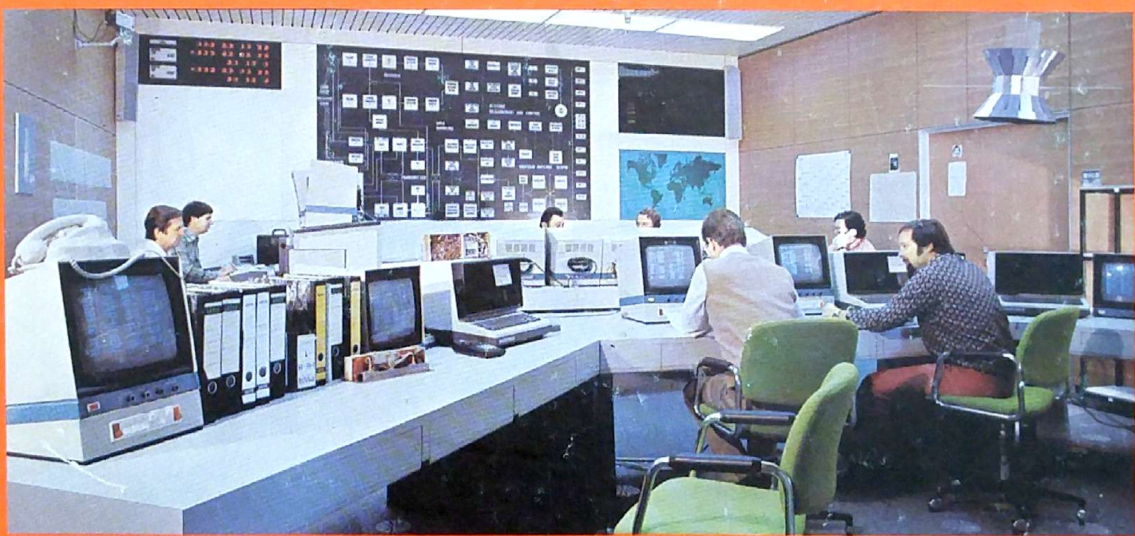
DEUTSCHE FORSCHUNGS- UND VERSUCHSANSTALT FÜR LUFT- UND RAUMFAHRT

HELIOS

INTERPLANETARY EXPERIENCE



GERMAN SPACE OPERATION CENTER (GSOC)

DEUTSCHE FORSCHUNGS- UND VERSUCHSANSTALT FÜR LUFT- UND RAUMFAHRT

HELIOS

INTERPLANETARY EXPERIENCE

GERMAN SPACE OPERATION CENTER (GSOC)

Dedicated to all those people which
spent many of their days and nights
for the Project

Edited by (1. October 1977): Joachim Kehr (HELIOS Mission Manager)

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0 INTRODUCTION

This volume is a summarization of the GSOC experience gained in the cooperative U.S./German Interplanetary Project HELIOS.
It is intended to allow a reader, who is familiar with Mission Operations Problems, a deep insight into our approach, implementation, experienced problems and resulting recommendations.
If any similar project comes along in a distant future, this summary might be used as a reference for avoiding a multitude of problems (the authors at least think) by using experiences already made.

0.1 GSOC CONCEPT

With the appointment of GSOC to plan, implement and conduct HELIOS Mission Operations, an overwhelming number of activities had to be started:

- Implementation of German Network and integration into the NASA Deep Space Network (DSN)
- Definition and implementation of a Ground and Mission Operations Organization
- Preparation and execution of the Mission
- Establishing and definition of all Ground and Mission Operations relevant interfaces to NASA

The GSOC concept in realizing those tasks can be described with the following implementation phases *(for time line refer to Fig. 0.1-1):*

- Training of HELIOS key personnel at NASA centers (JPL/GSFC).
  This phase started 5 years before launch in '69.
- Definition and Implementation Phase:
  This was started in forming a Ground and Mission Operations System Organization with the following responsibilities *(Fig. 0.1-2):*

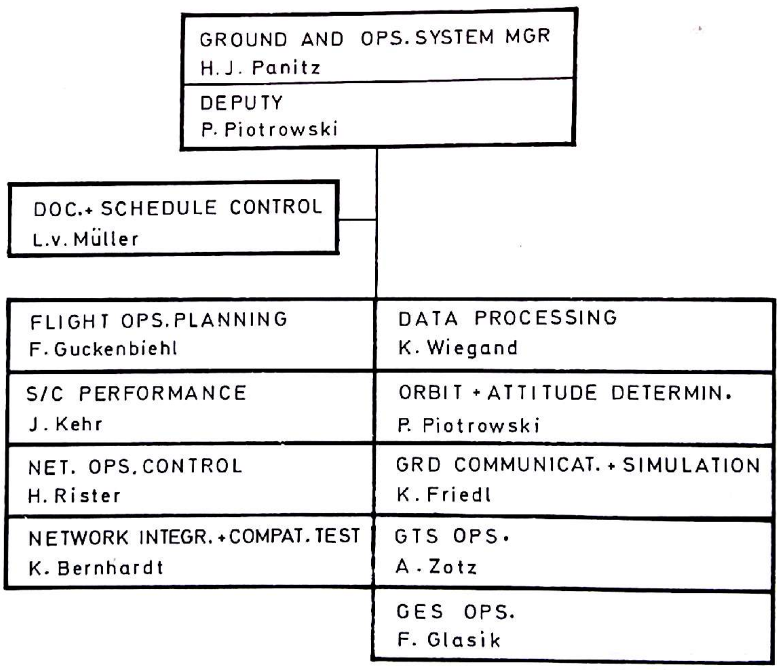


Figure 0.1-2: HGOS Organigram

The organization was finalized in '71, 3 years before launch.
The Ground and Operations System Manager was responsible for preparation (generation of specifications) and implementation (supervision and coordination) of all items relevant to the above shown fields of responsibilities.

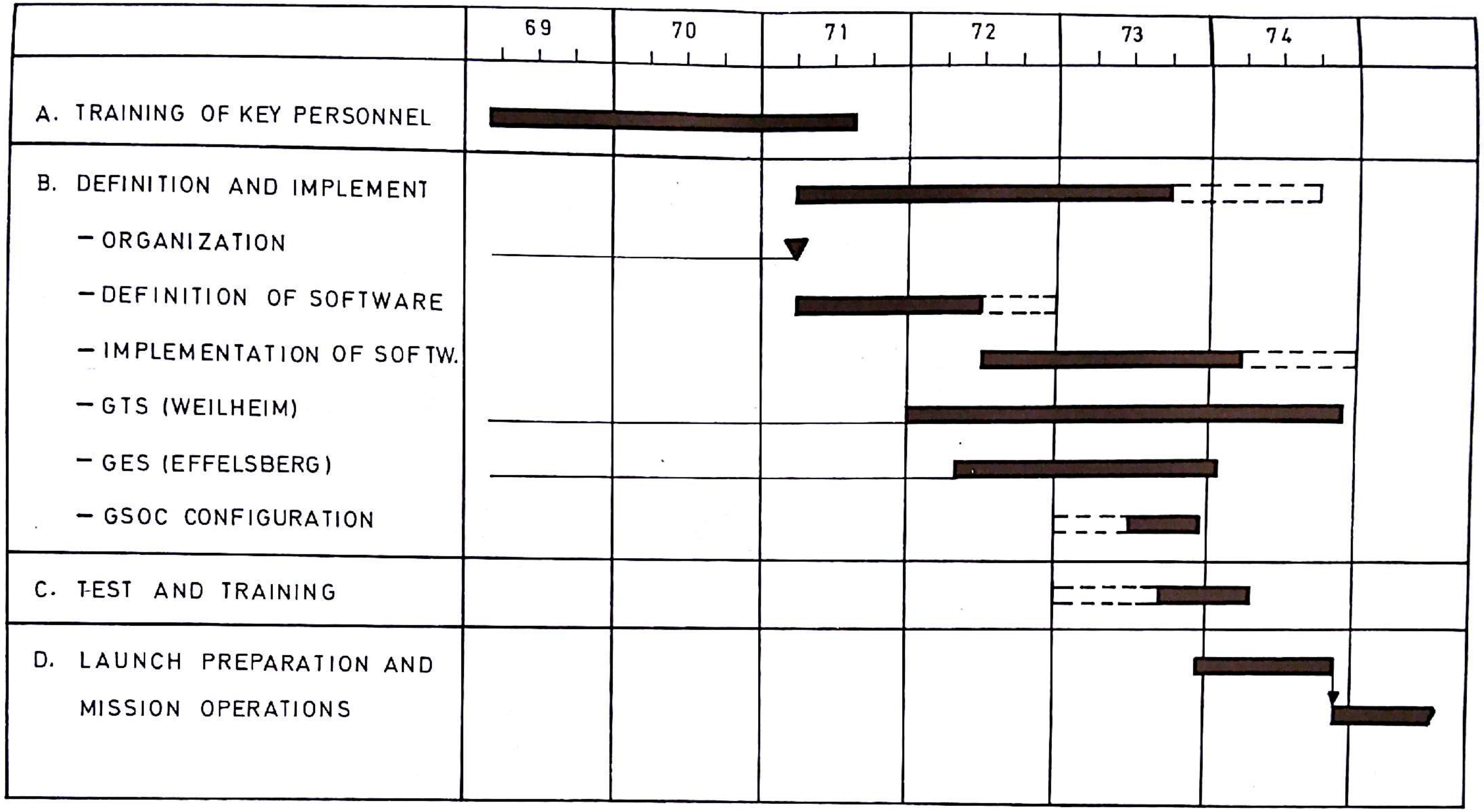


Figure 0.1-1: Overall HELIOS Ground and Mission Operations Implementation Schedule

— Test and Training Phase:
After most of the Ground System and Mission Operations relevant work packages were implemented, the test of the complete integrated system could start as well as the training of the operational personnel.
Of course there was an overlap between the implementation phase and the test phase but the accent shifted more and more to test and training.
This phase started at the begin of '73 with an overlapping period of approximately 9 months until end of '73.

— Launch Preparation Phase and Mission Operations Phase
The launch preparation phase started in spring of '74 and climaxed with the Operational Readiness Test (4 Dec. '74), where all systems (Flight S/C, Ground System, Operational Software and Operations Personnel) demonstrated their integrated readiness.
The mission operations phase started with the launch of the HELIOS-A S/C on 10 Dec. '74 and is still continuing.

0.2 MISSION OPERATIONS COSTS AND MANPOWER PROFILE

This chapter exceeds the adopted frame of this report because it summarizes the total cost and manpower for HELIOS-A and B.
A division of the costs according to HELIOS-A and B is not possible, because the mission has to be conceived as a DUAL mission requiring the quoted effort.

— COSTS
The total costs for preparation and execution of the two missions, covering the period from 1 Oct. 1972 to 31 Dec. 1977 sums up as follows:

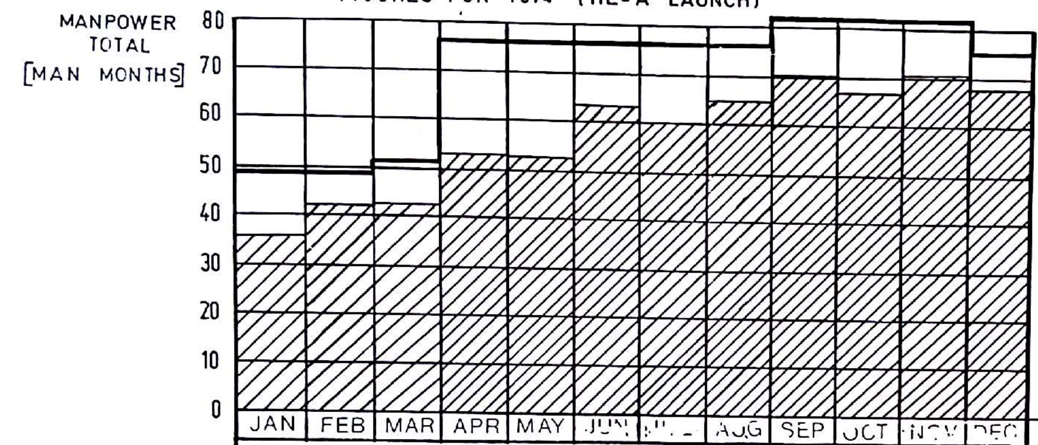
● Personnel costs	10.078.600,— DM
● Procurement and installation costs (Data lines ect.)	6.035.200,— DM
● Travelling costs	633.000,— DM
	16.746.800,— DM

Those costs do not include the installation of the WEILHEIM Ground Station and the personnel costs for the GSOC engineers. It includes all personnel costs for the operation of the WEILHEIM and EFFELSBERG stations by contractors.
The personnel costs for the GSOC engineers can be derived from the manpower profile by multiplying with a cost factor of approx. 70.000,— DM per man year.

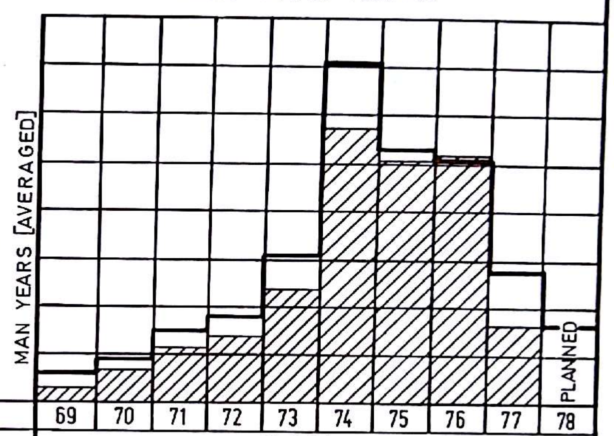
— MANPOWER PROFILE
The attached *Fig. 0.2-1* shows the GSOC manpower profile in detail for 1974 (HELIOS-A launch) and a summary overview, starting with 1969 *(right hand side of Fig. 0.2-1)*
As can be seen, a peak was reached in Nov. '74 (one month before launch) with a total of 70.5 man months (MM).
The build-up of contractor support started with the begin of 1974 with 5.7 MM, reaching a peak of 20 MM in Nov. '74. That was because most of the flight operations personnel was provided by contractors.
The planned/actual comparison shows, that the planned numbers were not matched and in practice it turned out, that the available actual man power was not enough for the hectic months of Nov. and Dec.'74 as it is reflected in the overtime figures. The ACTUAL STATUS 1969-77 shows the actual averaged man-years. It shall be pointed out, that for the detailed allocation of the manpower two schemes *(item 7-9 and 11-14 on the plot)* were used:

- *Items 7-9:* This shows the manpower differentiated according to:
  a. GSOC internal engineers (System management and GSOC sections)
  b. Contractors
  c. Support by other DFVLR Institutions
- *Items 11-14:* Allocates the same number of people according to GSOC sections, i.e. the contractors and support engineers are counted at the appropriate GSOC sections which they supported at that time.

FIGURES FOR 1974 (HE-A LAUNCH)



ACTUAL STATUS 1969 - 77



No.	Item	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		PLANNED / ACTUAL											
1	PLANNED MANPOWER	49	49	51	76	76	76	76	76	81	81	81	75
2	ACTUAL MANPOWER	36.6	41.7	42.2	53	52.8	63	60	64.8	70.1	66.3	70.5	68.6
3	OVERTIME (MANMONTHS)	1.29	2.10	2.22	3.72	1.52	2.09	3.10	1.93	2.96	1.9	3.7	5.9
4	PERSONAL AT NASA TRAINING												
5													
6	SYSTEMMANAGEMENT	11/11	11/11	11/11	11/11	11/11	11/11	11/10.8	11/10.9	11/10.7	11/10.6	11/10	11/10.7
7	SUPPORT BY GSOC SECTIONS	23/19.9	23/20	23/19	28/21.5	28/23	28/25	28/25.3	28/25.9	33/31.4	33/29.5	33/32.5	33/30.1
8	" BY CONTRACTORS	15/5.7	15/10.7	17/12.2	21/19.5	21/18.8	21/19	21/19.9	21/20	21/20	21/18.2	21/20	21/19.8
9	" BY GfW / DFVLR	–	–	–	16/1	16	16/8	16/4	16/8	16/8	16/8	16/8	11/8
10													
11	GSOC-SECTION HELIOS 2)	18/8.7	18/12.7	18/12.4	34/19	34/16.8	34/25	34/22	34/26	39/31	39/30.4	39/31	33/22.2
12	" CONTROL-CENTER	6/4	6/4	6/4	13/7	13/8	13/9	13/10.7	13/10.7	13/10.2	13/9.7	13/10.5	13/10.4
13	" DATA PROCESSING	10/8.9	10/10	10/10	10/8.5	10/9	10/10	10/8.4	10/9.1	10/10	10/9.6	10/10	10/9
14	" GND-STATIONS	15/15	15/15	17/15.8	19/18.5	19/19	19/19	19/18.9	19/19	19/18.9	19/16.6	19/19	19/19
15													
16	SECRETARIES	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/3	1/2	1/2	1/1	1/2

No.	Item	69	70	71	72	73	74	75	76	77	78
		ACTUAL									PLANNED
1	PLANNED MANPOWER	6.0	9.0	15.0	18.0	30.5	70.6	53.08	51,0	27,5	16.0
2	ACTUAL MANPOWER	3.0	7.0	11.5	14.0	24.0	57.5	50.2	52.0	16.0	16.0
3	OVERTIME (MANMONTHS)	-	-	-	0.2	0.4	2.7	0.61	2.5	-	-
4	PERSONAL AT NASA TRAINING	0.6	3.5	3.0	1.9	-	-	-	-	-	-
5											
6	SYSTEMMANAGEMENT	2.7	5.7	9.0	9.0	10.2	10.8	7.7	10.0	5.0	5.0
7	SUPPORT BY GSOC SECTIONS	0.3	1.3	1.5	3.5	9.3	25.3	19.4	25.0	4.5	4.5
8	" BY CONTRACTORS	–	–	1.0	1.5	4.5	17.0	20.9	17.0	6.5	6.5
9	" BY GfW / DFVLR	–	–	–	–	–	4.4	2.1	-	–	–
10											
11	GSOC-SECTION HELIOS 2)	1.2	3.0	4.6	6.5	7.1	21.4	23.1	29.8	8.5	8.5
12	" CONTROL-CENTER	1.0	1.4	2.8	3.4	4.3	8.2	5.2	8.2	0.5	0.5
13	" DATA PROCESSING	0.8	2.6	3.1	3.0	8.5	9.4	13.2	8.0	1.0	1.0
14	" GND-STATIONS	-	-	1.0	1.1	4.1	17.8	8.7	6.0	6.0	6.0
15											
16	SECRETARIES	-	-	1.0	1.0	1.0	1.4	1.0	1.0	0.5	0.5

REMARKS: 1) HELIOS A: START 10. DEC 1974 HELIOS-A PHASE I MISSION OPERATIONS AT JPL PASADENA
HELIOS B: START 15. JAN 1976

2) SUM OF ITEMS 7-9 EQUALS SUM 11-14 i.e. MANPOWER SPELLED OUT HERE ACCORDING TO GSOC SECTIONS (INCLUDING CONTRACTORS AND DFVLR / GfW SUPPORT)

Figure 0.2-1: GSOC Manpower Profile between 1969 and 1977

1 MISSION OPERATIONS ORGANIZATION

1.1 PHASES OF ACTIVITY

1.1.1 FLIGHT PREPARATION PHASE

During the period when the HELIOS-A Mission was prepared, three major phases could be distinguished:

- Requirements Definition Phase
- Implementation Phase
- Training Phase

All these three phases are characterized by a close working interface and information exchange between all involved parties as GfW, DFVLR and MBB in Germany, NASA, JPL, DSN, KSC, LeRC and AMES in the U.S. and the experimenters on both sides of the Atlantic. This interface was achieved by means of various joint meetings, as

— 10 HELIOS Joint Working Group Meetings:
From 1969 to 1974 all involved parties met alternately in the U.S. and Germany at different places to present and discuss all technical and operational interfaces concerning spacecraft, launch vehicle and operations facilities.

— Technical Meetings:
Numerous meetings to discuss technical problems in detail among cognizant personnel were held also at various places in the U.S. and Germany.

Some were:

- Near Earth Phase Study Group Meetings; Oct. '70 in Bonn and May 1971 at GSFC in USA
- Blind Acquisition Study Team Meetings; Nov. '72 in Porz-Wahn and May '73 at KSC in USA
- Technical Meetings at JPL. May '73
- DSN/Telecommunications Technical Meetings

— Reviews:
In order to present the systems status to the Project personnel and to other involved people, various status reviews and presentations were held also at various locations in the U.S. and Germany. Some representative reviews are mentioned here for reference:

- Informal Review of HELIOS Mission Operations Planning, GSOC, April 1972
- S/C Telecommunication System Presentation, JPL, May 1972
- HGOS Review, JPL, May 1973
- HELIOS-A Flight Readiness Review, MBB — Ottobrunn, Sept. 1974
- HGOS Readiness Review, JPL, Nov. 1974
- Launch Readiness Review, KSC, Dec. 1974

— Project Status Review Meeting (PSR)
Held on a monthly basis between GfW and MBB with GSOC participation, reviewing the progress and status of the development and manufacturing of the S/C.

1.1.2 FLIGHT OPERATIONS PHASE

For the purpose of Flight Control and Operations the HELIOS mission was divided into three phases:

Phase I
Phase I of the HELIOS Mission included the Launch Phase, the Near Earth Phase and the

initial portion of the Cruise Phase. Phase I of the HELIOS-A Mission was terminated 4 weeks after launch, at Jan 10, 1975, when the German Space Operation Center took over all mission control functions for HELIOS-A. During Phase I, Mission Operations and Control was carried out by HGOS personnel at JPL. JPL provided support for Mission Operations including tracking, orbit determination, data acquisition, software and facility operations, 24 hours per day.

- Launch Phase
  The Launch Phase consisted of prelaunch countdown, powered flight phase with parking orbit and ended with spacecraft separation.
- Near Earth Phase
  The Near Earth Phase consisted of the activities from the launch to the completion of Step II maneuver.

Phase II

Phase II of the HELIOS-A mission began with the end of Phase I and lasted to about the first solar occultation. The GSOC executed Mission Control during Phase II. Data acquisition and command operation were carried out by the combined German/NASA Deep Space Networks, 24 hours per day. However, the orbit determination and back-up command function still were carried out at JPL.

Phase III

Phase III of the mission started with the conclusion of the Phase II and will last until the end of the HELIOS-A mission. All mission operations and control functions are carried out at GSOC. Data acquisition and commanding is performed by the German network supported by the DSN whenever the DSN is available.

1.2 MISSION OPERATIONS FUNCTIONS AND RESPONSIBILITIES

The basic Mission Operations functions were as follows:
Testing functionally the integrated hardware and software needed for Mission Operations

- Training of all Mission Operations personnel
- Execution and coordination of all Mission Operations activities
- Performance analysis and command control of the HELIOS spacecraft

These functions and responsibilities were shared between the „JPL Mission Operations Support" (JPL-MOS)organization and the „HELIOS Ground and Operations System" (HGOS) organization at GSOC. A more detailed description of the responsibilities during the operational phase and the corresponding responsible organization is given in the following *Table 1.1-I.*

1.3 ORGANIZATION DURING MISSION OPERATIONS

According to the shared responsibilities for HELIOS Mission Operations, the Mission Operations Organization consists of two major groupings of elements:

- The Space Flight Operations Teams (HGOS/GSOC personnel), and
- The JPL-Mission Operations Support Team

Because of the different mission requirements and capabilities at JPL during Phase I and at GSOC during the other phases of the mission, two separate organizational structures were established.
The following paragraph describes the responsibilities within the organization during Phase I of the HELIOS-A Mission *(refer to Fig. 1.3.-1)* and subsequently during Phase II and III *(refer to Fig. 1.3.2).*

	RESPONSIBILITY OF	
	JPL - MOS	HGOS
DATA GATHERING		
● TLM DATA RECEPTION	X	PH II + III
● METRIC DATA GATHERING	X	
● ROUTING OF DATA TO MSA	X	PH II + III
COMMAND DATA TRANSMISSION	X	PH II + III
NETWORK AND FACILITY SUPPORT		
● PLANNING, COORDINATION AND SUPPLY OF NETWORK AND FACILITY SUPPORT	X	PH II + III
● OPERATION AND CONTROL OF COMMITTED NETWORK ELEMENTS AND FACILITIES	X	PH II + III
DATA PROCESSING		
● MONITORING AND ASSURING CORRECT OPERATION OF MISSION OPS SOFTWARE PROGRAMS	X	PH II + III
● R/T — DATA DISPLAY AND DISTRIBUTION	PH I	PH II + III
● GENERATION OF DATA FILES AND TAPES	X	PH II + III
S/C CONTROL		
● FORMULATION OF OPERATIONAL SEQUENCES		X
● GENERATION OF CONTINGENCY MODES		X
● R/T — S/C PERFORMANCE MONITORING AND CONTROL		X
● OFF LINE S/C ANALYSIS AND EVALUATION		X
● COMMAND INITIATION		X
● REPORTS		X
SCIENTIFIC INSTRUMENTS PERF. ANALYSIS ● ANALYSING SCIENCE TELEMETRY AND ENGINEERING DATA	PRINCIPAL INVESTIGATORS	
METRIC DATA EVALUATION		
● TRAJECTORY CALCULATION	X	
● ORBIT DETERMINATION	X	
● PREDICTS GENERATION	X	PH II + II
ATTITUDE DETERMINATION		
● S/C ATTITUDE CALCULATION		X
● ATTITUDE MANEUVER COMPUTATION		X
● S/C ANTENNA POINTING PREDICTS		X

Table 1.1-I: MOS RESPONSIBILITIES

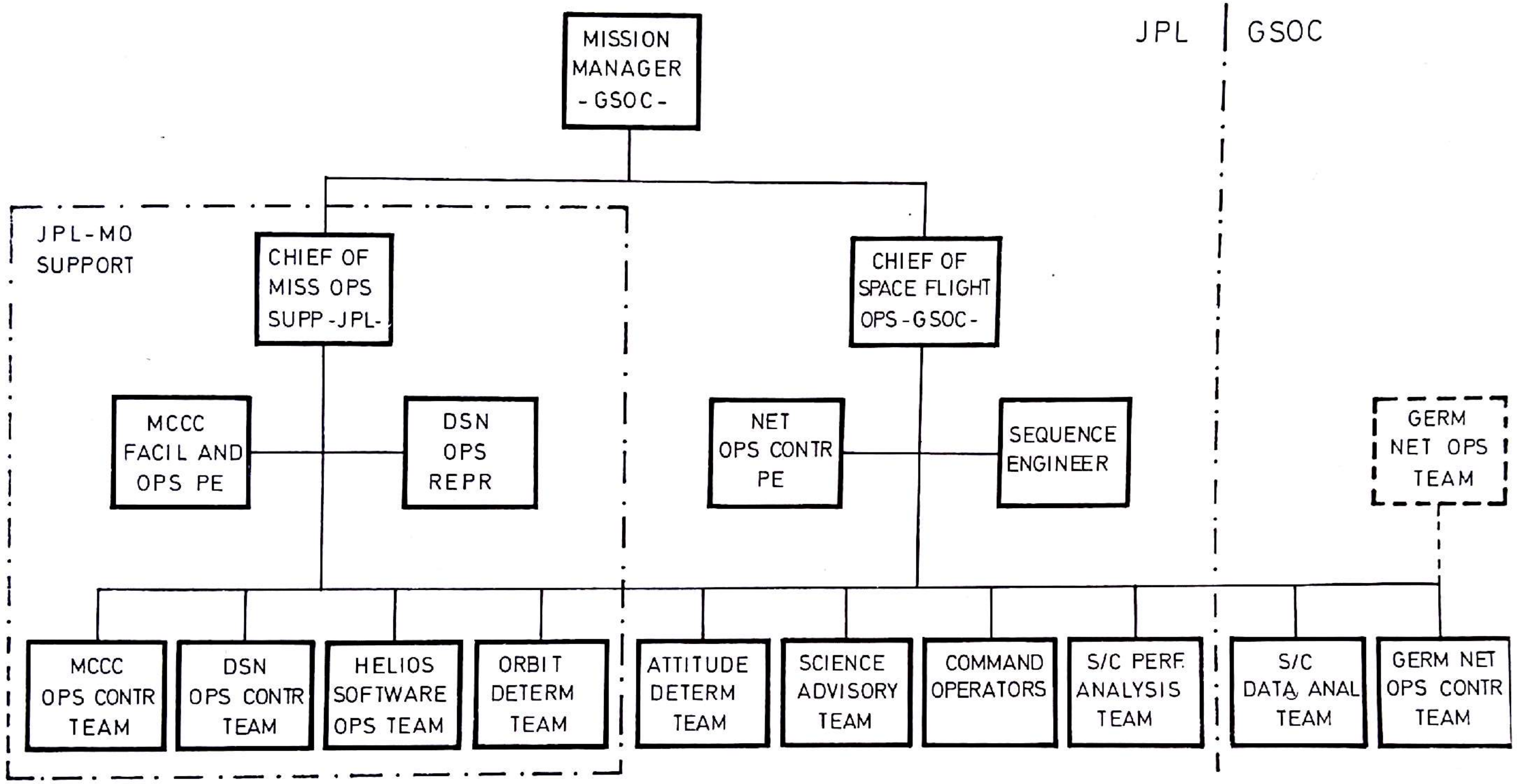


Figure 1.3-1: HELIOS Mission Operations Organization during Phase I (JPL)

1.3.1 HELIOS-A MISSION OPERATIONS ORGANIZATION DURING PHASE I (AT JPL)

Mission Manager

The Mission Operations Organization during all mission phases is headed by the Mission Manager who is responsible for mission planning, decisions involving mission redirection and risk assessment.

JPL — Mission Operations Support

- Chief of Mission Operations Support (CMOS)

  The Mission Operations Support organization (MOS) was headed by the CMOS. The CMOS did coordinate all JPL functions necessary to support the Helios mission.

- DSN — Operations Representative (DSN Ops.Rep.)

  The Ops.Rep. represented the DSN to the HELIOS Project. The DSN Ops. Rep. coordinated operations planning and scheduling of the combined U.S. — German network operations with the German Network Operations Representative (NET Ops. Control PE).

- MCCC Facility and Operations Project Engineer (FOPE)

  The FOPE was the prime interface for planning and coordination of JPL/MCCC facility support and resources scheduling.

- MCCC Operations and Control Team (MCCC Ops. Control Team)

  The MCCC Ops. Control Team operated and controlled all MCCC resources in support of HELIOS flight operations.

- DSN Operations and Control Team (DSN Ops. Control Team)

  The functions of the DSN Ops. Control Team were operations planning, configuration control, and operation of the committed U.S.-Network elements.

- HELIOS Software Operations Team (HELIOS Software Ops. Team)

  The Software Ops. Team did coordinate all data processing for the HELIOS Project to operate the mission support software.

- Orbit Determination Team (Orbit Determination Team)

  The Orbit Determination Team performed orbit and trajectory calculation.

HELIOS Space Flight Operations

- Chief of Space Flight Operations (CSFO)

  The CSFO (callsign HEOPS) coordinated and directed all flight operations related planning-, analysis- and execution functions. He coordinated JPL - support with the CMOS.

- Network Operations Control Project Engineer (Net.Ops. Contr. PE)

  The function of the Net.Ops. Control PE was to coordinate the joint operation of the German - Network elements with the U.S. - Network elements together with the DSN Ops. Rep.

- Sequence Engineer

  The Sequence Engineer generated the actual flight sequence of events in accordance with the CSFO (HEOPS).

- Attitude Determination Team

  The functions of the Attitude Determination Team were to analyse and calculate the spacecraft attitude and to generate HGA - reflector pointing predicts. During initial flight operations this team was responsible for carrying out the attitude orientation maneuvers.

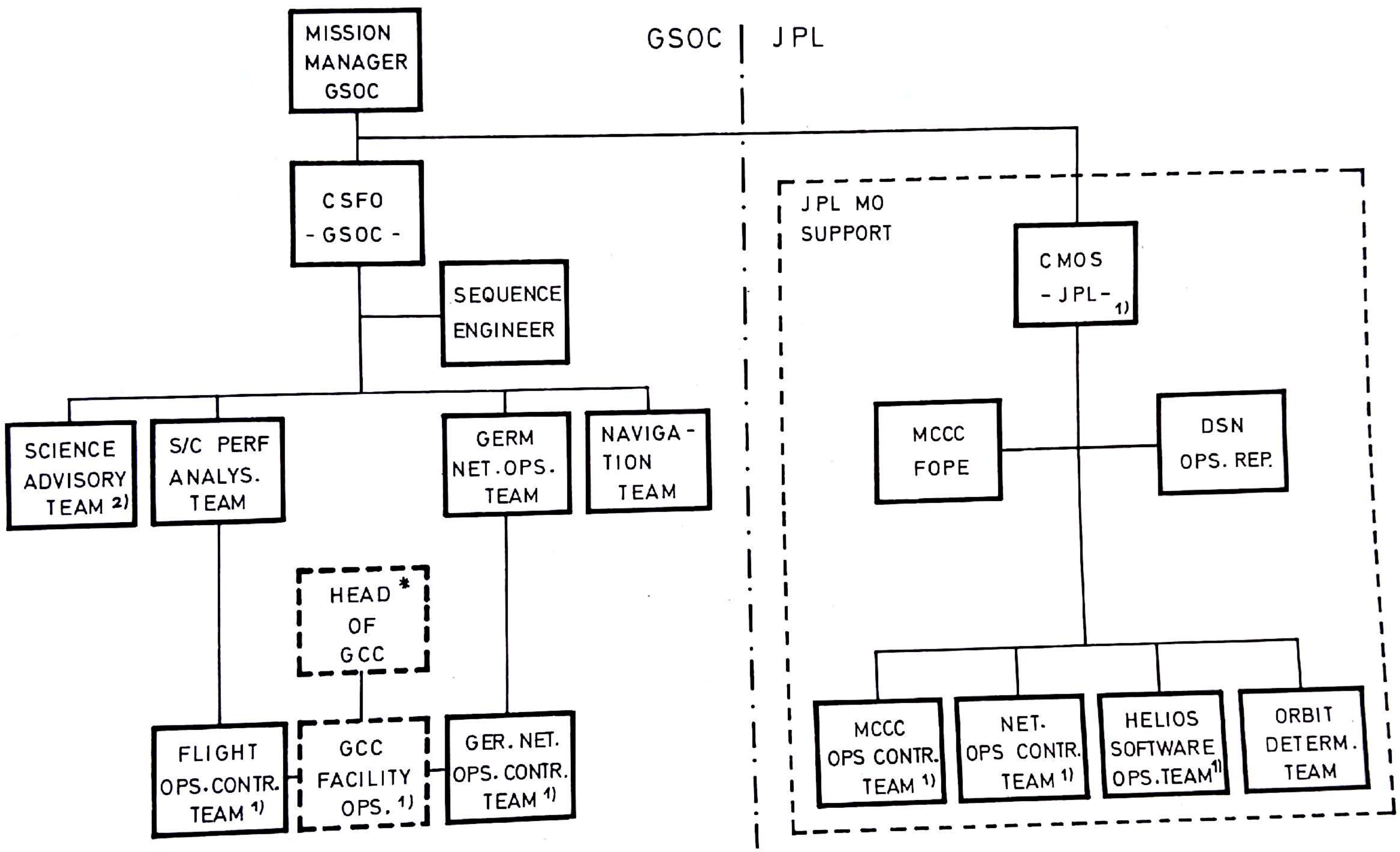


Figure 1.3-2: HELIOS Mission Operations Organization during Phase II, III (GSOC)

- Science Advisory Team (SAT)

  The SAT analysed science telemetry data with the intent to check science instrument status and performance.
- Command Operators

  The function of the Command Operators was to command the spacecraft according to the instructions from the CSFO (HEOPS).
- Spacecraft Performance Analysis Team (S/C PAT)

  The functions of the S/C PAT were S/C performance analysis and evaluation, prediction of S/C subsystems behaviour, translation of spacecraft operations requirements into command sequences and recommendation of remedial actions in any case of a S/C malfunction.

GSOC - Functions

- S/C Data Analysis Team

  Although the responsibility for spacecraft control was with the S/C Performance Analysis Team at JPL, at GSOC a S/C Data Analysis Team monitored S/C - TLM-Data also and proved GSOC readiness to take over for Mission Phase II.
- German Network Operations Team

  The principal functions of the German Net.Ops. Team were to coordinate off-line the network operation plans, schedules, sequences and procedures.
- German Network Operations Control Team

  The German Net.Ops. Control Team was responsible for the operation and control of all German Network elements.

1.3.2 HELIOS-A MISSION OPERATIONS ORGANIZATION DURING PHASE II/III (AT GSOC)

After Mission Control handover from JPL to GSOC the Mission Operations organization was modified to pay regard to the fact that all flight operations functions were now with GSOC *(refer to Fig. 1.3-2).*

Whereas the JPL Mission Operations Support organization remained unchanged *(refer to Phase II Organization)* the flight operations functions at GSOC are carried out by seven teams, a sequence engineer and the Chief of Space Flight Operations (CSFO).

The CSFO, the sequence engineer and the following teams:

- Spacecraft performance analysis team
- German network operations team
- Attitude determination team
- Science advisory team

perform basically the same functions as during Phase I, but off-line. Only during critical phases or phases of special events (i.e. perihel) members of these teams come on line. The routine real time operations functions are performed by the following teams:

- Flight Operations Control Team

  The Flight Ops.Control Team monitors the S/C telemetry data in real time and sends commands to the S/C according to a detailed operations sequence.
- German Network Operations Control Team

  The functions of the German Network Ops.Control Team are to operate and control all German Network elements.
- GCC Facility Operations

The function of operation and control of GCC facilities is (for all projects) performed by the GCC Organization within GSOC, 24 hours per day.

1.4 INTERFACES TO THE USERS

Since the HELIOS S/C - experiment design is so complex, that it is impossible to derive from the engineering data (analog values and status bits) alone the proper functioning of an experiment, additional means had to be established to give the USER (EXPERIMENTER) a better control over his experiment in realtime or almost realtime (Near Real Time).
This interface varied during the different mission phases:

PHASE I: Experiment Turn On and Checkout (JPL)

- For each experimenter an ON-LINE position was established at JPL providing experiment and S/C engineering data in real-time. The positions were manned 24 hrs by science representatives (SCIENCE ADVISORY TEAM)
- For each experiment at least one quicklook printout of SCIENCE DATA was specified and provided according to priority regulations (only two LINEPRINTERS for twelve experiments) in realtime.
- As a background support RECALLS of interesting phases during turn-on and during inflight checkout could be provided on request (NEAR REAL TIME)
- For four experiments OFF-LINE plot programs for science data were specified and provided on request.
- For one experiment a dedicated TELETYPE format was available providing a CONTINUOUS printout of science data.
- As an additional support a Mini-Computer-System (MICOS), implemented by Goddard Space Flight Center, served the experimenters with:
  - Realtime science display formats (3 screens available) including hardcopies
  - Near Realtime plots of science data
  - Near Realtime printouts of science data
- Command log and limit exceed log was provided on dedicated TELETYPE machines in the Science Advisory Team area.

PHASE II, III: Cruise Phase (GSOC)

- Limited on-line positions only during PERIHELION phases were available
- Realtime Science Printouts, only for experiment trouble shooting (1 LINEPRINTER), were possible.
- Realtime support by GSOC controllers using MICOS science RT data display for detection of SHOCKS was provided
- Near-Realtime support by GSOC and MICOS printouts in that way, that the printouts are MAILED on a regular basis to the experimenters home addresses.

As a general service the experimenter community is kept informed by:

- TWX about all S/C and experiment anomalies
- Daily engineering printouts (mailed weekly) together with graphic daily activity charts (information about station coverage, S/C bitrate, S/C configuration, special events).
- Special GSOC Reports covering all Perihelion and Aphelion phases.

For limit exceedings of engineering data of a certain experiment (monitored continuously by GSOC controllers) or other experiment anomalies which might be detected by routine science printout checks at GSOC the experimenter is consulted immediately by phone or TWX if no contingency actions are defined for GSOC.
This information system which has to serve experimenters in BRD, Italy and U.S.A. gives the investigators a good visibility of their experiments and enables them to:

- Select the proper (optimum) configuration for certain events (SHOCK waves, Perihels, Blackouts)
- Detect experiment malfunction long before the Experiment Data Records (EDR's) are evaluated at the experimenters place (usually month's after the recording)

1.5 NECESSARY OPERATIONS DOCUMENTS

The attached HGOS - Documentation tree *(Fig. 1.5-1)* shall not be discussed, but out of this multitude of documents (which were all necessary at a point of time) those will be identified which are important from a mission operations point of view and necessary during the ongoing mission. Special emphasis and attention has to be given to the quality and update status of those documents.

- S/C USERS HANDBOOK
  This is a document which had to be delivered by the S/C manufacturer and had to contain all user relevant information:
  - S/C Description
  - Command Directory
  - Engineering Directory
  - Nominal Sequences
  - Contingencies
  - Calibration Curves
  - Experiment Descriptions
- SOFTWARE PLAN
  Basic reference for all software related problems
  - Software Requirements Document
  - Software Design Book
  - Software Users Manual
- GERMAN NETWORK OPERATIONS PLAN
  - Operating Procedures

In addition to those basic documents other „USER"-oriented documents were created (not planned and not mentioned in the documentation tree) and proved to be necessary:

- HELIOS OPERATIONAL HANDBOOK
  It replaced the Space Flight Operations Plan and is a compilation of the essentials for the ROUTINE S/C OPERATIONS CONTRACTORS especially tailored to their needs, containing:
  - Command Operations Procedures
  - Communication Operations
  - Shift Requirements and Check Lists, Special Instructions, etc.
  - HELIOS Software User Information
  - General Support Procedures
- HELIOS-A S/C ANALYSTS' QUICKLOOK
  This document was established after launch and summarized the operational experiences (anomalies, particularities) with the in-flight S/C. It is the reference for in-detail analyses and trouble shooting, containing
  - Pertinent S/C subsystem information like actual hard and soft limits, relation between parameters, important values and their interpretation, etc.
  - Basic contingencies in case of downlink/uplink loss.
  - Tables for link analysis (S/C-ground antenna gain, VSO frequencies, thresholds).
  - Information about routine experiment operations (automatic calibration cycles, trigger commands, commanded calibration, critical temperature, current and high voltage exceedings)
  - In-flight measured power consumptions

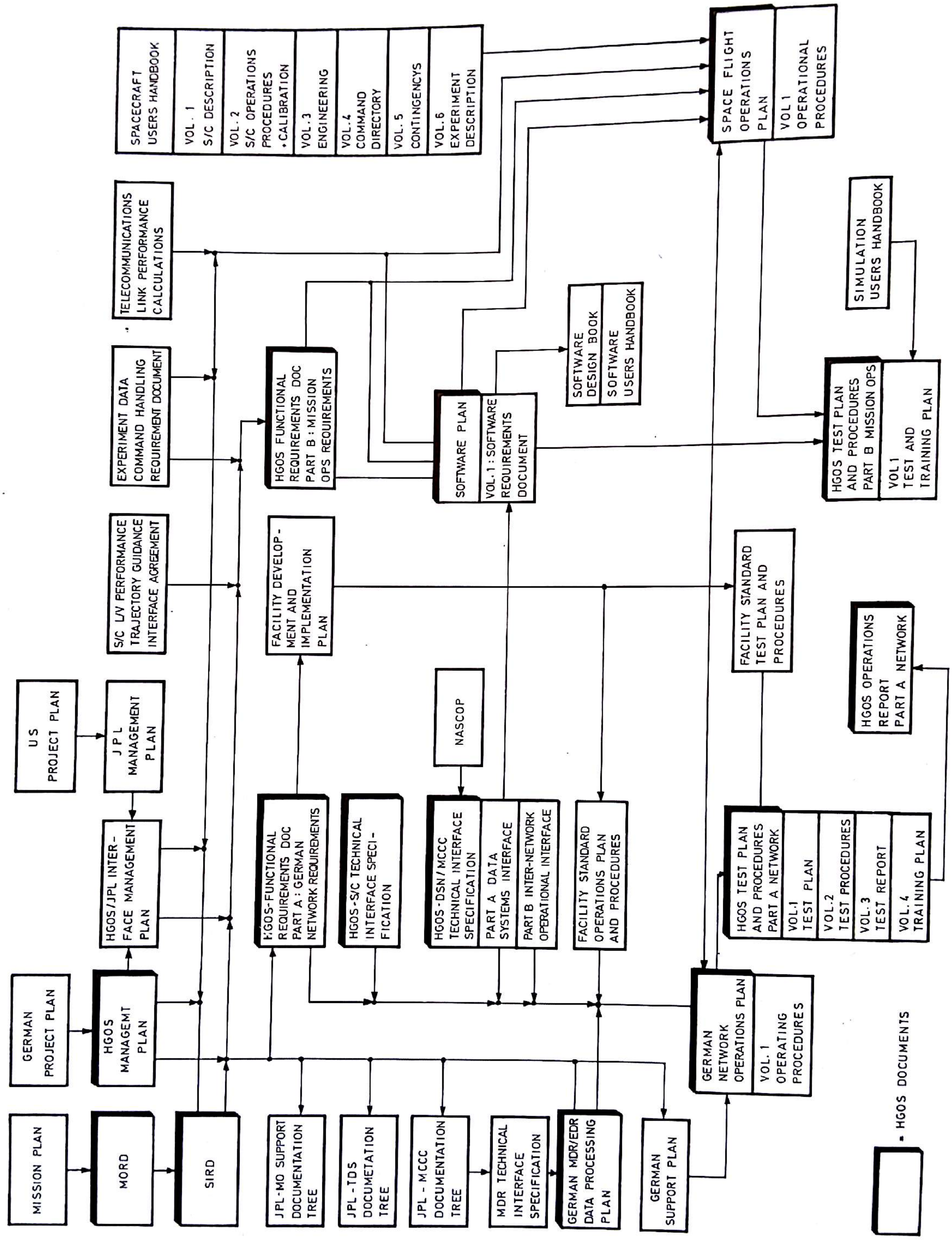


Figure 1.5-1: HGOS Documentation Tree

DFVLR
GSOC

- GROUND RULES FOR HELIOS S.O.E.
  This document was also created after launch when the actual behaviour of the S/C and demands of the experimenters became known step by step. It contains:
  - Standard D/H Sequences (accommodated to the experimenter desires)
  - Rules for using the different modes (memory operation, formats, bitrates, etc) and summarizing all detected constraints.
  - Special configuration tables for each experiment (taking the mission point into account)
  - Tables summarizing the daily science requirements
- FLIGHT OPS MANUAL
  This document was created right before launch and intended to concentrate the information provided in the S/C USERS MANUALS (7 VOLUMES) and SOFTWARE REQUIREMENTS DOCUMENT (1 VOLUME) into 1 Volume to use it as a kind of directory for the initial flight operations.

  This manual contained (arranged in subsystems and experiments):
  - Command Matrix with identified applicable subsystem commands.
  - Simplified Block-Diagrams of each subsystem, command function and telemetry information.
  - Listing of all subsystem commands with execution checks, special constraints (in BOOLEAN Logic), and display identification.

2 HELIOS MISSION OPERATIONS TEST AND TRAINING

2.1 OBJECTIVES

The objectives of the HELIOS Mission Operations Test and Training program were:

— To familiarize mission operations personnel with the equipment, software, data formats, facilities, and interfaces to be used during mission operations
— To train mission operations personnel in executing flight operations sequences and operational procedures
— To train all mission operations personnel (JPL and GSOC) to act as an integrated team

2.2 SCOPE

To achieve the goal of the test and training program the training was conducted twofold:

— Fundamental training at GSOC utilizing an Engineering HELIOS S/C Model (located at Weilheim)
— Operations training at JPL utilizing a computerized Mathematical S/C Model (MATH MODEL).

2.3 RESPONSIBILITY

GSOC personnel (Flight Operations PE) who performed, during flight operations, the function of a Chief of Space Flight Operations (CSFO; at JPL: HEOPS) was responsible for the planning and conduct of the training activities throughout all training phases.
For each training exercise the Flight Ops. PE had to:

— Provide the detailed procedure to be used during the exercise
— Define specific simulation requirements, i.e.: initial conditions, S/C parameters, prescheduled anomalies, network requirements.
— Conduct pre-test briefings
— Conduct post test reviews

2.4 TRAINING AND TEST PLAN

Since Mission Operations personnel at GSOC as well as Mission Operations personnel at JPL had to be trained, the following test- and training program was conducted:

2.4.1 TRAINING AT GSOC

— Lecture series
Classroom sessions and demonstrations for all personnel involved in HELIOS Operations regarding Spacecraft System, Mission Operations System and Ground Data System.
— Participation in „Ground-Data-System-Tests" and „Inter-Network Operational Verification Tests".
— Operational Compatibility Tests
Tests to verify the compatibility between the HELIOS Spacecraft (Engineering Model) and all elements of the German HELIOS Ground and Operations System

including mission software and procedures.
- Mission Operations Training
  Exercises utilizing the German Ground Data System and the Engineering Model S/C to train mission operations procedures and sequences.
- Passive participation in JPL - training exercises (see below)
- Mission Control Transfer Verification Test (see below)

The German prime-mission operations personnel departed from Germany after it had gathered basic experience during Mission Operations Training -exercises in mid - July 1974 to continue training exercises at JPL according to the program listed below, whereas the remaining personnel at GSOC continued the training as indicated above. Some parts of the training at GSOC were repeated during Aug. - Oct. 1974 for the benefit of new personnel.

2.4.2 TRAINING AT JPL

- Lecture series
  Classroom sessions and demonstrations for U.S.- and German personnel involved in HELIOS operations concerning U.S. Ground Data System, DSN-Network, Mission Operations System (U.S.) and Spacecraft System.
- Mission Operations Training with Mathematical S/C - Model:
  - Intra-Team Training: Familiarization of each operations team separately with its resources and procedures.
  - Inter-Team Training: Joint exercise of all operations teams without ground station support in basic mission operations sequences and procedures.
  - Combined Training: Joint exercise of all operations teams together with ground stations in the basic mission operations sequences and procedures
- Spacecraft/Ground Operations System End-to-End Test:
  This test was performed with the HELIOS-A Flight Spacecraft located at KSC and all operations teams at GSOC and JPL. Data were routed from the S/C to JPL and GSOC and processed at both locations in order to verify compatibility between the Flight Spacecraft and the Ground Operations System.
- Operational Demonstration Tests (ODT):
  The ODT's have been conducted to verify the capability of all operational elements to support launch, maneuver and cruise phase of the HELIOS mission. The tests were performed under flight-phase equivalent conditions. Simulated „surprise"-anomalies and failure conditions were introduced into various systems during the following series of exercises:
  - Launch Phase Test
  - Step II Coarse-Maneuver Test
  - Step II Fine-Maneuver and Nozzle Calibration Test
  - Launch to Cruise Phase Test
- Mission Control Transfer Test:
  This test was a joint JPL-GSOC exercise to verify GSOC readiness to take over mission control from JPL. This test was performed utilizing the Mathematical S/C-Model.
- Operational Readiness Test:
  With this test the launch readiness of the total Ground- and Mission Operations System was demonstrated.

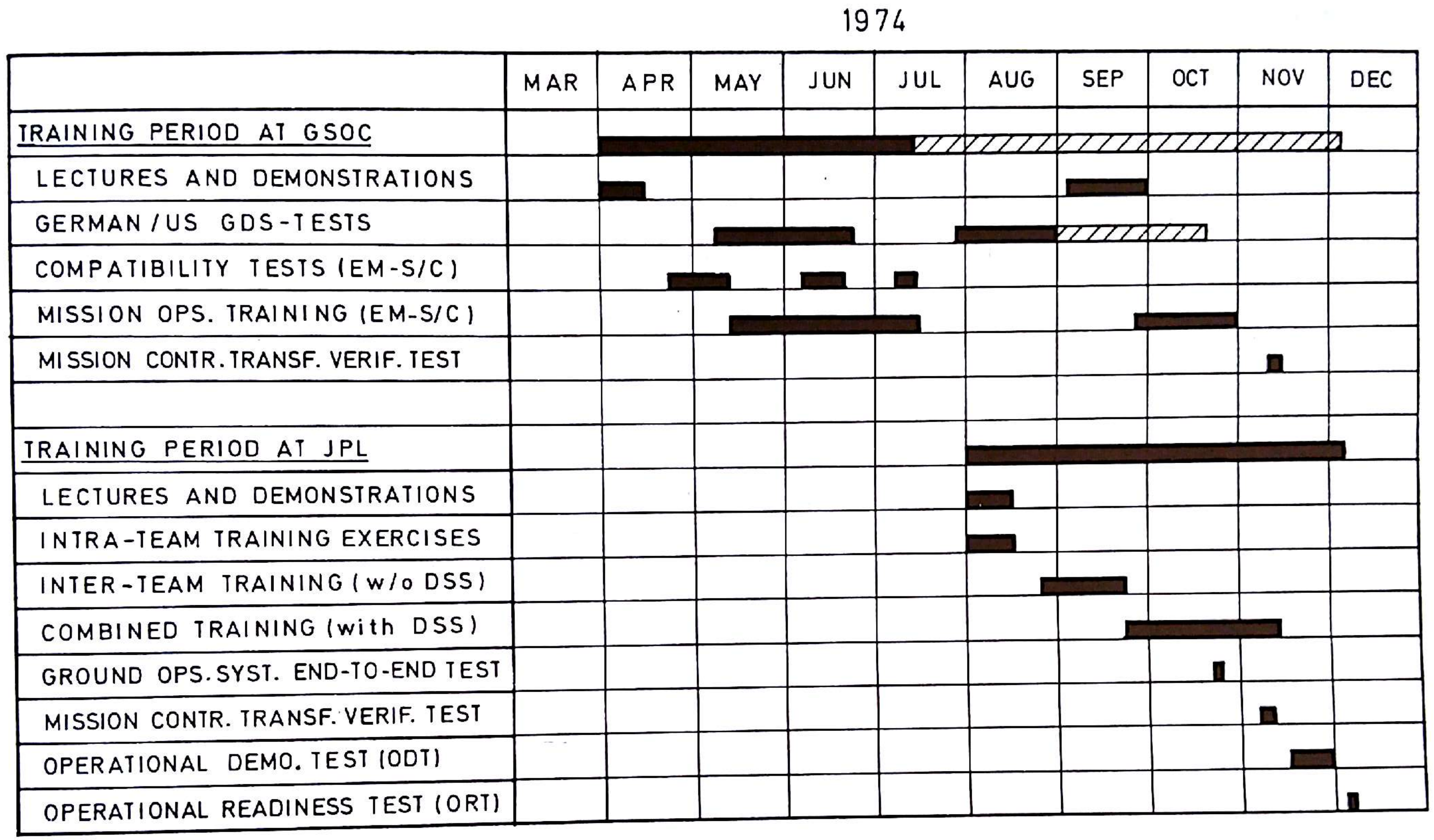


Figure 2.5-1: HELIOS-A Test and Training Schedule

2.5 TEST SCHEDULE

A time line spelling out how the different flight operations teams were formed and distributed between GSOC and JPL is shown in *Fig. 2.5-2.* A summary of the total HELIOS-A Mission Operations Test- and Training program schedule is given in *Fig. 2.5-1.*
Since the most important part of the training has been the mission operations training with the Mathematical S/C-Model at JPL, a detailed listing of all training activities at JPL is listed in *Tablê 2.5-I.*

2.6 OBSERVATION AND EXPERIENCE

Numerous lessons have been learned from the HELIOS Test- and Training program. The undoubtedly most important experience was the knowledge that the training was absolutely necessary in order to prepare operational procedures and sequences to train operations people and to gain experience with operations systems.
However the training with the Mathematical S/C-Model revealed various problems. Since the performance of the mathematical model depended very much on the accuracy and quality of the initial input parameters and the initialization procedure, the operational behaviour of the model very often was not as expected, especially in the beginning of the JPL - training period, when math. model software and the telemetry data processing software were not yet completely debugged. Very often it was hard to find out if an erroneous condition was caused by a failure in the mathematical model or in the telemetry software or both. Due to such malfunctions of the mathematical model the objectives of various test- and training exercises could not be achieved and the exercises had to be repeated. This happened very often especially in exercises concerning the HELIOS attitude maneuvers. But in summary the training with the mathematical S/C model was very helpful especially for mission sequence training.
On the other hand, the training with the Engineering Model S/C at GSOC was an excellent method to check out system readiness and to exercise procedures. But exercises of mission sequences were possible only to a certain extent, for example, no maneuver training was possible.
Very good experience could be gathered with combined JPL-GSOC training exercises utilizing the Mathematical S/C Model at JPL. Data were routed from JPL to GSOC and commands were sent from GSOC to the mathematical model at JPL using the RIC interface. This technique was used with good results for the „Mission Control Handover Test".
Also a very important test was the Spacecraft/Ground Operations System End-to-End Test to verify the compatibility of all elements on ground, especially software with the live flight-spacecraft. Numerous errors and problems could be discovered during this test.
Other experiences out of this whole training complex were:

- The establishing of the S/C SUBSYSTEM TEAM 1 8 months before launch *(see Fig. 2.5-2)* was too early. It was initially planned to establish this team 6 months before launch, but a 2 months time delay was introduced by the shift of the originally planned launch date. Six months before launch neither the R/T software was operational nor the training devices were available (EM, MATH MODEL).
- The 3 months period for the training of the CONTRACTORS (Command Operators) was sufficient.
- The effect of general lectures is too little, because of the number of people involved and their different background. It has turned out, that it is better to:
  - Assign specific tasks during the training period
  - Perform specialized training sessions in smaller groups (separate the different teams) and let the people rework the lectures by answering issued questions in writing between the sessions („home work").

- The ON-LINE training has to be built up gradually by:
  - First using flight sequences
  - Then, when the confidence (or nonconfidence) in the system is established, non flight representative sequences shall be used, where every subsystem expert is involved throughout the test by planned anomalies and varying command sequences during the test.

    The danger of using real flight sequences at this stage is, that it involves only one subsystem (attitude maneuvers) and the rest of the SUBSYSTEM EXPERTS is getting bored. Only the last tests before launch shall use actual flight sequences with planned anomalies (except the Operational Readiness Test).

HELIOS MISSION OPERATIONS TEST & TRAINING AT JPL

DATE	DURATION	TEST & TRAINING		DSN—SUPP.	GSOC-PART.
22-26.7	5x8 H	TLM—S/W Perf.Demo Tests		n.a.	
30. 7.74	7 H	Intra-Team-Training I		n.a	
1. 8.74	7 H	Intra-Team-Training II		n.a	
2. 8.74	4 H	x NEPH Data Flow Test PT-MCCC-GSOC		n.a.	yes
5. 8.74	10 H	x END-TO-END Test PT-MCCC-GSOC		n.a.	yes
9. 8.74	8 H	Intra-Team-Training III		n.a.	
14. 8.74	8 H	Intra-Team-Training IV		n.a.	
21. 8.74	8 H	x Phase III TLM-S/W Perf. Demo Test I		n.a.	
23. 8.74	8 H	x Phase III TLM-S/W Perf. Demo Test II		n.a.	
27. 8.74	8 H	Launch Phase Test -a-	(+)	-	partly
29. 8.74	8 H	x Math.Model Perform.Demo Test I		n.a.	
3. 9.74	10 H	x Math.Model Perform.Demo Test II		n.a.	
6. 9.74	8 H	Launch Phase Test -b-	(+)	-	
10. 9.74	10 H	Step II Man./HGA Pointing Test -a-	+	-	partly
13. 9.74	10 H	Step II Man./HGA Pointing Test -b-	+	-	partly
18. 9.74	8 H	Nominal Launch Phase Test	(+)	71 only	partly
20. 9.74	10 H	x Step II Man./HGA Point.Test -b- Retest 1	+	-	
24. 9.74	8 H	x Nominal Launch Phase Test -Retest 1-	+	71/42	
26. 9.74	8 H	x Math.Model Perform.Demo Test III		n.a.	partly
27. 9.74	10 H	x Step II Man./HGA Point.Test -b- Retest 2	+	12	partly
3.10.74	8 H	x Math.Model Perform.Demo Test IV		n.a.	
7.10.74	8 H	Nozzle Calibr./Step II Coarse Man.Test	(+)	12	
10.10.74	8 H	Step II Fine Man./HGA Pointing Test	(+)	12	
16.10.74	8 H	x Nozzle Calibr./Step II Coarse Man.T-Retest-		12	
17.10.74	8 H	x Step II Fine Man./HGA Point.Test -Retest-		-	
22.10.74	48 H	Launch-to-Cruise-Phase Test		71/42/62	yes
28.10.74	24 H	x F1-END-TO-END-Test: F1 MCCC-GSOC		71	yes
1.11.74	7 H	x Launch Phase Test -Retest 2-		71/42	partly
8.11.74	18 H	MISSION CONTROL TRANSFER TEST		61/GTS	yes
13.11.74	8 H	NOT-Nominal Launch Phase Test		71/42	partly
15.11.74	8 H	Step II Fine Man. ODT		12	yes
19.11.74	9 H	Launch Phase ODT		71/42	yes
21.11.74	9 H	Step II Coarse ODT		12	yes
26/28.11.	56 H	Launch-to-Cruise ODT		71/42/62/12	yes
4.12.74	11 H	ORT		71/42/44/62/ 11/12	yes
Total:	436 H				

x Originally not scheduled
\+ Test objectives not achieved

Table 2.5-I: HELIOS Mission Operations Test and Training Plan

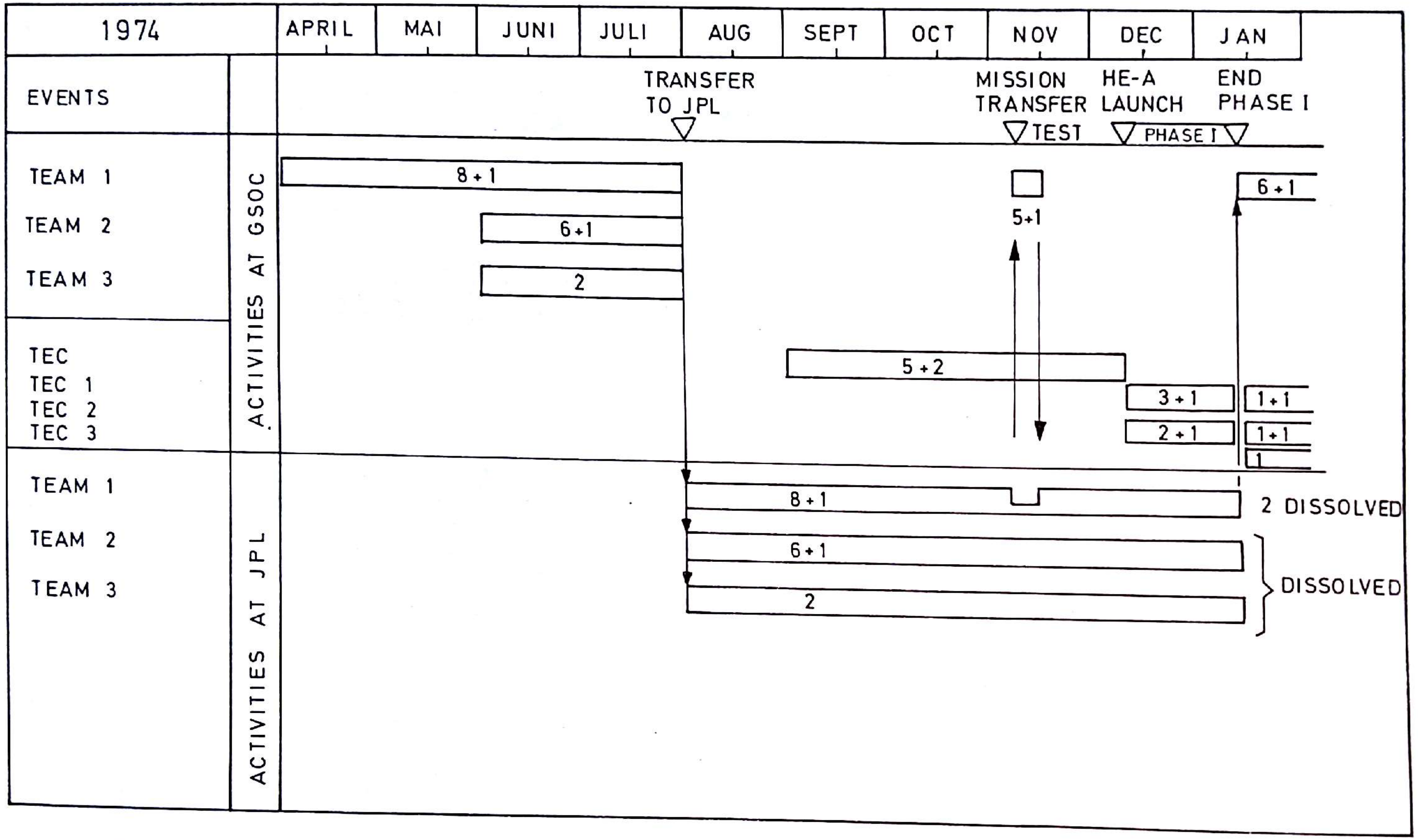


Figure 2.5-2: HELIOS-A Time Line for Establishing of the S/C Performance Analysis Teams

Annotations for the Time Line Establishing the S/C Performance Analysis Teams *(Fig. 2.5-2)*

As shown in the figure it can be distinguished between TEAMS 1,2,3 and the TEC-teams.
The TEAMS 1,2 and 3 consisted of S/C subsystem experts (one per subsystem in each TEAM) while the TEC-teams were composed of routine operators and GSOC teamleaders.

The concept was that TEAMS 1,2 and 3 had to perform the initial operations at JPL, while the TEC-teams rended back-up support during that time at GSOC and got prepared for taking over the responsibility after transfer of Mission Operations to GSOC. At the end of Phase I TEAMS 2 and 3 were dissolved while TEAM 1 and the TEC-team members carried on the routine mission operations up to now.

Of course during the 3—5 year lifetime of the HELIOS-A probe those teams got reduced further.
The current status is:

- Fife TEC-team members carrying out 24 hr Command Operations (one engineer per shift)
- Four TEAM 1 members performing the S/C sequencing and S/C analysis job in two shifts

for HELIOS-A and B simultaneously.

The numbers within the bars of *Fig. 2.5-2* indicate the number of persons plus the teamleaders.

3 CONTROL FACILITIES

3.1 HELIOS GROUND DATA SYSTEM

The HELIOS Ground Data System (HGDS) is a combination of the U.S. Ground Data System and the German Network. The U.S. Ground Data System is a combination of the Near-Earth Phase Network (NEPN) and the Deep Space Network (DSN) with 26m/64m stations located at California, Spain and Australia. The German Network consisted of a 30m Transmit Antenna at Weilheim and a 100m Receive Antenna at Effelsberg. *Figure 3.1-1* illustrates this configuration as interfaced to the German Control Center at Oberpfaffenhofen.

3.1.1 HELIOS GROUND DATA SYSTEM SUPPORT FUNCTIONS

The HELIOS Ground Data System support functions characterized by Network Systems and Station/Control Center are:

3.1.1.1 MISSION DATA

Tracking System: Generates radio-metric data i.e. angles, Doppler, range and transmits raw data to Mission Control *(Table 3.1-I)*.

