NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-426

Volume I

Tracking and Data System Support for the Pioneer Project

Pioneer VI. Prelaunch to End of Nominal Mission

N. A. Renzetti

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
February 1, 1970

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-426
Volume I

Tracking and Data System Support for the Pioneer Project

Pioneer VI. Prelaunch to End of Nominal Mission

6

N. A. Renzetti

OTHER VOLUMES ARE NOT
IN AND CAN NOT be locate

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
February 1, 1970

PRECEDING PAGE BLANK NOT FILMED.

Preface

The work described in this report was performed by the Tracking and Data Acquisition organizations of the Jet Propulsion Laboratory, Air Force Eastern Test Range, and Manned Space Flight Network and NASA Communications Network of Goddard Space Flight Center. This volume, the first in a series of four, covers the Tracking and Data System support for the *Pioneer VI* mission from the planning phase through the end of the nominal mission in June 1966. (For *Pioneer VI,* the nominal mission ended when data transmission by the Deep Space Network 85-ft-diam antenna system exceeded a bit-error rate of 1 error in 100.) Volumes II and III of this report present similar documentation relative to the *Pioneer VII* and *VIII* missions. Volume IV deals with *Pioneer IX* and with a subsequent planned but unsuccessful mission (*Pioneer E*).

Acknowledgment

The author acknowledges the considerable assistance of E. R. Allen, R. H. Grace, R. E. Purdue, A. J. Siegmeth, A. D'Amore, W. J. Ross, J. W. Davis, Jr., and J. W. Thatcher in compiling this report. The author also acknowledges the support, in the form of informal reports and material, of the operations staffs of the various networks, i.e., Air Force Eastern Test Range, Manned Space Flight Network, NASA Communications Network, and the Deep Space Network at Jet Propulsion Laboratory. The material relating to the launch vehicle and *Pioneer* spacecraft was abstracted from Ames Research Center and Goddard Space Flight Center reports. The author is indebted to the support of A. C. Belcher, and M. E. Binkley of the Office of Tracking and Data Acquisition, NASA Headquarters.

Contents

I. Introduction 1

A. Purpose 1

B. Objectives 2

C. *Pioneer* Project Development 2

D. Tracking and Data System 4

1. Near-earth phase 4

2. Deep space phase 4

E. *Pioneer VI* Spacecraft 6

F. Launch Vehicle 8

G. Scientific Experiments 9

1. Cosmic ray detector (University of Chicago) 10

2. Cosmic ray detector (Graduate Research Center of the Southwest) 10

3. Plasma detector (Massachusetts Institute of Technology) 11

4. Plasma detector (Ames Research Center) 11

5. Magnetometer (Goddard Space Flight Center) 12

6. Radio propagation (Stanford University) 13

7. Astronomical constants 13

II. *Pioneer VI* Tracking and Data System Requirements 13

A. Near-Earth Phase Support 13

1. AFETR acquisition support 14

2. AFETR Class I tracking 15

3. AFETR station support 15

4. Data processing support 15

5. Communications 15

6. Near-earth phase trajectory characteristics 15

7. S-band telemetry 15

8. JPL/AFETR operational support 19

Contents (contd)

B. *Pioneer VI* Deep Space Phase Requirements 20

C. Quality Control of Data 20

1. Metric data 20
2. Telemetry data 21
3. Telemetry data validation 22
4. DSN station logs 22
5. Ground Communications Facility 22
6. Receiving and processing mission data tapes 25

III. *Pioneer VI* Tracking and Data System Configuration 27

A. Near-Earth Phase Configuration 27

1. Metric data 27
2. Telemetry 29
3. Real Time Computer Facility 29
4. Joint facilities 29

B. Deep Space Phase Configuration 33

1. Deep Space Instrumentation Facility 36
2. Ground Communications Facility 46
3. Space Flight Operations Facility 53

IV. *Pioneer VI* Preflight Test Program 61

A. Preflight Review 61

B. Prelaunch Tests 63

1. Dual composite test summary 63
2. Acceptance and RFI test summary 63
3. All-systems test summary 64
4. Electrical systems test 64

C. Spacecraft Checkout 64

D. Deep Space Network Testing 64

1. Telemetry and command system acceptance tests 68
2. Subsystem acceptance test 68
3. Integration tests 68
4. Operational readiness tests 68
5. Conclusion 68

Contents (contd)

E. *Pioneer*/S-band Compatibility Tests 68
  1. Test program 69
  2. Test results 69

V. *Pioneer VI* Tracking and Data System Flight Support 70
  A. Near-Earth Phase Support 70
    1. Prelaunch 71
    2. Countdown 74
    3. Liftoff and first powered flight 75
    4. Parking orbit 75
    5. General coverage 76
  B. Deep Space Phase Support 76
    1. Deep Space Network 77
    2. Deep Space Instrumentation Facility 85

VI. *Pioneer VI* Tracking and Data System Performance Evaluation . . . 87
  A. Near-Earth Phase 87
    1. Requirements 101
    2. Performance 101
    3. Sequence of major events 105
  B. Deep Space Phase 105
    1. Deep Space Instrumentation Facility operations 105
    2. Received-signal levels 123
    3. Commands 123
    4. Telemetry 126
    5. Space Flight Operations Facility 133

Glossary 136

Bibliography 137

Tables

1. Principal elements of *Pioneer* Project 3
2. Deep Space Station designations and locations 6
3. Mark events for *Pioneer VI* mission 14
4. Deep Space Network *Pioneer VI* commitments 21
5. Data requirements in support of *Pioneer VI* mission 21

Contents (contd)

Tables (contd)

6. *Pioneer* data monitoring 21
7. Classification of mission data requirements 27
8. Near-earth phase facilities 27
9. Subcarrier link data 29
10. Near-earth phase telemetry commitments 29
11. DSS capabilities for *Pioneer VI* support 36
12. Compatibility matrix 37
13. Form and sequence of metric data transmitted from the Deep Space Stations 37
14. Deep Space Station tracking modes 40
15. Channel allocations 40
16. Ground communications facility circuits allocated to the *Pioneer* Project 54
17. *Pioneer VI* tests 68
18. Compatibility test summary 70
19. *Pioneer VI* error bit-rate summary 71
20. Weights, *Pioneer VI* 73
21. Mass properties, *Pioneer VI* 73
22. Orbital elements 75
23. Significant flight events 75
24. Normal power budget for the *Pioneer VI* telemetry link 84
25. First 40 min of on-line engineering data from initial acquisition of *Pioneer VI* by DSS 51 88
26. *Pioneer VI* Deep Space Stations operations summary 89
27. Comparison of normal and actual events during near-earth flight phase 100
28. *Pioneer VI* sequence of major events 106
29. *Pioneer VI* command errors 113
30. Deep Space Station tracking data, first four passes 114
31. Johannesburg commands, first four passes 116
32. Goldstone commands, first four passes 118
33. Tidbinbilla commands, passes 002–004 119
34. Format identification and operating log 124

Contents (contd)

Figures

1. Exploded view of the *Pioneer VI* spacecraft 8
2. *Pioneer VI* spacecraft flight and launch configurations 8
3. Thrust-augmented improved *Delta* (DSV-3E) launch vehicle . . . 9
4. *Pioneer VI* earth track 16
5. S-band telemetry equipment configuration for the *Pioneer VI* launch 17
6. Tel II predicted received signal strength vs time after launch . . . 17
7. Tel II predicted doppler offset vs time after launch 18
8. Grand Bahama Island predicted received signal strength vs time after launch 18
9. Grand Bahama Island predicted doppler offset vs time after launch 18
10. Antigua predicted received signal strength vs time after launch 19
11. Antigua predicted doppler offset vs time after launch 19
12. *Coastal Crusader* predicted received signal strength vs time after launch 20
13. *Coastal Crusader* predicted doppler offset vs time after launch 20
14. *Pioneer* telemetry data monitor 22
15. Communication lines, launch configuration 23
16. AFETR instrumentation forms 28
17. Metric data flow—launch phase 30
18. Metric data flow chart—orbital phase 31
19. Telemetry and tracking data flow from AFETR and the DSIF to the SFOF 32
20. *Pioneer* space flight operations facility data flow 34
21. *Pioneer* telemetry data flow and associated functions (excluding orientation-peculiar telemetry processing) 35
22. *Pioneer VI* typical Deep Space Station (S-band configuration) . . . 38
23. *Pioneer VI* typical Deep Space Station (L- and S-band conversion 39
24. Relationship of Deep Space Stations to the Space Flight Operations Facility 40
25. Deep Space Station location and coverage 41
26. Ground operational equipment functional block diagram 43

Contents (contd)

Figures (contd)

27. *Pioneer* ground operational equipment at DSS 12 45

28. Block diagram of electrical ground support equipment showing relationship to spacecraft 47

29. Electrical ground support equipment system test station 49

30. Command signal flow for normal operations, DSIF 50

31. *Pioneer VI* communication lines 51

32. First floor, Space Flight Operations Facility 55

33. *Pioneer* mission support area 56

34. Flight path analysis area 57

35. Computer subsystem 59

36. Complete data flow from the SFOF 61

37. *Pioneer* off-line data processing system 62

38. *Pioneer VI* test program 65

39. Malfunctions occurring during system tests of *Pioneer VI* 67

40. General block diagram—*Pioneer* compatibility test 69

41. *Pioneer VI* prelaunch activities at the AFETR 72

42. Typical functional organization for mission support operations 78

43. Mission operations design organization 79

44. Mission operations design process 80

45. Operational support of *Pioneer VI* mission: weekly tracking passes and hours and minimum commitment during nominal mission 82

46. Fixed earth–sun line heliocentric trajectory of *Pioneer VI* and telemetry threshold ranges 83

47. Carrier power received from *Pioneer VI* from January 1966 to February 1968, as reported by DSSs 12 and 14 85

48. *Pioneer VI* telemetry bit-error rates estimated at the DSS 12 bit-rate thresholds 86

49. Communication lines for Type II orientation 101

50. Launch trajectory relationships 101

51. Spacecraft telemetry coverage during launch 103

52. Near-earth free-flight trajectory of *Pioneer VI* 103

53. Near-earth trajectory parameters for *Pioneer VI* 104

Contents (contd)

Figures (contd)

54. Earth look-angle profiles for various spin-axis orientations to the ecliptic north pole 105

55. Earth and sun look-angle profiles for various spin axes 121

56. Telemetry measurements of total power received at *Pioneer VI* spacecraft receivers 125

57. Variations of spin rate with time for early portion of flight . . . 125

58. Carrier power from *Pioneer VI* reported by DSS 12 127

59. Normalized carrier level from *Pioneer VI* for DSSs 12, 42, 51, 41, and 61 128

60. Normalized carrier power from *Pioneer VI* for DSS 12 with additional calibration refinements 129

61. Telemetry measurements of traveling-wave tube power amplifier parameters 129

62. System noise temperature vs receiver noise spectral density . . . 130

63. Variation of system noise temperature at DSS 12 during early part of *Pioneer VI* mission 131

64. Real-time indication of telemetry bit-error rate at DSS 12 for *Pioneer VI* near communication limits 132

65. Variation of average ERR readings at DSS 12 with communication distance for *Pioneer VI* 133

66. Variation of average ERR readings at various Deep Space Stations with communication distance for *Pioneer VI* 133

67. Distance limitations for telemetry from *Pioneer VI* 134

68. Effect of proximity of *Pioneer VI* to earth–sun line on telemetry data error rate 135

Abstract

The *Pioneer VI* mission (inward trajectory, heliocentric orbit) employed six scientific instruments to accumulate information relative to interplanetary high-energy particles, solar phenomena, and plasma. The spacecraft also served as a celestial mechanics experiment reference point. The Tracking and Data System (comprised of the Air Force Eastern Test Range, Deep Space Network, Manned Space Flight Network, and NASA Communications Network) tracked the spacecraft from launch through near-earth and deep space phases. For near-earth tracking, all Tracking and Data System facilities responded to mission, launch vehicle, and range requirements. For deep space tracking, the Deep Space Network responded to tracking, telemetry, command, monitoring, simulation, and operations control requirements.

Tracking and Data System Support for the *Pioneer* Project

Pioneer VI. Prelaunch to End of Nominal Mission

I. Introduction

This document provides a record of the technical activities of the Air Force Eastern Test Range (AFETR), the Goddard Space Flight Center (GSFC), and the Deep Space Network (DSN) in support of the *Pioneer* space exploration project. Included in this report are descriptions of the tracking and data acquisition requirements, details of mission preparation on the part of the participating agencies, a comprehensive account of tracking operations, and a Tracking and Data System (TDS) performance evaluation summary. Brief descriptions of the TDS, Mission Operations System, the Spacecraft System, Launch Vehicle System, and mission objectives are also provided.

A. Purpose

The primary purpose of the *Pioneer VI* mission is to accumulate scientific information from deep space. The time required for the analysis of such data is considerable. This is attributable to the fact that the gathered data encompass a variety of technical disciplines; moreover, the responsibility of preparing the analyses rests with the individual scientific experimenters having instruments aboard the spacecraft.

Pioneer VI was the first spacecraft launched in this present series; hence, this report is the first description of the TDS activities in the Project and the first presentation and discussion of engineering information obtained in flight. To aid in understanding the information presented, the spacecraft, scientific instruments, and a portion of the related ground equipment are described in subsequent sections of this volume.

A listing is provided of major events and their time of occurrence during the *Pioneer VI* flight, from the preship review to the completion of the nominal mission phase when telemetry from the spacecraft could no longer be received by the 85-ft antennas. The test program and other activities are discussed in Section IV. In addition, the discussion of the preship review includes information pertaining to the test program conducted on the spacecraft and scientific instruments.

The performance during the mission of various elements of the *Pioneer* Project is discussed in Section V. Included is a description of the trajectory from launch and a discussion of the engineering performance of the spacecraft subsystems indicated by the telemetry data. The performance of the groups responsible for telemetry data retrieval and processing is also discussed.

A TDS performance evaluation of the mission is summarized in Section VI.

As a note of interest, *Pioneer VII*, the second spacecraft in the present series, was launched on August 17, 1966. The *Pioneer VII* trajectory lies between 1.0 and 1.1 astronomical units from the sun; after about 35 days from launch ($L+35$ days), the spacecraft was following the earth in its orbit about the sun. In contrast, the *Pioneer VI* trajectory lies between 0.8 and 1.0 astronomical unit from the sun; after approximately $L+65$ days, the spacecraft was leading the earth. In addition, because the difference in heliocentric celestial longitude between *Pioneers VI* and *VII* is continuously increasing, there is excellent azimuthal coverage of solar events. Any further mention of *Pioneer VII* is beyond the scope of the present report. Such information will be contained in a subsequent publication.

B. Objectives

Scientific observations of the characteristics of magnetic fields, plasma, and high-energy particles in interplanetary space beyond the influence of the earth can provide a better understanding of the mechanism related to the propagation through space of solar disturbances, terrestrial phenomena related to such disturbances, and the relationship between solar and galactic fields. These characteristics are influenced by solar phenomena, and vary both temporally and spatially. On a large time scale, it is believed that they are influenced by the magnitude of solar disturbances that vary periodically over an 11-yr cycle. Since such disturbances are generally localized on the sun's surface, and because the sun rotates, the spatial variation is surmised.

The objectives of the *Pioneer* Project are to conduct the aforementioned scientific observations and to determine the temporal and spatial variation of the interplanetary phenomena. To implement these objectives, the plan calls for five flights—*Pioneer VI* is the first—to be launched at intervals of 8–12 mo so as to cover the period from near minimum solar activity to maximum solar activity. Spatial effects will be determined by launching two spacecraft to move ahead of the earth with increasing time and three spacecraft to move behind the earth with increasing time. *Pioneer VI* is in the former category.

C. *Pioneer* Project Development

The Project began in the latter part of 1961 when a number of discussions between NASA Headquarters and Ames Research Center (ARC) personnel about the scientific value and technical feasibility of the missions culminated in the decision to have industry conduct a mission feasibility study. The study was concluded in April 1962 and became the basis of the technical information presented in a briefing to the NASA associate administrator in June 1962. The *Pioneer* Project effort was approved on November 9, 1962.

After a period of Project planning and specification preparation, industry was solicited for proposals pertaining to the spacecraft and related equipment on January 29, 1963. The period of proposal evaluation, precontract discussions with industry, and explorations by NASA of the type of contract to be awarded ended in the selection of TRW, Inc.—known at the time of selection as *Space Technology Laboratories, Inc., a subsidiary of Thompson Ramo Wooldridge, Inc.*—as the contractor for the spacecraft and mission-dependent ground operational equipment. The selection date was June 7, 1963. A letter contract was signed on August 4, 1963, and the contract was defined on July 30, 1964. The fixed-price-incentive contract was the first of that type awarded by NASA for the development of a spacecraft.

The scientific community was invited to submit proposals for instruments to be flown on *Pioneers VI* and *VII* on February 1, 1963. The six scientific experiments were selected on July 23, 1963.

The period of studies and project definition, in which the planning and performance of predesign activities were accomplished, culminated with the first coordination meeting on August 26 and 27, 1963. The meeting was attended by all experimenters and by personnel from Ames Research Center and TRW. Approximately 21 mo had elapsed since the Project began.

After the coordination meeting, the design of both the spacecraft and scientific instruments began. During this period, liaison and coordination with other groups that would provide launch and ground operation support was also initiated. The fabrication of spacecraft and instrument subsystems began during the second quarter of 1964, and the integration and test activities at TRW started during February 1965. The design and development phase for *Pioneer VI* ended with the preship review on September 29 and 30, 1965. This phase covered a period of 25 mo.

The number of organizations contributing to the success of *Pioneer VI* is several hundred or more when account is taken of the many subcontractors supplying components and subsystems. To list all such organizations is beyond the scope or intent of this report. However, a number of organizations have played particularly significant roles in the Project; these are by necessity cited frequently throughout the report. Such organizations, together with their responsibilities and relations to other groups within the Project, are described in Table 1.

Pioneer VI was the first deep space project to be managed by Ames Research Center. It was also the first non-JPL deep space project to be supported by the Deep Space Network, although some limited support had been given to *Pioneer V* (1960).

Table 1. Principal elements of *Pioneer* Project

Operation	Responsibility
Program	
Lunar and Planetary Programs Office within OSSA[a]	*Pioneer* Project direction at NASA Headquarters until shortly after *Pioneer VI* launch
Physics and Astronomy Program Office within OSSA	*Pioneer* Project direction at NASA Headquarters after transfer of responsibility from Lunar and Planetary Programs Office
Ames Research Center	Project management
Spacecraft, mission dependent ground operational equipment	
Ames Research Center	Spacecraft and GOE[b] system management; installation and checkout
TRW	Design, development, and fabrication of spacecraft and GOE; integration and testing of spacecraft and instruments at TRW and Cape Kennedy Air Force Station
W. V. Sterling, Inc.	Assessment of spacecraft reliability and monitoring of quality assurance activities at TRW
Scientific instruments	
Ames Research Center	Instrumentation systems management
Fermi Institute, University of Chicago	Design, fabrication, and testing of cosmic ray detector; reduction, analysis, and reporting of data from instrument
Goddard Space Flight Center	Design, fabrication, and testing of magnetometer; reduction, analysis, and reporting of data from instrument
Massachusetts Institute of Technology	Design, fabrication, and testing of plasma detector; reduction, analysis, and reporting of data from instrument
Graduate Research Center of the Southwest	Design, fabrication, and testing of cosmic ray detector; reduction, analysis, and reporting of data from instrument
Stanford University, Stanford Research Institute	Design, fabrication, and testing of radio propagation detector; reduction, analysis, and reporting of data from instrument
Ames Research Center	Plasma detector subsystem management; reduction, analysis, and reporting of data from instrument
Marshall Laboratories	Design, fabrication, and testing of Ames Research Center plasma detector
Launch vehicle	
Goddard Space Flight Center	Management of launch vehicle procurement
Douglas Aircraft Co.	Design and fabrication of *Thor* booster (first stage of *Delta* launch vehicle); integration and testing of *Delta* at Cape Kennedy Air Force Station
Douglas Aircraft Co.	Design and fabrication of second stage of *Delta*
Allegheny Ballistics Laboratory	Design and fabrication of third stage of *Delta*
Thiokol	Design and fabrication of first stage strap-on solid-propellant motors

[a] OSSA = Office of Space Sciences and Applications.

[b] GOE = ground operational equipment.

Table 1 (contd)

Operation	Responsibility
Launch activities	
Unmanned Launch Operations, Kennedy Space Center	Direction of launch operations
Air Force Eastern Test Range	Tracking and telemetry data acquisition during powered flight
Flight operations	
Ames Research Center	Planning, direction, and control of mission
Jet Propulsion Laboratory	Management of Deep Space Network
Deep Space Network	Tracking, telemetry data acquisition, and command transmission during free-flight trajectory
NASA Communications Network	Communications between the various stations conducting flight operations
Data processing and analysis	
Ames Research Center	Management of preliminary data-reduction activities; dissemination of telemetry data to users; analyses of spacecraft and instrument engineering measurements
Computer Sciences Corporation	Design, development, and operation of telemetry-data tape-processing station
Individual experimenters	Reduction, analysis, and reporting of scientific data by individual experiments
TRW	Support for analysis of spacecraft engineering measurements

D. Tracking and Data System

The TDS provides the tracking and communications link between the space vehicle and committed earth-based stations. For *Pioneer* missions, the TDS uses the facilities of: (1) the AFETR (for tracking and telemetry of the spacecraft and vehicle during the launch and near-earth phases), (2) the Deep Space Network (for precision tracking commands, telemetry, communications, data transmission, processing, and computing), and (3) the Manned Space Flight Network (MSFN) and the National Aeronautics and Space Administration Communications System (NASCOM), both of which are operated by Goddard Space Flight Center.

1. ***Near-earth phase.*** The AFETR extends from the eastern United States mainland through the south Atlantic area eastward into the Indian Ocean. It includes all stations, sites, ocean areas, and air space necessary to conduct missile and space vehicle test, development, and flight support. Administrative and management activities are largely concentrated at Patrick Air Force Base, and actual missile launches and flight tests are conducted at Cape Kennedy Air Force Station and over the downrange areas.

The AFETR uses major instrumentation systems to support those projects, programs, and organizations that use the AFETR launch facilities.

As a part of the TDS, the AFETR performs tracking and data acquisition functions for *Pioneer* missions during the countdown and launch phases of each flight. To meet the tracking and telemetry commitments for *Pioneer* missions, the AFETR has at its disposal: (1) land-based instrumentation sites, (2) range instrumentation ships, and (3) range telemetry aircraft.

The MSFN is under the direction of the Goddard Space Flight Center, Greenbelt, Md. The MSFN is part of a worldwide network designed for supporting the manned space flight effort.

From the MSFN facilities, launch, first tracking, and launch mark event activities are monitored. By use of the signaling, conferencing, and monitoring arranging (SCAMA), voice operations and control are linked to all MSFN tracking stations committed to support *Pioneer* missions.

2. ***Deep space phase.*** The Deep Space Network (DSN), established by the NASA Office of Tracking and Data Acquisition, is under the system management and technical direction of JPL. The DSN is responsible for two-way communications with unmanned spacecraft traveling from approximately 10,000 mi from earth to interplanetary distances. Present ground facilities permit simultaneous control of a newly launched spacecraft and a second one already in flight. In preparation for the increased number

of U.S. activities in space, a capability is being developed for simultaneous control of either two newly launched spacecraft plus two in flight, or four spacecraft in flight. Advanced communications techniques are being implemented to make possible the acquisition of data and the ground tracking of spacecraft on outer-planet missions.

The DSN is distinct from other NASA networks, such as the Space Tracking and Data Acquisition Network (STANDAN), which tracks earth-orbiting scientific and communication satellites, and the MSFN, which is used for tracking the manned *Gemini* and *Apollo* spacecraft. The DSN is composed of (1) the Deep Space Instrumentation Facility, (2) the Space Flight Operations Facility, and (3) the Ground Communications Facility.

The deep space tracking stations are situated in such a manner that three prime stations may be selected approximately 120 deg apart in longitude so that a spacecraft in or near the ecliptic plane is always within the field of view of at least one of the selected ground antennas. The Deep Space Stations and their respective locations are shown in Table 2.

The acquisition of a spacecraft signal by one of the Deep Space Stations may involve six different functions: (1) pointing the antenna at the spacecraft, (2) tuning and locking receivers to the spacecraft transmitted frequency, (3) tuning and locking the ground transmitter to the spacecraft receiver frequency, (4) establishing range lock, where applicable, (5) synchronizing the telemetry system, and in some cases, (6) providing for immediate command transmission to the spacecraft. Selected stations of the Deep Space Instrumentation Facility (DSIF) are equipped with special wide-field antennas mounted on the 85-ft antennas to assist in the acquisition process. These acquisition-aid antennas have beamwidths of approximately 16 deg and are accurately boresighted with the 85-ft antennas. They have angle-error outputs that are connected to a separate angle-channel receiver. By observing the angle errors generated simultaneously by both wide- and narrow-beamwidth antennas, a smooth change from tracking with the acquisition aid to tracking with the 85-ft antenna can be effected.

The Space Flight Operations Facility is located at JPL in Pasadena, Calif. Before launch, direction and status monitoring of the DSN, analysis of spacecraft and scientific instrument performance, and calculation of predictions for spacecraft acquisition by the DSN are performed there. Within minutes after a launch, mission control is transferred to this facility, where tasks associated with the mission and its control are performed. Several weeks after the *Pioneer VI* launch, mission control became the responsibility of Ames Research Center; at this time, the mission analysis teams were transferred to the Ames Research Center facility.

The DSN, managed by JPL, provided all tracking, data acquisition, and command capability for the free-flight phase of *Pioneer VI*. The Deep Space Stations (DSSs) within the network that have supported *Pioneer VI*, their designation, and their location are listed in the following tabulation:

Station designation	Location
DSS 11	*Pioneer* Station, Goldstone, Calif.
DSS 12	*Echo* Station, Goldstone, Calif.
DSS 14	Mars Station, Goldstone, Calif.
DSS 41	Woomera, Australia
DSS 42	Tidbinbilla, Australia
DSS 51	Johannesburg, South Africa
DSS 61	Robledo, Madrid, Spain

Deep Space Stations 12, 42, and 51 provided the principal support during the deep space phase of *Pioneer VI* since they were the only tracking stations with mission-dependent ground operational equipment. (Deep Space Station 71, also supplied with ground operational equipment, was used only for prelaunch checkout and did not track the spacecraft during the deep space phase.) A microwave system connecting DSS 12 with DSSs 11 and 14 provided the capability for using the ground operational equipment at DSS 12 in combination with the mission-independent equipment at DSSs 11 and 14.

With the exception of DSS 14, all the designated stations are equipped with 85-ft-diameter antennas. These antennas are parabolic reflectors of cassegrainian construction that operate without radomes and use polar mounts. To enhance the signal-sensing capability, a low-noise preamplifier is mounted in the cassegrainian cone assembly. The gain of the antenna is approximately 53 dB when receiving and 51 dB when transmitting. The beamwidth is 0.35 deg. Acquisition-aid antennas are also mounted on the reflectors at DSSs 41, 42, and 51. These

Table 2. Deep Space Station designations and locations

Location	DSS No.	Geodetic latitude	Geodetic longitude	Height above mean sea level, m	Geocentric latitude	Geocentric longitude	Geocentric radius, km
Goldstone, Calif. (*Pioneer*)	11	35.38950°N	243.15175°E	1037.5	35.20805°N	243.15080°E	6372.0341
Goldstone, Calif. (*Echo*)	12	35.29986°N	243.19539°E	989.5	35.11861°N	243.19445°E	6372.0176
Goldstone, Calif. (Venus)	13	35.24772°N	243.20599°E	1213.5	35.06662°N	243.20507°E	6372.2599
Goldstone, Calif. (Mars)	14	35.42528°N	243.12222°E	1160	35.24376°N	243.12127°E	6372.1341
Woomera, Australia	41	31.38314°S	136.88614°E	144.8	31.21236°S	136.88614°E	6372.5317
Canberra, Australia	42	35.40111°S	148.98027°E	654	35.21962°S	148.98027°E	6371.6686
Johannesburg, S. Africa	51	25.88921°S	27.68570°E	1398.1	25.73876°S	27.68558°E	6375.5415
Madrid, Spain (Robledo)	61	40.429°N	355.751°E	800	40.238°N	355.751°E	6370.0868
Cerebros, Spain	62	—	—	—	—	—	—
Cape Kennedy, Fla.	71	28.48713°N	279.42315°E	4.0	28.32648°N	279.42315°E	6373.2913
Ascension Island	72	7.95474°S	345.67242°E	526.7	7.89991°S	345.67362°E	6378.2386

waveguide horn antennas have a gain of approximately 21 dB when receiving and 20 dB when transmitting, and have a beamwidth of 16 deg. This broad width eases the problems associated with initial acquisition of the spacecraft following launch.

The Goldstone Mars Station (DSS 14) is equipped with a 210-ft-diameter parabolic antenna that uses an azimuth–elevation mount. The gain is approximately 62 dB when receiving and 60 dB when transmitting. The beamwidth is 0.1 deg. The antenna was dedicated on April 29, 1966 and was used on but few occasions during the nominal mission phase of *Pioneer VI.*

Transmitters at the Deep Space Stations operate with an output power between 0.2 and 10 kW. The maximum power is sufficient to transmit to the spacecraft whenever reception from the spacecraft is possible. The lower power can be used when the spacecraft is near the earth.

The Deep Space Stations are equipped with a parametric amplifier (paramp) and a helium-cooled traveling-wave maser system. At 2.295 GHz, the system noise temperature of the paramp is 270 ±50°K; that of the maser, between 35 and 50°K.

All station receivers employ a phase-lock loop and are tuned to the S-band frequency. These receivers lock to the carrier, detect the subcarrier signal, and supply the signal to the mission-dependent equipment for demodulation and further processing.

Each Deep Space Station is also equipped with two FR-1400 tape recorders and two SDS 910 or 920 computers for use by the flight projects. The tape units are used to record (1) telemetry data directly from the receivers and from the mission-dependent equipment, and (2) other information from instruments at the ground station. The ground instrumentation is used in the *Pioneer* system to perform such functions associated with telemetry and command as:

(1) Monitoring of spacecraft telemetry data and generation of alarms for out-of-tolerance performance.

(2) Selective editing of telemetry data and preparation for their teletype transmission to the mission operation areas.

(3) Verification of commands preceding actual radio transmittal to spacecraft.

E. *Pioneer VI* Spacecraft

The *Pioneer VI* spacecraft was launched from Cape Kennedy Air Force Station on December 16, 1965; it carried six scientific instruments to investigate the characteristics of magnetic fields, plasma, and cosmic rays in interplanetary space. All scientific instruments and spacecraft equipment have continued to operate normally since launch. There have been no malfunctions or anomalous performances that have affected the objectives of the mission. In addition, a mass of information presenting the measurements made by the scientific instruments and the performance of the spacecraft subsystems has been telemetered from the spacecraft and received on the ground since the launch. A number of organizations performing a variety of tasks have contributed to this success. This report describes a number of these tasks performed and discusses the performance of the spacecraft and the TDS.

The spacecraft was specially designed and fabricated to provide the means for exploring interplanetary particle and field phenomena at great distances from earth and to meet the constraints imposed by interfacing systems. The general requirements were to:

(1) Provide a stable platform on which to mount scientific instruments to measure interplanetary phenomena at distances up to 7.5×10^7 km from earth.

(2) Provide a capability for the instruments to scan 360 deg in the plane of the ecliptic.

(3) Provide a magnetically clean spacecraft with a field strength of less than 1 γ at the magnetometer.

(4) Operate in space for at least 6 mo.

(5) Weigh less than 150 lb (including scientific instruments).

(6) Provide a thermal environment favorable to the operation of on-board equipment.

(7) Provide a data system to sample readings from the instrumentation and transmit the information to earth.

(8) Provide a command system to permit changes in operating modes of on-board equipment by ground command.

The weight limitation and the requirements for flight in interplanetary space were compatible with the performance of the *Delta* launch vehicle. The spacecraft size and overall profile were also compatible with the fairing of the launch vehicle. Lastly, the structure met the strength and rigidity requirements to withstand the vibration and acceleration loads of the launch vehicle.

The telemetry and command communication subsystems are compatible with the requirements of the DSN and the need for communication at large distances. The communication subsystem operates at S-band frequencies. When the subsystem operates in a *coherent* mode, the spacecraft transmits a signal whose frequency is a fixed ratio of that received by the spacecraft; as a result, accurate doppler measurements could be made so that the spacecraft velocity relative to earth—and, hence, the trajectory—could be determined. The telemetry communication subsystem also operates at a frequency governed by an on-board oscillator to provide for occasions when the ground stations are not transmitting to the spacecraft or when doppler measurements are not required.

The spacecraft is spin-stabilized. Thus, the stability requirements can be met within the overall weight and lifetime constraints, since the necessity for attitude correction is minimized and the on-board orientation subsystem is small, lightweight, and reliable. Alignment of the spin axis perpendicular to the plane of the ecliptic for the major portion of the mission provided the required scan capabilities.

The spacecraft is cylindrical and has three radial booms, an antenna mast on the cylinder axis at the forward end of the spacecraft, and an antenna system at the aft end of the spacecraft for use in one of the scientific experiments (Stanford). Except for a small viewing band provided for the scientific instruments, the curved surface of the cylinder is covered with solar cells to supply the on-board power. Within the cylinder is a single platform on which all of the electronic equipment for the spacecraft and scientific instruments is located. Thermal louvers aft of the equipment platform cover a portion of the platform area and control the amount of heat radiated from that surface. These various components are shown in Fig. 1.

The three booms were capable of being folded against the antenna mast, and the Stanford antenna could be withdrawn against the cylinder, as illustrated in the sketch of Fig. 2. This arrangement allowed the spacecraft to fit within the launch vehicle fairing. After separation from the third stage, the booms and Stanford antenna were automatically deployed. The three booms augment the spacecraft moment of inertia about the spin axis to achieve the gyroscopic stabilization required for the mission.

One boom has a nozzle that, as part of the nitrogen gas jet system, provides the torque for attitude control of the spacecraft. The second boom, included for stability, is equipped with a wobble-damping mechanism. A

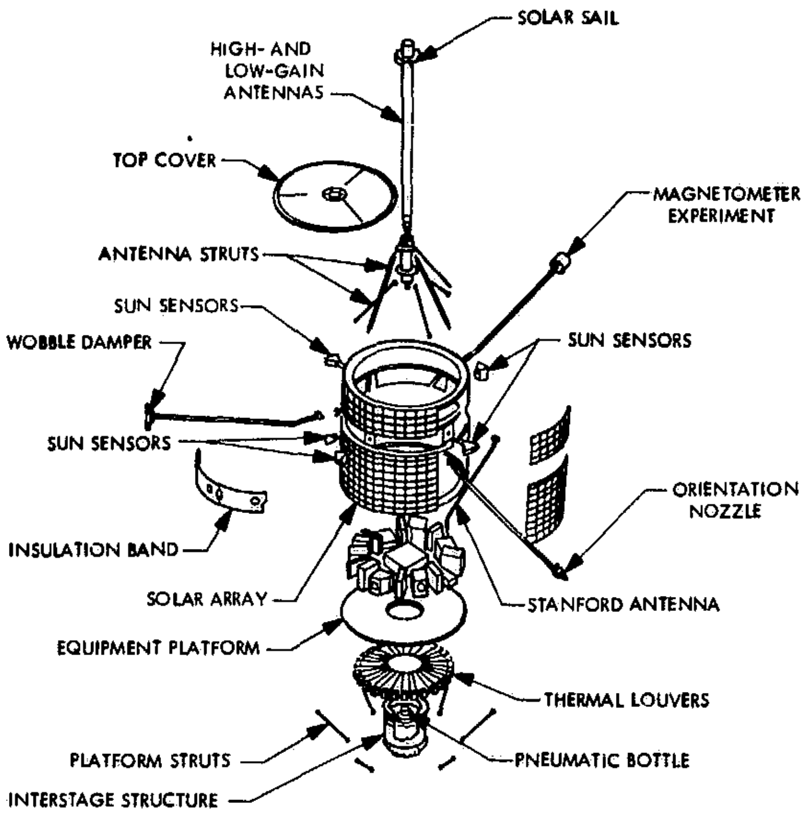


Fig. 1. Exploded view of the *Pioneer VI* spacecraft

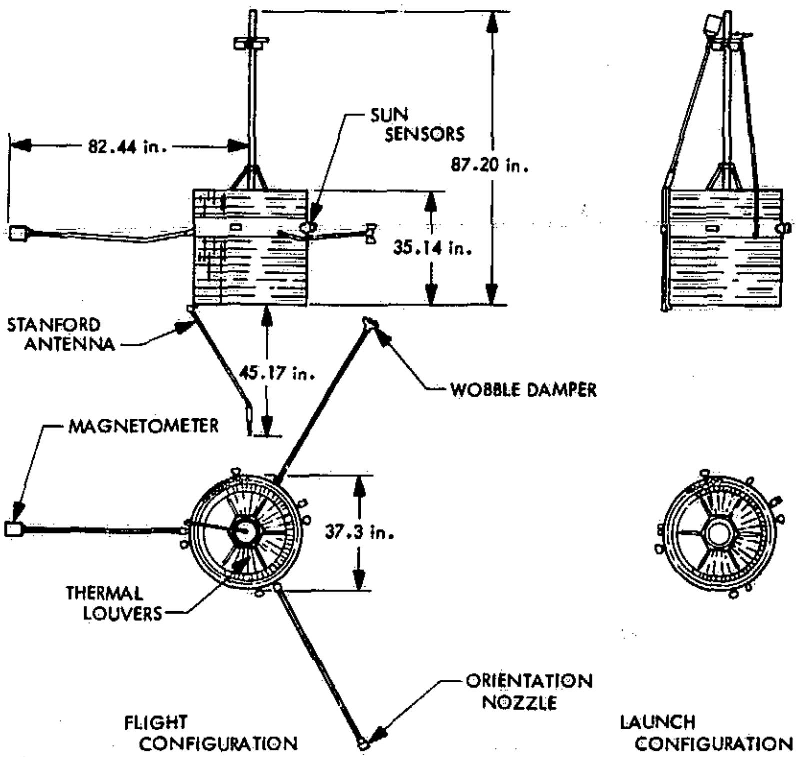


Fig. 2. *Pioneer VI* spacecraft flight and launch configurations

magnetometer, used for one of the scientific experiments, is incorporated onto the third boom. The magnetometer is deployed at the far end of its boom to provide as much isolation as possible from the on-board instrumentation (and its inherent radiation).

To provide the required communication capabilities within the constraints imposed by the electrical power subsystem, the antenna mast is a high-gain antenna having a disk-like pattern that is axially symmetric with respect to and perpendicular to the spin axis. Since the spin axis is perpendicular to the ecliptic plane, and since the earth and spacecraft are in the ecliptic plane, such a pattern assures that the earth is within the radiation plane of the spacecraft.

The magnetic-cleanness requirement is eased somewhat by placing the magnetometer sensor at the end of the boom rather than on the equipment platform. Nevertheless, careful selection of materials and components throughout the spacecraft, and use of magnetic-compensation design techniques, were necessary to fully achieve this requirement.

In the more detailed description to follow, the spacecraft is divided into these seven subsystems:

(1) Structure.

(2) Thermal control.

(3) Electric power.

(4) Orientation.

(5) Communication.

(6) Command.

(7) Data handling.

F. Launch Vehicle

The launch vehicle for *Pioneer VI* was the thrust-augmented improved *Delta* (DSV-3E). The prime contractor for the vehicle was the Douglas Aircraft Company. The vehicle had basically three stages, but it also had three solid-propellant motors that were included to augment the first-stage thrust. These components and their principal dimensions are shown in Fig. 3. The *Pioneer VI* launch was the first in which a *Delta* vehicle (*Delta 35*) placed a payload in an escape-from-earth trajectory.

The first stage of the vehicle was a modified *Thor* powered by a Rocketdyne MB-3 (Block III) engine and augmented by three Thiokol solid-propellant rockets. The liftoff weight was approximately 150,000 lb; the liftoff thrust was 325,000 lbf, of which 175,600 lbf was supplied by the *Thor*. The fuel was RP-1 kerosene, and liquid oxygen was the oxidizer for the *Thor* stage. The

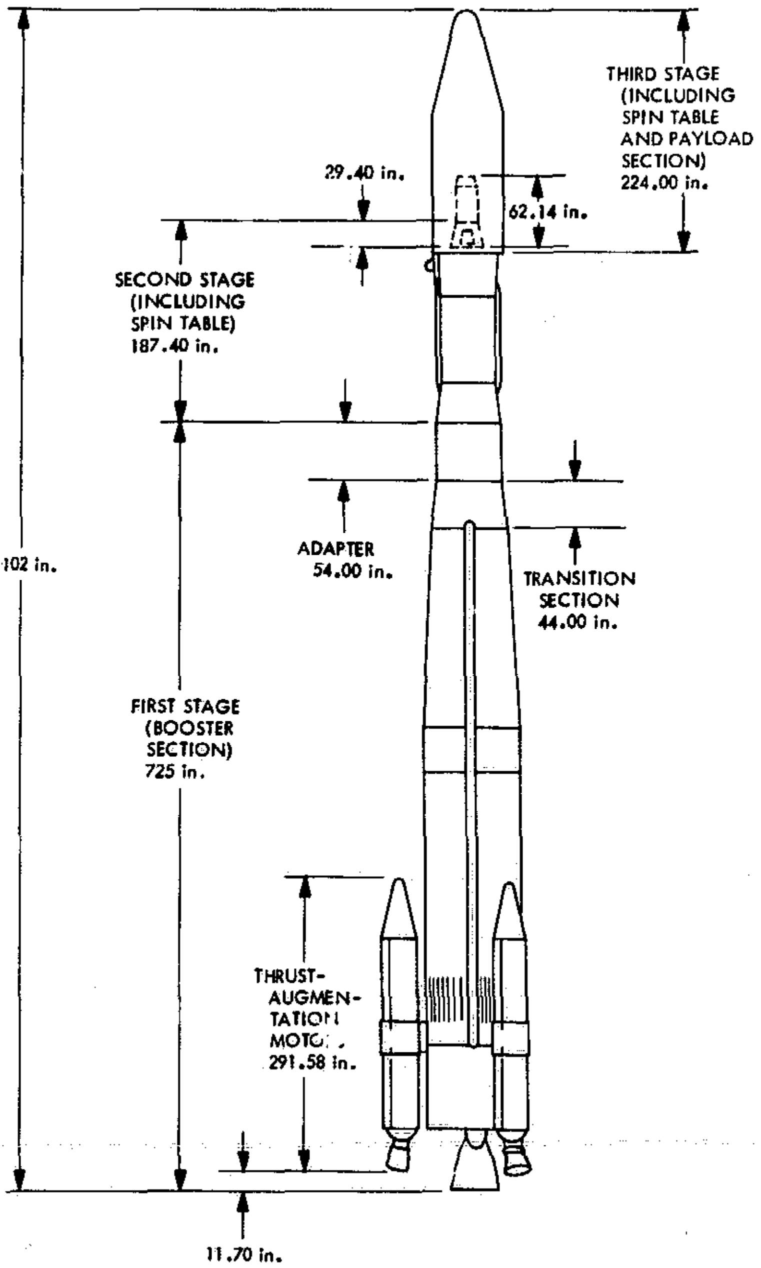


Fig. 3. Thrust-augmented improved *Delta* (DSV-3E) launch vehicle

main engine burned for 148 s. The three Thiokol solid-propellant rockets were started at the time of main engine start and burned for 40 s. About 70 s after burnout, the solid-rocket cases were ejected. During first-stage burn, the pitch and yaw control was effected by gimbaling the main engine in response to signals from an inertial reference package, which also maintained roll control by positioning the gimbaled vernier engines. A radio guidance system in the second stage also provided corrective steering signals for the first stage.

Second-stage thrust was supplied by a pressure-fed Aerojet General Corporation AJ10-118E liquid-propellant propulsion system. The approximate weight at ignition was 14,000 lb; the thrust was about 7400 lbf. The fuel was unsymmetrical dimethylhydrazine and the oxidizer was inhibited red fuming nitric acid. The motor burned for about 6½ min. During the power portion of the second-stage flight, the main engine was gimbaled to control pitch and yaw. Roll was controlled by four on–off cold gas jets, two of which reacted in a clockwise direction and two of which reacted in a counterclockwise direction. Both pitch and yaw control systems responded to commands from the second-stage programmer as well as from the radio guidance system and inertial reference package. A velocity cutoff system was also incorporated in the second-stage guidance compartment.

The launch vehicle could delay third-stage ignition until 1800 s after second-stage cutoff. For *Pioneer VI*, this delay time was 966 s. During this coasting phase, an on–off nitrogen gas jet used four solenoid-operated jets radially mounted on the aft end of the second stage for pitch and yaw control plus the four gas jets used during second-stage powered flight for roll control. The nitrogen gas was that previously used to pressurize the fuel tanks.

The third-stage propulsion for *Pioneer VI* was the ABL X-258 rocket engine. The weight at ignition was about 735 lb, including the spacecraft, and the thrust was about 6200 lbf. Attitude control for the third stage was maintained by spin-stabilizing the third stage (and spacecraft) before separation from the second stage. The third stage was quite large in relation to the spacecraft itself. The *Pioneer* spacecraft was mounted on an X-258 motor. The aerodynamic fairing for the third stage–spacecraft combination was the standard fairing of the improved *Delta*.

The information necessary to assess the performance of the launch vehicle was telemetered from the first and second stages. The telemetry frequency for both the first stage and the second stage was approximately 230 MHz. Modulation was PDM/FM/FM (a complex signal form using pulse-duration modulation of a frequency-modulated signal on a frequency-modulated carrier). The second stage was also provided with a C-band radar transponder system that was capable of transmitting a signal at a peak power of 500 W.

G. Scientific Experiments

The six scientific instruments that made up the scientific payload for *Pioneer VI* were: two cosmic ray detectors, two plasma detectors, a magnetometer, and a radio propagation instrument. One additional experiment required no special instruments on the spacecraft. The payload weighed 34.1 lb, approximately 25% of the total

Pioneer VI weight. The power consumption for the instruments (with one plasma detector operating in its low-power mode) was 9 W. This level doubled when the plasma detector operated in the high-power mode, bringing the overall power consumption of the instruments to 35% of the total spacecraft requirement.

The payload covered approximately 280 in.^{2} of platform. Approximately 72% of the telemetry data was allocated directly to the scientific payload for telemetering in the scientific data transmission mode. Except on rare occasions, this mode was used throughout the mission. Approximately 33% of the command capability was allocated directly to the payload for controlling the operating conditions of the instruments.

Power to the scientific instruments was supplied directly from the spacecraft primary bus; each instrument, therefore, was provided with its own converter. Power to all instruments was shut down by a single ground command, but each instrument was capable of being activated by individual commands.

The scientific instruments met the weight and structural integrity constraints imposed by the launch vehicle performance, acceleration, and vibration parameters. They also met stringent requirements for magnetic "cleanness." As with the spacecraft, materials and components were selected carefully and the use of magnetic minimization, or compensation, design techniques was necessary. The requirement for long lifetime was also met by careful selection of parts and by thorough parts screening.

Brief descriptions of the experiments and their related instruments are given in the following paragraphs to indicate the type of scientific information being gathered by *Pioneer VI*. As stated previously, the reporting of the scientific results is the responsibility of the individual experimenters and is beyond the scope of this report except where mentioned for the sake of clarity.

1. Cosmic ray detector (University of Chicago). This instrument measures the intensity and energy spectrum of protons and alpha particles. In addition, it measures electron energy over a limited range, as well as particle anisotropy. The measurement of proton and alpha particle energy spectrum is divided into the following energy windows: 0.6–13, 13–70, 70–190, and >190 MeV per nucleon. Detection of electron energy spectra is limited to the energy windows of 0.16–1 and 1–20 MeV.

The instrument has three solid-state lithium drifted detectors, a plastic scintillator cylinder designed to exclude particles not confined to the telescope cone angle of 60 deg, a photomultiplier tube, and associated electronics. Aside from the input discriminator logic typical of this type of instrument, the electronics basically consists of the necessary readout logic to interface with the spacecraft data handling subsystem, four counter registers that provide the nondestructive readout of four separate counting rates, one 128-channel pulse-height analyzer, one 32-channel pulse-height analyzer, and a solar aspect counter. The solar aspect counter uses spacecraft timing signals to generate timing signals within the instrument for indicating the direction of the instrument axis relative to the sun. This facilitates determination of the direction of the incoming particles.

The timing cycle began when the first signal occurred, when sun sensor E was illuminated by the sun; the instrument axis pointed 115 deg of spacecraft rotation ahead of the sun. The first internally generated signal occurred ¹⁄₁₆–⅛ s later. Succeeding signals were ⅛ s apart until the spacecraft completed the revolution and the cycle would start again. The interval between the last signal and the start of the next cycle was generally less than ⅛ s because of the tolerance in the time of the first signal and because the spacecraft spin rate was not a precise multiple of ⅛ s.

The instrument was capable of operating in one of two modes: normal and calibrate (selected by ground command). In the calibrate mode, the coincidence/anticoincidence logic circuitry was disabled to permit the individual counting rates of the three solid-state detectors to be read directly.

2. Cosmic ray detector (Graduate Research Center of the Southwest). This instrument measures the anisotropy of low-energy primary and solar cosmic radiation and measures its variation with energy, time, and nuclear species. The cosmic ray counting rates from four orthogonal directions in the plane of the ecliptic are recorded for energy windows of 7.5–45, 45–90, and 150–350 MeV per nucleon. The latter window records alpha particles or heavy nuclei alone. The lowest energy window, 7.5–45 MeV per nucleon, while intended to record protons or heavier nuclei, will also detect electrons in the energy range of 7.5–13 MeV. There is also an omnidirectional counting rate which records all particles of energy sized >7.5 MeV per nucleon.

The instrument consists of a scintillator crystal, an anticoincidence scintillator, two photomultiplier tubes, and associated electronics. The acceptance cone for the detector is 107 deg. Energy window discrimination is achieved by means of a four-channel pulse-height analyzer.

A time division circuit, the aspect clock, generates four time gates of precisely equal length. The first period starts when the detector axis points 139 deg west of the sun. Succeeding periods begin at precisely 90, 180, and 270 deg of spacecraft rotation. The three primary modes of operation—*dynamic range off*, *dynamic range on*, and *calibrate*—are selectable by ground command. In the *dynamic range off* operating mode, the length of each time period is equivalent to nearly 25% of a spacecraft revolution. In the *dynamic range on* mode, the length of each period is equivalent to approximately 1/32 of a spacecraft revolution. These time gates route the pulses from any one channel of the pulse-height analyzer into one of four binary accumulators corresponding to each of the four time gates. Hence, concurrent measurements of cosmic ray fluxes are obtained from each of the three energy bands enumerated above.

The *dynamic range off* mode is used during periods of relatively quiet solar activity, and *dynamic range on* is used during periods of extensive solar activity. The *calibrate* mode provides an in-flight check of the pulse-height analyzer threshold.

3. Plasma detector (Massachusetts Institute of Technology). The plasma detector measures the energy spectrum, flux, and angular distribution of positive ions and electrons of the interplanetary plasma. The energy per unit charge of the positive ions is determined in 14 intervals extending from 0.1 to 9.5 keV. The energy of the electrons is determined in four energy bands extending from 0.1 to 1.6 keV. The flux sensitivity range is from 2×10^5 to 2×10^9 particles/cm^2/s.

The instrument consists of a detector that utilizes a Faraday cup with an energy-determining grid, a split collector, and associated electronics. A voltage applied to the grid alternates at approximately 1800 Hz between two voltage levels, thus producing a pulsating current at the collector. The result is a passing and then repelling of incoming particles whose energy-to-charge ratio is within the applied voltage band. The electronics system is coupled to the collector and responds only to the pulsating component of the current. The current from half of the split collector and the total collector current are measured; the ratio of these currents gives an approximate indication of the direction of flow in the plane of the spin axis. Measurements to be telemetered are stored as 6-bit words in a 256-word memory. The viewing angle is ±20 deg in the plane perpendicular to the spacecraft spin axis and ±60 deg in the plane parallel to the spin axis.

The data recording sequence consists of 16 revolutions of the spacecraft in which no data are recorded, alternating with 16 revolutions in which the 14 ion-energy-per-unit-charge bands, a single electron-energy band, and a calibrate scan are covered. No data from the instrument are telemetered during this time. Thereafter, the data are telemetered until the memory is empty, at which time the recording sequence again commences, covering a different electron energy band. The angular distribution information is obtained by measuring the total particle flux in 28 consecutive intervals, each corresponding to 11¼ deg of spacecraft rotation. The first interval begins when the instrument axis is pointing 45 deg east of the sun and the last interval ends when the instrument axis has rotated westward 270 deg beyond the sun. Data are recorded in each of the first eight intervals (covering ±45 deg from the sun). In the remaining 20 intervals, only the maximum reading in each consecutive group of 4 intervals is recorded. In addition, the peak value of the flux striking half the collector in each revolution of the spacecraft, together with the interval number in which it occurred, is also recorded.

The instrument can be placed in one of two operating modes by ground command. In the primary mode, the instrument cycles through all the voltage intervals available. In the other mode, the four highest voltage intervals are excluded.

4. Plasma detector (Ames Research Center). The instrument measures the energy spectrum, flux, and angular distribution of positive ions and electrons of the interplanetary plasma. The energy per unit charge of the positive ions is determined in 16 logarithmically spaced bands extending from 0.2 to 10 keV. The energy of the electrons is determined in eight logarithmically spaced bands extending from 2 to 500 eV. The flux sensitivity range is from 1×10^5 to 1×10^9 particles/cm^2/s. The instantaneous viewing angle is approximately 15 deg in the plane perpendicular to the spacecraft spin axis (equatorial plane) and ±80 deg in the plane parallel to the spin axis. The latter is divided into eight channels, which are symmetrical about the equatorial plane and have widths, commencing at the equatorial plane, of 15, 15, 20, and 30 deg.

The instrument has a quadrispherical electrostatic analyzer, eight separate and contiguous current collectors (to provide the eight sectors), and associated electronics. The current or flux measurement is expressed as a 7-bit word, and is stored in a core memory together with other information identifying energy levels, positive or negative particles, collector, and equatorial interval. The instrument can record and transmit data simultaneously.

The angular distribution about the spin axis is obtained by measuring the total particle flux in 15 consecutive intervals; the first 4 and last 3 correspond to 45 deg of spacecraft rotation and the remaining 8 correspond to 5⅝ deg of spacecraft rotation. The first interval begins at 202½ deg of spacecraft rotation before the instrument axis points toward the sun; thus, the eight small intervals are symmetric with respect to the time of instrument axis and sun alignment.

The instrument is capable of four different data-recording sequences. When the spacecraft is transmitting at 512 bits/s, the particle flux or current at a given energy-per-unit-charge interval and for a single collector, together with associated identification information, is recorded for each of the 15 intervals during one revolution and for the interval and collector having the maximum flux during the second revolution. Twenty-four such pairs make up the full energy cycle; the full instrument cycle comprises eight such cycles (one for each collector). When the spacecraft is transmitting at 256 bits/s, the volume of data is compressed by recording only those data taken during the eight short intervals corresponding to 45 deg of spacecraft rotation symmetric with the sun direction (first short-scan mode). Or, alternately, the record can consist of that taken during the first seven of the eight short intervals (second short-scan mode). The mode can be selected by ground command. When the spacecraft is transmitting at 64 bits/s and lower, the volume of data is further compressed by acquiring data during a single interval and for the one collector that observed the maximum flux during a single rotation of the spacecraft. In this mode, the ion and electron data are separately acquired and stored before being telemetered. In addition to the above, a ground selectable calibrate mode is possible wherein a known voltage offset is provided that results in a simulated flux reading of approximately 64 counts (half-scale). This reading will continue to appear in the flux word position while the instrument remains in calibrate. The calibrate mode is terminated automatically when a transfer from the ion-energy-per-unit-charge level to the electron-energy level occurs. The mode may also be terminated by ground command.

*5. **Magnetometer (Goddard Space Flight Center).*** The magnetometer measures sequentially the magnitude of the three orthogonal components of the interplanetary magnetic field. The magnetometer has a range of ±64 γ.

The instrument has a single flux gate sensor and associated electronics. The sensor was mounted on the end of one of the three spacecraft booms where the residual magnetic field of *Pioneer VI* was less than 0.5 γ. It was aligned perpendicular to the boom axis and at an angle of 54 deg, 45 min to the plane containing the boom and spin axis. Thus, at any three positions separated by 120 deg of spacecraft rotation, the sensor direction at one position is orthogonal to that at the other two positions. The sensor consists of a saturable magnetic core that is excited at 13 kHz from positive to negative saturation by a solenoid drive coil. The magnitude of the 26-kHz second harmonic (measured by a tuned amplifier connected to a secondary coil winding) is proportional to the component of the external magnetic field along the sensor axis and the permanent magnetization of the core itself. A mechanical "flip" mechanism, which rotates the sensor through 180 deg, permits detection and, thus, elimination of the latter effect. The flip mechanism contains 22 small squibs grouped in pairs for redundancy. Each individually fired squib of a pair releases a spring with an escapement mechanism to reverse the direction of the sensor by precisely 180 deg.

The instrument is capable of four different data recording sequences. When the spacecraft is transmitting at 64 bits/s and higher, three orthogonal measurements are taken in a single rotation; each measurement is stored as an 8-bit word, and the measurements are telemetered in a group of 24 bits. The cycle repeats continuously. When the spacecraft is transmitting at 16 bits/s, measurements for each of the three positions are made and stored during each of four consecutive spacecraft rotations, and the average value at each position is telemetered. The cycle repeats continuously. At 8 bits/s, measurements are averaged for eight revolutions of the spacecraft. When the spacecraft is operating in *duty cycle store* mode, the number of measurements averaged is:

Time to fill, h	Number of measurements
2.4	64
4.8	128
9.5	256
19.0	256

The instrument can be commanded into a *calibrate* mode from the ground. In this mode, a bias voltage is furnished to the sensor corresponding to a 10-γ magnetic field offset. The instrument remains in the *calibrate* mode for a specific number of seconds (3584 divided by the spacecraft bit rate) and then returns automatically to the appropriate data recording mode.

6. Radio propagation (Stanford University). The propagation experiment involves the transmission of two modulated coherent carriers of 49.8 and 423.3 MHz from the ground and the reception of these signals by receivers aboard the spacecraft. The receivers are designed to measure the relative phase of the modulation envelopes of the two carrier frequencies. Since the higher frequency is relatively unaffected by the presence of ionization, the phase relationship provides a value for the integrated electron density. In addition, the rate of change of phase of one carrier with respect to the other is measured, thus accurately determining the time variation of the integrated electron density. Signal strength is also measured.

The instrumentation for this experiment consists of two ground-based transmitters operating into a 150-ft-diameter parabolic antenna located on the Stanford campus; a dual-channel, phase-locked-loop receiver aboard the spacecraft; the spacecraft telemetry; and the Deep Space Network. All of the elements of the system just described must operate simultaneously to provide a closed-loop operation.

From the ground, this instrument can be placed in a *calibrate* mode. The purpose of this mode is to obtain a calibration point on the modulation phase detector. This is effected by the command, which straps the inputs of the two receiver IF strips together and connects them to the output of the high-frequency RF mixer. The difference frequency count will then be zero. The relative phase of the modulation frequency between the two channels will also be read. The *calibrate* mode is terminated automatically.

7. Astronomical constants. The object of this experiment is to use the available metric data from all of the *Pioneer* missions to obtain primary determinations of the masses of the earth and moon, and to determine accurately the astronomical-unit distance and the interrelated elements of the orbit of the earth. *Pioneer* data are appropriate for this experiment because of the absence of midcourse orbit corrections and near-planetary encounters. In addition, solar-radiation-pressure effects are small for the *Pioneer* configuration.

The experiment does not require any additional on-board equipment, but makes use of the existing on-board receiver and transmitter equipment in conjunction with DSS equipment to obtain two-way doppler measurements.

II. *Pioneer VI* Tracking and Data System Requirements

A. Near-Earth Phase Support

The Tracking and Data System (TDS) near-earth phase support for *Pioneer VI* consisted of the committed facilities of the Air Force Eastern Test Range (AFETR), Goddard Space Flight Center (GSFC), and portions of the Deep Space Network (DSN).

The tracking and data acquisition coverage requirements placed upon the AFETR and GSFC are described in the following paragraphs. The requirement categories are: (1) *Pioneer VI* mission requirements, (2) launch vehicle requirements, and (3) range safety requirements.

As a result of the importance of the AFETR acquisition support to the DSN, the tracking requirement imposed on the AFETR involved in this support has been classified as Class I, defined as follows: *Class I requirements reflect the minimum essential needs to ensure accomplishment of primary test objectives; these are mandatory requirements which, if not met, may result in a decision not to launch.*

During the launch phase of any space mission—i.e., that period extending from launch to the initial Deep Space Station (DSS) acquisition—several events occur that have a major influence on the success of the mission. For example, all of the powered flight and separation events occur that lead to the injection of the spacecraft into its deep space trajectory and the subsequent final separation of the spacecraft from the third stage of the launch vehicle. The information gathered from tracking and telemetry during this period is used to continually evaluate the status of the flight.

As explained, the acquisition support by the AFETR was important for the successful initial acquisition by the first-viewing, committed Deep Space Station. This AFETR acquisition support was primarily directed toward evaluating the performance of the launch vehicle, including the third-stage burn (initial DSN acquisition occurs subsequent to third-stage burn). In addition to being vital to the acquisition effort, near-real-time evaluation of launch vehicle performance was of concern to spacecraft monitor personnel. For example, should the launch vehicle performance have been nonstandard during any portion of powered flight, and if an indication of the degree of abnormality of the flight could be obtained soon enough, there would have existed an opportunity to change the command sequence of the spacecraft events so as to maximize the likelihood of meeting the flight test objectives.

There are two general methods of evaluating the launch vehicle performance in near-real time. One method involves comparing the actual mark times of the significant launch vehicle events from telemetry with the predetermined norms (Table 3) and analyzing the differences. This method includes the general evaluation of all available telemetry. The other method requires tracking data to calculate the resultant trajectory subsequent to the first- and second-stage burns (*Thor/Delta*). A comparison of the actual trajectory with the anticipated norm gives an evaluation of the launch vehicle performance. By employing both of these methods, one can be used to determine the validity of the conclusions derived from the other.

The actual launch vehicle mark times for the *Pioneer* launches were determined by AFETR from telemetry data received at individual sites and reported by the supervisor of range operations over the AFETR communications network. In the launch vehicle telemetry laboratory, the telemetry data were analyzed and the mark times validated. The mission analyst also provided current reports to JPL regarding the launch vehicle performance based on all information available to him in real time, including mark times.

Table 3. Mark events for *Pioneer VI* mission

Mark	Event	Time from liftoff, s
0	Liftoff	*L*+0
1	Thrust-augmentation rocket jettison	*L*+70.0
2	Main engine cutoff	*L*+149.2
3	Sustainer engine ignition	*L*+153.2
4	Shroud jettison	*L*+179.2
5	Sustainer engine cutoff	*L*+551.1
6	Third-stage spinup	*L*+1486.2
7	Second-/third-stage separation	*L*+1488.2
8	Third-stage ignition	*L*+1501.2
9	Third-stage burnout; injection	*L*+1523.7
10	Third-stage/spacecraft separation	*L*+1582.2
11	Spacecraft boom deployment complete	*L*+1583.5
	Spacecraft traveling-wave tube amplifier on	*L*+1583.5
	Step I orientation initiated	*L*+1583.5

The accuracy to which the vehicle stages injected the combination third stage/spacecraft into the parking orbit was evaluated by tracking the *Delta* C-band beacon from Grand Turk and Antigua AFETR. Trajectory calculations by AFETR performed at the Real Time Computing Facility (RTCF) based on this tracking data were made to establish the degree of normality of the parking orbit. This evaluation was done by the flight-path analysis group at the Space Flight Operations Facility (SFOF) after receiving the parking orbit elements and injection conditions from the RTCF. Determining the performance of the third stage by AFETR in near-real-time was more difficult since this stage was not equipped with a radar tracking beacon. Two methods were conceived, however, which provided some indication of third-stage ignition and burn duration. One method involved examination of the doppler data in the RF signal on the carrier of the spacecraft S-band telemetry. The other method was dependent upon receiving a signal from a 136-MHz beacon installed on the third stage and retransmitting this signal to the telemetry laboratory for display and analysis of the doppler frequencies.

1. ***AFETR acquisition support.*** The first major event accomplished by the DSN during the flight was initial acquisition of the spacecraft by a Deep Space Station. To accomplish this, the acquiring station had to know the approximate spacecraft trajectory in terms of station predicts before the spacecraft came into view. Predicts, which included declination, hour angle, and doppler detector output frequencies correlated with time, were furnished to all Deep Space Stations before the launch. These predicts were based on *anticipated* launch vehicle performance; predicts based upon *actual* launch vehicle performance could have proved very useful during the initial acquisition by the DSIF, particularly if the performance had been substantially different from the stated norm. Because of the time required to receive the tracking data by AFETR, calculate the predicts, and transmit them to the SFOF for retransmission to the Deep Space Stations, the most timely predicts were those based on tracking data taken after injection into the parking orbit and a normal third-stage burn. Only the AFETR could supply these real-time predicts (by calculating the trajectory using radar tracking data). Since the trajectory of the mission was normal, DSSs 51 and 42 had no trouble acquiring; however, had the spacecraft been injected into a nonstandard trajectory, real-time AFETR predicts would have been critical for both stations.

2. AFETR Class I tracking. The stated minimum requirement for tracking coverage was from sustainer engine cutoff (SECO) to SECO+60 s. Since SECO was the injection point into the parking orbit, this tracking coverage constituted 60 s of the parking orbit.

3. AFETR station support. As a result of the combination of the trajectory characteristics and AFETR station locations, only Grand Turk and Antigua radars could view the launch vehicle–spacecraft after its injection into the parking orbit. Thus, to be able to provide 60 s of tracking into the parking orbit, at least one of these stations had to be operational. Since the view angle of the parking orbit was very close to the Grand Turk station's horizon (2 min maximum viewing time), the quality of any received tracking data could have been poor. It was therefore deemed preferable to gather data from Antigua, whose view afforded about 4 min of tracking.

4. Data processing support. It was mandatory that the CDC 3600 computers at the RTCF be operational to enable the AFETR to prepare Deep Space Station predicts. These computers processed the raw tracking data, and computed the parking orbit elements, the solar orbit elements (based on a normal third-stage burn), and the predicts.

The purpose of the CDC 3100 computer for JPL support was the conversion of octal raw tracking data into a decimal format before data transmittal to JPL. This enabled flight path analysis personnel at JPL to visually evaluate the data in real-time. Since this was a recent improvement in the AFETR–JPL interface, JPL still had the capability to receive and process octal data; consequently, it was not considered mandatory that the CDC 3100 computer be available to support the launch.

5. Communications.

a. Communications between Grand Turk or Antigua and RTCF. A high-speed data link was required between Grand Turk and the RTCF and between Antigua and the RTCF for the transmission of the raw radar data. Although the communications subcable was used, other links, providing the same capability, were considered necessary to cover the eventuality of a breakdown in subcable communications.

b. Communications between RTCF and AFETR Building AO. At least one voice line was mandatory for coordinating the JPL/RTCF interface. Also, one teletype line was available between the RTCF and Building AO for the transmission of the spacecraft frequency parameters to the RTCF and the DSIF predicts to Building AO.

c. Communications between Building AO and the SFOF. Coordination between JPL personnel at the AFETR and at the Pasadena facility required a minimum of one cross-country voice line. One teletype line was to be available for the cross-country transmission of the spacecraft frequency parameters from the SFOF to Building AO and the AFETR-generated DSIF predicts from Building AO to the SFOF.

d. Communications between DSS 71 and Building AO. One teletype line was required for communications between DSS 71 (the spacecraft monitoring station at the AFETR) and Building AO.

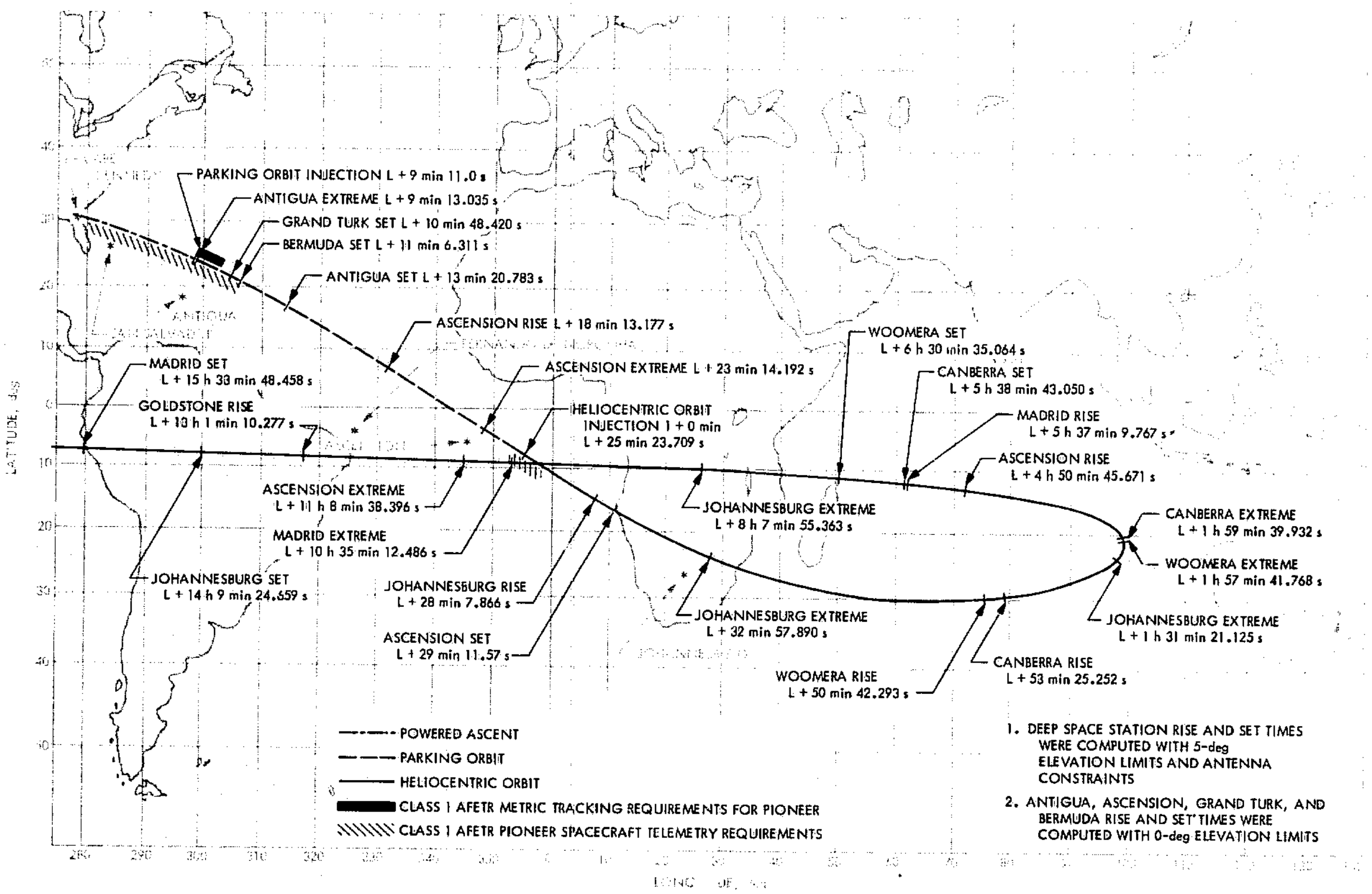
e. Communications between Building AE and SFOF. Since the mission director was located in Building AE, voice contact had been maintained between the mission director at Cape Kennedy and the DSN system manager in Pasadena. In case of a nonstandard communication situation, this requirement could be met with a conventional telephone line between Building AE and the SFOF.

