signal level for the radar stations is 29.6 dB less than that for the spacecraft, which is to the advantage of the downlink. After considering a small loss difference the uplink is seen to be the critical path by about 3 dB. This will vary to some extent for changing spacecraft attitudes since spacecraft transmitting and receiving antenna patterns differ somewhat. The AN/FPQ-6 and AN/TPQ-18 have 37.8 dB greater transmitted power than the spacecraft. Consequently for these stations, the downlink is the critical path.

Downlink plots are shown in Figures 6-1 through 6-10. The MSFN required signal level is shown on the plots as "Required Signal Power (Tracking)" and is the minimum value of received signal power that will provide a tracking signal. This level is also the 0 dB reference level for margin calculations.

Uplink plots are shown in Figures 6-11 through 6-14. The minimum value of received signal power that will interrogate the beacon is shown on the plots as the "Receiver Sensitivity Level," and is also the 0 dB reference level for margin calculations.

Data are plotted whenever the spacecraft is within line-of-sight of a ground station, i.e., whenever the elevation look angle of the ground station is above 0° . Times are also indicated on the graphs when the MSFN elevation look angles are 5° , and when major events occur.

The two LM C-band beacons will be operational at liftoff but the SLA panels will enclose the antennas until deployment. After SLA panel deployment the antennas will be partially shielded until the LM separates from the S-IVB.

Canary Islands, CYI, has an AN/MPS-26 radar but will not be able to track the LM C-band beacon effectively on the first orbit since the spacecraft antennas will be shielded by the SLA panels. On the second orbit the elevation angle will remain below 5° , and on remaining orbits line-of-sight will not exist to this station.

C-band signal margins are positive for both uplink and downlink throughout the mission with a few exceptions of short duration. No C-band tracking problems should exist for the mission when the spacecraft is within line-of-sight of a ground station.

Table 6-1. MSFN C-Band Coverage for Mission AS-204/LM-1

<u>MSFN Station</u>	<u>AN/ FPQ-6</u>	<u>AN/ TPQ-18</u>	<u>AN/ FPS-16</u>	<u>AN/ MPS-25</u>	<u>AN/ MPS-26</u>
MLA		X			
PAT	X				
GBI		X			
BDA	X		X		
ANT	X				
CYI					X
ASC		X			
PRE				X	
CRO	X				
HAW			X		
CAL			X		
WHS			X		
*TAN			X		
VAN (Type not designated)					

*TAN will track the S-IVB only.

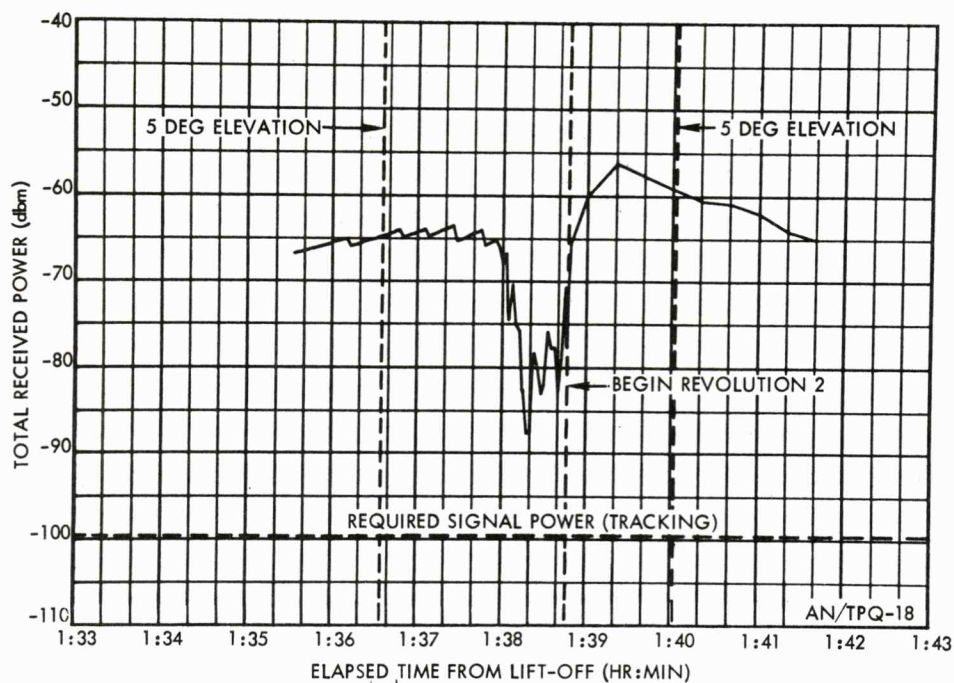


Figure 6-1a. MLA C-Band Downlink Total Received Power Versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 1-2

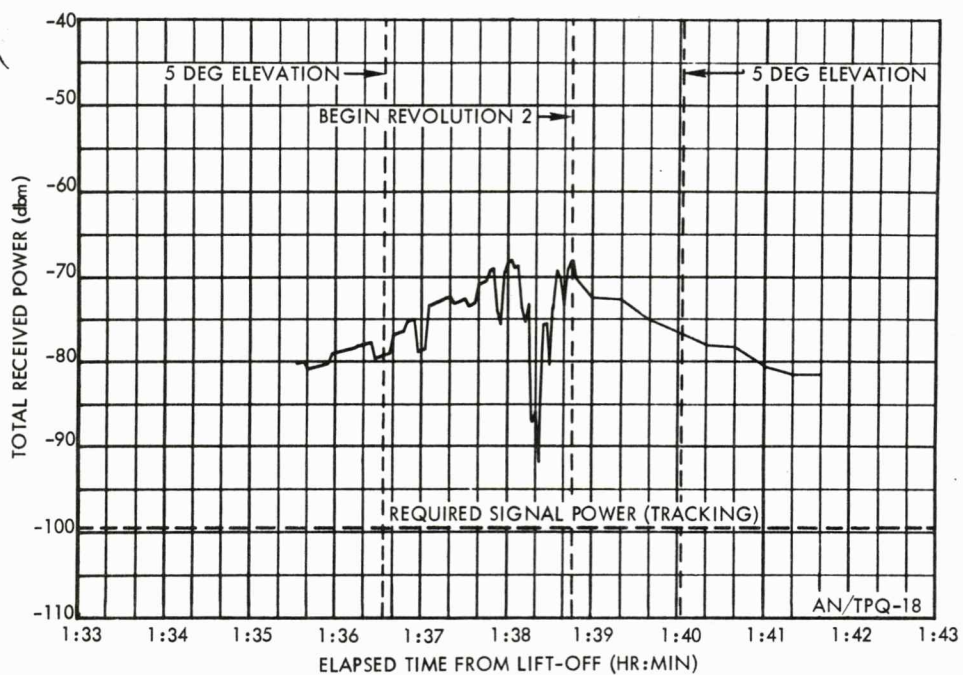


Figure 6-1b. MLA, Z Axis Antennas, Orbit 1-2

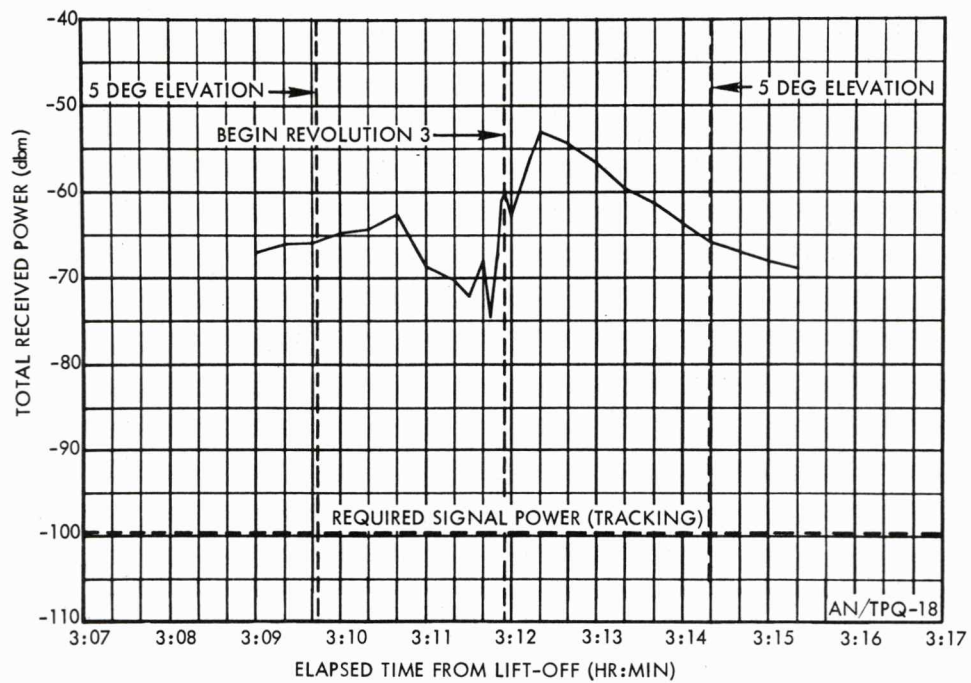


Figure 6-1c. MLA, Y Axis Antennas, Orbit 2-3

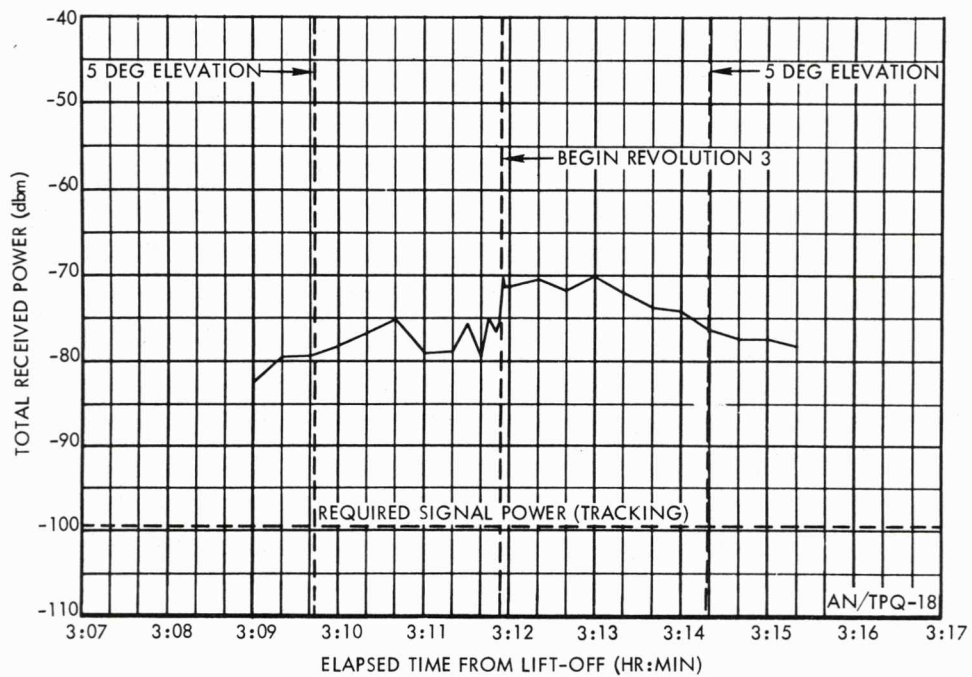


Figure 6-1d. MLA, Z Axis Antennas, Orbit 2-3

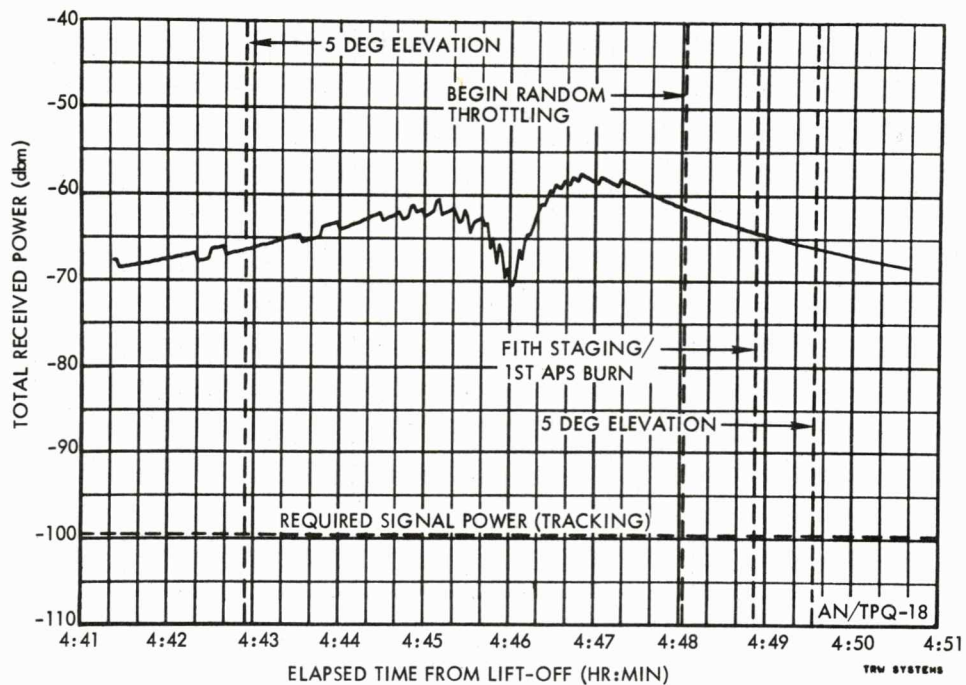


Figure 6-1e. MLA, Y Axis Antennas, Orbit 3-4

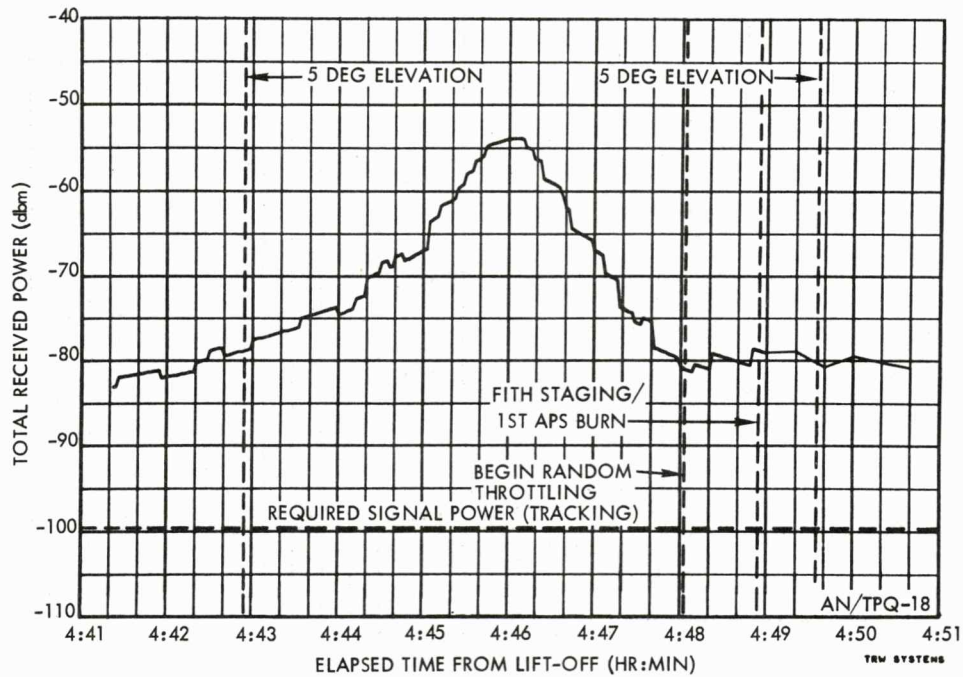


Figure 6-1f. MLA, Z Axis Antenna, Orbit 3-4

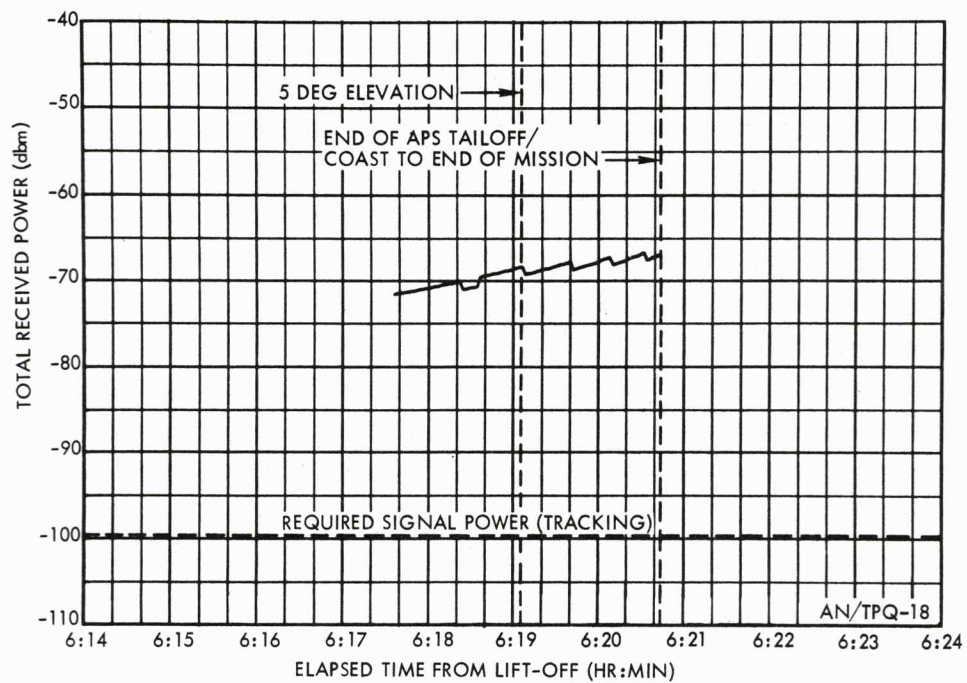


Figure 6-1g. MLA, Y Axis Antennas, Orbit 4

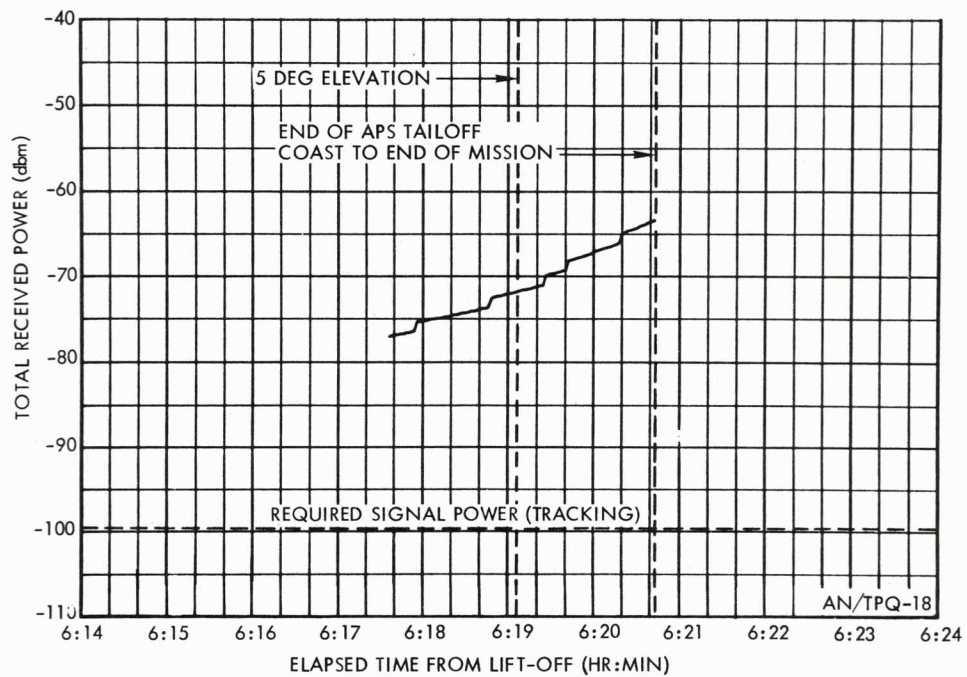


Figure 6-1h. MLA, Z Axis Antennas, Orbit 4

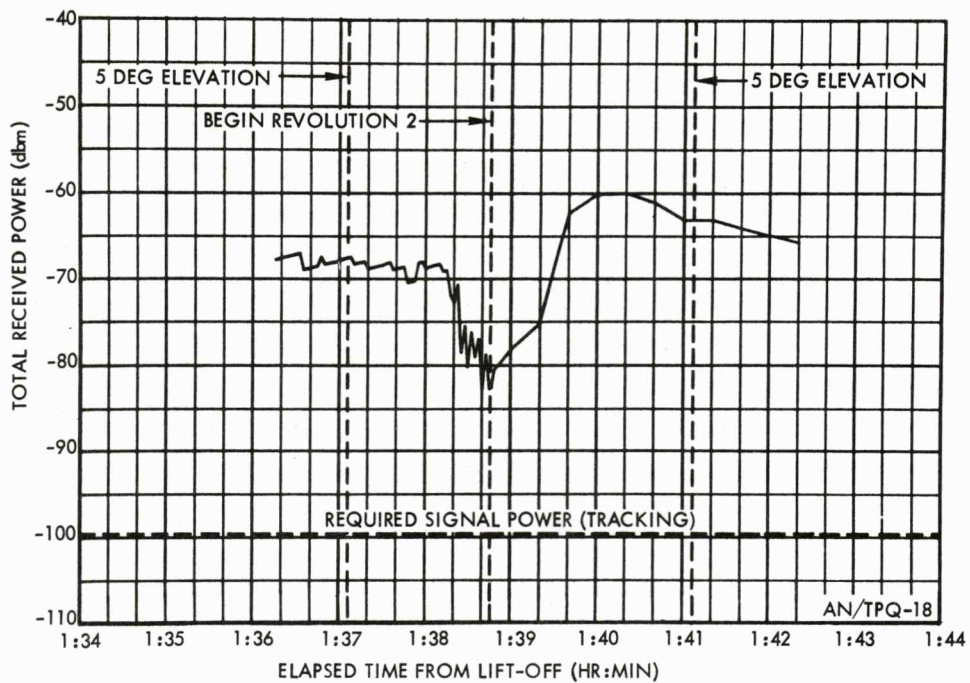


Figure 6-2a. GBI C-Band Downlink Total Received Power Versus Elapsed Time From Lift-Off, Y Axis Antennas, Orbit 1-2

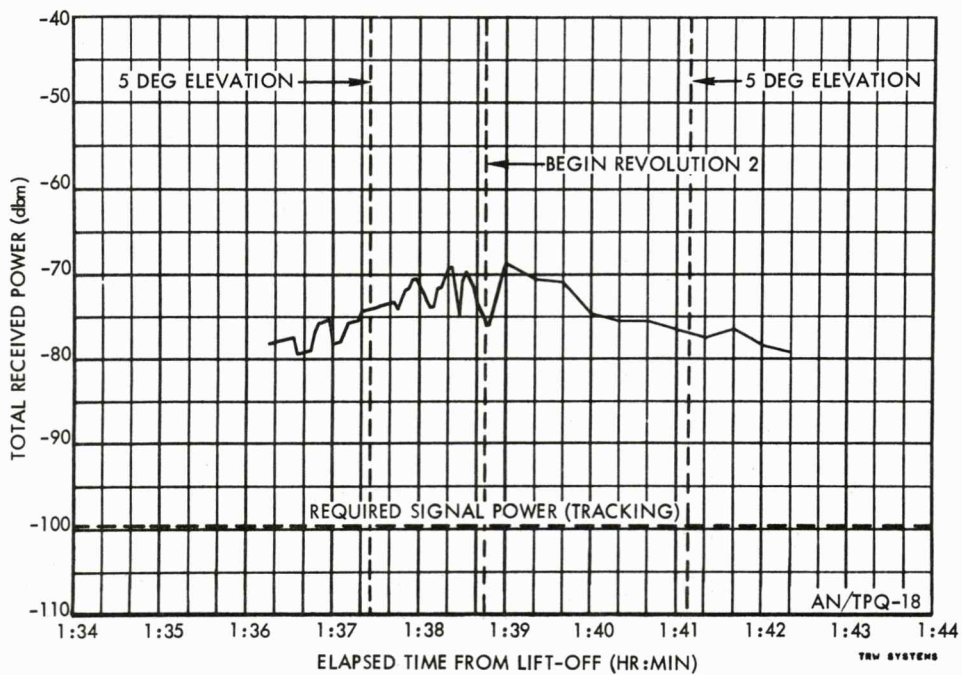


Figure 6-2b. GBI, Z Axis Antennas, Orbit 1-2

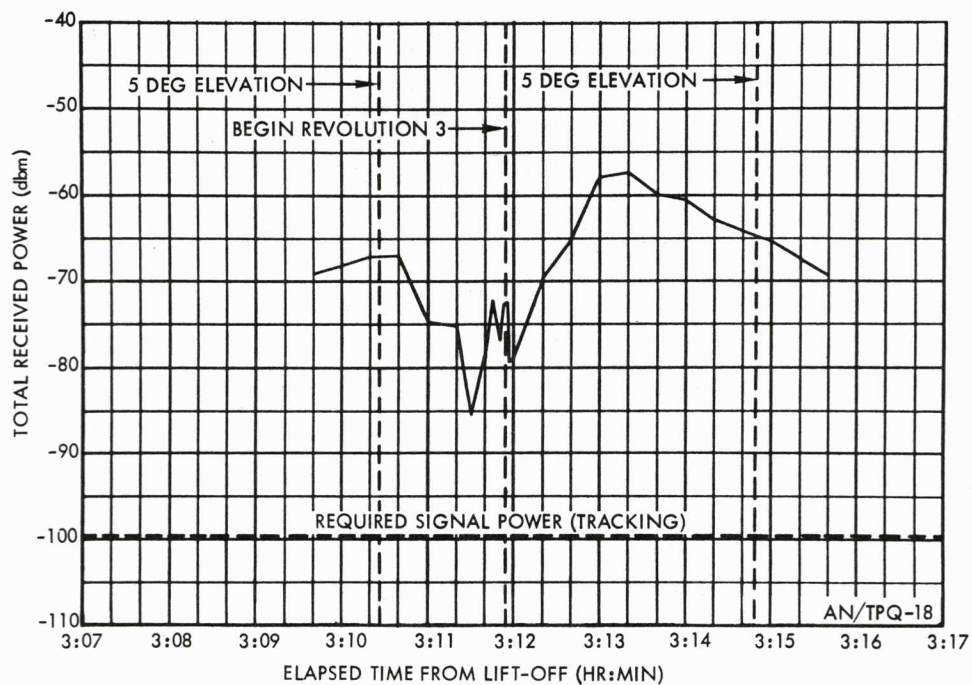


Figure 6-2c. GBI, Y Axis Antennas, Orbit 2-3

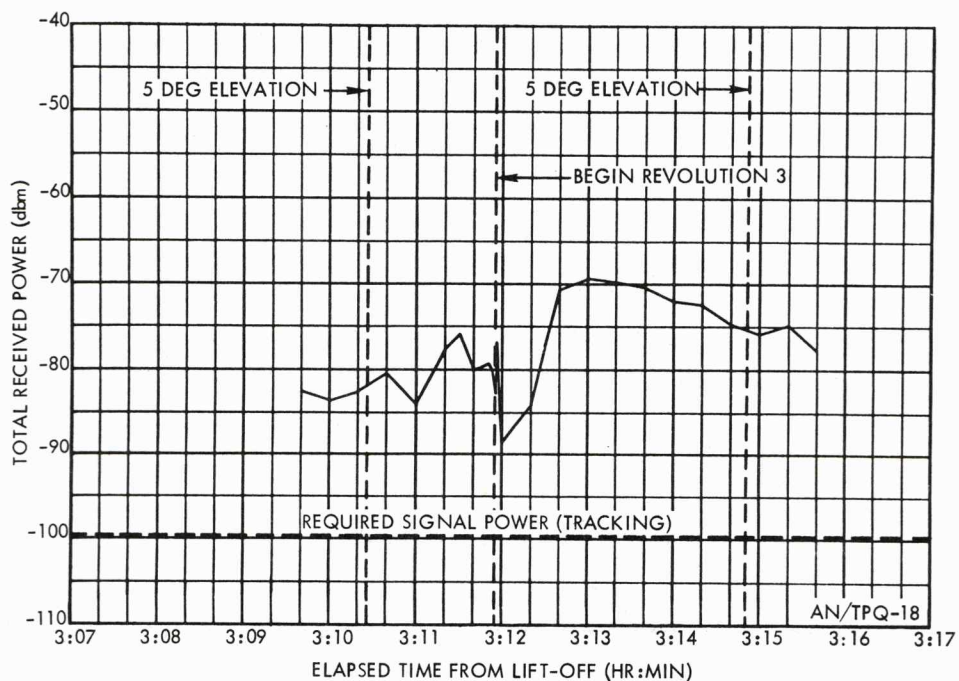


Figure 6-2d. GBI, Z Axis Antennas, Orbit 2-3

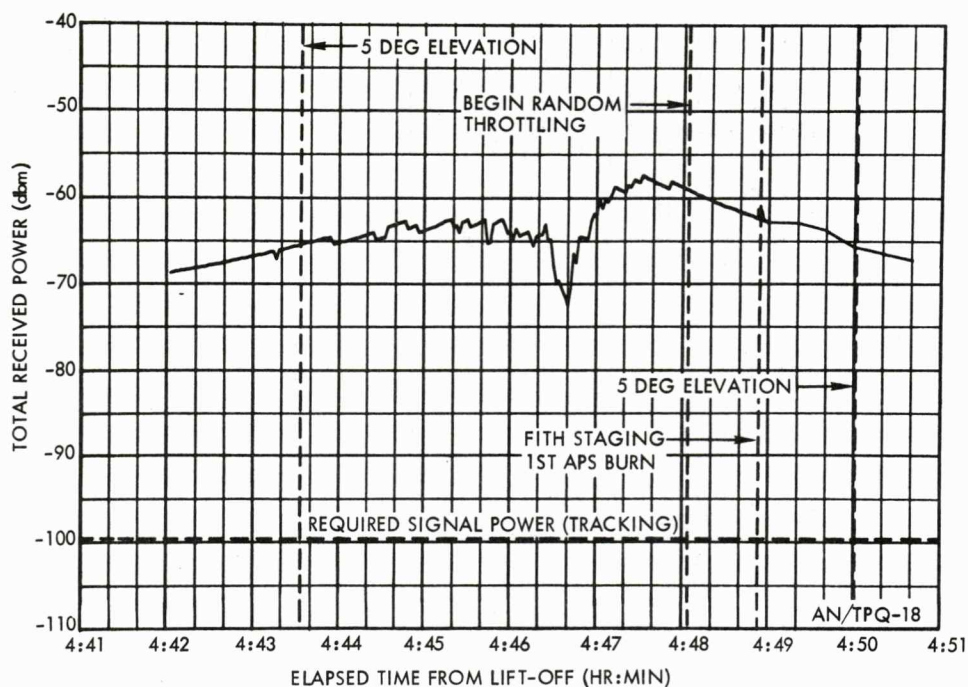


Figure 6-2e. GBI, Y Axis Antennas, Orbit 3-4

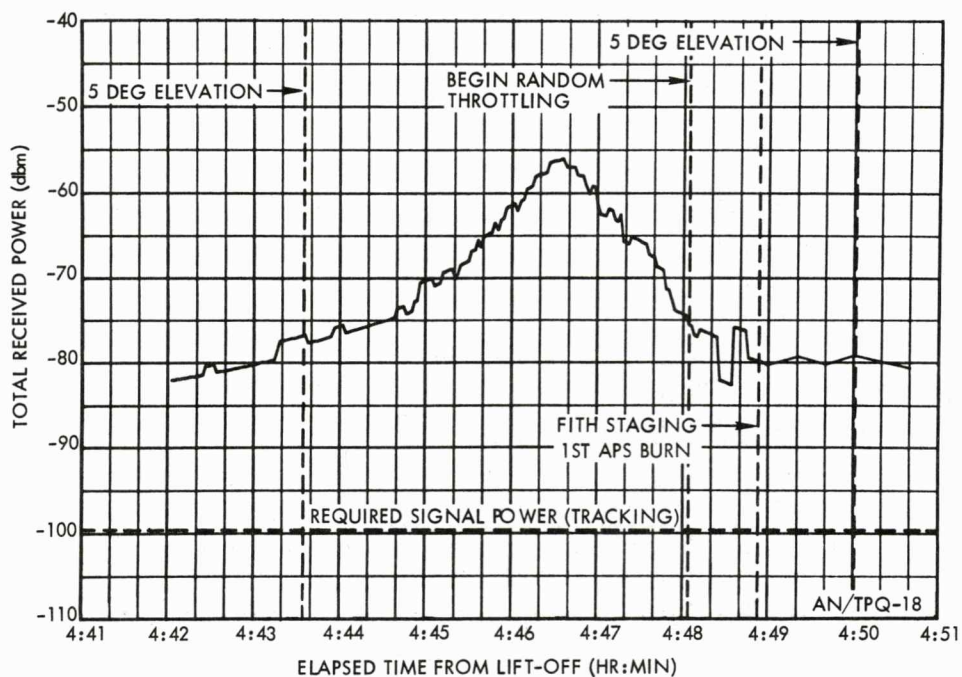


Figure 6-2f. GBI, Z Axis Antennas, Orbit 3-4

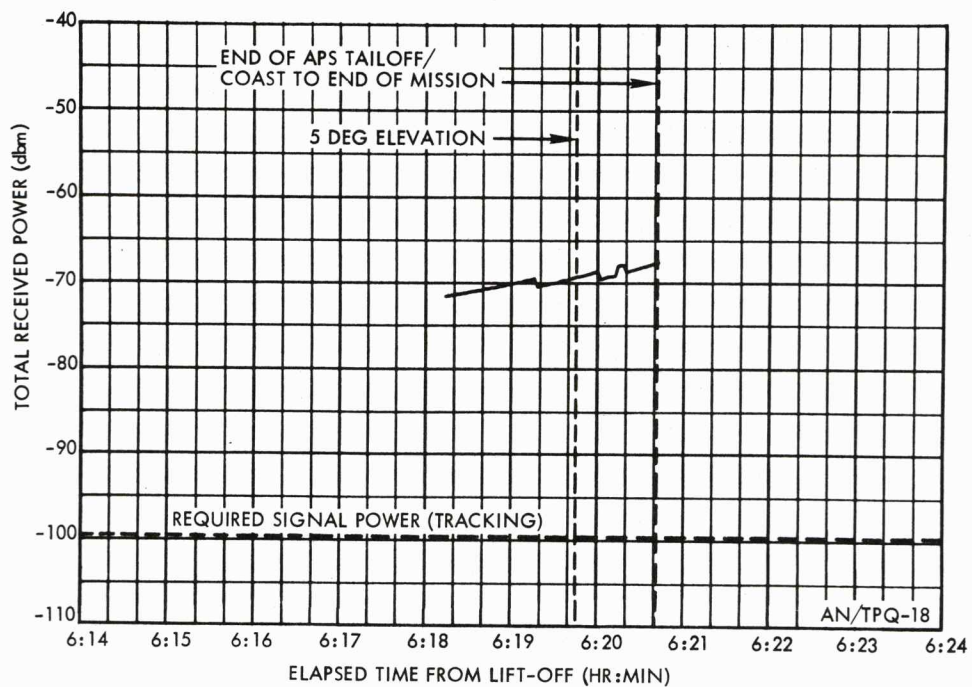


Figure 6-2g. GBI, Y Axis Antennas, Orbit 4

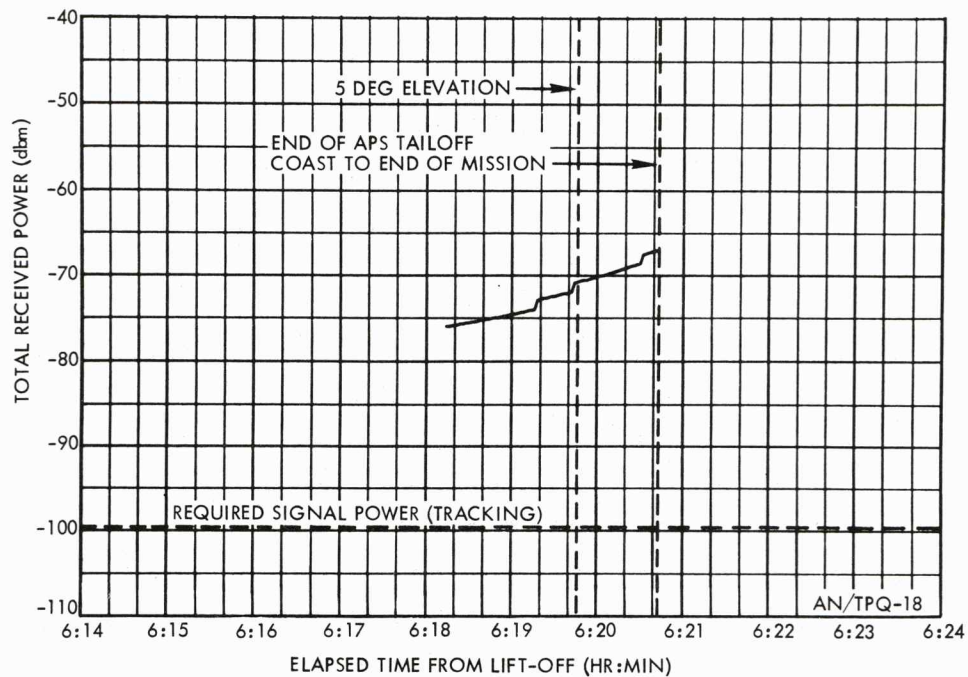


Figure 6-2h. GBI, Z Axis Antennas, Orbit 4

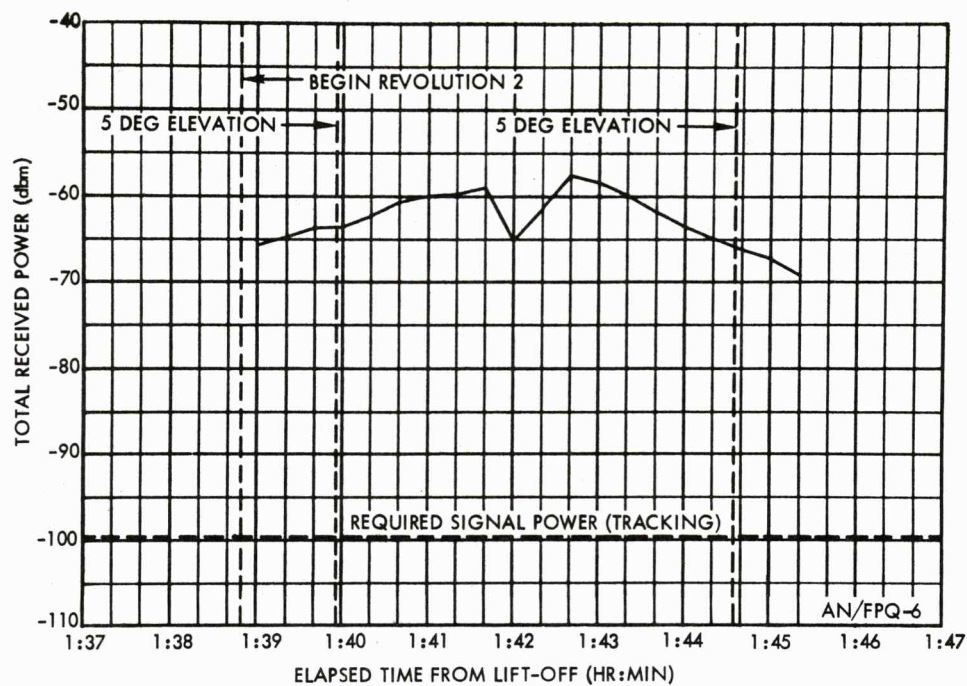


Figure 6-3a. BDA C-Band Downlink Total Received Power Versus Elapsed Time From Lift-Off, Y Axis Antennas, Orbit 2

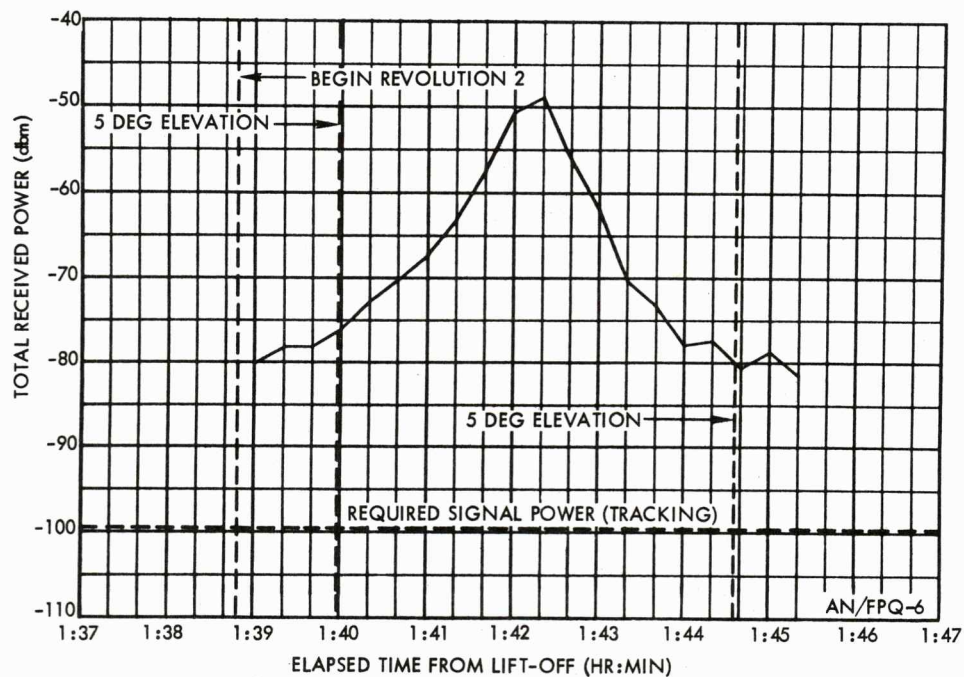


Figure 6-3b. BDA, Z Axis Antennas, Orbit 2

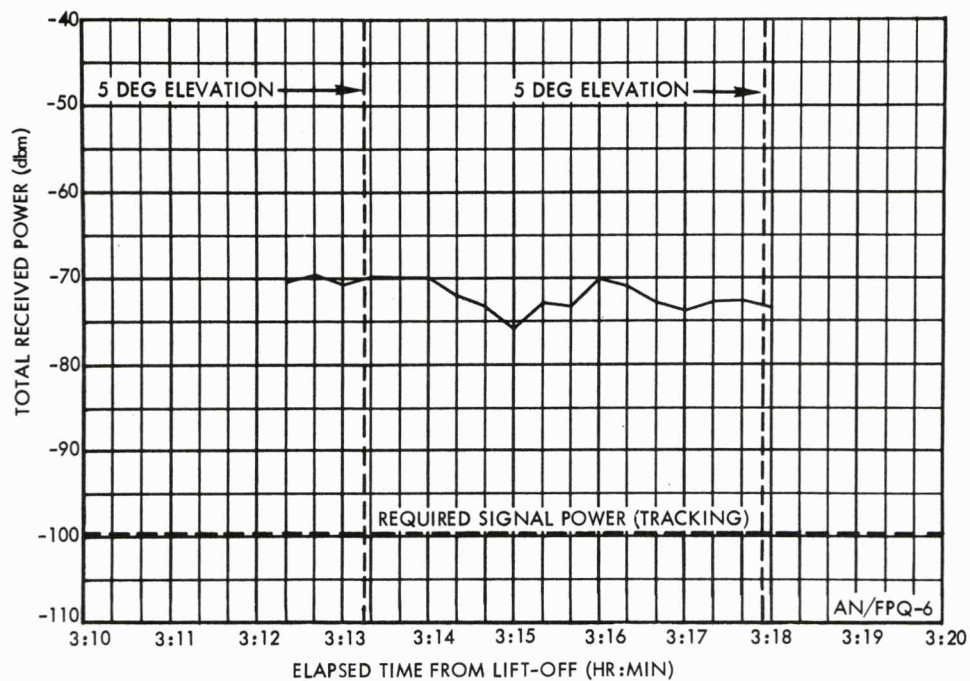


Figure 6-3c. BDA, Y Axis Antennas, Orbit 3

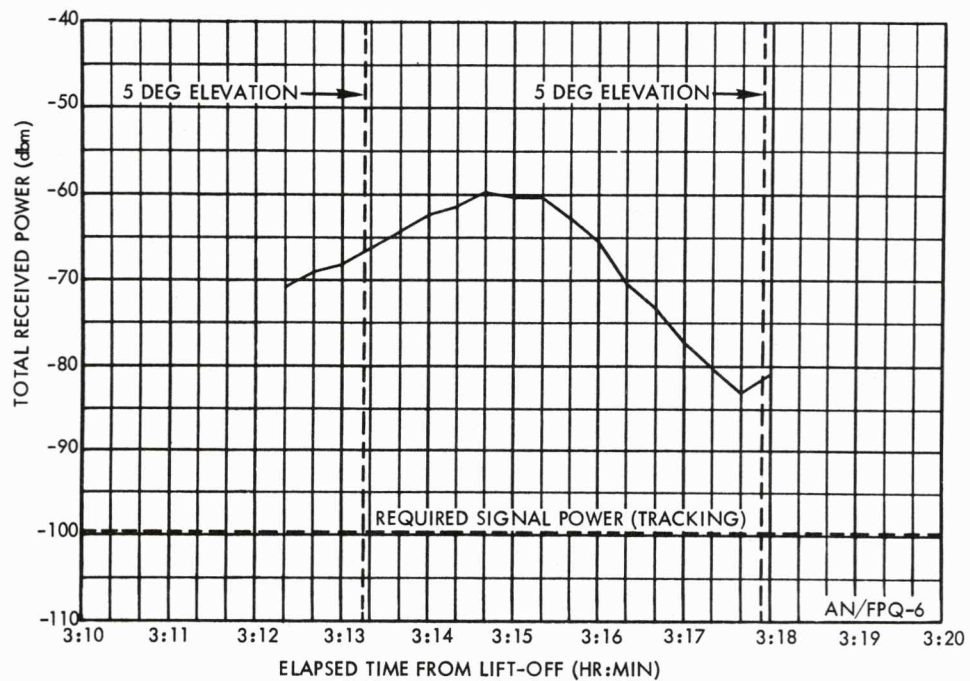


Figure 6-3d. BDA, Z Axis Antennas, Orbit 3

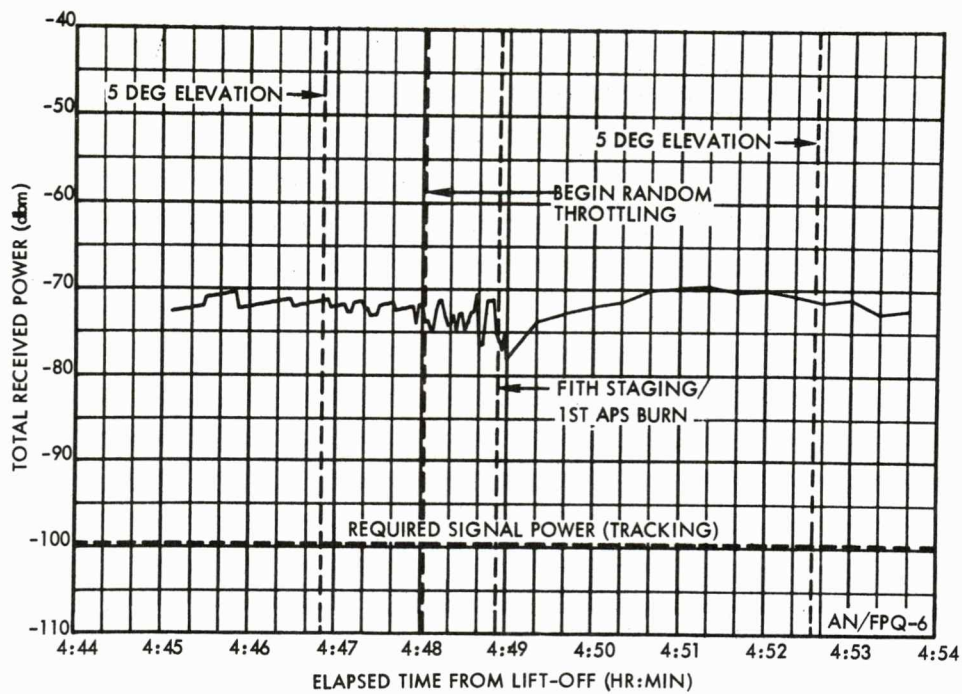


Figure 6-3e. BDA, Y Axis Antennas, Orbit 4

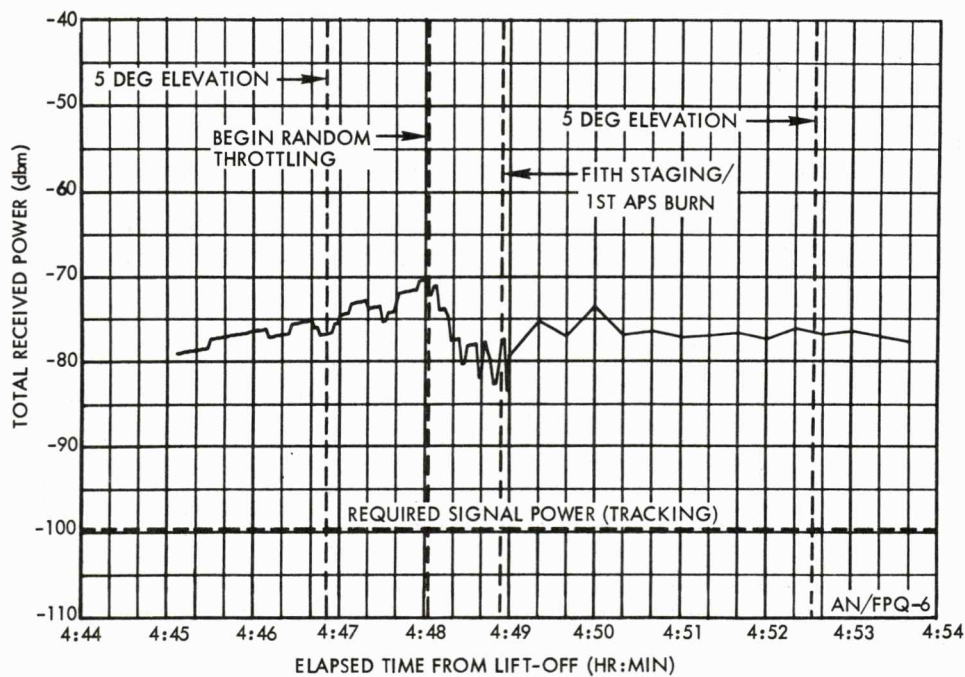


Figure 6-3f. BDA, Z Axis Antennas, Orbit 4

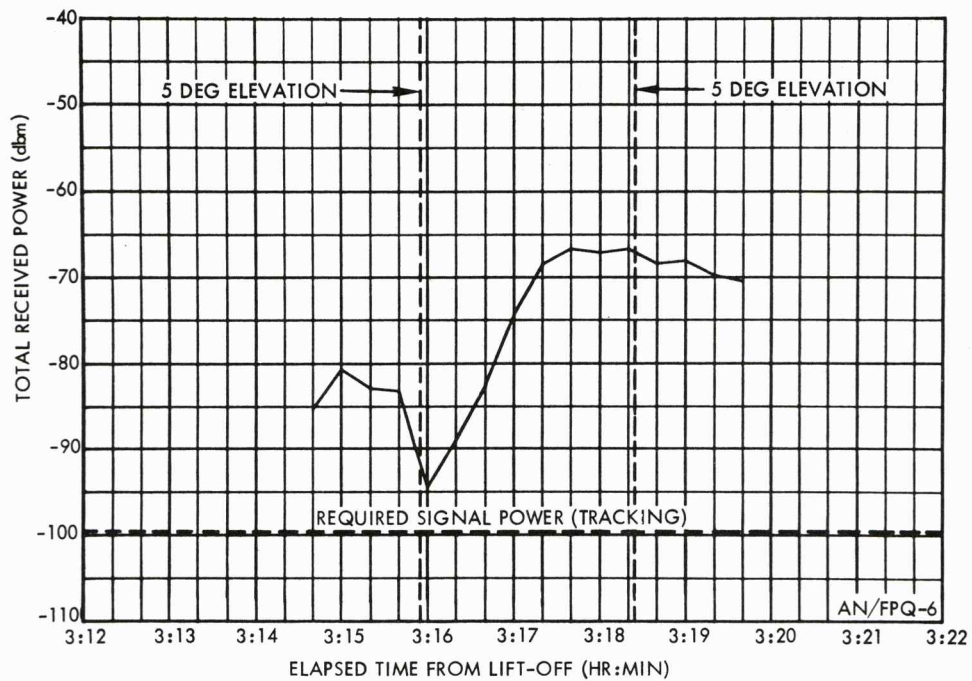


Figure 6-4a. ANT C-Band Downlink Total Received Power Versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 3

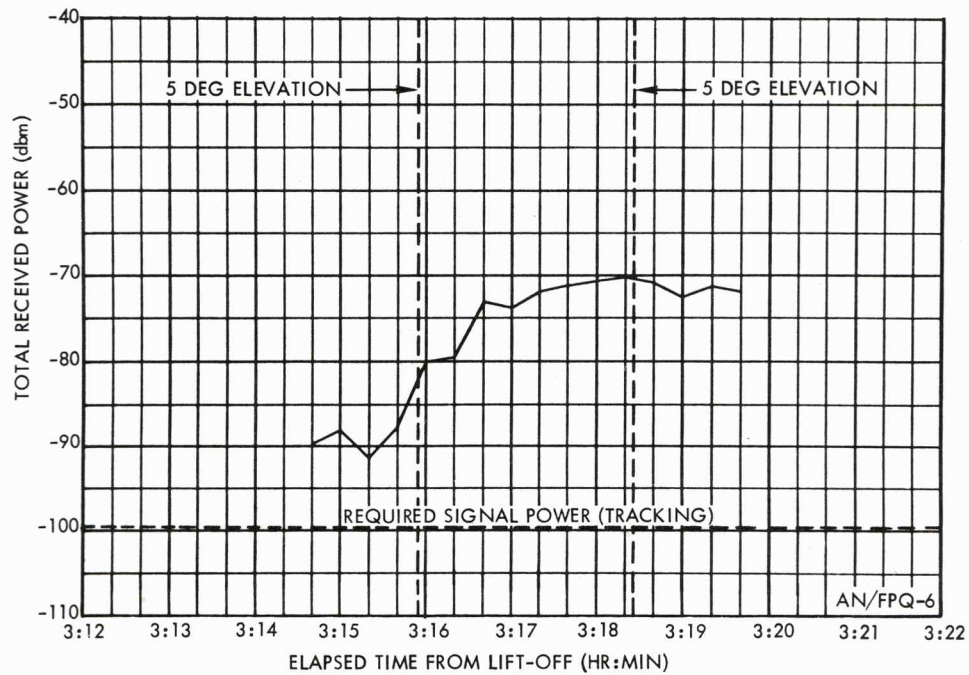


Figure 6-4b. ANT, Z Axis Antennas, Orbit 3

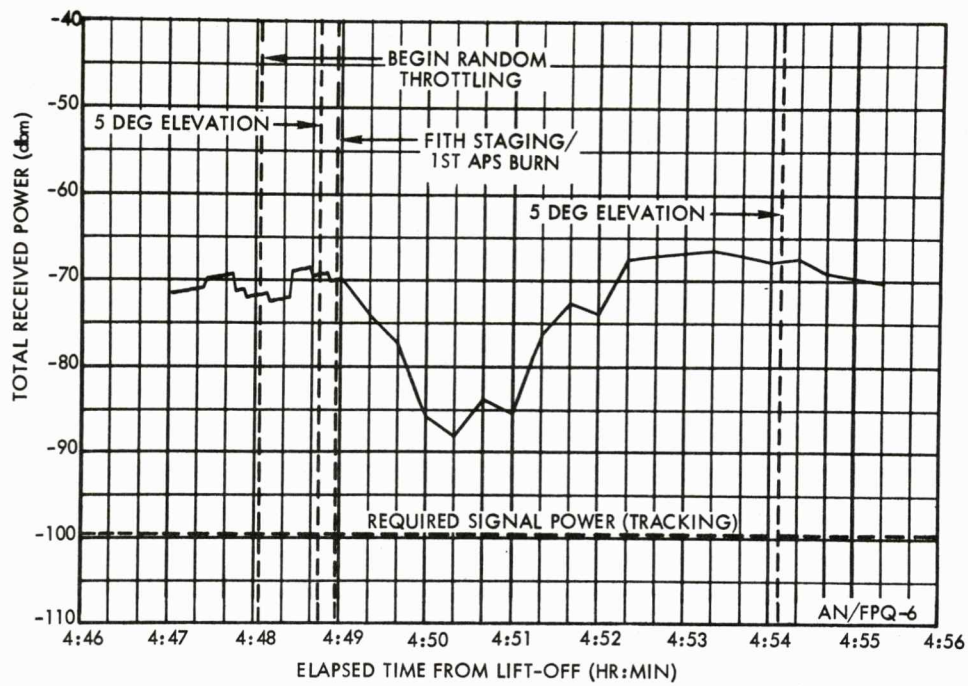


Figure 6-4c. ANT, Y Axis Antennas, Orbit 4

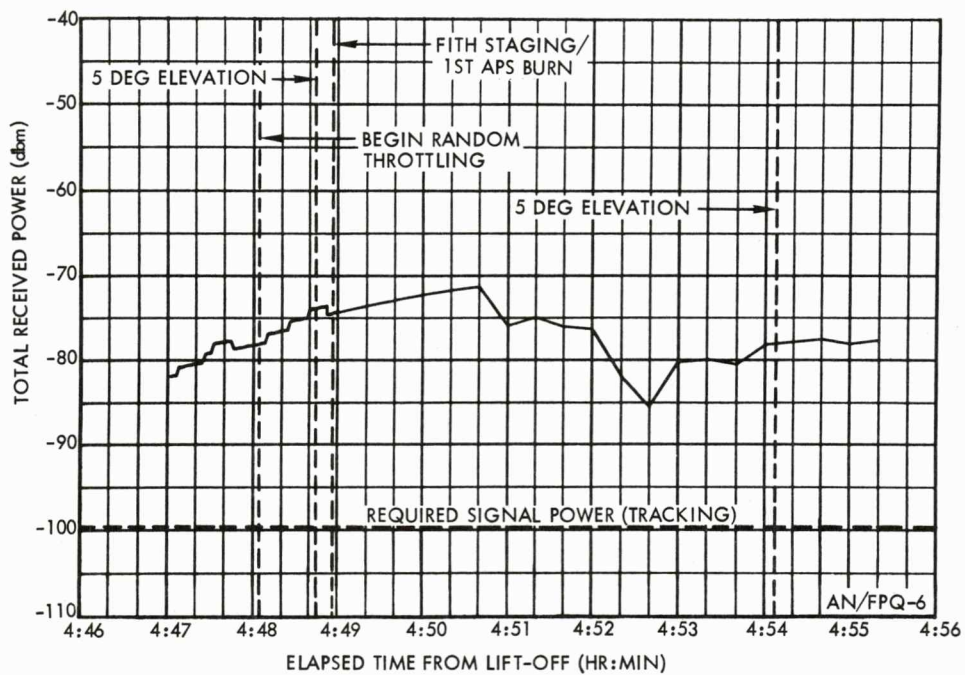


Figure 6-4d. ANT, Z Axis Antennas, Orbit 4

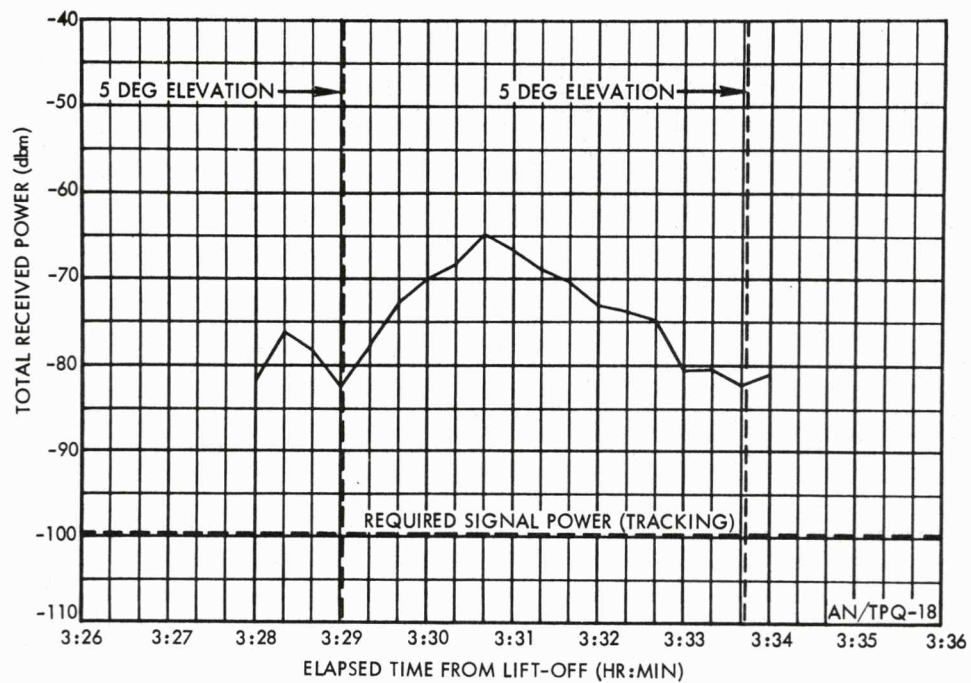


Figure 6-5a. ASC C-Band Downlink Total Received Power Versus Elapsed Time From Lift-Off, Y Axis Antennas, Orbit 3

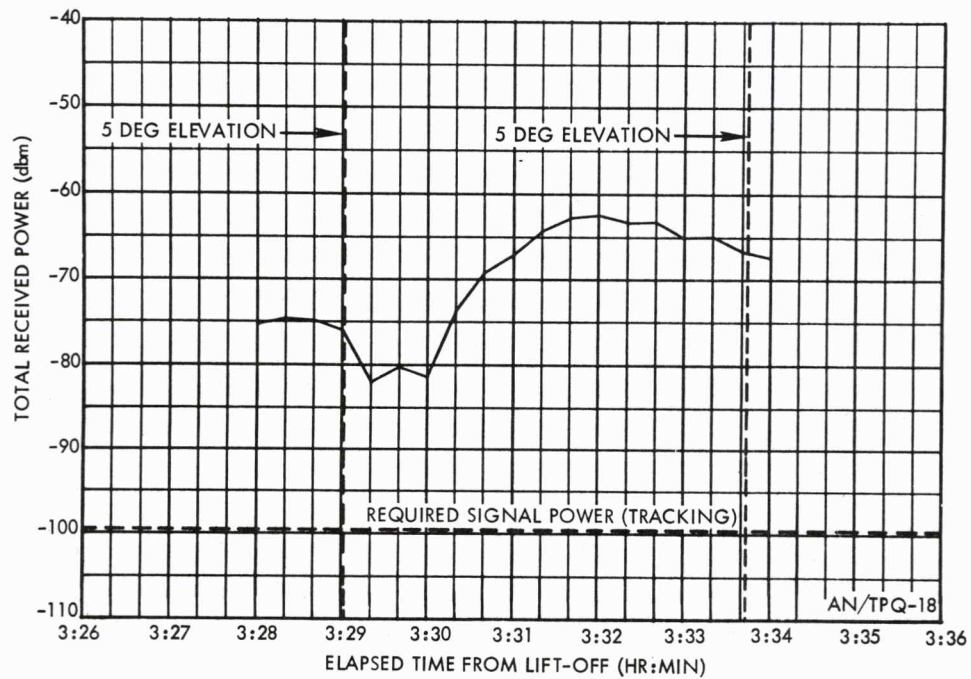


Figure 6-5b. ASC, Z Axis Antennas, Orbit 3

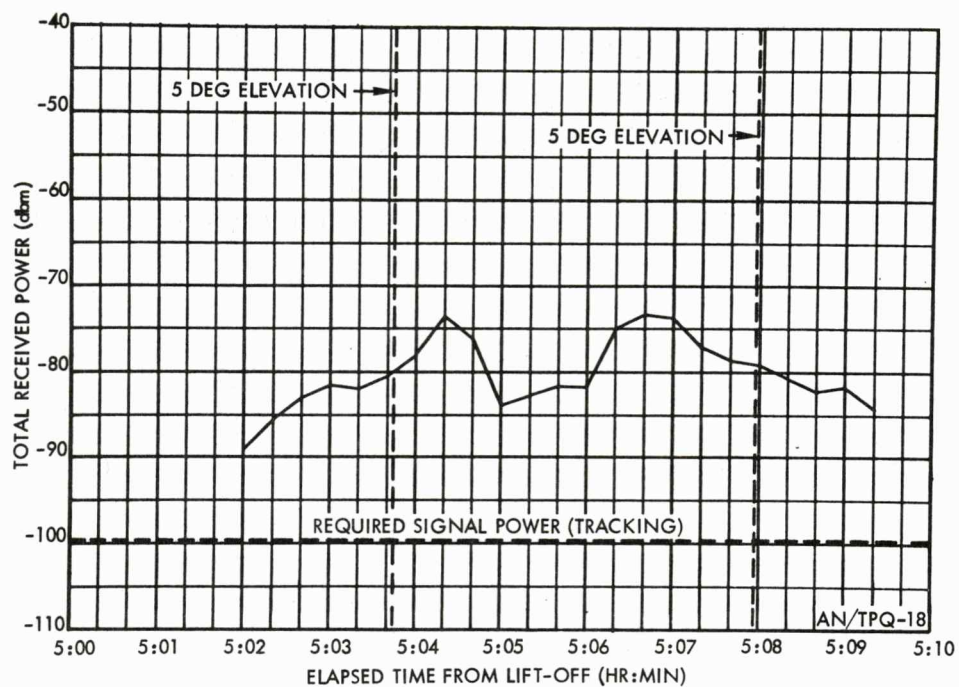


Figure 6-5c. ASC, Y Axis Antennas, Orbit 4

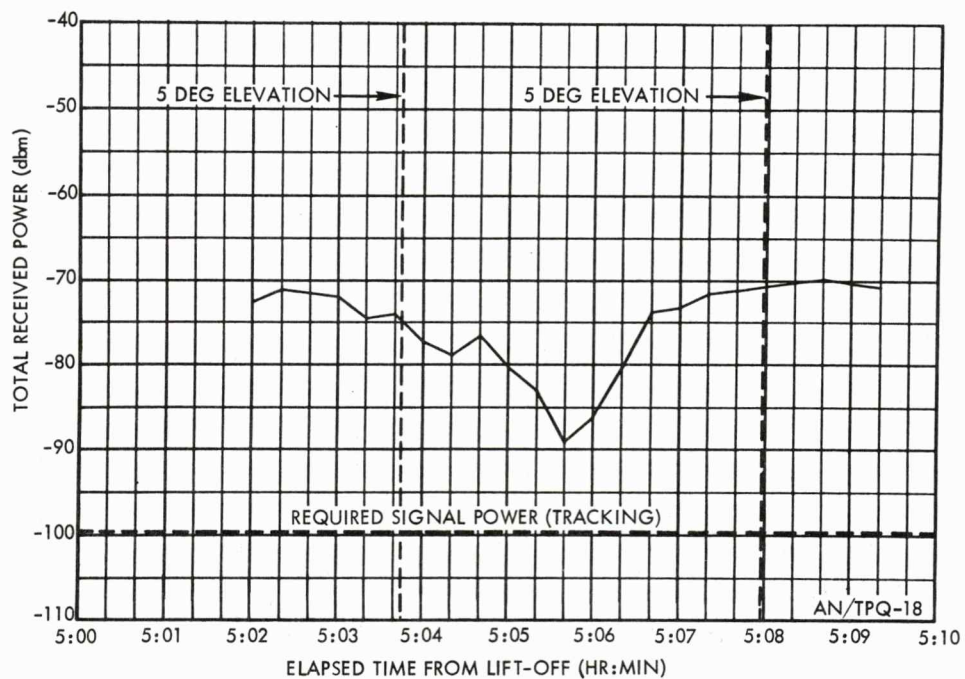


Figure 6-5d. ASC, Z Axis Antennas, Orbit 4

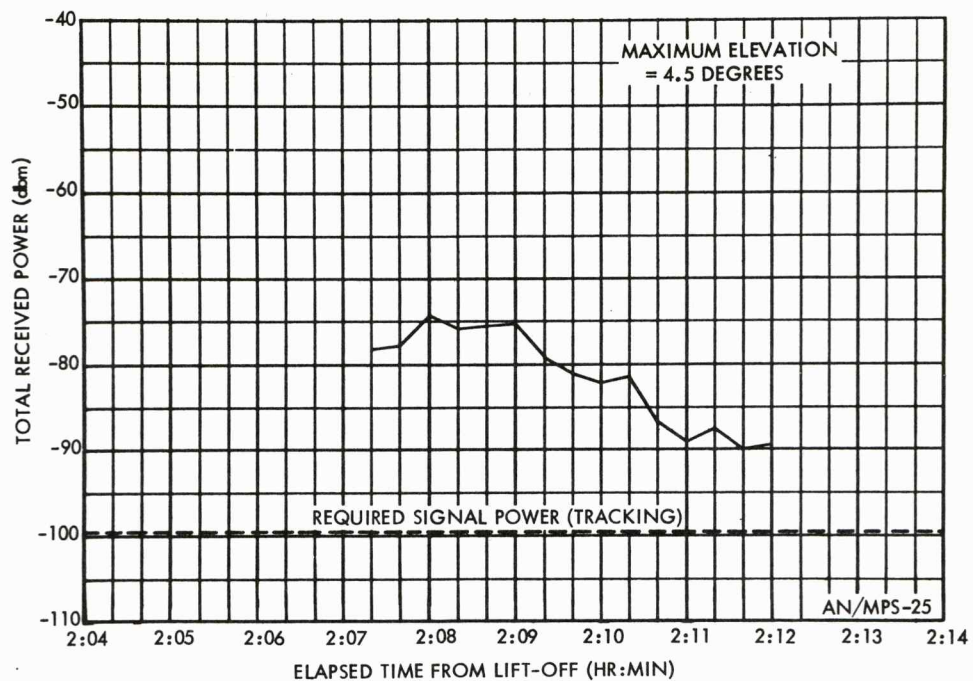


Figure 6-6a. PRE C-Band Downlink Total Received Power Versus Elapsed Time From Lift-Off, Y Axis Antennas, Orbit 2