Function	Performed by				
	Station			Control Center	
	DSS	GES	GTS	JPL	GCC
Point the antenna; set XMTR and RCVR freq.	X	X	X		
Transmit S-Band Uplink	X		X		
Acquire S-Band Downlink	X	X			
Generate observables (Doppler, Range, Angles)	X				
Time tag data	X				
Log metric data taken	X				
Format and transmit to Control Center	X				
Accept metric data blocks				X	
Decommutate metric data				X	
Generate data record entry				X	
Merge new entries into data record				X	
Manipulate metric data as required by Ops.Group				X	
Generate pseudo-residuals				X	
Transmit messages to stations (i.e. freq.changes, sample rate changes, etc.)				X	X
Generate station predicts and transmit to station				X	X
Provide display of validation data to Ops.Group				X	
Orbit determination during all mission phases				X	
Transmit Orbital Elements to Germany				X	
Provide orbit data for EDR entry				X	X

Table 3.1-I: Requirements and Functions: Tracking System

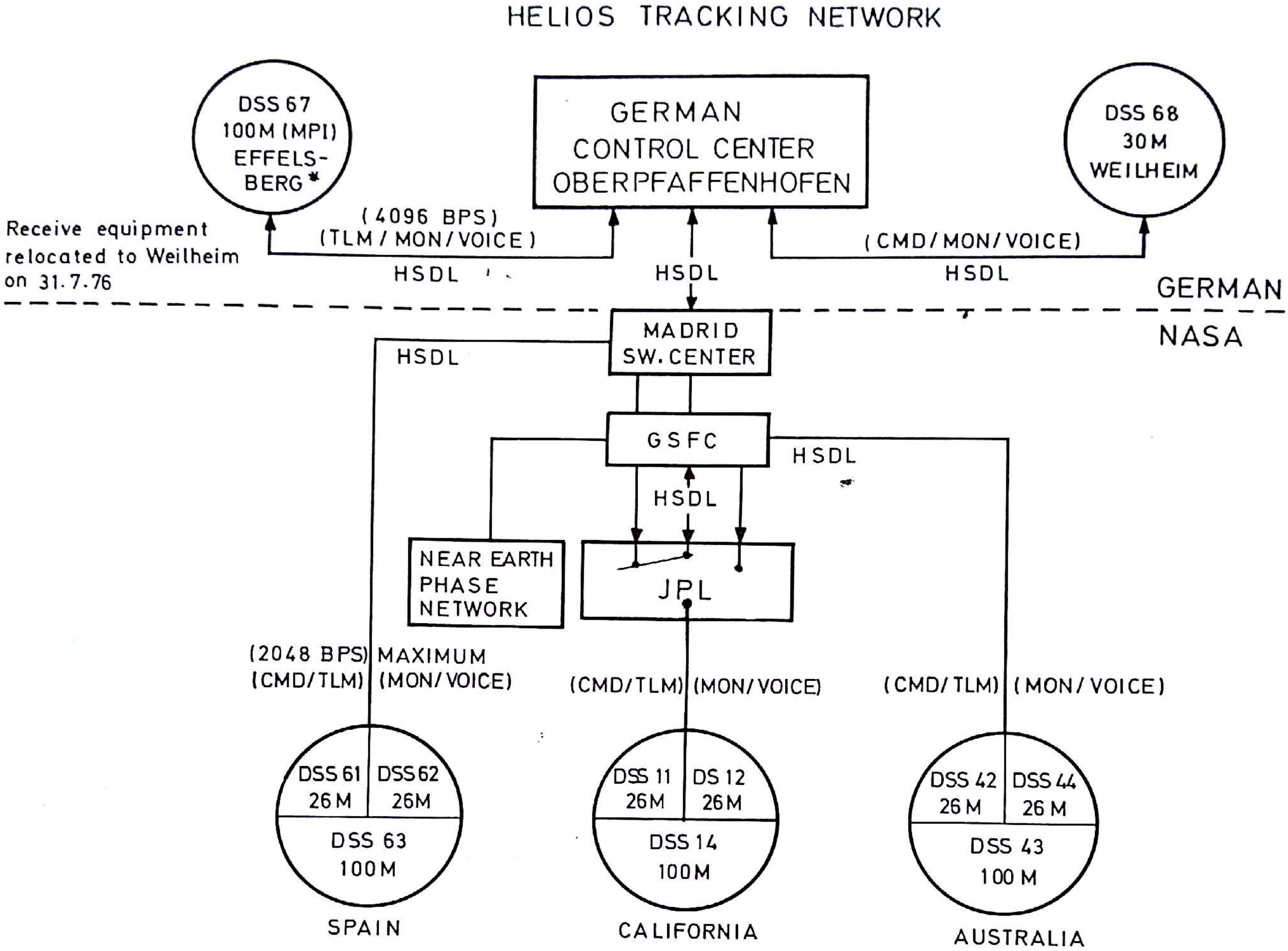


Figure 3.1-1: HELIOS Ground Data System

DFVLR
GSOC

Telemetry System: Receives, decodes, records and retransmits engineering and scientific data generated in the spacecraft to Mission Control *(Table: 3.1-II)*

Function	Performed by				
	Station			Control Center	
	DSS	GES	GTS	JPL	GCC
Receive RF carrier and separate subcarrier	X	X			
Demodulate subcarrier and detect bit stream	X	X			
Frame synchronize coded or uncoded data stream		X			
Decode convolutional coded data stream	X	X			
Time tag data	X	X			
Make a digital ODR of all received TLM data	X	X			
Format and transmit TLM data to Control Center	X	X			
Replay ODR's	X	X			
Accept TLM Blocks				X	X
Log data				X	X
Frame synchronize incoming data				X	
Data stream selection				X	X
Generate data record entry				X	
Decommutate TLM stream				X	X
Standard Processing (DN to EU conversion)				X	X
Special Processing				X	X
Display TLM data				X	X
Provide TLM data for MDR entry				X	X
Merge recalled data				X	X
Provide the station with selected S/C TLM parameters (or instructions for station ops.)				X	

Table 3.1-II: Requirements and Functions: Telemetry System

Command System: Accepts coded signals from Mission Control and transmit them to the spacecraft in order to initiate spacecraft functions in flight. *(Table: 3.1-III)*

Function	Performed by				
	Station			Control Center	
	DSS	GES	GTS	JPL	GCC
Accept input of CMD's and control directives				X	X
Manual CMD entry in alphanumeric form; safe-guarded against restricted commands				X	X
Manipulate command data				X	X
Translate commands				X	
Format for message transmission				X	X
Transmit messages to station or from RCC to MCCC				X	X
Remote Control Center (RCC) input/output processing				X	X
Log data				X	X
Display command data				X	X
Provide command data for MDR entry				X	X
Merge recalled data				X	
Accept command messages from Control Center	X		X		
Verify receipt of command messages	X		X		
Translate commands			X		

Function	Performed by				
	Station			Control Center	
	DSS	GES	GTS	JPL	GCC
Transmit commands to S/C	X		X		
Confirm transmission	X		X		
Manual command entry in alphanumeric form			X		
Manual command entry in octal form	X		X		
Make a digital ODR	X		X		

Table 3.1-III: Requirements and Functions: Command System

3.1.1.2 MISSION AND NETWORK TESTING

Simulation System: Generates and controls simulated data to support development, test, training and fault isolation within the network. Participates in mission simulation with Flight Projects. *(Table: 3.1-IV)*

Function	Performed by				
	Station			Control Center	
	DSS	GES	GTS	JPL	GCC
Generate calibration data for support of station internal integration testing	X	X			
Accept simulated TLM data and associated control data from Control Center	X				
Provide simulation data conversion	X				
Accept and process simulated commands	X				
Simulate time	X				
Accept and process operational commands during testing and training periods			X		
TELEMETRY DATA SUBSYSTEM:					
Generate calibration data for support of GDS integration and testing				X	X
S/C Model to generate static, manually adjustable values					X
S/C Model to generate dynamic, predefined ramps					X
S/C Model to generate command-responsive engineering data and fixed science data					
Simulate station TLM processing functions				X	
COMMAND DATA SUBSYSTEM:					
Simulate station CMD processing functions				X	
Simulate station CMD system response					X
Distribute CMDs to the S/C model				X	X
TRACKING DATA SUBSYSTEM:					
Simulate station TRK processing functions				X	

Table 3.1-IV: Requirements and Functions: Simulation System

3.1.1.3 NETWORK OPERATIONS CONTROL AND MONITOR

Operations Control System: Provides operational direction and configuration control of the network and primary interface with Flight Project mission control personnel. *(Table 3.1-V)*

Function	Performed by: Control Center JPL	Performed by: Control Center GCC
Control and coordinate network operations	X	X
Compare and evaluate network status	X	X
Obtain Flight Project status and performance criteria	X	X
Provide network status to Flight Project	X	X
Determine possible course of action	X	X
Update operations plans	X	X
Allocate network resources	X	X

Table 3.1-V: Requirements and Functions: Ops.Control System

Monitor System: Instruments, transmits, records and displays those parameters of the network necessary to verify configuration and validate network status and performance. *(Table 3.1-VI)*

Function	Station DSS	Station GES	Station GTS	Control Center JPL	Control Center GCC
Monitor subsystem status (configuration, mode, operational status)	X	X	X		
Use criteria data for alarm processing	X	X	X		
Display monitor data and alarms	X	X	X		
Time tag data	X	X	X		
Format & transmit data to Control Center	X	X	X		
Log data	X	X	X		
Monitor Telecomm link parameters, such as signal strength, system noise temp, etc.	X	X	X		
FACILITY FUNCTIONS:					
Comunications system configuration				X	X
Computer & peripherals processing/ interface status				X	X
Local display				X	X
Data transfer				X	X
Log data				X	X
Alarm generation				X	X
NETWORK FUNCTIONS:					
Receive facility monitor data & generate data summaries				X	X
Display data				X	X
Log data				X	X
Analyze monitor data				X	X
Generate criteria data				X	X

Table 3.1-VI: Requirements and Functions: Monitor System

3.1.2 HELIOS GROUND DATA SYSTEM SUPPORT

The combined U.S./German tracking network facilities ensured 24 hours/day coverage and were available during the primary phase of the HELIOS mission.
Figure 3.1-2 shows the total tracking support provided from January 75 through July 76.
A distinct advantage of the NASA network was its capability of being able to range the spacecraft and provide metric data used for orbit determination. In addition, the 64m antenna (DSS 14) could also provide a maximum uplink power when required of up to 400 kW whereby the rest of the combined U.S./German Network was limited to 20 kW.

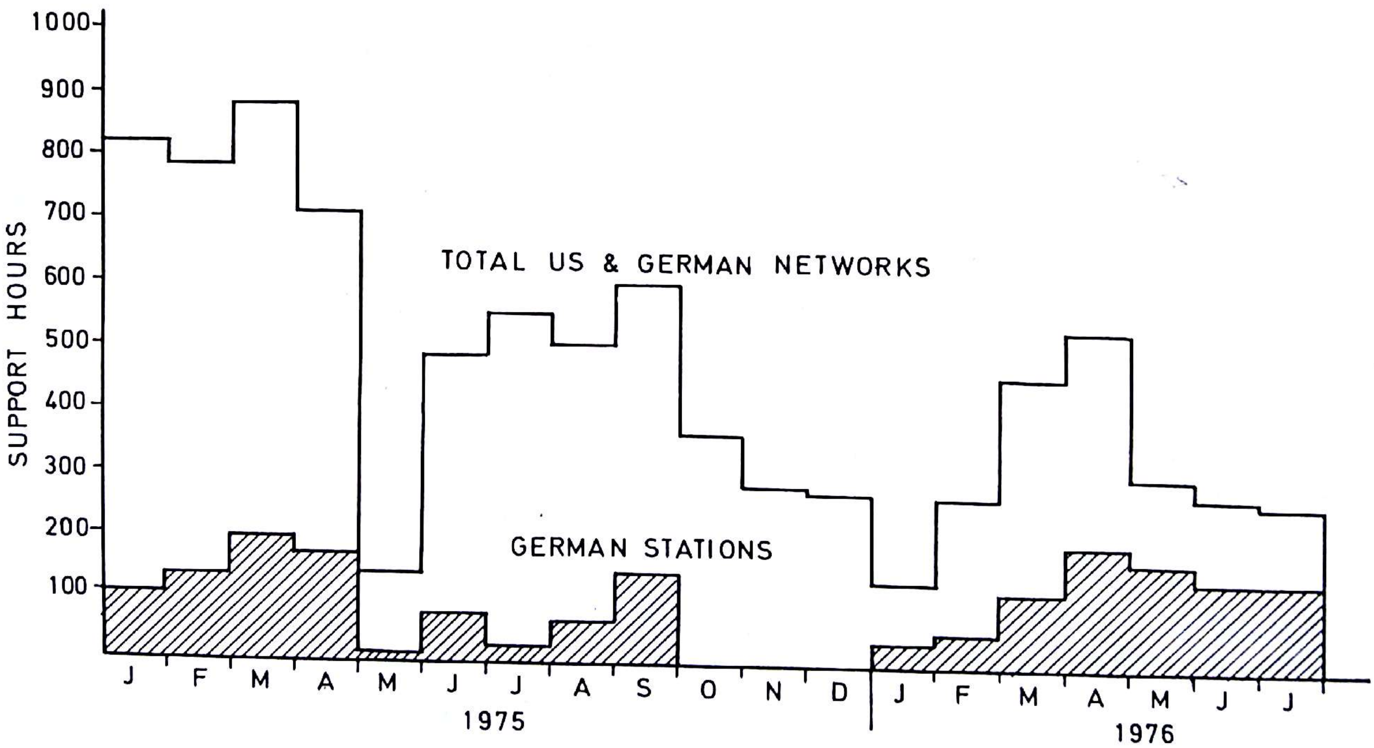


Figure 3.1-2: HELIOS Ground Data System Support

3.1.3 INTERNETWORK SCHEDULING

Scheduling of the combined U.S./German Networks in support of the HELIOS mission was a joint effort on behalf of the U.S./German support personnel. The prime interface between the two networks was the NOC PE (German Network) and the CMS (JPL). *(Refer to Fig. 3.1-3).*
The Scheduling Office at GCC (NOC SCHED) received from JPL on a routine basis, combined JPL mission utilization plans and extended mission forecasts that outlined tentative Deep Space Stations (DSS) support of the various JPL supported missions. This information, though tentative, plus the forecasted support of the German Network was plotted graphically to indicate the combined internetwork forecast for the HELIOS mission.
On Thursday of each week, the JPL HELIOS support schedule (final) plus one week forecasted was received via HSD text data. This schedule was compared with the forecast received the previous week and a multi-mission support schedule for the upcoming week was generated by NOC SCHED. Because all HELIOS schedule inputs for the upcoming week must be available to NOC SCHED on Thursday at the start of the work day, the JPL HSD schedule must be received by GCC not later than 0700 GMT on Thursday. On numerous occasions, the JPL generated HELIOS schedule/forecast had not been ready for transmission to GCC on-time and on some occasions a JPL project sort was transmitted for Viking or Pioneer in lieu of the HELIOS schedule. This plays havoc, not only on NOC SCHED, but also on the Project which must then rely on the forecast for the upcoming week. This has proven inadequate for scheduling purposes due to numerous last minute changes caused by change in support priorities. To compound this problem, it was then decided by JPL to change the requirement for HSD transmission of the JPL schedule from Thursday 0100 to Friday 0100 GMT. To assist NOC SCHED, CMS agreed to transmit via TTY a HELIOS Tracking Schedule vs. DSN Forecast Message which would list the changes in the upcoming week's final schedule with respect to the forecast received the previous week. It has been found that the changes indicated are valid for DSS supporting station and HELIOS S/C number, but one cannot rely on the AOS/LOS times. It must be said that the message is of value but the final schedule received via text is the final say and therefore is preferred.
Also on Thursday of each week, NOC SCHED conducts a GCC-internal scheduling meeting to compile all other GCC/other Mission Requirements for the upcoming support week and to resolve any conflicts that may remain. On the following morning, Friday, NOC SCHED will publish and distribute the final GCC Multi-Mission Schedule for the upcoming week.
On Monday of each week, a meeting is held between NOC SCHED and the HELIOS Project to review the forecasted support week and to ascertain adequate coverage and configuration requirements. When all aspects have been discussed and alternatives agreed upon for those areas that are in conflict, the next item for discussion is the preparation of the German Network 9th week advance forecast request message. This requirement is necessary to ensure that the use of the MPI 100m antenna will be available for HELIOS support.
Upon completion of the meeting by NOC SCHED with the HELIOS Project, NOC SCHED will then generate a TTY message to the CMS, designated „DSS Schedule Request Message", approving or disapproving the JPL forecasted support schedule. In addition, comments are provided that include suggested changes/additions to the forecast, plus the German Network final schedule for the upcoming week and the following week forecast is included.
Summary: The system of scheduling as performed by both networks is a working system, but it takes considerable effort on both sides.

SCHEDULING - HELIOS MISSION	WEEK 1							WEEK 2	WEEK 3	WEEK 9
	Mo	Tu	We	Th	Fr	Sa	So	Mo … So	Mo … So	Mo … So
GES/MPI ANTENNA REQUEST										
Scheduling meeting - NOC SCHED/CSFO	1300 ▽									
NOC SCHED send antenna request to GES/MPI via TTY			2000 ▽							TENTATIVE SCHEDULE
GES/MPI send antenna request reply to NOC SCHED via TTY								1200 ▽ FRIDAY		
GERMAN NETWORK GTS/GES										
Scheduling meeting - NOC SCHED/CSFO	1300 ▽									
NOC SCHED send final schedule plus 1 week forecast to GTS/GES via TTY			2000 ▽					FINAL SCHEDULE	FORECAST SCHEDULE	
DSN SUPPORT SCHEDULE										
Scheduling meeting - NOC SCHED/CSFO	1300 ▽									
NOC SCHED send schedule request to CMS via TTY		2000 ▽								
CMS send DSN schedule response to NOC SCHED via TTY				0600 ▽						
CMS send final DSN support schedule plus 1 week forecast via HSDL					0100 ▽			FINAL SCHEDULE	FORECAST SCHEDULE	

Figure 3.1-3: Timing Table for the weekly Network Schedule

3.1.4 INTERNETWORK FREQUENCY PREDICTIONS

The HELIOS Project S/C personnel, according to the internetwork agreement, were responsible for providing the predicted HELIOS S/C VCXO & VSO frequencies in the predict generation teams of both networks. This information, published weekly, for the period of two weeks in advance, is utilized in generation of the tracking predicts of both networks.
This function, for the past year, has been handled by the Network Operations Control (NOC) personnel at GCC as it was felt that the individual responsible for the actual predict generation could provide a more accurate assessment of the current versus predicted frequencies. Plotting of the predicted versus actual VSO frequency for the past year indicates that the average actual VSO frequency is within 1 kHz of the predicted and during the past 6 months, within 500 Hz. This difference is gradually being reduced as more data is compiled and plotted.
Due to the numerous variables that can cause a change in the VSO frequency it is extremely difficult to predict 2 weeks in advance what the actual frequency will be. A few of the most common items occuring are: Increase in internal temperature caused by the sun, increase/decrease in temperature caused by S/C-internal heater cycling (most difficult to predict), S/C deterioation and configuration of the S/C by the Project. All of these items can drastically change the actual VSO frequency.
One peculiarity noted during the past two perihelions of HE-1 is that maximum frequency change (plus) is noted 2 to 3 weeks either side of perihelion and that the frequency decreases by approximately 1 kHz from this maximum at perihelion. This is the opposite from HE-2 where as the temperature increases, frequency follows. *(Reference Figure 3.1-4).*

3.1.5 GERMAN NETWORK SUPPORT

3.1.5.1 GENERAL

Figure 3.1-5 provides a block diagram of that part of the German network utilized for HELIOS support. The support functions characterized by Network systems and Station/Control Center are listed under *paragraph 3.1.1.1 through 3.1.1.3.* whereby it should be noted that GCC ist utilized 24 hours/day for Mission Control regardless which Network stations are supporting.

3.1.5.2 GERMAN NETWORK STATION SUPPORT

Though the German Network stations were not designated as mandatory for the HELIOS primary mission phase, the two stations nevertheless were used extensively. From HE-1 launch through 30 September 1975, this Network provided 880 hours of actual tracking support. (See also *Figure 3.1-2.).*
Although the Effelsberg 100m antenna was not specifically designed for support of scientific satellites, the HELIOS Project did have the capability, if required, to receive telemetry data at 4096 bps whereas the NASA Network, including the 64m Stations were limited to 2048 bps. It must be stated that though the 100 m antenna was capable of this higher bitrate, the actual downlink SNR was comparable to the 64m antenna.
As additional advantage the inclusion of the Effelsberg 100m antenna to support the HELIOS mission provided the HELIOS Project with a station that could not be lost at the last minute due to higher priority requirements of the other projects. This allowed the Project to make maximum use of the stations capabilities and to receive a maximum amount of downlink data. The support could therefore be planned well in advance by the Project.

DFVLR
GSOC

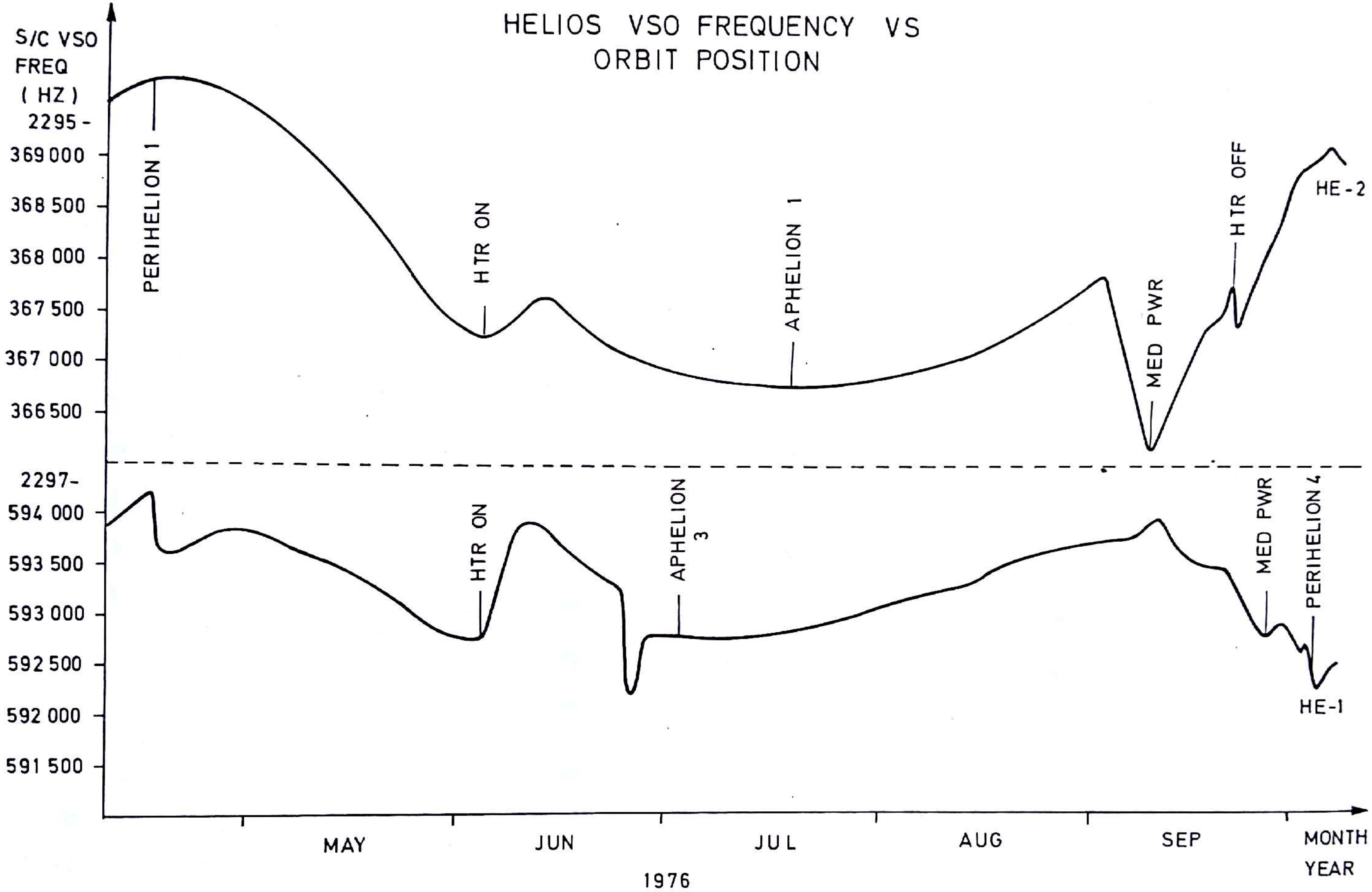


Figure 3.1-4: HELIOS VSO Frequency versus Orbit Position

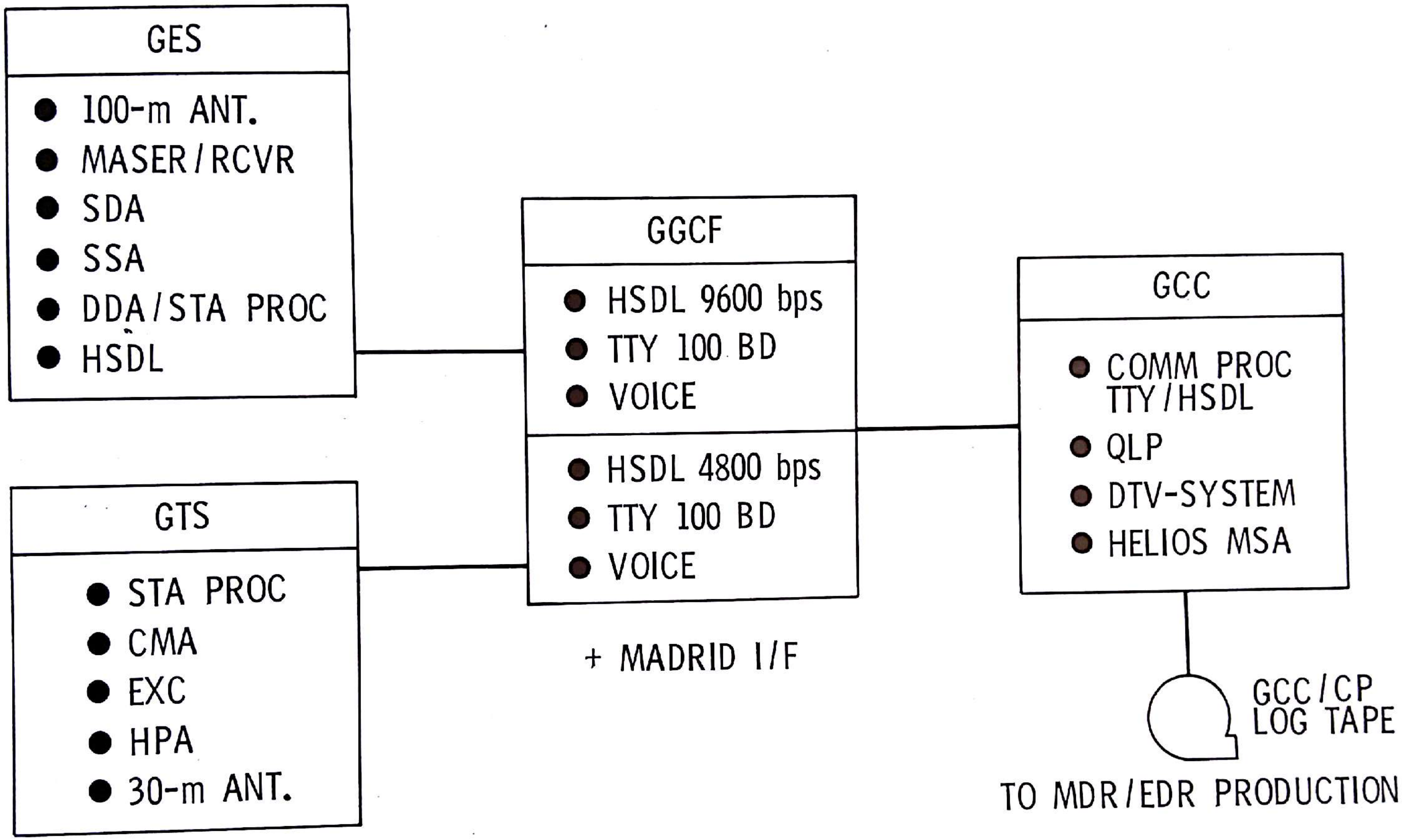


Figure 3.1-5: German Network Block Diagram

3.1.5.3 GERMAN NETWORK CONTROL CENTER SUPPORT

As mentioned previously, GCC was supporting the HELIOS mission on a 24 hour/day basis. *Figure 3.1-6* shows the average computer availability for the first 1 1/2 years of the HELIOS-A mission.

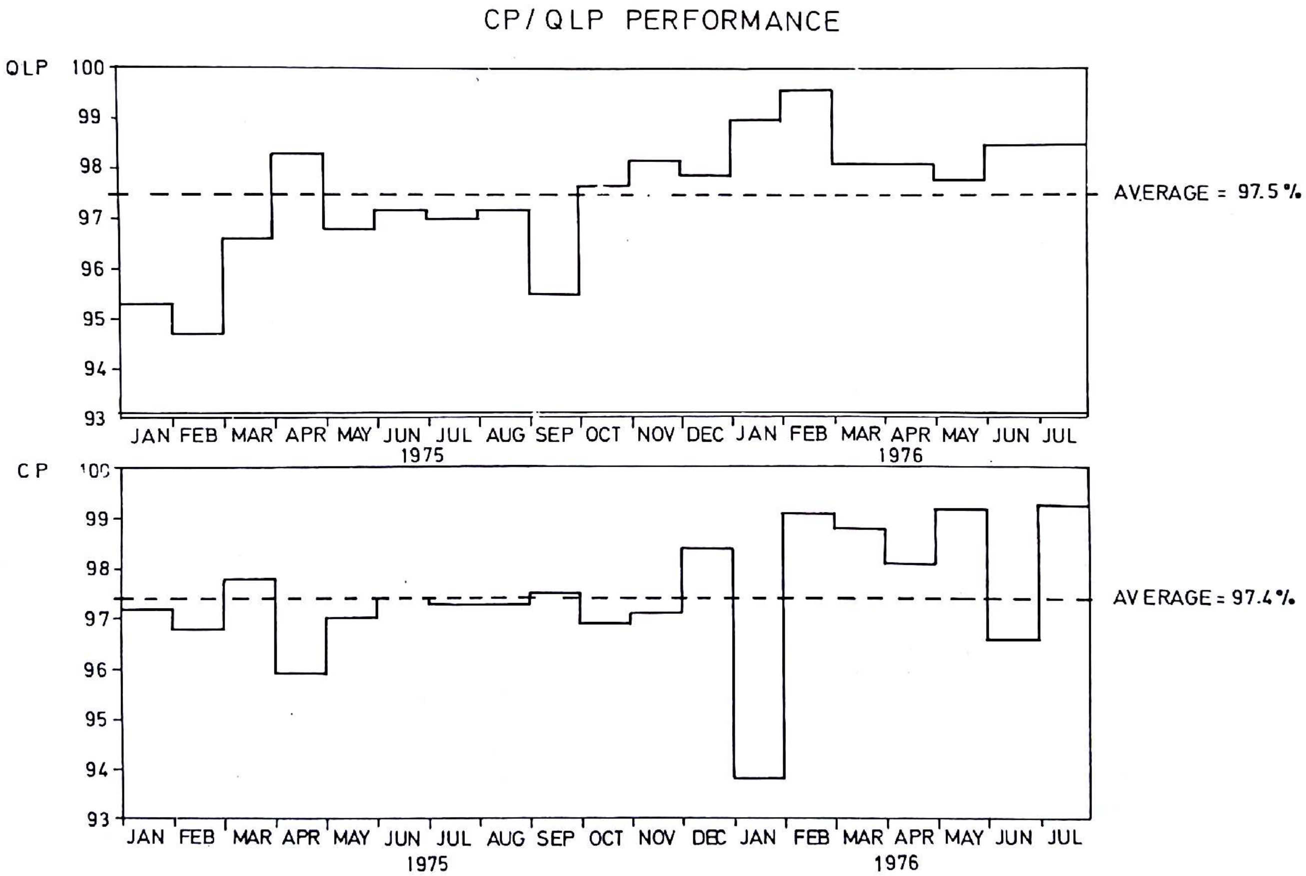


Figure 3.1-6: CP / QLP Performance for HELIOS

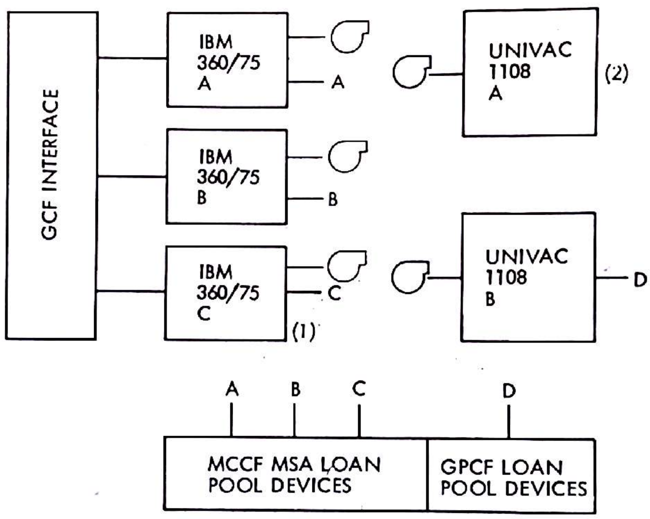
3.2 CONTROL CENTER

This paragraph describes the Control Center configurations, at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, and at DFVLR's German Space Flight Center (GSOC) in Oberpfaffenhofen near Munich, used to support the mission of HELIOS-A.

3.2.1 COMPUTER CONFIGURATIONS

3.2.1.1 JPL COMPUTER SYSTEM

The following block diagram *(Fig. 3.2-1)* shows the computer configuration committed to the HELIOS-A Project.



NOTE :

(1) USER TERMINAL EQUIPMENT IN THE MSA IS NORMALLY CONNECTED TO A UNIVAC 1108B, BUT CAN BE CONNECTED TO AN 1108A IF REQUIRED.

Figure 3.2-1: JPL Computer System

Prior to Mission Phase I, the IBM 360/75 computers were provided for software development, testing and training. Those computers were shared with other projects according to NASA priorities. During launch operations until after completion of the Step II maneuver a restricted 360/75 was provided, also a second 360/75 was provided as a hot backup during critical sequences. During normal mission phases, e.g. after end of Phase I the so called „Flight - 360" was used together with other projects - as it is today. The 360/75 computers are generally used for the following purposes:

- Realtime Telemetry Data Processing

- Command Data Processing
- Radiometric Data Processing
- Attitude Determination Programs
- Operations Control Tasks
- Various user Programs such as S.O.E. Program, Link Predictions etc.
- Simulation (Data Generator, Math. Model)
- MDR, EDR Processing

The UNIVAC 1108 Systems were used as OFFLINE machines for the following purposes:

- Orbit Determination
- Attitude Determination
- Sequence of Events Generation.

3.2.1.2 GSOC COMPUTER CONFIGURATION

The following blockdiagrams *(Fig. 3.2-2 and 3.2-3)* show the computer configuration committed to the HELIOS-A project.
Fig. 3.2-2 shows the four (4) computers and their use for the project.
Fig. 3.2-3 gives details about the prime realtime processing system. A limited backup support was provided by a Honeywell 516 computer (Media Conversion Processor) which generated near-realtime printouts of the engineering data.

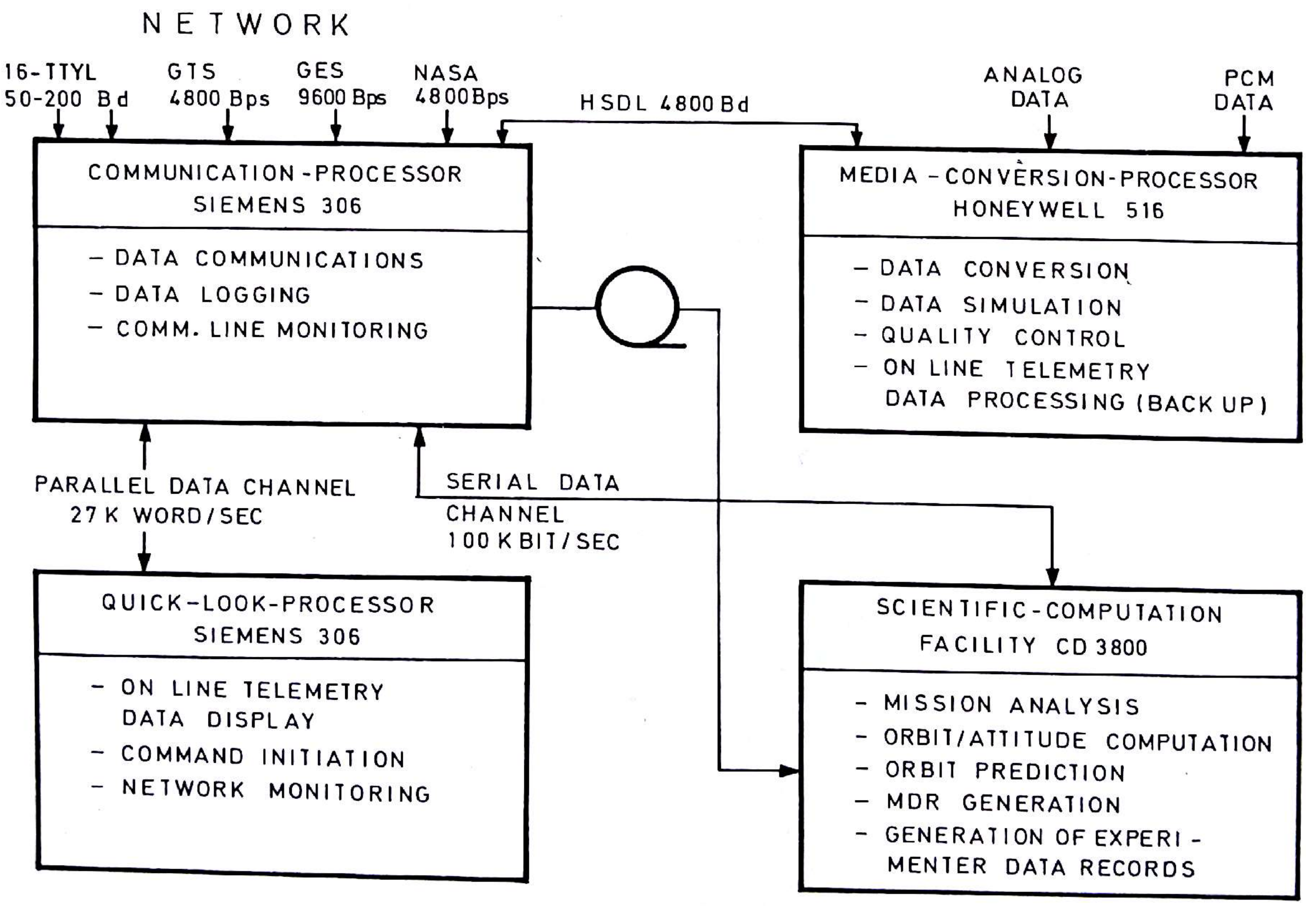


Figure 3.2-2: GSOC Computer System

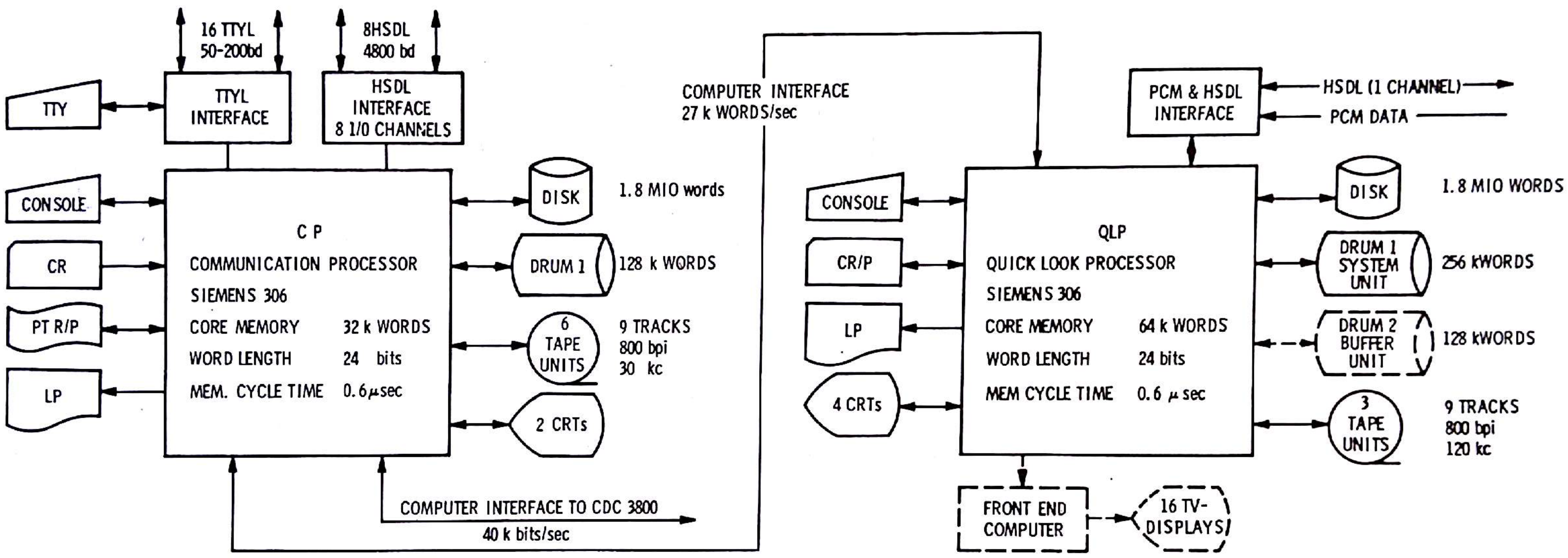


Figure 3.2-3: GSOC Prime Realtime System

3.2.2 **CONTROL ROOMS - MISSION SUPPORT AREAS AND EQUIPMENT**

3.2.2.1 **MSA AT JPL**

The following *Figure 3.2-4* gives the layout of the HELIOS mission support area in building 264 at JPL.

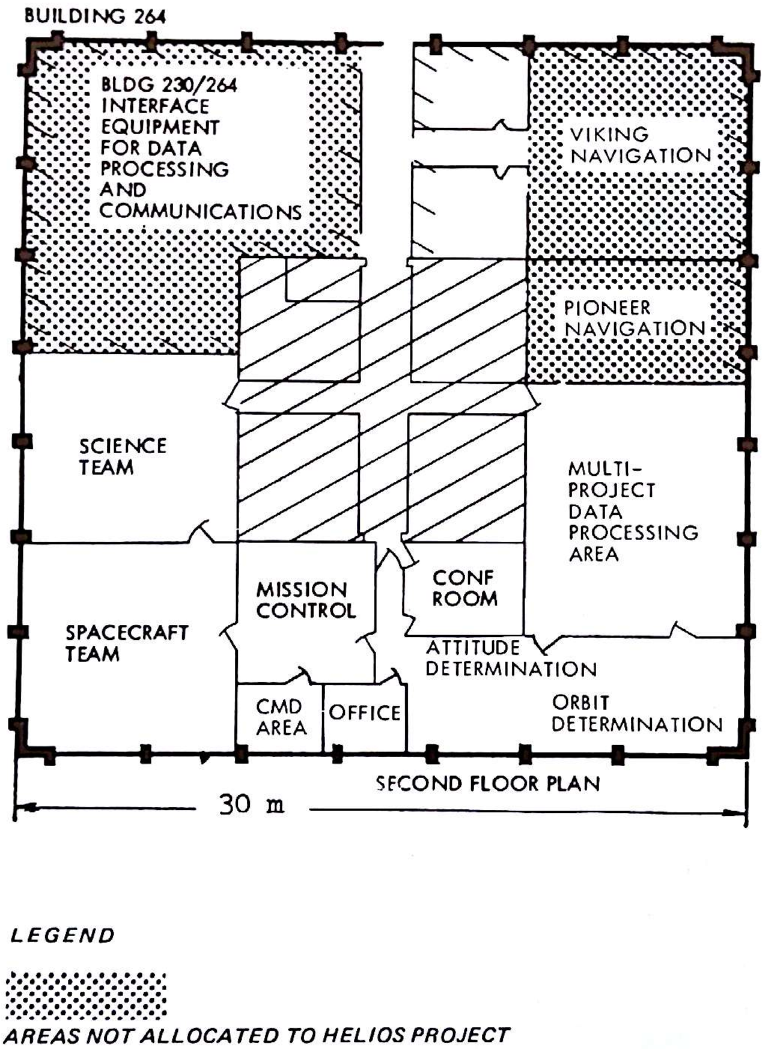


Figure 3.2-4: HELIOS Mission Support Area (Building 264)

The next paragraphs will give details about the different areas and describe the user equipment contained.

The following abbreviations will be used:

VOCA	Voice Communications Assembly
GDS	Ground Data System
TVSA	Television Subsystem Assembly
UIS	User Input Station (Keyboard)
UCP	User Character Printer
ULP	User Line Printer
UCR	User Card Reader
DTV	Digital Television

Office and Conference Area

These areas did not have an operational capability. Each area had listen only VOCA Stations for prime operational nets. The office had a multiple extension VOCA phone and the Conference Area had a single extension VOCA phone *(Fig. 3.2-5).*

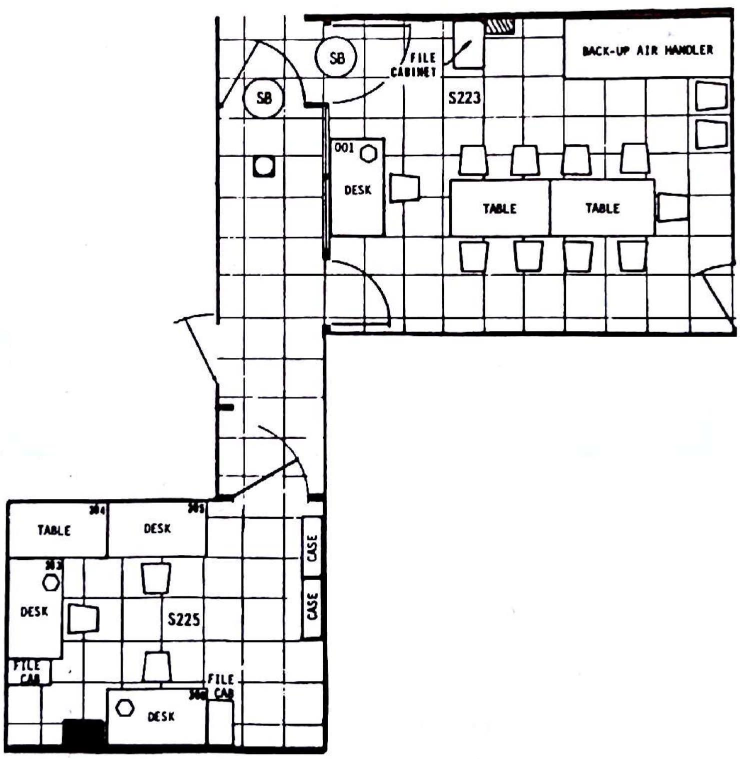


Figure 3.2-5: Conference Area

Mission Control and Command Area

The Mission Control Area and Command Area provided the required operational capability to support the HELIOS Mission Operations Control Team. The positions are listed below with corresponding location identification numbers: *(Fig. 3.2-6)*

401 — Data Chief (Realtime)
402 — Chief of Mission Operations Support (CMOS)
403 — Mission Manager (MM)
404 — Chief of Space Flight Operations (CSFO)
405 — Network Operations Control Project Engineer (NOC PE)
409 — GDS Operations
411 — Sequence Coordinator
302 — Command Operator (HE-CMD)

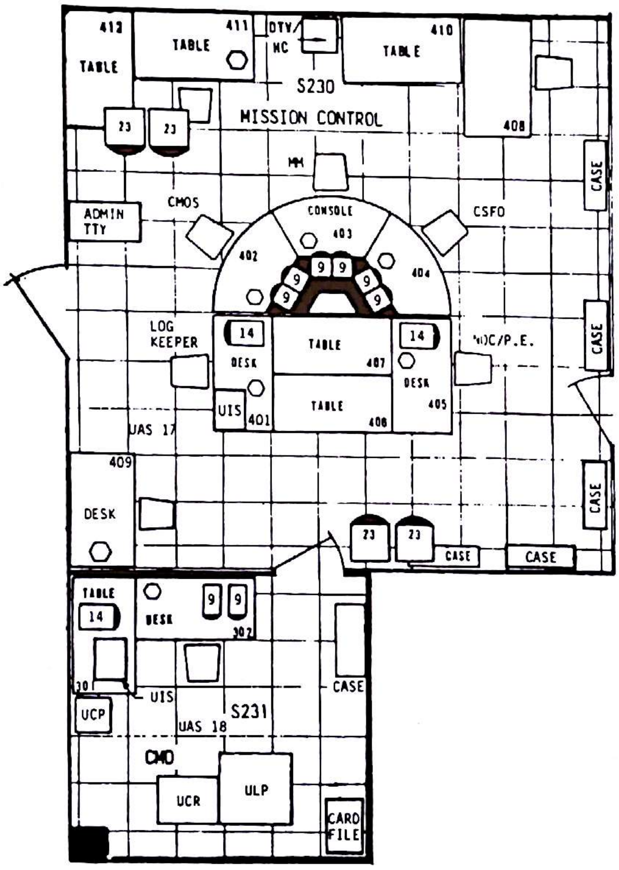


Figure 3.2-6: Mission Control and Command Area

The following equipment was available to the Mission Control and Command Team:

Abbreviation	used for
DTV HC	Digital Television Hardcopy machine to produce selectable hardcopies of the displays
ADMIN TTY	TELEX machine for administrative traffic (output only)
UIS (401)	User Input Station - Keyboard with display connected to the 360/75 computer Used for software operations and as a backup command input station.
UIS (301)	User Input Station see-above. Used as the main input station for telecommands assigned to the HELIOS command operator
UCP	User Character Printer. Used to log all command confirm messages
ULP	User Line Printer. Used to log all command system related entries at the UIS and their responses
UCR	User Card Reader Used to read CMD files from punched cards to the CMD system
23	TV Monitor — Number gives size of screen: 3 14 inch TV Monitors 8 9 inch Monitors 4 23 inch Monitors (Overhead) All those TV monitors (exept 23 inch) carry selector boxes which allow selection of different channels/formats (up to 40)
⬡	This sign indicates a voice communications assembly

Spacecraft Performance Analysis Area

This area was configured to support the operational requirements of the HELIOS S/C Performance Analysis Team (S/C PAT). The operational positions are listed below with corresponding location identification numbers *(Fig. 3.2-7)*.

501 — Spacecraft Team Chief
503 — Assistant Spacecraft Team Chief
506 — Spacecraft Attitude Subsystem
508 — Experiment 1-5 Housekeeping
510 — Experiment 6-10 Housekeeping
512 — Spacecraft RF Subsystem
515 — Spacecraft Data Handling Subsystem
518 — Spacecraft Power Subsystem
521 — Spacecraft Thermal Subsystem

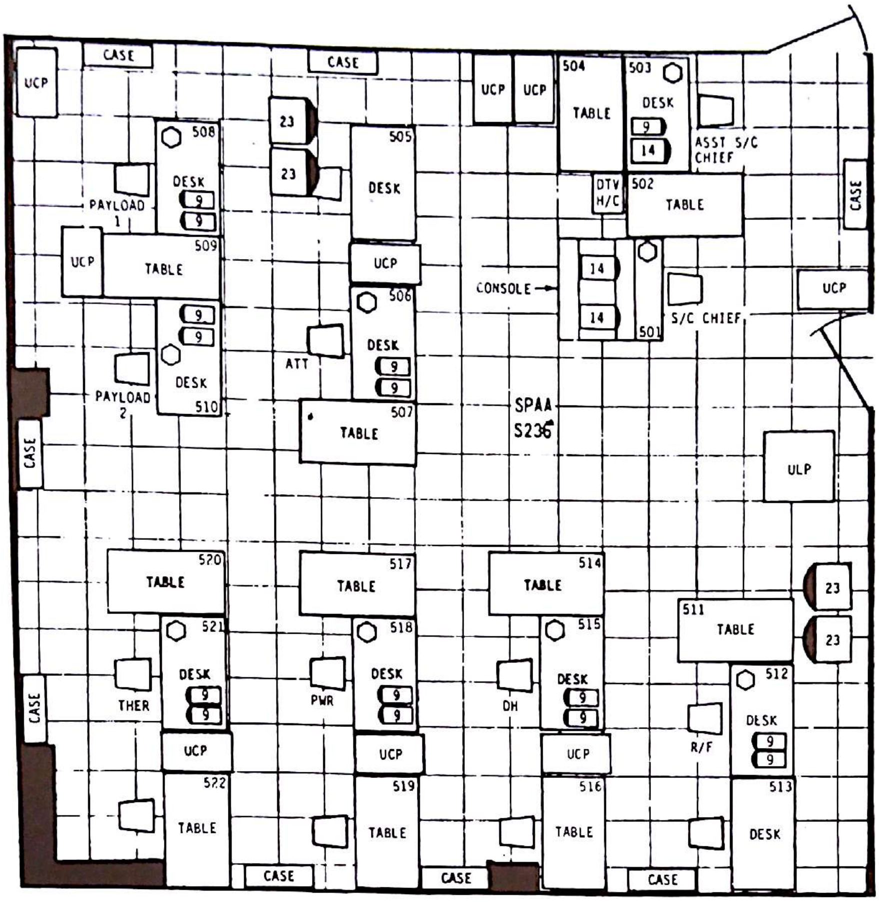


Figure 3.2-7: HELIOS Spacecraft Performance Analysis Area

The following equipment was available to the Spacecraft Performance Analysis Team:

Each subsystem analyst did have:

- 2 9inch TV monitors with selector box which allowed him to see all formats of interest
- 1 user character printer used to print all changing data channels (data suppression format)
- 1 voice communications assembly

The S/C Team Chief did have a console with:

- 2 14inch TV monitors which allowed him to see all available channels/formats
- 1 voice communications assembly

The Assistent S/C Team Chief did have:

- 1 9inch } TV monitor with selector box
  1 14inch }
- 1 voice communications assembly

In addition there were:

- — 1 DTV hardcopy machine
- — 3 user character printers
  used for the different logs
- — 1 user line printer
  used to print all engineering data in certain time intervalls
- — 4 23inch overhead TV monitors
  used for time — and general status display

Science Analysis Team Area

This Area was configured to support the operational requirements of the HELIOS experimenters *(Fig. 3.2-8)*. The operational positions are listed below with corresponding location identification numbers:

601 — Science Team Chief
602 — Assistant Science Team Chief
603 — Science Analyst Experiment E3
604 — Science Analyst Experiment E2
605 — Science Analyst Experiment E1
606 — Science Analyst Experiment E7
607 — Science Analyst Experiment E6
608 — Science Analyst Experiment E4
609 — Science Analyst Experiment E5B
610 — Science Analyst Experiment E5C
611 — Science Analyst Experiment E5A
612 — Science Analyst Experiment E8
613 — Science Analyst Experiment E9
614 — Science Analyst Experiment E10
615 — GSFC
616 — GSFC MICOS Operator 2
617 — GSFC MICOS Operator 1

Goddard Spaceflight Center (NASA) provided two minicomputer stations „MICOS“ to produce science data printouts and plots for the experimenters.
Those computers received data via high speed data line from the 360/75 system.

The following equipment was available to the science team:
Each scientist did have:

- — 1 9inch TV monitor with selector box which allowed him to see all channels/formats of interest
- — 1 voice communications assembly

Exp. 10 did have in addition:

- — 1 user character printer for special science data printouts

The Science Team Chief and his assistant each did have:

- — 1 14inch TV monitor with selector box which allowed him to see all channels/formats of interest
- — 1 voice communications assembly

In addition the area was equipped with:

- 2 23inch overhead displays for time and general status
- 2 user line printers for science and engineering data printouts
- 1 user character printer for the command verification log.

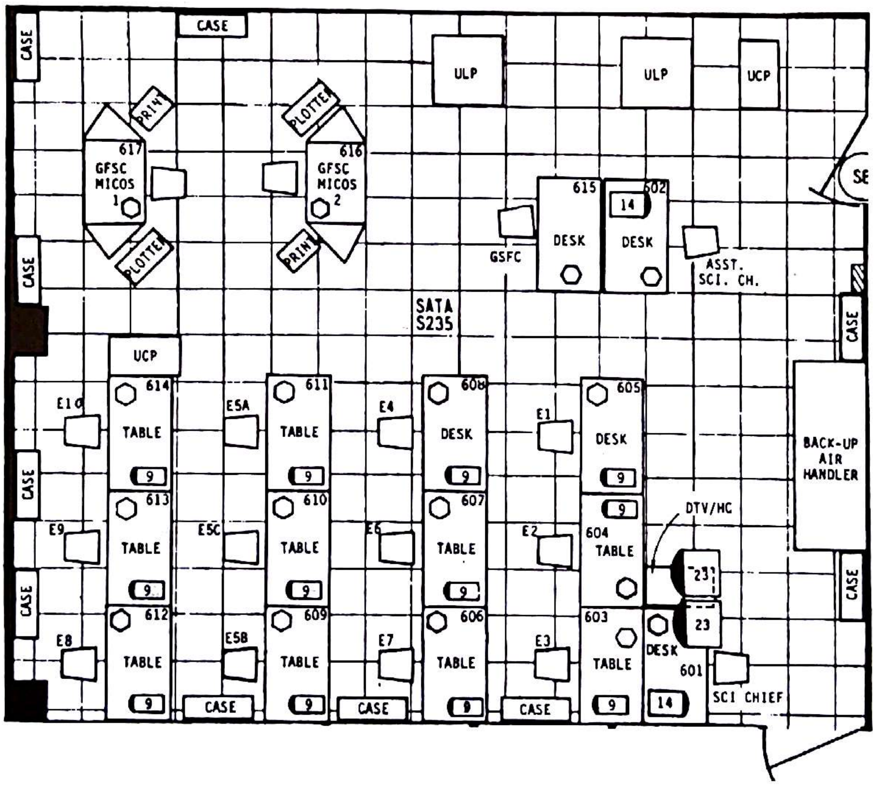


Figure 3.2-8: Science Analysis Team Area

Orbit / Attitude Determination Area

This area was configured to support the operational requirements of the HELIOS Orbit Determination and Attitude Determination Teams *(Fig. 3.2-9).* The operational positions are listed below with corresponding location identification numbers:

201 — Attitude Determination Chief
203 — Assistant Attitude Determination Chief
204 — Attitude Analyst 1
206 — Attitude Analyst 2
207 — LERC Representative
209 — Attitude Analyst 3
210 — Orbit Chief
212 — Assistant Orbit Chief
213 — Orbit Analyst 1
215 — Orbit Analyst 2
216 — Orbit Analyst 3
218 — Orbit Analyst 4

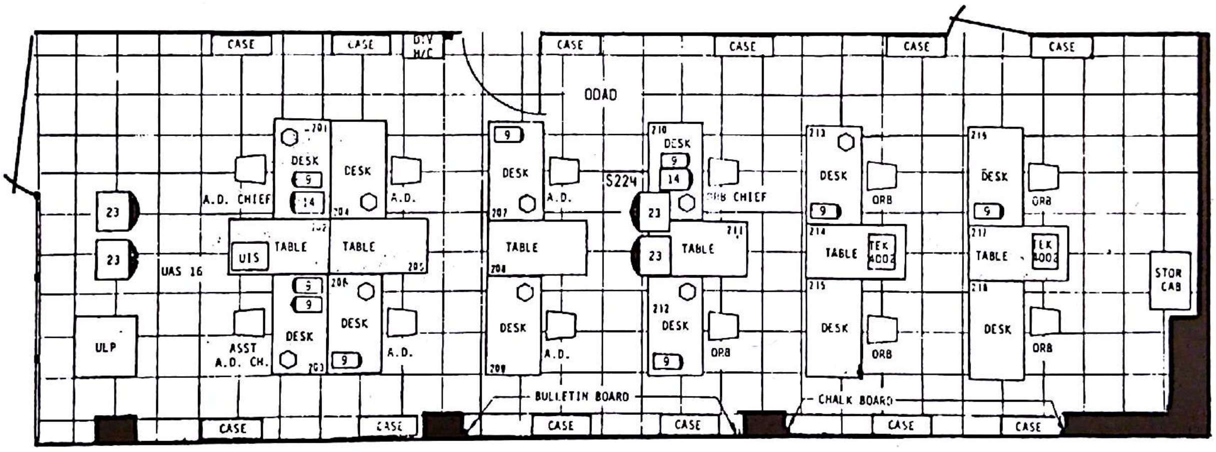


Figure 3.2-9: HELIOS Orbit / Attitude Determination Area

Equipment:

— 1 user input station to handle the attitude determination programs
— 1 user line printer for printed output from the attitude determination programs
— 1 DTV hardcopy machine
— 2 Tectronics 4002 input stations with graphical display connected to the 1108 System to run orbit determination programs
— several voice communication assemblies.

Multi-Project Data Processing Area

This area was configured to support the operational requirements of the HELIOS Software Operations Team *(Fig. 3.2-10)*. This area also supported Pioneer Navigation and Viking Data Compatibility Testing. The operational positions utilized by HELIOS are listed below with corresponding location identification numbers:

111 — HELIOS Orbit 1108 Operator
113 — Backup Software Operator
114 — Data Flow Operator
115 — Software Operator

Since this area was utilized by different projects mentioned above, there will be no detailed description.

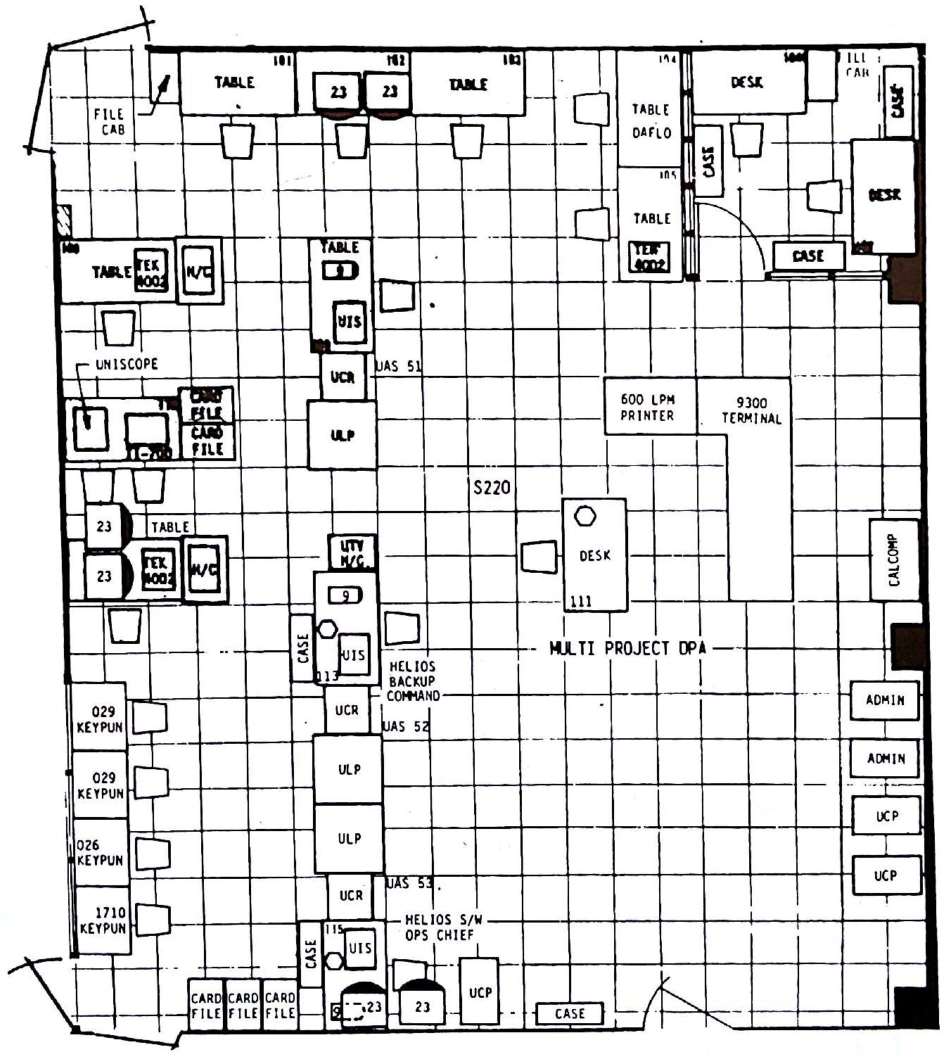


Figure 3.2-10: Multi-Project Data Processing Area

DFVLR
GSOC

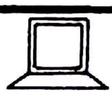
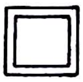
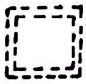
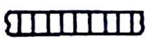
3.2.2.2 MSA AT GSOC

The HELIOS mission support area, located at GSOC, supported the HELIOS-A mission during Phase II and III and is supporting it in a different setup parallel with HELIOS-B today.

Fig. 3.-11 shows the layout of the HELIOS-A mission support area at GSOC. The operational positions are listed below with corresponding location identification numbers.

1 Spare for experimenters
2 Spare for experimenters
3 Spare for experimenters
4 Network control operator NOCC
5 Playload experts
6 Power subsystem expert
  Attitude subsystem expert
7 S/C team chief and commanding position
8 Radio frequency subsystem expert
  Data handling subsystem expert

Legend for Figure 3.2-1:

	DTV Monitor with Keyboard
	DTV Monitor with Selector buttons
	DTV Monitor if required
	TV Monitor
	Telephone
	NASCOM line
	VOCA device
	Wallboard with time display, projection board, status indication of the S/C

DFVLR
GSOC

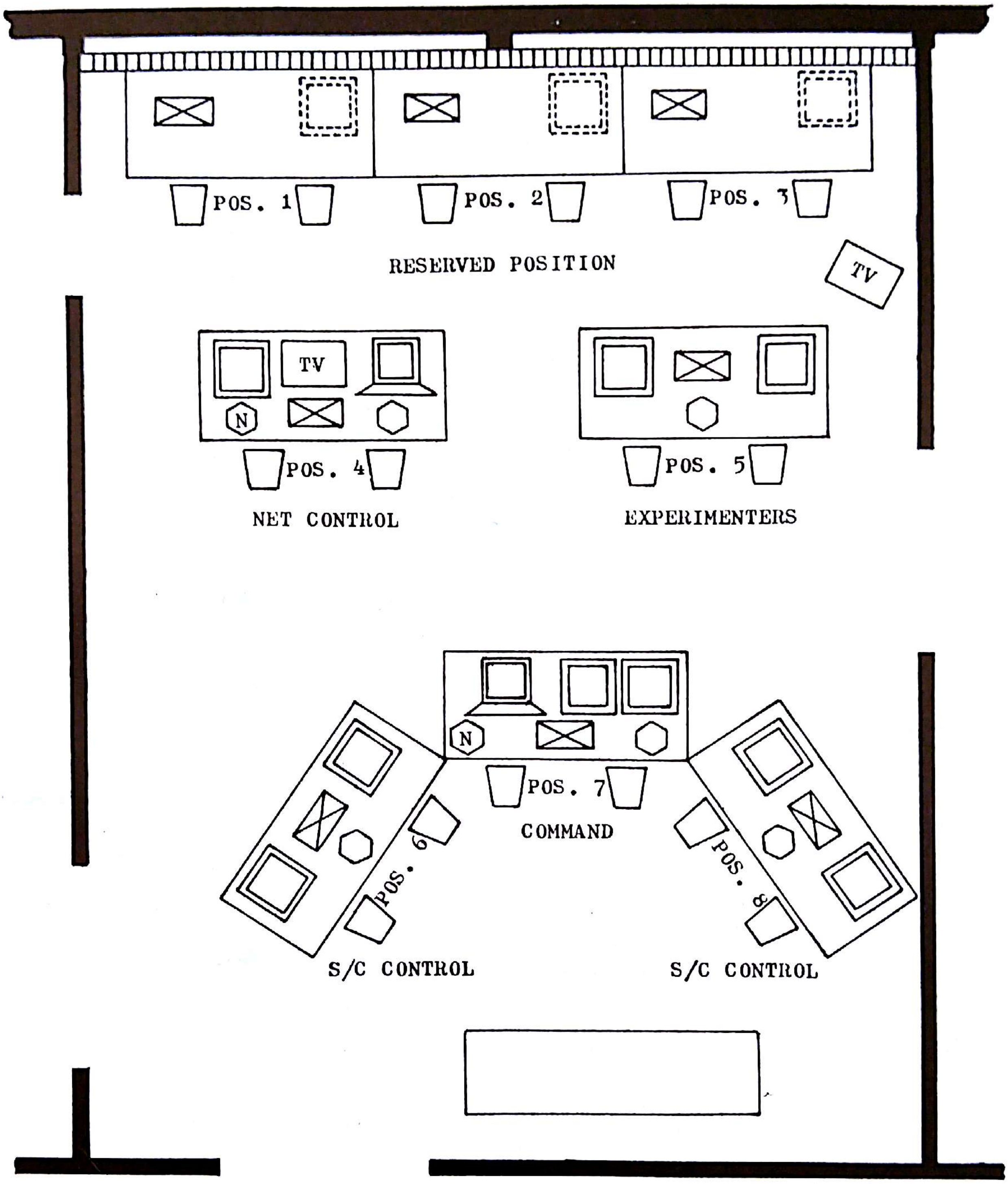


Figure 3.2-11: HELIOS-A MSA at GSOC

4 DATA RECORDS PRODUCTION

4.1 GENERAL REMARKS

The German Space Operations Center (GSOC) was committed to plan and realize the experiment data processing for the solar probe HELIOS-A. For the necessary programming and processing a computer type CDC 3800 was available. The central processing unit of this computer was provided by IABG (a government owned agency). This unit was at that time around five years old and was supplemented by new peripherals like tape drives, disks, card-readers and card-punch which were bought by GSOC. At the beginning of the experiment data processing in early 1975 the peripheral equipment had an age of about three years and was therefore relatively new compared with the eight years old central processing unit.

This computer *(Fig. 4.1-1)* was operated on a contractual basis by IABG personnel in three shifts five days a week. It was used for the projects AEROS, SYMPHONIE and HELIOS for all experiment data processing purposes and for all orbit and attitude computations.

In the following, a short summary of the time sequence, the software and the difficulties during the processing as well as the total effort will be given.

4.2 DATA ACQUISITION AND VALIDATION

As already described in *section 3.1,* data are acquired by the DSN-stations in Canberra (Australia), Goldstone (USA) and in Madrid (Spain) with the 26 m and 64 m Network and the German stations in Effelsberg *) and Weilheim respectively.

All data acquired by the DSN-stations are recorded on magnetic tapes by JPL *(Fig. 4.2-1).* In the first processing step the HELIOS-data are separated from other data and are recorded on SDR-tapes. These tapes are used to generate the so-called Master-Data-Records (MDR). These MDR's are written in a certain structure. All data of a certain cycle with the same bitrate, same format or distribution mode are written in one file named Telemetry File.

All command data which occurred during that file are compiled to a Command File.

These tapes are shipped to GSOC for further processing. The data acquired by the German stations are processed to MDR-tapes using the above described techniques.

Before further processing all MDR's are checked by a validation program. The purpose of this validation is to check against the MDR-specifications and eliminate incompatibilities.

After the validation process, the German and U.S.-MDR's are merged. By this process redundant data are eliminated and the remaining data time ordered.

In order to do a data evaluation, the experimenters need an accurate knowledge of the orbit and attitude of the probe. This information is generated at GSOC by special methods and provided on the orbit-attitude-tapes.

The next step of the data processing is the merging of the MDR's with the orbit-attitude-tapes. These tapes are called TOAC-tapes. This step was only done on special request by the experimenters. Later on the experimenters requested the orbit-attitude-tapes separately, so that the merging would not have been necessary any longer.

The last step of the processing consists of a decommutation of the data of the eight German experiments on eight separate tapes. Each experimenter receives on his Experiment Data Record (EDR) only data of his own experiment for further evaluation.

The information of the mode of operation of the HELIOS Probe which is contained in the telemetry data is decommutated and recorded on so-called „Engineering Tapes". These tapes are evaluated by the experimenters and by the spacecraft control personnel.

Command data are treated the same way.

*) *The Effelsbergstation discontinued the HELIOS-support by 31-7-76. The Weilheim station was expanded for telemetry reception and operational in Sept. 76.*

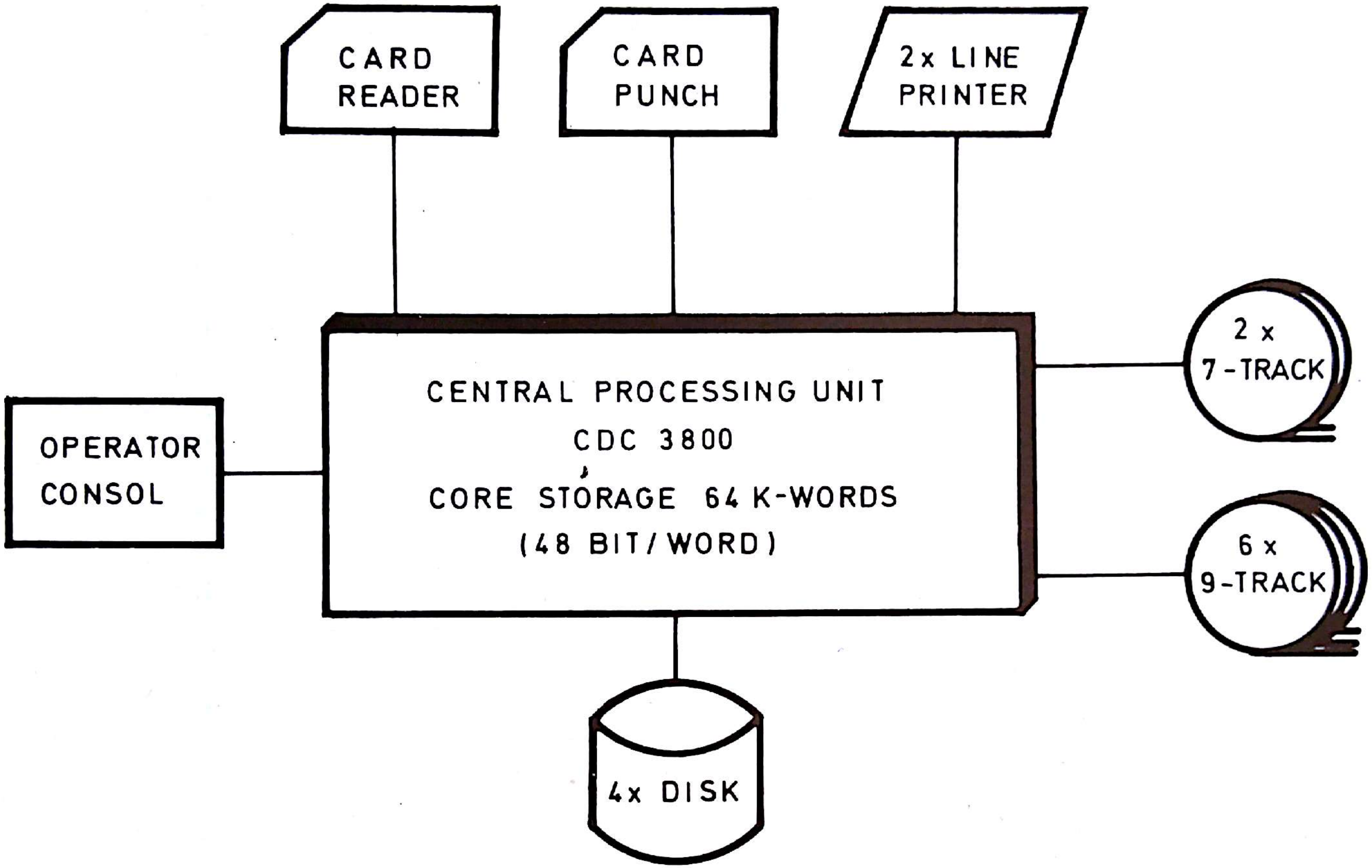


Figure 4.1-1: Experiment Data Processing Computer CDC 3800

4.3 SOFTWARE

The above mentioned steps of the data processing require computer programs. These programs have been specified and written by GSOC personnel and have the following tasks:

— Generation of MDR's
— Validation of MDR's
— Merging of MDR's
— Generation of TOAC's
— Generation of EDR's

This report gives only a short description of the programs.

4.3.1 MASTER DATA RECORDS

The purpose of this program is to generate the Master Data Records *(see also Fig. 4.3-1).* These records are exchanged between USA and Germany. Copies of the tapes are stored at GSOC and JPL respectively. The software for generation of those tapes consists of two parts. First HELIOS specific data are extracted from the LOG-tapes, telemetry and command data are recorded separately.

Second, both data streams are merged in files according to certain criteria. The spacecraft event time is computed with the help of the round trip light time and the ground receipt time. This information is added to every data frame.