6. Near-earth phase trajectory characteristics. Real-time flight analysis of the near-earth phase of the flight, as well as during the prelaunch countdown, was facilitated by the ready access to data pertaining to the launch window and trajectory.

To present a clear composite picture of the near-earth phase of the station coverages in relation to flight events and coverage requirements, an earth track of the trajectory up to about the first 15 h from launch is plotted in Fig. 4. An elevation constraint of 0.0 deg was established for the AFETR stations and 5 deg for the Deep Space Stations.

7. S-band telemetry. The data to be recovered during the launch phase were formatted into a 64-bit/s pulse-code-modulated signal biphase-modulating a 2048-Hz subcarrier. This subcarrier channel phase-modulated the S-band carrier with a peak deviation of 0.9 rad. The transmitter output power was 40 mW. Support requirements were based upon transmitting-antenna gains of 0–21 dB.

a. Class I requirements. The Class I S-band telemetry requirements included the receiving and recording of the spacecraft data from shroud jettison to SECO+120 s, and



1. DEEP SPACE STATION RISE AND SET TIMES WERE COMPUTED WITH 5-deg ELEVATION LIMITS AND ANTENNA CONSTRAINTS
2. ANTIGUA, ASCENSION, GRAND TURK, AND BERMUDA RISE AND SET TIMES WERE COMPUTED WITH 0-deg ELEVATION LIMITS

Fig. 4. *Pioneer VI earth track*

from third-stage spinup until 80 s after third-stage burnout. These values correspond to range times of: $L+179$ to $L+669$ s and $L+1460$ to $L+1604$ s. In addition, all downrange S-band stations and ships that received the *Pioneer* telemetry signal were required to provide a voice report to the Superintendent of Range Operations (SRO) (in near-real time) as to time of acquisition of signal, time of loss of signal, and signal strength of the S-band carrier.

b. Class II requirements. Class II requirements included the receiving and recording of the spacecraft data from $L-3$ min to $L+179$ s (shroud jettison), from $L+410$ to $L+630$ s, and from $L+630$ s until loss of signal at the AFETR station.

c. Station commitments. Based on the support requirements of AFETR Test 4867, it was determined that Cape Kennedy Tel II (Station 1), Grand Bahama Island (Station 3), Antigua (Station 9.1), and the *Coastal Crusader* (range instrumentation ship) were necessary to meet the Class I data requirements. The specific commitments for each site were as follows: Station 1, $L-120$ to $L+66$ s; Station 3, $L+56$ to $L+286$ s; Station 9.1, $L+320$ to $L+760$ s; and *Coastal Crusader* from $L+1245$ to $L+1653$ s. The general equipment configuration for each station is illustrated in Fig. 5.

d. Overlapping S- and P-band requirements. It became apparent at Grand Bahama Island and Antigua that there would be simultaneous Class I requirements for both S- and P-band data. Since both the TAA-2 telemetry antenna at Grand Bahama Island and the TAA-3A telemetry antenna at Antigua had broadband feed systems (thus allowing frequency diversity), no problem was anticipated in this area.

e. Tel II at Cape Kennedy. The telemetry support requirements in the launch area are met by Tel II. The S-band telemetry antenna at this site is a right-circular-polarized manual tracking antenna with a gain of 23 dB.

Prediction of the received signal level at Tel II was contingent on the transmitting antenna gain. Data relative to this were obtained by combining spacecraft aspect angle information and spacecraft antenna pattern information supplied by the range user. No S-band commitment was made for Tel II after $L+66$ s because the gain of the spacecraft antenna was not defined after that time.

Figure 6 is a plot of the predicted signal strength from $L=0$ to $L+180$ s. The signal strength shown from $L+66$ to $L+180$ s was made assuming a smooth decrease in spacecraft antenna gain with increase in aspect angle in this region.

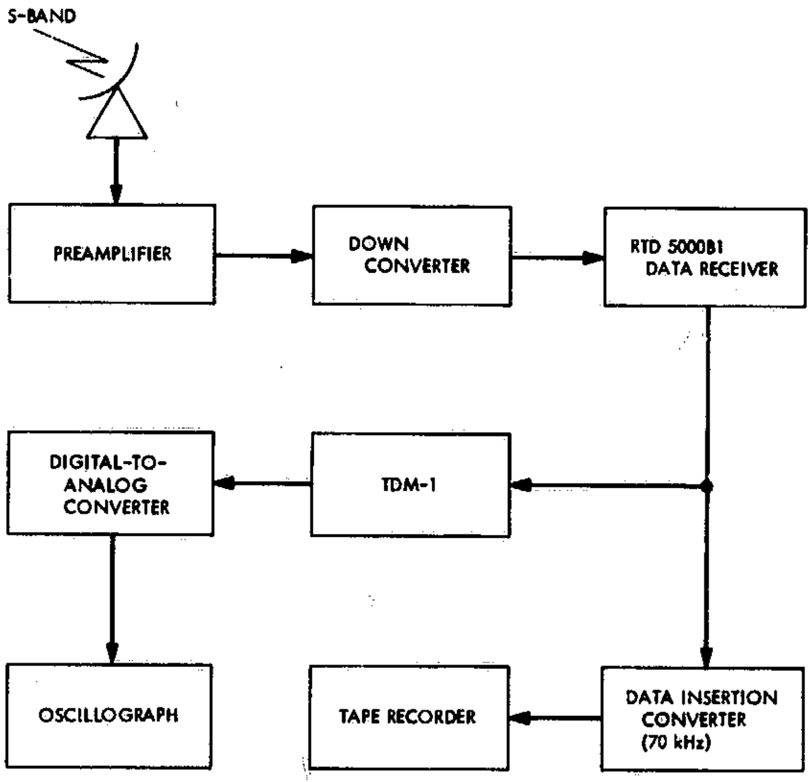


Fig. 5. S-band telemetry equipment configuration for the *Pioneer VI* launch

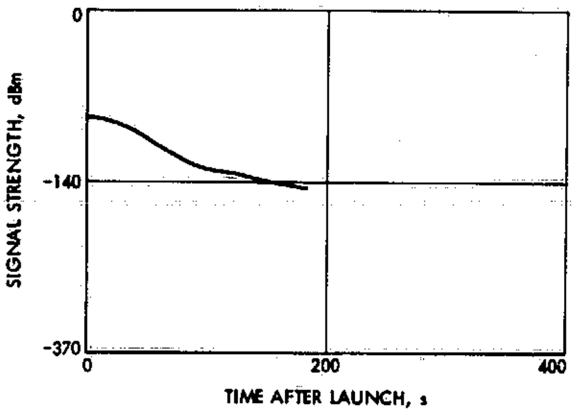


Fig. 6. Tel II predicted received signal strength vs time after launch

Figure 7 is a plot of the predicted doppler frequency shift at Tel II. The maximum doppler shift expected was 48 kHz and the maximum doppler rate was 410 Hz/s. Comparison of the signal strength and doppler curves with the receiver performance has shown that the doppler characteristics did not limit the data coverage.

f. Grand Bahama Island (Station 3). The antenna used for S-band telemetry support at Grand Bahama Island is

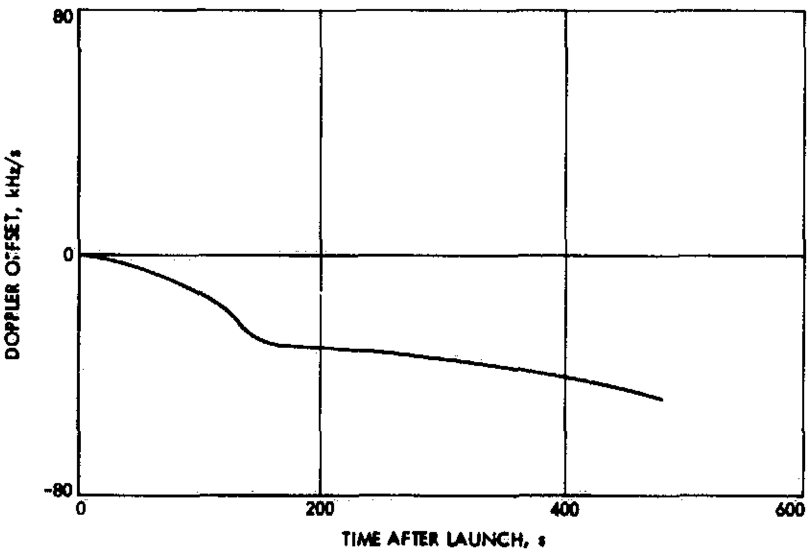


Fig. 7. Tel II predicted doppler offset vs time after launch

the TAA-2, with an effective gain of 48 dB. The antenna has dual polarization capability, but only right-circular polarization was required for data reception.

Figure 8 is a plot of the predicted signal-strength-vs-time values. After $L+294$ s, the spacecraft antenna gain was approximated, using the assumption that the gain would decrease smoothly with increasing aspect angle.

The sensitivity of the TAA-2 tracking receiver system was -113 dBm. From Fig. 8, it is apparent that the S-band commitment had to be ended at $L+286$ s. Since the data receivers were more sensitive, it was felt that the time coverage might be extended to the horizon limit at $L+508$ s if the antenna could be properly positioned. The prime tracking frequency at Grand Bahama Island for the *Pioneer VI* launch was to be 2.292 GHz, with 234 MHz as a backup. With the feed focused for S-band, a switch to P-band tracking should provide extended S-band data coverage.

The predicted doppler frequency shift at Grand Bahama Island is plotted in Fig. 9. The rate of frequency shift would be less than 40 kHz/s and the maximum doppler rate expected was 615 Hz/s. Comparison of the signal strength and doppler curves with the receiver performance showed that the doppler characteristics have in no way limited the data coverage.

g. Antigua (Station 9.1). The antenna used for S-band telemetry support at Antigua was the TAA-3A, with a gain of 40 dB. The antenna has dual polarization capability and both channels were implemented for S-band data reception.

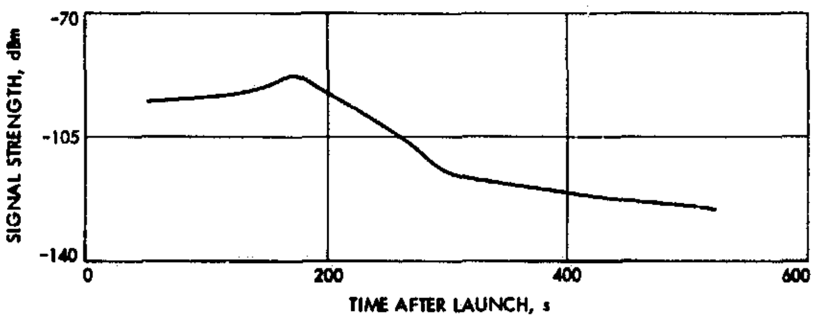


Fig. 8. Grand Bahama Island predicted received signal strength vs time after launch

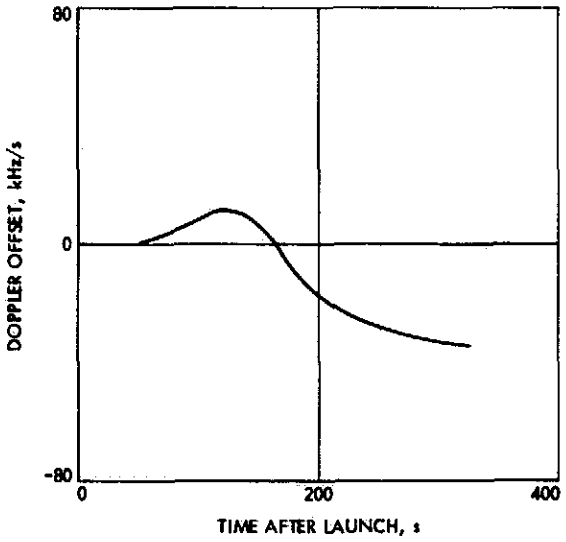


Fig. 9. Grand Bahama Island predicted doppler offset vs time after launch

The predicted received signal strength at Antigua is plotted in Fig. 10. It is apparent from this plot that the -113 dBm tracking receiver sensitivity of the TAA-3A would not permit S-band tracking at Antigua over the major portion of the pass. Since the P-band signal strength would be much greater and since the data receivers could acquire usable data over the entire pass, the tracking mode at Antigua was P-band tracking with the feed focused for S-band. Focus of the feed at S-band would cause only minor degradation to the P-band data. Sun-tracking tests of the antenna during vendor acceptance tests verified that the tracking axis for P- and S-band was the same.

The predicted doppler shift at Antigua is plotted in Fig. 11. The maximum rate of frequency shift expected was 46 kHz/s and the maximum doppler rate was 534 Hz/s. Comparison of the signal strength and doppler curves with the receiver performance showed that the doppler characteristics do not limit the data coverage.

h. Coastal Crusader. The *Coastal Crusader* range instrumentation ship had the most sensitive S-band antenna

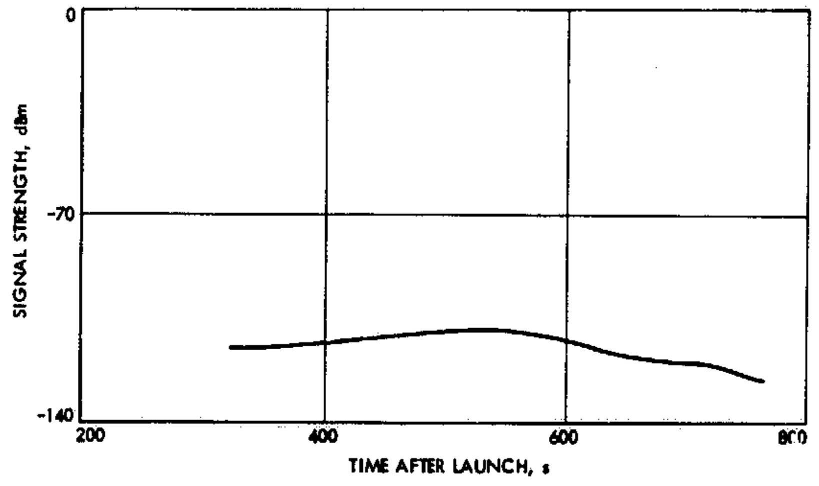


Fig. 10. Antigua predicted received signal strength vs time after launch

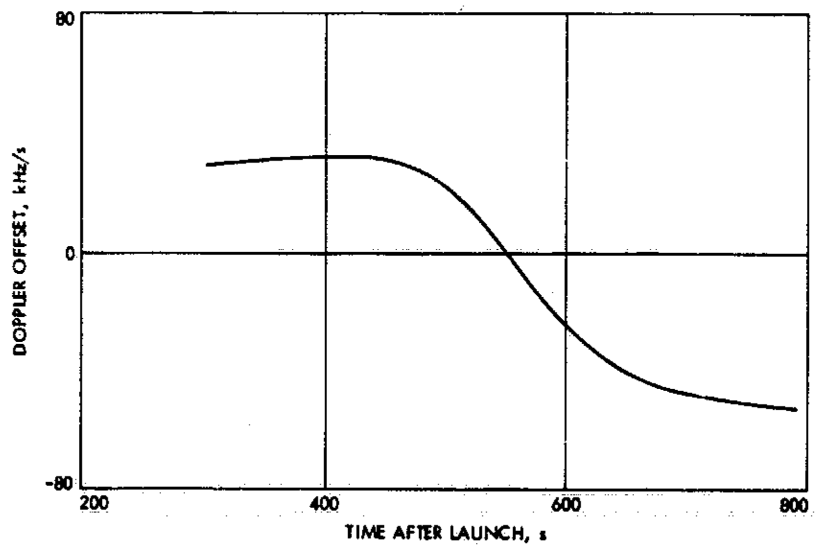


Fig. 11. Antigua predicted doppler offset vs time after launch

system on the AFETR, with a capability of acquiring and tracking signals as low as −140 dBm at the input to the S-band preamplifier. The antenna gain was 40 dB. The phase-locked receivers used for data acquisition were an integral part of the Tracking and Data System (TDS). The antenna has dual polarization capability, and both channels were implemented.

The predicted received signal strength for the *Coastal Crusader* is shown in Fig. 12. Since spacecraft trajectory information (after third-stage ignition) was not available, a large percentage of the plot is only a rough approximation. The increase in the transmitter output to 8 W is also shown. This plot indicates that the ship should have been able to acquire and track the S-band signal from $L+1210$ to $L+2000$ s.

Since there was no radar on the *Coastal Crusader* to aid in the initial acquisition of the telemetry signal, a Univac 1218 computer was installed in the ship to provide capability for processing received radar data. The computer was programmed to accept AFETR Type I and Type IV acquisition messages. The requested acquisition mode for the antenna was a digital sector scan of ±3 deg with a 2-deg elevation angle at the predicted azimuth acquisition angle. If the signal were not acquired within 20 s of the predicted time, the acquisition mode was to be switched to a digital slave, with a superimposed spiral search. The autotrack and automatic acquisition–reacquisition sequence was to be activated. Any time the signal was lost, the antenna operator was to revert to the digital slave mode with spiral scan. In addition, any time before third-stage ignition, slave to the autotracking P-band antenna (with circular scan) could be selected for S-band acquisition.

The predicted doppler characteristic for the *Coastal Crusader* is plotted in Fig. 13. The maximum doppler offset was 74 kHz/s, and the maximum doppler rate was 1.38 kHz/s. Comparison of the signal strength and doppler characteristics with the receiver performance showed that this did not limit the data acquisition.

*8. **JPL/AFETR operational support.*** The JPL/AFETR field station located at Cape Kennedy was to support the launch operations of *Pioneer VI* by providing the necessary operational interfaces between the DSN and Space Flight Operations in Pasadena and the AFETR and other project elements at AFETR. This operational interface comprised the following activities:

(1) Monitoring and keeping the DSN project engineer informed of the status of AFETR stations, ships and equipment, progress through the countdown, and the occurrence and time of in-flight events.

(2) Providing liaison between the flight path analysis and command group and the AFETR real-time computer facility through the JPL data coordinator.

(3) Receiving and retransmitting (to the SFOF) AFETR metric data and computed data, including injection conditions, orbital elements, and DSIF acquisition information.

(4) Relaying spacecraft telemetry data from DSS 71 to the SFOF, and to Building AM.

(5) Receiving from the SFOF, and retransmitting to Building AM, spacecraft telemetry data from DSS 51.

In addition to the launch phase operations, the field station participated in the prelaunch integration tests

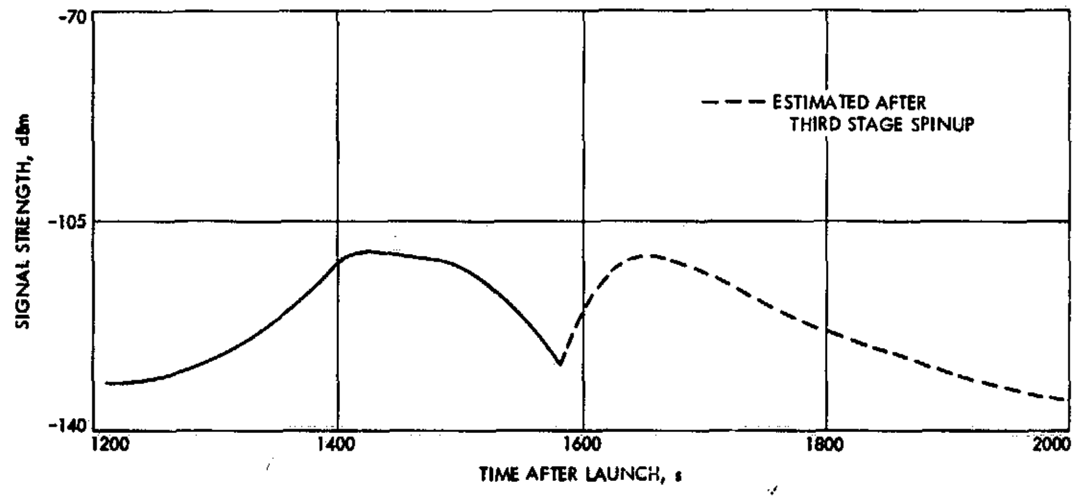


Fig. 12. ***Coastal Crusader*** **predicted received signal strength vs time after launch**

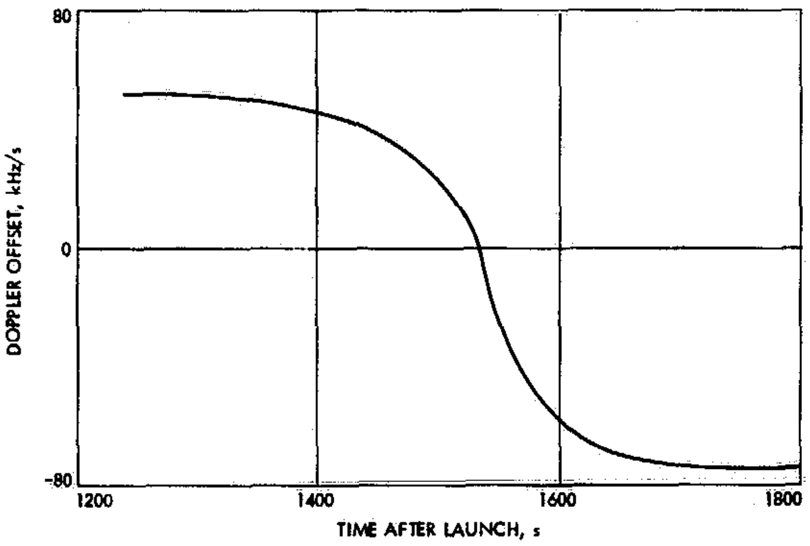


Fig. 13. ***Coastal Crusader*** **predicted doppler offset vs time after launch**

and operational readiness tests. These tests essentially duplicated the launch phase activity, with operations simulated where necessary.

B. *Pioneer VI* Deep Space Phase Requirements

Since the requirements placed upon the DSN systems are in support of the DSN commitments to the *Pioneer* Project, it is appropriate to list and describe these basic commitments. The DSN stations are listed in Table 4.

The following equipment was operational at the committed Deep Space Stations:

(1) Project-dependent equipment, consisting of command encoder, demodulator–synchronizer, and computer buffer.

(2) Exciter.

(3) Transmitter.

(4) Receiver.

(5) Modulator.

(6) Diplexer.

(7) Acquisition-aid antenna system.

(8) S-band cassegrainian monopulse (SCM) antenna system.

(9) Maser.

(10) FR-1400 tape recorders.

(11) SDS-910 computer.

(12) Frequency and timing system.

The data requirements of Deep Space Stations in support of space missions are listed in Table 5.

C. Quality Control of Data

1. Metric data. Metric data monitoring for the *Pioneer* Project was conducted in these three phases:

(1) Phase 1—L to $L+3$ days.

(2) Phase 2—$L+3$ to $L+30$ days.

(3) Phase 3—$L+30$ days to end of nominal mission.

Data monitoring was performed during each of these phases as outlined in Table 6.

Table 4. Deep Space Network *Pioneer VI* commitments

Station	Location	Coverage
DSS 12	*Echo* Station, Goldstone, Calif.	One complete pass per day during life of mission
DSS 14	*Mars* Station, Goldstone, Calif. (when available)	
DSS 42	Tidbinbilla, Australia	One complete pass per day for the first 30 days of mission
DSS 51	Johannesburg, South Africa	One complete pass per day for first 4 days of mission
DSS 71	Cape Kennedy, Fla.	Compatibility, integration, and operations tests for 30 days preceding launch

Table 5. Data requirements in support of *Pioneer VI* mission

Type of data	Specific requirements
Premission statistical data from Deep Space Stations	Predictions (consisting of antenna angles, transmit and receive voltage-controlled oscillator frequencies, doppler frequency vs time for a probable mission, AFETR and CCF launch predicts, etc.) Telemetry test tapes Tracking data test tapes Command tapes Telemetry calibration book
Premission calibration data from Deep Space Stations	Calibration data sheets containing: Measured system noise temperature Optical boresight angle readouts RF boresight shift vs polarization RF boresight vs signal strength (DSSs 11, 42, and 51) Receiver threshold sensitivity at various bandwidths Telemetry channel threshold sensitivity (75% in lock signal level) Serial number of test transponder used in tests Loss from test transponder output connector to low-noise-amplifier input connector Signal level vs automatic-gain-control voltage and channel 6 voltage-controlled-oscillator frequency from −90 dBm to threshold in 5-dB increments Star tracking data Measured antenna gain Measured maser gain Measured paramp gain Loss from feedhorn output connector to low-noise-amplifier input connector Antenna radiation and polarization patterns Feedhorn ellipticity
Log data (other than magnetic recordings)	Station identification Time (GMT) of start and finish of record Date record was made Record identification Mission designator
Station calibration and checkout sheets	Station identification Date of record Purpose of data (pretrack or posttrack calibration, etc.) Time (GMT) of record Name of operator Mission designator

Table 6. *Pioneer* data monitoring

Phase	Monitor area	Monitor frequency
1	A[a]	Continuous
1	B[b]	Every 4 h (*L* to *L*+20 h)
1	B	Every 8 h (*L*+20 to *L*+72 h)
2	B	Within 12 h of a 2-way pass
3	B	Within 72 h of a 2-way pass

[a] Area A = Goldstone computer facility.

[b] Area B = Space Flight Operations Facility.

Tracking data were monitored continuously in near-real time at the Goldstone computer facility during Phase 1 only. Data were monitored for high-frequency noise and compared with predicted data using the Goldstone prediction and monitor programs. The orbit determination program was used to validate tracking data for the project within the SFOF during all phases.

The purpose of near-real-time readouts at the Goldstone computer facility (Area A) was to monitor the metric data and provide near-real-time performance feedback to the DSN stations during critical periods.

2. *Telemetry data.* Telemetry data monitoring, on a random basis, was to be performed by the operator at the DSN station as diagrammed in Fig. 14. The nonreturn-to-zero computer (NRZ-C) data and sync status from both the *Pioneer* ground operational equipment and the reproduce head of the FR-1400 tape recorder were to be recorded on the Consolidated Electrodynamics Corp. (CEC) oscillograph. In addition, a dual-beam oscilloscope was to be connected to both the FR-1400 input and reproduce output of the 2.048-kHz telemetry data stream.

The CEC oscillographic data provided a record of the DSN station receiver in- and out-of-lock history and FR-1400 recording history. The real-time analysis of the

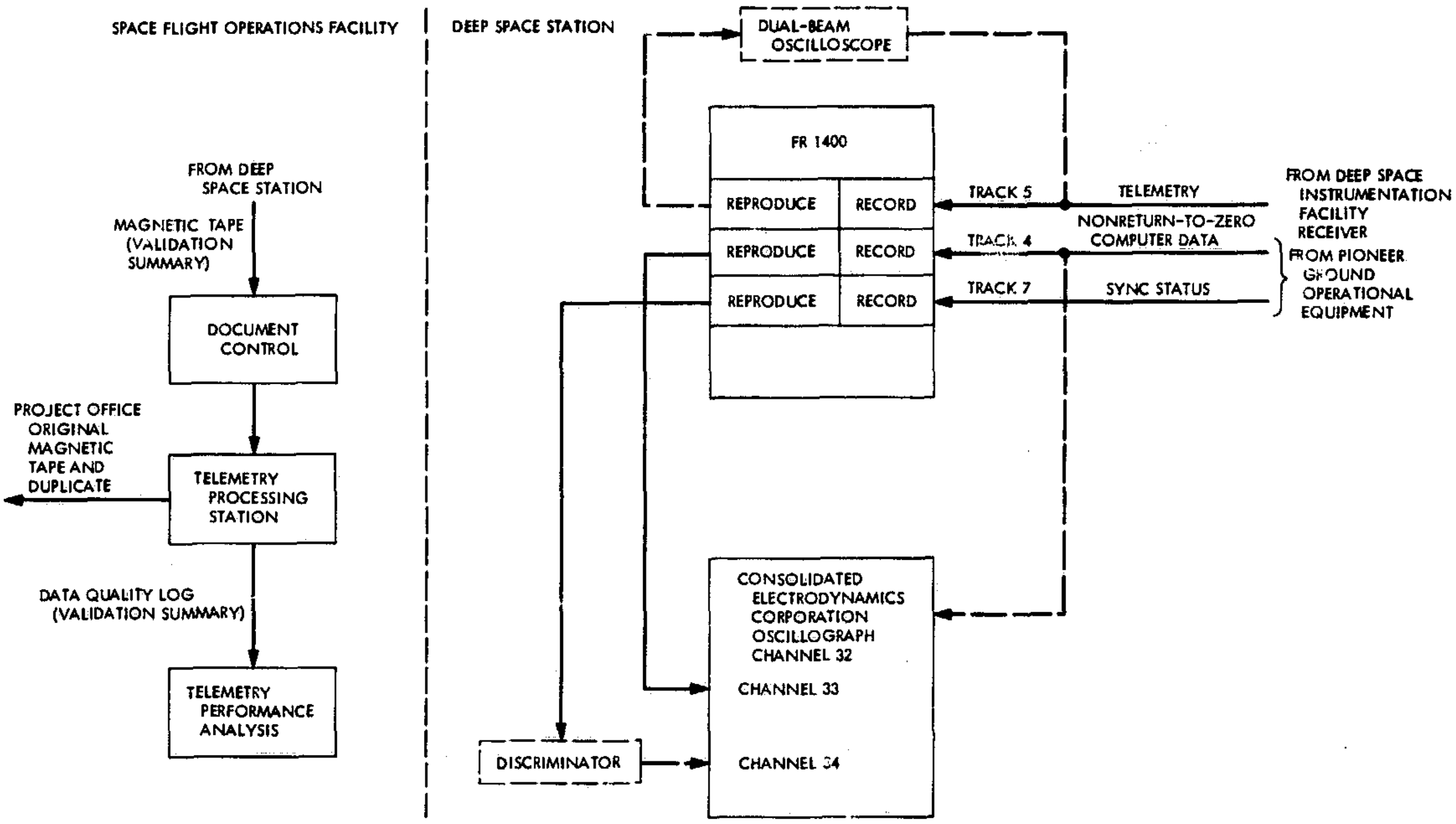


Fig. 14. ***Pioneer* telemetry data monitor**

FR-1400 recording performance was to be made by a visual comparison of the telemetry data stream from the DSN station receiver with that recorded on the FR-1400.

Summary reports concerning telemetry recovery have been published weekly during the mission. The reports cover telemetry demodulator in-lock times for each pass, and have contained such data as a tabulation of the percentages of gross coverage by station and network. Percentages were derived by abstracting receiver in- and out-of-lock times and demodulator in-lock times from the posttrack reports of the DSN stations. These times are added and then divided by each station's scheduled tracking period for each pass to give overall percentage coverage.

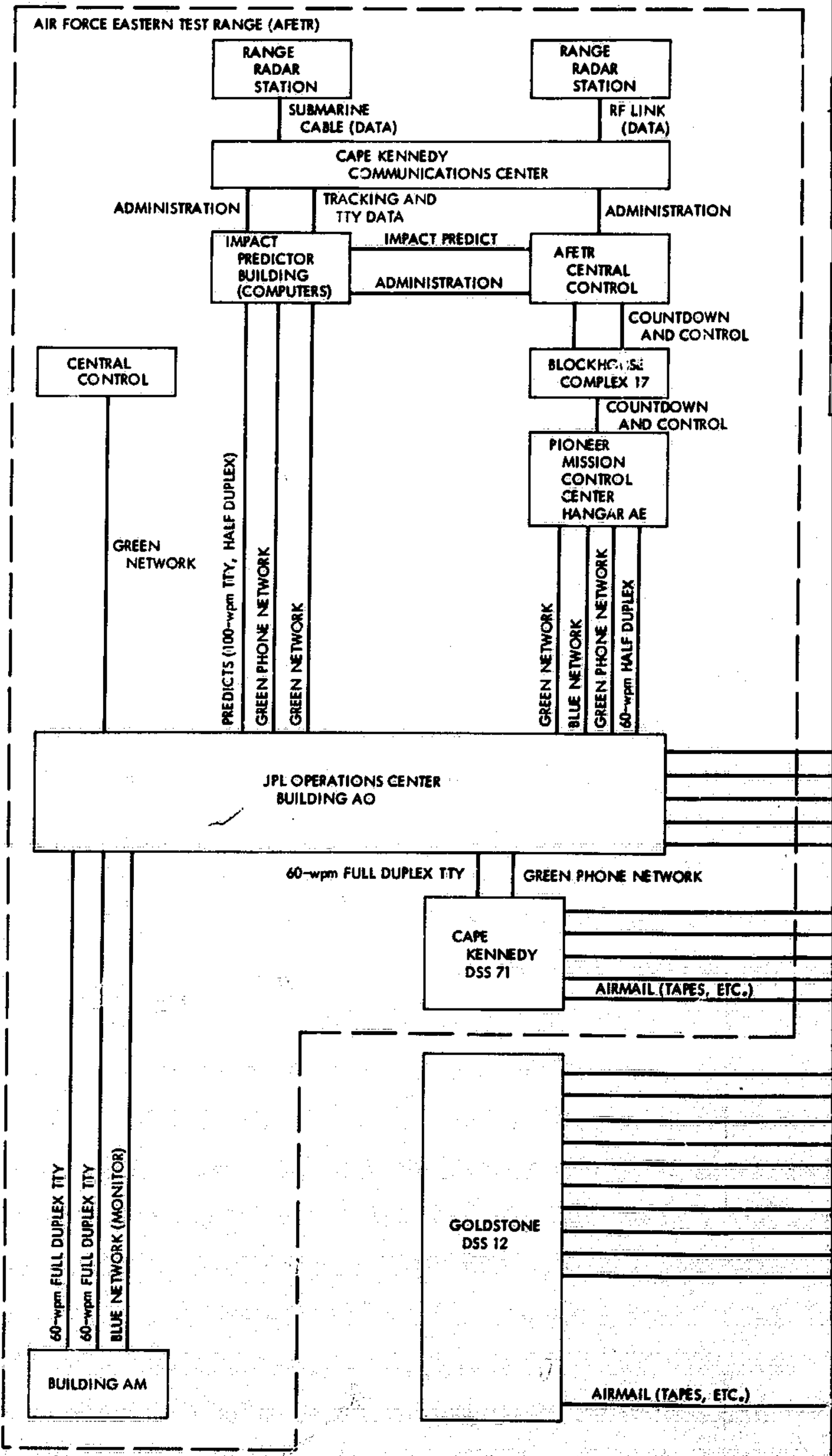
3. ***Telemetry data validation.*** The DSS would play back a random 10-min sample of each FR-1400 tape to verify that the *Pioneer* ground operational equipment could lock up to the recorded 2.048-kHz telemetry stream.

A summary of the tape playback performance was included in the data package forwarded to Operational Document Control in the SFOF.

4. ***DSN station logs.*** The Deep Space Stations employed a comprehensive logkeeping and reporting system to provide a complete record of system performance.

Any equipment outages or suspected malfunctions causing loss of data or spacecraft signal were to be immediately reported by voice to the network control area and documented by teletype reports and station logs. The station pretrack reports, tracking reports, and posttrack reports reflect all equipment anomalies plus station parameters, such as prepass calibration and postpass calibration of a Deep Space Station. These reports spell out the DSN performance in support of the assigned mission before, during, and after all tracking passes. Station logs and network control logs further were to reflect (in hours, minutes, and seconds) all equipment failures or loss of data encountered during any tracking pass. In addition, the operational voice circuits to the Deep Space Stations from the network control area are recorded by the JPL communication center.

5. ***Ground Communications Facility.*** Figure 15 is a schematic diagram of the planned communication lines as described. As indicated in this diagram, the DSN


AIR FORCE EASTERN TEST RANGE (AFETR)
RANGE RADAR STATION
RANGE RADAR STATION
SUBMARINE CABLE (DATA)
RF LINK (DATA)
CAPE KENNEDY COMMUNICATIONS CENTER
ADMINISTRATION
TRACKING AND TTY DATA
ADMINISTRATION
IMPACT PREDICTOR BUILDING (COMPUTERS)
IMPACT PREDICT
ADMINISTRATION
AFETR CENTRAL CONTROL
COUNTDOWN AND CONTROL
CENTRAL CONTROL
BLOCKHOUSE COMPLEX 17
COUNTDOWN AND CONTROL
PIONEER MISSION CONTROL CENTER HANGAR AE
GREEN NETWORK
PREDICTS (100-wpm TTY, HALF DUPLEX)
GREEN PHONE NETWORK
GREEN NETWORK
GREEN NETWORK
BLUE NETWORK
GREEN PHONE NETWORK
60-wpm HALF DUPLEX
JPL OPERATIONS CENTER BUILDING AO
60-wpm FULL DUPLEX TTY
GREEN PHONE NETWORK
CAPE KENNEDY DSS 71
AIRMAIL (TAPES, ETC.)
60-wpm FULL DUPLEX TTY
60-wpm FULL DUPLEX TTY
BLUE NETWORK (MONITOR)
BUILDING AM
GOLDSTONE DSS 12
AIRMAIL (TAPES, ETC.)

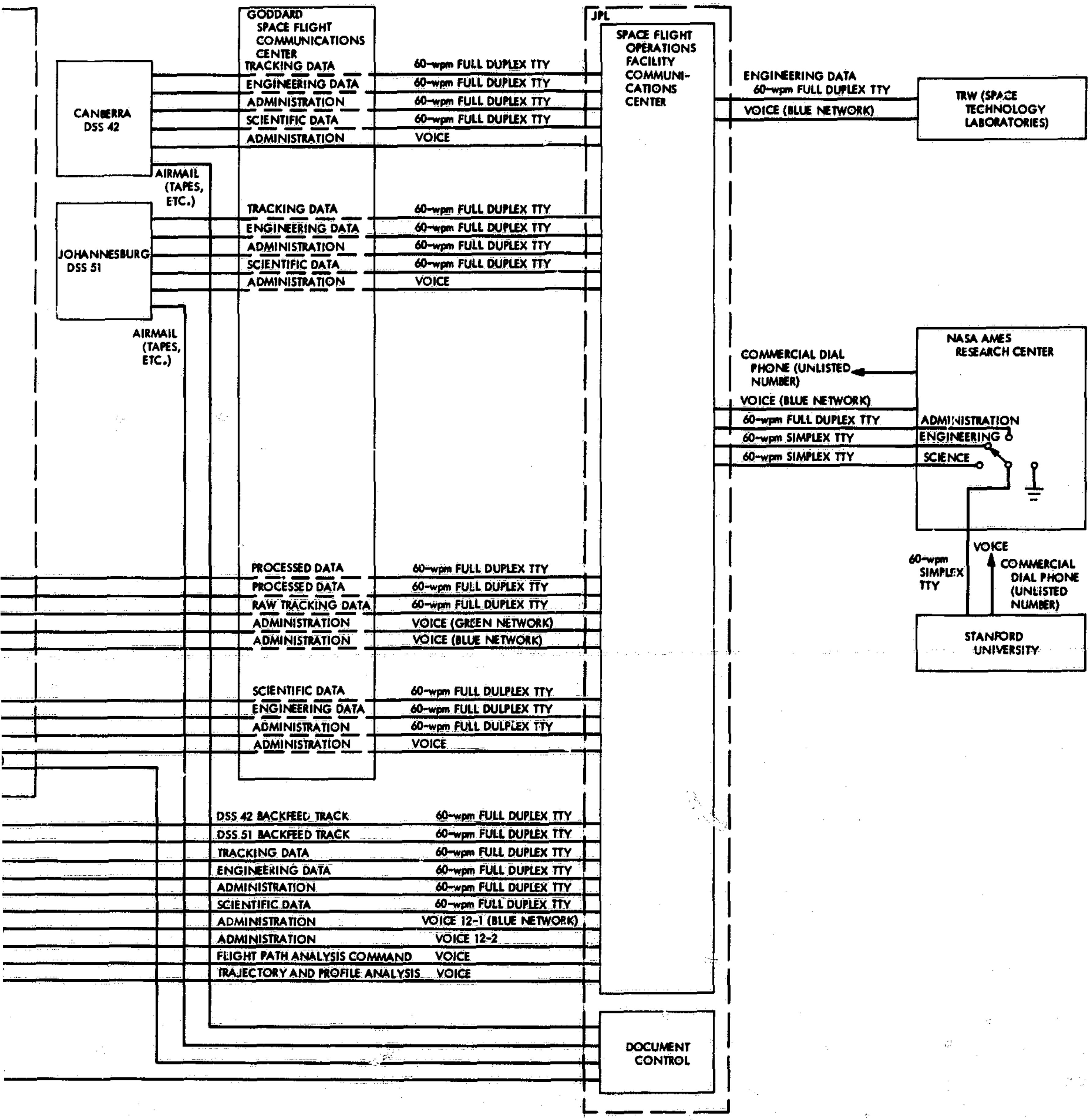


Fig. 15. Communication lines, launch configuration

FOLDOUT FRAME 2

internal communication requirements included communication lines between the committed DSN stations and the SFOF. A minimum requirement was that there be at least two teletype and one voice circuit operational between each DSN station and the SFOF.

Communication circuits presently committed to support the *Pioneer* Project consist of NASCOM circuits to the overseas stations and AFETR area, and DSN circuits to Goldstone utilizing the JPL/Goldstone microwave link.

a. NASCOM circuits. Technical control of all NASCOM circuits is the responsibility of GSFC. This is defined as the continuous function of maintaining the continuity and integrity of the communication circuits. The major policies and procedures used in accomplishing this responsibility are:

(1) Provide and maintain sufficient wire facilities to remote facility control points; commercial and overseas carriers' toll test centers and primary routing points; and JPL Communications Control for circuit and facilities coordination, trouble reporting, and fault location.

(2) Establish backup circuits and prepare diverse routing plans.

(3) Establish working relationships with the various communications carriers and establish mutual service restoral plans.

(4) Provide for the technical and administrative supervision of technical control centers at the primary switching and subswitching centers.

b. Mission operations control. In conjunction with technical control, JPL Communications Control had the responsibility for mission operational control of all communication circuits used to support the *Pioneer* Project. This included the control of the entire DSN ground communications facility as an entity, including the communication centers at the remote stations and the communication facilities linking them with Mission Control Center.

JPL Communications Control was to make sure that no marginal circuit was taken out of service for corrective action or for any other reason without prior approval of the Space Flight Operations Director or his authorized representative. All technical control tests and routine maintenance tasks were to be performed on a noninterference basis with respect to mission simulations and flight operations. JPL Communications Control was also to see that all mission and mission-related traffic had absolute priority on communications facilities devoted to mission support.

As part of the concomitant responsibility, Communications Control was to provide facilities and personnel to perform circuit quality monitoring, testing, and analysis of circuit performance. This was accomplished by using:

(1) Signal quality monitoring devices that serve as alarms and indicate when distortion levels of incoming data on teletype circuits exceed certain predetermined levels (normally 20 to 25% distortion).

(2) A Stelma analyzer (DAC-5) that provides, first, distortion and bias readings as either average, peak, or individual (marking or spacing bias); second, scope presentation of an incoming or outgoing teletype signal for visual analysis; and third, test patterns or individual letter tests at various speeds and desired amounts of distortion.

(3) A comprehensive method of recording circuit outages using trouble tickets and communication logs.

Communications Control established uniform and efficient DSN communications-related operating procedures and disciplines, requested and confirmed special or critical coverage from cognizant agencies during critical periods of the *Pioneer* mission, conducted circuit optimization testing on all circuits before release for mission support, and conducted periodic circuit assurance tests on all idle circuits during mission support periods.

c. JPL/Goldstone circuits. The procedures and policies used in maintaining the quality of circuits to Goldstone (DSS 12) are identical, where applicable, to those described for NASCOM circuits. In addition, microwave alarms were available that indicated loss of pilot tone or any other type of microwave outages on either a group or a microwave channel.

It was anticipated that use of the prepared policies, procedures, and hardware, and the addition of the signal quality monitoring devices and microwave alarms, would result in optimum communications support of the *Pioneer* data validation effort.

6. Receiving and processing mission data tapes. This subsection briefly describes the requirements pertaining to the receiving and processing of *Pioneer* mission data tapes for quality control and validation that took place in the SFOF.

a. Operational Data Control. Control of data coming into the SFOF from the Deep Space Stations was maintained to ensure proper handling and distribution. This control was performed according to specified SFOF procedures.

Received tracking data were forwarded to distribution in the flight path analysis area and to the Space Flight Operations Director for trajectory computations in accordance with the commitment document. Validation was performed by flight path analysis personnel.

Science data were separated from the engineering data subcommutator at the Deep Space Stations by computers and recorded on magnetic tape. The tapes were mailed to the SFOF, whose personnel forwarded them to Ames Research Center.

Magnetic tapes of recorded data received from the Deep Space Stations were forwarded by SFOF personnel to the telemetry processing station for duplicating and processing. After processing, the originals were returned along with the duplicate and one copy of the data log for shipment to the *Pioneer* Project Office at ARC.

b. Telemetry processing station. The telemetry processing complex in the SFOF provided one duplicate magnetic tape of each original DSS magnetic recording received. During the duplicating process, station personnel were required to ascertain that the recording technique was correct and that telemetry data, as well as station performance information, were available. Further validation included the following:

Monitoring and verification of recording levels. The quality of a recording was determined by applying quality control devices such as spectrum analyzers and bit-error detectors. Verification was also made that information was recorded in the proper standard being used by the Deep Space Stations.

Inspecting recorded data for continuity. A data time correlation was performed to determine that data dropout was not excessive and that data rates did not exceed the limitations of processing equipment.

A specially prepared data log on each tape contained the following indicators:

(1) Receiver flag (a time printout occurring each time there was a receiver out-of-lock state).

(2) Demodulator flag (a time printout occurring each time there was a demodulator out-of-lock state).

(3) Time flag (an error printout occurring when delta time disagreed with data rate).

All data validation was done on the duplicated tapes.

After processing, the telemetry processing station returned the original tape along with one copy of the data log for shipment to the *Pioneer* Project Office. Copies of validation reports were returned to the DSS for inclusion in the station performance summary report.

c. Computer. At least one of the two computer strings in Mode 2 was required to be operational. A computer string in Mode 2 consisted of an IBM 7044 computer and an IBM 7094 computer with a 1301 disk storage unit connected in tandem. This computer string was used by the flight path analysis and command team to compute acquisition prediction information for use by the Deep Space Stations and the Stanford tracking station, and to determine the best estimate of the actual spacecraft orbit so that accurate trajectory information would be available to *Pioneer* Project personnel.

d. Data flow and processing. The *Pioneer* mission operations are concerned with real-time, quick-look, and nonreal-time telemetry data requirements.

Real-time data. These data were to be received in real-time via hardline or radio communication link. They were then to be displayed on-line in the user areas as rapidly as operational priorities would permit. Data are classified as real-time if they are received at the SFOF within 5–10 min after receipt by the Deep Space Stations. Table 7 lists the functions monitored in real-time.

Quick-look data. These are selected data extracted on-site by the SDS 910 computer and transmitted in real-time to the SFOF upon request by the SFOD. These data are monitored in the *Pioneer* mission support area and simultaneously transmitted to the ARC data processing center and TRW.

Non-real-time data. These are data received at the SFOF either in the form of magnetic tape recordings or of delayed transmission from a communications link more than 30 min after receipt of data at the Deep Space Station. Functions monitored normally as non-real-time data are listed in Table 7.

The flow from the SFOF includes acquisition and tracking information and commands for the DSIF, general status information, and spacecraft performance data.

Table 7. Classification of mission data requirements

Function	Real-time[a]	Non-real-time[b]
Data demodulation[c]	X	
Data decommutation[c]	X	
Analog-to-digital conversion		
Data formatting[c]	X	
Data logging	X	
Engineering units conversion	X[d]	
Alarm monitoring	X[d]	
Orbit determination		X
Trajectory computation		X
Spacecraft orientation[e]	X	
Command generation[f]	X	
Command verification[c]	X	
Scientific data calibration	X	
Engineering data analysis	X[d]	X
Scientific data analysis	X[d]	X
Premission tests and training	X	X
Tape dubbing at Ames Research Center		X

[a] Real-time = 5 to 10 min after acquisition by DSIF.

[b] Non-real-time = Magnetic tape via airmail after acquisition by DSIF.

[c] To be done at DSIF sites.

[d] Selected data.

[e] To be done at Goldstone.

[f] To be initiated at the SFOF but generated at DSIF sites.

Table 8. Near-earth phase facilities

Agency	Station and location
Air Force Eastern Test Range	Station 1—Cape Kennedy/Patrick AFB, Fla. Station 3—Grand Bahama Island Station 7—Grand Turk Island Station 9.1—Antigua Island Station 12—Ascension Island Station 13—Pretoria, South Africa Range instrumentation ship *Twin Falls*—South Atlantic Range instrumentation ship *Coastal Crusader*—South Atlantic
Manned Space Flight Network	Bermuda Island station MSFN/USB site—Ascension Island Tananarive site—Malagasy Carnarvon site—Australia Goddard Space Flight Center, Md.
NASCOM	Worldwide facilities of NASCOM provided communications between supporting agencies
Jet Propulsion Laboratory facility at Air Force Eastern Test Range	Building AO at Cape Kennedy, Fla.
Deep Space Network	DSS 71—Cape Kennedy, Fla. DSS 72—Ascension Island DSS 51—Johannesburg, South Africa SFOF—Pasadena, Calif.

All DSS flight data are forwarded within 48 h to SFOF document control at JPL.

The incoming data circuits are routed through the communications center to the teletype machines and closed-circuit television in the user areas.

III. *Pioneer VI* Tracking and Data System Configuration

A. Near-Earth Phase Configuration

For near-earth support, the TDS was composed of selected resources of the Air Force Eastern Test Range (AFETR), Manned Space Flight Network (MSFN), NASCOM, and the Deep Space Network (DSN). Within each agency, specific supporting stations were as listed in Table 8.

Based on trajectory data and requirements, the TDS agencies selected the appropriate metric and telemetry data acquisition instrumentation from resources available at the sites listed in Table 8. Particular attention was given to Class I intervals to assure a high probability of providing the required coverage. The AFETR forms shown in Fig. 16 briefly describe these instruments, their location, common identifying nomenclature, agency, and general use.

*1. **Metric data.*** The AFETR was the primary agency responsible for meeting metric requirements during the launch and earth-orbital mission phases. The addition of MSFN radar instrumentation to that of the AFETR provided the required coverage with a reasonable degree of redundancy. Radars listed in Table 9 tracked the *Agena* C-band beacon in meeting both launch vehicle and spacecraft metric requirements. In addition, the AFETR optical tracking instruments listed in Table 10 provided accurate metric data from liftoff to 5000 ft.

Figure 17 illustrates the configuration of the metric system and data flow that supported the early launch phase. Optical instruments as well as C-band radars are shown. Figure 18 illustrates the metric configuration for supporting the near-earth orbital phase. The AFETR

(a) AFETR metric instrumentation

C-BAND RADAR NO.	1.16	14.18	0.18	3.16	3.18	7.18	91.12	12.16	12.18	13.16	TTR	
C-band radar	1	1	1	1	1	1	1	1	1	1		
Digital recorder	1	1	1	1	1	1	1	1	1	1		
Function recorder	1	1	1	1	1	1	1	1	1	1		
Event recorder	1	1	1	1	1	1	1	1	1	1		
Video recorder												
Servo recorder												
Video camera												

S-BAND RADAR SITE/STATION	1	3	7	12
S-band radar (Mod II)	1			
Digital recorder	0			
Function recorder	0			
Video camera	0			

X-BAND RADAR NO.	1.1	1.2	
X-band radar (Mod IV)	1	1	
AGC recorder	1	1	
Event recorder	1	1	

L-BAND RADAR NO.	1.8
L-band radar (AN/FPS-8)	1
PP camera	0

	T-AGM-			
SHIPBOARD RADAR	9	10	11	12
C-band radar				
L/X-band radar				
L/UHF band radar				
S-band radar				
Digital recorder				
Function recorder				
Event recorder				
C-band boresight camera				
L/X/UHF-band boresight camera				
Power monitor recorder				
Videotape recorder				
R/A video film recorder				
C-mount servo recorder				
L-mount servo recorder				
R/I video film recorder				

TRINIDAD RADAR STATION		
Radar 40.33, AN/FPN-33 (Quad)		
Radar 40.43, AN/FPS-43 (Tracker)		
Recorders	PB	RT
Ampex Magnetic Tape Unit		1
Potter Magnetic Tape Unit		1
IF Recorder		
R/A Camera, 15 Segment		
R/A Camera, 2 Segment		
R/T Camera, 15 Segment		
R/T Camera, 2 Segment		
A/T Camera		
Visicorder, 2 Channel		
Visicorder, 24 Channel		
Voice Recorder		
IEC Recorder		
Computer		1

PB - Playback RT - Real Time

(b) AFETR launch instrumentation

	Summary of Range Instrumentation		Stations										
			01	00	10	03	07	91	12	40	RIS	13	
Radar Pulse and CW	S-Band Pulse		1										
	X-Band Pulse		2										
	L-Band Pulse		1							1		1	
	C-Band Pulse		1	1	1	2	1	1	2			1	
	Azusa												
	Mistram												
	Udop												
	SP-104 Van		1										
Telemetry		Tel 2	Tel 3										
	Antennas	3				2		3	2		3	1	
	Receivers	10				7		11	6		8	4	R
	Combiners	3				3		3	2		2		R
	SS/CF Recorders	2				2		2	2				
	Tape Recorders	6				2		2	2		2	2	
	Oscillographs	0-5						1	1				
	DW Recorders	2-20						1	1				R
	PDM Decom	1-2											R
	Discriminators	3-20						3	2				R
Other Support	Mils												
	FCA		X					X					
	RTCF (orbit computation)		X										
	MCC-K		X										
Comm.	Radio, Point-to-Point		X						X	X	X	X	
	Radio, Air-to-Ground		X								X		
	Subcable		X			X	X	X					
	Timing		X	X	X	X	X	X	X	X	X	X	
Range Safety	Command/Control		X			X	X	X	X				
	Supv/Control		X			X	X	X					
	Asco												

	Type	No.	Type	No.	Type	No.	
Range Safety	Impact Pred. Comp.	1	Wire Screen	1	Plotting Board	5-10	
	Tel Elsse	1	TV Skyscreen	3			
Optics	16 mm Cine	5	70 mm Sequence	1	Cinetheodolite	4	
	35 mm Cine	3	Igor	1	Ribbon Frame Camera	5	
	16 mm H/S	17	Roti VB, CB, MB	3	Ballistic Camera		
	35 mm (aircraft)	2	Mitts-HR	1			R

		Remarks
Acft.	One Optics aircraft	Two RIS required for S-band telemetry.
	One R/S surveillance aircraft	One RIS for RU doppler gear.

Fig. 16. AFETR instrumentation forms: (a) metric instrumentation, (b) launch instrumentation

Table 9. Subcarrier link data

Signal, kHz	Application	Characteristics
0.40	Continuous	—
2.30	Continuous—link	228.2 MHz only
3.00	Continuous—link	228.2 MHz only
3.90	Continuous	—
5.40	Continuous	—
7.35	Continuous	—
10.50	Continuous	—
14.50	Continuous	—
22.00	±15% continuous	—
40.00	±15% continuous	—
70.00	±15% commutated	45 × 20, pulse-duration modulated

Table 10. Near-earth phase telemetry commitments

Station	Link frequency, MHz	Commitment
1 (Tel II)	228.2	−120 s to first-stage separation exclusive of staging dropouts
	234.0, 230.9	−120 to 466 s exclusive of staging and flame dropouts
	2292	—
3	228.2	L+56 s to first-stage separation plus 5 s
	234.0, 230.9	L+56 to L+508 s exclusive of noise due to flame
	2292	—
9.1	234.0, 230.9	L+320 to L+760 s
	2292	—
12	234.0, 230.9	L+1130 to L+1770 s
13	234.0, 230.9	L+1745 to L+2740 s
Coastal Crusader 9.8 deg south latitude, 4.5 deg west longitude	234.0, 230.9 2292	—

and MSFN C-band radars are shown, and the flow of data and their format are described.

2. *Telemetry.* The first- and second-stage vehicle was to radiate one PDM/FM/FM telemetry link. Frequency of the first-stage link was 228.2 ±0.125 MHz. The frequency of the second-stage link was 234.0 ±0.125 MHz. The subcarrier configuration of each link is shown in Table 9.

Table 10 lists the telemetry commitment, the station whose facilities were used to obtain such telemetry, and the operational links.

3. *Real Time Computer Facility.* The AFETR Real Time Computer Facility at Cape Kennedy, using CDC 3600 and 3100 computers, processed metric data received from the AFETR and MSFN sites. An important function during the near-earth phase was the computation and transmission of acquisition information to the various TDS sites supporting the mission. The flow of acquisition information in the form of interrange vectors and DSN predicts is illustrated in Fig. 19.

The Real Time Computer Facility used metric data for orbital computations and planetary mapping in meeting trajectory definition requirements. Various computer runs were made, based on actual parking-orbit conditions, estimated and actual transfer-orbit conditions, and actual postposigrade conditions.

The Real Time Computer Facility retransmitted teletype data from all radars to GSFC in octal format, and converted AFETR radar teletype data to decimal format for transmission to the JPL/AFETR operations center at Cape Kennedy via 100-wpm teletype circuits. Another function of the Real Time Computer Facility was to receive high-density data from Bermuda and Carnarvon radars, convert them to decimal format, and transmit the information to Building AO. The JPL personnel at Building AO selected appropriate metric data for retransmission to the SFOF via teletype as required.

4. *Joint facilities.* The facilities of the field station supporting the mission are the JPL/AFETR operations center and the JPL/AFETR communication center, both in Building AO.

a. Joint operations center. Control of JPL/AFETR operations during the launch phase was exercised from the JPL/AFETR operations center. The operations center contained status displays that indicated the status of all participating elements of the operation, a timing system, and consoles for the operating personnel.

Status displays. There are four display boards in the operations center. One of these, the operational status display board, is used to indicate operational status of Cape Kennedy instrumentation sites, the space vehicle, and communication links. Another, the in-flight events display board, is used to display the time of significant in-flight events. The AFETR and DSS status display

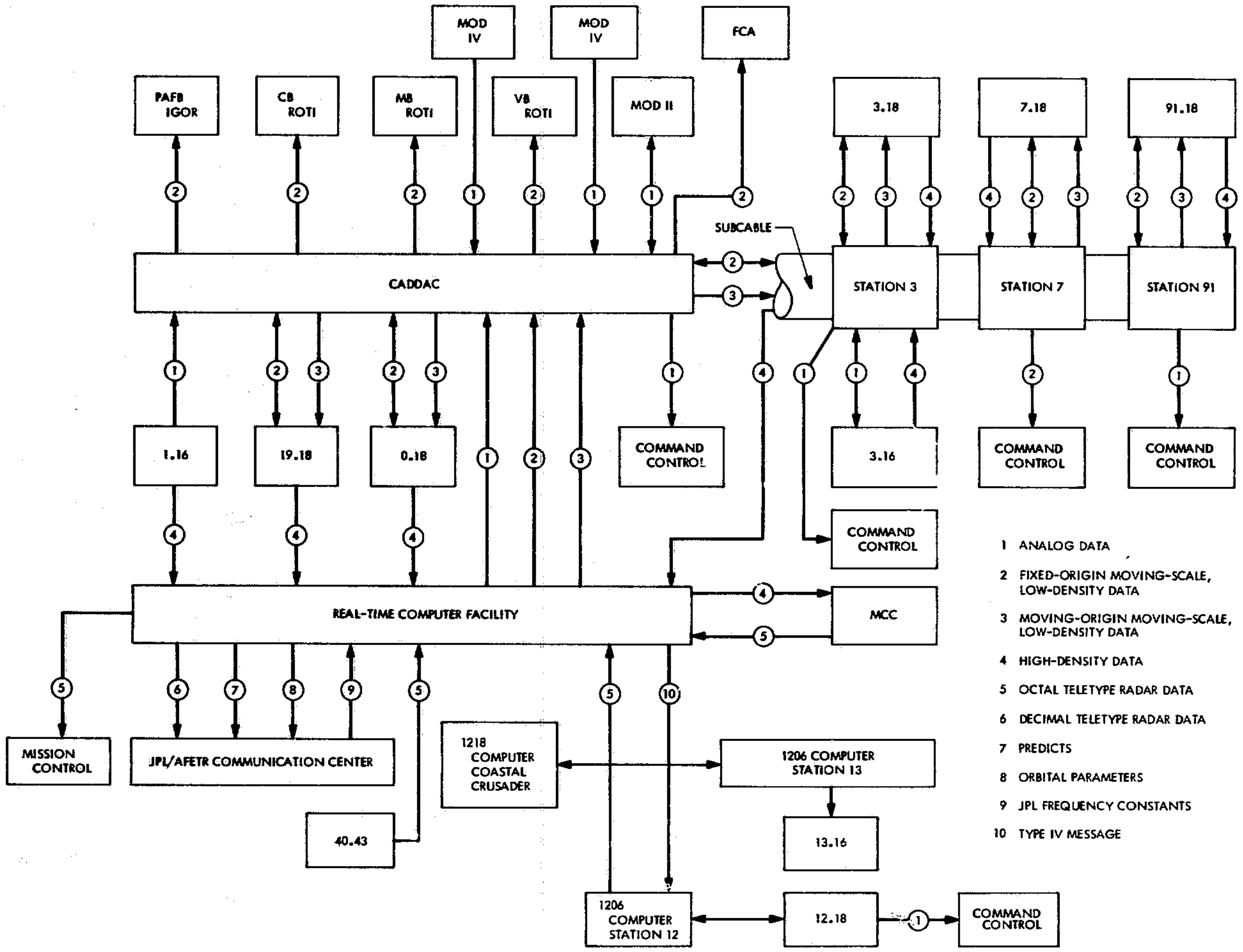
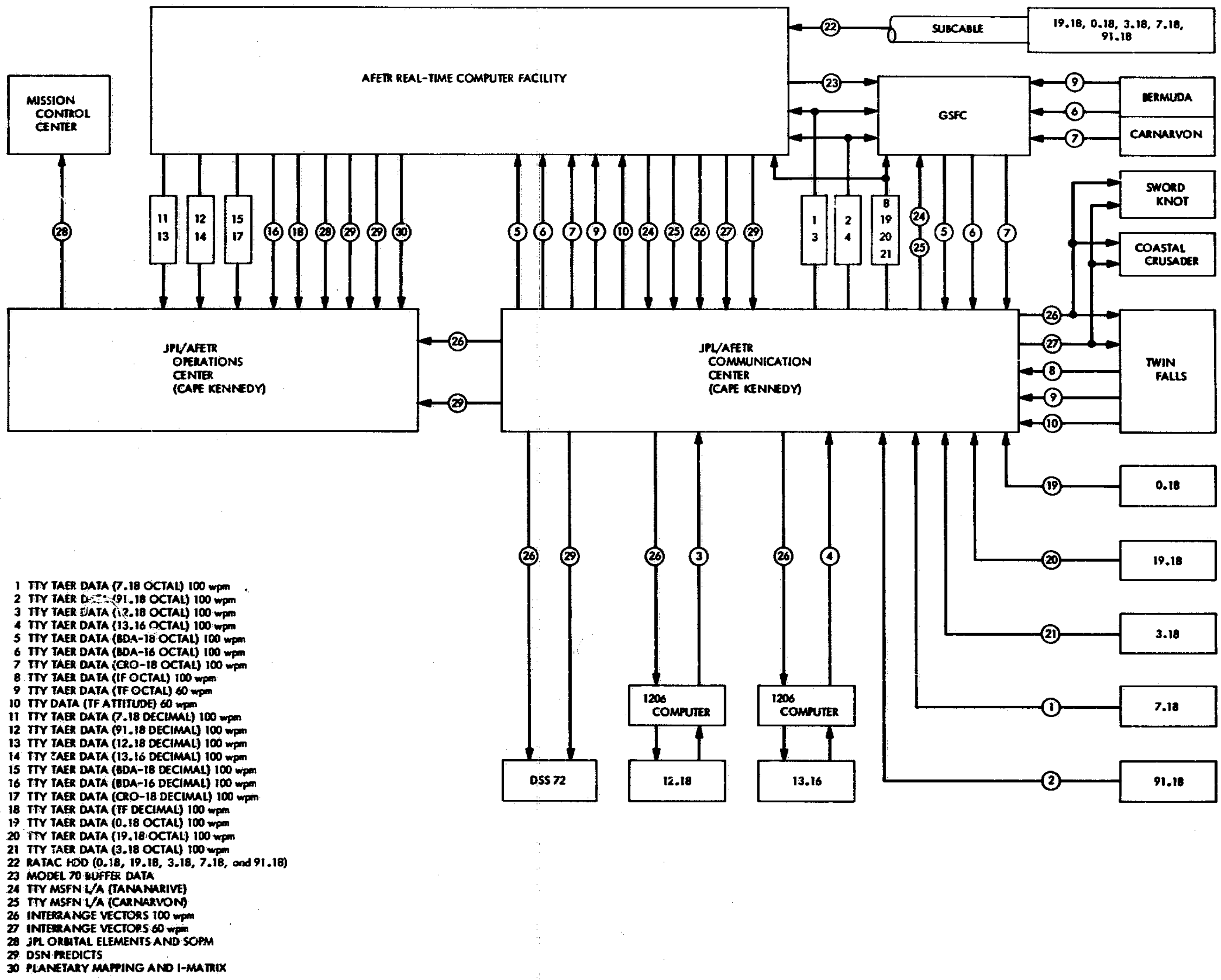


Fig. 17. Metric data flow—launch phase



1 TTY TAER DATA (7.18 OCTAL) 100 wpm
2 TTY TAER DATA (91.18 OCTAL) 100 wpm
3 TTY TAER DATA (12.18 OCTAL) 100 wpm
4 TTY TAER DATA (13.16 OCTAL) 100 wpm
5 TTY TAER DATA (BDA-18 OCTAL) 100 wpm
6 TTY TAER DATA (BDA-16 OCTAL) 100 wpm
7 TTY TAER DATA (CRO-18 OCTAL) 100 wpm
8 TTY TAER DATA (IF OCTAL) 100 wpm
9 TTY TAER DATA (TF OCTAL) 60 wpm
10 TTY DATA (TF ATTITUDE) 60 wpm
11 TTY TAER DATA (7.18 DECIMAL) 100 wpm
12 TTY TAER DATA (91.18 DECIMAL) 100 wpm
13 TTY TAER DATA (12.18 DECIMAL) 100 wpm
14 TTY TAER DATA (13.16 DECIMAL) 100 wpm
15 TTY TAER DATA (BDA-18 DECIMAL) 100 wpm
16 TTY TAER DATA (BDA-16 DECIMAL) 100 wpm
17 TTY TAER DATA (CRO-18 DECIMAL) 100 wpm
18 TTY TAER DATA (TF DECIMAL) 100 wpm
19 TTY TAER DATA (0.18 OCTAL) 100 wpm
20 TTY TAER DATA (19.18 OCTAL) 100 wpm
21 TTY TAER DATA (3.18 OCTAL) 100 wpm
22 RATAC HDD (0.18, 19.18, 3.18, 7.18, and 91.18)
23 MODEL 70 BUFFER DATA
24 TTY MSFN L/A (TANANARIVE)
25 TTY MSFN L/A (CARNARVON)
26 INTERRANGE VECTORS 100 wpm
27 INTERRANGE VECTORS 60 wpm
28 JPL ORBITAL ELEMENTS AND SOPM
29 DSN PREDICTS
30 PLANETARY MAPPING AND I-MATRIX

Fig. 18. Metric data flow chart—orbital phase

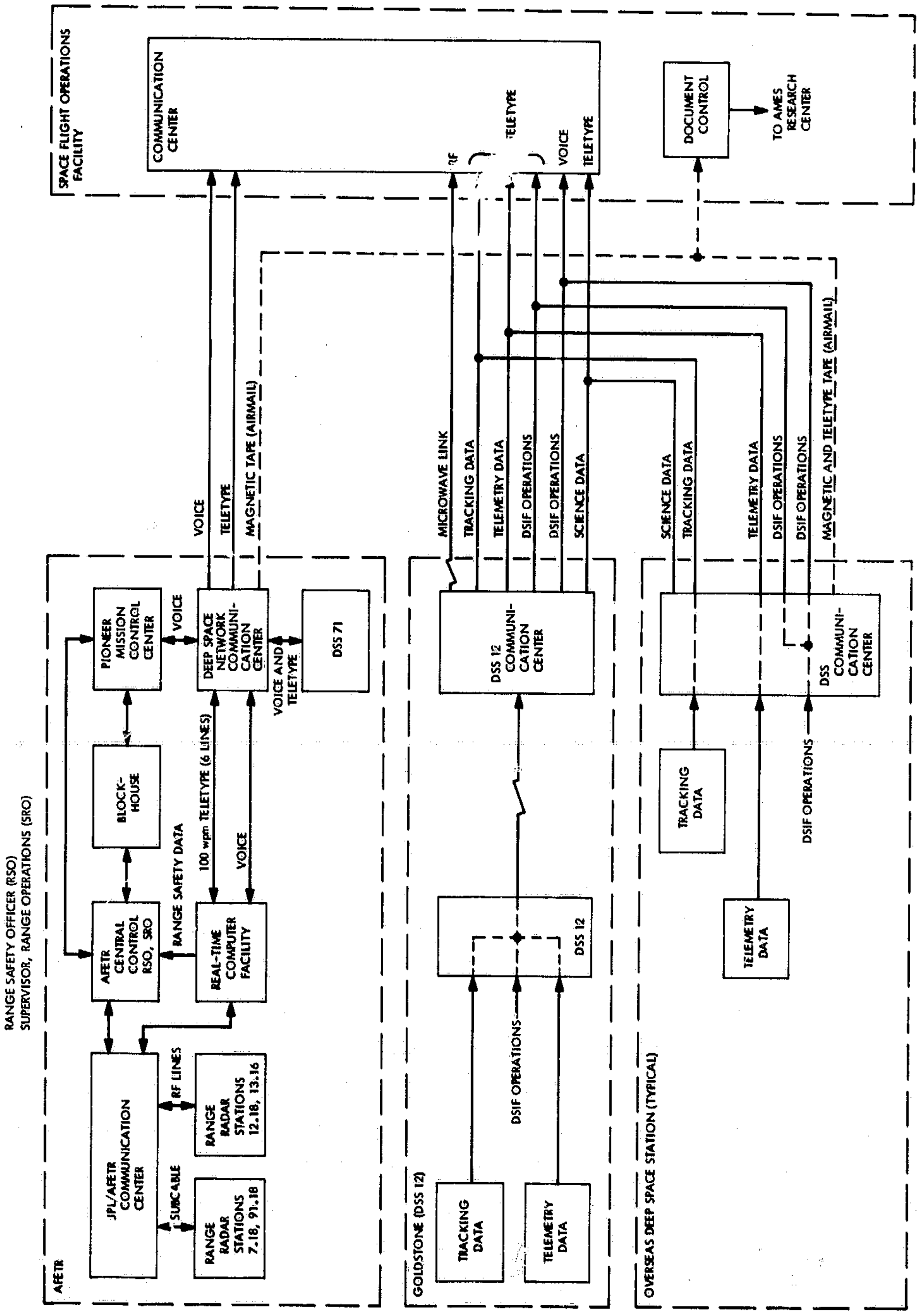


Fig. 19. Telemetry and tracking data flow from AFETR and the DSIF to the SFOF

boards are used to indicate the status of the participating AFETR facilities and Deep Space Stations.