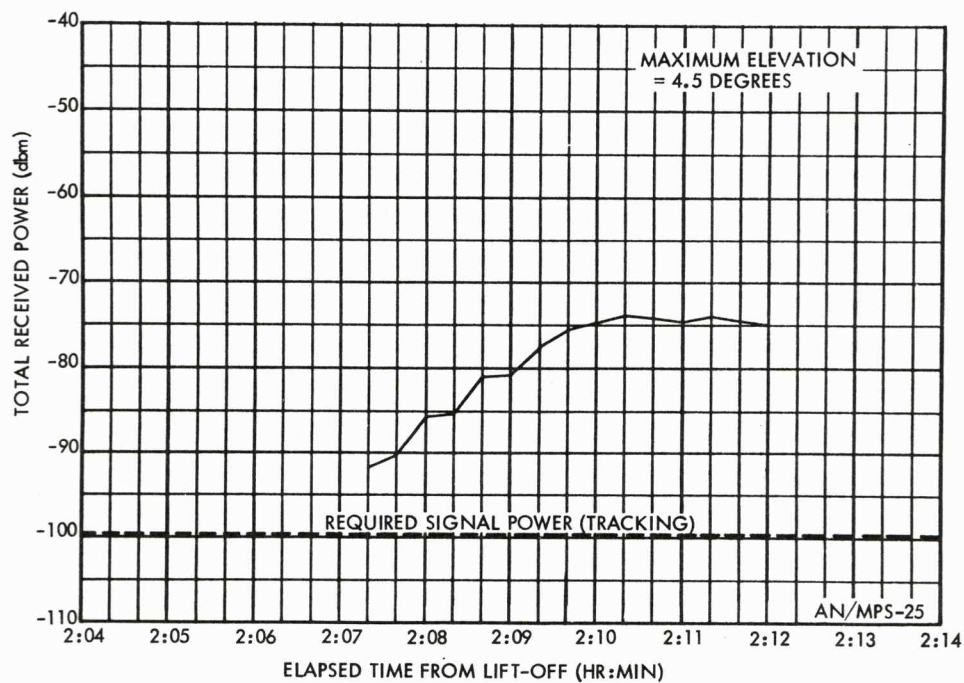


Figure 6-6b. PRE, Z Axis Antennas, Orbit 2

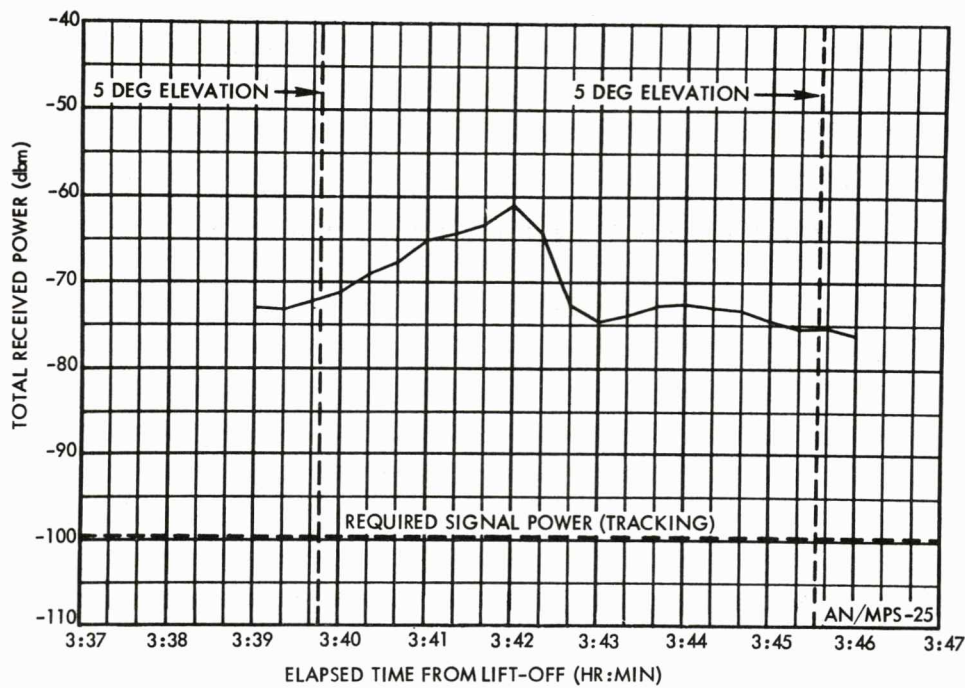


Figure 6-6c. PRE, Y Axis Antennas, Orbit 3

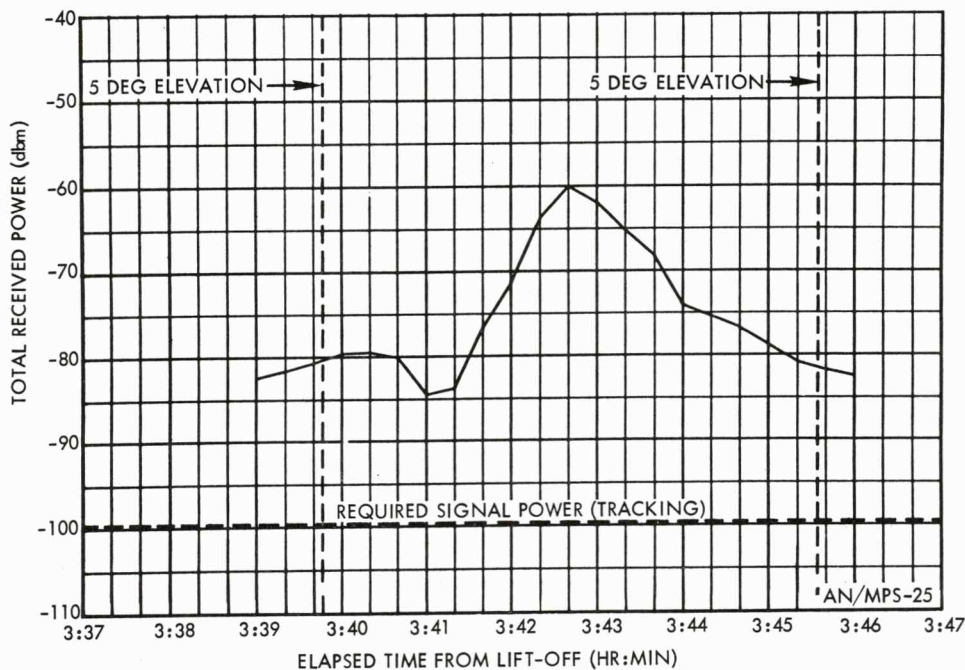


Figure 6-6d. PRE, Z Axis Antennas, Orbit 3

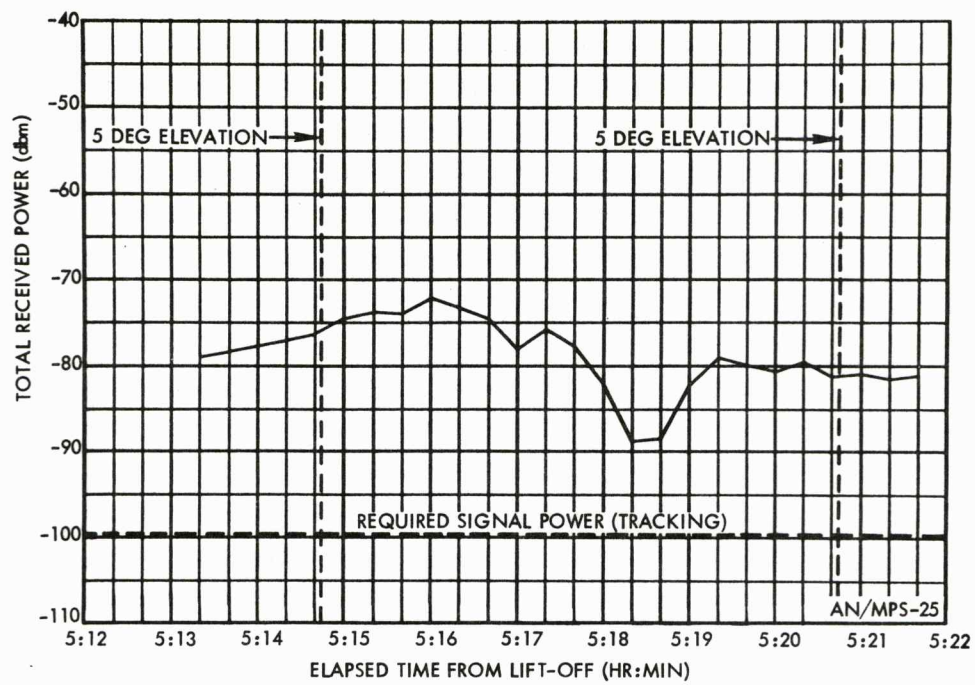


Figure 6-6e. PRE, Y Axis Antennas, Orbit 4

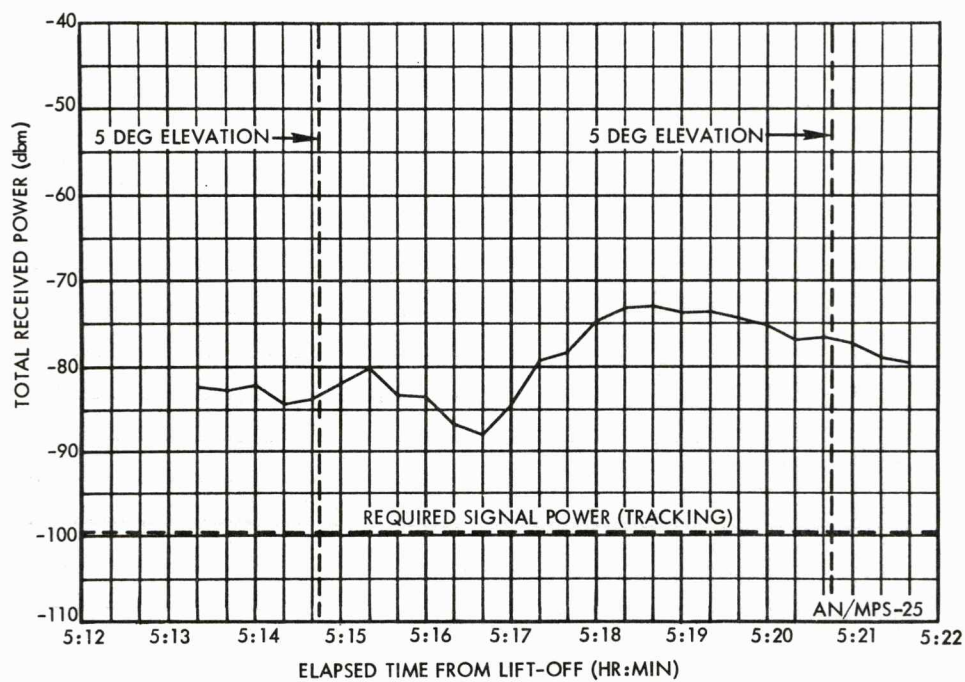


Figure 6-6f. PRE, Z Axis Antennas, Orbit 4

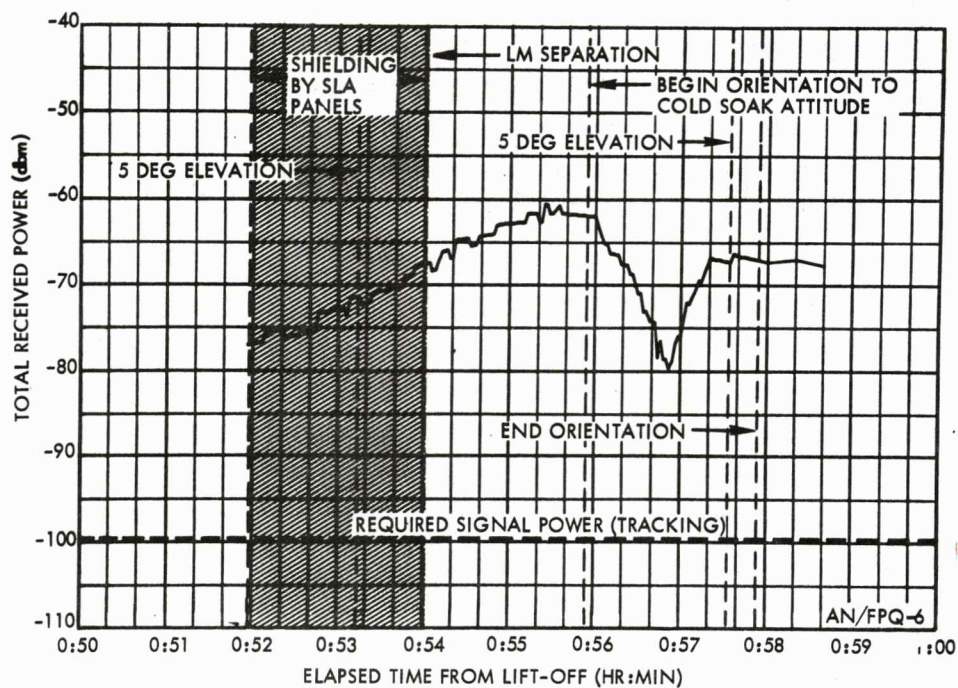


Figure 6-7a. CRO C-band Downlink Total Received Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 1

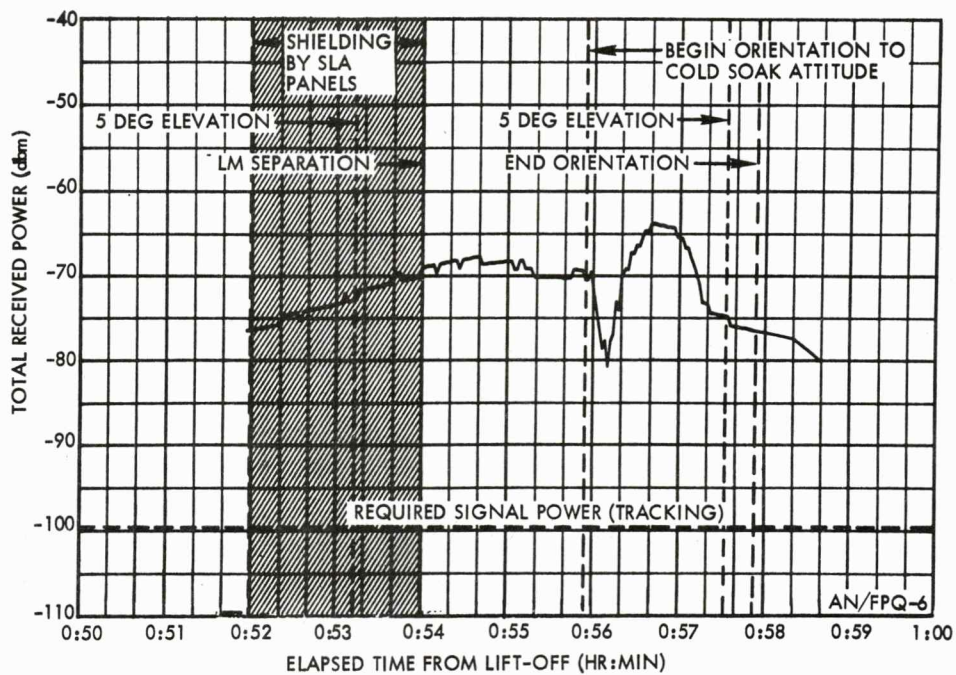


Figure 6-7b. CRO, Z Axis Antennas, Orbit 1

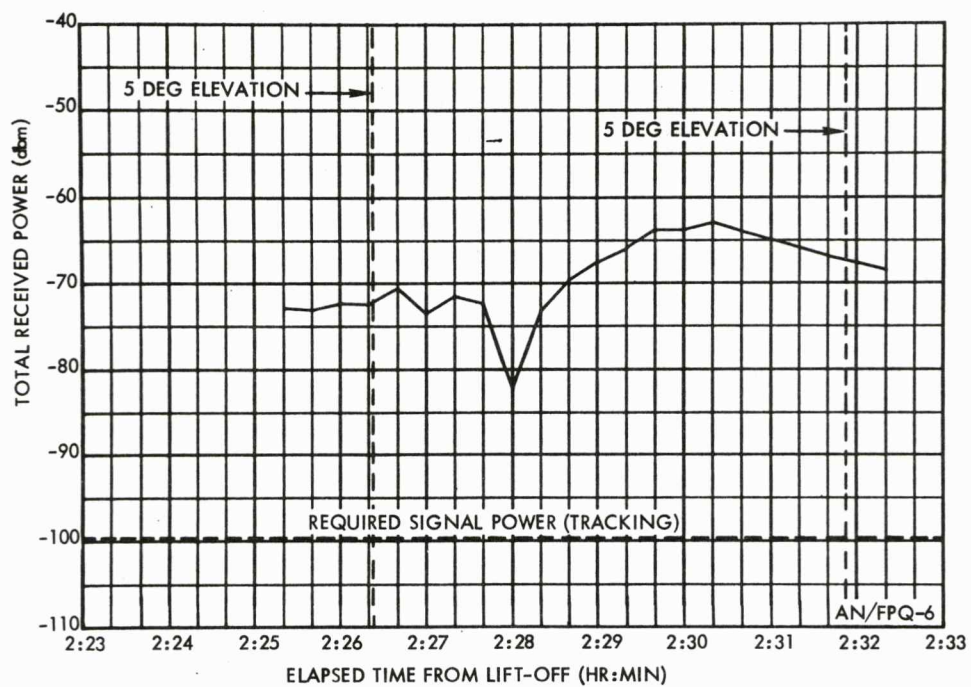


Figure 6-7c. CR0, Y Axis Antennas, Orbit 2

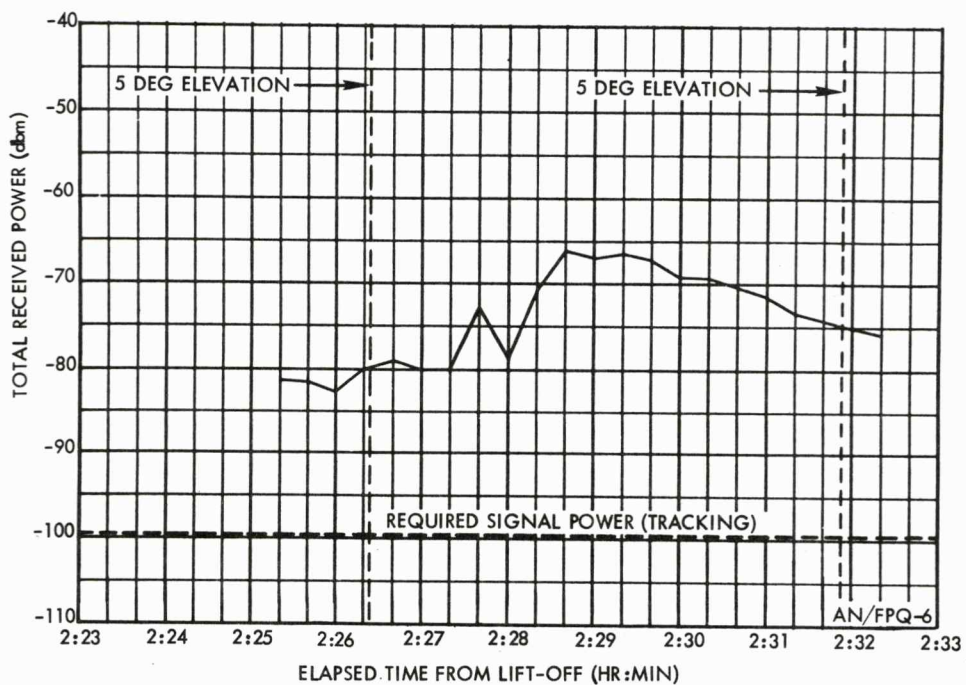


Figure 6-7d. CR0, Z Axis Antennas, Orbit 3

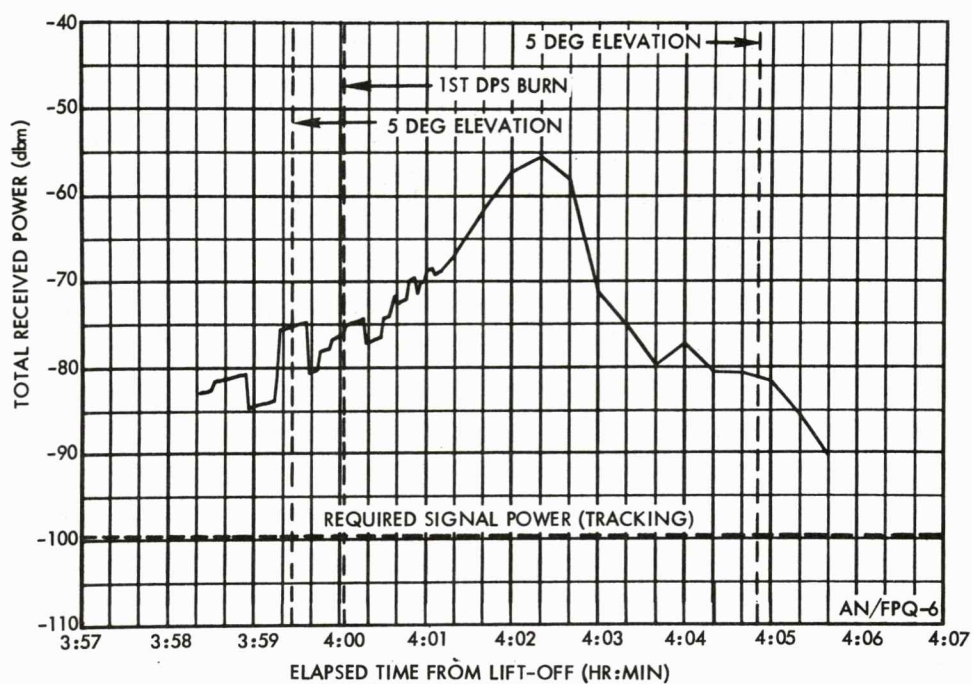


Figure 6-7e. CR0, Y Axis Antennas, Orbit 3

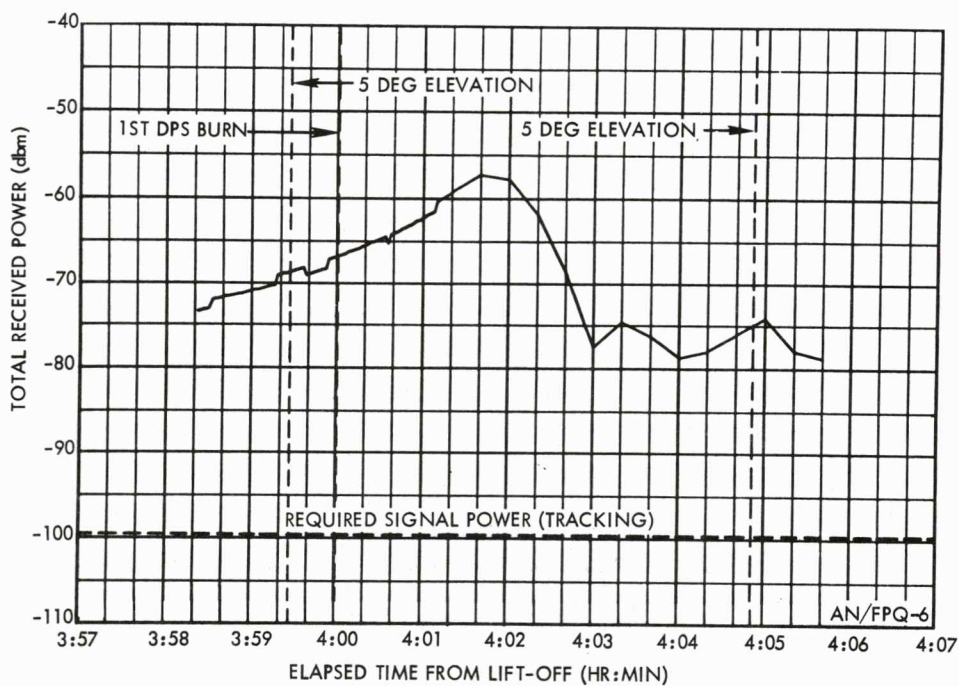


Figure 6-7f. CR0, Z Axis Antennas, Orbit 3



Figure 6-7g. CR0, Y Axis Antennas, Orbit 4

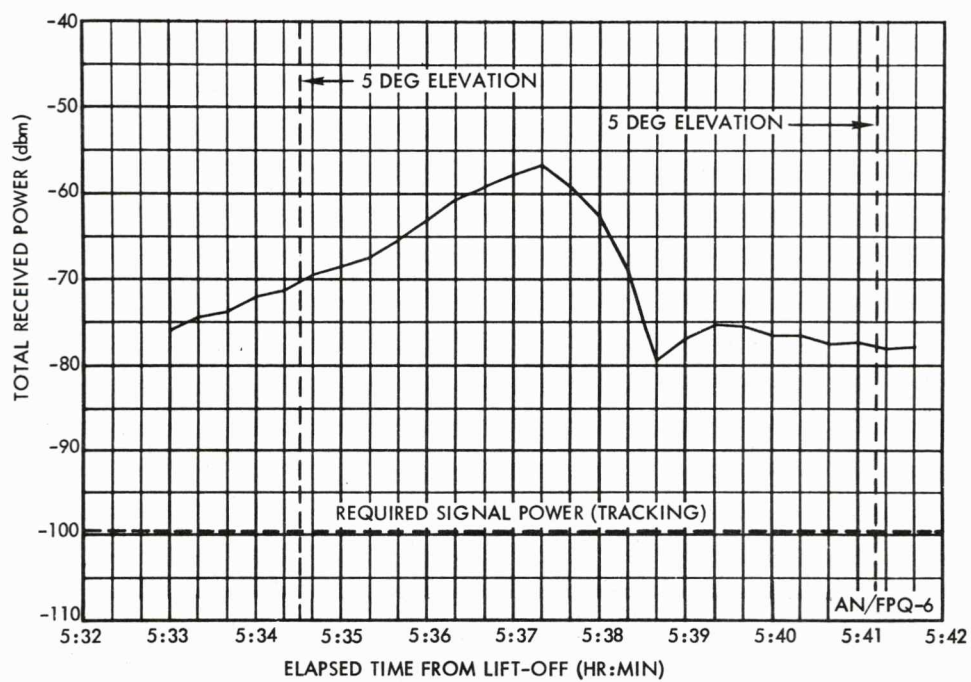


Figure 6-7h. CR0, Z Axis Antenna, Orbit 4

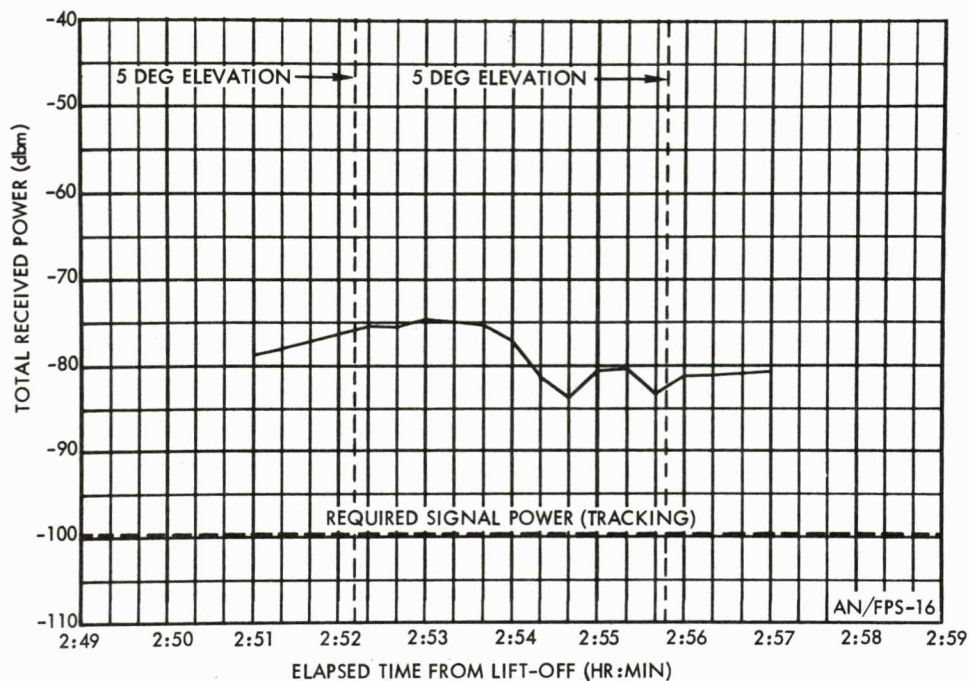


Figure 6-8a. HAW C-band Downlink Total Receiver Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 2

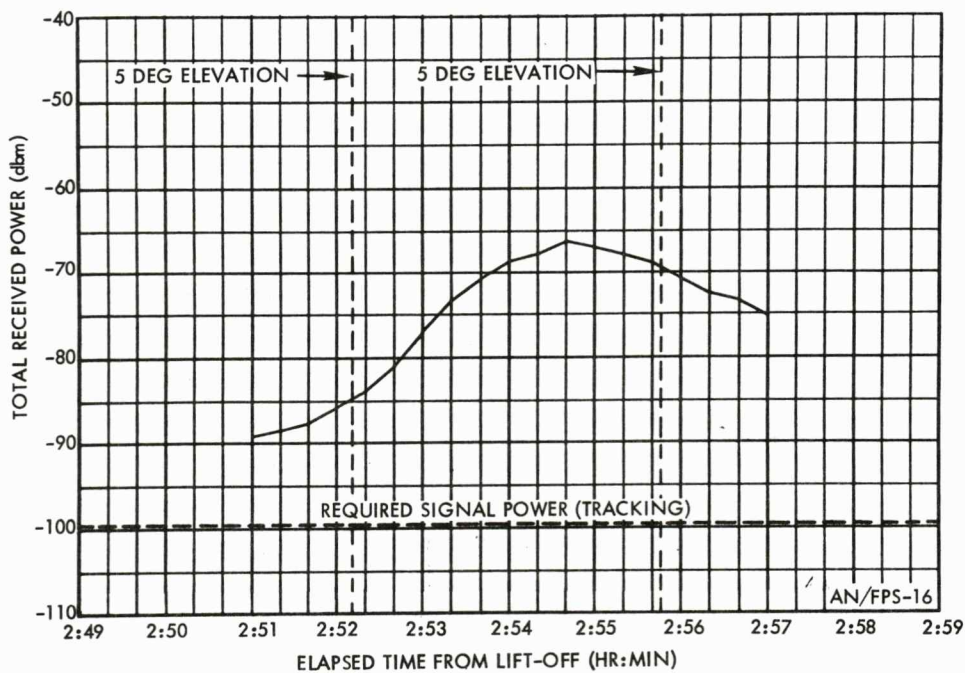


Figure 6-8b. HAW, Z Axis Antennas, Orbit 2

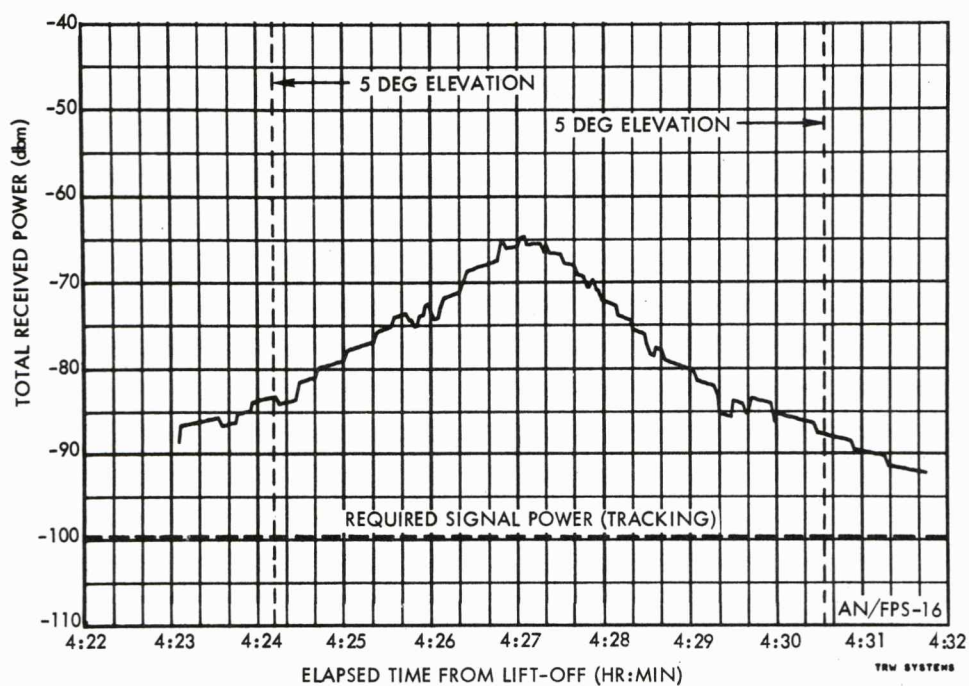


Figure 6-8c. HAW, Y Axis Antennas, Orbit 3

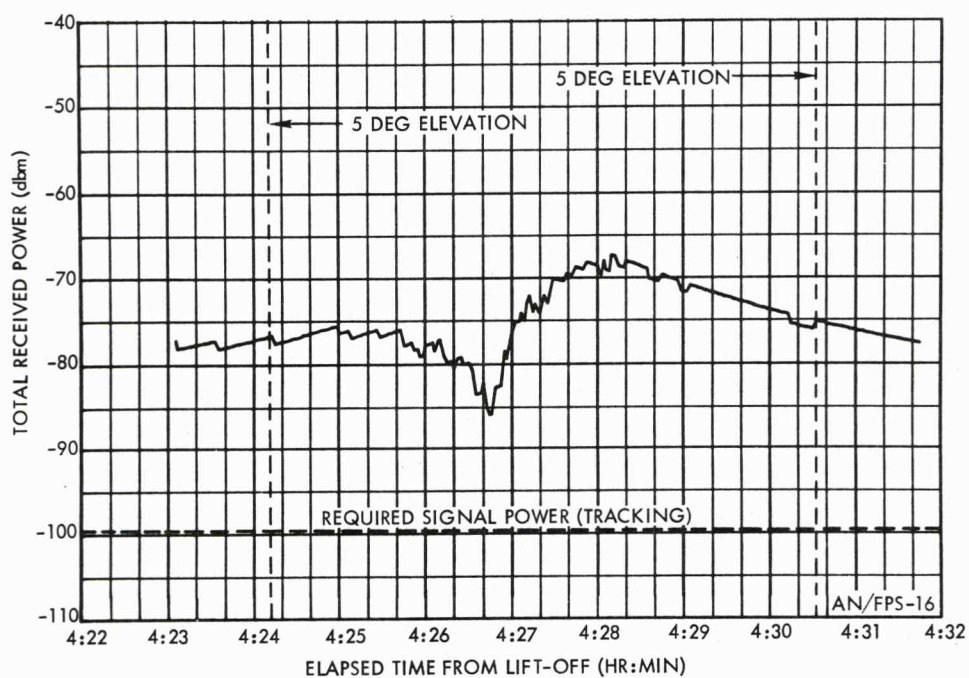


Figure 6-8d. HAW, Z Axis Antennas, Orbit 3

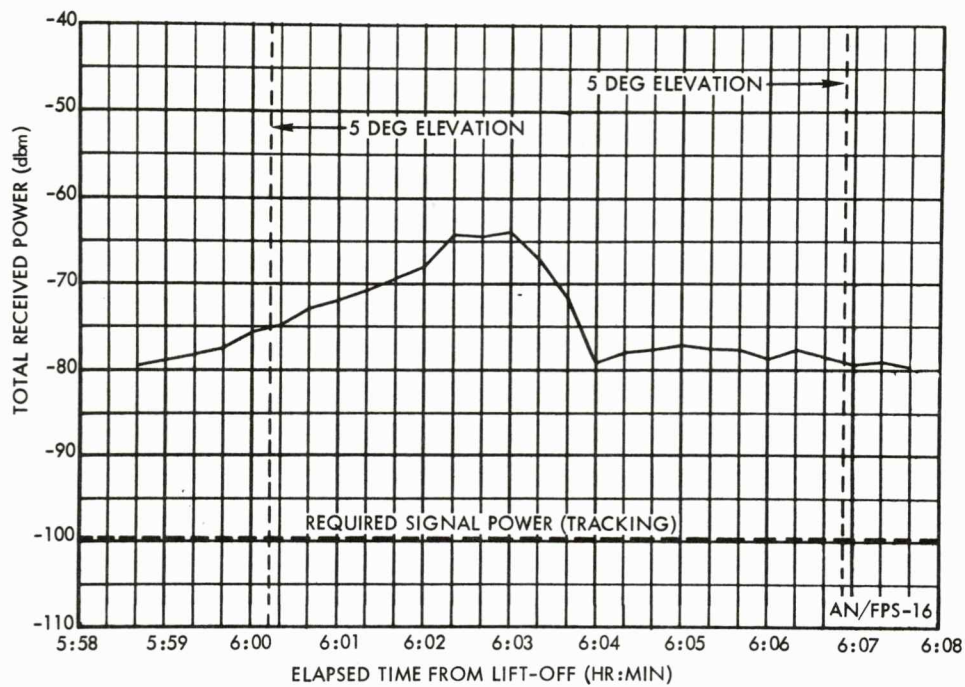


Figure 6-8e. HAW, Y Axis Antennas, Orbit 4

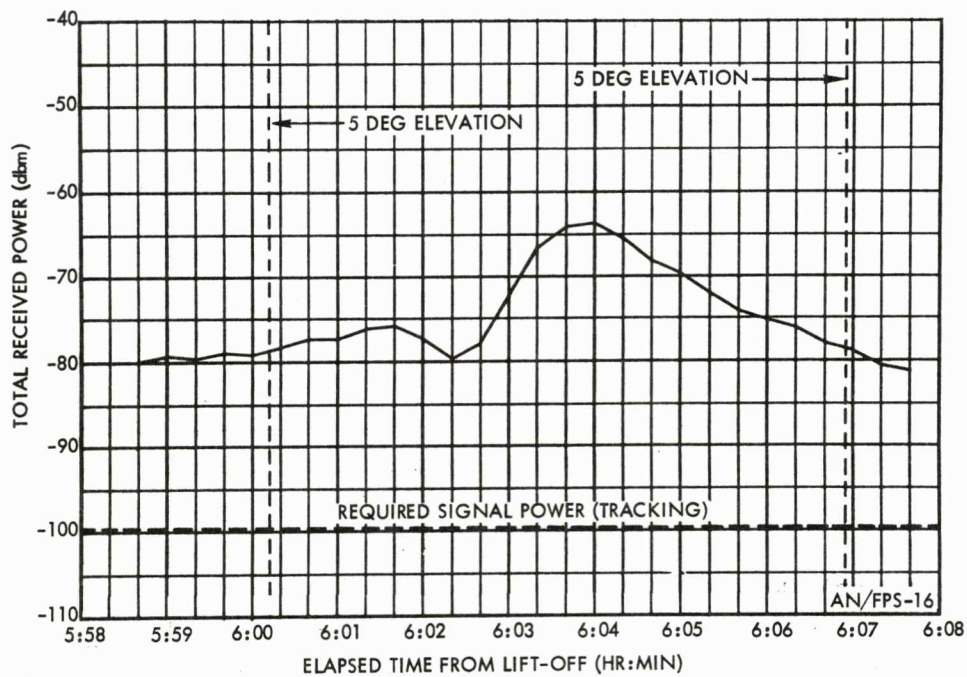


Figure 6-8f. HAW, Z Axis Antennas, Orbit 4

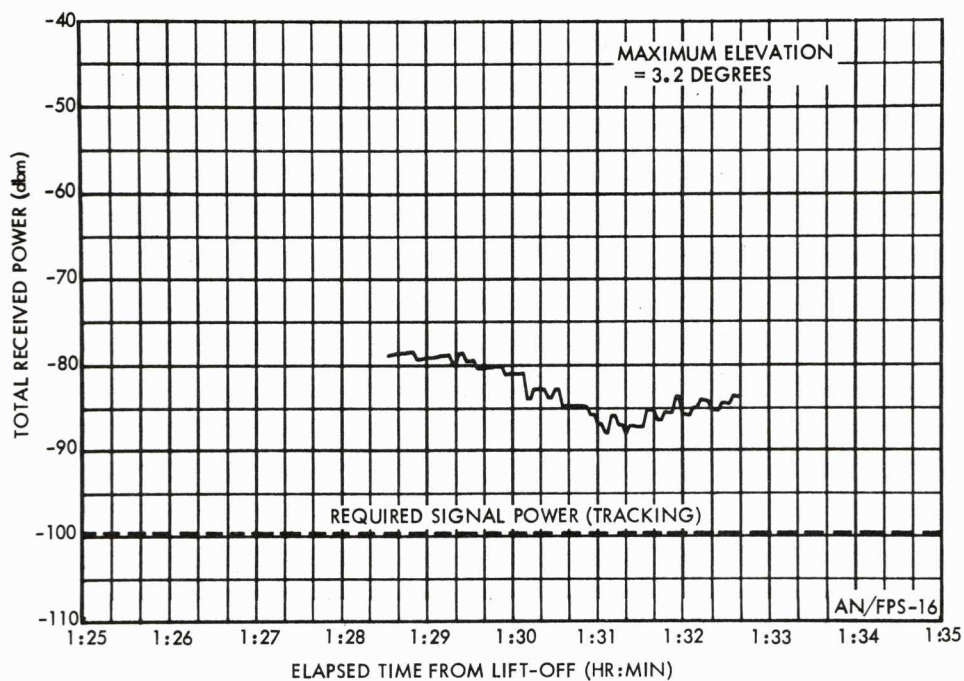


Figure 6-9a. CAL C-band Downlink Total Received Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 1

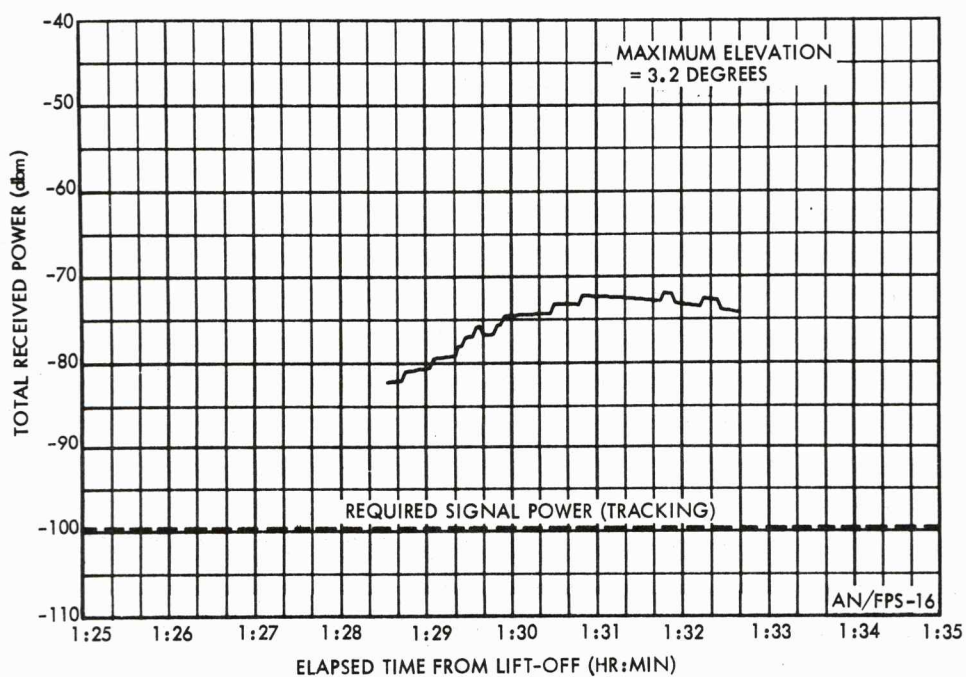


Figure 6-9b. CAL, Z Axis Antennas, Orbit 1

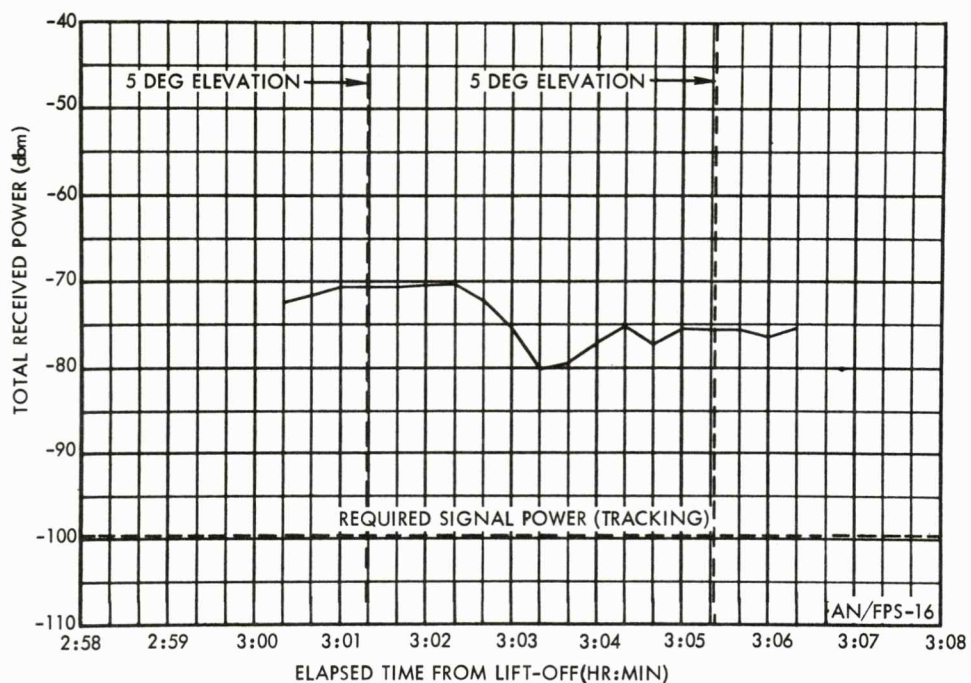


Figure 6-9c. CAL, Y Axis Antennas, Orbit 2

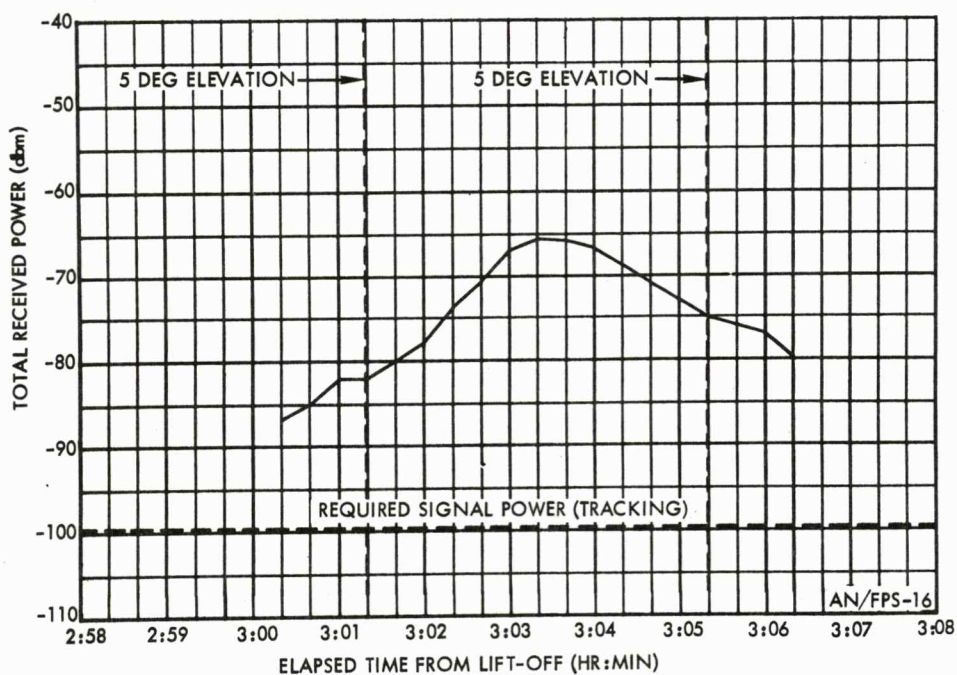


Figure 6-9d. CAL, Z Axis Antennas, Orbit 2

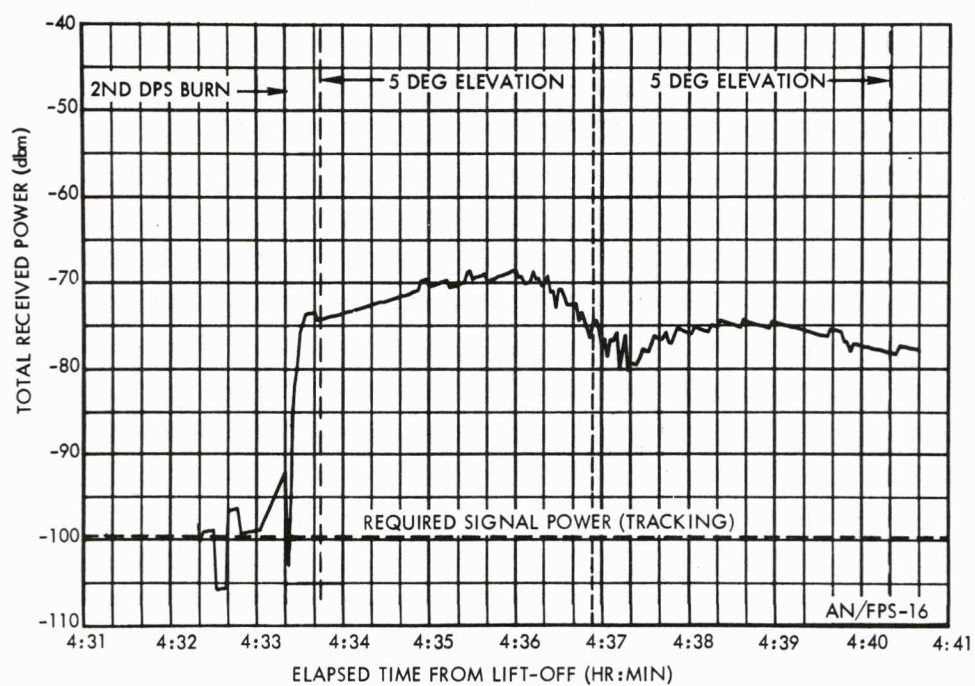


Figure 6-9e. CAL, Y Axis Antennas, Orbit 3

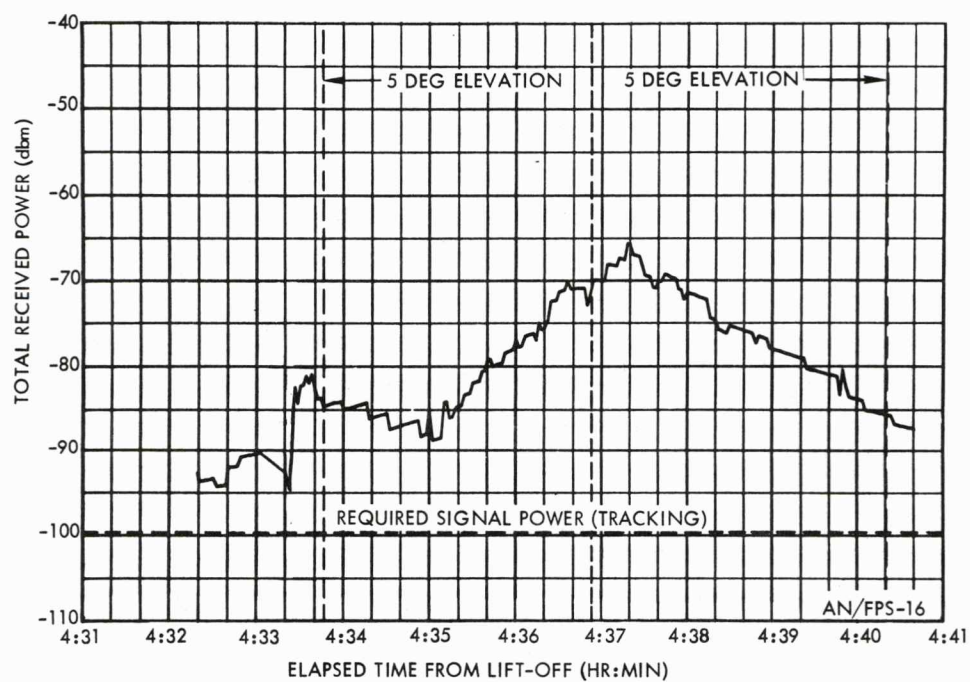


Figure 6-9f. CAL, Z Axis Antennas, Orbit 3

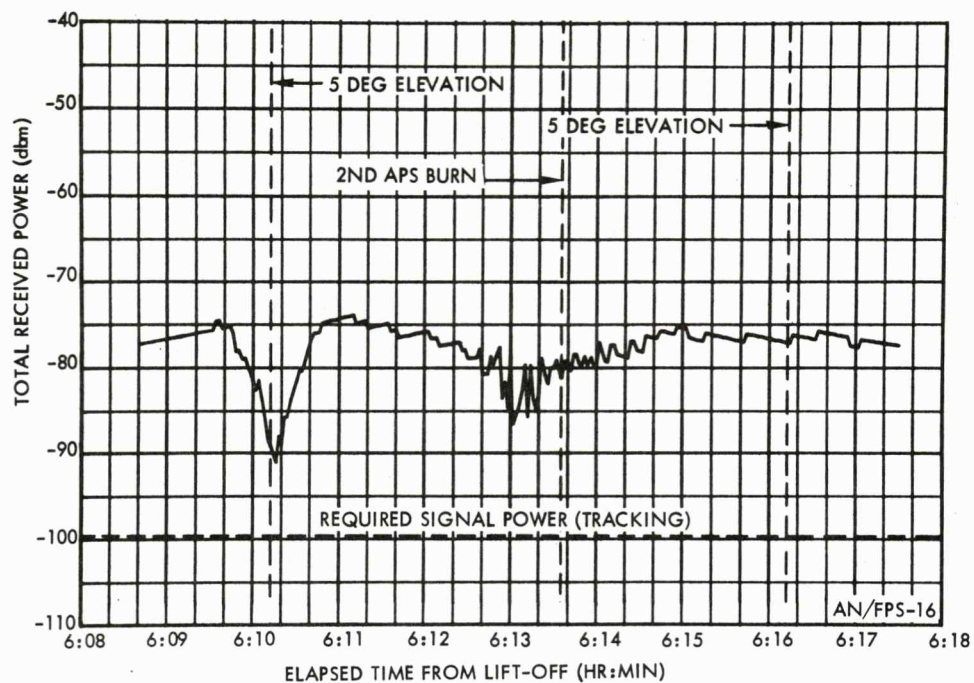


Figure 6-9g. CAL, Y Axis Antennas, Orbit 4

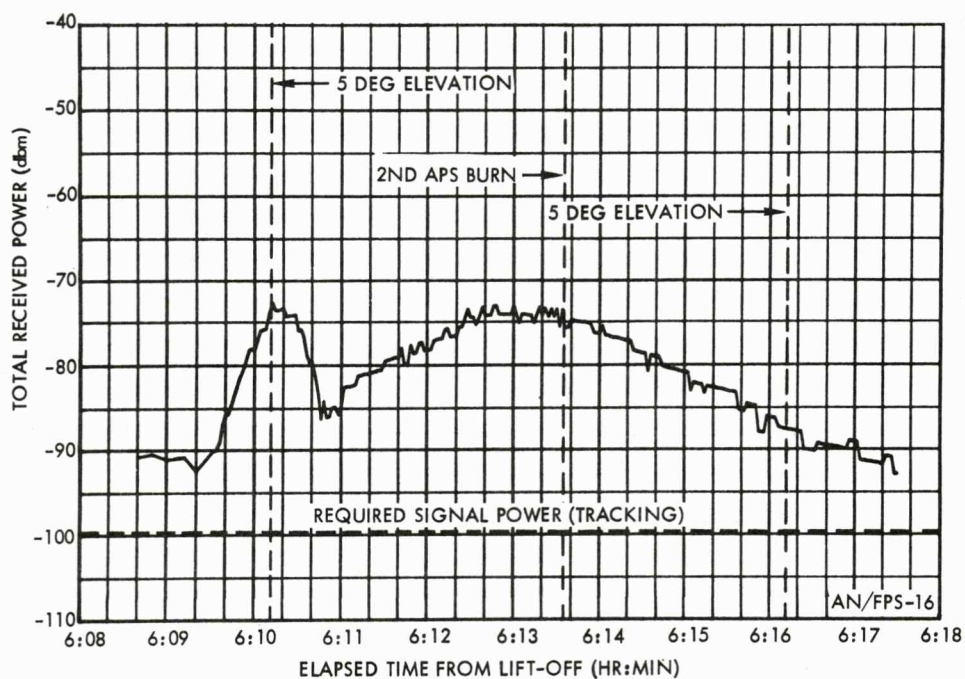


Figure 6-9h. CAL, Z Axis Antennas, Orbit 4

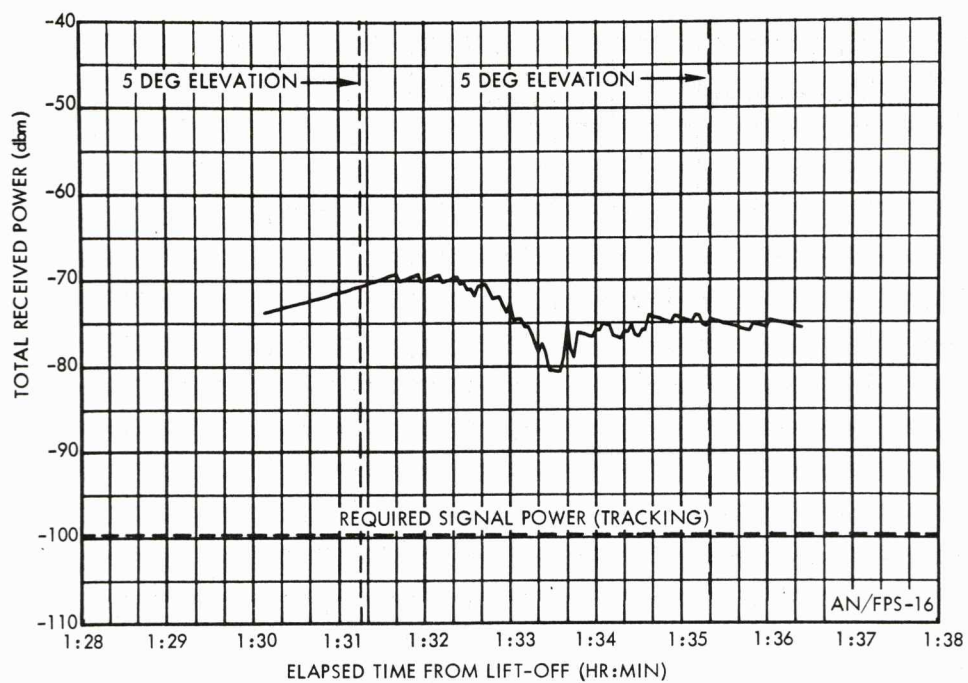


Figure 6-10a. WHS C-band Downlink Total Received Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 1

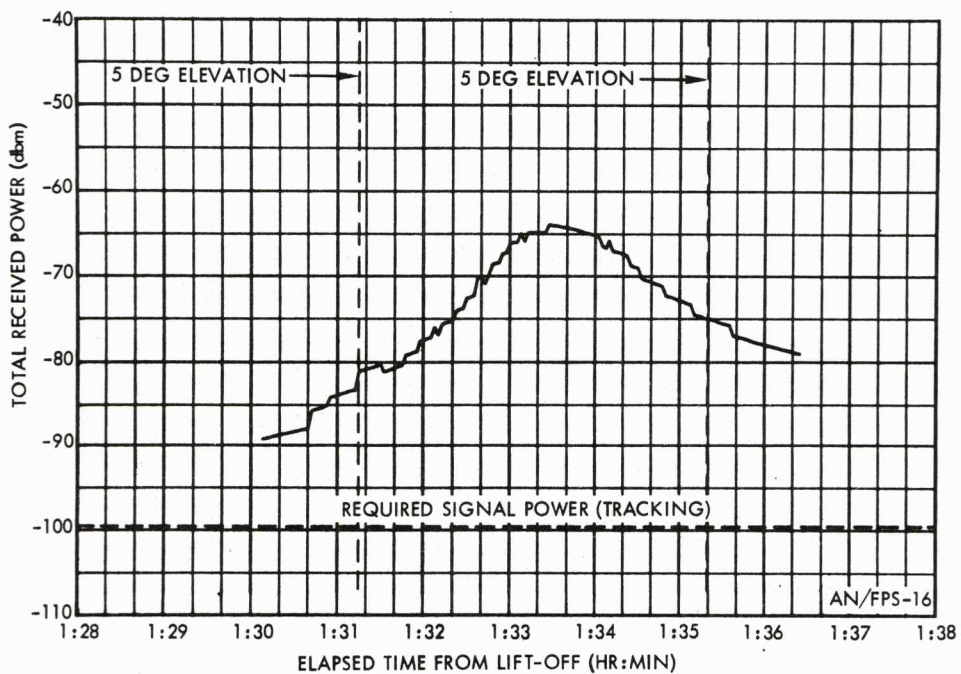


Figure 6-10b. WHS, Z Axis Antennas, Orbit 1

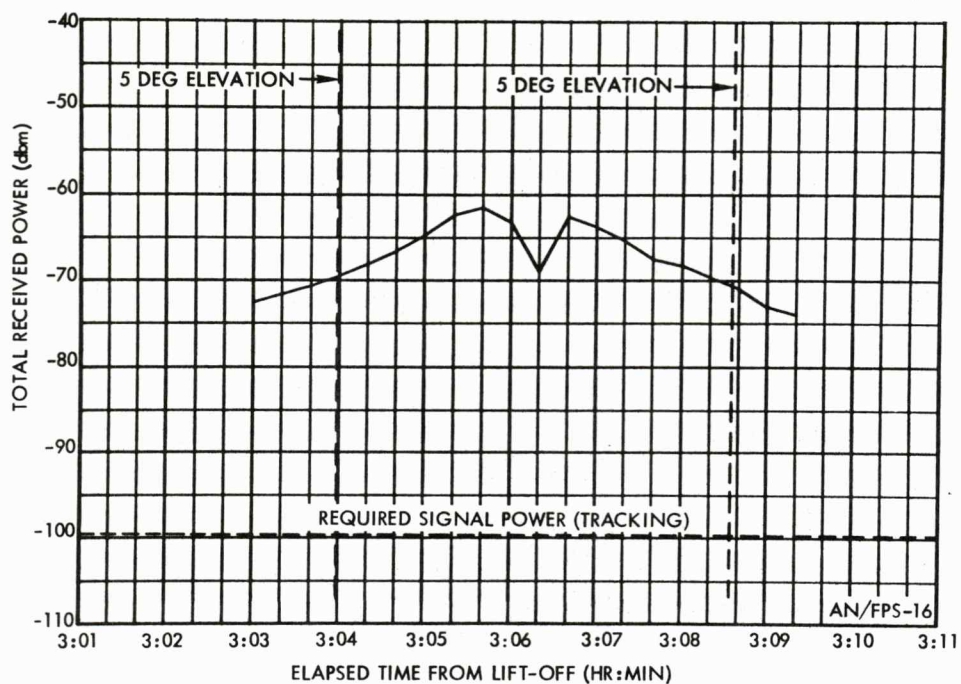


Figure 6-10c. WHS, Y Axis Antennas, Orbit 2

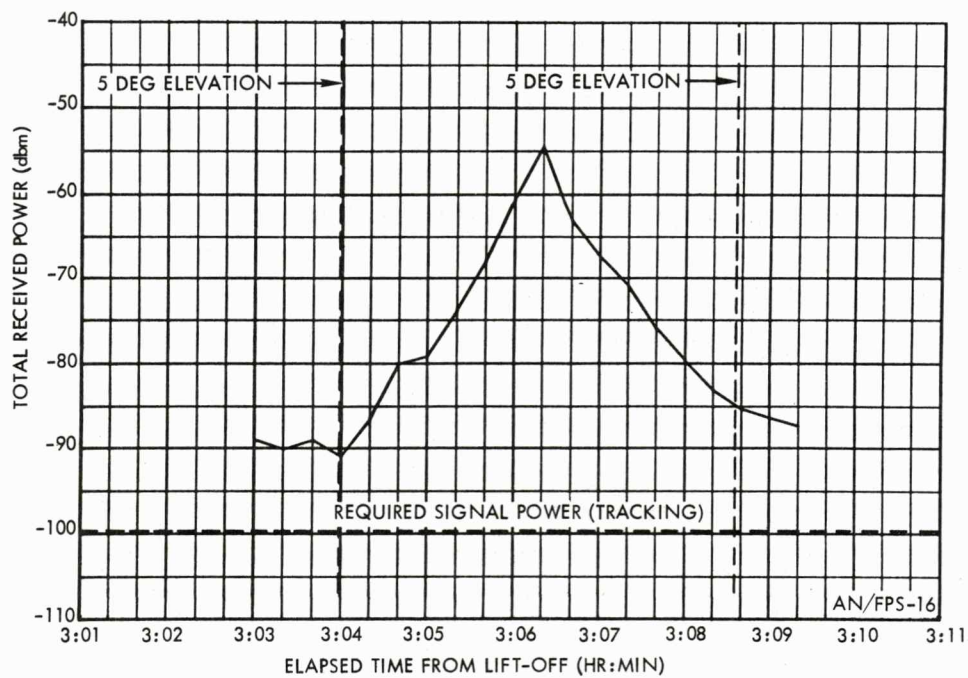


Figure 6-10d. WHS, Z Axis Antennas, Orbit 2

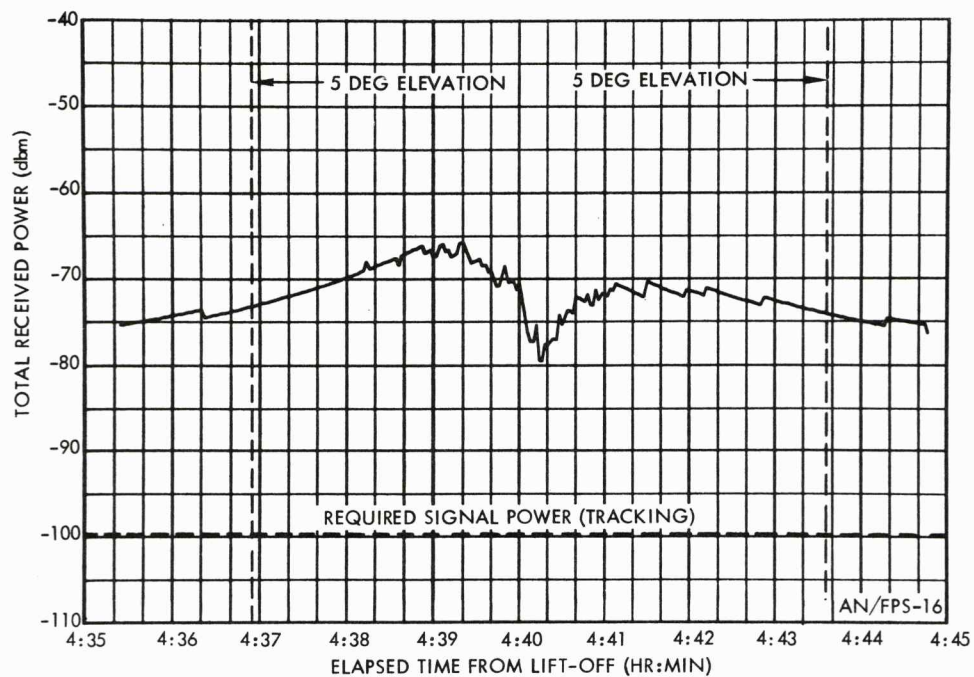


Figure 6-10e. WHS, Y Axis Antennas, Orbit 3

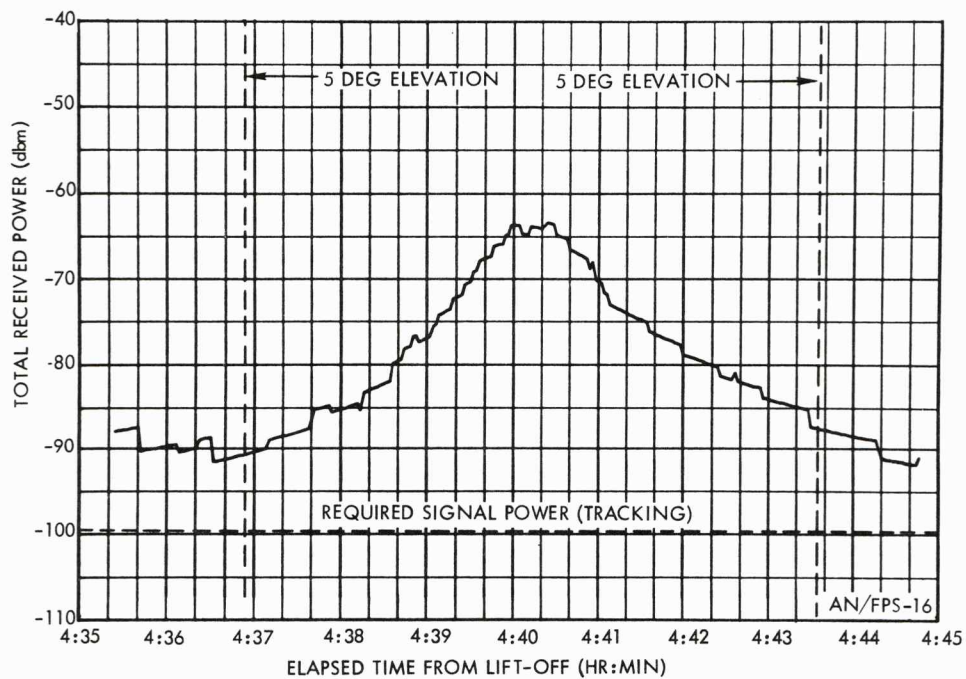


Figure 6-10f. WHS, Z Axis Antennas, Orbit 3

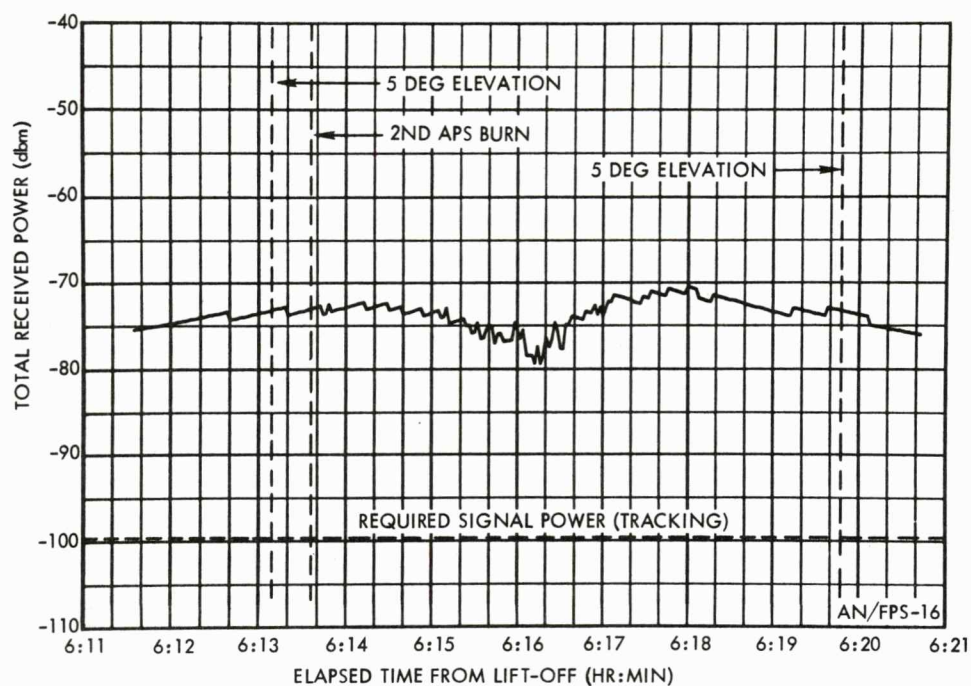


Figure 6-10g. WHS, Y Axis Antennas, Orbit 4

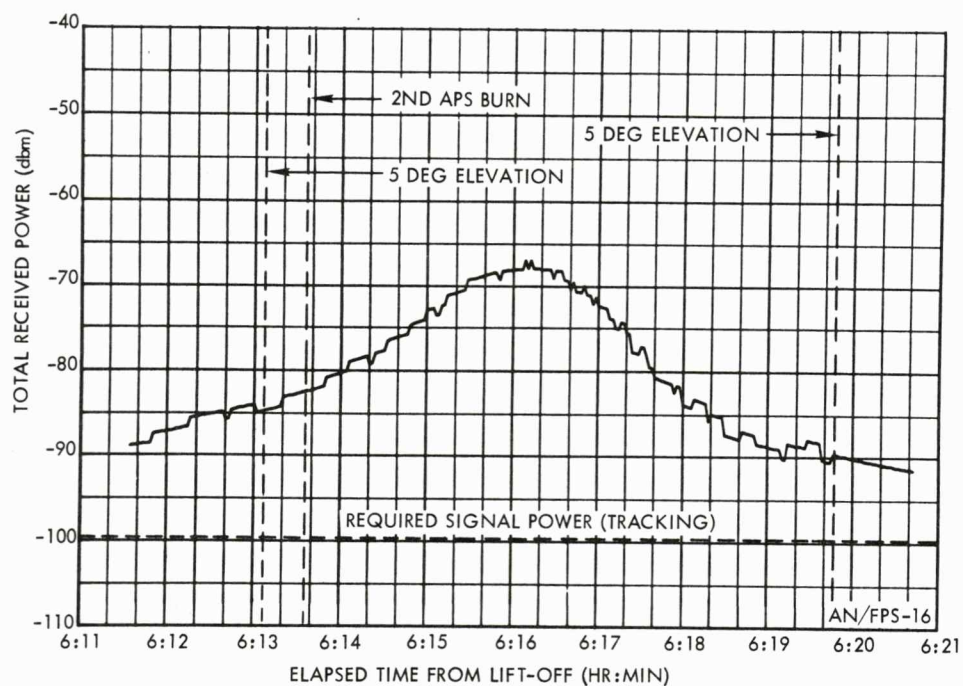


Figure 6-10h. WHS, Z Axis Antennas, Orbit 4

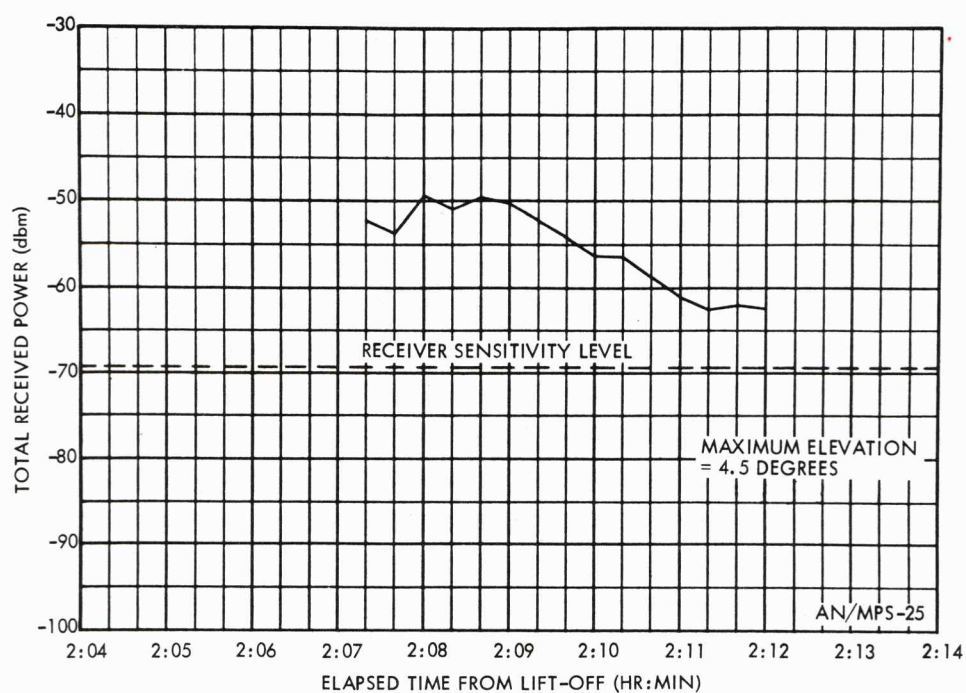


Figure 6-11a. PRE C-band Uplink Total Received Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 2