These tapes are checked carefully by certain control procedures. The same is done with the MDR's delivered from JPL. The errors which are checked for are e.g. parity errors, wrong times, missing frames, violations of file criteria. The purpose of this examination is to find out errors which delay and disturb further processing.

4.3.2 MERGE TAPES

This software is used to merge the German and U.S. MDR's. During this process the data are time ordered, sorted and redundant data is removed according to certain quality criteria.

4.3.3 ORBIT ATTITUDE TAPES

Besides telemetry and command data orbit and attitude data is one of the most important informations for the experimenters. By using tracking data which are generated and recorded at the stations, the orbit of the probe can be determined with high accuracy. The orbit information is computed for different coordinate systems and is recorded on magnetic tapes. Auxiliary data like the orbits of planets and moon and the attitude information of the probe is added to that tape.

4.3.4 TOAC-TAPES

The purpose of this computer program with the name TOAC (Telemetry Orbit Attitude Command) is to generate the master tape for the later EDR-production. Existing telemetry data is combined in main frames, missing frames are replaced by filler data. Orbit and attitude data is added to the telemetry files.

4.3.5 EDR-TAPES

This software package is very complex and is used for the generation of the final product of data processing: the Experiment Data Records. The necessary information for the eight experiment data records is extracted from the TOAC-tape. Essentially, a decommutation and preprocessing of the data is done in order to get the formats requested by the individual experimenter.

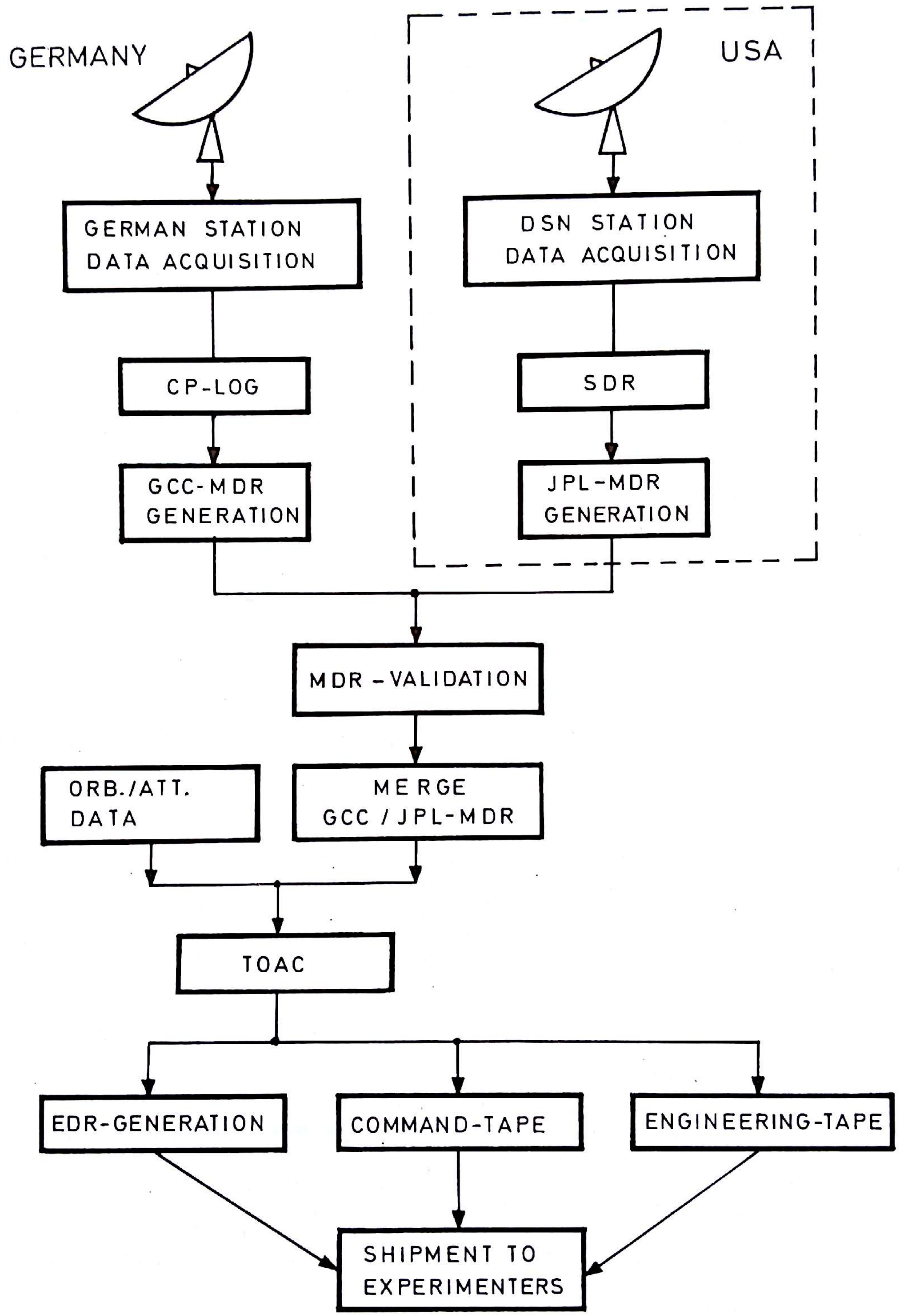


Figure 4.2-1: Experiment Data Flow

4.4 DATA PRODUCTION PROBLEMS

As an average, about 40 hours computer time per week is necessary to process the available data. Besides the fact, that the computer was used for the processing of the projects AEROS and SYMPHONIE too, a processing backlog of data should never have occured. In reality this was not the case. In spite of special shifts on week-ends, a backlog of about 1800 hours computer time was experienced in the first eight months of 1975. The reasons for this fact were:

- Hardware breakdowns
  The computer CDC 3800 is, as a computer of the second generation, extremely susceptible to power- and airconditioning-breakdowns. Because of these reasons, about 30 to 40 % of the capacity was lost due to hardware errors. In addition, the reliability of the computer dropped for about four weeks after every breakdown so extremely that jobs with runtimes of more than sixty minutes had often to be repeated.
- Missing redundancy
  Because of the age of the computer, a similar one was not available any more in Europe.
  Especially programs for the processing of telemetry data of satellites are using machine-dependent peculiarities in an extreme way. Therefore, the transfer of such programs into a different machine is very expensive.
- Anomalies
  Non nominal behaviour of satellites and ground stations request very often modifications of the programs and sometimes data of certain operational periods have to be reprocessed. It is clear that such additional loads which are necessary besides the normal operation multiply the workload for people and machine.

Besides those machine dependent difficulties, the programming of the HELIOS specific software made a lot of trouble. For different reasons it was not possible to complete the software in time. The main reasons are listed below:

- Software modifications for the EDR-processing
  In August 1974 test EDR's with actual satellite data have been delivered to the experimenters. Despite this fact, seven requests for program changes have been made by the experimenters. These modifications required considerable software changes. For example, a change in the magnetic field data evaluation for the experiments 1, 6, 8 and 12 had extreme consequences to the whole time schedule.
- Software modifications for the MDR processing
  Errors in the time correlation of the data which occured at the Effelsberg station requested changes in the MDR-software. These errors were detected by intensive tests of the EDR's.
- Modifications of the merge software
  The software for the generation of merge tapes had to be modified due to the fact that the U.S. MDR's did not observe the specifications completely.
- Compatibility problems
  During the test phase the U.S. MDR's had been written on older magnetic tapes which were compatible with the German tapedrives. For the routine production of the MDR's a new batch of tapes was used which led to big difficulties as far as tape compatibility was concerned.
- Hardware breakdowns
  Due to hardware problems the CDC 3800 could not be used between January 1975 and mid March 1975 for data processing.

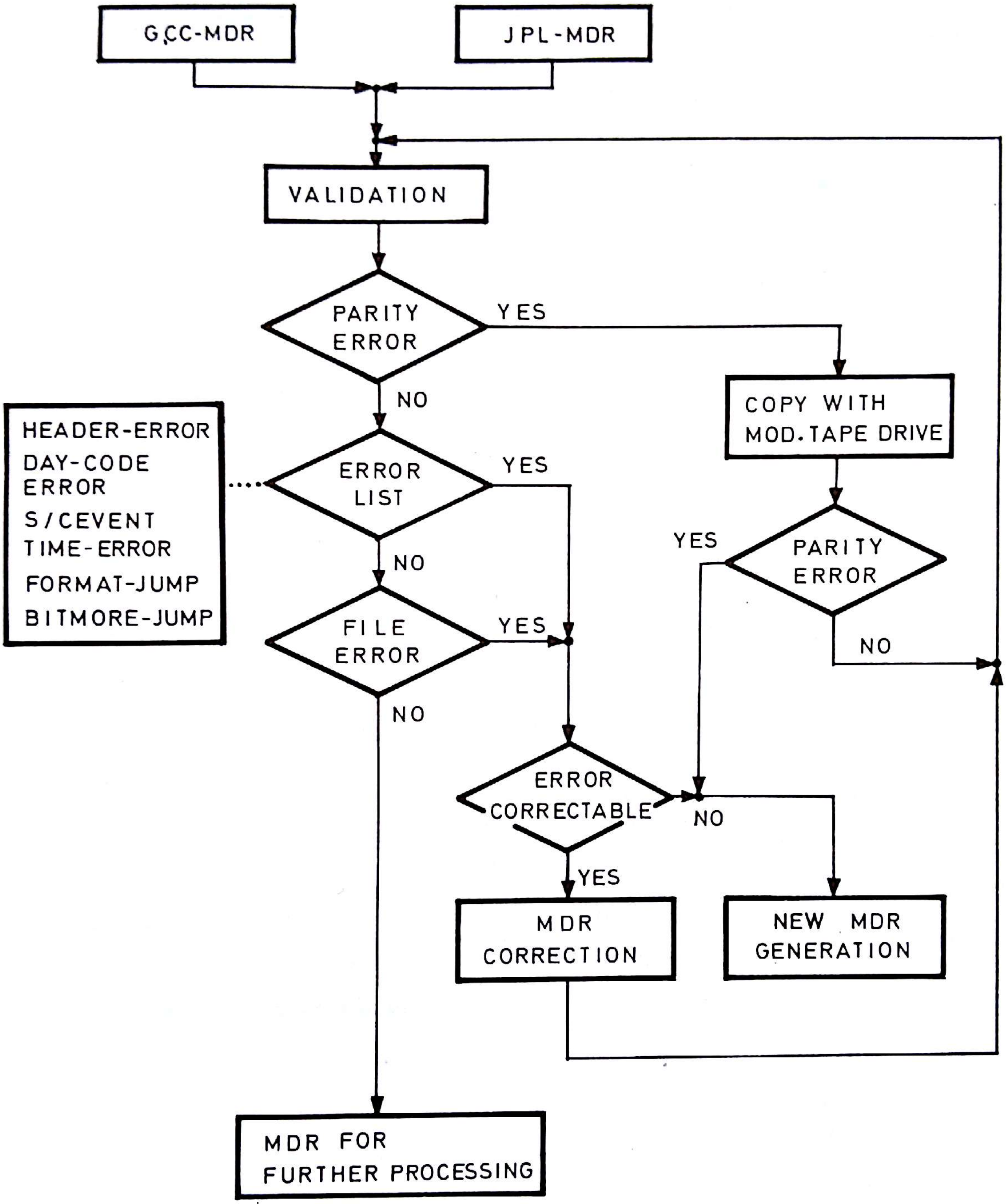


Figure 4.3-1: MDR Processing Steps

After the final completion of the data processing software priority was given to reduce the workload for that computer.

Especially:

- All orbit and attitude programs have been implemented on other computers
- The software for the telemetry data processing (EDR generation) was installed on a CDC 6400 computer. This backup possibility was available since spring 1976
- Part of the whole processing was done on a CDC 3800 of the „National Oceanographic and Atmospheric Administration" in Boulder / Colorado (USA).

4.5 SUMMARY OF THE TOTAL EFFORT

To give a short impression about the size and the effort which is necessary to perform the data processing job of a project like HELIOS a summary of the total number of generated tapes, the total computer time and the effort in time and personnel is described here:
The first preparations like the decision about the data exchange between Germany and the U.S.A. or the definition of the various tapes were started in 1969. The specification phase for the software lasted about eighteen months and was completed in mid 1973. The programming was finished by the end of 1974. The programming of the software for the experiment data record generation could not be completed in time. This was due to various change requests of the experimenters as already mentioned. Minor modifications of the software are done permanently until today. The reasons for those modifications are based on computer configuration changes at the experimenters' side or on certain anomalies of the probe. The generation of the experiment data records started in August 1975. In order to get rid of the enormous backlog of data a CDC 3800 of the NOAA in Colorado was used in addition to the GSOC computer. The size of the backlog was about 15 billion bits.

By mid 1976 this backlog disappeared completely. Needless to say that the new data is processed in realtime.

A detailed summary of all the tapes processed by the end of March 1977 looks like the following:

MDR/JPL	726	tapes
MDR/GSOC	367	tapes
Merge tapes	268	tapes
TOAC	714	tapes
Orbit/Attitude	28	tapes
EDR	4960	tapes

Altogether about 7000 tapes have been processed at GSOC for HELIOS-A.

The necessary computer time amounts to about 5600 hours for the production and about 800 hours for preparation and test. As an average five persons were involved in the work during the preparation phase and four persons in the production phase.

5 SOFTWARE

This section describes the main Software Packages used for HELIOS Mission Operations (except Data Record Production Software — *see section 4.)*

It is to be distinguished between

- Realtime (RT) or Near Real Time (NRT) Software
  and
- Off Line Software

Those distinct definitions (RT and NRT) shall point out the difference to the Off Line program (like S.O.E. or link program) which do not require any direct input from the incoming S/C data.

The RT and NRT Software packages comprise:

- Monitoring
- Telemetry
- Command
- Attitude

The Off Line Software programs are:

- S.O.E. Program
- Link Prediction Program

The basic features will be described in the following chapters.
It shall be mentioned that those packages had to be created at GSOC (completely new) and at JPL (by using already existing standard features), which basically means double effort in manpower and coordination whereby a lot of JPL and interface constraints had to be considered.

5.1 REALTIME AND NEAR REALTIME CAPABILITIES

In this section the features of the (operational) Realtime resp. Near Realtime Software will be described.
In this connection REALTIME means that the received information from the S/C is converted into interpretable data immediately i.e. without time delay — that means always the latest available information is being processed and displayed with high priority. In case of a very dense information flow into the computer a certain allowable back log is defined. If this back log is reached the processing is automatically skipped up to realtime again.

NEAR REALTIME in the HELIOS data processing could mean:

- Realtime processing, but output in defined intervals i.e. intermediate storage on tape like it was done for science printouts.
- Storage of raw data (or preprocessed) on tape and evaluation of those data on a different computer on the same day (within 24 hrs). Example: Plot generation of science data.

5.1.1 MONITOR SOFTWARE

5.1.1.1 SCOPE

The Monitor System provides the capability for sensing certain characteristics of the various elements of the German Network, processing and displaying data for use by operations personnel, and for storing data for later analysis or reference. Monitor data is used for determining status and configuration, for guidance in directing operations, for alarming non-standard conditions and for preofficial analysis of the quality and quantity of data provided to the project.

5.1.1.2 REALTIME QLP MONITOR SOFTWARE

The QLP Monitor Software is an external-storage program such as every of the other mission-type programs (i.e. HE-A or HE-B) which is activated in a time-multiplexed manner and controlled by the QLP executive.
The Monitor Software processes High Speed Data Blocks on-line from the QLP monitor and telemetry files or off-line from a CP-generated log tape and generates display or line printer formats. The Monitor Software handles monitor and textblocks for all stations and spacecraft supporting.
Figure 5.1-1 provides a diagram of the monitor data flow in general and *Figure 5.1-2* shows a matrix of the data stream type versus output formats specifically in support of the Helios mission.

5.1.1.3 MONITOR FUNCTIONS

The Monitor and Operations Control functions are performed with

6 Station/Network Monitor formats for DSN/MCCC/GES/GTS and COMM surveillance
4 CP Monitor formats for Communications Processor control, configuration and status and
2 QLP Monitor formats for the GCC Realtime Processor control, configuration and status

plus appropriate hardcopy and log capablities.
The monitor and control function is multi-mission and conducted by the Network Operation Control Group. All functions are non-automated and need proper action of the operations personnel to clear alarm-conditions.

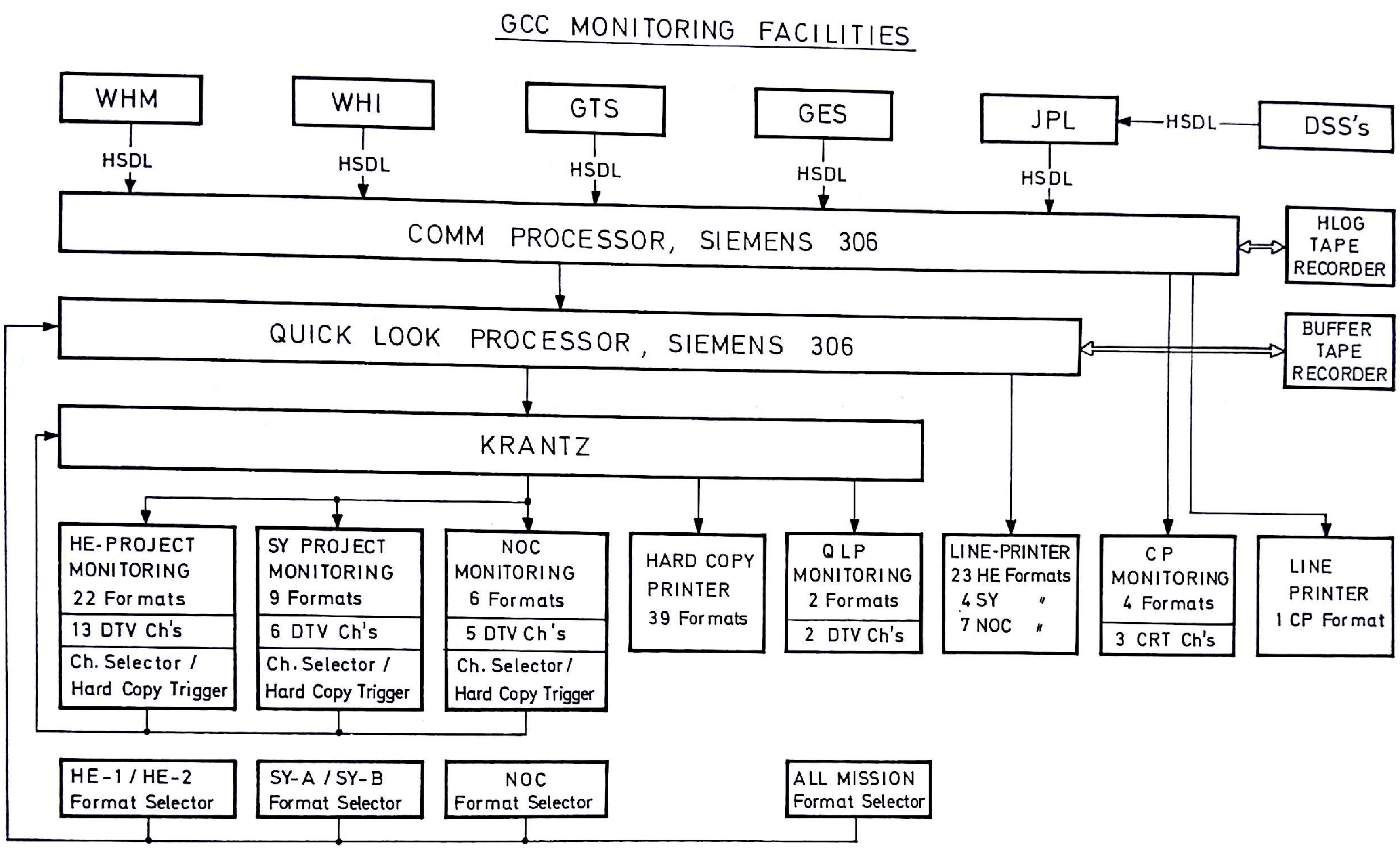


Figure 5.1-1: Monitor Data Flow

OUTPUT FORMATS / INPUT HSD BLOCKS	Command System Status	Telemetry System Status	General Status/ Alarms	Stdn and Configu- ration	Pass Summary log.	NOC Summary log.
GTS - Monitor	X		X			X
GTS Configuration				X		X
GTS - Stand a.Limits				X		X
GTS - Textblocks					X	
GES - Monitor		X	X			X
GES - Textblocks					X	
GES - Telemetry						X
DSN/MCCC Monitor	X	X	X			X
DSN/MCCC Textblocks					X	
DSN/MCCC Telemetry						X
GCC - Monitor			X			X

Figure 5.1-2: Monitoring Input/Output Capabilities

5.1.2 TELEMETRY

The *Figure 5.1-3* gives a summary of all R/T telemetry capabilities (valid for JPL and GSOC).
The common input (for data into GSOC or into JPL) is the Telemetry High Speed Data Block (HSDB-transmission rate 4.8 kBits, since December '76 with a rate of 7.2 kBits). The following main steps can be distinguished:

- Input processing
- Frame Number/Time Check
- Decommutation/Limit Check
- Science Data Processing
- Logic Tests
- Command Verification Program
- R/T Display Formats (CRT)
- Lineprinter Logs

At JPL those packages were established fully redundant on two IBM 360/75 computers.
At GSOC the packages were installed on the Siemens 306 (Quick-Look-Processor). As a back-up a very limited software package was implemented on a HONEYWELL Computer (since mid '75 being transferred onto a KRANTZ Computer) consisting of:

- Minimized input processing
- Decommutation
- R/T lineprinter display of selected engineering data

As an additional support for the experimenters a Goddard Space Flight Center supplied MINI COMPUTER SYSTEM (MICOS) was provided with

- Input processing
- Decommutation
- Science Data Processing
  (R/T CRT display and NRT printer/plotter display capability)
- Selected engineering data display

5.1.2.1 INPUT PROCESSING

The input processing is performed to

- Detect TLM data being affected by transmission errors
- Get information about ground station status as far as link is concerned

The first item is performed by:

- HSDB-error code Check (erroneous blocks are flagged)
- Ground Received Time (GRT) tag check in order to secure the data continuity or detect any missing data
- Frame Number (FN) correction in selected cases
- Data Quality (DQ) indication by taking the SNR (link quality) and HSDB-errors (data line quality) into account.

The second item is performed by:

- Deblocking and Ground Data System (GDS) information strip-off of the HSDB Blocks
  For judging the link performance the following Ground Station parameters are used: SNR, AGC, DDA Computations and DDA Errors.

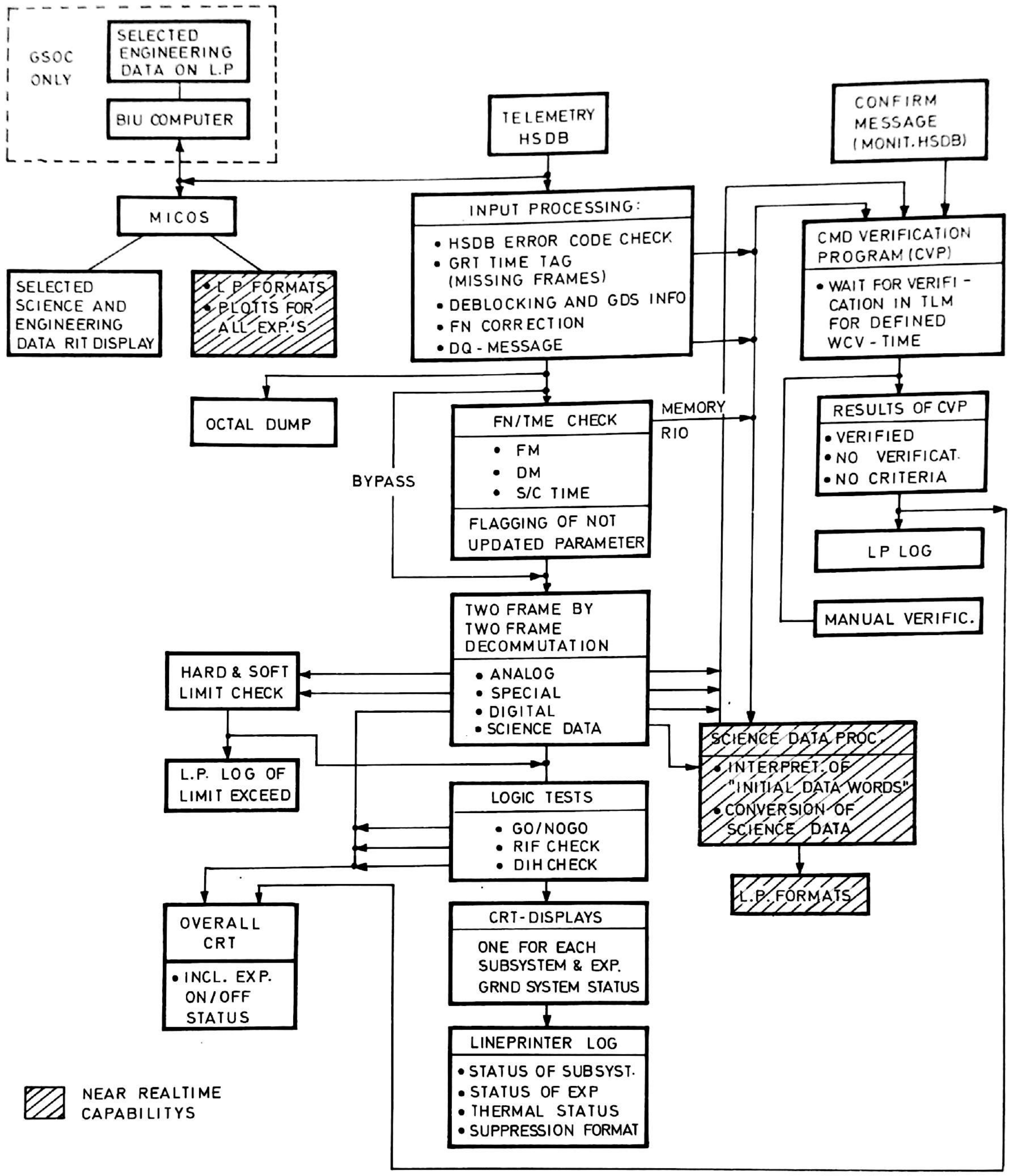


Figure 5.1-3: GSOC/JPL Software Capabilities

After having passed the input processing, the data are submitted to some logic tests in order to secure the correct decommutation. The purpose is to establish unambiguously the data mode the S/C is working in, by checking continuity of Format Mode (FM), Distribution Mode (DM) and S/C Time.

5.1.2.2 DECOMMUTATION

As a HELIOS particularity two frames have to be accummulated until decommutation starts, resulting in:

- Converted (according to calibration curves) analog values (V, °C, mA etc.)
- Special computed values (DEG, W etc.)
- Correct interpreted status bits (ON/OFF, HIGH/LOW etc.)
- Decommutation of science data and accummulation of experiment specific data-frames.

All analog values are submitted to a soft and hard limit check establishing whether a specific value is within the defined operational region.
Limit exceedings are displayed and recorded.

5.1.2.3 SCIENCE DATA PROCESSING

The science data are accumulated to experiment specific data frames. After an experiment data frame is identified the complete frame is interpreted according to more or less complicated rules (bit inversion and octal interpretation, logarithmic decompression, accumulation of 'HISTOGRAMS' etc.) and being stored on tape (buffered output = near real time). This buffered tape can be printed out on request.
At JPL it was possible to print out the science data for two different experiments at a time in realtime.
At GSOC only the buffered mode is possible, with a few exceptions at low bitrates.
A total of 17 different science formats have been implemented.

5.1.2.4 LOGIC TESTS

- GO/NOGO TEST
  The results of the limit check are logically interconnected on a subsystem basis, each subsystem (GO for all analog values within limits, NOGO for one or more hard limit exceedings)
- R/F CHECK
  Since HELIOS allows a total of 432 different combinations (because of the many redundancies) in the R/F system a logic test was designed to inform the controller about the current configuration.

In addition not all of those 432 combinations are allowed and desirable, therefore the following labelling was designed telling about the criticality of a particular configuration:

N = Normal mode
B/U = Back up mode
ILL = Illegal mode
F = Failure mode

- D/H CHECK
  This is a similar check as the R/F check. In the D/H Subsystem a total of 1680 different combinations is possible. The labelling is the same than for the R/F logic check.

5.1.2.5 COMMAND VERIFICATION PROGRAM

This program was designed to assist the S/C controllers in the verification of commands. Since HELIOS basically only uses 'discrete' commands (which means a command has only one function), for each command a set of verification criteria could be defined and stored in the computer. If a command is sent to the S/C (indicated by the Confirm-Message from the ground station), a routine is started waiting for the specific verification criteria coming back from the S/C in the telemetry data as a response to the command.
The verification program will always come to a conclusion:

V = Command verified
N = Command not verified after having waited for two telemetry updates
X = No verification criteria are defined

All results are displayed in R/T and logged on a lineprinter format *(see Fig. 5.1-4).*

5.1.2.6 R/T DISPLAY FORMATS (CRT)

The main tools for controlling the health of the S/C are the R/T CRT display formats. These are display formats arranged according to subsystems and experiments, containing the complete status of the appropriate subsystem (all analog values and status bits), including the results of the previous processing for **each** parameter as *(for example, see Figure 5.1-5: R/F Subsystem format):*

- Data Quality
- Missing Data Information
- Limit Check Results.

A total of 20 different subsystems CRT formats are defined.
As a master control format an 'OVERALL FORMAT' was defined containing as a directory the general status of the 20 Subsystem formats *(see Figure 5.1-4):*

- Digital Information
  Experiment ON/OFF Status
- Result of the GO/NOGO CHECK
  for each Subsystem and all Experiments
- Result of the R/F CHECK
- Result of the D/H CHECK
- Result of the Command Verification Program

The idea there was to use this format as the main control format and select in case of non desired results the appropriate subsystem format. This enables, later during routine operations, only one controller alone to supervise the status of the S/C.

5.1.2.7 LINEPRINTER LOGS

Since the CRT information is nominally not logged (although hardcopies of the CRT-formats are possible) the following lineprinter (L.P.) formats have been defined (running either in R/T or buffered):

- L.P.format summarizing the status (digital and analog) for all S/C subsystems
- L.P. format summarizing all temperatures
- L.P. format summarizing the status (digital and all experiments)
- Octal dump for trouble shooting
- Log for
  - Command Verification Program
  - Limit Exceedings
- Suppression format which logs each update of 6 different (out of all engineering data selectable) parameters at a time in order to keep track of very rapid transitions or for trouble-shooting purposes.

```
H-90 DSS-67   77 250 10:18:41    FB/FF=  3/   1   FMT 01
  B/R:   32     FM 3          DM 1-0                 FM:   39
    TLMS-TLML=      0         *  CMD-CT    230
RTLT                27:21.8   *  228 08:45:00      323-4TST V
MEMADR           1984         *  228 08:30:00      162-8DFB V
SCTIME      82  05:16:46.968  *  227 07:30:00      247-1PGB V
                        L032  *  225 07:01:00      203-2SCL V
002 RX   NO    013 E1 ON G    *  225 07:00:00      234-1PGA V
003 TX   G     014 E2 ON G    *  223 06:21:00      123-LMRG V
004 D/H  G     015 E3 ON G    *  223 06:20:00      613-D1F3 V
011 AC   G     016 E4 ON G    *  222 04:50:49      042-SSSS X
012 HG   NO    017 E5 ON G    *  219 03:30:59      275-5SID V
005 POW  G     017 5A ON G    *  219 03:29:59      247-1PGB V
007 TH1  G     020 5B ON G    *  219 02:59:59      234-1PGA V
008 TH2  G+    017 5C ON G+   *  218 01:59:59      332-1TCY V
009 TH3  G+    018 E6 ON G+   *  217 01:12:47      042-SSSS X
010 TH4  G     019 E7 ON G    *  213 23:50:00      247-1PGB V
               015 E8 ON G    *  208 23:32:00      215-8DFA V
RFMODE B/U     021 E9 ON NO   *MANUAL-IN:
DHMODE   N     022 E0 ON G+   *
```

Figure 5.1-4: Overall CRT Control Format

```
H-90 DSS-67   77 250 10:24:41   FORMAT 03: TELECOM-TX
  B/R:   32     FM 3         DM 1-0                 FM:   49

TX+26V    V +.2710E+02                   RF-MODE TEST
MODPWM  DB  -.2272E+01                RFMODE B/U   52
DRIVPM  DB  +.1495E+02                    ANT-D    ON
TWT1PM  DB  +.0000E+00                    ANT-P   OFF
TWT2PM  DB  +.4005E+02                    ANT-O   OFF
HLX-I   MA  +.5696E+01                    TXPOW   MED
TXRPM   DB  +.2450E+02                    DRIVER    1
                                          TWT-1   OFF
 TEMPERATURES                 STATUS      TWT-2    ON
TWT1OU    C +.6136E+01      TWTAP   MED   VCXO      1
TWT2OU    C +.1500E+02      CARSUP   LO   TXMODE NOC
COLL-T    C +.3989E+02                    RANG    OFF
VSO-T     C +.8956E+01      GROUND STATION MESSAGES
RFDUOU    C +.4431E+01        AVEERR            0
                              DDAERR            0
AGC      DB -.1216E+03        DDACOM       +.9000E+01
SNR         +.6843E+01        SNRTHR       +.3000E+01
```

Figure 5.1-5: R/F Subsystem CRT Format

5.1.3 COMMAND SOFTWARE SYSTEM

5.1.3.1 FUNCTIONAL DESCRIPTION

The Command System for HELIOS Mission Operations utilizes the command capabilities of the U.S. Deep Space Network and the German Network. In general it consists of the hardware and software required for generating, handling, processing and display of command data. These are basically a User Input Station (UIS) or a User Card Reader (UCR) to input commands, a computer which receives and processes the commands from the input devices, High Speed Data Lines (HSDL) which carry the commands, a Deep Space Station (DSS) which receives and processes the commands from the computer via the HSDL and radiates them to the S/C. Commands can be generated in the Mission Support Area at the Jet Propulsion Laboratory (JPL) for transmission from a NASA-DSS or in the Mission Support Area at GSOC in Germany for transmission from the German Telecommand Station (GTS) or also from a NASA-DSS. In this case GSOC is called a Remote Control Center (RCC). The HELIOS Command System accepts the input representation for each command and translates it into the appropriate bit pattern. Translated commands are ordered and stored in a queue according to associated command data. The queue contains thirty queue elements. Each HELIOS command translates into a complete queue element containing the command bit string and associated data.

No queue element will be sent to a ground station unless it has been enabled. This is accomplished by a message entry by the command operator. Enabled queue elements will be sent to the appropriate ground station, by HSD blocks.

When queue elements are received by a ground station, they are placed as instructed within one of the four modules comprising the CMD-stack or into the manual buffer. This buffer which is available only at NASA-DSS-Station provides emergency storage. It can be accessed locally at the DSS or remotely by the MCCC (JPL).

The first queue element in the Prime Module is transferred to the active register and will be transmitted when the specified time of transmission arrives. The second queue element in the Prime Module (Module 1) then becomes the first queue element (the 3rd queue element becomes the 2nd, etc.).

When the queue elements in the Prime Module are all transmitted, the queue elements in Module 2 are transferred to the Prime Module, the queue elements in Module 3 are transferred to Module 2, and the queue elements in Module 4 are transferred to Module 3. At this point, more queue elements can be accepted from the Control Center queue.

At all times, the top of the queue represents the image of the CMD-stack. An enabled queue element can be *inhibited*: If the queue element is in the CMD-stack, it will be removed from the stack. However, it will still remain in the queue, but as not-enabled. If the queue element is in the Control Center queue only, it will remain there but as not-enabled. An inhibited or not enabled queue element may be *deleted*. From the preceding paragraph, it follows that only queue elements in the queue can be deleted. If a queue element is in the CMD-stack also, it is necessary to inhibit it before it can be deleted.

When queue elements are received by a ground station and stored in a stack-module, an image of that module is sent back to the Control Center along with a checksum. This checksum is used to verify that the proper queue elements were received by the ground station. This process is know as *acknowledgement.*

As a queue element is transmitted, the Command Modulation Assembly (CMA) modulation is detected, demodulated and compared with the stored queue element. If any error is detected, transmission of the queue element is aborted and commanding is inhibited until further instructions are received. An image of the queue element involved is then sent to the Control Center in a confirm/abort message. These messages supply the basis for the Command System Data Record (SDR).

The command operator may also initiate a recall request to cause a read-out of the queue elements stored in any one module of the CMD-stack.

A summary description of the HELIOS Command System is given in *Fig. 5.1-4.*

5.1.3.2 MODES OF OPERATION

There are three modes in which the Command System operates. The first is the *Automatic Mode.* Automatic basically refers to the use of the on-line-computer at GSOC or JPL as the automatic

DFVLR
GSOC

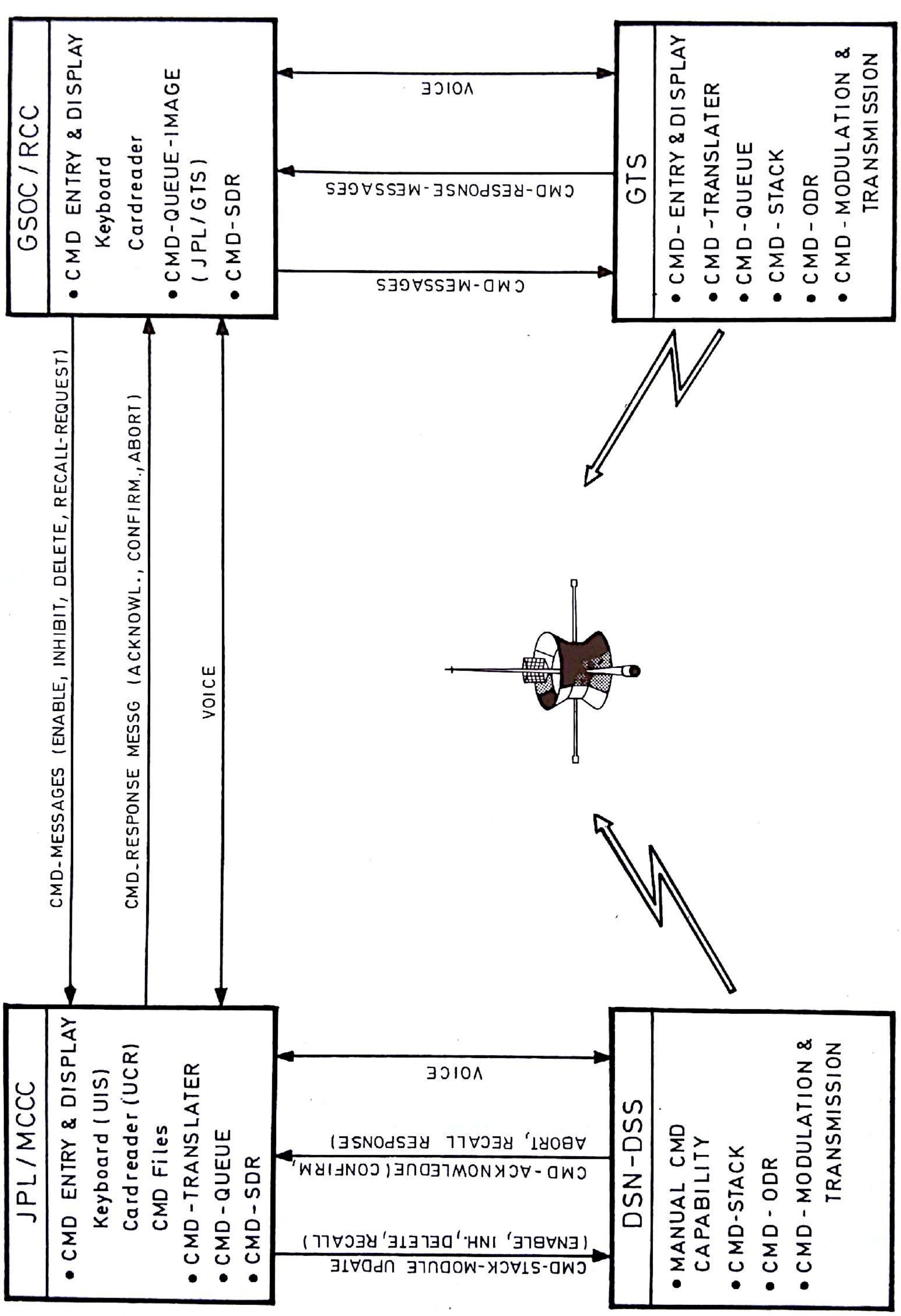


Figure 5.1-4: Helios Command System

command processor.
The second mode is the *Back-up Mode*. In this mode, commands will be transmitted to JPL via voice net from GSOC and there be input into the computer utilizing the UIS, or commands will be forwarded from GSOC to GTS via voice net and there be input via keyboard into the station computer.
The third mode is called *Manual Mode* and is normally used only in case of both S/C-emergency and Ground Data System break down. In this mode command instructions are transmitted from JPL or GSOC via voice net directly to the ground stations, where commands are manually entered into the manual buffer by their octal command designators. At GTS the octal command designators can be entered using a paper tape.
It is possible to send timed commands. Timed commands are radiated at the specified time which is part of the command message HSD-block. Non-timed commands are radiated immediately after enable or, in case that an enabled timed command is in the CMD-stack, immediately after the timed command was radiated.
At JPL/MCCC also exists the capability of command files. Such Command Files are assembled by the computer from punched cards which are manually loaded into a card reader in the Mission Control Area and can be used for automatic queue loading by adding an „offset-time". For HELIOS-B a similar capability exists at GSOC also.

5.1.4 ATTITUDE DETERMINATION R/T SOFTWARE

5.1.4.1 SYSTEM DESCRIPTION

The program package was operated on the IBM 360/75 R/T computers. A block diagramm of the attitude system is shown in *Fig. 5.1-5.*
The key element of the attitude program system was the Buffer Interface Program (BIP). This program established the interface between the HELIOS TLM and Tracking Data R/T processors and the attitude program modules.
The main function of the BIP was to build so-called Buffer Interface Records (BIR's) which contained selected TLM and AGC values. Optionally, the BIP performed a R/T time correlation function between TLM values and tracking data and placed the correlated tracking data in a BIR.
The BIR's were directed into two storage areas:

- In a circular buffer for access by the R/T program modules
- In a circular disk file for usage by the off-line program modules and for log tape generation purposes.

The BIP itself was activated/deactivated by manual input from a keyboard terminal. Once invoked, it started the BIR generation as mentioned above. Additionally it provided the following control functions via manual input:

- Start/stop of the R/T programe modules
- Parameter changes for the R/T modules
- Start of the off-line modules

5.1.4.2 DESCRIPTION OF R/T ATTITUDE PROGRAM MODULES

NUTOBS

This module was designed for sun sensor data evaluation. A certain set of data was accumulated and subsequently processed. The results provided were:

- Direction of angular momentum vector of S/C
- Nutation cone angle
- Range of spin rate
- Program status information

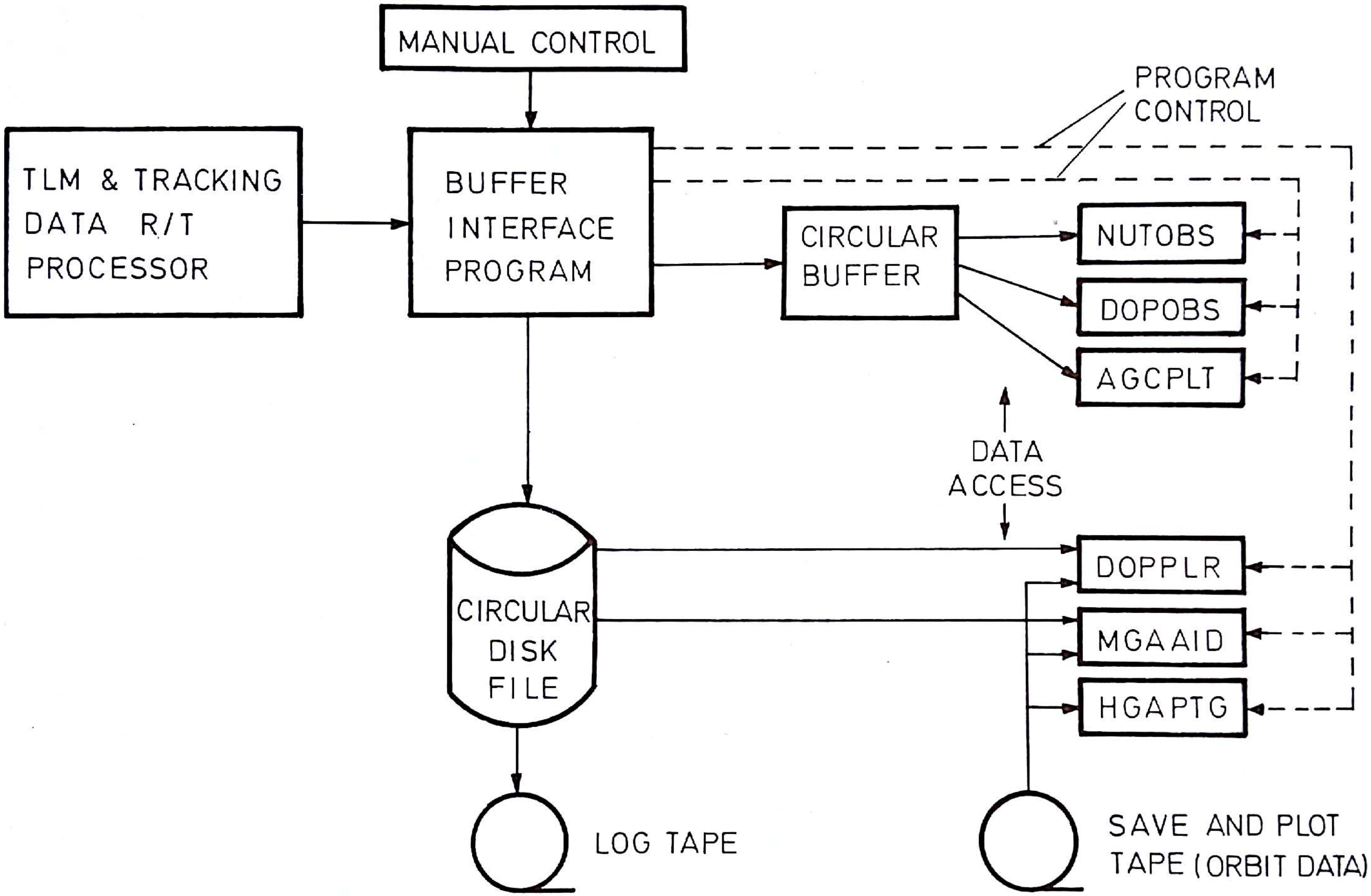


Figure 5.1-5: Attitude Determination Software System

The output was directed to a DTV format and a line printer format.
The Program was used throughout mission phase I.

DOPOBS

The purpose of this program was to process TLM and doppler data (Pseudo-residuals) and to provide an estimate of the amplitude of the doppler sine wave (introduced by the S/C horn antenna, *see also 6.4.11.1).*
This amplitude value and the information produced by the off-line program DOPPLER were the necessary inputs for the pitch angle determination procedure.
The program output was available on a DTV and a line printer format.
The program was used during the first part of the Step 2 maneuver.

AGCPLT

The program processed TLM and AGC data and provided a DTV-plot of ground receiver AGC versus pitch angle or number of precession commands. Besides that, link parameters and program status information were provided.
Due to the fact that plotting was only done during maneuvers the plot was basically an image of the S/C antenna pattern which was used to monitor the status of the Step 2 maneuver.
The output consisted of the plot mentioned above and a line printer format.

5.2 S.O.E. GENERATION PROGRAM CAPABILITIES

5.2.1 GENERAL

As described in other parts of this document *(section 2)*, a high number of test- and training sessions was to be performed during the preparation for the HELIOS-A launch and mission operations.
In order to generate the procedures for these sessions and to generate the rather complex launch Sequence Of Events (S.O.E.) *(section 6.)*, it was decided to use a computer program.
To show the size of the launch S.O.E.:
By means of this program approximately 1000 pages were generated just to cover the first four days of the HELIOS-A mission.
Also all test- and training - S.O.E's and later mission sequences were generated by use of this program.

5.2.2 CONSTRAINTS

Since the HELIOS-A launch- and initial operations had to be performed at NASA's JET PROPULSION LABORATORY in Pasadena, California, it was necessary to have the program operational there as well as at GSOC in Germany. In order to achieve that, the program was written in FORTRAN IV. Except for some special adaptions to the different computers, the same program was run at the CDC 3800 at GSOC and at the UNIVAC at JPL.

5.2.3 REQUIREMENTS TO THE PROGRAM

The primary purpose of the S.O.E. program was, to construct a listing of all events in the course of the operations in a time order and identified by a number.
The main portion of these events were commands to the spacecraft and subsequent checks of the returning telemetry for verification of the command. In addition, there were repetitive subsequences (Sequence Blocks), such as station handovers, data crosschecks and others.

The user of the program was to be able to:

- Call for such events at a certain time by using a simple code
- Specify these events in advance and record them in a „DATA BASE"
- Call for commands and verification within subsequences by a code.
- Sort the events by given characteristics such as importance to a certain subsystem expert, and suppress non important information.
- Recognize and incorporate the changing round trip light times in all time calculations.
- Adapt to the changing update-rate of telemetry channels depending on format and bitrate.
- Generate an output on the lineprinter to his desire.
- Refer to certain reference times such as launch, separation and others.

5.2.4 STRUCTURE OF THE PROGRAM

The following picture *(Fig. 5.2-1)* shows the simplified Input/Output (I/O) diagram for the S.O.E program.

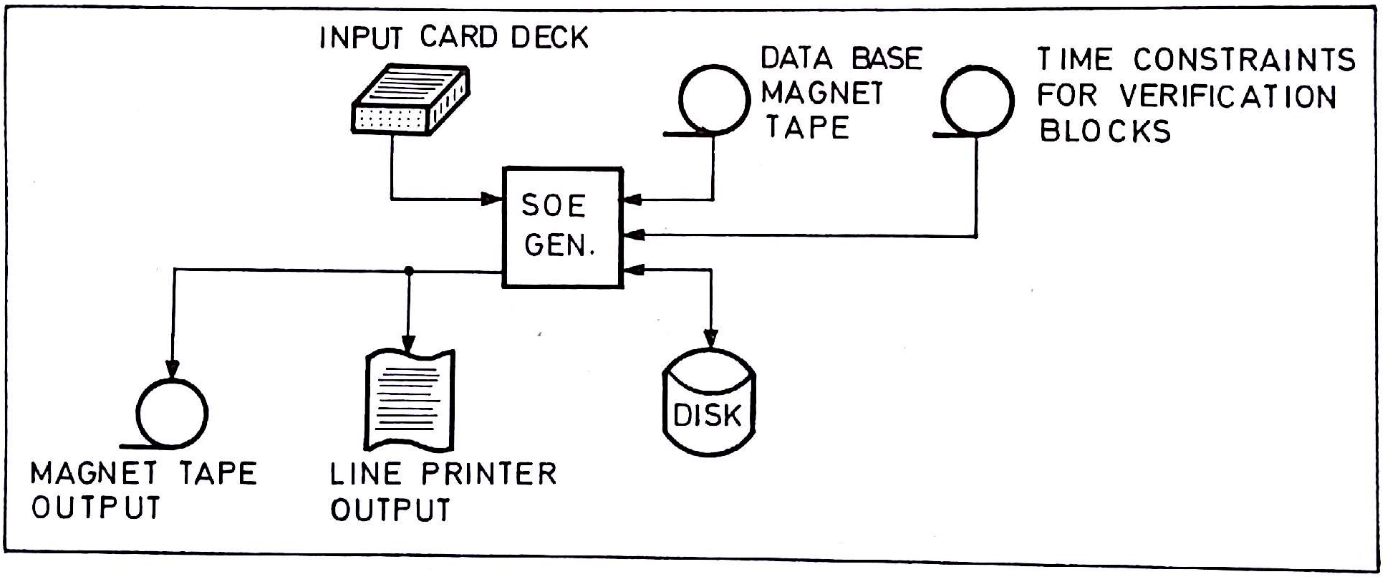


Figure 5.2-1: Input/Output Diagram

The first step in building the program was to generate a data base containing all possible HELIOS commands and their verification criteria. In addition so called subsequences were constructed.
This information was stored on magnetic tape and could be called within the program by simple codes.
Those codes were:

C and 3 digit number for commands
V and 3 digit number for verifications
S and 3 digit number for subsequences

For example C001 called CMD 001 with all its necessary information.
While setting up subsequences one could call for commands and/or verifications by using their codes. Since for HELIOS the return of telemetry for verification of a command is depending on the bitrate and

format modes and on the subcommutation of the engineering data, each verification block contained codes indicating the earliest possible and the worst case longest times. The actual times were precomputed for all possible bitrate and format mode combinations and stored on tape. The program was then told by a simple code, which combination was applicable at a time (e.g.: F1B 2048 stands for FORMAT 1 Bitrate 2048 BPS).
To actually run the program it was necessary to submit a deck of punched cards that contained the following:

- Specification of the Printout
  - Headline
  - Size
  - Number, size and contents of the columns
- Reference Times
  - Launch, Separation or GMT times
- Sorting criteria
- Round trip light times (to be used in computation of verification times)
- Format/Bitrate combination
- Actual Cards calling for commands etc.
- Single Event Cards
  Since not all events of the sequence could be precoded in „Blocks", it was necessary to input certain events on so called „Single Event Cards"
- Text Cards
  Cards of this type were printed out at the location in times where they occurred within the input deck.

Detailed explanation will be shown in the example.
After reading the input cards, the program checked which input information from the two tapes it needed. This information was then read from tape and stored on disc for random and fast access. The output was printed on lineprinter and in parallel written on a tape for later reproduction.
In the following a simple example will show some of the program capabilities and necessary inputs.

5.2.5 EXAMPLE FOR A SEQUENCE RUN

As mentioned above, the basic source for the program is the Data Base containing all information that could be predefined. An example for C- and V-Blocks of the Data Base for Command 106 is shown in *Figure 5.2-2.* The second source is a tape (file), that contains all verification time constraints.
These two sources are being used on all runs and usually are not modified (this can be done however in case of changes).
In addition the program works with three other input files:

- File No. 1 contains the values for the Round Trip Light Time for the period which is covered by the actual sequence
- File No. 2 specifies the actual sequence run (header, format, reference times and page numbering)
- File No. 3 defines the input, that will lead to the final sequence printout. An example is shown in *Figure 5.2-3.*

The final printout of the sequence for the short example defined in File No. 3 *(Fig. 5.2-3)* is shown in *Figure re 5.2-4.*

```
V106    A      B
    011         A+000000            CARSUP   HI    TX
      2         HIGH CARRIER SUPPRESSION                 TELECOM
    021                             *AGC     "     TX
      2         GROUND STATION RECEIVER AGC CHANGE TELECOM
    031                             *SNR     "     TX
      2         GROUND STATION RECEIVER                  TELECOM
      2         SIGNAL TO NOISE RATIO CHANGE
    041                             *DHMODE        D/H
      2         RESULT OF DH MODE LOGIC TEST SHOULDD/H
      2         BE NORMAL - LOG RESPECTIVE NUMBER
    051
      2         TELECOM REPORTS CMD 106-HICS             TELECOM
      2         VERIFIED TO CSFD
V106    E      F

C106    A
    011         A+000000  106-HICS
      2         HIGH CARRIER SUPPRESSION                 COMMAND
C106    E
```

Figure 5.2-2: Data Base Example for Command 106

DFVLR
GSOC

```
D                        H E L I O S  -  1     DSS-67/68   PASS 366
GMT          014  16  55  00
A067       S+000  00  00  00
E     001  S+000  00  00  00
         4         BITRATE 2048 BPS CODED HIGH CARRIER SUPPRESSION
         4         MED. POWER MODE / HIGH GAIN ANTENNA
P900       S+000  00  00  00
F1B2048M
C106       S+000  00  30  00
V106       S+000  00  30  00
C236       S+000  00  31  00
V236       S+000  00  31  00
A012       S+000  01  45  00
H6812      S+000  02  00  00
           S=
L067       S+000  00  05  00
C305       S+000  00  32  00
V305       S+000  00  32  00
```

Explanation:

D	gives the headline for the sequence printout
GMT	specifies the GMT-time for the sequence start
AO67	calls for a subblock that contains the AOS for station DSS-67
E....	specifies a so-called „single event"
P900	calls for a subblock that contains a printout requirement
F1B2048M	specifies format mode and bitrate (FM 1 BR 2048 bps)
C106	calls for a command block containing command 106
V106	calls for a verification block for command 106
C236 V236	same as for command 106
AO12	calls for the subblock that contains the AOS of station DSS-12
H6812	calls for the subblock that contains the handover between DSS-68 and DSS-12.
LO67	calls for the subblock that contains the LOS of station DSS-67
C305 V305	same as for command 106

Figure 5.2-3: File No. 3 and Explanations

HELIOS - 1 DSS-67/68 PASS 366 AOS CMD-CT:

ROUND TRIP LIGHT TIME 00:01:10 LOS CMD-CT:

ITM NR.	GMT DDD HH MM SS	CMD	MESS.NR.	CMD XMIT (ACT.) CHECK STATUS OF	REMARKS/ PRINTOUT REQUIREMENTS/ DESCRIPTION
001	014 16:55:00				AOS DSS-67
002	014 16:55:00				BITRATE 2048 BPS CODED HIGH CARRSUPR MED. POWER MODE / HIGH GAIN ANTENNA
003	014 16:55:00				SELECT MOD 30,31 32 TO 15 WITH TIME
004	014 17:25:00	106-HICS			HIGH CARRIER SUPPRESSION
005	014 17:26:00	236-8CON			EXP.8: INFLIGHT CALIBRATION ON
006	014 17:26:40			CARSUP HI	HIGH CARRIER SUPPRESSION
007	014 17:26:40			*AGC "	GROUND STATION RECEIVER AGC CHANGE
008	014 17:26:40			*SNR "	GROUND STATION RECEIVER SIGNAL TO NOISE RATIO CHANGE
009	014 17:26:40			*DHMODE	RESULT OF DH MODE LOGIC TEST SHOULD BE NORMAL - LOG RESPECTIVE NUMBER
010	014 17:26:40				TELECOM REPORTS CMD 106-HICS VERIFIED TO CSFO
011	014 17:27:40			INFCAL ON	EXP. 8 INFLIGHT CALIBRATION ON

Figure 5.2-4: Final Sequence of Events Printout

H E L I O S - 1 DSS-67/68 PASS 366 AOS CMD-CT:

ROUND TRIP LIGHT TIME 00:01:10 LOS CMD-CT:

ITM NR.	GMT DDD HH MM SS	CMD	MESS.NR.	CMD XMIT (ACT.) CHECK STATUS OF	REMARKS/ PRINTOUT REQUIREMENTS/ DESCRIPT ION
012	014 17:27:40				PAYLOAD REPORTS CMD 236-8CON VERIFIED TO CSFO
013	014 18:40:00				AOS DSS-12
014	014 18:50:00				DSS-68 CMD MOD OFF
015	014 18:55:00				DSS-68/DSS-12 UPLINK XFER
016	014 19:00:00				DSS-12 CMD MOD ON
017	014 19:00:00				LOS DSS-67
018	014 19:27:00	305-5BCL			EXP.5B: REFERENCE OSCILLATOR CALIBRATE
019	014 19:29:00			5BCAL ON	E5B CALIBRATION ON
020	014 19:29:00				PAYLOAD REPORTS CMD 305-5BCAL VERIFIED TO CSFO

Figure 5.2-4 (contd.): Final Sequence of Events Printout

5.3 HELIOS LINK PROGRAM

5.3.1 PURPOSE

The planning of optimal Helios telecommunication link configuration implies a selection among a variety of components:
For uplink configuration operations control has to choose among:

- 10 Transmitter (XMTR) stations or 6 different EIRP's
- 2 S/C receiver channels and
- 2 modulation modes

for downlink the selection has to be made among:

- 14 S/C XMTR configurations or 7 different EIRP's
- 10 S/C receiving stations with 4 different antenna sizes and more than 40 modulation modes, including
  - 10 bitrate modes
  - Convolutional encoding or not
  - Ranging modulation or not, as well as
  - Coherent or noncoherent S/C operation

This selection process should be simplified by the Helios link program providing also support and decision aids for

- Long term station scheduling
- Optimum configuration selection
- System checkout and failure detection

5.3.2 IMPLEMENTATION

The developed link program is able to accomplish all above defined requirements. Fed with orbital data it delivers calculations for AGC, SNR, maximum allowable bitrate and other significant link parameters for favorable, nominal and adverse conditions.
All output products, lineprinter forms or plots are automatically provided with legends identifying mode and configuration used for the calculations *(for examples see section 7.1.2).*

5.3.3 APPLICATIONS AND EXPERIENCES

The link program was previously designed for prediction of link parameters during the routine operation phases. The practice however showed, that because of

- Uplink (U/L) and Downlink (D/L) signal level fluctuations
- Ground Station calibration variations and
- Antenna elevation changes

the overall accuracy of the calculated values was not better than that obtained from manual extrapolation of real data (approx. 1..2 db).
Because of these disturbances, point by point comparison of calculated data with actual values was impossible. Therefore with great effort a software package had to be developed for selecting and averaging the desired actual parameters from telemetry and monitor HSD-logs. By using this method, the figures in *section 7.1.2* were produced.
On account of the mentioned accuracy limitations, the operational demands for predictions were more and more applied for non-routine phases:

- Phases with solar aspect angles smaller than 3 degrees
- Phases with attitude maneuvers

Exact calculations for the near sun phases were not very accurate because of the non predictable appearances of solar flares.
The full application of the program for attitude maneuvers like the Step II maneuver failed because of time shortage for the integration of an already developed mathematical model for the Low Gain Antenna (LGA) system, which was able to simulate the spin of the S/C.

6 SUMMARIZATION OF LAUNCH EVENTS

6.1 SEQUENCE OF EVENTS TIME LINE

The following graphics *(Fig. 6.1-1 to 6.1-4)* show the first 3 days after Helios-A launch. The major events are indicated as they actually occurred. The only two events not accounted for were:

— Malfunction of E-5 Antenna
— Switch to TWT High Power Mode at L + 14 HR (because of thermal reasons)

The malfunction of the E-5 Antenna led to extensive trouble shooting sequences which started on the 3rd day after launch (13.12.74) and were carried on until day 354 (20.12.74) with a total of 109 attempts to deploy the antenna which all were not successful.
All critical events were carried out by TEAM 1 consisting of S/C SUBSYSTEM EXPERTS trained for this task.

6.2 SEQUENCE OF EVENTS STRATEGY, CONSTRAINTS AND RULES

The generation of the final S.O.E. time line as displayed in *section 6.1 (Fig. 6.1-1 to 6.1-4)* was a joint effort of all involved organizations:

— Experimenters
— S/C builder
— L/V personnel
— Ground Station representatives
— Mission operations engineers

It was not always easy to integrate the sometimes contradicting requirements into an acceptable sequence.
The following strategy was applied to end up with a S.O.E. satisfying everybody:

- The S/C constraints overruled the experimenters desires
- All critical maneuvers had to be performed over the GOLDSTONE station because of the good accessibility from JPL
- Critical maneuvers were not carried over station handovers
- The time line for all critical actions (although sometimes very tight) had to have some slack time for unforseen events of the S/C or on Ground.
- All critical actions were performed by the most experienced teams (S/C Performance Analysis and Science Advisory teams)

As pointed out the S/C constraints overrode any Experiment desires during the initial configuration phase, this implied also that any S/C event which would not occur as planned, would have to be trouble shooted immediately (i.e. entering a prepared contingency sequence) before one would continue with experiment checkout configuration (which luckily had not to be applied on HE-A).
On the other hand, as much as possible, (as ground rule No. 1) all activities were arranged in sequence blocks which had an internal timing which had to be kept but the block could be shifted easily with respect to the absolute time line.
Typical HE-A S/C constraints were:

— Complete the Step I maneuver as soon as possible (thermal and power reasons)
— Turn on High Power Mode late (corona effects) but as soon as possible (thermal and link considerations)
— The spin rate had to be in the nominal range before the HGA could be turned on.
— Integrity check of all experiments and turn on of the so called „Near Earth Phase Experiments" before passing through the magnetopause.