Television monitors display the range safety flight-line and program-line television signals. These are part of a system for monitoring the flight path of the vehicle, both in the plane of the flight azimuth (flight-line) and normal to the plane of the flight azimuth (program-line). Finally, an optically projected map display (a map of the world projected onto the status board wall) shows the earth track of the flight azimuth as well as locations of key in-flight events. Colored circles, indicating metric coverage from each tracking station, are also superimposed on the map.

Timing system. An automated timing system continuously displayed Pacific, Eastern, and Greenwich Mean Time, countdown and launch-plus-time data, anticipated time to launch and actual liftoff time, accumulated hold time at any point in the countdown, and time remaining in the launch window for that day.

Consoles. In addition to the integrated communication consoles used by each of the operators, there are two dual television monitor consoles and the status display control console. Each of the integrated communication consoles contains a green phone switch panel, two communications panels, and a communication control panel. During operations, the green phone switch panel was used to provide direct point-to-point circuits between major operating facilities and the operations center. These were private-line automatic-signaling circuits used by key personnel. The green phone system was operable from emergency power, which allowed it to serve as a backup for the AFETR communications network. The AFETR communications panels provided party-line communications for operational testing. The panels, combined, provided the capability of monitoring 24 channels. These channels were the prime communication links for the conduct of launch operations. Access to two cross-country voice circuits from the SFOF at JPL/Pasadena is provided by the communication control panel. This panel is also used to answer administration telephone calls, and can be connected to the green phone switch panel and the AFETR communications panels.

Each of the two dual television monitor consoles contains a dual small-screen television monitor used to view the page printers for two of the outgoing teletype circuits to the SFOF. A separate permanent console is provided for status display. This console contains a range countdown indicator and control panels for the timing system and the status display boards.

b. Joint communication center. The JPL/AFETR communication center contains the necessary equipment to provide (1) a local terminus and interfaces for voice, teletype, and data circuits from both the SFOF in Pasadena and the AFETR and local project elements; and (2) local voice, teletype, and data circuits in support of prelaunch tests and launch operations. This equipment is described in the following paragraphs.

Voice circuits. The communication center has the capability of terminating up to 50 voice channels from various Cape Kennedy locations; any 24 of these can be patched into the communication system in the operations center. To provide direct voice circuits to the SFOF in Pasadena, two commercially leased lines (NASCOM) are terminated in two 4-wire bridges. Special telephone panels, which allow certain administrative phones to be switched into the 4-wire bridge, provide a backup for the two leased lines.

Teletype circuits. Six full-duplex, 60-wpm NASCOM teletype circuits from the SFOF are terminated in the JPL/AFETR communication center; three of these are routed on a "normal-through" basis to DSS 71. A local circuit from DSS 71 to the communication center is also provided. Nine incoming circuits from the AFETR are terminated in the communication center. These may be patched into six typing reperforators, which are operated taut-tape to six transmitter–distributors. These, in turn, can be patched to any of the outgoing circuits to Pasadena. Three additional local circuits, two from Building AM and one from the mission control center (Building AE), are terminated in the communication center. These may be patched to any of the SFOF, AFETR, or DSS 71 lines.

Data circuits. A NASCOM data line is routed between the SFOF and the JPL/AFETR communication center. This line is terminated in a patch panel in the communication center that allows either digital or analog data to be patched in. The data line also provides an alternate capability for voice use.

B. Deep Space Phase Configuration

The major elements of the DSN, configured to support the *Pioneer VI* mission, were (1) the DSIF, (2) the ground computer facility, and (3) the SFOF. Other *Pioneer*-peculiar facilities and equipment are also described in the following subsections.

Figures 20 and 21 give the generalized data flow of *Pioneer* tracking, telemetry, and reloaded data within the DSN.

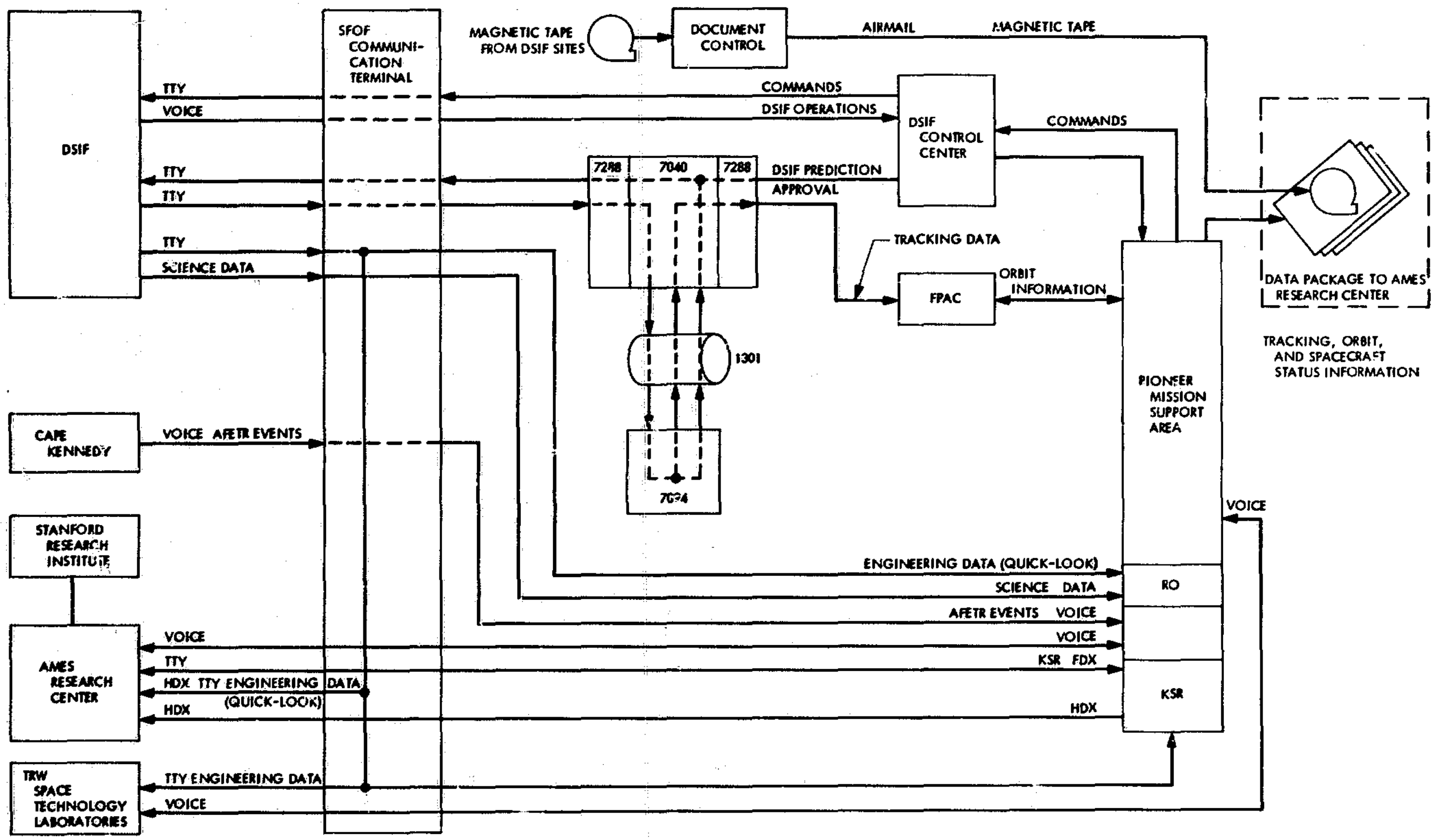


Fig. 20. *Pioneer space flight operations facility data flow*

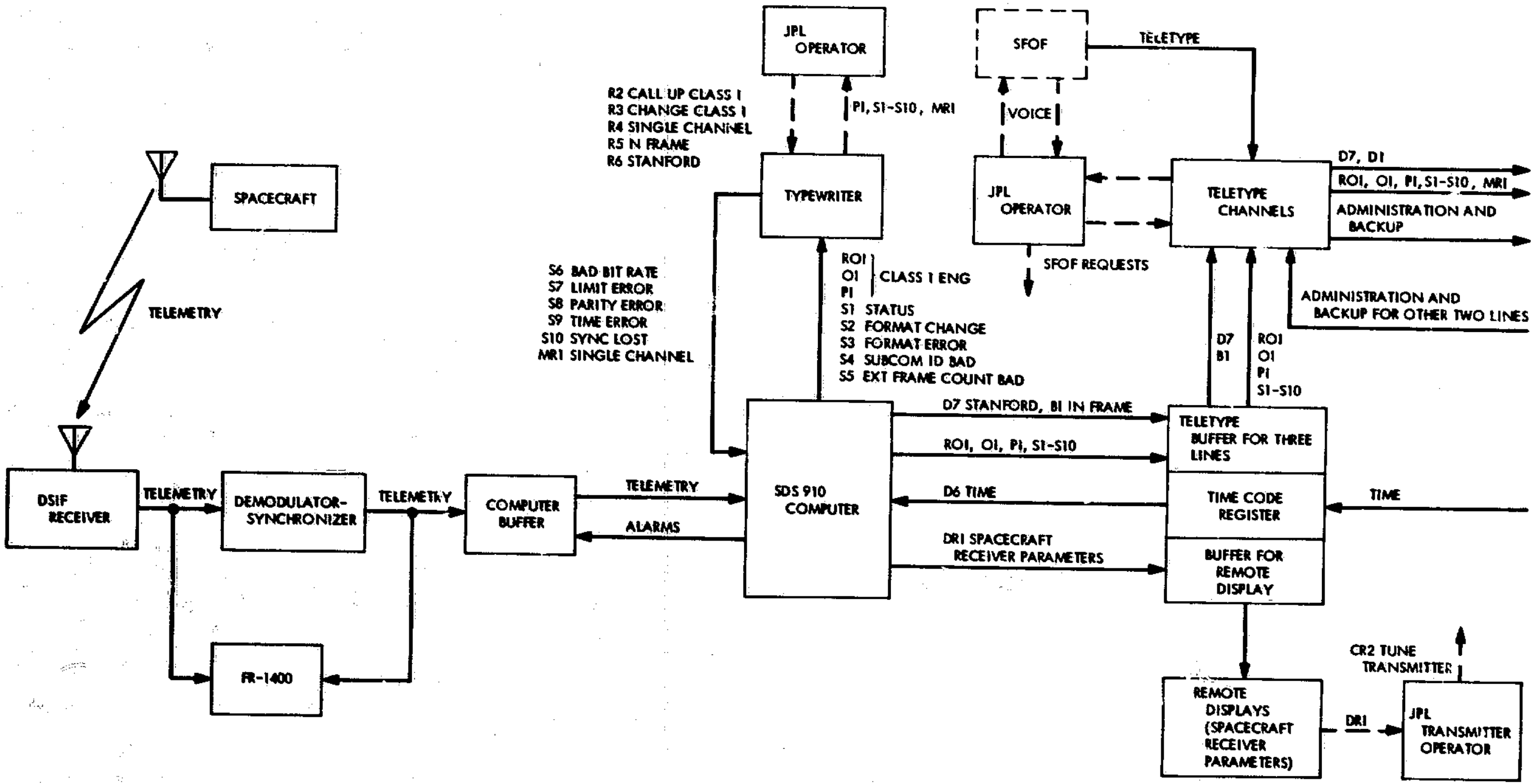


Fig. 21. *Pioneer* telemetry data flow and associated functions (excluding orientation-peculiar telemetry processing)

1. Deep Space Instrumentation Facility. The DSIF comprises the Deep Space Stations. The function of these stations was to obtain angular position, doppler, and telemetry data from the *Pioneer VI* spacecraft during the postinjection phase of the mission. Data obtained by the DSSs were to be transmitted to the SFOF in real-time via teletype circuits. In addition, the same data were to be recorded on magnetic tape at each Deep Space Station and dispatched to JPL by air service.

a. Deep Space Stations. The following Deep Space Stations were designated as primary in support of the *Pioneer VI* mission:

Station	Location
DSS 12	*Echo* Station, Goldstone, Calif.
DSS 42	Tidbinbilla, Australia
DSS 51	Johannesburg, South Africa
DSS 71	Cape Kennedy, Fla. (launch operations only)

The parameters and capabilities of each Deep Space Station are given in Table 11. Compatible telecommunications modes are listed in Table 12. The metric data format is shown in Table 13. Block diagrams of the stations are presented in Figs. 22 and 23.

Tracking modes. The Deep Space Station tracking modes are shown in Table 14. Each ground mode is prefixed with the letters GM, and contains two digits separated by a hyphen. The first digit (1–5) describes the tracking communication configuration; the last digit (1–5) describes the ground station antenna utilization. Thus, the code *GM-2-1* would indicate a ground mode employing a spacecraft–station 2-way capability, using the diplexer to allow simultaneous transmitting and receiving with the station feedhorn and 85-ft antenna.

The operational frequency allocations of the Deep Space Stations are shown in Table 15.

Figure 24 depicts the relationship of the Deep Space Stations assigned (for the *Pioneer VI* mission) to the SFOF within the DSN.

Deep Space Station coverage. The locations of and the coverage provided by the three selected Deep Space Stations are depicted in Fig. 25. For backup, three Deep Space Stations were available for emergency recording

Table 11. DSS capabilities for *Pioneer VI* support

Characteristic	Goldstone *Echo* S-band (Goldstone duplicate standard)	Canberra S-band (Goldstone duplicate standard)	Johannesburg L-to-S conversion kit[a]
Station identification	DSS 12	DSS 42	DSS 51
Receiver capability, quantity	2	2	1
Antenna type	85-ft parabolic reflector	85-ft parabolic reflector	85-ft parabolic reflector
Mount	Polar (hour angle–declination)	Polar (hour angle–declination)	Polar (hour angle–declination)
Maximum angular rate (both axes), deg/s	0.7	0.7	0.7
Antenna gain, dB			
Receiving	53.0	53.0	53.0
Transmitting	51.0	51.0	51.0
Antenna bandwidth, deg	0.4	0.4	0.4
Typical system temperature, °K	60	60	60
Transmitter power, kW	10	10	10
Data transmission (teletype)			
Angles	Real-time	Real-time	Real-time
Doppler	Real-time	Real-time	Real-time
Telemetry	Real- and near-real-time	Real- and near-real-time	Real- and near-real-time
Demodulated telemetry	Dual channel	Dual channel	Single channel
Command capability	Yes	Yes	Yes
Data pack air shipment time to JPL	1 day	6 days	5 days

[a] Basic difference between L-to-S conversion kit stations and Goldstone duplicate standard S-band stations is that L-to-S stations use doppler format and single receiver.

of the telemetry subcarrier on magnetic tape wherever possible throughout the mission. These stations were:

Station	Location
DSS 11	*Pioneer* Station, Goldstone, Calif.
DSS 41	Woomera, Australia
DSS 61	Madrid, Spain

Table 12. Compatibility matrix

Mode	Doppler (1-way)	Doppler (2-way)	Non-coherent doppler (2-way)	Angle tracking	Ranging	Command	Telemetering
Doppler (1-way)				X			X
Doppler (2-way)				X	X	X	X
Noncoherent doppler (2-way)				X[a]		X	X[a]
Angle tracking	X	X	X[a]		X	X	X
Ranging		X		X			X
Command		X		X			X
Telemetering	X	X	X[a]	X	X	X	

[a] Only at receiving station.

b. Mission-dependent equipment. A significant amount of special-purpose and mission-dependent equipment and many facilities were provided by the *Pioneer* Project for accomplishing the mission objectives. The spacecraft and scientific instruments are easily recognized as belonging to this group. In addition, however, electrical ground support equipment was provided for checking out the spacecraft and scientific instruments, and for verifying their launch readiness. Ground operational equipment was supplied to four Deep Space Stations for processing telemetry data and transmitting commands to the spacecraft. Equipment was specially designed and fabricated for decommutating and processing telemetry data recorded on magnetic tapes. General-purpose equipment was installed at ARC and SFOF to provide for mission control from these sites.

c. Ground operational equipment. The worldwide DSN provided the entire tracking, data acquisition, and command transmission during the free-flight portion of the *Pioneer VI* mission. To permit partial telemetry data processing in real time, three of the Deep Space Stations were supplied with mission-dependent equipment. As shown in the functional block diagram of Fig. 26, the in-line ground operational equipment consists of a command encoder, a computer buffer, and a demodulator–synchronizer. Associated test equipment consisting of a test transponder and an error-rate tester was also supplied to each of these three facilities; in addition, a data format generator was supplied to DSS 12. Display and plotting equipment for use during the Step II orientation was also supplied to DSS 12. Figure 27 is a photograph of the five racks of ground operational equipment supplied to DSS 12; at the other stations, only the three racks of ground operational equipment on the left (but without the data format generator) were supplied.

Table 13. Form and sequence of metric data transmitted from the Deep Space Stations

Sequence	Long-form format	Short-form format	Classification of data	Identification designation
1	C/R	C/R		Descriptor (precedes each data transmission)
	L/F	L/F	Station identification	
	F	F		
	XX S	XX S		
	02 S	03 S	Format identification	
	XX S	XX S	Spacecraft identification	
	XXXX S	XXXX S	Data condition	
	XXXXXX S	XXXXXX S	Greenwich Mean Time	
	XXX S	XXX S	Day of mission	
2	XXXXXXXXXX S	XXXXXXXXXX S	Doppler identification	Data transmission
3	XXXXXXXXXXX S	XXXXXXXXXXX S	Range and range dc	
4	XXXXXX S	—	Local hour angle	
5	XXXXXX S	—	Declination angle	

The in-line equipment, in conjunction with the mission-independent equipment shown in Fig. 27, processed the

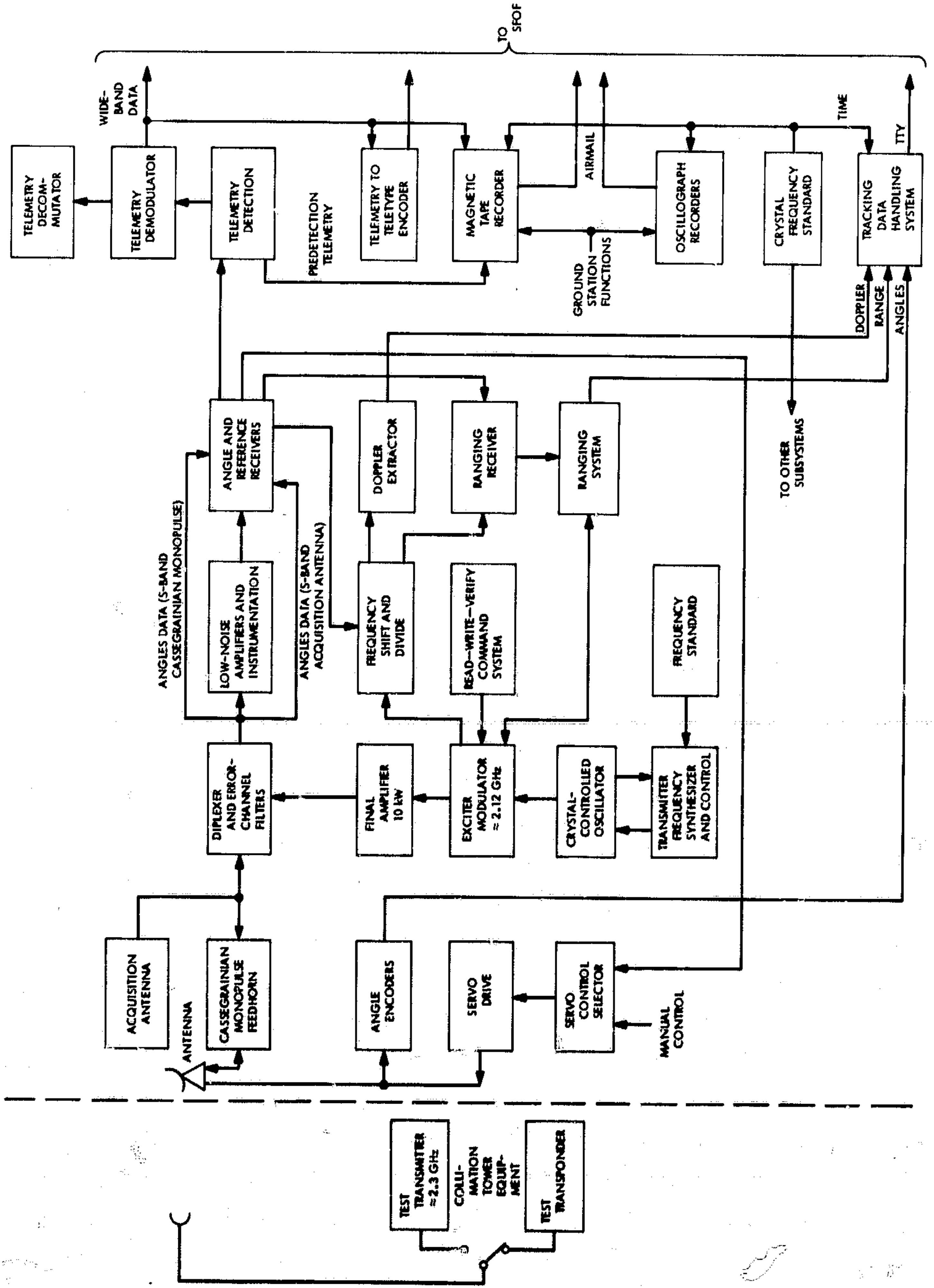


Fig. 22. *Pioneer VI typical Deep Space Station (S-band configuration)*

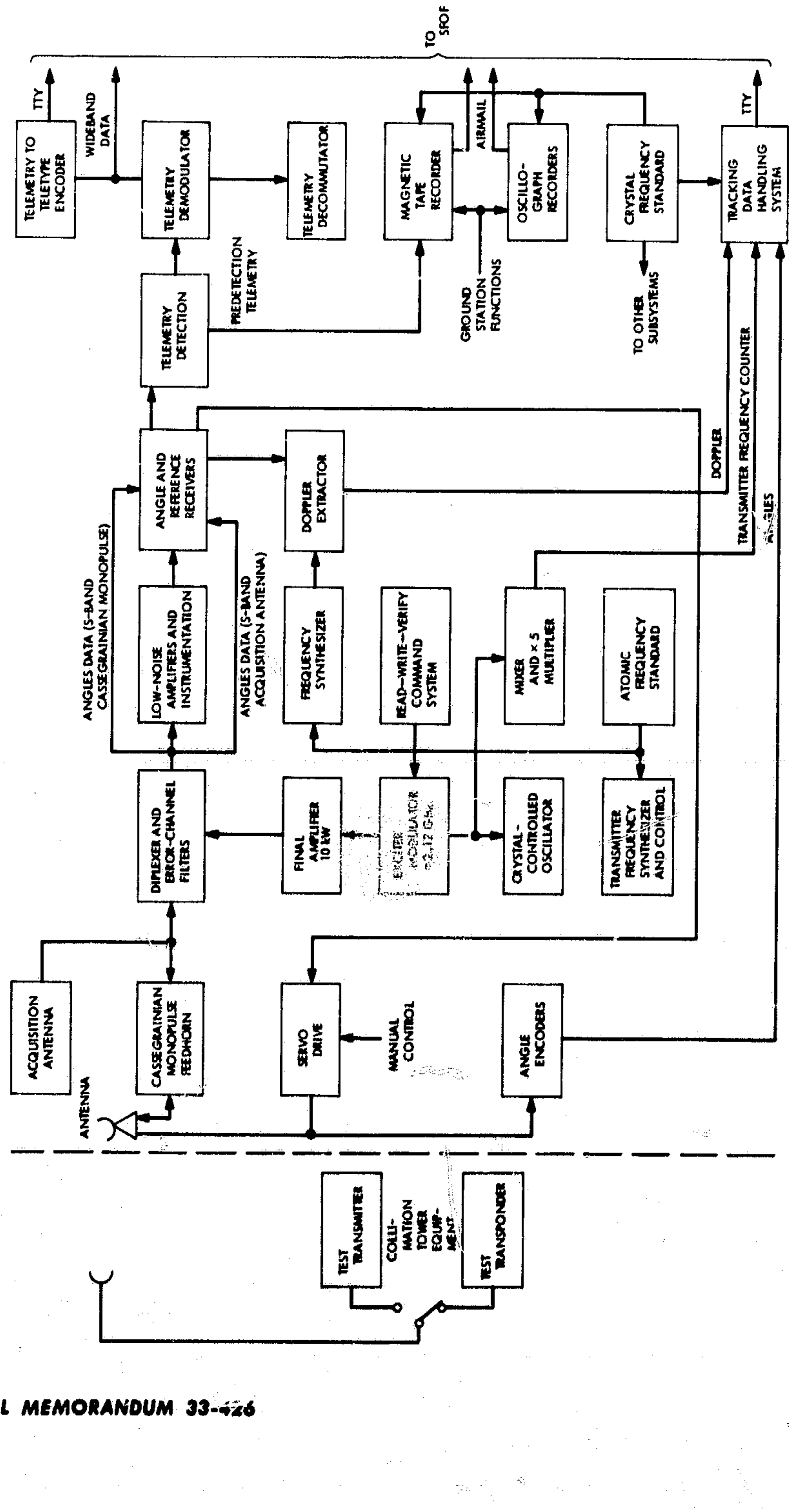


Fig. 23. Pioneer VI typical Deep Space Station (L- and S-band conversion)

Table 14. Deep Space Station tracking modes

Prefix	First digit identification		Last digit identification	
	Digit	Definition	Digit	Definition
GM	0	No receive (transmit only)	0	Not used
GM	1	1-way (receive only) doppler	1	Feedhorn–diplexer (85-ft antenna)
GM	2	2-way, 1-station (transmit–receive)	2	Acquisition antenna–diplexer (85-ft antenna)
GM	3	2-way, 2-station, noncoherent mode (receive only)	3	Acquisition antenna
GM	4	2-way, 2-station, coherent mode (receive, with reference signal from transmitting station)	4	Dipole (6-ft antenna)
GM	5	Receive only (no doppler)	5	Feedhorn without diplexer (85-ft antenna)

Table 15. Channel allocations

Channel	Mode	Frequency, MHz
6A	Receive	2292.037037
6B	Transmit	2110.584105
7A	Receive	2292.407407
7B	Transmit	2110.925154

spacecraft telemetry data to provide:

(1) Preselected spacecraft engineering data and up to 2176 words (7 bits long each) of consecutive spacecraft telemetry for immediate teletype transmission to the SFOF and ARC.

(2) Continuous evaluation of preselected engineering measurements and generation of alarm signals for teletype transmission to the SFOF and ARC (to indicate data-processing irregularities).

(3) Computer typewriter printout of preselected spacecraft engineering data and selectable engineering or scientific measurements.

(4) Displayed values of spacecraft parameters to verify uplink acquisition and the quality of spacecraft receiver lock.

(5) Preselected scientific data for immediate teletype transmission to Stanford University.

The system also prepares messages pertaining to the operating status of the ground operational equipment and computer and the parity error rate of the processed telemetry data for typewriter printout and teletype transmission.

Because of teletype limitations, the system could not transmit all the telemetry data received at the four highest bit rates. The telemetry data were therefore recorded on magnetic tape, together with command messages, verbal messages by station personnel during a *Pioneer* track, timing signals, and performance data pertaining to selected equipment, for later processing at the *Pioneer* off-line data processing station at ARC.

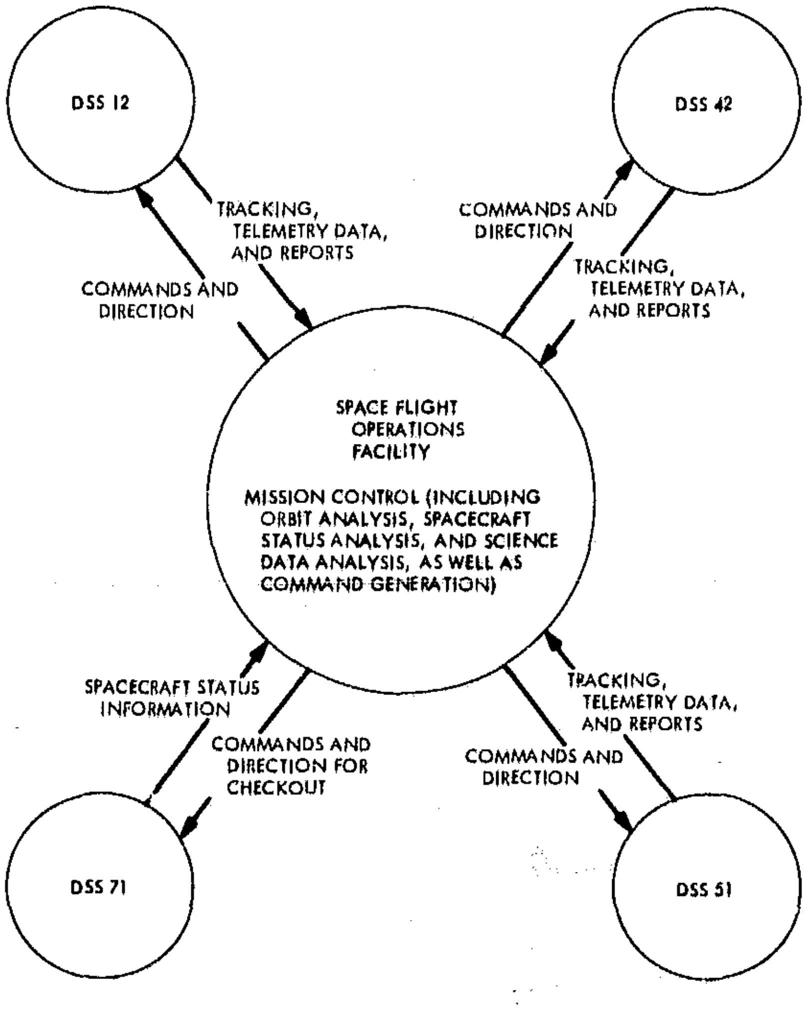


Fig. 24. Relationship of Deep Space Stations to the Space Flight Operations Facility

Demodulator–synchronizer. The function of the demodulator–synchronizer is to demodulate simultaneously the *Pioneer* telemetry subcarrier and generate a bit

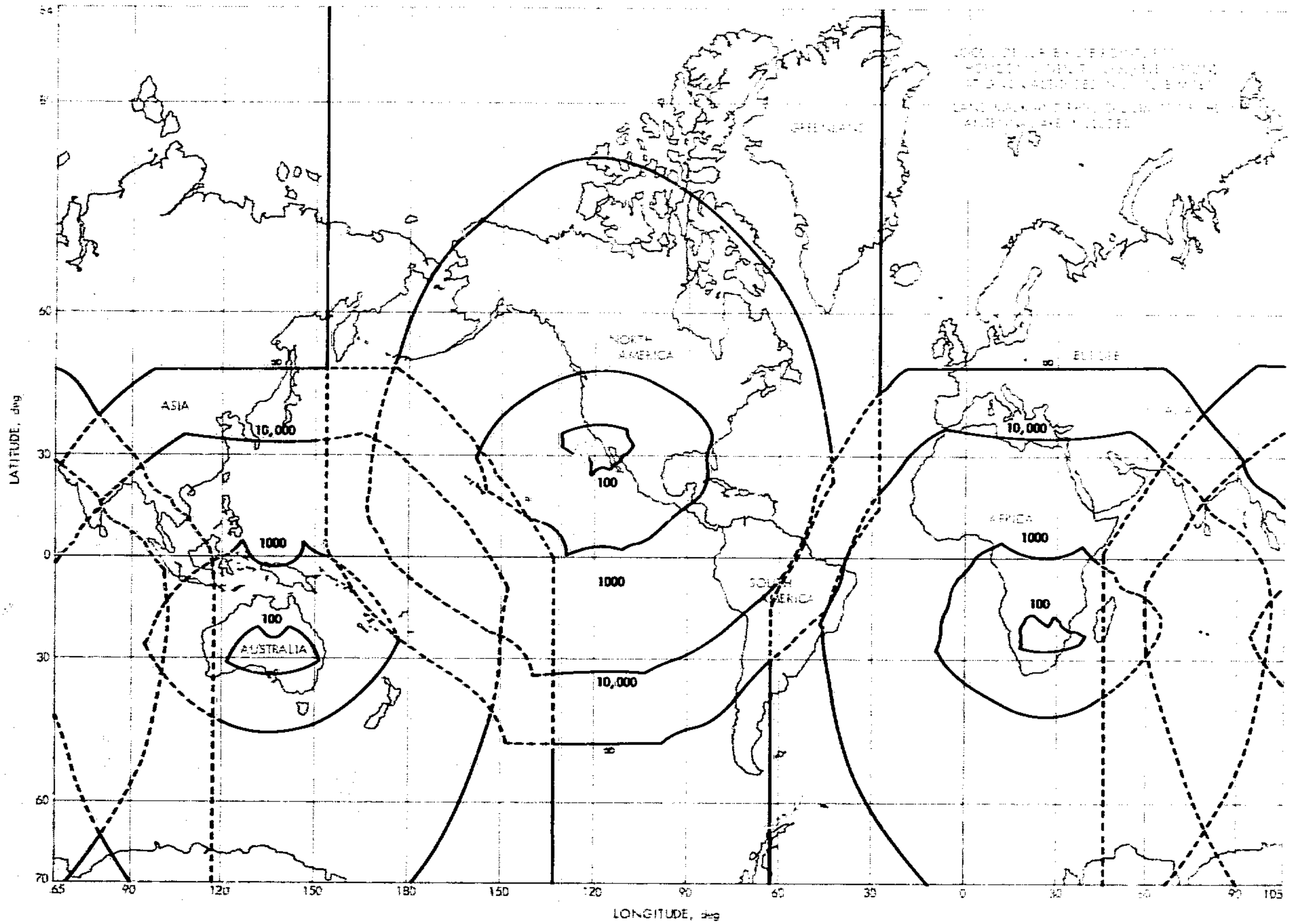


Fig. 25. Deep Space Station location and coverage

clock pulse train (synchronous with the data). The input to the demodulator–synchronizer is the biphase-modulated, 2.048-kHz subcarrier from the Deep Space Station receiver during tracking, but it can also be a similar signal from the data format generator, the error-rate tester, or the magnetic tape recorder during testing. (The output of the unit is a noise-free replica of the data bit stream, a pulse train synchronous with the data, and a sync status signal. For most conditions, operation of the demodulator–synchronizer is fully automatic except for source and bit rate selection.)

Command encoder. The command encoder produces a 23-s command message corresponding to a manually inserted command, which phase-modulated the Deep Space Station transmitter signal.

Command transmissions include a message that corresponds to a manually inserted command sequence. The computer was programmed to inhibit the transmission of such messages that were not included in the permissive command list. The command monitor receiver, in conjunction with the computer, provided verification that the transmitted message corresponded with the manually inserted command code.

The capabilities of the command communications system provide information relating to spacecraft command status, notation of the transmitted commands and their times of transmission, and verification (where possible) that commands have been acted upon within the spacecraft. These are accomplished by means of real-time computer typewriter printout at the Deep Space Stations.

Computer buffer. The computer buffer served as a communication link between the mission-dependent equipment and the computer. It accumulated data to be entered into the computer and distributed data from the computer. The buffer provided audible and visible alarms when either bit synchronization or word synchronization was lost or when spacecraft engineering data were out of limits.

Test equipment. Useful for all *Pioneer* missions, the test equipment simulated the spacecraft communications in all the various modes of operation for use during checkout of the in-line mission-dependent and -independent equipment. The test equipment also facilitates troubleshooting of the ground operational equipment.

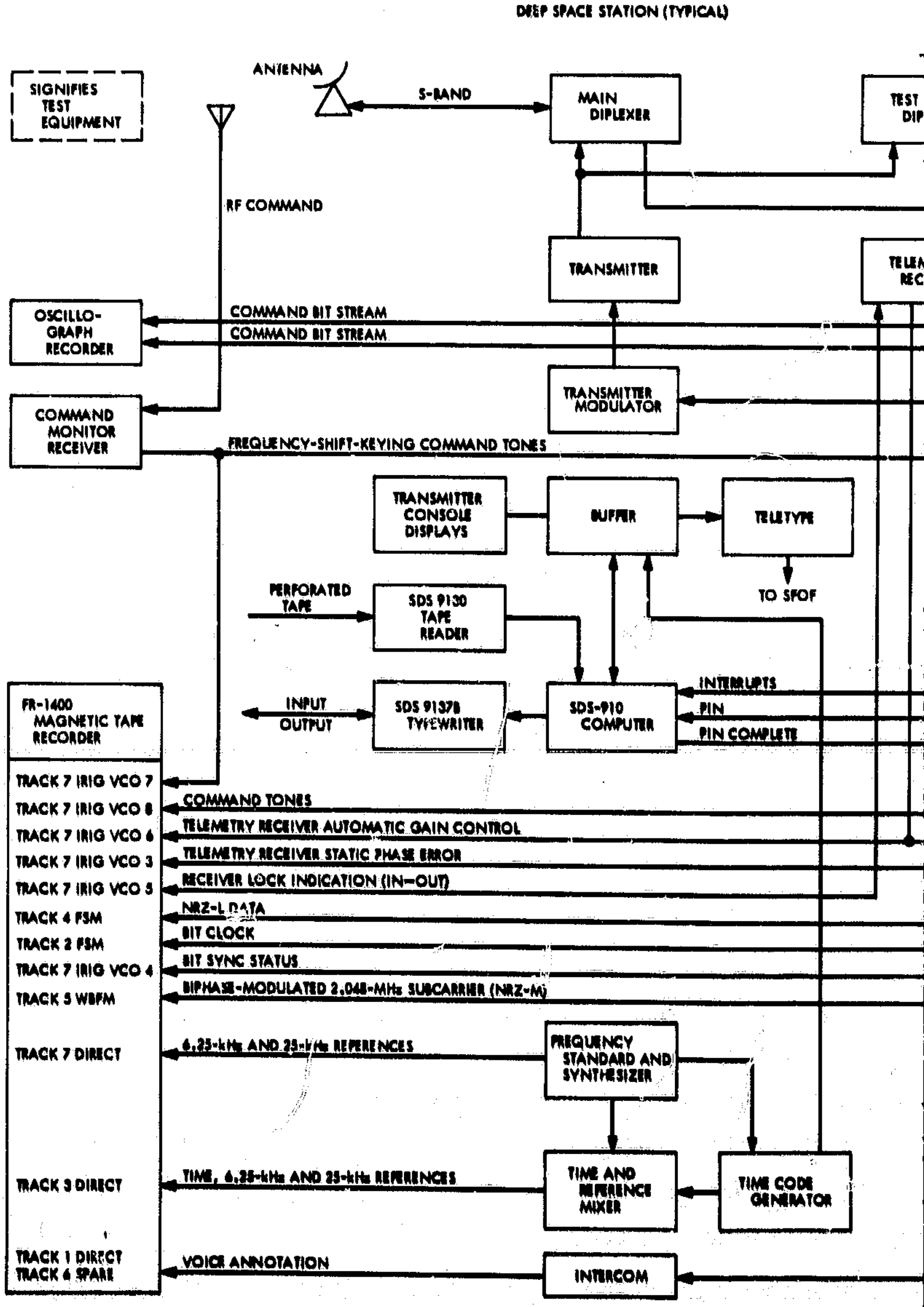
The transponder has a receiver (two receivers in the DSS 12 unit), a command decoder (a display in the DSS 12 unit), and a transmitter driver that can be suitably modulated and that produces an S-band signal whose strength can be attenuated over a range of 100 dB. The transponder can operate in either a coherent or noncoherent mode. The data format generator produces a simulated spacecraft data bit stream that can modulate the transponder or be sent directly to the demodulator–synchronizer or to the computer buffer. To evaluate the performance of the demodulator–synchronizer, the error-rate tester supplies the demodulator–synchronizer with a biphase-modulated 2.048-kHz square-wave subcarrier of selectable signal-to-noise ratio and known bit sequence. The tester compares the reconstructed data returned by the demodulator with the original bit sequence. The data stream available from the data format generator can be substituted for the bit sequence generated within the tester to simulate a modulated spacecraft telemetry subcarrier of known signal-to-noise ratio.

d. Electrical ground support equipment. The electrical ground support equipment of the *Pioneer* Project was designed and built to support testing and performance evaluation of the spacecraft before launch; it was the central point for test control and monitoring, command transmission, telemetry acquisition, spacecraft subsystem simulation, and the processing, display, and recording of spacecraft and scientific instrument data. This equipment, which comprises various assemblies, together with their relationship to the spacecraft, is shown in Fig. 28. Several of these assemblies (such as the demodulator–synchronizer, the command encoder, and the computer buffer) are similar to those used in the ground operational equipment.

The electrical ground support equipment (Fig. 29) is composed of a digital computer subsystem and five dolly-mounted consoles: the ground power console, test console, recorder console, radio-frequency console, and telemetry data console.

The digital computer subsystem, which processes (in real-time) spacecraft data received from the demodulator–synchronizer, consists of a digital computer, typewriter, line printer, paper tape reader, and paper tape punch. The subsystem controls the spacecraft status and telemetry data displays and performs a number of computations, so that the printout of spacecraft and scientific instrument data is in meaningful measurements and units and in a form suitable for analysis and evaluation.

The ground power console provides and controls power to the spacecraft during tests and monitors the spacecraft bus and battery voltages and currents.


DEEP SPACE STATION (TYPICAL)
SIGNIFIES TEST EQUIPMENT
ANTENNA
S-BAND
MAIN DIPLEXER
TEST
RF COMMAND
TRANSMITTER
OSCILLO-GRAPH RECORDER
COMMAND BIT STREAM
COMMAND BIT STREAM
TRANSMITTER MODULATOR
COMMAND MONITOR RECEIVER
FREQUENCY-SHIFT-KEYING COMMAND TONES
TRANSMITTER CONSOLE DISPLAYS
BUFFER
TELETYPE
TO SFOF
PERFORATED TAPE
SDS 9130 TAPE READER
INPUT
OUTPUT
SDS 91378 TYPEWRITER
SDS-910 COMPUTER
INTERRUPTS
PIN
PIN COMPLETE
FR-1400 MAGNETIC TAPE RECORDER
TRACK 7 IRIG VCO 7
TRACK 7 IRIG VCO 8
TRACK 7 IRIG VCO 6
TRACK 7 IRIG VCO 3
TRACK 7 IRIG VCO 5
TRACK 4 FSM
TRACK 2 FSM
TRACK 7 IRIG VCO 4
TRACK 5 WBFM
TRACK 7 DIRECT
TRACK 3 DIRECT
TRACK 1 DIRECT
TRACK 6 SPARE
COMMAND TONES
TELEMETRY RECEIVER AUTOMATIC GAIN CONTROL
TELEMETRY RECEIVER STATIC PHASE ERROR
RECEIVER LOCK INDICATION (IN—OUT)
NRZ-L DATA
BIT CLOCK
BIT SYNC STATUS
BIPHASE-MODULATED 2.048-MHz SUBCARRIER (NRZ-M)
6.25-kHz AND 25-kHz REFERENCES
FREQUENCY STANDARD AND SYNTHESIZER
TIME, 6.25-kHz AND 25-kHz REFERENCES
TIME AND REFERENCE MIXER
TIME CODE GENERATOR
VOICE ANNOTATION
INTERCOM

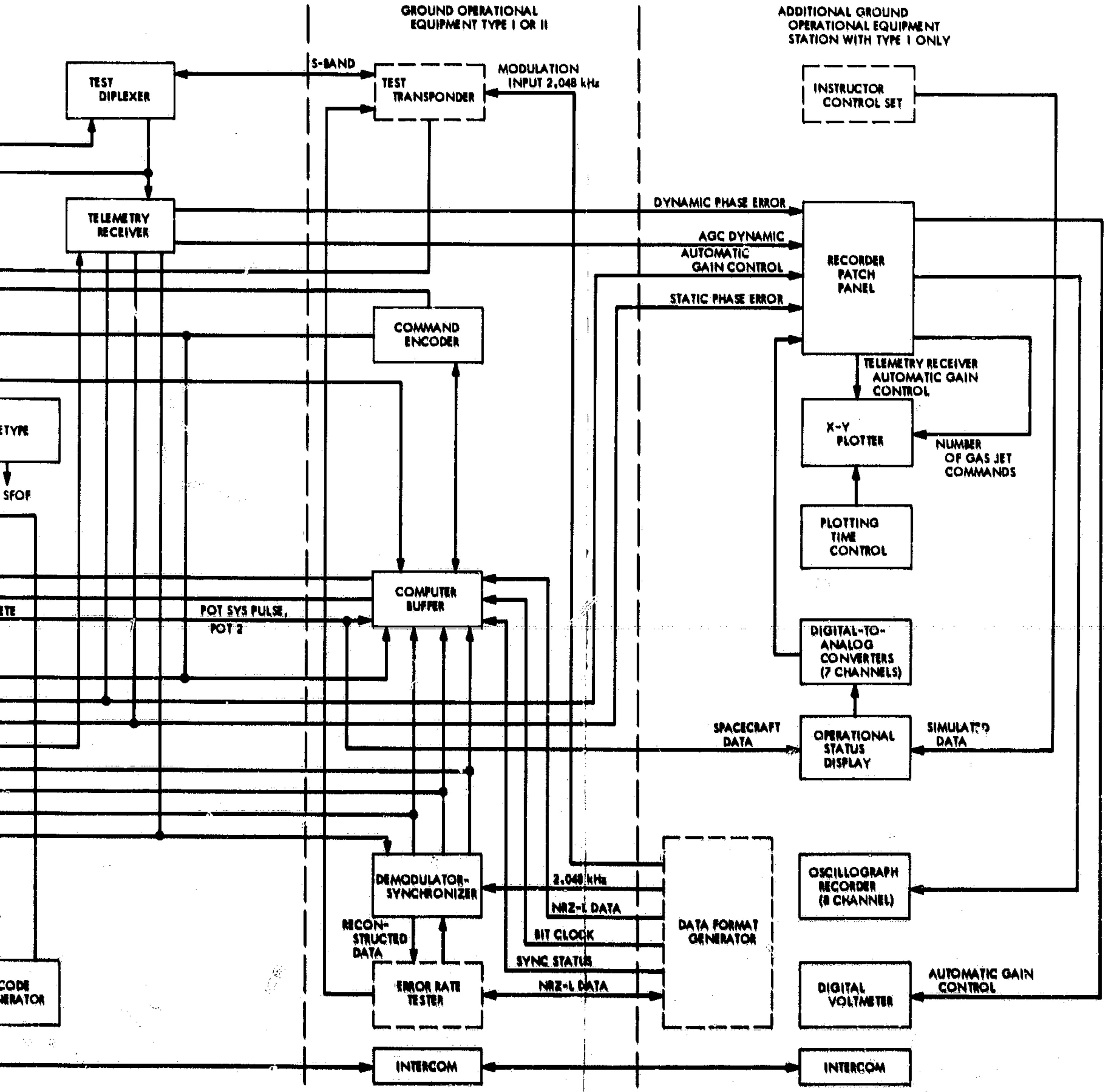


Fig. 26. Ground operational equipment functional block diagram

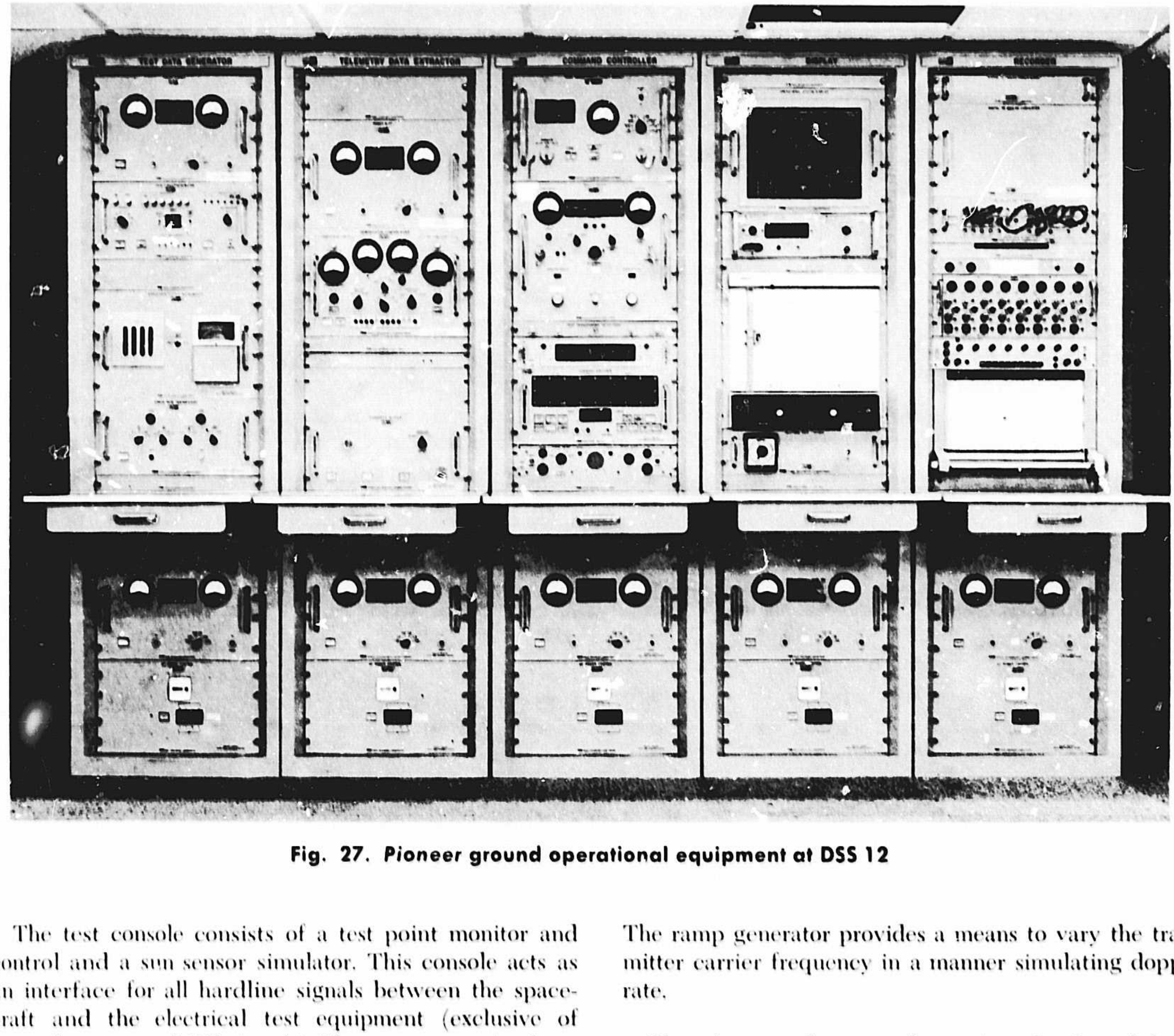


Fig. 27. *Pioneer* ground operational equipment at DSS 12

The test console consists of a test point monitor and control and a sun sensor simulator. This console acts as an interface for all hardline signals between the spacecraft and the electrical test equipment (exclusive of ground power and RF signals). The sun sensor simulator provides signals to the orientation subsystem that simulates operation of the five sun sensors. Various spacecraft spin rates can also be simulated.

The recorder console consists of an instrumentation patch panel, a direct-write analog eight-channel oscillograph, and a magnetic tape recorder. The latter provides the capability for recording signals and playing them back.

The RF console contains the command transmission and data receiving equipment, which consists of a command encoder, command transmitter, ramp generator, antenna, and telemetry receiver. The command encoder has no capability for a permissive command list check. The ramp generator provides a means to vary the transmitter carrier frequency in a manner simulating doppler rate.

The telemetry data console consists of a demodulator–synchronizer, computer buffer, data format generator, and display units, all with functions comparable to like units of the ground operational equipment.

In addition to the above, a sun sensor stimulator is available that can apply appropriate light pulses to the sun sensors to check their operation.

e. Commands. The *Pioneer* spacecraft command messages were generated semiautomatically under operator control in the command encoder. The encoder may generate up to 128 unique 23-bit command messages in the format recognized by the spacecraft, including preamble, sync, address, command complement, command, and postsquelch bits. The command and address portions of the messages were generated in binary-coded octal format and placed in a 10-bit register. The register contents were changed to frequency-shift-keying tones for RF transmission. A binary one (1) is represented by a 240-Hz sine wave and a binary zero (0) by a 150-Hz sine wave. Figure 30 is a block diagram of the DSS command signal flow for normal operations.

Any command or commands deemed necessary for corrective actions or for achieving a spacecraft mission required prior approval by the Space Flight Operations Director (SFOD). Upon concurrence of the project manager, the commands were transmitted to the Deep Space Station for execution. Command requests were made only by the technical and operations teams within the SFOF using approved command-decision procedures outlined in the spacecraft operating procedures.

Routine command sequences were listed in the daily operations plan for station passes. After approval of the daily operations plan by the project manager, the SFOD was responsible for routine execution of such commands. All *Pioneer* commands sent in the normal command mode were transmitted under computer control and then checked against a permissive command tape loaded into the SDS 910 computer at the beginning of a pass or segment of the operation.

The SDS 910 computer verified the commands sent to the spacecraft at three different times: (1) pretransmission, (2) during transmission, and (3) posttransmission.

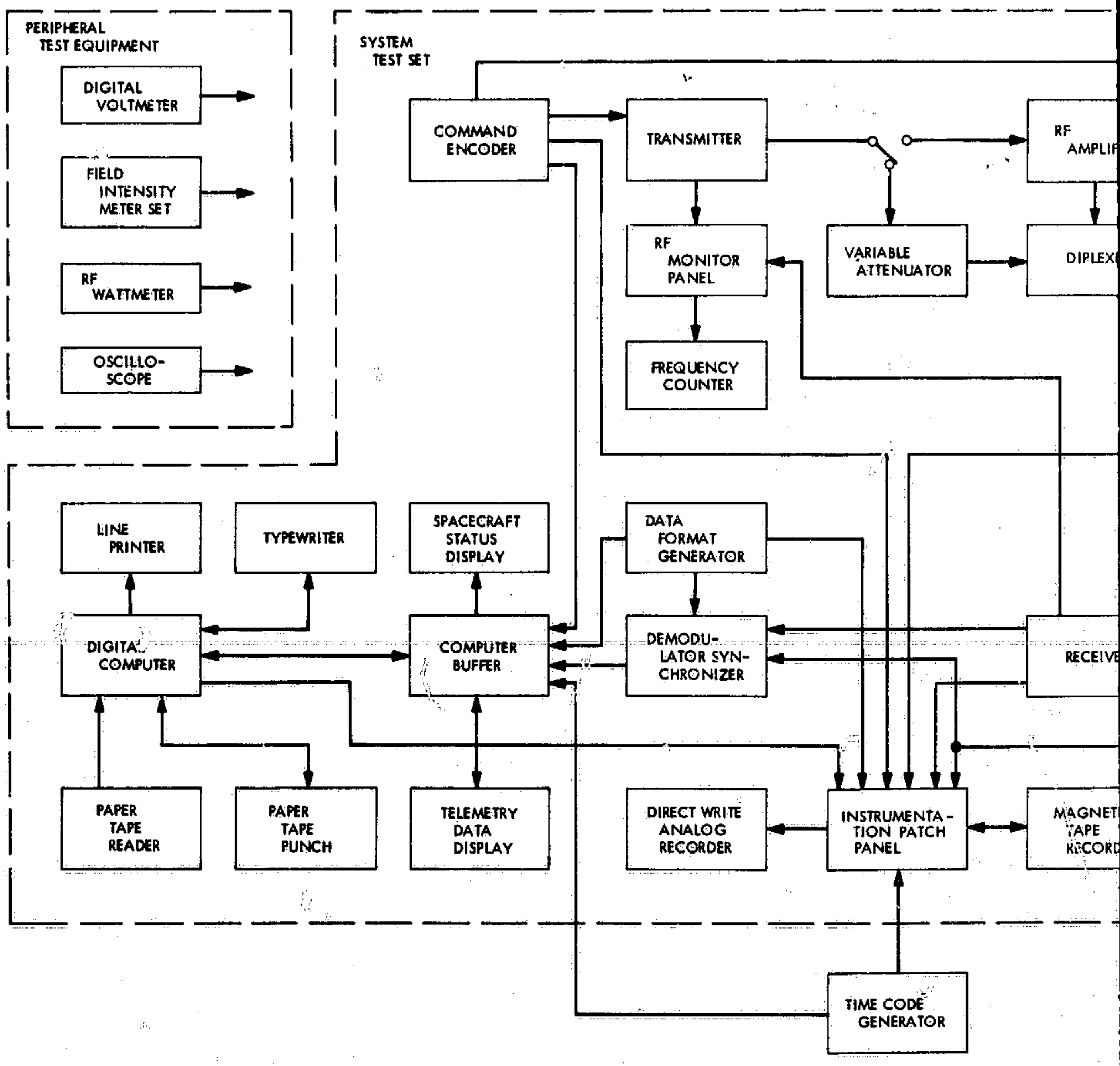
To accomplish pretransmission verification, a perforated tape was loaded into the computer (containing the applicable spacecraft command decoder address and all permissible commands) at the beginning of each pass. After the operator had manually selected both the spacecraft decoder address and the command, the computer could be interrogated (by use of a button on the command encoder that caused a computer interrupt) to verify that manual selection was indeed permissible for the pass. When the command was permissible, a signal was sent to the command encoder to visually indicate the fact. If the manual command was not permissible for any reason, an appropriate message would be typed out.

During each transmission of the command, the command generator sent 23 interrupts to the computer (at 1 bit/s). At the same time, the outputs of the command monitor receiver were also available as a computer input. On this basis, the computer could check each of the 23 bits as they were serially transmitted. If any of the bits were incorrect, the computer would generate an output signal to inhibit any further transmission; the computer would also type and punch an appropriate message to generate an alarm. If all 23 bits verified properly, a message was both punched and typed, indicating that a spacecraft command was sent to the spacecraft at the indicated time.

The posttransmission verification was based on received telemetry signals. If the transmitted command was verifiable, it was entered into a *command sent* storage list. Then, as changes were detected in the spacecraft status bits from the received telemetry, these changes would be verified against the contents of the *command sent* list. Should any status bits change without having been called for by a command, an appropriate message would be typed and punched, and an alarm signal generated. Furthermore, the contents of the *command sent* list were printed out at the end of each standard printout. Hence, if a command had been sent but not executed, this could be readily seen on the basis of the typed output.

Assuming normal spacecraft operation, all commands were prohibited during the launch phase through the completion of Step I. All commands were permitted after the conclusion of the initial Step I maneuver.

2. *Ground Communications Facility.* The DSN Ground Communications Facility is the means by which the Deep Space Stations communicate with the SFOF. The Ground Communications Facility provides interfacility as well as on-site communications and an overall operational communications complex for flight project support. Communications responsibilities for the *Pioneer* Project include controlling, operating, and maintaining all circuits, switching, and terminal equipment committed to *Pioneer.* Goddard Space Flight Center is responsible for technical control of all NASCOM circuits used by the DSN. (Technical control includes maintenance of the communications network.) In fulfillment of the responsibility for technical control, GSFC informs JPL of the availability and condition of alternate circuits during periods of use, but does not perform the actual switching without prior approval of JPL, which has responsibility for mission control of the NASCOM circuits used by the DSN. Mission control, by contrast, means the determination of what traffic will flow, when and to what points this traffic will flow, and on what circuits the flow will occur. Communication lines between the various Deep Space Stations and the SFOF are shown in Fig. 31. The AFETR communications and circuits to ARC, Stanford University, and TRW are also shown.


PERIPHERAL TEST EQUIPMENT
DIGITAL VOLTMETER
FIELD INTENSITY METER SET
RF WATTMETER
OSCILLO-SCOPE
SYSTEM TEST SET
COMMAND ENCODER
TRANSMITTER
RF AMPLIF
RF MONITOR PANEL
VARIABLE ATTENUATOR
DIPLEX
FREQUENCY COUNTER
LINE PRINTER
TYPEWRITER
SPACECRAFT STATUS DISPLAY
DATA FORMAT GENERATOR
DIGITAL COMPUTER
COMPUTER BUFFER
DEMODU-LATOR SYN-CHRONIZER
RECEIVE
PAPER TAPE READER
PAPER TAPE PUNCH
TELEMETRY DATA DISPLAY
DIRECT WRITE ANALOG RECORDER
INSTRUMENTA-TION PATCH PANEL
MAGNET TAPE RECORD
TIME CODE GENERATOR

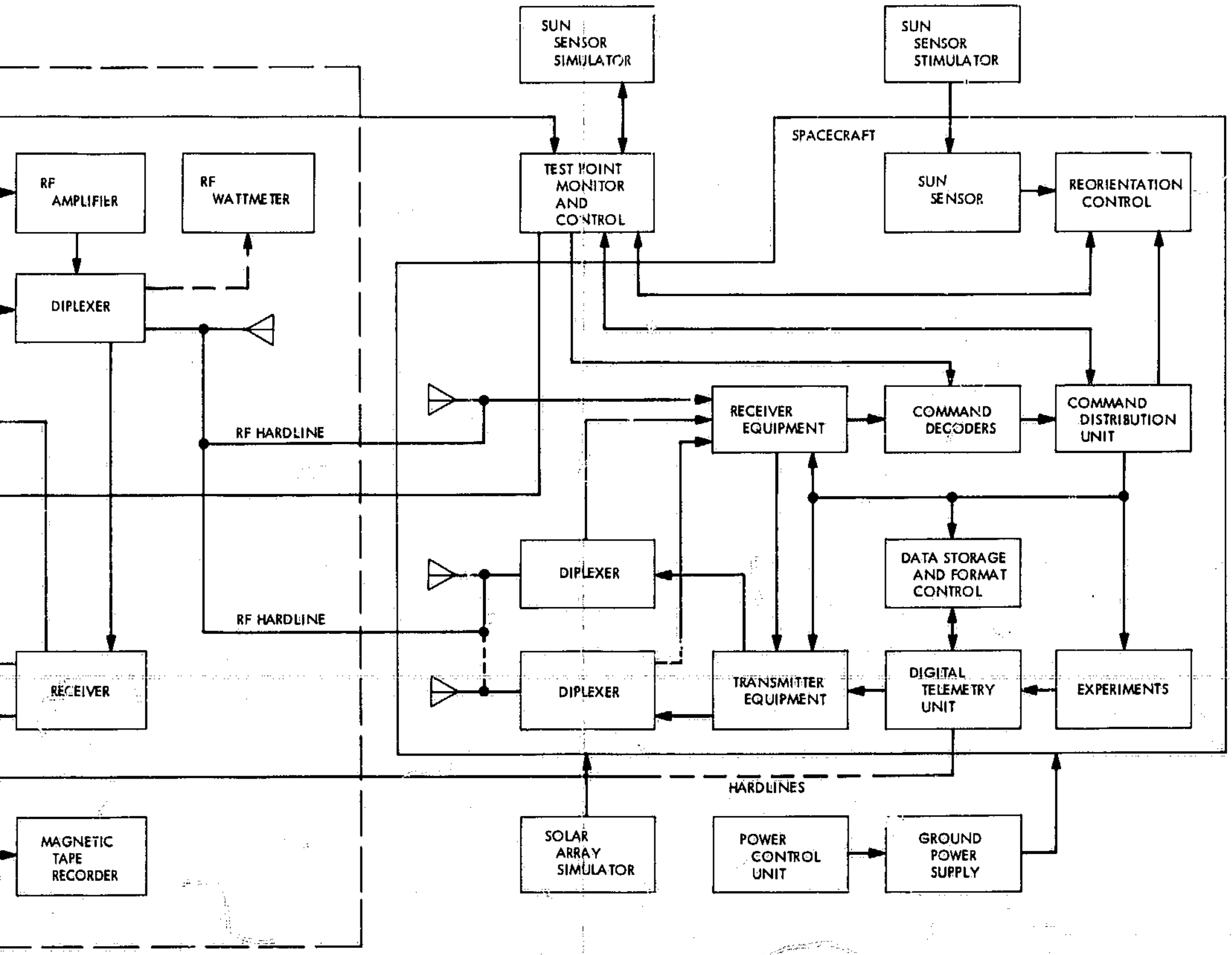


Fig. 28. Block diagram of electrical ground support equipment showing relationship to spacecraft

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED.