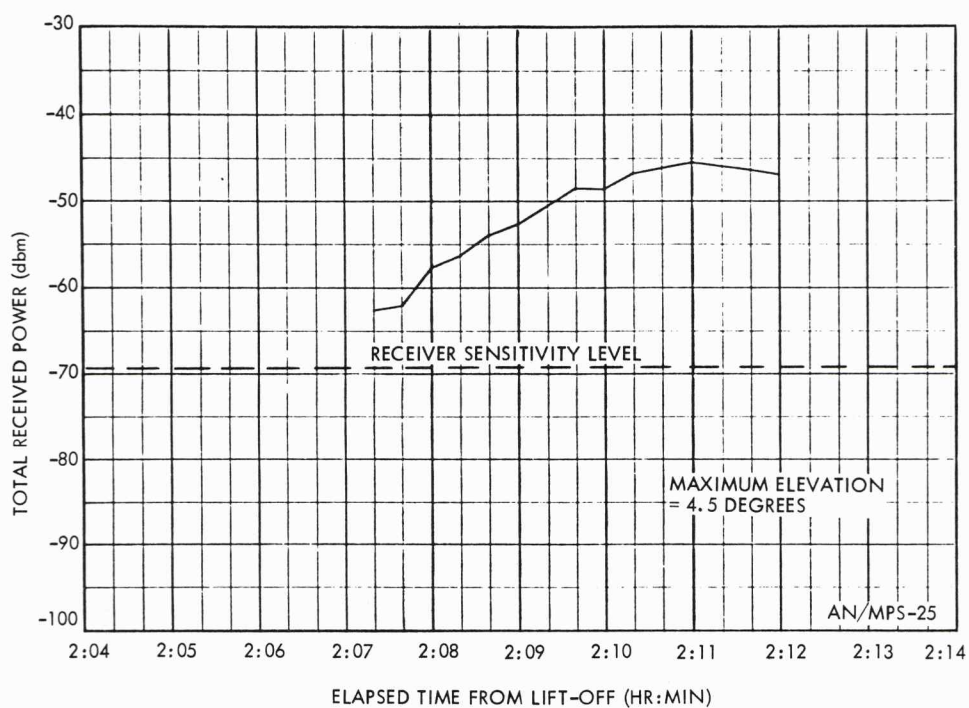


Figure 6-11b. PRE, Z Axis Antennas, Orbit 2

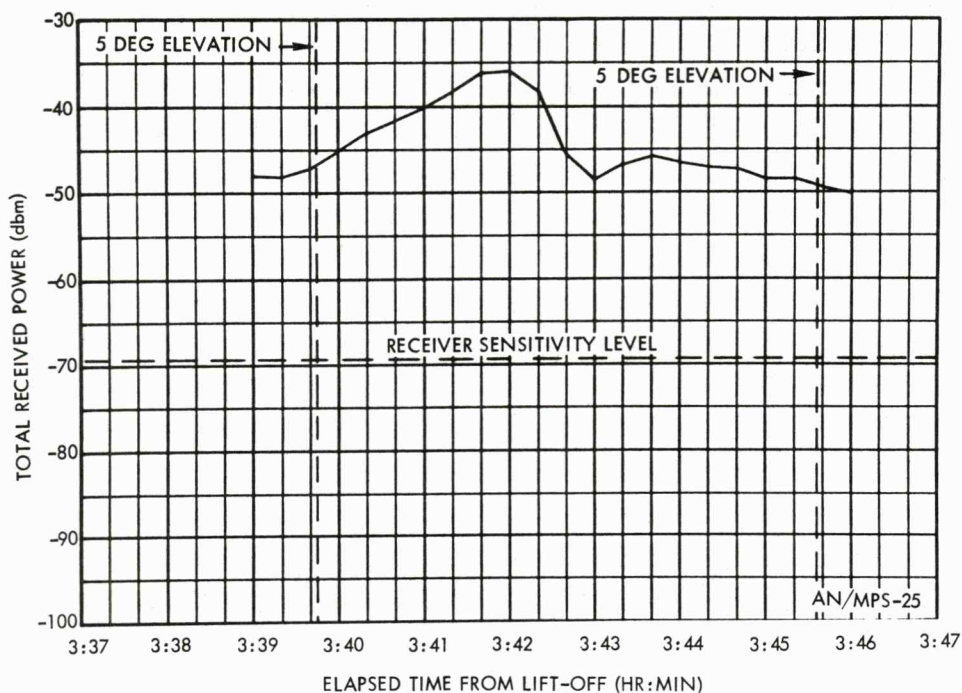


Figure 6-11c. PRE, Y Axis Antennas, Orbit 3

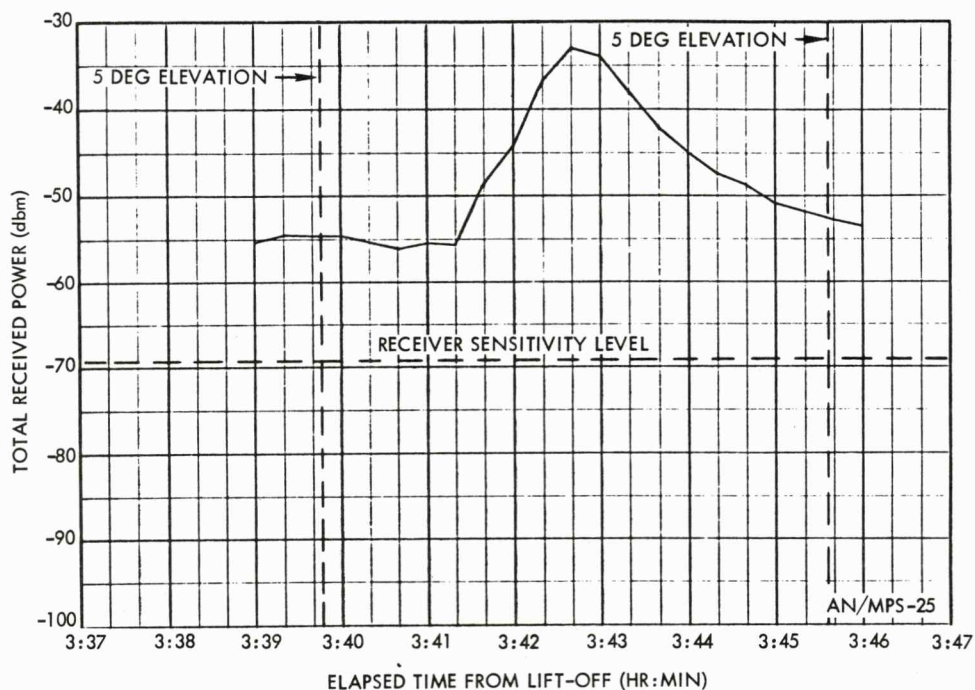


Figure 6-11d. PRE, Z Axis Antennas, Orbit 3

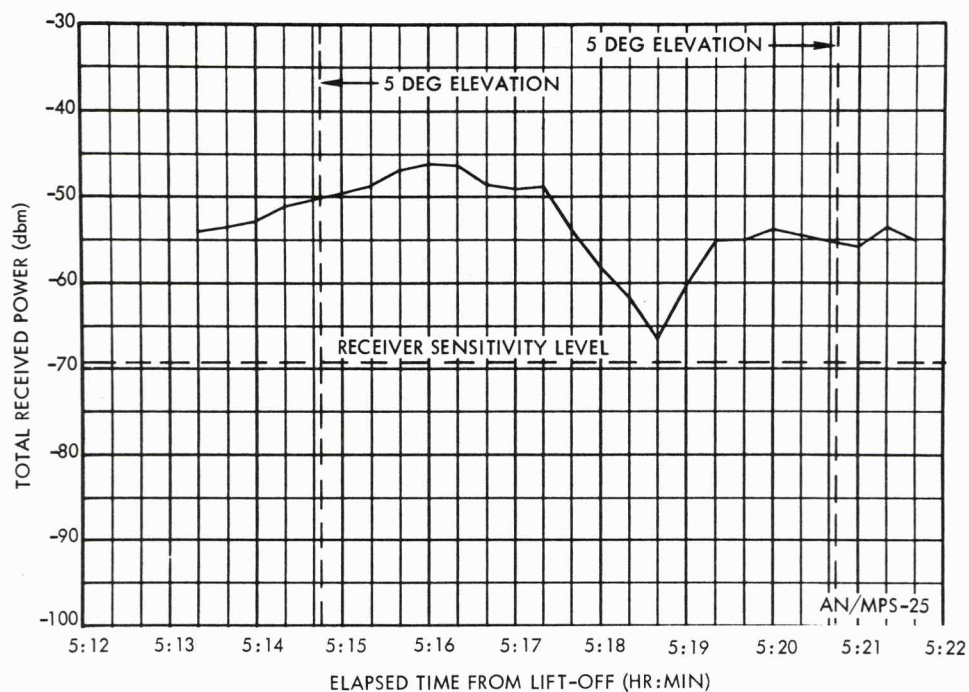


Figure 6-11e. PRE, Y Axis Antennas, Orbit 4

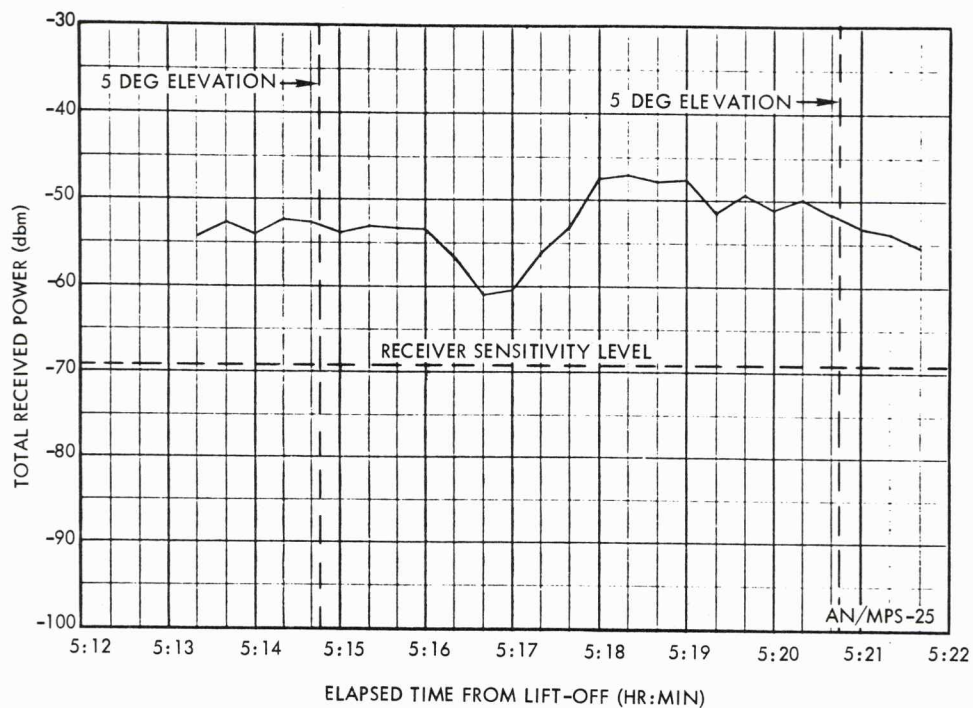


Figure 6-11f. PRE, Z Axis Antennas, Orbit 4

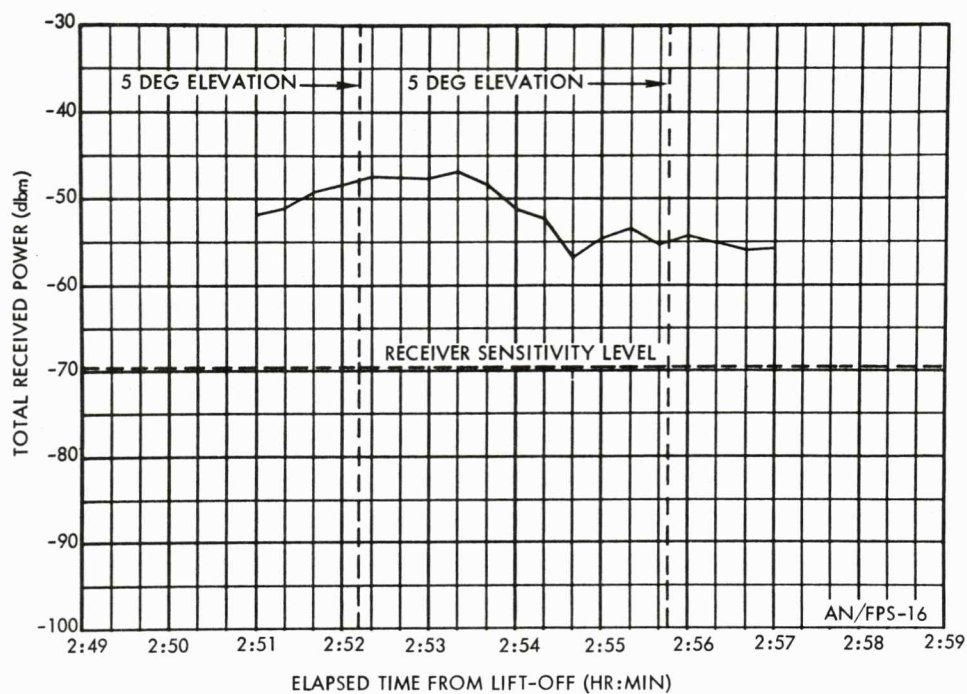


Figure 6-12a. HAW C-band Uplink Total Received Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 2

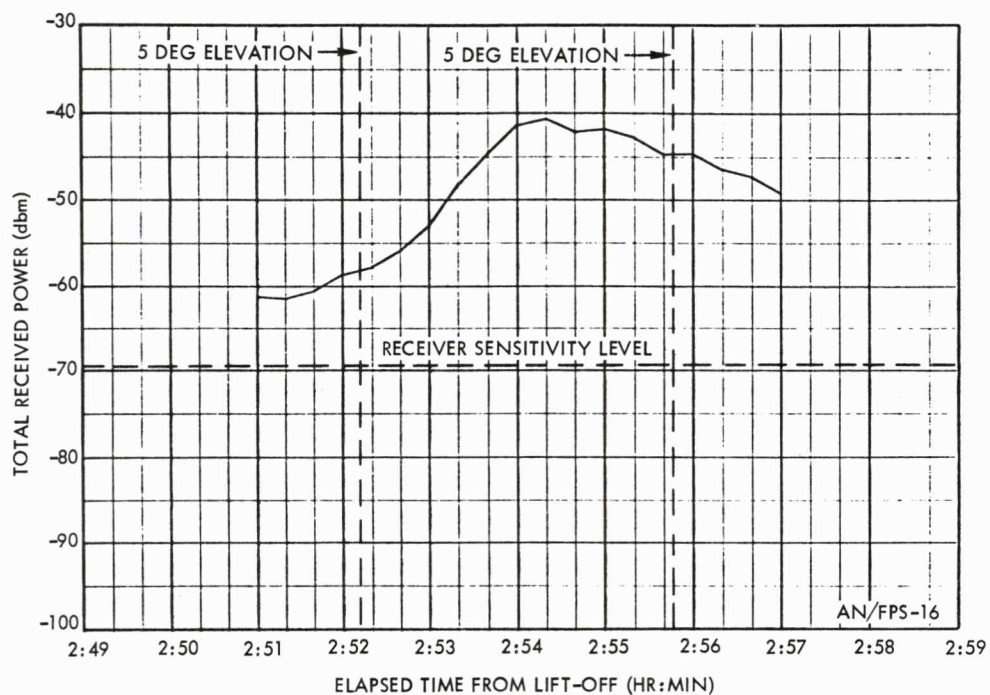


Figure 6-12b. HAW, Z Axis Antennas, Orbit 2

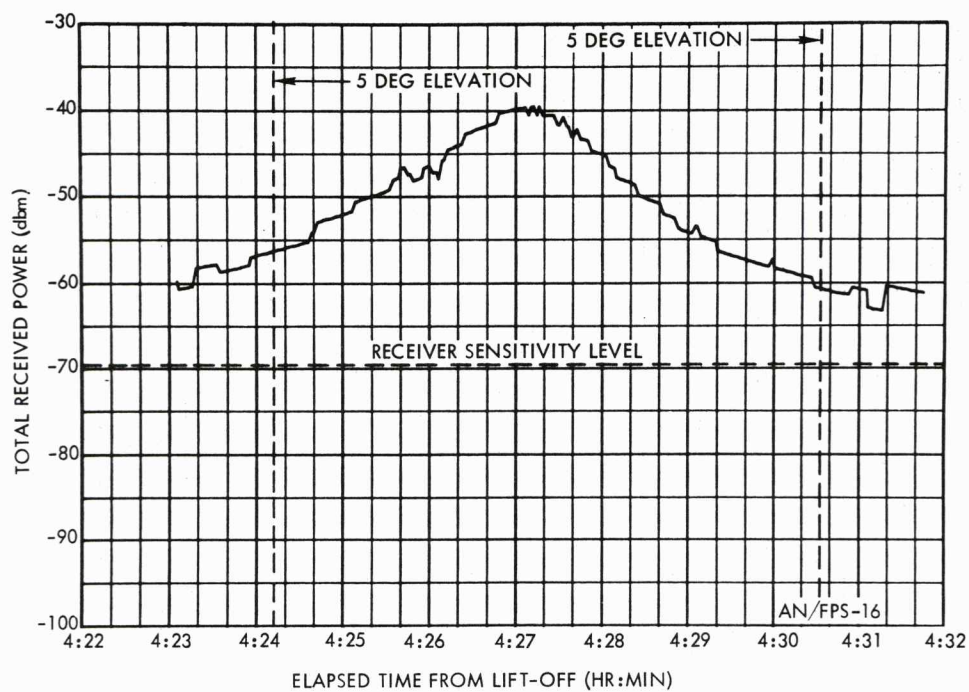


Figure 6-12c. HAW, Y Axis Antennas, Orbit 3

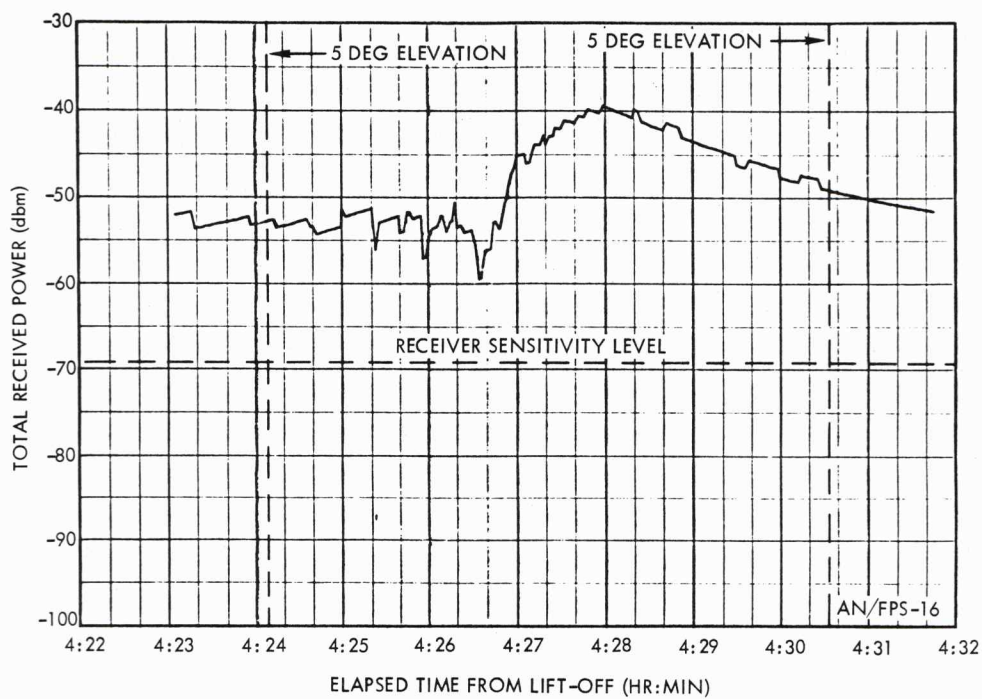


Figure 6-12d. HAW, Z Axis Antennas, Orbit 3

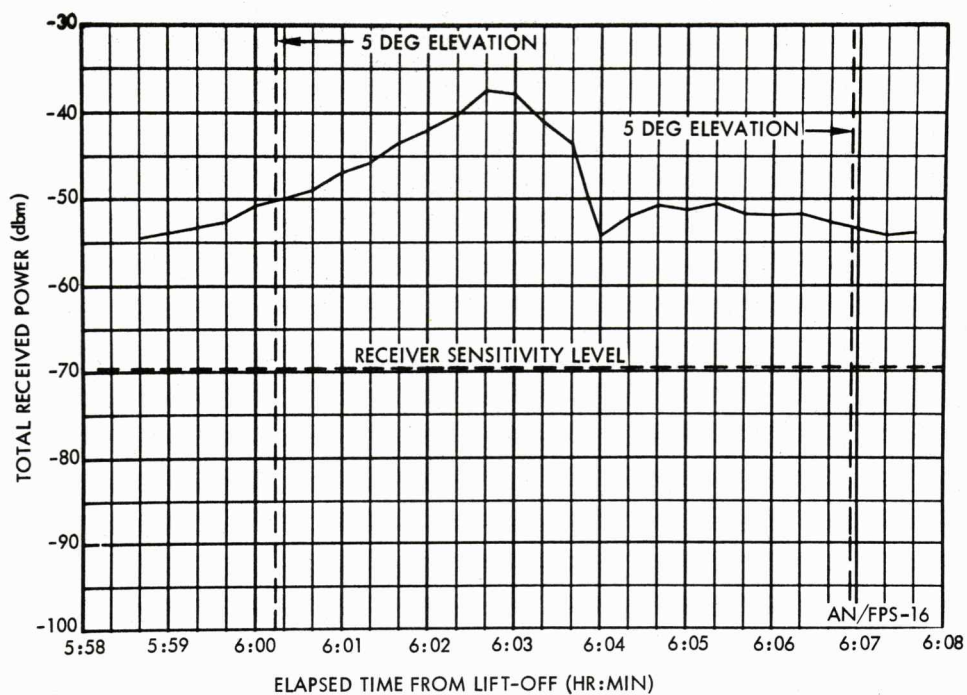


Figure 6-12e. HAW, Y Axis Antennas, Orbit 4

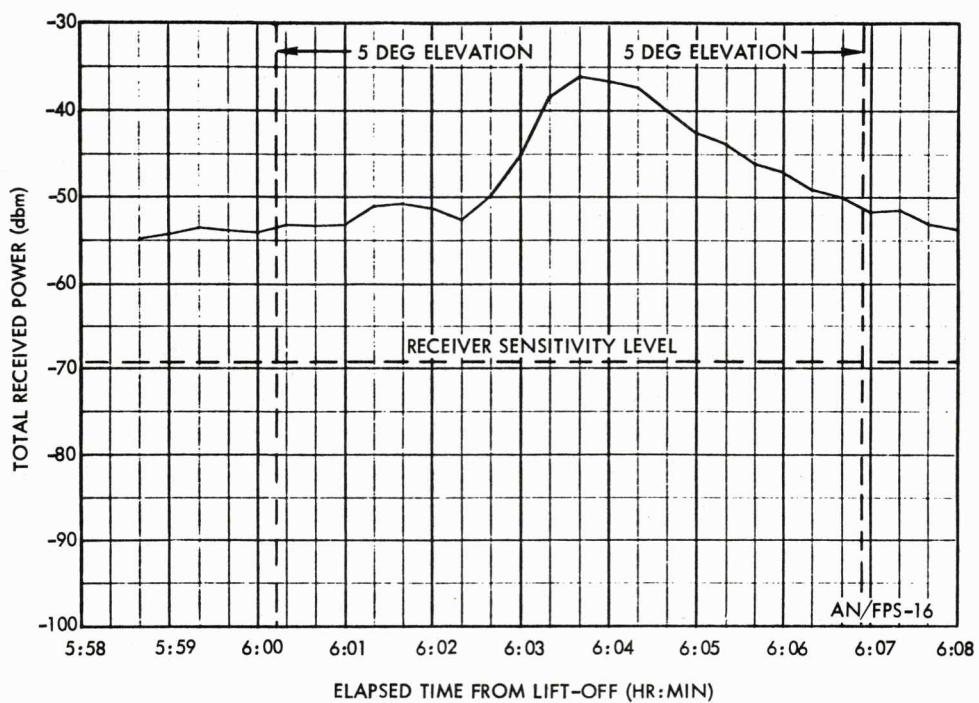


Figure 6-12f. HAW, Z Axis Antennas, Orbit 4

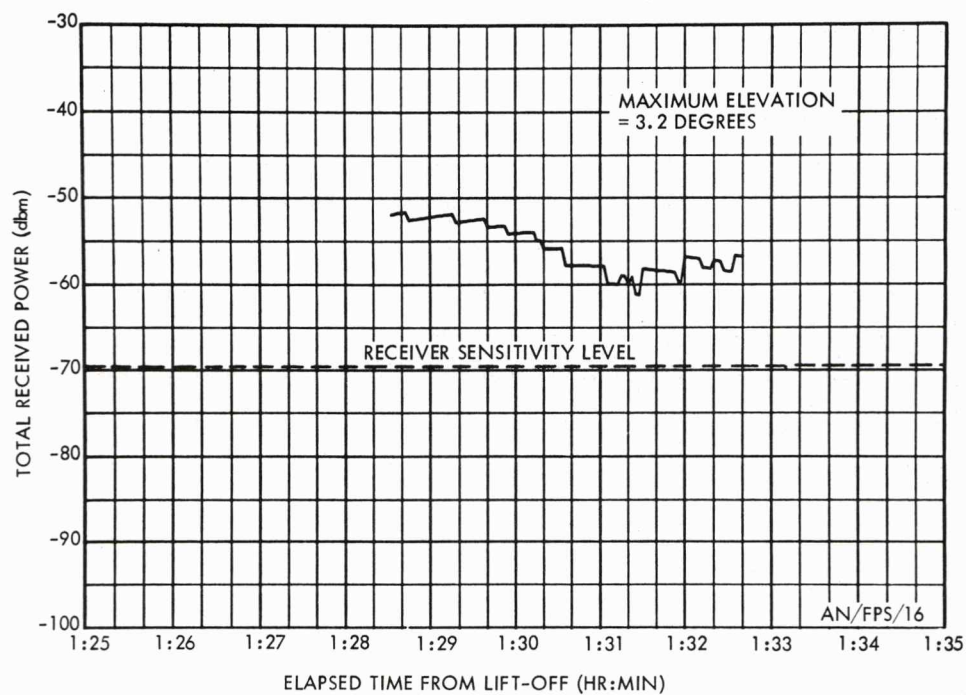


Figure 6-13a. CAL C-band Uplink Total Received Power versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 1

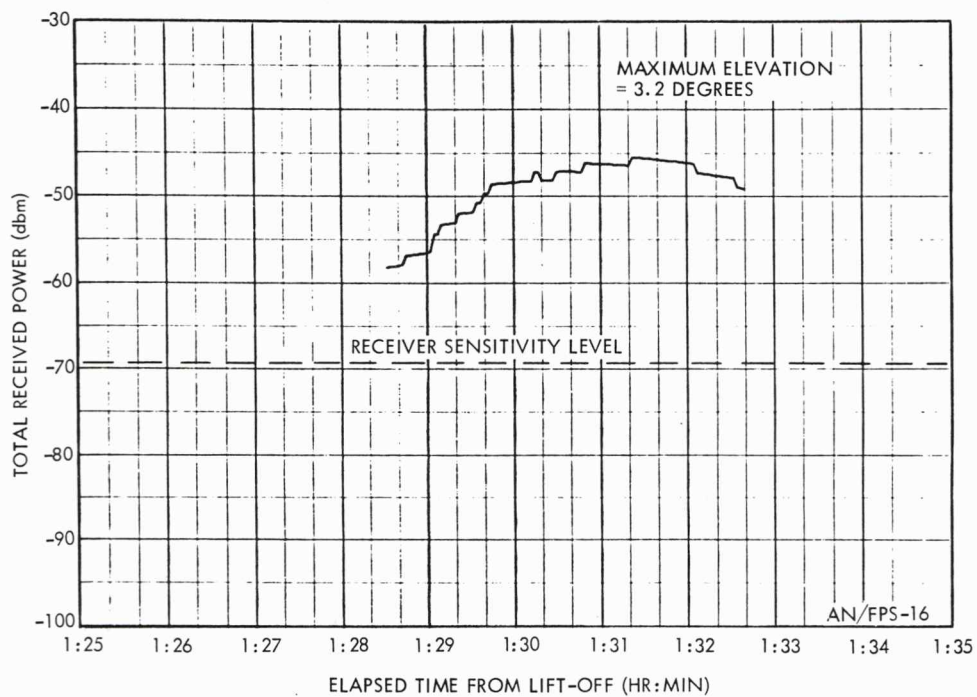


Figure 6-13b. CAL, Z Axis Antennas, Orbit 1

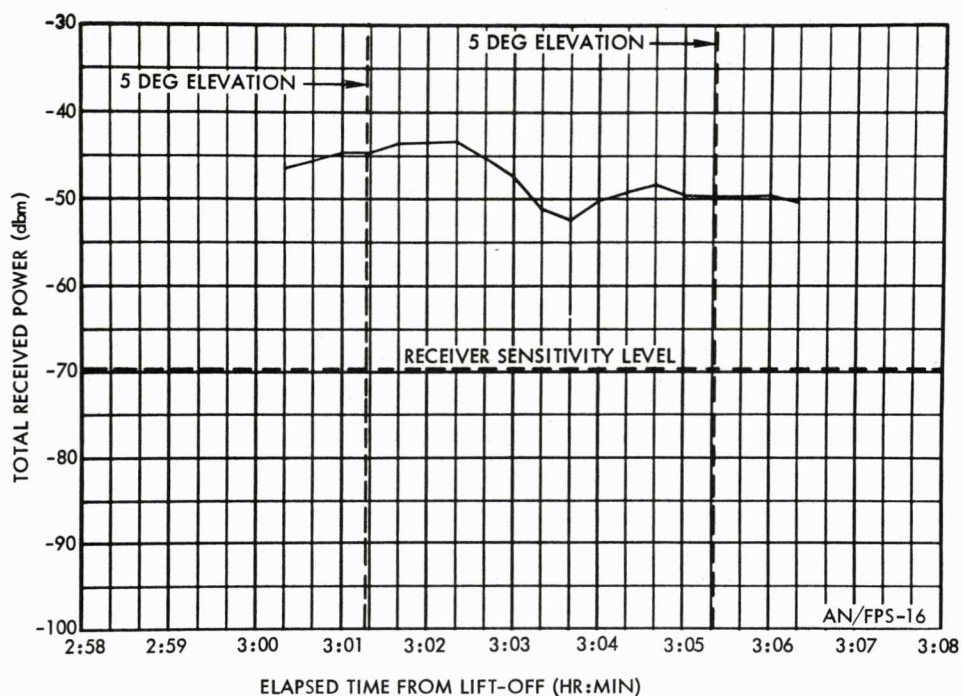


Figure 6-13c. CAL, Y Axis Antennas, Orbit 2

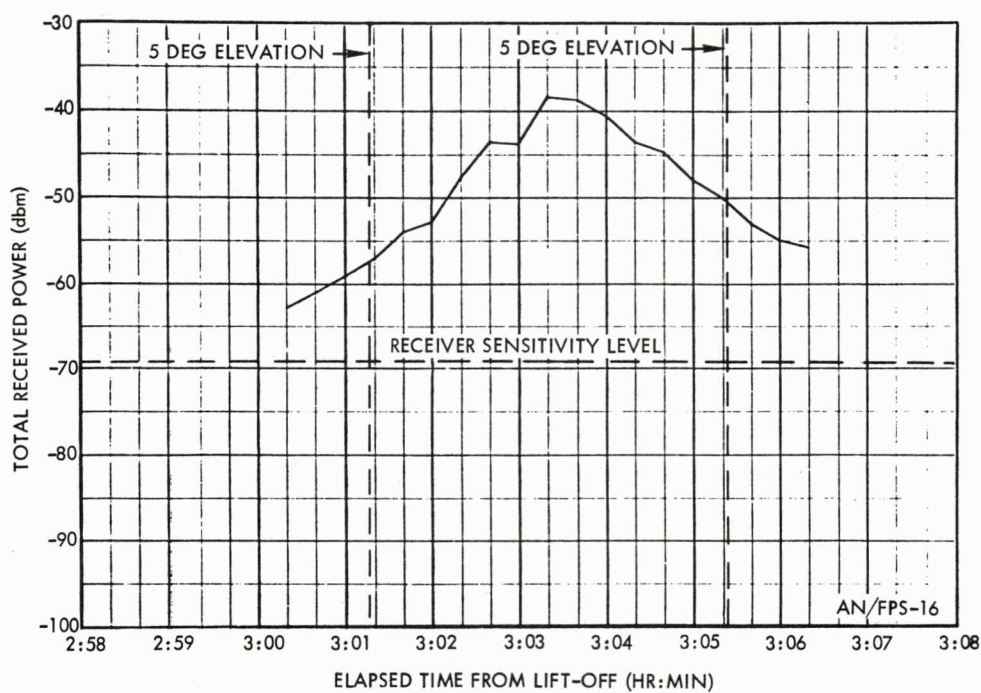


Figure 6-13d. CAL, Z Axis Antennas, Orbit 2

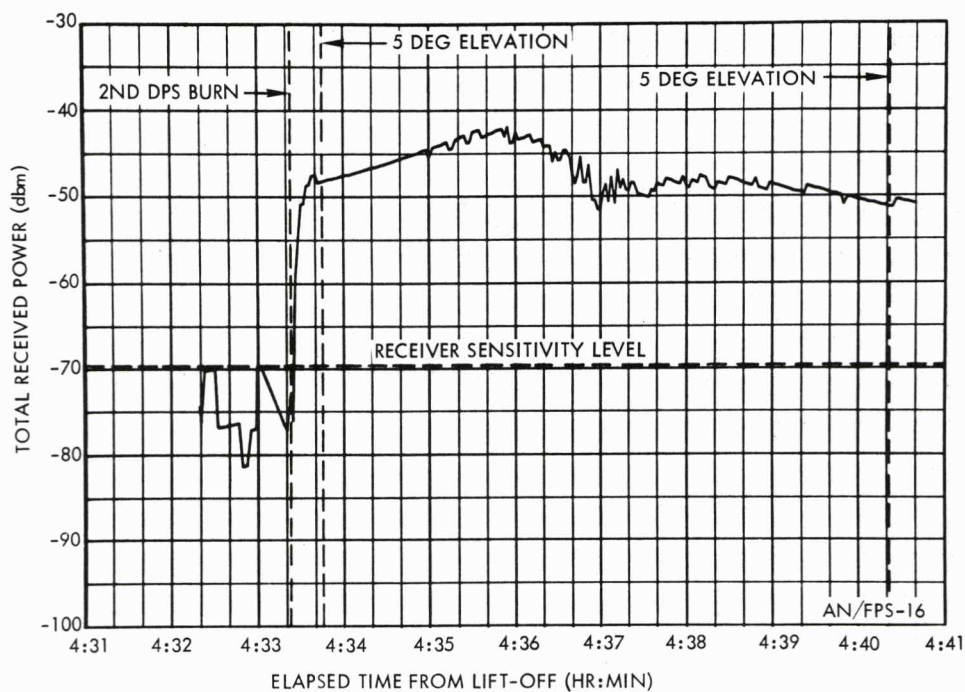


Figure 6-13e. CAL, Y Axis Antennas, Orbit 3

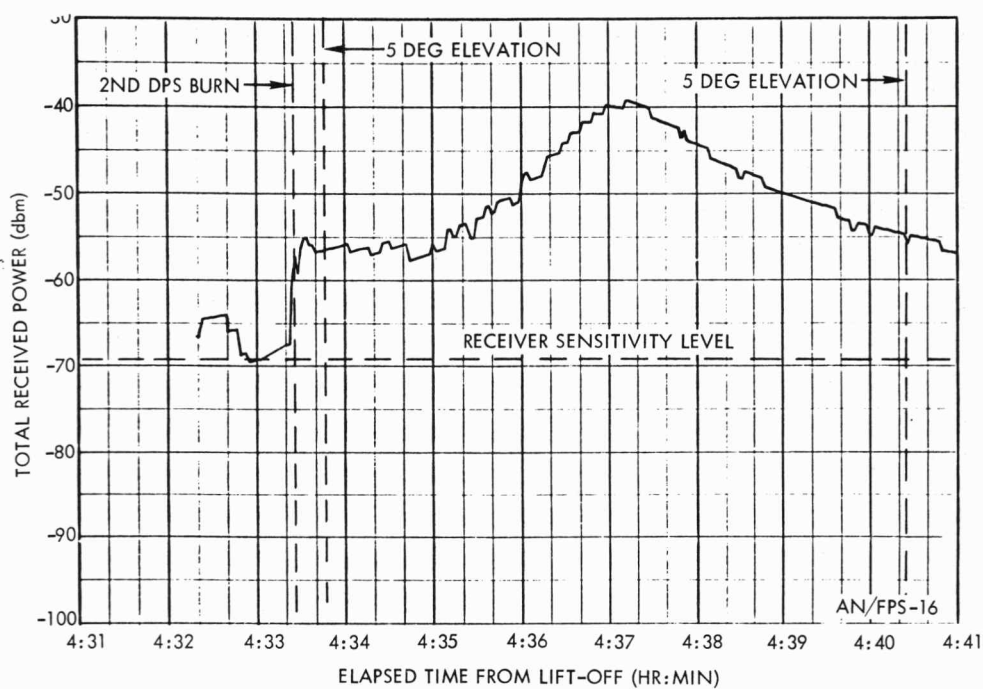


Figure 6-13f. CAL, Z Axis Antennas, Orbit 3

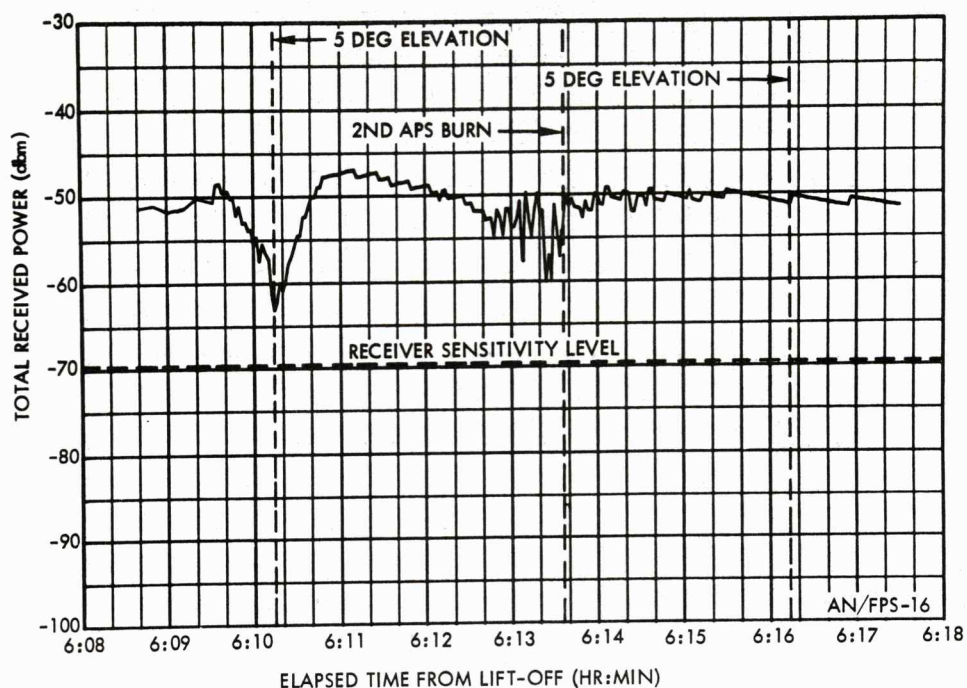


Figure 6-13g. CAL, Y Axis Antennas, Orbit 4

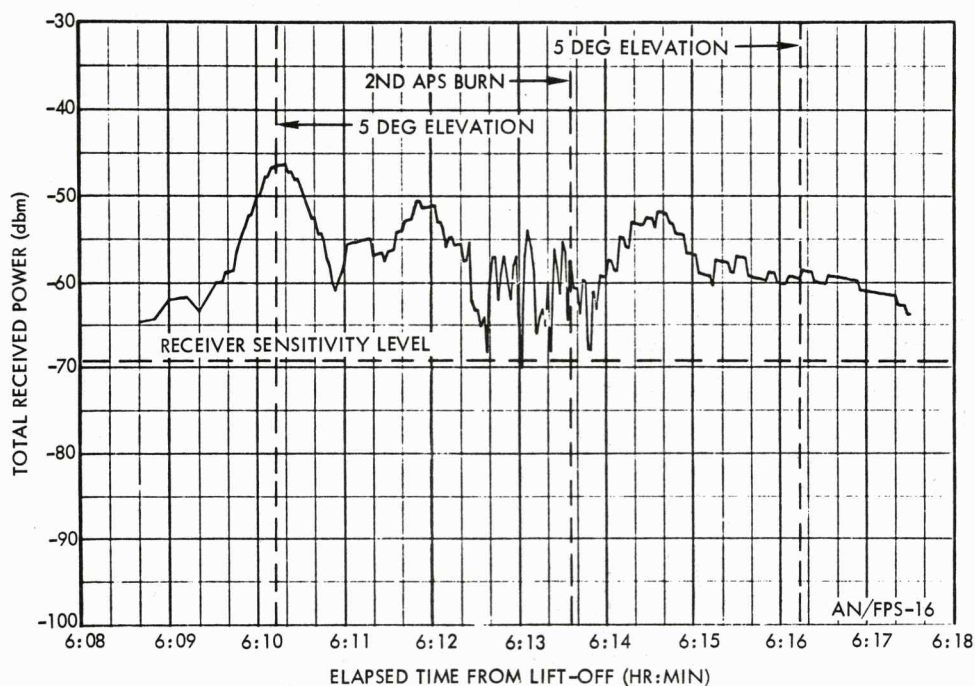


Figure 6-13h. CAL, Z Axis Antennas, Orbit 4

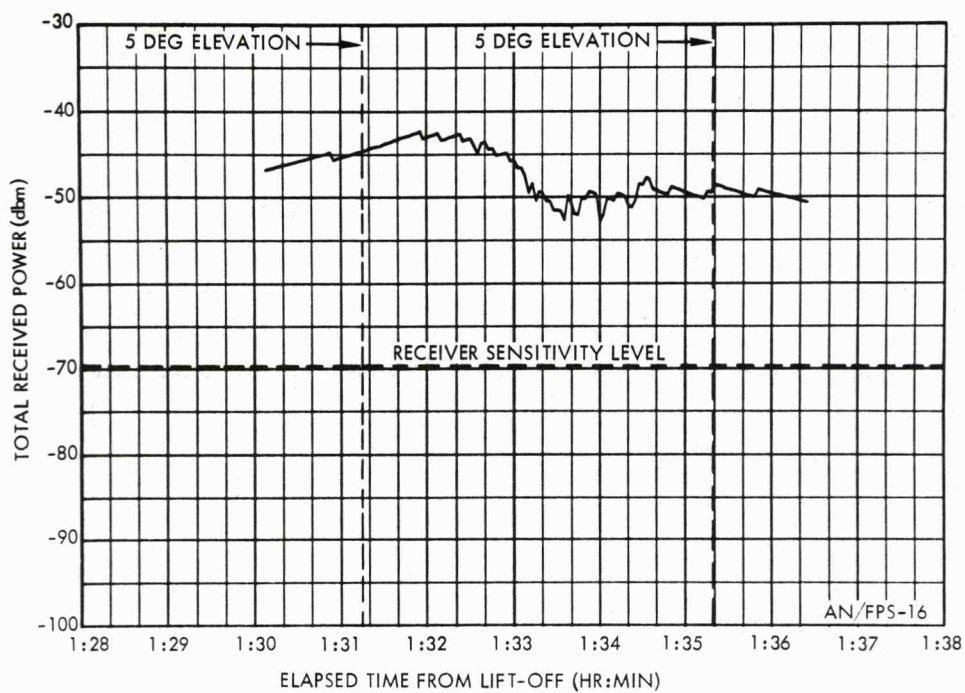


Figure 6-14a. WHS C-band Uplink Total Received Power Versus Elapsed Time from Lift-Off, Y Axis Antennas, Orbit 1

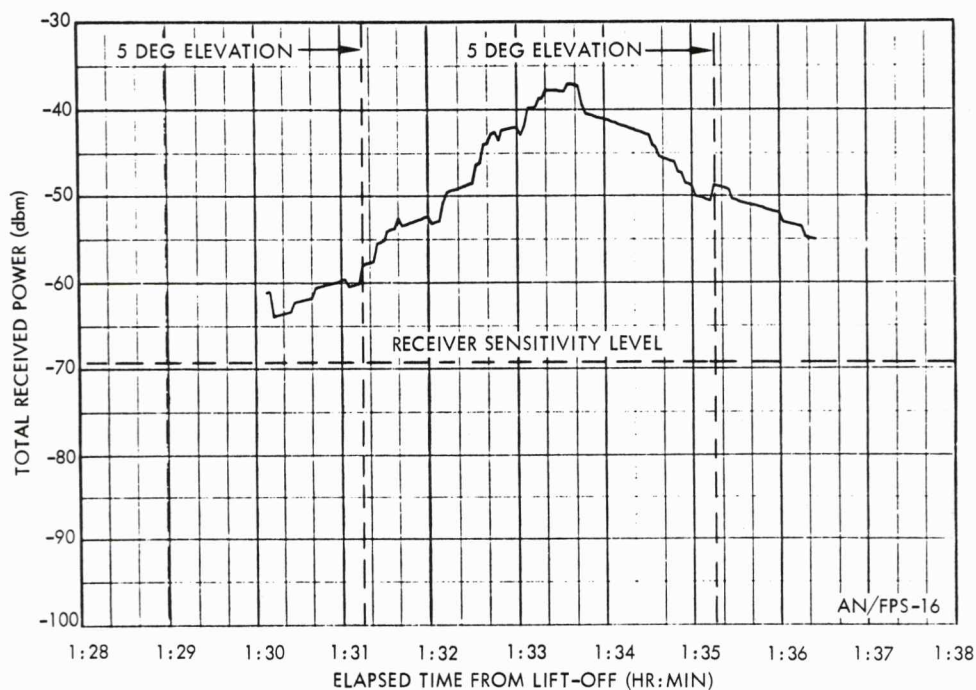


Figure 6-14b. WHS, Z Axis Antennas, Orbit 1

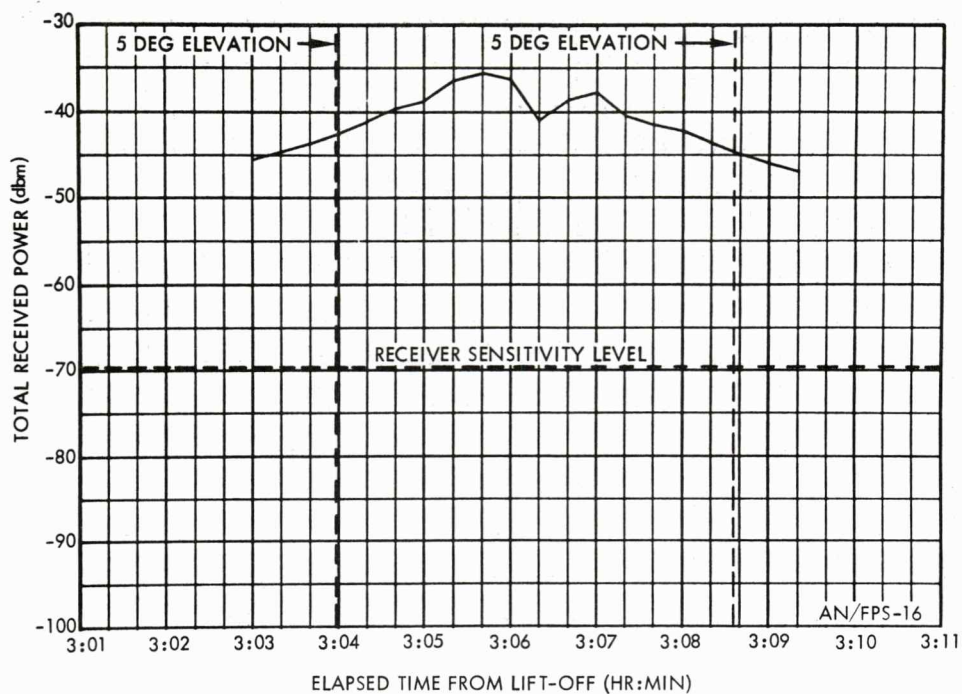


Figure 6-14c. WHS, Y Axis Antennas, Orbit 2

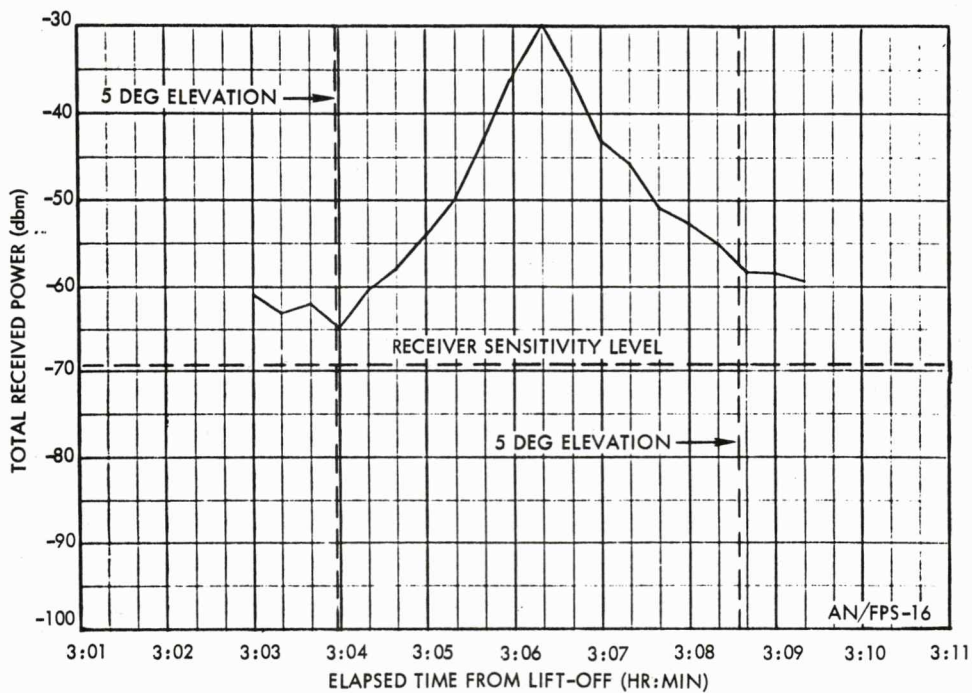


Figure 6-14d. WHS, Z Axis Antennas, Orbit 2

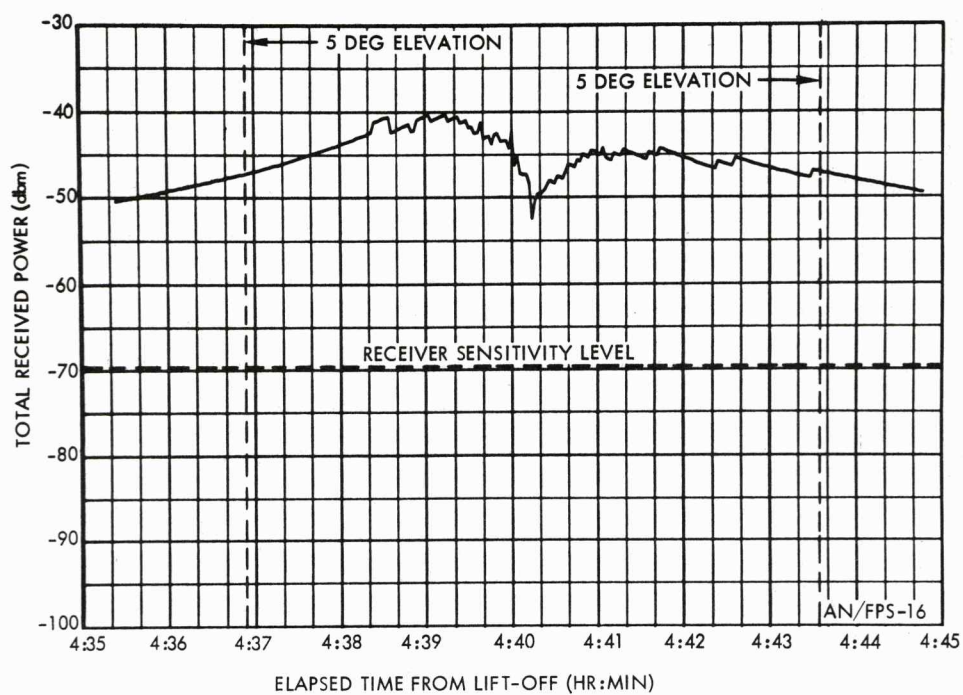


Figure 6-14e. WHS, Y Axis Antennas, Orbit 3

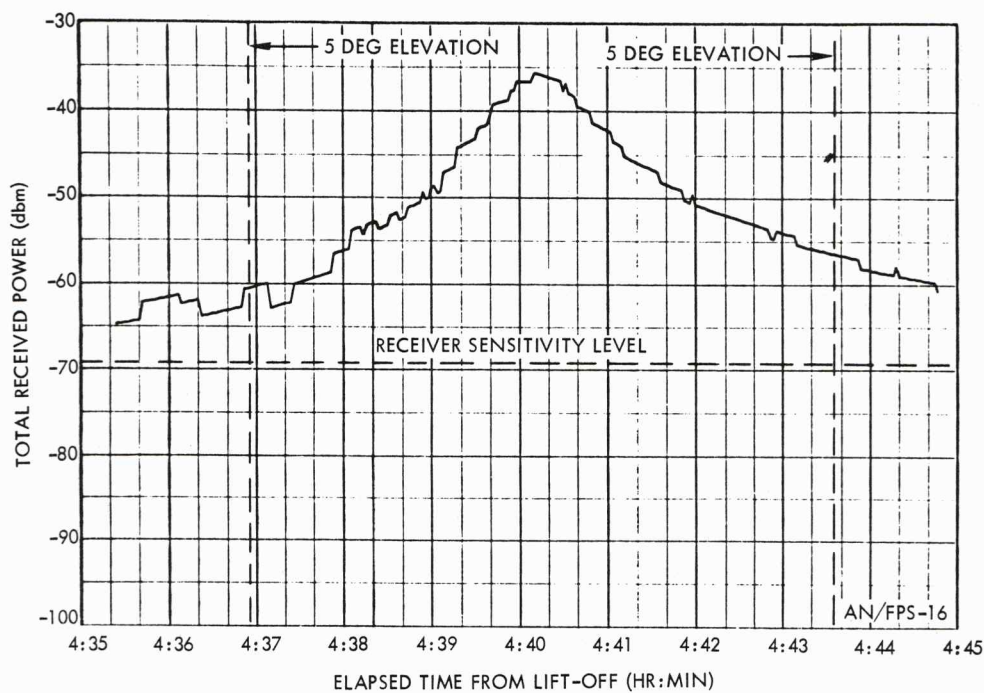


Figure 6-14f. WHS, Z Axis Antennas, Orbit 3

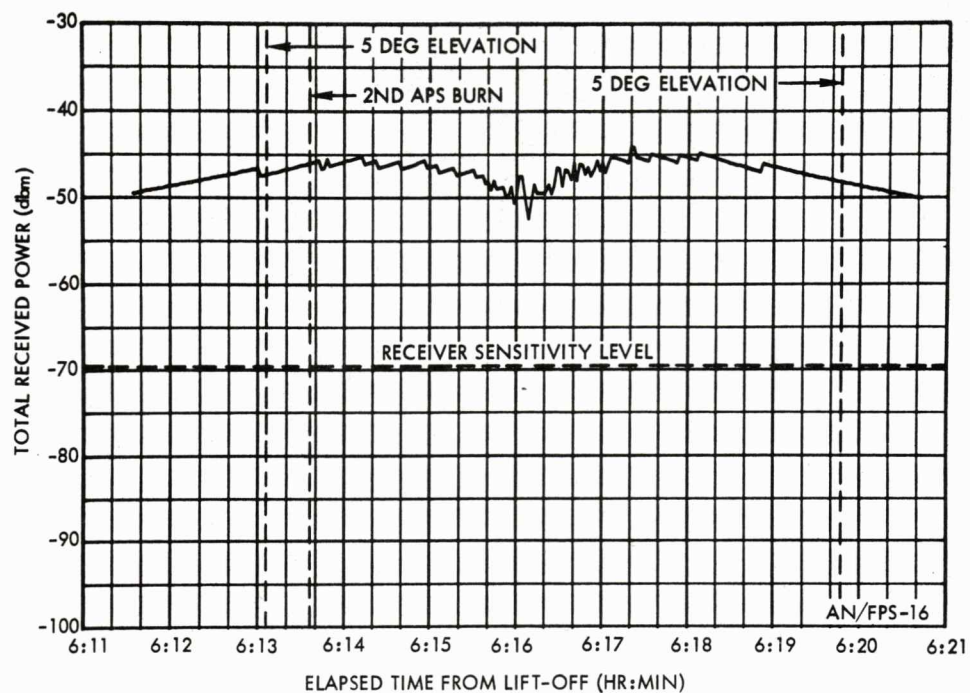


Figure 6-14g. WHS, Y Axis Antennas, Orbit 4

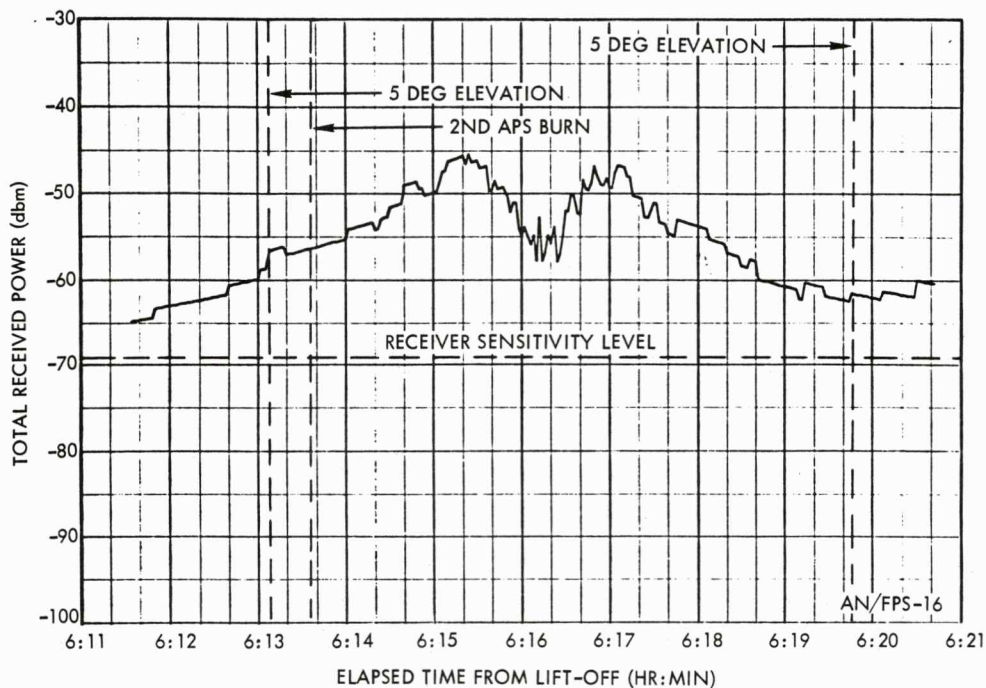


Figure 6-14h. WHS, Z Axis Antennas, Orbit 4

7.0 VHF

7.0 VHF SYSTEM COVERAGE

VHF telemetry coverage for the AS-204/LM-1 is performed by the following five Developmental Flight Instrumentation (DFI) links:

- 230.9 MHz Constant Bandwidth PAM/FM/FM Telemetry
- 237.8 MHz PCM/FM Telemetry
- 241.5 MHz Proportional Bandwidth PAM/FM/FM Telemetry
- 247.3 MHz Proportional Bandwidth PAM/FM/FM Telemetry
- 257.3 MHz Proportional Bandwidth PAM/FM/FM Telemetry

The five DFI transmitters utilize the SLA mounted VHF/UHF antennas prior to LM separation, and the LM mounted DFI antennas after separation. The VHF inflight antennas to be used on a lunar mission are not utilized during this mission.

The PAM/FM/FM links transmit data purely for developmental flight purposes. The PCM/FM link, however, operates in parallel with the S-band PCM telemetry and redundantly transmits PCM high bit rate spacecraft operational data. For mission requirement purposes the VHF system is classified as primary, and the S-band as secondary.

VHF data were obtained from a computer program which combined the spacecraft trajectory data, spacecraft one-sixth scale antenna gain patterns, transmitted power, circuit and space losses, and receiver performance characteristics to give plots of Total Received Power versus Elapsed Time from Liftoff. A flow chart of the computer program is shown in Figure D-1. Calculations were made at 2 second intervals during burns and orientation phases, and at 20 second intervals during coast phases. These data are shown in Figures 7-1 through 7-16. Worst case specified parameters were used for all calculations. Values used are shown in Appendix A and sample calculations are shown in Appendix B. Data are plotted whenever the spacecraft is within line-of-sight of the ground station, i.e., whenever the elevation look angle of the ground station is above 0° . Indicated on the graphs are the times when the MSFN elevation look angles are 5° , and when major events occur.

Zero db for the VHF/FM system is defined as the required signal-to-noise ratio for linear detector operation (FM threshold). Therefore, negative margins are not considered usable since equipment performance deteriorates drastically below FM threshold.

Plots for the PCM/FM system are shown in the report because telemetry obtained from this system will be compared with S-band telemetry. The PAM/FM/FM channel A system will have margins approximately 5 dB less than those for the PCM system. The other PAM/FM/FM channels are approximately 3 dB better than those for the PCM system.

The VHF telemetry systems are operational at lift-off. Launch vehicle trajectory data were used to obtain the computer plots until S-IVB shutdown, after which spacecraft operational trajectory data were used. A slight discrepancy between the two sets of trajectory data resulted in the discontinuity on the signal strength plot of BDA in Figure 7-3a.

Since the VHF will be operational from lift-off, flame effects and shadow effects from the first stage will be present. The signal level will be severely attenuated during these times. The amount of degradation is, however, not known. These will degrade the signals at only one of the stations covered in this report. The durations of these effects are shown in the VHF plot for MIL in Figure 7-1a.

VHF telemetry plots show positive signal margins during all phases of the mission except for a few short periods. VHF telemetry coverage is considered satisfactory for the mission.