Those constraints had to be considered not only within the nominal S.O.E. but also in every contingency sequence.
In addition to those constraints a lot of so called ground rules had to be observed. These were also con-

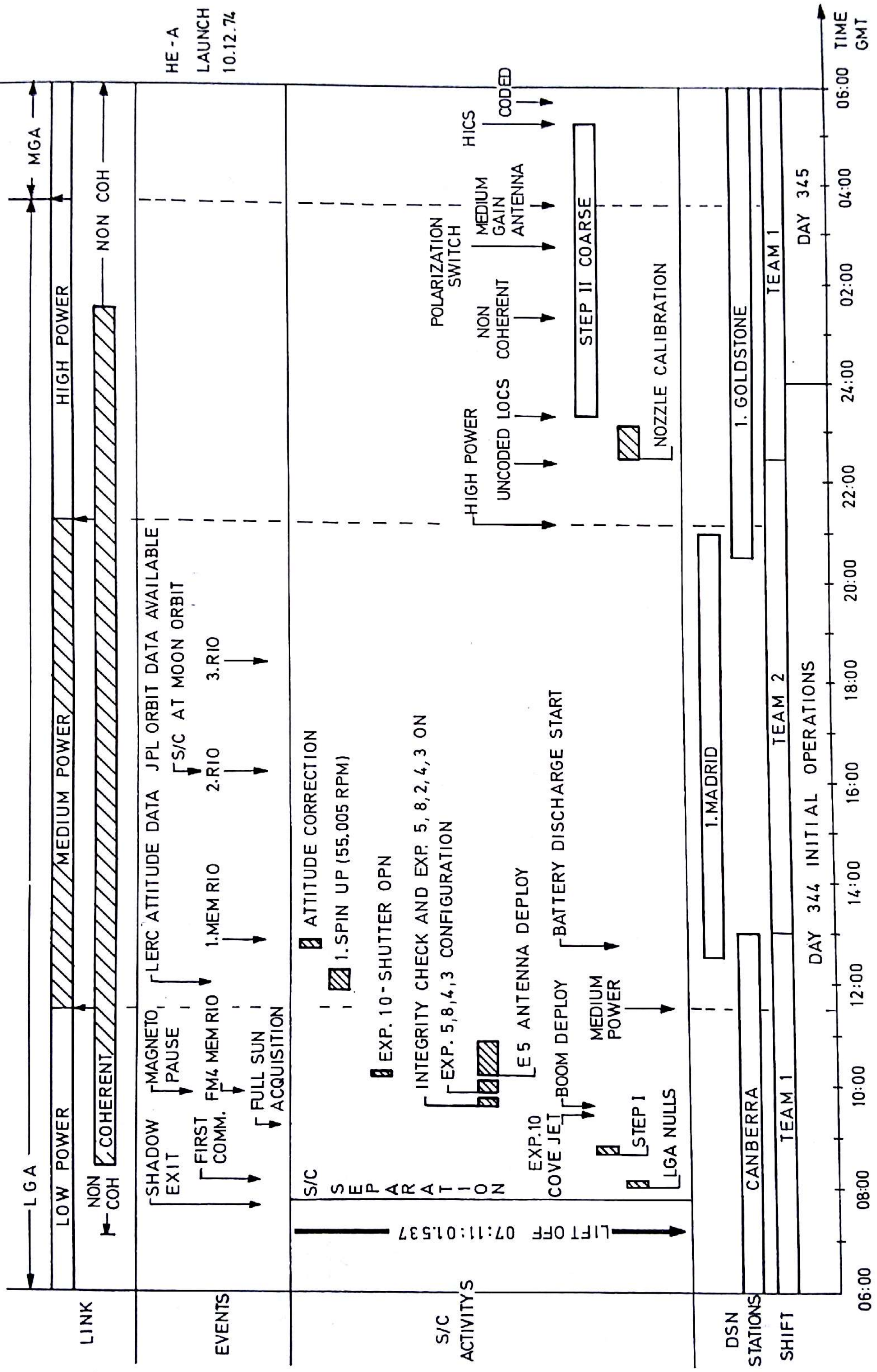


Figure 6.1-1: Launch and Initial Operations Time Line

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GSOC

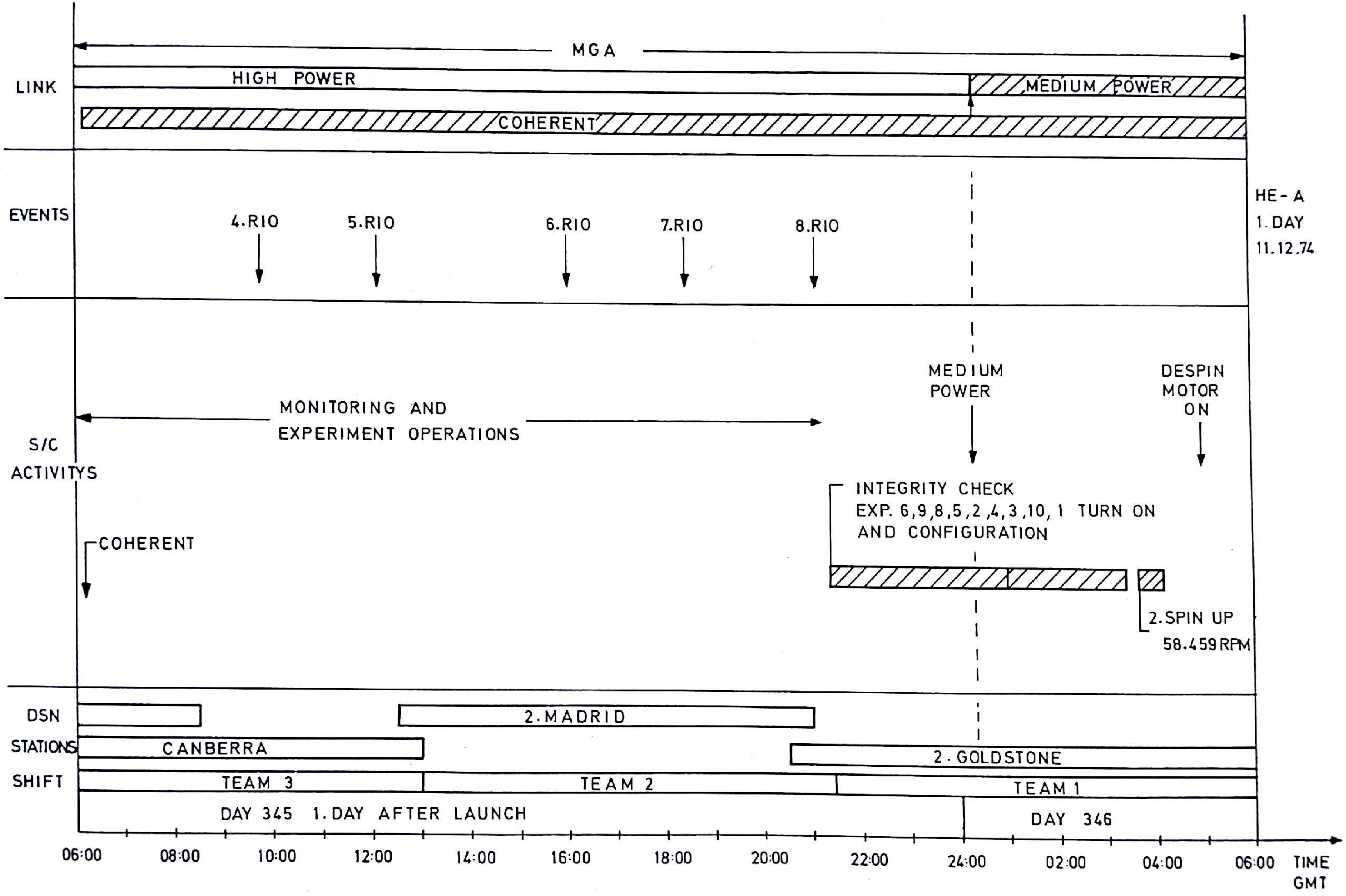

Figure 6.1-2: First Day after Launch Time Line

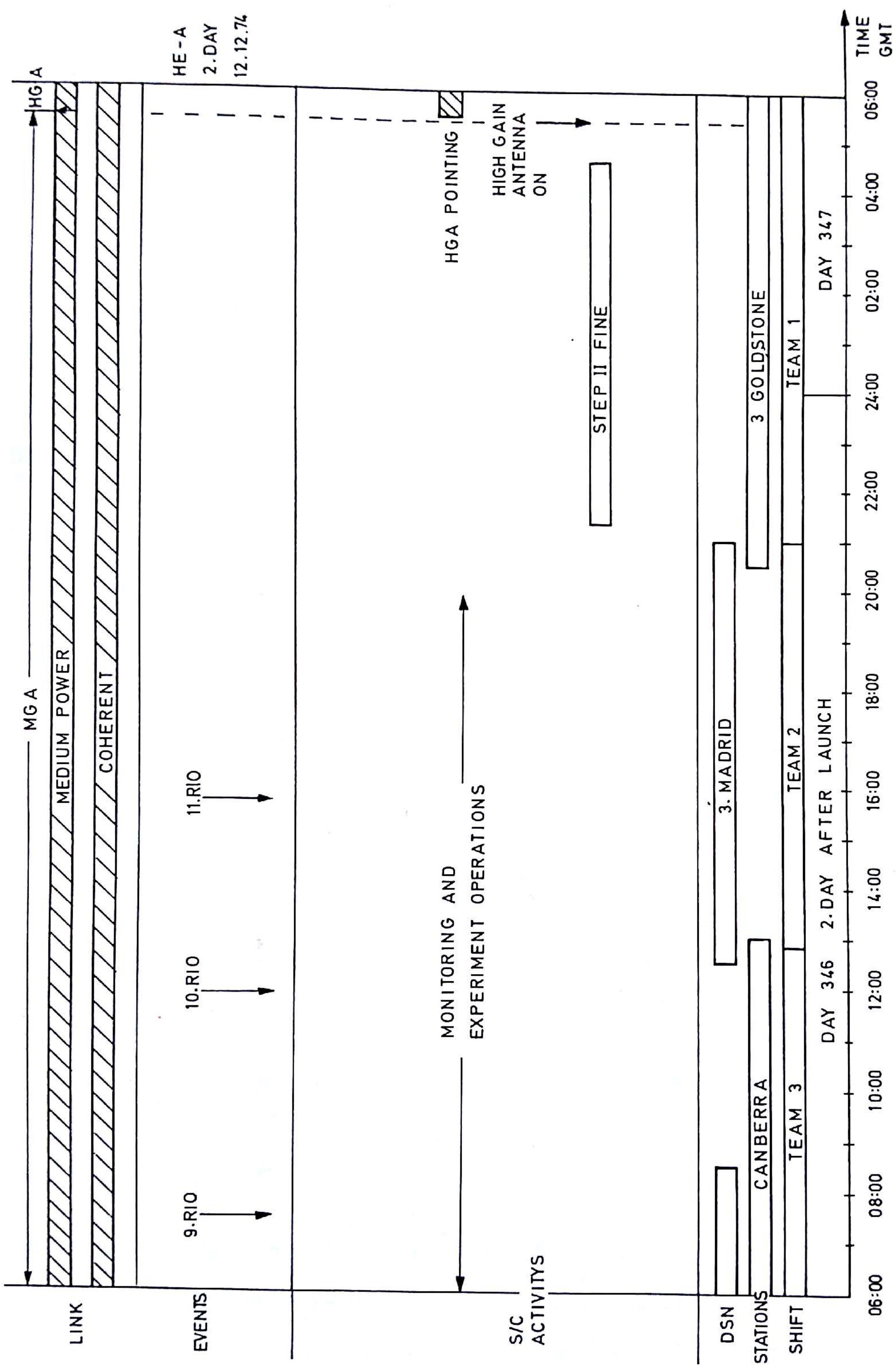

Figure 6.1-3: Second Day after Launch Time Line

DFVLR
GSOC

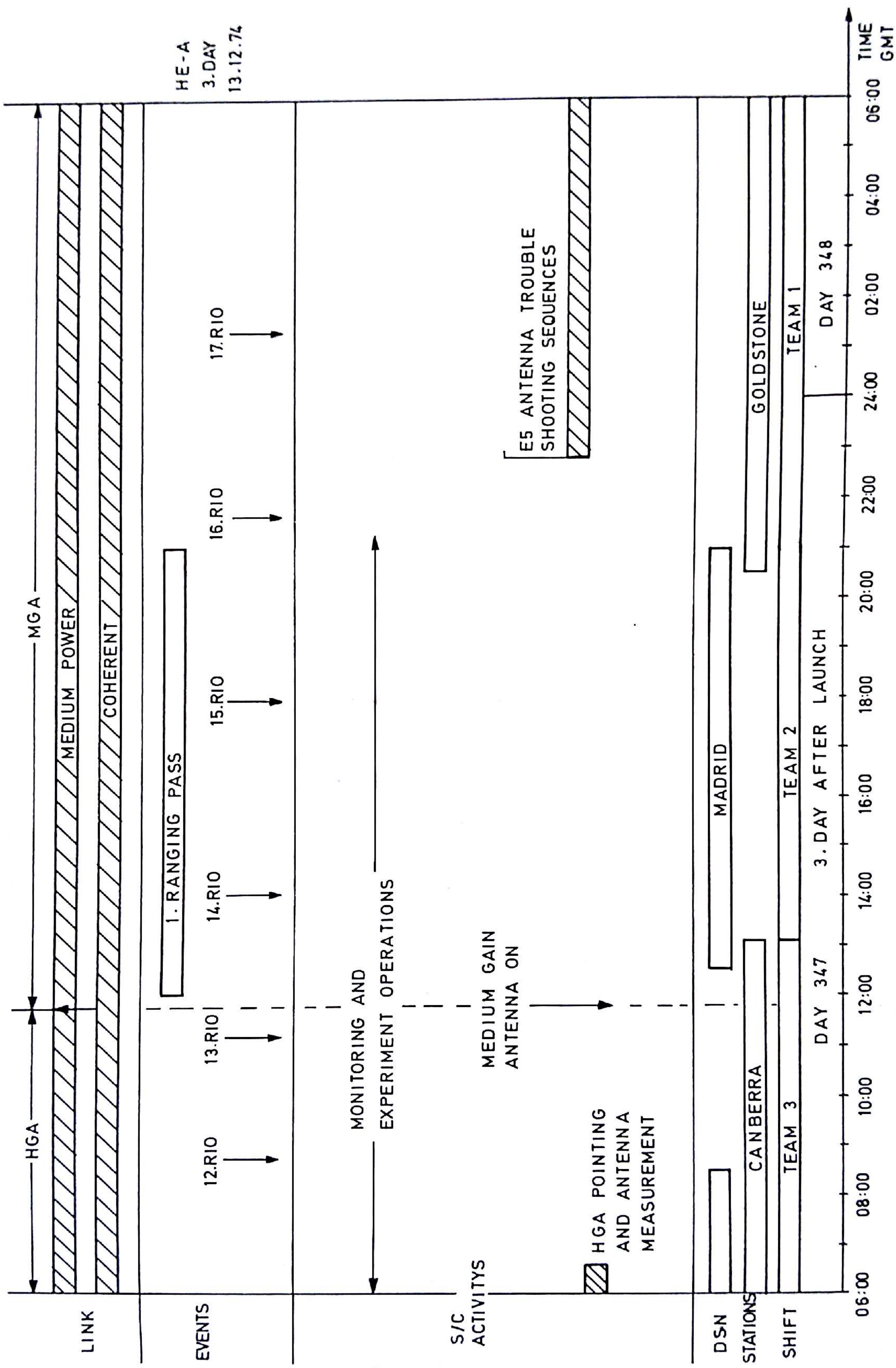

Figure 6.1-4: Third Day after Launch Time Line

straints which spun off from detected S/C design weaknesses which were not corrected on board but had to be handled on ground by operational means. Disregarding those ground rules would not be catastrophic to the S/C but could result in potential data losses.
Typical HE-A ground rules are:

- Do not perform word synchronous bitrate changes (loss of synchronization)
- Do not perform bitrate changes during memory read-in (no time correlation possible)
- A memory read-out shall only be performed over a network if the read-in was performed also partly over the same network (time correlation)
- Send certain experiment trigger commands after each mode change, because some experiments did not receive the mode change pulse
- Before a memory R/O is performed one has to be in the non-read-in mode (DM0) etc.

Another set of ground rules was established in flight because of S/C malfunctions:

- Switching between MGA and HGA whenever possible without impacting the data return (Multipactor effect)
- Operate the S/C in non- read-in mode for a certain time every day because one experiment was disturbed by the read-in current
- Command a distribution mode change after every B/O exit because the frame number counter gets hung up in Black-Out mode (DM5)
- Check Experiment 5 for coincidence of commanded and automatic calibration pulses (hang-up in the calibration cycle) etc.

So the S.O.E generation was not an easy job and its complexity asked for a computer program to do it in an economic, professional manner *(see section 5.2)*

6.3 INITIAL ACQUISITION

6.3.1 NEAR EARTH PHASE AND CONTINGENCIES

On December 20, 1974, at 7:11 hrs the TITAN CENTAUR with HELIOS-A as payload had lift-off. For about 40 minutes, until S/C separation, launch vehicle and S/C flew mechanically coupled together on a parking orbit in eastern direction.
During this common flight Near Earth Stations as well as special ship and aircraft receiving stations observed launcher and S/C performance. The received S/C telemetry data were immediately transferred to the HELIOS S/C analysis and operations team, situated at JPL in Pasadena.
Although the data coverage was not continuous, the received information revealed nominal S/C behaviour.
A further critical phase was endured with S/C separation from launcher stage TE 364-4. However, this maneuver passed normally. So DSS 42 could acquire S/C signal already near horizon, earlier than expected: an excellent result of DSN operations.
After establishing the command link and a short check-out the Step I attitude maneuver started: So the contingencies elaborated for eventual S/C emergencies *(see Figure 6.3-1)* needed not to prove completeness and accuracy.

6.3.2 STEP I/II MANEUEVERS FROM THE R/F POINT OF VIEW

During the Step I maneuver the S/C was moved automatically so that its spin axis was normal to the HELIOS - SUN line.
Pupose of the Step II maneuver was to rotate the spin axis about the SUN-line until the axis was perpendi-

DFVLR
GSOC

HELIOS TELEMETRY CONTINGENCY FOR NEAR EARTH PHASE

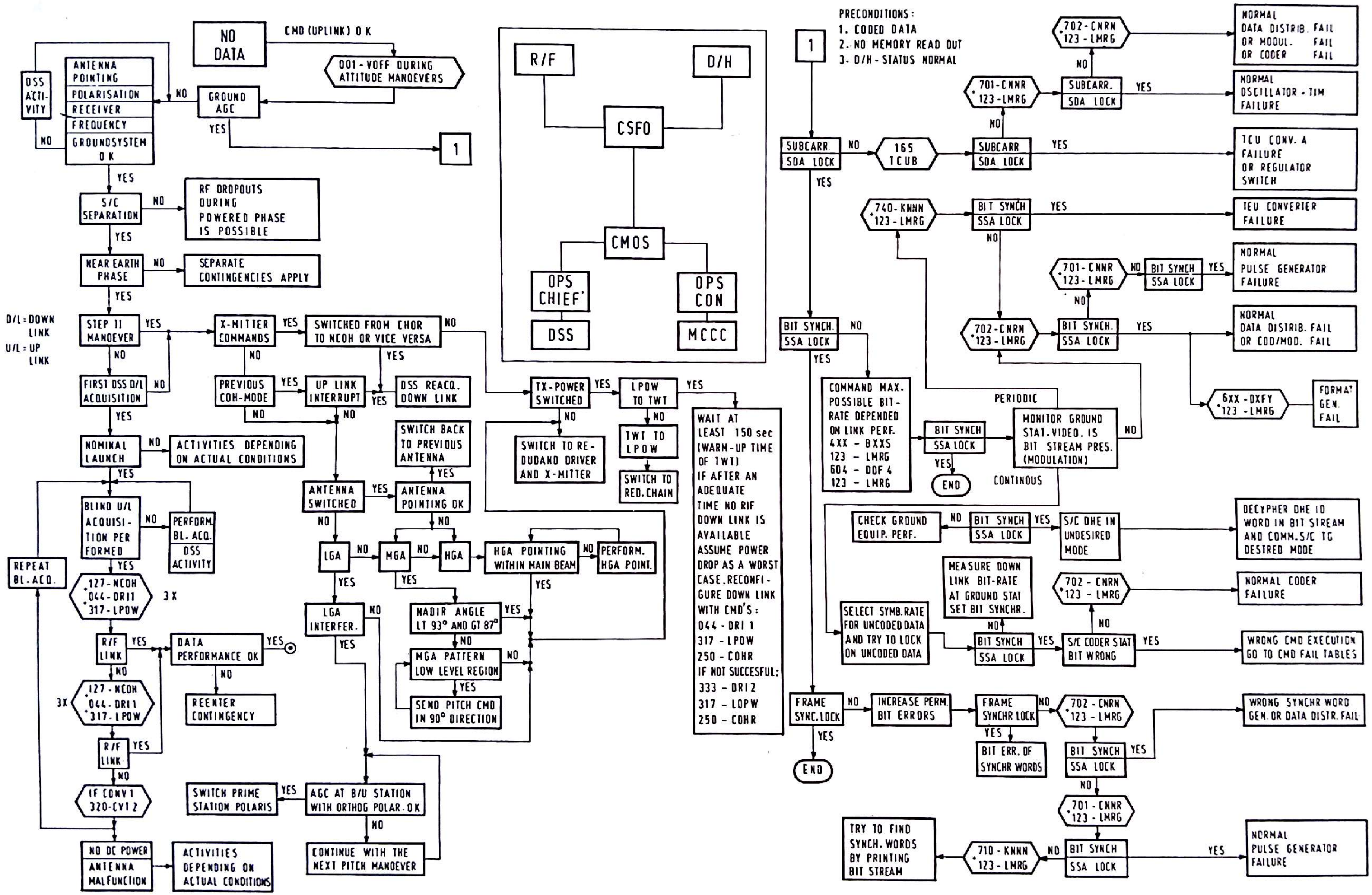

Figure 6.3-1: HELIOS Contingency for the NEAR EARTH PHASE

cular to the orbit plane. Thus, the Step II maneuver was an attitude maneuver, but because of the performance of the low gain antenna used for CMD and TLM operations during this phase, the maneuver had a very critical telecommunications aspect also.
The LGA, designed as a quasi omnidirectional antenna, consists of a dipole and a horn antenna. *Figure 6.3-2* shows the position of both antennas at the S/C body and their main radiation directions. *Figure 6.3-3* presents the radiation pattern of the LGA with the interference zone, the region where horn and dipole radiation overlap.
This interference zone with its deep dips of antenna gain must be crossed during the maneuver. A loss of uplink and/or downlink within this area was thought to be very dangerous for the further HELIOS mission. Thus the maneuver was realized with maximum ground station support as well as a special strategy concerning ground station antenna polarization:
Until begin of the interference zone prime (DSS 12) and back-up station (DSS 11) used linear horizontal antenna polarization. Then DSS 11 switched to linear vertical polarization: so while the critical region was crossed, one station used horizontal, the other vertical polarization. Afterward DSS 12, too, switched to vertical polarization.
Around end of the Step II maneuver the S/C transmitter was switched from LGA to MGA to admit attitude analysts to get more information about the reached actual spin axis direction.
Figure 6.3-4 shows the ground receiver AGC signal level profile of the Step II maneuver.

6.4 ATTITUDE MANEUVERS

6.4.1 INJECTION, S/C - TE 364-4 SEPARATION, INITIAL ATTITUDE

Shortly after a perfect orbital injection which occurred at 74 344 07:51 GMT the S/C was separated from the last stage of the launch vehicle.
S/C telemetry indicated a value of 74.5 ± 1° for the Solar Aspect Angle (SAA), the Spinrate (U) being 92.810 rpm. Both parameters were well in the range of the expected values. No nutation was observable within the accuracy of the coarse sun sensor.
The second attitude angle (Pitch Angle: PA) was unobservable at injection. However, it was later on determined from doppler measurements backed up by the LeRC attitude determination effort which was based on radar tracking and L/V (Centaur) guidance data. The PA values derived from both methods agreed rather well:

Doppler:	PA	=	(182.8 ± 1.5)°
LeRC:	PA	=	(181.8 ± 5.0)°.

6.4.2 STEP I MANEUVER

At 344 08:40 the Step I maneuver was initiated by a command which activated the precession nozzle 511 times. Subsequently, a closed loop maneuver was started which turned the S/C automatically to a desired SAA near 90°, namely 90.107°. A plot of both the coarse SAA and fine SAA is shown in *Fig. 6.4-1.*
Two types of crosscoupling affected the performance of the Step I maneuver:

- Roll commands decreased the spin rate (misalignment of precession nozzle). Based on the magnitude of the spin rate change (92.810 to 92.391 rpm) the misalignment was estimated to be in the order of 1°.
- Roll commands had an effect on the PA (timing error of precession nozzle). This effect was unobservable during Step I. It will be discussed in more detail *in 6.4.6.*

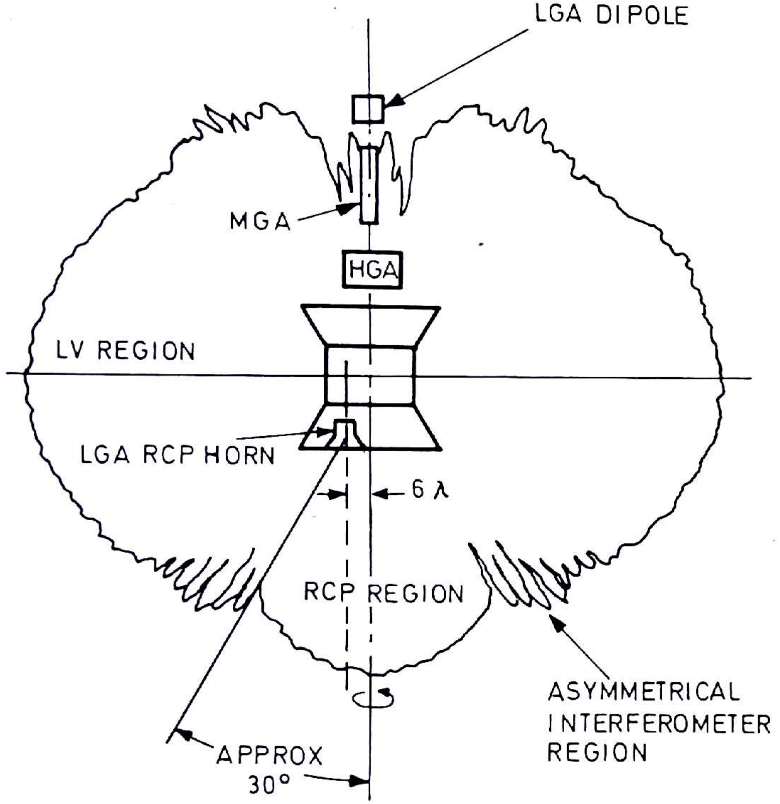

Figure 6.3-2: Low Gain Antenna Position

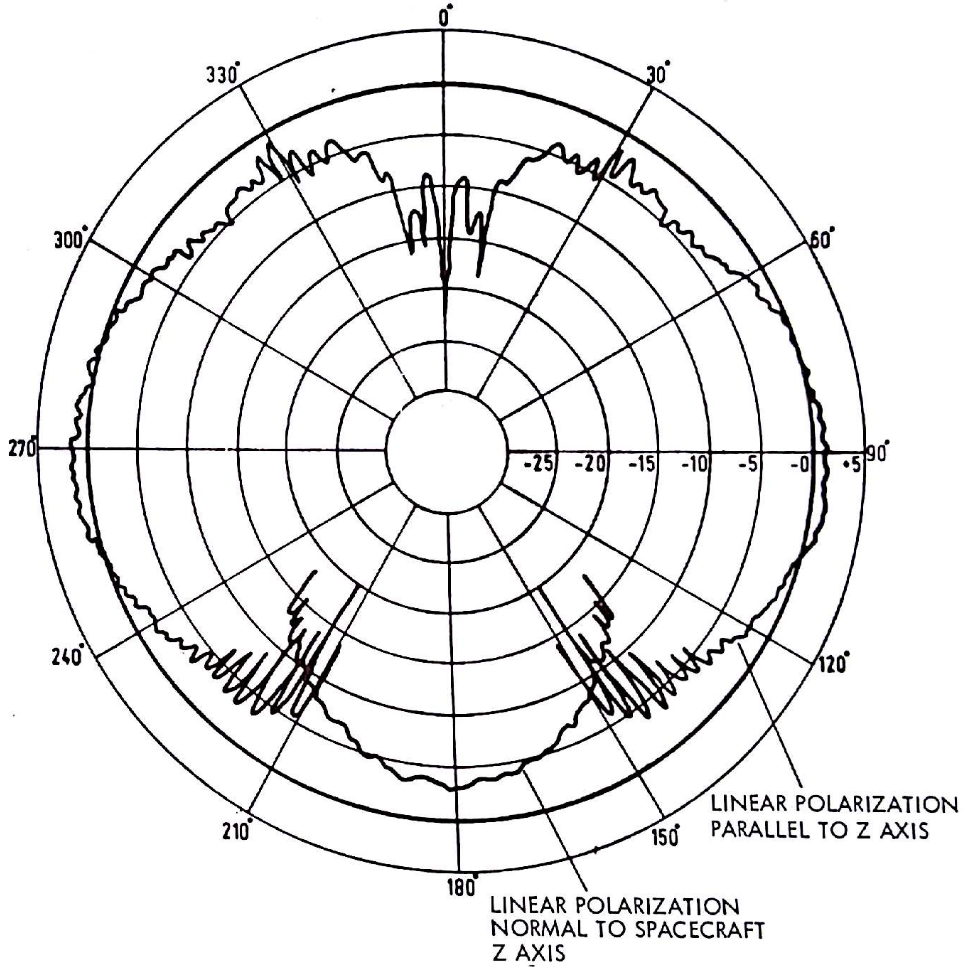

Figure 6.3-3: Low Gain Antenna Pattern

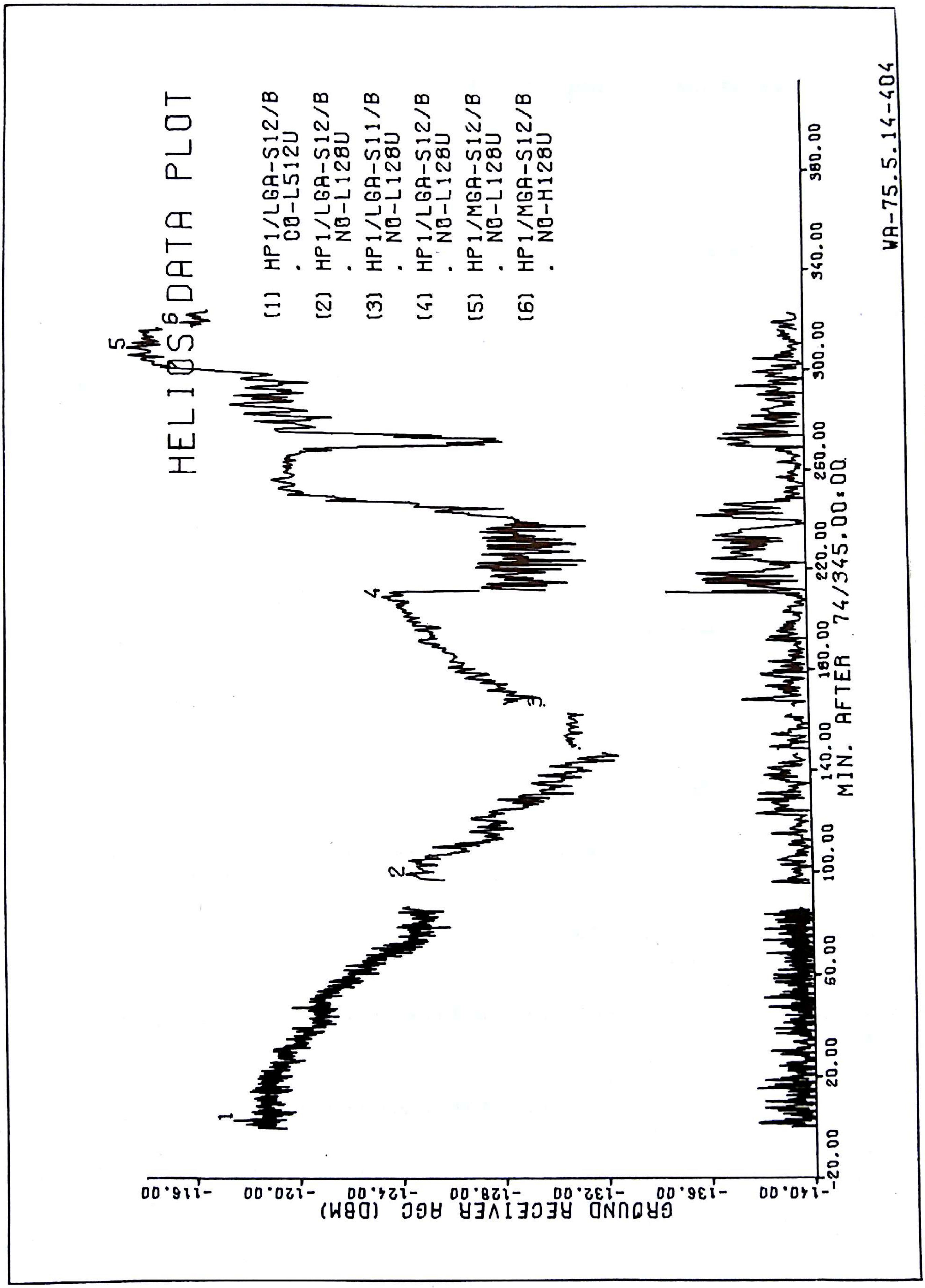

Figure 6.3-4: Ground Receiver AGC Level during STEP II Maneuver

6.4.3 MAGNETOMETER BOOM DEPLOYMENT

After the successful completion of the Step I maneuver the magnetometer booms were released at 344 09:25. The spinrate decreased to a value of 52.920 rpm which was close to the prediction. A detailed SAA evaluation revealed that due to the deployment a slight nutation (about 1° peak to peak) was induced and subsequently damped out in about 10 min. *(see Fig. 6.4-2).*

6.4.4 EXPERIMENT 5 ANTENNA DEPLOYMENT

The release of the antennas was initialized at 344 10:09 extending over a period of approximately 40 minutes. At the end it was obvious that this deployment maneuver was not successful. Besides the telemetry housekeeping values for the antennas which indicated a malfunction there was also attitude information showing that situation clearly *(Fig. 6.4-3)*

- The SAA changed from 90.106 to 90.301 , indicating an asymmmetric deployment of the antennas.
- the spin rate decreased to only 51.072 rpm, while a value of 49.3 rpm was expected based on predicted moments of inertia, again indicating that at least one antenna did not deploy completely.

As a result of this imperfect deployment the dynamic proportions of the S/C had been changed, i.e. the ellipsoid of moments of inertia had been tilted against its original orientation with respect to a body fixed coordinate system. Due to that the spin axis did no longer coincide with the S/C symmetry axis. This caused, among other things, a bias in the readings of the sun sensor. More details on that are provided *in 6.4.11.3*

6.4.5 SPIN UP MANEUVER No.1

In order to reach the desired spin rate for the Step II maneuver a sequence of 8 spin up commands was started at 344 11:54, each of them activating the nozzle during 16 S/C revolutions. After the last command the spin rate had reached a value of 55.005 rpm.

6.4.6. STEP II COARSE MANEUVER

At 344 21:20, shortly after the beginning of the first Goldstone pass, the preparations for the Step II maneuver were started, i.e. doppler measurements were taken at a sample rate of 1 per sec. in order to determine the initial pitch attitude. Subsequently a nozzle calibration maneuver sequence was carried out for the determination of the turn rate per precession command.

The initial attitude at the beginning of Step II was:

SAA = 90.108°
PA = 177.8°

The initial telecommunication configuration, partly determined by attitude determination purposes, was as follows:

- 2 way coherent link
- Horizontal DSS polarization
- S/C low gain (horn) antenna for both up and down link
- Bitrate 512 bps.

For configuration changes during the maneuver *see Fig. 6.4-4.*
At 344 23:37 the actual maneuver sequence was started and at 345 05:01 the Step II, the most crucial part of the initial maneuver phase, had been successfully completed. In the course of the maneuver the following commands were transmitted *(see also Fig. 6.4-4)*

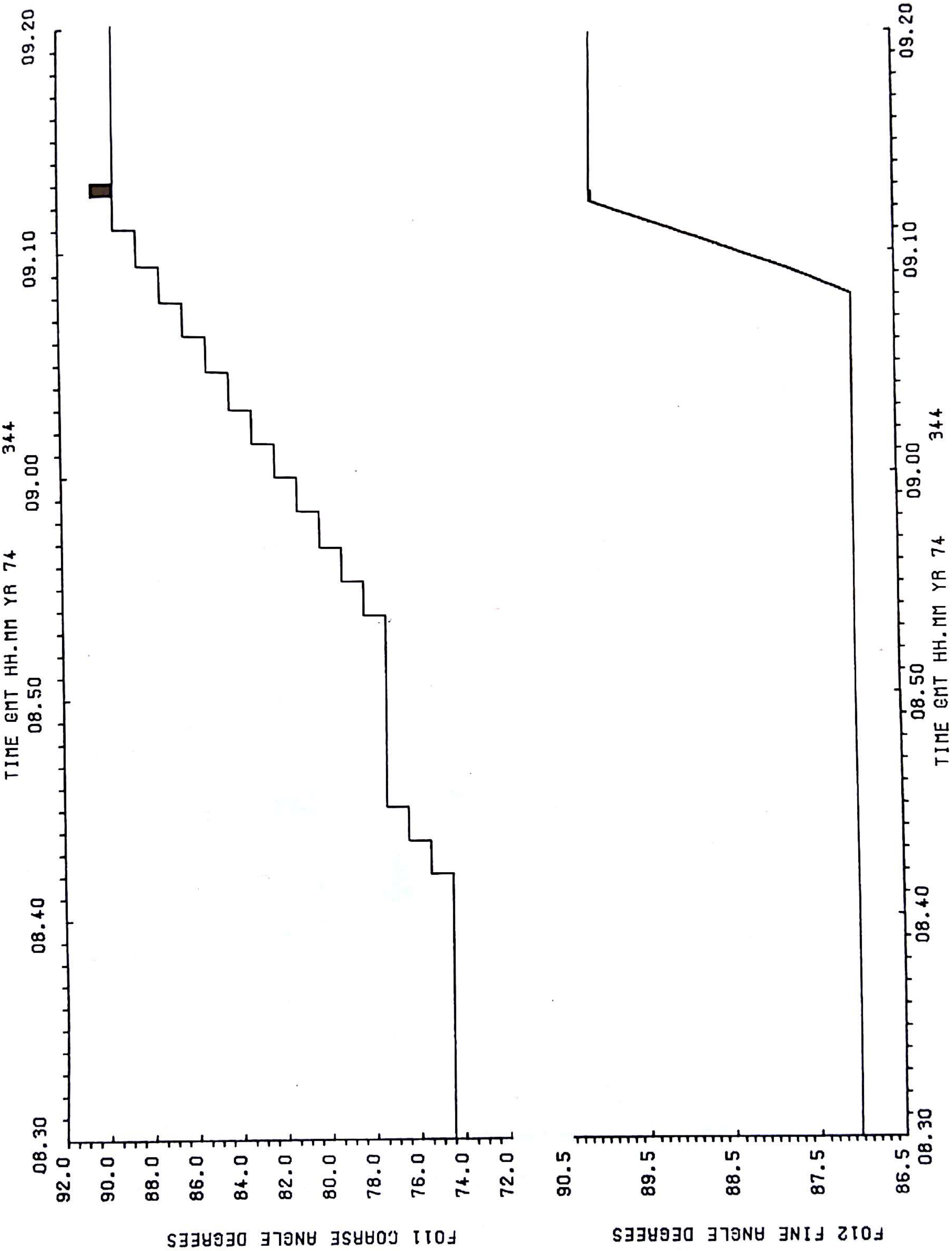

Figure 6.4-1: Coarse and Fine Sun Sensor Angles during Step I maneuver

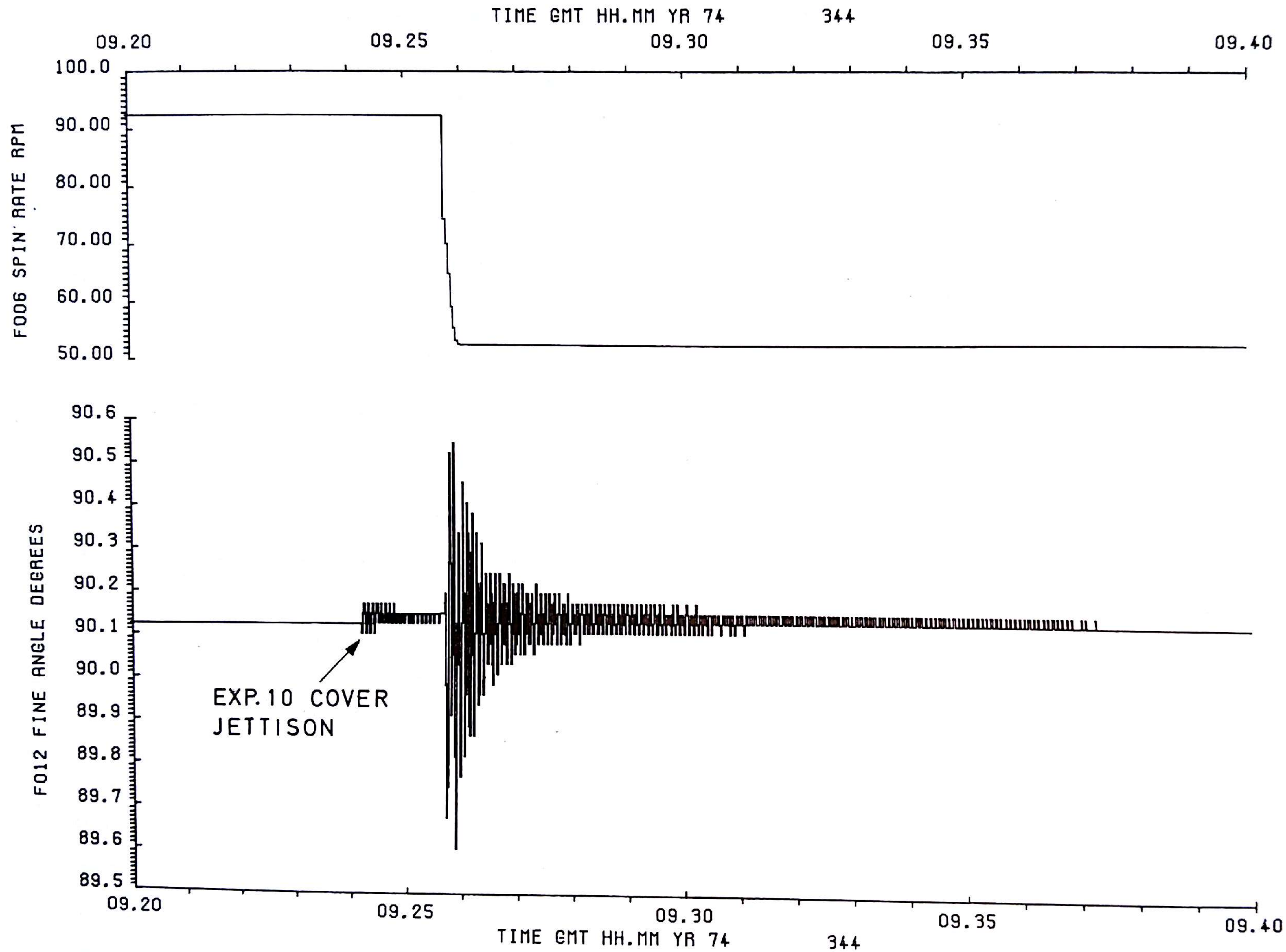

Figure 6.4-2: Experiment 10 Cover Jettison and Boom Deployment

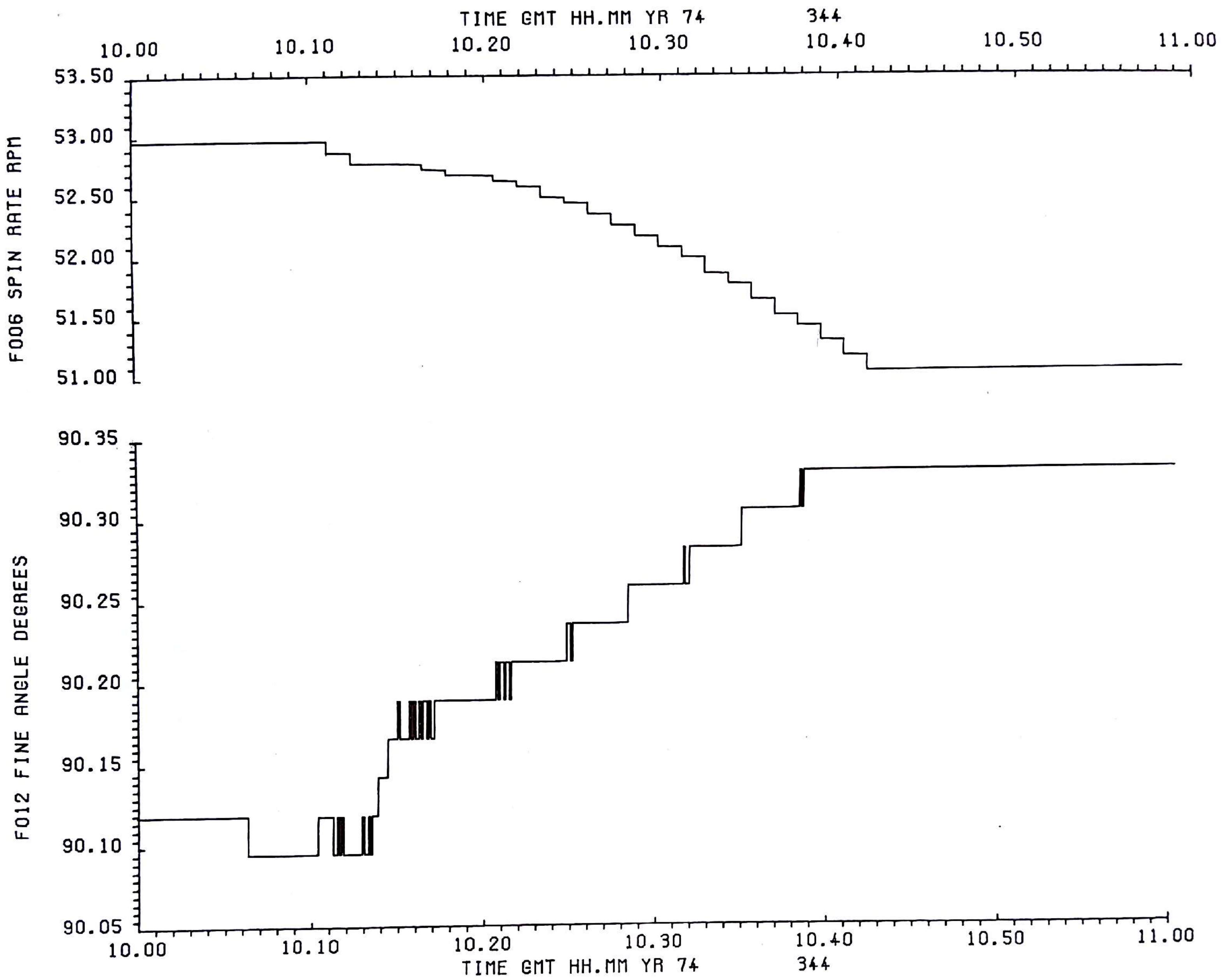

Figure 6.4-3: Experiment 5 Antenna Deployment

- 13 Pitch Positive (PP)
- 3 Closed Loop (CL)
- 2 Combined (CB).

As a result of this coarse part of the Step II the S/C attitude had changed to the following values:

SAA = 89.579°
PA = 92.7 °

Thus, according to the goal of the maneuver, the S/C had almost reached its cruise attitude establishing a safe communication capability via the main lobe of the medium gain antenna.
The specific difficulty involved in the Step II was that only the SAA was directly accessible by measurements. The PA was not observable in a similar way. Other sources had to be used to estimate the angle. This was achieved by using doppler information *(for a description of the method refer to 6.4.11)* and by R/T monitoring of the S/C low and medium gain antenna patterns by means of ground receiver AGC *(see Fig. 6.4-5, 6.4-6).*

Two crosscoupling effects influenced the performance of Step II:

- Roll ⟷ pitch crosscoupling, i.e. roll maneuvers change also the PA, pitch maneuvers change also the SAA.
  The 8 types of precession maneuvers which are available on HELIOS are all realized by one nozzle but different thrust timing. The observed coupling could be clearly identified as a result of incorrect timing. In order to determine an accurate estimate of the magnitude of the timing error an analysis was done using doppler measurements and SAA data. The average error was determined to be 32 ± 2msec.
  At 54.712 rpm (mean spin rate during the first 5 pitch positive commands of Step II) this timing error represents an 10.5° angular error. Due to this a decrease of the pitch angle of about 6° was accompanied by a decrease of the SAA by about 1°.
  During Step I, due to the higher spin rate, the crosscoupling was even stronger (17.8°), which means that the SAA increase of about 15.5° decreased the PA by about 5°.
- Precession ⟶ spin crosscoupling, i.e. precession maneuvers affect the spin rate.
  As already mentioned *in 6.4.1.* this effect has its explanation in a misaglignment of the precession nozzle in the order of 1°.
  For spin rate changes due to this effect during the Step II maneuver (1.4 rpm total). *see Fig. 6.4.-7.*

6.4.7 SPIN UP MANEUVER No.2

Upon request of the experimenters a sequence of 10 spin up commands was started at 346 03:40 (2nd Goldstone pass), each of them activating the nozzle during 16 S/C revolutions. The spin rate was increased from 53.613 to 58.459 rpm. This value was already close to the cruise spin rate (60 ± 1) rpm).

6.4.8 STEP II FINE MANEUVER

During the 3rd Goldstone pass a sequence of roll and pitch commands was started at 346 21:20 in order to do the final S/C spin axis adjustment. The method which was used is described *in 6.4.11.*
The planned maneuver sequence was performed. However, due to the relatively high noise level of the AGC data the applied procedure did not provide the desired accuracy improvement of spin axis orientation.
In order to gain improved knowledge of the S/C attitude a sun sensor data reduction process was started which provided the following results:

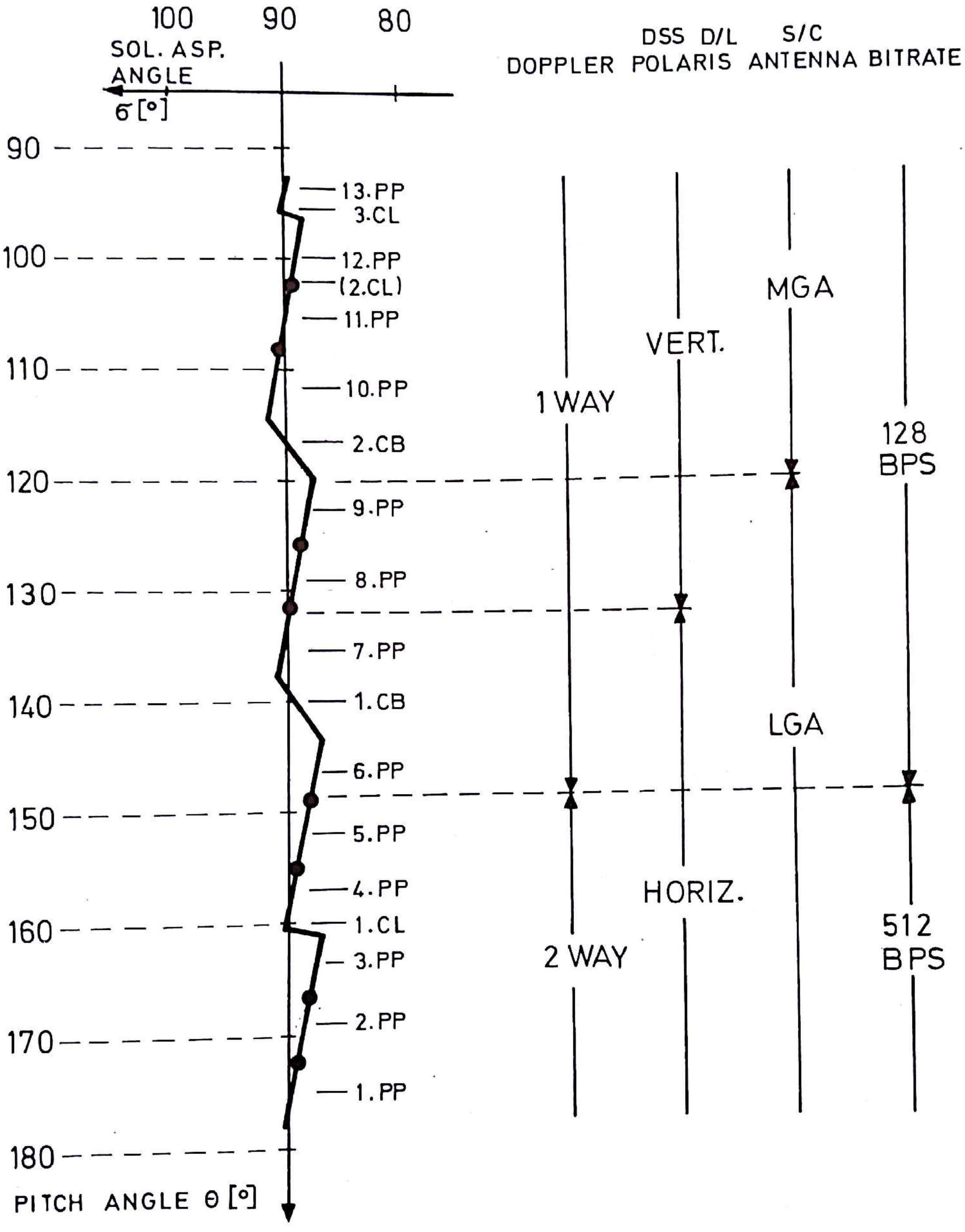

Figure 6.4-4: Step II Maneuver Graph

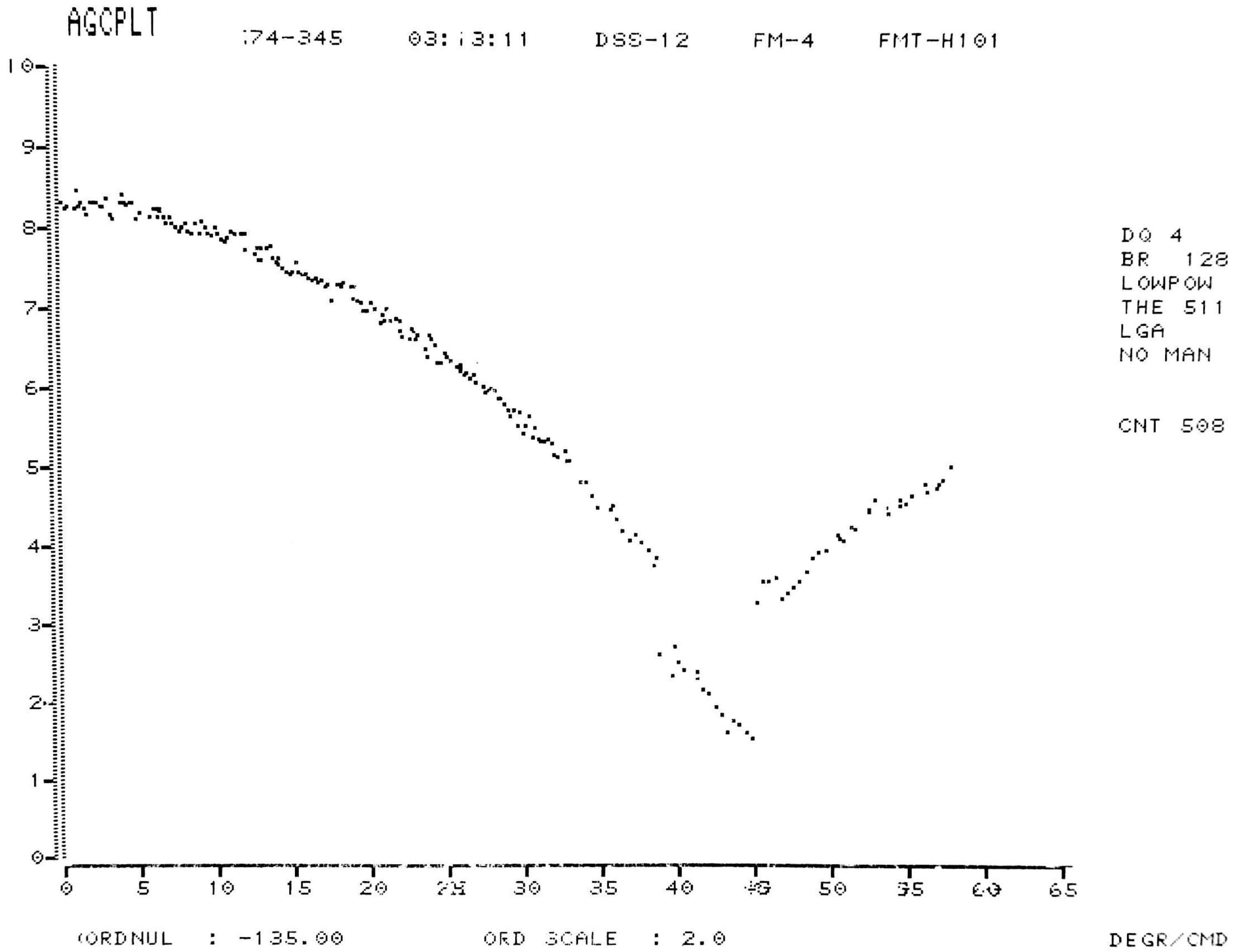

Figure 6.4-5: S/C Low Gain Antenna Pattern

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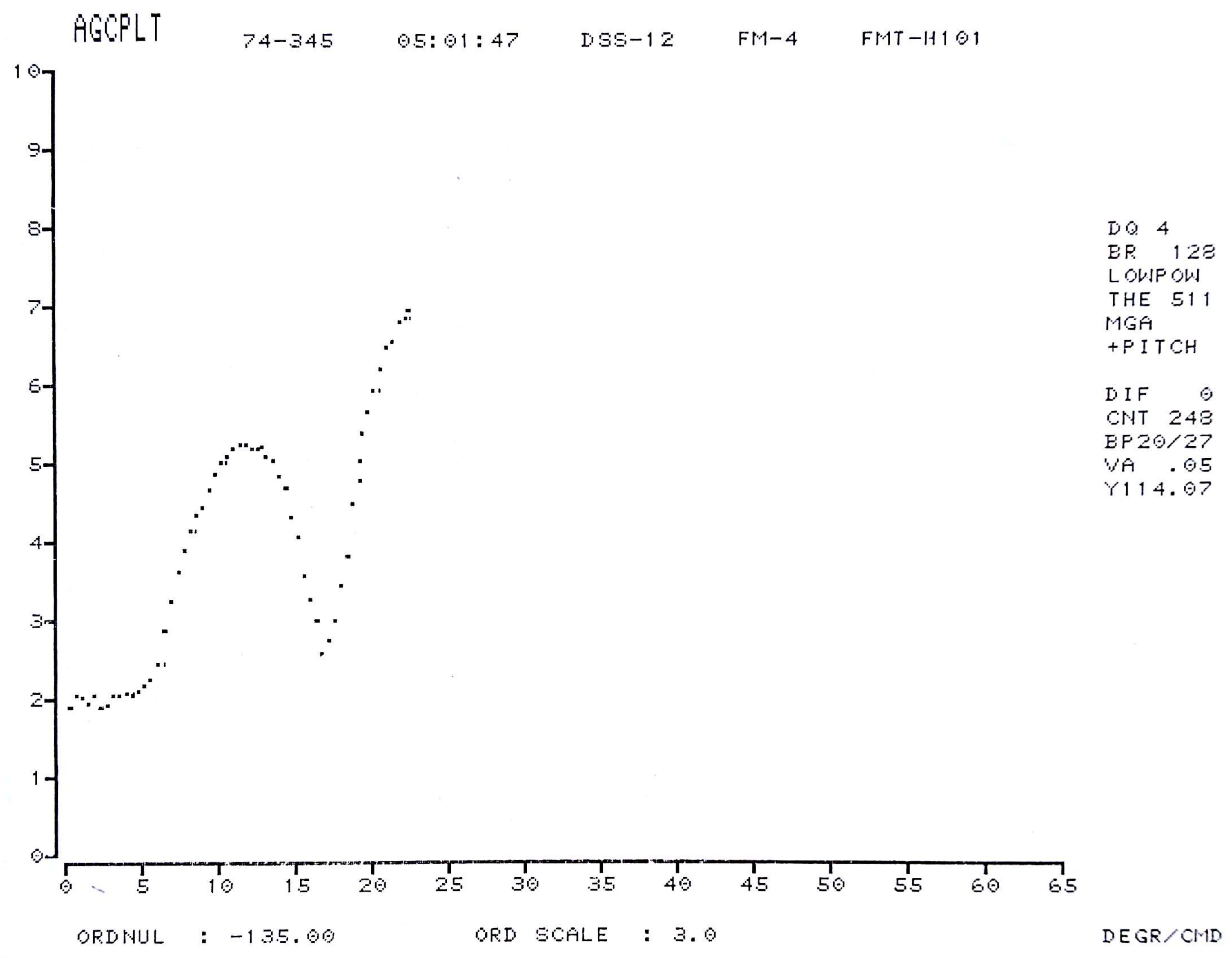


Figure 6.4-6: S/C Medium Gain Antenna Pattern

DFVLR
GSOC

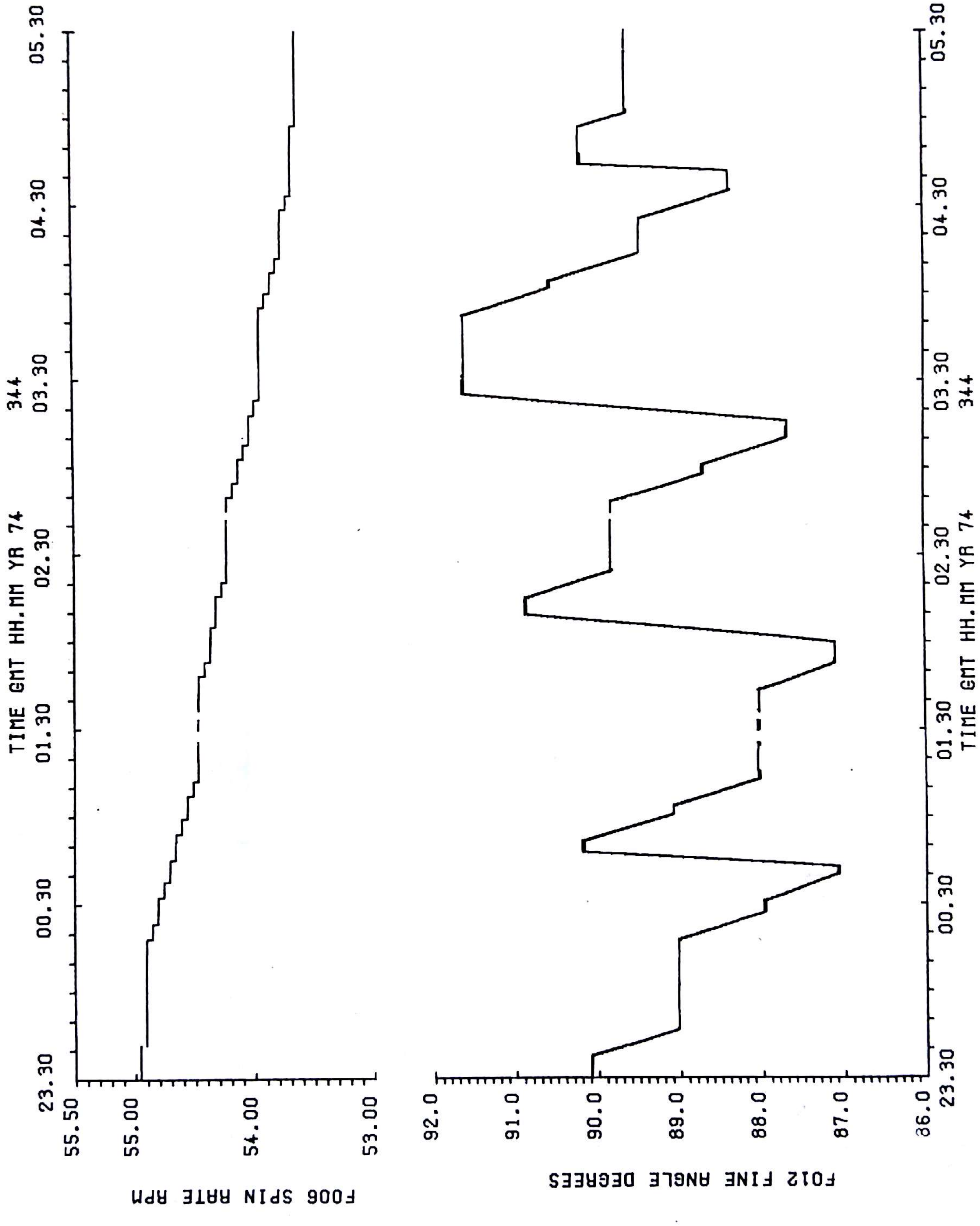


Figure 6.4-7: Spinrate and Fine Sun Sensor Angle during Step 2 Maneuver

SAA = 89.555°
PA = 90.5°.

With these values being within the range of nominal attitude, no further corrections were necessary and therefore, at the end of Step II fine, the S/C had reached its cruise attitude.

6.4.9 HIGH GAIN ANTENNA SWEEP MANEUVER

In order to determine a possible offset between nominal and actual main radiation direction of the high gain antenna a similar sweep maneuver as was used during Step II fine, was applied here too.
However, the same high noise level was observed on high gain antenna AGC data and it was impossible to determine an offset as mentioned above.

6.4.10 FINAL SPIN UP MANEUVER

A sequence of 6 spin up commands was transmitted between 354 19:40 and 354 21:20. They increased the spin rate from 58.292 to 60.354 rpm which was the target rate as selected for the benefit of Experiment 5.
This spin up terminated the initial maneuver phase the goal of which was to bring the S/C in full cruise condition.

6.4.11 EXPERIENCE GAINED, RECOMMENDATIONS

There are two basic topics which will be considered in this chapter:

- Use of doppler data for attitude determination purposes
- Final attitude adjustment using AGC data measurements

The first part will be discussed *in 6.4.11.1. through 6.4.11.3.*, the latter *in 6.4.11.4.*

6.4.11.1 GENERAL DESCRIPTION OF DOPPLER METHOD

In the case of a spinning S/C each R/F radiation center which is not located on the rotation axis produces a sinusoidal wobble with the period of the spin, on top of the slowly varying doppler shift which is caused by the orbital motion of the S/C.
As shown in *Fig. 6.4-8* the attitude dependent angle Ψ determines how much of the linear velocity of the radiation center is actually visible in the observation direction, i.e. the angle Ψ determines the amplitude of the doppler shift. *Fig. 6.4-9* shows a typical plot of doppler amplitude vs.PA (V-shaped set of curves). The other set of curves in *Fig. 6.4-9* (step function shape) is a plot of doppler phase difference between a doppler sine zero crossing and a reference mark (see sun pulse). The phase parameter contains additional attitude information and can be used to resolve the angular ambiguity which is there if evaluating the amplitude only *(see Fig. 6.4-9).*

6.4.11.2 APPLICATION OF DOPPLER METHOD TO THE STEP II MANEUVER

The excentricity of the radiation center of the HELIOS horn antenna was about 0.8m. The resulting spin wobble produced doppler amplitudes up to about 30 Hz. Taking into account the integrating characteristics of the doppler counter then there still remains an amplitude of about 3 Hz under the conditions of a 1/sec sampling rate, a 2-way coherent S-band link at 2115 MHz and a spin rate of 55 rpm.
This is a clearly visible signal *(see Fig. 6.4-10, 6.4-11)* which was used for PA determination purposes.

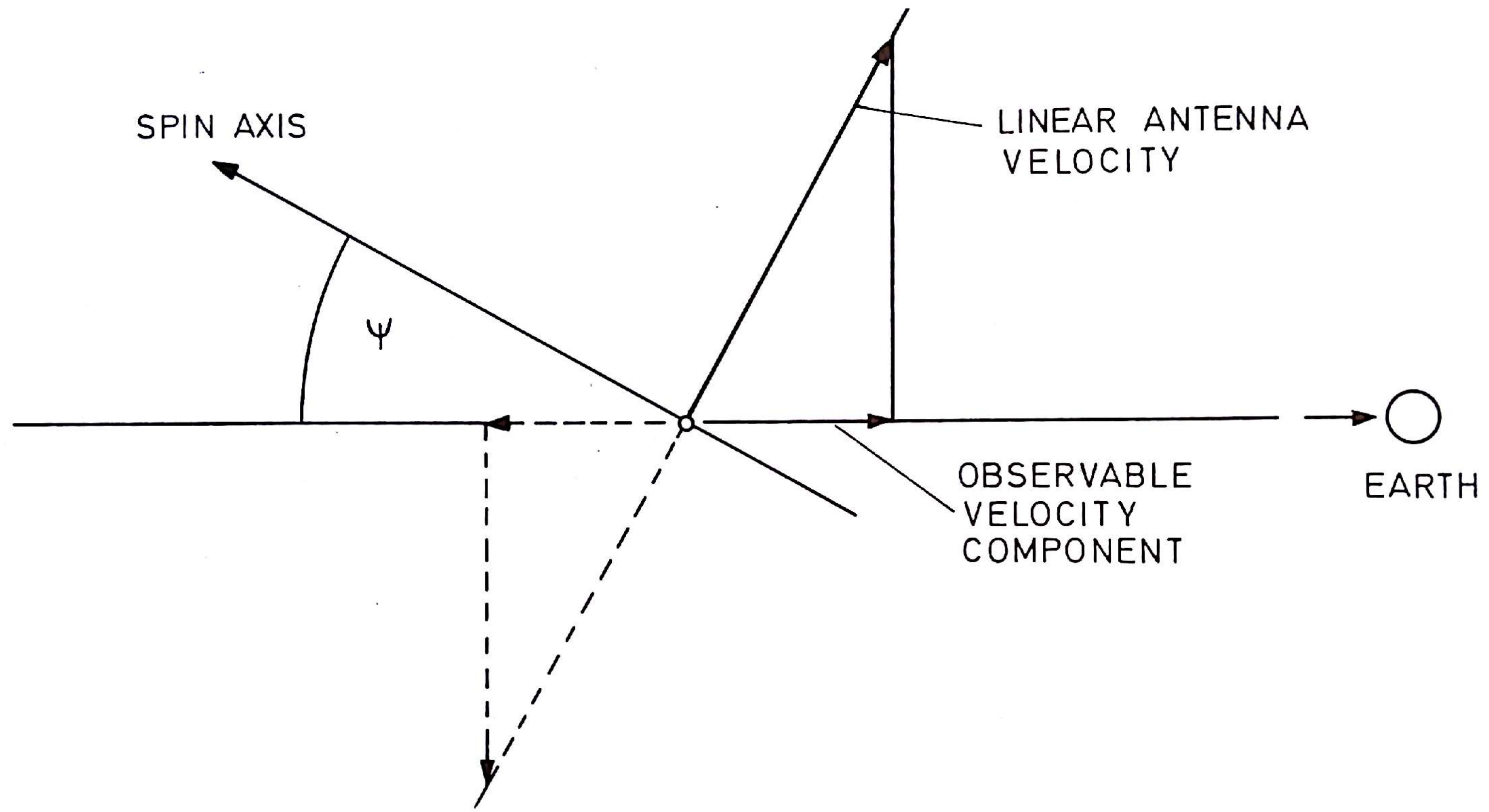


Figure 6.4-8: HELIOS Horn Antenna as a Doppler Source

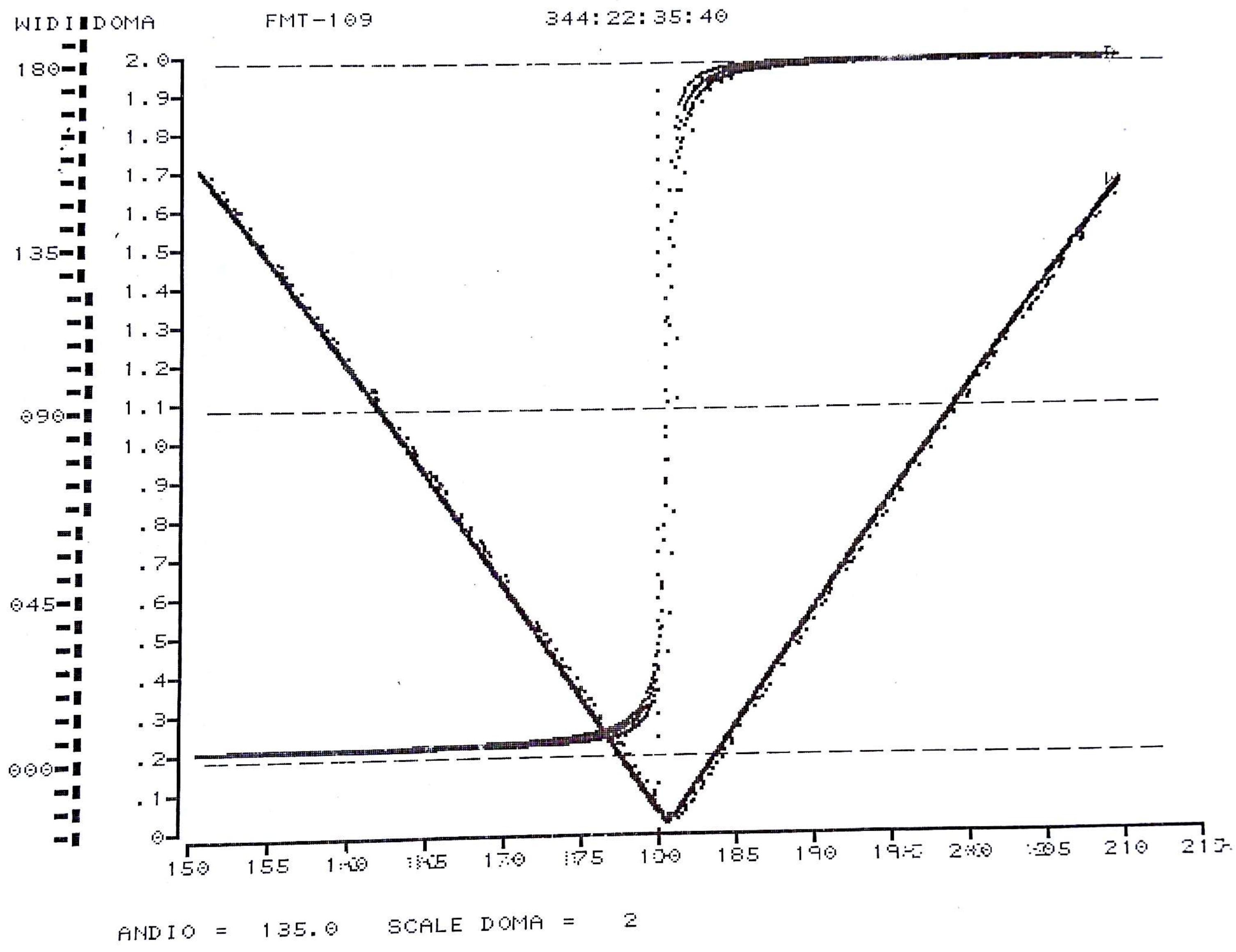


Figure 6.4-9: Doppler Amplitude and Phase vs. Pitch Angle

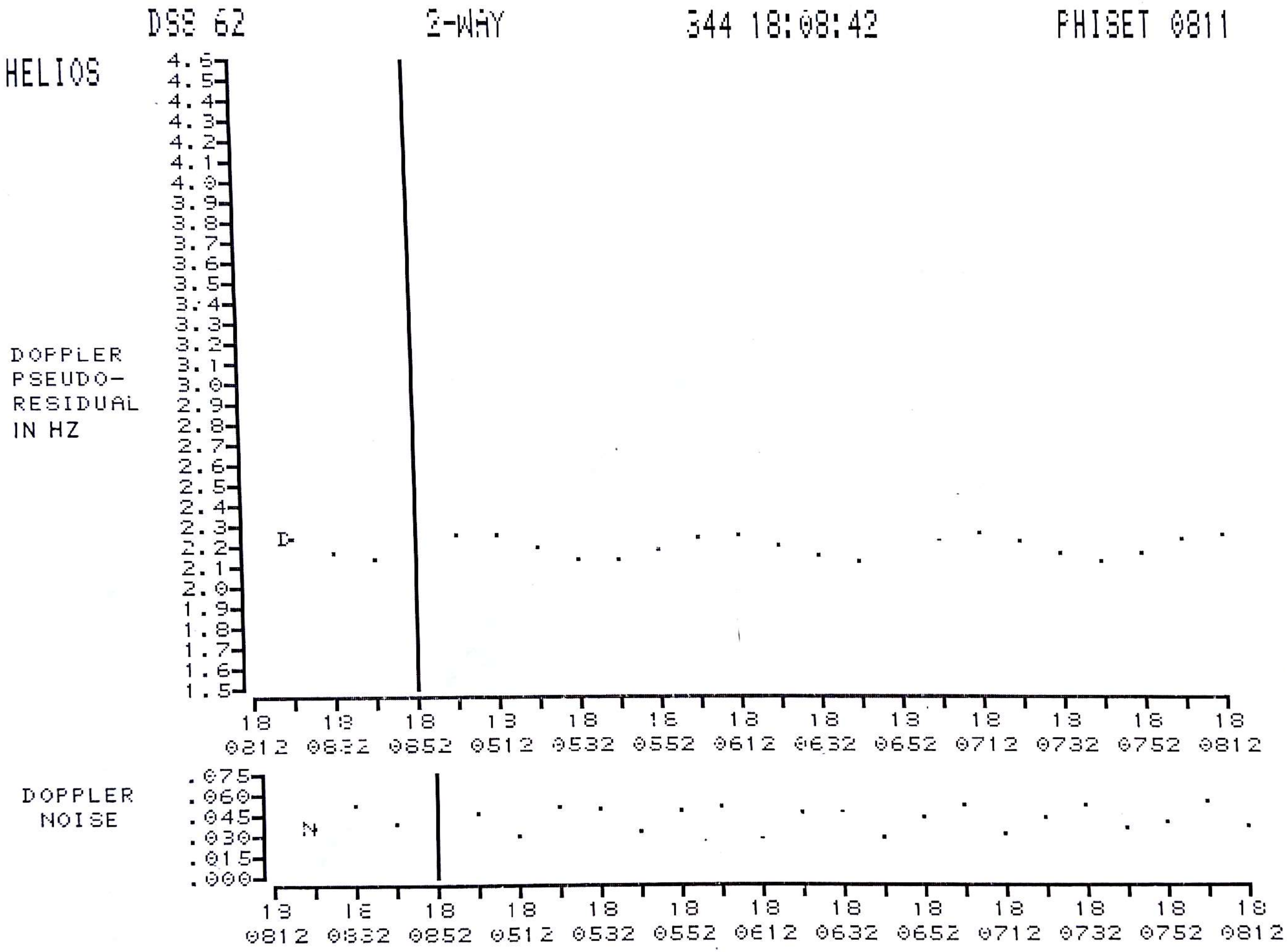


Figure 6.4-10: Sinusoidal Doppler near Minimum Observed Amplitude

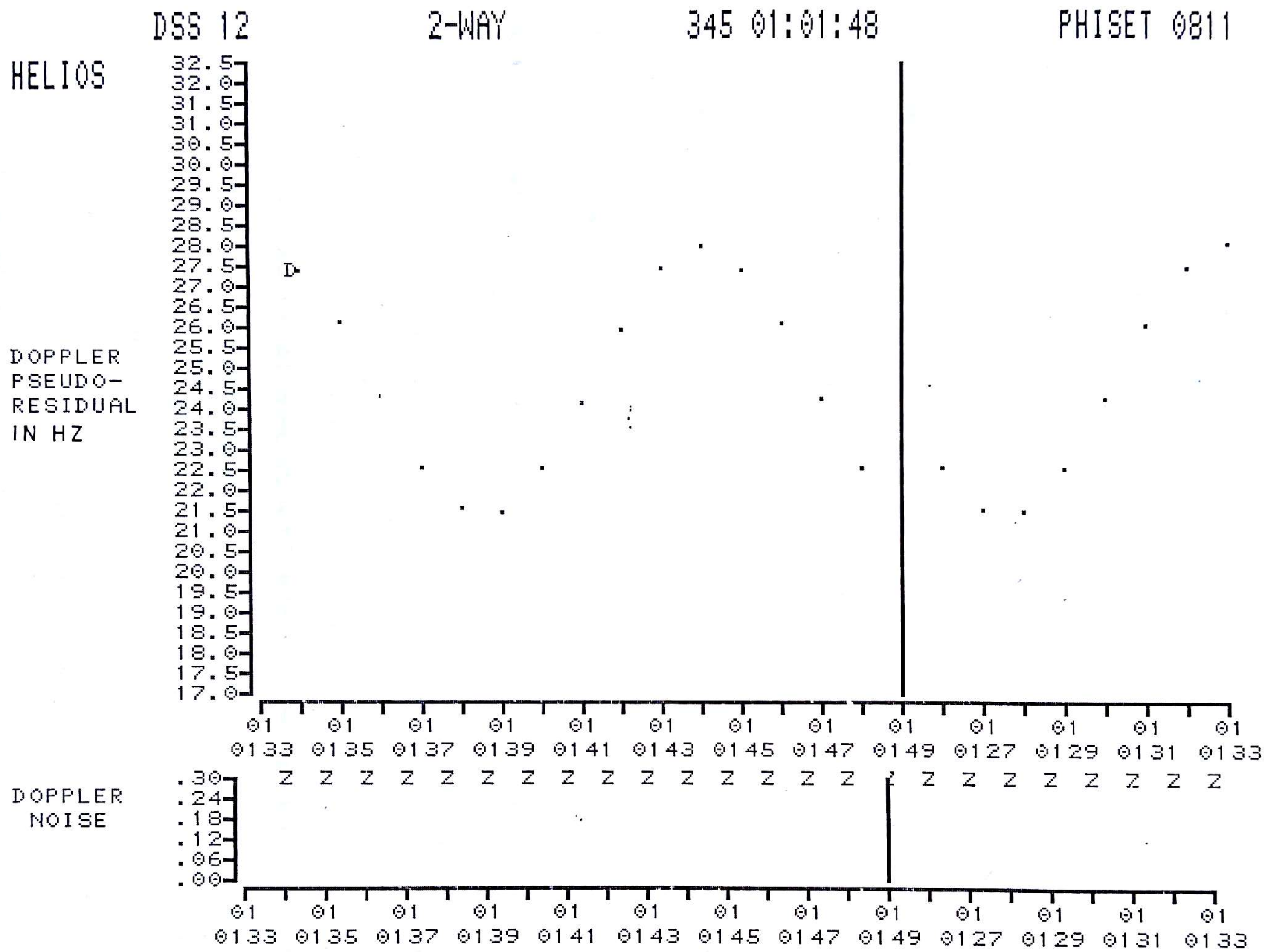


Figure 6.4-11: Sinusoidal Doppler near Maximum Observed Amplitude

The procedure which has been applied consisted of the following steps:

- Doppler predicts were computed (Doppler amplitude vs PA)
- Doppler data were reduced in order to determine the actual amplitude
- The observed amplitude was compared against the predicts and the related PA determined.

