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Volume I

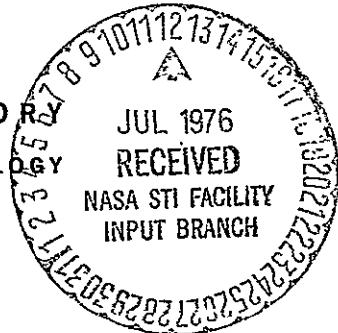
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for the Helios Project*

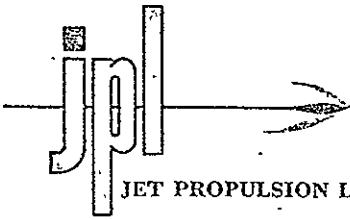
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Phase II*

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CALIFORNIA INSTITUTE OF TECHNOLOGY
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July 1, 1976





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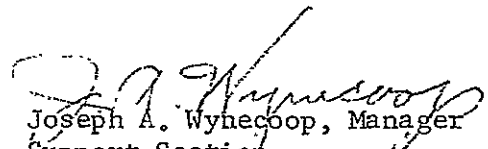
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Volume I

*Tracking and Data Systems Support
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*Project Development Through End of Mission
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P. S. Goodwin

M. R. Traxler

W. G. Meeks

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CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA**

July 1, 1976

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National Aeronautics and Space Administration

PREFACE

The work described in this report was performed by the engineering and operations personnel of the Tracking and Data Acquisition organizations of the Jet Propulsion Laboratory, Goddard Space Flight Center, Air Force Eastern Test Range, and John F. Kennedy Space Center. This is the first in a series of engineering reports describing support to the Helios Project, a joint German/U.S. solar probe mission, from its inception in 1966, through the launch of the first spacecraft, Helios-1, to the end of its primary mission at first superior conjunction. The Helios spacecraft, venturing toward the Sun at a perihelion of approximately 0.31 AU, is intended to achieve an orbit closer to the Sun than any yet attempted. Science experiments carried on the spacecraft are the primary reason for the mission. The spacecraft and the science instruments appear to have survived the thermal environment. The telecommunications performance of the flight and ground equipment has measured up to expectations and yielded new data on the propagation of electromagnetic waves through the solar corona.

ACKNOWLEDGMENT

The authors express their gratitude to the many JPL contributors whose skills in management, training, planning, and operation described in this report contributed so significantly to the success of the Helios Project, the first joint German/U.S. solar exploration project.

Further, the authors express their thanks for and acknowledge the contributions of Ants Kutzer of the German Society for Space Research and Gilbert W. Ousley of the Goddard Space Flight Center in providing the interface and coordination between our two countries.

Finally, and perhaps most important, the authors wish to recognize the very meaningful contributions of the NASA Headquarters team: the Office of Space Science (OSS) for its program direction to Project Helios and the Office of Tracking and Data Acquisition (OTDA) for continued foresight in providing the network facilities required to support such projects as Helios.

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ABSTRACT

This report summarizes the overall evolution of the Helios Project from its conception in September 1966 through to the completion of the Helios-1 Mission Phase II on April 13, 1975. Beginning with the Project objectives and concluding with the Helios-1 spacecraft entering its first superior conjunction (end of Mission Phase II), the narrative includes descriptions of the Project, the Mission and its phases, international management and interfaces, and DSN-Spacecraft engineering development in telemetry, tracking, and command systems to ensure compatibility between the U.S. Deep Space Network and the German-built spacecraft.

I. INTRODUCTION

A. PURPOSE

The purpose of this report is to provide a historical account of the JPL/Tracking and Data Acquisition (TDA) activities in the planning and development of the Helios Project from its conception in September 1966 through to the end of Phase II of the Helios-1 Mission on April 13, 1975.

B. SCOPE

This report discusses the support provided the Helios Project by the Near-Earth Phase Network and the Deep Space Network. The Near-Earth Phase Network consists of selected facilities of the Air Force Eastern Test Range (AFETR), Goddard Space Flight Center's Spaceflight Tracking and Data Network (STDN), the J. F. Kennedy Space Center, and the NASA Communications Network (NASCOM) which support both the near-Earth and deep space flight operations.

C. HISTORICAL INFORMATION

1. Background

The Space Act of 1958 authorized NASA to conduct programs of international cooperation with other nations in the peaceful exploration of space. To implement this article of the NASA Charter, the U. S. National Academy of Science, in behalf of NASA, introduced an offer of international space cooperation to the Committee on Space Research of the International Council of Scientific Unions. This, in turn, led to discussions between the U. S. and the Federal Republic of West Germany on the subject of a possible advanced cooperative space project. In September 1966 an agreement in principle was reached between the German Minister for Scientific Research, Gerhard Stoltenberg, and NASA Administrator James E. Webb to carry out a solar probe project, provided that a mission of mutual interest could be defined. This decision was made official during Chancellor Erhard's visit with President Johnson in November 1966. This first cooperative solar probe project, subsequently named Helios after the ancient Greek sun god, was another step in carrying out the policy and purpose of the Space Act of 1958: "Activities in space should be devoted to peaceful purposes for the benefit of all mankind."