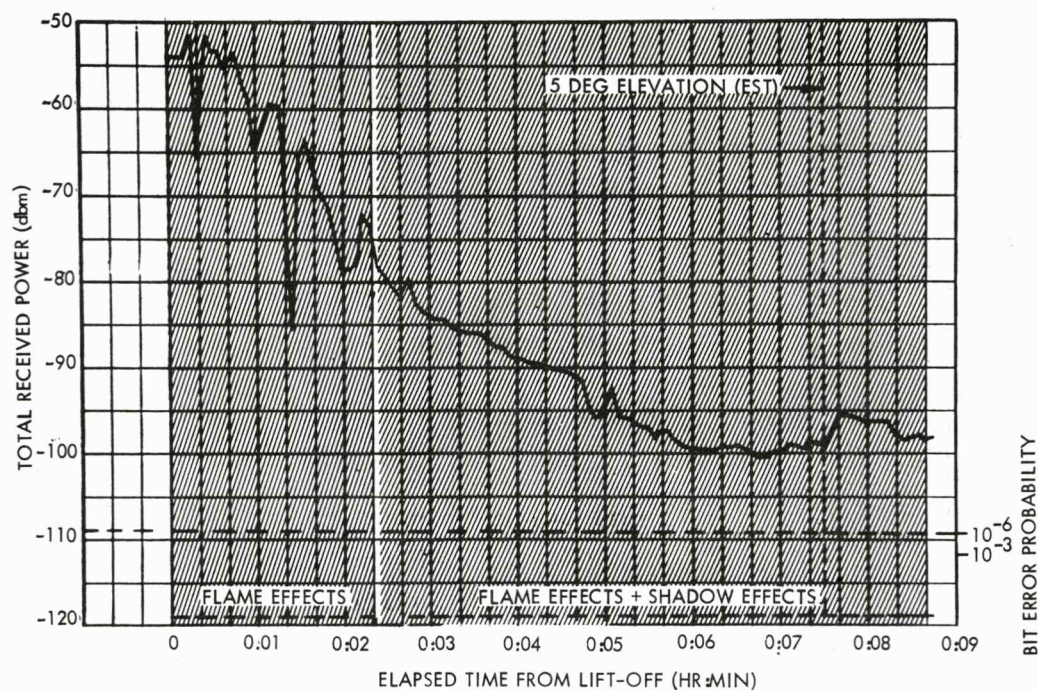


Figure 7-1a. MIL VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

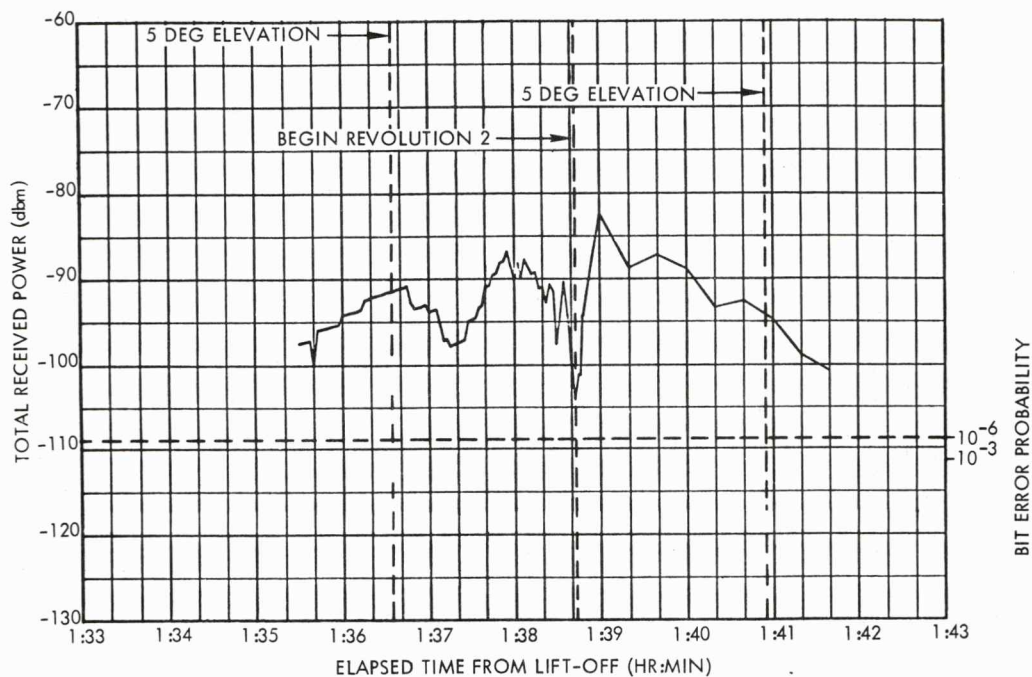


Figure 7-1b. MIL VHF, Orbit 1-2

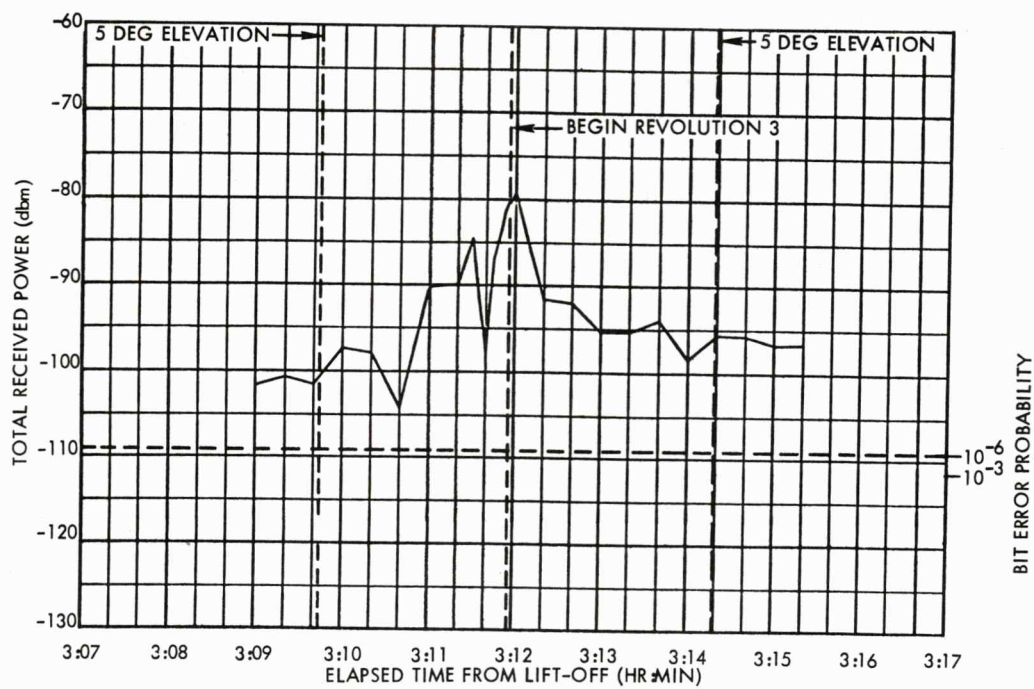


Figure 7-1c. MIL VHF, Orbit 2-3

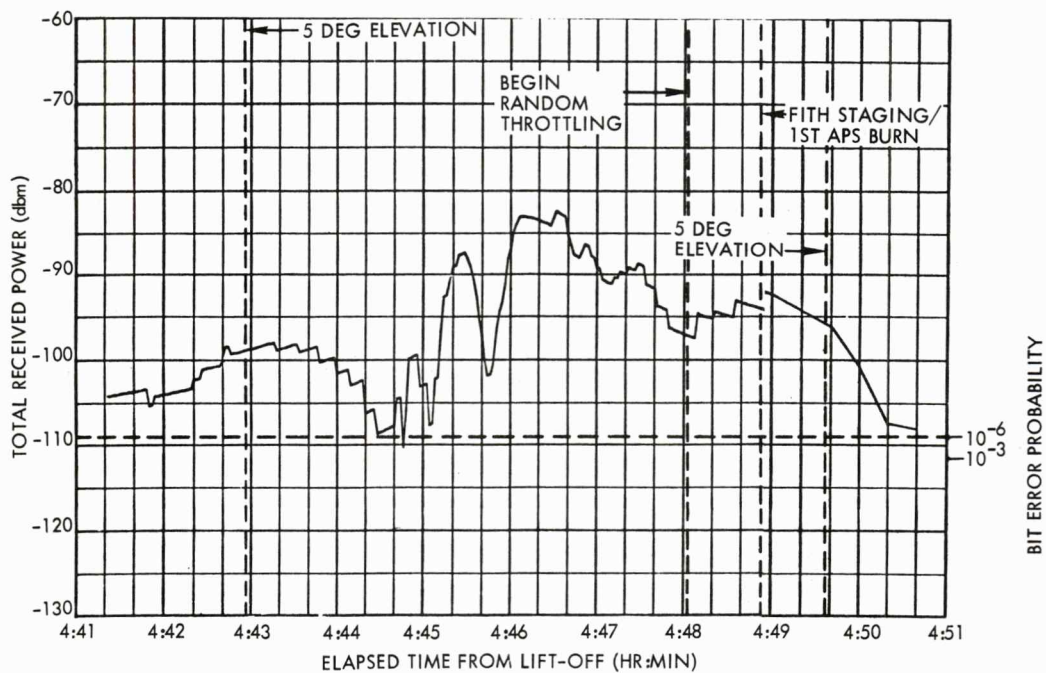


Figure 7-1d. MIL VHF, Orbit 3-4

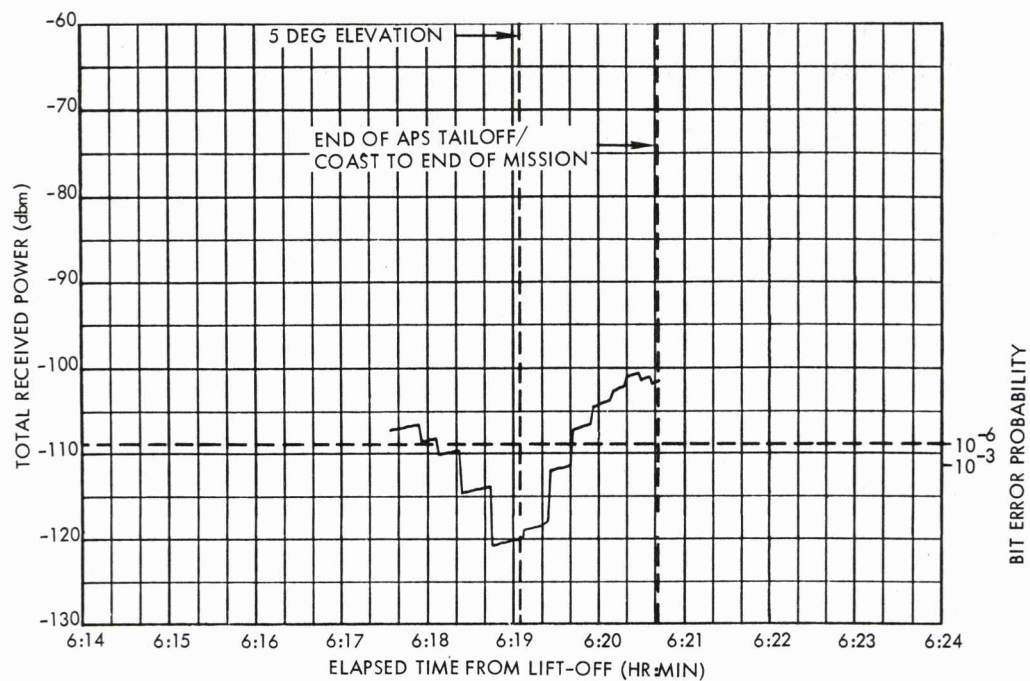


Figure 7-1e. MIL VHF, Orbit 4

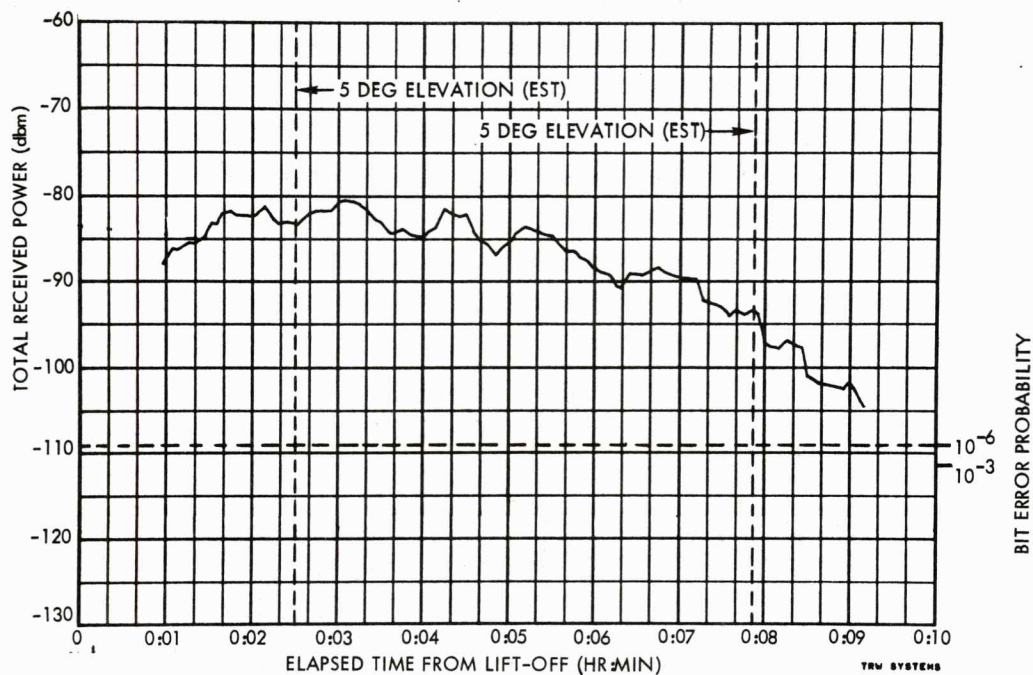


Figure 7-2a. GBI VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

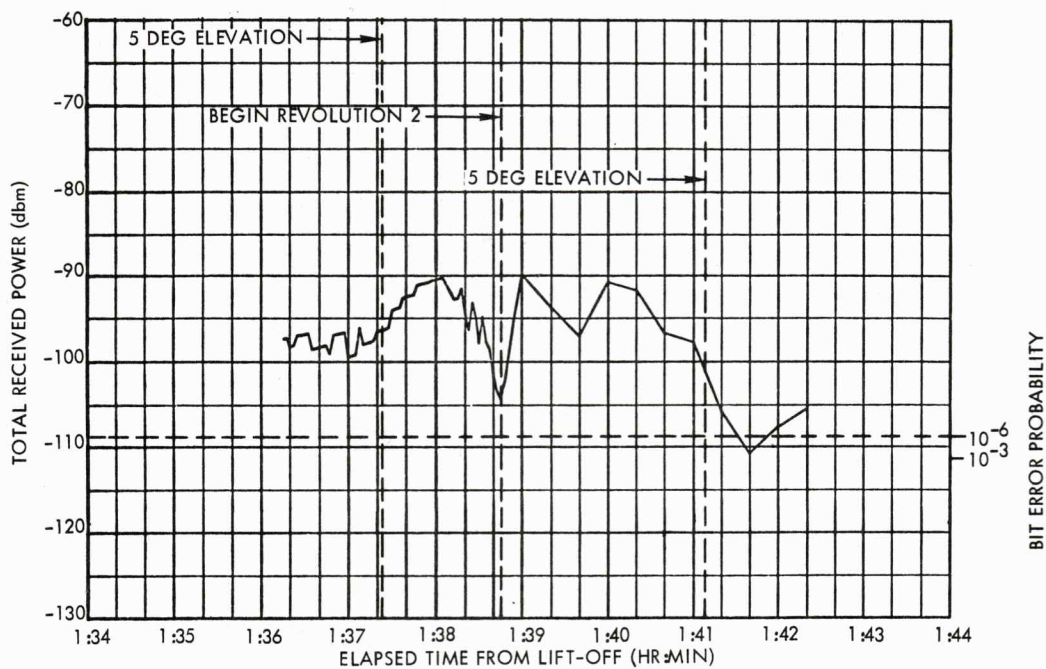


Figure 7-2b. GBI VHF, Orbit 1-2

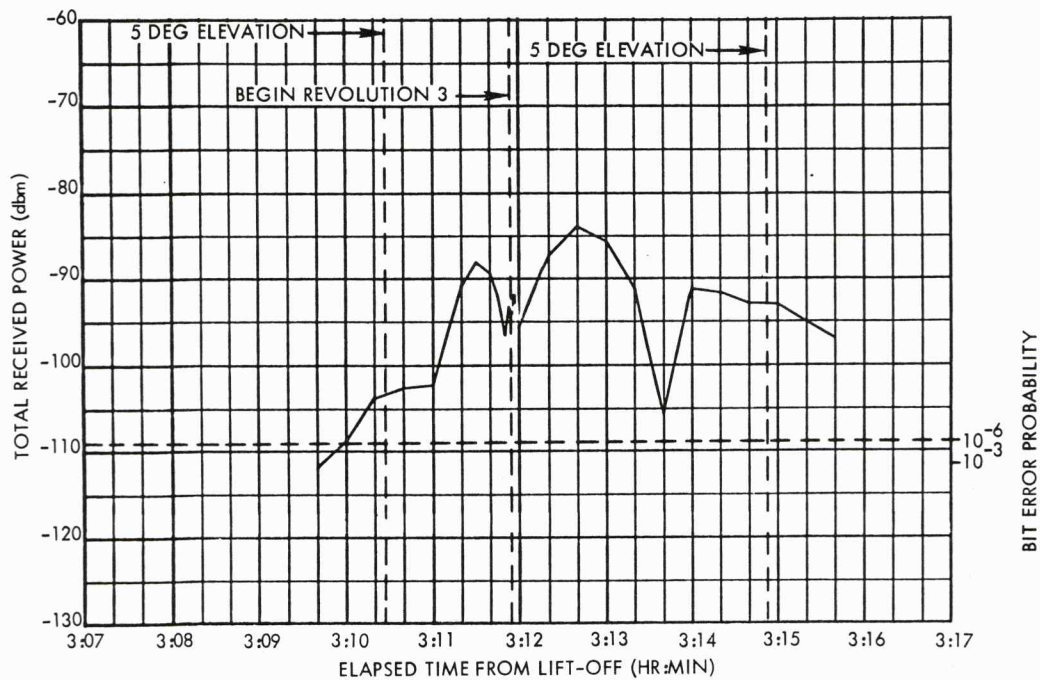


Figure 7-2c. GBI VHF, Orbit 2-3

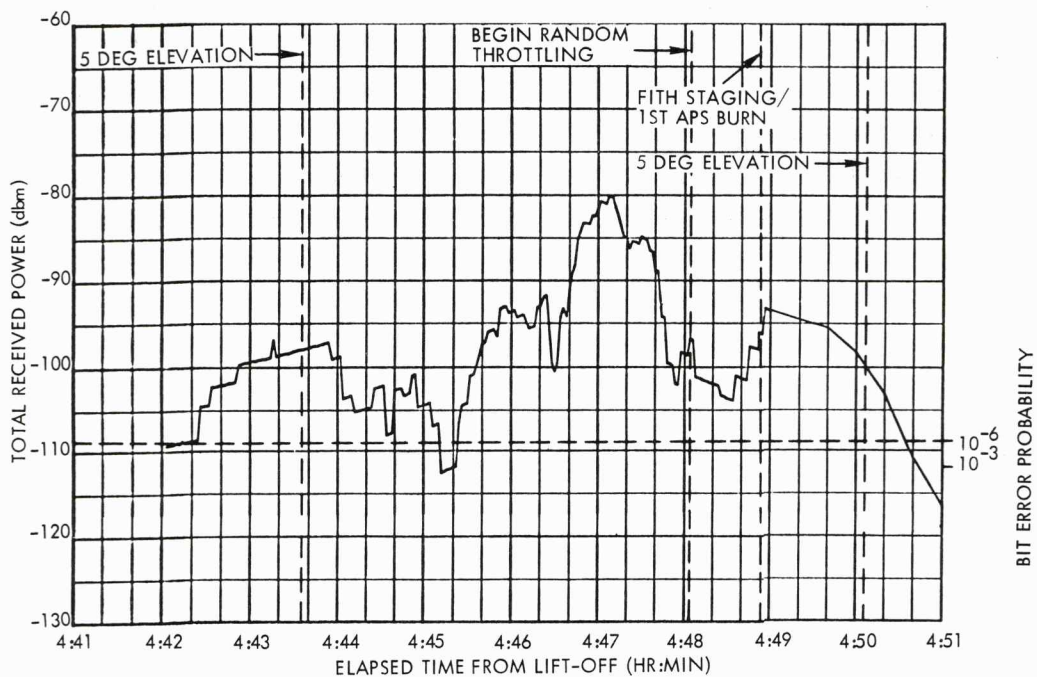


Figure 7-2d. GBI VHF, Orbit 3-4

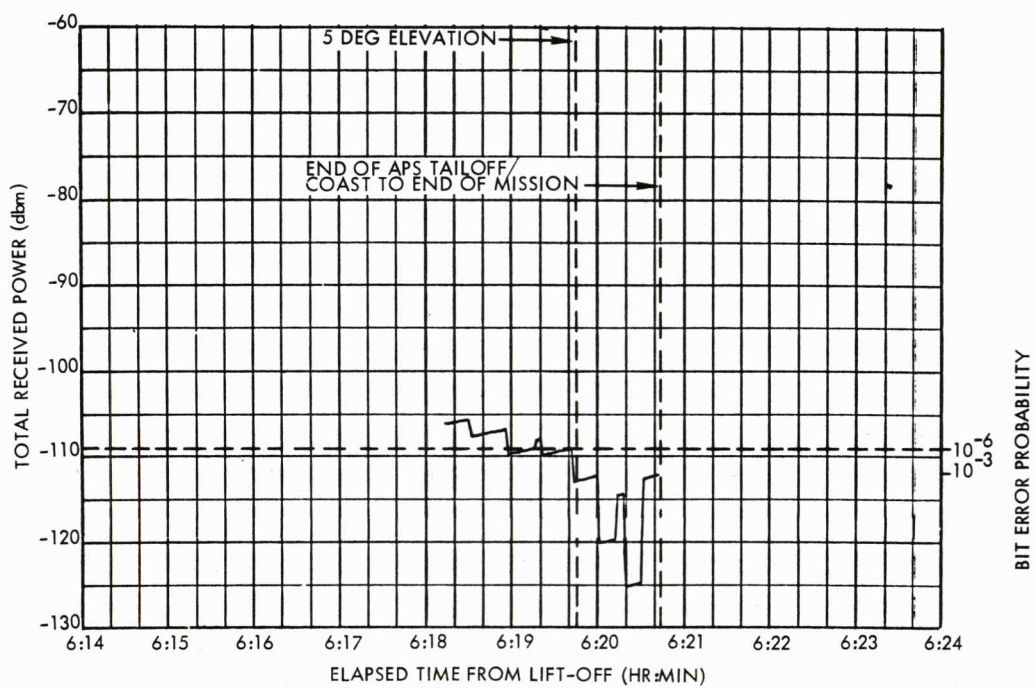


Figure 7-2e. GBI VHF, Orbit 4

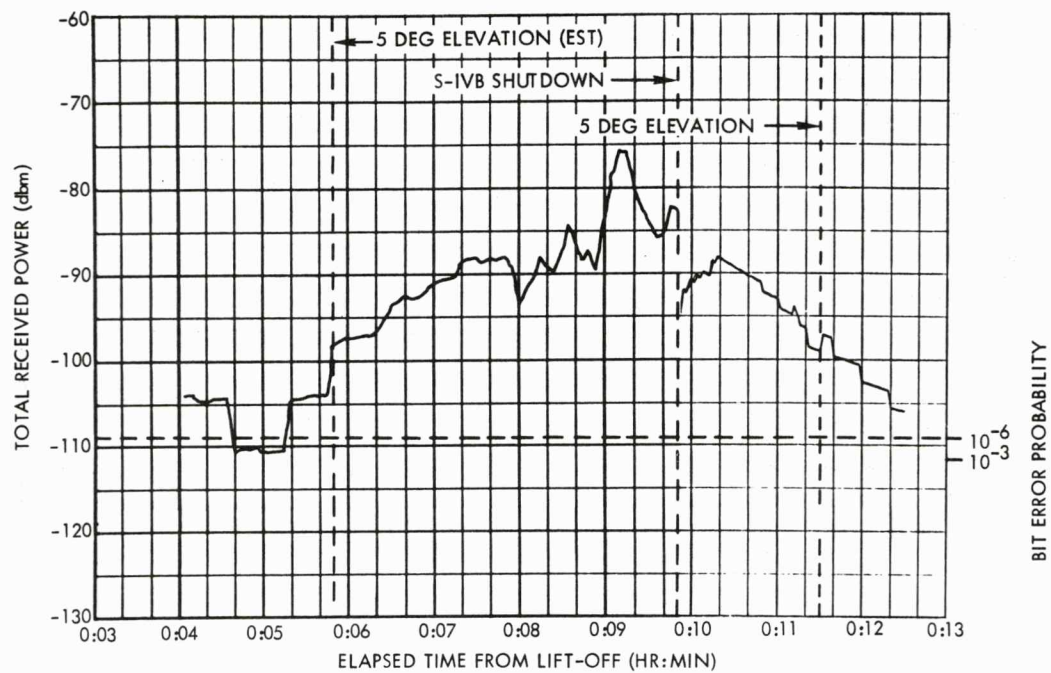


Figure 7-3a. BDA VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

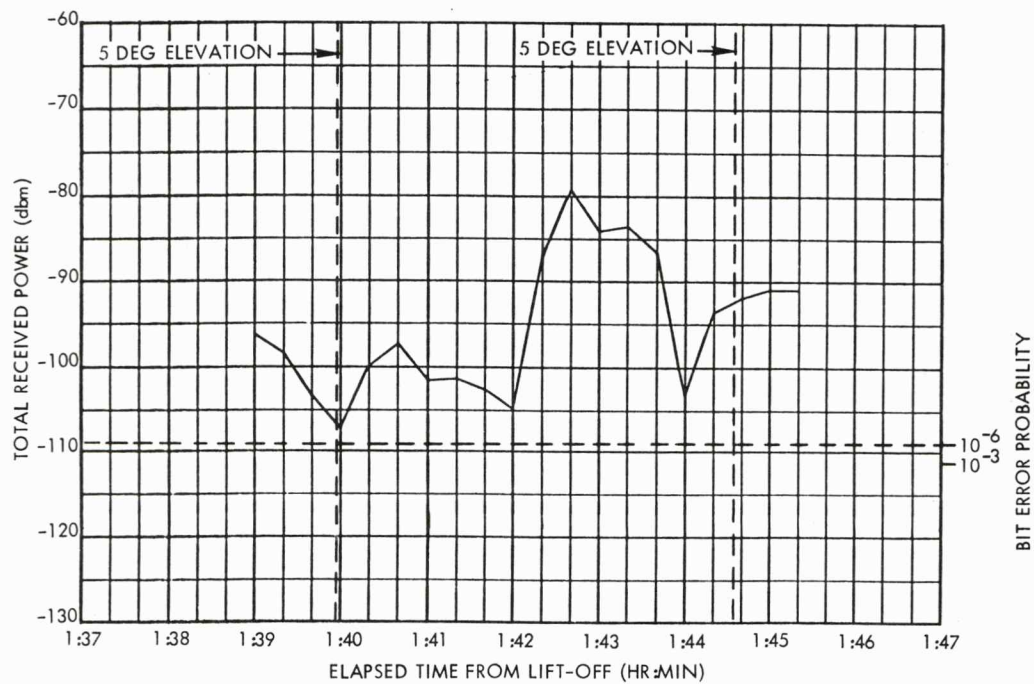


Figure 7-3b. BDA VHF, Orbit 2

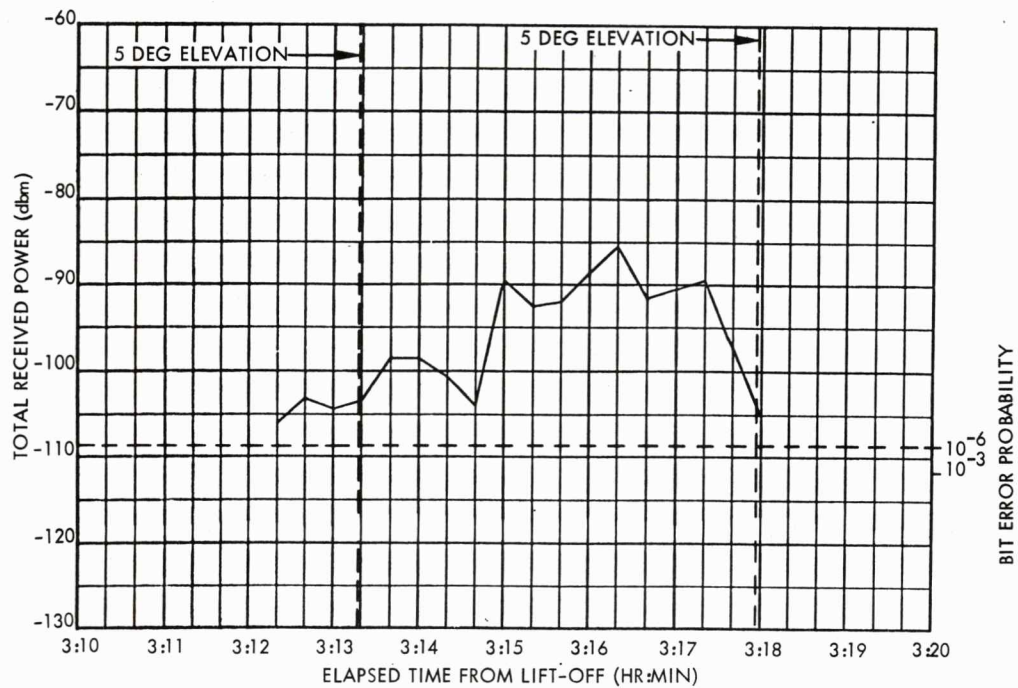


Figure 7-3c. BDA VHF, Orbit 3

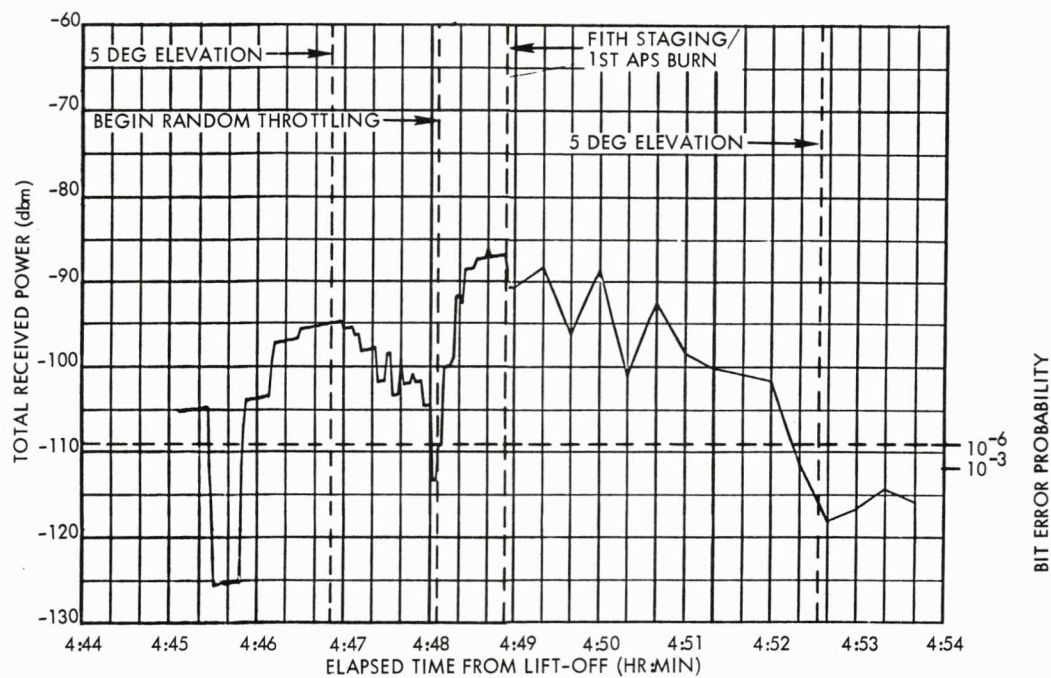


Figure 7-3d. BDA VHF, Orbit 4

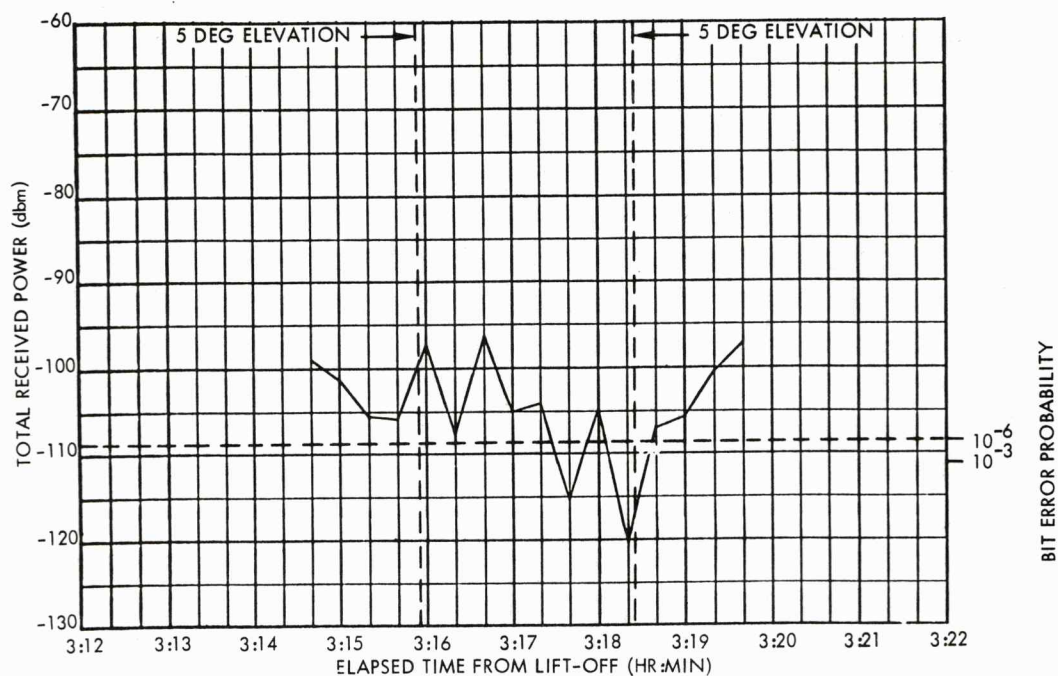


Figure 7-4a. ANT VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 3

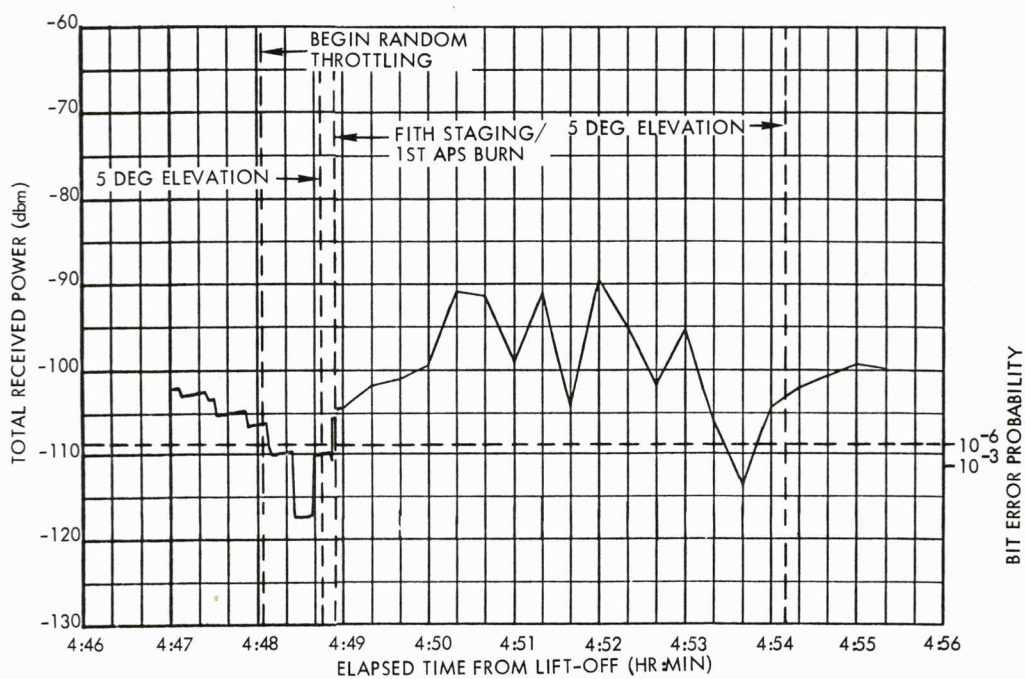


Figure 7-4b. ANT VHF, Orbit 4

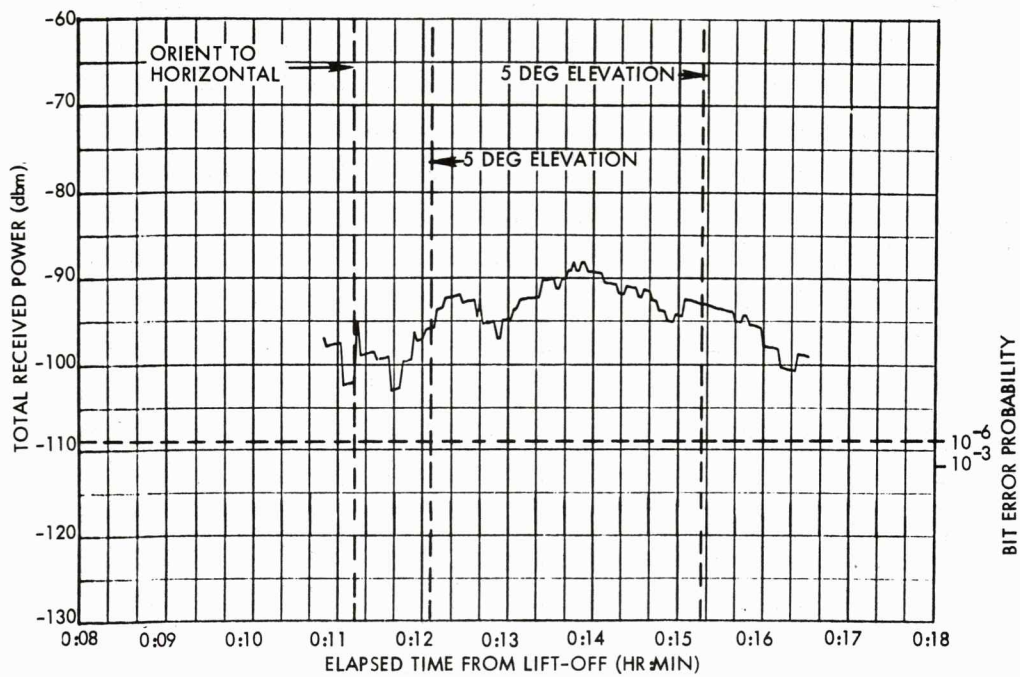


Figure 7-5a. VAN1 VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

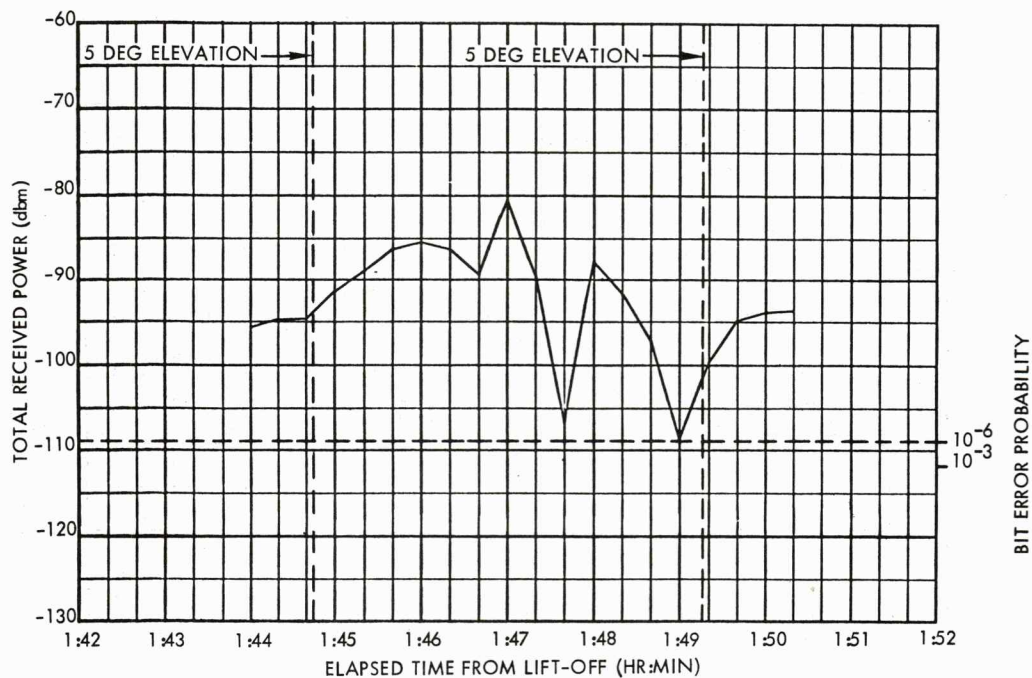


Figure 7-5b. VAN1 VHF, Orbit 2

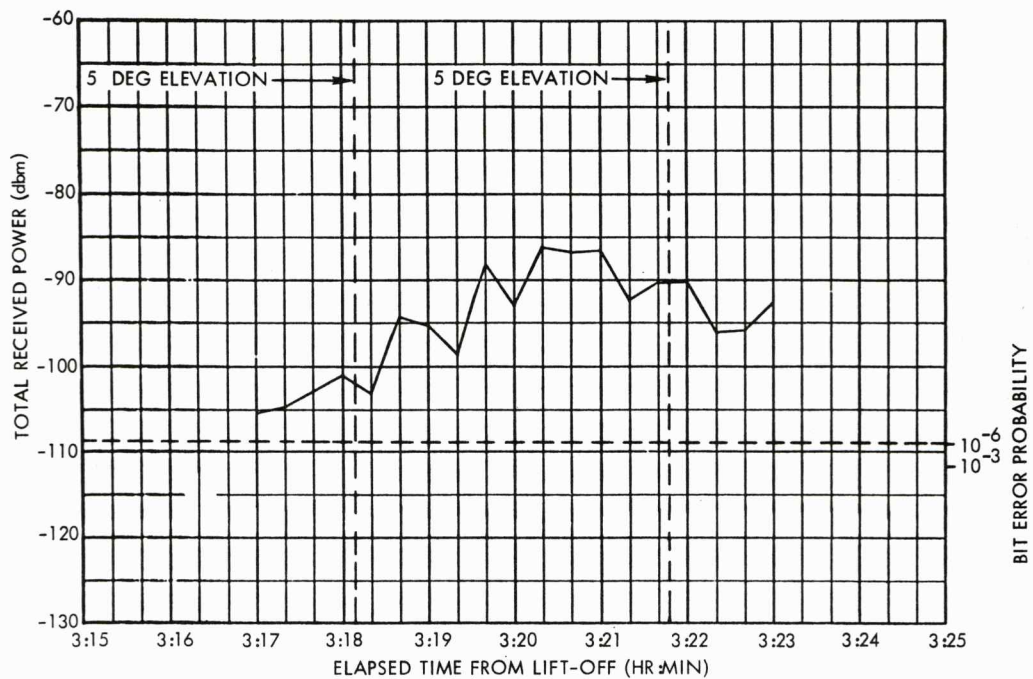


Figure 7-5c. VAN1 VHF, Orbit 3

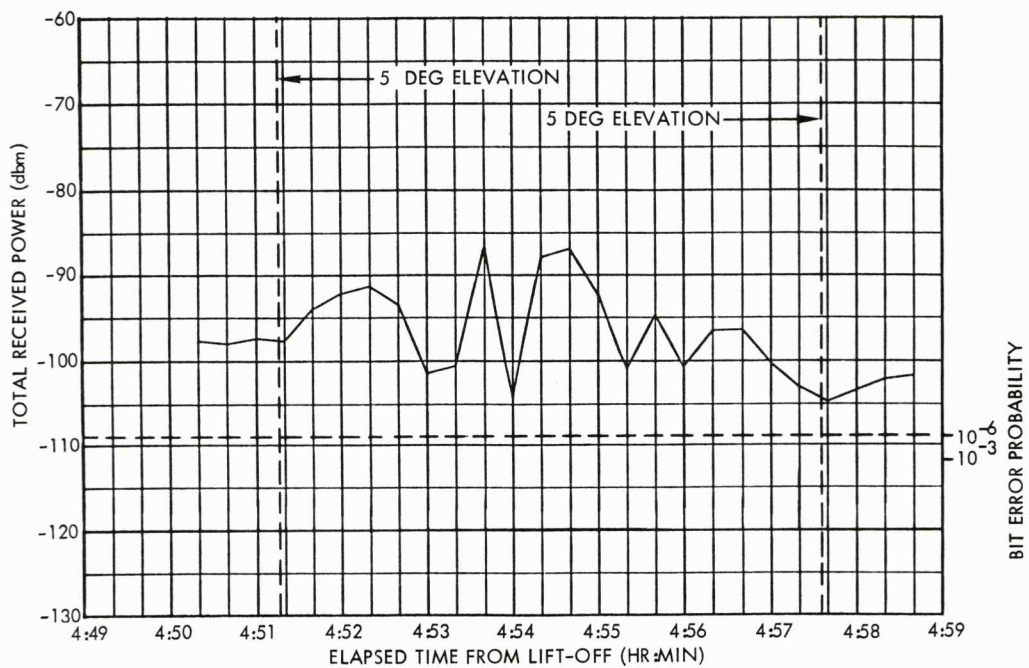


Figure 7-5d. VAN1 VHF, Orbit 4

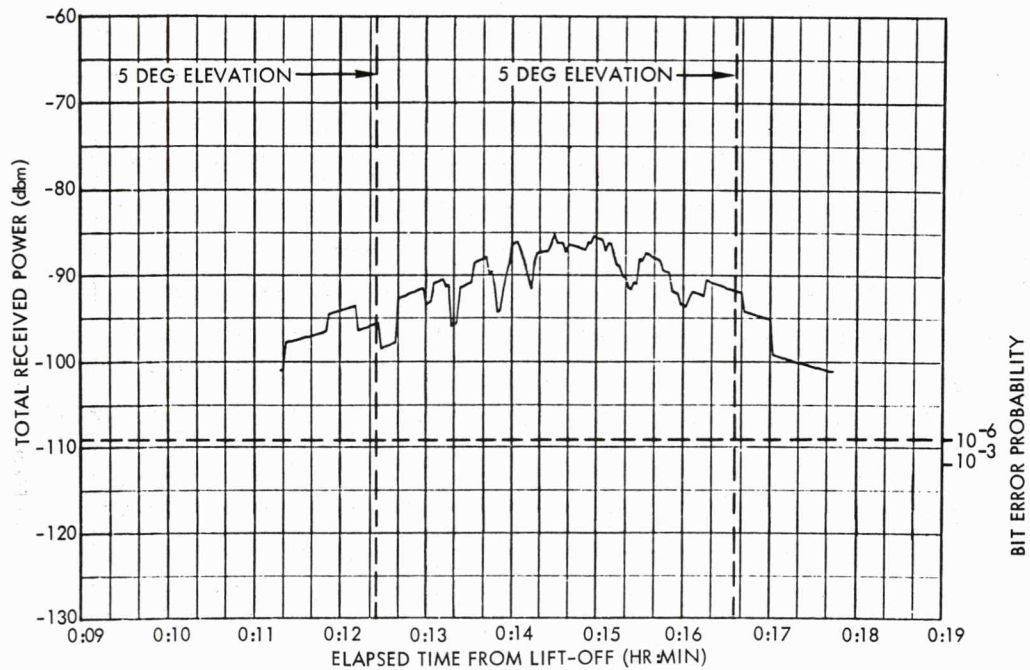


Figure 7-6a. VAN2 VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

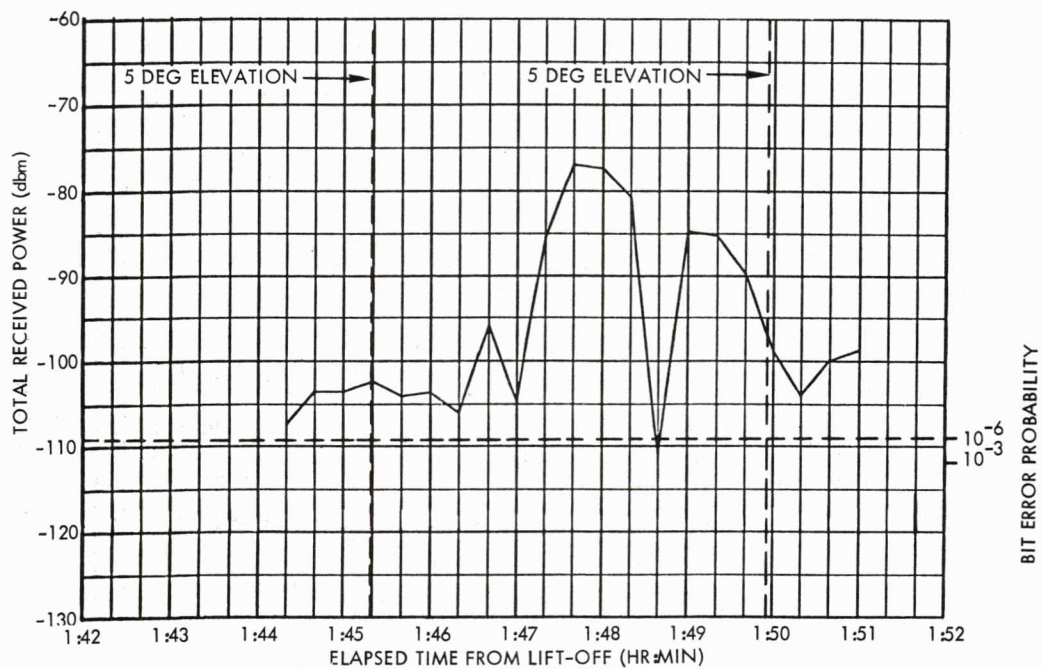


Figure 7-6b. VAN2 VHF, Orbit 2

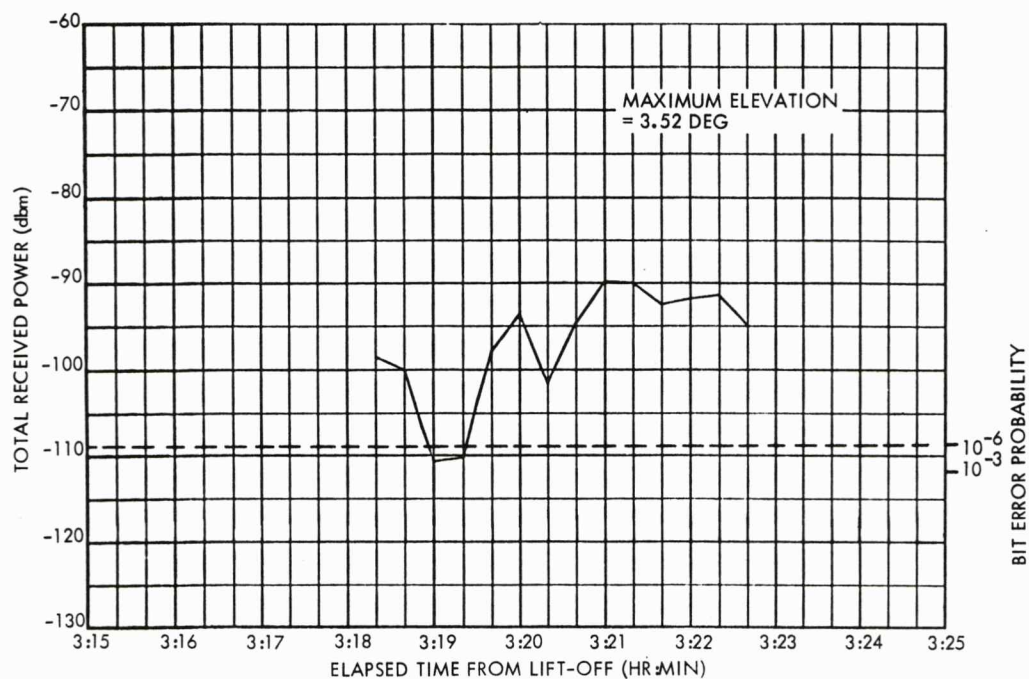


Figure 7-6c. VAN2 VHF, Orbit 3

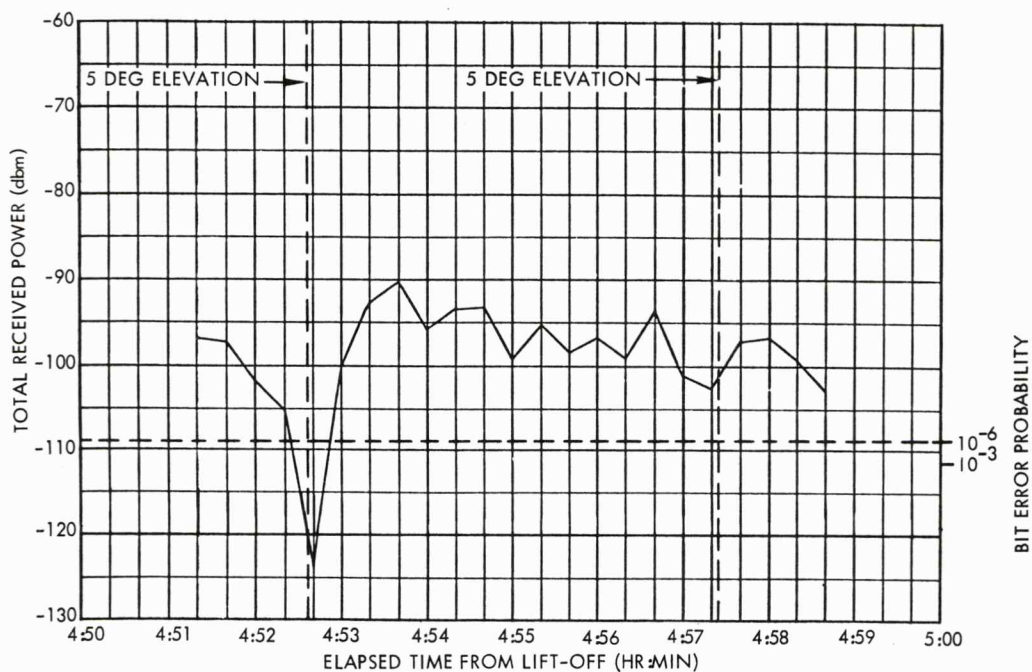


Figure 7-6d. VAN2 VHF, Orbit 4

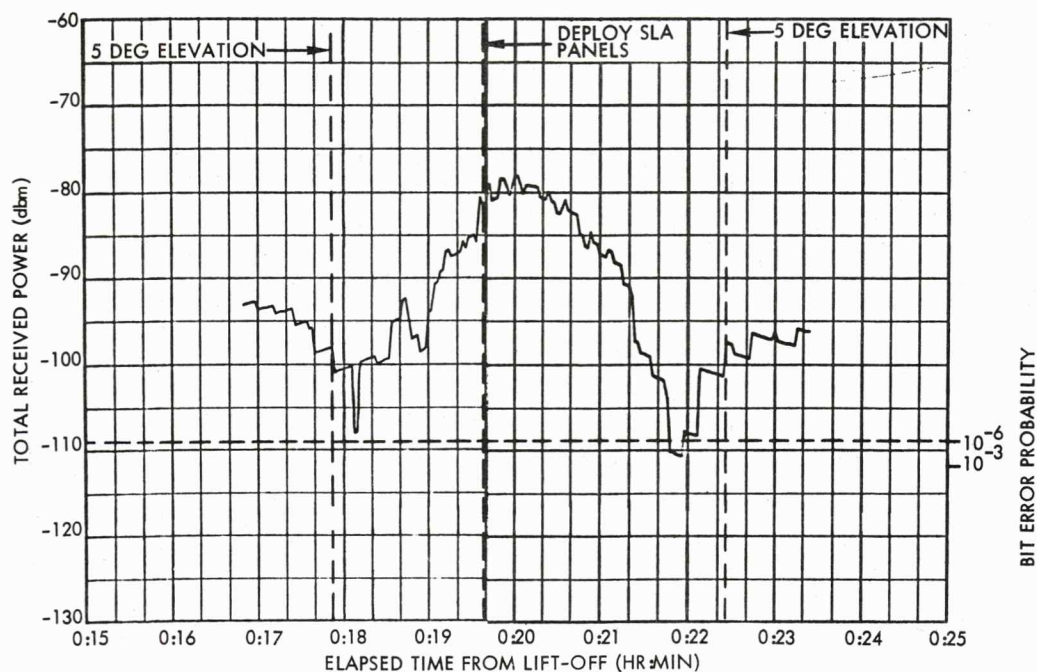


Figure 7-7a. CYI VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

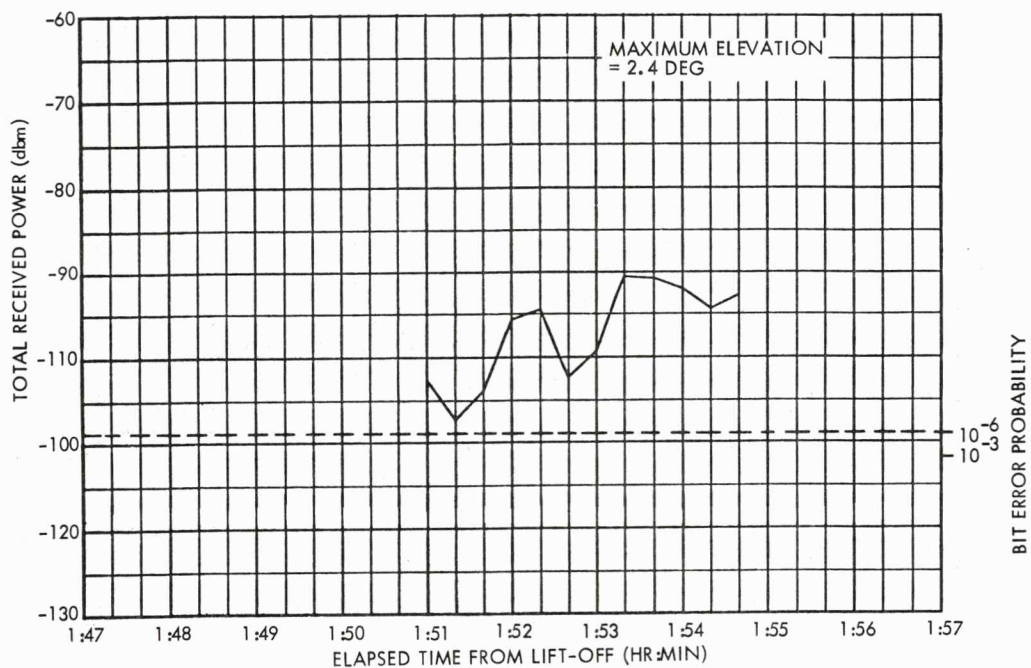


Figure 7-7b. CYI VHF, Orbit 2

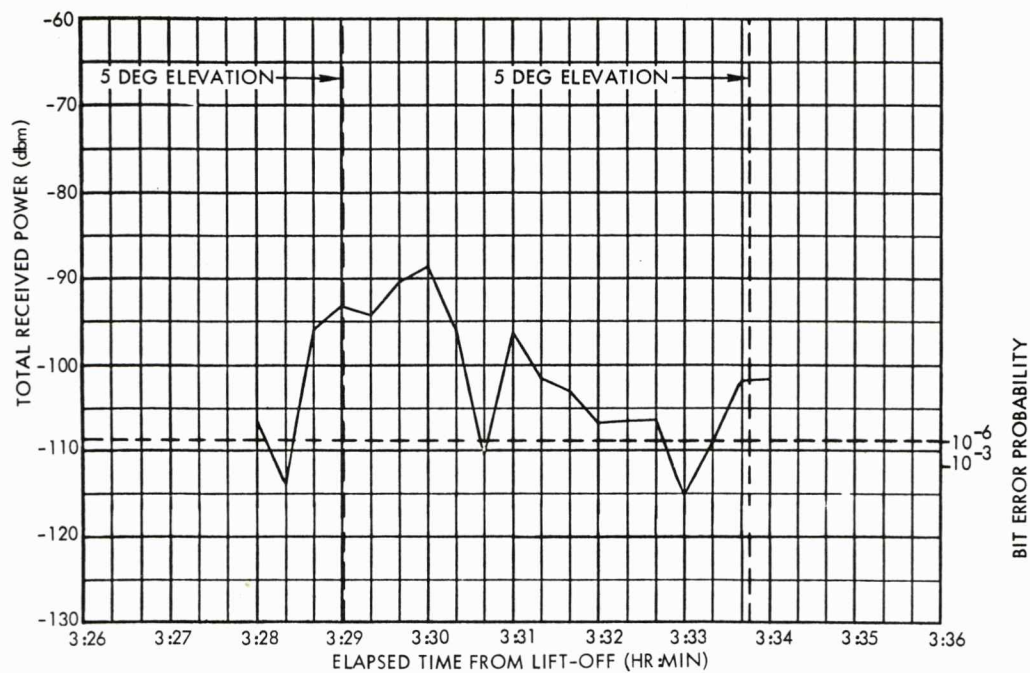


Figure 7-8a. ASC VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 3

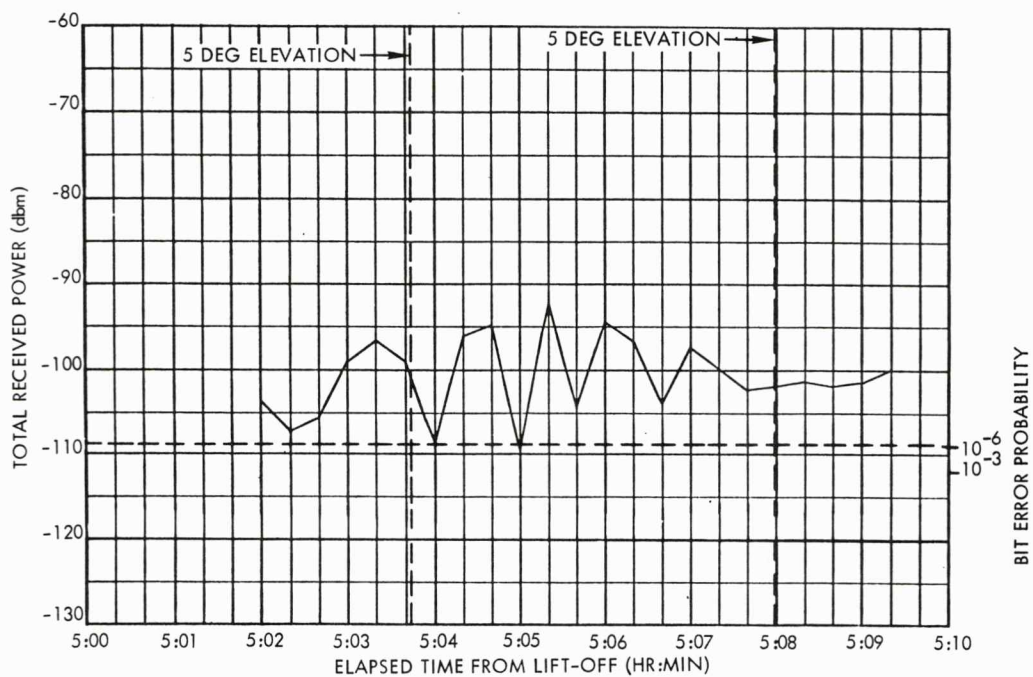


Figure 7-8b. ASC VHF, Orbit 4

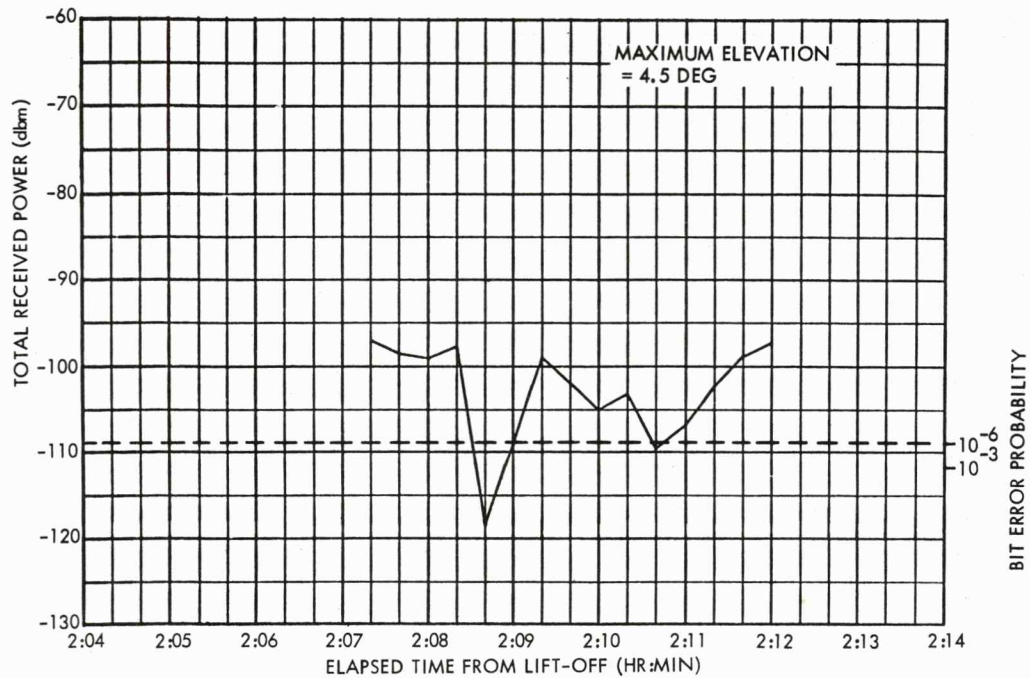


Figure 7-9a. PRE VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 2

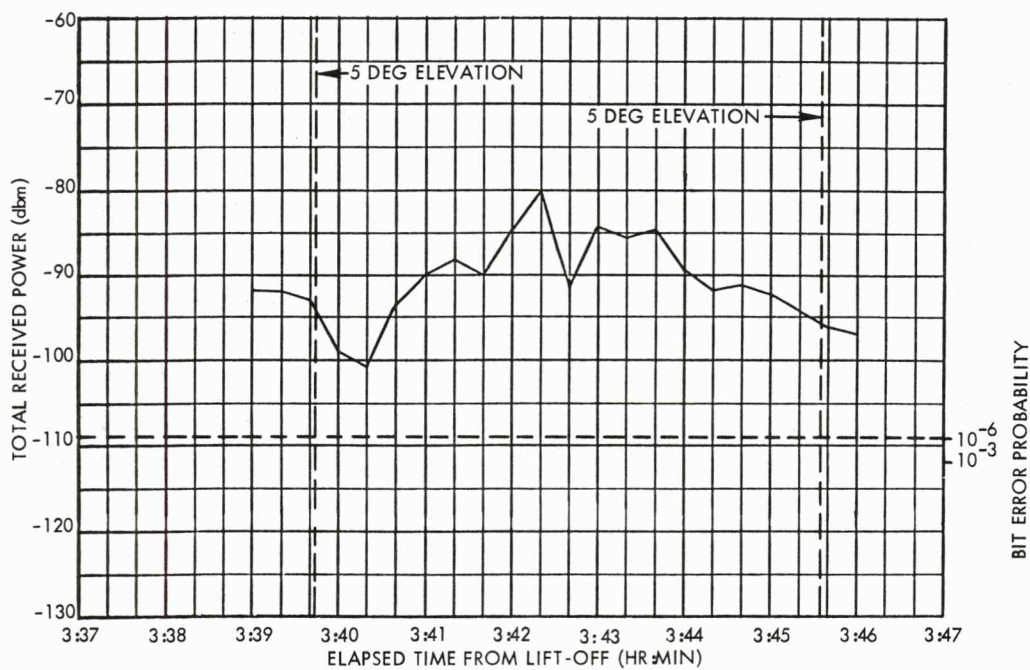


Figure 7-9b. PRE VHF, Orbit 3

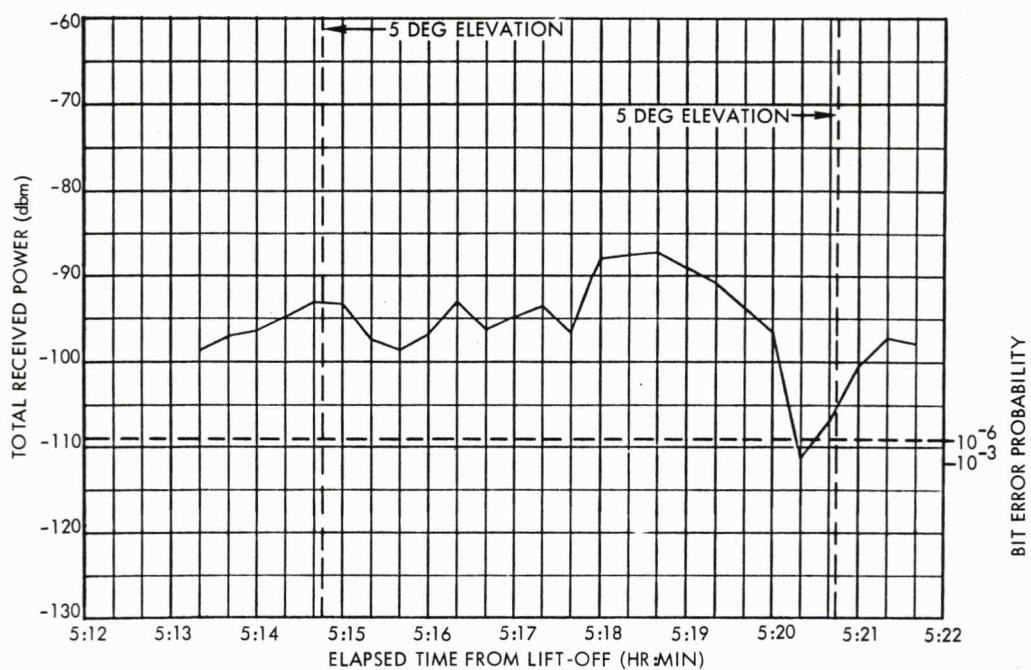


Figure 7-9c. PRE VHF, Orbit 4

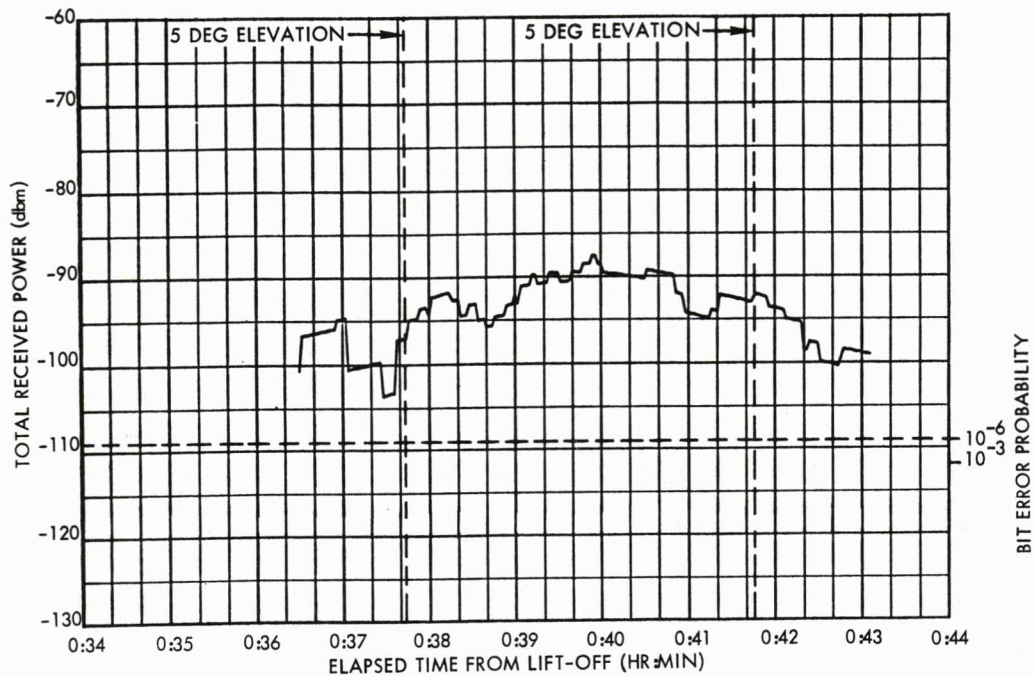


Figure 7-10a. TAN VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

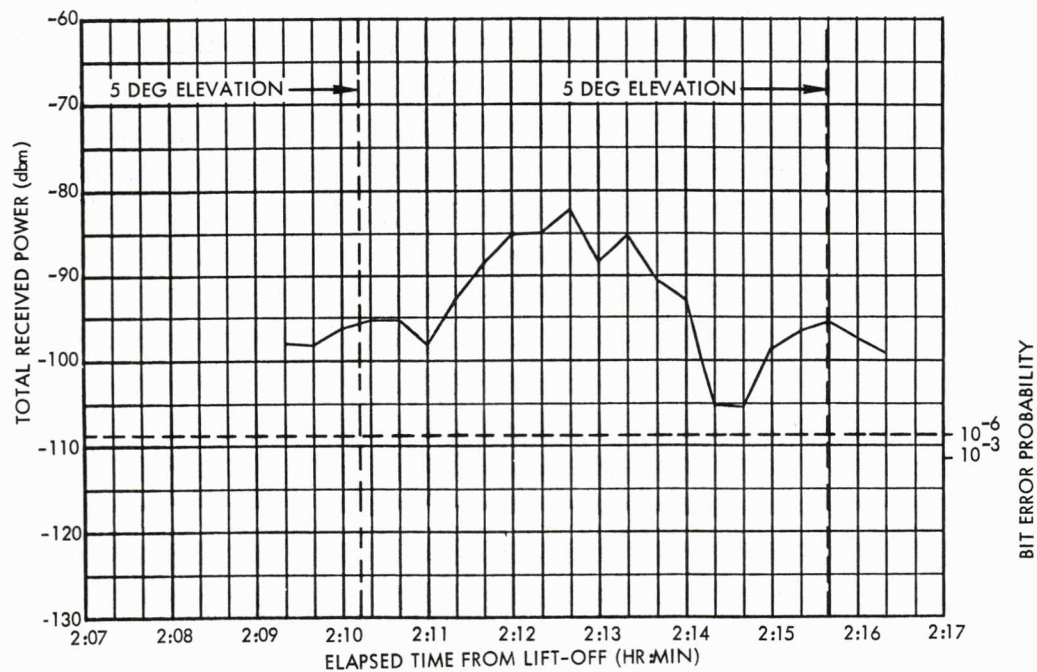


Figure 7-10b. TAN VHF, Orbit 2

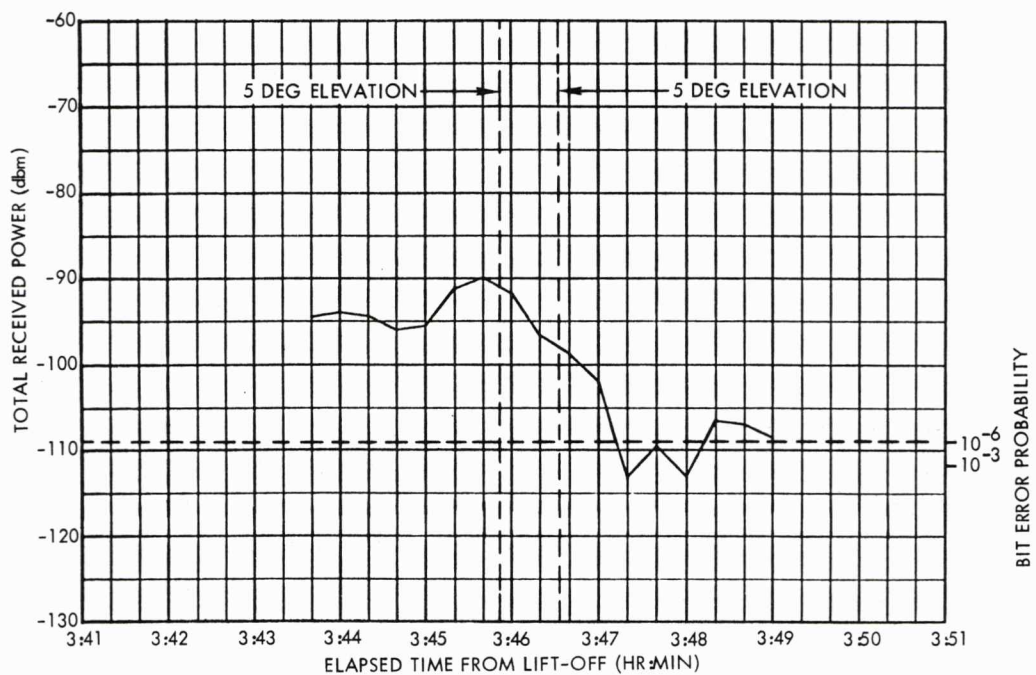


Figure 7-10c. TAN VHF, Orbit 3

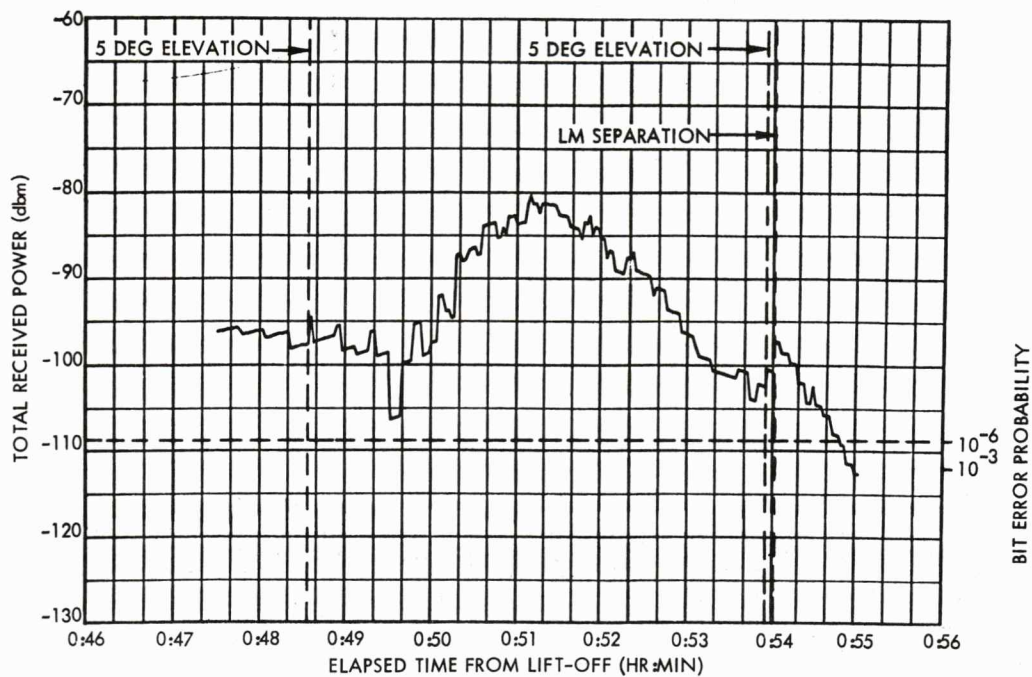


Figure 7-11a. RKV VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

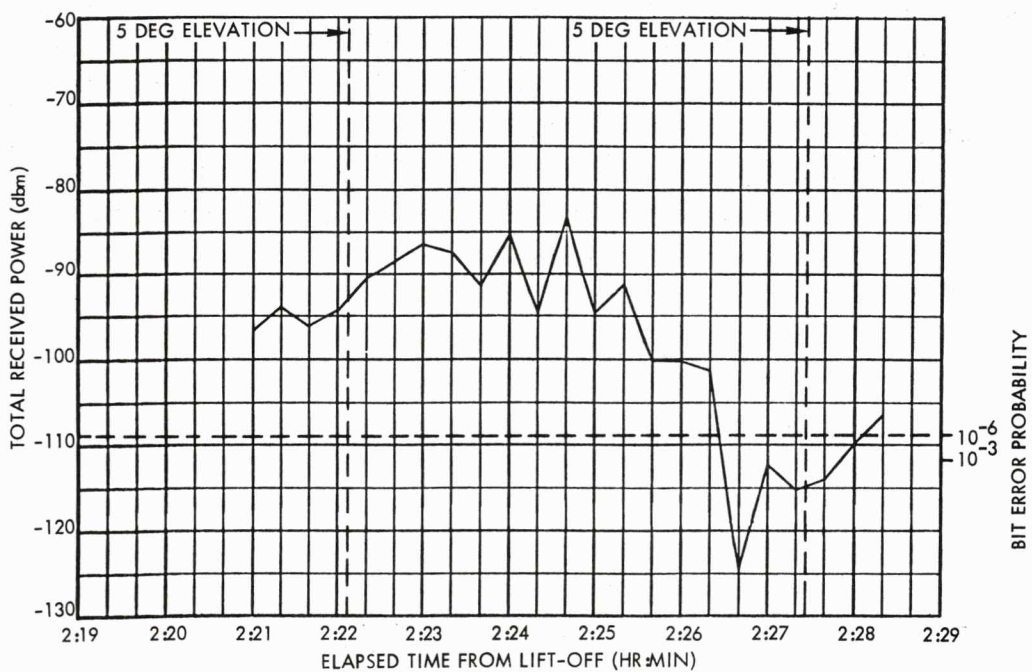


Figure 7-11b. RKV VHF, Orbit 2

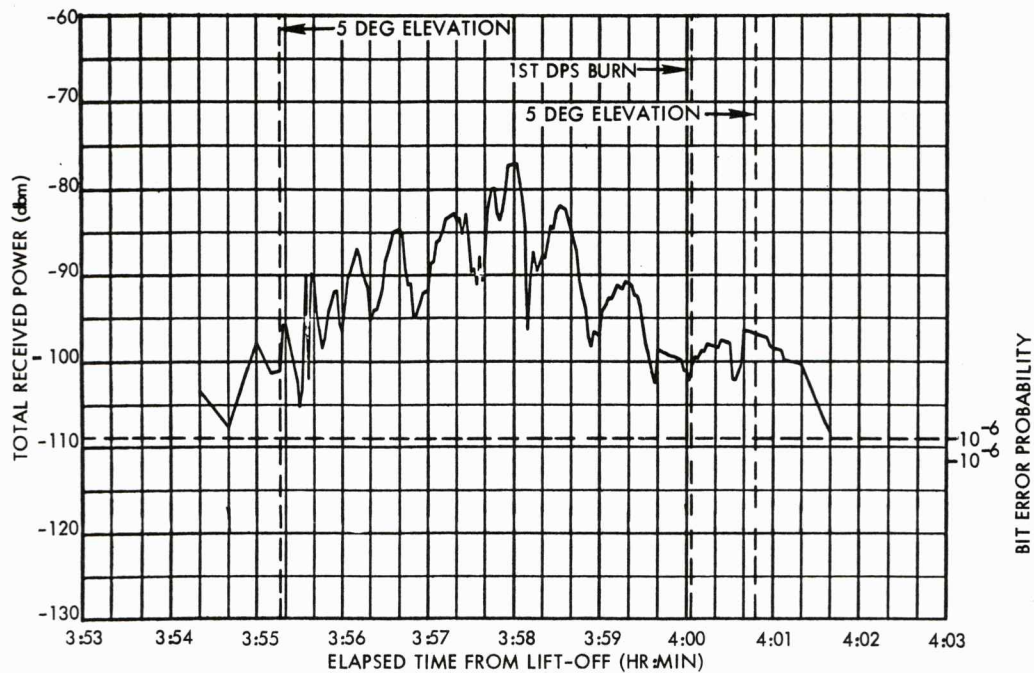


Figure 7-11c. RKV VHF, Orbit 3

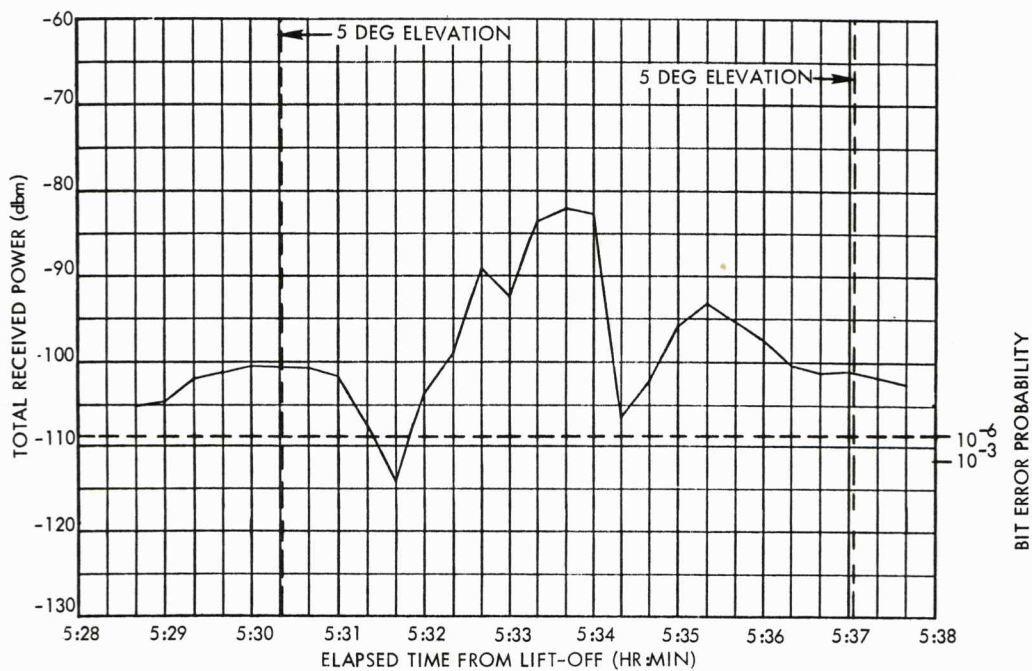


Figure 7-11d. RKV VHF, Orbit 4

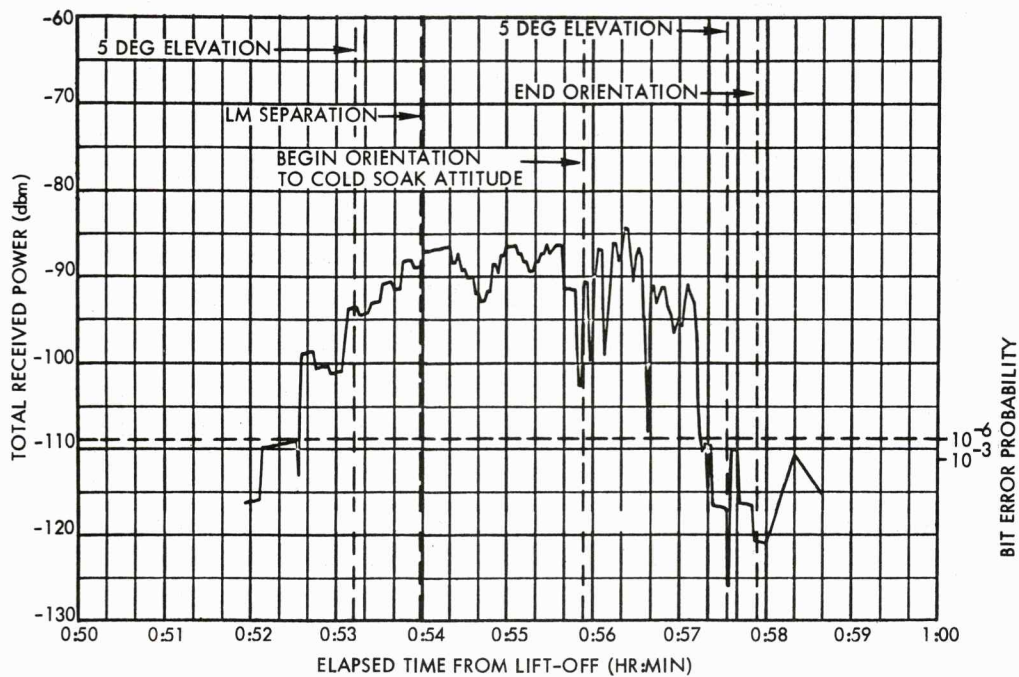


Figure 7-12a. CRO VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

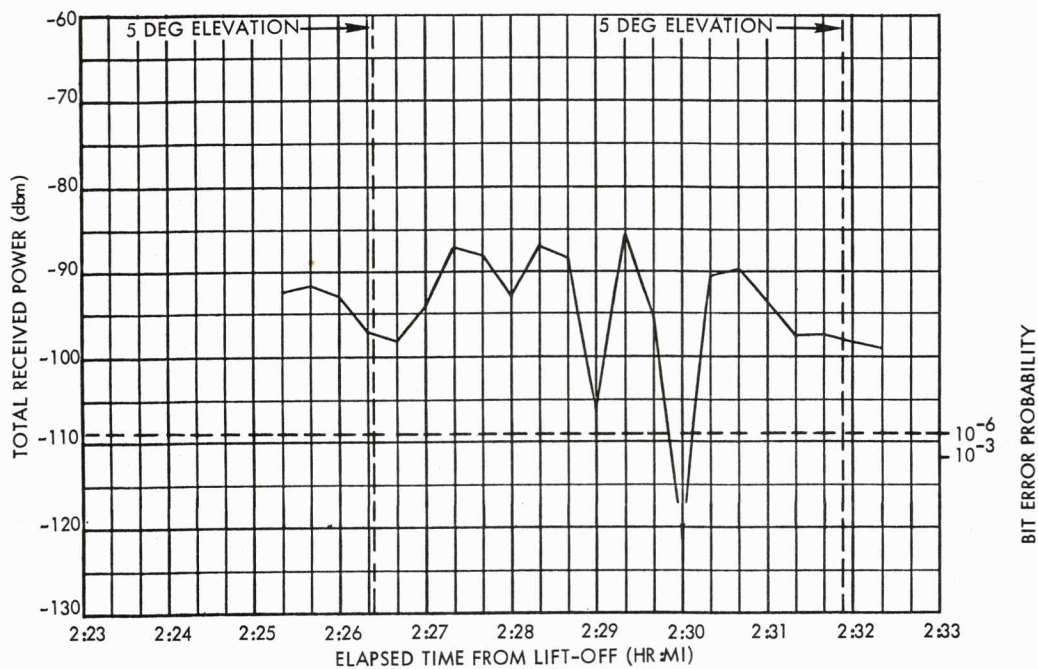


Figure 7-12b. CRO VHF, Orbit 2

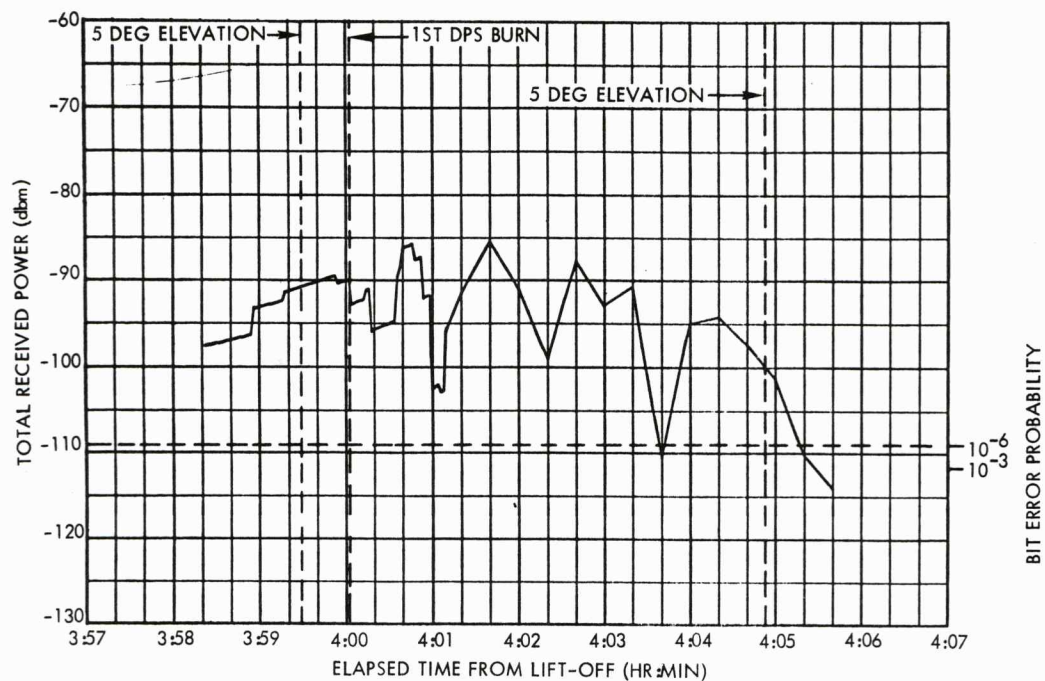


Figure 7-12c. CRO VHF, Orbit 3

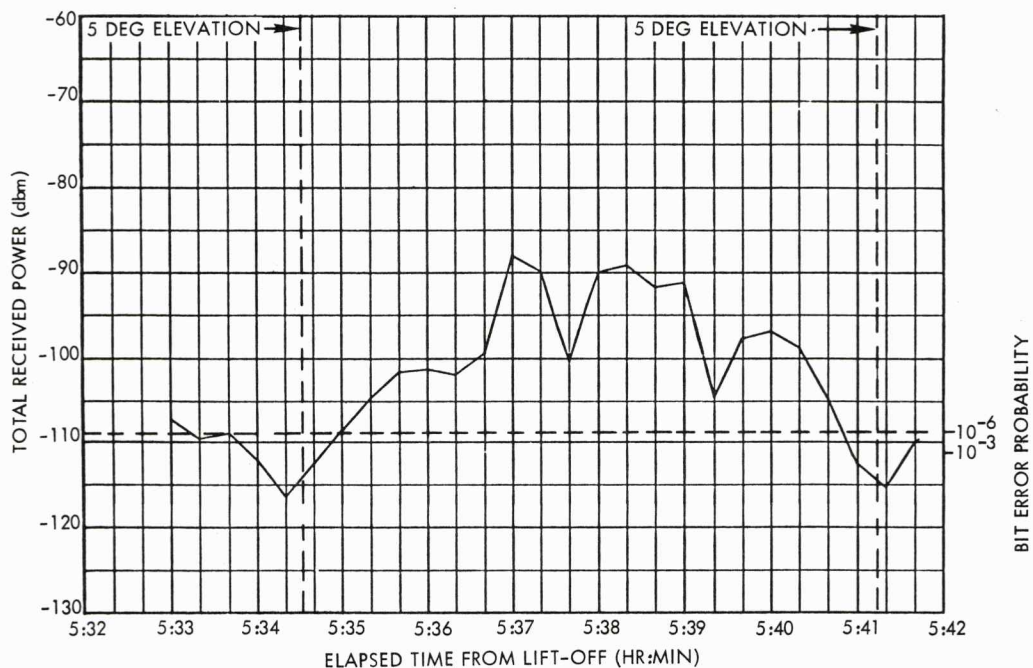


Figure 7-12d. CRO VHF, Orbit 4

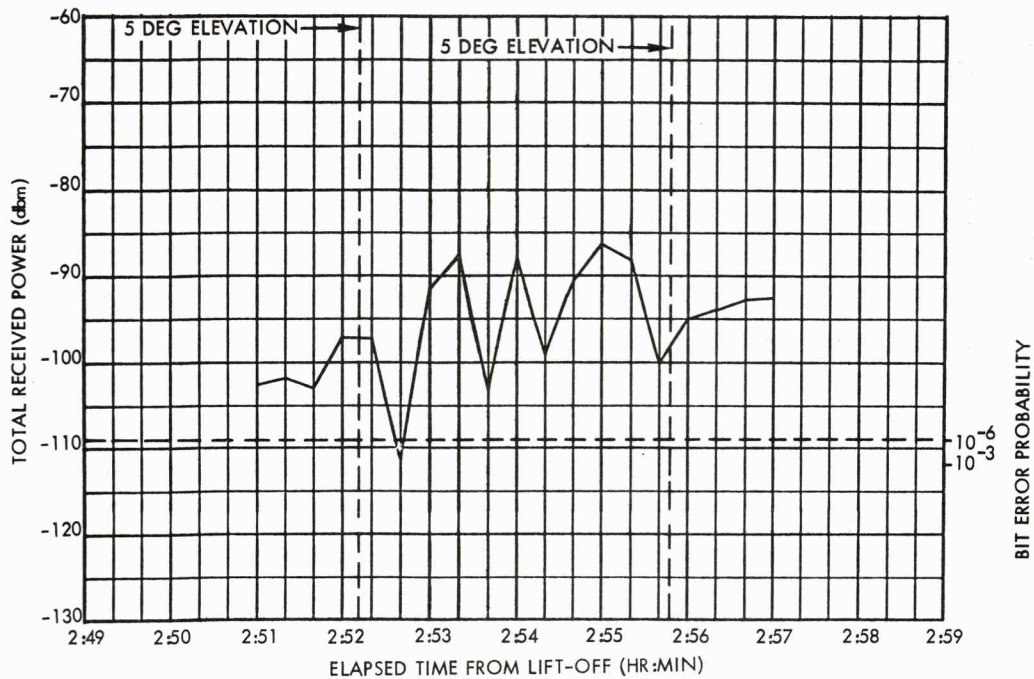


Figure 7-13a. HAW VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 2

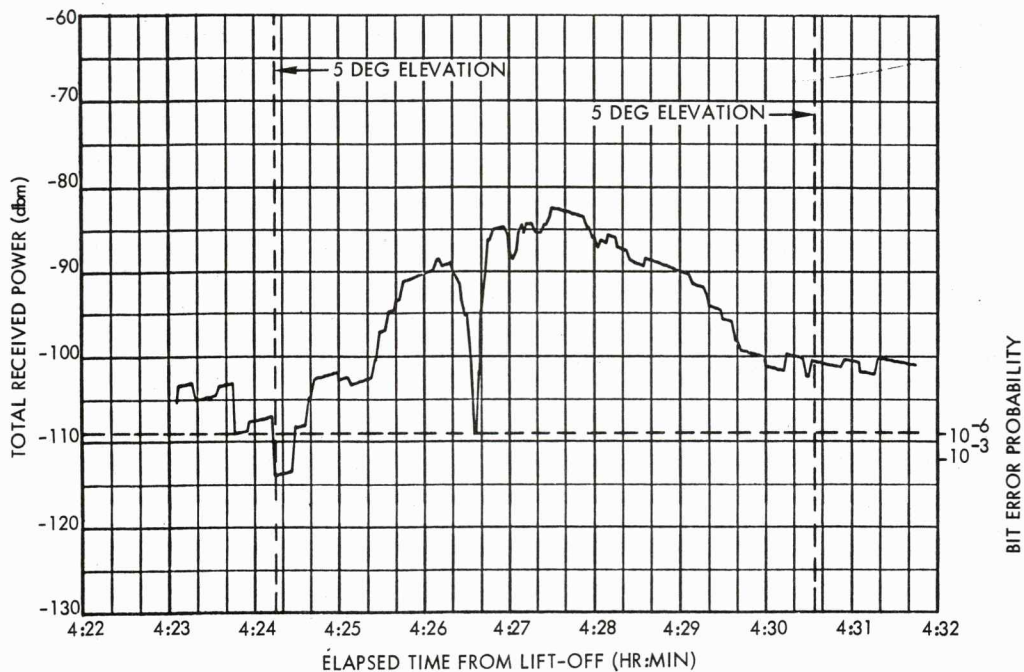


Figure 7-13b. HAW VHF, Orbit 3

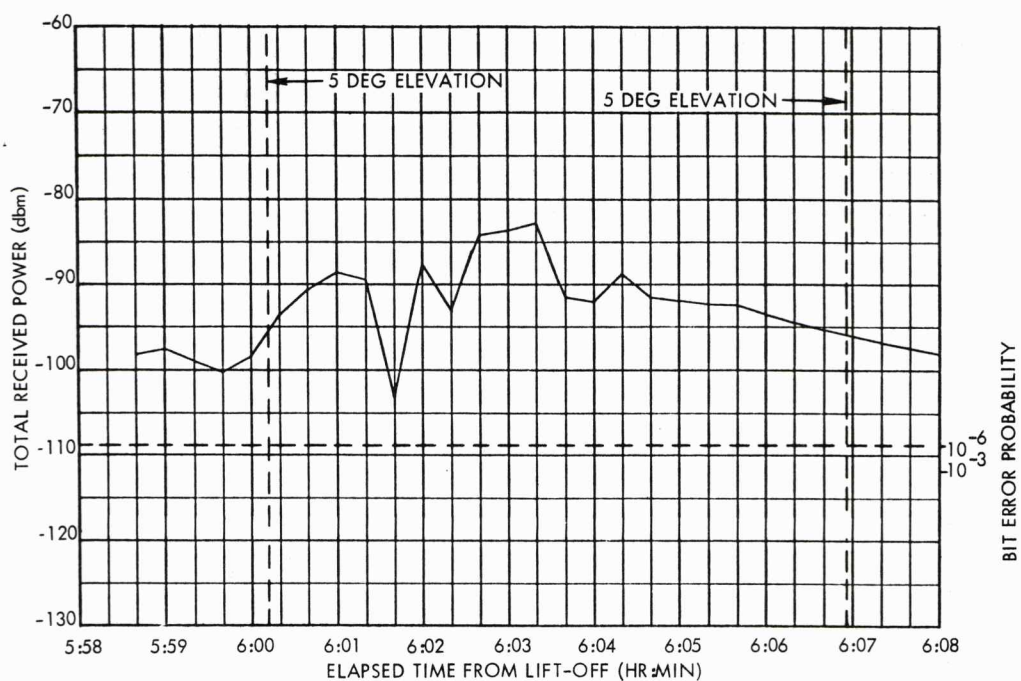


Figure 7-13c. HAW VHF, Orbit 4

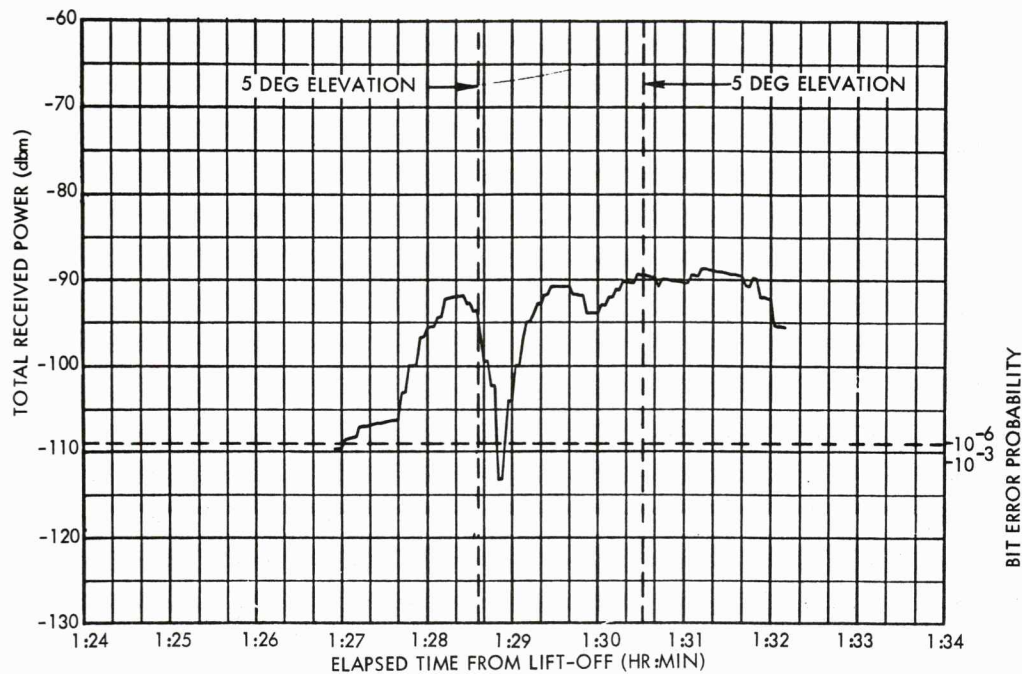


Figure 7-14a. CSQ VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

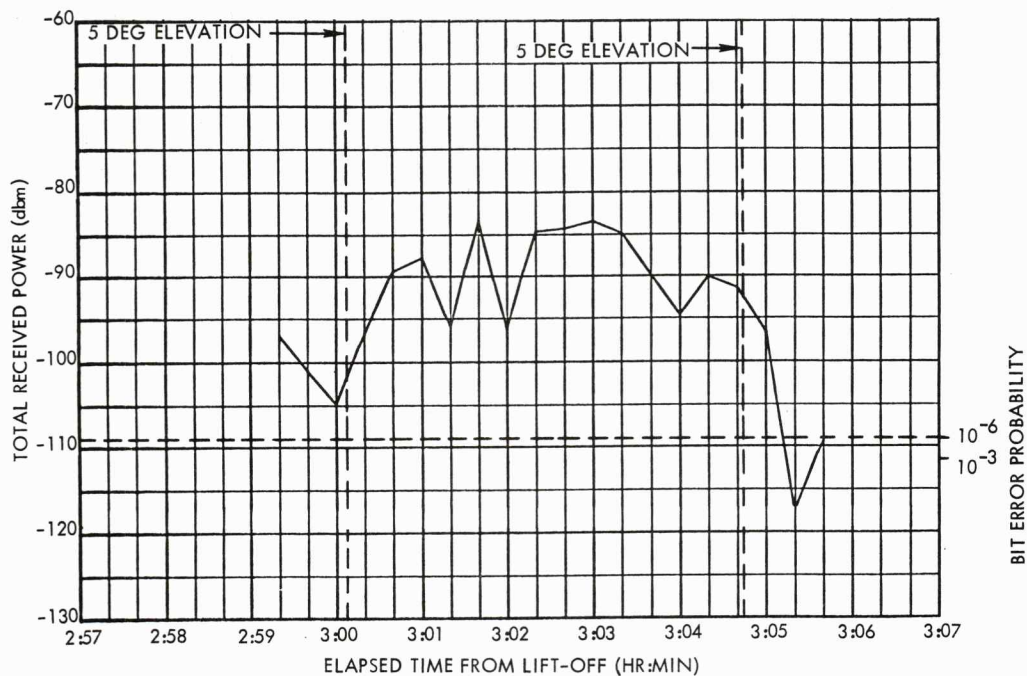


Figure 7-14b. CSQ VHF, Orbit 2

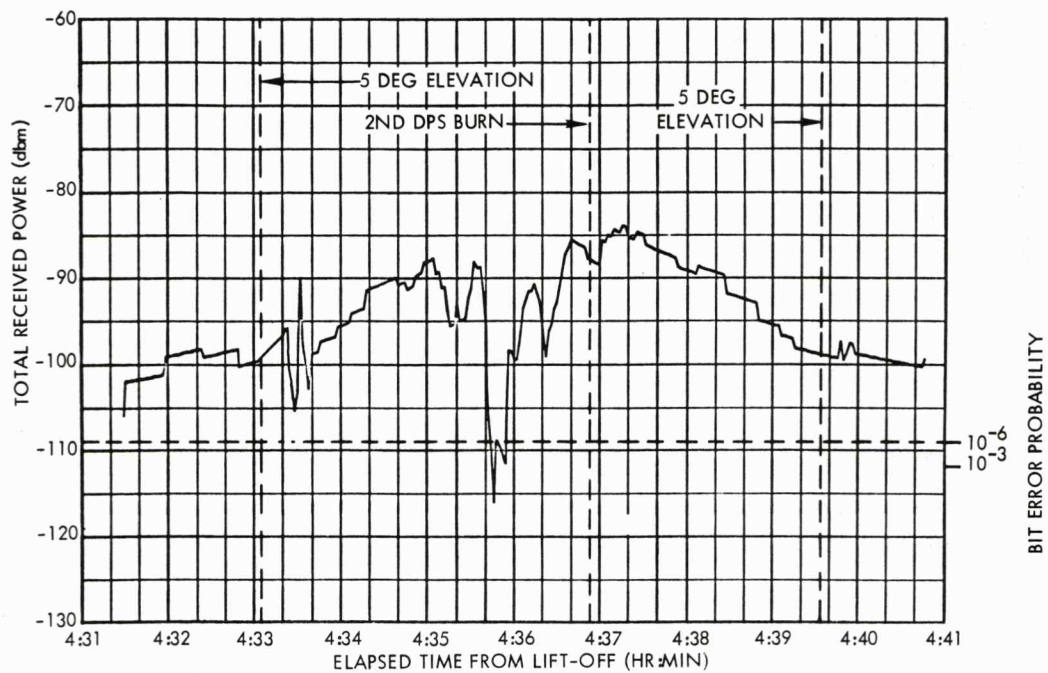


Figure 7-14c. CSQ VHF, Orbit 3

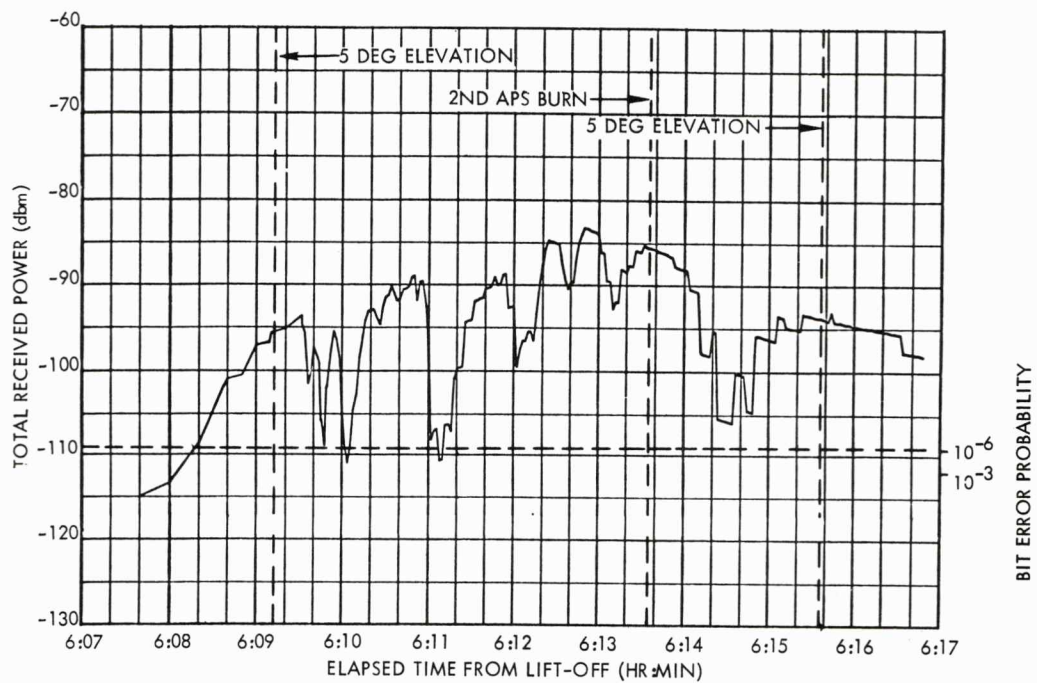


Figure 7-14d. CSQ VHF, Orbit 4

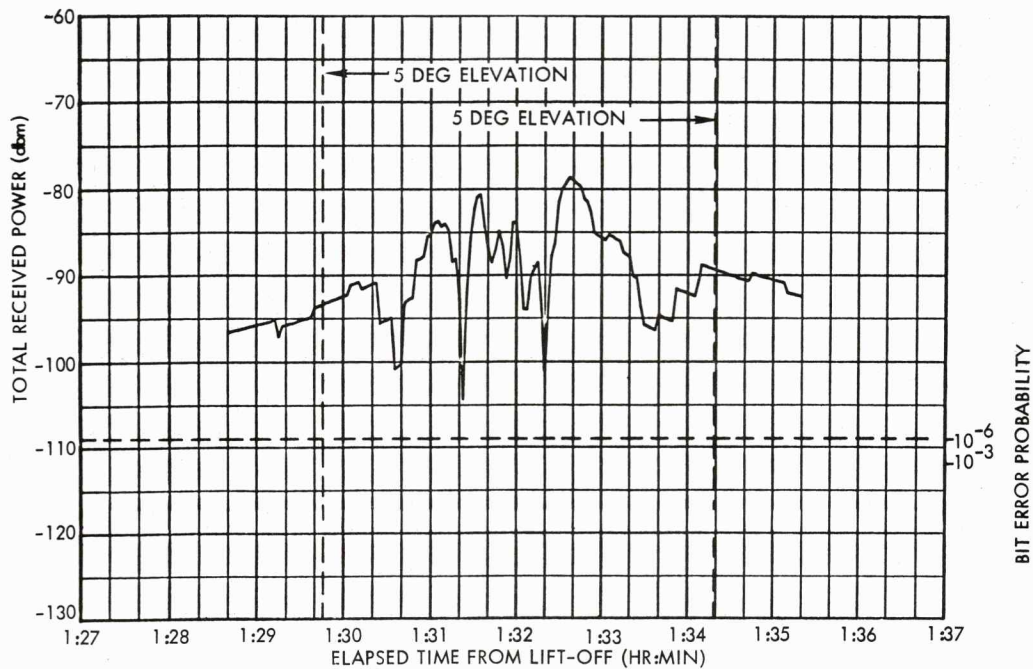


Figure 7-15a. GYM VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

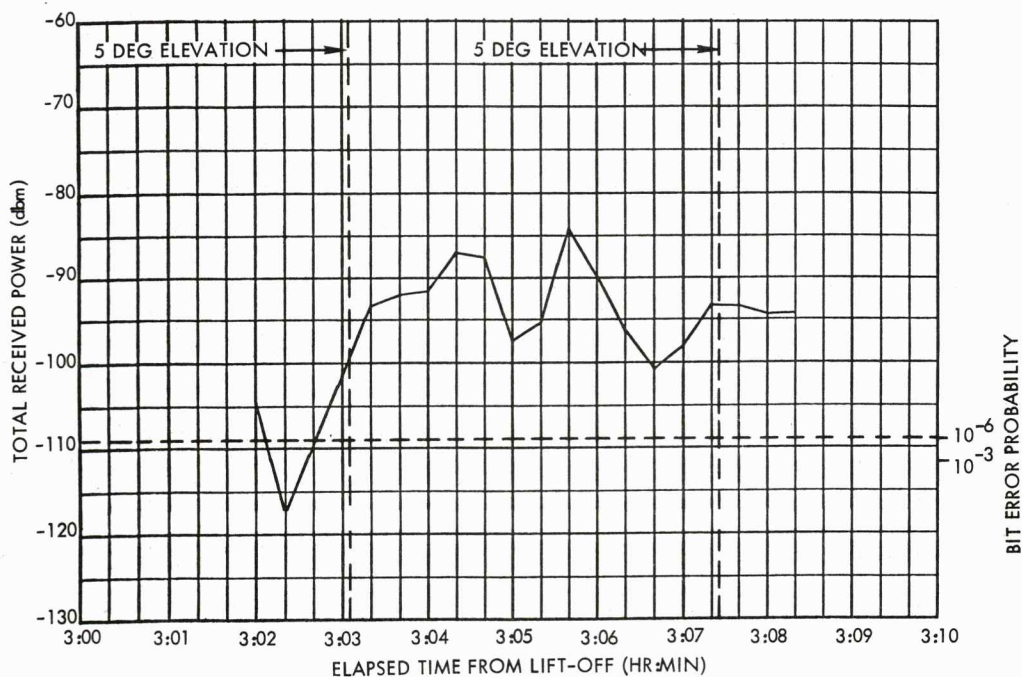


Figure 7-15b. GYM VHF, Orbit 2

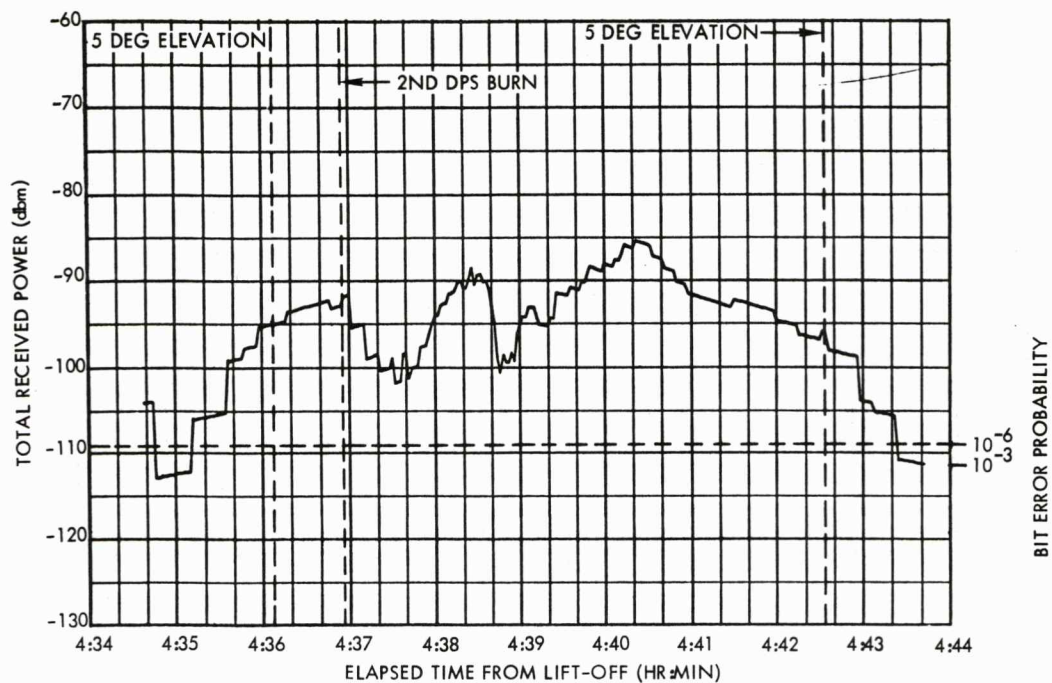


Figure 7-15c. GYM VHF, Orbit 3

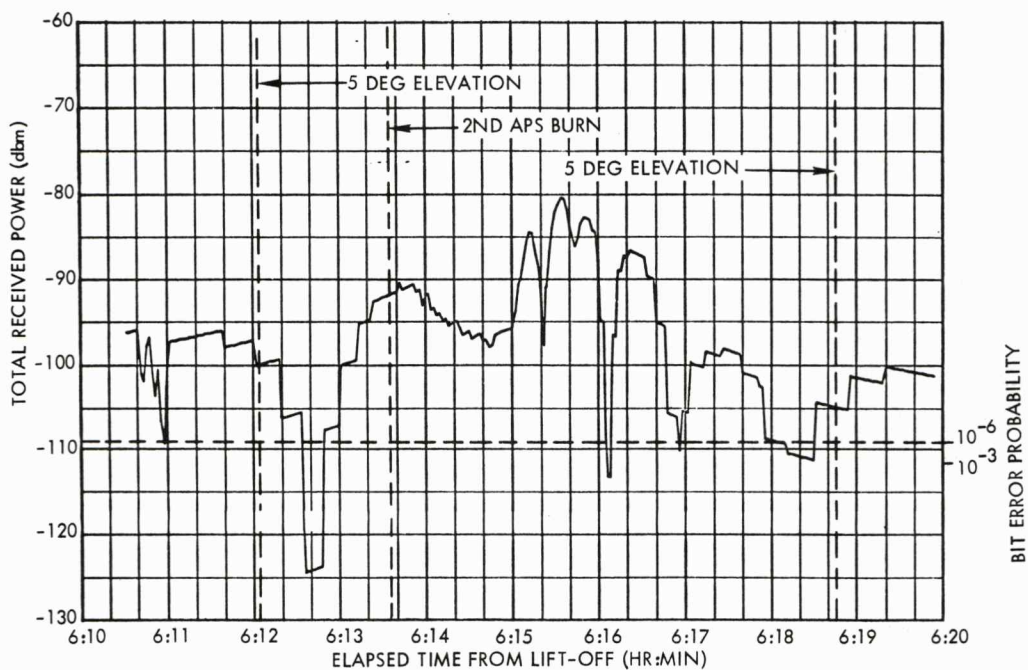


Figure 7-15d. GYM VHF, Orbit 4

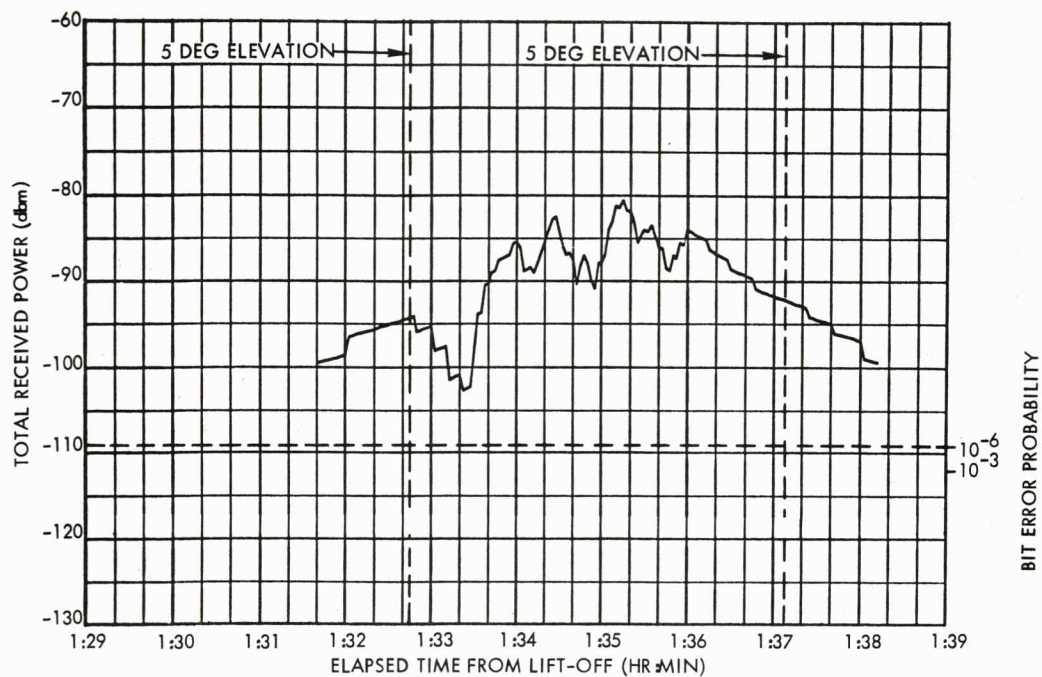


Figure 7-16a. TEX VHF PCM/FM Total Received Power Versus Elapsed Time from Lift-Off, Orbit 1

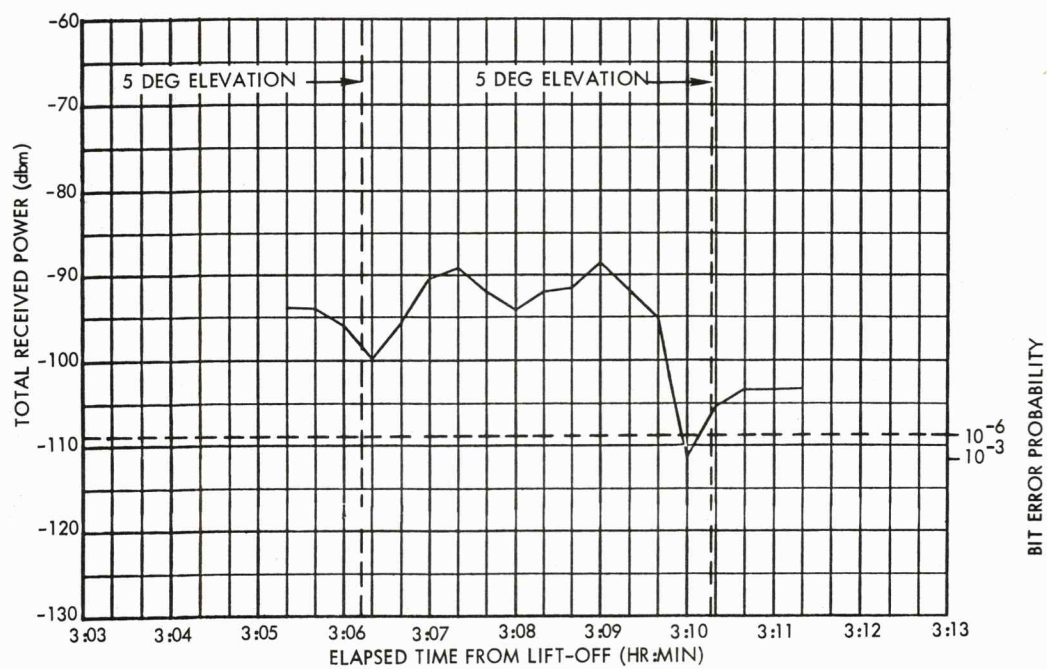


Figure 7-16b. TEX VHF, Orbit 2

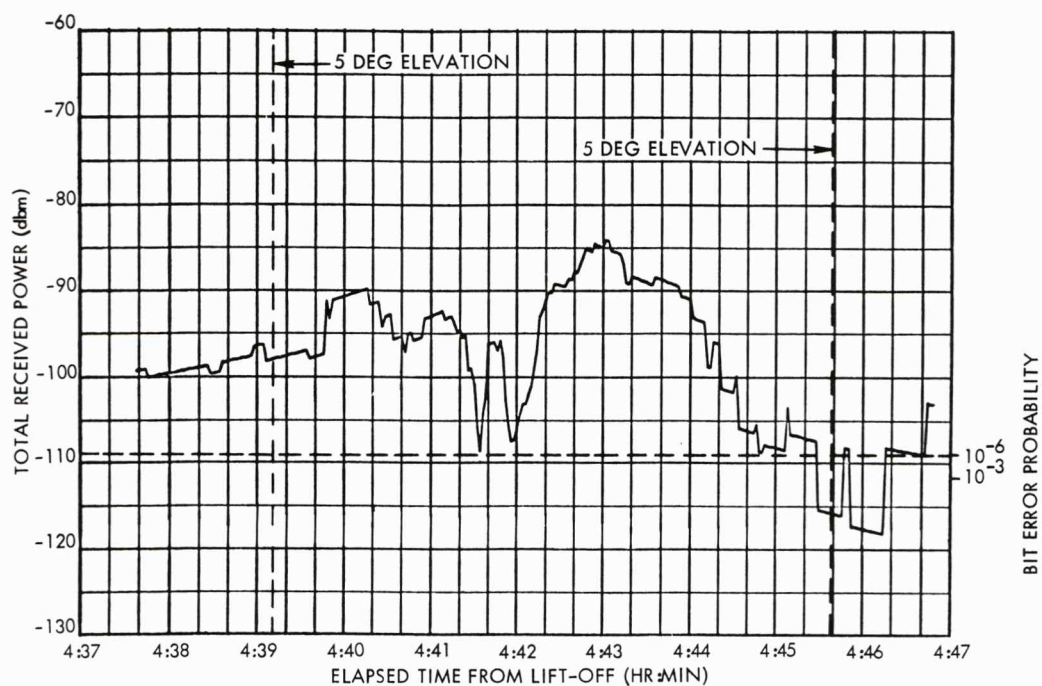


Figure 7-16c. TEX VHF, Orbit 3

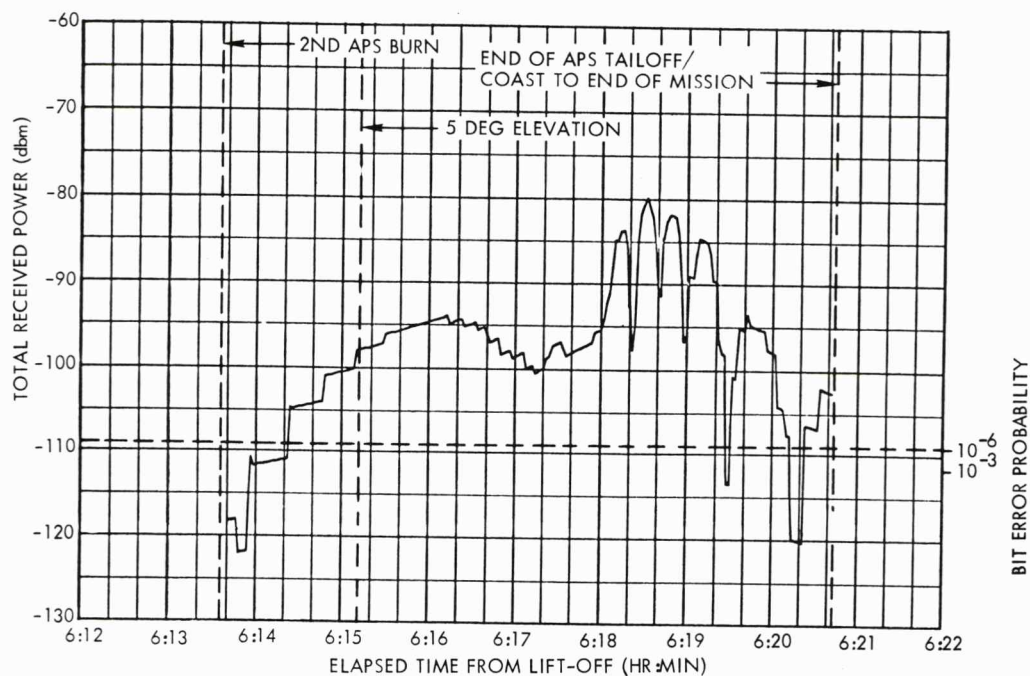


Figure 7-16d. TEX VHF, Orbit 4

8.0 UHF SYSTEM COVERAGE

The UHF system for the AS-204/LM-1 consists of a single link, operating on 450 MHz, which is used for sending updata and commands from the ground to the LM UHF receiver.

UHF data were obtained from a computer program which combined the spacecraft trajectory data, spacecraft one-sixth scale antenna gain patterns, transmitted power, circuit and space losses, and receiver performance characteristics to give plots of Total Received Power versus Elapsed Time from Liftoff. A flow chart of the computer program is shown in Figure D-1. Worst case specified parameters were used for all calculations. Values used are shown in Appendix A and sample calculations are shown in Appendix B.

Computer plots covering only the two DPS and two APS burns are shown in this report. UHF signal strengths were found to be very strong and the plots covering the four burns are typical of the entire mission. These plots are shown in Figures 8-1 through 8-8.

Data are plotted whenever the spacecraft is within line-of-sight of a ground station, i.e., whenever the elevation look angle of the ground station is above 0° . Indicated on the graphs are the times when the MSFN elevation look angles are 5° , and when major events occur.