The accuracy involved in the method was ± 1° and better, depending on the value of the PA itself. Doppler measurements were only available during a 30° arc of the Step II, while the total arc was about 90°.
The question arose how accurate an extrapolation from the 30° arc over the remaining 60° would be. For that purpose the following two values were estimated from doppler and sun sensor data of the 30° arc:

- Turn rate per precession command
- Nozzle timing error, i.e. magnitude of roll ⟷ pitch crosscoupling

These estimates together with actual sun sensor data were applied for the remaining 60° arc. The resulting attitude was compared against the one which was derived from cruise phase sun sensor data reduction. It turned out that these 2 values differed by only about 2 degrees. This is another proof for the good results which are obtainable by this method.
In summarizing and generally speaking, this usage of doppler data provided a means of quantitative PA determination which was otherwise not possible. In other words, the S/C horn antenna has been used as an attitude sensor which was available without additional cost.
This method in general might be of interest for other projects.

6.4.11.3 ESTIMATE OF S/C ASYMMETRY

Another interesting example for doppler data usage is the determination of a HELIOS A asymmetry which has been picked up during the imperfect Experiment 5 antenna deployment *(see 6.4.4.).* As a result of this the radiation center of the medium gain antenna did no longer coincide with the spin axis, thus producing a wobble.
In order to determine the offset, doppler data at a sample rate of 10/sec have been taken for several minutes and were subsequently processed by a program provided by the orbit determination group of the HELIOS project.
The plot output which is integrated doppler (range) vs time is shown in *Fig. 6.4-12.* It indicates very clearly the existence of the medium gain antenna range wobble.
Further evaluation of these data led to quantitative figures for the asymmetry. The half cone angle between spin axis and symmetry axis was determined to be (0.21 ± 0.05)° which means that the radiation center of the medium gain antenna moves on a circle with a radius of only 1.6 cm.
Besides the fact that this investigation was of principal interest for attitude determination the results obtained were also a very valuable input for Experiment 9. Magnitude and time correlation of the wobble explained an unexpected noise in the scientific data of this experiment.

6.4.11.4 AGC DATA USAGE FOR DETERMINATION OF ORIENTATION ANGLES

As mentioned *in 6.4.8. and 6.4.9.* two attempts have been made to use radiation characteristics of antennas to determine angular values respectively displacements.
The procedure which has been used consisted of the following steps:

- Antenna sweep maneuver through pattern maximum and simultaneous recording of AGC data
- Polynomial curve fit
- Determination of polynomial maximum
- Angle computation

However, the desired results could not be obtained. Due to the small gain changes near the pattern maximum and the relatively high noise level of AGC data (about 1 dB) the procedure could not provide enough accuracy. Due to that experience the related steps have been eliminated from the HELIOS B sequence.

DFVLR GSOC

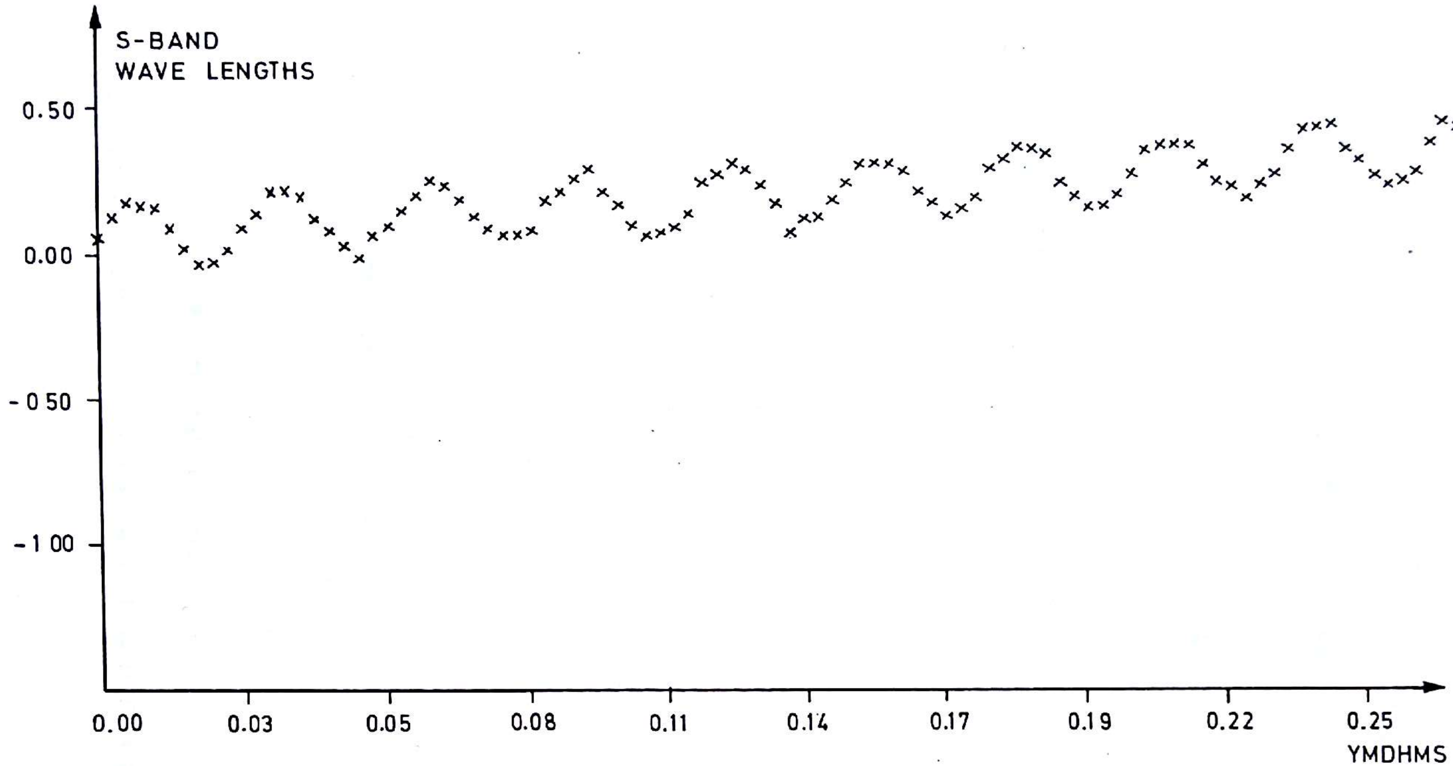


Figure 6.4-12: Medium Gain Antenna 10/sec Doppler Samples

7 INFLIGHT PERFORMANCE

7.0 GENERAL S/C CHARACTERISTICS

The *Fig. 7.0-1* shows all essential elements of the S/C structure:

- Antenna System consisting of:
  - Omnidirectional Antenna (horn and dipole)
  - Medium Gain Antenna
  - High Gain Antenna

- Solar Generator
  2 x 16 arrays covered with 49 % Solar Cells and 51 % Second Surface Mirrors

- Despin Motor
  supported by Tripod

- Temperature Control-Devices:
  - FINS for radiating the heat
  - LOUVERS for the Central Compartment
    (automatically controlled by temperature sensitive springs)
  - Heater mats within the Central Compartment

- Central Compartment with protecting Heat Shields

- Gastank for attitude maneuvers (cold gas system)

- Adapter (connection to the TE364-4 stage of the launch vehicle)

- Two Booms (double hinge) for Experiment 2, 3 and 4

- Spin Nozzle
  located on one boom at the central compartment for spin up/down corrections

- Precession Nozzle
  located on the inner rim of the lower solar array

- Two extensible antennas for Radio Wave Experiment E5A

- Sun Sensor plus Top and Bottom Triggers for S/C orientation measurements

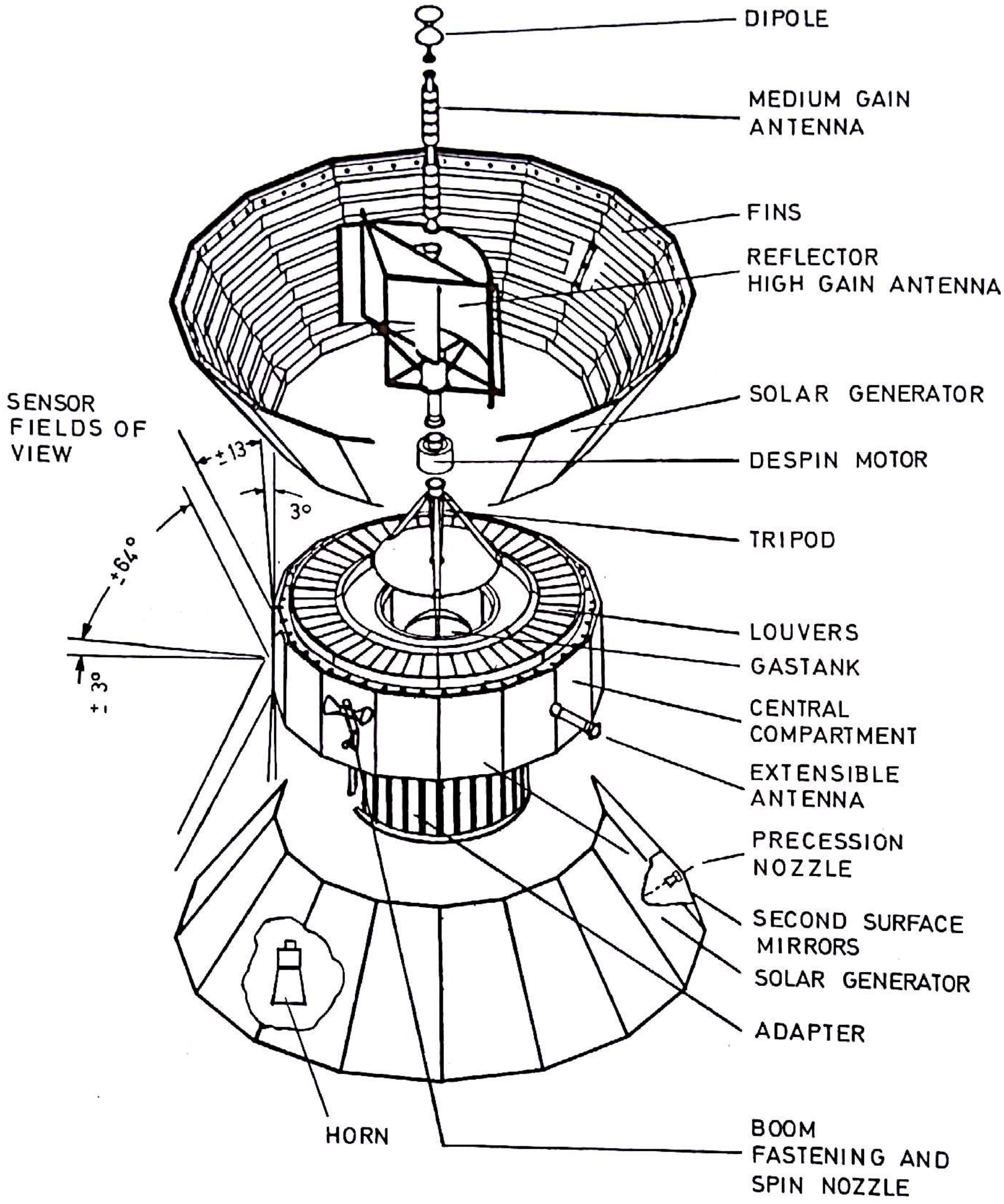


Figure 7.0-1: HELIOS S/C Configuration

Technical Data:

Structure	Overall height	4.21 m
	Cone height	1.62 m
	Cone diameter	2.77 m
	Cone angle	32.5°
	Central Compartment diameter	1.75 m
	Boom length (each)	4.62 m
	Antenna length (each)	15.87 m
	Total weight	369 kg
Power	Battery	36 V 8 Ahr
	Solar Generator	240W
	Bus Voltage	28 V ± 2 %
Transponder	Omnidirectional Antenna	0 db
	Medium Gain Antenna	9.4 db
	High Gain Antenna	23.1 db
	Transmitter Power:	0.5 W
	Medium Power TWT	8 W
	High Power TWT	20 W
	Modulation	S-band 2115 MHZ PCM/PSK/PM
	Coding	Convolutional
	Bitrates	8 — 4096 BPS
	Receiver Threshold (CMD)	— 142 dbm
Data Handling	Format Modes	6
	Distribution Modes	7
	Bitrates	10
	Commands	255
Attitude	Maneuver Capability:	
	Precession	200 Degrees
	Spin	20 RPM
	Nominal Spinrate	60 ± 1 RPM
	Nominal Attitude	90 ± 1°

7.1 TELECOMMUNICATION SYSTEM

The Ground Segment is described in section 3.1

7.1.1 BASIC CHARACTERISTICS OF THE S/C SEGMENT

7.1.1.1 GENERAL

As the detailed block diagram in *Fig. 7.1-1* shows, the HELIOS transponder system consists of:

- Two hardwire connected Receiver (RCVR) chains
- Two transmitter (XMTR) chains, and
- The true transponder units for transfer of
  - the VCXO1/VCXO2 derived signals from RCVR to XMTR, respectively
  - the demodulated ranging data from RCVR1 to XMTR1.

Three different antennas are available:

- The Low Gain Antenna System (LGA), consisting of a horn and a dipole antenna, offers a quasi omnidirectional radiation pattern to XMTR and RCVR chain 2.
- The Medium Gain Antenna (MGA) has an omnidirectional pattern in directions perpendicular to the S/C configuration axis only.
  The MGA is used for RCVR chain 1 as well as for transmission in Medium (MP) or High Power (HP) mode.
- The High Gain Antenna (HGA) is available for transmission in MP/HP mode only. It has directional characteristics.

Both RCVR/XMTR chains offer, respectively, redundant CMD and TLM operation capabilities. Ranging operations, however, are possible only when RCVR1 and driver/modulator 1 are in operation.
About twenty status and analog informations of this S/C section are telemetered to earth for performance control.

7.1.1.2. COMMAND RECEIVER

The two CMD RCVR's mutually independent and hardwire connected from antenna input to the CMD detector output, differ in following aspects:

- RCVR1 is connected to MGA, RCVR2 to LGA
- RCVR1 is equipped for ranging operations, RCVR2 not
- RCVR1 subcarrier demodulator expects a subcarrier frequency of 512 Hz, RCVR2 demodulator a subcarrier frequency of 448 Hz.

RCVR1 and RCVR2 expect an input signal carrier frequency of 2115.7 MHz for phase lock. The used modulation scheme is PCM/PSK/PM; the CMD data rate is 8 bps.
Table 7.1-I presents the used modulation angles and the minimum carrier signal levels for a CMD data bit error probability of 10^{-5}. These values are derived from compatibility test results.

MODE	MODULATION ANGLE (RAD)		USED CARRIER SUPPRESSION (DB)	CARRIER LEVEL FOR BEP 10^{-5}
	NOMINAL	USED		
CMD	0.771	0.771	2,89	— 144 dBm
CMD + RNG	0.39	0.771	2,89	— 144 dBm
	1.23	1.032	6.00	—

Table 7.1-I: Uplink Modulation Angles and Thresholds

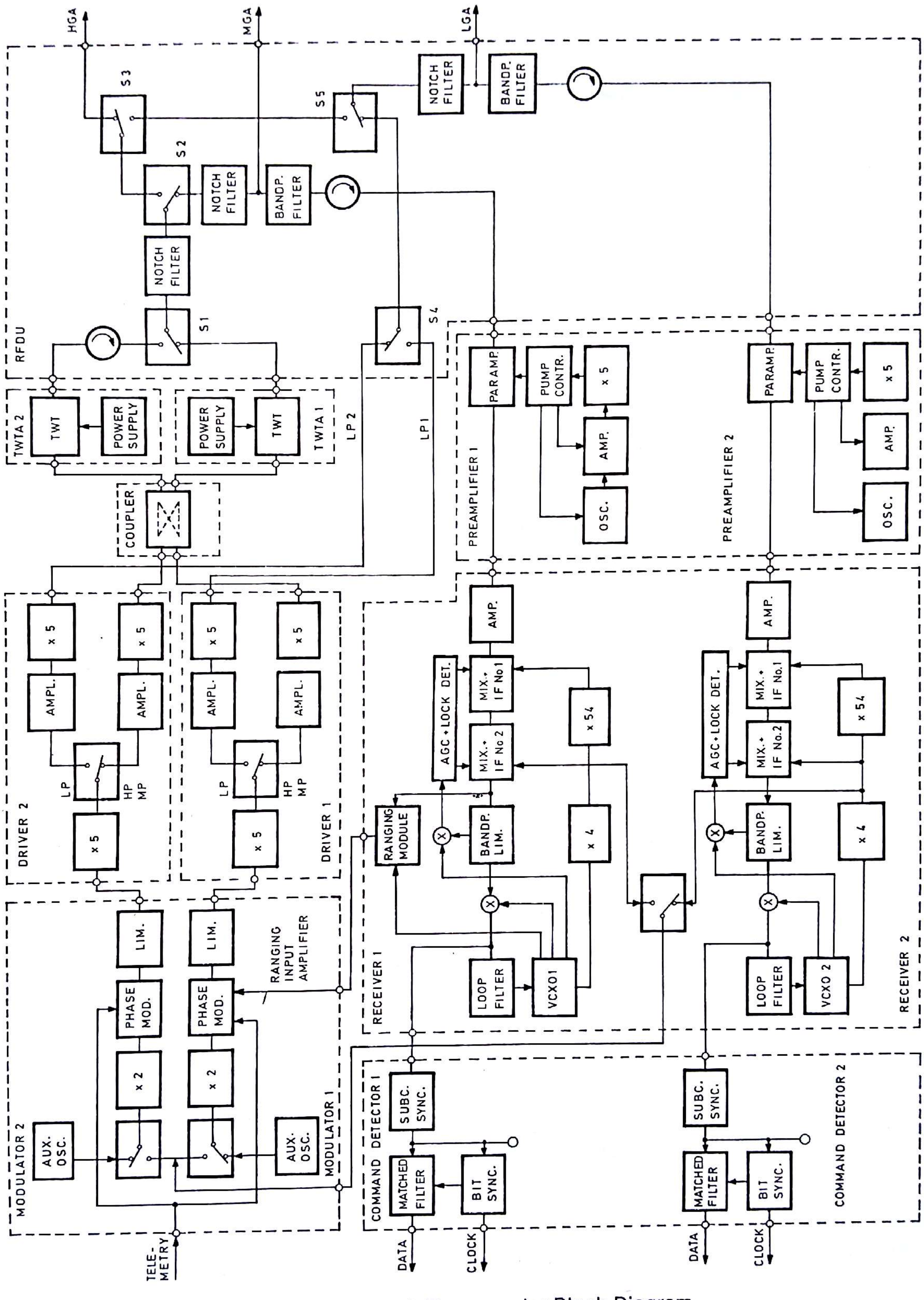


Figure 7.1-1: Transponder Block Diagram

These thresholds are applicable near earth. Near sun they are increased because of:

- Higher RCVR noise temperature as a consequence of the higher S/C temperature level
- Higher solar noise intensities
- Larger solar view angle

7.1.1.3. TELEMETRY TRANSMITTER

For TLM transmission S/C operations control can select by CMD among 26 different XMTR configurations:

- Three output power levels:
  - Low Power (LP) in connection with LGA
  - Medium Power (MP) and High Power (HP)
- Three transmit antennas:
  - LGA
  - MGA and HGA together with MP or HP modes
- Two Travelling Wave Tube (TWT) amplifiers
- Two modulator/driver units; unit 1 is equipped for ranging modulations.

In spite of these 26 different configurations only among 7 different radiation power levels can be chosen. They are arranged in *Table 7.1-II.*

No.	OUTPUT POWER		ANTENNA		LOSSES	EIRP
	MODE	LEVEL	MODE	GAIN		
1	HP	43.35	HGA	23.1	2.62	63.84
2	MP	40.28				60.77
3	HP	43.35	MGA	9.4	3.60	49.56
4	MP	40.28				46.49
5	HP	43.35	LGA	2.5	2.3	40.7
6	MP	40.28				37.63
7	LP	28.72			1.4	26.73

Table 7.1-II: XMTR Radiation Power Levels

For the signal to be transmitted, 60 different modulation modes are possible, which means, S/C operations control can select by command:

- That the signal carrier frequency is derived from:
  - XMTR-VS01 or XMTR-VS02 (noncoherent mode), or
  - RCVR-VCX01 resp. RCVR-VCX02 (coherent mode)

- That telemetry data to be modulated is:
  - Convolutional coded, or
  - Uncoded
- One of ten bitrates between 8 bps and 4096 bps, inculsively the recommended modulation angle
- if modulator/driver 1 is in operation: that ranging data gets modulated on the XMTR signal, or not.

The nominal carrier signal frequency at XMTR output is 2297.6 MHz. The modulation scheme is PCM/PKS/PM. The used PM modulation angles are collected in *Table 7.1-III.*

BITRATE	MODULATION ANGLE (RAD)		CARRIER SUPPRESSION(DB)
	TLM	RNG	
8—32	0.734	—	2.58
	0.734	0.423	3.27
64—4096	0.953	—	4.76
	0.953	0.423	5.43

Table 7.1-III: XMTR Signal Modulation Angles

7.1.2 LINK SEGMENT

For the following mission phases:

- Near earth phase
- Attitude maneuver phases
- Phases with solar aspect angles Sun-Earth-Probe (SEP) smaller than 3 degrees, inclusive
- Phases with extreme solar events

the essential link parameter values were analytically determined and compared with the actual results. For a better understanding of the attached plots, the following explanations:

The dotted lines repeat the calculated (predicted) values. It shall be noted, that the predictions were only generated for one sample configuration e.g.:

- S/C-RXAGC1 for DSS61 (26m Dish), 10KW being received via Medium Gain Antenna. But the used configurations were 100m Dish, 20 KW; 26m Dish, 20KW; 30m Dish, 10 KW and 20KW. This is shown in the different steps on the actual plot.

  This comment is applicable for the other predictions as well.

The different steps on the actual data plots are deviations from this sample configuration.
The configuration plotted can be derived from the code attached to each figure by using the following interpretation:

First line:
(Uplink)

S61	10 kW	26 m	MGA
DSS-Nr	Uplink Power	Dish	S/C Antenna (receiving)

Second line:
(Uplink)

TUD	RG
Carrier and Data	Ranging

Third line:
(Downlink)

MP1	HGA — S 61	1	26 m
TWT Power Nr	transmitting S/C Antenna	DSS-Nr	Dish

Fourth line:
(Downlink)

CO	H 2048 * K	12 LV
Coherent	High 2048 * coded	Loop B/W: 12 HZ
	Carrier Suppression	Polarization LV

Such a representative comparison is realized in the following, with actual information being obtained during the period of October 1975.

7.1.2.1 UPLINK

The curves of the *Figures 7.1-2 and 7.1-4* show the actual S/C RCVR AGC1 and AGC2 levels respectively; the *Figures 7.1-3 and 7.1-5* present the corresponding calculated values. The envelopes of these curves are represented in the *Figures 7.1-2 and 7.1-4* as dotted lines.

The deviation between these dotted lines and the actual data during ranging operations is approx. 1.3 dB. This is the difference between the project defined carrier suppression of 7.3 dB and the used suppression of 6 dB for ranging modulation, which was normally applied most of the time.

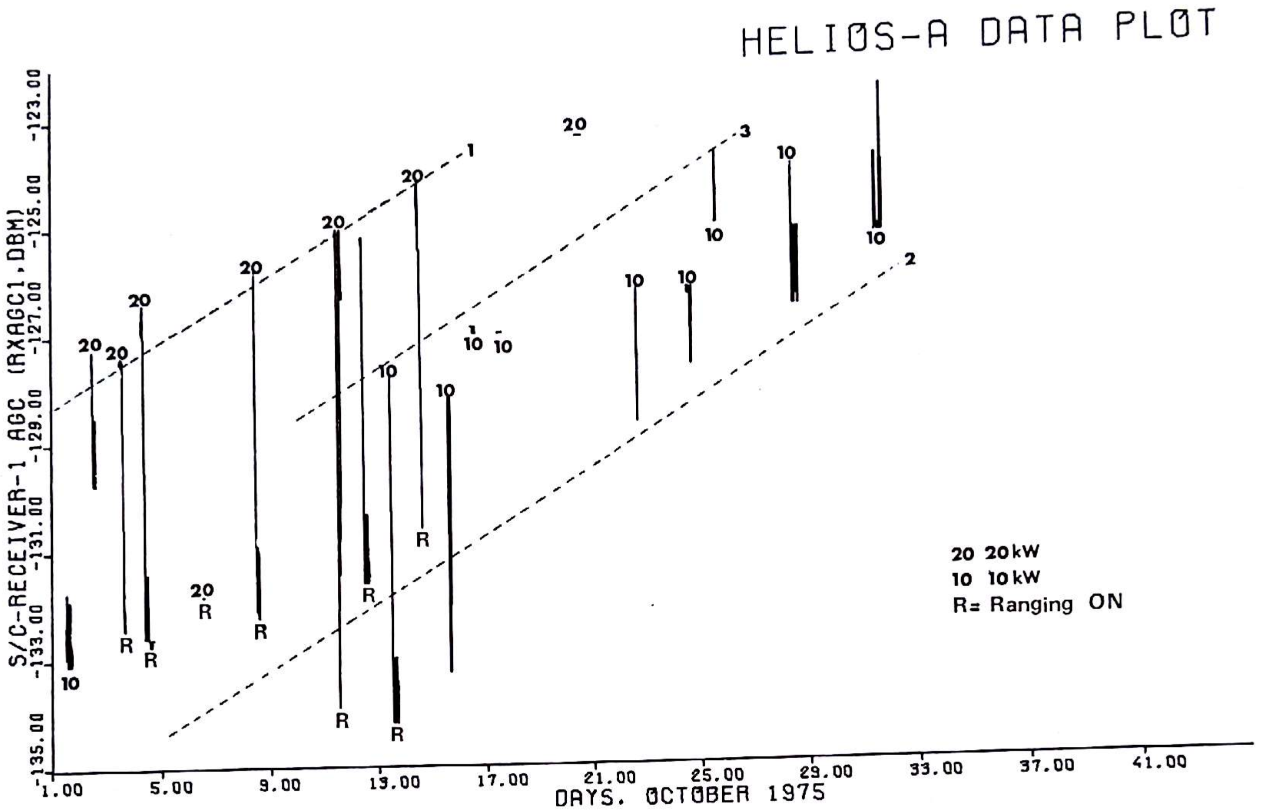
Table 7.1-IV shows the essential link parameter values being used for the computations.

S/C RECEIVER	DSS 61 EIRP (DBM)	HELIOS-A ANTENNA GAIN & LOSSES dBi	BIAS (dB)
RCVR1	121.8	9.8	— 0.75
	124.8	9.8	— 0.75
RCVR2	121.8	1.8	— 1.15
	124.8	1.8	— 1.15

Table 7.1-IV: Uplink Parameter Values

7.1.2.2 DOWNLINK

The *Figures 7.1-6 and 7.1-8* present the actual DSS AGC and SNR levels respectively; the *Figures 7.1-7 and 7.1-9* show the corresponding computed curves. These are represented again in the *Figures 7.1-6 and 7.1-8* as dotted lines.



8.13-1.01-1.01-1

Figure 7.1-2: Actual Receiver 1 AGC (Oct. 75)

WA-76.11.8

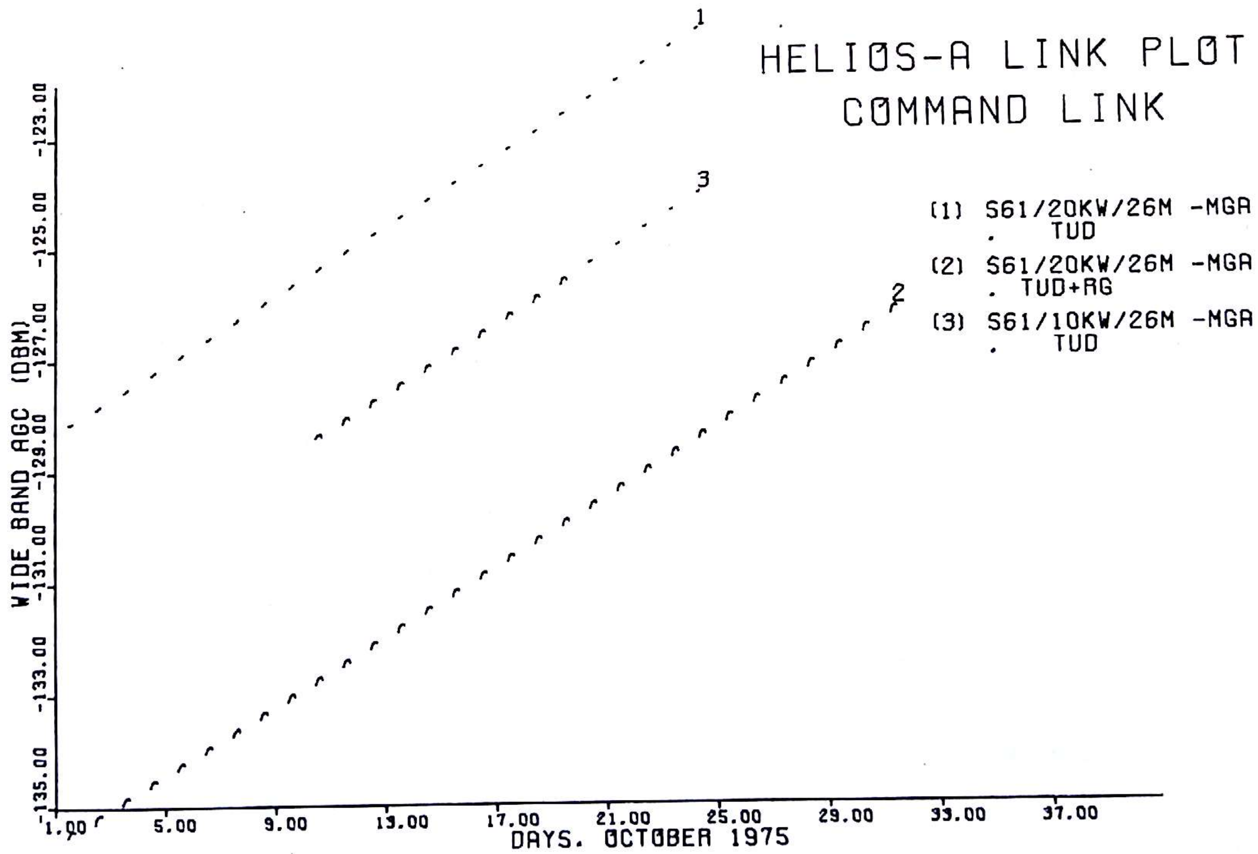


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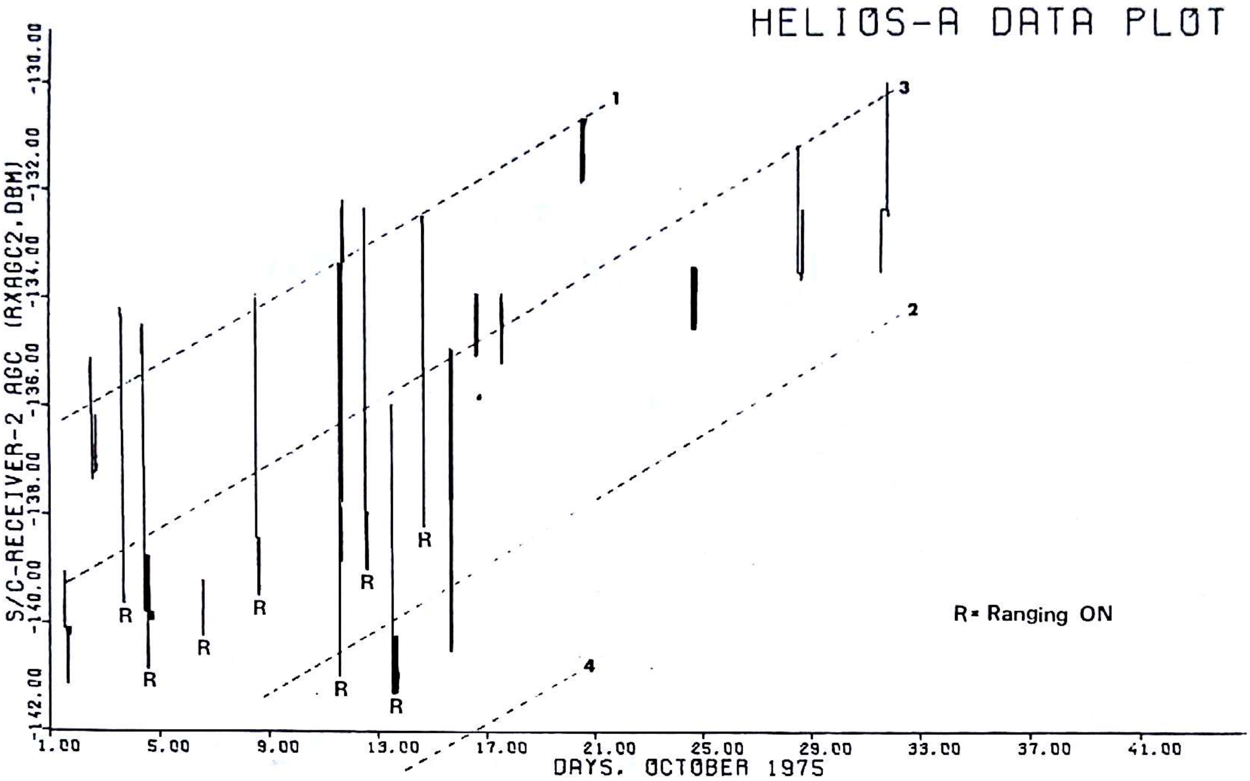
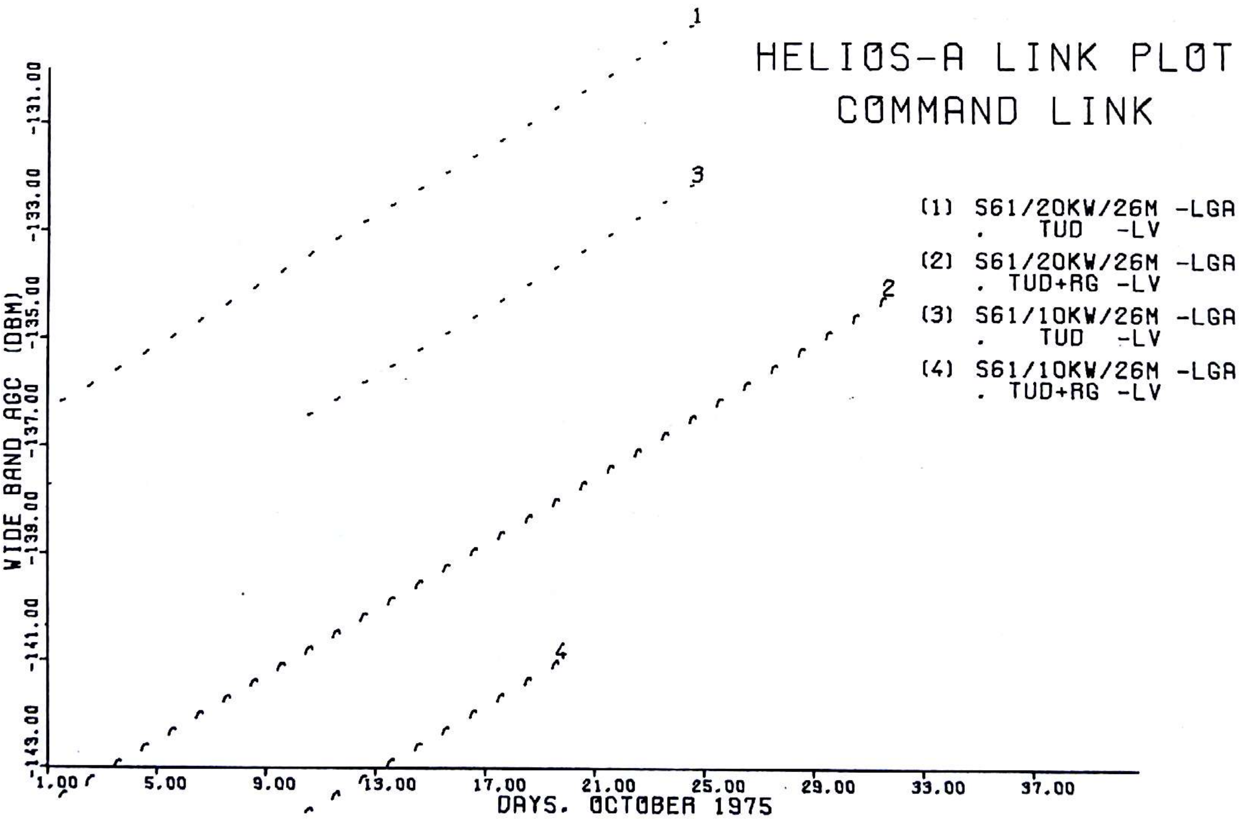
Figure 7.1-3: Predicted Receiver 1 AGC (Oct. 75)

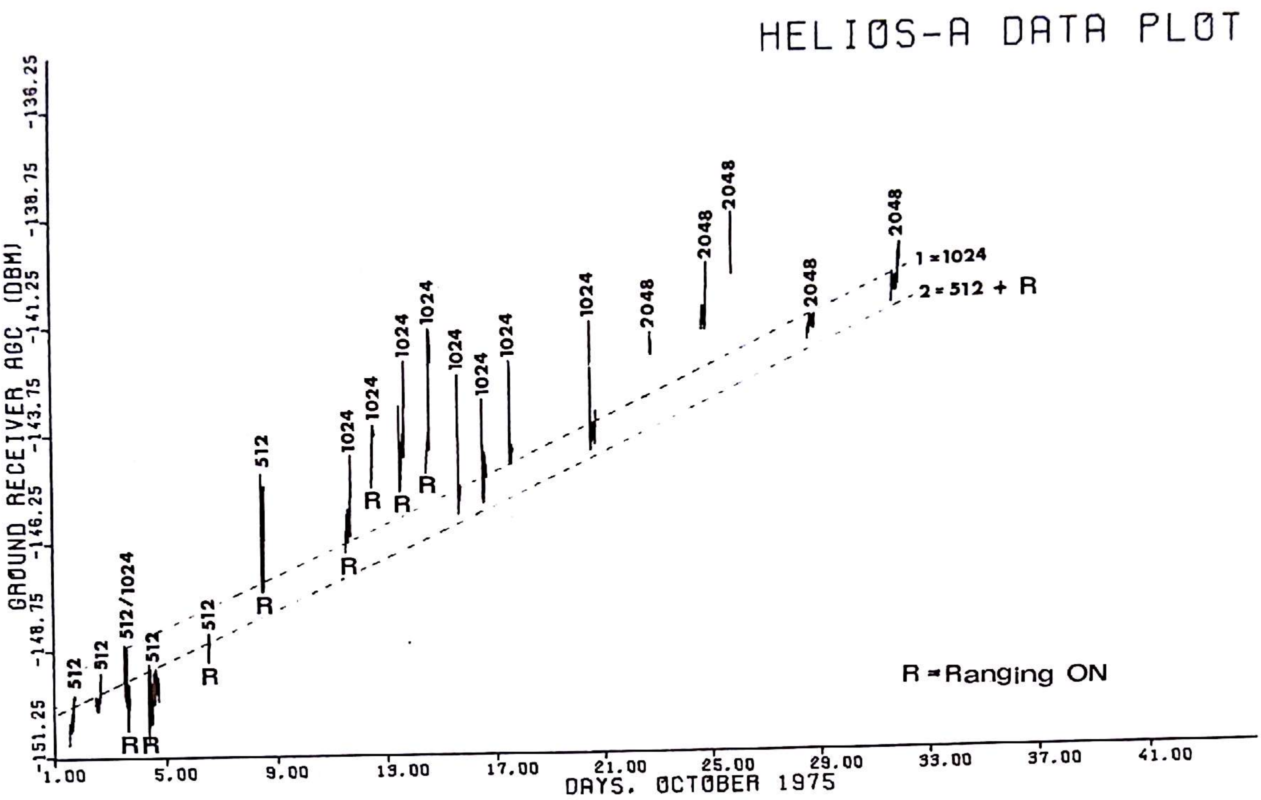
WA-76.11.10



8.13-1.01-1.01-1 Figure 7.1-4: Actual Receiver 2 AGC (Oct. 75) WA-76.11.9



LAUNCH: 74.12.10, 7:11 Figure 7.1-5: Predicted Receiver 2 AGC (Oct. 75) WA-76.11.11



B.13-1.01-1.01-1

Figure 7.1-6: Actual Ground Receiver AGC (Oct. 75)

WA-76.11.8

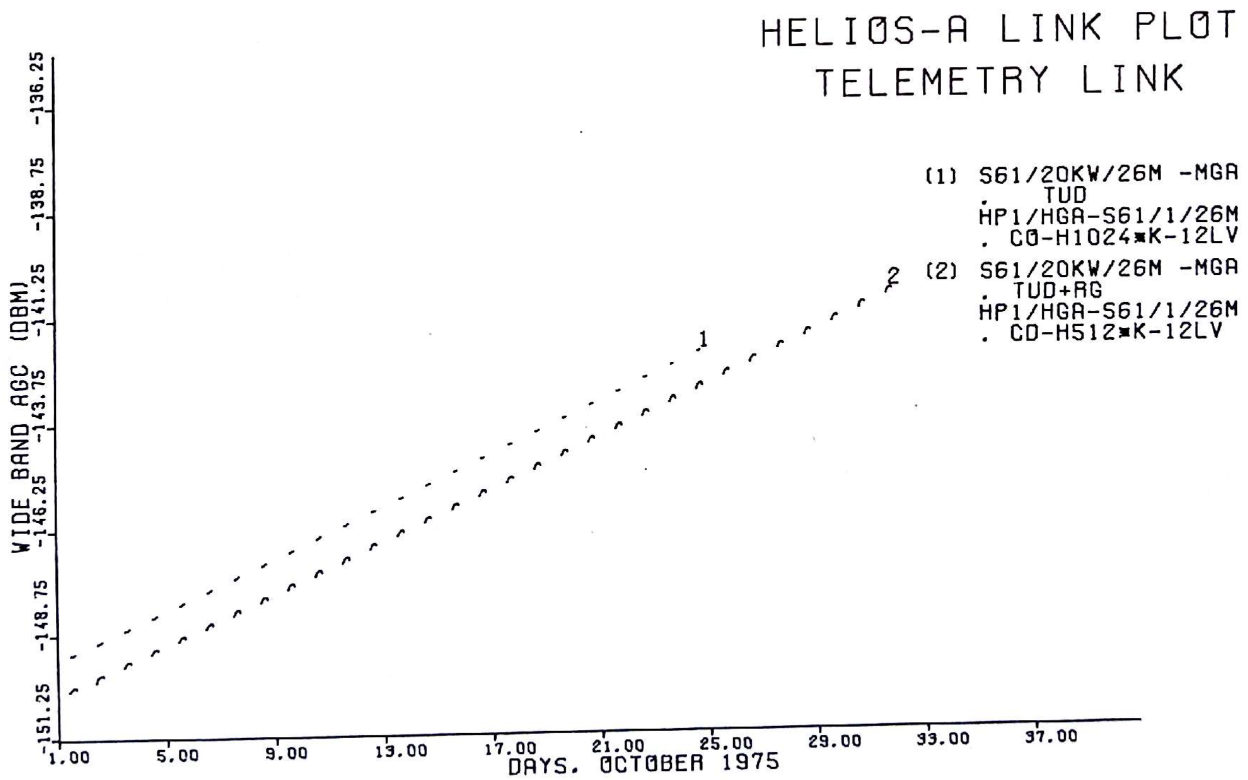


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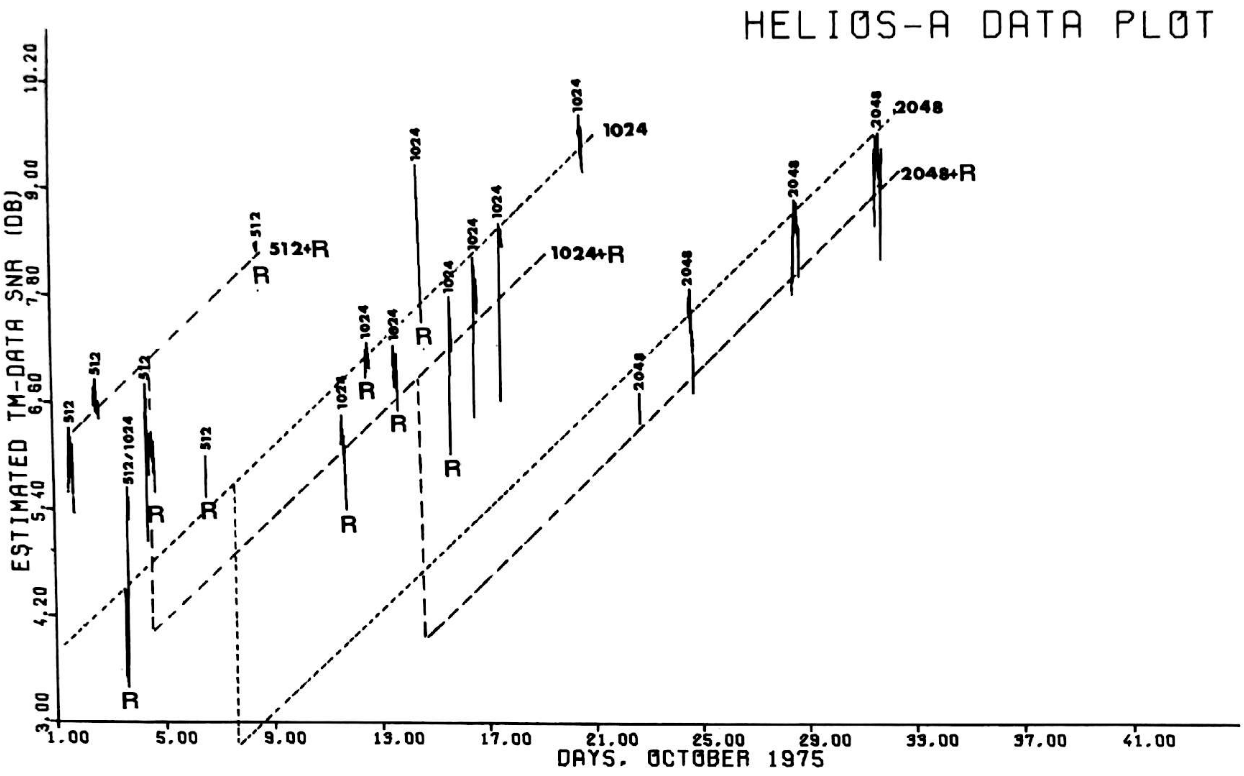
Figure 7.1-7: Predicted Ground Receiver AGC (Oct. 75)

WA-76.11.10

DFVLR
GSOC



8.13-1.01-1.01-1

Figure 7.1-8: Actual Ground Station SNR (Oct. 75)

VA-76.11.9

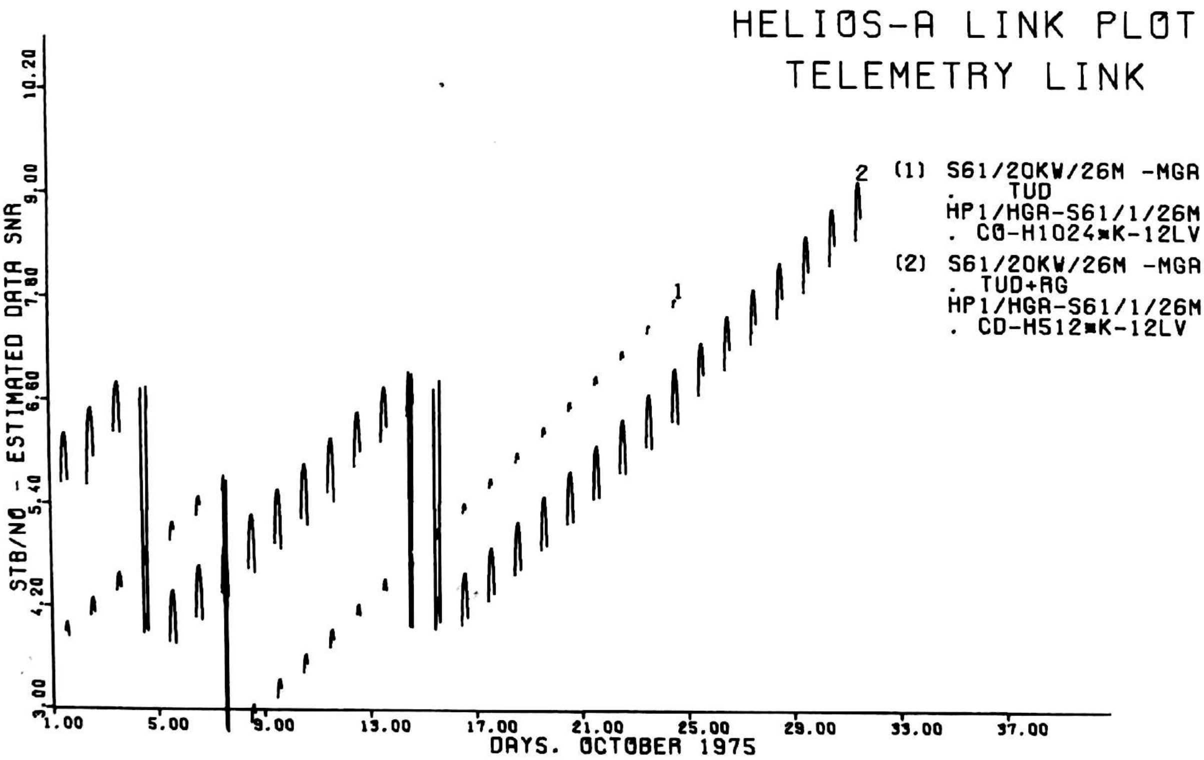


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Figure 7.1-9: Predicted Ground Station SNR (Oct. 75)

VA-76.11.10

In *Table 7.1-V* the essential link parameter values being used for the computations are collected.

S/C EIPR	DSS 61		BIASES	
	ANTENNA GAIN	NOISE TEMP	SIGNAL	NOISE
63.8 dBm	53.3 dBi	33 deg	- 1.5 dB	- 2.4 dB

Table 7.1-V: Downlink Parameter Values

mission profiles versus distance HELIOS-Earth were computed for following parameters:

- S/C-RXAGC1
- Maximum usable bitrate for coded data
- Ground station RCVR AGC and TLM data SNR.

The results inclusive the necessary informations about S/C and station configurations are presented in the *Figures 7.1-10, 7.1-12, 7.1-14 and 7.1-16.*

The *plots 7.1-11, 13, 15 and 17* give the actual performance as measured during the 5. Orbit (8. January to 18. Juli '77).

7.1.3 GRAYOUT AND BLACKOUT

During cruise phase, HELIOS trajectory several times penetrates the solar view cone, being formed by earth as the peak and sun disk as the circular section. If this penetration occurs, with respect to terrestrial observers,

- in front of the sun: the S/C is called to be in grayout
- behind the sun : the S/C is called to be in blackout.

The crossings are shown in *Fig. 7.1-18.*

For HELIOS telecommunications,grayout implies additional solar noise on ground received TLM signals. Blackout signifies: no communications possible because of missing visibility.

More important than the grayout and blackout phases are the transition phases: The sun is surounded by a fluctuating and scintillating plasma of highly dissipating charcteristic, the corona. The research of this corona, however, was one of the main targets of the scientific mission. The chance for that offered the investigation of the distortions which occurred while the telecommunication signals were passing through the corona. Thus, the maintenance of the telecommunication links during the critical blackout entry/exit phases was a scientific request.

In this report, however, only the degradation of signal reception during grayout and blackout transition phases interests, not its cause.

So *Figure 7.1-19* shows the influence of the solar noise on the TLM data SNR at grayout entry in March 1975 as function of the view angle SEP (Sun-Earth-Probe angle).

The *Figures 7.1-21 to 7.1-25* demonstrate as an example some characteristic receiver parameters during the blackout approach in April 1975. *Figure 7.1-20* shows in a survey the selected 26-m ground stations

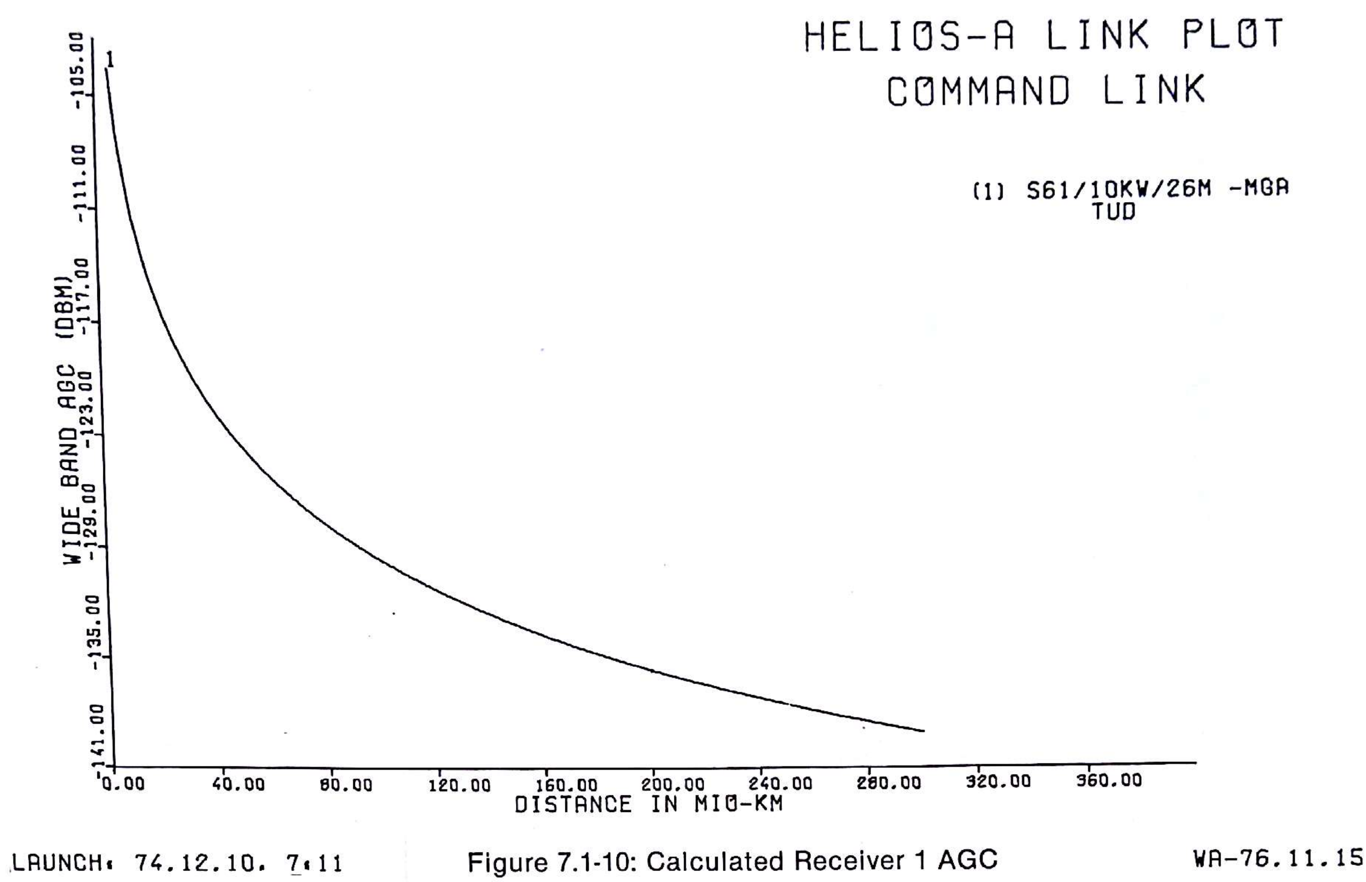

Figure 7.1-10: Calculated Receiver 1 AGC

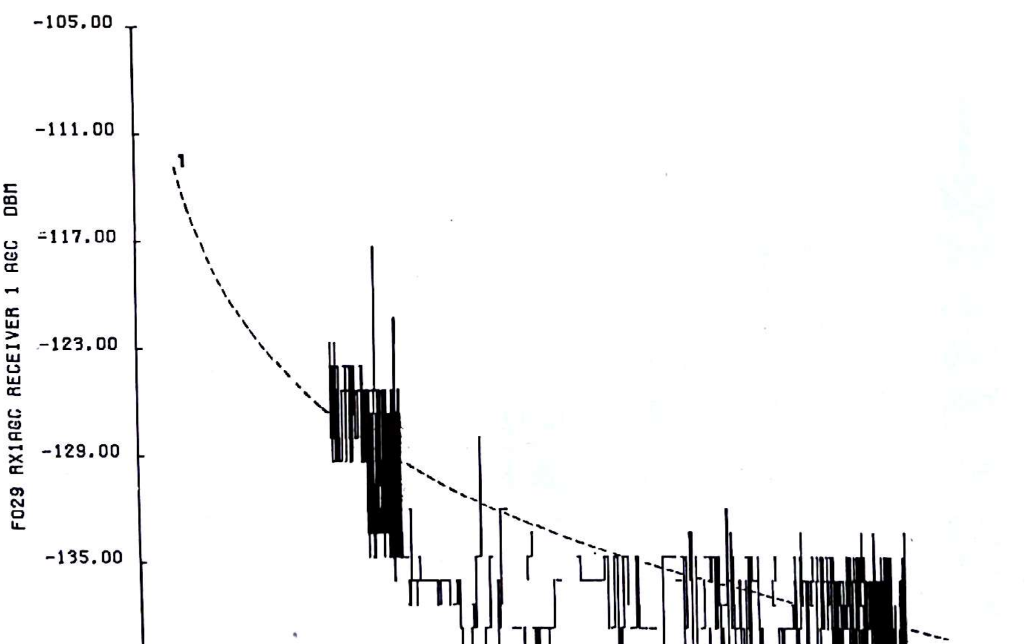

Figure 7.1-11: Actual Receiver 1 AGC (5. Orbit)

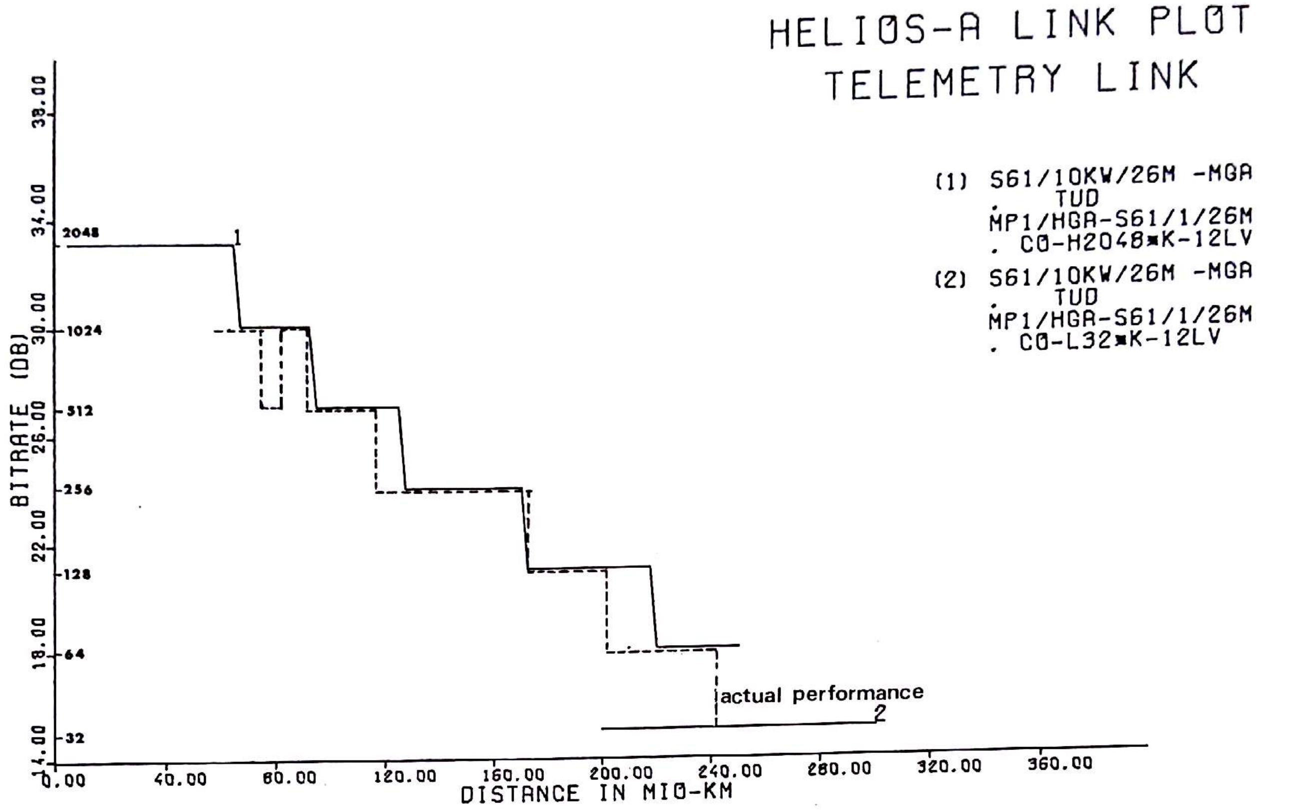

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Figure 7.1-12: Calculated Bitrate Steps

WA-76.11.15

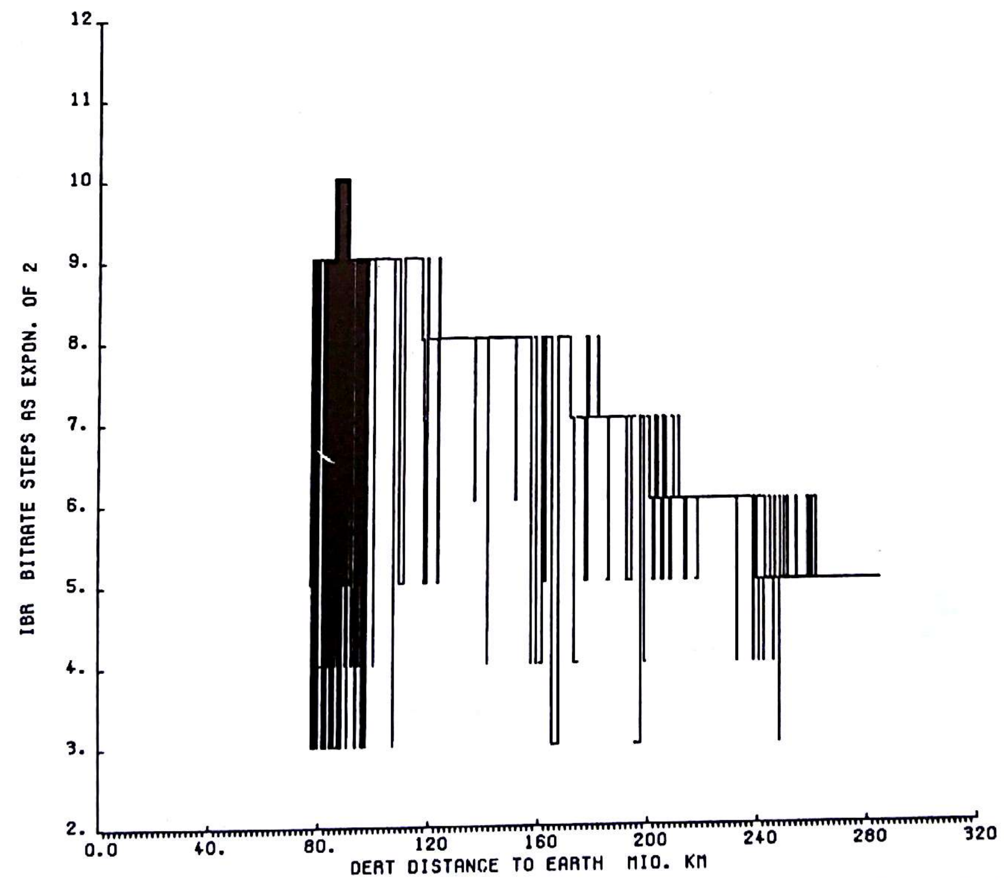

Figure 7.1-13: Actual Bitrate Steps (5. Orbit)

DFVLR
GSOC

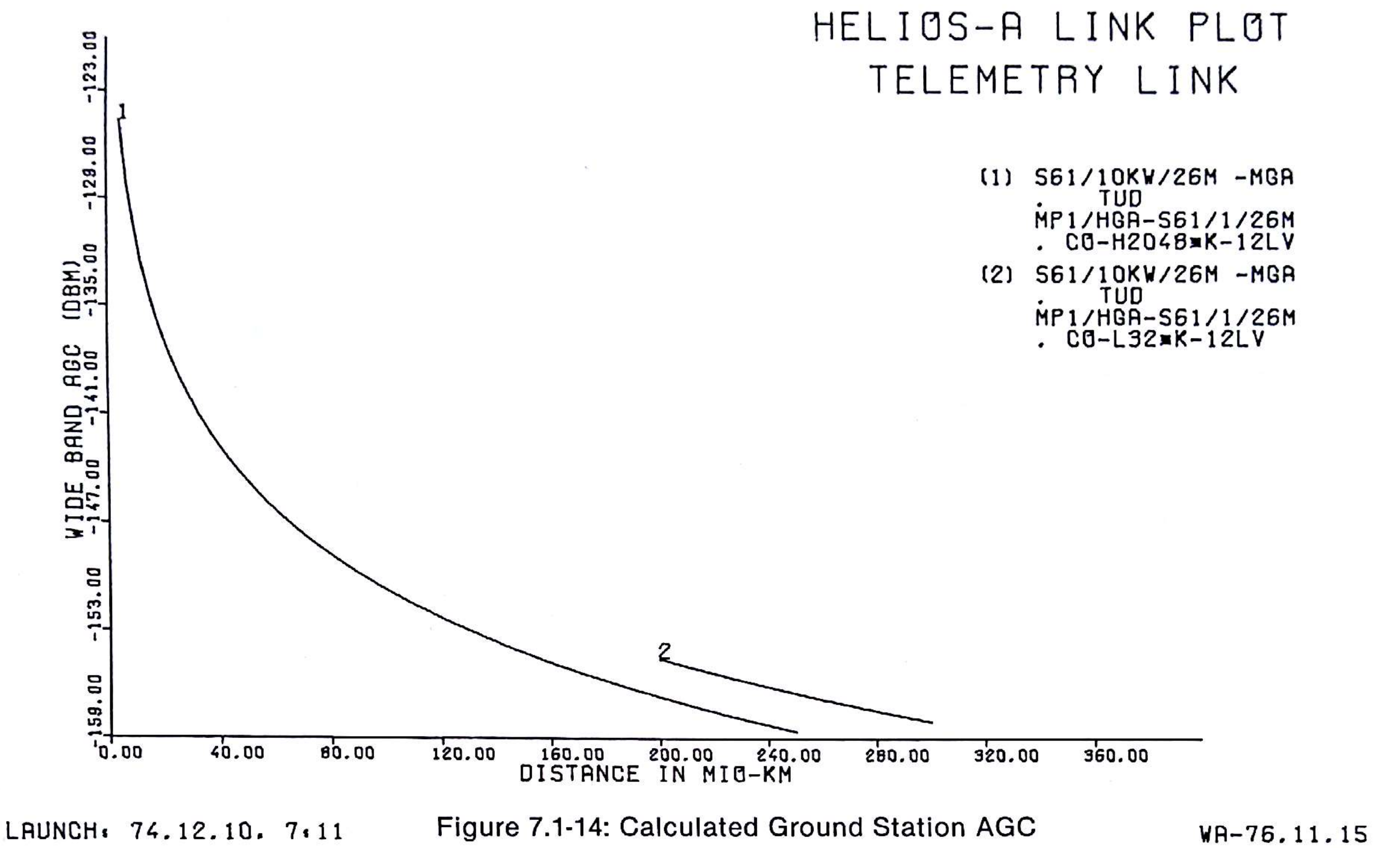

Figure 7.1-14: Calculated Ground Station AGC

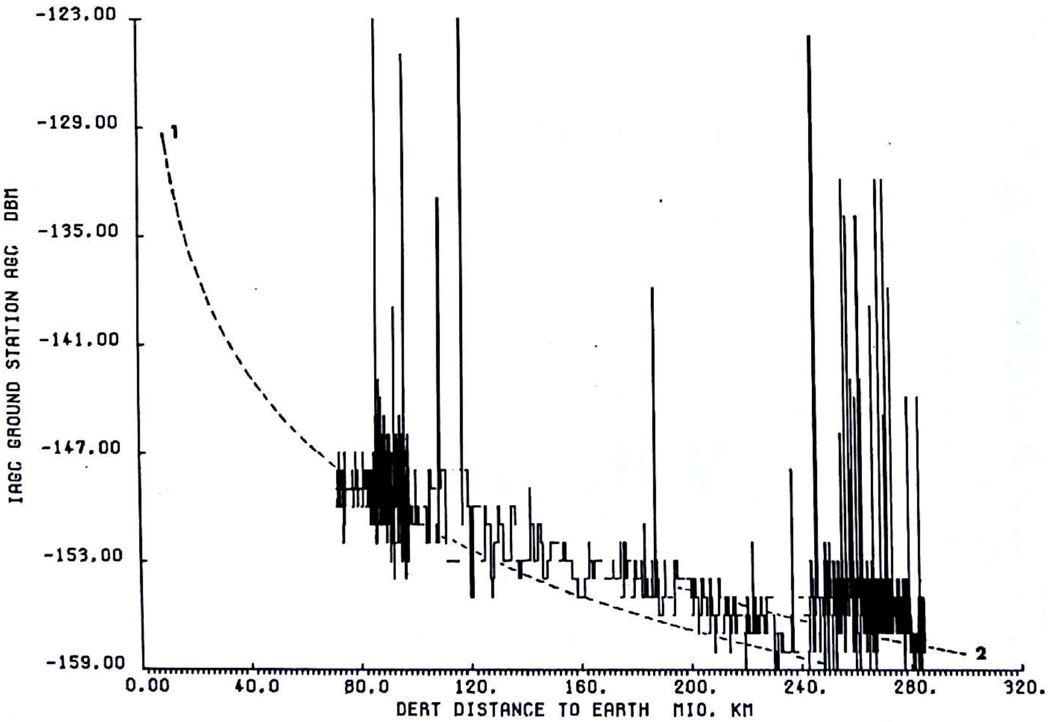

Figure 7.1-15: Actual Ground Station AGC (5. Orbit)