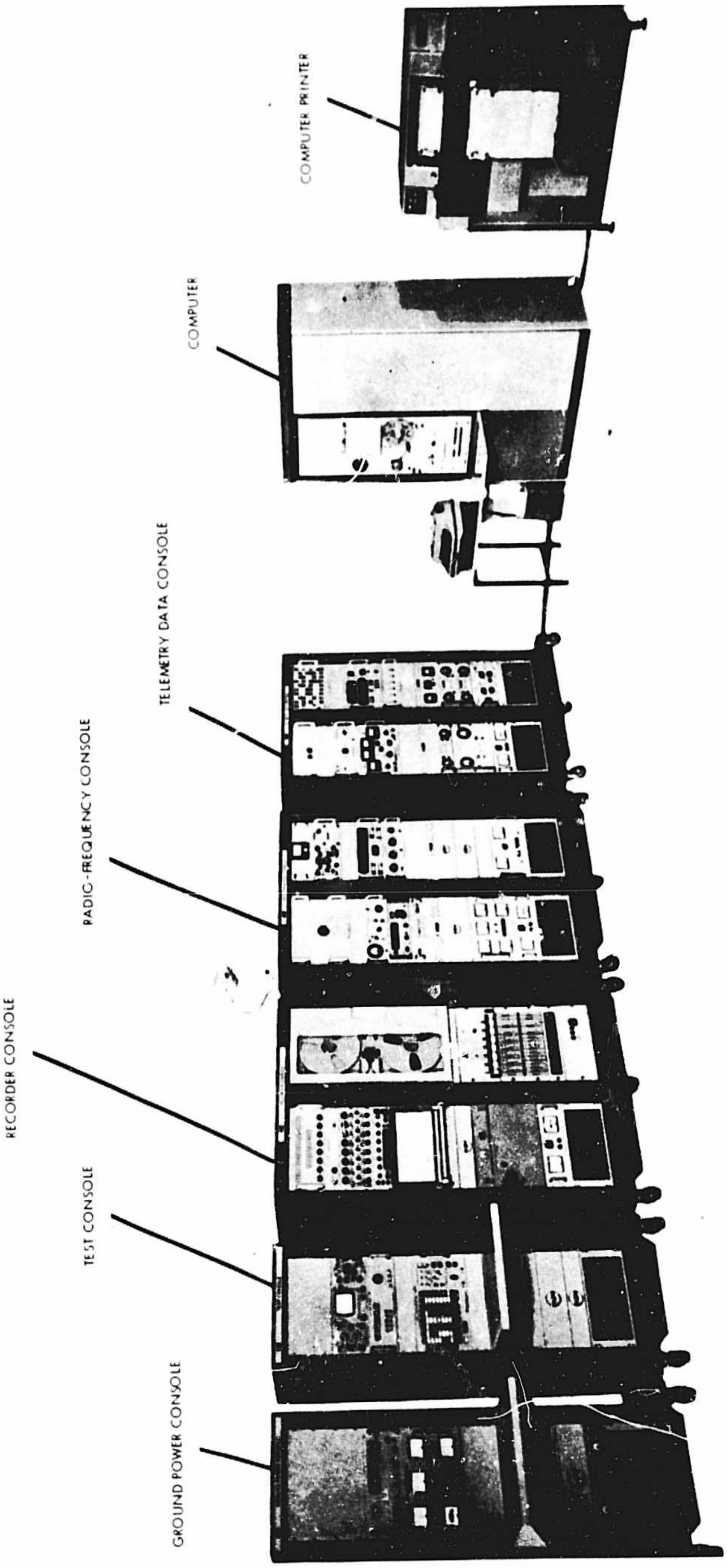


Fig. 29. Electrical ground support equipment system test station

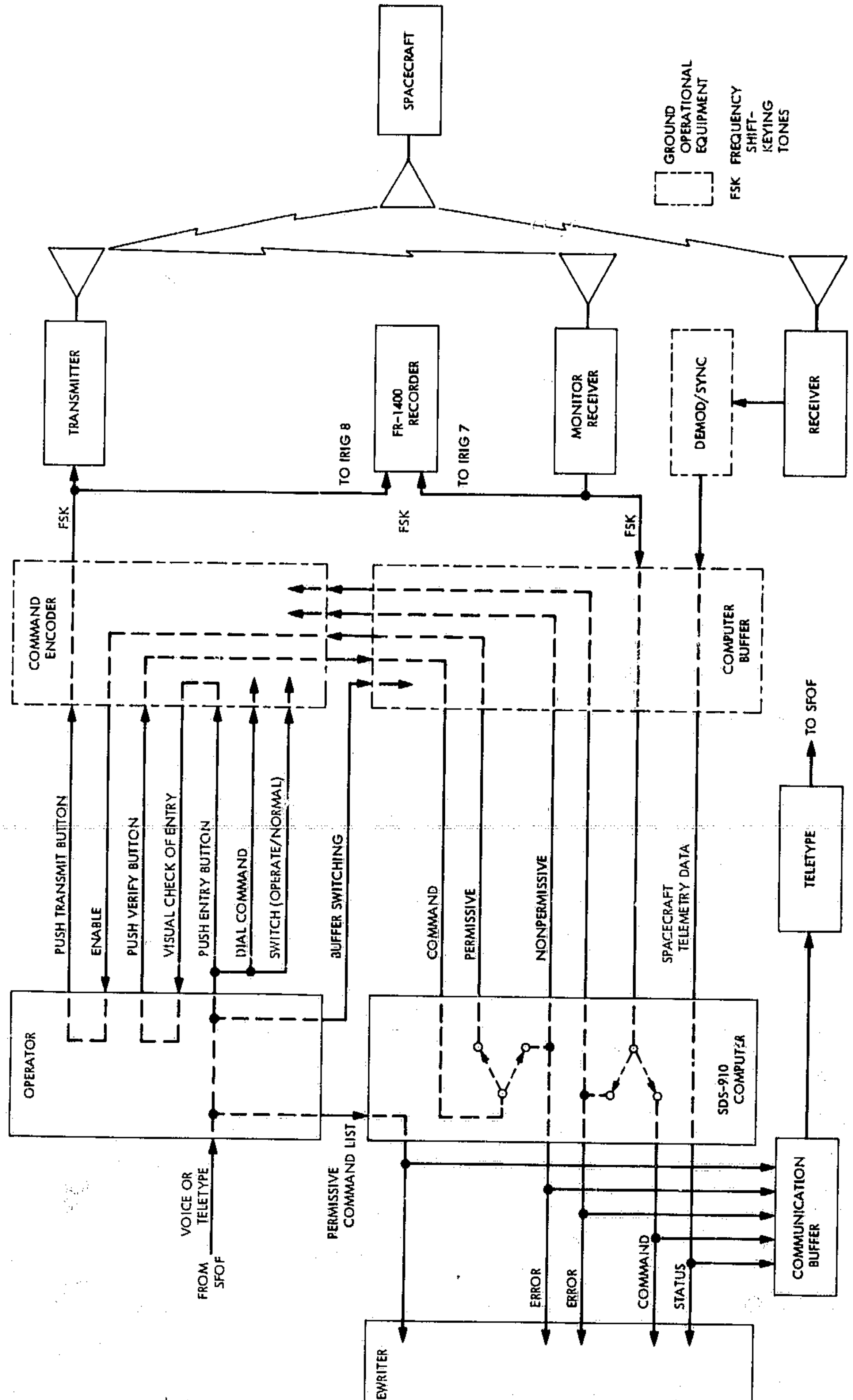
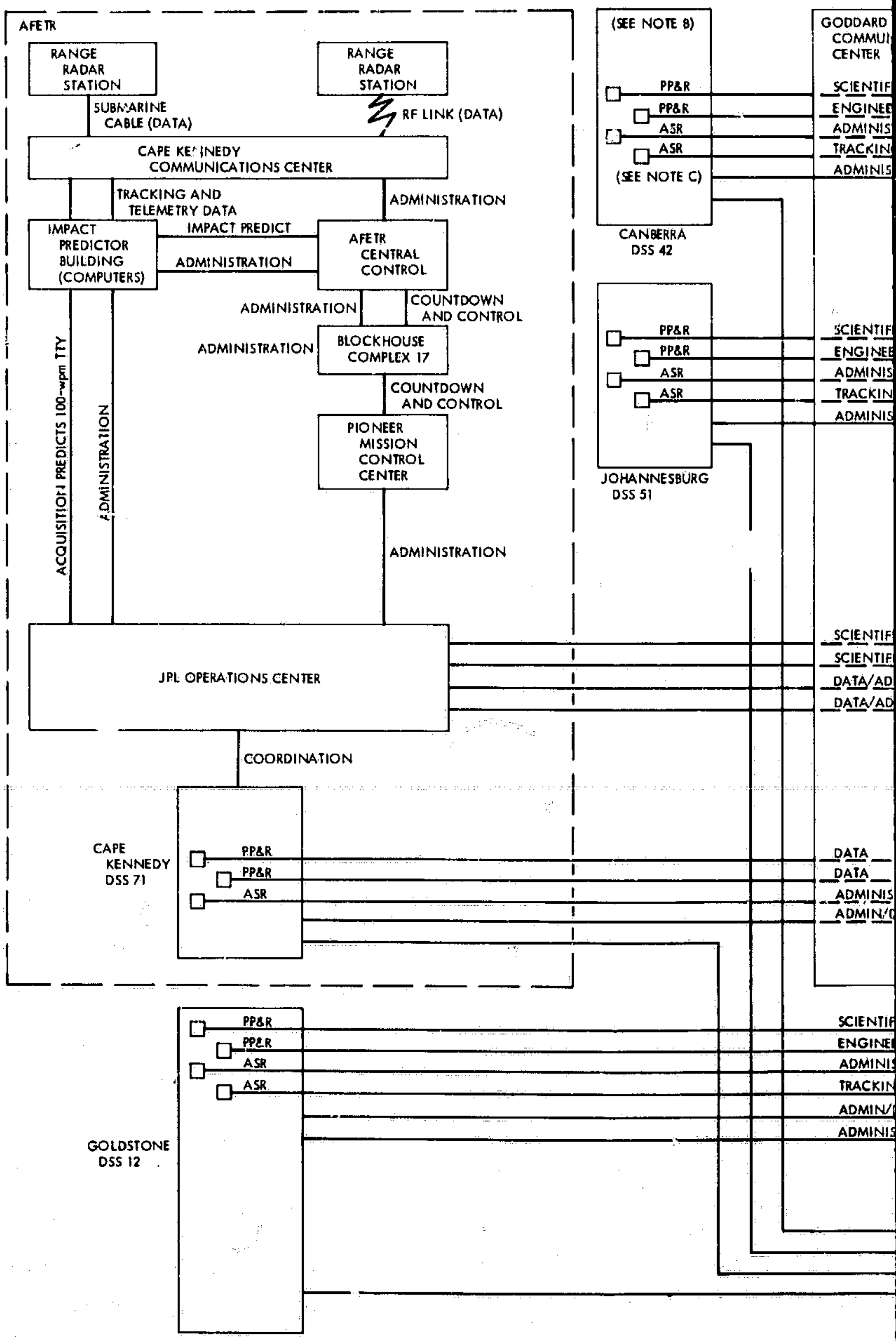
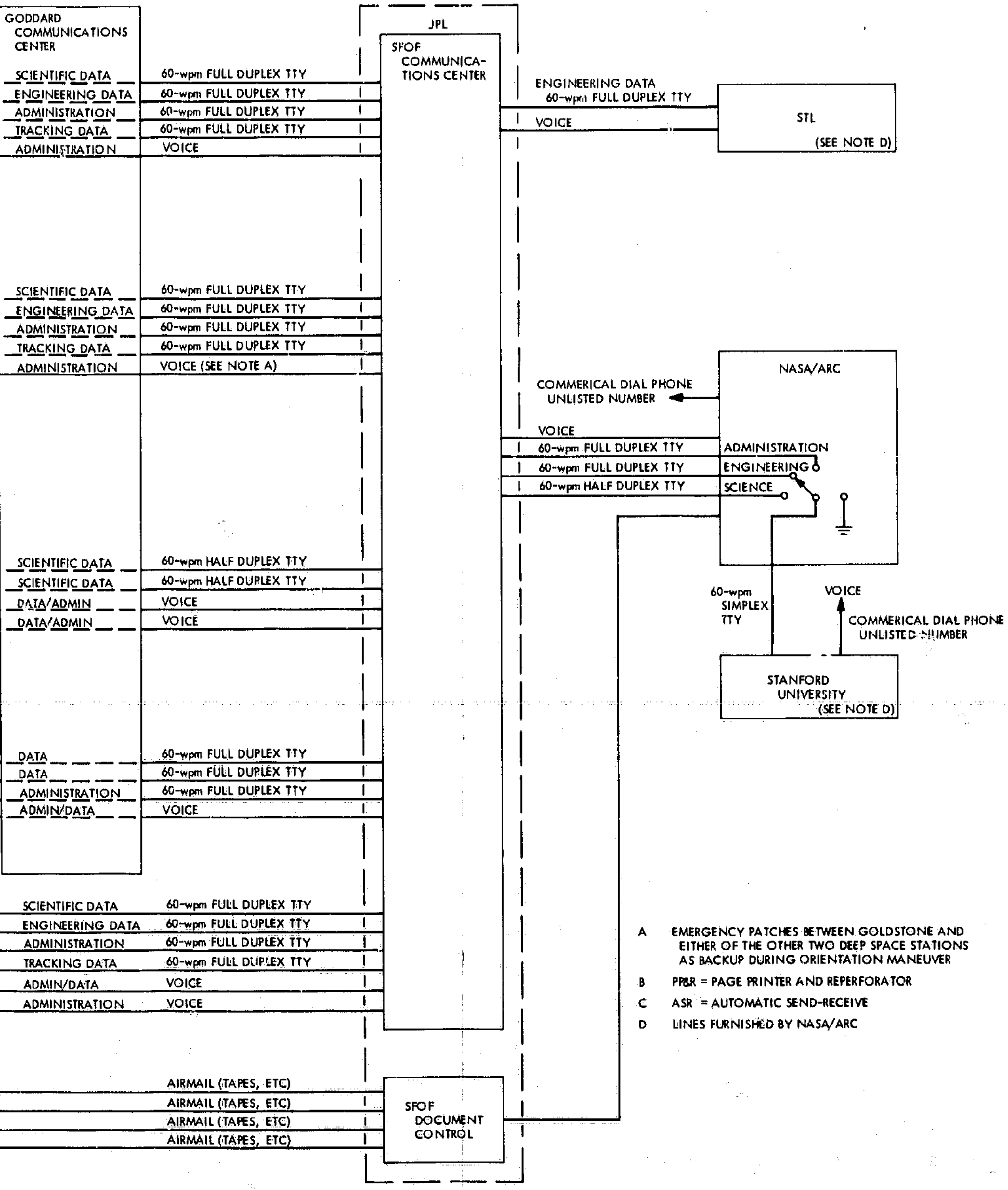


Fig. 30. Command signal flow for normal operations, DSIF


AFETR
RANGE RADAR STATION
RANGE RADAR STATION
SUBMARINE CABLE (DATA)
RF LINK (DATA)
CAPE KENNEDY COMMUNICATIONS CENTER
TRACKING AND TELEMETRY DATA
ADMINISTRATION
IMPACT PREDICTOR BUILDING (COMPUTERS)
IMPACT PREDICT
ADMINISTRATION
AFETR CENTRAL CONTROL
ADMINISTRATION
COUNTDOWN AND CONTROL
ADMINISTRATION
BLOCKHOUSE COMPLEX 17
COUNTDOWN AND CONTROL
PIONEER MISSION CONTROL CENTER
ACQUISITION PREDICTS 100-wpm TTY
ADMINISTRATION
ADMINISTRATION
JPL OPERATIONS CENTER
COORDINATION
CAPE KENNEDY DSS 71
PP&R
PP&R
ASR
GOLDSTONE DSS 12
PP&R
PP&R
ASR
ASR
(SEE NOTE B)
PP&R
PP&R
ASR
ASR
(SEE NOTE C)
CANBERRA DSS 42
PP&R
PP&R
ASR
ASR
JOHANNESBURG DSS 51
GODDARD COMMU
CENTER
SCIENTIF
ENGINEE
ADMINIS
TRACKIN
ADMINIS
SCIENTIF
ENGINEE
ADMINIS
TRACKIN
ADMINIS
SCIENTIF
SCIENTIF
DATA/AD
DATA/AD
DATA
DATA
ADMINIS
ADMIN/
SCIENTIF
ENGINE
ADMINIS
TRACKIN
ADMIN/
ADMINIS



A EMERGENCY PATCHES BETWEEN GOLDSTONE AND EITHER OF THE OTHER TWO DEEP SPACE STATIONS AS BACKUP DURING ORIENTATION MANEUVER

B PP&R = PAGE PRINTER AND REPERFORATOR

C ASR = AUTOMATIC SEND-RECEIVE

D LINES FURNISHED BY NASA/ARC

Fig. 31. *Pioneer VI* communications lines

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED.

a. Circuits. Table 16 lists the circuit types and functions that are the responsibility of the DSN in support of the *Pioneer* Project. Although the actual circuit designations are given, NASCOM has reserved the privilege of using alternate circuits of different designations when it is considered that such actions are justified. At the time of launch, all allocated circuits were ready to support the mission. Figure 31 shows the communication lines between the various agencies supporting *Pioneer VI.*

b. Personnel. Through simulation testing, local communications personnel became familiar with Project-peculiar requirements. These personnel, therefore, were qualified to effectively support the Project by launch date.

c. Procedures. Normal communications procedures involving facility configuration freeze and NASCOM special coverage were provided for the launch period.

3. *Space Flight Operations Facility.* The SFOF is a flexible facility in which areas and hardware can be set up and restructured as required to meet the needs of various projects.

a. Areas. The DSN, in meeting the requirements of the *Pioneer VI* mission, makes use of the following areas (see also Fig. 32):

(1) *Pioneer* mission support area (Fig. 33).

(2) Operations area, Room 113.

(3) Mission control, Room 2.

(4) Flight path analysis area, Room 117 (Fig. 34).

(5) Project manager, Room 115A.

(6) Gallery.

(7) DSIF control, Rooms 101 and 101A.

(8) DSN control, Room 118.

b. Systems. The data processing, telemetry, and support systems are used in support of the *Pioneer* missions as described in the following subparagraphs.

The data processing system includes the processing of tracking data for the establishment of a maximum-accuracy orbit and for DSS predicts. The telemetry processing station processes data for validation purposes. This station receives telemetry magnetic tapes for reproduction. During the reproduction (duplicating) process, the telemetry station provides data validation by monitoring and verifying recording levels, and by inspecting recorded data for continuity.

A data log on each tape is generated, containing the following indications:

(1) Receiver flag (a time printout occurring each time there is a receiver out-of-lock state).

(2) Demodulator flag (a time printout occurring each time there is a demodulator out-of-lock state).

(3) Time flag (an error printout occurring when the *delta* time disagrees with the data rate).

Validation is accomplished on the duplicated tape. After processing, the telemetry processing station returns the original tapes along with the duplicate and one copy of the data log to the SFOF operational document control office for shipment to the *Pioneer* Project Office.

All areas within the SFOF assigned to *Pioneer* have a complement of intracommunications devices.

c. Support system. The DSN/SFOF support system includes:

(1) Maintenance of electrical and air-conditioning systems.

(2) Preparation of display boards.

(3) Receiving, distribution, and shipping of data by the operational document control group.

(4) Technical assistance.

(5) Scheduling.

The following paragraphs give a brief summary of the status and activities of each of these functions.

Electrical and air-conditioning system. These systems, including the backup power system, have been maintained in their normal manner and are ready to support *Pioneer* requirements in the SFOF.

Displays. The SFOF operations group prepares all displays that are not the responsibilities of the data processing and communications groups. All displays are operational. These displays include those in the flight path analysis area.

Operational document control. In its nonreal-time, mission-independent function, this group receives, logs, and distributes data from the Deep Space Stations. Data are forwarded to the telemetry processing station. After processing, the data packages are shipped to ARC.

Table 16. Ground communications facility circuits allocated to the *Pioneer* Project

Circuit	Type	Interconnecting	Remarks
NST 3004	Full-duplex teletype	PMSA[a]–ARC[b]	Full period[c]
NST 3010	Half-duplex teletype	PMSA–ARC	Full period
NST 3011	Half-duplex teletype	PMSA–ARC	Full period
GP 58336	Voice	PMSA–ARC	Full period
NST 3012	Full-duplex teletype	PMSA–TRW (STL)[d]	Full period
GP 58337	Voice	PMSA–STL	Full period
GT 58935/GT 58925	Full-duplex teletype	SFOF[e]–DSS 71	Scheduled[f]
GT 58936/GT 58926	Full-duplex teletype	SFOF–DSS 71	Scheduled
GT 58937/GT 58927	Full-duplex teletype	SFOF–DSS 71	Scheduled
GDA 58487/GDA 58490	Voice	SFOF–DSS 71	Scheduled
GT 58938/GT 58928	Full-duplex teletype	SFOF–Building AO	Scheduled
GT 58939/GT 58929	Full-duplex teletype	SFOF–Building AO	Scheduled
GT 58947/GT 58891	Full-duplex teletype	SFOF–Building AO	Scheduled
GDA 58472[g]/GDA 58193[g]	Voice	SFOF–Building AO	Scheduled
GDA 58473[h]/GDA 58195[h]	Voice	SFOF–Building AO	Scheduled
TK 1	Full-duplex teletype	SFOF–DSS 12	Scheduled
TK 2	Full-duplex teletype	SFOF–DSS 12	Scheduled
TK 3	Full-duplex teletype	SFOF–DSS 12	Scheduled
TK 4	Full-duplex teletype	SFOF–DSS 12	Scheduled
TK 5	Full-duplex teletype	SFOF–DSS 12	Scheduled
TK 6	Full-duplex teletype	SFOF–DSS 12	Scheduled
GDA 7215	Full-duplex teletype	SFOF–DSS 12 (backup for TK circuits)	Real-time[i]
02205[j]	Voice	SFOF–DSS 12	Scheduled
02207	Voice	SFOF–DSS 12	Scheduled
02212	Voice	SFOF–DSS 12	Scheduled
02208[k]	Voice	SFOF–DSS 12	Scheduled
GP 7206	Voice	SFOF–DSS 12 (backup for 02205)	Real-time
GP 7207	Voice	SFOF–DSS 12 (backup for 02208)	Real-time
NST 3050W	Full-duplex teletype	SFOF–DSS 42	Scheduled
GT 58888/NST 3050E	Full-duplex teletype	SFOF–DSS 42	Scheduled
GT 58889/NST 3009	Full-duplex teletype	SFOF–DSS 42	Scheduled
GT 58887/GT 58883	Full-duplex teletype	SFOF–DSS 42	Scheduled
GDA 58187/GDA 58186	Voice	SFOF–DSS 42	Scheduled
NST 3260/NST 3007	Full-duplex teletype	SFOF–DSS 51	Scheduled
NST 3261/NST 3006	Full-duplex teletype	SFOF–DSS 51	Scheduled
TGP 18/NST 3008	Full-duplex teletype	SFOF–DSS 51	Scheduled
TGP 24/GT 58882	Full-duplex teletype	SFOF–DSS 51	Scheduled
GDA 58433/GDA 58160	Voice	SFOF–DSS 51	Scheduled

[a] PMSA = *Pioneer* mission support area.
[b] ARC = Ames Research Center.
[c] Full period = private lines operating continuously without requirement for scheduling.
[d] STL = Space Technology Laboratories (now TRW).
[e] SFOF = Space Flight Operations Facility.
[f] Scheduled = common user lines requiring Form 24 scheduling.
[g] Normally interconnected to Blue spacecraft communications network (AFETR).
[h] Normally interconnected to Green spacecraft communications network.
[i] Real-time = facilities provided as backup, to be used if needed.
[j] Normally interconnected to DSS 12 spacecraft communications network.
[k] Normally interconnected to DSS 12 (II) spacecraft communications network.

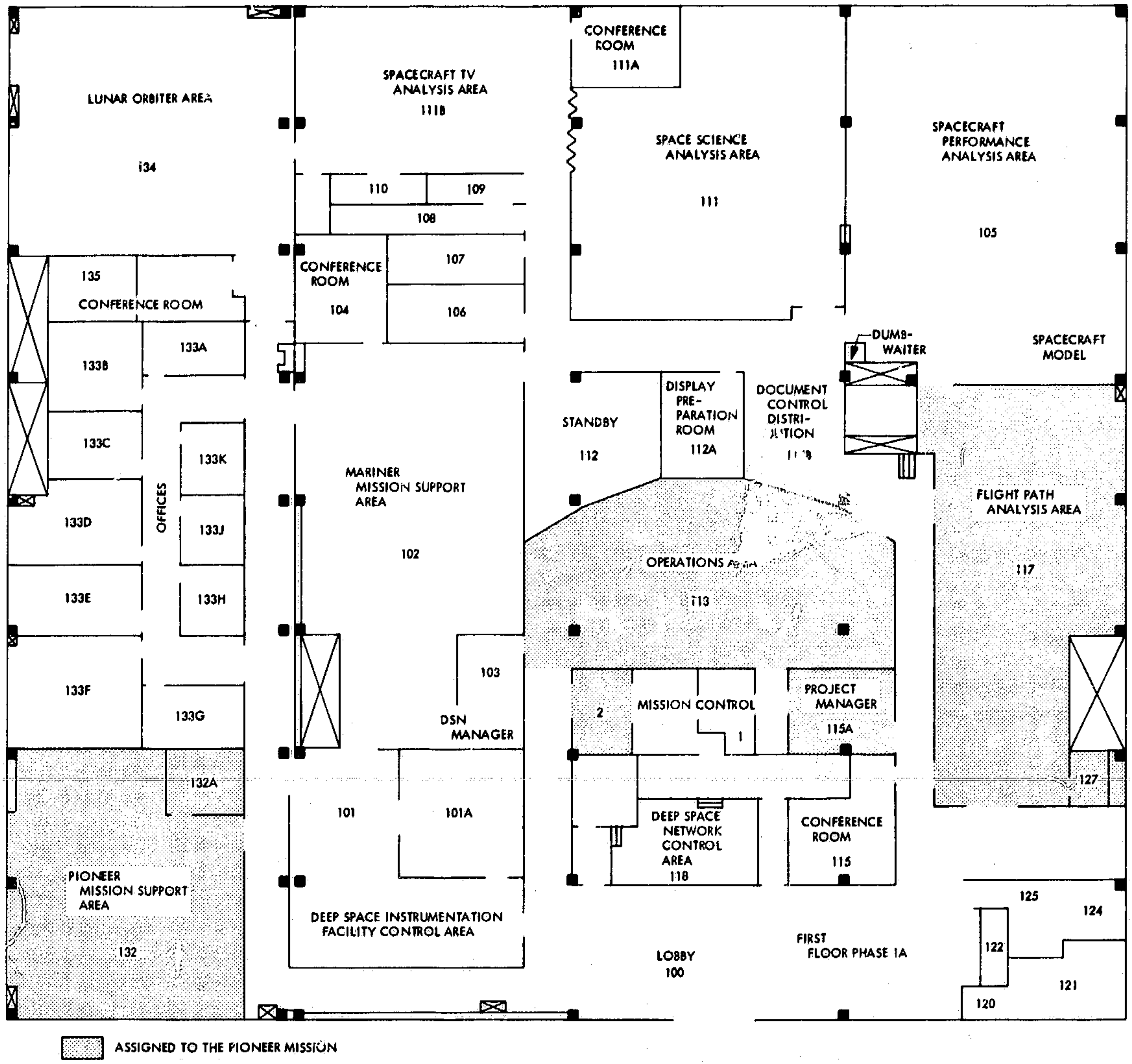


Fig. 32. First floor, Space Flight Operations Facility

Technical assistance. At least one technical area assistant is provided, as requested, in the *Pioneer* mission support area. The functions of the assistant include the distribution of data printouts throughout the area, the maintenance of teletype machines in the area, and the performance of other miscellaneous duties pertinent to *Pioneer.*

Scheduling. Areas and equipment are ready for operations according to the DSN utilization schedule and the DSN 10-day schedule.

d. Data processing system. The SFOF data processing system is organized into the computer subsystem (Fig. 35),

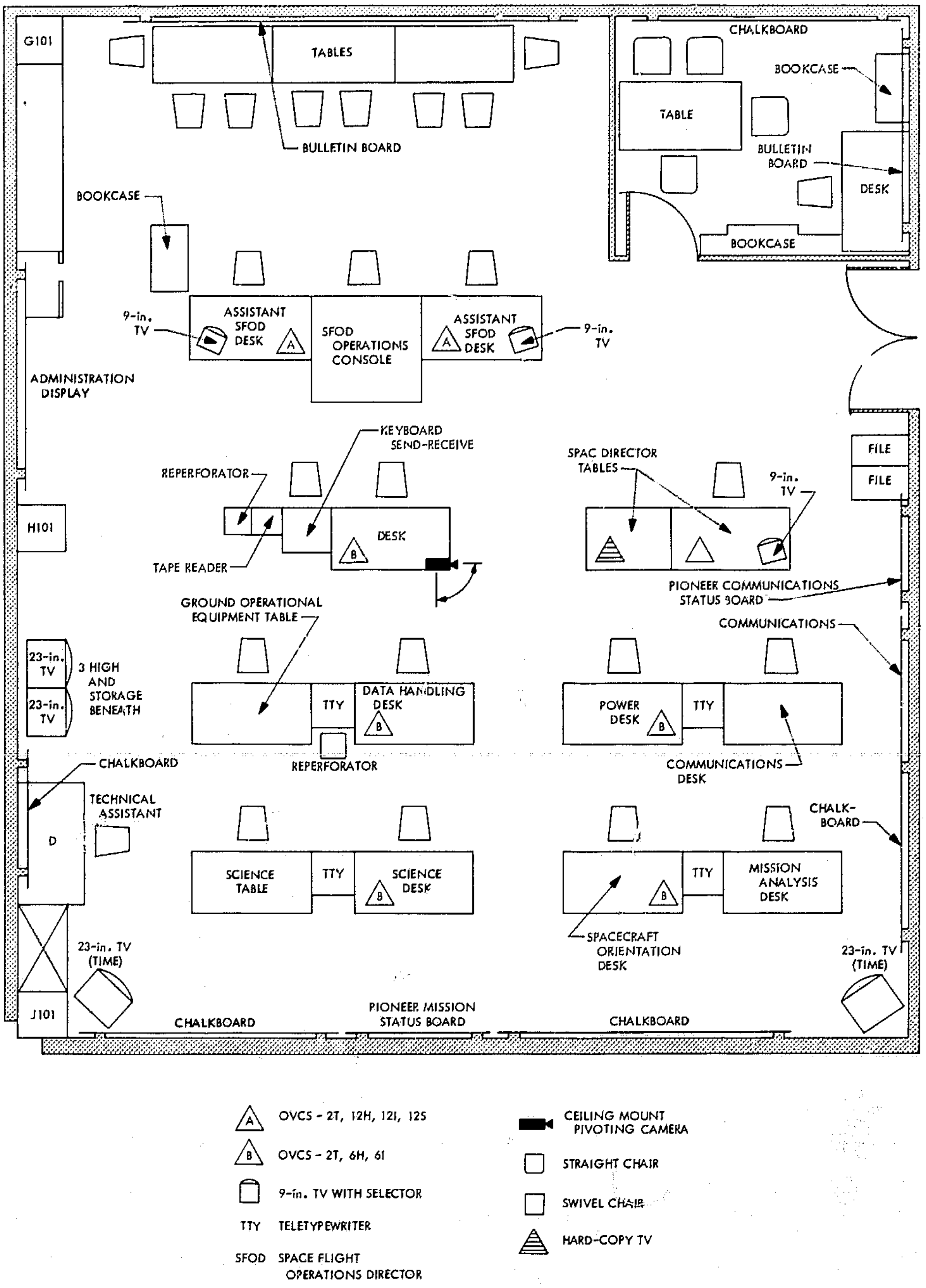


Fig. 33. Pioneer mission support area

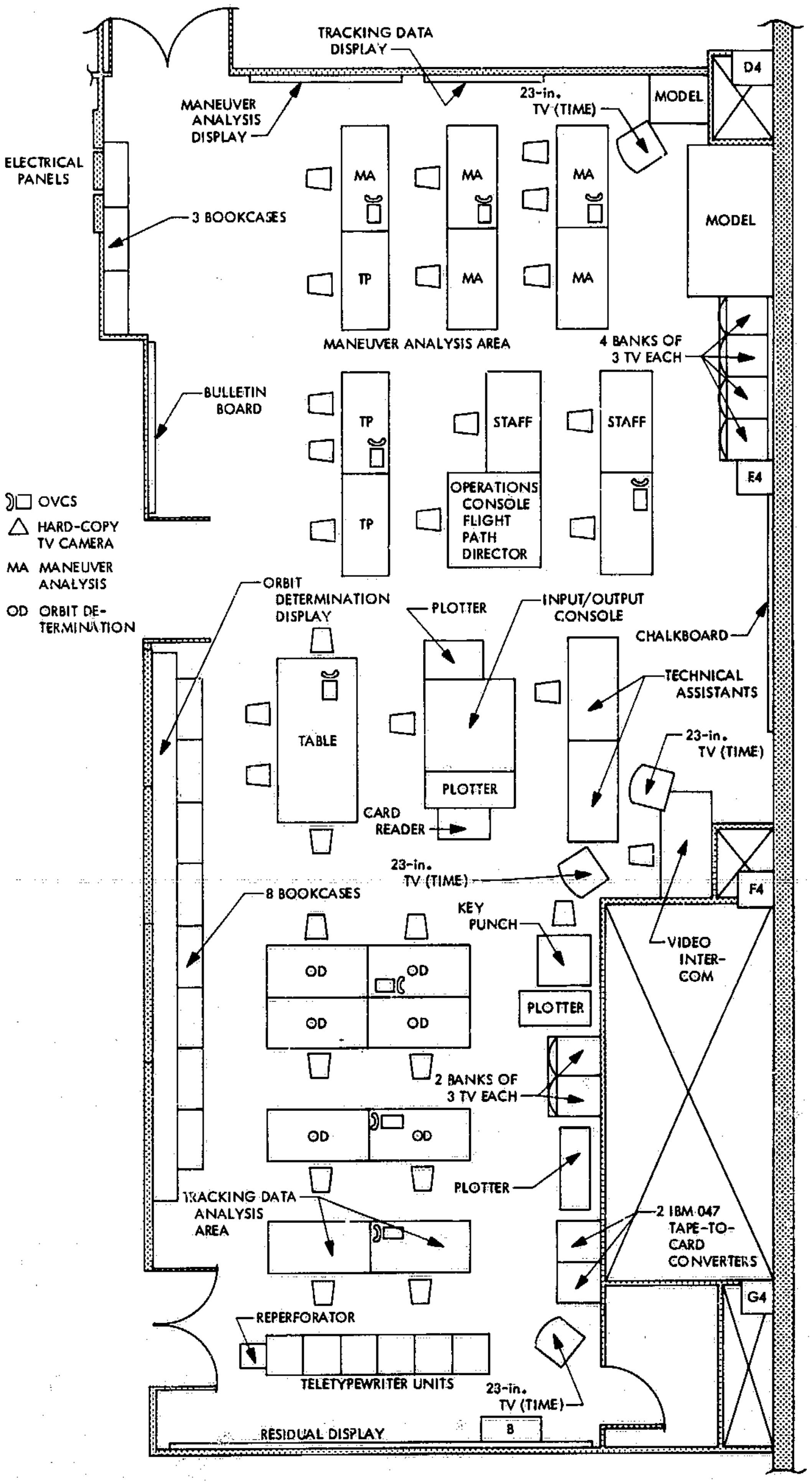


Fig. 34. Flight path analysis area

the telemetry processing station subsystem, the data processing control and display subsystem, and the programming subsystem. The only tasks performed in support of the *Pioneer* Project by the SFOF data processing system are the processing of tracking data for the establishment of a medium-accuracy orbit and DSS predicts. All other processing of data (except for the science data) is done at the Deep Space Stations with SDS 910 computers.

Engineering data. These data are received via teletype lines from the Deep Space Stations. At the SFOF, data are relayed in real-time directly to the *Pioneer* mission support area, to ARC, and to TRW. The computer-selected Class I engineering measurements, printed out in the mission support area, are then routed to the various agencies. Figure 36 shows the complete data flow from the SFOF.

The engineering data received in the SFOF *Pioneer* mission support area are analyzed by analysts from ARC and TRW.

Scientific data. These data are separated from the engineering data subcommutator at the Deep Space Stations by the SDS 910 computers. The information is recorded on magnetic tape. A duplicate of this tape is mailed to the SFOF, from which it is forwarded to ARC for computer processing.

Scientific data analysis is performed at ARC by NASA representatives and the experimenters.

Flight path data. During the launch phase (less than 24 h) there is:

1. Continuous transmission of tracking data from each Deep Space Station committed to track the *Pioneer* spacecraft.
2. Mode I operation of the SFOF data processing system until one day's predicts have been prepared; shifting to Mode IIA for the remainder of the launch phase.
3. A fully manned flight path analysis and command team in real-time operation until three days' predicts have been prepared. (Metric data from about half of the first Goldstone pass are required before the launch phase is considered completed.)

From completion of launch phase through Step II reorientation plus one day (about $L+10$ days), there is:

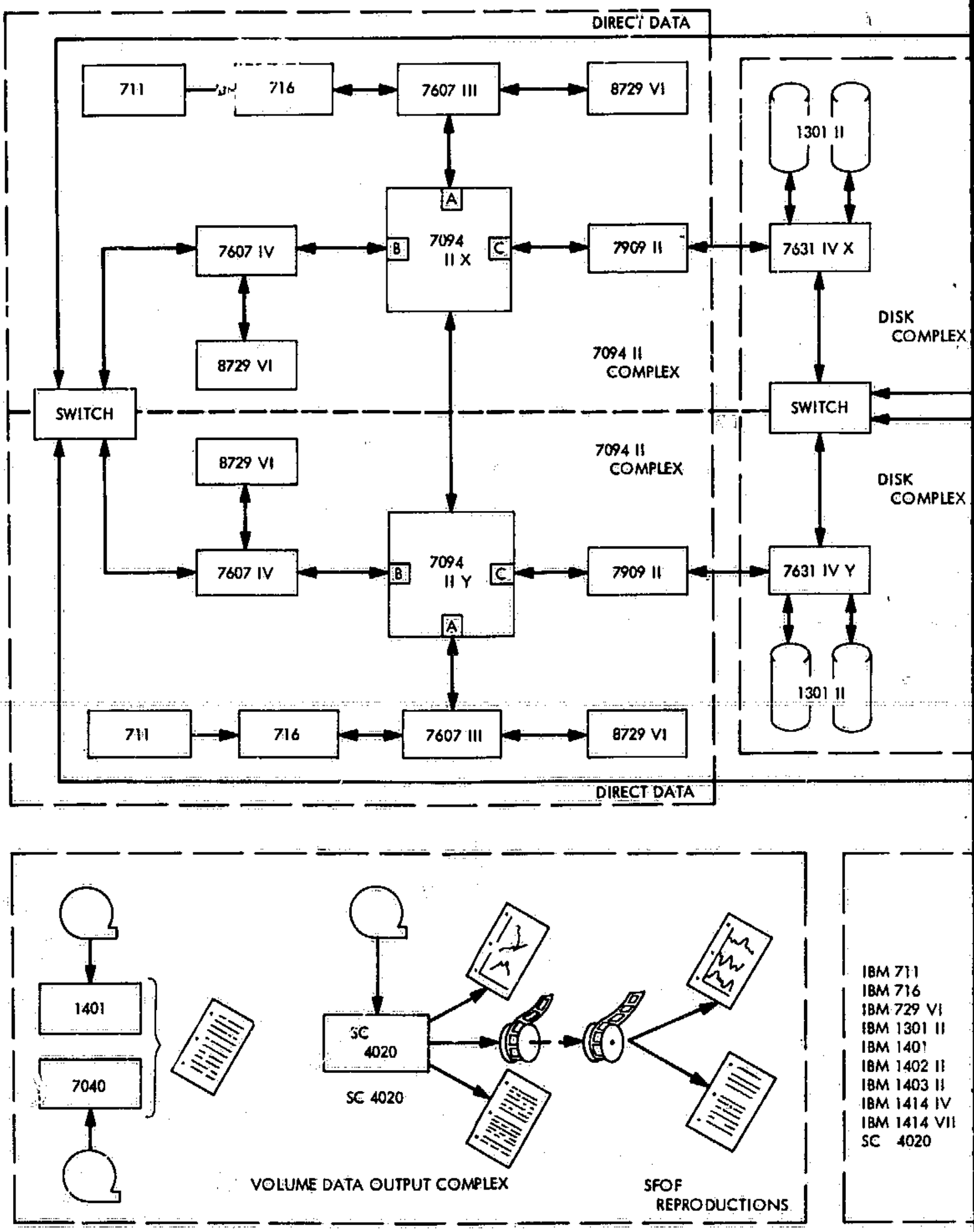
1. Batch transmission of metric data from each Deep Space Station committed to track the *Pioneer* spacecraft, with "on call" continuous transmission of tracking data, if required by the flight path analysis and command team.
2. Mode IIIA operation of the SFOF data processing system when metric data are being transmitted.
3. Determination of an orbit each day by flight path analysis and command and preparation of 10 days' predicts, if necessary, using a Mode IV configuration of the SFOF data processing system.

After completion of Type II orientation, there is:

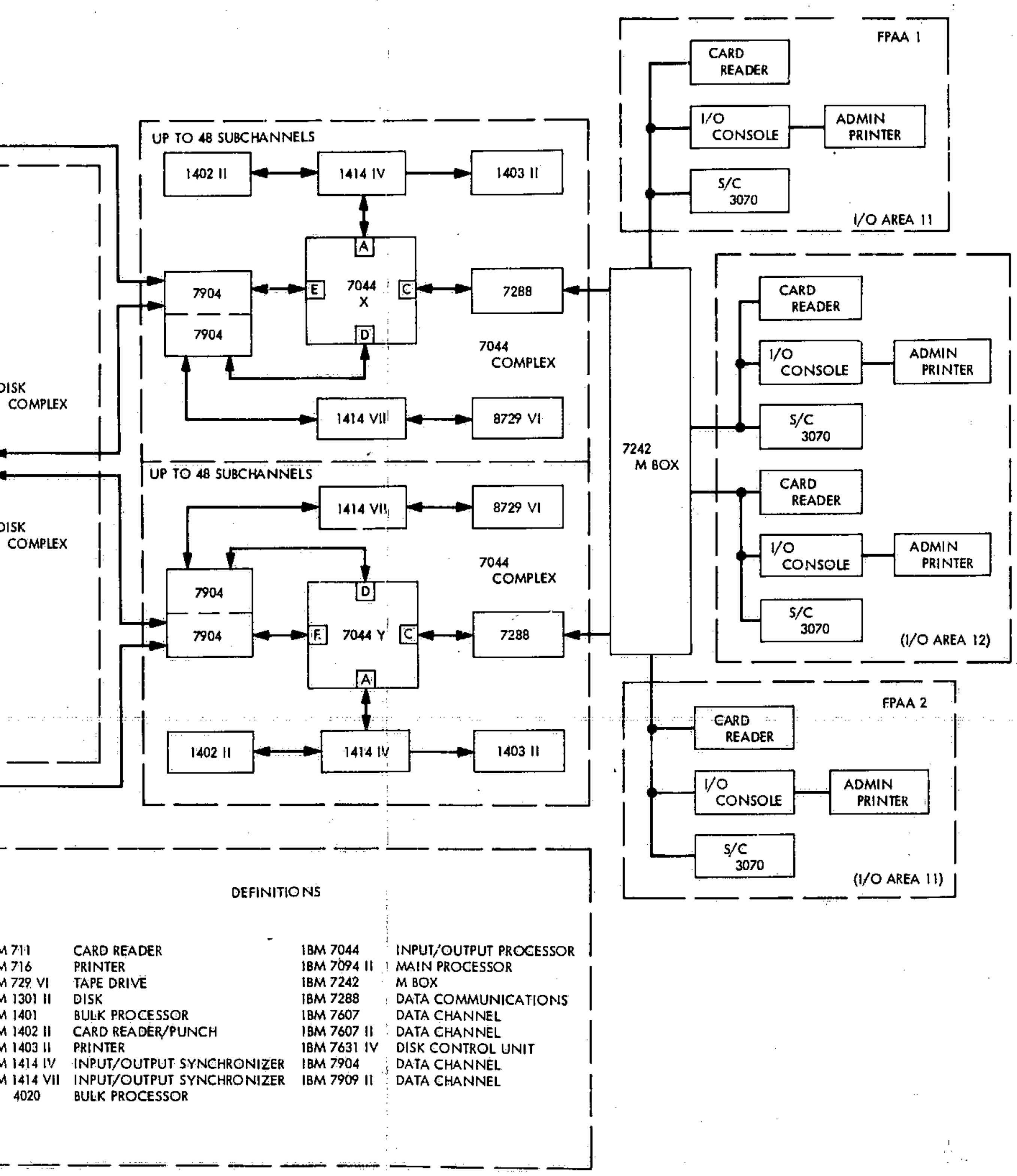
1. Batch transmission to track the *Pioneer* spacecraft.
2. Mode IIIB operation of the SFOF data processing system when tracking data are being transmitted.
3. Determination of an orbit once a week by flight path analysis and command and preparation of 10 days' predicts using Mode IV operation of the SFOF data processing system.

Ames Research Center data processing. The volume of telemetry data from the spacecraft (together with other information and measurements made at the Deep Space Stations) that are required by the data user is too large for teletype transmission to the central processing station and subsequent dissemination to the user. The data are transmitted primarily by shipment of magnetic tapes. This data flow, indicated functionally in Fig. 37, begins when the spacecraft telemetry data and other necessary information are recorded on two FR-1400 tape recorders operating in parallel at the Deep Space Station. The time for tape loading on each machine is staggered to avoid loss of data during such periods. One set of tapes, selected to contain all data received, is then shipped to JPL, where it is examined to ensure the quality of the reproduction. These tapes are then shipped to the *Pioneer* off-line data processing station at ARC for data processing and subsequent dissemination to the user.

The data are processed at ARC in a two-level system. The first level translates the seven channels of data on the FR-1400 tapes into a digital format. The equipment includes a tape playback unit, a demodulator–synchronizer, three racks containing digital logic, and an SDS 910 digital computer with associated peripheral equipment. This equipment, known collectively as the tape processing station, can process data from any Deep Space Station whether or not it is equipped with ground operational equipment.



FOLDOUT FRAME 1



DEFINITIONS

M 711	CARD READER	IBM 7044	INPUT/OUTPUT PROCESSOR
M 716	PRINTER	IBM 7094 II	MAIN PROCESSOR
M 729 VI	TAPE DRIVE	IBM 7242	M BOX
M 1301 II	DISK	IBM 7288	DATA COMMUNICATIONS
M 1401	BULK PROCESSOR	IBM 7607	DATA CHANNEL
M 1402 II	CARD READER/PUNCH	IBM 7607 II	DATA CHANNEL
M 1403 II	PRINTER	IBM 7631 IV	DISK CONTROL UNIT
M 1414 IV	INPUT/OUTPUT SYNCHRONIZER	IBM 7904	DATA CHANNEL
M 1414 VII	INPUT/OUTPUT SYNCHRONIZER	IBM 7909 II	DATA CHANNEL
4020	BULK PROCESSOR		

Fig. 35. Computer subsystem

FOLDOUT FRAME 2

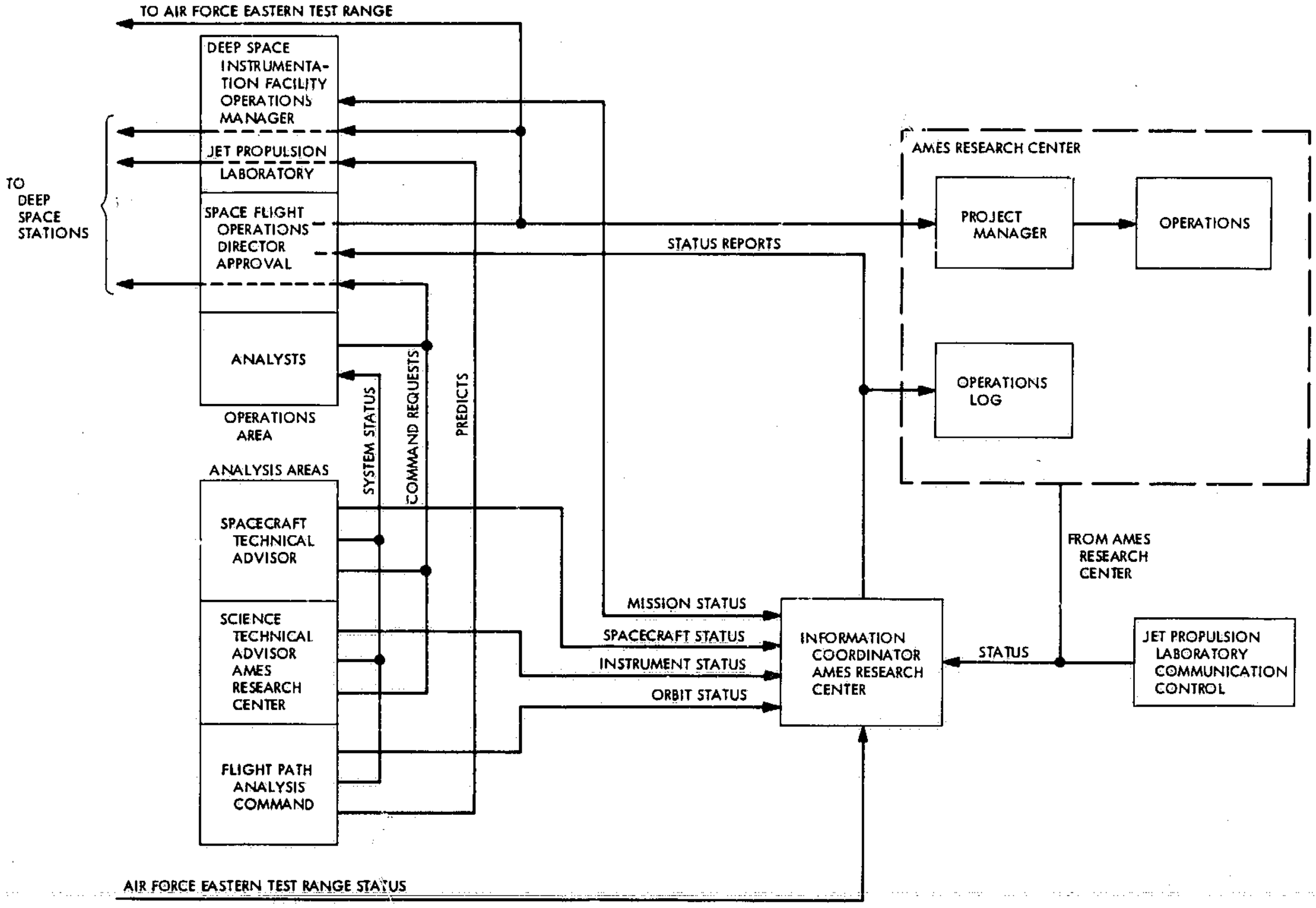


Fig. 36. Complete data flow from the SFOF

The output of the tape processing station, a multifile digital tape, is the input to the second level of processing. This level utilizes an IBM direct-coupled 7040/7094 computer system, and consists of timing the data, checking the spacecraft word parity, validating the commands sent to the spacecraft, qualifying the data on the basis of the ground station parameters measured at the Deep Space Station, and decommutating the data stream so that each experimenter receives only data from his instrument and any of the telemetered engineering data required. These output data are recorded on a digital magnetic tape in a format and density compatible with the particular computer system each experimenter uses to analyze his data.

In addition to the spacecraft telemetry data, trajectory tapes are also sent to the experimenters several times during the mission. This periodically updated information, originating at JPL, contains spacecraft position in three coordinate systems as a function of time. The data on the tape are reprocessed at ARC and put into the format and density compatible with each experimenter's computer facility.

IV. *Pioneer VI* Preflight Test Program

The *Pioneer VI* mission required a great deal of preflight testing support to ensure mission success. The *Pioneer VI* launch culminated 2 yr of intensive testing and proving.

The following paragraphs show a small part of the aforementioned test program.

A. Preflight Review

One of the major *Pioneer VI* program evaluation meetings, the preflight review, was held at TRW, Redondo

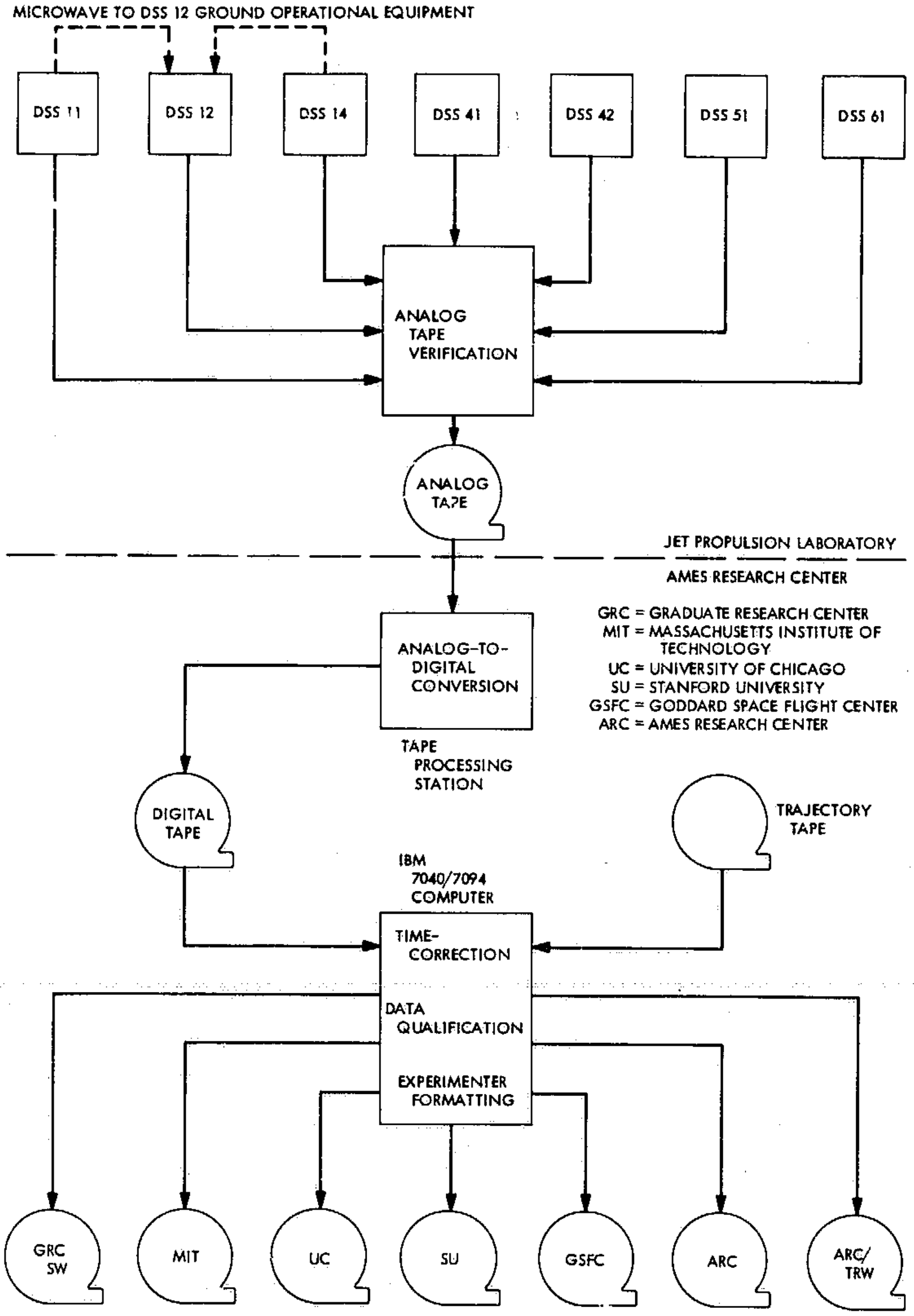


Fig. 37. ***Pioneer off-line data processing system***

Beach, Calif., on September 29 and 30, 1965. Participants included representatives of NASA Headquarters, GSFC, JPL, ARC, the experimenters, and TRW. The purpose of the meeting was to review the program, evaluate the preparedness of the spacecraft and instruments for commencement of launch activities at Cape Kennedy, and obtain approval from the participating agencies for shipping the spacecraft and instruments to Cape Kennedy.

During the preflight review, the spacecraft and instrument development programs were described in detail to provide assurance of the suitability of the design to accomplish the mission objectives and the reliability of the design to achieve long lifetime. Events occurring during the three design reviews and the use of breadboard and engineering models of the spacecraft and instruments during the development phase were discussed.

The test program was discussed in detail during the preflight review so that its adequacy in evaluating the reliability and quality of the equipment could be determined. The test programs for both the spacecraft and scientific instruments were described with the aid of a test-flow diagram, which is reproduced in Fig. 38. It was explained during the discussion that all equipment destined to be flight hardware had been acceptance-tested at the assembly level and then at the system level at expected flight environmental conditions, whereas the qualification assemblies and prototype spacecraft had been tested at environmental conditions more severe than those to be encountered in flight.

Before discussing the test results, the philosophy of the *Pioneer* Project pertaining to "failures" was explained to the reviewers. Any nonconformance to specifications, malfunctions, defects, improper test setups, procedural errors, anomalous test data, etc., had been classified as "failures." All such failures had required a formal review and evaluation by a failure review board.

During the review meeting, all failures of the spacecraft and instrument assemblies since fabrication and the corrective actions and retest results were reviewed. The malfunctions that had occurred during nearly 1000 h of system testing of the spacecraft were summarized; events were shown (as in Fig. 39) in relation to the time of occurrence and position in the test program. A study of these events showed that a large portion were minor electrical malfunctions and had been corrected as they occurred. It was concluded that the majority of problems would not have affected or degraded the objectives of this mission because of the presence of redundant equipment.

At the time of the review, two problem areas involving flight spacecraft equipment had not been cleared by the failure review board. One was a clamp bonding problem on the lower solar array and the other was design and development problems associated with the antenna (which had prevented completion of acceptance testing). Suitable progress was being made in solving these problems, however.

There were no open items from the failure review board on any of the scientific instruments at the time of the preflight review. However, there was some concern because it had been necessary on several occasions to transmit calibration commands to the GSFC magnetometer several times before the command was executed. (It was later learned that this characteristic was a peculiarity of instrument operation and not a malfunction.)

Based on the information presented, it was concluded by the participating agencies that although some problems remained to be resolved, the spacecraft and instruments were flightworthy. The prototype and flight spacecraft were shipped to Cape Kennedy on October 1, 1965.

B. Prelaunch Tests

The AFETR prelaunch testing operations for the *Pioneer VI* mission are covered in the following paragraphs. The milestones and significant prelaunch events are listed below.

Date	Event
7/10/65	Second stage arrival
8/27/65	First stage arrival
10/5/65	First-stage grid area checks started
10/15/65	Second-stage grid area checks started
11/12/65	Dual composite test performed
11/15/65	First stage transported to pad and erected
11/19/65	Second stage transported to pad and erected
12/2/65	Acceptance and RFI tests performed
12/8/65	All-systems test performed
12/13/65	Electrical systems test performed $T-2$ days

1. Dual composite test summary. During the dual composite test, the second-stage engine start sequence exhibited an abnormal oxidizer valve opening as indicated on propulsion oscillographic recordings. Troubleshooting revealed a loose pneumatic fitting. The fitting was tightened and a normal start sequence was obtained.

2. Acceptance and RFI test summary. The following problems occurred while on external power:

(1) The telemetry stations at Buildings AE and M reported a noisy 230.9-MHz link.

(2) Dropouts on CDR 2 were noted during destruct checks. It was found that the range command system was improperly set up for this test. The command was set at ±60 kHz with compression but should have been ±62.5 kHz without compression. Destruct checks were satisfactorily rerun with the proper command setup.

(3) During most of the programmer run, the second-stage engine was in a hard "pitch up" condition.

This was caused by incorrect Western Electric Co. (WECO) guidance programming, which did not send the proper signals to keep the gyros on scale. This was not considered a problem because the WECO setup was used only for test purposes.

(4) The second-stage hydraulic accumulator leaked internally; it was replaced the following day.

The only problem that developed while on internal power was one involving the first motion switch. The switch mounting bracket, which prevented actuation of the switch, was modified to allow proper switch operation.

Shortly after turn-on of the C-band beacon during the RFI test, it was noted that something was triggering the beacon. This was found to be Station 19.18 radar tracking during beacon warmup.

3. ***All-systems test summary.*** Several delays were encountered during the performance of this test because of AFETR tracking commitments to other programs.

Before the start of testing, it was found that the ground support equipment (GSE) cables used to monitor the third-stage dimple motors were not available. Several modifications had been made to the attach fitting, and some cabling for these modifications was not made; therefore, the dimple motor check function was not made during this test.

The external power test was interrupted when the *Gemini* mission control center requested that the 230.9-MHz link be turned off because of interference with Tel III calibration to track another program vehicle. External power testing was completed later without any problems. The internal power test was also interrupted for the same reason, but was completed later with only one problem. The WECO unit stopped transmitting 208 s after main engine cutoff (MECO+208 s) during the programmer run. On this test, WECO had been asked not to send a VCS initiate command during the programmer run. When WECO took this function out of the program, they also accidentally removed all other programming (except drift rates) by placing a jump switch in the wrong position.

4. ***Electrical systems test.*** No problems were encountered during this test.

C. Spacecraft Checkout

During experimenter final inspection on December 10, two wires to a boom deployment switch were inadvertently broken. The next day, a chemical soldering iron was used on the stand to repair the wires.

Spacecraft checks during the $T-2$-day countdown started at daybreak. These checks, which included spacecraft and experimenters' checks, final pneumatic pressurization, and final cleaning of the Ness magnetometer, were completed about 7 h later. The spacecraft ordnance installation task started at the beginning of the vehicle ordnance task, and was completed the same afternoon.

Spacecraft red-tag item removal and final preparation for fairing installation were completed and the fairing was installed on the morning of December 14.

Spacecraft umbilical and RF checks were started a half-hour early (1630 EST) at the beginning of the $T-0$-day countdown on December 15. These checks were completed within 3½ h. The spacecraft ordnance was armed at the beginning of the vehicle ordnance task. Spacecraft final checks commenced at 2035 EST, and the third stage 136-MHz beacon was turned on 10 min later.

Power was lost to the spacecraft when the second-stage umbilical was inadvertently disconnected. The spacecraft was disarmed at 1155 EST. After power was restored to the spacecraft, special revalidation checks were conducted. The spacecraft was rearmed at 0045 EST on December 16. Spacecraft final checks were completed when the terminal count was started (at 0145 EST).

No spacecraft problems were encountered during terminal count.

D. Deep Space Network Testing

The tests that have been conducted to ensure the readiness of all elements of the DSN committed to support the *Pioneer VI* mission are classified as follows:

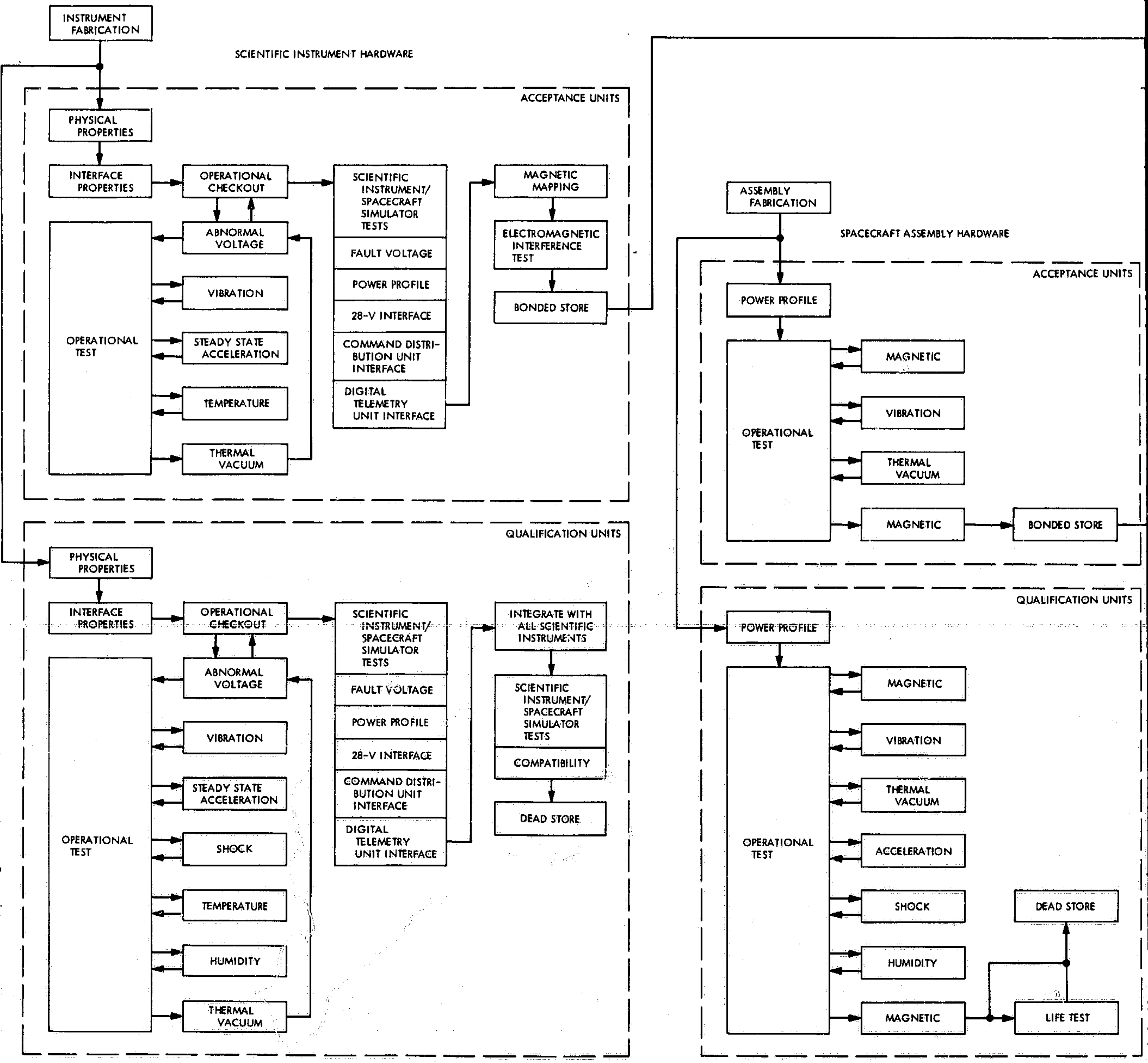
(1) Telemetry and command system acceptance tests.

(2) Subsystem acceptance tests.

(3) Integration tests.

(4) Operational readiness tests.

Descriptions of these tests, involving segments of the DSN, are given in the paragraphs that follow. The scheduling of the tests is presented in Table



F[redacted]RAME

FOLDOUT FRAME 1

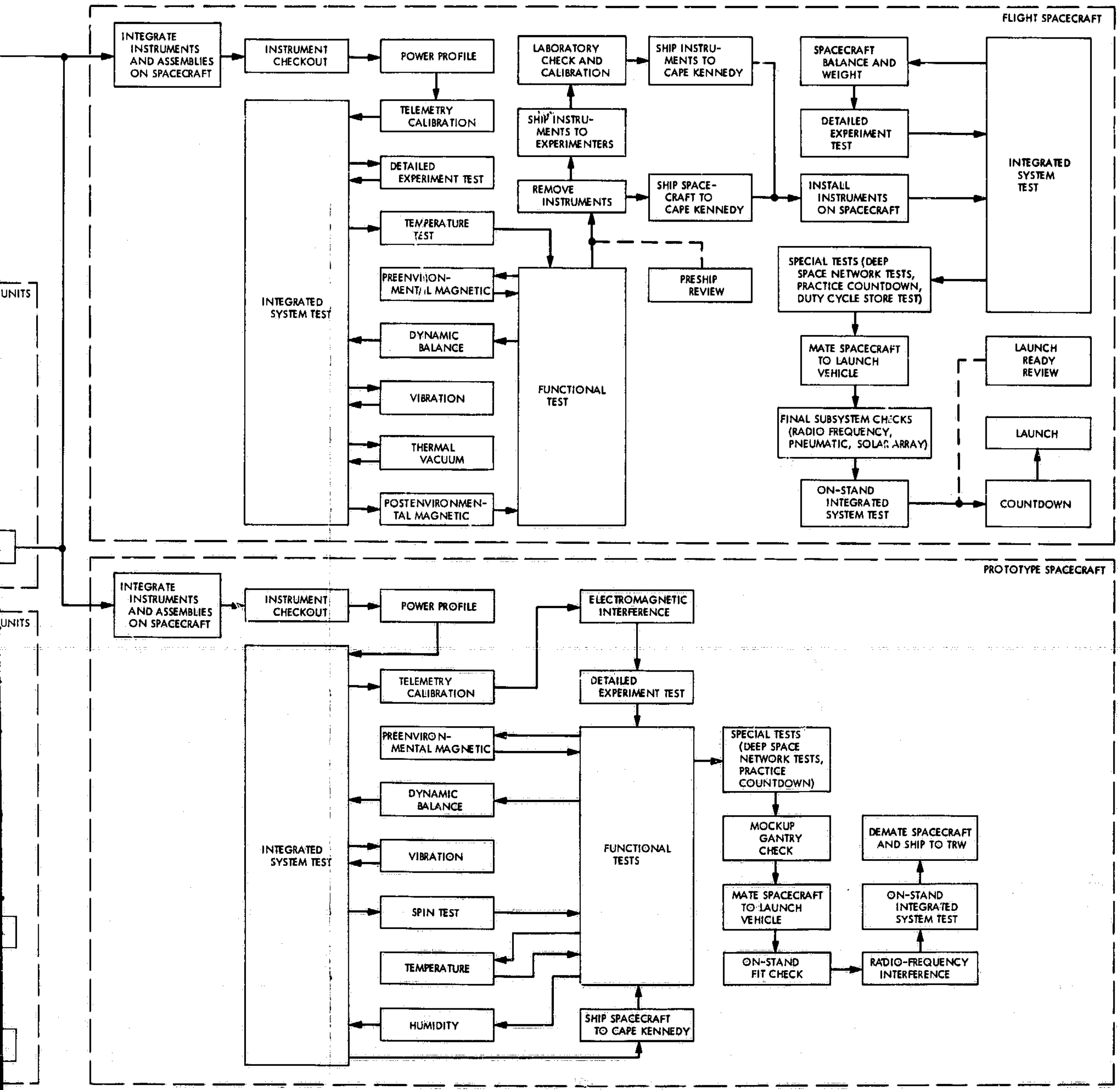
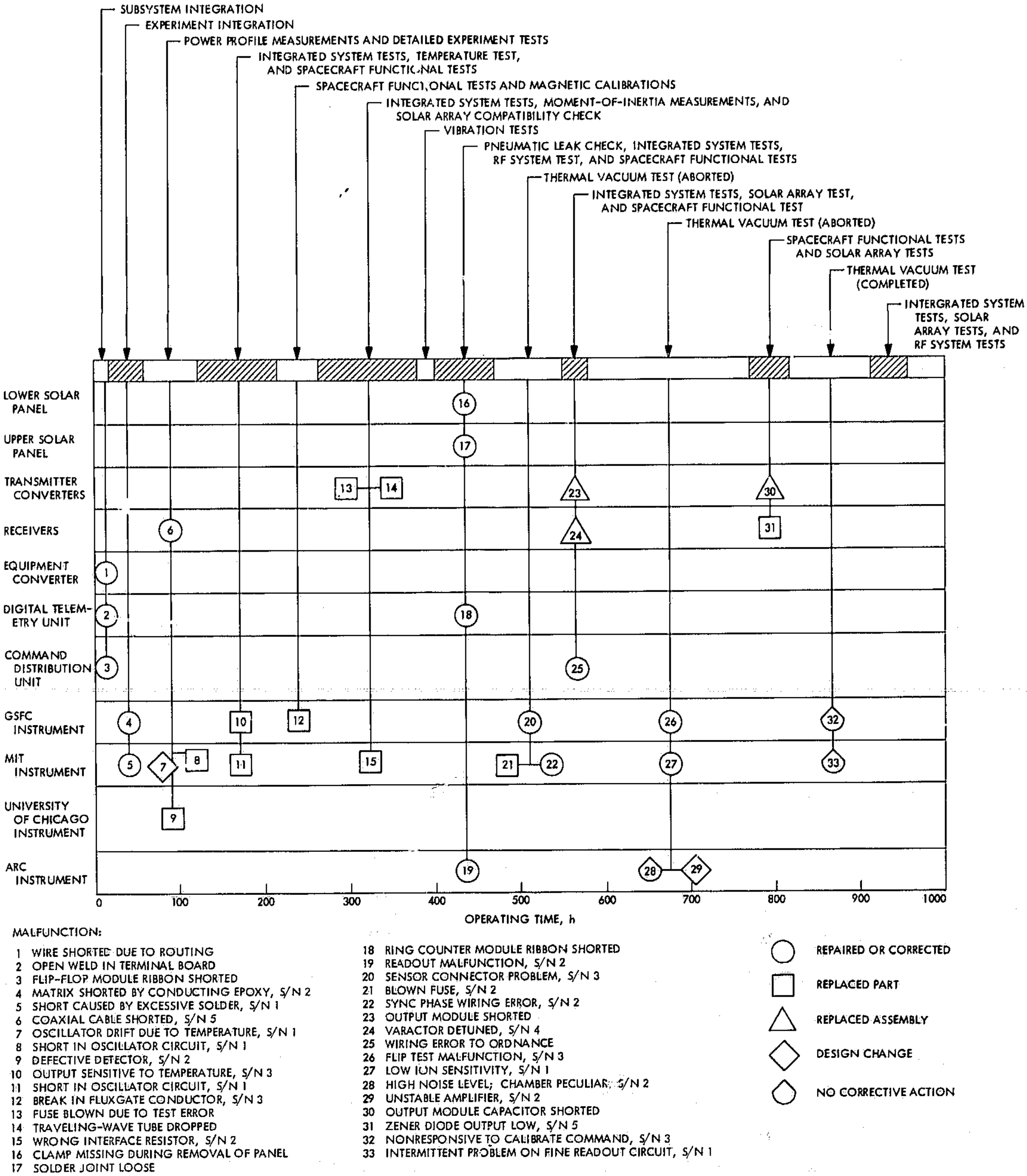


Fig. 38. ***Pioneer VI test program***

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED.