The required signal level for UHF is shown on the plots as the minimum value of total received power which will give the required receiver signal to noise ratio (10 db) for command operation. This level is also the 0 dB reference level for margin calculations.

The UHF system is operational at liftoff using the SLA panel VHF/UHF antennas. After LM separation the LM mounted VHF/UHF antennas are utilized.

UHF signal strengths are noted to be very strong throughout the mission with continuous positive margins.

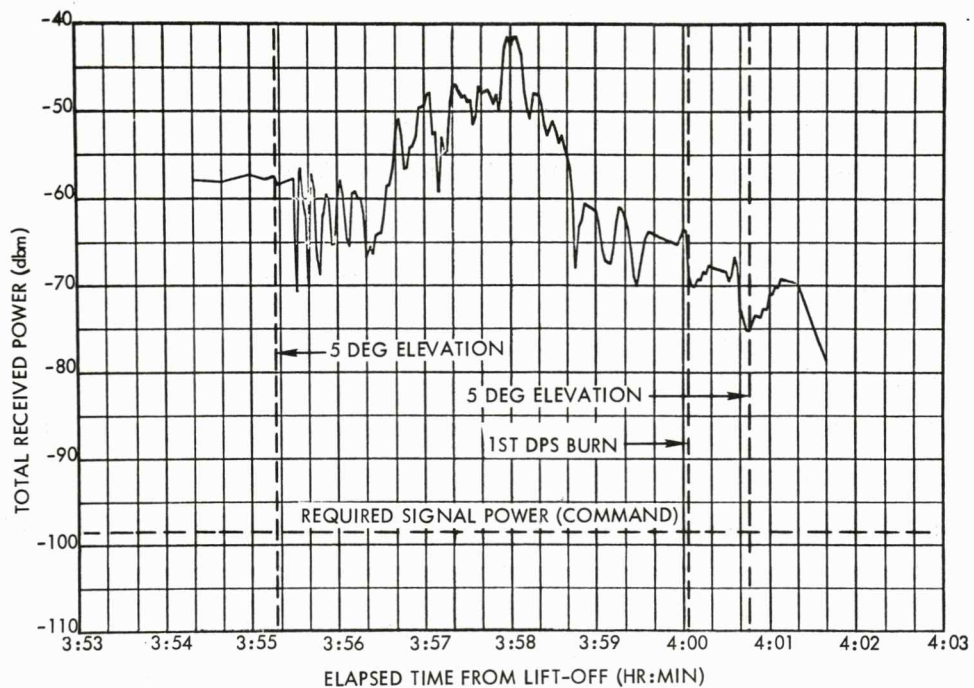


Figure 8-1. RKV UHF Total Received Power Versus Elapsed Time from Lift-Off, 1st DPS Burn

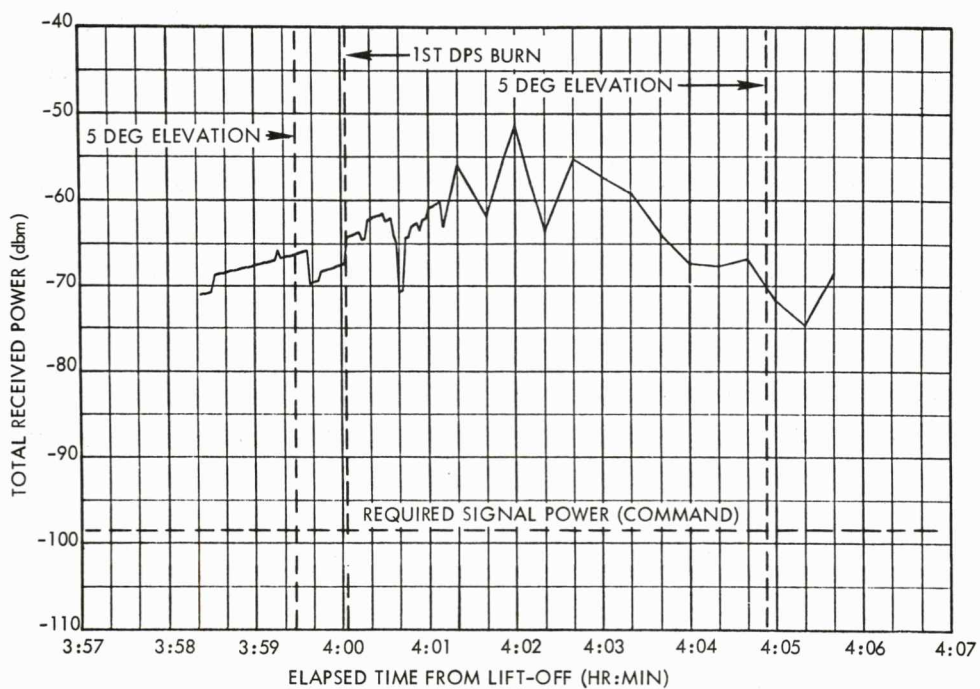


Figure 8-2. CRO UHF Total Received Power Versus Elapsed Time from Lift-Off, 1st DPS Burn

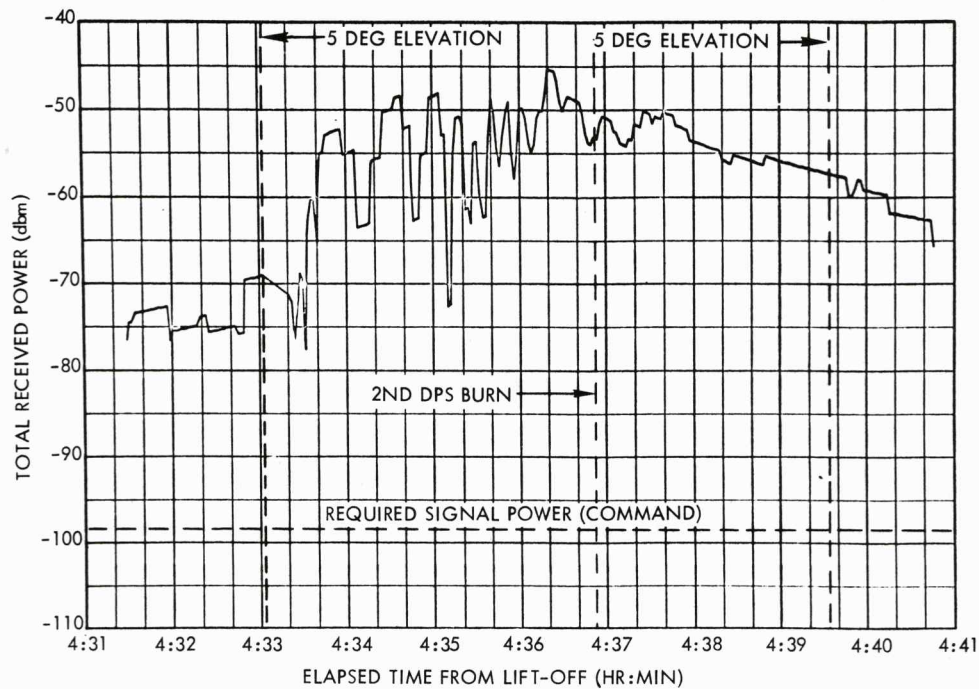


Figure 8-3. CSQ UHF Total Received Power Versus Elapsed Time from Lift-Off, 2nd DPS Burn

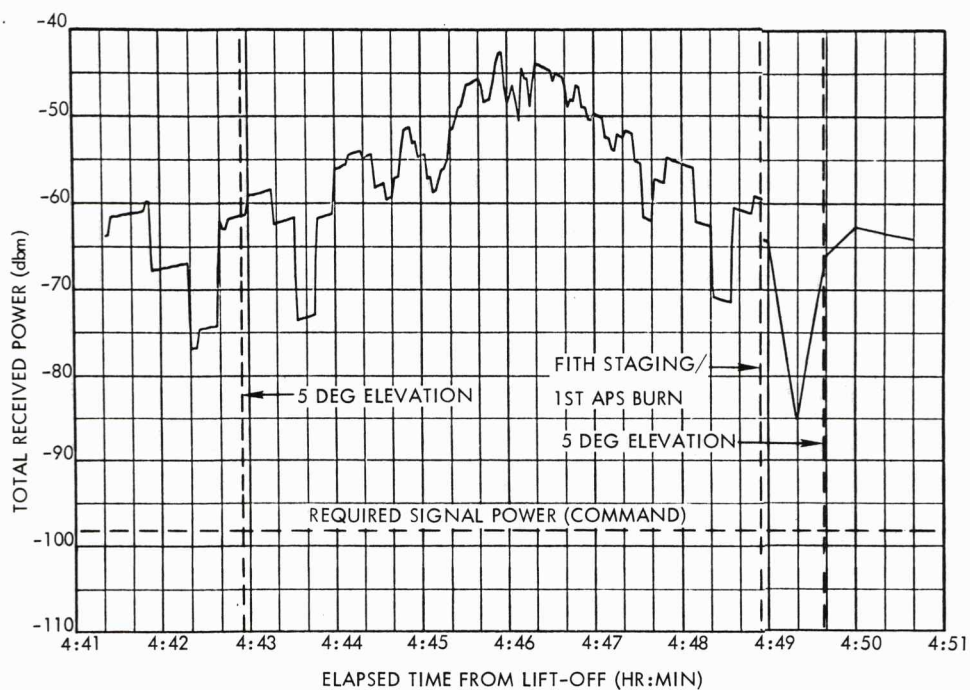


Figure 8-4. MIL (CNV) UHF Total Received Power Versus Elapsed Time from Lift-Off, 1st APS Burn

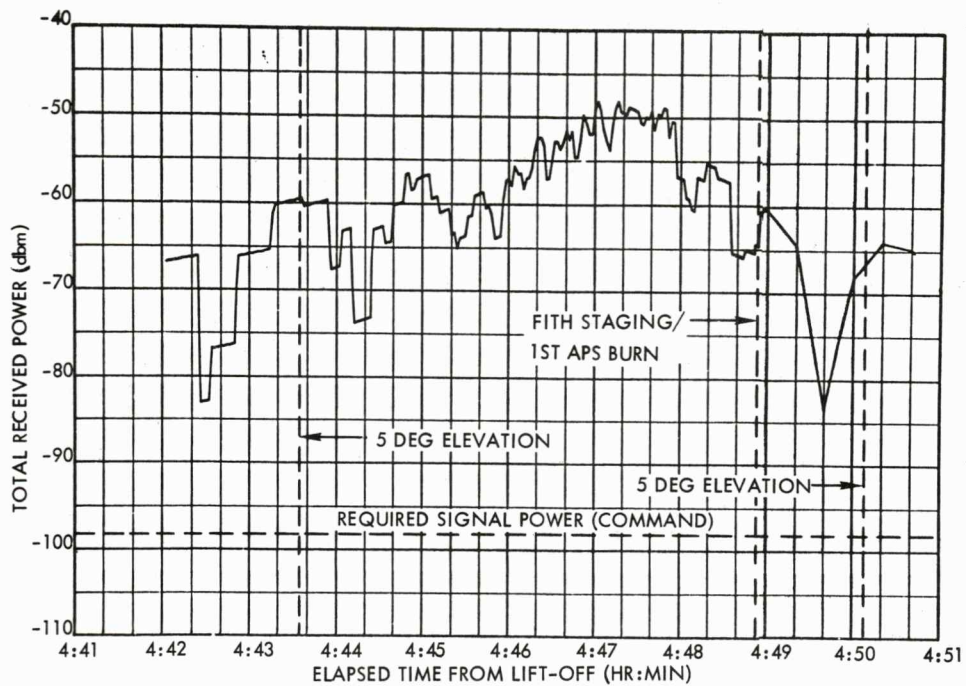


Figure 8-5. GBI UHF Total Receiver Power Versus Elapsed Time from Lift-Off, 1st APS Burn

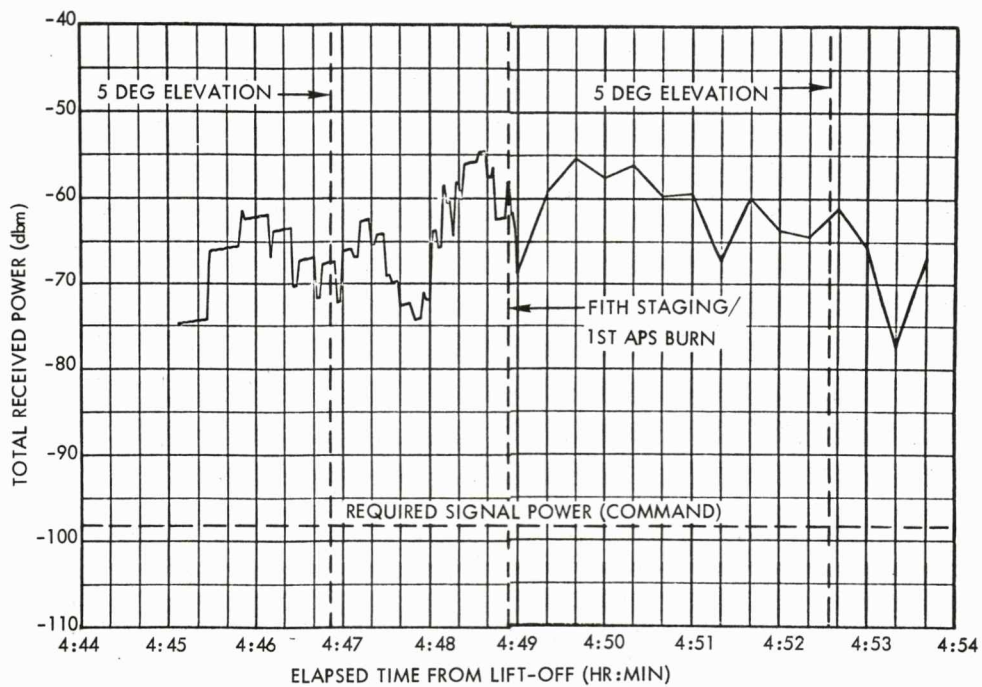


Figure 8-6. BDA UHF Total Received Power Versus Elapsed Time from Lift-Off, 1st APS Burn

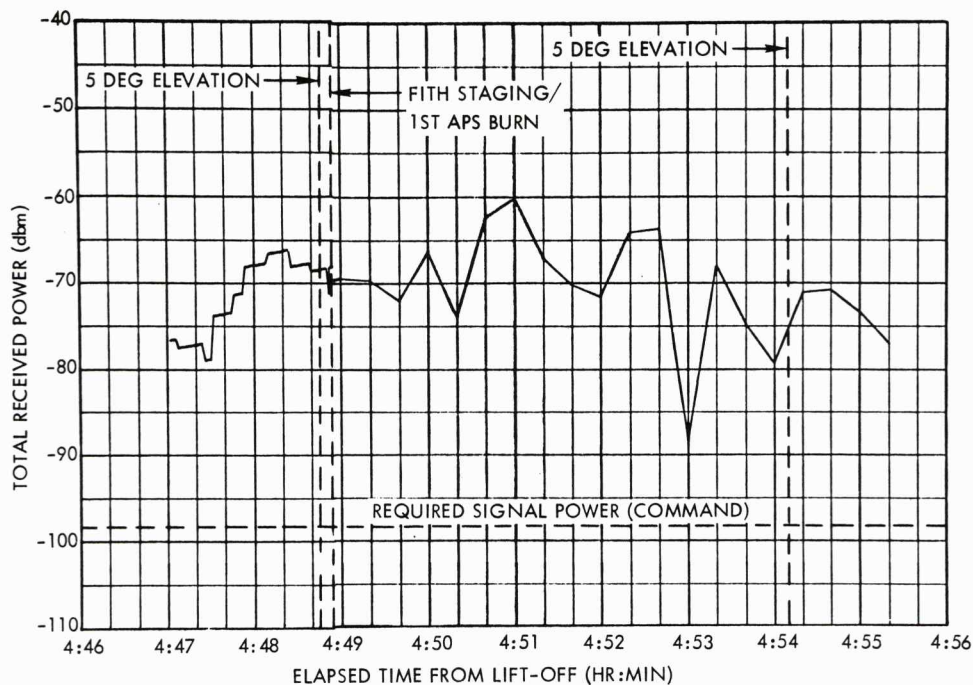


Figure 8-7. ANT UHF Total Received Power Versus Elapsed Time from Lift-Off, 1st APS Burn

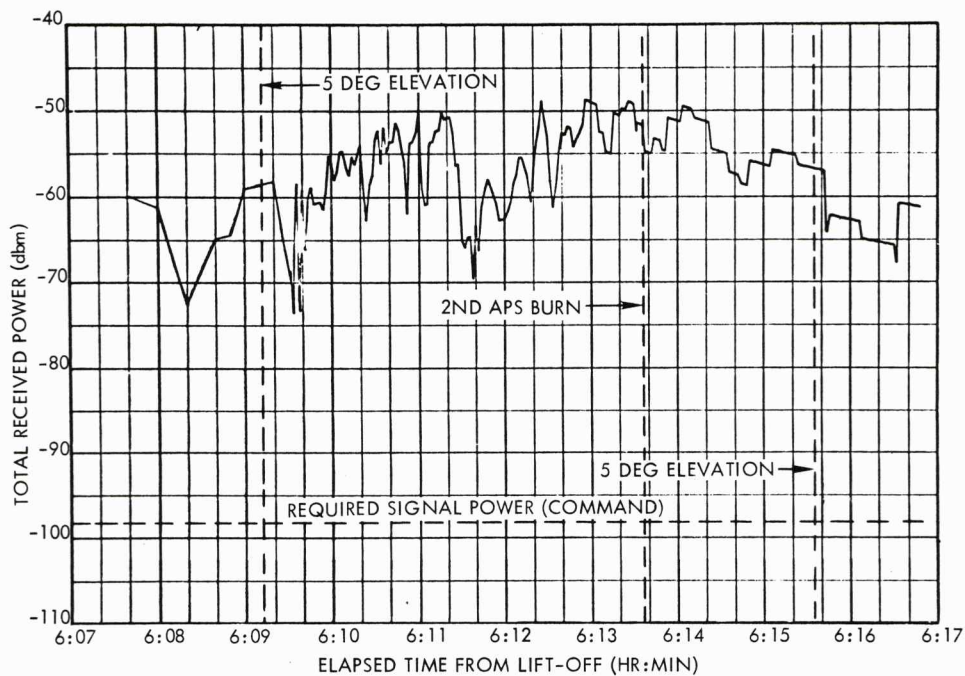


Figure 8-8. CSQ UHF Total Received Power Versus Elapsed Time from Lift-Off, 2nd APS Burn

9.0 REFERENCES

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* NOTE: Mission AS-204/LM-1 was formerly Mission AS-206.

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18. "C-Band Antenna Patterns Per ICD LIS-380-15001 Para. 3.3.1.2," Grumman Aircraft Engineering Corporation Report No. LED 380-14, 24 May 1967.
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APPENDIX A
PARAMETERS

C-BAND PARAMETERS (Reference 13)

- (a) AN/FPQ-6 and AN/TPQ-18 to LM C-band transponder
 - (1) Transmitter power = 94.5 dBm
 - (2) Transmitter circuit loss = 2.6 dB
 - (3) Transmitter antenna gain = 51 dB
 - (4) Transmitter frequency = 5690 MHz
 - (5) Spacecraft receiver antenna gain = From Measured Pattern
 - (6) Spacecraft receiver circuit loss = 4.5 dB
 - (7) Spacecraft receiver sensitivity = -70 dBm
- (b) AN/FPS-16 or AN/MPS-25 to LM C-band transponder
 - (1) Transmitter power = 83.4 dBm
 - (2) Transmitter circuit loss = 2.0 dB
 - (3) Transmitter antenna gain = 44 dB
 - (4) Transmitter frequency = 5690 MHz
 - (5) Spacecraft receiver antenna gain = From Measured Pattern
 - (6) Spacecraft receiver circuit loss = 4.5 dB
 - (7) Spacecraft receiver sensitivity = -70 dBm
- (c) LM C-band transponder to AN/FPQ-6 or AN/TPQ-18
 - (1) Spacecraft transmitter power = 57.0 dBm
 - (2) Spacecraft transmitter circuit loss = 4.5 dB
 - (3) Spacecraft transmitter antenna gain = From Measured Pattern
 - (4) Spacecraft transmitter frequency = 5765 MHz
 - (5) MSFN receiving antenna gain = 51 dB
 - (6) MSFN receiver circuit loss = 2.3 dB
 - (7) Required receiver input SNR = 10 dB
 - (8) MSFN receiver noise bandwidth = 1.6 MHz
 - (9) Receiver system noise temperature = 503°K
- (d) LM C-band transponder to AN/FPS-16 or AN/MPS-25
 - (1) Spacecraft transmitter power = 57.0 dBm
 - (2) Spacecraft transmitter circuit loss = 4.5 dB
 - (3) Spacecraft transmitter antenna gain = From Measured Pattern
 - (4) Spacecraft transmitter frequency = 5765 MHz
 - (5) MSFN receiving antenna gain = 44 dB
 - (6) MSFN receiver circuit loss = 2.15 dB
 - (7) Required receiver input SNR = 10 dB
 - (8) MSFN receiver noise bandwidth = 1.6 MHz
 - (9) Receiver system noise temperature = 503°K

UHF PARAMETERS (Reference 14)

- (a) Ground station transmitted power = 69 dBm
- (b) Ground station frequency = 450 MHz
- (c) Transmitting antenna gain = 18 dB
- (d) Modulation = PSK-FM 1000 Hz sync

- (e) Transmitting circuit loss = 1.2 dB
- (f) Ground station pointing loss = 0 dB
- (g) Polarization Loss = 0 dB
- (h) Spacecraft antenna gain = From Measured Pattern
- (i) Spacecraft receiving circuit loss = 4 dB
- (j) Spacecraft receiver noise power = -108.5 dBm
- (k) Spacecraft receiver required signal-to-noise ratio = 10 dB

VHF PARAMETERS FOR PAM TELEMETRY (Reference 12)

- (a) Type of modulation: PAM/FM/FM
- (b) Spacecraft transmitting frequencies: 230.9, 241.5, 247.3, 257.3 MHz
- (c) Spacecraft transmitting power = 40.0 dBm
- (d) Spacecraft transmitting antenna gain = From Measured Pattern
- (e) Transmitting circuit losses = 5.5 dB
- (f) MSFN receiving antenna gain = 18 dB
- (g) MSFN pointing loss = 0 dB
- (h) Polarization loss = 0 dB
- (i) MSFN receiving circuit loss = 1.5 dB
- (j) MSFN receiver required S/N = 10.0 dB
- (k) MSFN noise spectral density = -169.2 dBm/Hz
- (l) MSFN receiver noise bandwidth = 300 KHz

VHF PARAMETERS FOR PCM TELEMETRY (Reference 12)

- (a) Type of modulation: PCM/FM
- (b) Spacecraft transmitting frequency = 237.8 MHz
- (c) Spacecraft transmitting power = 40 dBm
- (d) Spacecraft transmitting antenna gain = From Measured Pattern
- (e) Transmitting circuit losses = 5.5 dB
- (f) MSFN receiving antenna gain = 18 dB
- (g) MSFN pointing loss = 0 dB
- (h) Polarization loss = 0 dB
- (i) MSFN receiving circuit loss = 1.5 dB
- (j) MSFN receiver required S/N = 10.0 dB
- (k) MSFN noise spectral density = -168.9 dBm/Hz
- (l) MSFN receiver noise bandwidth = 100 KHz
- (m) FM Signal to Noise Improvement (above threshold) = 6.2 dB

S-BAND PARAMETERS (Reference 11)

I. MSFN Parameters

A. Transmitting Frequency	2101.802 MHz
B. 30 ft. Antenna Gain	
1. Transmit	43 dB
2. Receive	42 dB *
C. 85 ft. Antenna Gain	
1. Transmit	50.0 dB
2. Receive	50.5 dB
D. Polarization Loss	0.0 dB
E. Pointing Loss	0.0 dB
F. Transmitter Output Signal Power (Single Transmit Mode)	9.5 Kw
G. System Noise Temperature	
$T_s = A + BP_c$	
P_c = Received Carrier Power in watts (computed)	
1. Constant A	
a) Cooled Paramp	96°K
b) Uncooled Paramp	250° K
2. Constant B	3.05×10^{15}
H. IF Noise Bandwidth	5.3 MHz

II. LM Parameters

A. Transmitting Frequency	2282.5 MHz
B. Omni Antenna Gain	From antenna patterns
C. Polarization Loss	0.0 dB
D. Circuit Losses	
1. Transmit	5.4 dB
2. Receive	6.2 dB
E. Transmitter Output Power	17.0 watts

* The specified value is 44 dB.