DFVLR
GSOC

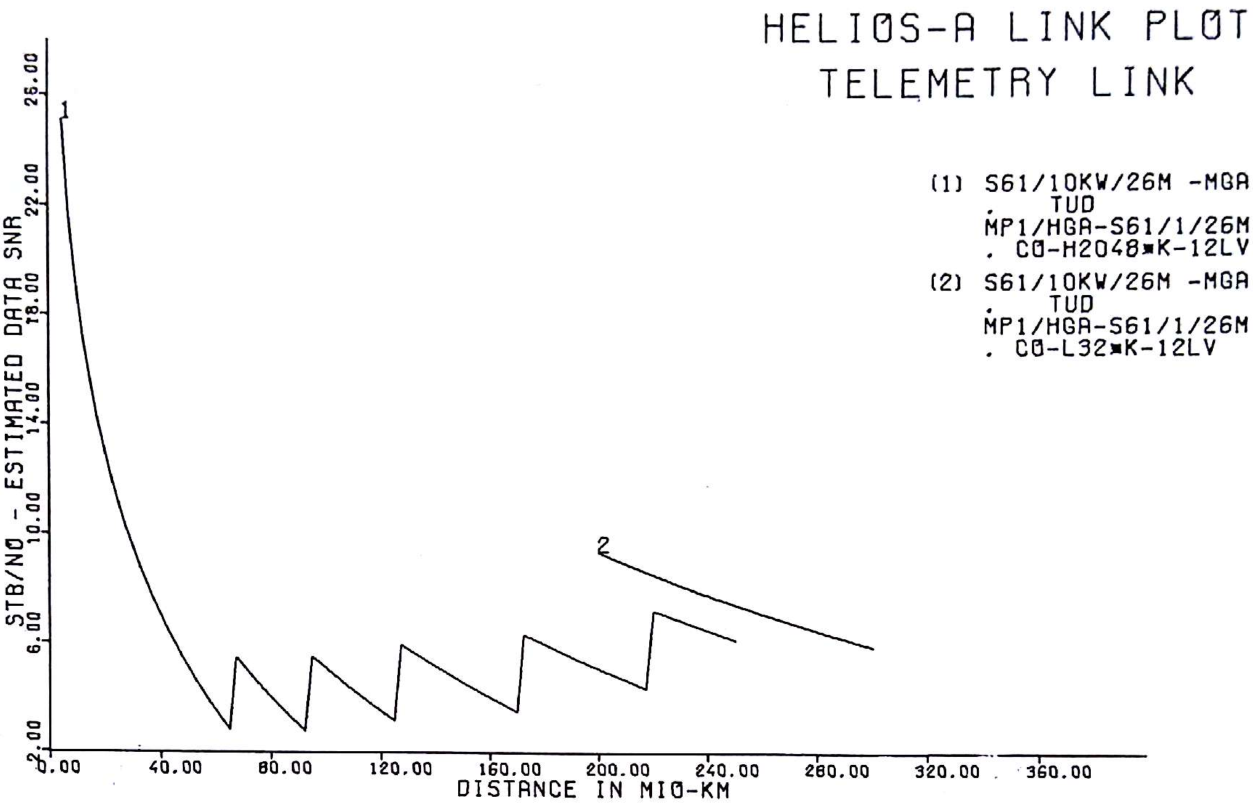

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Figure 7.1-16: Calculated Ground Station SNR

WA-76.11.15

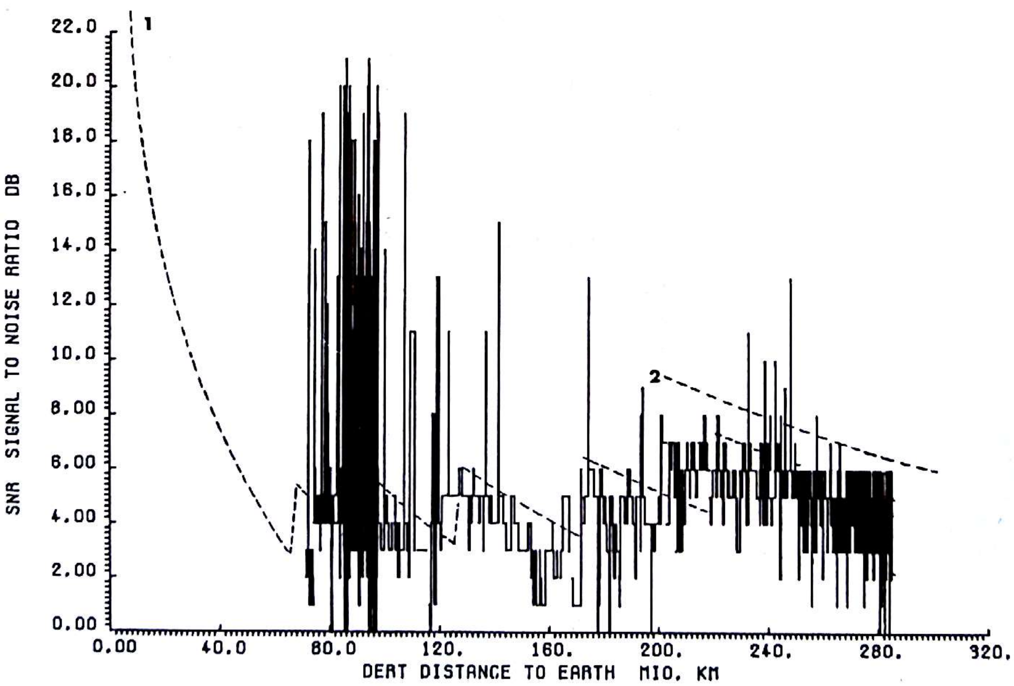

Figure 7.1-17: Actual Ground Station SNR (5. Orbit)

HELIOS 1

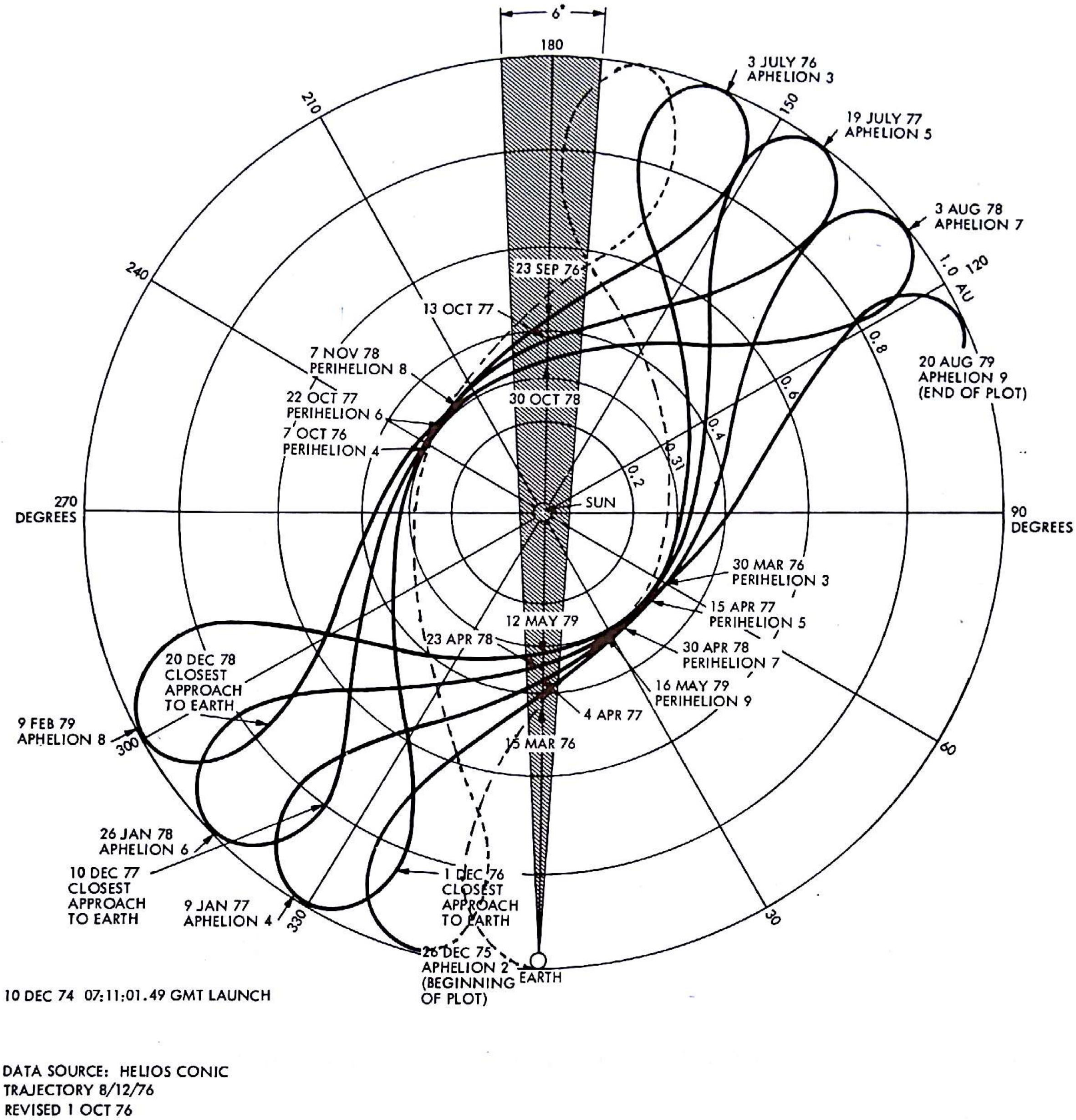

Figure 7.1-18: HELIOS A Grayout and Blackout Crossings

and the used bitrates versus view angle SEP and time; in *Table 7.1-IV* the essential orbit parameters for the concerned time interval are collected.

For the interpretation of the presented plots some additional remarks: The data received from ground stations were averaged and the maxium deviation respectively the maximum value within the averaging interval determinated. From these sample points one for each subsequent 15 minute period were plotted, if the concerned maximum deviations did not exceed the limit of 2 dB (SNR) respectively 5 dB (AGC). Suppressed samples are bridged by straight lines (see RXAGC1 curve).

YY	MM	DD	HH			ENTFERNUNG SONNE-SONDE (AU)	ENTFERNUNG ERDE-SONDE (AU)	WINKEL SONNE-ERDE-SONDE (GRAD)
75	4	1	0	0	0	0.460	1.428	7.9394
75	4	2	0	0	0	0.473	1.446	7.4275
75	4	3	0	0	0	0.486	1.463	6.9382
75	4	4	0	0	0	0.499	1.480	6.4713
75	4	5	0	0	0	0.512	1.496	6.0266
75	4	6	0	0	0	0.525	1.512	5.6038
75	4	7	0	0	0	0.538	1.527	5.2024
75	4	8	0	0	0	0.550	1.542	4.8219
75	4	9	0	0	0	0.563	1.556	4.4618
75	4	10	0	0	0	0.575	1.570	4.1215
75	4	11	0	0	0	0.587	1.583	3.8004
75	4	12	0	0	0	0.599	1.597	3.4979
75	4	13	0	0	0	0.611	1.610	3.2133
75	4	14	0	0	0	0.623	1.622	2.9462
75	4	15	0	0	0	0.634	1.635	2.6960
75	4	16	0	0	0	0.646	1.647	2.4619
75	4	17	0	0	0	0.657	1.659	2.2436
75	4	18	0	0	0	0.668	1.670	2.0403
75	4	19	0	0	0	0.678	1.681	1.8516
75	4	20	0	0	0	0.689	1.692	1.6770
75	4	21	0	0	0	0.699	1.703	1.5159
75	4	22	0	0	0	0.709	1.714	1.3680
75	4	23	0	0	0	0.719	1.724	1.2326
75	4	24	0	0	0	0.729	1.734	1.1093
75	4	25	0	0	0	0.738	1.744	0.9978
75	4	26	0	0	0	0.748	1.754	0.8976
75	4	27	0	0	0	0.757	1.763	0.8083
75	4	28	0	0	0	0.766	1.772	0.7295
75	4	29	0	0	0	0.774	1.781	0.6609
75	4	30	0	0	0	0.783	1.790	0.6020

Table 7.1-IV: Characteristic Orbit Parameters; April 75

In the following the different parameter curves are discussed in detail:

— RXAGC1 *(Fig. 7.1-21)*

The dot-dash-line represents the expected S/C AGC signal level in absence of blackout effects. The dashed line is the result of the attempt to reconstruct the RXAGC1 course for DSS 62.

— GROUND RECEIVER AGC *(Fig. 7.1-22)*

The dot-dash line represents again the expected course in absence of blackout effects. The step on April 9 is a consequence of the change of the modulation index to low carrier suppression.
The dashed lines present the profiles of the actual AGC signal levels for DSS 12 and DSS 62. Specially the DSS 62 curve demonstrates that, indeed, the decrease from

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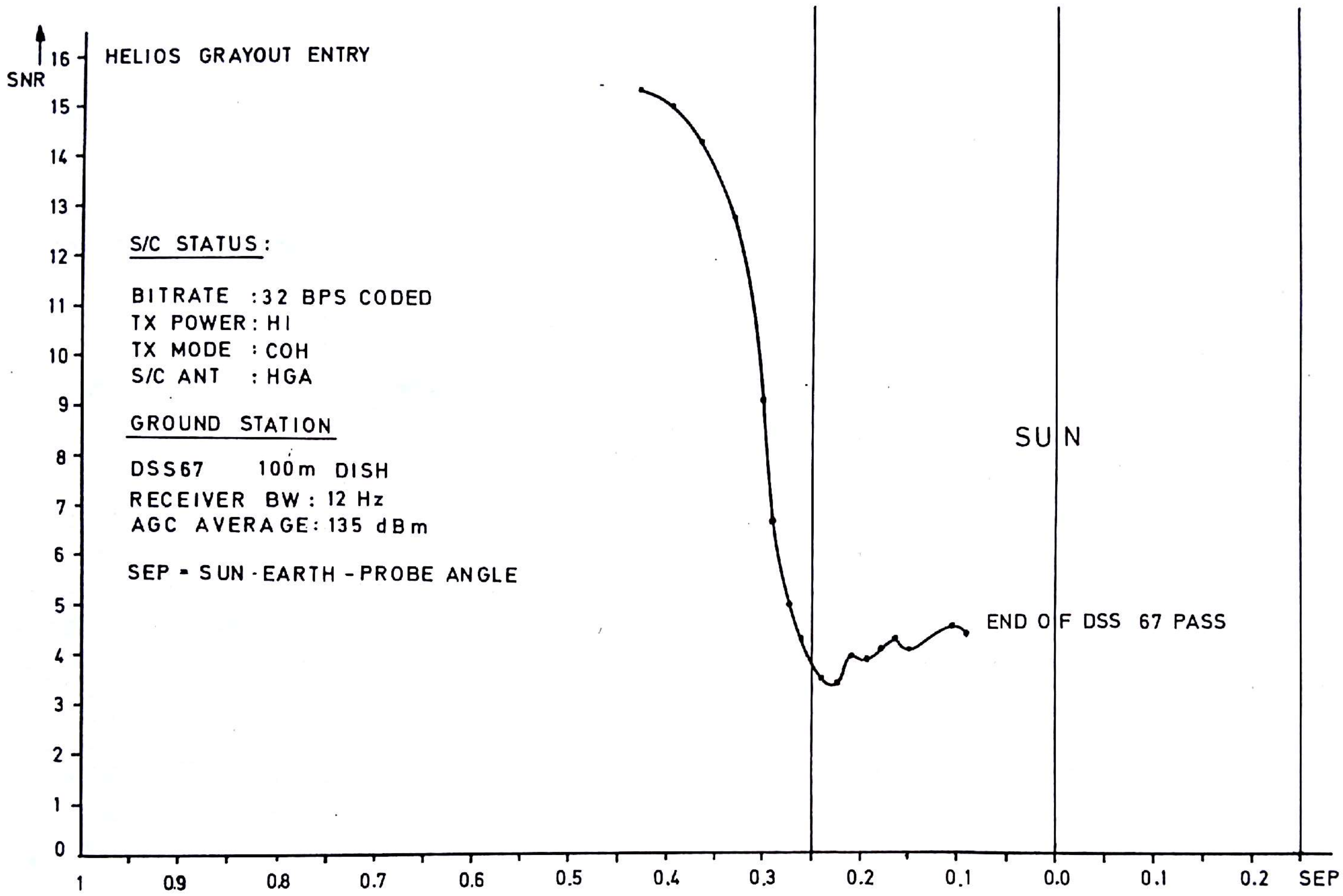
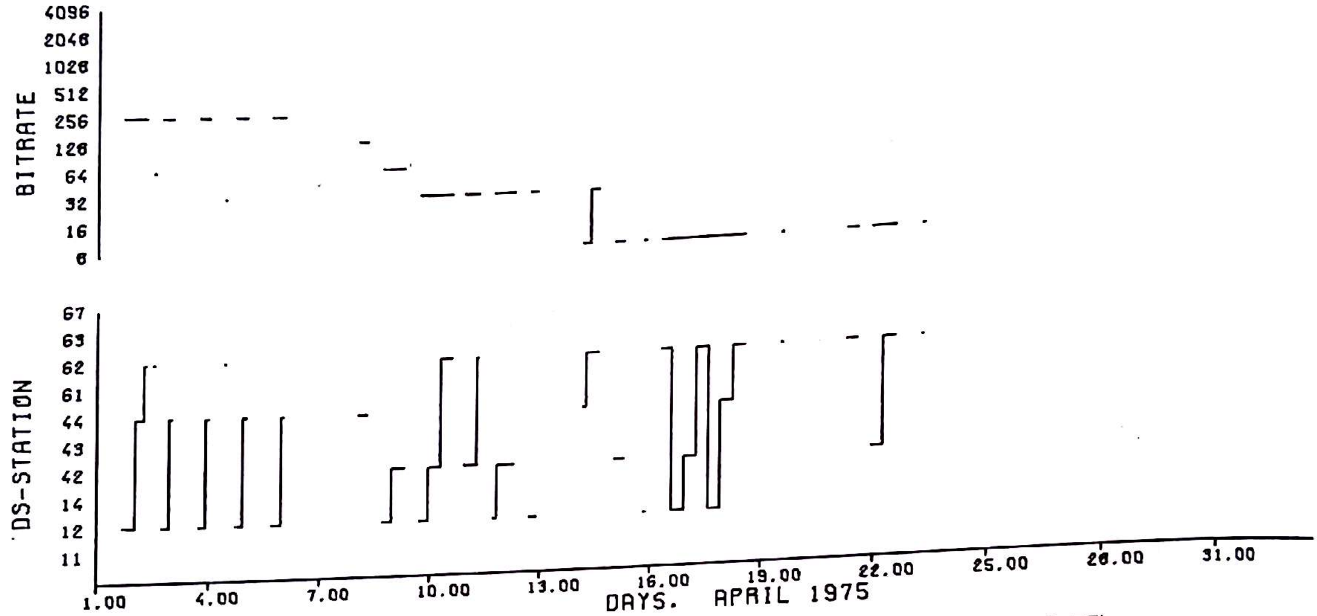


Figure 7.1-19: First Grayout Entry on 18. January 75

HELIOS-A DATA PLOT

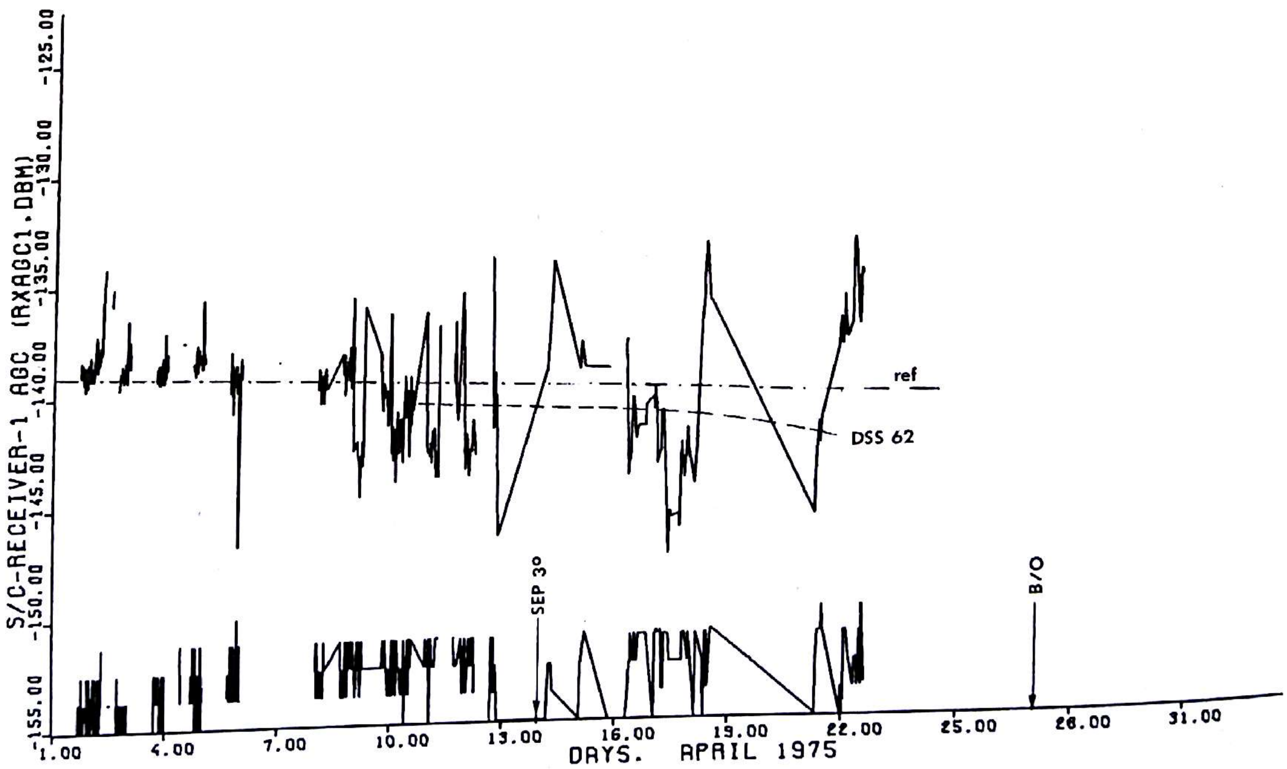


8.16-1.01-1.01-3

Figure 7.1-20: Ground Stations and Bitrate Steps (April 75)

VA-76.11.2

HELIOS-A DATA PLOT



8.16-1.01-1.01-3

U/C: AVERAGE L/C: MAX.DEV

VA-76.11.2

Figure 7.1-21: Actual Receiver 1 AGC (April 75)

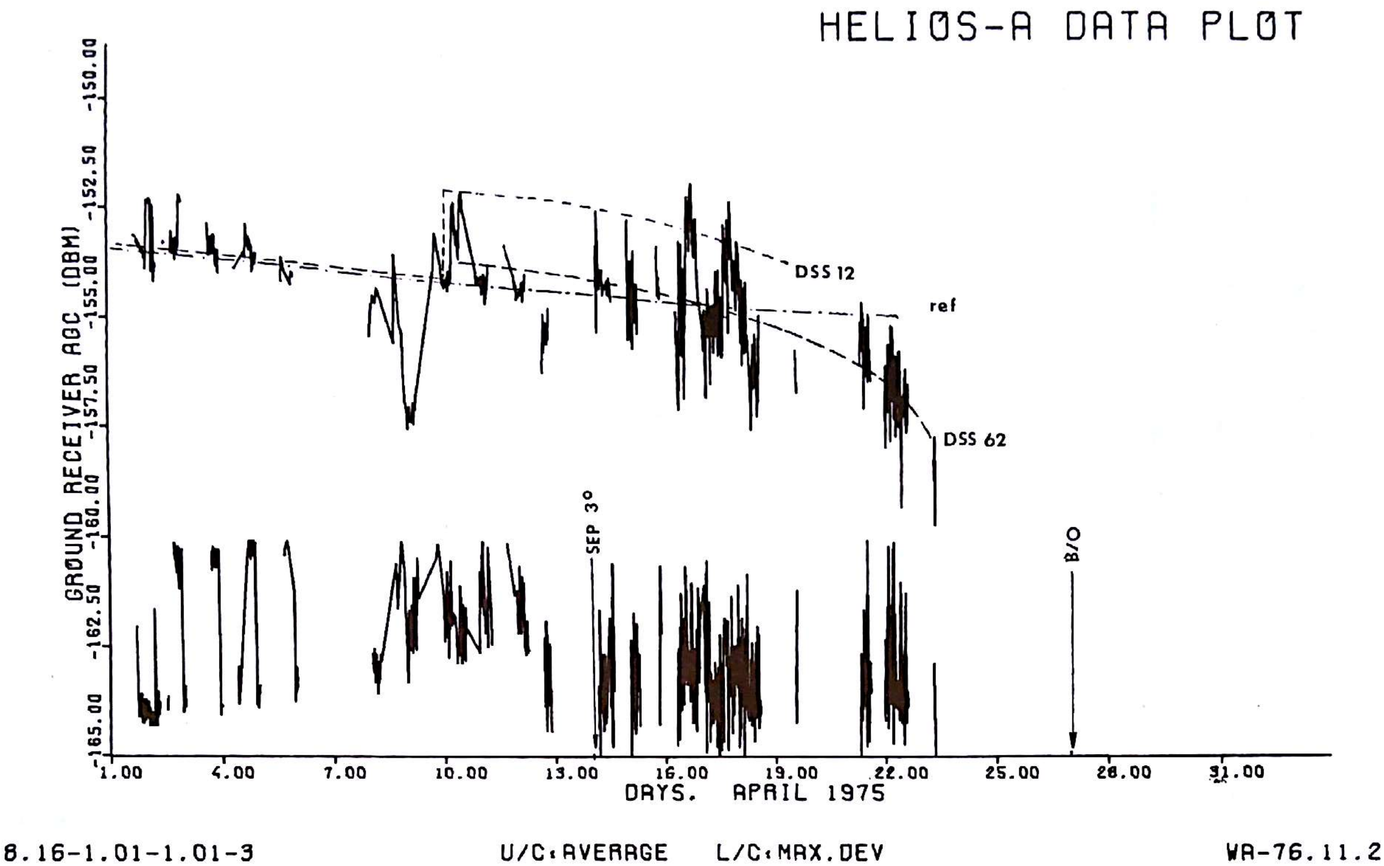


Figure 7.1-22: Actual Ground Station AGC (April 75)

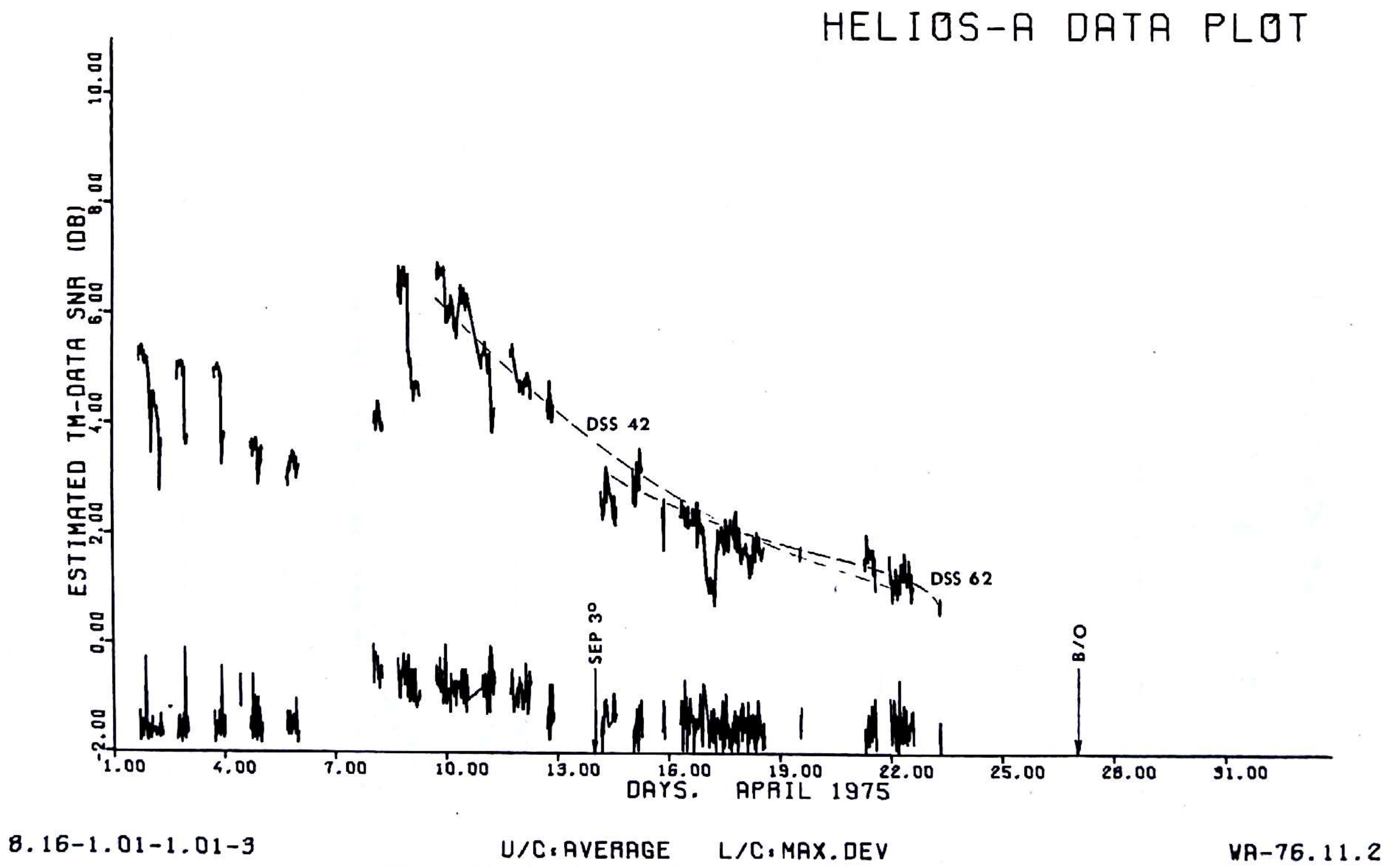


Figure 7.1-23: Actual Ground Station SNR (April 75)

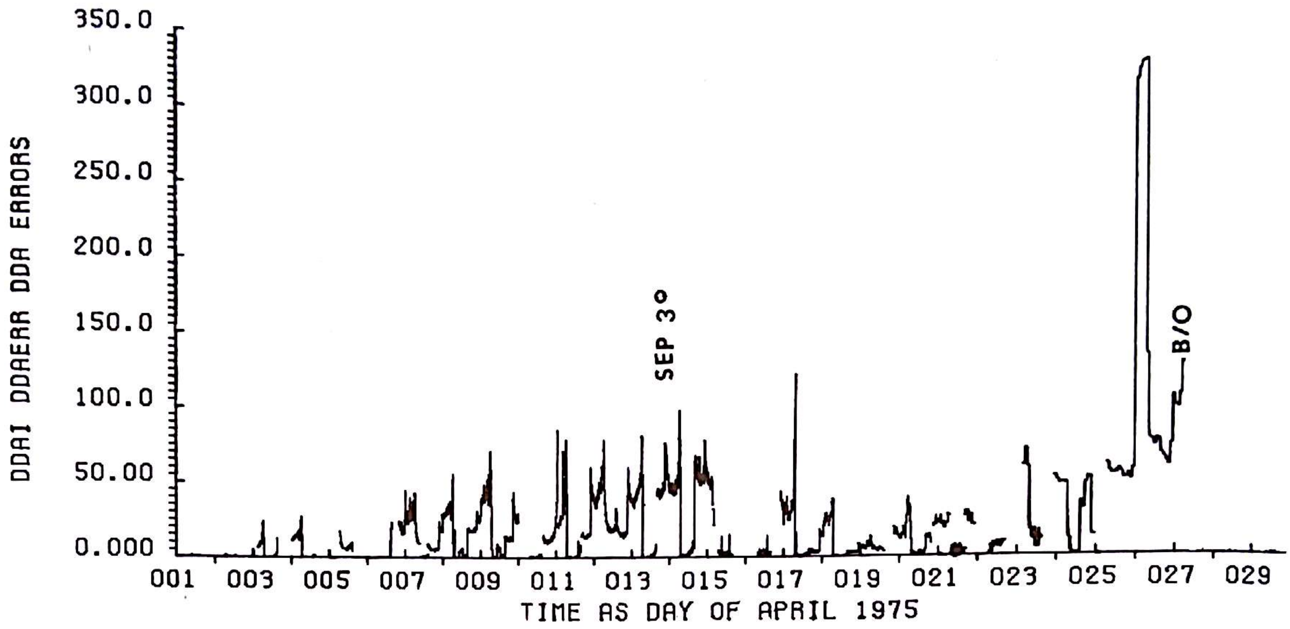


Figure 7.1-24: DDA Input Errors (April 75)

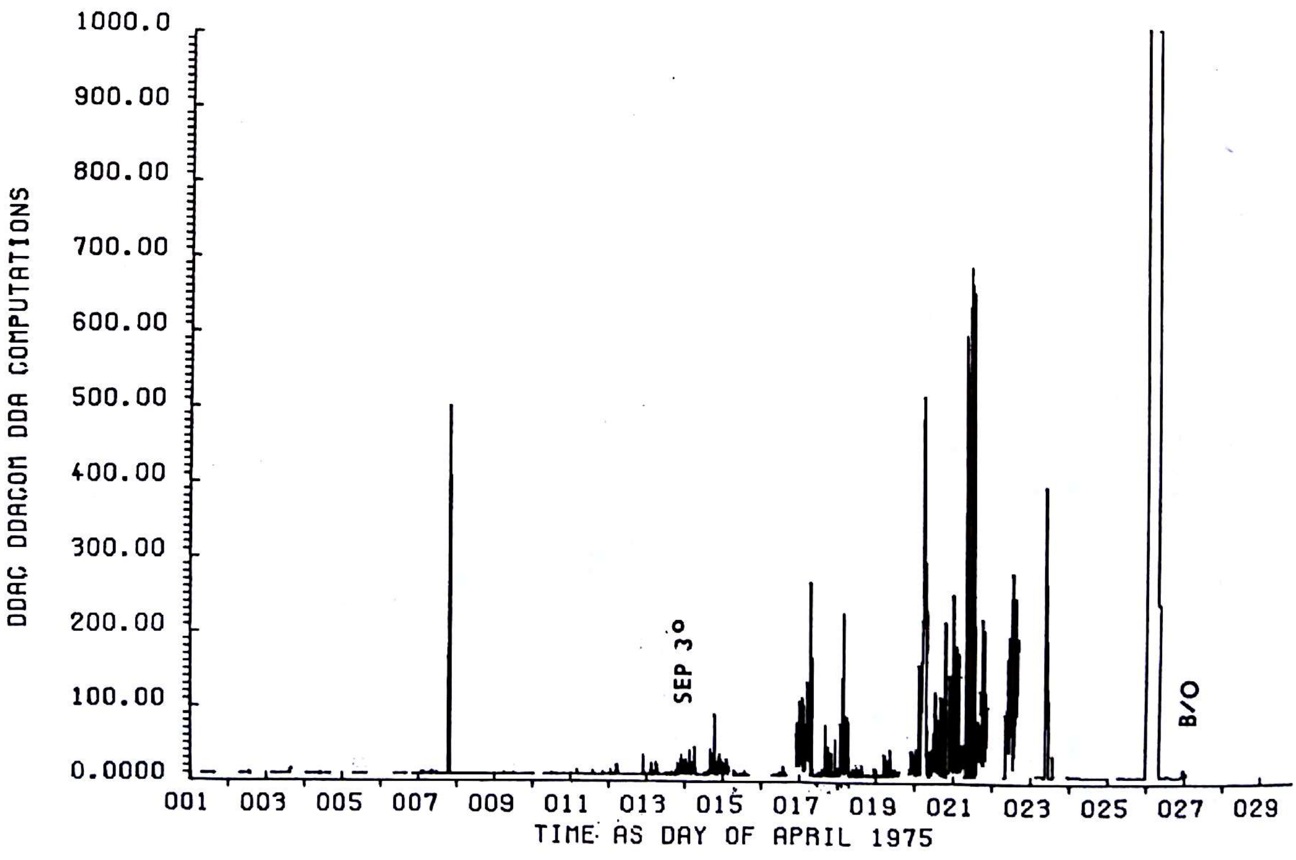


Figure 7.1-25: DDA Computations (April 75)

'expected levels' starts already at view angles SEP of about 3 degrees. The deviations, however, reach higher magnitudes only after passing the SEP = 1.5 degree mark.

The plot (lower curve) shows another interesting phenomenon : Between April 2 and April 6 the telecommunication links were very much affected by violent ionosphere disturbances (confirmed by AEROS, too). The maximum deviations (see lower curve) indicate that the AGC level variations during this time were even higher than during blackout entry. Also the variation periods seemed to be different.

— TELEMETRY DATA SNR *(Fig. 7.1-23)*

Whereas above described AGC effects are essentially caused by influences affecting the signal itself the SNR responds to both: signal disturbances and additive noise.

— DDA ERRORS and DDA COMPUTATIONS *(Fig. 7.1-24; 7.1-25)*

DDA errors/computations are indications for the quality of the received coded data processed in the DATA DECODING ASSEMBLY (DDA).

Because quantitative correlations between these two parameters and SNR/frame-deletion-rate are not avaible, more than above statement cannot be presented.

7.1.3.1 TABLE OF ENTRY AND EXIT PARAMETERS

The following little table *(Table 7.1-VII)* shows all relevant performance parameters of HE-A Grayouts and Blackouts experienced so far.

Table 7.1-VII: HELIOS-A Occulation Phases

NR	TYPE	CORE **) DATE	ENTRY		EXIT				STATION		TWT
							EN	EX	EN	EX	PWR
1	GRAY	18.2.75	18.2.	14:30:00	18.2.	22:30:00	0.4	o.4	67*)	12	HP
1	B/O	6.5.75	27.4.	18:00:00	16.5.	17:00:00	0.75	0.7	14	14	HP
2	B/O	1.9.75	29.8.	12:00:00	1.9.	09:43:00	0.7	0.64	14	67	HP
2	GRAY	14.3.76	13.3.	18:47:00	14.3.	08:25:00	0.41	0.76	14	67*)	MP
3	B/O	23.9.76	19.9.	06:40:00	23.9.	21:05:00	1.7	2.0	44	44	HP
3	GRAY	3.4.77	2.4.	22:54:00	3.4.	11:32:00	0.77	0.4	42	63	MP

Table 7.1-VII: HELIOS-A Occulation Phases

*) From Sept. '76 on: DSS 67 was installed at Weilheim using the 30m dish.
Previously: 100 m DSS 67 at Effelsberg

**) CORE DATE indicates the day of the minimum S.E.P. angle i.e. for B/O transitions S.E.P. = 0°

STATIONS:
DSS12 = 26 m Antenna
DSS14 = 64 m Antenna
DSS42 = 26 m Antenna
DSS44 = 26 m Antenna
DSS63 = 64 m Antenna

7.1.4 TRANSMITTER PERFORMANCE PARAMETERS

The following plots shall give an example of the performance of the transmitter (using the most actual in-flight data). The transmitter parameters are temperature dependent, therefore a complete temperature cycle is shown on the plots using the GASTANK temperature *(Fig. 7.1-26)* as representative central compartment temperature.

- COLLECTOR TEMPERATURE *(fig. 7.1-28)*

  This temperature varies slightly with the changing compartment temperature. TWT 2 is in medium power (MP) mode.
- HELIX CURRENT *(Fig. 7.1-27)*

  The telemetered helix current is slightly increasing with increasing temperature. TWT2 in MP.
- TWT - PM OUTPUT POWER MONITOR *(Fig. 7.1-30)*

  The TWT2-PM is decreasing vs. temperature. Valid for MP.
- DRIVER PM (POWER MONITOR) *(Fig. 7.1-29)*

  The driver PM is decreasing vs. temperature
- TXRPM REFLECTED POWER *(Fig. 7.1-31)*

  This is an indication for the quality of the matching between TWT and antenna. As can be derived from the plot, the matching is better at higher temperatures.

7.1.5 SIGNIFICANT ANOMALIES AND RECOVERY

1. **Ranging Failure**

On October 10, 1975 DSN reported for the first time the loss of ranging capability with HELIOS-A.

Since that time the ranging signals got lost within the S/C, when the VSO temperature was between +5 and +18 degrees Celsius.

The failure could be very soon attributed to the ranging transponder. For, if the uplink signal was nominally ranging modulated and the S/C ranging transponder was switched through:

- Both S/C RCVR AGCs reacted nominally with a decrease of about 6 dB
- Ground station AGC and SNR values showed no response: they 'reacted' as if no ranging data were modulated on the downlink signal.

To get more information about the exact failure cause, four different test series were realized. But only with small success:

- With the most sensitive test receiver, for a short time, a very weak response to the transmitted test signals could be detected on the downlink.
- Spectrum plots being produced after the last test series show after switch to ranging modulation „On“ a significant increase of something like noise within the 500 kHz region. This is the area where in nominal case the highest ranging power density is expected.

So all facts suggest that the cause for the ranging signal loss is a systematic effect affecting the ranging transponder front-end stages.

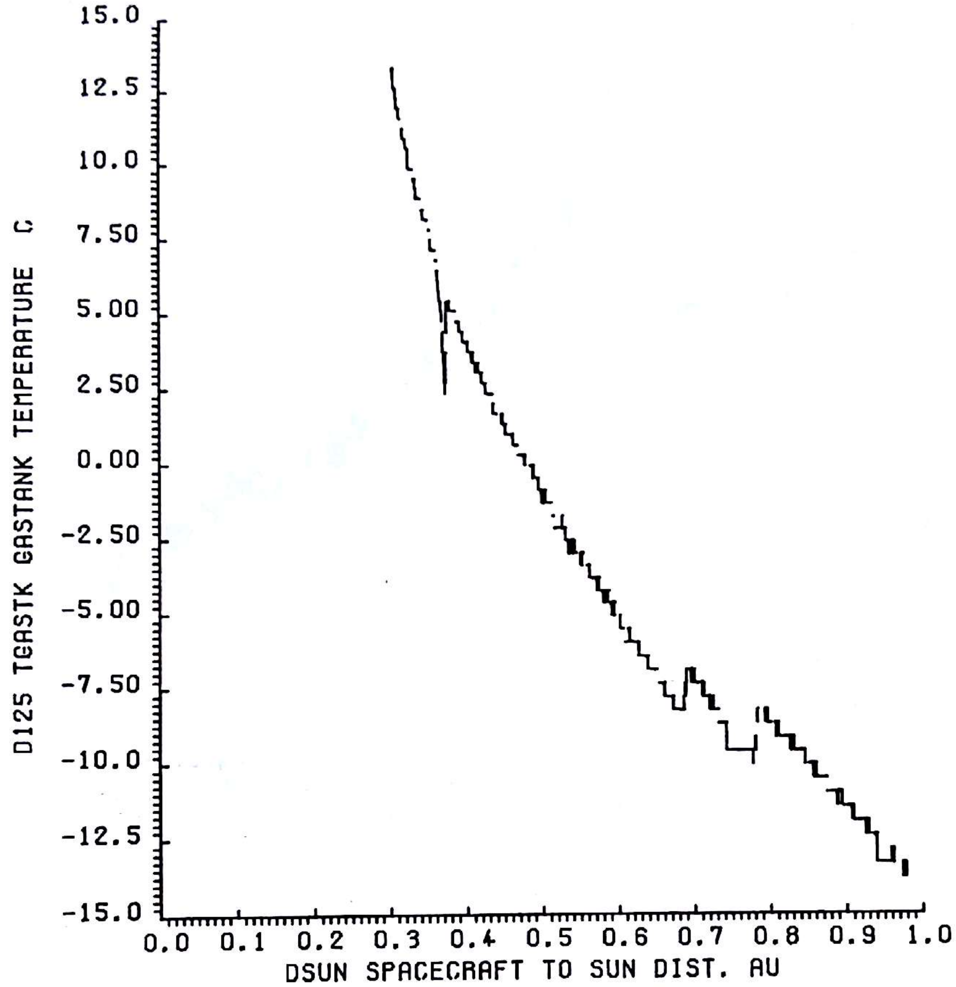


Figure 7.1-26: Gastank Temperature

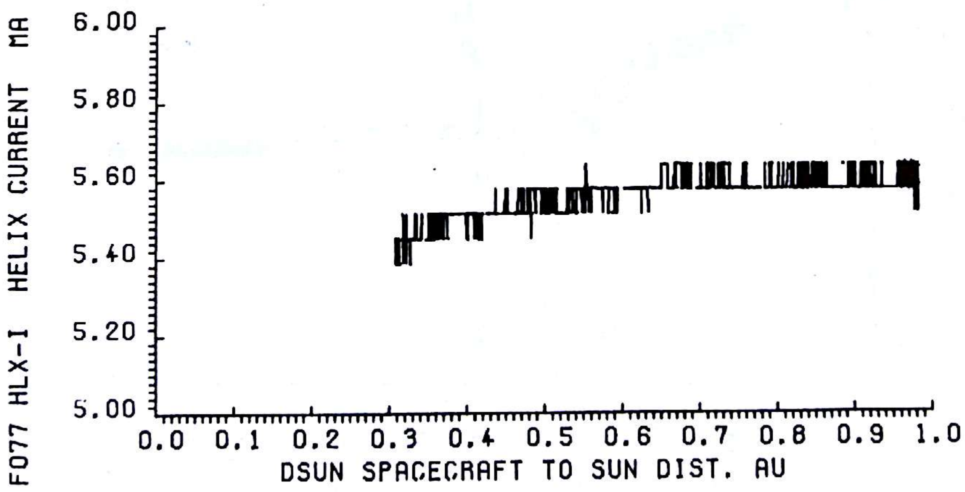


Figure 7.1-27: Helix Current

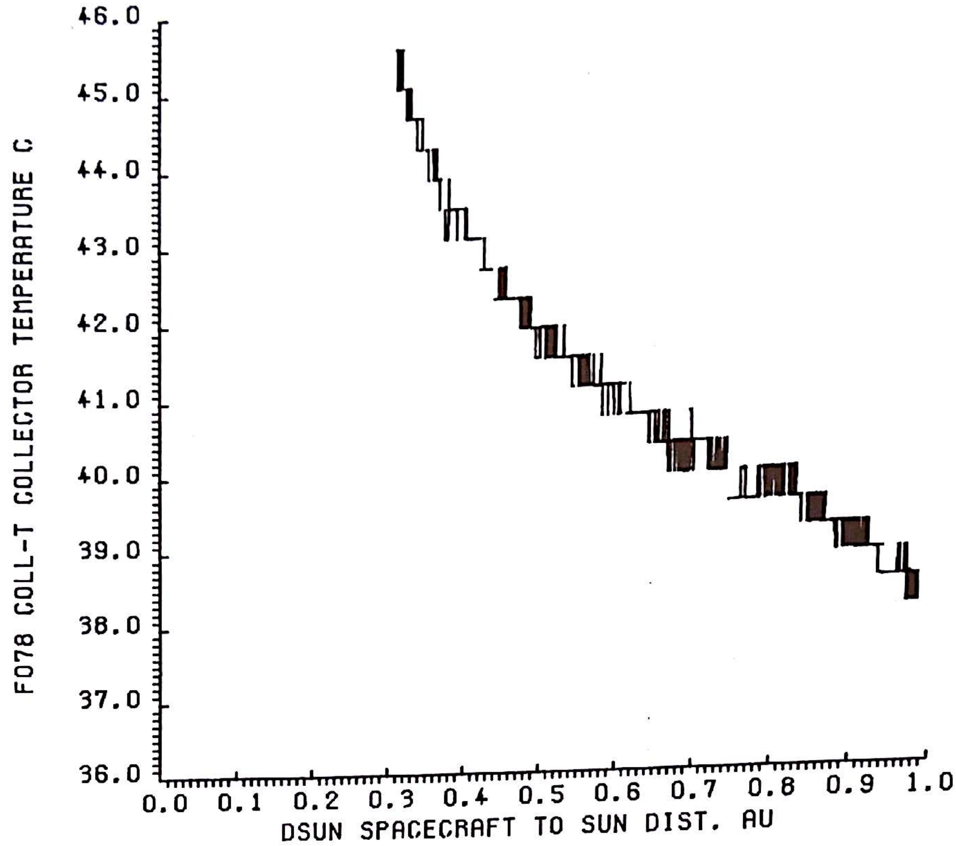


Figure 7.1-28: Collector Temperature

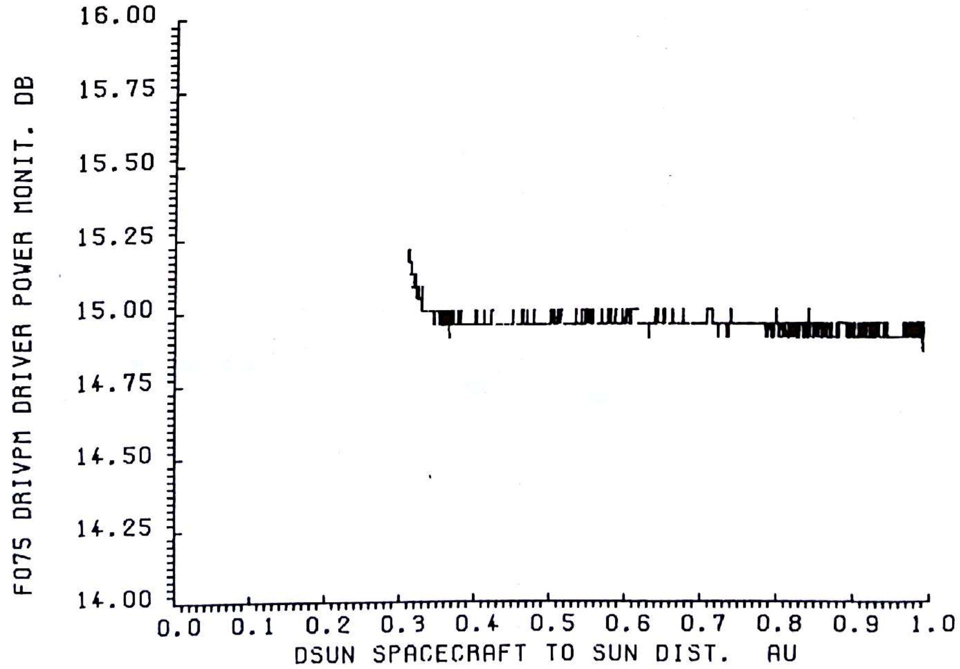


Figure 7.1-29: Driver Power Monitor

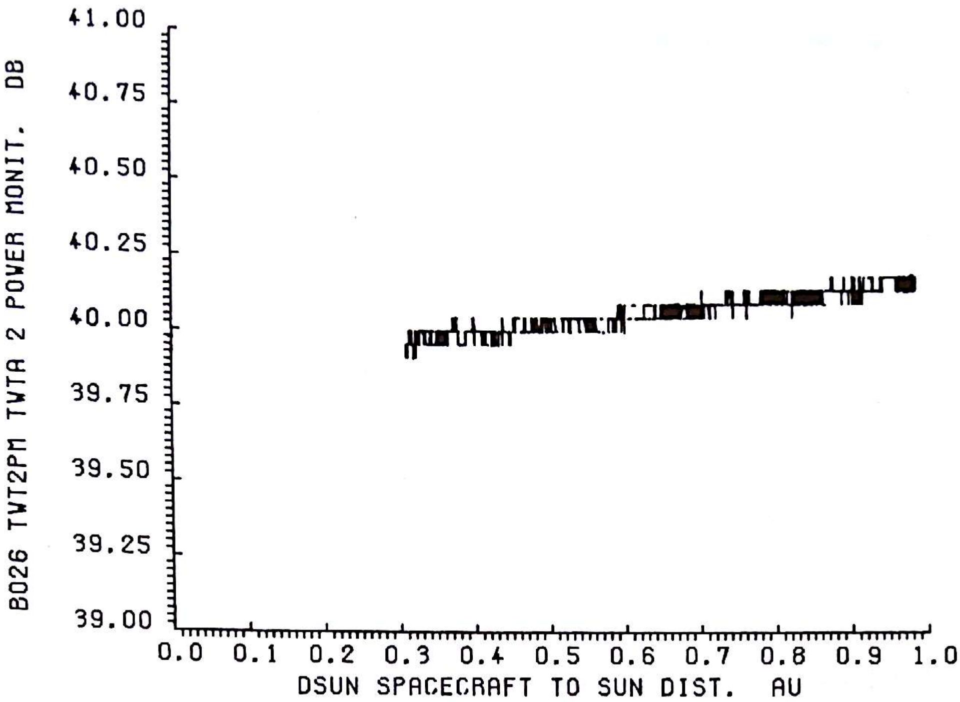


Figure 7.1-30: TWT2 Output Power Monitor

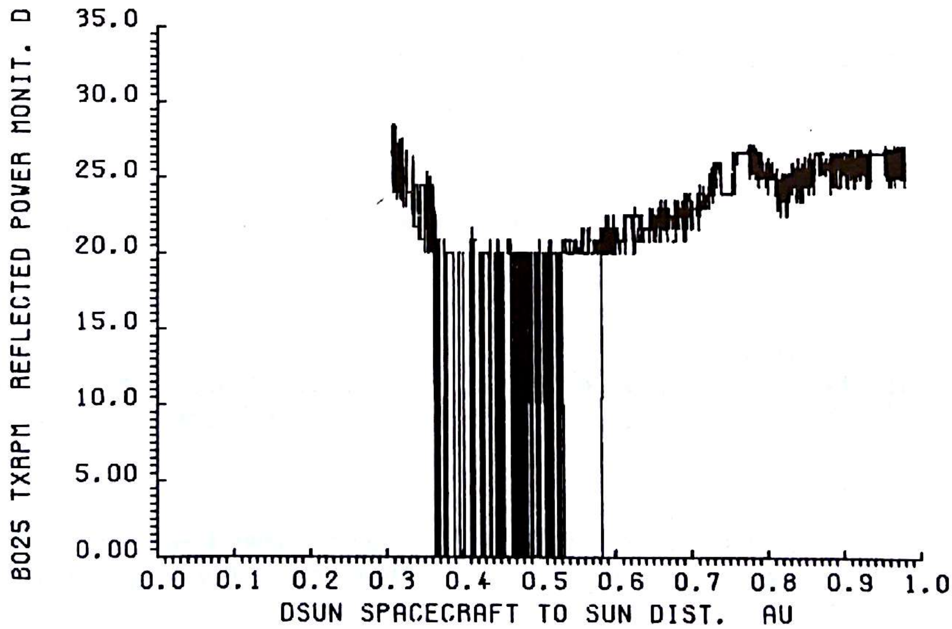


Figure 7.1-31: TX Reflected Power

2. **Multipactor Effect**

Very soon after the first switch to HGA the scientists of the Experiments 1 and 5 reported noisy data starting at that time when the HGA was in operation.

A switch back to HGA proved that the HGA indeed was the noise source.

Intensive investigations revealed that the cause of this disturbance was the so-called multipactor effect: A secondary electron emission effect between the slots of the HGA.

As a consequence the slots of the HGA device, provided for HELIOS-B, were enlarged.
Recovery: With an extraordinary scheduling and S.O.E. coordination effort (approx. 100 switches back and forth) phases of MGA-use (64, 100m Ground Antennas) and HGA-use were scheduled without degrading the data return too much, in order to provide the disturbed experimenters with sufficient data.

2. **TWT1 Failure**

On October 31, 1975, at 18:34:31 hrs DSS 11 lost downlink. The last received TLM data showed a strong increase of helix current and collector temperature of TWT1, which was operating in HP mode.

After DSS11 did not succeed in signal reacquisition a degradation of TWT1 efficiency because of thermal overload was assumed. At 21:21:19 TWT1 was therefore switched to MP mode. And indeed the ground station could reaquire the lost S/C signal.

At 22:53:23 hrs, however, the downlink signal got lost a second time. S/C XMTR was subsequently switched to TWT2, which is in operation until now.

The cause for these TWT1 failures is unknown.

7.1.6 RECOMMENDATIONS / CRITICAL REVIEW

A series of imperfections, which could have been corrected without additional effort during the design phase, are listed in the following S/C Transponder design critique:

Recommendation No. 1

The modulator, driver and TWT power monitors are rather temperature sensitive. More temperature independence of important R/F parameters is recommended from an operational point of view.

Recommendation No. 2

Since the R/F System parameters are the most vital ones for the performance of a S/C, the sampling rate should be as high as possible, not using the lowest subcommutation rate as HELIOS does.

Recommendation No. 3

With the experienced ranging failure it turned out, that it would have been very informative to have an indication whether a ranging signal is routed through the ranging transponder or not.

Recommendation No. 4

In order to optimize tracking operations, a better solution for exact VCXO best lock frequency determination would be desirable. The HELIOS used method implies 1...2 hr periods in noncoherent mode with no uplink.

7.2 POWER SUBSYSTEM

7.2.1 BASIC CHARACTERISTICS

7.2.1.1 POWER SUPPLY

The basic block diagram is shown *in Fig. 7.2.-1.* The S/C power is provided by:

- Battery
- Solar Generator

The battery is a Silver-Zinc type battery with 18V and 36V output to the Pulse Conditioning and Distribution Unit (PCDU) and 36V to the Regulator.
The battery (8AH) is used only from 5 minutes before launch until the Solar Array takes over automatically about 30 min after launch[1]. Another function of the battery was to provide power to the pyrotechnic circuits.
The solar generator has to operate at a sun-S/C distance from 0.25 AU to 1.00 AU.
The Solar Array (S/A) has full performance after completion of STEP I maneuver (sun perpendicular to the S/C spin axis).
Both systems, battery and S/A are connected in parallel to the regulator separated by diodes.
Once the S/A voltage exceeds the battery voltage, the S/A will take over automatically.
The battery then is disconnected from the bus and discharged to a defined level in order to prohibit outgassing of the battery.

7.2.1.2 REGULATOR

Regulator and Converter are held in cold redundancy, in event of failure, they are brought on line automatically, also any combination of regulators and converters can be selected by telecommand. The regulator stabilizes the output voltage to 28V ± 1 % and distributes the main bus into:

- Essential load bus (28V to subsystems)
- Non-Essential load bus (28V to experiments)
- Converter-bus (28V to converter).

The maximum allowable regulator output current is 8.5A (238W). At an output current of 10A the regulator will switch automatically after 100 msec to the redundant regulator. The regulator input voltage is ranging from 32V to 75V at full load conditions, or 32V to 85V under no load conditions. The regulator efficiency depends on the regulator output-current, regulator temperature, and regulator input voltage.

Example: With the worst case — regulator input voltage 75V, regulator output current 6A and regulator temperature 0° C the efficiency is 88.2 %.

7.2.1.3 CONVERTER

The converter is a self-oscillating converter with 16 output voltages given by 5 separate windings with different tappings, the converter input-voltage will normally be 28V ± 1 %, it provides various stabilized output voltages to the different subsystems. The stability of the output voltages is within ± 5 % of the nominal value. The efficiency of conversion is 74 %.

[1] This corresponds with the shadow exit time at nominal injection, the total capacity of the battery would be approx. until 2 hrs after lift-off.

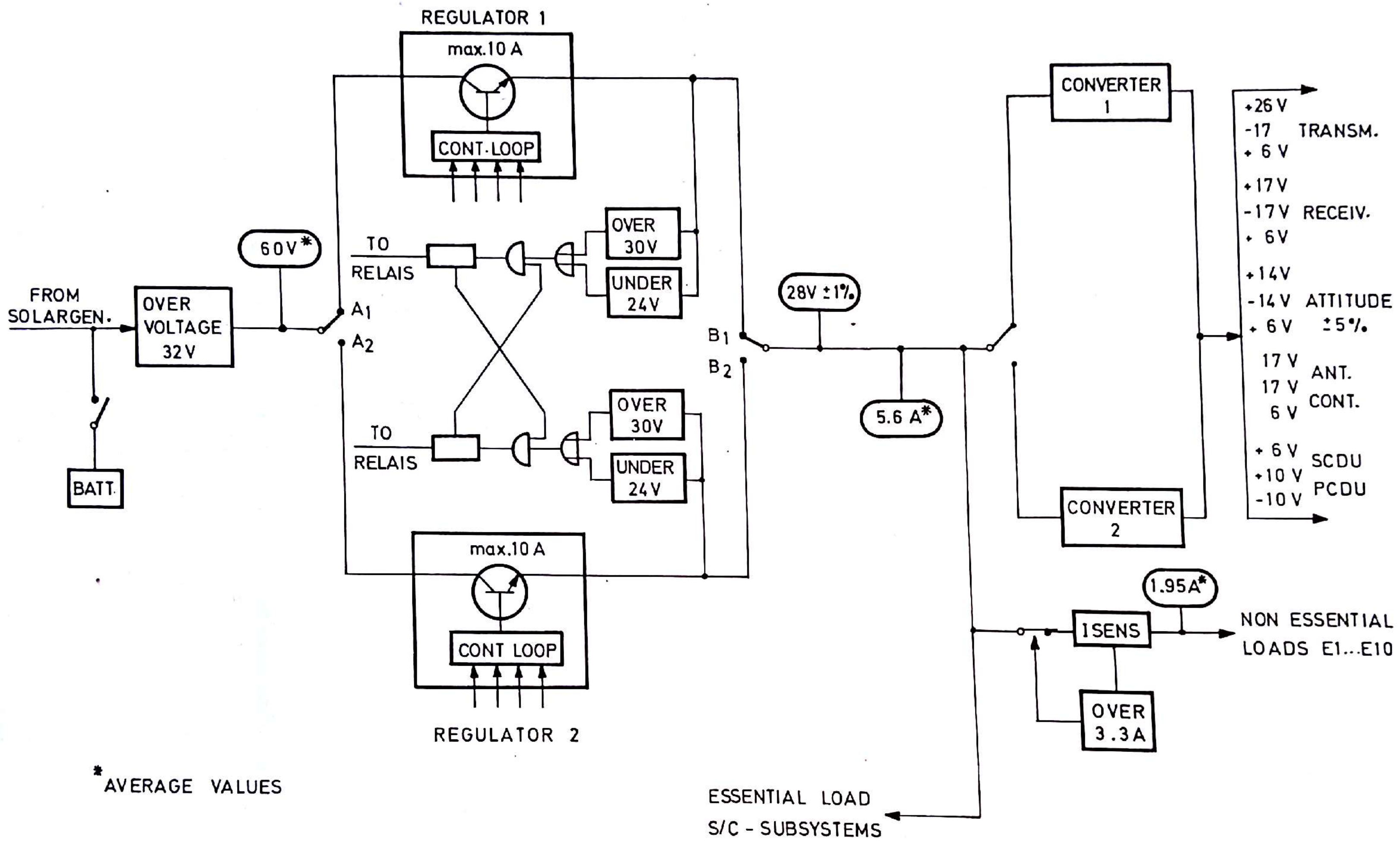


Figure 7.2-1: Power Subsystem Block Diagram

7.2.1.4 PROTECTION FEATURES

The power subsystem has the following automatic protection features:

- Input over-voltage protection shunt
- Output under- and over-voltage detection circuits
- Over-current protection (cut off) for the non essential bus
- Failure detection for converter.

The input over-voltage protection at the regulator input is obtained by a detection logic which switches the overload into a shunt.

The output-over voltage (> 30V) and under voltage (<28V) protection is provided by separately powered failure detection circuits which switch automatically to the redundant regulator if one of the conditions appears for longer than 100 µsec.
In order to allow a proper start up of the redundant regulator, the failure detection circuit is hibited for 50 msec.
Together with a regulator switch the following safety measures happen automatically:

- Disconnection of the Non Essential Bus
- R/F SILENT MODE (disconnection of the Modulator/Driver unit)
- D/H SAFE MODE: 8 BPS, FM4, DMO.

The over-current protection for the non essential bus is also performed automatically whenever the current exceeds 3.3A, by disconnecting all experiments.

The failure detection circuit for the converter consists of an additional winding on the output. Any voltage drops will trigger a switch to the redundant converter.

7.2.2 SPACECRAFT POWER DEMAND

The following tables and figures shall demonstrate the performance of the power subsystem on typical examples, and also show the development up to the 4. Orbit.

- Regulator Output Power (RGOUTP)

  Fig. 7.2-2 gives an overall picture (1. Orbit) of the total spacecraft power consumption at 28V Regulator Output Voltage. The maximum power drawn was 218 Watts which occured at o.95 AU spacecraft-sun distance in high-power mode right after launch. At the same distance (at o.95 AU) during the 1. Aphelion the power consumption was 208 Watts, which means that 1 heater less came up.
  At 1. Perihelion the spacecraft drew 197 Watts, with all experiments enabled.
  The steps in the profile indicate the gradual switch off (resp. switch on) of the thermostat controlled heaters (6. . .1oW per step).

  Further power subsystem performance evaluation:

  Table 7.2-I: The power requirements for each spacecraft load evaluated during the mission are shown in this table.

  Tàble 7.2-II: Gives an overlook on the heater power consumption, the switch temperatures, thermostat and heater locations.

  Table 7.2.-III: This is a comparison between 1. and 4. Orbit. The comparison-points have the same S/C-sun distance and the same solar-intensity values.