MALFUNCTION:

1 WIRE SHORTED DUE TO ROUTING
2 OPEN WELD IN TERMINAL BOARD
3 FLIP-FLOP MODULE RIBBON SHORTED
4 MATRIX SHORTED BY CONDUCTING EPOXY, S/N 2
5 SHORT CAUSED BY EXCESSIVE SOLDER, S/N 1
6 COAXIAL CABLE SHORTED, S/N 5
7 OSCILLATOR DRIFT DUE TO TEMPERATURE, S/N 1
8 SHORT IN OSCILLATOR CIRCUIT, S/N 1
9 DEFECTIVE DETECTOR, S/N 2
10 OUTPUT SENSITIVE TO TEMPERATURE, S/N 3
11 SHORT IN OSCILLATOR CIRCUIT, S/N 1
12 BREAK IN FLUXGATE CONDUCTOR, S/N 3
13 FUSE BLOWN DUE TO TEST ERROR
14 TRAVELING-WAVE TUBE DROPPED
15 WRONG INTERFACE RESISTOR, S/N 2
16 CLAMP MISSING DURING REMOVAL OF PANEL
17 SOLDER JOINT LOOSE
18 RING COUNTER MODULE RIBBON SHORTED
19 READOUT MALFUNCTION, S/N 2
20 SENSOR CONNECTOR PROBLEM, S/N 3
21 BLOWN FUSE, S/N 2
22 SYNC PHASE WIRING ERROR, S/N 2
23 OUTPUT MODULE SHORTED
24 VARACTOR DETUNED, S/N 4
25 WIRING ERROR TO ORDNANCE
26 FLIP TEST MALFUNCTION, S/N 3
27 LOW ION SENSITIVITY, S/N 1
28 HIGH NOISE LEVEL; CHAMBER PECULIAR, S/N 2
29 UNSTABLE AMPLIFIER, S/N 2
30 OUTPUT MODULE CAPACITOR SHORTED
31 ZENER DIODE OUTPUT LOW, S/N 5
32 NONRESPONSIVE TO CALIBRATE COMMAND, S/N 3
33 INTERMITTENT PROBLEM ON FINE READOUT CIRCUIT, S/N 1

Fig. 39. Malfunctions occurring during system tests of *Pioneer VI*

Table 17. *Pioneer VI* tests

Date	Type of test
8/5–12/10	Weekly checkout of FPAC *Pioneer* flight programs
8/27	Telemetry and command test
9/13	DSS 51/flight path analysis and command acceptance test
9/15	DSS 12/Space Flight Operations Facility acceptance test
9/22	DSS 12 daily operations test
9/22	DSS 42/Space Flight Operations Facility acceptance test
9/22	DSS 51 daily operations test
9/23	DSS 12 daily operations test
9/23	DSS 42/Space Flight Operations Facility/flight path analysis and command acceptance test[a]
9/23	DSS 51 daily operations test
9/24	DSS 42 daily operations test
9/30	DSS 51/Space Flight Operations Facility acceptance test
10/1	DSS 51/Space Flight Operations Facility acceptance test
10/6	Flight path analysis command acceptance test (internal)
10/12	DSS 12/Space Flight Operations Facility integration test
10/12	DSS 42/Space Flight Operations Facility integration test
10/13	DSS 12 program checkout with Space Flight Operations Facility
10/15	DSS 51/Space Flight Operations Facility integration test
10/20	DSS 12/Space Flight Operations Facility integration test
10/22	Air Force Eastern Test Range/Space Flight Operations Facility/DSS 51 integration test[b]
11/3	DSS 71/Space Flight Operations Facility integration test
11/18	DSS 12 daily operations integration test
12/2 and 12/3	Operational readiness test 1[c]—48-h test
12/6	Operational readiness test 2[c]—24-h test
12/9	Operational readiness test 3[c]—24-h test

[a] Program and procedures poor.

[b] Severe problem with data processing system forced early termination (2 h early).

[c] Participants were Air Force Eastern Test Range, Deep Space Network, Ames Research Center, TRW, and Stanford University.

1. Telemetry and command system acceptance tests. The purpose of these tests was to evaluate the performance of men and equipment associated with the telemetry data and command systems. These tests were conducted at DSSs 12, 42, and 51.

2. Subsystem acceptance test. The purpose of this test was to demonstrate to the SFOD, operating from the SFOF, the satisfactory performance of equipment and personnel of each element of *Pioneer* operations. The subsystem acceptance test comprised the following tests:

(1) Daily operations tests and Type II orientation tests (DSS 12).

(2) Daily operations tests (DSS 42).

(3) First acquisition test. This test involved station performance during the initial pass of the spacecraft, including critical activities of first acquisition (DSS 51).

(4) Flight path analysis and command, spacecraft performance analysis and command, and space science analysis and command groups (Space Flight Operations Facility).

3. Integration tests. The purpose of these tests was to familiarize space flight operations personnel with all phases of *Pioneer* procedures and intercommunications. Actual operation of the *Pioneer* mission was performed in the exercise of all elements.

Deep Space Stations 12, 42, and 51 repeated the subsystem acceptance test listed above.

4. Operational readiness tests. The purpose of these tests was to demonstrate that all personnel and equipment participating in the flight operations of the spacecraft were prepared to support the mission. Every unit was activated for these tests. The three tests were developed so as to reflect sequential improvement, thereby ensuring maximum operational readiness.

5. Conclusion. All testing has proved the operational readiness, within current commitments and time constraints, of all elements to support the *Pioneer VI* mission.

The DSN manager provided the project manager with a real-time operational readiness evaluation at $T-5$ days to confirm that all systems were prepared to go.

E. *Pioneer*/S-band Compatibility Tests

These tests were conducted at Patrick Air Force Base on July 22, 23, and 26, and August 19, 1965, to verify the compatibility of the AFETR user equipment and its capability to support the *Pioneer* S-band telemetry requirements. The primary test objective was to simulate the *Pioneer* transmitted data, and to receive, translate, and record them with the AFETR telemetry system to evaluate how successfully the range user equipment could recover such data.

These tests successfully demonstrated that the AFETR and range user equipment, planned for the *Pioneer* S-band telemetry, were compatible.

*1. **Test program.*** In the tests conducted in July 1965, the capability of the demodulator-synchronizer to lock to simulated *Pioneer* data was evaluated as a function of modulation index, data rate, 10-kHz or 30-kHz IF bandwidth, and S-band preamplifier input signal level. The tests run on August 19 again did this and measured the bit-error rate. The general block diagram of the test setup is shown in Fig. 40. The error-rate tester, test transponder, and demodulator–synchronizer were range user equipment furnished for the test. The preamplifier, down converter, data receiver, tape recorder, and discriminator were AFETR equipment similar to that being used to support the *Pioneer* Project.

The error-rate tester generated a simulated data signal and the test transponder modulation index was selected between 0.8 and 1.2. The S-band signal from the test transponder was adjusted to a desired signal level close to system threshold. The data receiver (Space General RTD 5000B) was phase-locked to this signal using the 100-Hz loop bandwidth position. The video output of the receiver was recorded and played back on a CEC 5-752 tape recorder. A 70-kHz voltage-controlled oscillator, deviated ±15%, was used for data insertion. An EMR tunable discriminator was used to recover the recorded data, which were then fed to the demodulator–synchronizer. The video output filter of the discriminator was set at 5 kHz when the 10-kHz IF bandwidth was used, and at 15 kHz when the 30-kHz IF bandwidth was used.

The ability of the demodulator to lock was noted and the bit-error rate measured by the error-rate tester. The error-rate tester totaled the number of bits in error in 10^4 bits for bit rates of 512, 256, and 64, and totaled the number of bits in error in 10^5 bits for bit rates of 16 and 8.

*2. **Test results.*** Tables 18 and 19 summarize the results of the compatibility tests. Table 18 presents the results of the July 22, 23, and 26 tests and Table 19 presents the results of the August 19 tests. The data-bit rates evaluated were 512, 256, 64, 16, and 8 bits/s. A point worthy of note is the difference in the input signal levels required for acceptable performance in the July and the August tests. This was caused by a difference in the S-band system noise figure during the tests. In July, the noise figure was 5.5 dB; in August, it was 19.2 dB.

Tests have demonstrated that the use of a 30-kHz IF amplifier will result in slightly better data (lower bit-error rate) than the use of a 10-kHz IF amplifier. However, this is achieved at a sacrifice in system threshold of approximately 2 dB, due to loss of receiver lock at a higher input signal level.

Assuming the system noise bandwidth is equal to the data rate, and assuming there are no threshold effects encountered at the signal levels noted in Table 19, the error rates measured are close to those that should be achieved with a synchronous demodulator.

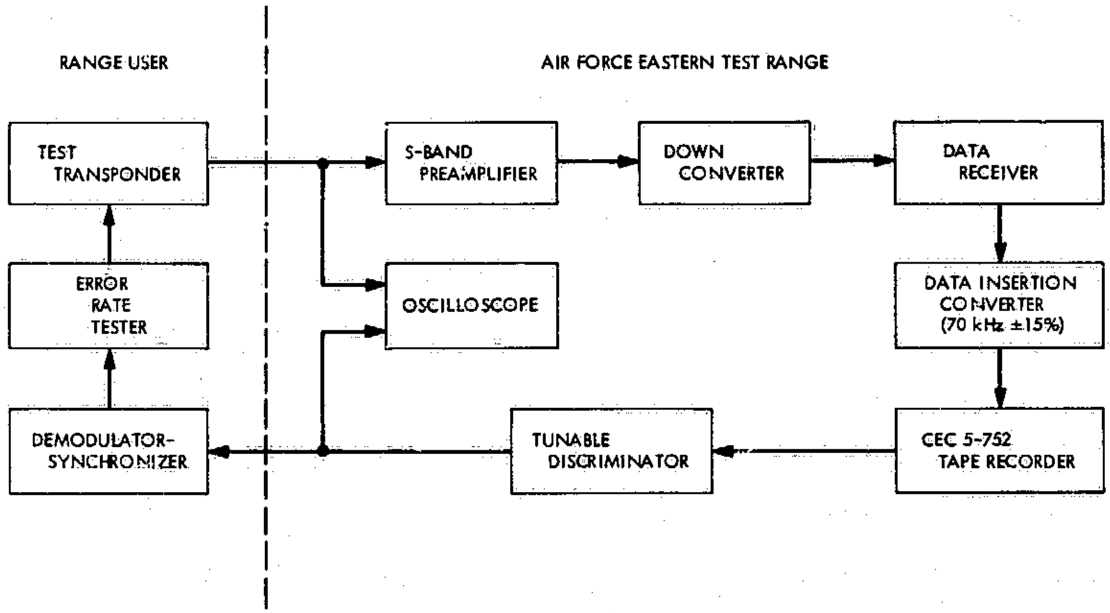


Fig. 40. General block diagram—*Pioneer* compatibility test

Table 18. Compatibility test summary

Test/ picture	IF bandwidth, kHz	Signal level, dBm	Modulation index	Comments
A	10	−130	1.0	Lock at all bit rates
B	10	−140	1.0	No lock at 512 bits/s; lock at all others
C	10	−120	1.0	Lock at all bit rates
D	30	−120	1.0	Lock at all bit rates
E	30	−130	1.0	Lock at all bit rates
F	30	−140	1.0	Receiver would lock but would not stay locked long enough for demodulator to lock
1	30	−137	1.0	Lock at all bit rates
G	30	−137	1.2	Receiver would not stay locked long enough to lock demodulator
2	30	−135	1.2	Lock at all bit rates
3	30	−125	1.2	Lock at all bit rates
4	30	−120	1.2	Lock at all bit rates
5	10	−120	1.2	Lock at all bit rates
6	10	−120	0.8	Lock at all bit rates
7	10	−130	0.8	Lock at all bit rates
8	10	−140	0.8	No lock at 512 and 8 bits/s; lock at others
9	10	−137	0.8	Lock at all bit rates
10–14	10	−120	0.8	Lock at all bit rates
15–19	10	−120	1.0	Lock at all bit rates
20–24	10	−120	1.2	Lock at all bit rates
25–29	10	−130	0.8	Lock at all bit rates
30, 31	10	−130	1.0	Lock at all bit rates
32, 33	10	−130	1.2	Lock at all bit rates
34	10	−140	0.8	Demodulator would not lock
35–39	10	−137	0.8	Lock at all bit rates
40–44	10	−137	1.0	Lock at all bit rates
H	10	−137	1.2	Receiver would not hold lock
45–49	10	−134	1.2	Lock at all bit rates
50	10	−135	1.2	Lock at 512 bits/s
51	10	−136	1.2	Lock at 512 bits/s
52	10	−137	1.2	Lock at 512 bits/s
53, 54	30	−135	1.2	Lock at all bit rates
I	30	−136	1.2	Receiver would not hold lock
55, 56	30	−120	1.2	Lock at all bit rates

V. *Pioneer VI* Tracking and Data System Flight Support

A. Near-Earth Phase Support

To achieve the mission objectives, the *Pioneer VI* spacecraft was launched on December 16, 1965, which was within the period of the international Quiet Sun year (January 1964 to December 1965). The systems of the spacecraft and the associated scientific instrumentation measured and transmitted data concerning interplanetary phenomena at distances up to 4.2×10^6 nmi from the earth.

The *Pioneer* spacecraft was launched from the AFETR into the ecliptic using the improved thrust-augmented *Delta* launch vehicle. The spacecraft spin axis was oriented perpendicular to the ecliptic so that scientific instruments, mounted perpendicular to the spin axis of the spin-stabilized spacecraft, were able to scan 360 deg of the ecliptic.

After injection into orbit, tracking and data acquisition were accomplished by the Deep Space Network throughout the duration of the deep space phase of the mission.

Table 19. *Pioneer VI* error bit-rate summary

Test	IF bandwidth, kHz	Signal level, dBm	Modulation index	Error-bit rate				
				512×10^{-4}	256×10^{-4}	64×10^{-4}	16×10^{-3}	8
1	10	−123.8	1.0	170	24	0	—	—
2	10	−126	1.0	500	128	—	—	—
3	10	−123.8	0.9	575	152	0	0	0
4	10	−128	0.9	No lock	554	33	2	0
5	10	−124	0.9	266	27	0.3	0	0
6	10	−121	0.9	23	2	—	—	—
7	30	−121	0.9	21	0	—	—	—
8	30	−124	0.9	230	138	0	—	—
9	30	−126	0.9	579	138	0	—	—
10	30	−128	0.9	No lock	438	27	Receiver would not remain locked long enough	
11	30	−119	0.9	2	0	0	—	—
12	10	−119	0.9	5	0	—	—	—

1. Prelaunch. The prelaunch activities were the final checkout phase of *Pioneer VI* in preparation for the countdown-to-launch operation. The prelaunch activity phase started on October 1, 1965, when the spacecraft was received at Cape Kennedy, and terminated with the countdown phase on December 13, 1965.

An important phase of the prelaunch activities involved the prototype spacecraft in trial runs, evaluations, and special tests as indicated in Fig. 41. This approach provided maximum preparedness for the flight spacecraft without exposing it to unproved or hazardous conditions, and resulted in the application of proved equipment and tested checkout procedures during actual launch operations with the flight spacecraft.

As shown in the lower part of Fig. 41, the test program for the flight spacecraft was similar to that for the prototype. One difference between prototype and flight-spacecraft activities related to the scientific instruments: The prototype spacecraft had been delivered to Cape Kennedy as an integrated system with all six scientific instruments on board. In contrast, the scientific instruments for the flight spacecraft, except the Stanford University instrument, had been returned to the laboratories of the experimenters for final calibration and checking before delivery to Cape Kennedy. It was necessary, therefore, that these instruments be reintegrated into the flight spacecraft and tested as a system. This activity occurred during the first week of October.

The traveling-wave tubes (TWTs) and TWT converters of the flight spacecraft were temporarily replaced by the units from the prototype spacecraft to allow inspection of the former for a high-voltage breakdown (a problem encountered on another unit due to faulty potting). They were reinstalled on the flight spacecraft about 2 wk later when found to be in a satisfactory condition. In addition, a malfunction (nonstandard bit rate) in the digital telemetry unit required a replacement unit. The malfunction was readily corrected and the flight unit was reinstalled on the flight spacecraft within a week. The MIT plasma detector was replaced by the spare unit because of a possible intermittent arcing problem. The weight and balance checks proved the flight spacecraft to be within specification values. The final values of the mass properties are given in Tables 20 and 21.

During November, special tests, training, and practice runs for different phases of the countdown were made with the flight spacecraft. During the first half of the month, numerous round-the-clock duty-cycle store tests were conducted. Deep Space Station training exercises and detailed experiment tests were also performed.

Despite fit checks with the prototype spacecraft, a misfit between the launch vehicle interstage structure and the flight spacecraft, resulting from fabrication tolerances, was discovered during mating of the spacecraft and the third-stage motor. The situation was corrected and the activity completed on December 6.

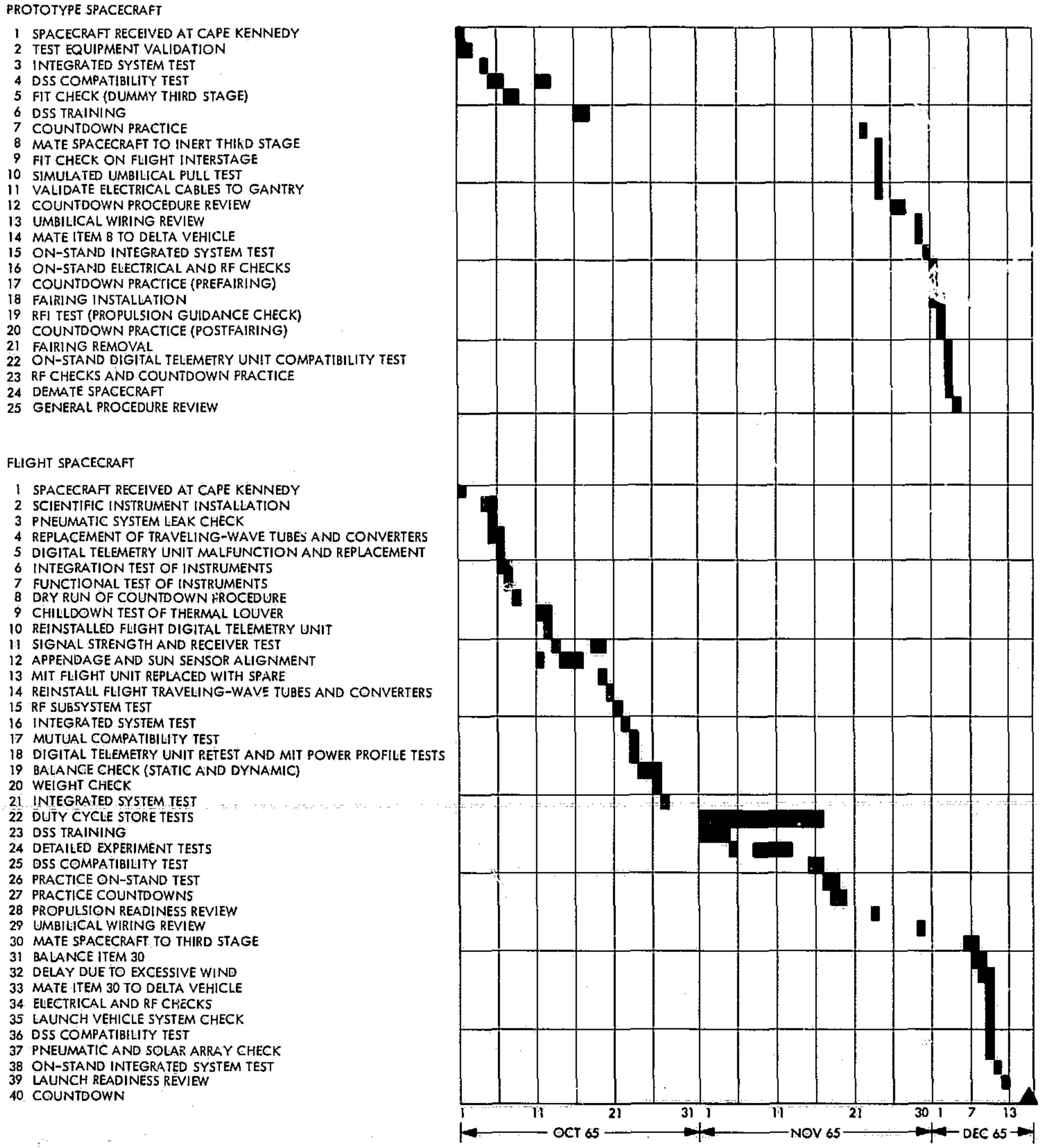


Fig. 41. ***Pioneer VI* prelaunch activities at the AFETR**

On December 8, the third-stage motor–spacecraft combination was mated with the launch vehicle on the launch stand.

During the on-stand integrated system test on December 13, 1965, which was the last system check before launch countdown, three minor defects in electrical ground support and test equipment were found and rectified on that date. The overall system of the spacecraft and launch complex was then ready for the launch countdown.

To ensure tracking, data acquisition, and flight control during powered and free flight, training exercises and tests were conducted with the various launch and flight support groups. Personnel were indoctrinated, equipment

Table 20. Weights, *Pioneer VI*

System element	Weight breakdown, lb	Subsystem total, lb
Structure		19.84
Platform	7.01	
Booms and associated components	4.38	
Interstage	1.17	
Solar array support	2.96	
Other	4.32	
Thermal control		6.80
Louvers, structure, actuators	2.12	
Insulation	4.68	
Electric power		33.58
Solar array	13.98	
Battery	2.19	
Equipment converters	3.02	
Traveling-wave tube converters	4.52	
Cabling and connectors	9.87	
Orientation		7.14
Sun sensors	0.86	
Pneumatic assembly	3.97	
Gas	0.87	
Electronics	0.98	
Wobble damper	0.46	
Communication		14.35
Antenna (spacecraft)	2.01	
Transmitter driver	1.31	
Traveling-wave tube	1.89	
Receivers	6.14	
Other	3.00	
Command		10.72
Decoders	5.60	
Command distribution unit	5.12	
Data handling		10.65
Digital telemetry unit	8.57	
Signal conditioner	1.73	
Data storage unit	0.35	
Balance weight		0.72
Total weight of spacecraft subsystems		103.80
Scientific instruments		34.11
Electronics and sensors	32.15	
Antenna	1.96	
Total weight		137.91

was checked, and operation procedures for normal and emergency situations were tested thoroughly. In this way, the readiness of the various domestic and overseas stations, the worldwide communications networks, and the launch and flight procedures were thoroughly evaluated.

Table 21. Mass properties, *Pioneer VI*

Parameter	Stowed position,[a] lb-in.^{2}	Deployed position,[b] lb-in.^{2}
Roll moment of inertia	23,621	43,509
Pitch moment of inertia	30,383	32,115
Inertia ratio	0.76	1.32

[a] In the stowed position, the center of mass was 14.66 in. from separation plane.

[b] In the deployed position, the center of mass was 13.14 in. from separation plane.

The training exercises were conducted in three different phases. The first was the training of personnel and checking of equipment and procedures at individual stations. The second phase was the operation of a remote station in conjunction with the mission control center at JPL or Cape Kennedy to evaluate and correct any interface deficiencies. The third phase consisted of the operational readiness tests. The entire system and personnel that would be operational from the launch countdown through the cruise mode of flight participated in these tests. The operational readiness tests concentrated on the sequence of events and procedures covering the time period from 4 h before launch until completion of orientation about 44 h after launch. Tracking stations were supplied with spacecraft trajectory predictions so that they could generate pseudometric data to exercise the metric data handling system. Also, the tracking stations were supplied with telemetry data prerecorded on tapes to simulate spacecraft and instrument behavior and to rehearse the ground operational system and personnel. The three operational readiness tests were conducted on December 2, 6, and 9, 1965.

Upon satisfactory completion of the on-stand integrated system test and the third operational readiness test, a launch readiness review meeting was held on December 10, 1965, at Cape Kennedy, with representatives from all responsible agencies. The highlights of the meeting are presented below.

a. Spacecraft status. The spacecraft was reported to be in a satisfactory condition for launch. The scientific instruments removed at the contractor's plant before shipping the spacecraft to Cape Kennedy had been successfully reintegrated. All qualification and acceptance tests had been completed, and all failure reports had been disposed satisfactorily under the cognizance of the failure review board. A malfunction in the digital telemetry unit had occurred at Cape Kennedy. The fault had been corrected, and the unit had been retested at the contractor's California plant, then returned to Cape Kennedy and integrated on the flight spacecraft. The spacecraft had since completed 450 h of failure-free operation. The TWT and TWT converter high-voltage breakdown, which had been encountered on another unit at TRW, was no longer considered a potential problem. The new potting design had been tested for 800 h of failure-free operation in thermal vacuum. The spacecraft had logged over 1500 h of operation and testing, including a 2-wk continuous test run, before mating with the launch vehicle.

b. Experiment status. The experiments were considered acceptable for launch. The status of the MIT plasma experiment remained unchanged. Operation of the spare unit had been satisfactory at Cape Kennedy, and difficulties encountered with the replaced unit had not recurred. The GSFC magnetometer experiment occasionally failed to enter its calibrate mode on command; however, it responded properly to repeated commands, and thus was considered acceptable.

c. Launch vehicle status. Minor details were to be completed (e.g., selection of third-stage motor squib) before countdown, and these were expected to be completed before the launch period.

d. Flight operation readiness. The final operational readiness test had indicated that the Cape Kennedy facilities, AFETR, DSN, and the SFOF were ready to support the *Pioneer* mission. There was a possibility that *Pioneer VI* could suffer at most a 1-day delay because of a conflict with *Gemini VI.*

e. Conclusion. All systems would be ready for launch 5 days hence, on December 15, 1965—the earliest scheduled date.

2. Countdown.

a. Countdown tasks. The launching of *Pioneer VI* was scheduled for December 15, 1965. On December 13, the launch countdown was initiated as planned. The tasks in the countdown for the spacecraft and instruments are described below:

Task I—preparation. The spacecraft and electronic ground support equipment (EGSE) were prepared for the countdown operation. The EGSE was checked and turned on for the required warmup period.

Task II—spacecraft and instrument functional checks. The launch readiness of the spacecraft and the instruments was evaluated. Radio-frequency checks were made with both spacecraft receivers. All instruments were turned on and commanded to various operating modes. The spacecraft was commanded into all the different formats, modes, and bit rates. The flight battery was installed as the last step.

Task III—final pneumatic pressurization. The orientation pneumatic subsystem of the spacecraft was pressurized for the last time, and a final gross system check was made.

Task IV—ordnance installation and checks. The resistance of the ordnance devices and their associated firing cables was measured and compared with previous resistance measurements.

Task V—final preparation. This task completed preparations and secured the spacecraft. All protective covers were removed, the final configuration was checked, and a visual inspection was made. The spacecraft was ready for fairing installation when this task was completed.

Task VI—umbilical and RF checks. This task included a continuity check of the umbilical cables, connection of umbilical cables to the spacecraft, adjustment of lanyard length, and visual inspection of all lines and terminations.

b. Countdown sequence. The countdown proceeded normally until approximately $L-90$ min, when the second-stage electrical umbilical was accidentally disconnected from the vehicle. This was caused by the weight of the second-stage air-conditioning duct being inadvertently applied on the handle of the umbilical carriage release system. This caused the lanyard (connected between the electrical umbilical trip mechanism and the carriage) to tighten, disconnecting the plug. The result was loss of power to the second stage and spacecraft. The 60-min built-in hold was to revalidate vehicle and spacecraft systems. The connector was reinstalled after eliminating the lanyard, and then requalified by running special engine slew checks, internal system turnons, and second-stage pressurization trials. The elimination of the lanyard resulted in the loss of one of the three redundant plug separation modes. This was deemed acceptable for flight.

c. Terminal count. The terminal count was started at 0145 EST ($L-35$ min), and proceeded normally until approximately $L-2$ min, at which time another hold was called to investigate an abnormal WECO radio guidance airborne magnetron current telemetry trace. After the initial apparent current surge at $L-2$ min, the system stabilized, and it was decided to resume the count. However, this anomaly is still under investigation. The count was recycled to $T-8$ min and was restarted. The count then proceeded to liftoff.

The teletype network during the countdown was marginal because of atmospheric conditions. However, all teletype networks were operational at liftoff.

*3. **Liftoff and first powered flight.*** The powered-flight phase for *Pioneer VI* was considered to extend from liftoff on December 16, 1965, at 0731:20.4 through separation of the third stage from the spacecraft. During this period, primary control of the mission was transferred from the mission control center at Building AE to the *Pioneer* mission support area at the SFOF. Other activities during this period relate primarily to tracking and telemetry acquisition; these are discussed in Section VI as part of the performance evaluation of the various elements.

The *Delta 35* vehicle and *Pioneer VI* spacecraft were launched from Complex 17-A on Cape Kennedy Air Force Station, Fla., at 0231:20.5 EST on December 16, 1965.

Because no instruments were required to be on during the launch phase, the spacecraft was launched with the telemetry system in an engineering data format (Format C) and a data rate of 64 bits/s. The moderately low data-bit rate was selected to increase the probability of obtaining good diagnostic data if the TWT should fail to turn on automatically after injection or if difficulties were encountered because of spacecraft orientation during initial acquisition by DSS 51.

The AFETR range safety charts showed the vehicle to be well within the 3σ limits during plotted flight. Vertical plane charts showed actual plot to be about 0.5σ high of the predicted X-Z norm, but about 1σ low of predicted Y-Z norm from 25 s.

Position charts showed actual plot to be left of normal X-Y about 0.7 nmi at MECO and about 0.2 nmi high of the X-Z norm at MECO. Trajectory appeared to be close to the established norm for the remainder of the plot and on time.

Impact predictor charts showed the actual plot to be left of the plotted norm until about MECO + 100 s; then WECO guidance brought the vehicle back to the predicted norm for the rest of the plot. The MECO instantaneous impact point was about 40 nmi downrange of the predicted point, but the rest of the plot appeared to be on time.

Orbital elements from the real-time computer facility, based on actual second-stage radar data (Station 91.18), are listed in Table 22.

The significant flight events are listed in Table 23.

Table 22. Orbital elements

Parameter	Expected	Parking orbit
Eccentricity	0.076319	0.07181
Inclination angle, deg	30.168	30.196
Period, min	101.375	100.604
Apogee, nmi	743.1	704.8
Perigee, nmi	150	149.1
Semimajor axis, nmi	3888.7	3868.9

Table 23. Significant flight events

Event	Expected time, s[a]	Actual time, s[b]
Solid motor separation	$T+70$	$T+69.8$
Main engine cutoff	$T+149.2$	$T+148.0$
Second stage ignition	$T+152.0$	$T+152.0$
Jettison fairing	$T+178.0$	$T+178.0$
Sustainer engine cutoff	$T+551.1$	$T+531.3$
Spinup	$T+1337.0$	$T+1337.0$
Separation	$T+1339.0$	$T+1338.6$
Third stage ignition	$T+1500.0$	$T+1497.5$
Third stage burnout	$T+1522.6$	$T+1521.3$

[a] Liftoff time ($T=0$) was 0145:00.0 EST.

[b] Liftoff time ($T=0$) was 0231:20.5 EST.

Early launch vehicle mark times were not reported in near-real-time. Apparently the first reported mark time was that of sustainer engine cutoff (SECO). This report placed SECO some 19 s earlier than the norm. At the time, it appeared that such a difference was not compatible with that which could be expected for a normal flight. (Until loss of signal of the VHF telemetry at Cape Kennedy, examination of the telemetry in real-time indicated a normal flight.)

*4. **Parking orbit.*** A parking orbit was calculated by the real-time computer facility based upon parking orbit raw tracking data from the Antigua radar, which indicated the actual orbit to be quite close to the norm. It was concluded, after reception of the calculated parking orbital elements, that the normalcy of the orbit was of greater significance in establishing the status of the flight than the abnormal SECO time.

First DSS 51 predicts generated by the real-time computer and transmitted to the SFOF were based upon an incorrect liftoff time. A second set of DSS 51 predicts was subsequently requested by the JPL data coordinator based upon the correct liftoff time. These were satisfactorily prepared, and sent to JPL. However, the real-time computer was not able to prepare predicts successfully for DSS 42 (Tidbinbilla).

The first and only indication of launch vehicle third-stage ignition in near-real-time was the sudden dropout of VHF telemetry from the *Delta* stage at the AFETR Ascension Island station when supposedly the plume of the third stage impinged upon the *Delta* stage. The time of the dropout, as reported by the launch vehicle monitor, agreed with the time of ignition subsequently determined from analog doppler data.

Voice communications with Ascension Island in real-time were out because of RF propagation problems; this precluded getting any indication of third-stage performance in real-time. (Apparently, when a performance report was finally received from Ascension Island, it indicated that the third-stage burn duration was only 50% of the expected duration. It was later learned that the wrong scale was read on the doppler plot, and indeed the burn was about normal.) It appeared that Ascension Island was able to transmit its analog doppler data from tracking the 136-MHz beacon on the third stage. The doppler data were analyzed in postreal-time at Ascension Island to establish the ignition and burnout times of the solid motor in the third stage. As a result of this analysis, the burn duration was determined to be about 23.8 s (the norm was 22.5 s).

Trouble with the doppler equipment aboard the *Coastal Crusader* telemetry ship prevented gathering any doppler data from either the 136-MHz beacon on the *Delta* stage or from the S-band carrier of the telemetry from the spacecraft.

It was reported by AFETR that Tel 2, Grand Bahama Island, and the *Coastal Crusader* obtained S-band telemetry. The latter received about 600 s of S-band data. Of the stations committed to S-band reception, only Antigua was unable to acquire any signal. Ascension Island also did not get a signal, but it was used only on an engineering test basis, and was not committed to the Project.

No voice reporting of third-stage performance was received from Ascension Island, but there was a report from the launch vehicle monitor that the 135-MHz beacon doppler data received at Building AE indicated a normal third-stage burn.

There was no real-time reporting of the acquisition and loss of signal and signal strength from the AFETR S-band stations.

The raw tracking data received from Grand Turk, Antigua, and Ascension Island, after being processed by the Orbit Determination Program, indicated a normal parking orbit.

No acquisition data were provided for Canberra. The first computation of Johannesburg (DSS 51) acquisition data was in error, apparently because of a timing mismatch. The second computation of DSS 51 acquisition data was correct, but late.

5. General coverage. There was no S-band coverage from Station 91, so portions of the Class I telemetry were not met. The reporting of the occurrence of in-flight events was satisfactory; however, identification of the times of occurrences was late.

Telemetry from the 228.2- and 234.0-MHz links was excellent. Ionization losses were nonexistent. The special 230.9-MHz link data were very poor. Real-time pulse-duration-modulated data from Antigua were excellent, but the continuous data were very poor. Enough data were obtained from Antigua to verify spinup and third-stage ignition. All data, except the 3.9-kHz spin rate, were very poor from Ascension Island. Data recorded in Building AE during the first orbit were good, and it was indicated that all systems were still functioning properly, and that all batteries were still well charged.

B. Deep Space Phase Support

The DSN, as part of the Tracking and Data System (TDS) for a flight project, is normally assigned to support the deep space phase of each mission. Responsibility for providing TDS support from liftoff until the end of the mission was assigned to the JPL office of tracking and data acquisition. A TDS manager worked with the JPL technical staff at the AFETR to coordinate the support of the AFETR, MSFN, and NASCOM with certain elements of the DSN needed for the near-earth phase support. A DSN manager and DSN project engineer, together with representatives from the DSIF, SFOF, and the ground communications facility, formed a design team for the planning and operational phases of flight support. A typical functional organization chart for operations is shown in Fig. 42.

Mission operations design was accomplished in a closely coordinated effort by the Mission Operations System (MOS) and TDS managers. Mission operations, an activity distinct from the management element MOS, included: (1) a data system, (2) a software system, and (3) an operations system.

The data system included all earth-based equipment provided by all systems of the flight project for the receipt, handling, transmission, processing, and display of spacecraft data and related data during mission operations. Except for relatively small amounts of mission-dependent equipment supplied by the flight project, all equipment was provided and operated by the DSN. In the near-earth phase, facilities of the AFETR and the MSFN were included. The DSN also operated and maintained the mission-dependent equipment.

The software system included all computer programs and associated documentation. The mission-independent software was provided as part of the DSN support. The mission-dependent software developed by the flight project was operated and maintained for the project by the DSN.

The operations system included the personnel, plans, and procedures (provided by both the MOS and TDS) required for execution of the mission operations. The mission operations design organization was supported by the DSN in the manner shown in Fig. 43. The DSN project engineer headed a design team composed of project engineers from various elements of the DSIF, GCF, and SFOF. This team was primarily concerned with the data system defined above. The designs of the other systems were the responsibilities of the software system design team and the mission operations design team. The DSN supported these activities through its representative, the DSN project engineer.

The mission operations design process supported by the DSN is shown in Fig. 44. From the project development plan and the mission plan and requirements are derived the guidelines for operational planning and the project requirements for TDS support. The mission operations design team formulated system-level functional requirements for the data, software, and operations systems. From these requirements, as well as from the TDS support requirements, the DSN design team formulated the DSN configuration to be used in support of the project. It also supported, through the DSN project engineer, the activities of the software and mission operations design teams in designing the software and operations systems. The interface definitions were accomplished by working groups from these design teams.

The TDS support required by the project was formulated in the support instrumentation requirements document and the project requirements document. The project requirements document states project requirements for support by the U. S. Department of Defense through the AFETR.

1. Deep Space Network.

a. Mission support. The extent to which the facilities, equipment, and personnel of the DSN were committed to the support of the *Pioneer VI* mission was officially defined on January 7, 1965. The hardware, software, and organizational interfaces between the *Pioneer VI* mission and the DSN were also established at that time. The functional organization was that shown in Fig. 42. The DSN commitment included the furnishing of a medium-accuracy orbit for *Pioneer VI* and the development, jointly with the *Pioneer* Project, of all hardware, software, and interface documentation necessary to ensure efficient teamwork between the project and DSN management.

The Johannesburg, Tidbinbilla, *Echo,* and Cape Kennedy DSSs were assigned for basic support of the *Pioneer VI* mission. The *Echo* DSS was committed for one complete pass per day for the first 30 days; beginning on the thirty-first day until the end of the mission, three complete passes per week were planned. The Tidbinbilla DSS was committed for one complete pass per day for the first 30 days. The Johannesburg DSS was committed for one complete pass per day during the first 4 days of the mission. In addition, it was planned, within the limits of DSN loading and station availabilities, to use any or all of these stations to provide a minimum average coverage of the equivalent of one pass per day from the thirty-first day to the end of the mission. The Robledo, *Pioneer,* and Woomera DSSs, which were not equipped with *Pioneer* mission-dependent ground operating equipment, would also be available on an emergency backup basis to track and record the telemetry subcarrier on magnetic tape.

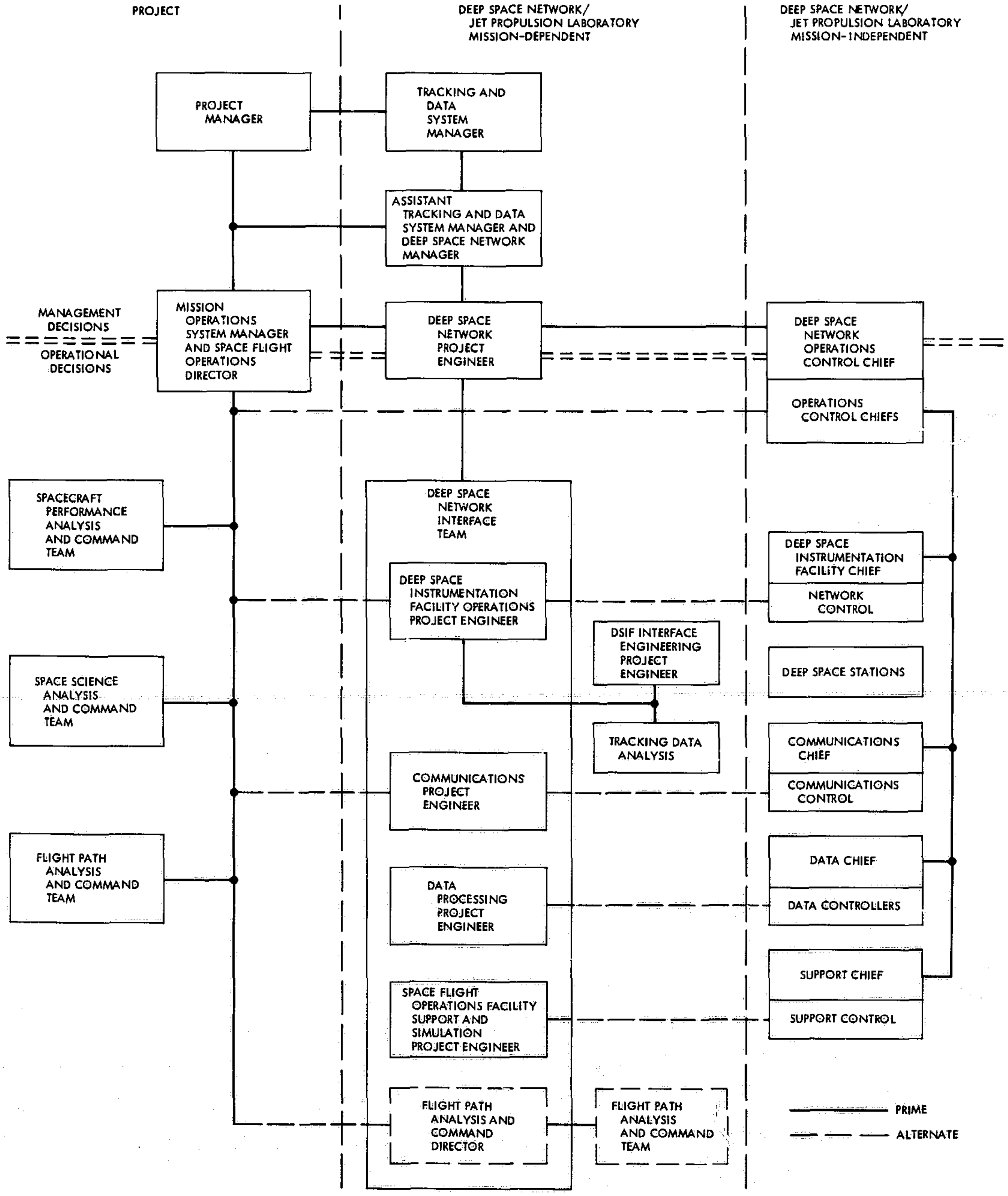


Fig. 42. Typical functional organization for mission support operations

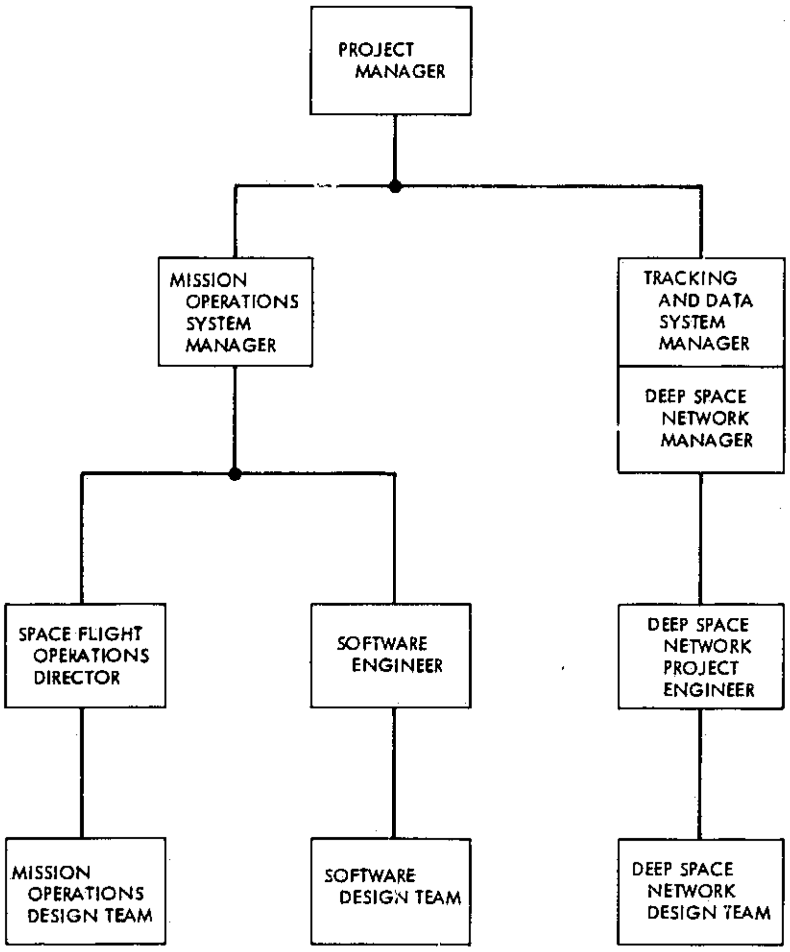


Fig. 43. Mission operations design organization

It was intended to meet all of the basic requirements of the *Pioneer* Project for support of the *Pioneer VI* mission, with the understanding that, should circumstances permit, the maximum requirements would be met. Since the time of the original commitment, revisions were made, on a periodic basis, as required to meet the changing needs of the *Pioneer* Project and to make the commitment compatible with the advancing capabilities of the DSN. At the time of the commitment, the DSN had capabilities to support the *Pioneer VI* mission only during the first 8 mo after launch. It was stipulated that, if the telemetry bit-error rate reached an unacceptable level, *Pioneer VI* support by the DSN would be terminated, based upon mutual agreement with the *Pioneer* Project Office. When, some 8 mo after launch, the telemetry detection threshold of the *Pioneer VI* S-band downlink signal was reached within the 85-ft antenna network, the Mars DSS, with its 210-ft antenna, was made available on an uncommitted best-effort basis.

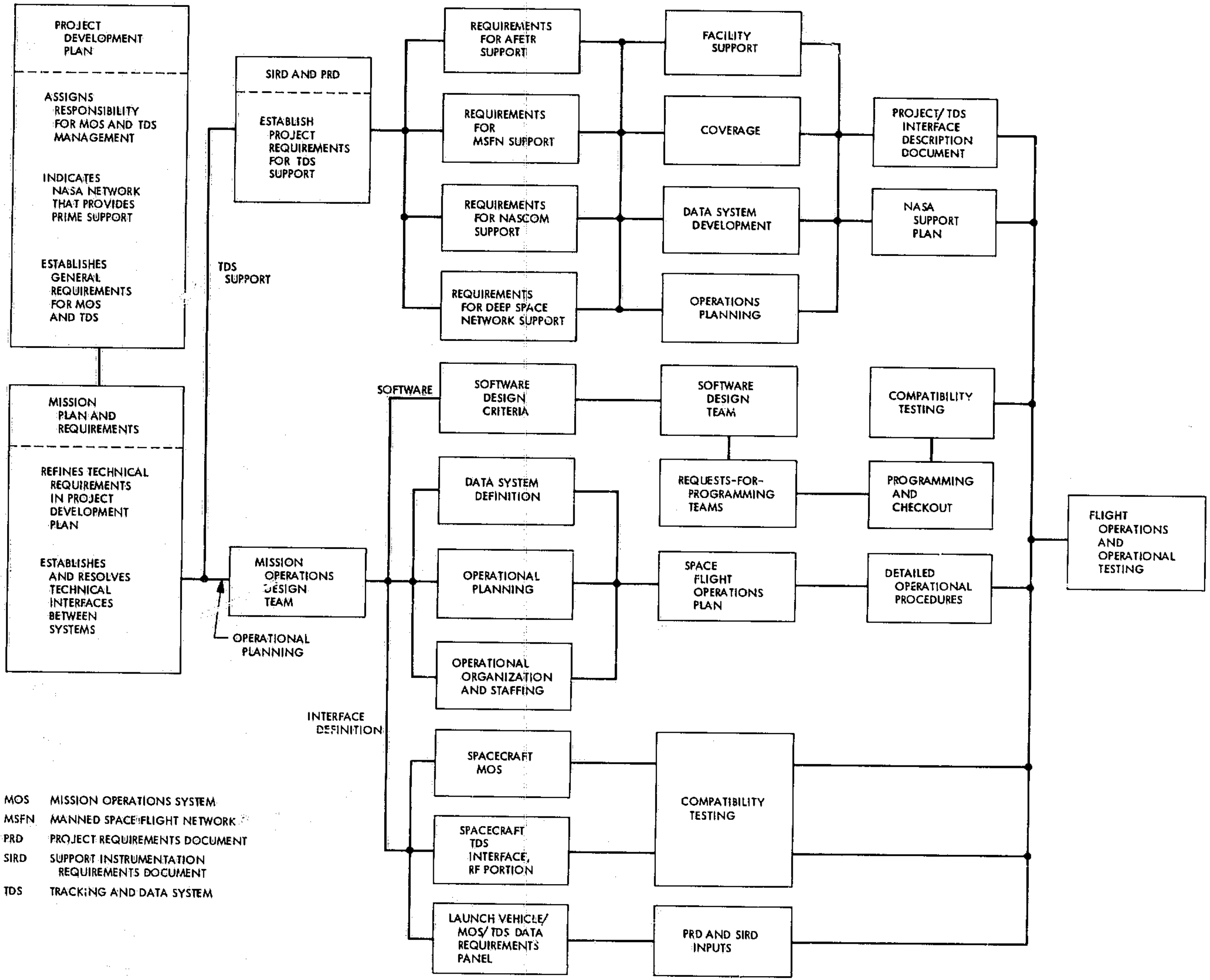
b. Prelaunch operations. Prelaunch checkout and preparation of the spacecraft and its scientific instruments were conducted at Building AN at the Cape Kennedy Air Force Base station (DSS 71). During this period, tests of the RF link between the spacecraft and DSS 71 were performed. Deep Space Station 71 contained mission-independent and -dependent equipment (*Pioneer* ground operational equipment) functionally identical to that of the standard DSSs. This test was the first opportunity to validate the compatibility of the *Pioneer VI* communications subsystem with the DSN.

During countdown, DSS 71 received telemetry data from the spacecraft and monitored continuously the spacecraft communications subsystem performance and the compatibility of the subsystem with the DSN. The direction and status monitoring of the DSN were performed at the SFOF. Also, the performance of the spacecraft and scientific instruments was analyzed at the SFOF from spacecraft telemetry data sent via teletype from DSS 71. These activities served as backup to similar tasks performed at Building AN.

c. Flight support. The *Pioneer VI* spacecraft was launched on December 16, 1965. During the near-earth phase of the mission, the AFETR network tracked the launch vehicle and received telemetry data from the spacecraft during the powered-flight phase. The Cape Kennedy station, stations at Grand Bahama Island and Antigua, and the *Coastal Crusader* tracking ship participated in these activities. The telemetry data, recorded on magnetic tape for later processing and analysis (excluding those from the ship), were dispatched via teletype to the real-time computer facility at DSS 71, where the characteristics of the trajectory were calculated for predictions to be used for the initial DSN spacecraft acquisition. Similar activities were performed at the SFOF using the AFETR tracking data.

Following the powered-flight phase, the Johannesburg station (DSS 51) made initial acquisition, starting the deep space phase of the mission. This and all of the other DSSs supporting the *Pioneer VI* mission tracked, received telemetry data from, and transmitted commands to the spacecraft. Computing equipment at the SFOF processed the tracking data from each DSS during or immediately following a pass of the spacecraft for orbit determination, and calculated the predictions as an aid in subsequent acquisitions by the DSSs and by the 150-ft transmitting antenna at Stanford University. As part of its radio propagation investigation, Stanford University transmitted 50- and 430-MHz signals to the two Stanford receivers aboard the spacecraft.

The SFOF mission support area was used for mission control during the initial phases of the mission, except for critical orientation maneuvers. For *Pioneer VI*, the initial



MOS	MISSION OPERATIONS SYSTEM
MSFN	MANNED SPACE FLIGHT NETWORK
PRD	PROJECT REQUIREMENTS DOCUMENT
SIRD	SUPPORT INSTRUMENTATION REQUIREMENTS DOCUMENT
TDS	TRACKING AND DATA SYSTEM

Fig. 44. Mission operations design process

acquisition and partial orientation were directed from DSS 71, and the final orientation was controlled from the Goldstone *Echo* station (DSS 12).

During the deep space phase of the mission, principal support was provided by DSSs 12, 42, and 51, as these were the only tracking stations equipped with mission-dependent ground operational equipment. A microwave system connecting DSS 12 with the *Pioneer* and Mars stations (DSSs 11 and 14) provided a capability for using the ground operational equipment at DSS 12 in combination with the mission-independent equipment at DSSs 11 and 14. The Robledo and Woomera stations (DSSs 61 and 41), also unequipped with mission-dependent ground operational equipment, were used on an emergency backup basis.

The mission operations center is located at Ames Research Center. Both the SFOF mission support area and the ARC mission operations center received, in near-real-time by teletype from the tracking stations, sampled and processed telemetry data for use in monitoring the performance of the spacecraft and its scientific instruments, and as an aid in planning mission operations. The ARC facility also received from the DSSs all spacecraft analog telemetry data recorded on 0.5-in. magnetic tape. All analog tapes are validated at the SFOF. Special- and general-purpose equipment at ARC was used to process the engineering and scientific data, which were then forwarded to the principal scientific investigators for study and assessment. The DSN also furnished data packages on the orbits and view periods, as well as information on the roundtrip time required for RF signals to travel between the spacecraft and the DSSs.

Every phase of the mission thus far has been successful, and all flight instruments are still operating. The DSN not only met all basic *Pioneer VI* support commitments, but also provided a large amount of additional tracking support from its 85-ft antenna network during the routine mission period. This is illustrated in Fig. 45, which shows the DSN operational support rendered during the mission.

The only anomaly that has caused some operational problems during recent months was erratic behavior of the voltage-controlled oscillator of the channel 7 spacecraft receiver. Because of this instability, *Pioneer VI* now operates in a one-way mode using the auxiliary oscillator. The telemetry science and engineering information is still satisfactory, and has a low bit-error rate (lower than that in the 2-way mode). The instability of the channel 7 receiver has impeded the celestial mechanics investigation by *Pioneer VI*, since precision 2-way doppler tracking data were not available.

The fixed earth–sun line heliocentric trajectory of *Pioneer VI* is shown in Fig. 46. The variable data transmission bit rate to the spacecraft made it a highly desirable monitoring platform. By sending proper commands from earth, the telemetry link could be switched to operate at five discrete bit rates: 512, 256, 64, 16, and 8 bits/s. The bit rate was lowered as the earth-to-spacecraft distance increased to reduce the possibility of data errors. The higher bit rates provided science data with higher resolution.

When communications distance criteria required a low bit rate, the spacecraft could be commanded into a higher bit rate with on-board storage. The stored data could be read out later at the required lower bit rate. To assure the highest science and engineering data quality, the *Pioneer* Project specified a telemetry bit stream error limit of 1 error/10^3 detected bits, with the stipulation that, in certain situations, a bit-error rate of 1 error/10^2 detected bits would be acceptable.

As the communications range of the spacecraft gradually increased, the telemetry bit rate was switched to the next lower level, as shown in Fig. 46. The 85-ft antenna telemetry threshold (8 bits/s) was reached in early June 1966.

The normal power budget of the *Pioneer VI* telemetry link is given in Table 24. These data are compatible with the capabilities of DSSs with standard 85-ft antennas. All DSN measurements during the first 180 days after launch showed excellent agreement with the data in Table 24. The practical deviations were well within the limits of measurement and calibration uncertainties.

Figure 47, which gives the carrier power levels recorded at DSSs 12 and 14, demonstrates that the design goals of the S-band communications link were met satisfactorily.

The telemetry bit-error rates measured at DSS 12 at the various bit-rate thresholds are shown in Fig. 48. As

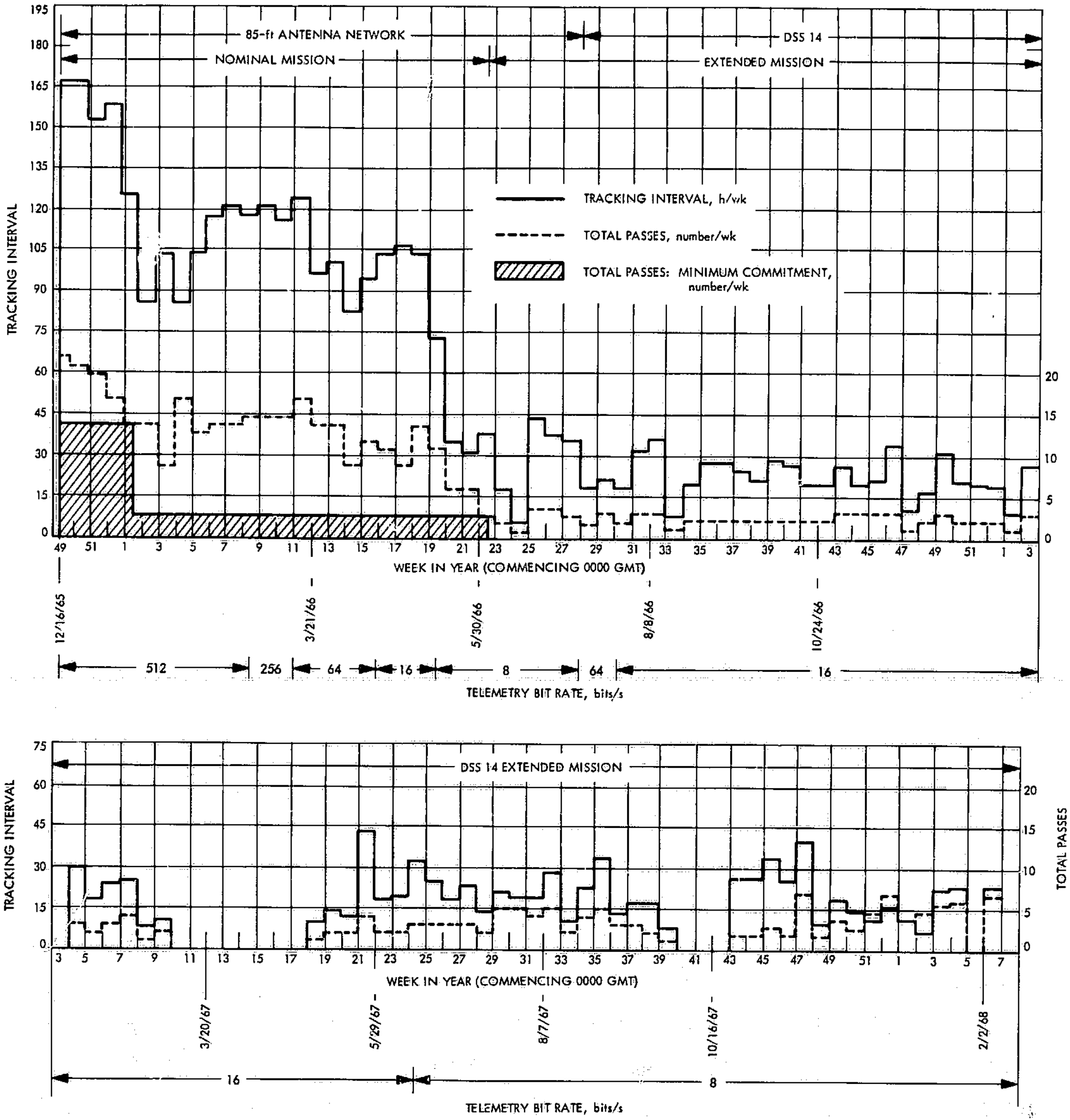


Fig. 45. Operational support of *Pioneer VI* mission: weekly tracking passes and hours and minimum commitment during nominal mission

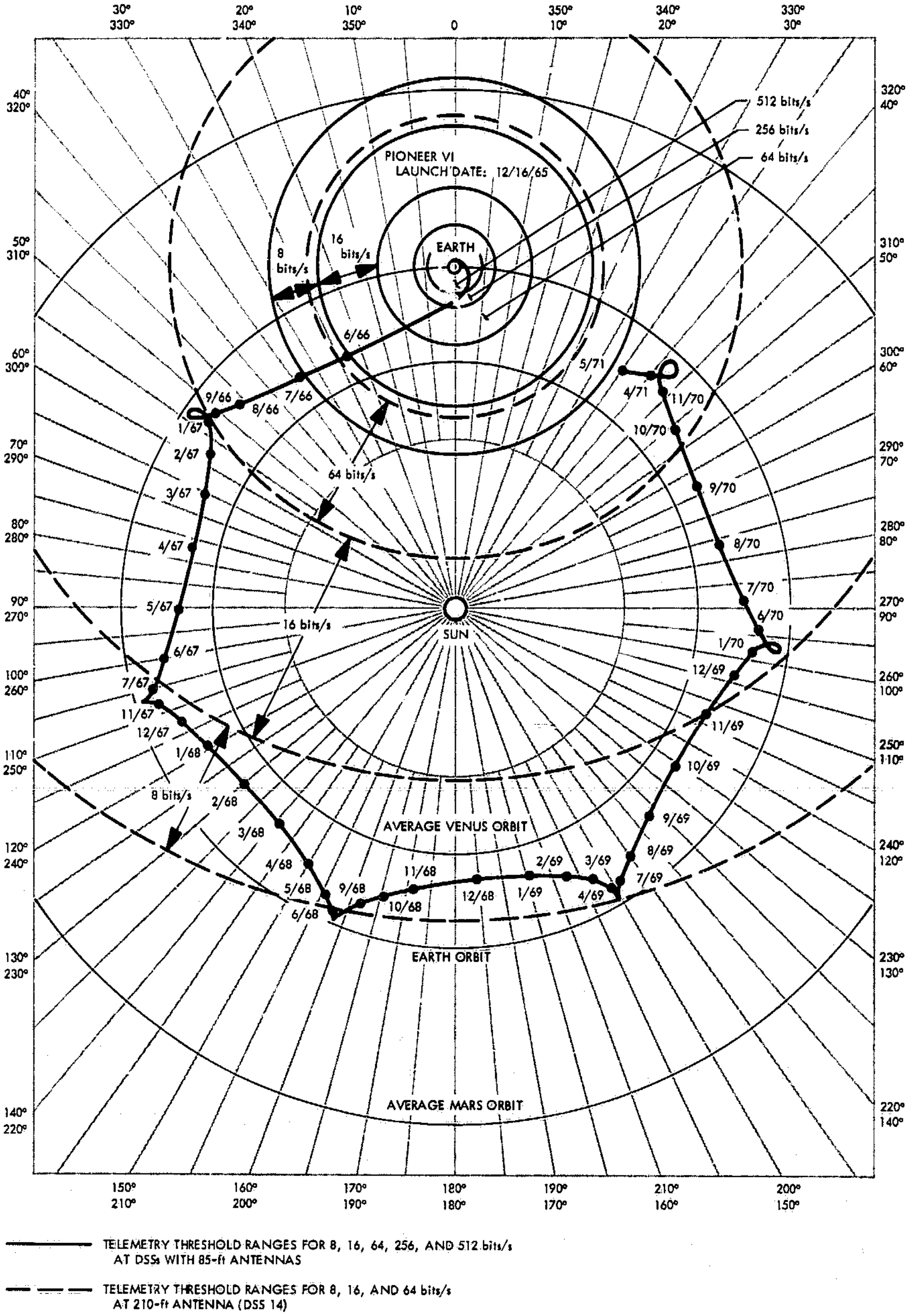


Fig. 46. Fixed earth–sun line heliocentric trajectory of *Pioneer VI* and telemetry threshold ranges

the communications range increased (corresponding to the increasing pass numbers), the bit-error rate during each pass also increased. The bit-error rate during the middle portion of the tracking passes was quite uniform, but showed a tendency to increase at the beginning and end of each tracking period. This increase was caused by a degradation in telemetry signal-to-noise ratio, which was caused by the fact that the system noise temperature of the antenna receiving system is lowest at high elevation angles but increases at lower elevation angles.

Nearly 3×10^9 bits of information have been collected by the DSN during the first 26 mo after the launch of *Pioneer VI*. This information may be categorized as follows:

Type of information	Number of bits $\times 10^6$
Total bits	2953
Science data	2110
Engineering data	164
Parity check	386
Data identification	272
Unassigned	21

Table 24. Normal power budget for the *Pioneer VI* telemetry link[a]

Parameter	Bit rate, bits/s				
	512	256	64	16	8
Total transmitter power, dBm	38.4	38.4	38.4	38.4	38.4
Transmitting circuit loss, dB	1.6	1.6	1.6	1.6	1.6
Transmitting antenna gain, dB	11.0	11.0	11.0	11.0	11.0
Space attenuation (2.292 GHz), dB	242.0	245.0	251.0	256.1	258.0
Polarization loss, dB	3.0	3.0	3.0	3.0	3.0
Receiving antenna gain, dB	53.4	53.4	53.4	53.4	53.4
Receiving circuit loss, dB	0.2	0.2	0.2	0.2	0.2
Total received power, dBm	−144.0	−147.0	−153.0	−158.1	−160.0
Receiver noise spectral density (at 45°K), dBm/Hz	−182.1	−182.1	−182.1	−182.1	−182.1
Carrier performance					
Carrier modulation suppression (modulation index = 0.9 rad), dB	4.1	4.1	4.1	4.1	4.1
Received carrier power, dBm	−148.1	−151.1	−157.1	−162.2	−164.1
Carrier automatic-phase-control noise bandwidth ($2B_{LO} = 12$), dB	10.8	10.8	10.8	10.8	10.8
Threshold signal-to-noise ratio in $2B_{LO}$, dB	6.0	6.0	6.0	6.0	6.0
Threshold carrier power, dBm	−165.3	−165.3	−165.3	−165.3	−165.3
Carrier performance margin, dB	17.2	14.2	8.3	3.1	1.2
Data channel					
Subcarrier modulation suppression, dB	2.2	2.2	2.2	2.2	2.2
Received subcarrier power, dBm	−146.2	−149.2	−155.2	−160.3	−162.2
Bit rate ($1/T$), dB	27.1	24.1	18.1	12.0	9.0
Required ST/N ($P_e = 10^{-3}$), dB	8.8	8.8	8.8	8.8	8.8
Receiver losses and degradation, dB	0	0	0	1.0	2.1
Threshold subcarrier power, dBm	−146.2	−149.2	−155.2	−160.3	−162.2
Data performance margin, dB	0	0	0	0	0
Range, km $\times 10^6$	13.2	18.6	37.0	66.5	82.8
Time after launch, days	78.5	92.6	122.6	156.8	174.4

[a] The symbols used herein are defined as follows:

B_{LO} = carrier tracking loop bandwidth at threshold levels, Hz.
T = time per information bit, s.
S = signal power, W.
N = noise spectral density, W/Hz.
P_e = probability of data error.

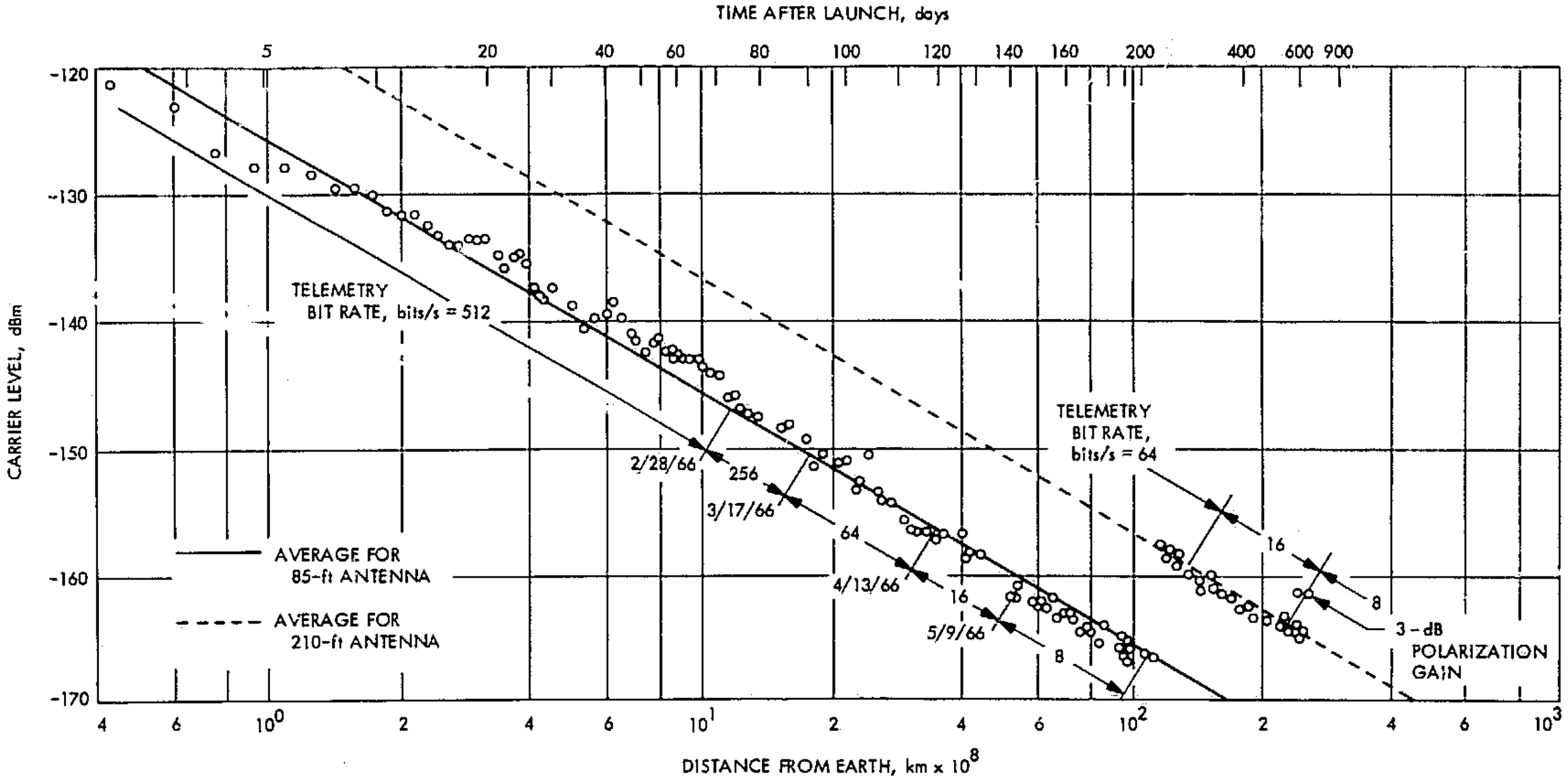


Fig. 47. Carrier power received from *Pioneer VI* from January 1966 to February 1968, as reported by DSSs 12 and 14

Throughout the flight, the spacecraft has operated primarily in the real-time data transmission mode. The spacecraft duty-cycle storage mode, generally used between tracking periods, provided approximately 20% of the data coverage. However, because of intermittent data sampling, this mode contributed only about 0.06% of the total data received.