F.	System Noise Temperature	
1.	Constant A	3360 K
2.	Constant B	1.26×10^{14}
G.	IF Noise Bandwidth	5.1 MHz
III.	Telemetry Channel Parameters	
A.	Phase Deviations	
1.	Uplink	0.76 radian
2.	51.2 kbps Down Data	0.7
B.	Predetection Noise Bandwidth	
1.	51.2 kbps data	198 kHz
C.	Required Signal-to-Noise Ratios in Predetection Bandwidth	
1.	51.2 kbps	8.5 dB
IV.	Voice Channel Parameters	
A.	Phase Deviation	
1.	Uplink	1.0 radian
B.	Predetection Noise Bandwidth	
1.	Uplink	22 kHz
V.	PRN Ranging Channel Parameters	
A.	Phase Deviation	0.5 radian
B.	Video Bandwidth	1.8 MHz
C.	Transponder Ranging Gain Constant	0.63
D.	Required PRN Signal-to-Noise Ratio at MSFN Station (in a one Hz bandwidth)	32 dB
VI.	Carrier Parameters	
A.	Carrier Loop Noise Bandwidth	
1.	Uplink	1500 Hz
2.	Downlink	840 Hz
B.	Required Carrier Signal-to-Noise Ratio	
1.	Uplink	12 dB
2.	Downlink	12 dB

APPENDIX B

EQUATIONS AND SAMPLE CALCULATIONS

EQUATIONS FOR C-BAND, VHF, UHF

$$P_R = P_{TR} - L_S - L_T - L_R - L_{PZ} - L_P + G_{TR} + G_R$$

where

P_R = power received in dBm

P_{TR} = power transmitted in dBm

$L_S = 20 \log R_{nm} + 20 \log f_{MHz} + 37.8$ = space losses in dB

L_T = transmitter losses in dB

L_R = receiver loss in dB

L_{PZ} = polarization loss in dB

L_P = pointing loss in dB

G_R = gain receiving antenna in dB

G_{TR} = gain transmitting antenna in dB

SAMPLE CALCULATIONS FOR C-BAND and VHF

C-Band Tracking

(a) MSFN to LM (AN/FPQ-6 or AN/TPQ-18 radar)

$$P_{TR} = 94.5 \text{ dBm}$$

$$R = 100 \text{ nautical miles}$$

$$L_S = 20 \log 100 + 20 \log 5690 + 37.8 \\ = 152.9 \text{ dB}$$

$$G_R = -6.0 \text{ dB (specified value)}$$

$$G_{TR} = 51.0 \text{ dB}$$

$$L_T = 2.6 \text{ dB}$$

$$L_R = 4.5 \text{ dB}$$

$$L_{PZ} = L_P = 0 \text{ dB}$$

$$P_R = 94.5 - (152.9 + 2.6 + 4.5) - 6.0 + 51.0$$

$$= -20.5 \text{ dBm}$$

Required Signal Power (Tracking) = Receiver Sensitivity = -70 dBm

Performance Margin = -20.5 - (-70.0) = 49.5 dB

(b) MSFN to LM (AN/FPS-16 or AN/MPS-25 radar)

$$P_{TR} = 83.4 \text{ dBm}$$

$$R = 100 \text{ nautical miles}$$

$$L_S = 152.9 \text{ dB}$$

$$G_R = -6.0 \text{ dB (specified value)}$$

$$G_{TR} = 44.0 \text{ dB}$$

$$L_T = 2.0 \text{ dB}$$

$$L_R = 4.5 \text{ dB}$$

$$L_{PZ} = L_P = 0 \text{ dB}$$

$$P_R = 83.4 - (152.9 - 2.0 - 4.5) - 6.0 + 44$$

$$= -38.0 \text{ dBm}$$

Required Signal Power (Tracking) = Receiver Sensitivity
= -70.0 dBm

Performance Margin = 32.0 dB

(c) LM to MSFN (AN/FPQ-6 or AN/TPQ-18 radar)

$$P_{TR} = 57.0 \text{ dBm}$$

$$R = 100 \text{ nautical miles}$$

$$L_S = 20 \log 100 + 20 \log 5765 + 37.8$$

$$= 153.0 \text{ dB}$$

$$G_{TR} = -6.0 \text{ dB (specified value)}$$

$$G_R = 51.0 \text{ dB}$$

$$L_T = 4.5 \text{ dB}$$

$$L_R = 2.3 \text{ dB}$$

$$L_{PZ} = L_P = 0 \text{ dB}$$

$$P_R = 57.0 - (153.0 + 4.5 + 2.3) - 6.0 + 51.0$$

$$= -57.8 \text{ dBm}$$

$$P_N = 10 \log B_R + 10 \log KT$$

where

P_n = Received Carrier Noise Power

B_R = MSFN Receiver Noise Bandwidth

K = Boltzman's Constant

$$= 1.38 \times 10^{-20} \text{ m watts/Hz/K}^\circ$$

T = Receiver System Noise Temperature

$$\begin{aligned} P_N &= 10 \log (1.6 \times 10^6) + 10 \log [(1.38 \times 10^{-23})(503.4)] \\ &= 62.0 - 198.6 + 27.0 \\ &= -109.6 \text{ dBm} \end{aligned}$$

$$\begin{aligned} \text{Carrier-to-Noise Ratio (available)} &= -57.8 - (-109.6) \\ &= 51.8 \text{ dB} \end{aligned}$$

$$\text{Carrier-to-Noise Ratio (required tracking)} = 10.0 \text{ dB}$$

$$\text{Performance Margin} = 41.8 \text{ dB}$$

$$\begin{aligned} \text{Required Signal Power (Tracking)} &= -57.8 \text{ dBm} - 41.8 \text{ dB} \\ &= -99.6 \text{ dBm} \end{aligned}$$

(d) LM to MSFN (AN/FPS-16 or AN/MPS-25 radar)

$$P_{TR} = 57.0 \text{ dBm}$$

$$L_S = 153.0 \text{ dB}$$

$$G_{TR} = -6.0 \text{ dB}$$

$$G_R = 44.0 \text{ dB}$$

$$L_T = 4.5 \text{ dB}$$

$$L_R = 2.15 \text{ dB}$$

$$L_{PZ} = L_P = 0 \text{ dB}$$

$$\begin{aligned} P_R &= 57.0 - (+153.0 + 4.5 + 2.15) - 6.0 + 44.0 \\ &= -64.65 \text{ dBm} \end{aligned}$$

$$\text{Received Carrier Noise Power} = -109.6 \text{ dBm}$$

$$\begin{aligned} \text{Carrier-to-Noise Ratio (available)} &= -64.65 - (-109.6) \\ &= 44.95 \text{ dB} \end{aligned}$$

$$\text{Carrier-to-Noise Ratio (required tracking)} = 10.0 \text{ dB}$$

$$\text{Performance Margin} = 34.95 \text{ dB}$$

$$\begin{aligned} \text{Required Signal Power (tracking)} &= -64.65 \text{ dBm} - 34.95 \text{ dB} \\ &= -99.6 \text{ dBm} \end{aligned}$$

VHF PCM/FM Telemetry

LM to MSFN

$$P_{TR} = 40.0 \text{ dBm}$$

$$L_S = 20 \log 100 + 20 \log 237.8 + 37.8 \\ = 125.3 \text{ dB}$$

$$G_{TR} = -9.0 \text{ dB (specified value)}$$

$$G_R = 18.0 \text{ dB}$$

$$L_T = 5.5 \text{ dB}$$

$$L_R = 1.5 \text{ dB}$$

$$L_{PZ} = L_P = 0 \text{ dB}$$

$$P_R = 40.0 - (125.3 + 5.5 + 1.5) - 9.0 + 18.0 \\ = -83.3 \text{ dBm}$$

$$P_N = 10 \log B_{IF} + 10 \log KT$$

where

$$P_N = \text{IF Noise Power}$$

$$B_{IF} = \text{IF Noise Bandwidth}$$

$$10 \log KT = \text{Noise Spectral Density (dBm/Hz)}$$

$$P_N = 50.0 \text{ dB} - 168.88 \text{ dBm} \\ = 118.88 \text{ dBm}$$

$$\text{Carrier-to-Noise Ratio (C/N)*} = -83.3 - (-118.88) \\ = 35.6 \text{ dB}$$

$$\text{MSFN Receiver Required C/N} = 10 \text{ dB}$$

$$\text{Carrier Circuit Margin} = 35.6 - 10.0 \\ = 25.6 \text{ dB}$$

$$P_{N_{PCM}} = 10 \log B_{PCM} + 10 \log KT$$

where

$$P_{N_{PCM}} = \text{Telemetry Noise Power}$$

$$B_{PCM} = \text{Telemetry Noise Bandwidth}$$

$$P_{N_{PCM}} = 47.09 - 168.88 \\ = -121.79 \text{ dBm}$$

* Carrier Power = Total Received Power

$$P_{PCM} = P_R + S/N_{IPM}$$

where

$$P_{PCM} = \text{Telemetry Signal Power}$$

$$S/N_{IPM} = \text{FM Signal-to-Noise Improvement}$$

$$\begin{aligned} P_{PCM} &= -83.3 + 6.2 \\ &= -77.1 \text{ dBm} \end{aligned}$$

$$\begin{aligned} \text{Telemetry Signal-to-Noise Ratio} &= -77.1 - (-121.79) \\ &= 44.7 \text{ dB} \end{aligned}$$

Required Telemetry S/N for 10^{-6} Bit Error Probability = 18 dB

Telemetry Margin = 26.7 dB

Threshold for the VHF-PCM/FM Telemetry System is determined by the carrier threshold. Thus,

$$\begin{aligned} \text{Required Carrier Power (} 10^{-6} \text{ Bit Error Probability Telemetry)} \\ &= -83.3 \text{ dBm} - 25.6 \text{ dB} \\ &= -108.9 \text{ dBm} \end{aligned}$$

EQUATIONS AND SAMPLE CALCULATIONS FOR S-BAND

This section contains sample calculations for the S-band system. The sample calculations below are for the carrier, PRN, and 51.2 kbps on the downlink assuming PRN, voice and updata on the uplink. The parameters listed in Appendix A were used in these calculations. The equations used in the following calculations are given in Reference 2.

<u>Step</u>	<u>Value</u>	<u>Units</u>
(1) LM Transmit Power	42.3	dBm
(2) LM Omni Antenna Gain * (includes circuit losses)	0	dB
(3) LM Antenna Pointing and Polarization Loss	0.0	dB
(4) Circuit Loss	-5.4	dB

* Actual value obtained from antenna pattern, 0 dB assumed for sample calculation.

	<u>Step</u>	<u>Value</u>	<u>Units</u>	(cont)
(5)	Space Loss (f = 2282.5 MHz R = 100 nm)	-145.0	dB	
(6)	MSFN 30 ft Receive Antenna Gain (includes pointing and circuit losses)	42.0	dB	
(7)	MSFN Total Received Power (sum 1 through 6)	-66.1	dBm	
		<u>Carrier</u>	<u>PRN</u>	<u>51.2 Kbps TLM</u>
(8)	Modulation Loss (includes loss due to turnaround noise and uplink subcarrier	-1.8	-15.6	-7.3 dB
(9)	Channel Power (7 + 8)	-67.9	-81.7	-73.4 dBm
(10)	Noise Spectral Density (uncooled paramp)	-141.25	-141.25	-141.25 dBm
(11)	Channel Noise Bandwidth	29.44	0.0	53.0 dB
(12)	Channel Noise Power (10 + 11)	-111.81	-141.25	-88.25 dBm
(13)	Noise + Interference Power (due to cross Modulation product)	---	---	-88.25 dBm
(14)	Channel SNR (9-12)	43.91	59.55	14.85
(15)	Required SNR	12.0	32.0	8.5 dB
(16)	Circuit Margin (14-15)	31.91	27.55	6.35

SAMPLE CALCULATION OF REQUIRED CARRIER LEVEL FOR 10^{-6} BIT ERROR PROBABILITY

The required carrier level for 10^{-6} bit error probability as denoted by the dotted line in Figures 5.1 through 5.11 is calculated as follows:

The required telemetry subcarrier power is:

$$\begin{aligned}
 P_{TM} &= S/N_{req} + P_{noise} \\
 &= S/N_{req} + KT B_{TM} \\
 &= 8.5 \text{ dB} + (-198.6 \text{ dBm}) + 24.8 \text{ dB} + 53.0 \text{ dB} \\
 &= -112.3 \text{ dBm.}
 \end{aligned}$$

The corresponding received signal level is

$$P_{\text{rec}} = P_{\text{TM}} + M_{\text{TM}} + L_{\text{LIM}}$$

where

M_{TM} = Telemetry Modulation Loss

L_{LIM} = Limiter Degradation.

Thus,

$$P_{\text{rec}} = -112.3 \text{ dBm} + 7.3 \text{ dB} + 0 \text{ dB} = -105.0 \text{ dBm}.$$

Now, the required carrier level for 10^{-6} bit error probability is

$$P_{\text{C}} = P_{\text{rec}} - M_{\text{LC}} - L_{\text{LIM}}$$

where

M_{LC} = Carrier Modulation Loss.

Thus,

$$\begin{aligned} P_{\text{C}} &= -105.0 \text{ dBm} - 1.8 \text{ dB} - 0 \text{ dB} \\ &= -106.8 \text{ dBm}. \end{aligned}$$

This carrier level was calculated for a MSFN station with an uncooled parametric amplifier. A cooled parametric amplifier would reduce the required signal by $10 \log (250/96)$, or $P_{\text{C}} = -110.7 \text{ dBm}$.

APPENDIX C

DETERMINATION OF LM SPACECRAFT ATTITUDE ANGLES

S-BAND ANTENNA PATTERNS

The AS-206 Operational Trajectory computer program uses different references for determining the spacecraft attitude angles than those which were used when the S-band antenna patterns were taken using the LM spacecraft coordinate system. The two systems are defined and related to each other as follows

The LM spacecraft coordinate system is a right handed system with +X at the top of the spacecraft (heads of the astronauts), +Y to the right of the astronauts, and +Z to the front of the vehicle (and the astronauts). The X axis is the yaw axis, the Y axis is the pitch axis and the Z axis is the roll axis. The spacecraft attitude angles are designated theta and phi. Theta is measured from the +X axis and phi is measured clockwise from the +Z axis when looking toward +X. Theta can have values from 0° to 180° and phi can have values for 0° to 360° . Plus X corresponds to a theta of 0° , +Y to a theta and phi of 90° and 270° , and +Z to 90° and 0°

The spacecraft trajectory computer printout spacecraft attitude angles are called RLA1 and RLA2. RLA1 is the angle between the X axis and the ground station line-of-sight. RLA2 is the angle between the Z axis and the ground station line-of-sight projected on a plane perpendicular to the X axis; from the -Z axis of the spacecraft the angle is measured clockwise when looking toward +X.

The correspondence between the two sets of angles can be seen by assuming the spacecraft to be in an upright position in which +X will be up. As seen on Figure C-1, $\theta = 180^\circ - \text{RLA1}$ and $\phi = \text{RLA2} + 180^\circ$ for $\text{RLA2} < 180^\circ$, and $\phi = \text{RLA2} - 180^\circ$ for $\text{RLA2} \geq 180^\circ$.

VHF ANTENNA PATTERNS

For the SLA mounted VHF antennas theta is determined as above ($\theta = 180^\circ - \text{RLA1}$) but $\phi = \text{RLA2}$ for all values of RLA2.

For LM mounted VHF antennas theta and phi are determined the same as for the S-band.

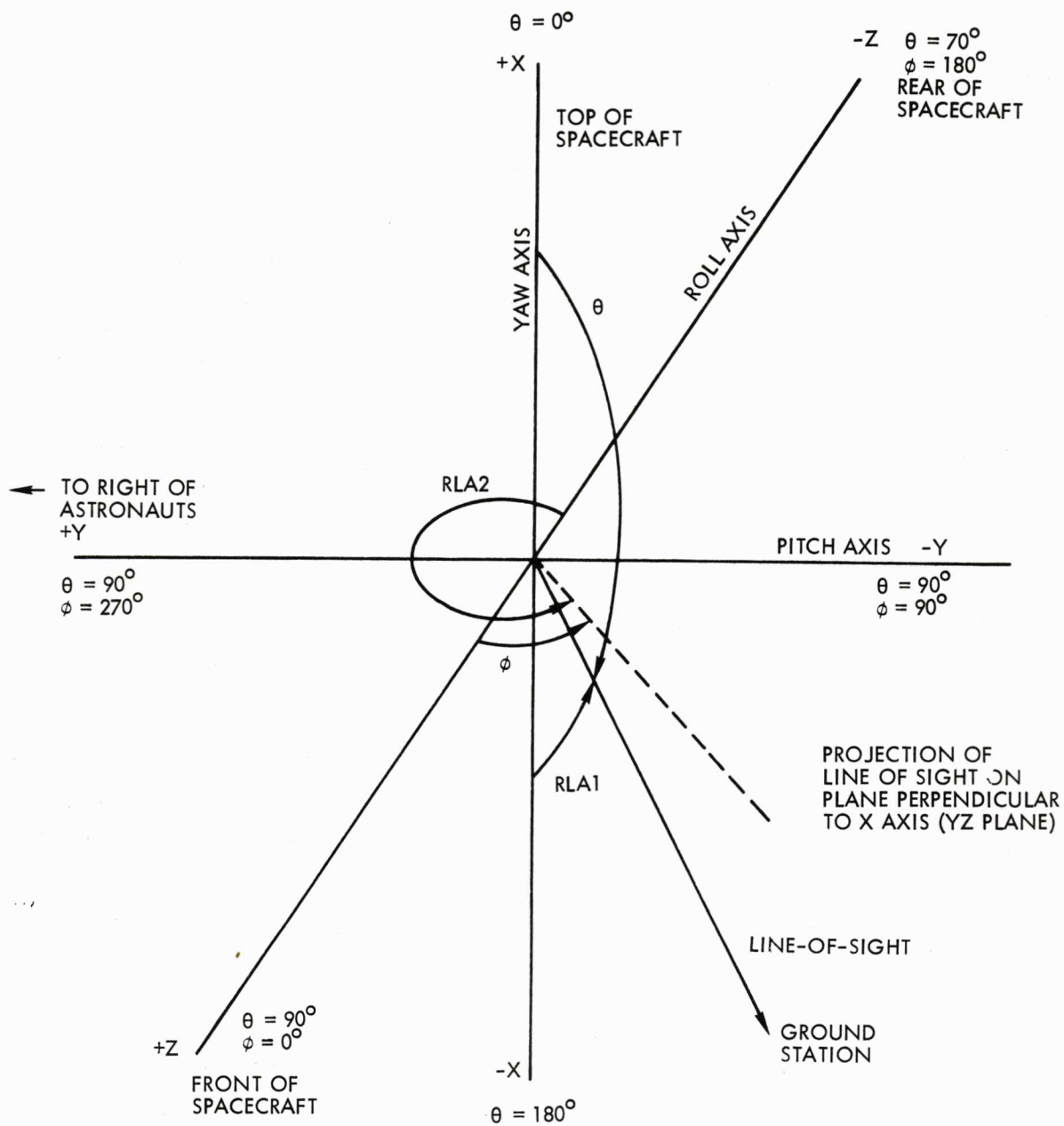


Figure C-1. Spacecraft Attitude Angles

APPENDIX D

COMPUTER PROGRAM

A mathematical model type of flow chart for the computer program used for determining signal strengths versus time is shown in Figure D-1.

The computer program consists of reading into and storing in memory, in matrix form, the antenna pattern of interest. The antenna pattern has previously been broken into $2^\circ \times 2^\circ$ segments covering the surface of a sphere and put onto magnetic tape. This antenna pattern, or Radiation Distribution Plot, is shown in the diagram as RDP (θ, ϕ), or Radiation Distribution Plot as a function of θ and ϕ . To accommodate the isotropic level of the RDP's a constant K is also fed into the computer.

The equation solved by the computer to determine the received signal power, P_R , is

$$P_R = P_{TR} - 20 \log f_{\text{MHZ}} - 20 \log R_{\text{NM}} - 37.8 - L_R - L_T - L_P - L_{PZ} + G_R + G_{SC}$$

The symbols in the above equation are defined in Appendix B of this report.

The only variables are range in nautical miles, R_{NM} , and the spacecraft antenna gain, G_{SC} . The non-variable elements of the equation are determined by hand calculation and are fed into the computer as a combined constant, C.

A solution is found for P_R by inputting a simulated trajectory stored on a magnetic tape which contains the variables θ , ϕ , and R_{NM} for given mission times. This signal power as a function of time may then be printed or plotted by the computer as desired.

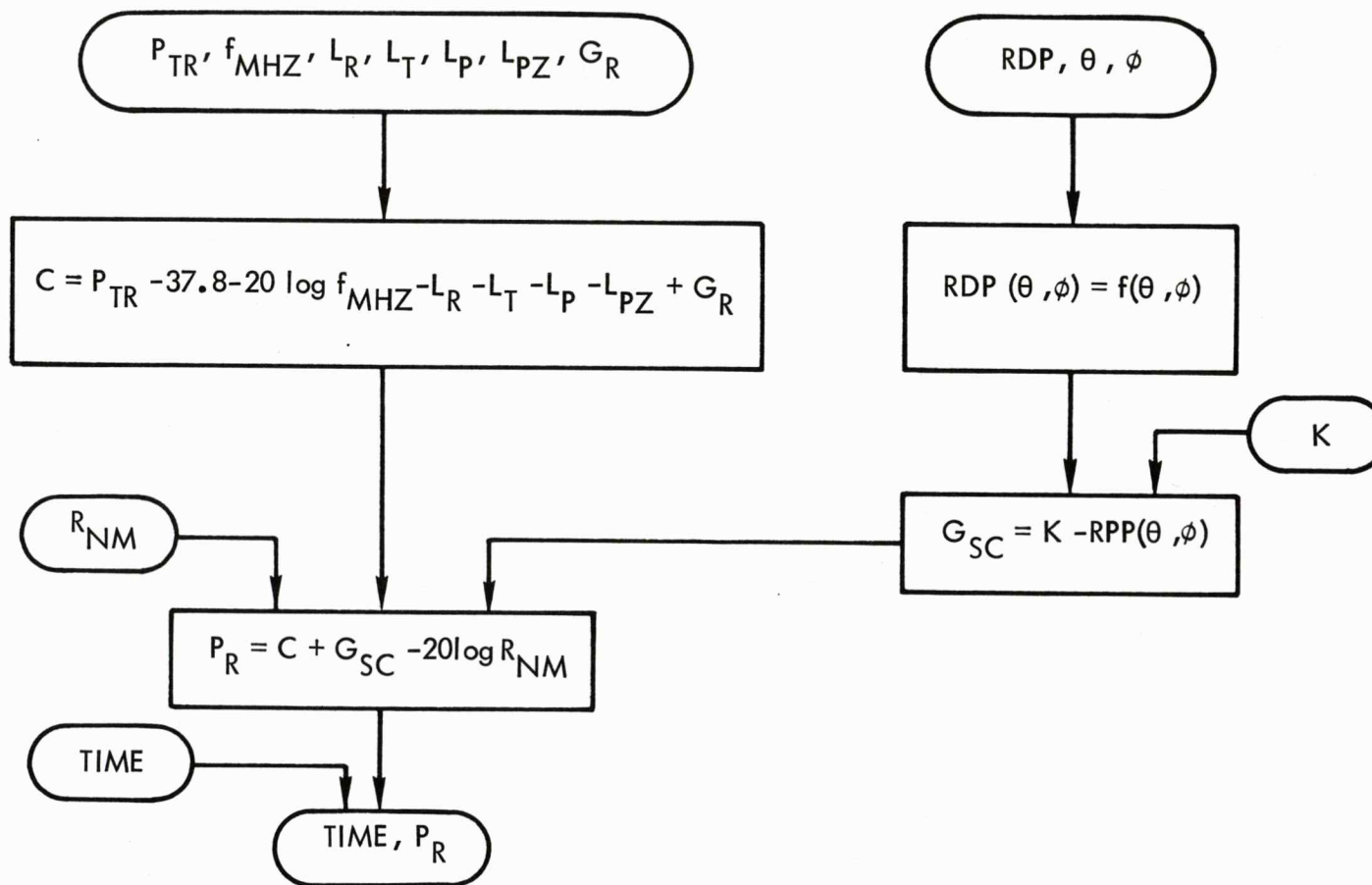


Figure D-1. Flow Chart of Computer Program for Determining Signal Strengths vs Time

APPENDIX E

DOPPLER SHIFT PREDICTIONS

One way doppler shift predictions for the S-band sites are presented in this section. Uplink doppler shift predictions are used to estimate the required MSFN transmitted frequency offset required for minimum stress in the spacecraft carrier tracking loop. Downlink doppler predictions are used to estimate the MSFN receiver offset frequency required for minimum stress in the carrier tracking loop.

The equation used to calculate the doppler shift is

$$\Delta f = \frac{f}{c} V(t)$$

where

Δf = change in received frequency due to doppler in Hz

f = transmitted frequency in Hz

c = speed of light = 9.835×10^8 ft/sec

$V(t)$ = range rate as a function of mission time in ft/sec

The following graphs are computer plots obtained from a program which combined the operational trajectory data and the above equation. For convenience purposes the offset required to compensate for the doppler effect is shown for uplink in Figures E-1 to E-36 and for the downlink in Figures E-37 to E-51.

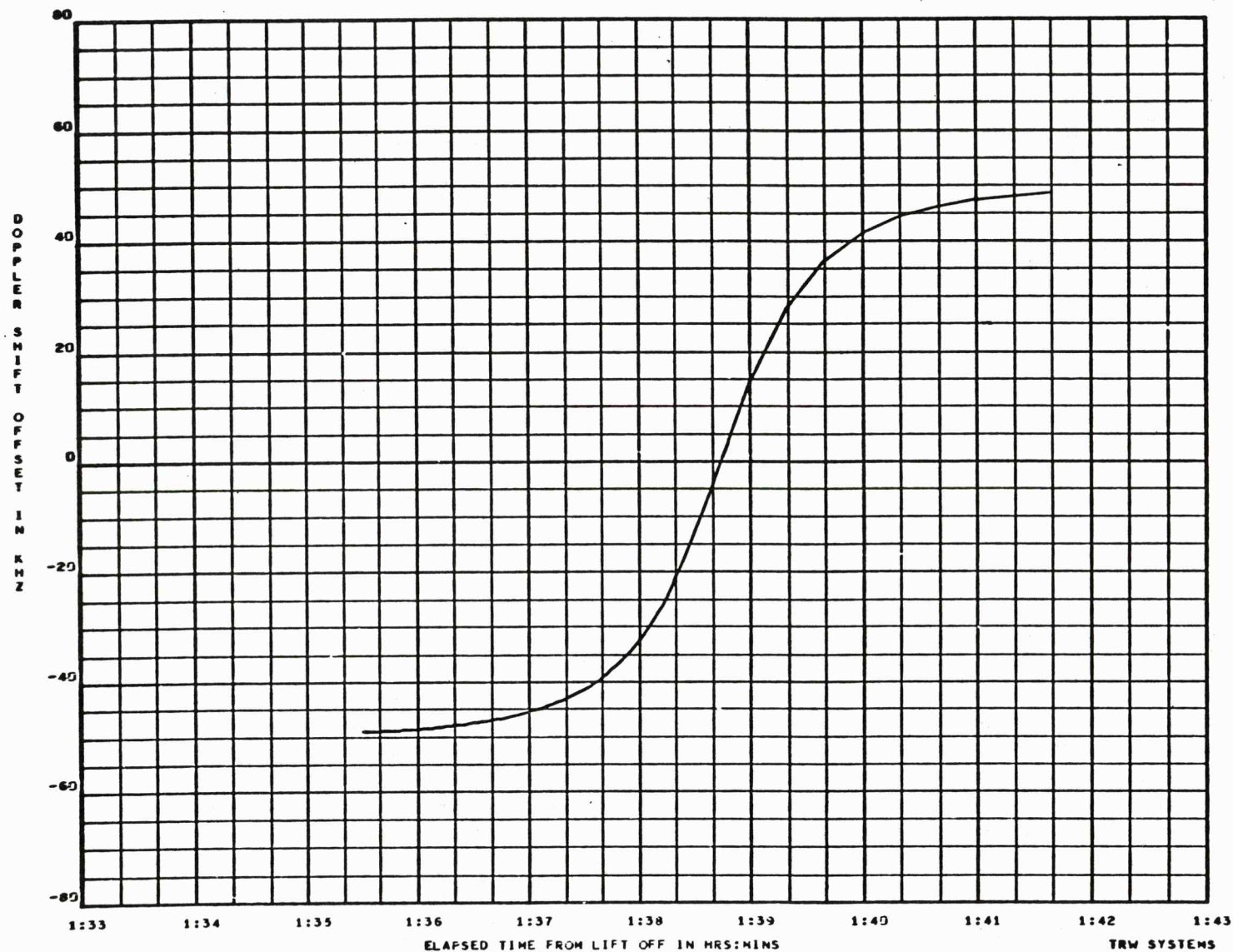


Figure E-1. MIL S-Band Uplink Doppler Frequency Offset vs Time for Orbit 1 - 2

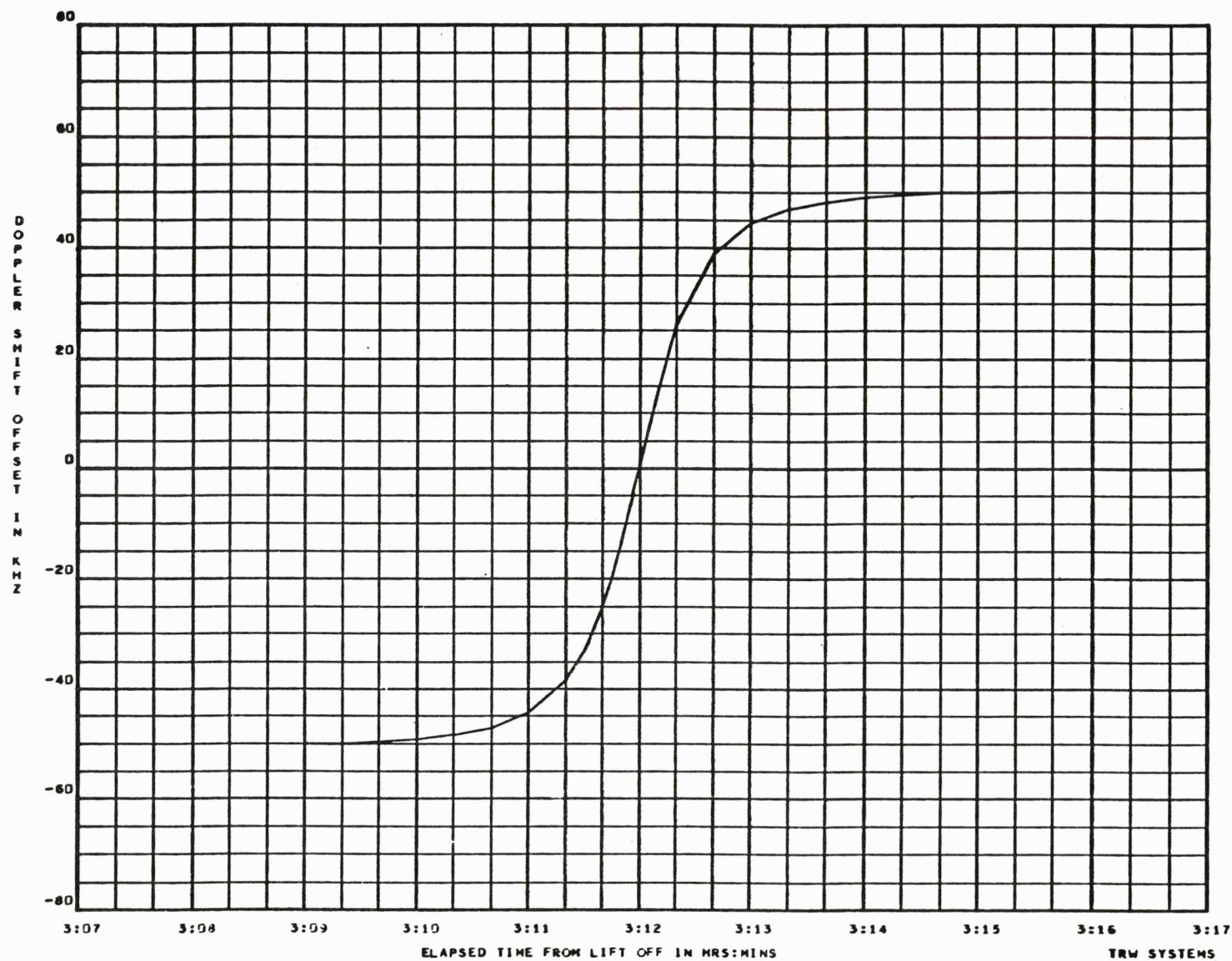


Figure E-2. MIL S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2 - 3

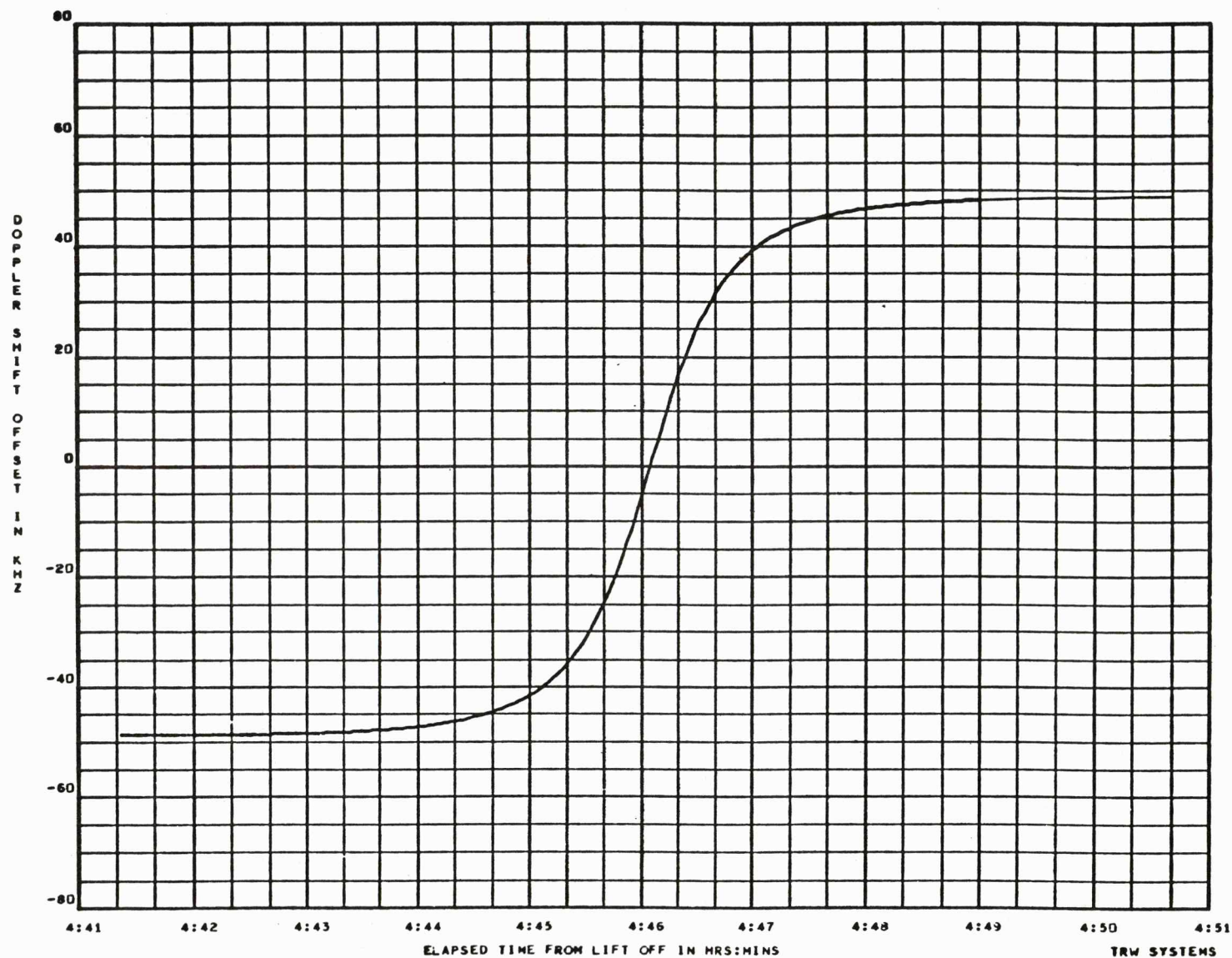


Figure E-3. MIL S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3 - 4.

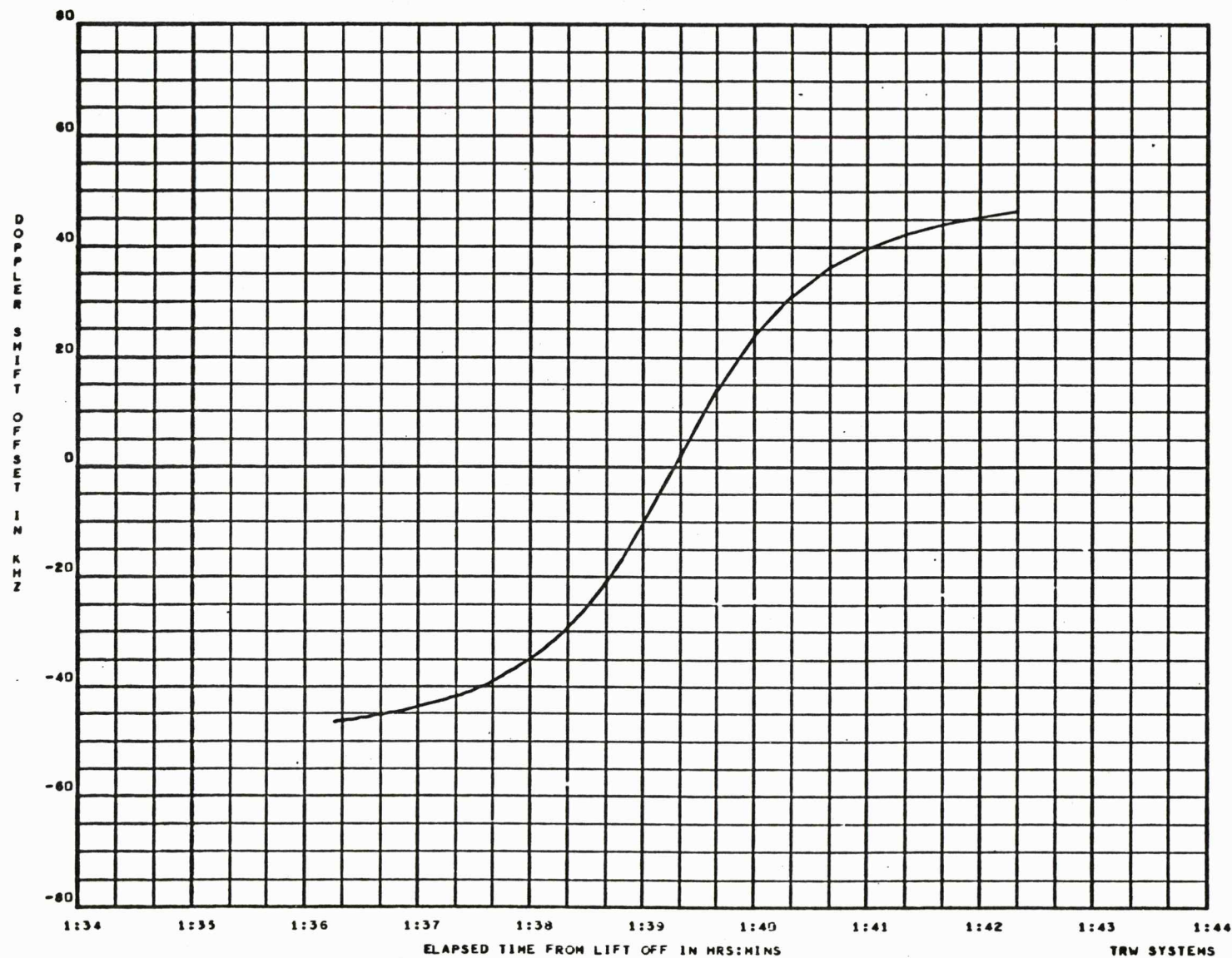


Figure E-4. GBM S-Band Uplink Doppler Frequency Offset vs Time for Orbit 1 - 2

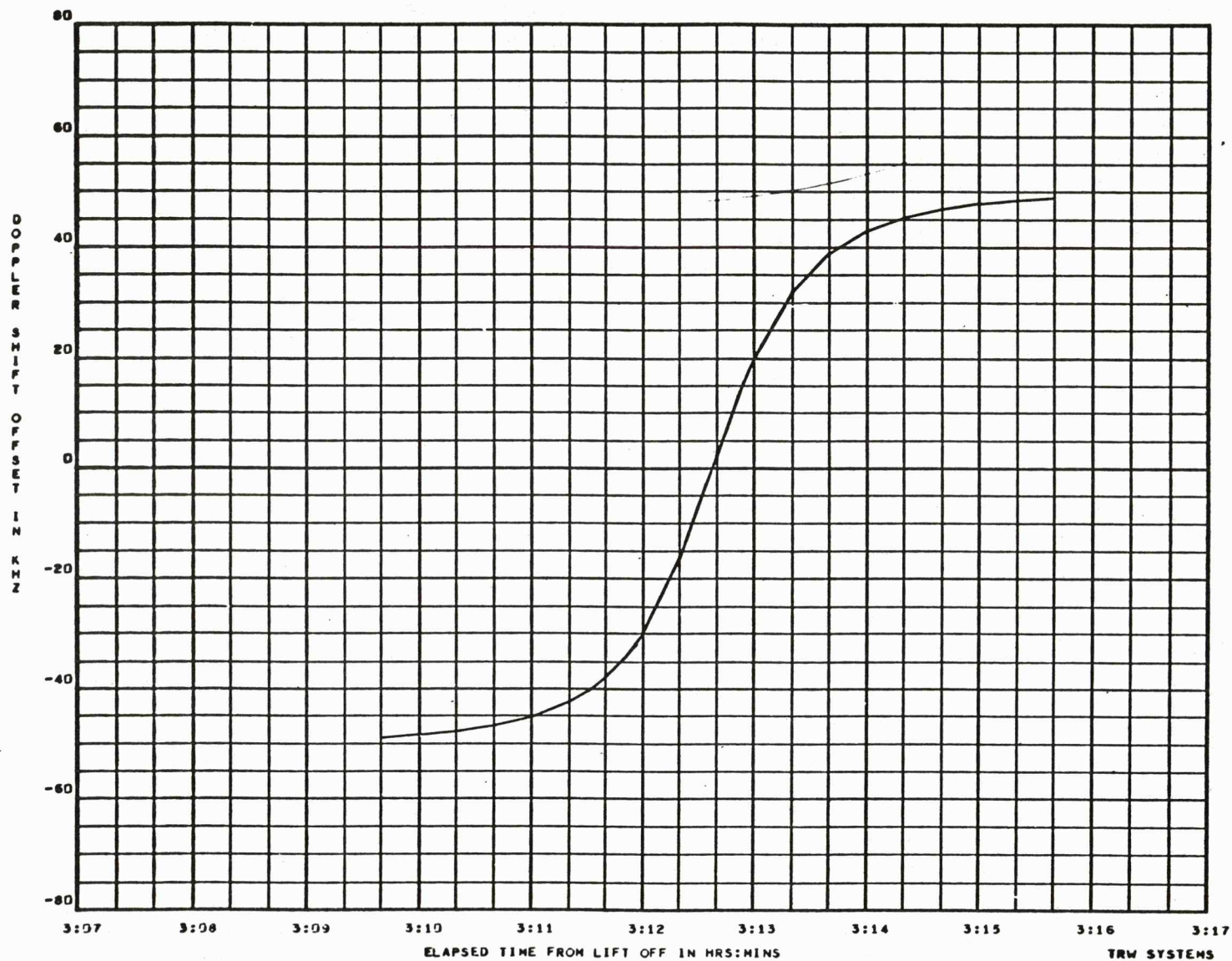


Figure E-5. GBM S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2 - 3

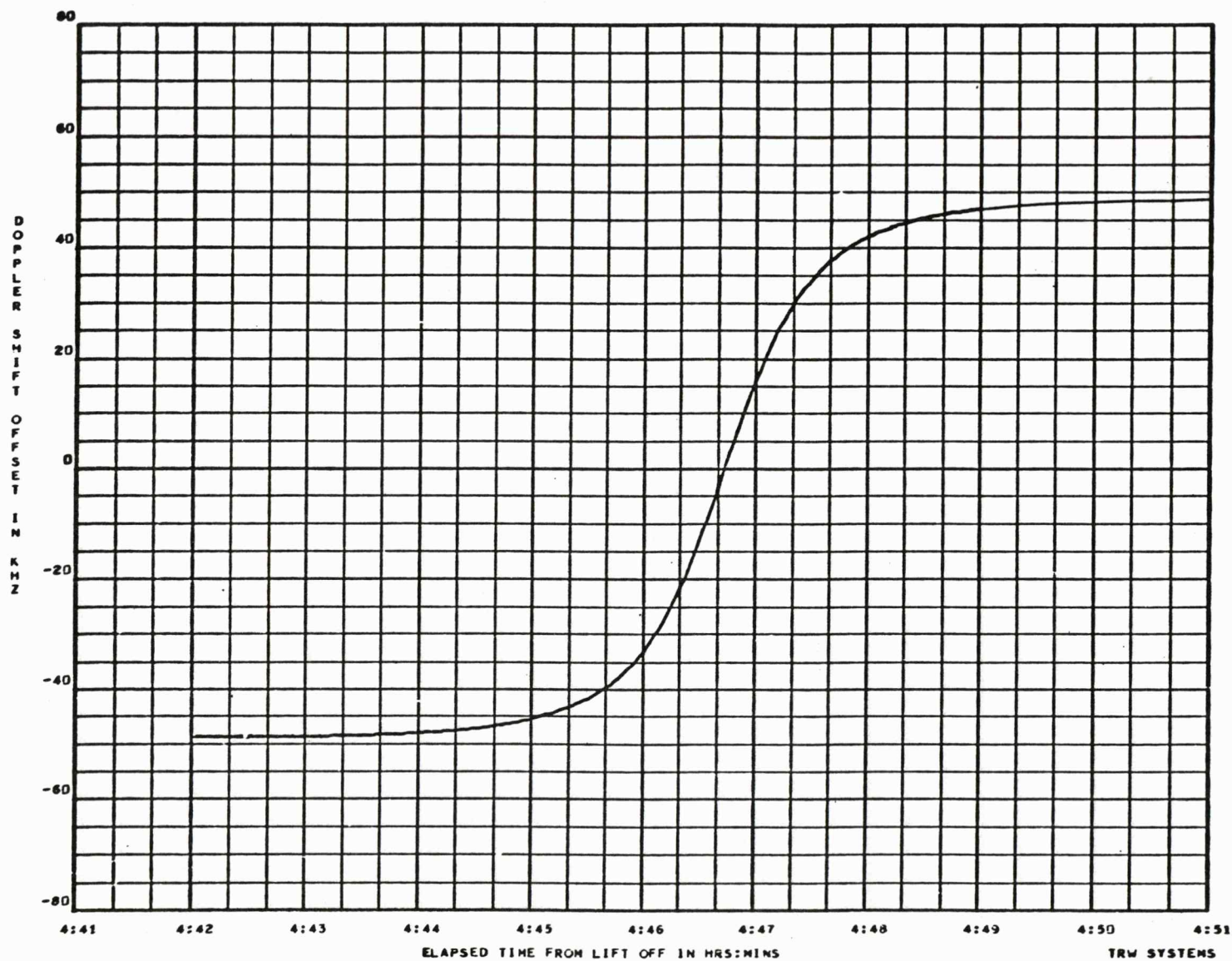


Figure E-6. GBM S-Band Uplink Doppler Frequency Offset
Offset vs Time for Orbit 3 - 4