- Regulator Input Voltage (RGINPV)

  Fig. 7.2-3 gives a comparison between 1. and 4. Orbit of the regulator input voltage. The degradation from APHEL to PERIHEL is averaged 3V. An interesting effect is that the curve after Perihelion for the 4. Orbit follows more closly the 1. Orbit curve

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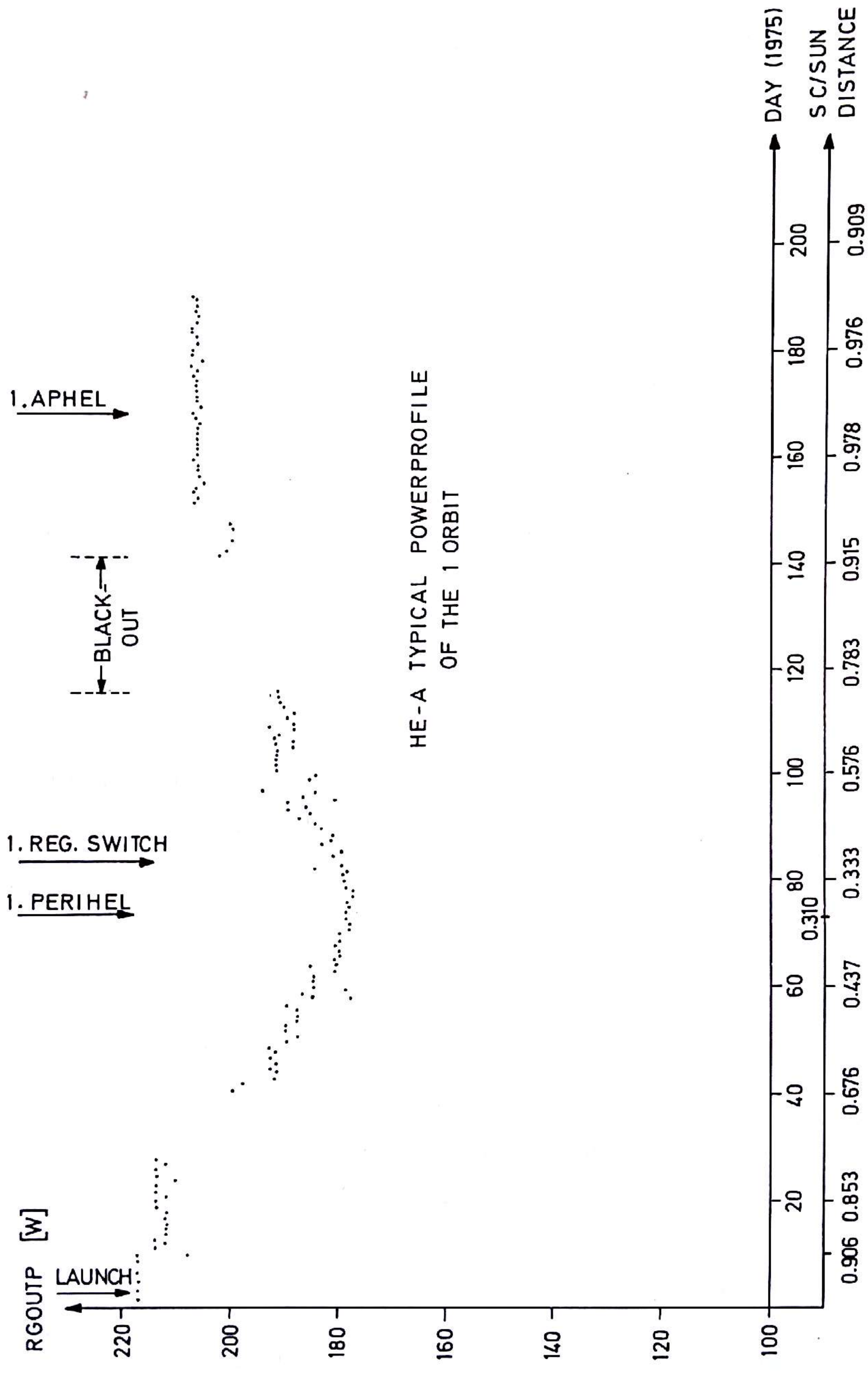

Figure 7.2-2: Regulator Output Power for the first Orbit

SPACECRAFT LOAD	POWER (WATTS)	REMARKS
Experiment 1	9.2	Minimum Power
	11.4	Maximum Power
2	6.2	
3	2.8	
4	4.5	
5A	2.8	
5B	1.1	
5C	2.2	
5DPU	0.8	
6	4.2	
7	3.9	
8	3.9	
9	7.3	
10	6.1	High voltage mode
Nozzle power pulse	10.1	
DDA heater	5.6	
DDA motor	1.0	
RF Modes:		
Low to medium power	33.0	
Medium to high power	28.7	
Antenna 1 motor	14.8	Faulty antenna
Antenna 2 motor	11.2	

Table 7.2-I: Power Demand of Essential S/C Loads

HEATER GROUP	HEATER LOCATION / THERMOSTAT-LOCATION	TOTAL POWER W	SWITCH TEMPS. °C	REMARKS
I	E2A	3.5	- 15 ON + 37 OFF	CYCLING
	E3A	4.0	+ 3 ON + 16 OFF	CYCLING
	E4A	4.0	+ 5 ON + 25 OFF	CYCLING
II	E9A	3.4	+ 10 + 20	
	E9B	4.33	- 20 + 10	
	E0A	3.65	- 10 + 20	
	E0B	2.45	+ 5 + 15/25	
III	ON RECEIVER, PREAMPL. ON WALL 16	4.8	- 15 - 8	
	$R_1 + R_2$ ON BOTTOM COMP. 1 $R_3 + R_4$ ON BOTTOM COMP. 8 ON WALL 15/16	16.4	- 19 - 12	
	$R_5 + R_6$ ON BOTTOM COMP. 7 ON WALL 12/11	6.8	- 19 - 12	
	$R_7 + R_8$ ON WALL 11 ON BOTTOM COMP. 6	14.4	- 15 - 8	
	$R_9 + R_{10}$ ON BOTTOM COMP. 5 ON WALL 8	6.8	- 19 - 12	
	R_{11} R_{12} ON BOTTOM COMP. 4 ON BOTTOM COMP. 4	6.8	- 19 - 12	
	R_{13} R_{14} ON WALL 5 ON BOTTOM COMP. 3	6.8	- 15 - 8	
	R_{15} ON BOTTOM COMP.2 ON WALL 2/1		- 15 - 8	
	R_{20} ON BATTERY ON BATTERY	3.4	+ 5 + 15	CYCLING

Table 7.2-II: Heater Power Demand

a) MISSION POINT (DAYS) b) DAYS OF YEAR 1976	S/C SUN DISTANCE (AU)	SOLAR INTENSITY	SOLAR ARRAY TEMPERATURE	REGULATOR		POWER FROM SOLAR ARRAY	DIFFERENCE
				INPUT VOLTAGE	POWER AT 28 VOLTS		
a) 02 b) 181	1.0 0.984	1.0 1.0	- 53.5 - 47.0	74.85 71.5	183 197	208 222	14
a) 34 b) 215	0.9 0.9	1.24 1.24	- 42.0 - 37.5	74.10 71.45	206 195	235 222	13
a) 48 b) 230	0.8 0.8	1.56 1.5	- 27.3 - 23.0	72.9 71.0	206 197	235 223	12
a) 67 b) 251	0.6 0.6	2.78 2.8	+ 10.4 + 6.0	67.66 65.0	193 185	217 209.7	7.3
a) 75 b) 259	0.5 0.5	4.0 4.0	+ 38.7 + 41.0	62.87	182-193 185	204-216 207.3	3.3
a) 95 b) 279	0.31 0.31	10.41 10.4	+ 130.2 + 138,9	45.09 43.0	178* 150**	196* 167**	29

* HIGH POWER
**MEDIUM POWER

Table 7.2-III: Comparison between 1. and 4. Orbit

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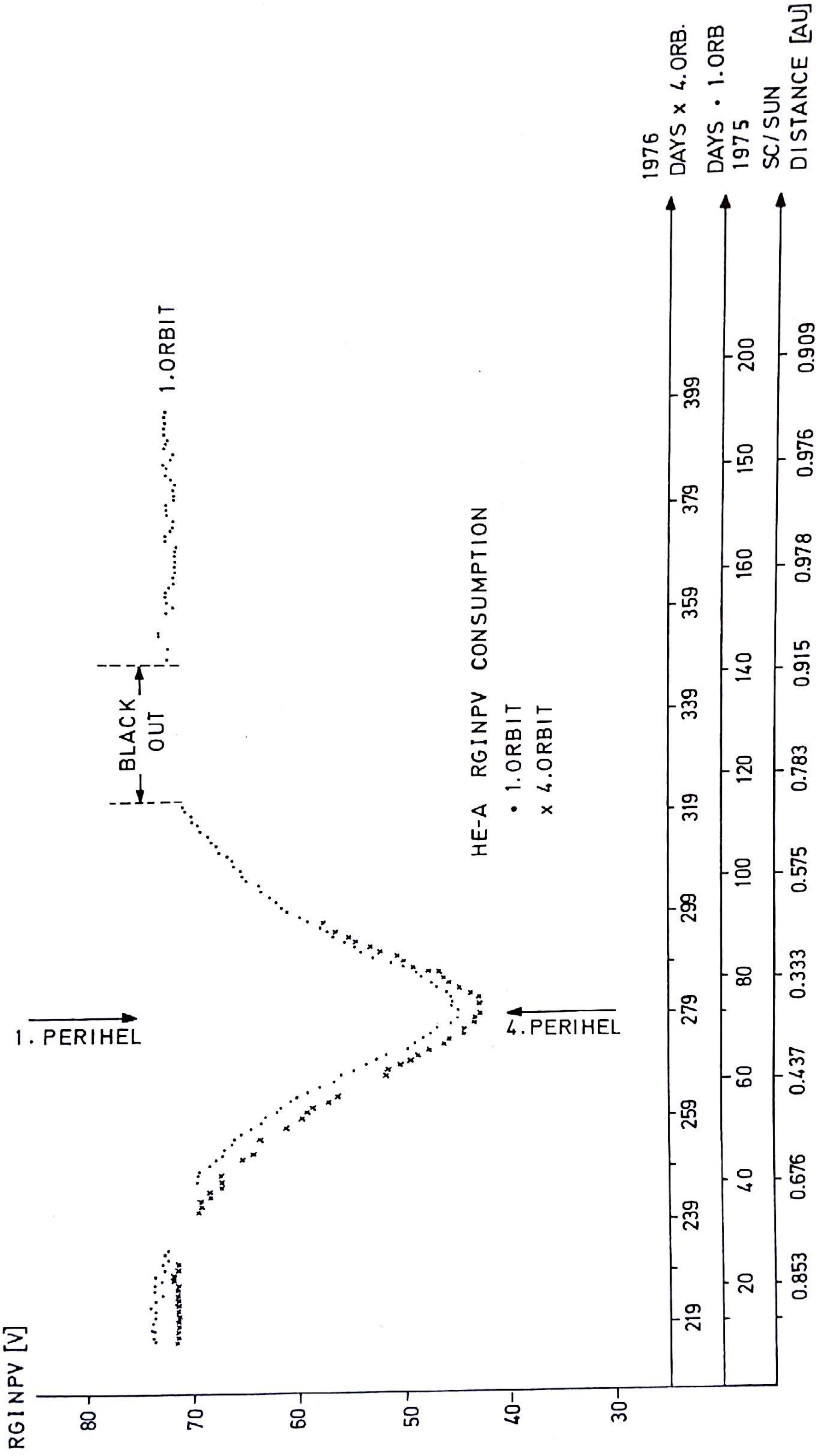

Figure 7.2-3: Regulator Input Voltage for first and fourth Orbit

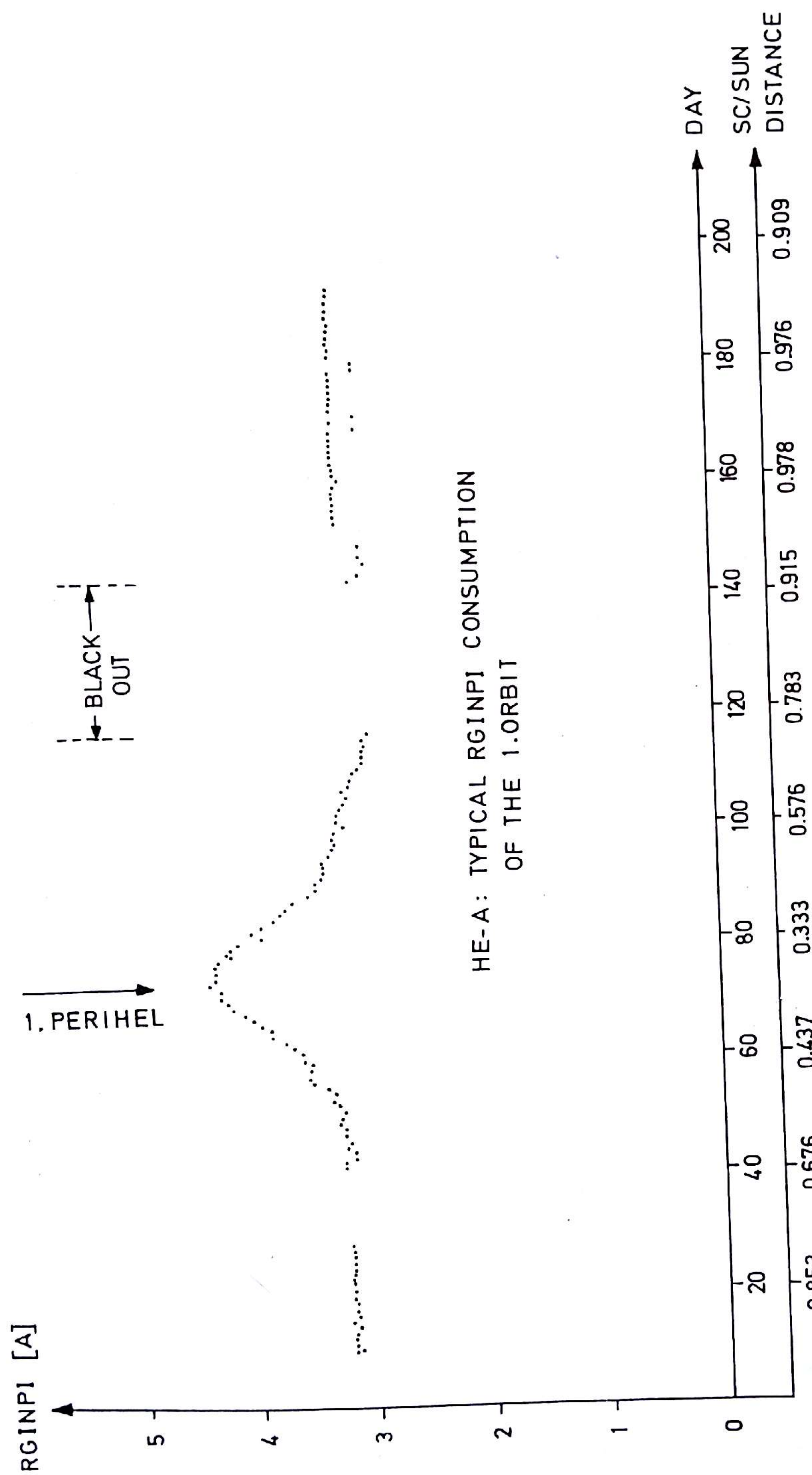

Figure 7.2-4: Regulator Input Current for the first Orbit

(difference approx. 1V). It is explainable by the fact that from 4. Perihel on the TWT 2 was switched to Medium Power Mode.

— Regulator Input Current (RGINPI)

Fig. 7.2-4 shows the Regulator Input Current for the 1. Orbit.

The maximum current is drawn at Perihelion: 4.3 A

7.2.3 DEGRADATION, FUTURE POWER MARGINS

The evaluation of the power data over the up to now available 5 orbits led to the following degradation formula:
Starting with a S/A output power of 240W at launch, leads to an available Regulator Output Power of 212W (Regulator efficiency 0.883%).
From this value 5W per orbit (Aphelion) are subtracted. The 5W can be attributed to a degradation of:

- 2% per Aphelion
- 2W per 5° S/A temperature increase at Aphelion.

The *Table 7.2-IV* shows the values up to 5. Aphelion.

7.2.4 SIGNIFICANT ANOMALIES AND RECOVERY

1. **Experiment 5A Antenna Deployment**

As one of the initial configuration events the E5A antenna was deployed (approx. 3 hrs after lift-off).
Both antenna motors were started at the same time and the antennas deployed simultaneously. While antenna 1 deployment was stopped automatically at full extension the antenna 2 did not. Subsequent analysisses indicated that antenna 2 was not deployed or did not leave the ion-guard (iron pipe to guide the unroll of the antenna during the first inches of deployment).

A total of 11o contingency sequences was carried out during the first weeks trying to rock the stuck antenna back and forth in order to loosen it.

Recovery: None
But this experience led to a redesign (extension) of the ionguard and the preparation of a special deployment sequence for HELIOS-B

2. **Non Essential Bus Drop**

The second non-nominal event affecting the power conditioning units occurred on launch + 104 days (Day 083-75 15:14:14).
The non-essential bus was switched off leaving all experiments unpowered.
In addition the following relays in the PCDU changed state due to this disturbance, from ON to OFF:

- Heater group 2
- Heater group 3
- Nozzle power
- Antenna Motor 2

The antenna motor 2 changed to ENABLE and antenna motor direction changed to FORWARD. This relay state appeared to be random, therefore the conclusion of the following extensive analysis was, that

Event	Initial limit from last Aphel	S/A 2 % degradation (W)	Limit with degrad.	Power loss due to temp increase	Total power avail. limit (W)*)	Operat. power limit at operational power margin (-6W)
Launch HE-A 12/10/74	212	0		0	212	206
1st APHELION HE-A 06/17/75	212	4.3	207.7	0.7	207	201
2nd APHELION	207	4.1	202.9	0.9	202	196
3rd APHELION HE-A 07/02/76	202	4.0	198	1.0	197	191
4th APHELION	197	3.9	193.1	1.1	192	186
5th APHELION HE-A 07/18/77	192	3.8	188.2	1.2	187	181

*)Regulator Output Power

Table 7.2-IV: Future Power Margins

the Non Essential Bus was accidentally turned off by a spike on the ground or command lines, rather than by the overcurrent protection of the Non Essential Bus. This was also supported by the following reconfiguration of the experiments which was done according to the experiment integrity check-out procedure, which checks for each experiment separately whether a short circuit has developed or not. The Regulator showed no deterioration after reconfiguration.

Recovery: Checkout and reconfiguration of all experiments. Reconfiguration of the switched relays.

3. **Regulator Switch**

On day 174 1976 at 03:49:10 a third non-nominal event in the Power Subsystem occurred, ten days before the third Aphelion:
Very fast breakdown of all supply voltages within 10 minutes and then loss of downlink. An analysis of the last received data revealed that apparently — due to overload of the solar generator — an automatic regulator switch had occurred leaving the S/C in „SILENT MODE".

Recovery: After various contingency sequences the S/C was recovered using the Medium Gain Antenna (the voltage breakdown caused a mispointing of the High Gain Antenna). The total load was reduced (according to new degradation numbers — *see also 7.2.3)* to a total of max. 197 Watts.

This reduced available output power prohibited that all experiments could be turned on again (in addition more heaters came on than expected due to the reduction of heat dissipation within the central comparment) so a priority list was established and experiments were gradually switched on as heaters switched off after the Aphelion.

Two more regulator switches occurred in the course of the mission: On day 093-77 17:16:19, and on day 192-77 23:54:00 the downlink was lost because of regulator switches. Extensive command sequences were necessary to reconfigure the spacecraft.

The reason for those regulator switches is believed to be corona effects between isolated parts of the structure due to charging, causing spikes on the internal power lines.

7.2.5 RECOMMENDATIONS

Recommendation No. 1

Direct indication of heater operation. Since there is no direct indication which heater is actually drawing power (heating), it is very difficult to determine from adjacent temperatures which heater might have switched on. This business becomes almost impossible if the switch occurs during a gap were no data is available.

In addition, heater switches are masked by „cycling" heaters which have such a low hysteresis between turn ON/OFF temperatures that they cycle over month's between on and off status.

Recommendation No. 2

The implemented „SILENT MODE" is a non desirable state after regulator switch. Since the silent mode was introduced to reduce the load on the regulator in case of an overload, it was implemented not all the way, because only the Driver/Modulator is switched off (saving approx. 1.5W) but the TWT stays powered (approx. 30W).

Two options in this case seem to be meaningful:

— TWT and Driver stay on in case of a regulator switch

  Advantage: Data is available after a regulator switch, but difficult recovery in case the TWT has caused the switch.
  Disadvantage: No power reduction from TWT side

- TWT and Driver are disconnected in case of a regulator switch.

  Advantage: Power reduction of 30W and automatic disconnection of a faulty TWT.
  Disadvantage: No Data.

7.3 THERMAL SUBSYSTEM

7.3.1 BASIC CHARACTERISTICS

The Thermal Control System for Helios has to keep the Central Compartment in a temperature region of -10° C to 10° C at varying solar intensities: 1 Solar Constant (SC) at Aphelion and 10,4 SC at Perihel. This has been achieved by a Thermal Control concept which employs active and passive control means.

7.3.1.1 ACTIVE TEMPERATURE CONTROL

Active Temperature Control is achieved by thermostat controlled heater groups. The Helios S/C has three different independent heater groups, which are power supplied from the 28 V board net (Essential Bus):

- Heater group I
  This heater group provides the boom-mounted experiments (2,3,4) with active heaters. The heaters are „ON" all the time except ± one week around Perihelion.

- Heater group II
  That heater group keeps the two experiments (9,10), whose sensors are not located within the Central Compartment but inside the cone, at specified temperatures.

- Heater group III
  This heater group comprises most of the heater mats and has to balance the temperatures within the Central Compartment over the entire orbit.

7.3.1.2 PASSIVE TEMPERATURE CONTROL

- Louver System
  The Louvers open and close automatically being controlled by bi-metal springs attached to each louver blade. The location of the louver-rings is on the top and bottom of the central compartment.

- Super Insulation
  The central compartment which has the most rigid temperature requirements is insulated with layers of mylar-kapton foils (super insulation).

- Second Surface Mirrors (SSM)
  The total outside of the central compartment and also 50% of the Solar Array Panels is covered with SSM's which reflect approximately 90% of the applied energy.

- Fins
  A so-called fin system is installed on the inside of the upper and lower cone. This system reflects the heat, which might be conducted into the inside of the cones, to the outer space again.

- Radiators, Thermal Counductive Paint
  Where applicable additional passive control is achieved by thermal sensitive plates and paints radiating heat to the outside.

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7.3.1.3 SIGNIFICANT PARAMETERS

In order to demonstrate the performance of the subsystem the following parameters shall be stated:

- Measurement Points:
  The total number of the measuring points in the S/C is 110. For the engineering subsystem 58, for the experiments 52, the number of the individual heater mats 43; the number of controlling thermostats 24.

- Highest Temperature:
  The highest measured temperature during 1. Perihelion (March 15, 1975) was + 154,2° C on Medium Gain Antenna (ANT-PT)

- Lowest Temperature
  The lowest measured temperature during 1. Aphelion (June 17, 1975) was -53.0° C on Solar Array Panel (P + 12U2)

- Average Temperature
  The averaged central compartment temperature (Gastank temperature):
  1. Perihelion: + 9.545° C
  2. Aphelion: —10.47 ° C

- Power Consumption
  The power consumption of the active control system is:

Heater group I	11.5 W
Heater group II	7.7 W
Heater group III	88.o W
Total	107.2 W

7.3.2 HEATER ARRANGEMENT, DISADVANTAGES, RECOMMENDATION

The complexity of the active control system shall be demonstrated by the arrangement of the heater mats and controlling thermostats of Heater group III *(refer Fig. 7.3-1).* As can be seen from the figure, one thermostat controls more than one heater mat, which are in turn located in different places, influencing not only the controlling thermostat but also thermostats of other heater mats.

The heater groups (I, II, III) are enabled throughout the mission i.e. the thermostat is activated to turn on or off the power to the appropriate heater mats depending on the specified switching temperatures. In addition to that, some thermostats have a hysteresis, which causes the thermostats to switch on/off (cycling) several times during a week over most of the time within one orbit.
The difficulty now is, that an exact assessment, whether a heater is heating (drawing power) or not, is difficult to determine, because the real status of each thermostat (ON,OFF) is not available in the S/C telemetry. To determine, if a specific heater is heating or not, the change of the average power consumption (averaged per day) has to be evaluated together with surrounding temperatures of a specific heater which is suspected to have switched.
The problem is, that for several heaters the temperatures are so far off from the activated heater mats that they might be influenced as well by another heater.

In addition the thermal effect of one heater on a specific temperature might be masked by the „cycling" heaters.
On the other hand it is also very difficult to develop a history of the heater switches over one orbit, because each time the configuration within the central compartment (and so the heat dissipation) is different due to S/C difficulties (TWT switches, experiment turn off's, ect.).

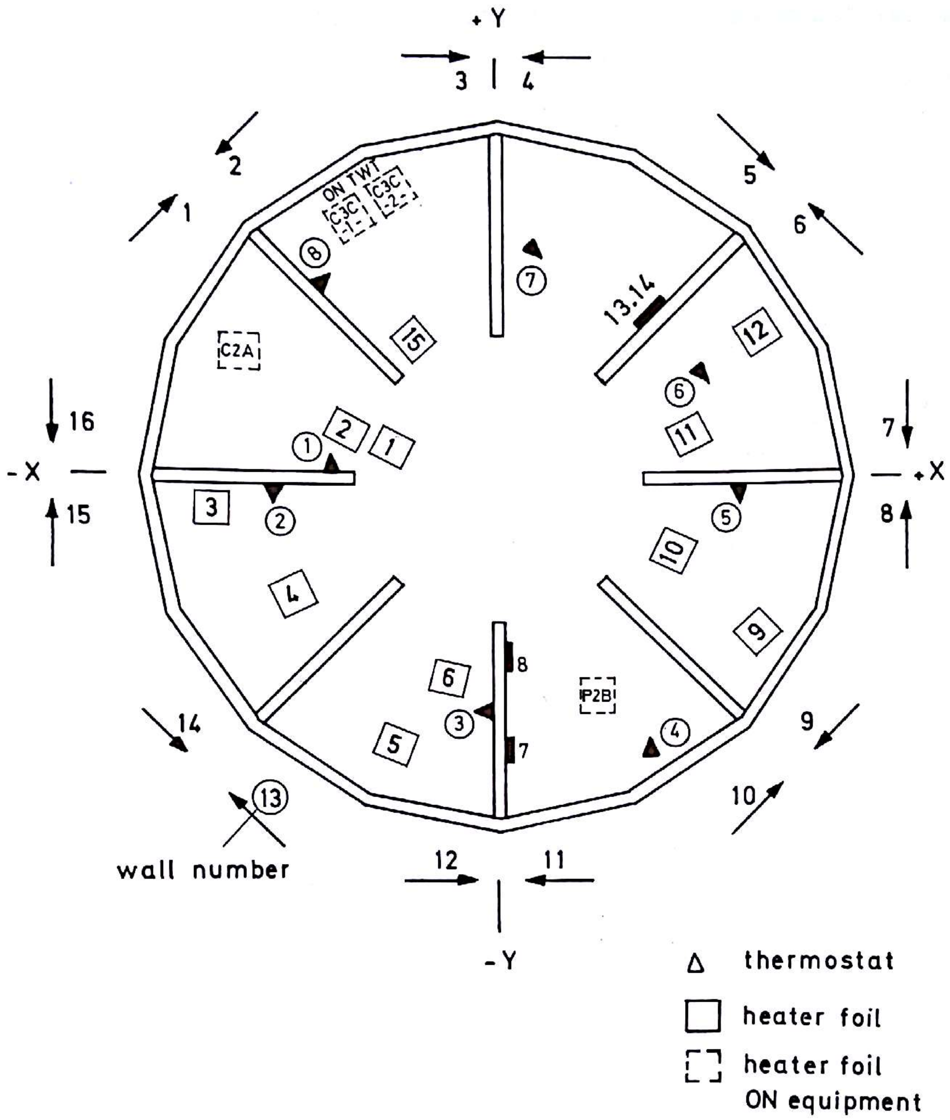

Figure 7.3-1: Heater and Thermostat Arrangement

Recommendation

In order to take the „guess"-work out of the heater power consumption and to allow a orbit prediction of the future heater development (important also for frequency predictions and power assessments) it is recommended to have:

- either a status bit (ON/OFF) indication of each thermostat
- or have temperature measuring points being telemetered which allow unambiguously to determine which heater mat is heating.

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7.3.3 TYPICAL TEMPERATURES AND COMPARISON: 1. through 5. Orbit

The first group of temperature plots shows a comparison of the central compartment.

- Gastank temperature: This temperature represents the average central compartment temperature *(refer to Fig. 7.3-2, TGASTK)*
- Sun sensor: This temperature represents the sun facing elements within the central compartment *(refer to Fig. 7.3-3, SUNSOU)*
- Heatshield: Measurement of the temperatures in the outer walls of the central compartment *(refer to Fig. 7.3-4, HEAT1; Fig. 7.3-5, HEAT12)*

The second group of graphs shows the thermal behaviour of typical subsystem temperatures in the central compartment.

- Transmitter: RFDUOU *(Fig. 7.3-6)*
  The RF Distribution Unit is mounted on wall 2 in the central compartment
- Receiver: VCXO1T *(Fig. 7.3-7)*
  The voltage controlled oscillator is mounted on wall 1 in the central compartment
- Data Handling: CORE-T *(Fig. 7.3-8)*
  The core unit of the Data Handling system is located on wall 6 in the central compartment
- Power subsystem: REGLOU *(Fig. 7.3-9)*
  The regulator of the power subsystem is located on wall 2 in the central compartment.

The third group shows the temperature behaviour of the solar array panels.

- Solar array temperature P+10M *(Fig. 7.3-10)*
  The thermistor is mounted in the middle of an upper solar array panel. The measurement range of this thermistor: —100°C to +200°C
- Solar array temperature: P-10M *(Fig. 7.3-11)*
  This temperature represents the temperature of a lower solar array panel
- The averaged temperature of the solar array panels with respect to the Aphels/Perihels is shown in the following *Table 7.3-I.*

	1. Perihel 128,3°C	2. Perihel 132,5°C	3. Perihel 135,5°C	4. Perihel 138,4°C
DEGRADATION:	3,17 %	2,26 %	2,14 %	

	1. Aphel —50,0°C	2. Aphel —47,14°C	3. Aphel —45,12°C
DEGRADATION:	6,02 %	4,52 %	

Table 7.3-I: Degradation for PERIHELS/APHELS

The 4. group is a comparison of outside temperatures:

- Medium Gain Antenna: ANT-PT *(Fig. 7.3-12)*
  This measurement point is located on the top of the antenna
- Adapter temperature: ADAPT *(Fig. 7.3-13)*
  This measurement point is located on the adapter on the bottom of the S/C
- Boom +X1 temperature: BOM+X1 *(Fig. 7.3-14)*
  This thermistor is located on the top of the +X-boom
- Spin thruster temperature: SPTHRU *(Fig. 7.3-15)*
  The spin thrusters are mounted on the +X-boom.

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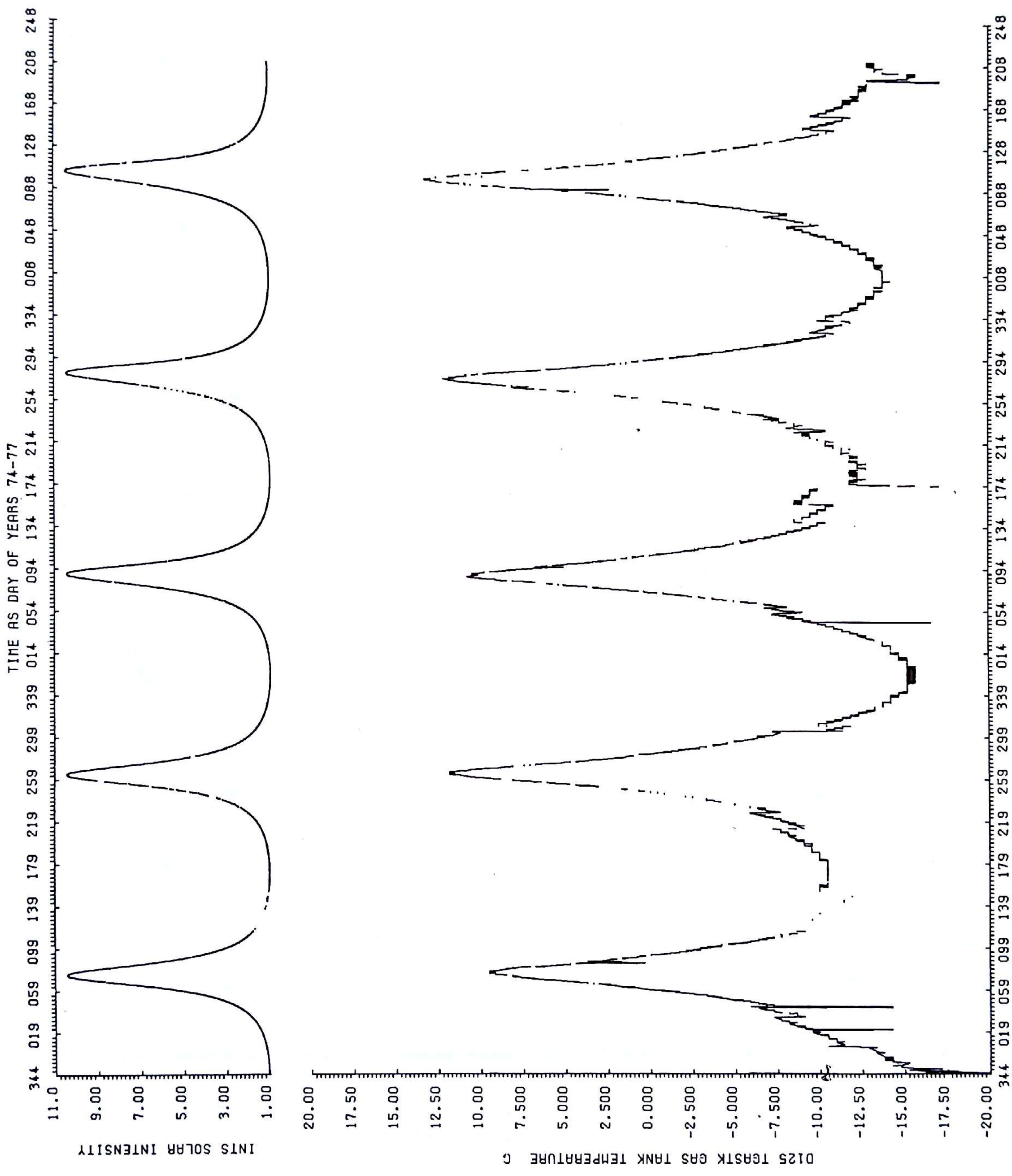

Figure 7.3-2: Gastank Temperature (TGASTK)

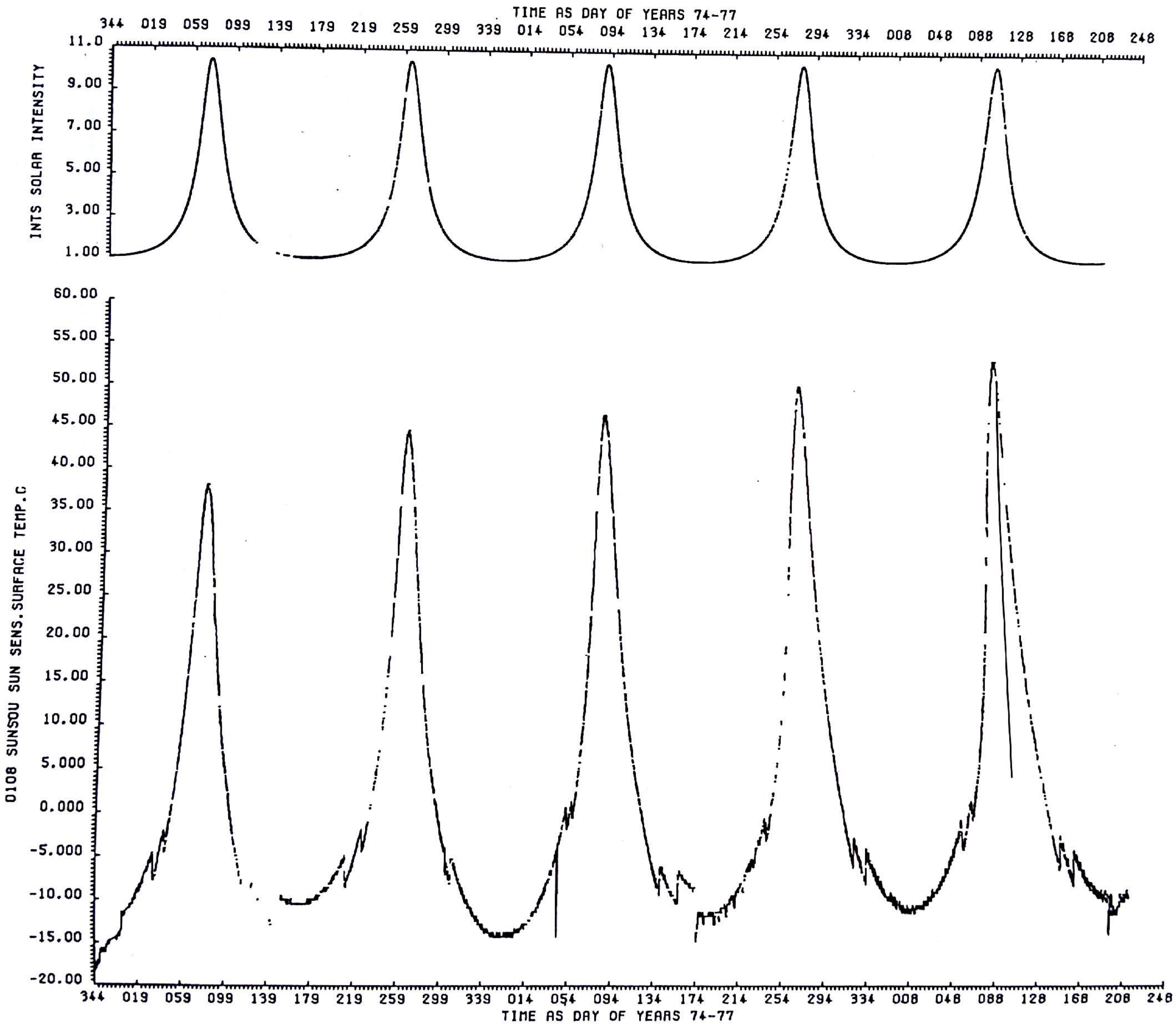

Figure 7.3-3: Sun Sensor Temperature (SUNSOU)

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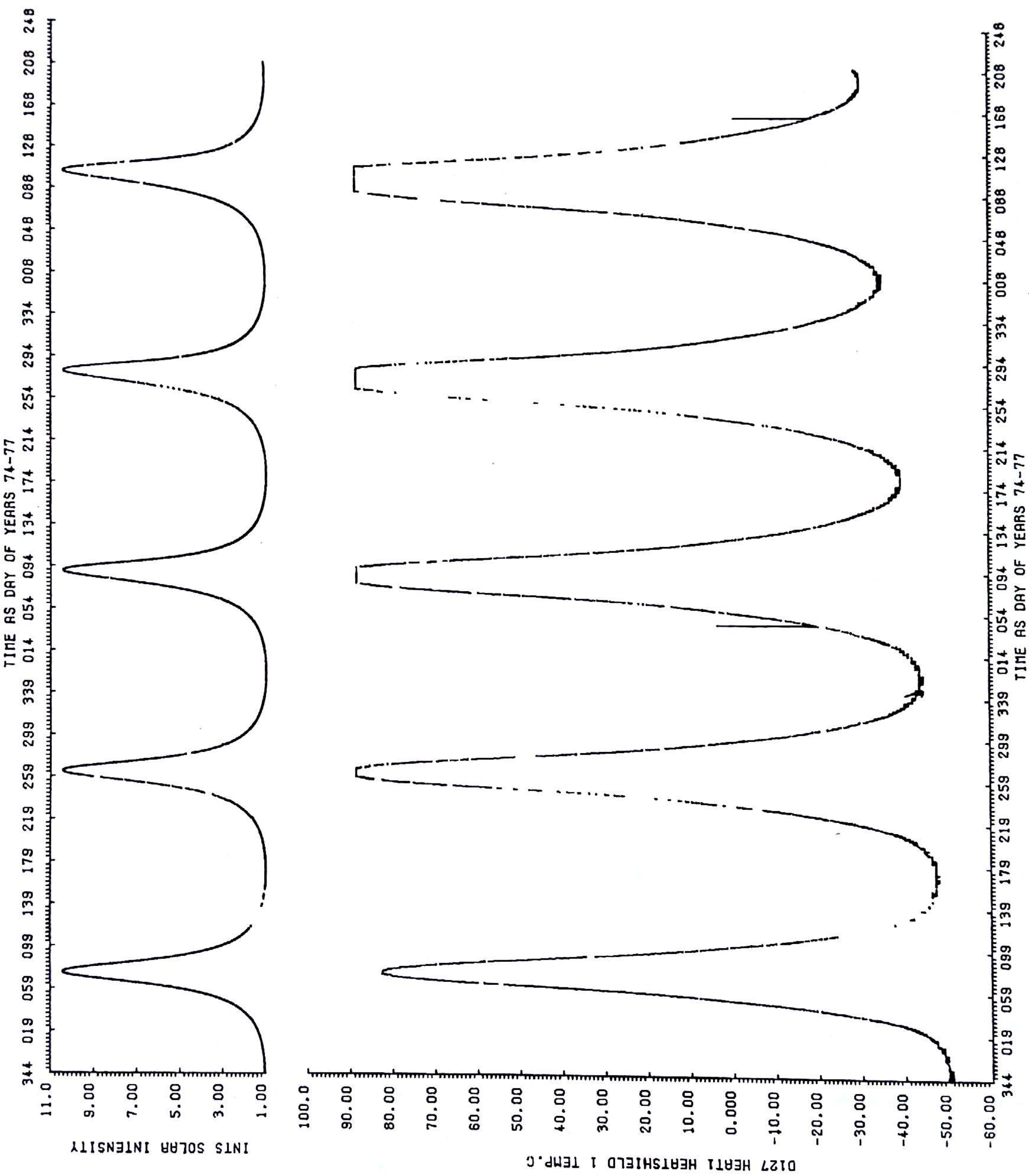

Figure 7.3-4: Heatshield Temperature (-50 C to + 90 C Region): HEAT 1

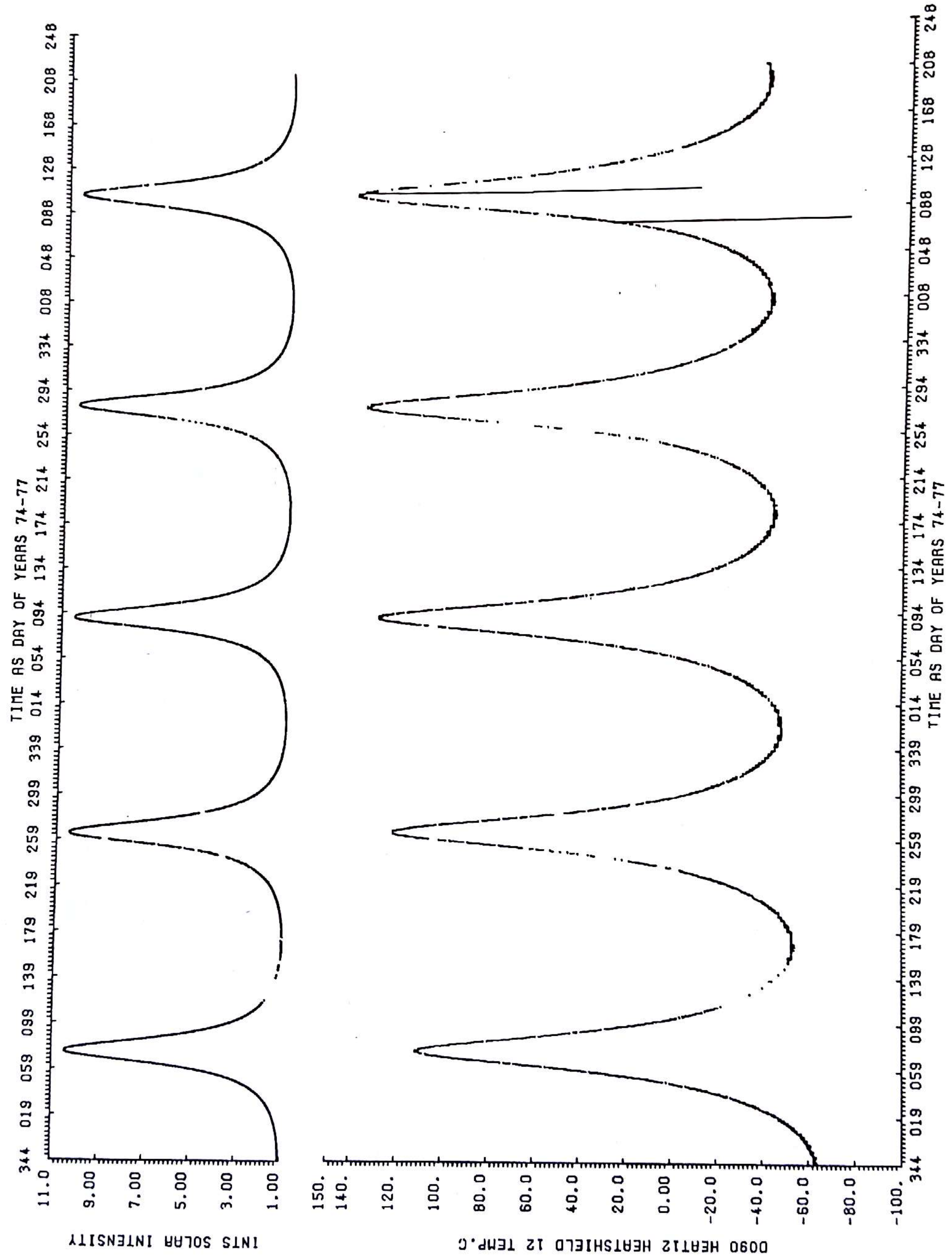

Figure 7.3-5: Heatshield Temperature (-100 C to + 200 C Region): HEAT 12

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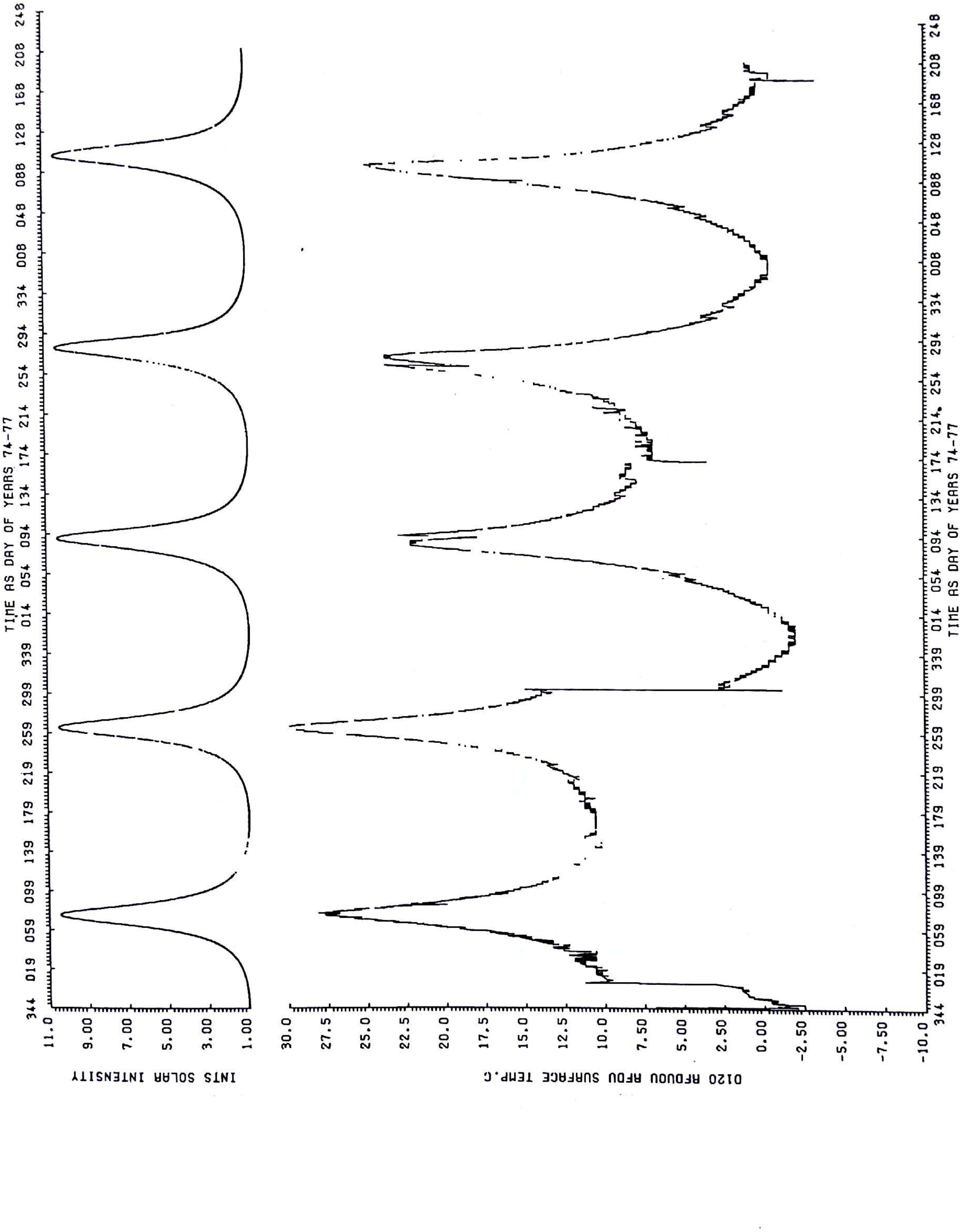

Figure 7.3-6: RF Distribution Unit Outer Temperature (RFDUOU)

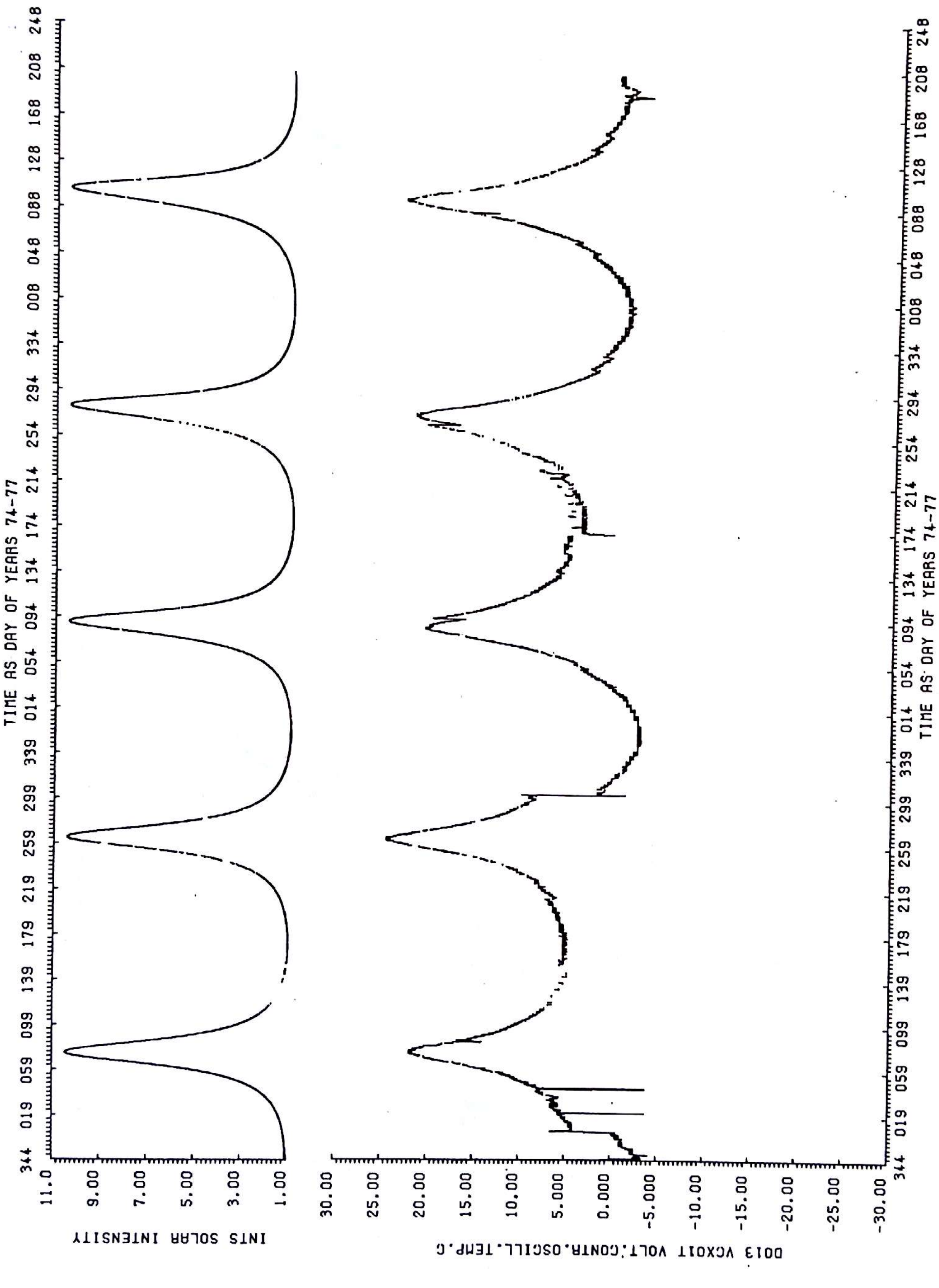

Figure 7.3-7: Voltage Controlled Oscillator Temperature (VCXO1T)

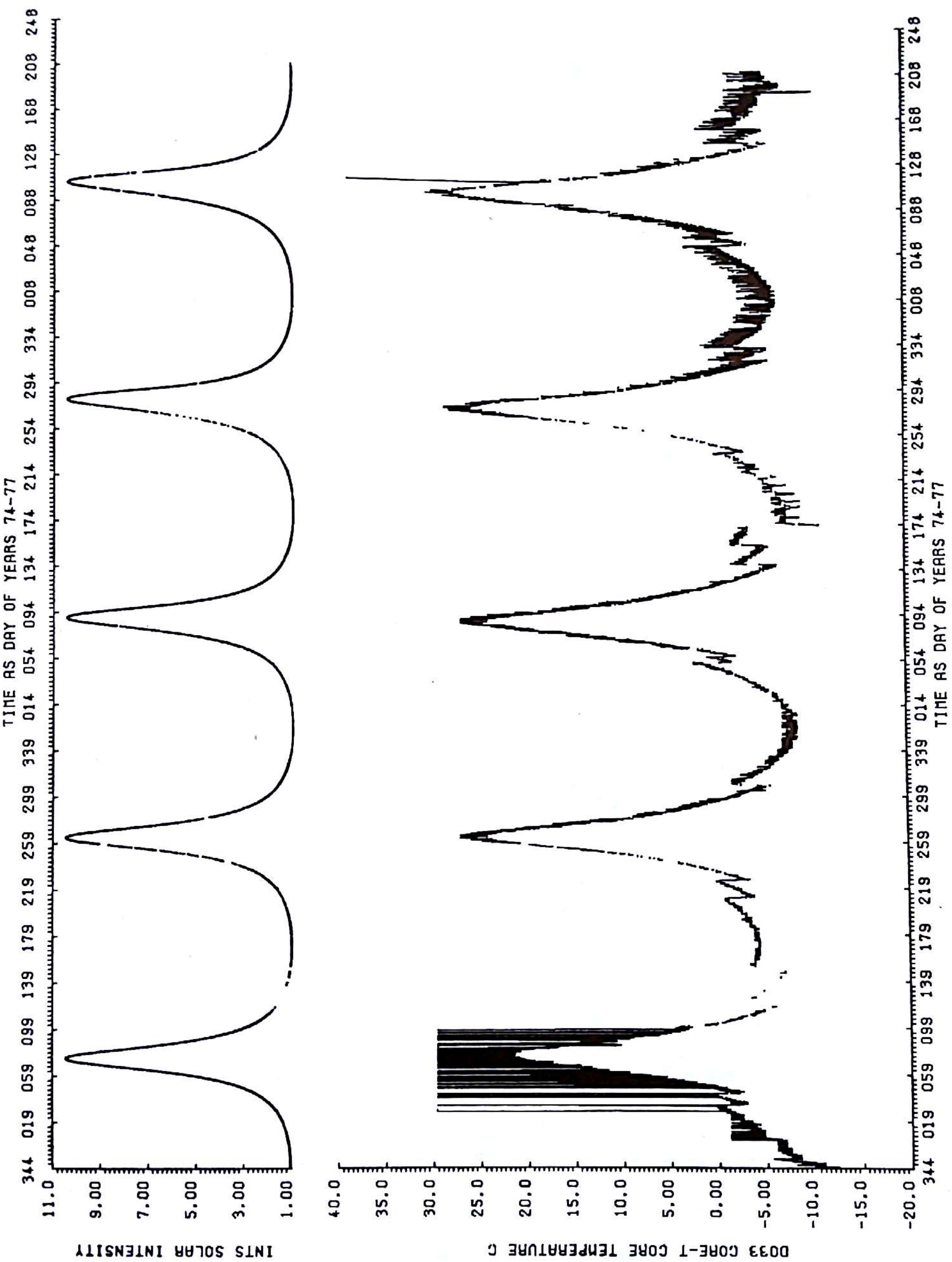

Figure 7.3-8: Core Memory Outer Temperature (CORE-T)

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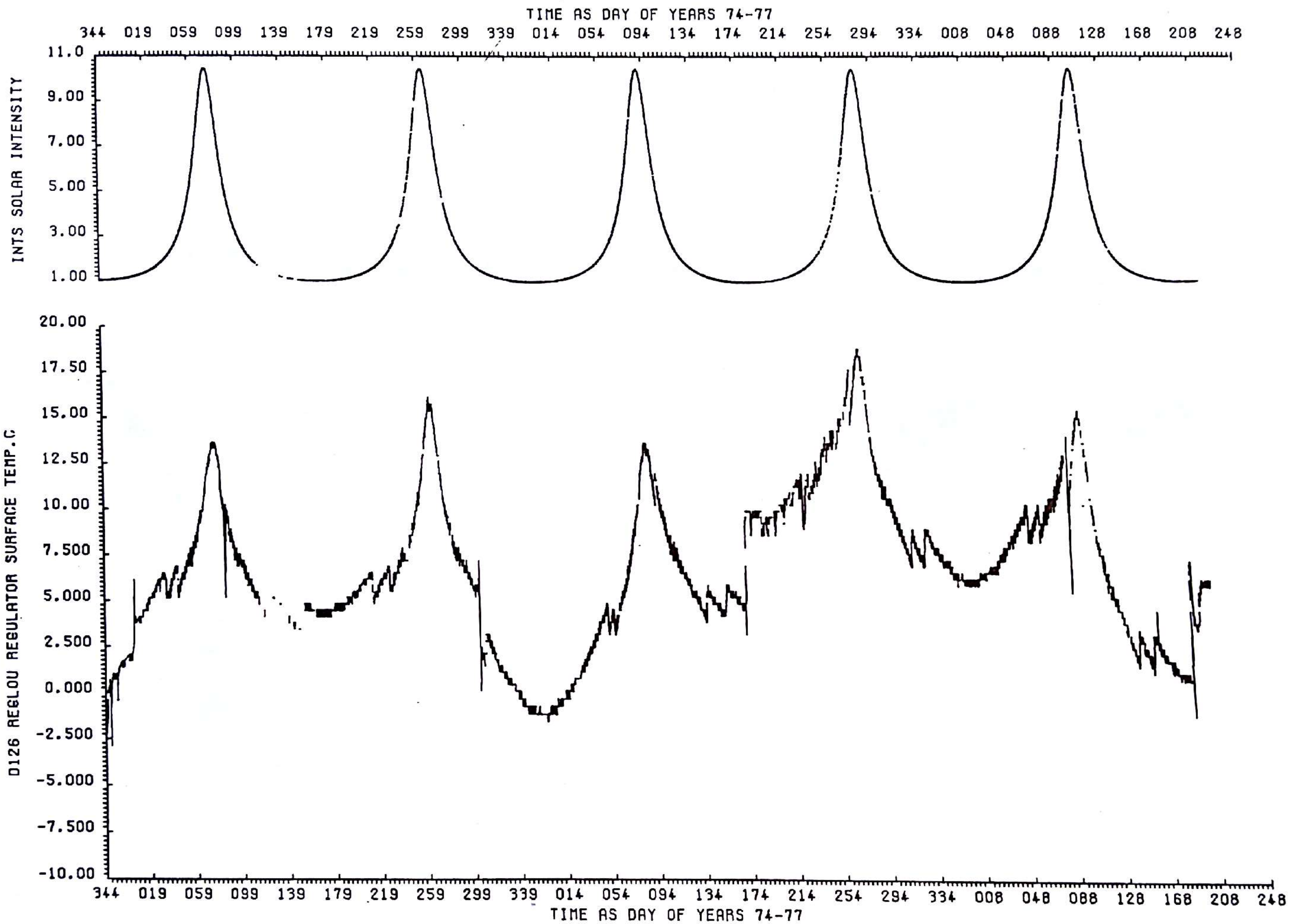

Figure 7.3-9: Regulator Outer Temperature (REGLOU)

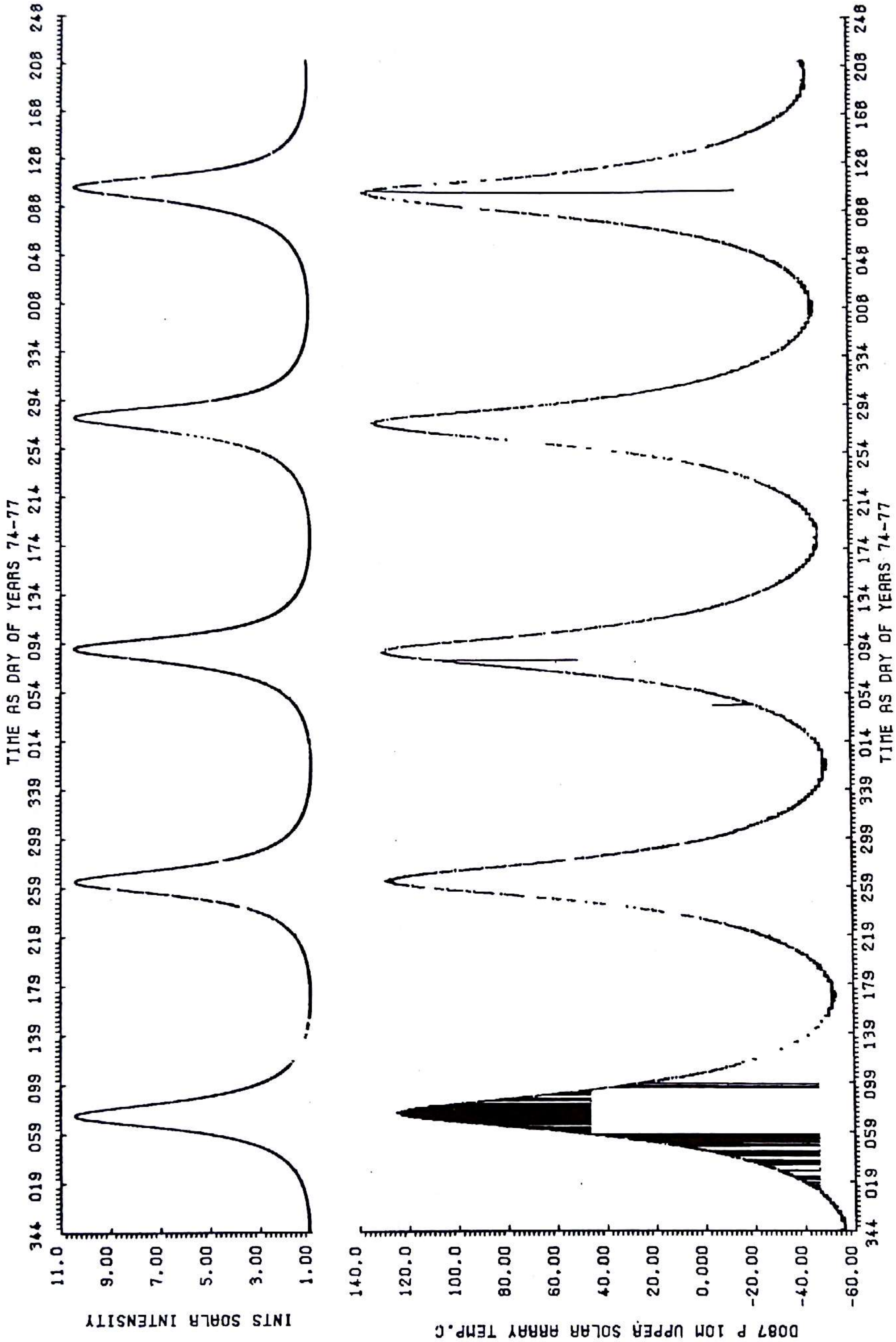

Figure 7.3-10: Upper Solar Array Panel Temperature (P+1OM)

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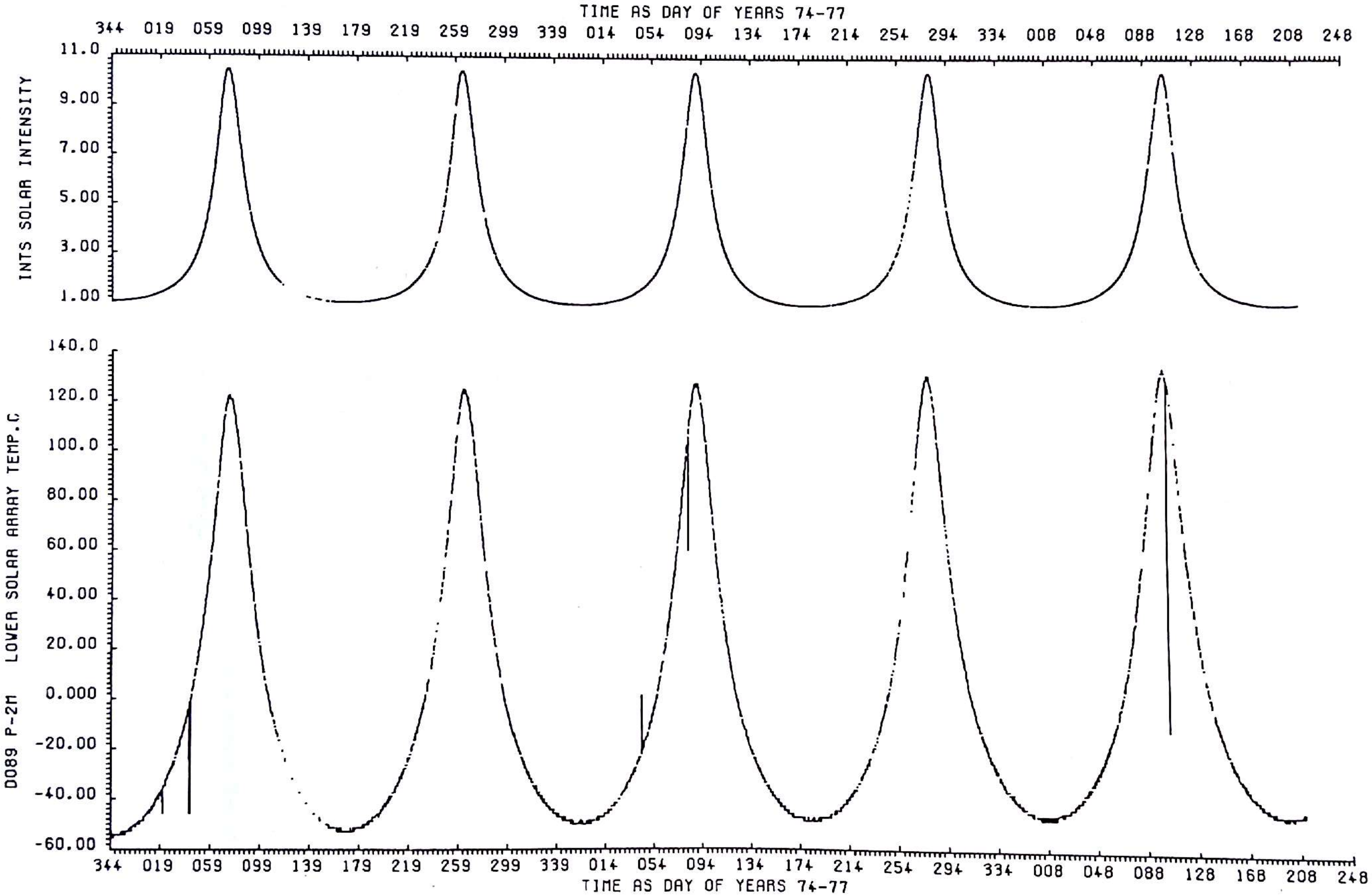

Figure 7.3-11: Lower Solar Array Panel Temperature (P-2M)

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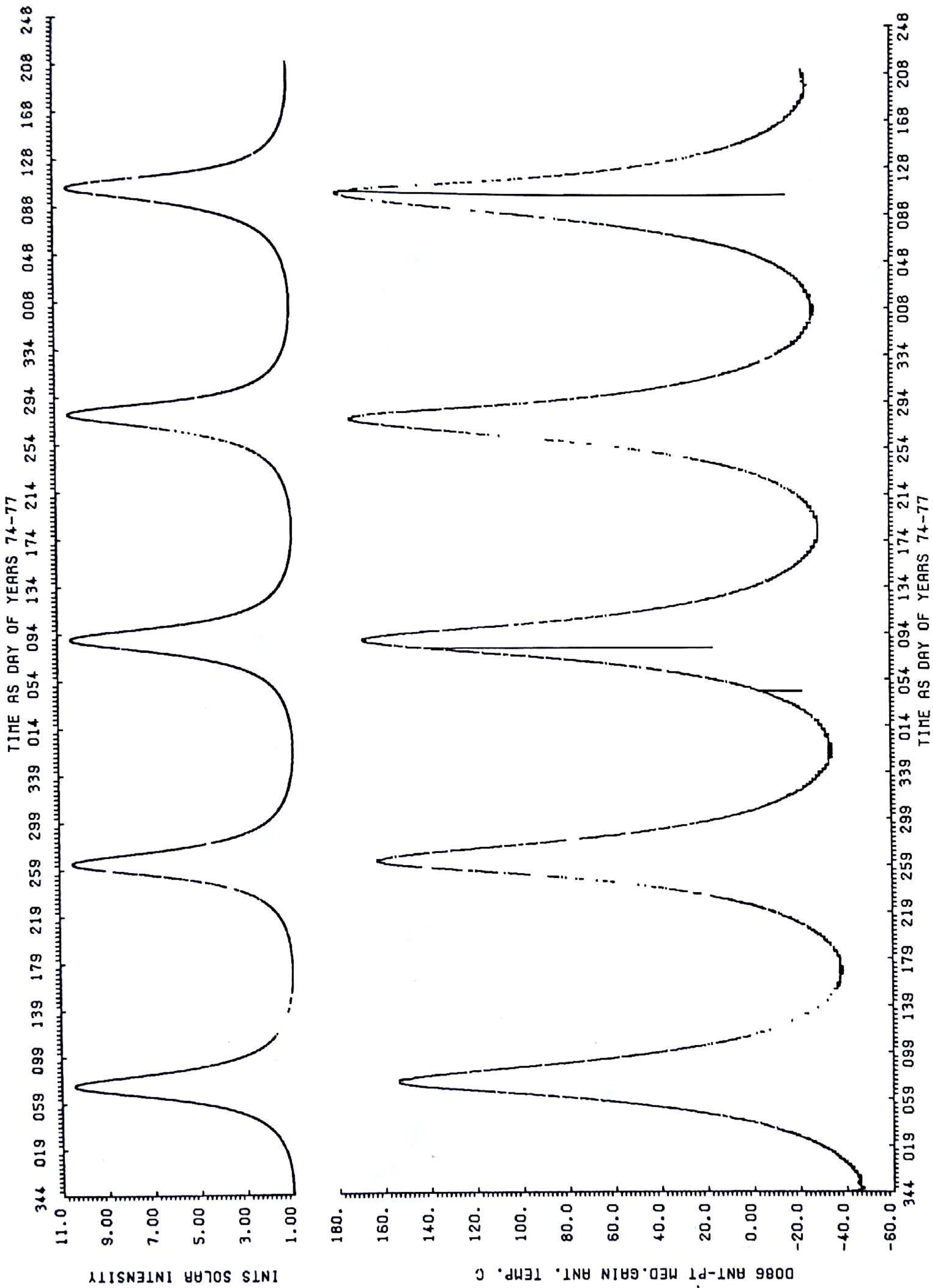

Figure 7.3-12: Medium Gain Antenna Temperature (ANT-PT)

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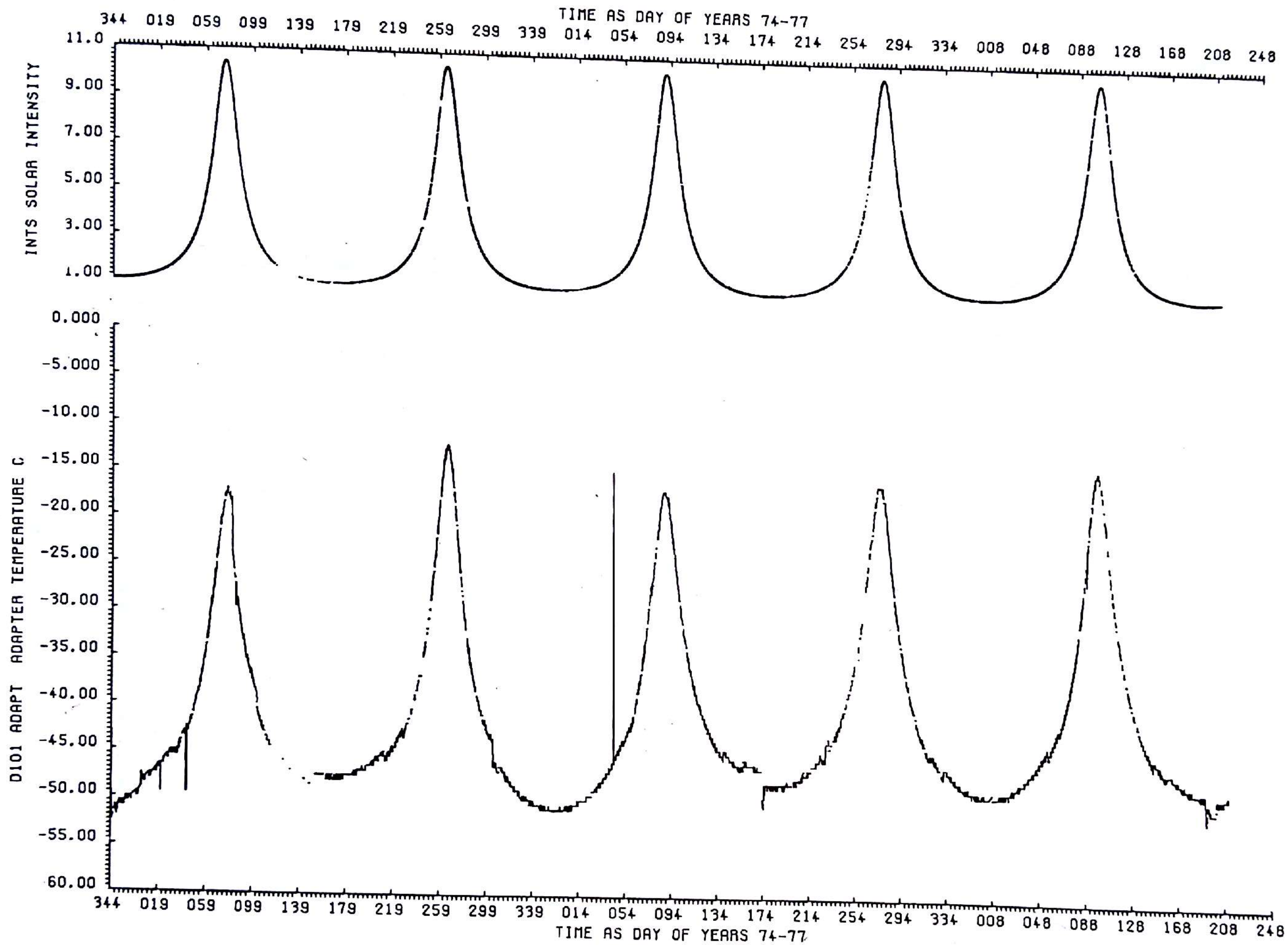

Figure 7.3-13: S/C Adapter Temperature (ADAPT)

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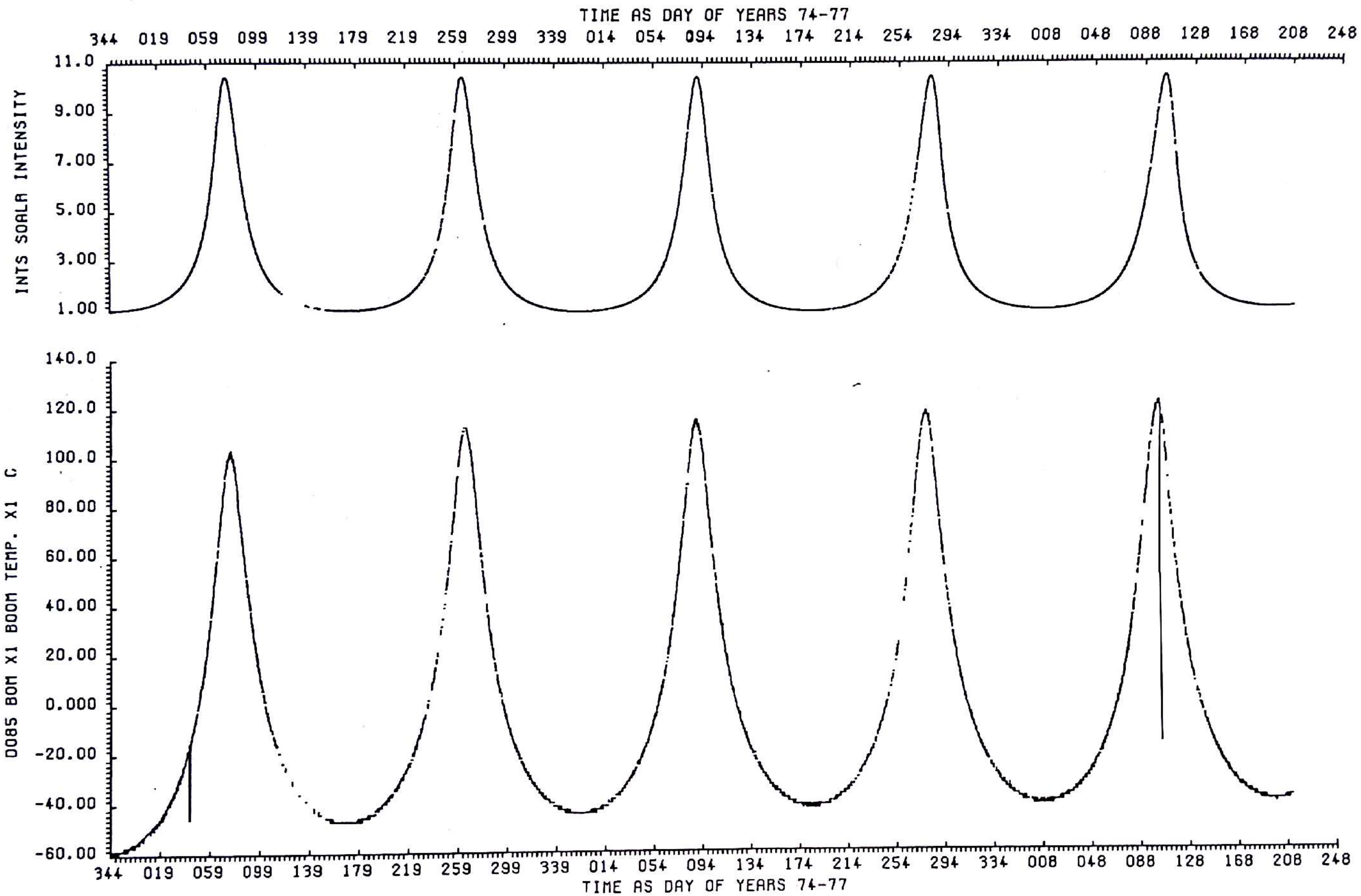

Figure 7.3-14: Experiment Boom Temperature (BOM + X1)

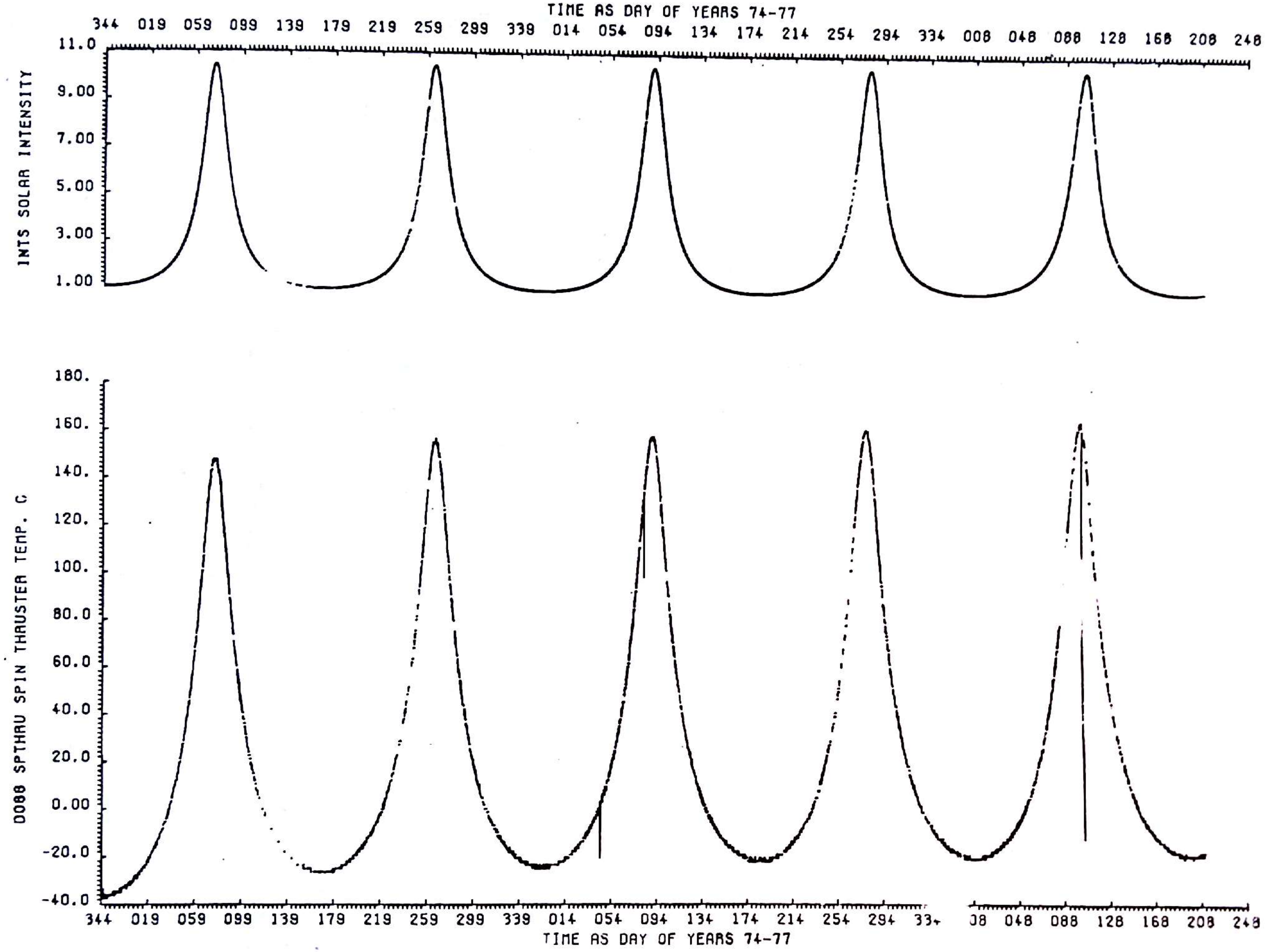

Figure 7.3-15: Spin Thruster Temperature (SPTHRU)

7.4 ATTITUDE SUBSYSTEM

7.4.1 BASIC CHARACTERISTICS

The task of the attitude subsystem is to measure the S/C attitude and provide control functions for both spin axis orientation and spin rate. Furthermore, the subsystem contains the control mechanism for the despun High Gain Antenna.
Thus, the subsystem consists of three main parts:

- Attitude measurement system
- Attitude control system
- High Gain antenna despin control system.