Based upon its performance thus far, the estimated total lifetime of the *Pioneer VI* spacecraft is approximately 5 yr. During November 1968, the spacecraft had a solar occultation; the *Pioneer* Project and DSN management personnel coordinated preparations for the support of special experiments to be conducted at that time. The detection capability of the 85-ft antenna network will again be reached by *Pioneer VI* during the spring of 1971.

2. Deep Space Instrumentation Facility. The *Pioneer VI* spacecraft was launched from Cape Kennedy on December 16, 1965, at 0731:20 GMT. The initial acquisition was performed by DSS 51, with downlink lock being achieved at 0759:53 GMT followed by 2-way lock at 0806:26 GMT.

At the time of acquisition, the booms had been deployed and the spin rate was 59 rev/min. The cold gas system pressure had dropped the planned 600 psi to indicate that the orientation maneuver had occurred. The bit rate had increased from 64 to 512 bits/s. One experiment was enabled, and it was verified that the solar array was working properly. Early DSS 51 calculations gave a perihelion of 0.817 astronomical unit (AU) and an inclination to the ecliptic of 0.15 deg.

Later tracking data indicated that all spacecraft systems were functioning normally. The estimation was that it would take 154.8 days to reach a perihelion of 0.8143 AU, and that the aphelion would be 1.0 AU. The inclination of the spacecraft to the ecliptic was 0.17 deg. It was estimated that the spacecraft would be 4.7 × 10^6 nmi from the earth in 180 days.

The activities performed at DSS 51 during the first pass can be grouped in the following task categories:

(1) Establish communications with spacecraft.

(2) Determine initial operating mode of spacecraft.

(3) Evaluate initial performance of spacecraft.

(4) Change operating mode of spacecraft in preparation for deep space phase of mission.

(5) Perform partial Type II orientation.

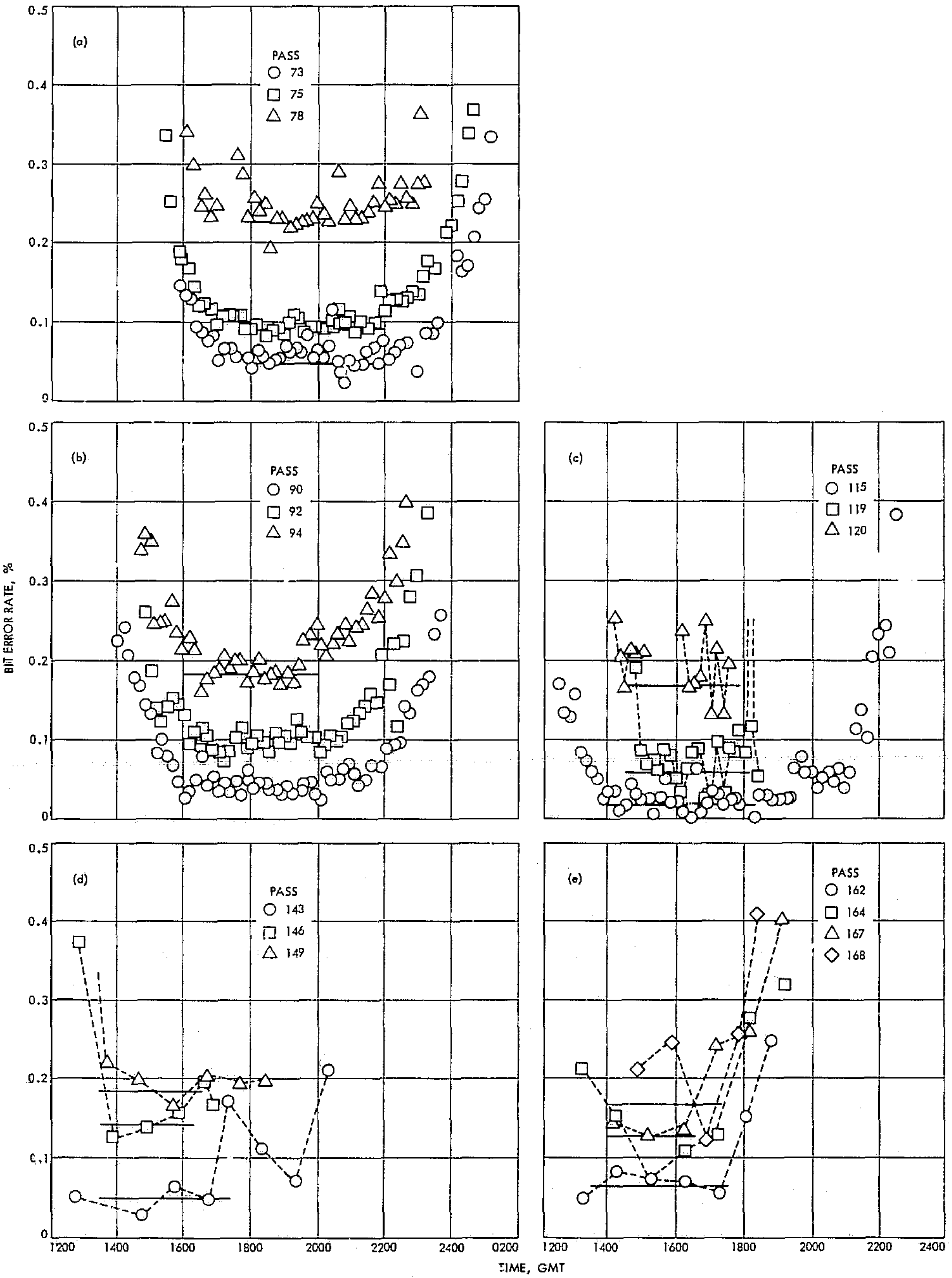


Fig. 48. *Pioneer VI* telemetry bit-error rates estimated at the DSS 12 bit-rate thresholds of (a) 512, (b) 256, (c) 64, (d) 16, and (e) 8 bits/s

a. Communications. As soon as telemetry communication was established with the spacecraft and the computer locked on the data, the information was sent via teletype from DSS 51 to the SFOF at JPL. The teletype information received for the first 40 min of the pass is shown in Table 25, and is representative of that used in making the critical decisions during the first pass.

To ease problems associated with initial acquisition of the telemetry signal from the spacecraft, the receivers at DSS 51 were initially connected to the acquisition-aid antenna. Although the gain of this antenna is about 32 dB less than that of the 85-ft antenna, sufficient power in the spacecraft signal would be available at initial acquisition to permit its use, and it provided the significant benefit of a 16-deg beamwidth in contrast to the 0.35-deg beamwidth for the 85-ft antenna.

The acquisition-aid antenna is mounted on the 85-ft antenna with its beam axis coincident with that of the larger antenna. Before the expected time of spacecraft arrival, both antennas were pointed 10 deg above the local horizon along the expected flight path of the spacecraft.

The predicted time for the spacecraft to rise above the local horizon was 0759:40 GMT. While the spacecraft was still below the horizon, an audio detector in the receiver indicated the first signal. Signal strength increased rapidly thereafter, and by 0759:57 GMT the ground receiver, demodulator–synchronizer, and computer were locked on the spacecraft telemetry signal. By 0800:28 GMT, the antenna was switched to the automatic tracking mode. (The hours of day indicated in the subsequent paragraphs are all in Greenwich Mean Time.)

The coherent mode of operation for the spacecraft receiver was enabled before launch. Thus, whenever the spacecraft receiver was locked to a ground signal, the frequency of the signal transmitted from the spacecraft was a fixed ratio of the received signal frequency; when not in lock, the frequency is controlled by the on-board crystal oscillator. The probability of both frequencies being within the self-acquisition range of the ground receiver, with no tuning adjustment required, was very remote. Therefore, to preclude the possibility of an interruption in telemetry because of a change in the frequency of the telemetry signal as the spacecraft receiver went in or out of lock, the ground transmitters were scheduled to be off until after the status and performance of the spacecraft were assessed. By 0805, spacecraft status and performance had been assessed and found normal. The ground transmitter was therefore energized. At 0806, the ground receiver lost the telemetry signal, indicating that the spacecraft had acquired the ground signal and was operating coherently. Within 1 min, the ground receiver was again in lock. This activity is indicated by the teletype printout at 0806.

At 0807, tracking of the telemetry signal was normal, and the ground receiver was switched from the acquisition-aid antenna to the 85-ft antenna. The ground transmitter was similarly switched at 0816. By 0817, the 85-ft antenna was operating in the automatic tracking mode. At 1210, while operating in the automatic tracking mode, the strength of the signal received from the spacecraft suddenly reduced by 15 dB. It was suspected that the tracking of the spacecraft signal had shifted from the main lobe of the 85-ft antenna to a side lobe because a discrepancy between the predicted antenna orientation and actual orientation was observed. At 1322, the antenna was switched to manual track in an attempt to increase the signal strength, but without success. Finally, at 1355, a second attempt was made in which the antenna was manually changed to the predicted position for that time. The strength of the signal immediately increased, and the antenna was switched back to the automatic tracking mode. At 2031, the anomalous performance recurred, and was similarly corrected. At all other times during the first pass, the antenna system operation was normal.

b. Orientation maneuvers. The Type I orientation was performed by the spacecraft early in the launch pass over DSS 51 on December 16, 1965.

The Type II orientation was performed in two parts, the first over DSS 51 and the second over DSS 12, both on the first pass. Figure 49 shows the special communications configuration used for these operations.

Table 26 gives the *Pioneer VI* DSS operations summary for passes 1–196.

VI. *Pioneer VI* Tracking and Data System Performance Evaluation

A. Near-Earth Phase

From liftoff through injection, the performance of the thrust-augmented improved *Delta* launch vehicle was

Table 25. First 40 min of on-line engineering data from initial acquisition of *Pioneer VI* by DSS 51

```
JOB0100
SS JJPL
DE LJ09 010M
16/0756Z

E1*0800 LOCK
J0800 FORMAT C RT
J0800 D350, FORMAT C, STATUS IS  0010 7556 6515 6244 4435 $$
J0800 D350, FORMAT C, STATUS IS  0010 7556 6615 6244 4441 02
J0800 STATUS CHANGED, STATUS IS  0310 7556 6615 6244 4441 20
J0800 STATUS CHANGED, STATUS IS  0010 7556 6615 6244 4441 02
J0800 STATUS CHANGED, STATUS IS  0210 7556 6615 6244 4441 02
J0801 STATUS CHANGED, STATUS IS  0010 5556 6515 6244 4441 00
J0801 STATUS CHANGED, STATUS IS  0010 7556 6615 6244 4441 00
J0801 STATUS CHANGED, STATUS IS  0010 7556 6615 6244 4441 03
J0801 STATUS CHANGED, STATUS IS  0010 5556 6515 6244 4441 02
J0801 STATUS CHANGED, STATUS IS  0010 5556 6615 6244 4441 00
J0802 STATUS CHANGED, STATUS IS  0010 7556 6515 6744 4441 00
J0802 STATUS CHANGED, STATUS IS  0010 5556 6515 6244 4441 02
J0802 STATUS CHANGED, STATUS IS  0012 5556 6615 6244 4441 22
J0802 STATUS CHANGED, STATUS IS  0010 5556 6615 6244 4441 00
J0802 STATUS CHANGED, STATUS IS  0310 7556 6515 6244 4441 02
J0803 STATUS CHANGED, STATUS IS  0010 5556 6515 6244 4441 03
J0803 STATUS CHANGED, STATUS IS  0010 7556 6515 6244 4441 00
J0803 STATUS CHANGED, STATUS IS  0010 7556 6515 6244 4441 02
J0803 STATUS CHANGED, STATUS IS  0012 7556 6515 6044 4441 03
J0803 STATUS CHANGED, STATUS IS  0010 5556 6615 6244 4441 03
J0804 STATUS CHANGED, STATUS IS  0210 7556 6615 6244 4441 02
J0804 STATUS CHANGED, STATUS IS  0010 7556 6615 6744 4441 00
J0804 227 LIM CK, 65
J0804 228 LIM CK, 74
J0804 229 LIM CK, 56
J0804 227 LIM CK, OK
J0804 247 LIM CK, 17
J0804 258 LIM CK, 27
J0804 229 LIM CK, OK
J0804 247 LIM CK, OK
J0805 ESTIMATED BITRATE IS 64
STIME        ERR

      PRIM BATT NITR TWIC TWT  REF  TWT  RCVR SIG
      VOLT TEMP TEMP TEMP NMBR VOLT TEMP NMBR STNG

      PRIM BATT NITR                CATH HELX      LOOP
      CURR CURR PRES                CURR CURR      STRS


J0805
      30.4 82.7 57.1 73.4 0201 -936 94.3 0001 -155
      1.43 .016 2578                38.9 7.50      2.55


J0806 LOST BIT SYNC 00000014,00020207
J0806 LOST BIT SYNC 00002003,00000020
J0806 LOST W/F SYNC 00000000,02000020
J0806 LOCK
J0806 STATUS CHANGED, STATUS IS  0010 7556 6625 6244 4441 00
J0806 220 LIM CK, 36
J0806 246 LIM CK, 50
J0807 247 LIM CK, 43
J0807 246 LIM CK, OK


J0806        .000
      $$$$$$$$$ 57.1 73.4 0001 -936 95.9 0001 -137
      $$$$$$$$$ 2578                38.9 7.00      -36.


J0807 247 LIM CK, OK
J0807 SPIN COUNTER IS 077, 059 RPM
J0807 PARITY ERROR RATE BAD
J0807 68 FRAMES REQUESTED
J0808 PARITY ERROR RATE OKTE
```

```
J0809
      29.9 82.7 57.1 73.4 0001 -936 97.7 0001 -127
      1.43 .032 2578                38.9 7.00      -39.

E

J0810
      29.9 82.7 57.1 73.4 0001 -936 97.7 0001 -121
      1.43 .024 2578                38.9 7.00      -24.

-------------------------------------------------------------
J0810 LIMIT CHANGE ON 222 LO 00 HI 40
J0811 STATUS CHANGED, STATUS IS  0010 7556 6665 6044 4441 20
J0811 CMND 004 SENT TO DECODER ADDRESS 4
J0811 LOST W/F SYNC 00000214,00020161
J0811 LOCK
J0811 STATUS CHANGED, STATUS IS  0040 7556 6605 6244 4441 0350
J0811 PARITY ERROR RATE BAD
J0812 220 LIM CK, OK
J0812 PARITY ERROR RATE OK
J0812 237 LIM CK, 37
J0812 239 LIM CK, 43
J0812 237 LIM CK, OK
J0812 244 LIM CK, 32
J0812 239 LIM CK, OK
J0812 246 LIM CK, 67
J0812 244 LIM CK, OK


J0812
      29.9 82.7 57.1 75.4 0001 -936 99.5 0201 -121
      1.43 .016 2578                38.9 7.00      -3.0


J0813 246 LIM CK, OK
J0813 STATUS CHANGED, STATUS IS  0040 7556 6665 6244 4441 00
J0813 258 LIM CK, OK
J0813 CMND 021 SENT TO DECODER ADDRESS 4
J0813 STATUS CHANGED, STATUS IS  0040 7556 6605 6044 4441 00
J0814 ESTIMATED BITRATE IS 512
J0814 SPIN COUNTER IS 077, 059 RPM
J0814 LIMIT CHANGE ON 258 LO 14 HI 30
J0814 69 FRAMES REQUESTED
J0814 LIMIT CHANGE ON 244 LO 60 HI 71
J0814 LIMIT CHANGE ON 245 LO 30 HI 61
J0815 01 FRAMES WERE SENT TO COMM. BUFFER.
J0815 SPIN COUNTER IS 077, 059 RPM
J0816 STATUS CHANGED, STATUS IS  0040 7556 6605 6044 4446 00
J0816 LOST BIT SYNC 02000024,00001254
J0816 LOST BIT SYNC 00000300,00000020
J0816 LOST W/F SYNC 00000000,00000000
J0816 227 LIM CK, 42
J0816 LOCK
J0816 STATUS CHANGED, STATUS IS  0040 7556 6605 6044 4441 00
J0817 PARITY ERROR RATE BAD
J0817 239 LIM CK, 35
J0817 PARITY ERROR RATE OK
J0817 227 LIM CK, OK
J0877 244 LIM CK, 44
J0817 239 LIM CK, OK
J0817 246 LIM CK, 50
J0817 244 LIM CK, OK
J0817 PARITY ERROR RATE BAD


J0816        .000
      $$$$ $$$$ 57.1 73.4 0001 -939 101. 0001 -129
      $$$$$$$$$$2578                38.9 7.00      7.65


J0818 PARITY ERROR RATE OK
J0818 246 LIM CK, OK
J0818 SPIN COUNTER IS 077, 059 RPM
J0819 SPIN COUNTER IS 077, 059 RPM
```

```
J0821 SPIN COUNTER IS 077, 059 RPM
J0822 PARITY ERROR RATE BAD
-------------------------------------------------------------
J0822 PARITY ERROR RATE OK


J0823
      30.4 82.4 57.1 75.7 0031 -936 103. 0201 -119
      1.43 .024 2578                38.9 7.02      12.7


J0823 26 FRAMES WERE SENT TO COMM. BUFFER.
J0824 STATUS CHANGED, STATUS IS  0040 7556 6665 6044 4441 00
J0824 SPIN COUNTER IS 077, 059 RPM
J0824 CMND 110 SENT TO DECODER ADDRESS 4
J0824 CMND 110 CHECK, STATUS IS  0040 7156 6625 6244 4441 00
J0824 STATUS CHANGED, STATUS IS  0042 7156 6605 6244 4441 00
J0825 69 FRAMES REQUESTED
J0826 SPIN COUNTER IS 076, 058 RPM


J0826        .109
      30.4 80.4 57.1 75.7 0021 -939 102. 0021 -119
      1.43 .024 2578                38.9 7.00      12.7


J0828 SPIN COUNTER IS 077, 059 RPME
J0830 SPIN COUNTER IS 077, 059 RPM
J0832 SPIN COUNTER IS 077, 059 RPM
J0834 SPIN COUNTER IS 076, 058 RPM
J0835 STATUS CHANGED, STATUS IS  0042 7156 6601 6044 4441 00
J0835 STATUS CHANGED, STATUS IS  0040 7156 6601 6044 4441 00
J0835 STATUS CHANGED, STATUS IS  0040 7156 6601 6044 4441 02
J0836 LOST W/F SYNC 00000259,00005278
J0836 LOCK
J0836 STATUS CHANGED, STATUS IS  0240 7156 6601 6044 4441 00
J0836 LOST W/F SYNC 00000040,00000090
J0836 LOCK
J0836 STATUS CHANGED, STATUS IS  0040 7156 6601 6044 4441 00
J0836 STATUS CHANGED, STATUS IS  0040 7156 6601 6244 4441 00
J0837 LOST W/F SYNC 20000078,00000148
J0837 LOCK
J0837 STATUS CHANGED, STATUS IS  0040 7156 6601 6044 4441 00
J0837 STATUS CHANGED, STATUS IS  3640 6175 5654 3540 4441 33
J0837 LOST W/F SYNC 00000247,00202147
J0837 LOST W/F SYNC 20000015,00300031
J0837 LOCK
J0837 STATUS CHANGED, STATUS IS  0040 7156 6601 6244 4441 00
J0838 LOST W/F SYNC 00003313,00000289
J0838 LOST W/F SYNC 00000027,02000030
J0838 LOCK
J0838 STATUS CHANGED, STATUS IS  0040 7156 6601 6244 4441 00
J0838 STATUS CHANGED, STATUS IS  0040 7156 6607 7544 5741 00
J0838 LOST W/F SYNC 00000052,00200148
J0838 LOCK
J0839 STATUS CHANGED, STATUS IS  0042 7156 6601 6044 4441 00
00038 STATUS CHANGED, STATUS IS 00040 7156 6601 6244 4441 0-.J0


      00000141
J0839 LOCK
J0839 LOST W/F SYNC 00000029,00000043
J0839 STATUS CHANGED, STATUS IS  6740 5156 5654 3141 6641 00
J0839 LOST W/F SYNC 00000026,00000002
J0840 LOCK
J0840 LOCK
J0840 LOST W/F SYNC 20000014,00000021
J0840 STATUS CHANGED, STATUS IS  0040 7156 6606 6044 4441 00
J0842 LOCK
```

Table 26. *Pioneer VI* Deep Space Stations operations summary

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
Launch	71	0	−125.0	—	1-way	Station lost lock on spacecraft at time of shroud jettison
1	51	89	−120.4	1.10	1-, 2-, and 3-way	Initial acquisition of signal was perfect Command monitor receiver would not lock up until transmitter frequency was changed because particular frequency fell between tuning ranges of the two receivers. Commands were sent in *abnormal* mode until frequency changed Channel 7 receiver apparently locked up by spurious emission of ground transmitter 24 dB below carrier level. Problem was solved by reducing power
	12	10	−124.1	0.30	2- and 3-way	Transmitter power reduced from 600 to 100 W
	42	0	−121.5	—	3-way	
2	42	9	−125.5	0.13	1-, 2-, and 3-way	
	51	5	−129.7	0.30	2- and 3-way	
	12	198	−128.4	0.60[a]	2- and 3-way	Type II orientation maneuver performed during this pass Acquisition 20 min late due to incorrect prepass instructions
3	42	6	−116.5	0.60	2- and 3-way	
	51	4	−122.1	0.60	2- and 3-way	
	12	9	−123.0	0.60	2- and 3-way	
4	42	4	−119.5	0.60	2- and 3-way	
	51	4	−124.4	0.60	2- and 3-way	
	12	2	−126.7	0.60	2- and 3-way	
5	42	12	−121.5	0.60	2- and 3-way	Operator error caused delay in transmission of a command (command modulation not on)
	51	4	−126.5	0.60	2- and 3-way	Station tracked on paramp because maser inoperative
	12	2	−127.8	0.60	2- and 3-way	Station tracked on paramp because maser inoperative
6	42	4	−122.0	0.60	1-, 2-, and 3-way	Both receivers failed for more than 1 h due to short circuit
	51	5	−127.4	0.60	1-, 2-, and 3-way	
	12	5	−128.2	0.60	2- and 3-way	
7	42	4	−125.4	0.60	1-, 2-, and 3-way	During transfer, station lost downlink lock due to failure of incoming station to maintain uplink signal
	51	2	−129.2	0.60	1-, 2-, and 3-way	During transfer, station lost uplink and downlink lock for 9 min
	12	5	−128.2	0.60	2- and 3-way	Station performed test to determine *rest* frequency of spacecraft
8	42	10	−128.1	0.60	1-, 2-, and 3-way	
	51	4	−130.4	0.60	2- and 3-way	On two occasions, station experienced difficulty with N-frame callup; problem cleared up without determination of cause
	12	6	−129.7	0.60	2- and 3-way	
9	42	10	−128.3	0.70	2- and 3-way	
	12	9	−129.7	0.60	1-, 2-, and 3-way	
10	42	9	−129.0	0.60	2- and 3-way	
	12	6	−130.0	0.60	1-, 2-, and 3-way	During period of 4 h, station used incorrect VCO setting
11	42	10	−129.5	0.75	2- and 3-way	
	12	7	−131.3	0.60	1-, 2-, and 3-way	
12	42	4	−130.8	0.60	2- and 3-way	
	51	6	−132.7	1.25	1-, 2-, and 3-way	
	12	5	−131.7	0.70	1-, 2-, and 3-way	

[a] Power was increased to 10 kW during orientation maneuver.

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
13	42	4	−131.6	0.75	1-, 2-, and 3-way	
	51	6	−133.5	1.00	1-, 2-, and 3-way	
	12	8	−133.6	Variable[b]	1-, 2-, and 3-way	
14	42	5	−131.6	0.90	1-, 2-, and 3-way	
	51	6	−133.9	1.25	2- and 3-way	
	12	3	−132.5	1.15	2- and 3-way	
15	42	4	−132.5	1.70	1-, 2-, and 3-way	
	51	6	−134.7	1.70	1-, 2-, and 3-way	
	12	9	−133.0	1.50	1-, 2-, and 3-way	
16	42	12	−132.5	1.70	1-, 2-, and 3-way	
	12	12	−134.0	1.80	1-, 2-, and 3-way	
17	42	4	−133.0	1.70	2- and 3-way	
	51	4	−135.3	1.50	1-, 2-, and 3-way	Transmitter failed for ≈3 h due to insulation breakdown
	12	8	−134.1	1.70	1-, 2-, and 3-way	
18	42	6	−133.7	1.70	1-, 2-, and 3-way	
	51	4	−136.5	1.50	2- and 3-way	
	12	4	−133.5	1.70	2- and 3-way	Digital instrumentation system out of lock for 15 min during typewriter change
19	42	9	−134.5	1.60	2- and 3-way	Numerous system temperature spikes noted due to transmitter tuning
	61	—	−135.8	0	1- and 3-way	Transmitter inoperative due to failure. Station awaiting arrival of new equipment from United States
	12	8	−135.8	1.70	1-, 2-, and 3-way	
20	42	11	−133.7	1.75	2- and 3-way	End of track to duty-cycle store. Bit rate 512 bits/s
	12	20	−133.7	2.00	1-, 2-, and 3-way	Operator error lost 100 min of TDS data. Bit rate 512 bits/s
21	42	2	−135.0	1.70	2- and 3-way	Bit rate 512 bits/s
	61	—	−136.6	0	1-way	Minor TDS operator error occurred
	12	14	−133.8	2.00	1-, 2-, and 3-way	Some difficulty experienced in lockup. Minor human errors occurred in computer operation. Bit rate 512 bits/s
22	42	15	−134.9	2.00	2- and 3-way	Bit rate 512 bits/s
	12	21	−135.9	2.00	1-, 2-, and 3-way	Maser failed, but restored with circuit breaker reset. Bit rate 512 bits/s
23	42	11	−135.0	2.00	2- and 3-way	Station advised they would soon run out of tape. Bit rate 512 bits/s
	61	—	−137.8	0	1- and 3-way	
	12	12	−135.0	2.50	1- and 2-way	Bit rate 512 bits/s
24	42	19	−135.5	3.00	1-, 2-, and 3-way	Best-lock frequency tests performed on channels 6 and 7. Bit rate 512 bits/s
	12	18	−134.8	2.70	1-, 2-, and 3-way	Station missed one callup due to internal error. Bit rate 512 bits/s
25	42	17	−136.2	3.00	2- and 3-way	End of track to duty-cycle store. Bit rate 512 bits/s
	12	19	−135.5	2.50	1-, 2-, and 3-way	Bit rate 512 bits/s

[b] Transmitter power varied up to 2 kW for tests. Channels 6 and 7 were calibrated on this pass.

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
26	42	13	−136.3	3.10	2- and 3-way	No 3-way predicts available for DSS 61. Bit rate 512 bits/s
	61	—	−138.4	3.00	1-, 2-, and 3-way	Meter smoldered in receiver
	12	15	−135.8	3.00	1-, 2-, and 3-way	Computer was unable to stop Stanford data via BP4 switch. Bit rate 512 bits/s
27	42	16	−136.7	2.30	2- and 3-way	Catastrophic error in computer required program reload. End of track to duty-cycle store. Bit rate 512 bits/s
	12	16	−137.3	3.20	1-, 2-, and 3-way	Computer problem caused 8 min of real-time data loss; bit rate 512 bits/s
28	42	12	−137.2	2.90	2- and 3-way	Computer down briefly due to inadvertent power turnoff. Bit rate 512 bits/s
	61	—	−138.6	3.00	2- and 3-way	
	12	2	−138.0	3.50	1- and 2-way	Maser failed. Station changed to paramp and later relieved from tracking. DSS 11 picked up tracking. Bit rate 512 bits/s
29	42	16	−137.5	3.00	1- and 2-way	Digital instrumentation system B and its tape unit malfunctioned. Bit rate 512 bits/s
	12	16	−138.3	2.50	1- and 2-way	Bit rate 512 bits/s
30	61	—	139.4	3.50	1-, 2-, and 3-way	Receiver noise problems occurred simultaneously with system temperature-measurement problem
	12	13	−137.4	4.00	1- and 2-way	Bit rate 512 bits/s
31	—	—	—	—	None	No tracking occurred on this pass
32	42	15	−137.5	4.00	1- and 2-way	Commands erroneously sent at low power. Transmitter interlock problem caused numerous interruptions to uplink. Bit rate 512 bits/s
33	51	10	−140.8	6.00	1-, 2-, and 3-way	Through operator error, command 004 transmitted (should have been 060). Bit rate 512 bits/s
	11	0	−140.4	7.50	2- and 3-way	Bit rate 512 bits/s
34	12	11	−138.9	5.00	1- and 2-way	Station late in acquiring uplink due to low power. Bit rate 512 bits/s
35	51	15	−140.8	6.70	1- and 2-way	Command 004 transmitted 9 min early due to error in reading digital clock. Bit rate 512 bits/s
36	42	9	−138.5	7.00	1-, 2-, and 3-way	Command 100 inhibited by undetermined equipment malfunction. Bit rate 512 bits/s
	61	0	−140.2	7.00	1-, 2-, and 3-way	Transmitter caused noise in receiver; transmitter failed. Bit rate 512 bits/s
	12	11	−140.6	3.00	1-, 2-, and 3-way	Rubidium frequency standard inoperative; transmitter failed. Bit rate 512 bits/s
37	42	8	−137.6	2.00	1-, 2-, and 3-way	Abnormal error rate experienced due to test scope. Bit rate 512 bits/s
	61	0	−139.9	—	1-, 2-, and 3-way	Transmitter failed due to arcing. Bit rate 512 bits/s
	11	0	−140.5	3.00	1-, 2-, and 3-way	Antenna HA brake failed. Bad doppler counter. Bit rate 512 bits/s
38	42	12	−138.1	2.10	2- and 3-way	Bit rate 512 bits/s
	12	24	−139.8	1.40	1- and 2-way	One command transmission started early. One digital instrumentation system request initiated at incorrect time. Bit rate 512 bits/s
39	51	13	−142.2	2.80	1-, 2-, and 3-way	Receiver dropped lock due to undetermined cause. Bit rate 512 bits/s
	11	0	−141.8	3.00	2- and 3-way	Recorder inoperative due to lack of spare parts. Bit rate 512 bits/s

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
40	61	0	−140.7	0	1-way only	Transmitter inoperative. Bit rate 512 bits/s
41	42	11	−138.7	2.40	1- and 2-way	Bit rate 512 bits/s
	12	16	−139.4	2.30	1- and 2-way	Command acted upon by spacecraft while receiver was locked onto sideband. Bit rate 512 bits/s
42	51	16	−141.9	2.10	1- and 2-way	Bit rate 512 bits/s
43	42	14	−139.3	2.80	1- and 2-way	Bit rate 512 bits/s
	12	16	−138.7	2.40	1- and 2-way	Bit rate 512 bits/s
44	—	—	—	—	None	No tracking occurred on this pass
45	42	10	−139.6	2.70	1- and 2-way	Bit rate 512 bits/s
	51	6	−142.7	3.00	2- and 3-way	Poor communications experienced. Inclement weather curtailed posttrack calibrations. Station 6 min late in turning off transmitter due to operator error. Bit rate 512 bits/s
	12	9	−139.9	2.60	2- and 3-way	Loss of real-time data occurred for 76 min due to open patch cord on teletype line. Bit rate 512 bits/s
46	—	—	—	—	None	No tracking occurred on this pass
47	42	10	−139.5	3.50	1- and 2-way	Bit rate 512 bits/s
	51	4	−143.2	3.40	1-, 2-, and 3-way	Receiver dropped lock for no apparent reason. Bit rate 512 bits/s
	11	0	−142.4	3.00	2- and 3-way	Faulty patch plug caused 20 min loss of TDS data. Bit rate 512 bits/s
48	51	7	−143.4	3.00	1-, 2-, and 3-way	Bit rate 512 bits/s
	12	6	−140.0	3.00	2- and 3-way	Recorder output distorted. Bit rate 512 bits/s
49	41	0	−141.7	3.30	2- and 3-way	Bit rate 512 bits/s
	11	0	−142.7	4.40	1-, 2-, and 3-way	No posttrack calibration performed. Bit rate 512 bits/s
50	42	5	−140.0	3.20	2- and 3-way	Bit rate 512 bits/s
	51	6	−144.2	3.30	2- and 3-way	Channel 7 recorder failed. Bit rate 512 bits/s
	12	12	−141.7	2.80	1-, 2-, and 3-way	Bit rate 512 bits/s
51	41	0	−142.9	3.30	2-way	Bit rate 512 bits/s
	61	0	−145.0	0	1-way	No transmitter used because of equipment problems. Bit rate 512 bits/s
	11	0	−145.0	3.30	1-, 2-, and 3-way	Bit rate 512 bits/s
52	42	11	−140.6	5.00	1- and 2-way	Bit rate 512 bits/s
	12	12	−142.5	3.30	1- and 2-way	Bit rate 512 bits/s
53	41	0	−142.8	3.20	1-, 2-, and 3-way	Voltage-controlled-oscillator counter operated erratically. Bit rate 512 bits/s
	51	5	−144.8	3.50	2- and 3-way	Command 100 delayed by faulty monitor receiver. Channels 3 and 7 failed. Noise spikes degraded receiver threshold. Bit rate 512 bits/s
	12	11	−142.0	3.30	2- and 3-way	Command 053 sent 9 min early due to operator error. Bit rate 512 bits/s
54	51	10	−145.0	3.50	1-, 2-, and 3-way	Bit rate 512 bits/s
	12	12	−141.8	3.20	2- and 3-way	Rubidium frequency standard inoperative; Knight oscillator F-68 used. Request occurred 30 min early. Bit rate 512 bits/s
55	41	0	−143.5	3.30	2-way	Bit rate 512 bits/s
	12	7	−141.3	3.00	1-, 2-, and 3-way	Transmitter turned off 1 s late due to operator error. Bit rate 512 bits/s

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
56	41	0	−143.6	3.00	1- and 2-way	Bit rate 512 bits/s
	51	12	−144.7	3.90	1-, 2-, and 3-way	Receiver in C_1 mode instead of C_3 due to operator error. Bit rate 512 bits/s
57	42	14	−140.0	3.00	1- and 2-way	Bit rate 512 bits/s
	12	18	−142.3	3.50	1- and 2-way	Bit rate 512 bits/s
58	51	15	−145.0	4.10	1- and 2-way	Bit rate 512 bits/s
59	42	12	−141.1	3.00	1- and 2-way	Bit rate 512 bits/s
	12	15	−142.2	4.00	1-, 2-, and 3-way	Signal interference caused by test translator being left on. Bit rate 512 bits/s
60	42	11	−140.8	4.00	1- and 2-way	
	12	12	−143.0	4.00	1-, 2-, and 3-way	Command 050 delayed 2 min due to operator error
61	42	9	−141.9	4.40	2- and 3-way	
	51	11	−146.0	5.00	1-, 2-, and 3-way	
	12	17	−142.7	3.80	1- and 2-way	
62	12	5	−143.0	4.00	1-, 2-, and 3-way	
63	42	9	−141.0	4.60	2- and 3-way	
64	42	18	−141.2	4.60	1- and 2-way	Transmitter tripped off twice due to faulty design of 400-Hz main circuit protector
	12	9	−143.0	5.00	1-, 2-, and 3-way	
65	51	9	−147.0	5.20	2- and 3-way	Low signal level occurred at acquisition because antenna erroneously left in near-field focus position
	42	4	−140.6	4.60	2- and 3-way	
66	41	0	−145.5	5.00	1- and 2-way	Transmitter tripped off due to low flow rate of coolant
	51	7	−140.0	5.50	1-, 2-, and 3-way	Transmitter malfunctioned; undetermined cause
	12	9	−143.0	5.00	1-, 2-, and 3-way	
67	42	9	−143.3	5.00	2- and 3-way	
	12	11	−143.7	4.50	1-, 2-, and 3-way	
68	51	9	−146.0	5.10	1-, 2-, and 3-way	Two commands sent late because of operator error
	41	0	−146.2	3.80	2-way	
69	41	0	−145.6	5.00	1-, 2-, and 3-way	
	51	10	−148.0	5.90	1-, 2-, and 3-way	
	12	13	−144.1	6.00	1-, 2-, and 3-way	Command delayed because of primary power failure at station
70	41	0	−146.0	4.30	2-way	
	51	17	−147.0	6.50	2- and 3-way	Command transmitted late because of operator error
71	42	13	−143.2	6.00	1- and 2-way	
	12	15	−144.3	7.00	1- and 2-way	
72	51	17	−148.0	7.00	1- and 2-way	Station clock slow by ≈120 ms
73	42	16	−146.3	7.00	1- and 2-way	
	12	24	−146.0	7.00	1- and 2-way	Acquisition 10 min late because antenna in prelimits (faulty predicts)
74	51	14	−146.8	7.50	1- and 2-way	
	11	0	−147.0	7.50	1-, 2-, and 3-way	
75	42	11	−143.5	6.90	2- and 3-way	
	12	14	−146.0	7.00	1-, 2-, and 3-way	Higher parity error rate than usual because of very small sun–earth–spacecraft angle

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
76	41	0	−147.7	7.00	2- and 3-way	Synthesizer loop shorted, causing loss of lock for 3 min
	51	7	−147.0	8.00	2- and 3-way	Digital instrumentation system intermittently out of lock; TDS taken off line for 8 min
	12	7	−147.0	9.00	2- and 3-way	Station subjected to high winds of 40–60 mi/h
77	41	0	−147.2	7.00	2- and 3-way	Error light indicated nonpermissive command attempted
	51	6	−148.0	9.50	2- and 3-way	
	11	0	−147.2	0	1- and 3-way	TDS teletype tape punch failed
78	42	13	−144.4	8.00	1- and 2-way	
	12	17	−147.1	9.00	1- and 2-way	Primary power failure caused loss of data for 38 min
79	51	12	−148.0	9.00	1-, 2-, and 3-way	Acquisition 6 min late due to delay in completing pretrack calibrations. Transmitter drive failed due to loose connection. One command nonpermissive due to incompatibility with prepass instructions. Maser inoperative due to JT-tap breakdown
	41	0	−149.4	9.00	1-, 2-, and 3-way	Posttrack calibration of automatic gain control not completed due to failure of test signal source
80	51	8	−148.5	10.00	1- and 2-way	Command 006 was nonpermissive because prepass instructions were incorrect; maser inoperative
	12	14	−147.6	9.00	1-, 2-, and 3-way	
81	51	14	−147.9	10.00	1- and 2-way	Maser inoperative
82	42	17	−145.6	9.00	1- and 2-way	
83	42	23	−146.2	10.00	1- and 2-way	
	12	17	−148.1	9.00	1- and 2-way	Transmitter off for approximately 2 min because of coolant flow problem and high-voltage-rectifier failure
84	11	0	−149.3	10.00	2- and 3-way	Momentary out-of-lock conditions occurred because antenna was not tracking properly in HA. Analog instrumentation system oscillograph channel inadvertently turned off for entire pass
	51	14	−149.0	10.00	1-, 2-, and 3-way	Transmitter beam voltage tripped. Recorder B failed
85	41	0	−149.4	10.00	1-, 2-, and 3-way	
	51	11	−149.5	10.00	2- and 3-way	Digital instrumentation system unable to lock up at certain times because of degradation while using paramp. Maser inoperative. Recorder B failed
	12	16	−148.7	10.00	1-, 2-, and 3-way	Transmitter failed because of coolant flow problem
86	51	11	−149.5	10.00	1- and 2-way	Maser inoperative. Nonreturn-to-zero input to recorder lost because of loose cable
87	41	0	−149.3	10.00	1- and 2-way	Maser inoperative
	51	9	−149.3	10.00	2- and 3-way	Time code generator failure caused bad time-word readout. Through operator error, 12 min operation of tape recorder A3 lost
	12	21	−148.0	10.00	2- and 3-way	Because of DIS operator error, 28 min engineering data lost
88	41	0	−142.5	10.00	1- and 2-way	
	51	16	−149.6	10.00	3-way	Maser inoperative. Numerous momentary losses of lock occurred while in 256-bits/s rate due to paramp effect upon demodulator threshold. In one instance, it was necessary to inhibit one command due to loss of demodulator lock
	11	0	−149.2	10.00	1-, 2-, and 3-way	

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
89	42	16	−148.0	10.00	2- and 3-way	Maser inoperative due to compressor failure. All magnetic tape recordings from recorder B suspected to be defective. Cause of defects undetermined
	51	8	−149.4	10.00	2-way/paramp	From 1446:16 GMT to end of track (1502:12), demodulator was in and out of lock 17 times. Bit rate 16/256 bits/s
	11	—	−148.7	10.00	2- and 3-way	Voice communication lost twice. Bit rate 256 bits/s
90	42	15	−147.9	10.00	1-, 2-, and 3-way	Transmitter tripped off at 2139:55 and resumed operation at 2147. Failure probability report (FPR) 0219 applies. At 0351:04, both receivers dropped lock. (FPR 0218 applies.) Bit rate 16/64 bits/s
	12	18	−149.1	10.00	1- and 2-way	Nonreturn-to-zero data not recorded on tapes 1A and 1B due to mispatch on analog instrumentation system panel. Bit rate 256/64 bits/s
91	51	13	−150.9	10.00	1- and 2-way/ paramp	Transmitter tripped off at 0943:23 due to operation of beam overcurrent interlock. Interlock setting was at approximately 2.2 A, which was too close to actual beam current. Interlock reset at 2.5 A and transmitter returned to normal operation at 0948:00. (TFR-51, TXR-010, and DSIF FPR 0223 apply.) Bit rate 16/64/256 bits/s
92	41	—	−150.6	10.00	1-, 2-, and 3-way	Bit rate 256/64 bits/s
	51	8	−150.6	10.00	2- and 3-way paramp	Demodulator was constantly in and out of lock until switched to 16 bits/s. Wow and flutter were suspected on tape A3. Tape was allowed to run 8 min for investigation, and loose plug in modem unit found. (TFR-51-REC-033 applies)
	12	14	−151.7	10.00	1-, 2-, and 3-way	Transmitted frequency was outside bandpass of monitor receiver, so all commands were to be sent without monitor receiver in lock or abnormal mode. Bit rate 256/64 bits/s
93	51	11	−151.3	10.00	1- and 2-way	Leak occurred in declination low-speed hydraulics valve, and faulty O-ring was replaced. (TFR-51-ANT-007 and DSIF FPR 0225 apply.) Bit rate 16/64 bits/s
94	42	16	−151.7	10.00	1- and 2-way	Bit rate 16/256/512 bits/s
	12	18	−150.5	10.00	1-, 2-, and 3-way	Bit rate 16/256/64 bits/s
95	42	6	−151.6	10.00	2- and 3-way	Bit rate 64/256/16 bits/s
	51	6	−152.3	10.00	2- and 3-way	Station on paramp. Bit rate 16 bits/s
	12	7	−150.7	10.00	2- and 3-way	Bit rate 16/256/64 bits/s
96	42	8	−151.1	10.00	2- and 3-way	Bit rate 64/256 bits/s
97	41	—	−151.9	10.00	1-, 2-, and 3-way	Bit rate 16 bits/s
	51	7	−152.2	10.00	2- and 3-way	Station on paramp. Bit rate 256/16/64 bits/s
	12	17	−151.1	10.00	1-, 2-, and 3-way	Winds gusting to 60 mi/h opened airflow interlock on heat exchanger at 1445:55 GMT
98	41	—	−152.1	10.00	2- and 3-way	Bit rate 16 bits/s
	51	15	−153.5	7.50	2- and 3-way	Station on paramp. Bit rate 16/64 bits/s
99	42	22	−150.2	10.00	1- and 2-way	Command 034 sent 1 min late due to confusion caused by incorrect information. Bit rate 16/64/256 bits/s
	61	—	−150.2	10.00	2- and 3-way	Rubidium was on internal reference because of operator error; corrected to rubidium standard. Bit rate 64 bits/s

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
	12	19	−151.0	10.00	2- and 3-way	Engineering reperforator tape jammed at 1411 GMT; cleared at 1437 GMT. Thomas couplers in hour angle and declination servo transmitters were changed before this track because of a 0.040-deg error appearing in star track data
100	41	—	−152.3	10.00	2- and 3-way	Bit rate 16 bits/s
	61	—	−150.7	10.00	1-, 2-, and 3-way	Bit rate 64 bits/s
	12	14	−152.7	10.00	1- and 2-way	TDS experienced several dropouts of doppler printouts. No reason indicated
101	41	0	−153.5	10.00	1-, 2-, and 3-way	
	61	0	−150.9	10.00	1-, 2-, and 3-way	
	12	24	−153.2	10.00	1-, 2-, and 3-way	Noise from preamble generator caused series of computer interrupts. Bit rate 64/256 bits/s
102	51	12	−153.9	4.00	1-, 2-, and 3-way	Power interruption caused transmitter to cut out during transfer to DSS 12. Bit rate 64 bits/s
	12	8	−152.5	10.00	1-, 2-, and 3-way	Maser crosshead failed. Bit rate 64 bits/s
103	42	8	−151.8	10.00	2- and 3-way	Bit rate 16/64 bits/s
	12	22	−155.5	10.00	1- and 2-way	Station operated on paramp due to maser outage. Bit rate 8/64 bits/s
104	61	0	−151.6	10.00	1- and 2-way	
	12	13	−150.5	10.00	1- and 2-way	Bit rate 8/16/64 bits/s
105	12	10	−154.4	10.00	1- and 2-way	
106	41	0	−153.9	10.00	2- and 3-way	
	12	7	−153.5	10.00	1- and 2-way	Transmitter failed for 9 min due to operation of thermal interlock. Bit rate 64 bits/s
107	42	13	−153.1	10.00	1-, 2-, and 3-way	Bit rate 16/64 bits/s
	12	10	−154.2	10.00	1-, 2-, and 3-way	Brief interruption occurred due to primary power failure. One command sent late because of poor communication between station and SFOF. Bit rate 16/64 bits/s
108	42	4	−153.2	10.00	1-, 2-, and 3-way	Bit rate 64 bits/s
	51	9	−155.3	10.00	1- and 2-way	Acquisition late due to maser problem. Bit rate 64 bits/s
109	42	9	−153.4	10.00	1-, 2-, and 3-way	Bit rate 16/64 bits/s
	61	0	−152.9	10.00	2- and 3-way	
	12	16	−154.4	10.00	1-, 2-, and 3-way	Station experienced considerable difficulty in acquiring 2-way signal. Fault appeared to be combination of operator errors. Bit rate 16/64 bits/s
110	51	13	−155.5	10.00	1- and 2-way	Bit rate 16/64 bits/s
111	42	10	−154.2	10.00	1- and 2-way	Bit rate 64 bits/s
	12	15	−155.0	10.00[c]	1- and 2-way	Bit rate 16/64 bits/s
112	12	18	−155.7	10.00	1- and 2-way	Bit rate 16/64/512 bits/s
113	12	15	−155.7	8.5	1- and 2-way	Bit rate 8/16/64 bits/s
114	12	10	−157.0	10.00	1- and 2-way	Bit rate 8/16/64 bits/s
115	12	24	−155.8	10.00	1-, 2-, and 3-way	Bit rate 16/64 bits/s
116	42	4	−155.2	10.00	2- and 3-way	Bit rate 64 bits/s
	51	13	−156.6	10.00	2- and 3-way	Transmitter beam voltage tripped off. Cause undetermined. Bit rate 8/16/64 bits/s

[c] Power reduced to 8.5 kW because of low drive.

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
117	51	17	−157.1	10.00	1- and 2-way	Transmitter interlock tripped off twice. Cause undetermined. Bit rate 16/64 bits/s
118	42	13	−156.1	10.00	1- and 2-way	Bit rate 16 bits/s
	12	16	−156.5	10.00	1-, 2-, and 3-way	Transmitter tripped off due to airflow interlock operation. Bit rate 16/64 bits/s
119	42	5	−156.1	10.00	2- and 3-way	Excessive parity errors occurred because received signal level was only 2 dB from telemetry threshold level. Bit rate 16/64 bits/s
	61	0	−155.7	10.00	2- and 3-way	
	12	3	−156.3	10.00	2- and 3-way	Bit rate 64 bits/s
120	42	10	−155.3	10.00	2- and 3-way	Bit rate 16/64 bits/s
	12	12	−157.2	10.00	1- and 2-way	Bit rate 8/16/64 bits/s
121	—	—	—	—	None	No tracking occurred on this pass
122	42	15	−156.8	10.00	1- and 2-way	Bit rate 16/64 bits/s
	12	13	−156.8	10.00	1- and 2-way	Bit rate 16/64 bits/s
123	51	14	−158.3	10.00	1- and 2-way	Command delayed because commands were too closely spaced in initial instructions, causing digital instrumentation system to be out of lock. Bit rate 8/16/64 bits/s
124	51	12	−159.8	10.00	1- and 2-way	Transmitter klystron delivered low power. Bit rate 16/64 bits/s
125	42	10	−157.9	10.00	1-, 2-, and 3-way	Bit rate 16/64 bits/s
	51	8	−159.3	10.00	2- and 3-way	Fluctuations of 3 dB observed in received signal strength, believed due to changes in maser gain. Bit rate 16/64 bits/s
126	42	13	−158.3	10.00	1-, 2-, and 3-way	Transmitter drive lost twice; defective module suspected. Bit rate 16/64 bits/s
	51	10	−159.3	10.00	2- and 3-way	Bit rate 16/64 bits/s
127	42	12	−157.8	10.00	1- and 2-way	Bit rate 16 bits/s
	12	11	−156.9	10.00	1- and 2-way	Bit rate 8/16 bits/s
128	12	13	−158.8	10.00	1- and 2-way	Bit rate 8/16 bits/s
129	12	13	−158.3	10.00	1- and 2-way	Bit rate 16/64 bits/s
130	51	12	−158.5	10.00	1- and 2-way	Bit rate 8/16 bits/s
131	51	9	−159.5	10.00	1- and 2-way	Bit rate 16 bits/s
	12	10	−158.5	10.00	1-, 2-, and 3-way	Bit rate 16/64 bits/s
132	51	9	−159.7	10.00	1- and 2-way	Bit rate 16 bits/s
	12	18	−158.3	10.00	2-way	Bit rate 16/64 bits/s
133	51	13	−158.9	10.00	1- and 2-way	Bit rate 16/64 bits/s
134	42	14	−158.1	Variable[d]	1- and 2-way	Channel 7 receiver on spacecraft commanded to high-gain antenna; approximately 10-dB improvement noted. Bit rate 16/8 bits/s
135	42	12	−158.6	10.00	1- and 2-way	Transmitter turned off intentionally for 111 min to allow local survey work to proceed. Bit rate 16 bits/s
136	42	20	−159.1	10.00	1- and 2-way	Bit rate 16 bits/s
	51	30	−160.5	9.50	1-, 2-, and 3-way	Receiver dropped lock numerous times; cause unknown. Bit rate 16/64 bits/s

[d] Ground transmitter power varied to calibrate spacecraft channel 6 receiver.

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
137	42	9	−158.1	10.00	1-, 2-, and 3-way	Bit rate 16 bits/s
	61	0	−161.9	10.00	2- and 3-way	
138	42	14	−159.0	10.00	1- and 2-way	Bit rate 16/256 bits/s
	61	0	−159.6	10.00	1- and 2-way	
139	42	34	−159.2	10.00	1-, 2-, and 3-way	Bit rate 8/16 bits/s
	61	0	−159.4	10.00	2- and 3-way	
	12	4	−160.6	10.00	1-, 2-, and 3-way	Station brought up for a short pass because of unusual cosmic-ray activity. Bit rate 8/16 bits/s
140	41	0	—	—	—	Pass aborted because of maser failure
	12	32	−160.4	10.00	1- and 2-way	Bit rate 8/16/64 bits/s
141	51	23	−161.4	10.00	1- and 2-way	Bit rate 8/16 bits/s
	12	20	−161.8	10.00	2-way	Bit rate 8/16/512 bits/s
142	51	10	−159.2	10.00	2- and 3-way	Station had excessive difficulty in acquiring suitable downlink signal to maintain computer lockup. Defective voltage-controlled-oscillator crystal. Command 052 delayed 15 min because digital instrumentation system was out of lock. Out-of-lock condition was result of failure by operator to change the demodulator sync bit rate switch. Bit rate 8/16 bits/s
	12	25	−161.2	10.00	2- and 3-way	Bit rate 8/16/64 bits/s
143	51	21	−160.9	10.00	1- and 2-way	Bit rate 8/16 bits/s
	12	30	−160.7	10.00	2-way	One command transmitted late due to slow communication. Bit rate 8/16/256/512 bits/s
144	51	23	−161.0	10.00	2-way	Receiver dropped lock numerous times. Cause undetermined. Bit rate 8/16 bits/s
145	42	25	−160.6	10.00	1- and 2-way	Transmitter tripped off once due to interlock. Bit rate 8/16 bits/s
146	42	11	−160.0	10.00	1- and 2-way	Bit rate 16 bits/s
	12	26	−161.6	10.00	1- and 2-way	Abnormally high bit-error rate reported and investigated. Bit rate 8/16/512 bits/s
147	61	0	−160.4	10.00	1- and 2-way	
148	61	0	−160.4	10.00	1- and 2-way	
149	12	15	−162.3	10.00	1-, 2-, and 3-way	Investigation of excessively high bit-error rate continued. Bit rate 8/16/512 bits/s
150	42	5	−160.3	10.00	1- and 3-way	Complete disruption of communications with SFOF occurred for 30 min due to electrical fire in SFOF. Service restored through emergency facilities, and command sequences resumed satisfactorily. Bit rate 8 bits/s
	12	7	−162.6	10.00	1-, 2-, and 3-way	Investigation of excessively high bit-error rate continued. Bit rate 8 bits/s
151	42	0	−161.1	10.00	1-, 2-, and 3-way	Digital instrumentation system failed to lock up because of incorrect switch setting. Wideband FM signal not recorded because of operator error in patching
	12	11	−162.3	10.00	1- and 2-way	Bit rate 8/16 bits/s
152	41	0	−161.0	0	1-way	
153	41	0	−162.0	10.00	1- and 2-way	
	12	8	−162.6	10.00	1- and 2-way	Bit rate 8/16 bits/s
154	41	0	−163.9	9.80	1- and 2-way	

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
155	41	0	−163.3	10.00	1- and 2-way	Maser failed, causing premature end of track at 0459 GMT
	12	14	−162.1	10.00	1- and 2-way	Station had trouble acquiring signal on channel 11; finally acquired at 25 Hz below predicts. Bit rate 8/16/512 bits/s
156	41	0	−160.5	10.00	1- and 2-way	Synthesizer power supply failed
157	41	0	−163.6	10.00	1- and 2-way	
	12	9	−163.4	10.00	1- and 2-way	Bit rate 8 bits/s
160[e]	12	13	−162.6	10.00	1- and 2-way	Computer inhibited command; cause undetermined. Bit rate 8/16/512 bits/s
	41	0	−164.6	10.00	1- and 2-way	
162[e]	41	0	−163.9	0	1-way	
	12	12	−163.2	10.00	1- and 2-way	Bit rate 8/512 bits/s
164	41	0	−164.3	10.00	1-way	Maser warmed up after pass, but cooled down again for posttrack calibration
	12	8	−163.5	10.00	1- and 2-way	Random receiver malfunction occurred from 1812 GMT through remainder of pass; cause undetermined
167[f]	41	0	−163.2	0	1-way	Maser failed, causing premature end of track
	12	4	−164.5	10.00	1- and 2-way	Station encountered difficulty in acquiring signal, probably because of no bias on predicts. Bit rate 8 bits/s
168	12	8	−164.4	10.00	1- and 2-way	Station experienced difficulty in locking up computer using receiver 1. Bit rate 8/16 bits/s
170	12 and 14	5	−154.0	10.00	1- and 2-way	Special test performed using DSS 14 receiver and DSS 12 ground operational equipment. Bit rate 8/16/64 bits/s
171	12	37	−164.1	10.00	1- and 2-way	Type I and II orientations performed. Bit rate 8/256/512 bits/s
172	12	9	−164.8	10.00	1- and 2-way	Bit rate 8 bits/s
176[f]	12	21	−165.0	10.00	1- and 2-way	Type II orientation performed. Transmitter kicked off several times due to high room temperature (air conditioner was being repaired)
179	12	3	−164.6	10.00	1- and 2-way	Bit rate 8 bits/s
No tracking on passes 180–186 due to maser failure at DSS 12						
187	42	3	−162.4	10.00	1- and 2-way	Bit rate 8 bits/s
188	42	5	−163.8	10.00	1- and 2-way	Bit rate 8 bits/s
	12	7	−165.6	10.00	1- and 2-way	Bit rate 8 bits/s
189	12	3	−164.8	10.00	1- and 2-way	Lost first 4 h of scheduled tracking because of inoperative maser. Bit rate 8 bits/s
190	12	20	−165.0	10.00	1- and 2-way	Special pass scheduled because of solar flare alert. Bit rate 8 bits/s
191	12	8	−166.3	10.00	1-, 2-, and 3-way	Bit rate 8 bits/s
192	12	0	−166.7	0	1-way	Pass was record only for solar flare alert
193	42	9	−163.5	10.00	1-, 2-, and 3-way	Special pass for solar flare alert

[e] No tracking on passes 158, 159, 161, and 163.

[f] No tracking on passes 165, 166, 169, 173, 174, 175, 177, and 178.

Table 26 (contd)

Pass	DSS	Number of commands	Received signal strength, dBm	Transmitter power, kW	Ground modes	Remarks
194	42	9	−164.3	10.00	1- and 2-way	Limited pretrack calibrations were performed because of short notice. Special pass scheduled due to solar flare alert. Bit rate 8 bits/s
	12	8	−166.1	10.00	1- and 2-way	Bit rate 8 bits/s
196[k]	42	4	−164.2	10.00	1- and 2-way	Final pass for 85-ft antenna stations. Bit rate 8 bits/s

[k]No tracking on pass 195.

Table 27. Comparison of normal and actual events during near-earth flight phase

Time, GMT	Event	Time from launch, s	
		Actual	Normal
0731:29	*Pioneer VI* liftoff	0	0
0732:02	Solid motors burnout	42.2	43
0732:15	AFETR station 3 (GBI) rise	55	56
0732:30	Solid motors jettison	70	70
0733:48	Main engine cutoff	148	149.2
0733:52	Second-stage engine ignition	152	153.2
0733:53	First stage jettison	152.8	154.3
0734:18	Fairing jettison	178.8	179.2
0734:21	DSS 71 set	181	66
0734:40	AFETR station 1 (Tel 2) set	200	68
0736:40	AFETR station 9.1 (Antigua) normal rise	(Not acquired)	320
0737:33	AFETR station 3 (GBI) acquired	373	56
0740:11	Second-stage engine cutoff	531.4	551.1
0740:17	AFETR station 3 (GBI) set	537	286
0741:19	Begin coast-phase pitch program	599	600.2
0744:30	AFETR station 9.1 (Antigua) normal set	(Not acquired)	790
0746:20	End coast-phase pitch program	900	901.2
0751	Transferred control from SFOF to DSS 51	1200	1200
0752:05	AFETR tracking ship normal rise	(Acquired at 0802 GMT)	1245
0756:05	Third stage spinup	1485	1486.2
0756:07	Second stage jettison	1487	1488.2
0756:17	Third-stage engine ignition	1496.9	1501.2
0756:41	Third-stage engine burnout	1520.7	1523.7
0757:40	Third stage/spacecraft separation Power to orientation electronics Initiated Type I orientation	1580	1583
0757:41	Booms and Stanford antenna deployed Turn on TWT 1 Switch transmitter driver to TWT 1 Switch TWT 1 to low-gain antenna	1581	1584

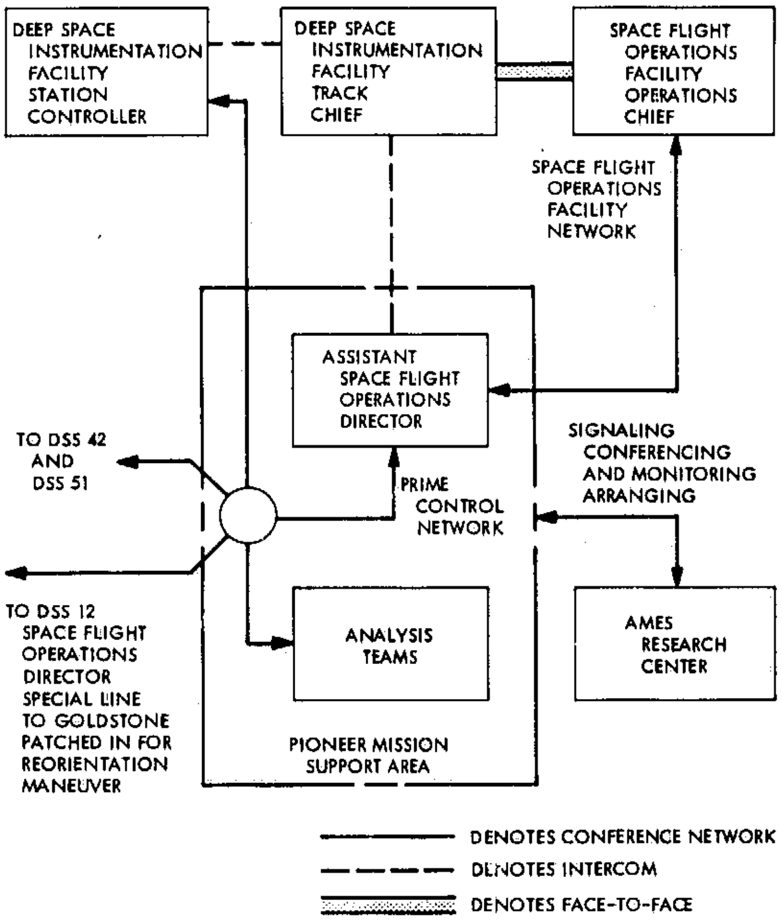


Fig. 49. Communication lines for Type II orientation

near normal and well within the predicted 3σ variation. The normal time and actual time of events occurring during the launch phase of the flight are compared in Table 27. The relationships of altitude, range, and time from launch for the launch trajectory are given in Fig. 50.

1. Requirements. In addition to the usual launch vehicle and range safety constraints, the following spacecraft and Project constraints were imposed in selecting the particular heliocentric orbit-injection conditions for a given date:

(1) Near-ecliptic heliocentric orbit.

(2) Nominal perihelion of 0.80 astronomical unit.

(3) Angle between spacecraft spin axis and spacecraft sun line at injection greater than 25 deg.

(4) Same ground station in view for first 3 h after injection.

(5) Earth–spacecraft distance for 180 days in orbit of less than 9×10^7 km.

Consideration of the launch date and the various vehicle and mission constraints dictated the launch window—an initial launch azimuth of 101 deg and a coast period of 950 s in an elliptical parking orbit between shutdown of the second-stage motor and ignition of the third-stage motor. In the following tabulation, the normal and actual parking-orbit parameters are compared; parenthetical values represent norms, whereas numbers not in parentheses represent actual values.

Parking orbit parameters	Value	
Time of injection after launch, s	(551.1)	531.4
Altitude of apogee, km	(1376.6)	1288.1
Altitude of perigee, km	(277.2)	270.6
Inclination to equatorial plane, deg	(30.2)	30.2
Eccentricity	(0.076)	0.071
Period, min	(101.4)	100.5

2. Performance. During the early part of the coast period between second- and third-stage propulsion, the second-stage guidance and control system provided a programmed nosedown attitude change of 71.2 deg in the plane of the orbit. The difference in direction between the inertial velocity vectors at the beginning and end of the coast period was 61.2 deg. A 10-deg nosedownward alignment of the thrust vector relative to the inertial velocity vector at ignition of the third stage

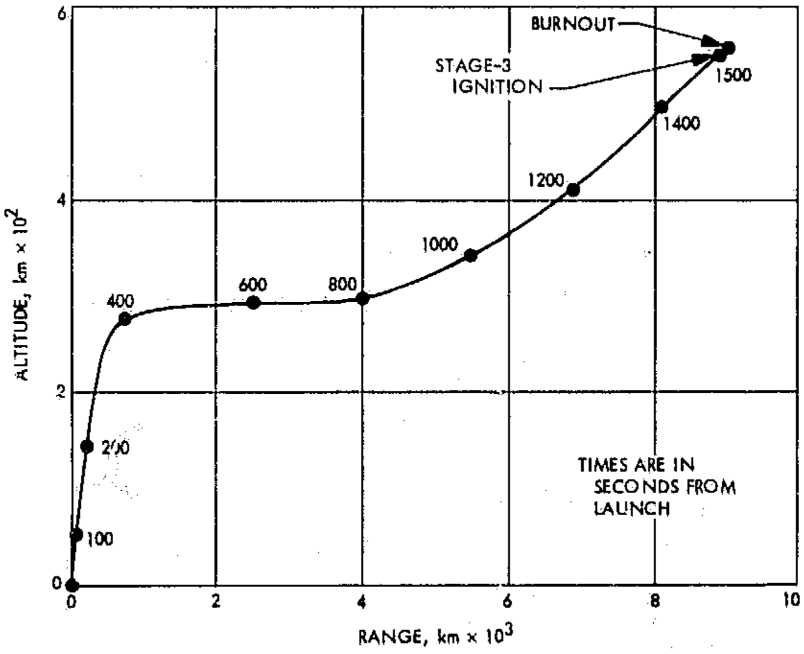


Fig. 50. Launch trajectory relationships

was necessary to achieve the appropriate burnout conditions.

The rockets on the spin table between the second and third stages were fired just before jettison of the second stage and ignition of the third stage. Telemetry data indicated that the spin rate of the third stage and undeployed spacecraft due to the spin motors was 104.9 rev/min compared to a predicted value of 106.4 rev/min. The measured value was well within the anticipated accuracy of ±10%.

The heliocentric orbit injection conditions obtained for *Pioneer VI* are given below. For comparison purposes, the estimated conditions for a normal launch-vehicle performance are included (norms are enclosed in parentheses).

Parameter	Values	
Time (GMT)	(0710–0802) (Dec. 16, 1965)	0756:41.1 Dec. 16, 1965
Altitude, km	(558.7)	564.1
Range, km	(9100.3)	9072.0
Geodetic south latitude, deg	(7.9)	7.8
West longitude, deg	(4.3)	4.6
Inertial velocity, km/s	(10.8333)	10.8488
Inertial flight path elevation angle α, deg	(1.6)	1.7
Inertial flight path azimuth angle β, deg	(119.2)	119.3
Vehicle axis inertial elevation angle θ, deg	(−4.51)	−3.65
Vehicle axis inertial azimuth angle ϕ, deg	(119.28)	119.33

Several stations of the AFETR tracked the spacecraft and received telemetry data from it during powered flight. AFETR station 1 at Cape Kennedy acquired the spacecraft signal first; station 3 on Grand Bahama, station 9.1 on Antigua, and finally the *Coastal Crusader* tracking ship followed in succession. The NASA Deep Space Station at Cape Kennedy (DSS 71) also received telemetry data from the spacecraft. Actual and anticipated periods of tracking and telemetry reception are compared in Fig. 51. In general, the stations committed to track the spacecraft telemetry signal during powered flight did not acquire and lock on the signal as early as had been predicted. However, once a solid lock on the signal was obtained, tracking continued for longer than had been anticipated. The differences between the actual and anticipated acquisition and set times are not entirely understood. The trajectory during powered flight was very near that which had been expected. It is doubtful that the strength of the signal from *Pioneer VI* was less than expected because measurements by DSS 51 over a considerable period of time and a number of varying spacecraft attitudes confirmed the expected value. The differences between the actual and anticipated acquisition and set times for the various stations are being investigated.

The free-flight trajectory for *Pioneer VI* has been well established by tracking measurements made by the Deep Space Stations. The measurements include local hour angle and declination, and doppler shift of the communication frequencies. The measurements were transmitted in near-real-time to a computer complex in the Space Flight Operations Facility, where a mathematical trajectory that best fit the tracking data was derived from computer programs that incorporated all known perturbation effects. Three trajectories were computed: one using the first 2 h of tracking data, the second using the first 30 days of data, and the third using the first 60 days of data. Although small differences in the results were evident, they were not significant for the *Pioneer* Project.

Besides providing the multibody perturbation trajectory, the computer programs also derived the characteristics of a two-body conic trajectory. The characteristics are given in Fig. 52 for the conic approximating the *Pioneer VI* trajectory during the first 24 h of flight, when the effects of the solar gravitational field were insignificant. The conic trajectory was an escape hyperbola with an asymptote vector oriented to 2.9 deg south celestial latitude and 359.9 deg celestial longitude. When *Pioneer VI* was injected into this escape hyperbola, the velocity vector of the earth was parallel to the ecliptic and in the direction of 174.4 deg celestial longitude.