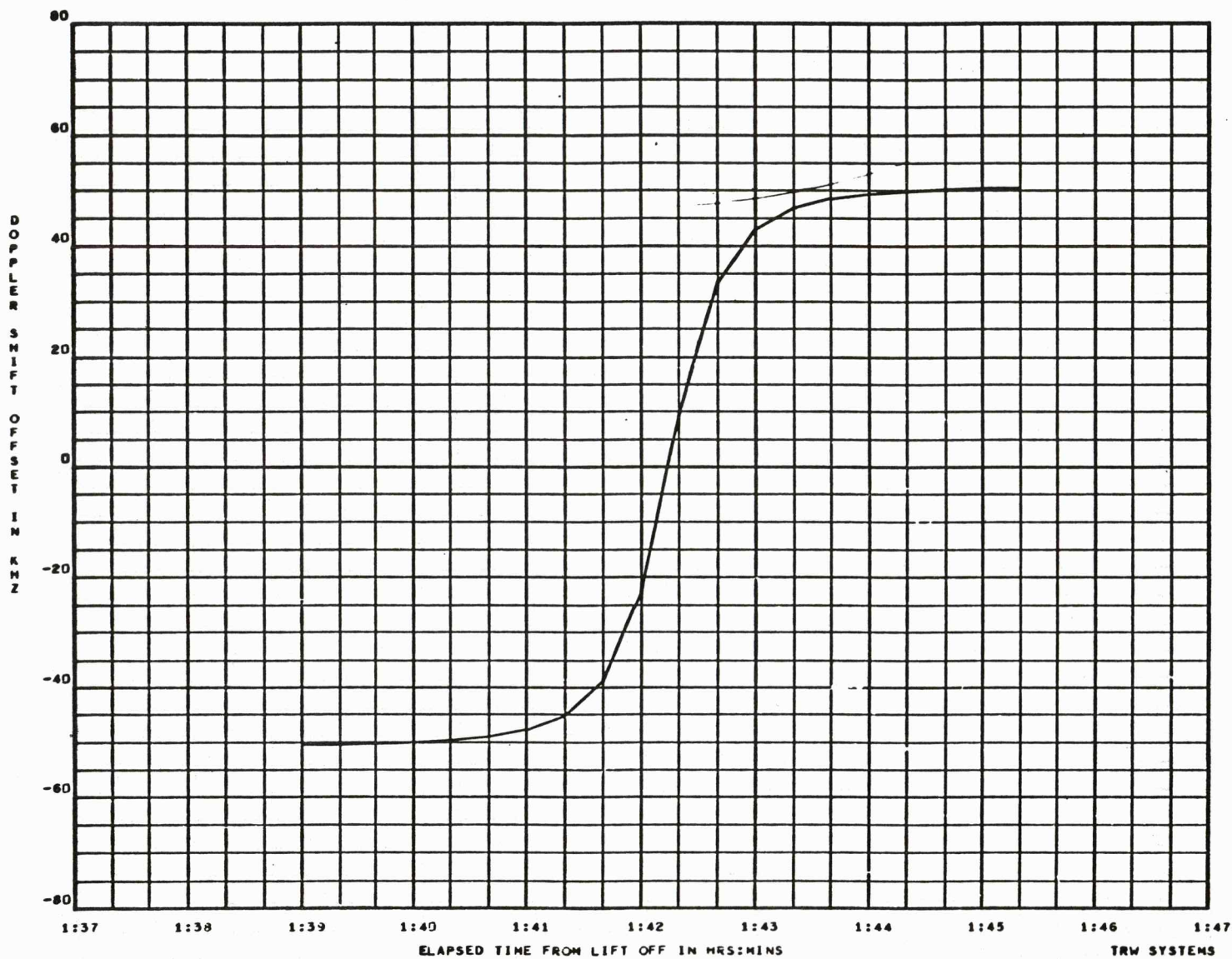


Figure E-7. BDA S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 2

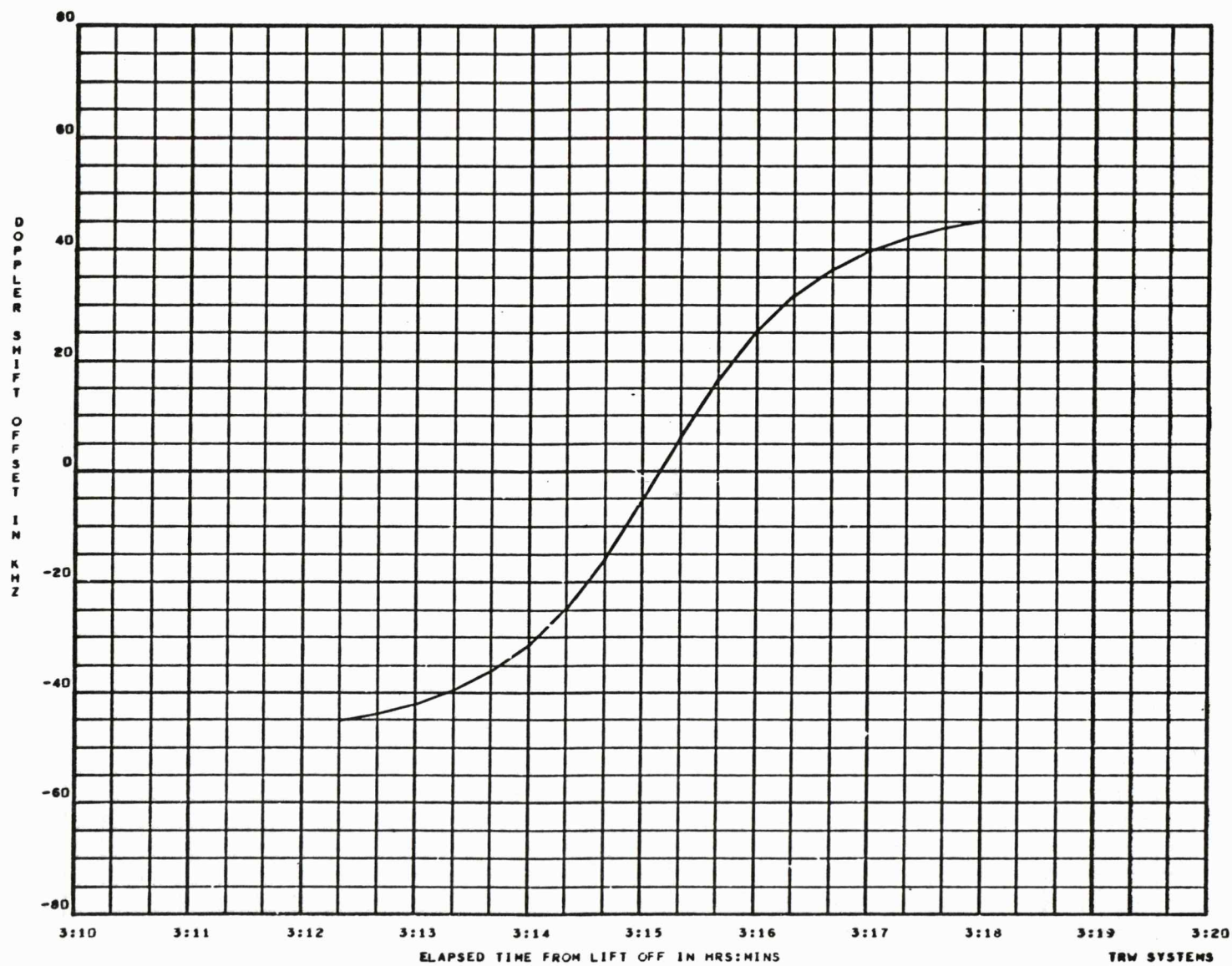


Figure E-8. BDA S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3

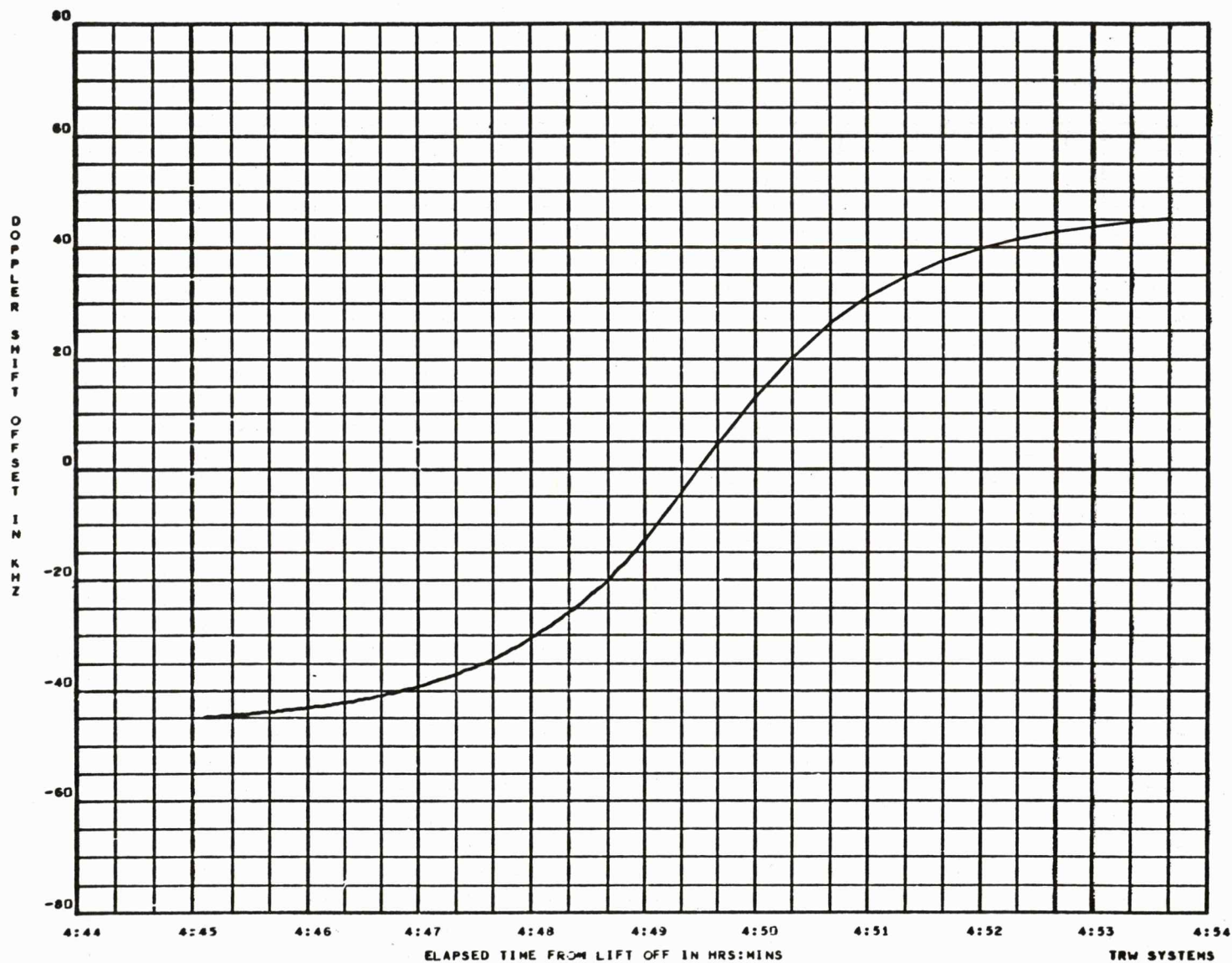


Figure E-9. BDA S-Band Uplink Doppler Frequency Offset vs Time for Orbit 4

E-11

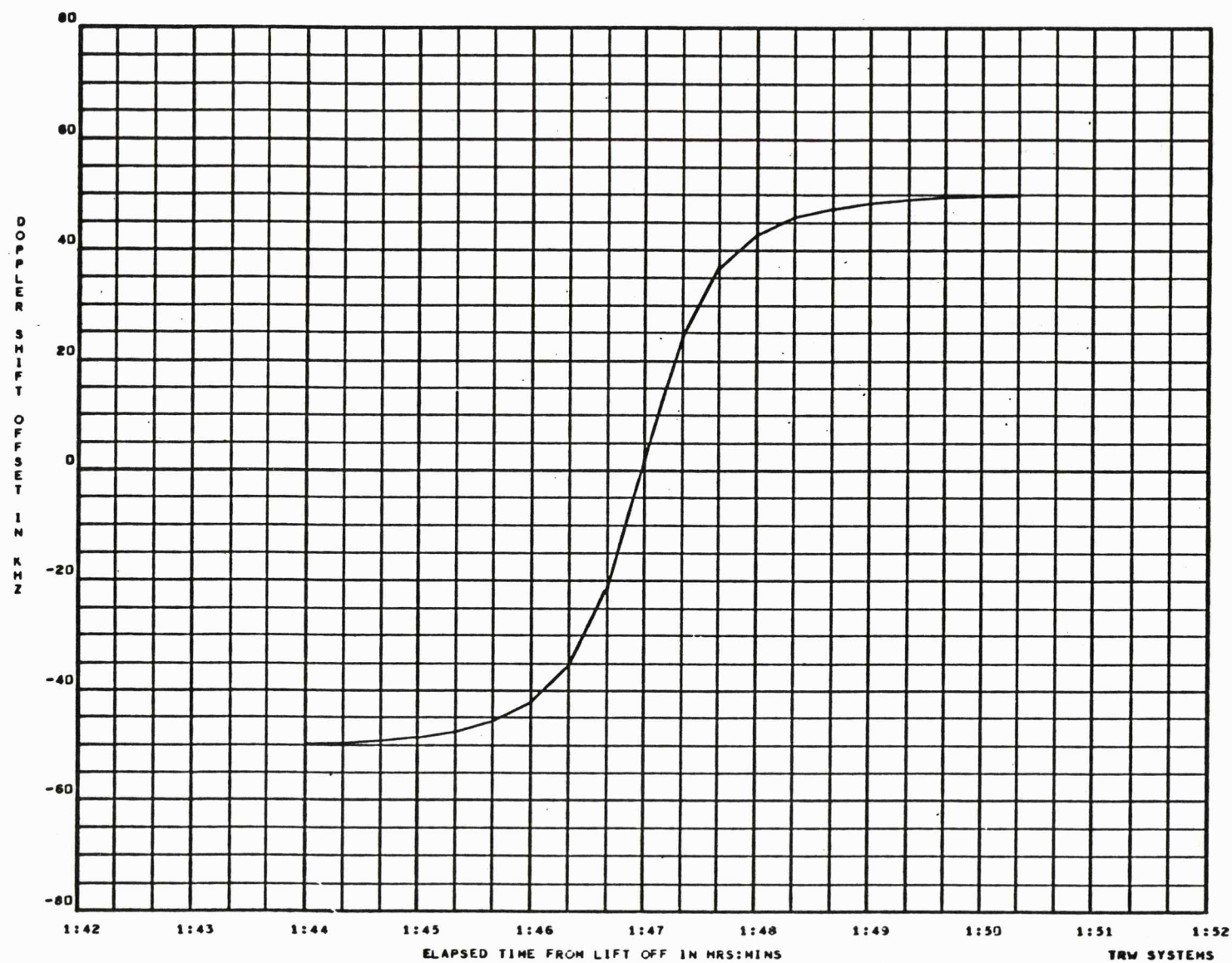


Figure E-10. VANI S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 2

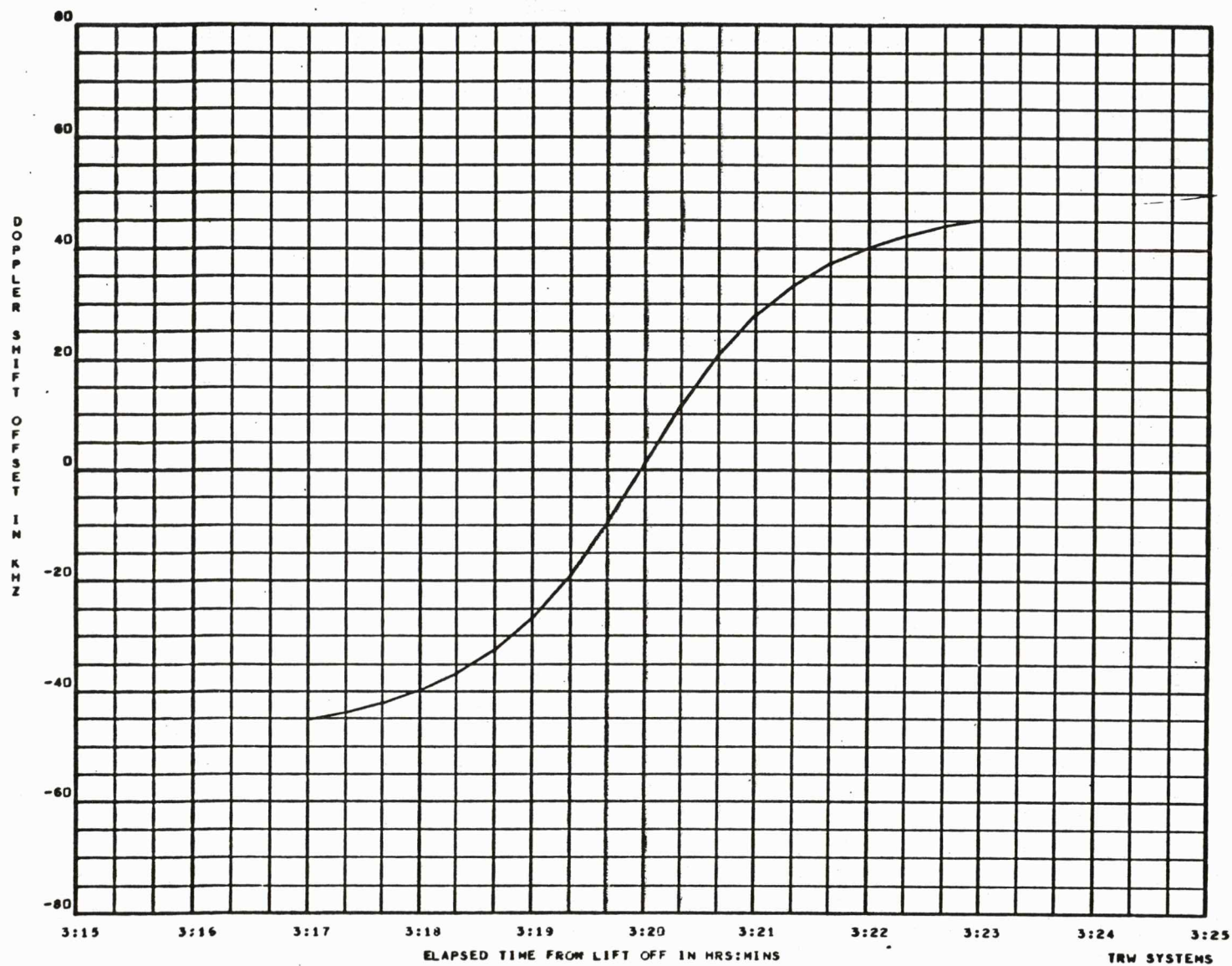


Figure E-11. VAN1 S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 3

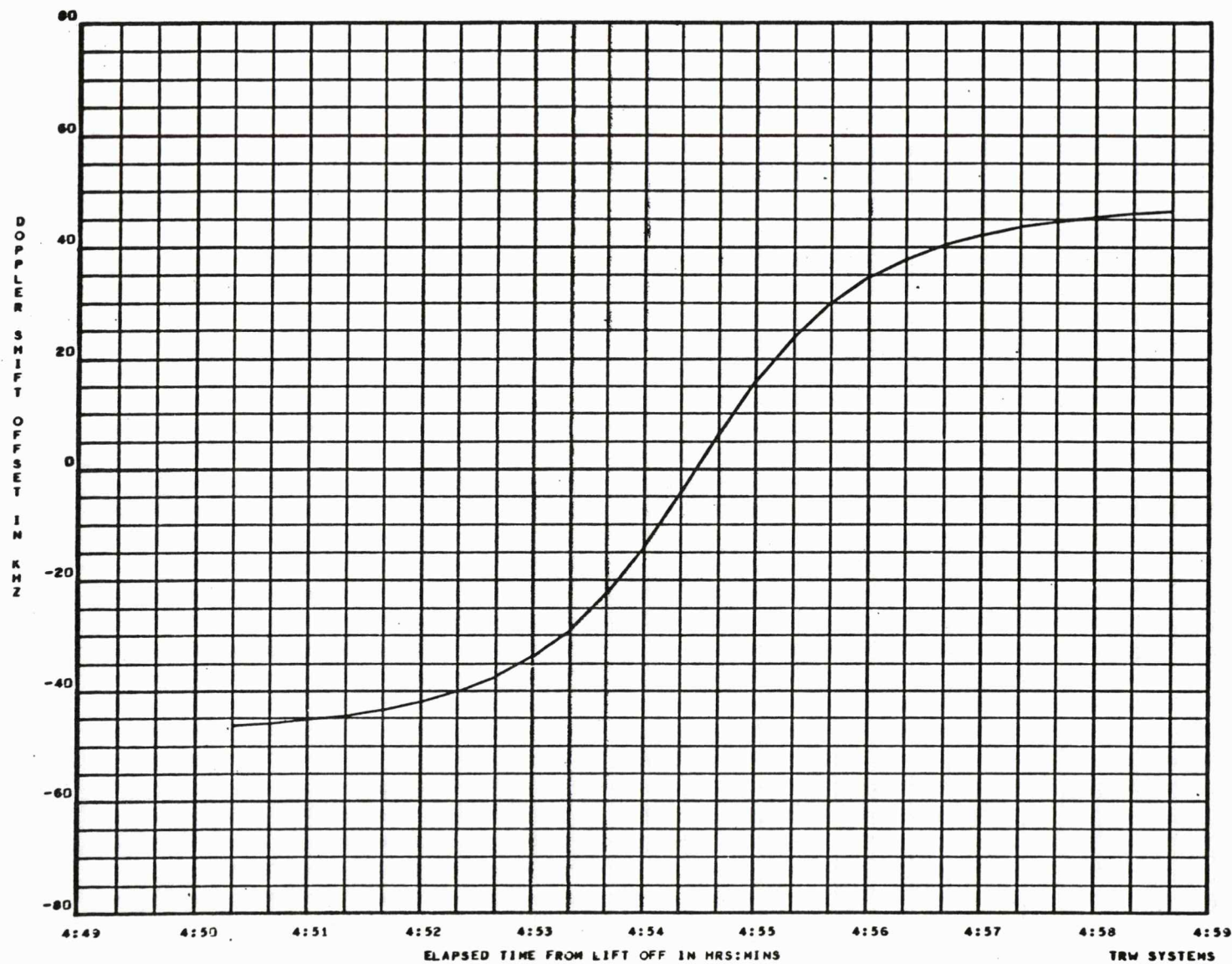


Figure E-12. VAN1 S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 4

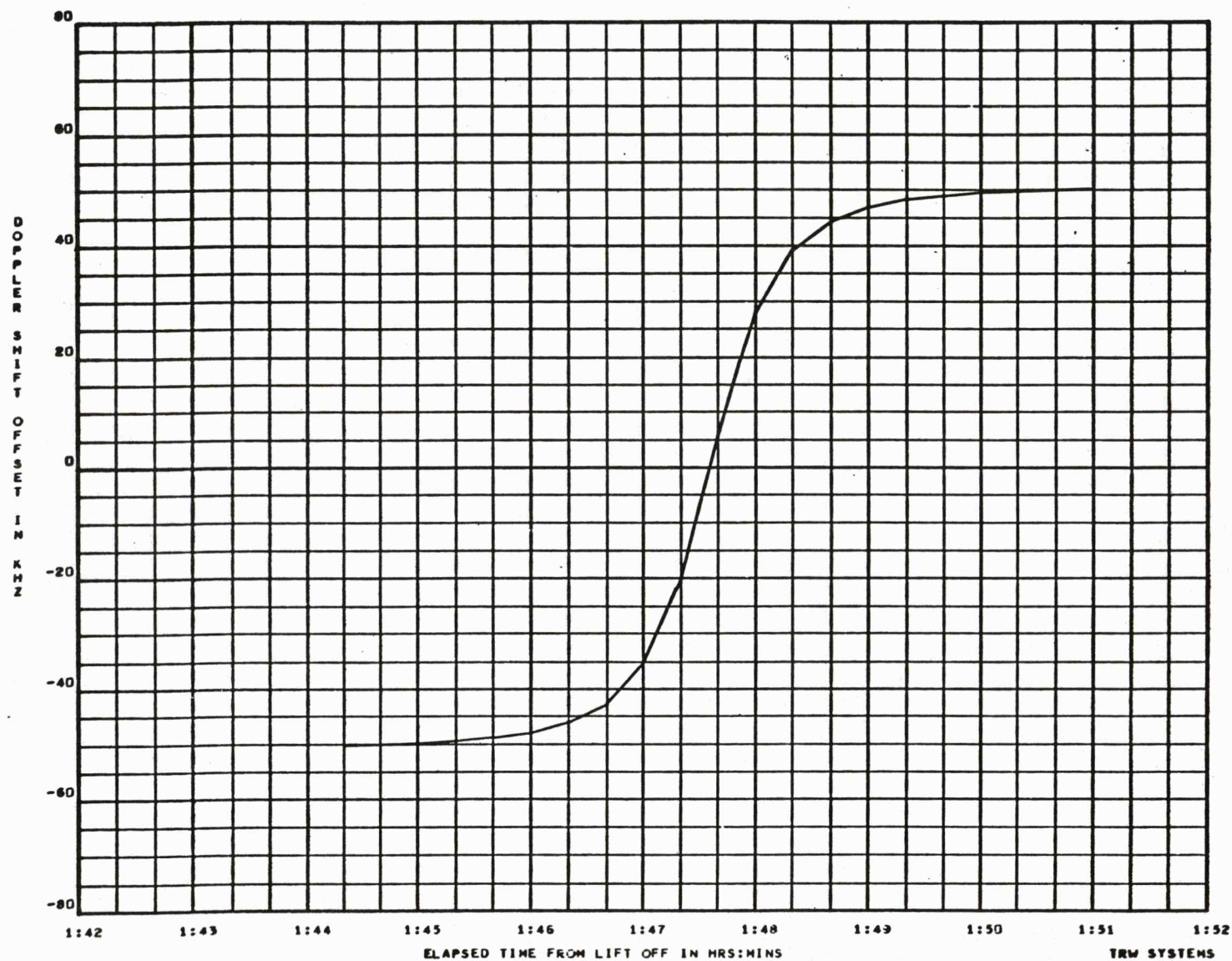


Figure E-13. VAN2 S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 2

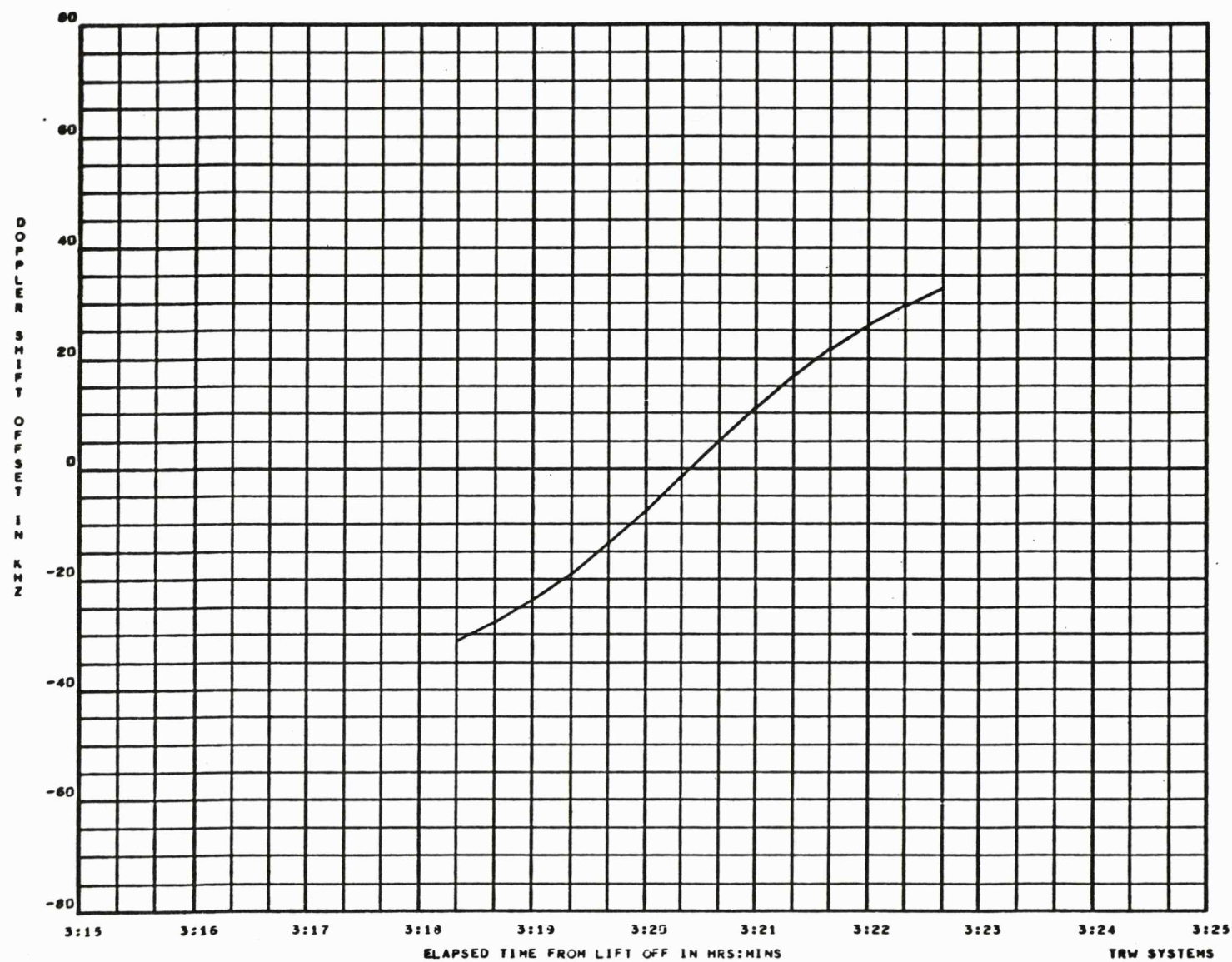


Figure E-14. VAN2 S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3

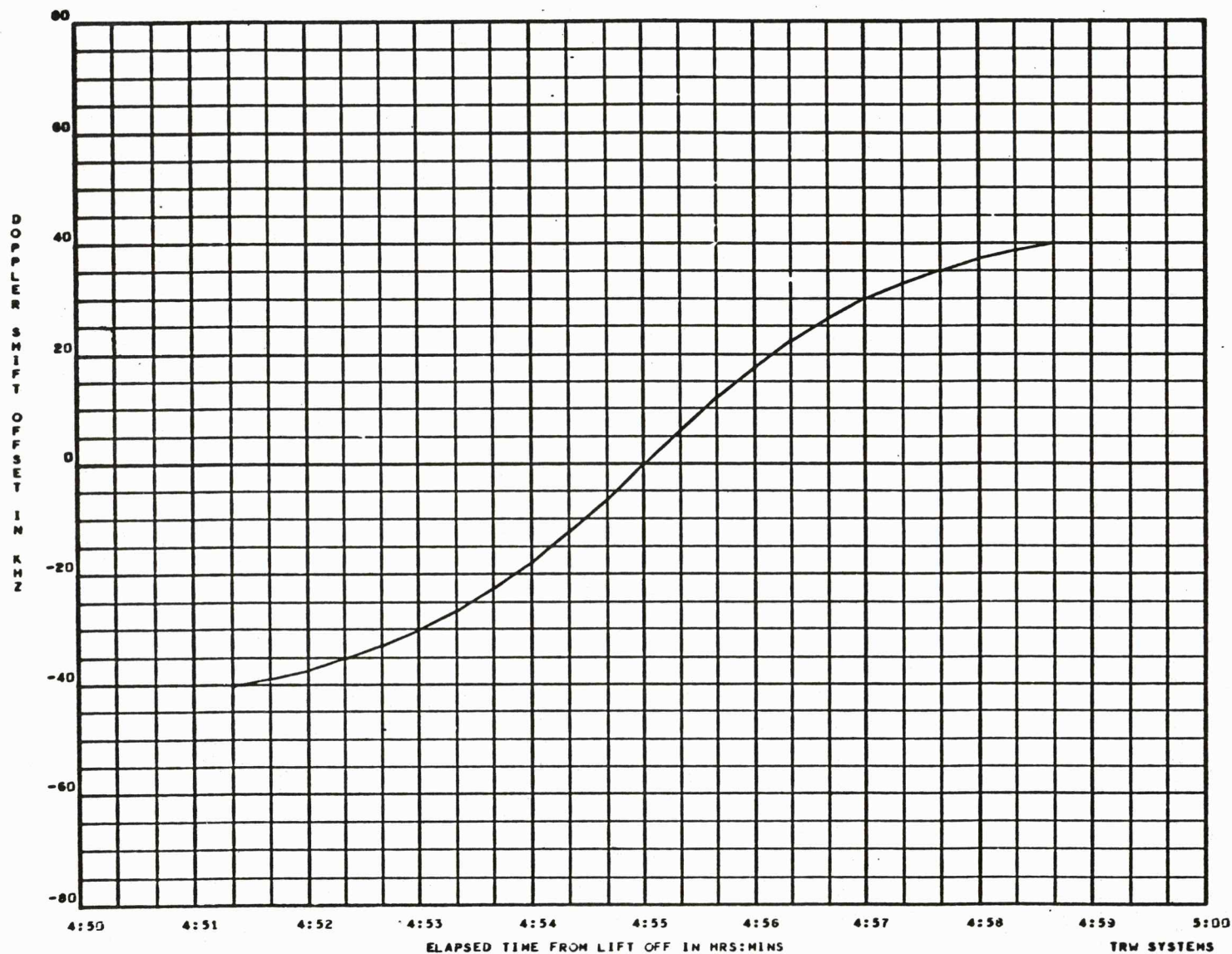


Figure E-15. VAN2 S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 4

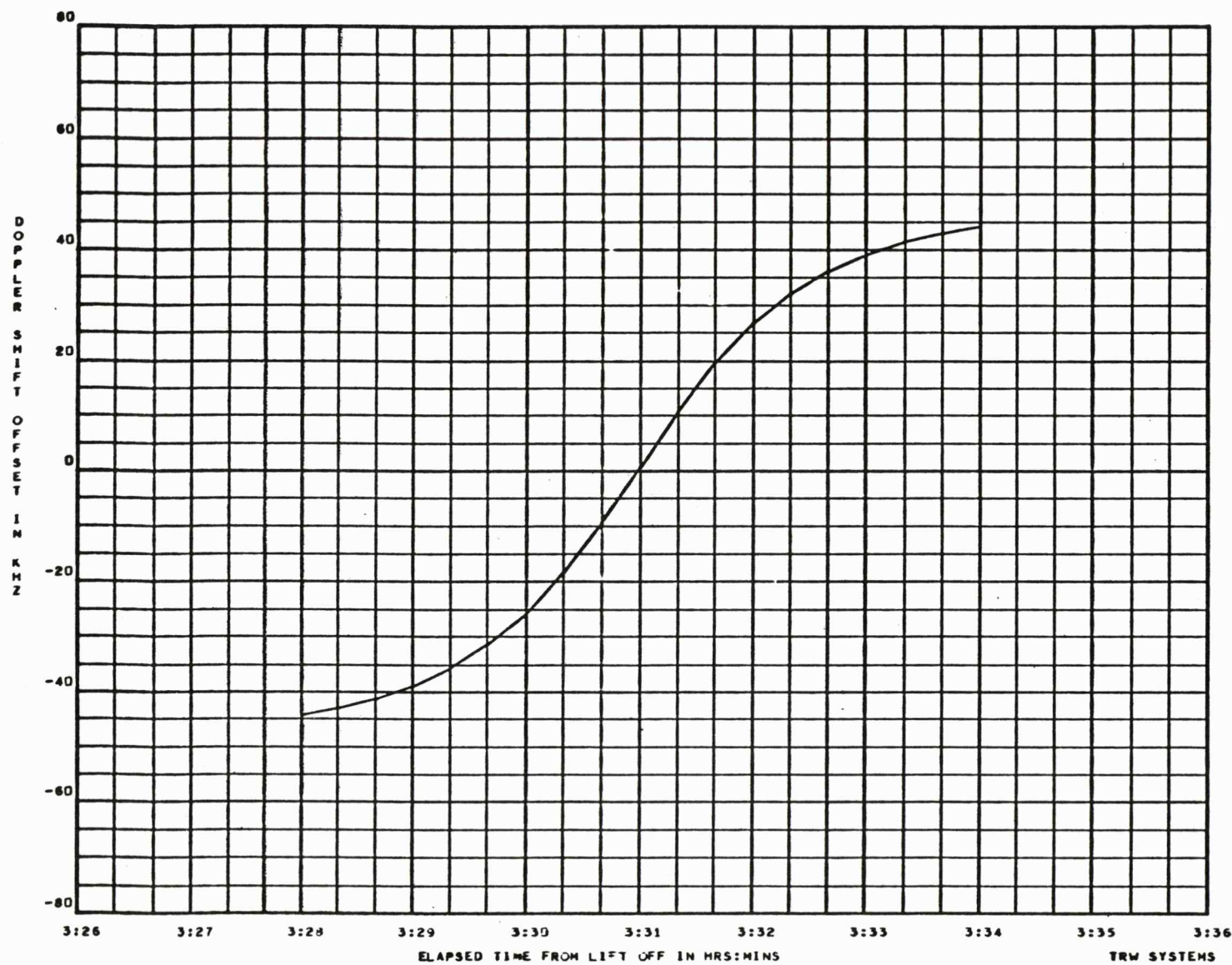


Figure E-16. ACN S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3

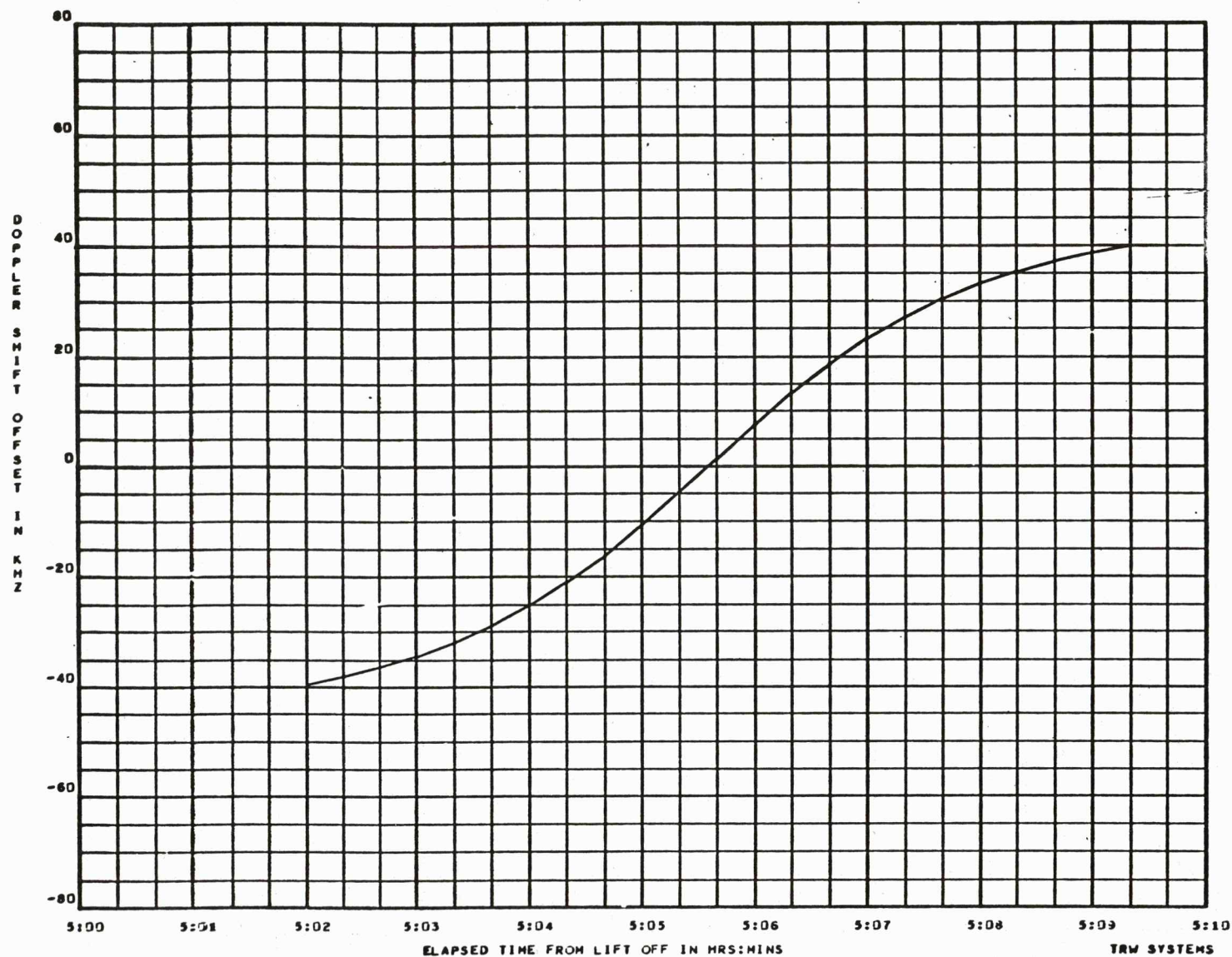


Figure E-17. ACN S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 4

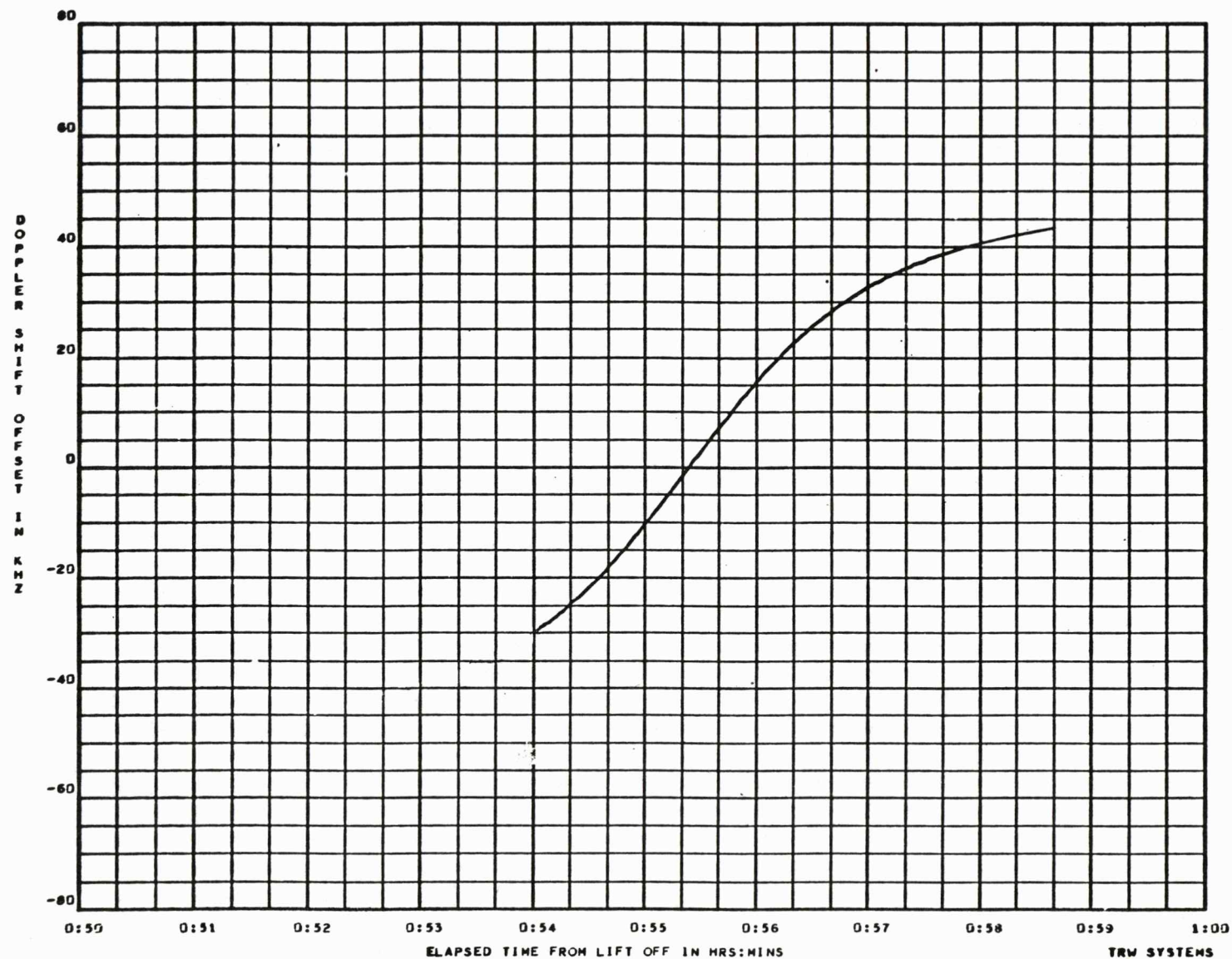


Figure E-18. CRO S-Band Uplink Doppler Frequency Offset vs Time for Orbit 1

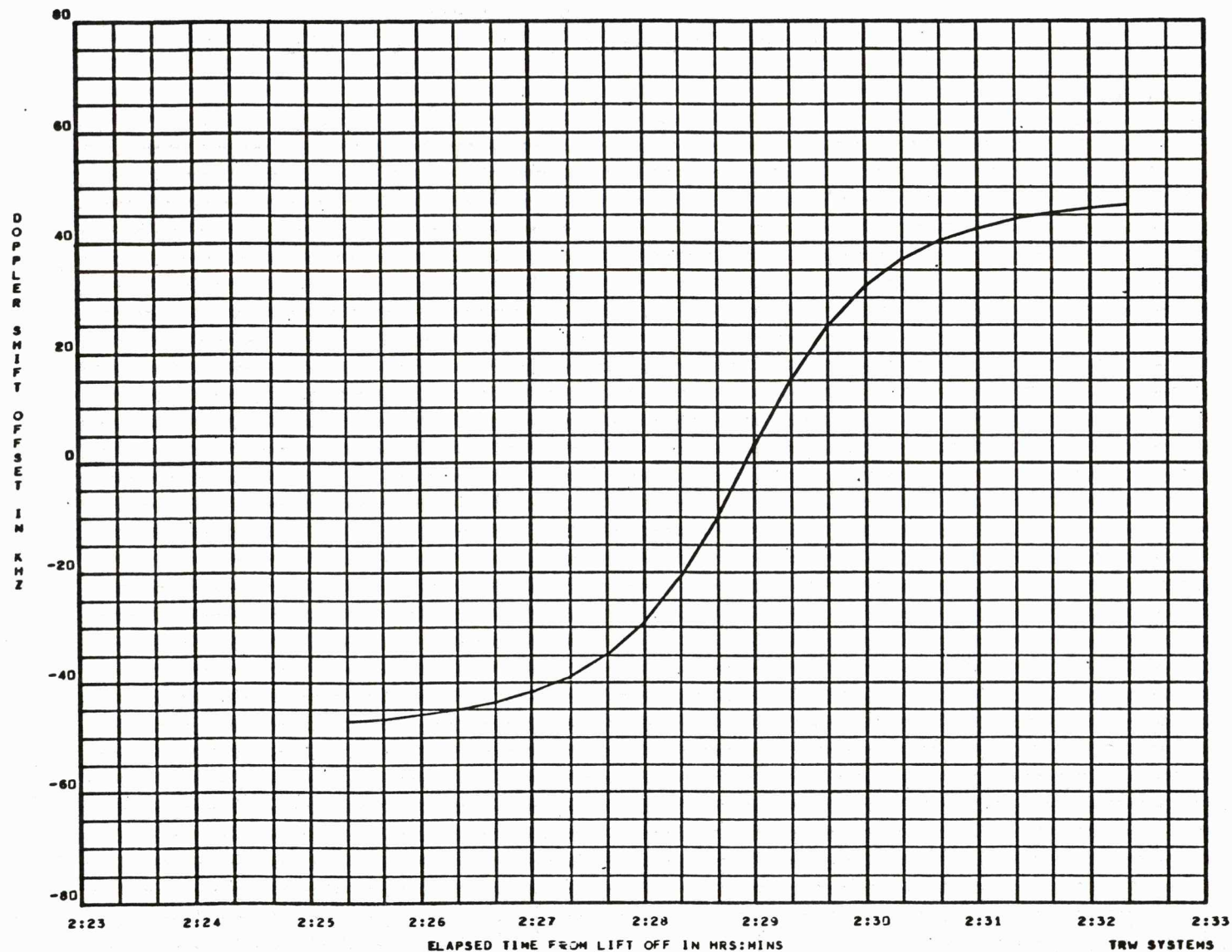


Figure E-19. CRO S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2

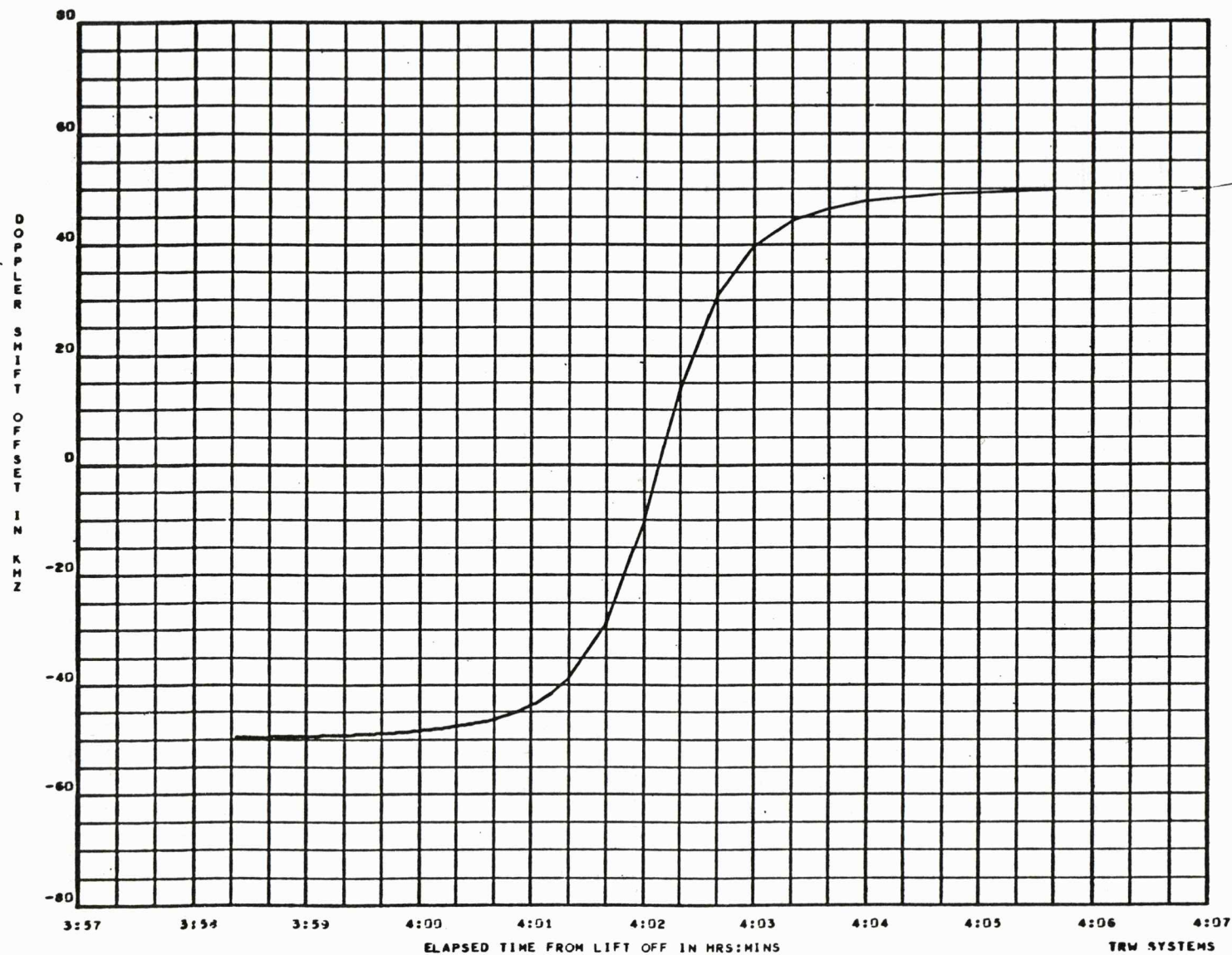


Figure E-20. CRO S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3

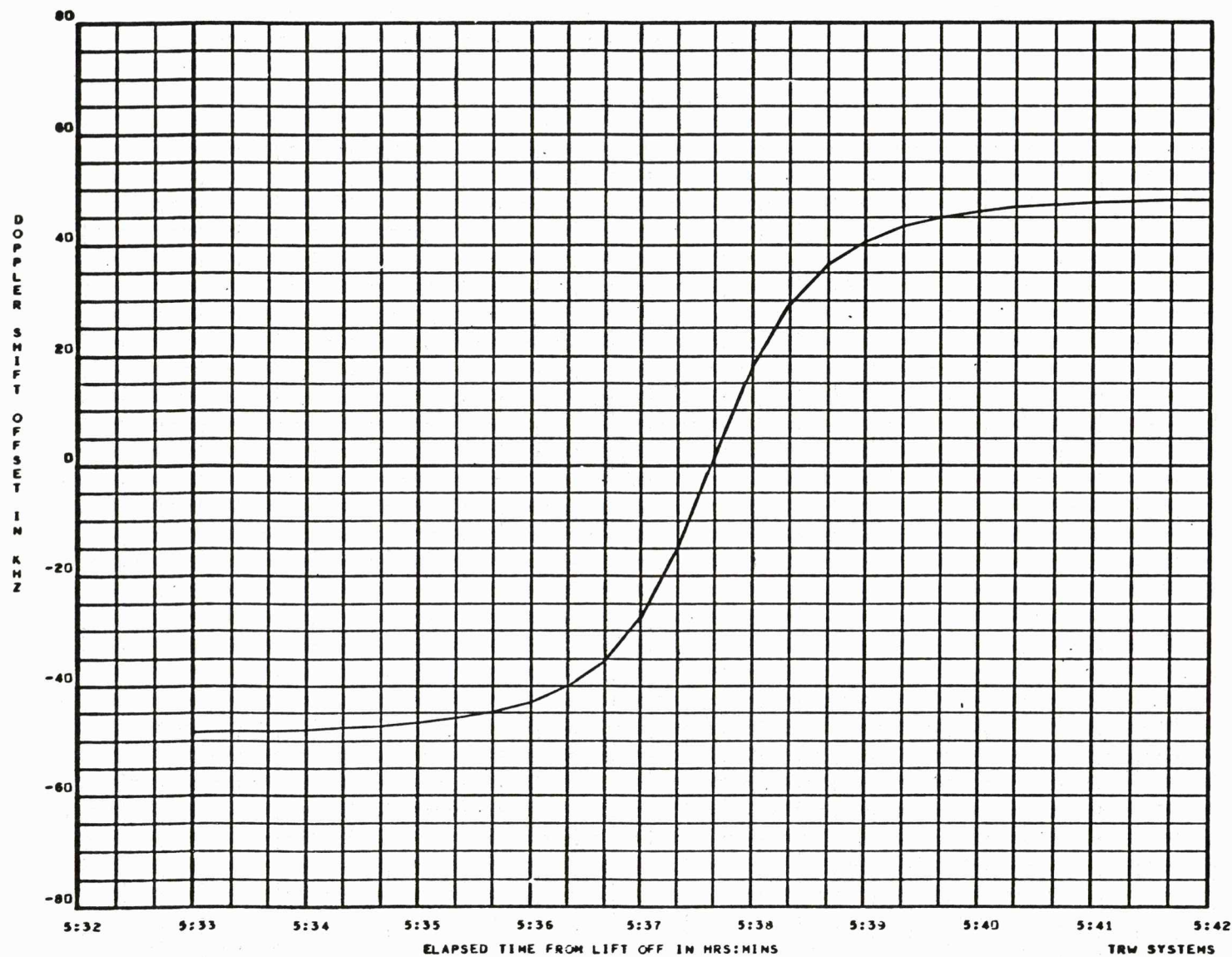


Figure E-21. CRO S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 4

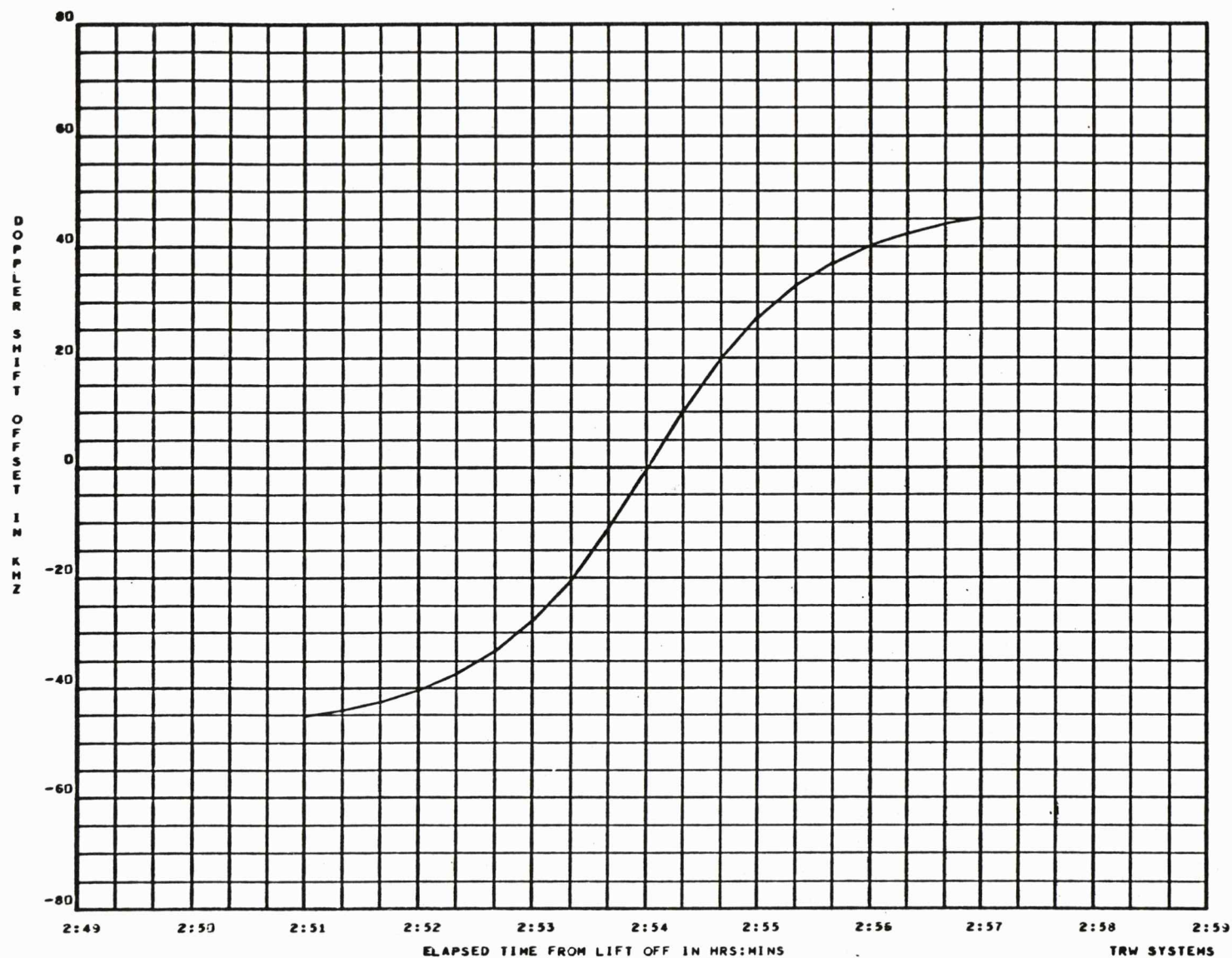


Figure E-22. HAW S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2

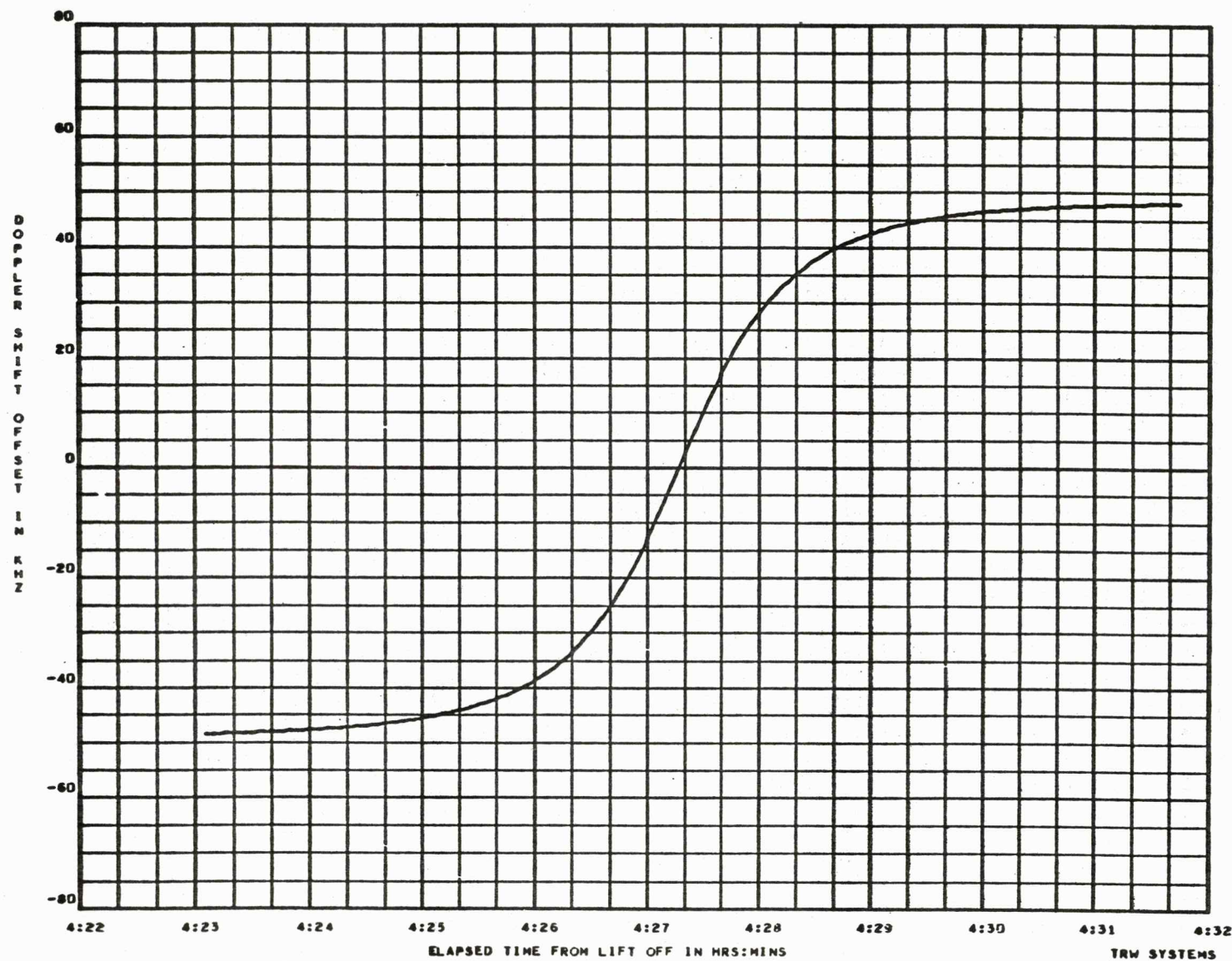


Figure E-23. HAW S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3

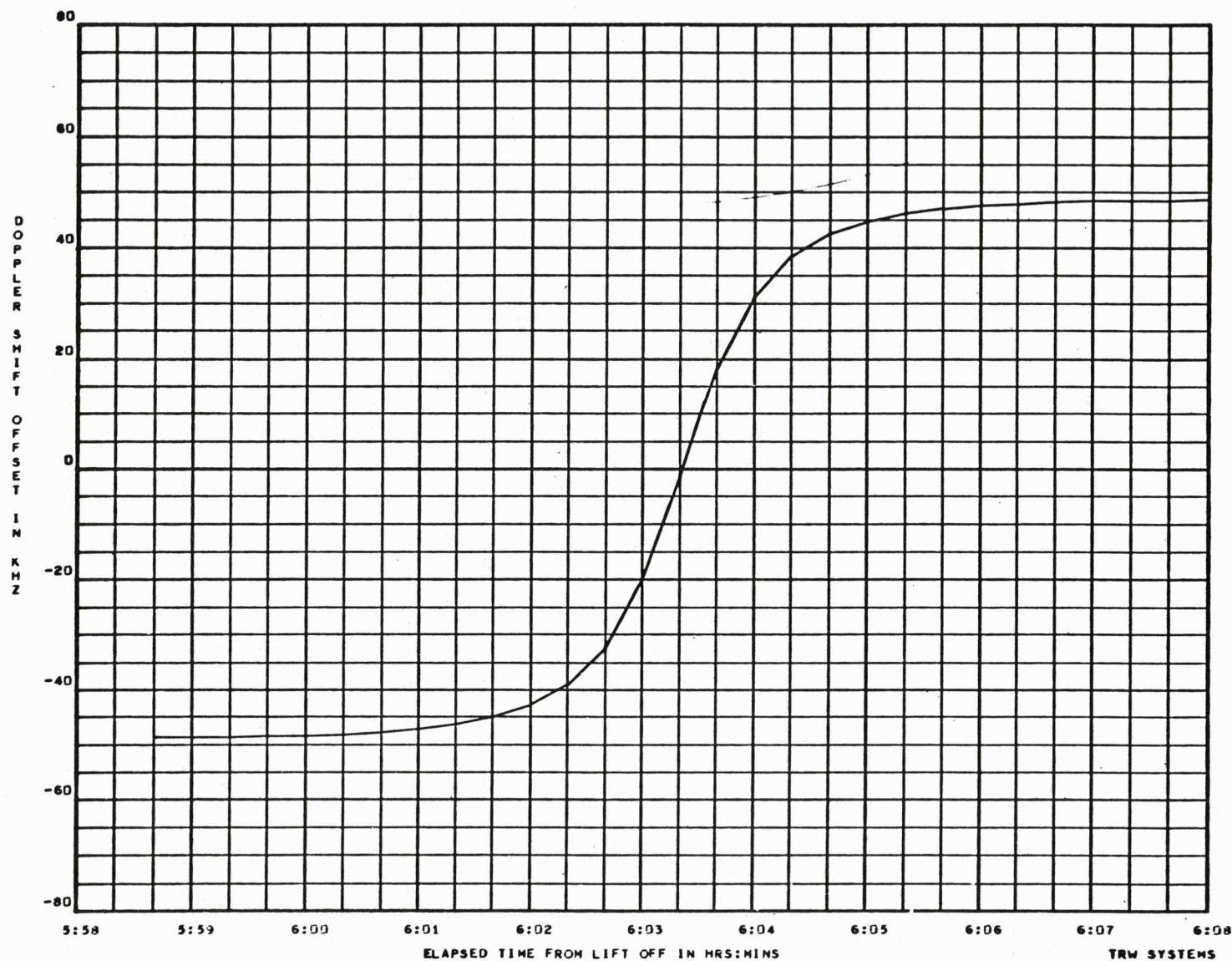


Figure E-24. HAW S-Band Uplink Doppler Frequency Offset vs Time for Orbit 4

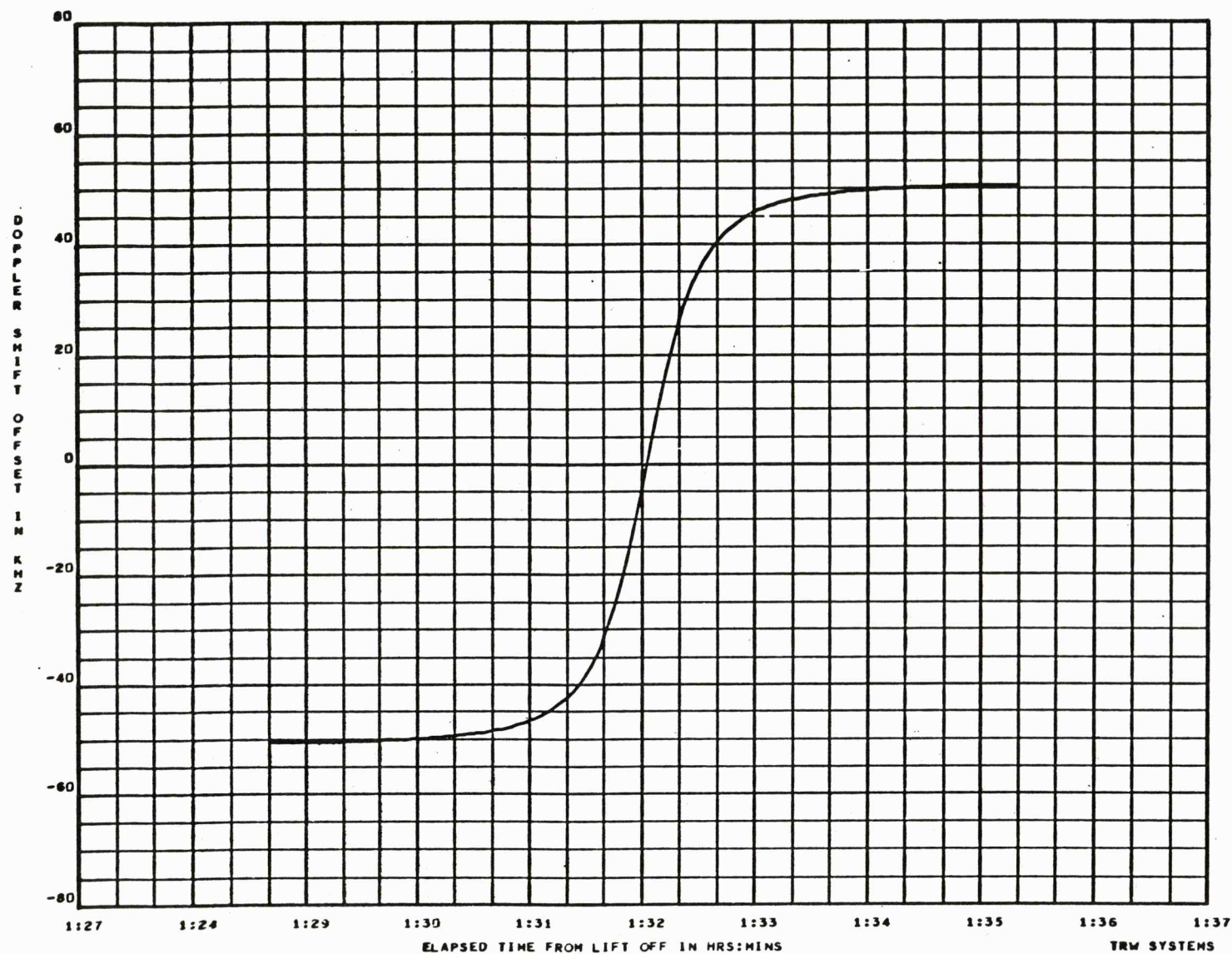


Figure E-25. GYM S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 1

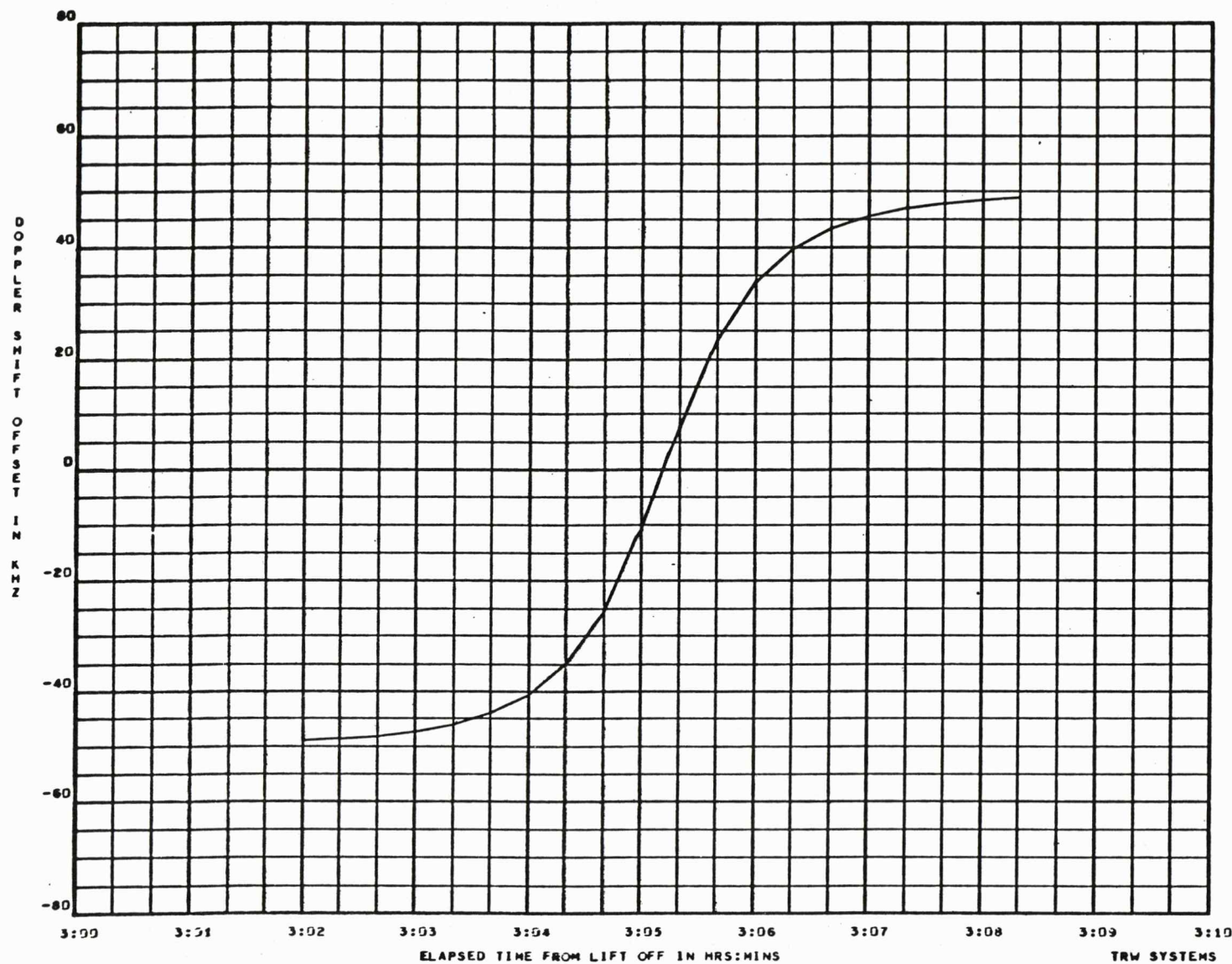


Figure E-26. GYM S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2

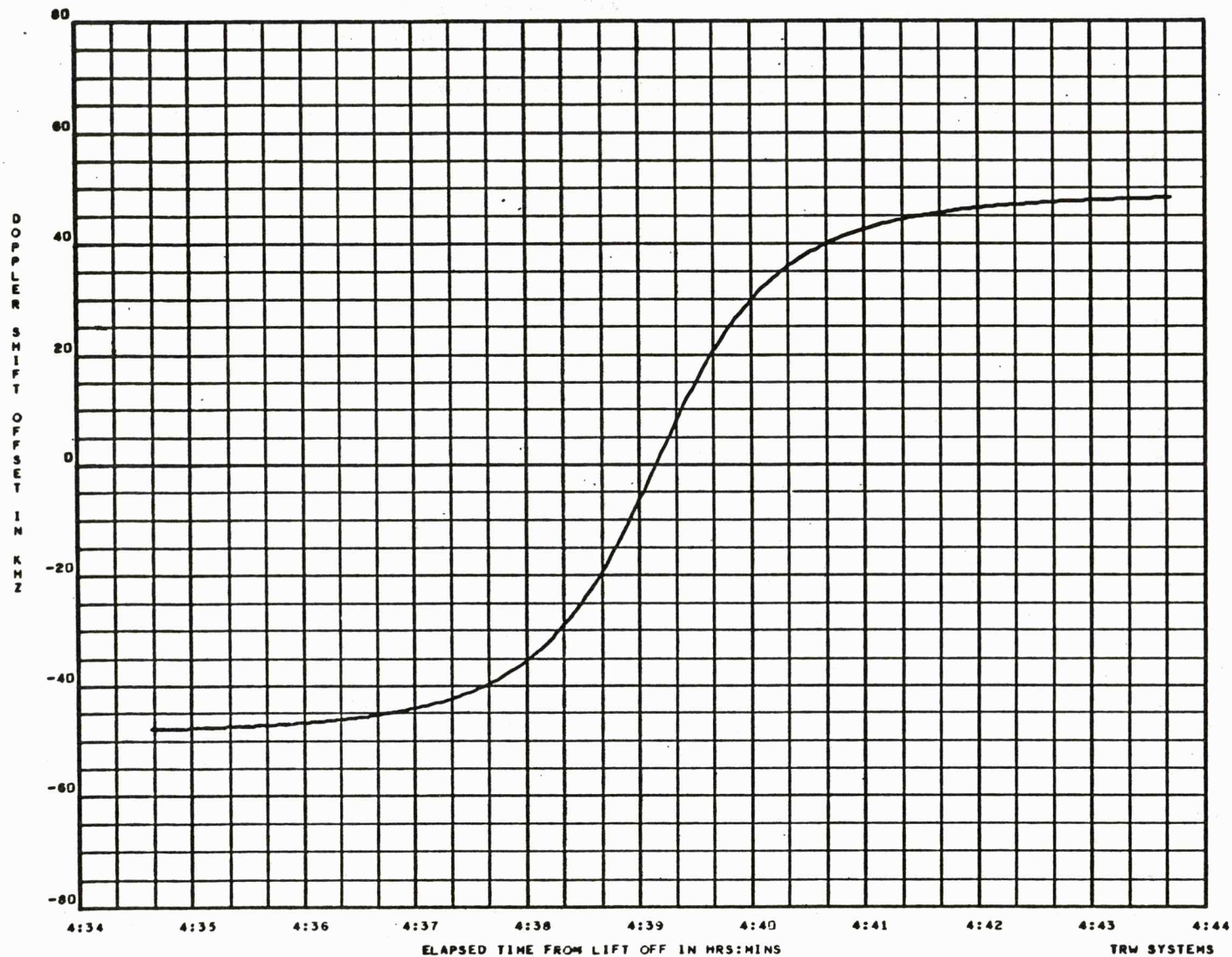


Figure E-27. GYM S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 3

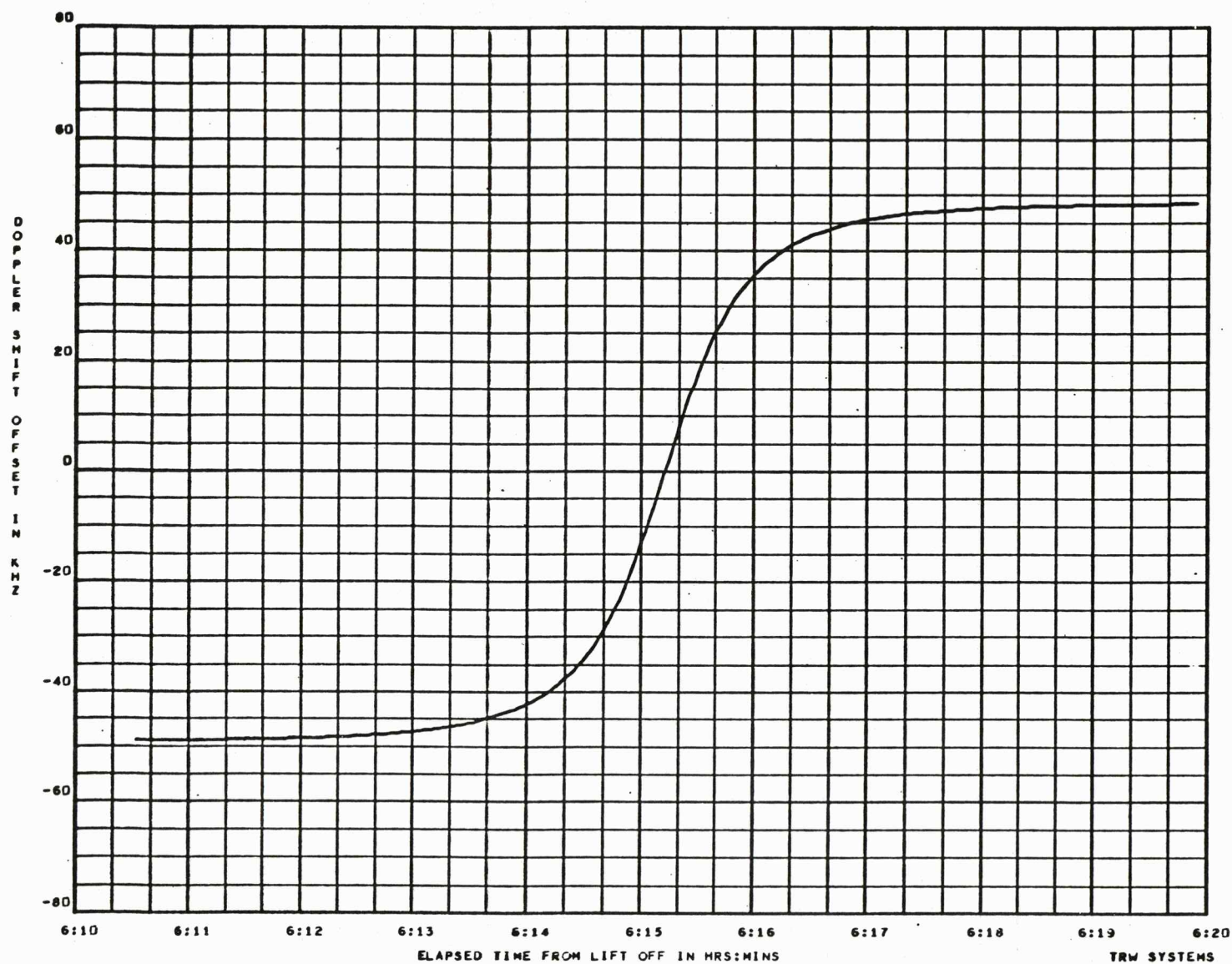


Figure E-28. GYM S-Band Uplink Doppler Frequency Offset vs Time for Orbit 4



Figure E-29. GDS S-Band Uplink Doppler Frequency Offset vs Time for Orbit 1