7.4.1.1 ATTITUDE MEASUREMENT SYSTEM

The attitude measurement system *(see Fig. 7.4-1)* consists of a coarse sensor with a field of view of ± 64 deg, a fine sensor (± 3 deg), a top and a bottom sensor. The information of the four sensors is processed in the sun sensor electronic system. The functions of the sun sensors are: measurement of the solar aspect angle and delivery of the trigger pulse. The trigger pulse is generated at maximum sun light in the fine or coase sensor; therefore this pulse is called also „See Sun Pulse". The fine sensor has priority to select the puls if the sun is in coarse and fine sensor field of view. Only in case of a failure of this sensor, the trigger pulse will be delivered by the coarse sensor. The D/H system uses the trigger pulse for correlation between the time words of a telemetry data frame and the time tags of the experiment data blocks.
The coarse sun sensor provides data since its first sun acquisition during the powered ascent phase. In the course of the subsequent Step I maneuver also the fine sensor had its first sun acquisition and since that time the latter is used as the prime sensor (as described above).

7.4.1.2 ATTITUDE CONTROL SYSTEM

The attitude control system *(see Fig. 7.4.-1)* consists of the control electronics, the cold gas tank, piping, regulation nozzles and a nutation damper.
The functions to be performed are roll and pitch, spin up and down maneuvers and nutation damping.

The roll and pitch maneuvers are all performed by one nozzle which is located inside the lower solar array. The different maneuver directions are accomplished by respective thrust timing. The maneuvers are initiated by a command which enables the nozzle 16 or 511 times. Additionally, in the roll direction, there is a so-called closed loop maneuver available. It turns the spin axis automatically to a solar aspect angle of 90 deg. The mean turn rate for roll and pitch maneuvers is 0.0093°/puls (at 60 rpm).
The spin maneuvers are realized by a pair of nozzles which is located on one of the booms, close to the central compartment. A command opens the respective nozzle during 4 or 16 S/C revolutions, effecting a change of 0.46 rpm (near 60 rpm) in the latter case.
Nutation damping is accomplished by a circular quartz tube which is partially filled with mercury. It is mounted on top of the central compartment. The damping characteristics can be seen *in Fig. 6.4-2.*

7.4.1.3 DESPIN CONTROL SYSTEM

This is a combination of despin motor and despin control electronics *(see Fig.7.4-2)* to point the high gain antenna reflector permanently towards earth.
The control loop maintains a certain pointing according to the contents of the so-called ALPHA register. The ALPHA values have to be predicted from orbit data and then transmitted to the ALPHA register by command. Step-by-step and automatic update modes are available for that.

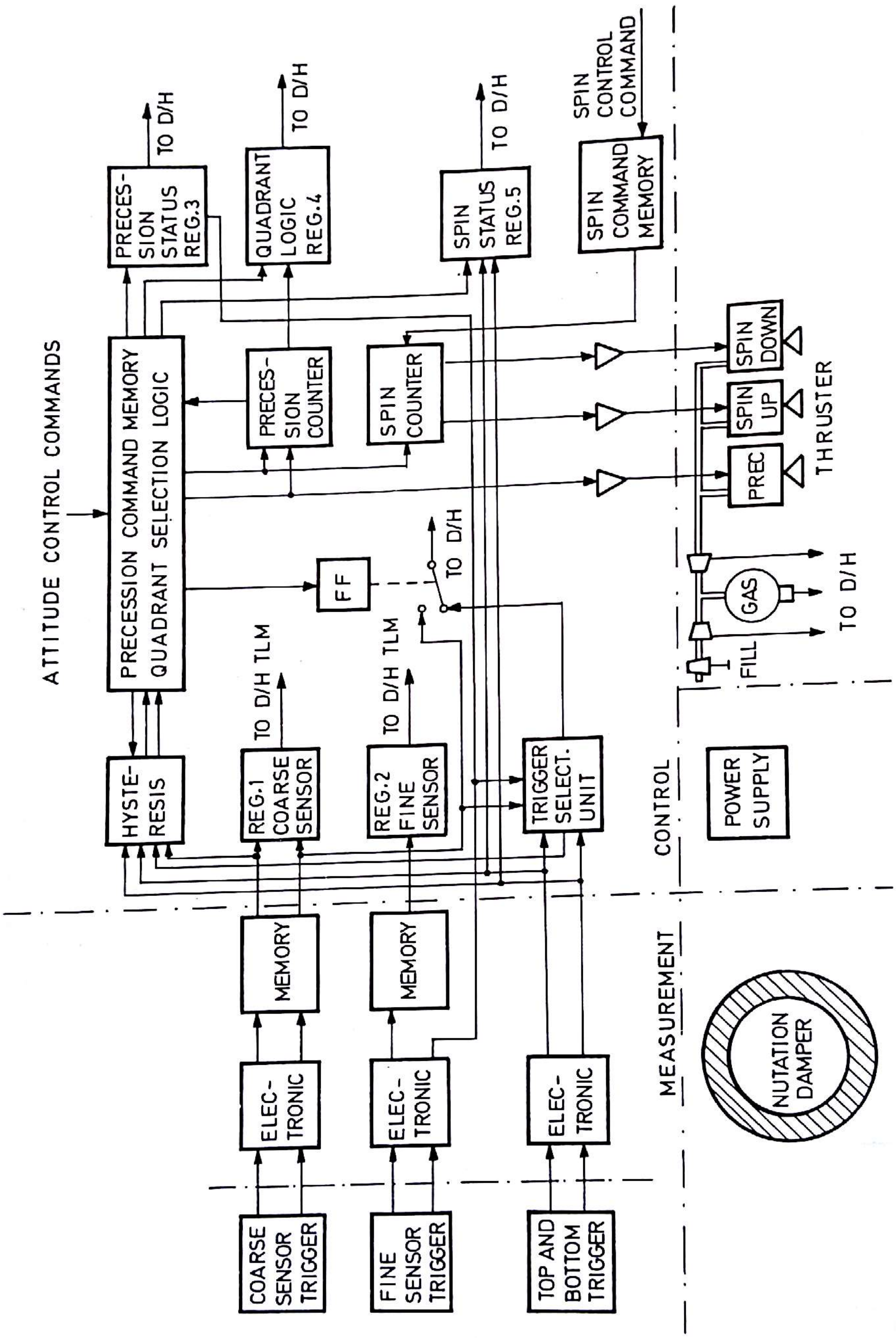

Figure 7.4-1: Attitude Measuring and Control Block Diagram

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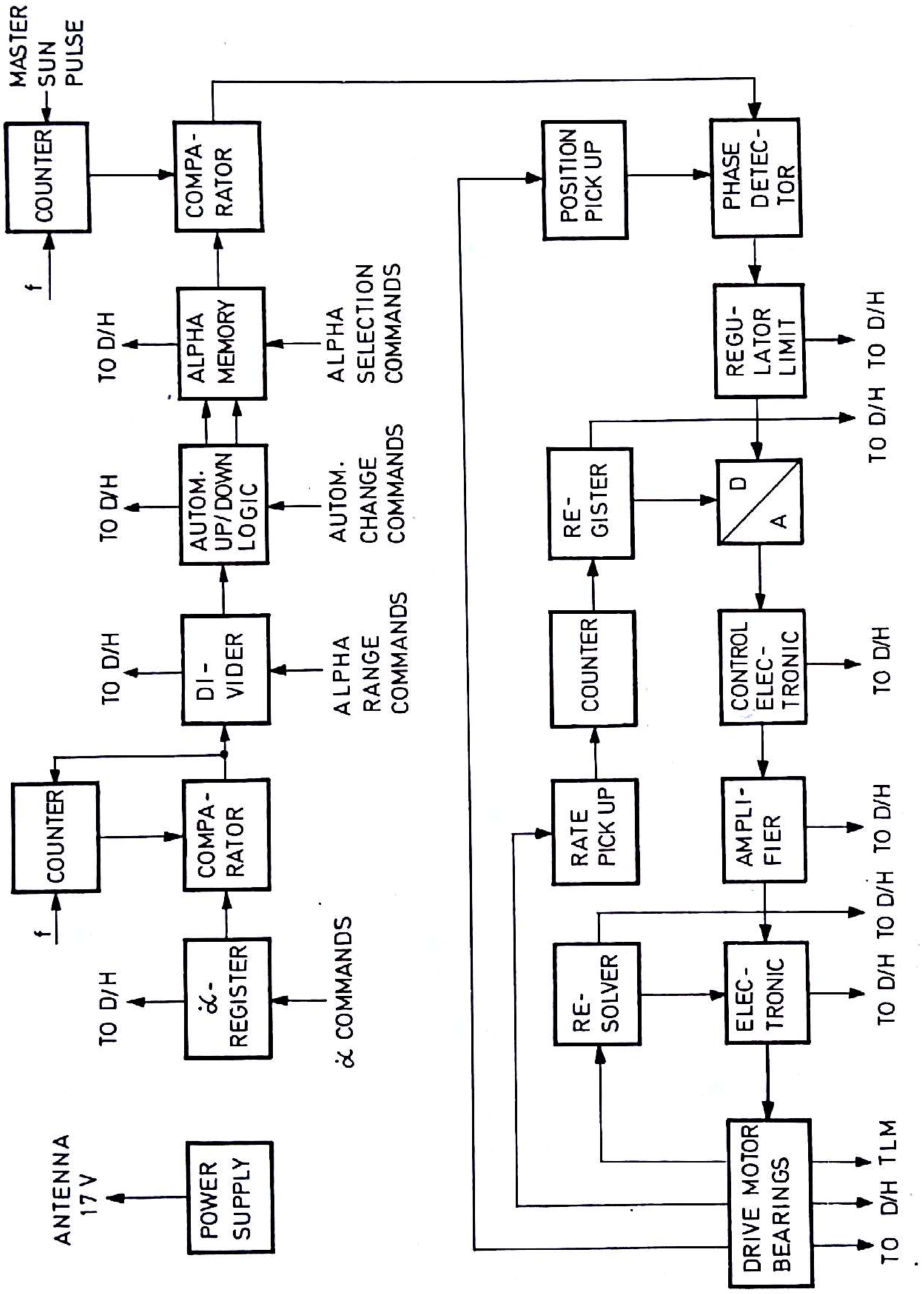

Figure 7.4-2: Despin Drive for the High Gain Antenna-Block Diagram

7.4.2 SIGNIFICANT ATTITUDE EVENTS

1. January '75 Sun Sensor Readings

Fig. 7.4-3 shows the readings of the fine sun sensor during the very early part of the mission. While the dashed line indicates the approximate course of the expected readings, the figure also shows the actual values. The discrepancy is obvious.
An explanation was difficult. The S/C has only this one sensor and there were no secondary sources of attitude information available. Thus, it was impossible to determine whether the readings have been caused by a malfunction of the sensor or by an actual attitude displacement.
However, the fact that the sun sensor behaviour after the anomaly period was absolutely normal seemed to indicate that the S/C had actually undergone an attitude change.
Several attempts have been made to identify forces which could have caused the possible attitude drift. But none of them could explain the effect in its entirety.
Finally, in November 1976, Experiment 9 had completed the detailed evaluation of its scientific data for the period in question. The results suggest with a high degree of probability that there was no irregular attitude drift.
Taking this into account, the most reasonable conclusion at this time is, that the fine sun sensor had an anomaly during January 1975.

2. Attitude Maneuver prior to start of First B/O

Several attitude maneuvers had been performed since the S/C reached its cruise attitude on December 13, 1974. They were all done on request of Experiment 9 in order to provide a favourable attitude for this experiment.
In mid-April 1975, however, the S/C was just about to enter its first black out period and the prime consideration at that time was to command the S/C into a more stable attitude.
Therefore, on April 12, 1975, a maneuver sequence was started which changed the S/C attitude in the following way:

	solar aspect angle	pitch angle
prior to maneuver	91.11 deg	88.8 deg
after maneuver	90.64 deg	90.3 deg

3. Attitude Maneuver prior to Third Perihel

While the S/C attitude was in a favourable position from a system point of view, Experiment 8 (E8) wanted to change the attitude in order to improve the conditions for the experiment near the third and the following Perihels.
Due to the fact that the maximum solar aspect angle occurred near the perihel, E8 had to operate under maximum stray light influence in that region.
Thus, a correction maneuver was planned in order to minimize the solar aspect angle at Perihelion. A compromise had to be worked out between E8 requirements and S/C system aspects.
The maneuver was performed an March 17, 1976, with the following attitude changes:

	solar aspect angle	pitch angle
prior to maneuver	90.83 deg	89.8 deg
after maneuver	90.61 deg	90.5 deg

A graphical representation of the maneuver is shown in *Fig. 7.4-4.*

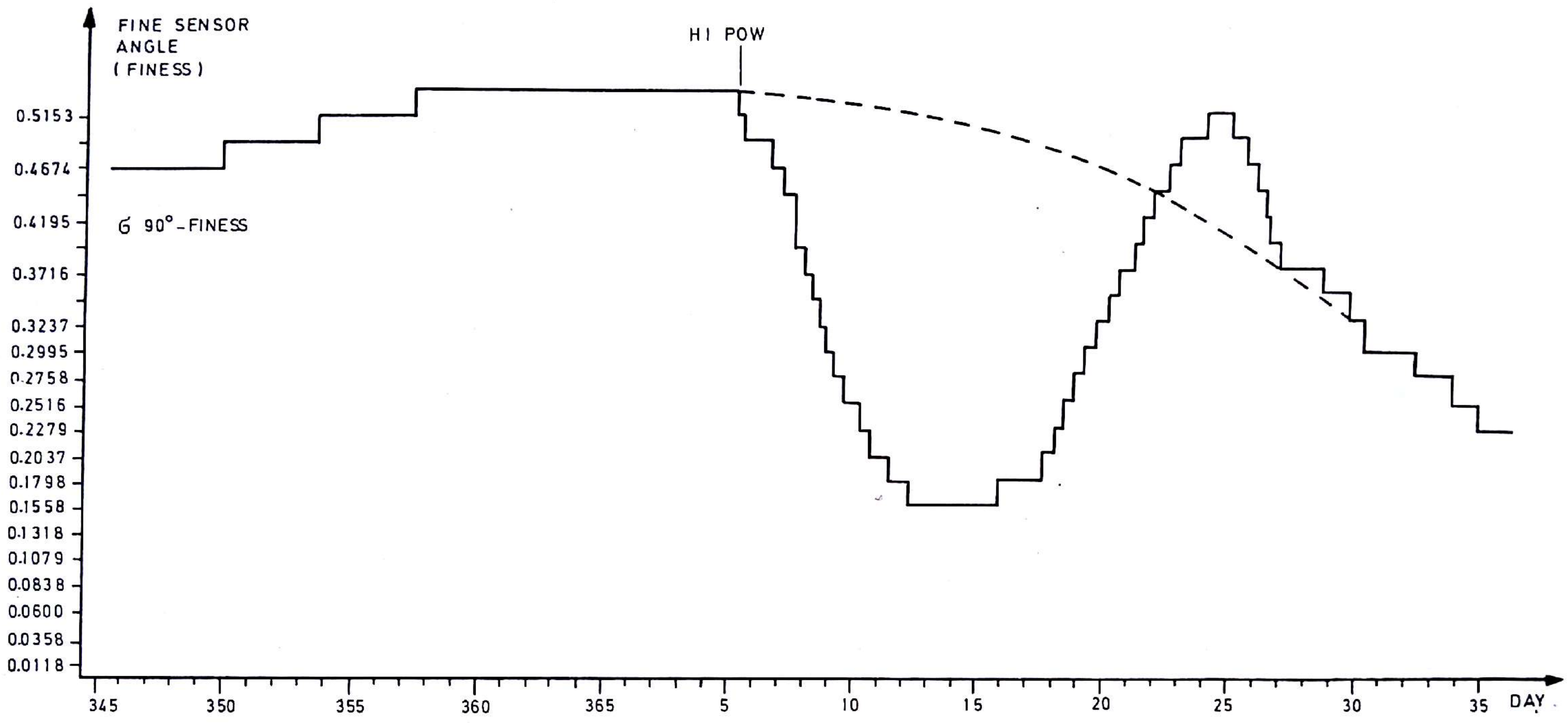

Figure 7.4-3: Fine Sun Sensor Reading during the early Mission Part

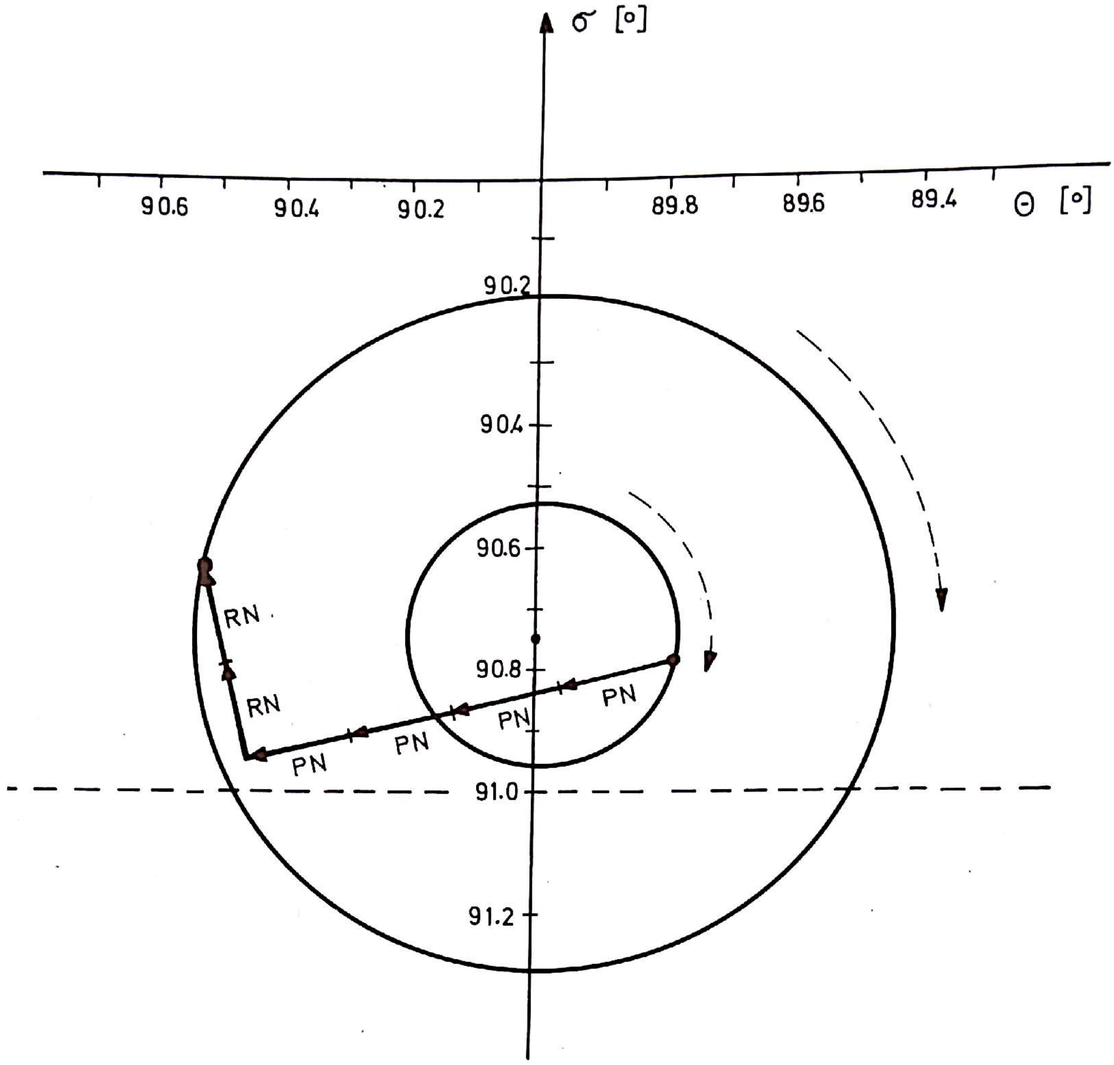

Figure 7.4-4: Graphical Representation of the Attitude Correction Maneuver prior to Third Perihel

7.4.3 HGA POINTING PHILOSOPHY FOR BLACK-OUT AND REASONING

The first black-out entry was expected approx. 5 months after launch of the solar probe. The question was, at what time or at what sun-earth-probe (SEP) angle the loss of the downlink could be expected. According to the experience of several US-projects (Pioneer and Mariner S/C's) the begin of the blackout was predicted at a SEP angle of 3 deg. Black-out means, that the transmitted signal of the S/C has to go through the corona or is shadowed by the center body of the sun, causing a degradation resp. loss of the signal.
On the other hand especially this region is of high interest for the passive experiments (Faraday Rotation, analyzing the influence of the sun on the electromagnetic telemetry waves).
The task is to keep the S/C downlink as long as possible, but also to ensure that the black-out duration is as short as possible i.e. the High Gain Antenna has to point correctly to the earth at the predicted exit time.
Fig. 7.4-5 shows the calculated angle (ALPHA) for the HGA-reflector together with an allowable deviation band (+ 1dB). Due to loss of the uplink during the B/O period the HGA-reflector has to be pointed prior to black-out entry, aiming for the correct ALPHA angle for the predicted exit. Referencing the curve *(Fig. 7.4-5)*, good reacquisition was expected just turning the automatic pointing mechanism off and keeping the ALPHA angle constant. The first assessment for B/O duration (basis SEP = 3 deg) was 56 days. An offset of 5.3 deg (for ALPHA) would have to be accepted (worst case).
The S/C was prepared for B/O at the 3 deg.point. But at SEP 2.5 and even at 1.9 deg.the signal (up- and down-link) was still good and the ALPHA angle was updated accordingly. The final loss of link at 0.7 deg suggested also an earlier B/O exit.
Due to the updated pointing of the HGA the ranging and polarization switch measurements were longer possible than expected. The offset of the HGA reflector in worst case was only 2.1 deg.

Influence of the used stations:
The 26m stations have a relative wide beam width and an antenna gain of 53 dB. Since the link quality depends on the Signal to Noise Ratio (SNR) the 26m station lost lock on data at a SEP angle of 2.7 deg. At the exit of B/O they locked up at this angle again (symmetrical exit). The beam width of the 64m stations is more narrow together with a higher antenna gain (61 dB). This is the reason why those stations tracked the S/C until a SEP angle of 0.7 deg.at entry and exit of B/O.

SUMMARY
26m station B/O entry/exit SEP 2.7 deg.
64m station B/O entry/exit SEP 0.7 deg.
Those new values were used for predicting the following Black-Outs, and could be confirmed in all cases.
One explanation for the deviation from the US-experience is that the sun was less active during HELIOS black-out than during Pioneer/Mariner black-outs.

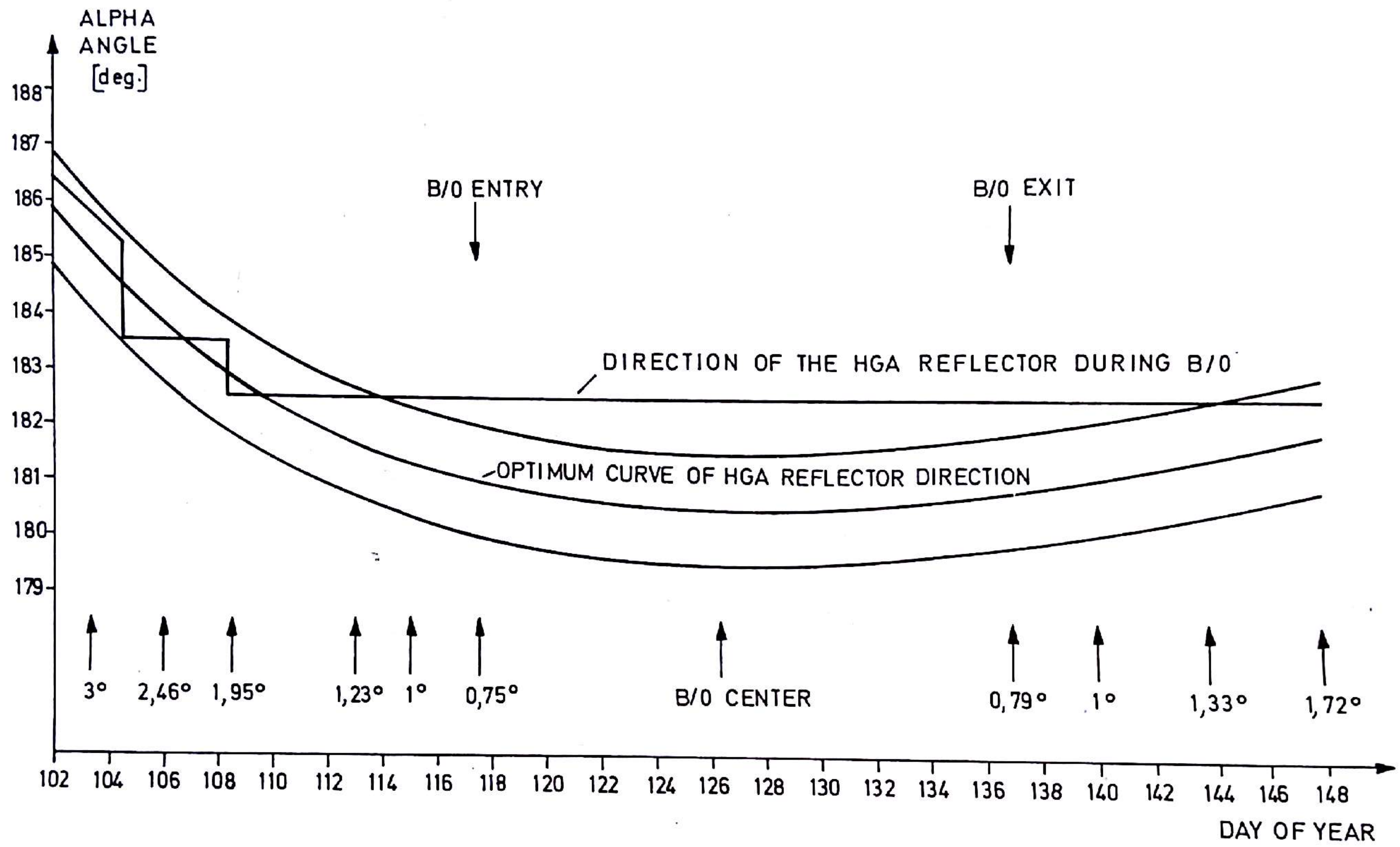

Figure 7.4-5: High Gain Antenna Pointing for the First Blackout

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7.5 DATA HANDLING

7.5.1 BASIC CHARACTERISTICS

The attached simplified block diagram *(Fig. 7.5-1)* shows all essential features of the D/H system.

7.5.1.1 COMMANDING

As shown in the command decoder box, the D/H system uses special D/H commands (to be distinguished from the 255 DISCRETE commands) which are used by the other S/C subsystems. The basic difference of the D/H commands is that a „Preparation" command (Command Addresses 400-777) can be stored in the Mode Control unit and executed (after verification on Ground) by a second command (Command 123).
With the existing redundancies and cross-strappings a total of 1680 different combinations (taking bit-rates, distribution modes, format modes into account) are commandable whereby no on board logic prohibits any illegal modes with one exception (Black-Out-mode: DM5, FM3, 8 bps which is hardwired).
This design allows on the one hand a very high flexibility in selecting the appropriate combinations (e.g. on HE-A Extended Mission passes illegal modes are used on a routine basis in order to cover station gaps) on the other hand it complicates mission operations enormously:

Illegal modes (unwanted) could not be excluded entirely (although a special D/H logic test was implemented at the Control Center to help control the D/H modes) especially in critical phases.

7.5.1.2 NOMINAL CONFIGURATION/REDUNDANCIES

The block diagram shows the nominal configuration (heavy lines) and the shock (FM6) data flow which has to use core memory.
It should be pointed out that two D/H redundancies do not provide the same capabilities as the normal units:

- The redundant multiplexer handles only science data i.e. engineering data are lost
- The redundant mode control unit provides only a very limited number of mode combinations which are very complicated to be handled because frame synchronisation of the mode changes is missing. Using this loop would mean a very degraded mission.

The other units provide full redundancy. All redundancies have to be commanded using D/H SPECIAL commands (no automatic failure detection or switch-over is implemented except the D/H SAFE MODE described below). The data distribution, conditioning, modulation strings can be cross-strapped but have to be selected as a string whereby a bypass of the convolutional encoder is only possible in the normal string.
Data cannot be removed from the downlink by command i.e. one string is always is in operation.
The on-board timing units are fully redundant

- Oscillator and timing (resolution 2^{-5} sec)
- Sector pulse generation (timing for spin synchronous measurements).

As a special protection feature the D/H SAFE MODE was implemented: In case of a regulator switch, in order to be able to recover the S/C in a defined mode, the D/H system will go automatically into a minimum power consuming mode which is:

- Realtime Transmission only (DMO)
- Engineering data transmission (FM4) only
- Lowest possible Bitrate (8 bps)

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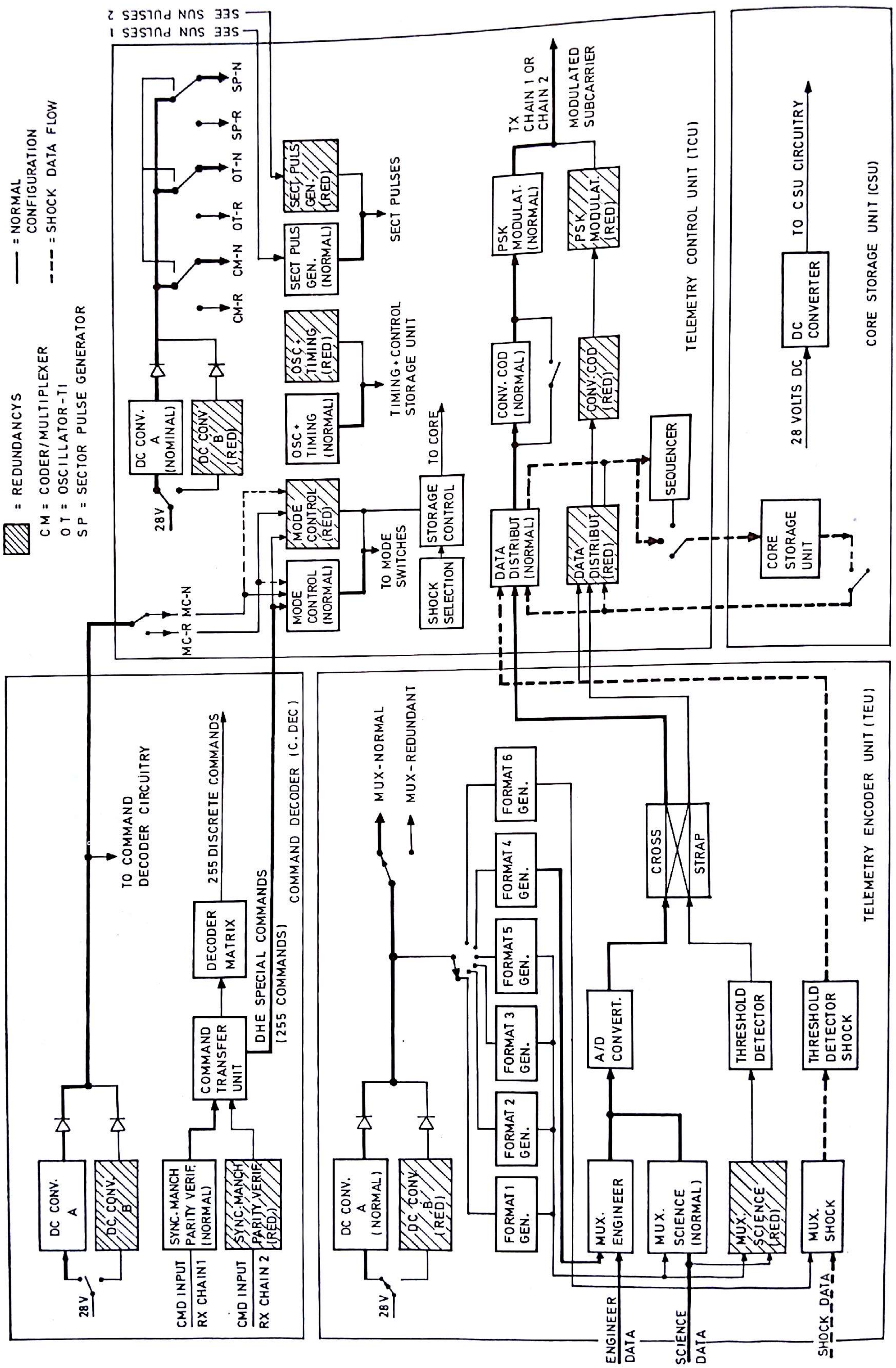

Figure 7.5-1: Data Handling Block Diagram

7.5.1.3 **DATA HANDLING MODES**

On *Table 7.5-I* the possible (legal) mode combinations are defined.

The basic on board data streams are:

- Real time transmission only (TRANSMIT ONLY)
- Realtime transmission plus simultaneous shock data (FM6) read in
- Realtime transmission plus simultaneous storage of the transmitted data
- Black-Out configuration (Realtime transmission plus storage)
- Read out of whatever was stored in the core memory

All D/H modes are commandable with the special D/H commands and are executed according to the following rules:

- Format mode changes are executed main frame synchronous (e.g. one main frame consists of four frames in FM 4, of 72 frames in all other formats, except FM6)
- Distribution mode changes executed frame synchronous
- Bitrate changes can be executed either word synchronous or coupled with the next format mode change (FM-mode synchronous)
- Special rules apply (FM and DM change word synchronous) in connection with distribution mode 4 (DM4)

All above mentioned changes can also be executed „Conditionally" which means the desired mode will be executed by reaching the memory end address.

7.5.1.4 **CORE MEMORY OPERATIONS**

The core memory has 3 different modes of operation depending on the stored format:

- If FM6 is stored (SHOCK FORMAT) the memory is arranged that way that only the highest detected shock (determined by magnetic or electric field measurement) is stored (previous ones being overwritten) together with the starting and decreasing slope
- If any other realtime format is stored (using DM4) the memory will cycle, which means it will jump from the end address to start address overwriting the previous data
- If Black-Out mode (DM5) is in operation the memory does not cycle but fills just once, then switching automatically into realtime transmission only.

For DM4 and DM5 operation a SEQUENCER can be used in order to extend the readin period (storing not a continuous data stream but taking only samples by deleting every n-th mainframe).

7.5.2 **SIGNIFICANT ANOMALIES AND RECOVERY**

1. **Experiment 6 Interference**
The science data of Experiment 6 (Cosmic Rays) is corrupted by the current used for memory operations (DM1, 2, 3). This was known already before launch and Experiment 6 negotiated with the other experimenters for daily periods (2 hrs) without memory operations.

2. **Automatic Black-Out Exit**
The black-out mode was designed that way, that once the memory is filled the D/H mode would switch automatically into a R/T only transmission mode (DMO, FM3, 8 BPS) saving the stored memory contents.

As an anomaly, the mode switched to DM0 but the frame number counter got hung up and did not increase which means the data could not be decommutated.

Recovery: Two alternatives have been developed to overcome this problem:

- Repeat command sequence for DM0, FM3 after B/O acquisition
- Select a read-in period (using the sequencer) which allows longer memory read-in mode than the expected black-out period and interrupt the read-in after reacquisition.

3. **Memory Operations**

At one occasion during realtime operations a disturbance of the memory contents was detected:
Almost 80 % of the stored data was a constant bit-pattern (repetition of the last good data line received).
Recovery: None — the stored science data were lost, no explanation could be given. It must be assumed that this could have happened several times during the mission but was not detected in realtime.

4. **Bit Rate Changes**

The most constraints came from, how to perform bitrate changes:

- From tests before launch it was known that, if word synchronous bitrate changes are performed, the identification and S/C time words are „scrambled" for one mainframe, therefore all those bitrate changes were banned during mission operations
- Another operational constraint from before launch was, that no bitrate change is allowed during memory read-in operations because a S/C event time correlation is not possible in this case
- During mission operations several cases were experienced when also „scrambled" data occurred with format mode synchronous bitrate changes.
  Recovery: Automatically after one mainframe
- During mission operations it turned out that some D/H bitrate and distribution mode change pulses did arrive at some experiments (E7, E8), not selecting the appropriate configuration.
  Recovery: After each bitrate or distribution mode change a couple of experiment trigger commands simulating the mode change pulses from the D/H system had to be inserted
- During mission operations it was experienced that also a format mode synchronous bitrate change being executed conditionally led to „scrambled" data.
  Recovery: No usage of those sequences.

Critique: The nonavailability of all word synchronous bitrate changes makes it impossible at low bitrates to make optimum use of the available station coverage periods because of the long execution times (2:52 hrs at 8 BPS).

5. **Format 6 Problem**

A specific HELIOS (built-in) problem is the S/C time being transmitted in the shock format (FM6): This format was designed to contain only an unambiguous time for approx. 30 min (turn over of the counter after 30 min) in difference to all other formats which contain an unambiguous time for approx. 3.5 years. Since a normal shock read in-period takes approx. 4 hrs (together with the particular cycling of the memory in DM 1,2,3) a time correlation to the GMT is not easily made, and additional correlation algorithms had to be implemented on ground.
From the operational point of view additional constraints spun of this FM6 time problem:

- No DM 1,2,3 operation at day time changes (00:00)
- After network handovers (DSN to GES) DM 1,2,3 have to be operated before a read-out could be made
- No read-out at day time changes (00:00).

SUMMARY:

The above listed D/H constraints and anomalies make it very difficult to make optimum use of the available station coverage in particular if no continuous coverage is available and the available stations have different characteristics (STDN, DSN, GES).

7.5.3 RECOMMENDATIONS

Recommendation No. 1

The D/H System allows too many combinations, additional onboard logic blocking should have been implemented.

Recommendation No. 2

With the word synchronous bitrate change prohibition the frame and main frame length is too long for low bitrates and no continuous coverage.
A shorter frame length would have also been more advantageous for the reduction of the deletion rate.

Recommendation No. 3

One should have implemented the complete S/C time information also for FM6. The efforts and constraints on ground are not comparable to sparing additional four 8 bit words for the S/C time.

Recommendation No. 4

A command should exist which clears the memory (defined-read-in of zeros) before a new read-in.
Since old data is stored as long as it is not overwritten by new data, together with the insufficient time resolution in FM6 it is highly confusing to process a read-out with mixed times.
Another advantage of this command would be to allow a check-out of the memory.

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	DISTRIBUTION MODES (DM)	TRANSMIT FORMAT (FM)	MEMORY READ-IN FORMAT (FM)	SEQUENCER CONTROL	BITRATE MODE TRANSMITTED (BM) (bps)									
					3 / 8	4 / 16	5 / 32	6 / 64	7 / 128	8 / 256	9 / 512	10 / 1024	11 / 2048	12 / 4096
TRANSMIT ONLY	DMO	FM1	—	—							X	X	X	
	DMO	FM2	—	—				X	X	X	X			
	DMO	FM3	—	—	X	X	X	X						
	DMO	FM4	—	—	X	X	X	X	X	X	X	X	X	X
	DMO	FM5	—	—									X	X
TRANSMIT PLUS SHOCK DATA READ-IN	DM1	FM1		—							X	X	X	
	DM1	FM2	FM6	—				X	X	X	X			
	DM1	FM3	4096 bps	—	X	X	X	X						
	DM1	FM4		—	X	X	X	X	X	X	X	X	X	X
	DM2	FM1		—							X	X	X	
	DM2	FM2	FM6	—				X	X	X	X			
	DM2	FM3	8196 bps	—	X	X	X	X						
	DM2	FM4		—	X	X	X	X	X	X	X	X	X	X
	DM3	FM1		—							X	X	X	
	DM3	FM2	FM6	—				X	X	X	X			
	DM3	FM3	16,384 bps	—	X	X	X	X						
	DM3	FM4		—	X	X	X	X	X	X	X	X	X	X
TRANSMIT PLUS READ-IN	DM4	FM1	FM1											
	DM4	FM2	FM2											
	DM4	FM3	FM3											
	DM4	FM4	FM4	YES					X					
	DM4	FM5	FM5											
BLACKOUT	DM5	FM3	FM3	YES	X	—	—	—	—	—	—	—	—	—
READ-OUT ONLY	DM7	FM1	—	—										
	DM7	FM2	—	—										
	DM7	FM3	—	—	X	X	X	X	X	X	X	X	X	X
	DM7	FM4	—	—	X	X	X	X	X	X	X	X	X	X
	DM7	FM5	—	—										
	DM1,2,3	FM6			X	X	X	X	X	X	X	X	X	X
CARRIER SUPPRESSION		LOW			X	X	X	+	+	+	+	+	+	+
		HIGH			+	+	+	X	X	X	X	X	X	X

X = NORMAL MODES
— = FAILURE MODES
UNMARKED = ILLEGAL MODES
\+ = BACK-UP MODES

Table 7.5-I: Data Handling Mode Combinations

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7.6 PLAYLOAD OPERATIONS

7.6.1 EXPERIMENT LIST

No.	Titel	Investigators (Princ.Invest. underlined)	Affiliation	Scientific Objectives: Measurement of
1	Plasma Experiment	**H. Rosenbauer** R. Schwenn B. Meyer H. Miggenrieder J.H. Wolfe	MPI f. Physik u. Astrophysik, Institut f. Extraterr.Physik, Garching/München NASA Ames Research Center, Moffet Field, Cal.	low energy protons, alphy particles and electrons (solar wind)
2	Flux Gate Magnetometer (Braunschweig)	**G. Musmann** F.M. Neubauer A. Maier	TU Braunschweig, Inst. f. Geophysik u. Meteorologie	interplanetary quasistatic magnet field a. shock wave
3	Flux Gate Magnetometer (Roma, GSFC)	**N.F. Ness** L.F. Burlaga F. Mariani C. Catarano	NASA GSFC, Greenbelt, Md. Universita degli Studi, Instituto di Fisica „G.Marconi" Roma	interplanetary quasistatic magnetic field and shock waves
4	Search Coil	**G. Dehmel** F.M. Neubauer G.F. Schirenbeck R. Karmann	TU Braunschweig, Institut für Nachrichtentechnik	magnetic field fluctuations, shock wave analysis
5	Plasma and Radio Wave Experiment	**D.A. Gurnett** G.W. Pfeifer P.J. Kellogg S.J. Bauer R.G. Stone R.R. Weber	University of Iowa, Dep. of Physics & Astronomy, Iowa City, Iowa University of Minnesota, School of Physics & Astron., Minneapolis, Minnesota, Md. NASA GSFC, Greenbelt, Md.	Electrostatic and electromagnetic wave phenomena, shock wave analysis
6	Cosmic Ray Experiment (Kiel)	**H. Kunow** R. Müller G. Green H.G. Hasler	Universität Kiel, Institut f. Reine und Angewandte Kernphysik	high energetic nuclei and electro of solar and galactric origin

Table 7.6-1: HELIOS Experimenter List

7.6.1 **EXPERIMENT LIST (cont'd)**

No.	Titel	Investigators (Princ.Invest. underlined)	Affiliation	Scientific Objectives: Measurement of
7	Cosmic Ray Experiment (GSFC)	**J.H. Trainor** F.B. McDonald B.J. Teegarden E.C. Roclof K.G. Mc Craken	NASA GSFC, Greenbelt, Md. University of New Hampshire CSIRO, Melbourne, Australia	medium and high energy particles and X-rays
8	Electron Detector	**E. Keppler** B. Wilken G. Umlauft W. Williams	MPI f. Aeronomie, Institut Stratosphärenphysik, Lindau/Harz ESSA, Boulder, Colorado	medium energy electrons protons positrons
9	Zodiacal Light Photometer	**C. Leinert** E. Pitz	MPI f. Astronomie, Heidelberg	interplanetary dust distribution by observation of zodiacal light
10	Micrometeoroid	**H. Fechtig** J. Kissel E. Grün P. Gammelin	MPI f. Kernphysik, Heidelberg	properties of dust particles
11	Celestial Mechanics Experiment	**W. Kundt** W.G. Melbourne J.D. Anderson	Universität Hamburg, I. Institut f. Theoretische Physik JPL, Pasadena, Calif.	orbit elements in order to determine parameters of the gravitation theory
12	Faraday Rotation	**G.S. Levy** Ch.T. Stelzried H. Volland	JPL, Pasadena, Calif. Astronomisches Institut der Universität Bonn, Bonn	investigation of the solar corona
13	Wave Propagation	**P. Edenhofer** V. Stein	DFVLR, Oberpfaffenhofen Institut für Flugfunk und Mikrowellen	plasma distribution in the solar corona

Table 7.6-I: HELIOS Experimenter List (continued)

7.6.2 DETECTED ANOMALIES AND RECOVERY

Preface:

Lift-off of HELIOS 1 took place at 10.12.74 (344) 07:11:00 GMT. Listed below are the experiment turn-on events after spacecraft separation:

10.12.74-Day 344	Near Earth Phase turn on	
	09:42:00	E5ON, E8ON
	09:44:00	E2ON
	09:45:00	E4ON
	09:46:00	E3ON
11.12.74-Day 345	Experiment Integrity Check	
	21:20:00	E4 OFF, E3 OFF, E2 OFF, E8 OFF, E5 OFF
	21:30:00	E6 ON, E9 ON
	21:35:00	E8 ON, E5 ON, E2 ON, E4 ON, E3 ON
12.12.74-Day 346	Configuration E1, E10	
	00:01:00	E10 ON
	00:01:15	E1 ON
14.12.74-Day 348	Configuration E7	
	22:11:00	All experiments off
	22:16:00	E7 ON
	22:40:00	Start of reconfiguration of all experiments.
15.12.74-Day 349	07:00:00	ALL EXPERIMENTS CONFIGURED

1. **Experiment 5 Antenna Deploy Anomaly.**

On day 344 10:10:03 GMT the deployment of E5 antennas was started. No automatic switch-off of the antenna 1 (+ Y axis) motor occurred. The change in spinrate was less than expected. Also noise at experiment 5 input was detected, which indicated that antenna 1 was short circuit connected to the spacecraft chassis. It was decided to carry out a troubleshooting sequence on day 347.

Day 347 to 354 Events:

Attempts were made, to retract the antenna 1 of Experiment 5. The following sequences were used:

a. 030-1A1E
051-ADCR
326ADMR ---MOTOR STARTS RUNNING REVERSE — Retraction Sequence
072-ADSR
072-ADSR ---MOTOR STOPS RUNNING

b. 030-1A1E
326-ADMR---MOTOR STARTS RUNNING FORWARD — Deployment Sequence
072-ADSR
072ADSR ---MOTOR STOPS RUNNING

Sequence (a) was sent 79 times, sequence (b) 28 times. In neither case there was any indication that the motor ran.

The effect on experiments 5A, B, and C ist that they are disturbed, and that they have a reduced sensitivity by the short in the E5 antenna.

2. **D/H Mode Change Pulses for Experiments 5B and 8.**

It was noted that after format or bitrate changes science data of E8 and E5B were mixed up. The cause were missing Mode Change Pulses from the D/H System to those experiments. The experimenters defined therefore certain trigger commands to be transmitted after each format or bitrate change in order to simulate the missing Mode Change Pulse.

3. **Experiment 4, 6, and 7 Disturbance.**
The data of E4 are slightly disturbed by the current of E4 heater. E6 is slightly disturbed by memory read in, and E7 is interfered by E6 as demonstrated by several in-flight interference tests. The data of those experiments are good, however, so no action was necessary.

4. **Multipactor Effect**
After the switch from Medium to High Gain Antenna it was detected that the science data of experiments 5A, 5B and 1, Sensor 2 were disturbed. A special test was performed on 27. Jan. '75 with the following configurations:

MEDIUM POWER HIGH GAIN ANTENNA	→	MEDIUM POWER MEDIUM GAIN ANTENNA	→	HIGH POWER MEDIUM GAIN ANTENNA
(1)		(2)		(3)

Figure 7.6-1: Multipactor Effect Test Configurations

Only version (2) and (3) resulted in undisturbed data. Therefore it was decided, to turn on Medium Gain Antenna during most Effelsberg passes (100 m Antenna). The reason for the disturbed data was the „Multipactor Effect“, by which electrons are generated on the slots of the High Gain Antenna feeder.

5. **Experiment 10 Data Anomaly.**
At 05.02.1975 the E10 experimenters detected that E10 data were completely scrambled. On the engineering format of E10 was no indication of a failure condition. E10 was switched off for 10 minutes, switched on again and completely reconfigured. After that, E10 data were correct again. For the configuration of E10 a total number of approximately 100 commands is necessary. The same problem occurred again on 05.02.75, 13.02.75, 21.02.75, 03.03.75, 07.03.75, 23.03.75.
The procedure in all these cases was to switch E10 off and reconfigure it.

6. **Experiment 2 Flipper Failure**
On 05.03.1975 a command was sent for changing the flipper position of E2 for calibration purposes. The status bit on the experiment format and also the science printouts were indicating that the flipper position remained unchanged. No switching was possible any longer. The effect on the experiment was, that the offset value for component 'U' of the three axis Fluxgate Magnetometer could not be determined any longer. This offset value is known, however, and rather stable, as long as E2 is switched on.

7. **Experiment 3 Flipper Anomaly.**
At the same day, it was detected, that the automatic flipping of E3 did not work. A command was sent to change the flipper position, but the position remained unchanged. On 14.03.75 the command was repeated, and the E3 sensor flipped. The status up to now is, that the automatic flipping works approx. 2 times per week, instead of the 4 times per week.

8. **Experiment 5B Calibration Cycle.**
On 18.03.75 it was detected, that the calibration cycle of E5B was not automatically switched off. The reason is, that the reset function fails, if the automatically initiated calibration cycle is on, when the command 305-5BCL is getting into the spacecraft. In this case the calibration cycle has to be switched off by command.

9. **Experiment 10 HV break down.**
On 23.03.1975 the high voltages of both E10-sensors broke down

Sens A: 3.339kV ⟶ 0.7 kV
Sens B: 3.099kV ⟶ 0.48 kV

This drop was probably caused by a spike on the non essential bus line. After switch-off/on and reconfiguration, science data were correct again, no experiment anomalies were detected during reconfiguration and inserted test-steps.

10. **Non Essential Bus Shut-off.**

On 24.03.75 a possible spike caused the spacecraft to switch to the following status:

- B/R to 8 BPS
- 2 heater groups and 4 experiment relais switched to OFF
- The Non Essential Bus was shut down and all experiments were unpowerd

The reason for this switch was unknown, so the experiment overcurrent fault identification had to be performed to check out whether there was any short in the payload subsystem. For this purpose, the experiments were switched on separately, to check the power consumption, voltages, currents and temperatures of each experiment. The sequence was as follows:

XXX — EXON	Experiment „X" ON (X = 1. . .10)
036 — NLON	Experiment bus ON

CONFIGURATION
COMMANDS

164 — NLOF	Experiment bus OFF
XXX — EXOF	Experiment „X" OFF

In this way the Experiments 1 - 9 were checked out and no failure was detected. Therefore the experiments could be completely configured. The checkout of E10 was postponed because of the precious HV breakdown.
The described sequence was started at 18:00:00 and finished at 01:57:00. The number of commands was 124.
The second part of the sequence started next day at 11:20:00. To check out E10, all experiments were switched off again.

164 — NLOF	Experiment bus OFF
152 — EOON	Experiment 10 ON
036 — NLON	Experiment bus ON

CONFIGURATION
COMMANDS

This sequence is prescribed in SCUM VOL II, but according to the experimenter this sequence results in a not defined reset. Therefore E 10 was switched off and on again.

173 — EOOF	Experiment 10 OFF
036 — NLON	Experiment bus ON
152 — EOON	Experiment 10 ON

CONFIGURATION
COMMANDS

After final configuration E10 worked correctly. At 14:40:00 the configuration sequence for E1 — 9 was started and completed at 17:25:00. The total number of commands sent after the non essential bus switch was 388.

11. **Experiment 2 OFF/ON Consequences.**

26.03.75: As Experiment 2 was switched off and on, due to the S/C emergency, the offset value for 'Z' component was set to its maximal value. This wrong value is used for the Shock Identification Computer, which was processing wrong results, too. The offset value can only be corrected by flipping the sensor 'Z' component away from z — direction. Therefore the signal of E3 was used by sending the command:

266 — 2ON3

By this command the signal from E3 was routed to electronics of E2. After flipping of E3 the high offset value was calculated down to nominal values, the Shock Identification Computer could be used again. On 27.03.75 the signal of E3 was switched back to E3 electronics by the command:

132 — 2OF3

12. **Vanishing of Multipacator Effect.**

04.04.75: Since this day it was no longer necessary to switch from High to Medium Gain Antenna, because the science data of E5A, B, and C and of E1 Sensor 2 were no longer disturbed.

13. **Experiment 8 Data Disturbance.**

14.09.75: It was detected that the internal block count of E8 was disturbed. Trigger commands were sent without success. Also a switch-off for 5 minutes, followed by a reconfiguration sequence was not successful. The effect of this block count disturbance are mixed lines in science data, prohibiting any E8 science data to to be printed out.
Recovery: Software — Change omitting the block count.

14. **Experiment 1/10 Anomaly.**

22.03.76: At the beginning of a pass it was detected, that E1 was unpowered. Also the high voltage of E10 was broken down for unknown reasons. The E1 configuration sequence was sent, and no anomaly could be observed.
After switch-on of Experiment 10, the Sensor B current showed a H+. The experiment main-contractor was consulted, who decided to configure the experiment two days later.
The configuration sequence was sent on 24.03.76. The H+ limit disappeared with increasing of Sensor B high voltages.

15. **Experiment 2 Flipper: Remedial Action.**

06.04.76: A spin maneuver was activated in order to lessen the centrifugal force on the E2 flipper mechanism. The spinrate was decreased from 60 rpm to 52.9rpm. A flipper command was sent to activate the flipper, with no success. The spinrate was increased then back to 60 rpm.

16. **Regulator Switch.**

22.06.76: A regulator switch took place, because of a regulator overload. The switch was not performed as designed, and the S/C went into an undefined status. A change of the ALPHA-Register resulted in a completely wrong High Gain Antenna Pointing, and downlink was lost. The S/C could not be acquired until Medium Gain Antenna was switched on by command. It took approxcimately 8 hrs and 600 commands to switch the S/C into a defined status. Decreasing temperatures caused a total of 20 W additional heater power to be turned on.
After configuration of only E8 and E2 and switching E1 into power consumption mode, the output power was 195 W, which was close to the upper limit (197 W).

23.06.76: A 16 W heater switched off, and E1, E3 E10 and E4 were configured. The output power was now 195 W again. No more experiments could be switched on, before the next heater would switch off. E9 and E6 expected serious problems in case that their experiment remained off for a too long period. Therefore, the following experiment switches were necessary:

29.06.76	181	E2 OFF ⟶ E3 OFF ⟶ E9 ON
		T = 10 Hours
		E9 OFF ⟶ E2 ON ⟶ E3 ON
08.07.76	190	E2 OFF ⟶ E3 OFF ⟶ E9 ON
		T = 28 Hours
		E9 OFF ⟶ E6 ON ⟶ E3 ON

The above sequence was repeated on days:

13.07.76	(195)
20.07.76	(202)
27.07.76	(209)
03.08.76	(216)
11.08.76	(224)

The final configuration of the experiments after switch-off of the heaters took place on:

16.08.76	(229)	E9ON
25.08.76	(239)	E7ON
26.08.76	(239)	E7ON
		DPU ON
		E5A ON
27.08.76	(244)	E5B ON, E5C ON

7.6.3 OPERATIONAL ASPECTS AND RECOMMENDATIONS

The many idiosyncrasies described above led to more control activities for the experiments than planned before lift-off.
These are:

- Checking out housekeeping data of the experiments against limits and undefined status changes
- Making sure that the experiments are working in a correct mode
- Performing realtime printouts of all experiments
- Performing data recalls of special events
- Sending test and trigger commands on a routine basis
- Sending mode and range change commands depending on bitrates and formats
- Sending special test sequences in case of limit exceedings and undefined status changes and upon request of experimenters
- Check of science data for disturbances

In addition the anomalies enhanced the routine sequences drastically as an example demonstrates:

Gap coverage with B/R — change:

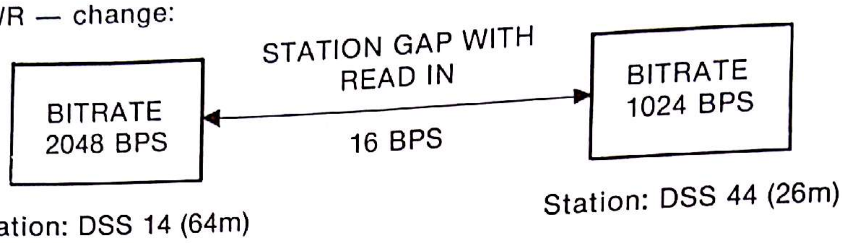

Figure 7.6-2: Schematic Presentation for Gap-Coverage

The command sequence for a data read in during a station gap is as follows:

Without payload commands	with payload commands
424-BM42	424-BM4S
123-LMRG	123-LMRG
643-XXXX	643-XXXX
123-LMRG	123-LMRG
271-LOCS	271-LOCS
	236-8CON
432-B10S	305-5BCL
123-LMRG	351-7BLK
601-DOF1	301-3REX
123-LMRG	013-3RM1
106-HICS	076-3RMO
	301-3REX
	141-8COF
	162-8DFB
	213-1NDM
	432-B10S
	123-LMRG
	601-DoF1
	123-LMRG
	106-HICS
	236-8CON
	301-3REX
	013-3RM1
	301-3REX
	305-5BCL
	351-7BLK
	141-8COF
	162-8DFB
	122-1HDM
10 commands	29 commands

Table 7.6-II: Command Sequences for GAP-Coverage

The E8, E5B commands are necessary because of the synchronization problem of those experiments. The E3, E7, and E1 commands are sent, to put the experiments into a proper mode.

Recommendation No. 1

Payload configuration sequences for routine operations should be as short as possible in order to minimize command activities.
Mode and range changes of the experiments should occur automatically to make sure, that in case of command problems or operational errors, the experiment is running in a correct mode. Only in case of malfunction it should be necessary to change modes or ranges by command, but also those sequences should be as short as possible:
In case of any problems, it is much easier, to send a short sequence, than a long one. There are many problems, which may make it impossible to send the trigger, mode and range change commands after the bitrate change commands:

- Operational errors
- Line problems at GSOC, JPL
- Station problems (transmitter failure, wrong antenna pointing)
- Bad uplink conditions

In these cases, the experiments would have disturbed data, or run in a wrong mode during the gap.

Recommendation No. 2

Avoid 'toggling' commands and 'chained' commands (i.e. commands have to be sent in a certain order):

During bad uplink conditions (Gray Out, Black-Out Periods) important commands are sent several times, to make sure, that one of them is getting into the spacecraft. This cannot be done with the trigger commands, because they are working only in the specified sequence, selecting an unwanted mode if one CMD out of the sequence is missing.
If a toggling command is sent twice, the mode will be the same, as without command (no prophylactic repetitions possible).

Recommendation No. 3

Cascade or 'Stepper' Commands should be reduced to a minimum.

For example: Experiment 10 requires approximately 120 repetitions of the same command in order to step up the high voltages to the desired level.
A turn -on procedure is very time consuming and may lead to confusions at long round-trip-light-times and bad uplink conditions.

Recommendation No. 4

Each experiment should have a 'Reset' command which switches the experiment into a defined mode in case of synchronization or data collection disturbances.
With several experiments it is only possible to resynchronize the experiment by turning it off and then on again with following configuration, which is:

- Hazaradous for the total payload (a welding of the 'ON' relay would disable the entire payload)
- Very time consuming for experiments with long turn-on sequences.

8 LIST OF ABBREVIATIONS

ADMIN	Administrative
AGC	Automatic Gain Control
AMES	Ames Research Center (NASA)
AOS	Acquisition of Signal
BEP	Bit Error Probability
BIP	Buffer Interface Program
B/O	Black Out (Superior Conjunction with the Sun)
B/R	Bitrate
BPS	Bits per Second
CMA	Command Modulation Assembly
CMD	Command
CMOS	Chief of Mission Operations Support
CMS	Chief of Mission Support
CP	Communications Processor
CRT	Cathode Ray Tube (Realtime Display Device)
CSFO	Chief of Spaceflight Operations
DDA	Digital Decoding Assembly
DDA (S/C)	Despin Drive Assembly
DFVLR	Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt
D/H	Data Handling (System)
DM	Distribution Mode
DN	Data Number (Decimal Representation of a Telemetry Value)
DPU	Data Processing Unit (Experiment 5)
DQ	Data Quality
DSN	Deep Space Network (NASA)
DSS	Deep Space Station
DTV	Digital Television
DTV-HC	Digital Television Hardcopy Machine
EDR	Experiment Data Record
EIRP	Effective Isotropic Radiated Power
EM	Engineering (S/C) Model
EU	Engineering Unit (Analog Representation of a Telemetry Value)
FM	Format Mode
FN	Frame Number
FOPE	Facility Operations Project Engineer (for MCCC)
GCC	German Control Center
GDS	Ground Data System
GES	German Effelsberg Station
GfW	Gesellschaft für Weltraumforschung
GMT	Greenwich Mean Time
GRT	Ground Receipt Time
GSFC	Goddard Space Flight Center (NASA)
GSOC	German Space Operation Center
GTS	German Telecommand Station (Weilheim)

HE-CMD	Helios Command Operator
HEOPS	Callsign for GSOC Chief of Spaceflight Ops PE at JPL
HGA	High -Gain Antenna
HGDS	Helios Ground Data System
HGOS	Helios Ground and Operations System
HP	High Power
HSDL	High Speed Data Line
HV	High Voltage
IABG	Industrie Anlagen Betriebs Gesellschaft
I/O	Input/Output
JPL	Jet Propulsion Laboratory (NASA)
JSC	Johnson Space Center (NASA)
KSC	Kennedy Space Center (NASA)
LeRC	Lewis Research Center
LGA	Low Gain Antenna
LOS	Loss of Signal
LP	Line Printer
L/V	Launch Vehicle
MATH MODEL	Mathematical (S/C) Model
MBB	Main Contractor for Helios
MCCC	Mission Control and Computing Center (JPL)
MDR	Master Data Record
MGA	Medium Gain Antenna
MICOS	Mini Computer System
MM	Mission Manager
MP	Medium Power
MPI	Max Planck Institut
MSA	Mission Support Area
MOS	Mission Operations Support
NEPN	Near Earth Phase Network
Net Ops	Network Operations
NOAA	National Oceanographic and Atmospheric Administration
NOCC	Network Operations and Control Chief
NOC PE	Network Operations Control Project Engineer
NOC SCHED	Network Operations Control Scheduling
ODR	Original Data Record
OPS	Operations
PA	Pitch Angle
PAT	Performance Analysis Team (S/C)
PCDU	Power Conditioning and Distribution Unit
PCM	Pulse Code Modulation
PE	Project Engineer
PH	Phase (Helios Mission Phase)
PM	Phase Modulation
PSK	Phase Shift Key (Modulation)
PSR	Project Status Review (Meeting)
PT	Prototype (S/C)

DFVLR
GSOC

QLP	Quick Look Processor
RAD	Radian
RCC	Remote Control Center
RCVR	Receiver
RF	Radio Frequency (System)
RIC	Remote Interface Control
RNG	Ranging
RPM	Revolutions/Minute
R/T	Real Time
S/A	Solar Array
SAA	Solar Aspect Angle
SAT	Science Advisory Team
S/C	Spacecraft
S/C PAT	Spacecraft Performance Analysis Team
SCUM	Spacecraft Users Manual
SDR	System Data Record
SEP	(Angle between) Sun-Earth-Probe
SC	Solar Constant
SNR	Signal to Noise Ratio
S.O.E	Sequence of Events
SSM	Second Surface Mirrors
S/W	Software
STDN	Spaceflight Tracking and Data Network
TLM	Telemetry
TOAC	Telemetry, Orbit, Attitude and Command (Tape)
TRK	Tracking
TTY	Teletype
TVSA	Television Subsystem Assembly
TWT	Travelling Wave Tube
TWX	Telex
UCP	User Character Printer
UCR	User Card Reader
UIS	User Input Station
ULP	User Line Printer
VCXO	Voltage Controlled Oscillator
VOCA	Voice Communications Assembly
VSO	Very Stable Oscillator
XMTR	Transmitter