The trajectory during the first 24 h of flight is shown in Fig. 53 plotted in the orbit plane. The position of

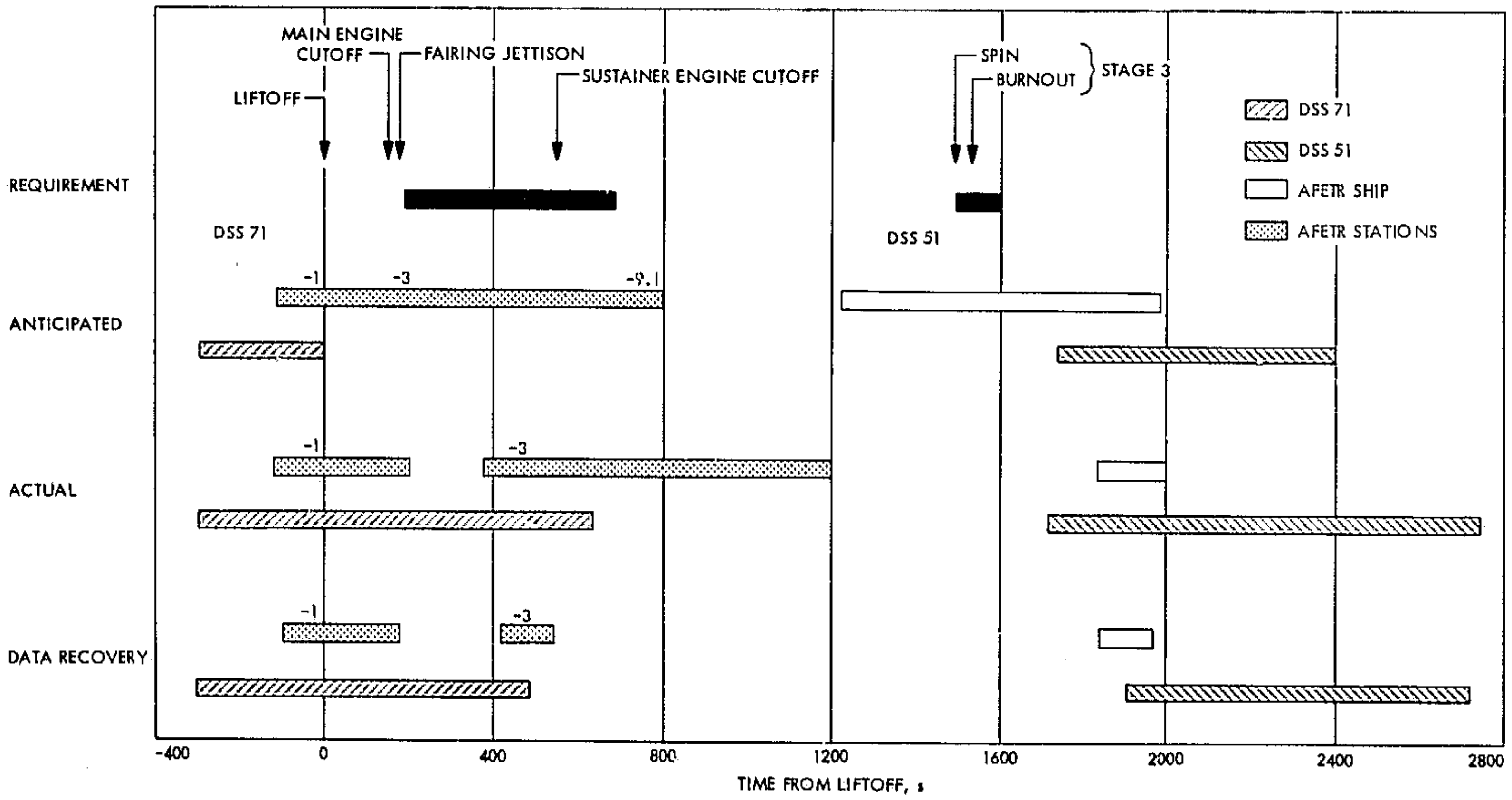
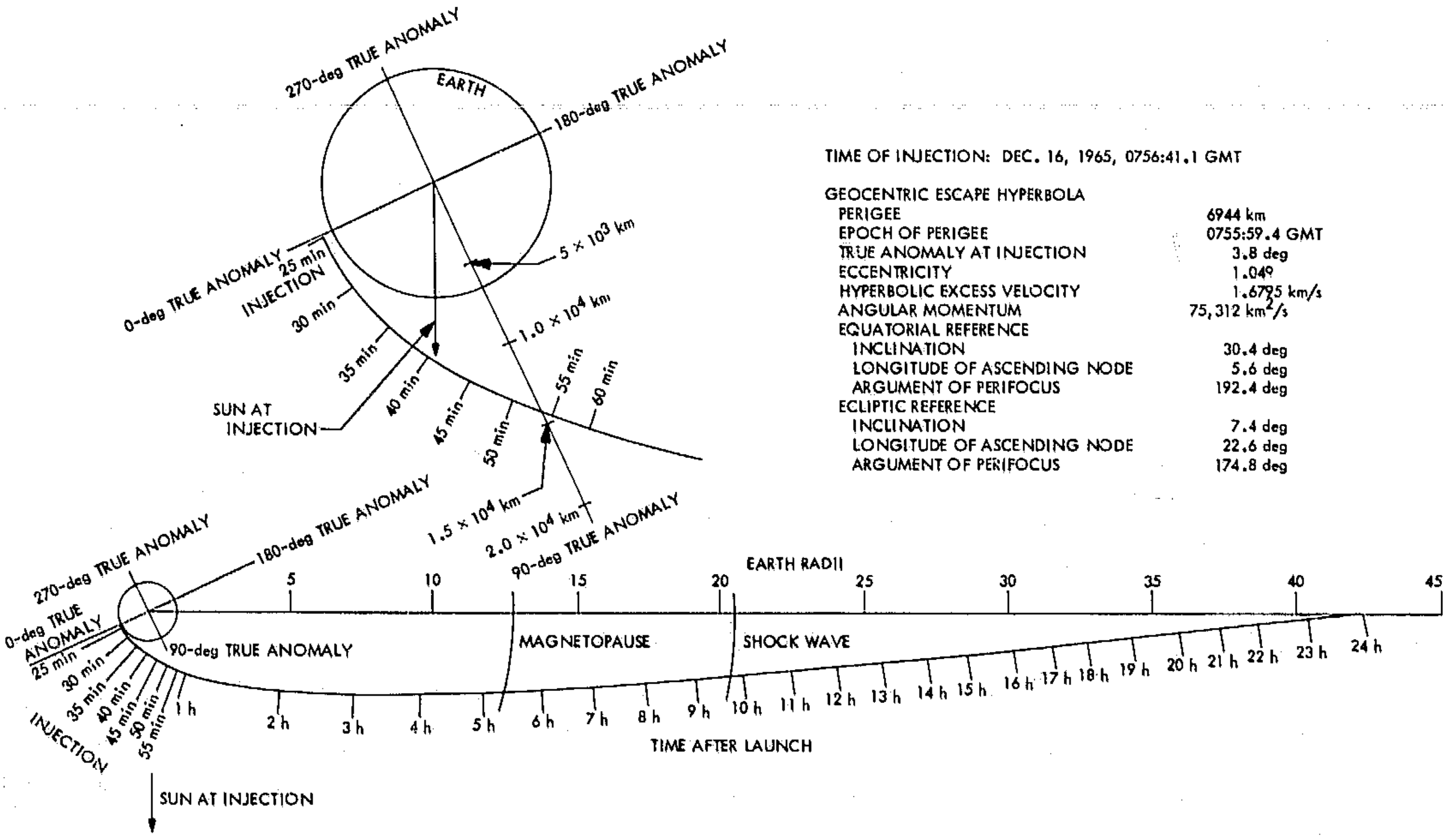


Fig. 51. Spacecraft telemetry coverage during launch



TIME OF INJECTION: DEC. 16, 1965, 0756:41.1 GMT

GEOCENTRIC ESCAPE HYPERBOLA	
PERIGEE	6944 km
EPOCH OF PERIGEE	0755:59.4 GMT
TRUE ANOMALY AT INJECTION	3.8 deg
ECCENTRICITY	1.049
HYPERBOLIC EXCESS VELOCITY	1.6795 km/s
ANGULAR MOMENTUM	75,312 km^2/s
EQUATORIAL REFERENCE	
INCLINATION	30.4 deg
LONGITUDE OF ASCENDING NODE	5.6 deg
ARGUMENT OF PERIFOCUS	192.4 deg
ECLIPTIC REFERENCE	
INCLINATION	7.4 deg
LONGITUDE OF ASCENDING NODE	22.6 deg
ARGUMENT OF PERIFOCUS	174.8 deg

Fig. 52. Near-earth free-flight trajectory of *Pioneer VI*

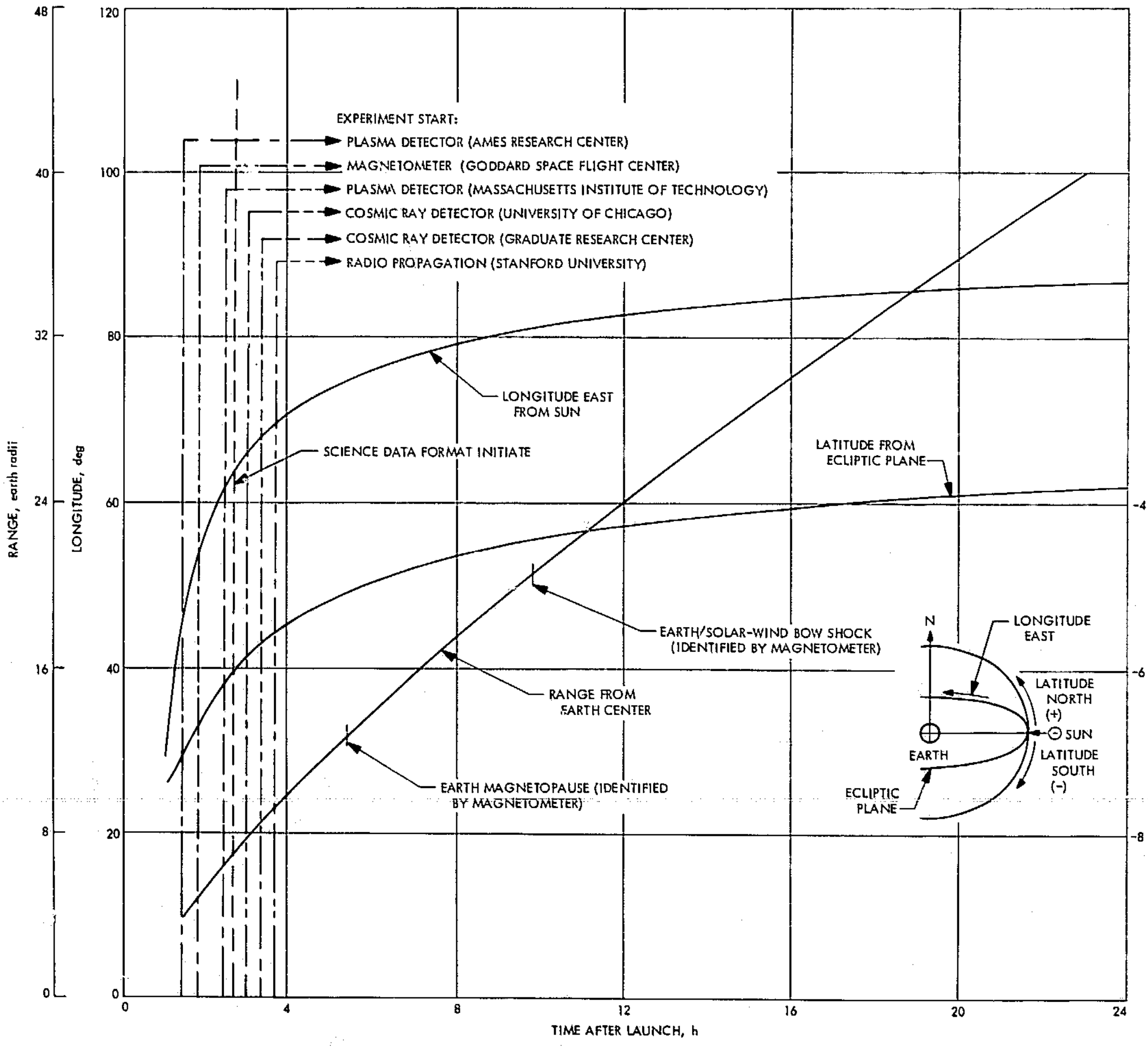


Fig. 53. Near-earth trajectory parameters for *Pioneer VI*

Pioneer VI relative to the earth–sun line in an earth-centered ecliptic coordinate system during the same period is shown in Fig. 54. In both figures, the location of the magnetopause and solar-wind bow shock determined from data obtained by the Goddard Space Flight Center magnetometer is indicated. The two events occurred well after all of the scientific instruments had been turned on.

The AFETR tracked the launch vehicle and received telemetry data from the spacecraft during the powered-flight phase of the mission. Stations at Cape Kennedy, Grand Bahama Island, and Antigua, and the *Coastal Crusader* tracking ship participated in this activity for *Pioneer VI*. The telemetry data were recorded on magnetic tape for later processing and analysis. However, the tracking data, excluding those from the ship, were transmitted via teletype immediately and continuously to the Real Time Computer Facility at Cape Kennedy, where the characteristics of the trajectory were calculated. Predictions to be used for initial acquisition of the spacecraft by the Deep Space Network were also determined. Similar activities were performed at the Space Flight Operations Facility, using the AFETR

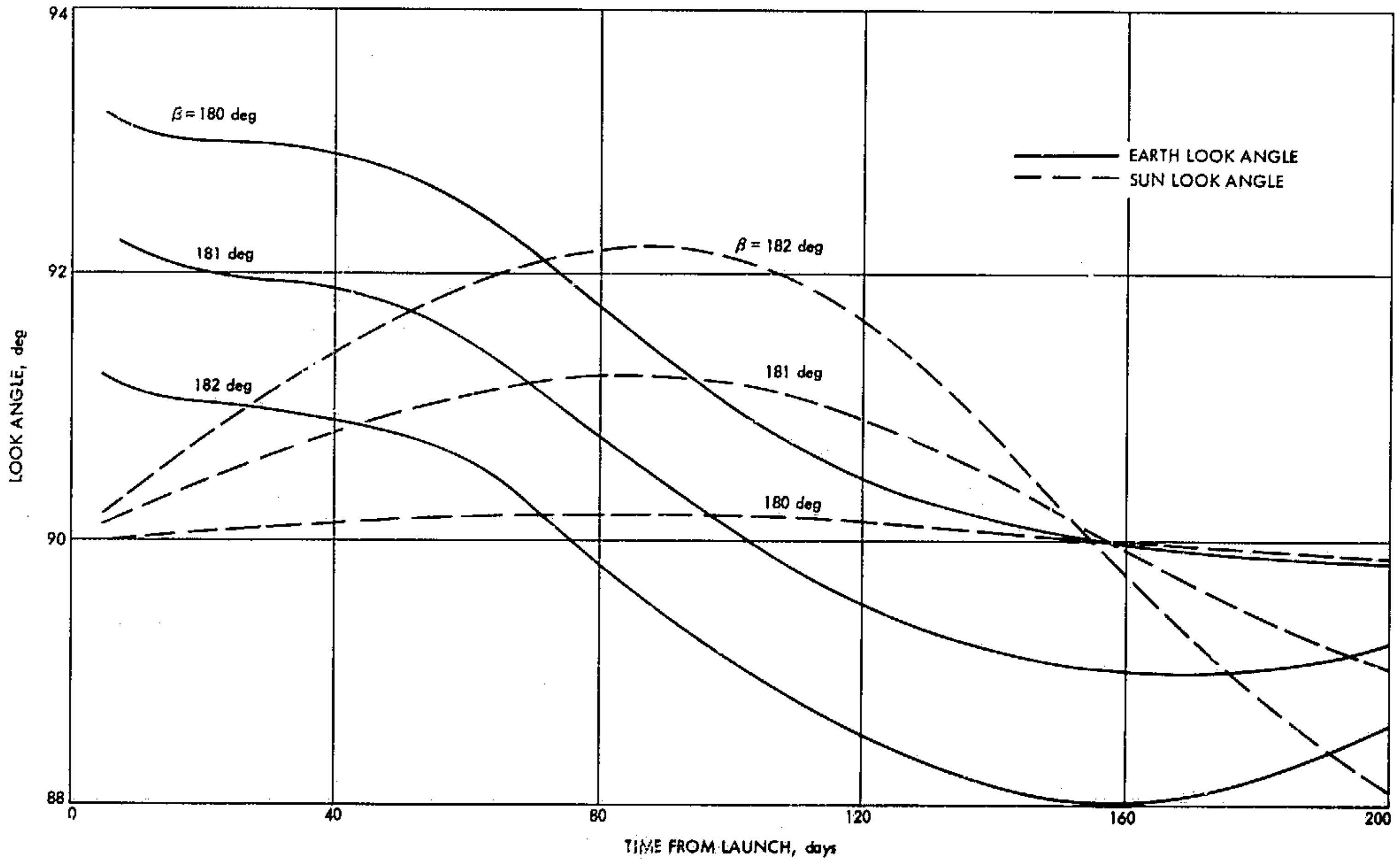


Fig. 54. Earth look-angle profiles for various spin-axis orientations to the ecliptic north pole (L + 6 days orbit with solar radiation pressure)

tracking data as a backup for the real-time computer facility.

3. *Sequence of major events.* A sequence of events associated with *Pioneer VI* is presented in Table 28. The events listed begin with the preship review held at the TRW facilities before the spacecraft was shipped to Cape Kennedy, and end with the last acquisition of *Pioneer VI* signals by DSS 12. For ease in following the sequence, the individual events are grouped according to their corresponding major activity.

B. Deep Space Phase

Following the near-earth phase, the DSN tracked, received telemetry data from, and transmitted commands to the spacecraft. Computing equipment at the Space Flight Operations Facility (SFOF) processed the tracking data teletyped from the Deep Space Stations during or immediately following a pass of the spacecraft. Computations were accomplished for orbit determination and calculation of predicts for aid in subsequent acquisitions of the spacecraft by the Deep Space Stations and by the 150-ft antenna at Stanford University. (The latter facility transmits only to two receivers aboard the spacecraft as part of the radio propagation investigation conducted by Stanford University.)

The DSN provided consistently high-quality data in support of *Pioneer VI.*

1. *Deep Space Instrumentation Facility operations.* The performance of the Deep Space Stations in support of *Pioneer VI* was excellent. The initial acquisition by DSS 51 was perfect. Effort made to exceed the one pass per day expected by the *Pioneer* Project Office resulted in an average of two passes per day. All mission objectives were met by the Deep Space Instrumentation Facility (DSIF).

Of concern to DSN management were the command errors that occurred during the mission. However, these errors did not perturbate the *Pioneer VI* spacecraft, nor deprive the *Pioneer* Project Office of scientific data. No catastrophic command errors were experienced. A list of command errors by station and pass is given in Table 29.

Table 28. *Pioneer VI* sequence of major events

Activity	Date, 1965	Time, GMT		Event
		Start	End	
Prelaunch events Sept. 29 to Dec. 16, 1965	Sept. 29	—	—	Preship review to evaluate operations readiness
	Oct. 1	—	—	Prelaunch activities started at Cape Kennedy
	Dec. 2	0700	—	First operational readiness test; simulating liftoff through Type II orientation
	Dec. 6	0700	—	Second operational readiness test; simulating liftoff through Type II orientation
	Dec. 9	0700	—	Third operational readiness test; simulating liftoff through Type II orientation
	Dec. 10	1400	2200	Launch readiness review, including interstation conference at 2400 for confirmation of readiness
	Dec. 13	1100	1157	Launch countdown, Task I (preparation for Task II)
		1158	1442	Launch countdown, Task II (spacecraft and instrument checks)
		1509	1621	Launch countdown, Task III (final pneumatic pressurization)
		1715	2058	Launch countdown, Task IV (ordnance installation checks)
	Dec. 14	0312	0545	Launch countdown, Task V (red-tag item removal and final preparation)
		—	1140	Fairing installation completed
		1200	1250	Launch countdown, Task VI (Part 1: umbilical checks completed)
		1745	—	*Pioneer* launch scrubbed because of *Gemini VI* weather delay
	Dec. 15	2134	—	Launch countdown, Task VI resumed (Part 2: RF checks completed)
	Dec. 16	0042	0047	Launch countdown, Task VII (spacecraft standby status preparation)
		0111	0124	Launch countdown, Task VIII (ordnance connection and final secure)
		0333	—	Launch countdown, Task IX started (terminal count)
		0354	—	Second-stage umbilical accidentally disconnected, requiring hold for spacecraft check and umbilical reconnect
		0521	0526	Repeat of Task VII
		0526	0539	Repeat of Task VIII
		0547	—	Repeat of abbreviated Task IX started
		0645	—	Terminal count at $T-35$ min initiated
		0656	—	Spacecraft on internal power
		0718	—	Launch vehicle hold established because of abnormal telemetry trace
		0720	—	Spacecraft on ground power
		0723	—	Terminal count at $T-8$ min resumed
		0726	—	Spacecraft on internal power
Events during powered-flight phase	Dec. 16	0731:20	—	Liftoff (launch window: 0645–0737 GMT)
		0732:02	—	Solid motors burnout
		0732:15	—	AFETR station 3 rise (receiver in and out of lock until 0737:33; rise norm: 0732:16)
		0732:30	—	Solid motors jettison
		0733:48	—	Main engine cutoff
		0733:52	—	Second-stage engine ignition
		0733:53	—	First/second-stage separation
		0734:18	—	Fairing jettison
		0734:21	—	DSS 71 set (norm: 0732:26)
		0734:40	—	AFETR station 1 set (norm: 0732:26; partial coverage)
		0736:40	—	AFETR station 9.1 normal rise (not acquired)
		0737:33	—	AFETR station 3 acquired (normal rise, 0732:16)
		0740:11	—	Second-stage engine cutoff
		0740:17	—	AFETR station 3 set (norm: 0736:06)
		0741:19	—	Begin coast-phase pitch program
		0744:00	—	AFETR station 9.1 normal set (not acquired)

Table 28 (contd)

Activity	Date, 1965	Time, GMT		Event
		Start	End	
Beginning events during DSS 51 initial acquisition	Dec. 16	0746:20	—	End coast-phase pitch program
		0751	—	Control transferred from SFOF to DSS 51 for partial Type II orientation and turn-on of instruments
		0756:05	—	Third-stage spinup
		0756:07	—	Second/third-stage separation
		0756:17	—	Third-stage ignition
		0756:41	—	Third-stage burnout
		0757:40	—	Third-stage/spacecraft separation; power to orientation electronics initiated Type I orientation
		0757:41	—	Booms and Stanford antenna deployed; TWT 1 on, driver to TWT 1, TWT 1 to low-gain antenna
		0759	—	Initial downlink acquisition at DSS 51 on acquisition-aid antenna
		0800	—	Initial spacecraft data teletyped to SFOF from DSS 51 indicated Type I orientation under way and spacecraft status normal
		0802	0805	*Coastal Crusader* telemetry (approximate coverage: 0752–0759 GMT)
		0804:14	—	Type I orientation terminated
		0805	—	Initial Class I engineering printout indicated spacecraft parameters normal
		0806	—	DSS 51 transmitter activated (10 kW) on acquisition-aid antenna
		0807	—	First spacecraft spin-rate indication showed normal spin rate
		0807	—	Ground receiver transferred to 85-ft antenna and maser
		0811	—	Executed command for 512 bits/s (changed from 64 to 512 bits/s)
		0813	—	Type I orientation restart command executed (no pulse indicated)
		0816	—	Ground transmitter transferred to 85-ft antenna
		0817	—	Ground receiver to 12-Hz bandwidth
		0824	—	Undervoltage-protection command executed
		0825	—	Initial downlink acquisition at DSS 42
		0835	—	First indication second spacecraft receiver activated; reduction of ground-received signal strength
		0836	—	First loss of computer lock (intermittent)
Partial Type II orientation and instrument turn on	Dec. 16	0846	—	Type I orientation restart command executed[a]
		0851	—	Single ccw Type II orientation command executed
		0856	0911	ccw Type II orientation commands (32) executed
		0914	—	Ames Research Center plasma detector turn-on command executed
		0922	—	Last indication of signal present in second spacecraft receiver
		—	—	Ground-received signal recovered and steady
		0922	—	Single ccw Type II orientation command executed
		0925	—	Goddard Space Flight Center magnetometer turn-on command executed
		0931	0947	ccw Type II orientation commands (32) executed
		0957	—	Plasma detector turn-on command executed
		1013	—	Format A command executed (scientific format)
		1020	—	DSS 51 transmitter power reduced to 2.5 kW
		1031	—	University of Chicago cosmic ray detector turn-on command executed
		1032	—	University of Chicago cosmic ray detector normal-mode command executed

[a] During command modulation, second spacecraft receiver lost signal, and ground-received signal strength increased.

Table 28 (contd)

Activity	Date, 1965	Time, GMT		Event
		Start	End	
Final events during DSS 51 initial acquisition	Dec. 16	1050	—	Graduate Research Center cosmic ray detector turn-on command executed
		1051	—	Graduate Research Center cosmic ray detector *dynamic range off* command executed
		1110	—	Stanford instrument turn-on command executed
		1130	—	Type I orientation restart command executed; single pulse indicated
		1140	—	Type I orientation restart command executed; single pulse indicated
		1144	—	Control transferred from DSS 51 to SFOF, partial Type II orientation being completed
		1148	—	DSS 51 transmitter power reduced to 600 W; spacecraft receiver signal remained strong
		1210	—	Ground-received signal dropped 15 dB, but still recorded good data
		1212	—	DSS 51 transmitter power raised to 1.25 kW
		1238	—	DSS 51 transmitter power reduced to 650 W
		1255	—	Spacecraft penetrated earth magnetopause at 12.8 earth radii from earth
		1312	—	End of first acquisition by DSS 42 (downlink only)
		1355	—	Regained 15 dB on ground-received signal as a result of manual antenna track adjustment (antenna probably on secondary lobe)
		1416	—	First Graduate Research Center cosmic ray detector calibrate command executed
		1510	—	DSS 51 transmitter power reduced to 300 W; spacecraft receiver signal remained strong
		1615	—	Second Graduate Research Center cosmic ray detector calibrate command executed
		1710	—	Spacecraft penetrated earth/solar-wind bow shock at 20.5 earth radii from earth
		1815	—	Third Graduate Research Center cosmic ray detector calibrate command executed
		1912	—	First Stanford experiment data obtained on teletype
		2003	—	First acquisition by DSS 12
		2015	—	Fourth Graduate Research Center cosmic ray detector calibrate command executed
		2031	—	DSS 51 receiver lost lock (antenna probably on sidelobe)
		2040	—	DSS 51 receiver solid lock as result of manual antenna track adjustment
		2100	—	Transmission discontinued from DSS 51 and initiated from DSS 12 at 600 W (first transfer of command link)
Events during Type II orientation	Dec. 16	2130	—	Plasma detector command to high-voltage mode executed
		2152	—	DSS 51 set
		2200	—	DSS 12 transmitter power reduced to 300 W
		2210	—	DSS 12 transmitter power reduced to 100W
		2255	—	Fifth Graduate Research Center cosmic ray detector calibrate command executed
	Dec. 17	0055	—	Sixth Graduate Research Center cosmic ray detector calibrate command executed
		0223	—	Second acquisition by DSS 42
		0300	—	Transmitter turned off at DSS 12 and turned on at DSS 42 at 100 W
		0345	—	First Stanford instrument calibrate commands (3) executed
		0400	—	Seventh Graduate Research Center cosmic ray detector calibrate commands (2) executed

Table 28 (contd)

Activity	Date, 1965	Time, GMT		Event
		Start	End	
		0445	—	Transmitter turned off at DSS 42 and turned on at DSS 12 at 100 W
		0515	—	Second Stanford instrument calibrate commands (3) executed
		0530	—	Third Stanford instrument calibrate commands (3) executed
		0630	—	Transmitter turned off at DSS 12 and turned on at DSS 42 at 100 W
		0653	—	DSS 12 set
		0810	—	Eighth Graduate Research Center cosmic ray detector calibrate commands (2) executed
		1024	—	Second DSS 51 acquisition
		1210	—	Ninth Graduate Research Center cosmic ray detector calibrate commands (2) executed
		1215	—	First telemetry data magnetic tapes arrived at Ames Research Center from DSS 12
		1230	—	Transmitter turned off at DSS 42 and turned on at DSS 51
		1349	—	DSS 42 set (second pass)
		1600	—	Tenth Graduate Research Center cosmic ray detector calibrate commands (2) executed
		1615	—	Eleventh Graduate Research Center cosmic ray detector calibrate command executed
		2000	—	Twelfth Graduate Research Center cosmic ray detector calibrate commands (2) executed
		2008	—	Second acquisition by DSS 12
		2100	—	Transmitter turned off at DSS 51 and turned on at DSS 12 at 600 W
Events during Type II orientation	Dec. 17	2120	—	Control transferred from Space Flight Operations Facility to DSS 12 for completion of Type II orientation; first data sent to experimenters from Ames Research Center tape processing station
		2125	—	Format C command executed
		2128	—	Type I orientation restart command executed; seven gas pulses counted
		2132	—	Type I orientation restart command executed; one gas pulse counted
		2136	—	Executed command for 16 bits/s
		2142	—	Noncoherent mode command executed
		2149	—	Malfunction in DSS 12 autotrack system
		2154	—	DSS 12 antenna operation switched to aided track mode for remainder of pass
		2158	—	TWT to high-gain antenna command executed
		2159	—	DSS 51 set (second pass)
		2210	—	Started sequence of 33 ccw Type II orientation commands at the rate of one command per minute
		2242	—	Transmitted command 33
		2250	—	Executed command for 512 bits/s
		2254	—	Type I orientation restart command executed; four gas pulses counted
		2258	—	Format A command executed
		2313	—	Format C command executed
		2317	—	Executed command for 16 bits/s
		2321	—	Started sequence of 67 ccw Type II orientation commands at the rate of one command per minute
	Dec. 18	0027	—	Transmitted command 67
		0031	—	Started sequence of 10 ccw Type II orientation commands at the rate of one command per minute

Table 28 (contd)

Activity	Date, 1965/1966	Time, GMT		Event
		Start	End	
		0041	—	Transmitted command 10
		0045	—	Executed command for 512 bits/s
		0048	—	Type I orientation restart command executed; four gas pulses counted
		0056	—	Format A command executed
		0108	—	Format C command executed
		0110	—	Executed command for 16 bits/s
		0114	—	Started sequence of 15 ccw Type II orientation commands at the rate of one command per minute
		0130	—	Transmitted command 15
		0132	—	Executed command for 512 bits/s
		0137	—	Type I orientation restart command executed; one gas pulse counted
		0144	—	Started sequence of three cw Type II orientation commands at the rate of one command per minute
		0146	—	Transmitted command 3
		0148	—	Started open-end sequence of ccw Type II orientation commands at the rate of one command per minute
		0214	—	Commands stopped after command 27
		0220	—	Type I orientation restart command executed; three gas pulses counted
		0223	—	Started sequence of 10 cw Type II orientation commands at the rate of one command per minute
		0232	—	Transmitted command 10
		0233	—	DSS 42 third acquisition
		0345	—	Started sequence of 10 cw Type II orientation commands at the rate of one command per minute
		0354	—	Transmitted command 10
		0409	—	Type I orientation restart command executed; one gas pulse counted
		0411	—	Orientation electronics off command executed
		0413	—	Format A command executed
		0415	—	Coherent mode command rejected as nonpermissive
		0418	—	Coherent mode command transmitted in emergency mode and executed
		0424	—	Mission control transferred to SFOF, orientation being complete
Events following Type II orientation to June 3, 1966	Dec. 18	0500	—	Transmitter turned off at DSS 12 and turned on at DSS 42
		0600	—	Thirteenth Graduate Research Center cosmic ray detector calibrate commands (2) executed
		0645	—	First magnetometer calibrate command executed
		0704	—	DSS 12 set
	Dec. 21	—	—	First University of Chicago cosmic ray detector calibrate command executed
	Dec. 23	—	—	First magnetometer flip command executed
	Dec. 24	1300	2013	First duty-cycle store mode (first lack of DSS coverage)
	Dec. 30	—	—	First "indication of importance 2" solar flare
	1966			
	Jan. 3	—	—	DSS 61 first acquisition
	Jan. 6	—	—	Second magnetometer flip command executed
	Jan. 12	—	—	DSS 11 first acquisition
	Jan. 13	—	—	Sharing of control between JPL and Ames Research Center initiated
	Jan. 16	2057	—	First time period with no data coverage
	Jan. 17	—	0053	
	Jan. 19	—	—	Second "indication of importance 2" solar flare

Table 28 (contd)

Activity	Date, 1966	Time, GMT		Event
		Start	End	
	Jan. 27	—	—	Third magnetometer flip command executed
	Feb. 2	—	—	DSS 41 first acquisition
	Feb. 12	—	—	Scientific data from first report period shipped to experimenters
	Feb. 23	—	—	Transfer of mission control to Ames Research Center completed
	Feb. 28	—	—	Change of bit rate from 512 to 256 bits/s; bit-error rate of 10^{-3} at DSS 12, spacecraft 1.21 × 10^7 km from earth
	Mar. 2	0530	—	Closest approach to syzygy; spacecraft 1.84 deg from sun (below) as seen from earth
	Mar. 3	—	—	Fourth magnetometer flip command executed
	Mar. 14	—	—	DSS 11 last acquisition
	Mar. 17	—	—	Change of bit rate from 256 to 64 bits/s and change from format A to B; bit-error rate of 10^{-3} at DSS 12, spacecraft 1.8 × 10^7 km from earth
	Apr. 13	—	—	Change of bit rate from 64 to 16 bits/s; bit-error rate of 10^{-3} at DSS 12, spacecraft 3.42 × 10^7 km from earth
	Apr. 19	—	—	Presentation of preliminary scientific report at forty-seventh annual meeting of American Geophysical Union
	Apr. 29	2205	—	Format C (engineering) command executed; preparation for receiver antenna change
		2220	—	Spacecraft receiver 2 switched to high-gain antenna (near threshold of low-gain antenna)
		2255	—	Format B (scientific) command executed
	May 8	—	—	DSS 51 last acquisition
	May 9	—	—	Change of bit rate from 16 to 8 bits/s; bit-error rate of 10^{-3} at DSS 12, spacecraft 5.53 × 10^7 km from earth
	May 18	0315	—	Spacecraft at ascending node
	May 20	0254	—	Spacecraft at perihelion; sun–spacecraft distance was 1.22 × 10^8 km (0.814 astronomical unit), and earth–spacecraft distance was 6.4 × 10^7 (0.433 astronomical unit)
	May 10	—	—	DSS 61 last acquisition
	May 27	—	—	DSS 14 first acquisition (test only; non-GOE[b] station)
	May 30	—	—	DSS 14 last acquisition
	June 3	—	—	DSSs 14 and 12 first acquisition (first microwave transmission link with DSS 12 GOE)
Events to determine spacecraft attitude	June 4	1200	—	Control transferred from Ames Research Center to DSS 12 to check attitude of spacecraft; DSSs 12 and 14 tracking; real-time telemetry data displayed at DSS 12
		1244	—	Noncoherent mode command executed
		1259	—	Memory readout command executed
		1259:30	—	Real-time telemetry command executed
		1300	—	Format C command executed (for maximum engineering data)
		1309	—	Noncoherent mode command executed
		1322	—	Executed command for 256 bits/s
		1334	—	Telemetry store mode command executed
		1334:30	—	Orientation electronics on command executed
		1335	—	Orientation electronics off commands (2) executed
		1336:30	—	Executed command for 8 bits/s
		1337	—	Format C command executed
		1342	—	Changed to display of real-time telemetry data from DSS 14 to improve data quality
		1404	—	Memory readout command executed (data stored during turn-on of orientation power obtained for immediate study)

[b] GOE = ground operational equipment.

Table 28 (contd)

Activity	Date, 1966	Time, GMT		Event
		Start	End	
		1448	—	Executed command for 512 bits/s
		1448:30	—	Telemetry store mode command executed
		1449:30	—	Executed command for 8 bits/s
		1450	—	Format C command executed
		1502	—	Memory readout mode command executed
		1538	—	Orientation electronics on command executed
		1541	—	Sequence of three ccw Type II orientation commands executed at the rate of one per minute
		1606	—	Sequence of three ccw Type II orientation commands executed at the rate of one per minute
		1626	—	Sequence of three ccw Type II orientation commands executed at the rate of one per minute
		1641	—	Change to display of real-time telemetry data from DSS 12
		1717	—	Sequence of nine cw Type II orientation commands executed at the rate of one per minute
		1804	—	Orientation electronics off command executed
		1805	—	Executed command for 512 bits/s
		1806	—	Telemetry store mode command executed
		1807	—	Executed command for 8 bits/s
		1808	—	Format C command executed
		1823	—	Memory readout mode command executed
		1859	—	Format B command executed
		1910	—	Coherent telemetry mode command executed
		1950	—	Control transferred from DSS 12 to Ames Research Center, orientation operation being complete
Change of spacecraft attitude and end of nominal mission	June 7	—	—	Normal data threshold for 8 bits/s at DSS 12; bit-error rate of 10^{-8}; spacecraft 8.15×10^7 km from earth
	June 9	1339	—	Noncoherent mode command executed to initiate activity for spacecraft attitude change during DSS 12 tracking period
		1404	—	Format C command executed
		1421	—	Orientation electronics on command executed
		1509	—	Sequence of six ccw Type II orientation commands executed at the rate of one command per five minutes
		1542	—	Orientation electronics off commands (2) executed
		1554	—	Memory readout mode command executed
		1554:30	—	Real-time mode command executed
		1604	—	Executed command for 256 bits/s
		1604:30	—	Telemetry store mode command executed
		1605	—	Spacecraft battery off command executed
		1634	—	Format C command executed
		1635	—	Memory readout mode command executed
		1719	—	Format B command executed
		1744	—	Coherent mode command executed as activity for attitude change and turning off of battery completed
	June 28	—	—	DSS 42 last acquisition
	June 29	—	—	Regular operation with DSSs 14 and 12; microwave link began
	July 11	—	—	Terminated Stanford experiment because spacecraft out of range
	July 13	—	—	DSS 12 last acquisition

Table 29. *Pioneer VI* command errors

Station	Pass	Remarks
51	070	Command transmission delayed due to operator error
51	068	Commands 100 and 101 transmitted late due to operator error
51	079	Command 060 delayed 2 min due to computer alarm
12	053	Command 053 sent 9 min early due to operator error
12	107	One command sent late due to poor communication between station and SFOF
42	099	Command 034 sent 1 min late due to confusion through being given incorrect instructions
51	068	Command 005 delayed 2 min by appearance of error light (cause unknown)
51	053	Command 100 delayed by faulty monitor receiver
42	036	Command 100 inhibited by an undetermined equipment malfunction
12	060	Command 050 delayed 2 min due to operator error
51	035	Command 004 transmitted 9 min early due to error in misreading digital clock
51	123	Command delayed due to error in initial instructions in which too-close spacing of commands caused DIS[a] to be out of lock
51	142	Command 052 delayed 15 min because DIS out of lock (operator failed to change demodulator sync bit rate switch)

[a]DIS = digital instrumentation system.

The following seven stations, employing 85-ft antennas, supported the *Pioneer VI* operation at various times:

(1) DSS 11 (*Pioneer*), Goldstone, Calif.

(2) DSS 12 (*Echo*), Goldstone, Calif.

(3) DSS 41 (Island Lagoon), Woomera, Australia.

(4) DSS 42 (Tidbinbilla), Canberra, Australia.

(5) DSS 51 (Johannesburg), Johannesburg, South Africa.

(6) DSS 61 (Robledo), Madrid, Spain.

(7) DSS 71 (Cape Kennedy), Cape Kennedy, Fla.

Deep Space Station 71 supported the prelaunch tests and checkout; DSSs 12, 42, and 51 were prime ground-operational-equipment stations; DSSs 11, 41, and 61 provided record capability as backup stations. The Goldstone Mars station (DSS 14) supported the routine phase of the mission with its 210-ft antenna for downlink only. The 10-kW transmitter at DSS 12 was used for uplink. The DSS 12 transmitter was committed for transmission to the spacecraft at least twice each week. To conduct command and real-time data transmission activities, the microwave link was used between DSSs 12 and 14. Cape Kennedy (DSS 71) was directed to lock up on each of the spacecraft frequencies and pull them back to rest frequency. This was accomplished, and channel 6 was verified to be within this area.

At 0630:00 GMT, Johannesburg (DSS 51) was advised that it was to turn on transmitter power at $L+34$ s instead of $L+34.5$ s because of frequency uncertainties. Johannesburg was advised to remain at this transmitter voltage-controlled oscillator frequency until $L+36.5$ s and—if no acquisition—to go to the predicted frequency for $L+40$ s and search for the spacecraft.

At 0708 GMT, DSS 71 reported a −98-dBm signal from the spacecraft, and at 0729 the station reported the spacecraft auxiliary oscillator frequencies. Liftoff occurred at 0731:20 GMT, 16 min beyond the closing of the "optimum" launch window. The delay was caused by problems associated with the prior spacecraft power loss.

Table 30 shows tracking station particulars for the first four passes of the *Pioneer VI* spacecraft. The paragraphs that follow describe the operational details of these prime tracking stations.

a. Cape Kennedy (DSS 71), pass 001. Deep Space Station 71 performed all assigned tasks satisfactorily. The station acquired PN-6 at 0731:20 GMT and reported loss of lock at 0734:21 GMT, which was the time of shroud jettison. Loss of signal appeared to be due to normal attenuation because of obscured antenna "look" angles. No equipment failures were reported.

The following data apply to the DSS 71 portion of the track:

Time	Signal level
Liftoff	−100 dBmW
$L+60$ s	−115 dBmW
$L+90$ s	−125 dBmW
$L+120$ s	−130 dBmW
$L+150$ s	−135 dBmW
$L+160$ s	−138 dBmW
$L+175$ s	−144 dBmW
$L+180$ s	−146 dBmW
$L+181$ s	Lock lost

b. Johannesburg (DSS 51), pass 001. Transmitted power was an initial 10 kW, reduced to 1250 W and then to 650 W. Before the start of Type II orientation, the loop bandwidth was switched from 152 to 12 Hz. The purpose of this change was to provide all available signal margins in case the spacecraft attitude should be

Table 30. Deep Space Station tracking data, first four passes

Pass	Deep Space Station	Location	Acquisition		End of pass		System noise temperature, °K	Low-noise antenna gain, dB	Threshold sensitivity, dBm		Transmitter power, kW
			Time, GMT	Date, 1965	Time, GMT	Date, 1965			Receiver 1	Receiver 2	
001	DSS 51	Johannesburg	0759:53	Dec. 16	2151:35	Dec. 16	42.70	—	−172.0	—	10, 1.25, 0.65
001	DSS 42	Tidbinbilla	0825:02	Dec. 16	1312:09	Dec. 16	40.80	36.4	−172.1	−171.1	0
001	DSS 12	Goldstone	2003:20	Dec. 16	0652:50	Dec. 17	42.50	37.5	−163.0	−163.0	0.60, 0.10
002	DSS 42	Tidbinbilla	0223:27	Dec. 17	1349:00	Dec. 17	39.60	37.2	−171.9	−171.9	0.13
002	DSS 51	Johannesburg	1024:19	Dec. 17	2158:29	Dec. 17	41.70	—	−171.0	—	0.30
002	DSS 12	Goldstone	2008:10	Dec. 17	0704:12	Dec. 18	41.90	37.0	−172.0	—	0.60, 10.0
003	DSS 42	Tidbinbilla	0233:16	Dec. 18	1352:00	Dec. 18	39.90	36.8	−171.1	−170.0	0.60
003	DSS 51	Johannesburg	1034:32	Dec. 18	2210:12	Dec. 18	49.20	36.8	−171.0	—	0.60
003	DSS 12	Goldstone	2008:30	Dec. 18	0705:31	Dec. 19	41.60	37.0	−172.0	—	0.60
004	DSS 42	Tidbinbilla	0234:44	Dec. 19	1350:00	Dec. 19	40.22	36.9	−169.2	−168.4	0.60
004	DSS 51	Johannesburg	1029:53	Dec. 19	2203:15	Dec. 19	48.70	—	−171.0	—	0.60
004	DSS 12	Goldstone	2004:42	Dec. 19	0318:10	Dec. 20	42.40	19.8	—	—	0.60

such that it might go through a deep null (30 to 50 dB drop) during these maneuvers.

Upon receipt of the AFETR predicts, checks revealed the presence of significant errors. Deep Space Station 51 was directed to disregard these and go to set 12A based upon nominals.

In spite of the difficulty in stabilizing spacecraft voltage-controlled-oscillator (VCO) frequencies, the initial acquisition by DSS 51 was normal. The station acquired the spacecraft signal on schedule (see Table 30) in the 1-way mode, using the S-band acquisition antenna (SAA) and maser. The receiver, ground operational equipment, and digital instrumentation system were locked on almost immediately, and good data were observed on the teletype link.

At 0806:02 GMT, the uplink was locked to the VCO frequency. The downlink was reestablished, and good data were indicated at 0806:55 GMT. Subsequently, tracking was via the S-band cassegrainian monopulse (SCM) system (and maser).

Type I orientation had not been completed at acquisition; then 20 status changes were printed out because of gas-jet toggling. Type I gas-jet activity ceased at 0804 GMT, and the standard engineering status printout was received at 0805 GMT.

The following initial spacecraft actions, received as a status printout, were exactly as predicted:

(1) Format C, real-time mode, 64 bits/s, redundancy A.

(2) Stage 3 separated.

(3) Booms deployed.

(4) Stanford antenna deployed.

(5) Undervoltage override on.

(6) Orientation power on.

(7) Traveling-wave tube amplifier 1 on and connected to low-gain antenna.

(8) Both equipment converters on.

(9) Both receivers not addressed.

(10) Experiments off.

Tracking mode and times were as follows:

Mode	Period, GMT
1-way, SAA–maser	From 0759:53 to 0806:02
2-way, SAA–maser	From 0806:26 to 0807:18
2-way, SCM–maser	From 0807:18 to 2100:01
2-way, SCM–maser	From 2100:01 to 2151:35

Deep Space Station 51 reported the FR-1400B, 2230 FSM record modules would not oscillate internally. The problem was corrected by replacing a module. A gassy tube was replaced in the 30-MHz mixer. This occurred during station countdown preceding the launch pass.

At 0835 GMT, it was observed that both spacecraft receivers were addressed. Simultaneously, the ground automatic gain control was observed to decrease in amplitude. This condition disappeared without corrective action at the station at 0846, then reappeared from 0915 to 0921 GMT. During the latter period, a spectral analysis of the DSS 51 ground transmitter revealed spurious sidebands at approximately 400 kHz from the center frequency (within the passband of the channel 7 receiver), and at approximately 23 dB below carrier power level.

After the first few status commands, at approximately 0838:58 GMT, a series of several momentary receiver dropouts was observed. The first group of these dropouts lasted until 0844:53. At this time, DSS 42 reported observation of the DSS 51 radiated signal on a spectrum analyzer, and that there was considerable noise and spurious modulation on the carrier. The DSS 42 observers also reported what appeared to be a significant spur present. As a result, DSS 51 personnel were requested to check their output on an analyzer. After the check, DSS 51 confirmed the presence of sidebands at ±400 kHz, approximately 20 dB down from the carrier.

Based upon this information, as well as the reported fact that spacecraft receiver 2 indicated that it was being addressed from engineering telemetry, it is assumed that this sideband (at extremely high power conditions and with the aforementioned doppler and loop-stress deviations) probably was sweeping across receiver 2, causing it to indicate address. There is a possibility that this receiver was injecting the noise into the driver/mixer, thus causing interference with the normal output of receiver 2. The frequency spread between receivers 1 and 2 is approximately 370 kHz, and this figure matches this theory quite well.

The receiver momentary dropouts continued at brief intervals until approximately 1020:00 GMT, at which time the transmitted power was reduced by 6 dB. There were no further problems from this source. Investigation of this problem is continuing.

A sudden drop in signal strength (20 dB) was reported by DSS 51 at 1210 GMT. This was attributed to the antenna autotrack system introducing a bias that offset the antenna from predicted angles. Signal strength returned to normal upon going to aided track and correcting antenna angles in accordance with current predicts.

All spacecraft commands were transmitted in the abnormal mode until 1309 GMT, at which time the transmitter frequency was changed to permit the monitor receiver to operate in the proper frequency range. Once the monitor receiver was on the proper frequency, the station transmitted commands in the normal mode. Table 31 shows the identification and times of all DSS 51 commands during the first four passes.

Communication was spotty on both teletype and voice between JPL and DSS 51. JPL Communications placed a commercial telephone call to the station to support the signaling, conferencing, and monitoring arranging (SCAMA) voice circuit, which was down for considerable periods before acquisition by DSS 51. Communication to DSS 51 during the 13-h tracking period was generally good, and the commercial telephone call was dropped shortly after DSS 51 acquisition.

Telemetry and tracking data were received from DSS 51 in real-time. Engineering and tracking data were usable. Station performance was satisfactory, and initial acquisition was perfect.

c. Tidbinbilla (DSS 42), pass 001. The Tidbinbilla Deep Space Station acquired the spacecraft in the 3-way mode on the SAA–paramp at 0825:02 GMT, as shown in the table of particulars (see Table 30). The tracking modes and times are given below.

Mode	Period, GMT
3-way, SAA–paramp	From 0825:02 to 0835:30
3-way, SCM–maser	From 0835:30 to 0837:40
3-way, SAA–paramp	From 0837:40 to 0839:40
3-way, SCM–maser	From 0839:40 to 0850:10
3-way, SAA–paramp	From 0850:10 to 0852:40
3-way, SCM–maser	From 0852:40 to 1312:09

At 1024 GMT, a patchcord shorted in the JM digital instrumentation system, causing loss of four and eight bits in the most significant digit of the doppler readout. The backup 400-Hz converter for transmitter power was not operational.

No commands were transmitted by DSS 42 during the first pass; full-time voice and teletype were available, and JPL communication was good. Telemetry and tracking data were also good, and station performance was satisfactory.

d. Goldstone (DSS 12), pass 001. The Goldstone station acquired the *Pioneer VI* spacecraft at 2003:20 GMT. The transmitter power was initially set at 600 W, and

Table 31. Johannesburg commands, first four passes

Pass	Date, 1965	Time, GMT	Command	Event
001	Dec. 16	0810	004	512 bits/s rate
001	Dec. 16	0813	021	Type I restart
001	Dec. 16	0824	110	Traveling-wave-tube amplifier (TWT) power off
001	Dec. 16	0846	021	Type I restart
001	Dec. 16	0851	040	Type II counterclockwise
001	Dec. 16	0855–0911	040	Type II counterclockwise
001	Dec. 16	0914	054	Experiment G, power on
001	Dec. 16	0922	040	Type II counterclockwise
001	Dec. 16	0925	055	Experiment B, power on
001	Dec. 16	0931–0947	040	Type II counterclockwise
001	Dec. 16	0957	013	Experiment C, power off
001	Dec. 16	1013	034	Format A
001	Dec. 16	1031	076	Experiment A, power on
001	Dec. 16	1032	070	Experiment A, normal mode
001	Dec. 16	1050	116	Experiment D, power on
001	Dec. 16	1050	100	Experiment D, dynamic range off
001	Dec. 16	1110	077	Experiment E, power on
001	Dec. 16	1130	021	Type I restart
001	Dec. 16	1140	021	Type I restart
001	Dec. 16	1415	100	Experiment D, dynamic range off
001	Dec. 16	1416	101	Experiment D, calibrate
001	Dec. 16	1615	100	Experiment D, dynamic range off
001	Dec. 16	1616	101	Experiment D, calibrate
001	Dec. 16	1815	100	Experiment D, dynamic range off
001	Dec. 16	1816	101	Experiment D, calibrate
001	Dec. 16	2015	100	Experiment D, dynamic range off
001	Dec. 16	2016	101	Experiment D, calibrate
002	Dec. 17	1600	100	Experiment D, dynamic range off
002	Dec. 17	1601	101	Experiment D, calibrate
002	Dec. 17	1615	101	Experiment D, calibrate
002	Dec. 17	2000	100	Experiment D, dynamic range off
002	Dec. 17	2001	101	Experiment D, calibrate
003	Dec. 17	1600	100	Experiment D, dynamic range off
003	Dec. 17	1601	101	Experiment D, calibrate
003	Dec. 17	1615	101	Experiment D, calibrate
003	Dec. 17	2000	100	Experiment D, dynamic range off
003	Dec. 17	2001	101	Experiment D, calibrate
004	Dec. 18	1350	100	Experiment D, dynamic range off
004	Dec. 18	1351	101	Experiment D, calibrate
004	Dec. 18	1800	100	Experiment D, dynamic range off
004	Dec. 18	1801	101	Experiment D, calibrate

later reduced to 100 W. (See also station particulars for this pass in Table 30.)

Goldstone tracking modes and times for the first pass are shown below.

Mode	Period, GMT
3-way, SCM–maser	From 2003:20 to 2100:00
2-way, SCM–maser	From 2100:00 to 0300:14
3-way, SCM–maser	From 0300:14 to 0445:00
2-way, SCM–maser	From 0445:00 to 0601:40
2-way, SCM–maser	From 0606:30 to 0630:01
3-way, SCM–maser	From 0630:50 to 0652:50

From 0510 to 0512 GMT, DSS 12 tried to initiate command 071. An error light came on, inhibiting the command. The read–write–verify (RWV) receiver was found to be out of lock, though indications were that it was in lock.

At 0601:40 GMT, the undercurrent interlock relay deactivated the transmitter. The problem was associated with the backpressure in the hydraulic system at a specific antenna pointing angle.

Table 32 shows all commands initiated by DSS 12 during the first four passes.

There were no communication outages during the first pass. Telemetry and tracking data were good, and station performance was satisfactory.

e. Tidbinbilla (DSS 42), pass 002. The *Pioneer VI* spacecraft acquisition was achieved in the 3-way mode (SCM–maser) at 0223:27 GMT. Autotrack began at 0230:30. (See Table 30 for station particulars for the first four passes.) The tracking modes and periods are shown below.

Mode	Period, GMT
3-way, SCM–maser	From 0223:00 to 0305:00
2-way, SCM–maser	From 0305:00 to 0445:01
3-way, SCM–maser	From 0445:01 to 0602:13
1-way, SCM–maser	From 0602:13 to 0605:22
3-way, SCM–maser	From 0605:22 to 0630:00
2-way, SCM–maser	From 0630:00 to 1230:16
3-way, SCM–maser	From 1230:16 to 1349:00

There was a slight jitter on the HA antenna, caused by a slight reduction in hydraulic pressure at 0512 GMT. At 0847, the gearbox lubrication pump was stopped to allow foaming oil to settle.

No spacecraft commands were initiated during the first pass, as noted previously. Those commands transmitted on the second, third, and fourth passes are identified in Table 33.

Communication conditions during the second pass were normal, and no outages were recorded. Data conditions for both telemetry and tracking were good. The station performance was satisfactory.

f. Johannesburg (DSS 51), pass 002. The *Pioneer VI* spacecraft signal was acquired at 1024:19 GMT. Autotrack was initiated at 1026:30. (For tracking particulars pertinent to the first four passes, see Table 30.)

The DSS 51 tracking modes and periods are shown below for the second pass.

Mode	Period, GMT
3-way	From 1024:19 to 1230:05
2-way	From 1230:17 to 2100:01
3-way	From 2100:01 to 2158:29

The B2 reel covering the period from 1332 to 1709 GMT rewound unevenly as a result of a flaw in the early portion of the tape, and the Consolidated Electrodynamics Corporation recorder incurred paper jams at 1349 and 1925. The demodulator lost lock at 1524, apparently because of a faulty connector on the receiver Darlington amplifier. This problem was corrected at 1528 by a temporary repair.

Five commands were transmitted during the second pass; these are identified in Table 31. The communication conditions for the second pass were fair, and telemetry and tracking data conditions were good. Station performance was satisfactory.

g. Goldstone (DSS 12), pass 002. Pioneer VI spacecraft acquisition was achieved in the 2-way mode at 2008:10 GMT, with the DSS 12 transmitter set at 600 W. The power was increased to 10 kW for the Type II orientation maneuver, but lowered again to the 600-W level immediately thereafter. Detailed particulars pertaining to Goldstone tracking during the second pass are shown in Table 30.

Table 32. Goldstone commands, first four passes

Pass	Date, 1965	Time, GMT	Command	Event
001	Dec. 16	2130	112	Experiment B, mode change 2
001	Dec. 16	2255	100	Experiment D, dynamic range off
001	Dec. 16	2256	101	Experiment D, calibrate
001	Dec. 17	0055	100	Experiment D, dynamic range off
001	Dec. 17	0056	101	Experiment D, calibrate
001	Dec. 17	0515–0516	071	Experiment E, calibrate[a]
001	Dec. 17	0530–0531	071	Experiment E, calibrate[a]
002	Dec. 17	2125	037	Format C
002	Dec. 17	2128	021	Type I restart
002	Dec. 17	2132	021	Type I restart
002	Dec. 17	2136	016	16-bits/s rate
002	Dec. 17	2142	043	Noncoherent mode on
002	Dec. 17	2158	047	Traveling-wave-tube amplifier to high-gain antenna
002	Dec. 17	2201–2242	040	Type II counterclockwise
002	Dec. 17	2250	004	512-bits/s rate
002	Dec. 17	2258	034	Format A
002	Dec. 17	2315	037	Format C
002	Dec. 17	2317	016	16-bits/s rate
002	Dec. 17 Dec. 18	2321– 0026	040	Type II counterclockwise[b]
002	Dec. 18	0031–0041	040	Type II counterclockwise[c]
002	Dec. 18	0045	004	512-bits/s rate
002	Dec. 18	0048	021	Type I restart
002	Dec. 18	0056	034	Format A
002	Dec. 18	0108	037	Format C
002	Dec. 18	0110	016	16-bits/s rate
002	Dec. 18	0114–0123	040	Type II counterclockwise[c]
002	Dec. 18	0126–0130	040	Type II counterclockwise[d]
002	Dec. 18	0132	004	512-bits/s rate
002	Dec. 18	0137	021	Type I restart
002	Dec. 18	0144–0146	031	Type II clockwise[a]
002	Dec. 18	0148–0214	040	Type II counterclockwise[e]
002	Dec. 18	0220	021	Type I restart
002	Dec. 18	0223–0232	031	Type II clockwise[c]
002	Dec. 18	0345–0354	031	Type II clockwise[c]
002	Dec. 18	0409	021	Type I restart
002	Dec. 18	0411	042	Orientation power off
002	Dec. 18	0413	043	Noncoherent mode on
002	Dec. 18	0418	030	Noncoherent mode off
003	Dec. 18	2135	100	Experiment D, dynamic range off
003	Dec. 18	2136	101	Experiment D, calibrate
003	Dec. 19	0135	052	Memory readout
003	Dec. 19	0136	060	Real-time data
003	Dec. 19	0245	100	Experiment D, dynamic range off
003	Dec. 19	0246	101	Experiment D, calibrate
003	Dec. 19	0345	050	Format D
003	Dec. 19	0345	004	512-bits/s rate
003	Dec. 19	0346	034	Format A
004	Dec. 19	2300	100	Experiment D, dynamic range off
004	Dec. 19	2301	101	Experiment D, calibrate

[a] Command transmitted 3 times.

[b] Command transmitted 66 times.

[c] Command transmitted 10 times.

[d] Command transmitted 5 times.

[e] Command transmitted 27 times.

Table 33. Tidbinbilla commands, passes 002–004

Pass	Date, 1965	Time, GMT	Command	Event
002	Dec. 17	0345–0346	071	Experiment E, calibrate[a]
002	Dec. 17	0400	100	Experiment D, dynamic range off
002	Dec. 17	0401	101	Experiment D, calibrate
002	Dec. 17	0401	100	Experiment D, dynamic range off
002	Dec. 17	0810	100	Experiment D, dynamic range off
002	Dec. 17	0811	101	Experiment D, calibrate
002	Dec. 17	1210	100	Experiment D, dynamic range off
002	Dec. 17	1211	101	Experiment D, calibrate
003	Dec. 18	0600	100	Experiment D, dynamic range off
003	Dec. 18	0601	101	Experiment D, calibrate
003	Dec. 18	0645	061	Experiment B, calibrate
003	Dec. 18	1000	100	Experiment D, dynamic range off
003	Dec. 18	1001	101	Experiment D, calibrate
004	Dec. 19	0700	100	Experiment D, dynamic range off
004	Dec. 19	0701	101	Experiment D, calibrate
004	Dec. 19	1100	100	Experiment D, dynamic range off
004	Dec. 19	1101	101	Experiment D, calibrate

[a] Command transmitted three times.

The DSS 12 tracking modes and periods are shown below for the second pass.

Mode	Period, GMT
3-way, SCM–maser	From 2008:10 to 2100:00
2-way, SCM–maser	From 2100:00 to 0500:00
3-way, SCM–maser	From 0500:00 to 0704:12

The only reported problem during the second pass was an inability to autotrack for much of the time. This was attributable to the low declination rates during the pass.

Commands initiated during the second pass are identified in Table 32. Of specific interest were the Type II orientation commands, initiated to align the spin axis of the spacecraft perpendicular to the earth–spacecraft line. The purpose of the alignment maneuver was to bring the main lobe of the spacecraft high-gain antenna into a position that favored the DSS.

The Type II orientation was very successful, all objectives for spacecraft orientation being met. The spin vector was biased from the normal to the ecliptic plane so that trimming orientation changes should not be required for more than 6 mo.

The Type II orientation maneuver started at 2210 GMT on December 16, 1965, and was performed in a completely normal manner. This maneuver consisted of 125 ccw commands followed by 3 cw commands to verify that the spacecraft could be torqued in both directions, 27 more ccw pulses, and 20 final cw pulses. Combined with two Type I pulses used for trim, a total of 177 pulses were recorded during the final Type II maneuver. The final Type II orientation maneuver was completed at 0411 GMT on December 17. During the orientation maneuver, a portion of the high-gain antenna pattern for the downlink frequency was plotted as a means of precisely determining spacecraft orientation with respect to its orbital plane. The portion of the pattern obtained appeared to be normal.

Trajectory data. The data supplied 16 h after launch ($L+16$ h) reflected the best trajectory estimate for an epoch preceding the Goldstone second-pass reorientation activity. The actual reorientation was based upon the JPL-supplied $L+3$ h trajectory estimate (also referenced below).

Procedure. For the ideal trajectory in which $\mathbf{V}_\infty$ is parallel to the ecliptic and the spacecraft is sufficiently far from the earth so that the ground station is effectively in the ecliptic as seen from the spacecraft, the final reorientation procedure would be simply to center the main lobe to the ground station, thereby aligning the spin axis with the south ecliptic pole. Subsequently, the sun and earth look angle remain effectively at 90 deg for the remainder of the mission (neglecting precession due to solar radiation pressure).

The station look angle was required to be related to the north ecliptic pole (which served as an inertial reference). This aspect orientation, which involved rotating the spacecraft to obtain the proper angle between the spacecraft spin axis and the earth–spacecraft line, was necessary because:

(1) The spacecraft was relatively close to the earth during the first two Goldstone passes.

(2) The declination of Goldstone to the ecliptic was time-varying (due to earth rotation).

(3) $\mathbf{V}_u$ was inclined to the ecliptic.

The TRW procedure for the final Type II reorientation maneuver was to determine the sun and earth look-angle history vs the spacecraft spin-axis declination to the north ecliptic pole.[1] This is depicted in Fig. 54. The angle β that the spacecraft spin axis makes is defined as the ccw angle from the north ecliptic pole to the spin axis. This is consistent with the sense of spacecraft rotation for a commanded Type II ccw rotation. The desired sun and earth look-angle history of Fig. 54 was used to determine the necessary spin-axis orientation to the ecliptic north pole.[2]

The main lobe of the high-gain antenna was identified at approximately 0131 GMT, after 125 Type II ccw commands were completed, corresponding to a rotation of approximately 37.5 deg. Three Type II cw commands were conducted at 0144 GMT to verify Type II cw rotation capability. Also, 27 additional Type II ccw commands swept through the main lobe to approximately the −3-dB point (0215 GMT). Ten Type II cw commands were initiated at 0223 and completed at 0232 GMT, effectively centering the main lobe to DSS 12. The required main-lobe biasing with respect to DSS 12 was determined by selecting the desired earth and sun look-angle history (shown in Fig. 54). It was decided that a spin-axis orientation of 181 deg was to be achieved for the main-lobe bias. The selection of this value was based solely upon geometric considerations. Optimization with respect to bit rate or total information transmitted during the lifetime of the mission was not considered in the selection of the desired spin-axis orientation. In addition, solar-radiation effects were not considered. Main-lobe centering at 0225 GMT corresponded to a spin-axis orientation of 184.0 deg with respect to the north ecliptic pole (see Table 34). A 3-deg cw rotation was initiated at 0345 GMT, consisting of 10 Type II cw commands.

The effects of solar-radiation pressure upon the earth and sun look-angle history are depicted in Fig. 55, which is also based upon later trajectory data ($L+6$ days). It is apparent from this figure that the spin-axis orientation of 181 deg selected during the DSS 12 maneuvers provided satisfactory look-angle profiles for the remainder of the *Pioneer VI* mission.

Station performance. Voice and data communication conditions during the second pass were good, and station performance was satisfactory in all respects. The Goldstone station supported the Type II orientation with transmission of 174 discrete commands, all of which were successfully executed by the *Pioneer VI* spacecraft.

h. Tidbinbilla (DSS 42), pass 003. The *Pioneer VI* spacecraft was acquired at DSS 42 for the third pass at 0233:16 GMT. (See Table 30 for DSS 42 tracking particulars.) The station began autotracking at 0234:43 GMT. Acquisition of the spacecraft was delayed 20 min because of incorrect arrival at DSS 42 of prepass instructions.

Tracking modes and periods for DSS 42 during the third pass are listed below.

Mode	Period, GMT
3-way, SCM–maser	From 0233:16 to 0500:00
2-way, SCM–maser	From 0500:00 to 1200:00
3-way, SCM–maser	From 1200:00 to 1352:00

Five commands were initiated by DSS 42 during the third pass; these are identified in the Tidbinbilla command tabulation (see Table 33).

Communication conditions were normal, and telemetry and tracking data conditions were good. The bit rate was 512 bits/s. The station performance was fully satisfactory.

---

[1] It is assumed at all times that the Type I maneuver is completed before the Type II maneuver, so that the spacecraft spin axis is perpendicular to the spacecraft–sun line.

[2] The sun and earth look-angle histories depicted in Fig. 54 are also a function of the time at which the final Type II orientation is made. However, they are effectively the same for the first several days after launch.

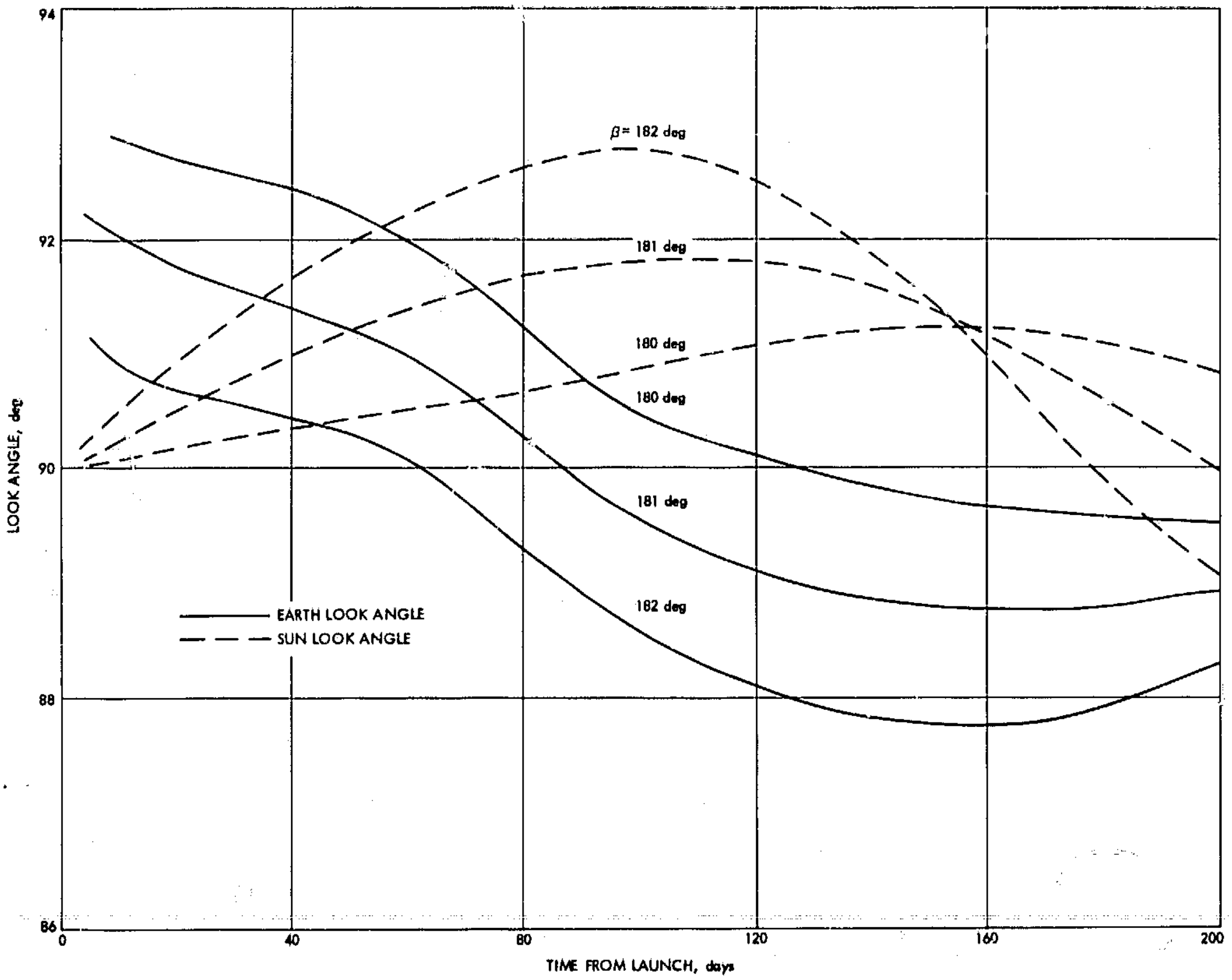


Fig. 55. Earth and sun look-angle profiles for various spin axes

i. Johannesburg (DSS 51), pass 003. The *Pioneer VI* spacecraft acquisition by DSS 51 occurred in the 2-way mode at 1034:32 GMT. Autotracking began at 1035:12 GMT. (See DSS 51 tracking particulars for the third pass in Table 30.) The initial acquisition involved reception of a spacecraft sideband signal; however, after two attempts, the main beam was acquired at 1045:34 GMT. Autotracking after reacquisition was regained at 1046:00 GMT.

Tracking modes and periods for DSS 51 during the third pass are listed below.

Mode	Period, GMT
2-way, SCM–maser	From 1034:32 to 1200:00
2-way, SCM–maser	From 1200:00 to 2100:01
2-way, SCM–maser	From 2100:01 to 2210:12

Four command transmissions were successfully initiated during the pass; these consisted of two Experiment D commands, each sent twice. (See Johannesburg command identification list, Table 31.)

Communication conditions were normal, and telemetry and tracking data conditions were good. The bit rate was 512 bits/s.

The doppler counter transfer pulse for switching from counter 1 to counter 2 had to be reset at board A-3; this was accomplished after posttrack calibration. With the exception of the spacecraft sideband acquisition on the first RF lockup attempt, the performance of DSS 51 was satisfactory.

j. Goldstone (DSS 12), pass 003. Initial spacecraft acquisition of the *Pioneer VI* spacecraft on its third DSS 12 pass occurred at 2008:30 GMT on December 18.