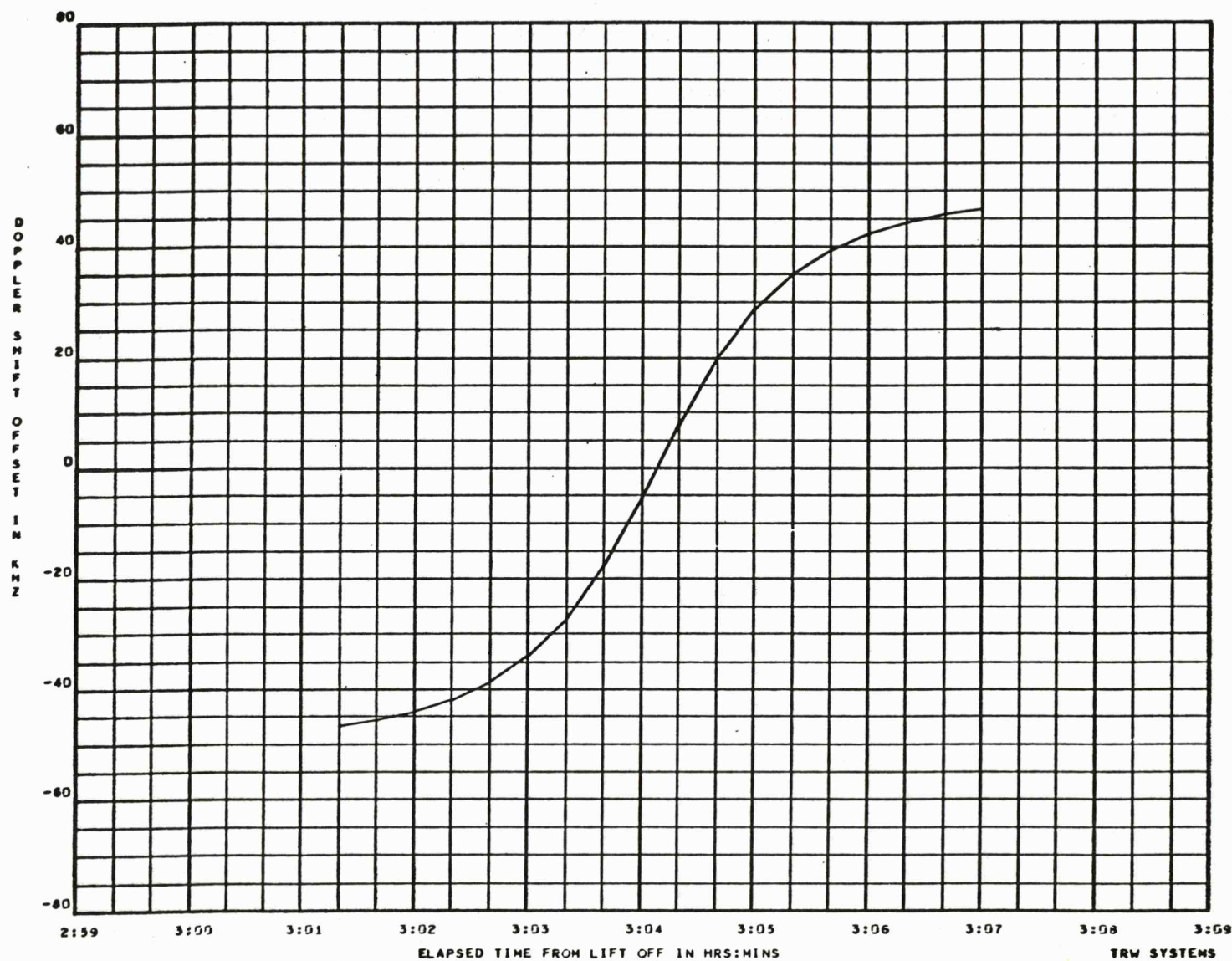


Figure E-30. GDS S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2

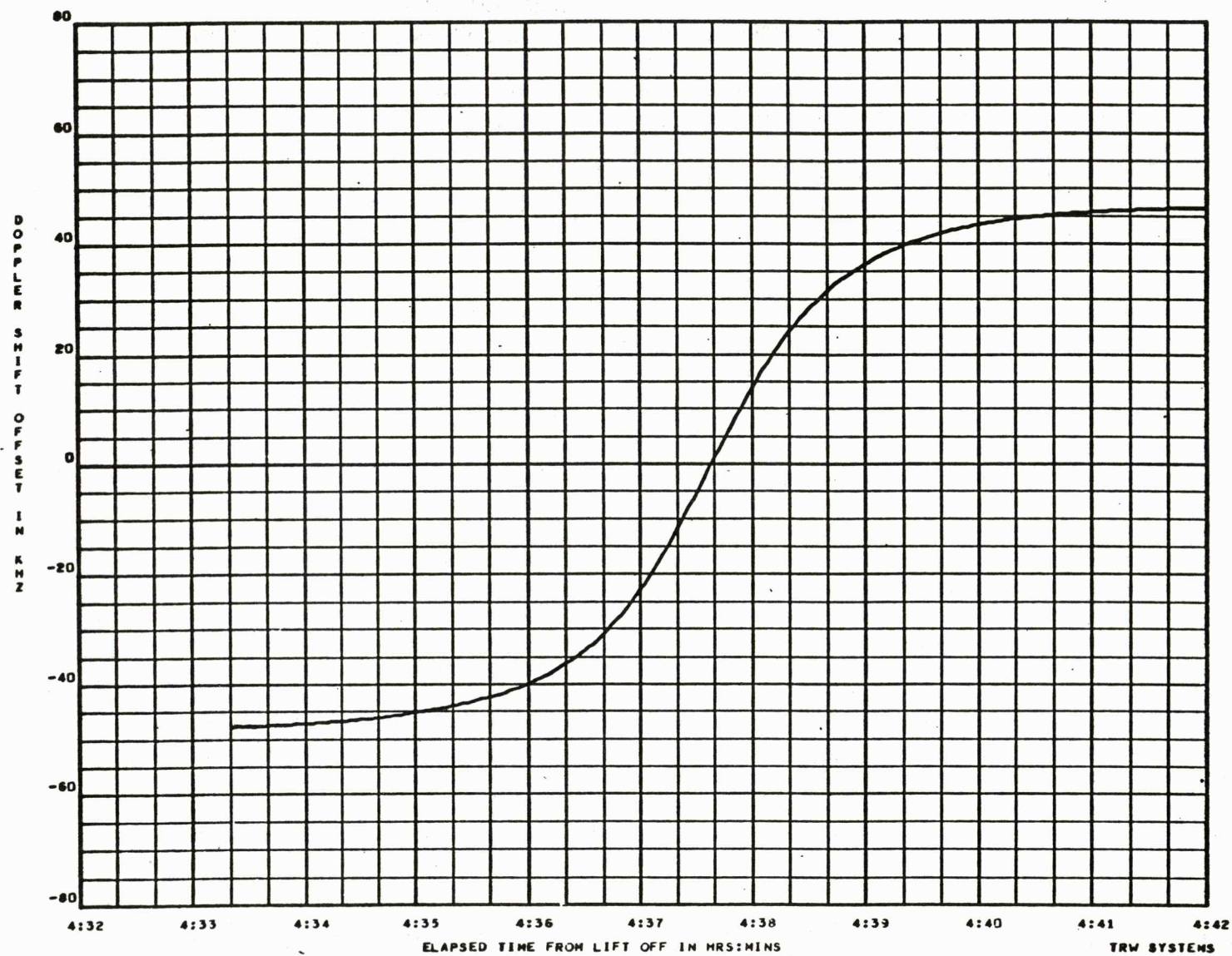


Figure E-31. GDS S-Band Uplink Doppler Frequency Offset
vs Time for Orbit 3

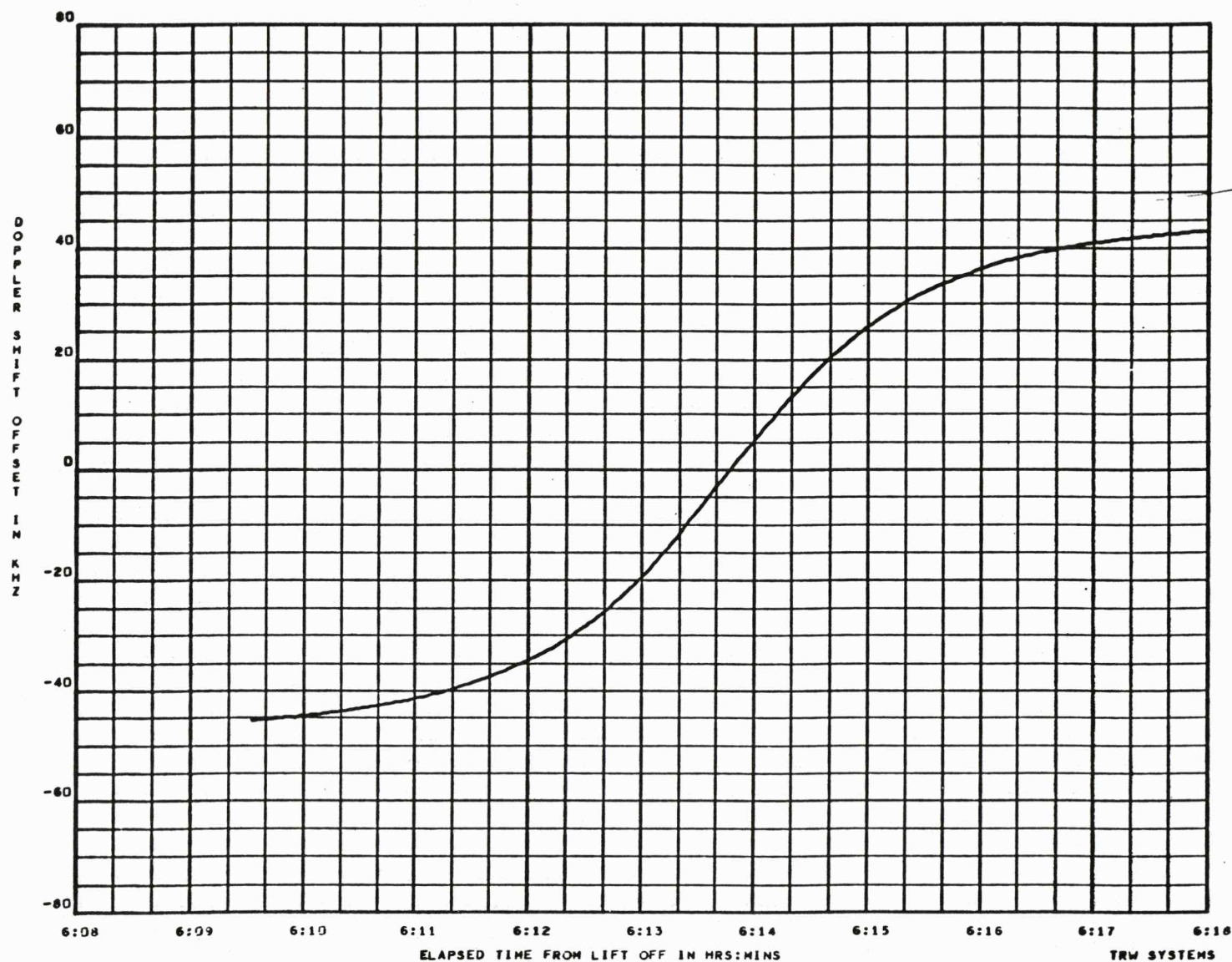


Figure E-32. GDS S-Band Uplink Doppler Frequency Offset vs Time for Orbit 4

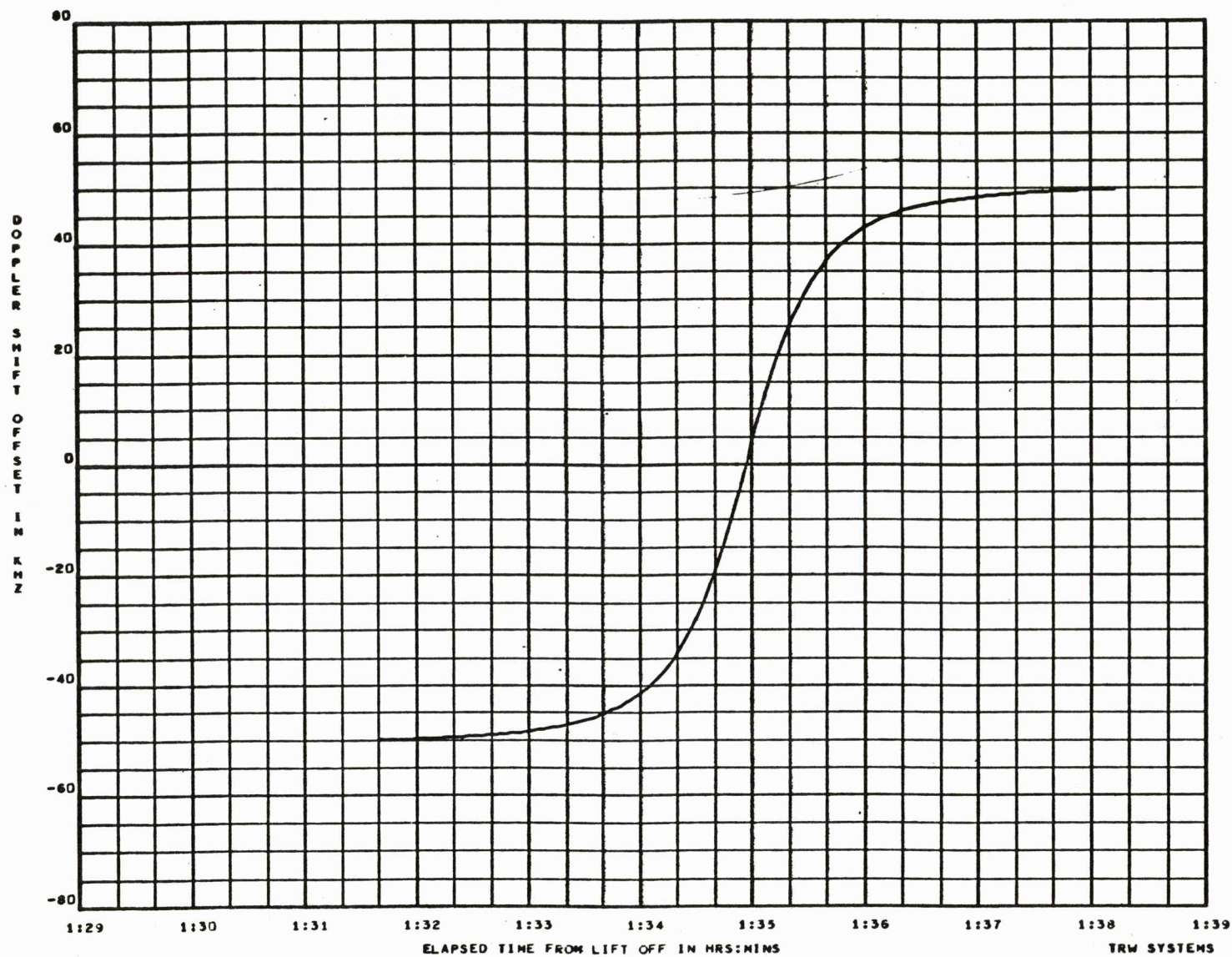


Figure E-33. TEX S-Band Uplink Doppler Frequency Offset vs Time for Orbit 1

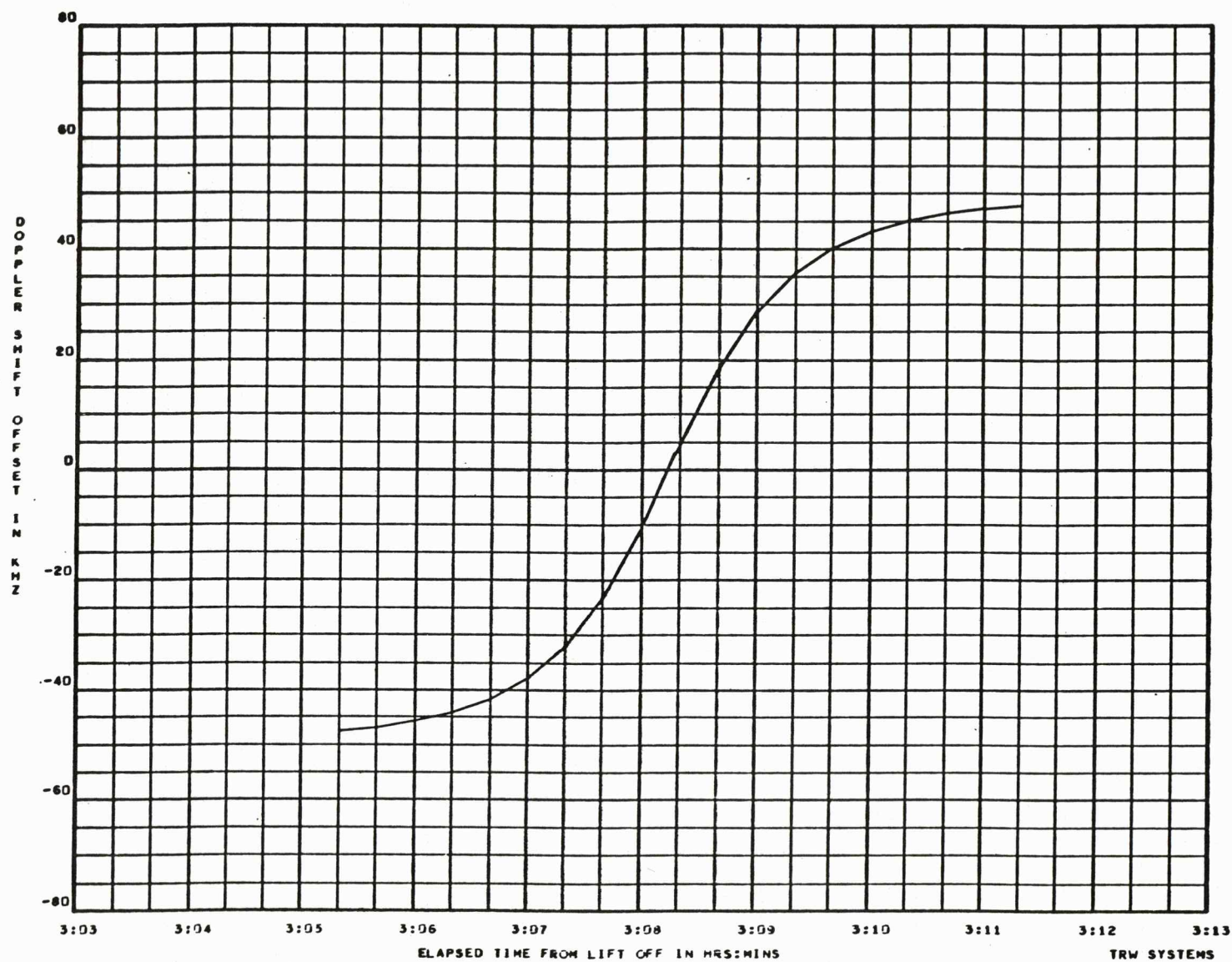


Figure E-34. TEX S-Band Uplink Doppler Frequency Offset vs Time for Orbit 2

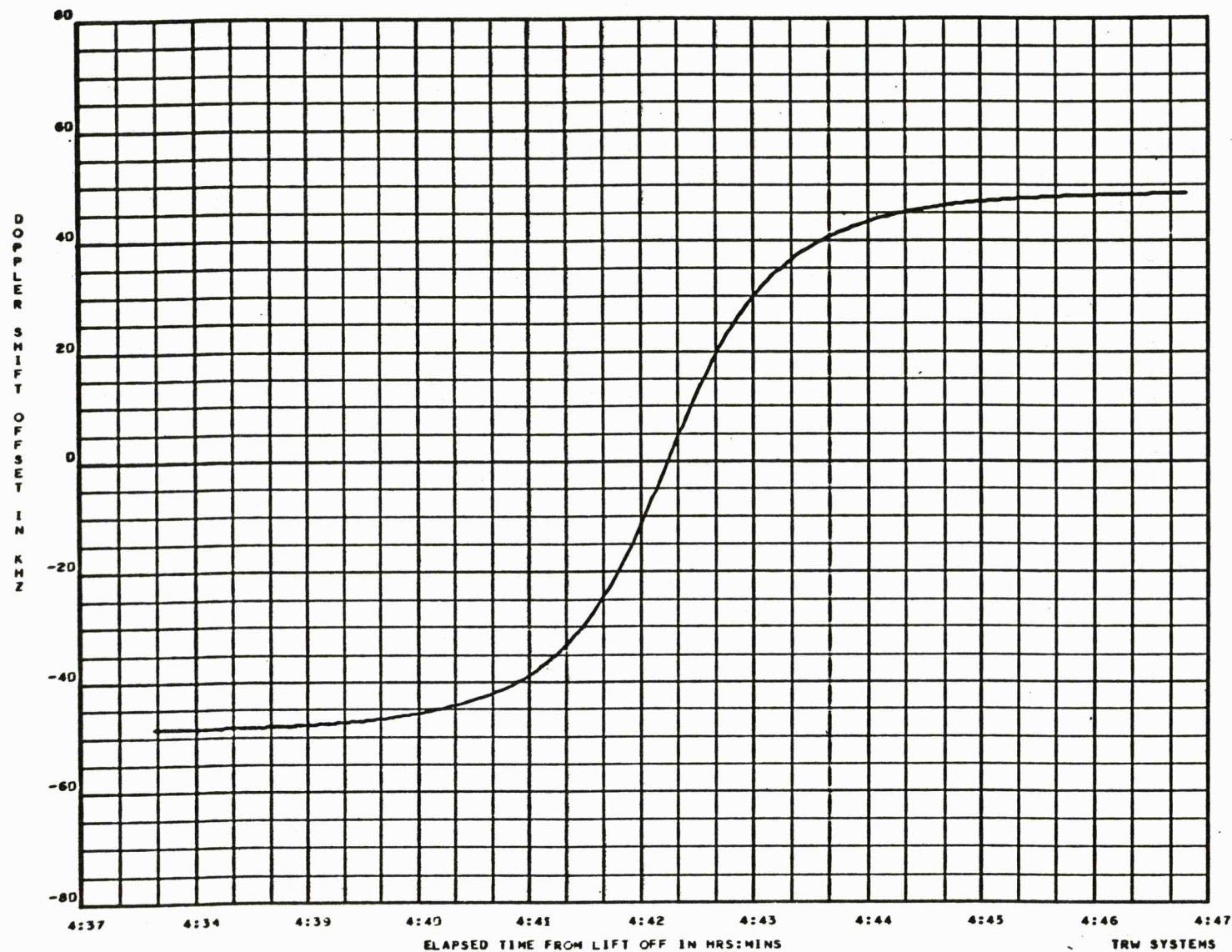


Figure E-35. TEX S-Band Uplink Doppler Frequency Offset vs Time for Orbit 3

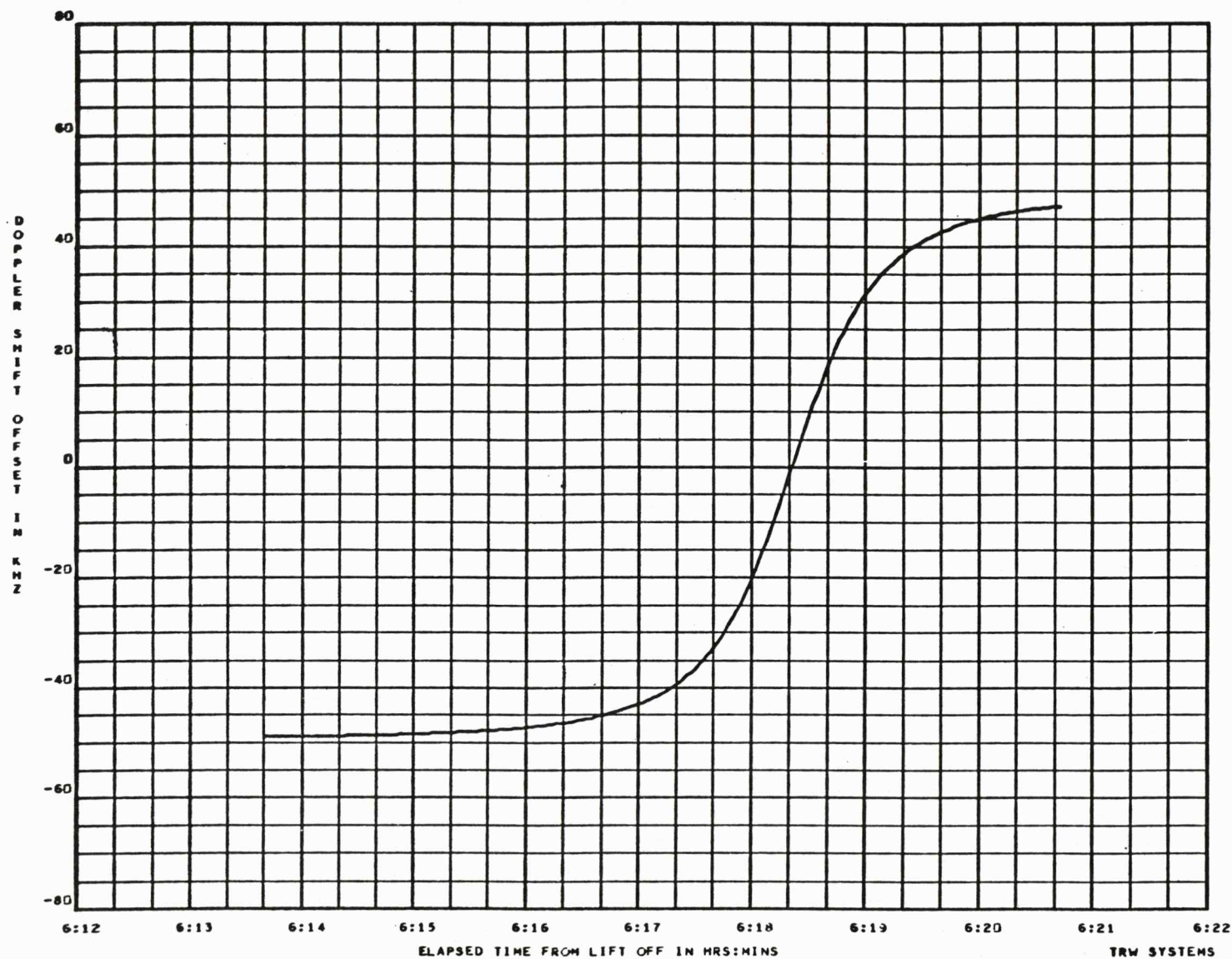


Figure E-36. TEX S-Band Uplink Doppler Frequency Offset vs Time for Orbit 4

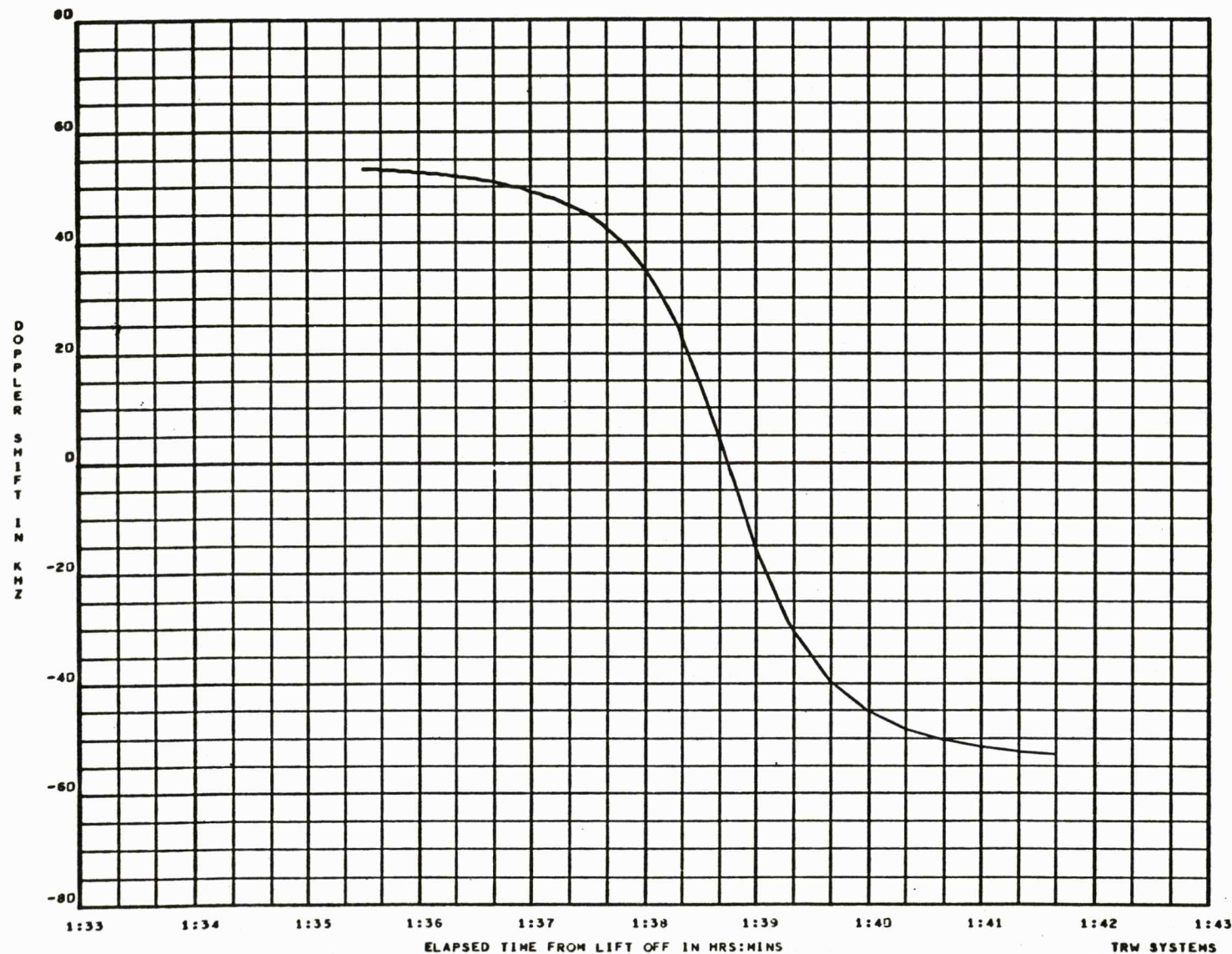


Figure E-37. MIL S-Band Downlink Doppler Frequency Shift vs Time for Orbit 1 - 2

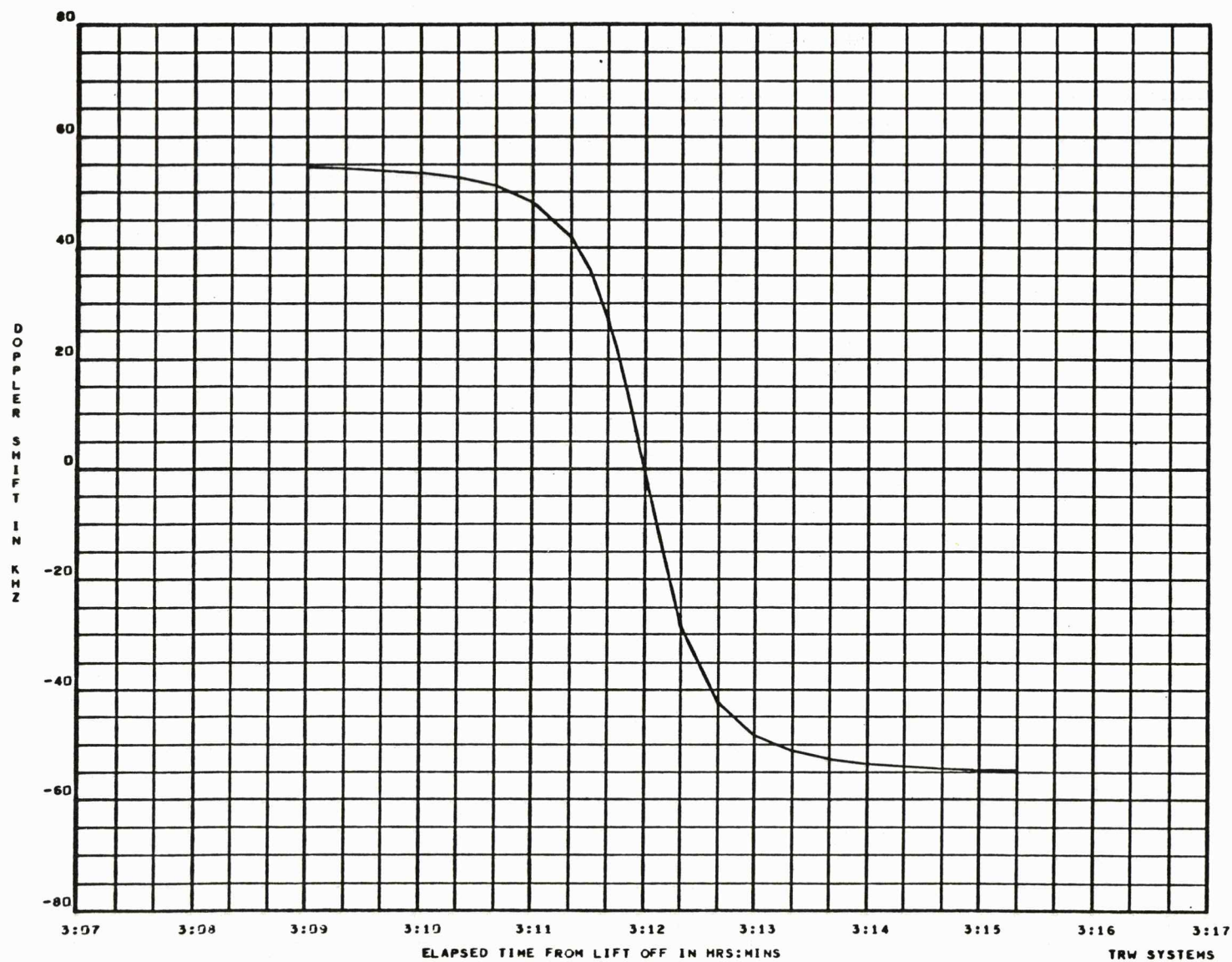


Figure E-38. MIL S-Band Downlink Doppler Frequency Shift
vs Time for Orbit 2 - 3

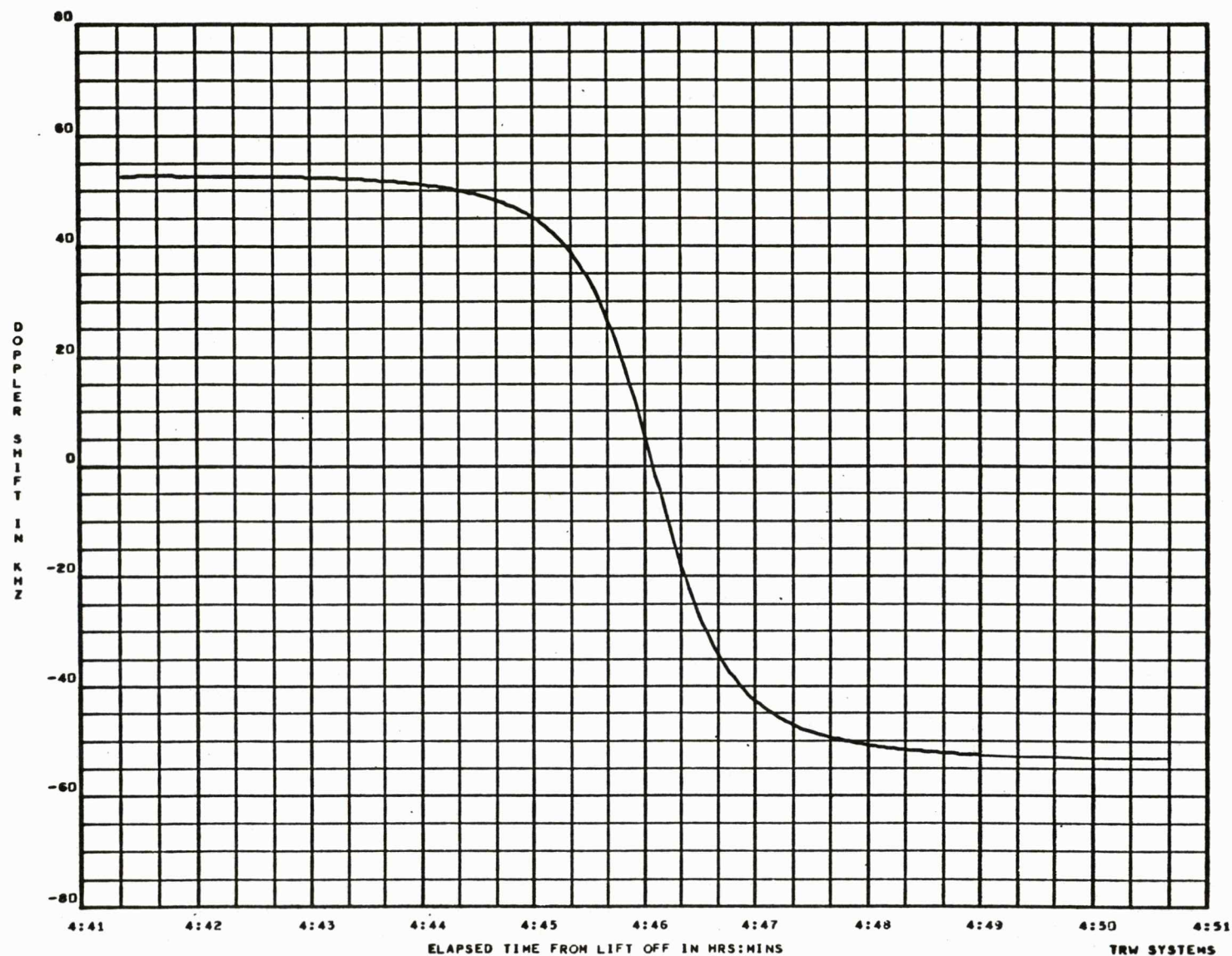


Figure E-39. MIL S-Band Downlink Doppler Frequency Shift
vs Time for Orbit 3 - 4

E-41

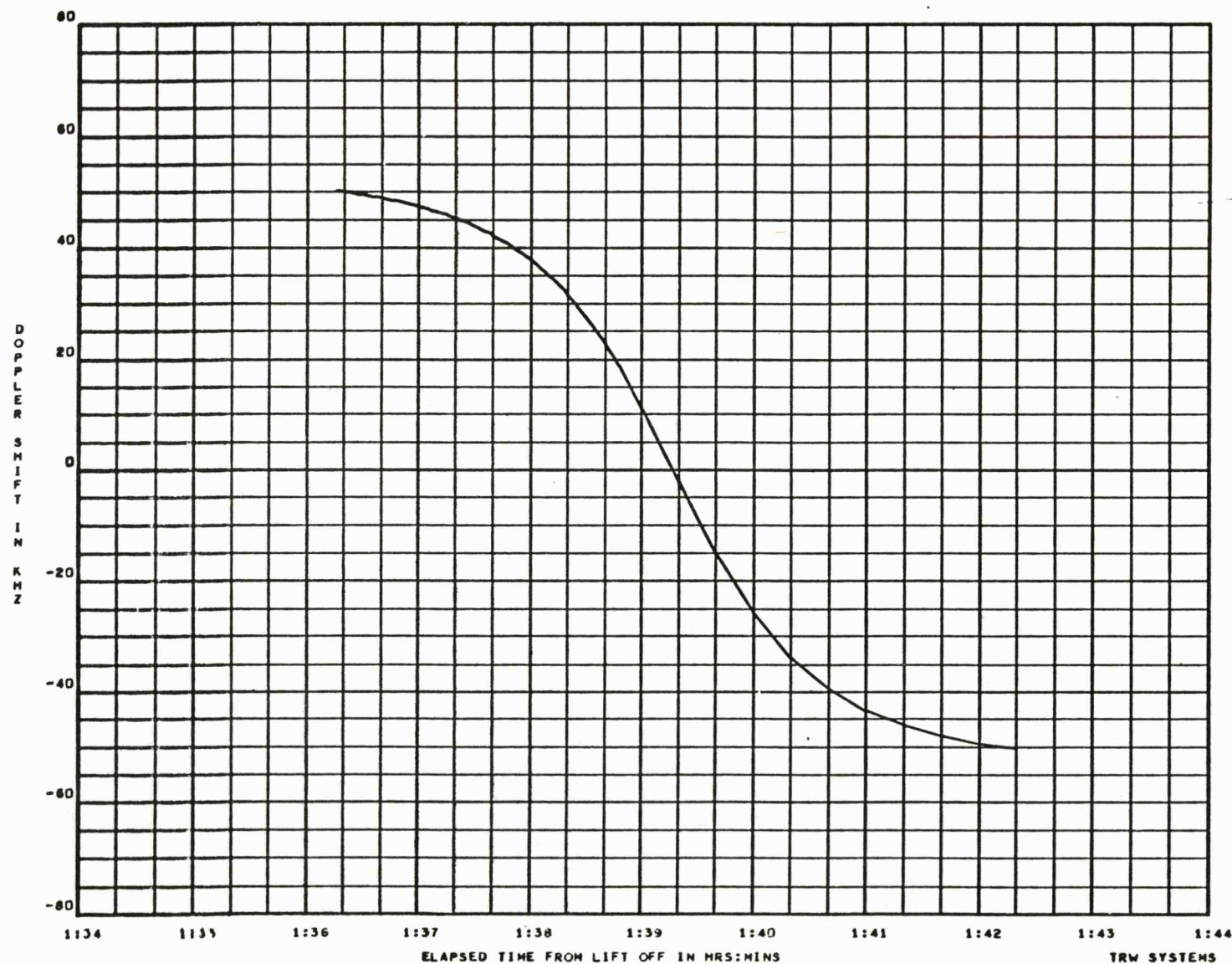


Figure E-40. GBM S-Band Downlink Doppler Frequency Shift vs Time for Orbit 1 - 2

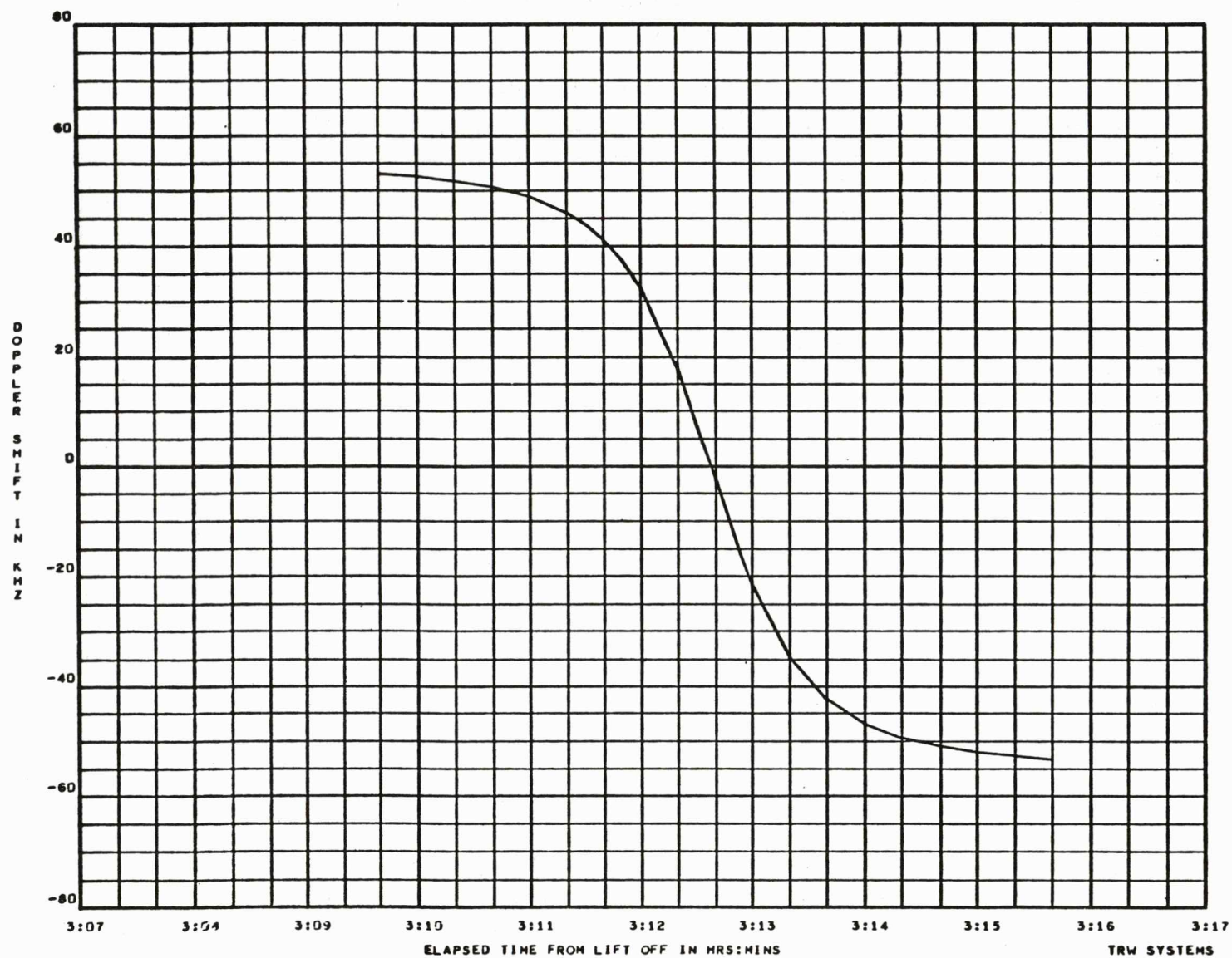


Figure E-41. GBM S-Band Downlink Doppler Frequency Shift vs Time for Orbit 2 - 3

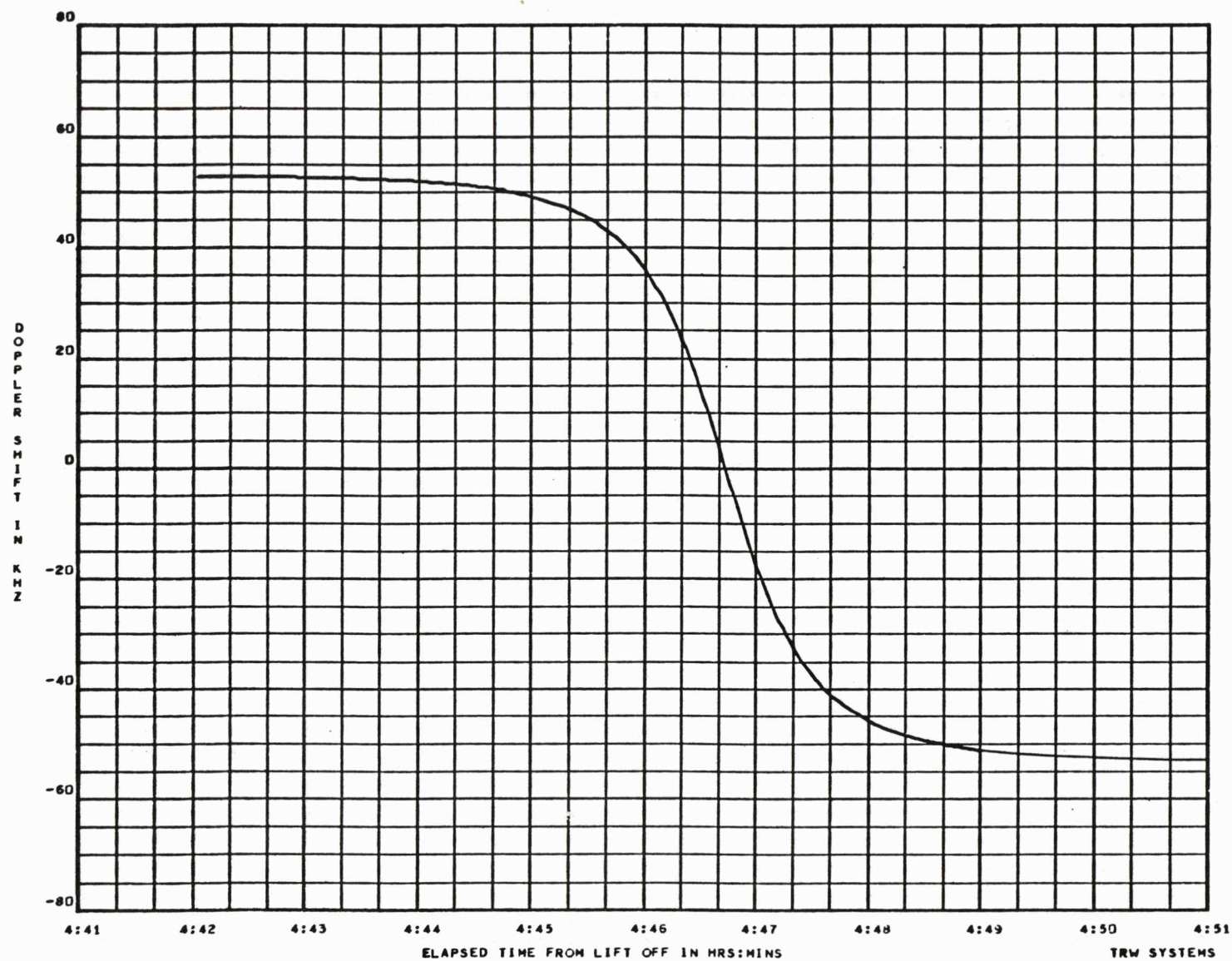


Figure E-42. GBM S-Band Downlink Doppler Frequency Shift vs Time for Orbit 3 - 4

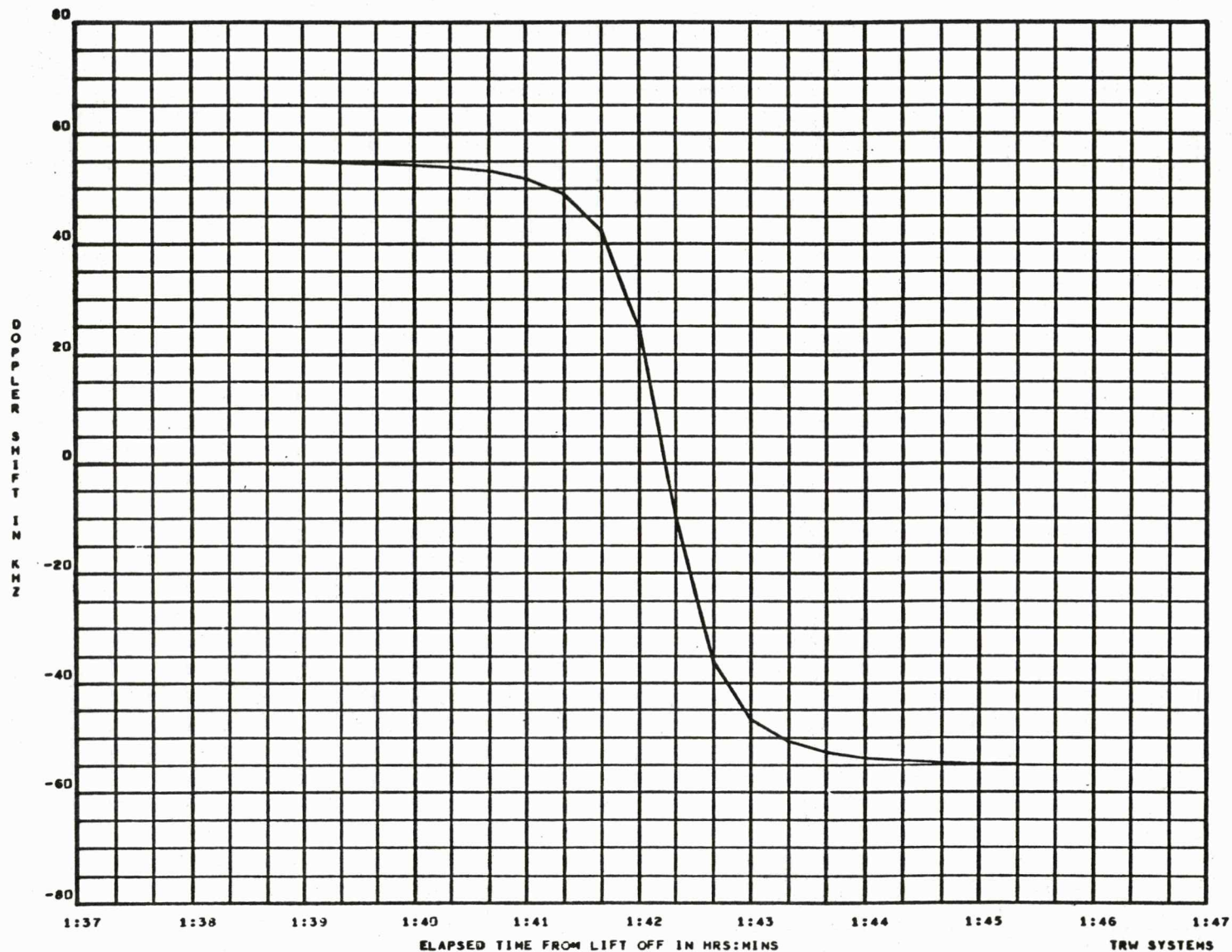


Figure E-43. BDA S-Band Downlink Doppler Frequency Shift vs Time for Orbit 2

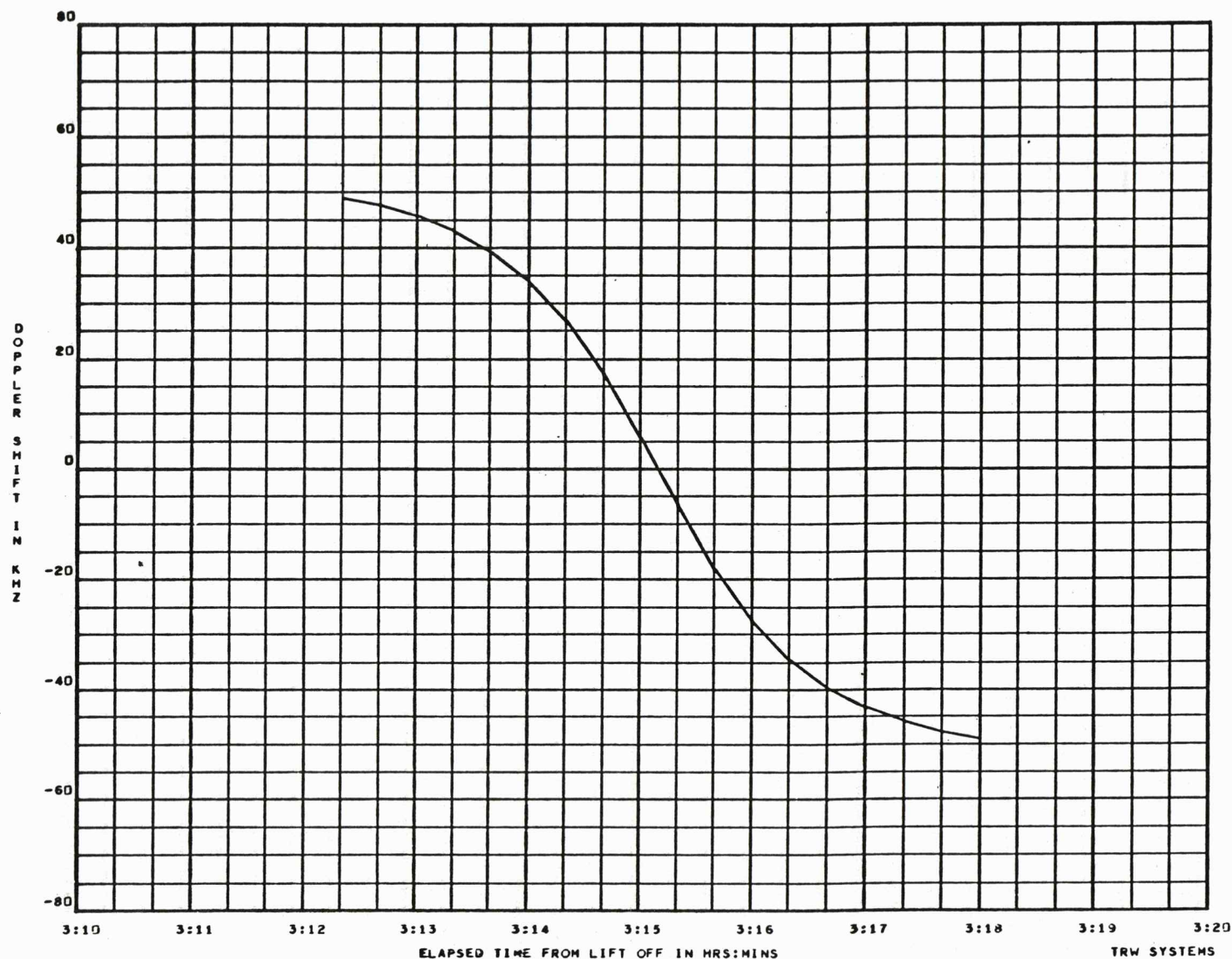


Figure E-44. BDA S-Band Downlink Doppler Frequency Shift vs Time for Orbit 3

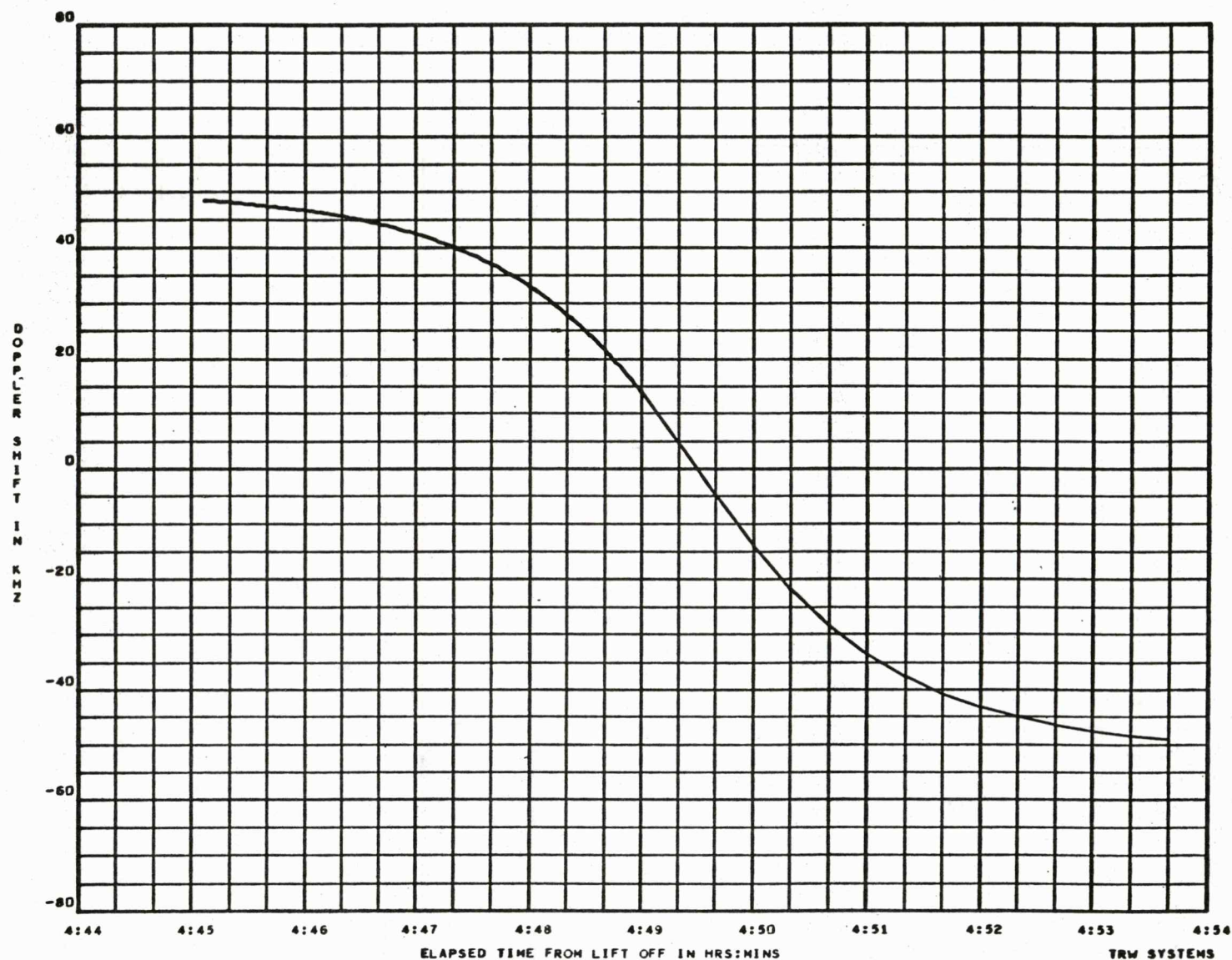


Figure E-45. BDA S-Band Downlink Doppler Frequency Shift vs Time for Orbit 4

E-47

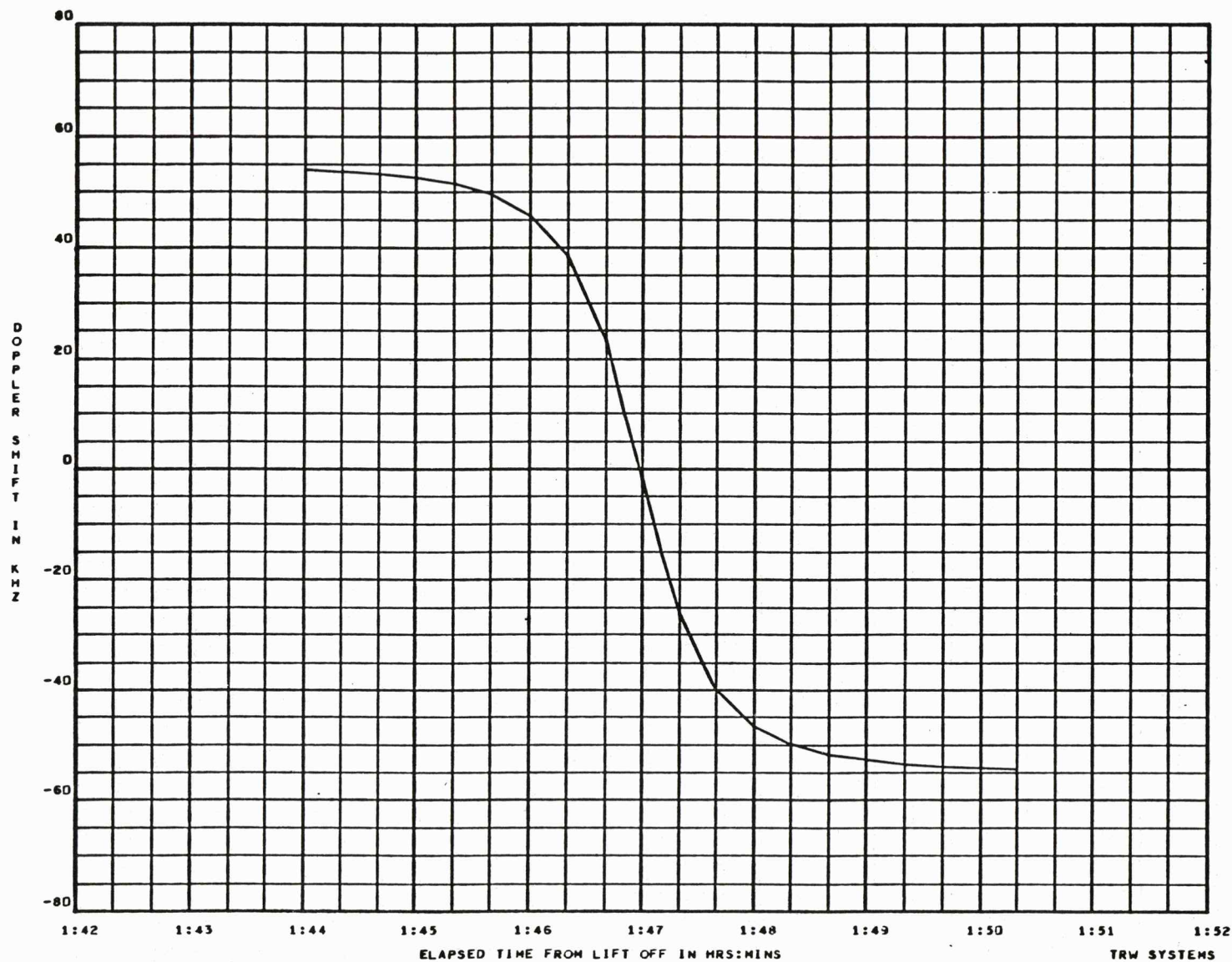


Figure E-46. VAN1 S-Band Downlink Doppler Frequency Shift vs Time for Orbit 2

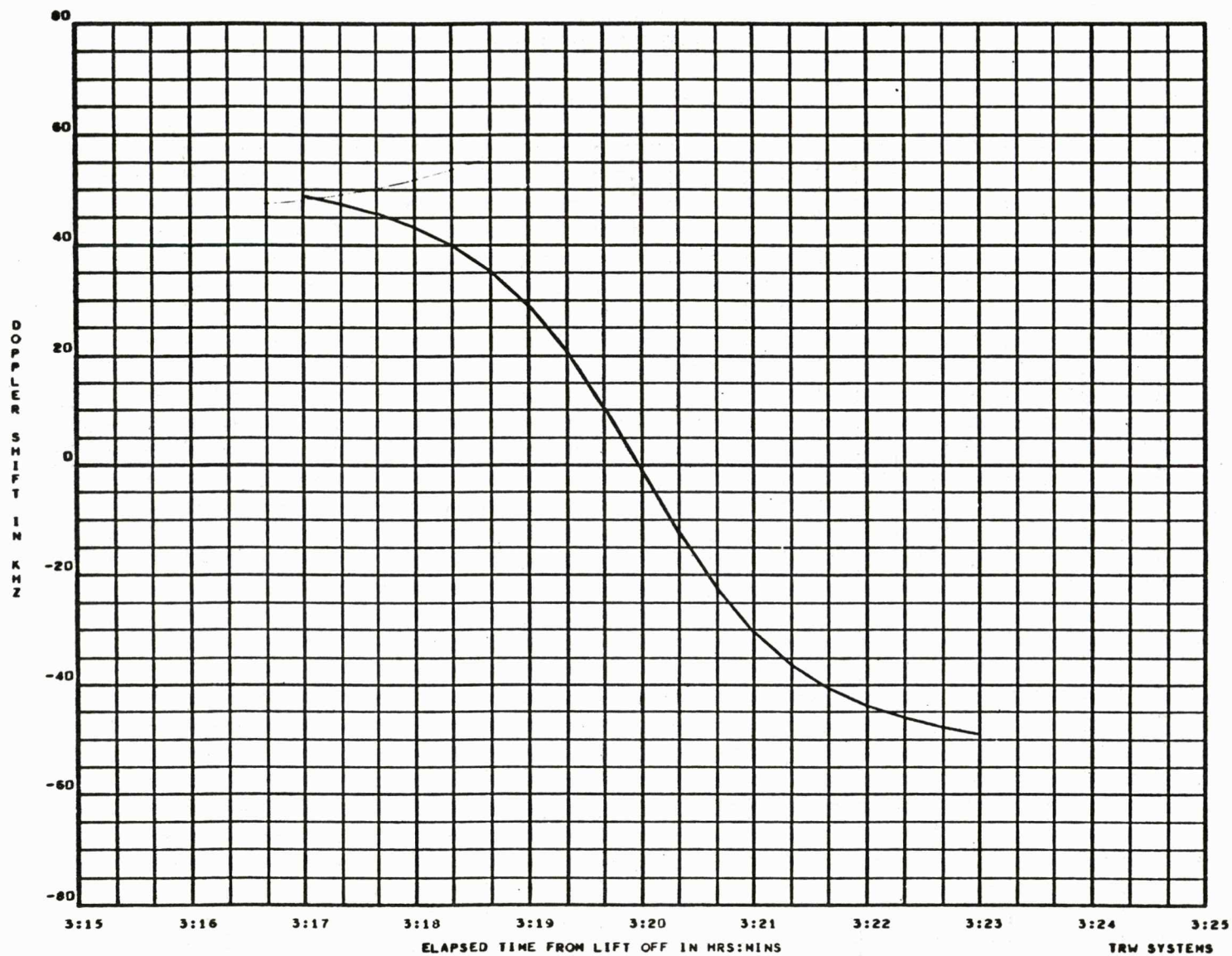


Figure E-47. VAN1 S-Band Downlink Doppler Frequency Shift vs Time for Orbit 3

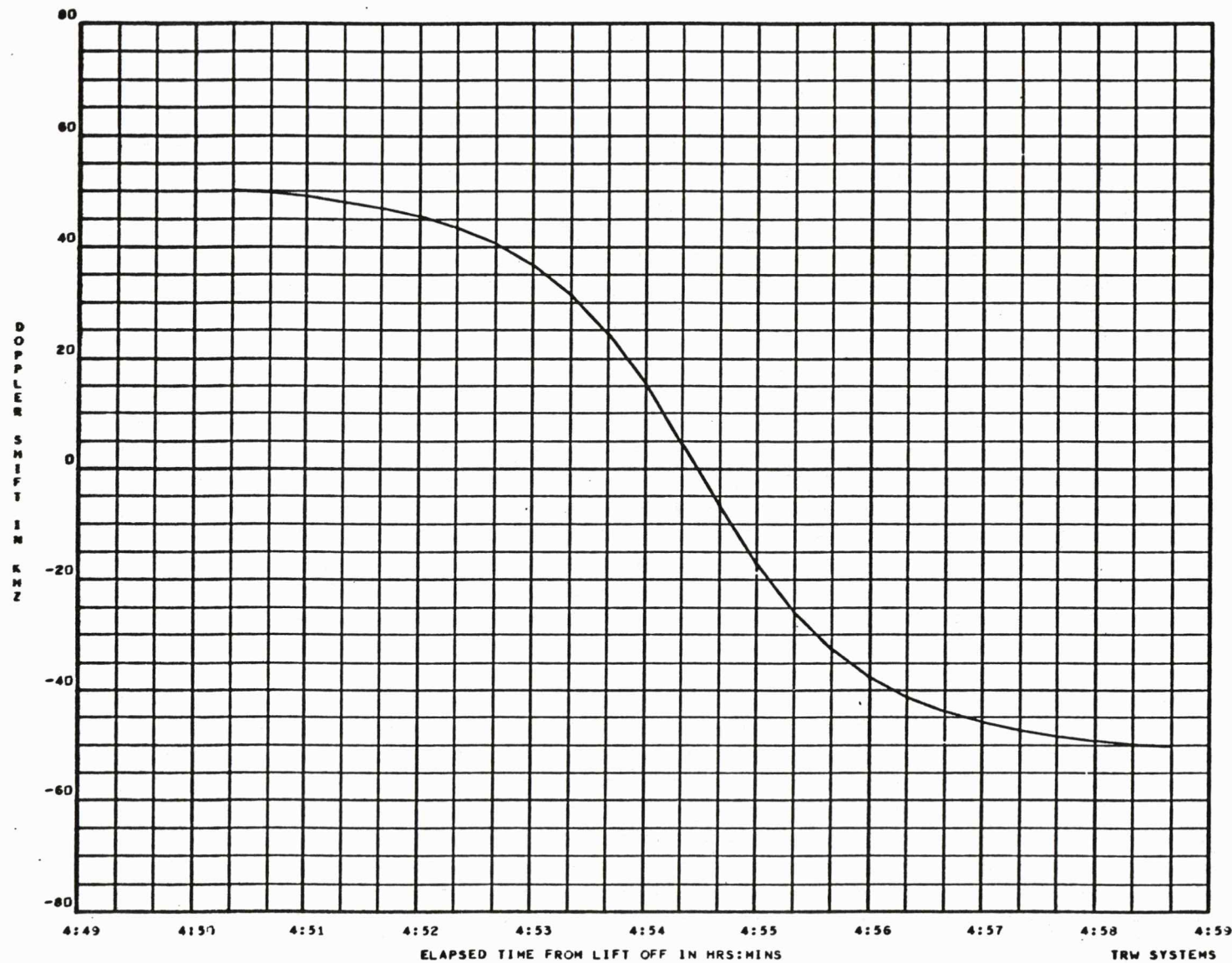


Figure E-48. VAN1 S-Band Downlink Doppler Frequency Shift vs Time for Orbit 4

E-50

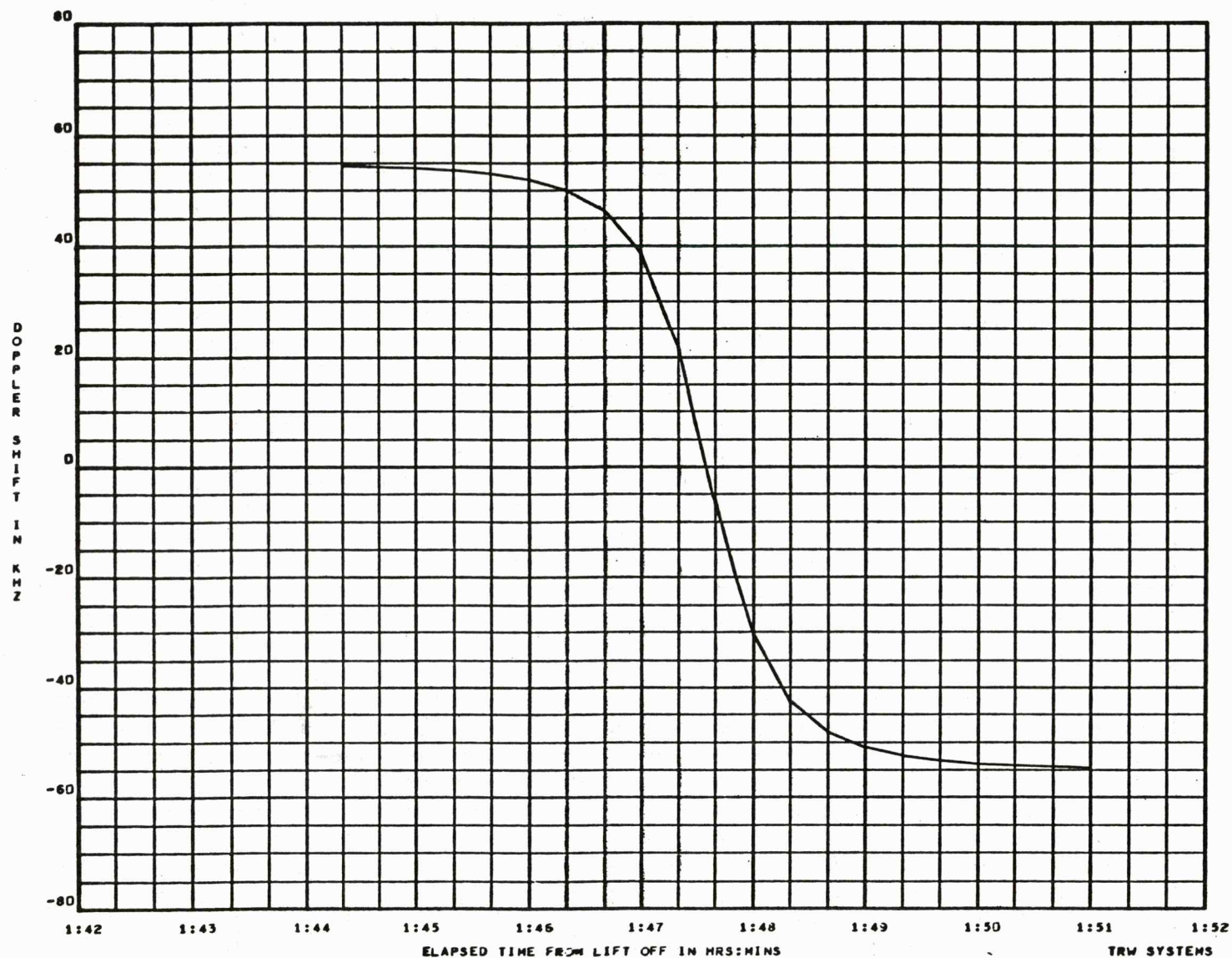


Figure E-49 VAN2 S-Band Downlink Doppler Frequency Shift vs Time for Orbit 2

E-51

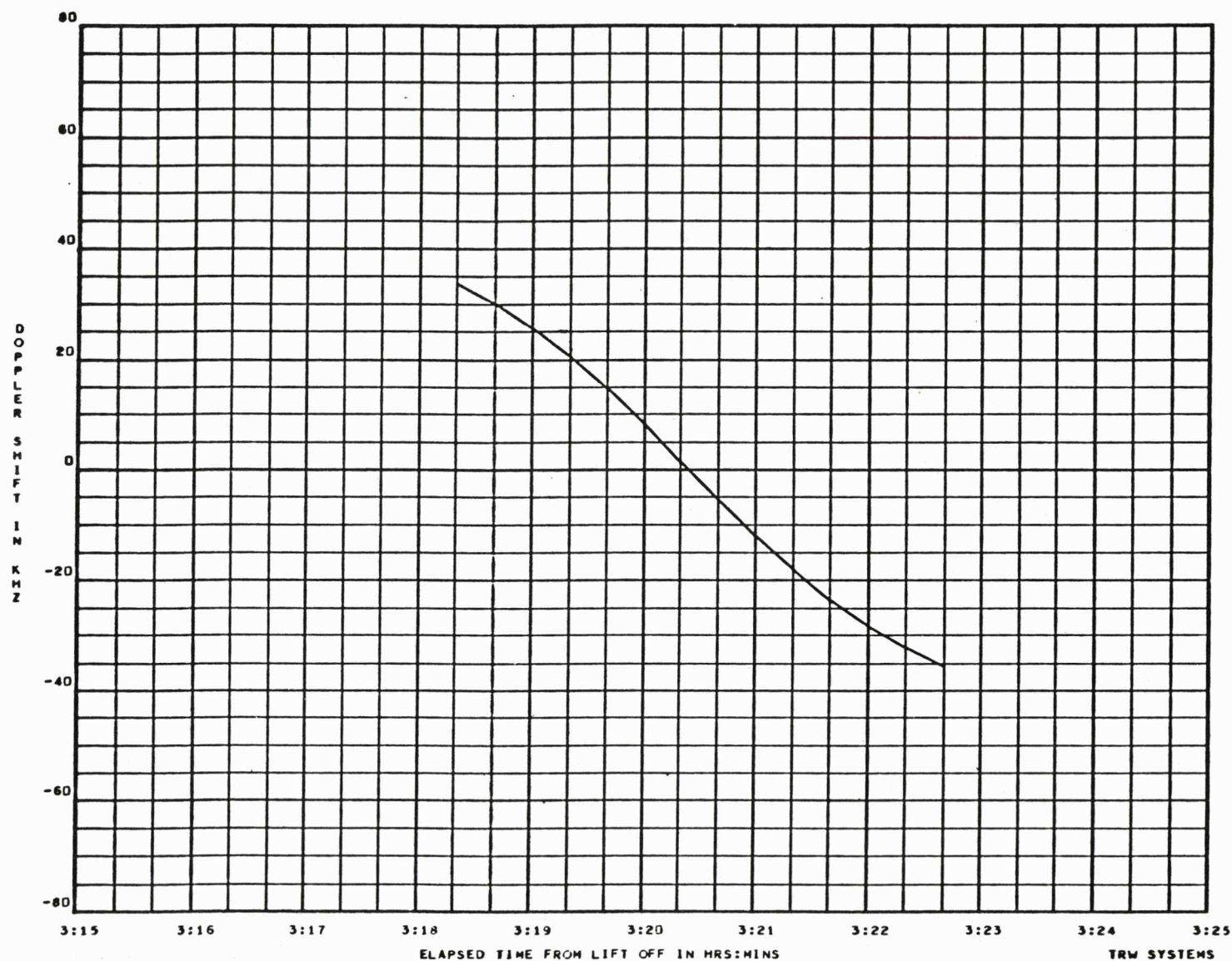


Figure E-50 VAN2 S-Band Downlink Doppler Frequency
Shift vs Time for Orbit 3

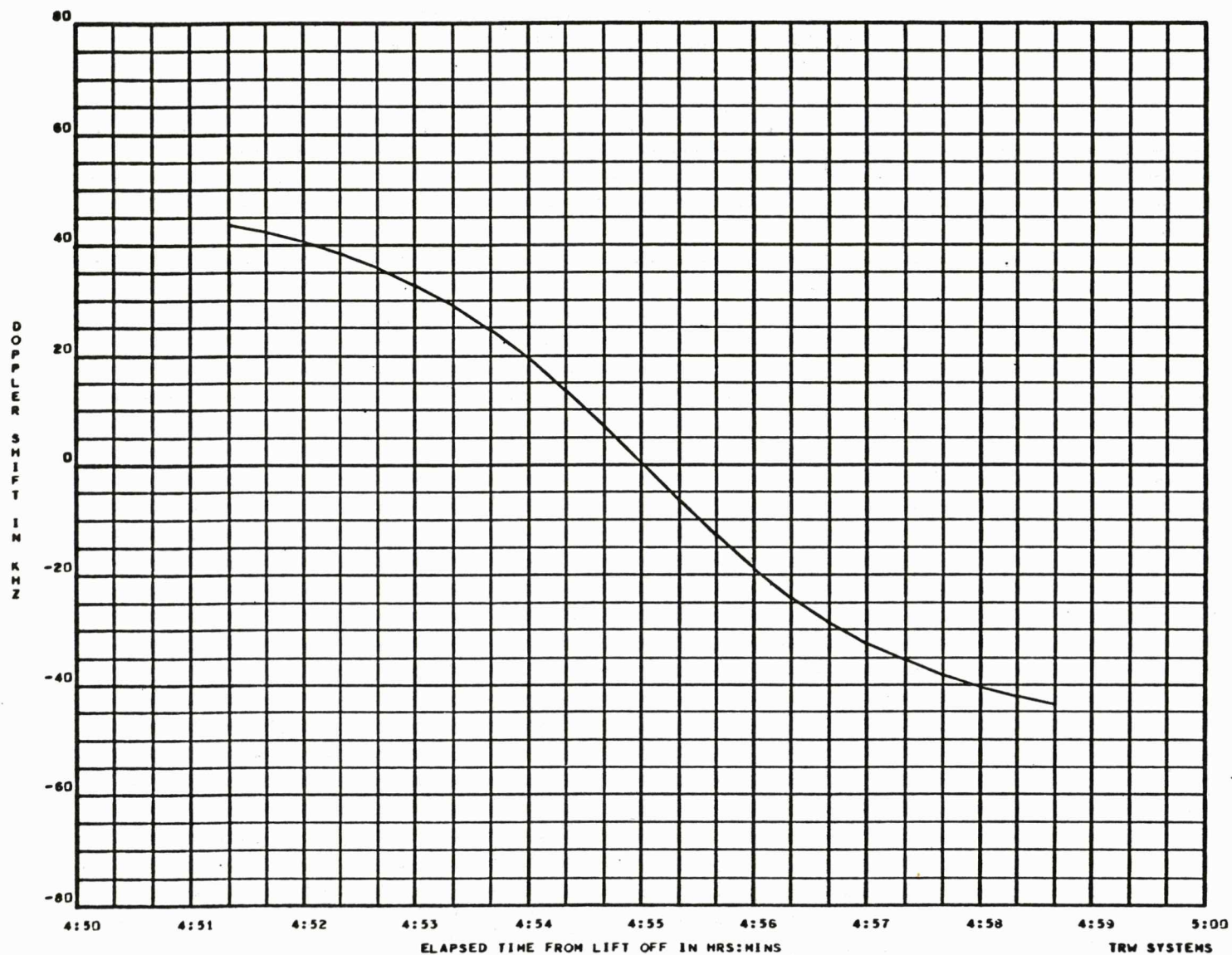


Figure E-51. VAN2 S-Band Downlink Doppler Frequency Shift vs Time for Orbit 4