Tracking particulars are listed in Table 30. Autotracking began at 2011:07 GMT, and transfer of the spacecraft transponder from DSS 51 to DSS 12 was effected at 2100:00 GMT on December 18. Transponder transfer to DSS 42, the succeeding station, took place the following day at 0430:00 GMT without incident.

The tracking modes and periods for DSS 12 during the third pass are listed below.

Mode	Period, GMT
3-way, SCM–maser	From [illegible]08:30 to 2100:00
3-way, SCM–maser	From 2100:00 to 0430:01
3-way, SCM–maser	From 0430:01 to 0705:31

Nine command transmissions were successfully made during the third pass; these are identified in the list of Table 32.

Communication conditions were considered adequate, and tracking and telemetry data conditions were good. The bit rate for the pass was 512 bits/s. The performance of DSS 12 was satisfactory.

k. Tidbinbilla (DSS 42), pass 004. Spacecraft acquisition for the fourth pass was achieved in the 3-way mode at 0234:44 GMT on December 19. Autotracking began at 0238:40 GMT.

The tracking modes and periods for DSS 42 during the fourth pass are listed below.

Mode	Period, GMT
3-way, SCM–maser	From 0234:44 to 0430:00
2-way, SCM–maser	From 0430:00 to 1130:00
3-way, SCM–maser	From 1130:00 to 1350:00

During the pass, the DSS 42 backup 50-kW, 400-Hz power unit was repaired and reinstalled. Also, between 0928:00 and 1008:00 GMT, an outage occurred with the cable teletype system. The trajectory during the third pass deviated from predicts, as indicated by a 3-kHz shift when DSS 51 participated in the 3-way mode.

Four command transmissions (two commands, each repeated) were made without difficulty. (See DSS 42 command list, Table 33.)

l. Johannesburg (DSS 51), pass 004. Spacecraft acquisition for the fourth pass was achieved in the 3-way mode by DSS 51 at 1029:53 GMT, December 19. Autotracking began at 1029:54 GMT. Transponder operation was transferred from DSS 42 at 1130:00 GMT.

The tracking modes and periods for DSS 51 during the fourth pass are listed below.

Mode	Period, GMT
3-way, SCM–maser	From 1029:53 to 1130:00
2-way, SCM–maser	From 1135:50 to 2100:00
3-way, SCM–maser	From 2108:50 to 2203:15

The computer did not respond to an F-68 request initiated at 1501:51 GMT, but a subsequent request (1502:15 GMT) was successful. All communications were good, and the station performed well during the pass. The commands initiated previously by DSS 42 were repeated successfully. (The identification and times of initiation are listed in Table 31.)

m. Goldstone (DSS 12), pass 004. The spacecraft was acquired for the fourth DSS 12 pass at 2004:42 GMT on December 19. Acquisition was made in the 3-way mode (SCM–paramp). Autotracking began at 2006:05 GMT. Transponder transfer (from DSS 51) was made without difficulty. (Table 30 lists the major tracking particulars.)

The tracking modes and periods for DSS 12 during the fourth pass are listed below.

Mode	Period, GMT
3-way, SCM–paramp	From 2004:42 to 2100:00
2-way, SCM–paramp	From 2100:00 to 0300:01
3-way, SCM–paramp	From 0300:01 to 0318:10

No problems were encountered, although it was noted that the SCM–paramp klystron drew excessive plate current during countdown. Operation during the pass, however, was normal. Also, the TDS transmitter counter was incorrect during the 26-min period from 2000:00 to 2026:00 GMT, December 19.

Two commands (Experiment D) were successfully initiated by DSS 12 during the fourth pass.

Voice and data conditions during the pass were good. The data-bit rate was 512 bits/s. Station performance was degraded somewhat by unavailability of real-time data printouts. (The station was originally set up for storage mode by network control, but it was later converted to real-time data processing to allow quick-look checks.)

2. ***Received-signal levels.*** The most serious anomaly in the telemetry and command system occurred from 0835 to 0922 GMT, December 16. At 0835, the strength of the signal received by the ground receiver began to decrease rapidly, causing concern that either the spacecraft transmitting system was failing or that the spacecraft attitude had so changed that the signal was in the direction of small antenna gain. By 0836, the signal had weakened to such an extent that the computer lost lock; a period of *lock* and *lost word/frame sync* teletype printouts continued until 0846 GMT, indicating erratic behavior of the communication system.

A possible spacecraft misorientation suggested that the planned activities at DSS 51 for the partial Type II orientation maneuver proceed, so an orientation command was transmitted. Concurrent with reduced signal strength, a teletype status printout indicated that a signal was present in both spacecraft receivers. This condition continued until the spacecraft began to receive the command message (0846 GMT), at which time the signal-present indication in the second receiver disappeared and the signal strength at the ground receiver began to increase. Upon termination of the command message, spacecraft receiver 2 indicated presence of a signal again, and the behavior of the communication system became erratic.

Between 0846 and 0922 GMT, several spacecraft commands were transmitted, and on each occasion the system operated as described above. It was obvious that the two phenomena were related. It was diagnosed that the condition resulted from the manner in which the spacecraft communication system operated when in the coherent mode. Two alternatives appeared possible: (1) command the spacecraft to operate in the noncoherent mode or (2) reduce the strength of the ground-transmitted signal so that the strength of the signal into receiver 2 would be reduced to less than its threshold. The former was undesirable because it would eliminate two-way doppler metric data during a critical tracking period. The latter was possible because the signal into receiver 1 was sufficiently strong. Furthermore, the results of a ground-signal spectrum analysis became available, which showed sidebands near the frequency of spacecraft receiver 2 sufficiently strong to activate the receiver when the ground transmitter was operating at full power (but not modulated by a command message). When modulated, the strength of the carrier signal at the spacecraft was reduced approximately 4 dB, so that the strength of the sideband frequency was less than the threshold of receiver 2. The power of the ground transmitter was reduced from 10 to 2.5 kW at 1020 GMT. The transmitter was operated at several other power levels until, at 1510 GMT, it was finally reduced to 300 W.

It is noted above that the anomaly did not commence until 0835 GMT, approximately 29 min after the ground transmitter was turned on. Further, the anomaly was not observed after 0922 GMT, about an hour before the transmitter power was reduced. An analysis of all engineering data transmitted from the spacecraft at this time (obtained from the later processing of the magnetic tapes recorded at DSS 51) showed that the difference between the operating and rest frequencies for receiver 1 was, in general, as follows:

(1) Before 0835 GMT: −42 to +10 kHz.

(2) From 0835 to 0922 GMT: +13 to 15 kHz.

(3) After 0922 GMT: greater than 18 kHz.

The accuracy of these measurements is ±1.5 kHz for negative values and ±1.3 kHz for positive values. Presumably, the frequency of the signal at receiver 2 relative to its rest frequency varied in the same manner. Because of the weakness of the signal, lockup occurred only when the received frequency was very close to the rest frequency and was not changing at a significant rate. When lockup of receiver 2 was first indicated in the telemetry data, the operating frequency was 3 kHz above the rest frequency, and remained at that value throughout the period of erratic behavior (except for several minutes when it increased to 10 kHz above).

3. ***Commands.*** The first command was transmitted to the spacecraft at 0810 GMT, December 16. The command monitor receiver at DSS 51 was not used at this time because of difficulties associated with the large rate of change of doppler. Thus, the transmitted command signal could not be checked against the manually inserted command number. The remainder of the command and telemetry systems performed correctly, however, and execution of the command by the spacecraft was verified by the teletype status printout at 0811. At 1309 GMT, the command monitor receiver was placed in operation when the rate of change of doppler was small; thereafter, the command message could be checked.

All command sequences were performed in a satisfactory manner.

During the first 200 days after launch, 3189 spacecraft commands were transmitted. There was a distribution of this total among 57 possible commands. Of the total, the largest number (1810) was used in calibrating or changing the operating ranges of the scientific instruments. The next largest number (1082) was used in changing the operating mode of the data system. This large activity is associated with use of the duty cycle store mode, which was used whenever *Pioneer VI* was not being tracked by the Deep Space Network. When switching to this mode, bit-rate commands were required to select the desired duty cycle. Also, upon completion of this mode as well as the telemetry store and Format D modes, the digital telemetry unit automatically switched to Format B at 16 bits/s. When the desired mode was different from that obtained automatically, commands had to be sent to change it. The primary mode of operation of the data system when the Deep Space Network was tracking was a function of the distance between the spacecraft and earth. In general, the modes (for tracking by DSS 12) conformed to those shown in Table 34.

Table 34. Format identification and operating log

Format	Bit rate, bits/s	Period of operation
A	512	Dec. 16, 1965 to Feb. 28, 1966
A	256	Mar. 1, 1966 to Mar. 17, 1966
B	64	Mar. 18, 1966 to Apr. 13, 1966
B	16	Apr. 14, 1966 to May 9, 1966
B	8	May 10, 1966 and thereafter

During the attitude maneuvers previously discussed, 282 commands were transmitted to turn the orientation electronics on and off and to operate the gas valve. The coherent mode was the prime transmission mode throughout the 200 days; the noncoherent mode was used for brief periods during the orientation and test periods. To effect these changes, 19 commands were required.

The performance of the command link from the ground station to *Pioneer VI* cannot be defined in the same detail as can the performance of the telemetry link because only limited measurements could be made on the spacecraft receiver. In addition, since large amounts of communication power were available from the ground station, near-threshold conditions were obtained only once during normal operations (at the time that it was necessary to switch spacecraft receiver 2 from the low- to the high-gain antenna). Because the low-gain antenna is considerably less directional than the high-gain antenna, the former was used for the command link for as long as possible as a precaution against loss of command signal should there be an inadvertent attitude change.

The telemetry measurements on *Pioneer VI* relating to the command link included the carrier power and the phase-lock loop stress of the spacecraft receiver. The status of the antenna switch and an indication of a signal in either receiver were also provided in the telemetry data. The indication of spacecraft receiver loop stress was used as a real-time operational aid for the ground transmitter operator.

Presented in Fig. 56 are telemetry measurements of the total power input to spacecraft receiver 2 for a 10-kW output from the ground station transmitter. Data included are based upon operations with DSS 12 only; no differences were evident between these data and those from DSSs 42 and 51. The measurements for the first 3 mo of the flight are not shown because, during this period, the ground station transmitter power was adjusted to provide an aribitrary signal level in the spacecraft receiver between −128 and −132 dBm. As in the case of other telemetry measurements, changes in power were telemetered as discrete steps. The instrumentation aboard the spacecraft actually provided an indication of carrier power; however, the data of Fig. 56 were obtained during periods of command inactivity, when no modulation of the carrier power was present, and hence represent total power input to the receiver.

The two solid lines on Fig. 57 represent the total power that would have been obtained with "typical" ground station and spacecraft performance for the low- and high-gain spacecraft antennas. These "typical" performance lines are based upon the following values for pertinent parameters:

Parameter	Value
Ground transmitter power (10 kW), dBm	70.0
Ground transmitter antenna gain, dB	51.0
Ground transmitting circuit losses, dB	−0.4
Polarization loss, dB	−3.0
Spacecraft low-gain antenna gain, dB	−0.6
Receiving circuit losses, dB	−0.5
Spacecraft high-gain antenna gain, dB	10.5
Receiving circuit losses, dB	−1.5

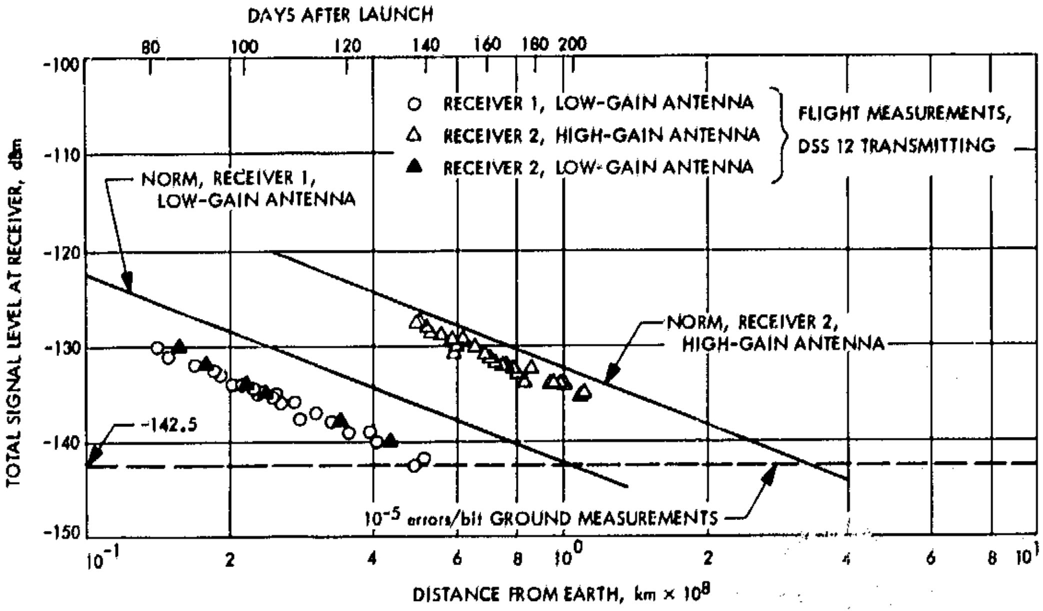


Fig. 56. Telemetry measurements of total power received at *Pioneer VI* spacecraft receivers

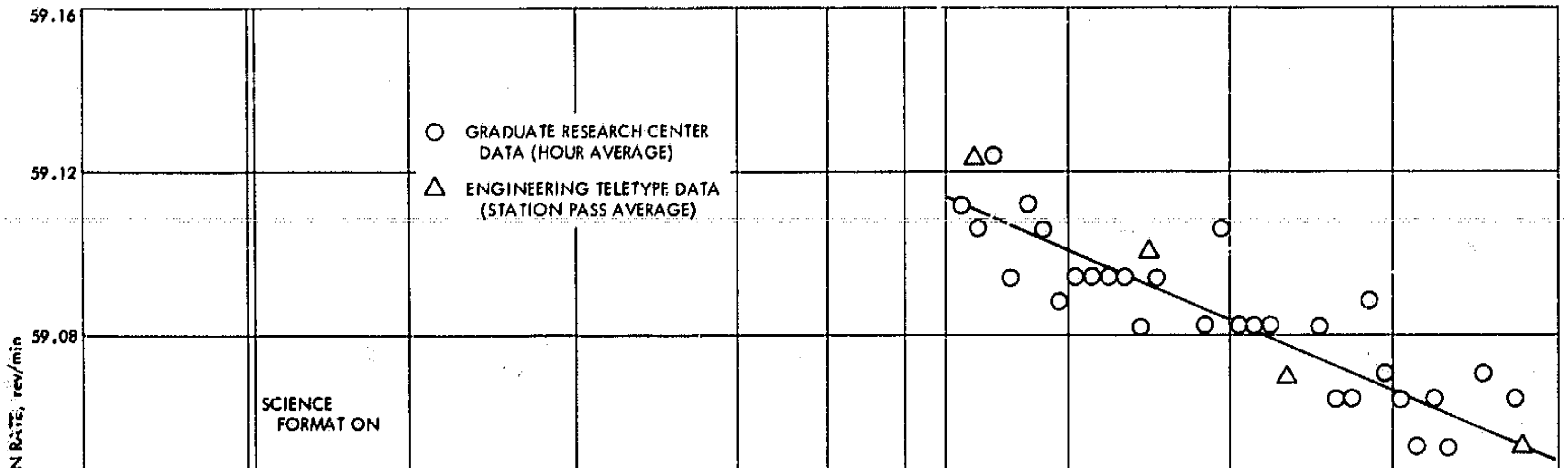


Fig. 57. Variation of spin rate with time for early portion of flight

The power measurements with the receiver on the low-gain antenna indicated a mean value approximately 5 dB less than the norm throughout the time of measurements. This difference was greater than the expected tolerances in the system. Perhaps it was due to a deterioration of the system before the time that the first data were obtained. This possibility was considered remote, however. More likely, the difference was due to inaccuracies in the calibration of the received signal strength and to additional losses within the spacecraft communication system (using the low-gain antenna) not considered in the above listing. These possibilities seemed reasonable because the measured results with the receiver on the high-gain antenna were within 1 dB of the estimated value.

The threshold value for an error rate of 10^{-5} was obtained from preflight ground measurements of total power input to the spacecraft receiver in relation to bit-error rate from the spacecraft decoder. The data indicate that, just before the receiver was switched to the high-gain antenna, the probable per-bit error rate was less than 10^{-5}. No evidence of a command not being accepted by the spacecraft (or the generation of a false command) was obtained during this period.

The probability of false commands was low because an affirmative check of the 7 bits of the command with those of the command complement was required on the spacecraft before execution of the command. As previously noted, problems were encountered on several occasions when transmitting to the spacecraft. The first occasion was during the initial acquisition at DSS 51.

Several times, later in the mission, difficulties were encountered when attempting to acquire the spacecraft receivers with the signal transmitted from the ground. These difficulties were associated with establishing the proper frequency of the ground transmitter. Complicating factors were long communication transit times, slow return of the spacecraft receiver to its rest frequency following operation with a stressed phase-lock loop, and a significant effect of temperature on the rest frequency of the spacecraft receiver. The difficulties were overcome with procedural changes that gave proper consideration to the complicating factors.

4. Telemetry. An indication of the power received at the stations was obtained at DSS 12 at the carrier frequency from measurements of the voltage developed for automatic gain control (AGC) by the ground station receiver. Calibrations of the AGC voltage as a function of known power levels, made before each station acquisition, provided the relationship between AGC voltage and received carrier power. The received carrier power values thus measured at DSS 12 for the first 200 days of flight are presented in Fig. 58. The data are values averaged only for a period of several hours near the maximum elevation angle of the ground antenna as it tracked the spacecraft, as an appreciable decrease in carrier power was evident near the horizon. The solid line on Fig. 58 is the carrier power corresponding to "typical" spacecraft and ground station performance norms. These norms are based upon the values for pertinent spacecraft and ground-equipment parameters (see Table 24). For the radiated frequency for *Pioneer VI* and distance d (in kilometers), the space attenuation (in dB) is as follows: $-99.6 - 20 \log_{10} d$. Hence, the solid line is an estimate of the ground-received carrier power, with all factors constant except space attenuation. In general, the data agree with the estimate, although differences of as much as several decibels were present.

One factor not considered in the estimate shown in Fig. 58 is the variation of spacecraft antenna gain that is caused by the change with time of the angle between the spacecraft spin axis and the line of sight from the ground station to the antenna (earth look angle). Because of the trajectory and the spacecraft attitude established upon completion of the Type II orientation (181.3 deg), some variation of spacecraft antenna gain would be expected. The measurements of carrier power made by the Deep Space Stations with *Pioneer VI* have been adjusted for the estimated effect of earth look angle on antenna gain, and compared with the normal carrier power discussed above. The increments between the adjusted carrier power and the normal carrier power are shown in Fig. 59 for nearly all of the tracking periods for *Pioneer VI* by the DSN. The same general values were used for the performance of each ground station, so that differences between the data for the various stations would be expected as a result of differences in the performance of the equipment or calibration accuracies at the various stations. Even considering that fact, however, it is difficult to distinguish any general trends in the data that are consistent for all stations and that would, therefore, be indicative of spacecraft performance.

Jet Propulsion Laboratory has maintained a continuing program to improve the accuracy of signal-strength measurements by the Deep Space Stations. The best calibration information available (Y factors, in JPL terminology) were applied to the carrier-power measurements

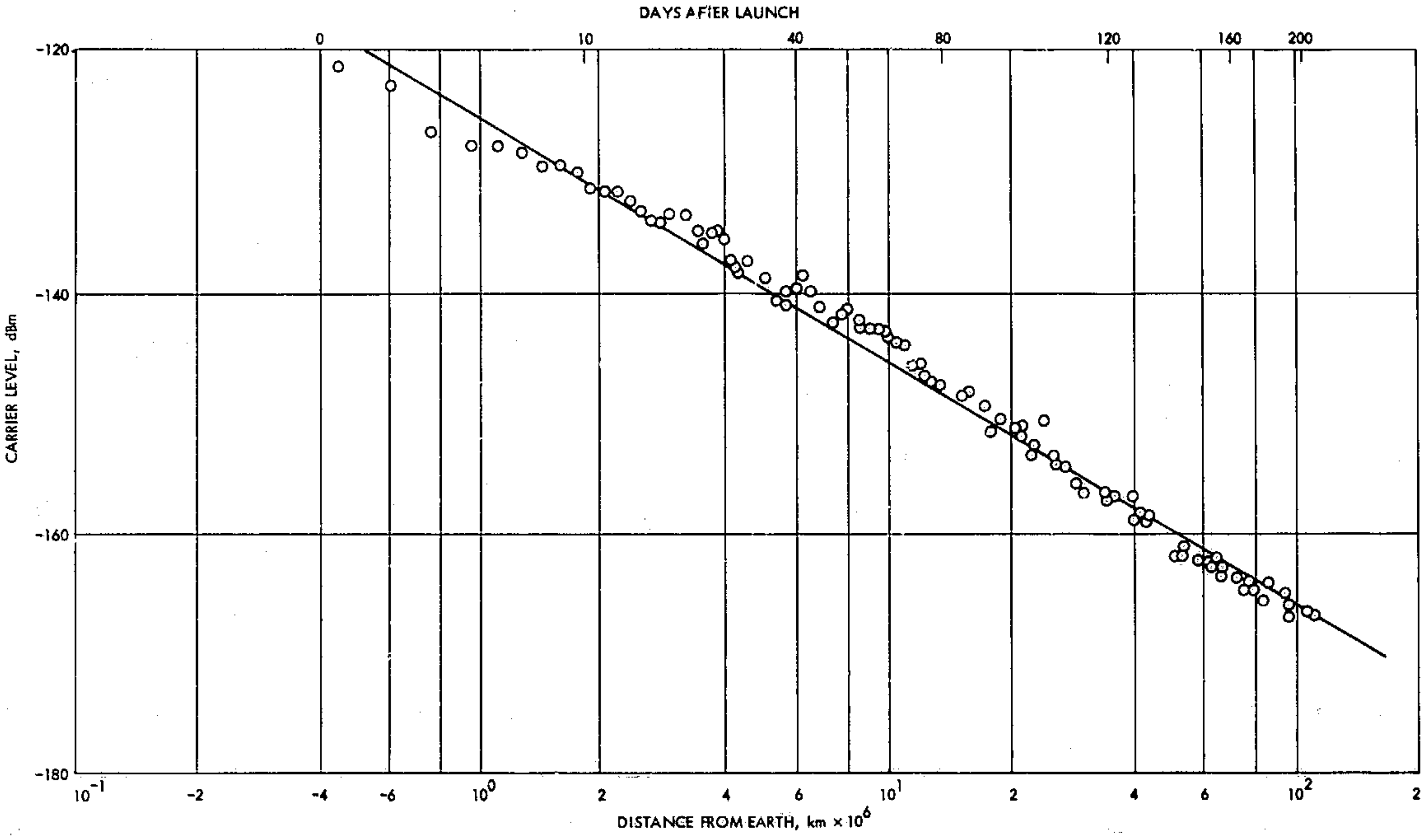


Fig. 58. Carrier power from *Pioneer VI* reported by DSS 12

of DSS 12 from *Pioneer VI* for the period from 40 to 155 days after launch. The difference between these recalibrated values of carrier power, adjusted for the estimated effect of earth look angle on spacecraft antenna gain, and the "typical" values of carrier power discussed above, is shown in Fig. 60. The data in Fig. 60 are the same as those in Fig. 59 for DSS 12, except that the additional calibration factors have been applied. Hence, Fig. 60 should provide the best indication of real trends in spacecraft carrier power with time.

These results indicated a gradual decrease in the mean carrier power of about 1.5 dB between 40 and 155 days after launch. Nevertheless, there was sufficient dispersion in the data so that the possibility of no change in spacecraft performance cannot be discounted.

Measurements of TWT anode voltage, cathode current, and helix current—the only measurements on the spacecraft related to the performance of the spacecraft transmitter—are presented in Fig. 61 for the first 200 days of flight. Temperatures were measured near the TWT power amplifiers. The horizontal lines at a constant value represent telemetry readings obtained on consecutive days. The vertical lines represent the range of telemetry readings obtained on those days. The anode voltage and cathode current were, effectively, constant throughout the 200-day period. The helix current, however, showed a slow but continuous rise from 7.00 to 7.75 mA for this same period. These values are well within the normal operating range; however, the reason for the change in helix current is not known. This change may be evidence of a gassy tube, which would lower the power output (and might be related to the apparent decrease of carrier power discussed in relation to the data in Fig. 60).

a. Threshold. One parameter that determines the threshold of the ground receiver for acquiring the carrier signal from the spacecraft is the receiver noise spectral density, which is dependent upon system noise temperature. (This relationship for the range of operational temperatures of the Deep Space Stations is given in Fig. 62.) The Deep Space Stations measure the system noise temperature before and after each tracking period with the antenna pointing toward the zenith. The results of these measurements for all *Pioneer VI* tracking periods (by DSS 12, which provided the greatest coverage) are presented in Fig. 63. For the first 90 days of the flight,

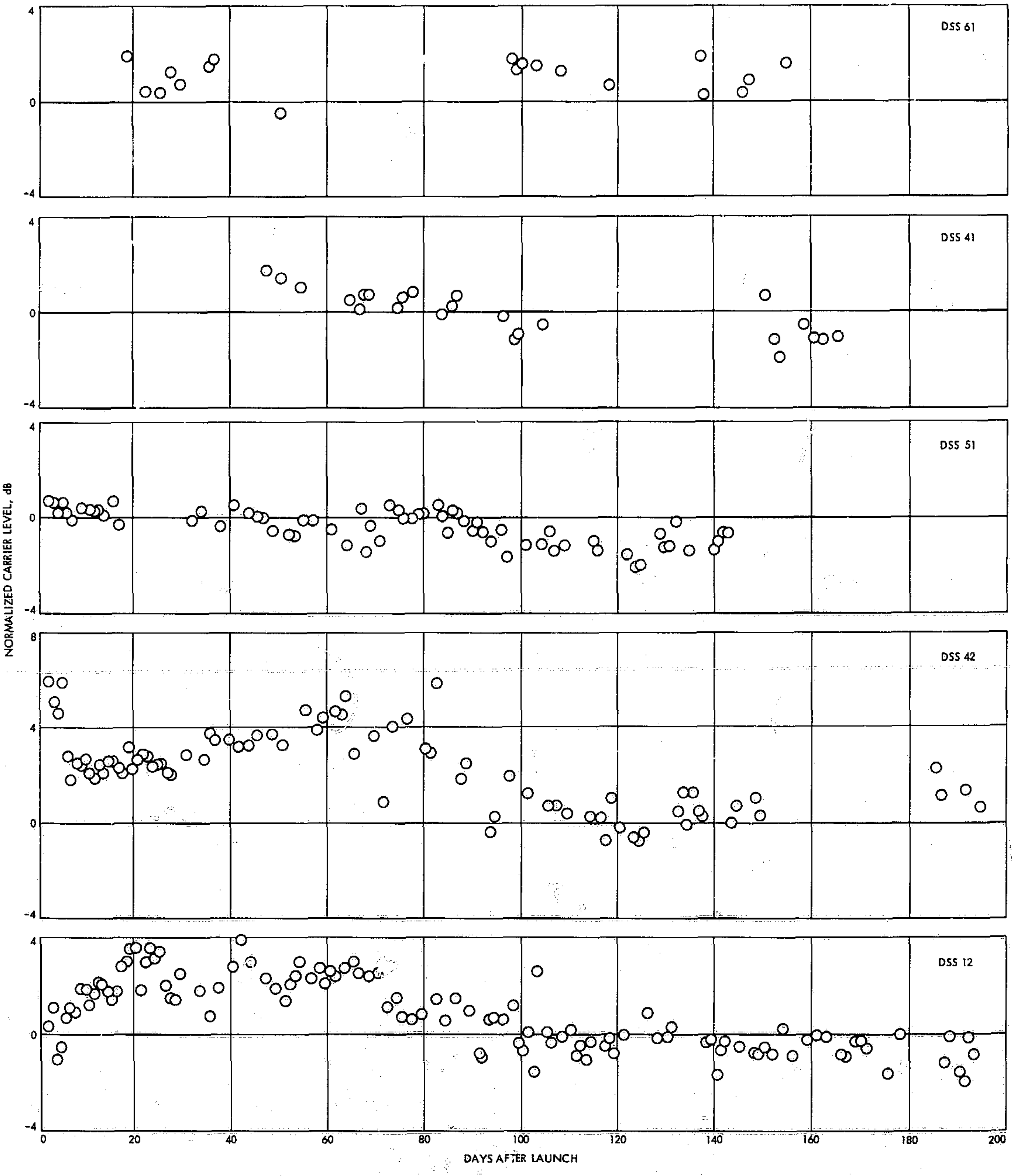


Fig. 59. Normalized carrier level from *Pioneer VI* for DSSs 12, 42, 51, 41, and 61

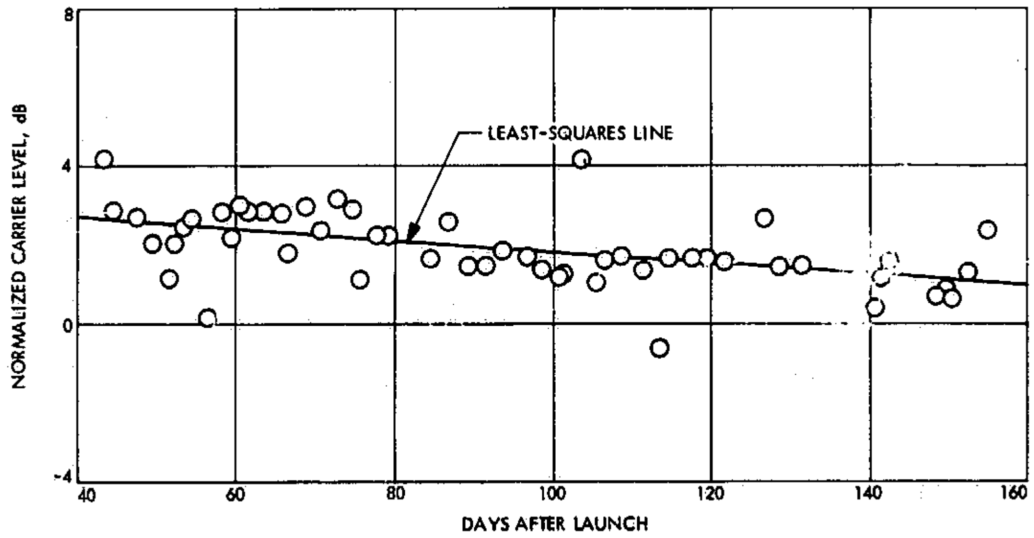


Fig. 60. Normalized carrier power from *Pioneer VI* for DSS 12 with additional calibration refinements

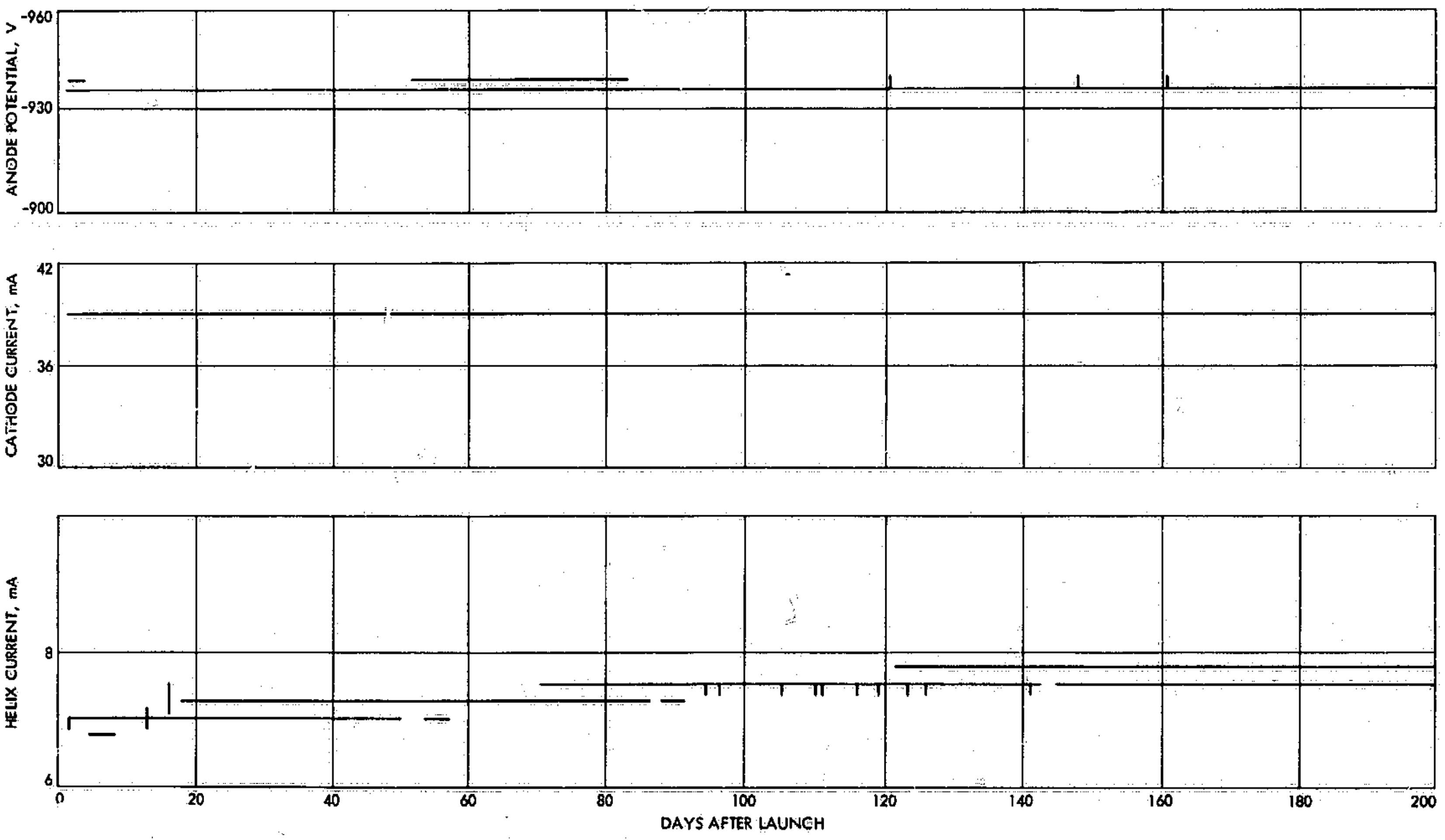


Fig. 61. Telemetry measurements of traveling-wave tube power amplifier parameters

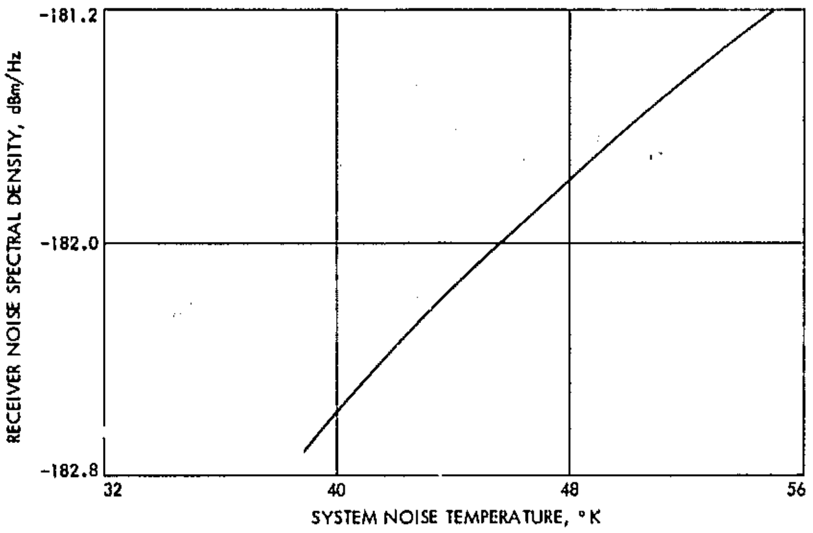


Fig. 62. System noise temperature vs receiver noise spectral density

the system noise temperatures were usually around 43°K, and differences between prepass and postpass measurements were rarely greater than 2°K. During the next 90 days, however, the temperatures were frequently around 50°K, and the differences between prepass and postpass measurements were often greater than 3°K. Reading variations of ±1.5°K between prepass and postpass calibrations, and between successive days, may be accounted for by variations of such factors as galactic noise, atmospheric noise, relative position of the sun and moon with respect to the ground antenna, and differences in operator techniques. Operator technique alone can account for reading variations of ±0.5°K Variations of greater than ±1.5°K probably indicate equipment deterioration, maladjustment, or malfunction.

Efforts to reduce the system noise temperature at DSS 12 were successful; consequently, from an average of 45.3°K at $L+178$ days, the system noise temperature decreased to 38.3°K at $L+193$ days. The carrier-power thresholds corresponding to these temperatures, and for a noise bandwidth of 12 Hz for the phase-lock loop and a signal-to-noise ratio in the loop of 6 dB, are −165.3 and −166.0 dBm, respectively. This improvement of −0.7 dB in threshold can significantly affect the maximum range for maintaining carrier lock and the quality of the data as the communication distance approaches the range limits for the various data-bit rates.

b. Bit-error rates. For bit rate and other factors constant, the error rate in the data at the output of the demodulator–synchronizer increases as the strength of the data subcarrier reduces at the ground station. In addition, the required signal strength for a constant error rate is proportional to the bit rate. Considering the general trend in performance of the communication system, the strength of the carrier signal reduced continuously as the distance of the spacecraft increased; the strength of the data subcarrier reacted similarly. Thus, during the mission, the error rate in the data would (1) increase with time, (2) exceed the desirable value, and (3) be reduced by commanding the spacecraft to operate at the next lower of the five available bit rates.

The error rate in the telemetry data obtained at DSS 12 during three tracking periods near the time at which the rate exceeded the desirable value is presented in Fig. 64 for each of the five bit rates. The error rate is expressed as ERR reading, which is the number of parity errors in a 32-word frame averaged for a specified time interval dependent upon the bit rate. This rate assessment is performed continuously by the computers at the Deep Space Stations, and immediately teletyped to the mission controllers at the end of each time interval. The ERR reading is statistically related to the bit-error rate Pe by

$$Pe = 0.00862 \text{ ERR}$$

The tracking periods covered by the data are identified by the pass number, which is the number of times since launch that the spacecraft was above the horizon of a particular station.

The ERR readings show a considerable dispersion, particularly at the lower bit rates. Consistent trends are discernible, however. For example, near the beginning and end of each pass, the error rates were considerably higher than those during the middle of the pass. (Previous statements referring to the general trend in communication performance are restricted to these latter data.) This characteristic is probably caused by ground reflections or an increase in atmospheric noise when the ground antenna is pointing near the horizon. Because of this characteristic, it was frequently necessary to reduce the bit rate near the beginning and end of a pass to obtain usable telemetry data.

The ERR reading that best represents the performance during the middle of each pass is indicated by the horizontal lines in Fig. 64. These values, together with others obtained in a similar fashion for all tracking periods by DSS 12 when the ERR reading was significant, are shown in Fig. 65. Similar data for the other Deep Space Stations, as well as DSS 12, are shown in Fig. 66. In both Figs. 65 and 66, the average ERR reading is shown in relation to

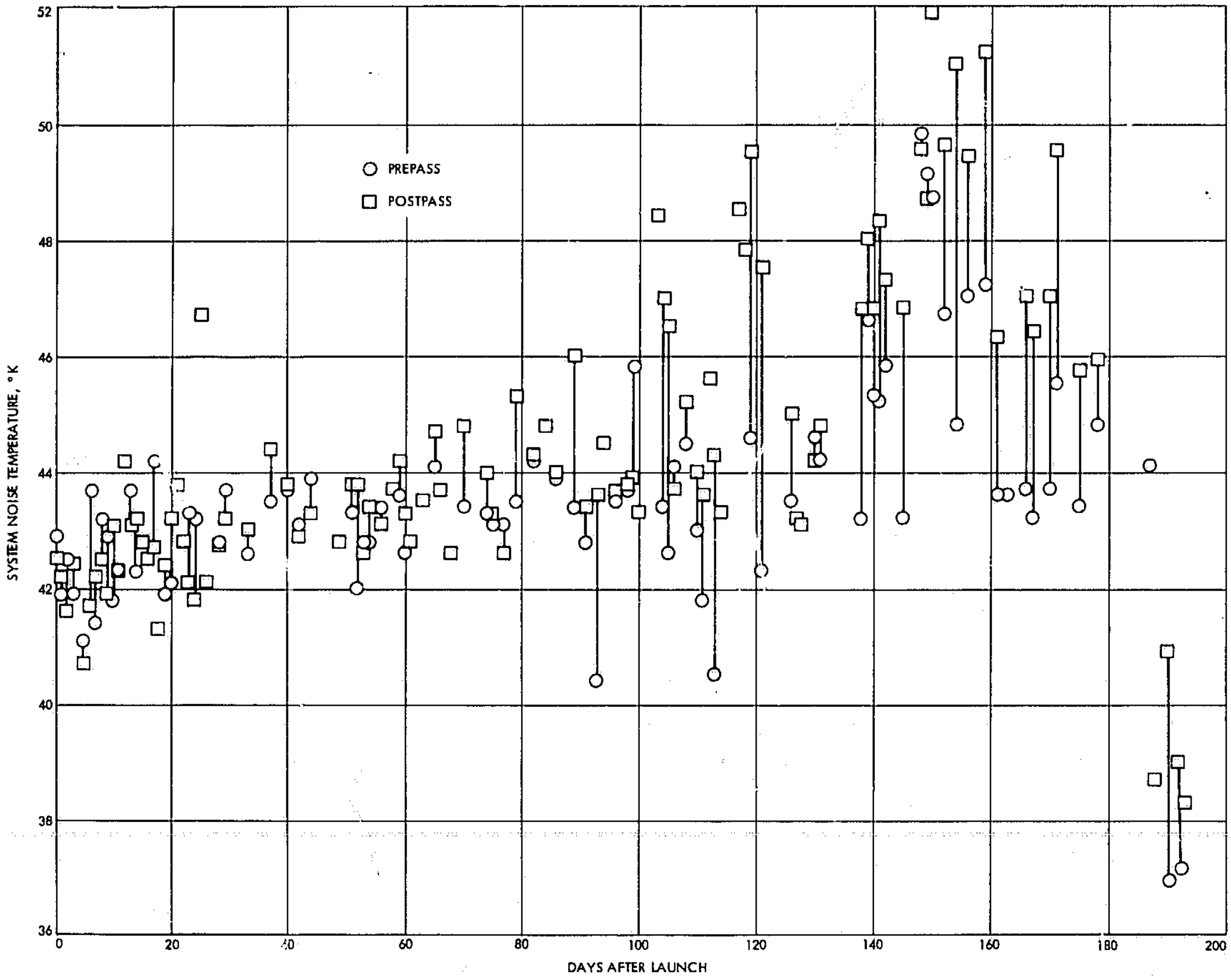


Fig. 63. Variation of system noise temperature at DSS 12 during early part of *Pioneer VI* mission

the distance of *Pioneer VI* from the ground station at the time of the reading. The lines labeled *theoretical approximation* represent the best fit of the theoretical variation to the measured data. In general, the measured error rate closely follows the theoretical variation.

Attention is called to the fact that, for a given station and at the same bit rate, the ERR readings shown for commanded noncoherent operation were considerably less than those for coherent operation. A poorer performance in the coherent mode may be due to frequency jitter or noise that can be introduced into the telemetry carrier by the ground-transmitted signal and the voltage-controlled oscillator within the spacecraft receivers in this mode. Such disturbances are absent in the noncoherent mode. A portion of the difference shown for 8 bits/s with DSS 12, however, should be attributed to a change in system noise temperature. As stated, a 0.7-dB improvement in threshold was accomplished by a reduction in system noise temperature at DSS 12 between $L+178$ and $L+193$ days. The spacecraft-to-earth distance during this time increased from about 8.6×10^7 km to about 9.8×10^7 km; the 0.7-dB improvement in threshold would account for an increase in the communication range for a given error rate of about 7×10^6 km.

The communication range for *Pioneer VI* at the five available bit rates, an error rate of one error per thousand

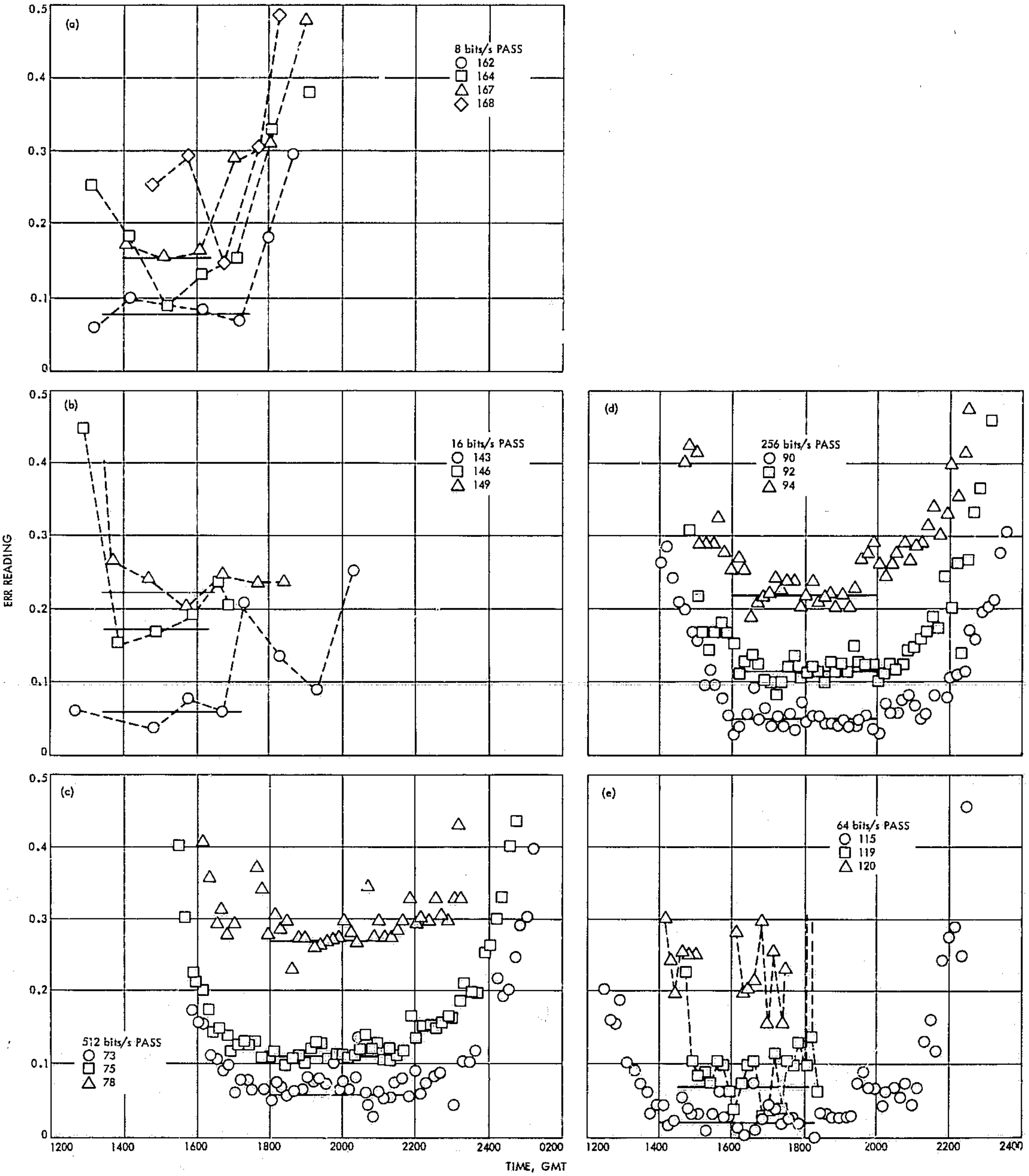


Fig. 64. Real-time indication of telemetry bit-error rate at DSS 12 for *Pioneer VI* near communication limits

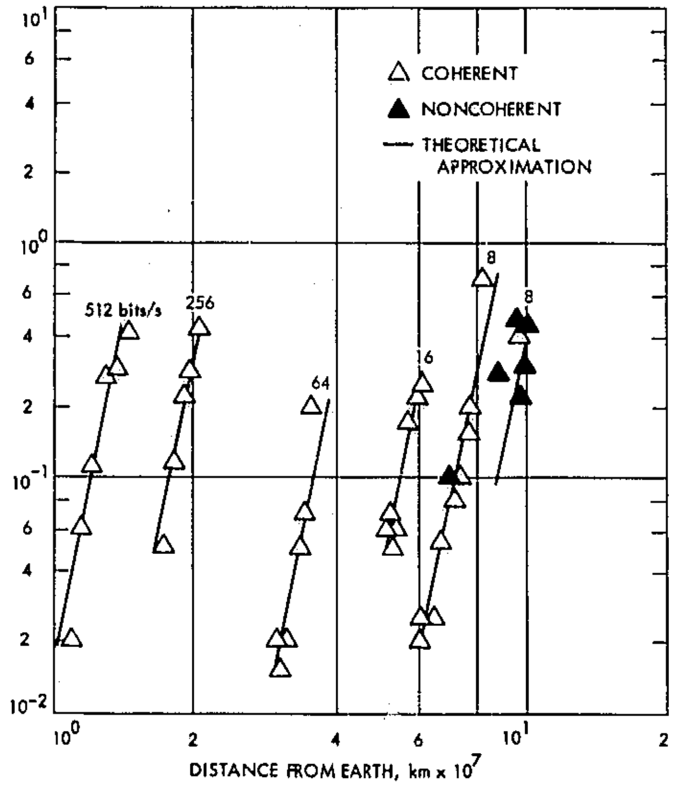


Fig. 65. Variation of average ERR readings at DSS 12 with communication distance for *Pioneer VI*

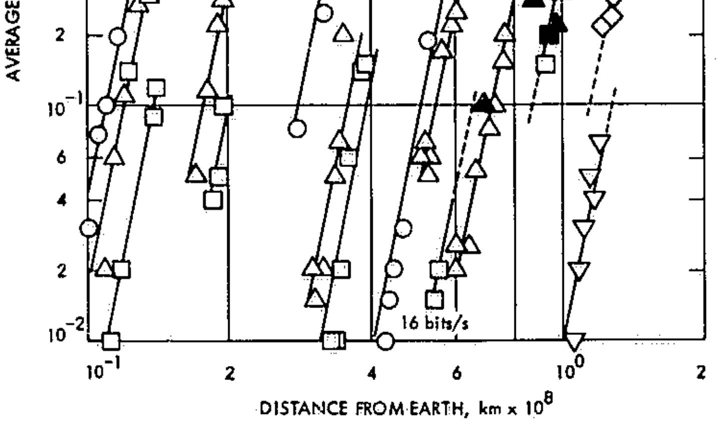


Fig. 66. Variation of average ERR readings at various Deep Space Stations with communication distance for *Pioneer VI*

bits, and in the coherent mode, is summarized in Fig. 67. For comparison, the normal communication limits are also presented; the solid line includes the effects of space attenuation as the only variable and the broken line includes the estimated receiver losses and degradation. The data agree with the latter estimation except at a bit rate of 16 bits/s. This difference was perhaps caused by a system noise temperature (see Fig. 63) about 6°K higher in the period around May 9, 1966 ($L+145$ days) than the value used for the normal limits, which is more representative of overall performance.

At about the time that *Pioneer VI* was approaching the limiting distance for communication at 8 bits/s using the 85-ft ground antennas, DSS 14 with its 210-ft antenna was being tested, and was used to track the *Pioneer VI* spacecraft. The station could obtain good spacecraft data at that time at a bit rate of 64 bits/s, which indicated at least a 9-dB improvement in performance over that for the other Deep Space Stations. The error-rate measurements for DSS 14 are also shown in Fig. 66 for a data-bit rate of 64 bits/s. The data for DSS 14 for 64 bits/s and an error rate of one error per thousand bits (see Fig. 67) show that DSS 14 extended the range capability for 64 bits/s from 3.3×10^7 to 1.1×10^8 km, an effective gain of about 10.5 dB. The largest portion of this gain is attributed to the greater antenna capture area; the remainder is attributed to a considerable improvement in system noise temperature (29°K) and other ground system performance elements. Figure 67 gives the distance limitations for telemetry from the *Pioneer VI* spacecraft. Figure 68 shows the effect of proximity of *Pioneer VI* to the earth–sun line upon telemetry data-error rate.

5. Space Flight Operations Facility. Shortly after launch, and for the following several weeks (excluding periods when the Type II orientation was being directed from DSS 51 or DSS 12), the *Pioneer VI* mission was controlled from the SFOF at JPL. This facility contained various communication and display equipment arranged to meet the needs of *Pioneer* flight operations.

The television monitors and camera in the mission control area were part of a closed-circuit system at the SFOF used for surveillance of areas, display of teletype data and other information, time-code display, and visual intercommunications. Any of 132 television channels could be selected at the operations console monitors; any of 20 channels could be selected at the other monitors.

Voice communication was provided by a system composed of three integrated subsystems. The intercom

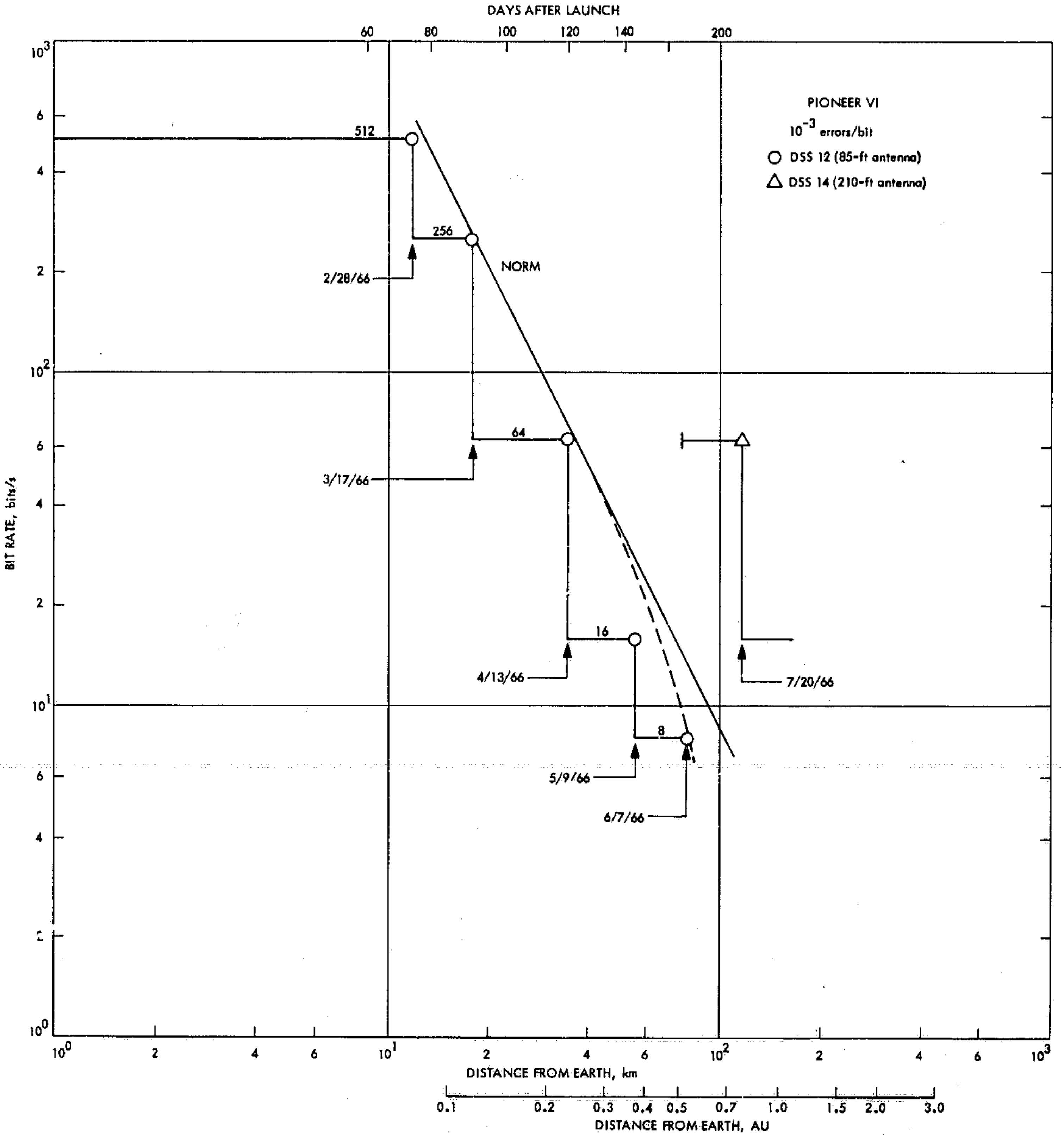


Fig. 67. Distance limitations for telemetry from *Pioneer VI*

subsystem was a means of voice communication within the SFOF. The telephone subsystem provided voice communication within the SFOF, with access to commercial telephone lines. The conference subsystem provided the primary means of communication within SFOF and the capability to monitor and participate in network conferences. Twelve separate networks could be used during the several hours before and after launch. These networks connected the *Pioneer* area with other areas within the SFOF, with the mission areas and real-time computer facility at Cape Kennedy Air Force Station, and with the three prime Deep Space Stations.

The teletype equipment consisted of four receive-only page printers, a send–receive unit, a tape reader, and two

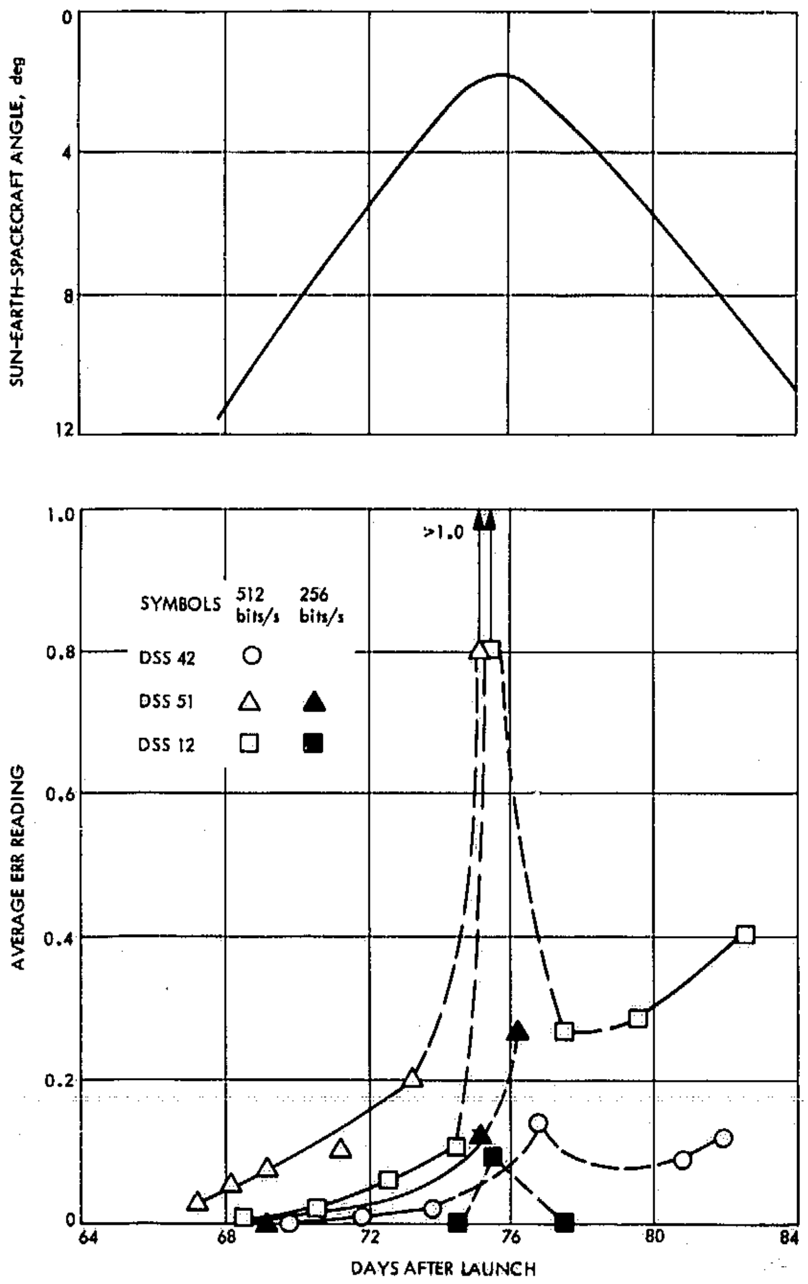


Fig. 68. Effect of proximity of *Pioneer VI* to earth–sun line on telemetry data error rate

typing reperforators. Each of the receive-only printers was equipped with a selector box that permitted the user to select any of 36 incoming teletype circuits.

The principal display, the *Pioneer* mission status board, was manually operated; it contained such information as spacecraft status and the values of selected engineering parameters that were received via teletype from Cape Kennedy before launch and from the Deep Space Stations following their respective acquisitions.

Approximately 4 wk after the *Pioneer VI* launch, direction of the mission was transferred from the *Pioneer* mission area at the SFOF to the *Pioneer* mission area at Ames Research Center. This change did not basically affect the method of flight operations because, in both cases, instructions from the mission area to the Deep Space Stations pertaining to spacecraft command activity, on-site data processing, and data transmission by teletype were relayed via voice and teletype by the DSN controller at the SFOF. The patching of voice and teletype circuits between the mission area and the Deep Space Stations was performed in the communications area at the SFOF. All tasks associated with orbital determination and preparation of predicts were performed at the SFOF.

The *Pioneer* mission area at ARC contained voice and teletype circuits that received data from (and directed commands to) the spacecraft and the Deep Space Stations. The teletype equipment installed in the mission area consisted of three receive-only page printers, a send–receive unit, a tape reader, and two reperforators. Any of the four incoming lines could be connected to any of the receivers and to a receiver at Stanford University (for use when that facility was transmitting to the Stanford instrument aboard the spacecraft).

A Dataphone was also installed so that a portion of the data from the University of Chicago experiment received via teletype could be retransmitted to the computer at the university for data processing. Voice communication consisted of a SCAMA (signaling, conferencing, and monitoring arranging) circuit between ARC and the SFOF, a commercial telephone circuit, and an additional telephone circuit operating through the central ARC switchboard. As at the SFOF, the principal display was the manually operated mission status board.

The mission support area at the SFOF was used for mission control during the initial phases of the mission except for critical orientation maneuvers. For *Pioneer VI*, the initial acquisition and partial orientation were directed from DSS 51, and the final orientation was controlled from DSS 12. The mission control site was at ARC during the deep space phase of the mission.

The mission support areas at the SFOF and at ARC both received in near-real-time via teletype from the tracking station, processed telemetry data for use in monitoring performance of the spacecraft and scientific instruments, and as an aid in planning mission operations. The ARC facility also received all of the telemetry data that are recorded on magnetic tape. Special- and general-purpose equipment at ARC was used to process the data, which were then shipped to the appropriate users.

Glossary

AFB	Air Force Base
AFETR	Air Force Eastern Test Range
AGC	automatic gain control
ARC	Ames Research Center
CCF	Central Computing Facility
CEC	Consolidated Electrodynamics Corporation
DIS	digital instrumentation system
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
DSS	Deep Space Station
EGSE	electronic ground support equipment
ERR	average number of parity errors in a 32-word data frame averaged for a specified time interval dependent on bit rate
FM	frequency-modulated
FPAC	flight-path analysis and command
FPR	failure probability report
GBI	Grand Bahama Island
GCF	Ground Communications Facility
GM	ground mode
GOE	ground operational equipment
GSE	ground support equipment
GSFC	Goddard Space Flight Center
HA	hour angle
IBM	International Business Machines
JPL	Jet Propulsion Laboratory
L	launch (plus time)
MECO	main engine cutoff
MIT	Massachusetts Institute of Technology
MOS	Mission Operations System
MSFN	Manned Space Flight Network
NASCOM	NASA Communications Network
NRZ-C	nonreturn-to-zero computer
OSSA	Office of Space Services and Applications
PDM	pulse-duration-modulated
PMSA	*Pioneer* mission support area
RFI	radio-frequency interference
RTFC	Real Time Computing Facility
RWV	read–write–verify
SAA	S-band acquisition aid (antenna)
SCAMA	signaling, conferencing, and monitoring arranging
SCM	S-band cassegrainian monopulse
SECO	sustainer engine cutoff
SFOD	Space Flight Operations Director
SFOF	Space Flight Operations Facility
SRO	supervisor of range operations
STADAN	Space Tracking and Data Acquisition Network
STL	Space Technology Laboratories (now TRW)
T	liftoff time (plus time)
TDS	Tracking and Data System
TRW	Thompson Ramo Wooldridge, Inc. (formerly STL)
TWT	traveling-wave tube
USB	upper sideband
VCO	voltage-controlled oscillator
WECO	Western Electric Company

Bibliography

Anderson, J. D., *Determination of the Masses of the Moon and Venus and the Astronomical Unit From Radio Tracking Data of the Mariner II Spacecraft,* Technical Report 32-816. Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1967.

Berman, A. L., *Tracking System Data Analysis Report, Ranger VII Final Report,* Technical Report 32-719. Jet Propulsion Laboratory, Pasadena, Calif., June 1, 1965.

Cain, D. L., and Hamilton, T. W., *Determination of Tracking Station Locations by Doppler and Range Measurements to an Earth Satellite,* Technical Report 32-534. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1, 1964.

Hamilton, T. W., et al., *Ranger IV,* Technical Report 32-345. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1962.

Lorell, J., and Sjogren, W. L., *Lunar Orbiter Data Analysis,* Technical Report 32-1220. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1967.

McNeal, C. E., *Ranger V Tracking Systems Data Analysis Final Report,* Technical Report 32-605. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1965.

Melbourne, W. G., et al., *Constants and Related Information for Astrodynamical Calculations,* Technical Report 32-1306. Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1968.

Miller, L., et al., *Atlas–Centaur VI,* Technical Report 32-911. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1966.

Mulholland, J. D., and Sjogren, W. L., *Lunar Orbiter Ranging Data,* Technical Report 32-1087. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 6, 1967.

Muller, P. M., and Sjogren, W. L., *Consistency of Lunar Orbiter Residuals With Trajectory and Local Gravity Effects,* Technical Report 32-1307. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1968.

Muller, P. M., and Sjogren, W. L., *Lunar Mass Concentrations,* Technical Report 32-1339. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 16, 1968.

Null, G. W., Gordon, H. J., and Tito, D. A., *Mariner IV Flight Path and Its Determination From Tracking Data,* Technical Report 32-1108. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 1, 1967.

Pease, G. E., et al., *Mariner V,* Technical Report 32-1363. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 1969.

Renzetti, N. A., *Tracking and Data Acquisition for Ranger Missions I–V,* Technical Memorandum 33-174. Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1964.

Renzetti, N. A., *Tracking and Data Acquisition for Ranger Missions VI–IX,* Technical Memorandum 33-275. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1966.

Bibliography (contd)

Renzetti, N. A., *Tracking and Data Acquisition Support for the Mariner Venus 1962 Mission,* Technical Memorandum 33-212. Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1965.

Renzetti, N. A., *Tracking and Data Acquisition Report, Mariner Mars 1964 Mission: Volume I. Near-Earth Trajectory Phase,* Technical Memorandum 33-239. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 1, 1965.

Renzetti, N. A., *Tracking and Data Acquisition Report, Mariner Mars 1964 Mission: Volume II. Cruise to Post-Encounter Phase,* Technical Memorandum 33-239. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 1, 1967.

Renzetti, N. A., *Tracking and Data Acquisition Report, Mariner Mars 1964 Mission: Volume III. Extended Mission,* Technical Memorandum 33-239. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1968.

Renzetti, N. A., *Tracking and Data System Report for Surveyor, Volumes I Through V, for Missions I Through VII,* Technical Memorandum 33-301. Jet Propulsion Laboratory, Pasadena, Calif. (to be published).

Renzetti, N. A., *Tracking and Data System Report for Mariner Venus 1967: Volume I. Planning Phase Through Midcourse, Volume II. Midcourse Through End of Mission,* Technical Memorandum 33-385. Jet Propulsion Laboratory, Pasadena, Calif. (in preparation).

Sjogren, W. L., *The Ranger III Flight Path and Its Determination From Tracking Data,* Technical Report 32-563. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 15, 1965.

Sjogren, W. L., et al., *Physical Constants as Determined From Radio Tracking of the Ranger Lunar Probes,* Technical Report 32-1057. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 30, 1966.

Sjogren, W. L., et al., *The Ranger VI Flight Path and Its Determination From Tracking Data,* Technical Report 32-605. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1964.

Sjogren, W. L., et al., *Ranger V,* Technical Report 32-562. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 6, 1963.

Sjogren, W. L., and Trask, D. W., *Physical Constants as Determined From Radio Tracking of the Ranger Lunar Probes,* Technical Report 32-1057. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 30, 1966.

Sjogren, W. L., *Proceedings of the JPL Seminar on Uncertainties in the Lunar Ephemeris,* Technical Report 32-1247. Jet Propulsion Laboratory, Pasadena, Calif., May 1, 1968.

Vegos, C. J., et al., *Ranger VIII,* Technical Report 32-766. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 30, 1965.

Vegos, C. J., et al., *Ranger IX,* Technical Report 32-767. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1, 1968.

Bibliography (contd)

Winn, F. B., "Selenographic Location of *Surveyor VI*," *Surveyor VI Mission Report: Part II. Science Results,* Technical Report 32-1262. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 10, 1968.

Winn, F. B., "Post Landing Tracking Data Analysis," in *Surveyor VII Mission Report: Part II. Science Results,* Technical Report 32-1264. Jet Propulsion Laboratory, Pasadena, Calif., Mar. 15, 1968.

Winn, F. B., "Post Lunar Touchdown Tracking Data Analysis," in *Ibid.*

Wollenhaupt, W. R., et al., *Ranger VII Flight Path and Its Determination From Tracking Data,* Technical Report 32-694. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1964.

NASA — JPL — Coml., L.A., Calif.