In July 1968, in order to implement this international agreement, the NASA Administrator and the West German Minister of Science established a Helios Mission Definition Working Group whose objectives were to define a mission concept, a feasible approach, and a method of implementation. This group's effort culminated in the publishing of the Helios Program Mission Definition Group Report, dated April 1969. This report recommended that two solar probes be launched toward the Sun - one each in 1974 and 1975 - to achieve a perihelion distance from the Sun of approximately 0.3 AU.¹

¹Astronomical unit is a unit of length equal to the mean radius of the Earth's orbit about the Sun (93 million miles or 150 million kilometers).

Each spacecraft would carry 10 scientific experiments² to perform fields and particle measurements in the region between the Earth and the Sun. The target perihelion distance of 0.3 AU was selected because it was a heretofore unexplored region of interplanetary space and was within the estimated extrapolation of the state-of-the-art for the high-temperature solar cells necessary to generate spacecraft power. The size and weight of the proposed Helios spacecraft was recommended to be compatible with NASA's Atlas/Centaur launch vehicle.³

2. Project Objectives

The primary objective of the Helios Project was to develop, launch and operate an automated spacecraft for scientific missions near the Sun in order to obtain scientific information and explore new positions within the interplanetary region as well as the outer solar corona to provide a new understanding of fundamental solar processes and solar terrestrial relationships (Ref. 1).

In general, the objectives of the Helios Project were threefold:

- (1) The primary goal was to provide a group of U.S. and German experimenters the opportunity of designing and flying a well-integrated set of experiments aimed at specific investigations of the properties and processes in interplanetary space by approaching the Sun to approximately 0.3 AU. While the scientific results from each experiment were to provide valuable information individually, the selected experiments in their entirety complemented and supplemented each other. Thus the planned combination of the U.S. and German experiments allowed a more complete understanding of the phenomena that were to be investigated by the spacecraft as a whole.
- (2) A secondary objective of the Helios Project has been to develop the technical and technological expertise of German industry, thus advancing toward better equipment, better techniques, and experiments in the future to carry out similar advanced projects in other national and international space and technological programs.
- (3) Finally the characteristics of the large, multiple-organization solar probe program provided Germany the opportunity to develop more effective and sophisticated management experience and capabilities, which are needed for the solution of many of the major social, economic, and technological problems facing all modern nations.

²This was changed to 12 experiments later, with the inclusion of two Earth-based experiments.

³This was changed to the Titan III/Centaur launch vehicle in September 1971.

3. Scientific Experiments

In situ observations of interplanetary space had previously been carried out in the region between the orbits of Venus and Mars within the ecliptic. Therefore, from a scientific standpoint, it was highly desirable to widen this region inward toward the Sun and outward away from the Sun, as well as toward high ecliptic latitudes. The Helios mission was planned to continue the chain of space exploration conducted by the Pioneer and Mariner Projects. The main scientific objectives of the first Helios mission were:

- (1) To study the spatial gradient of the interplanetary medium by measuring the magnetic field, density, temperature, velocity and direction of the solar wind. In this respect, efforts were made to distinguish between electrons, protons, and alpha particles.
- (2) To study discontinuities, shocks, etc., in the interplanetary medium magnetically and electrically and by observing the behavior of the solar wind particles.
- (3) To study in situ the electron plasma oscillations believed responsible for Type III radio bursts and other wave-particle interactions.
- (4) To study the propagation of solar cosmic rays and, to a certain degree, their spectral composition.
- (5) To measure the spatial gradient of galactic cosmic rays, to separate the solar and galactic components of the low-energy cosmic ray flux, especially with respect to protons and electrons, and to study the spatial gradient and the dynamics of the interplanetary dust and the chemical composition of dust grains by observing the zodiacal light and by counting and analyzing individual dust particles.

These measurements would provide for a detailed review of the static and dynamic states of the interplanetary space and the influence of the Sun on them. Also included was X-ray monitoring of the solar disc by means of a Geiger-Muller counter, which would enable the experimenters to monitor the far side of the Sun from orbit regions far from the Earth. It was also proposed to make supporting observations by means of ground observations of the Sun.

The Helios orbit with its high eccentricity and close approach to the Sun provided the opportunity to conduct unique studies of the quadruple mass distribution of the Sun and important relativity effects as well as to improve estimates of the mass and orbital elements of the inner planets.

Table 1 provides a list of the experiments, together with the experimenters and their affiliations. The following are brief summaries of the scientific experiments carried on board the Helios spacecraft.

Table 1. Helios scientific experiments

(Principal Investigators indicated by asterisks)

No.	Experiment	Investigators	Affiliation	Scientific objective
1	Plasma Experiment	H. Rosenbauer*	Max Planck Institute, Garching	Solar wind velocity measurement
		R. Schwenn		
		J.H. Wolfe	Ames Research Center (NASA)	
2	Flux-Gate Magnetometer	G. Musmann*	Technical University of Braunschweig	Interplanetary magnetic field measurement
		F.M. Neubauer and A. Maier		
3	Flux-Gate Magnetometer	N.F. Ness*	Goddard Space Flight Center (NASA)	Interplanetary magnetic field measurement
		L.F. Burlaga		
		F. Mariani	University of Rome	
4	Search-Coil Magnetometer	G. Dehmel*	Technical University of Braunschweig	Interplanetary magnetic field measurement from 4.7 Hz to 2.2 kHz
		F.M. Neubauer		
5	Plasma and Radio Wave Experiment	D.A. Gurnett*	University of Iowa	Plasma measurement from 10 Hz to 100 kHz; radio wave measurement from 50 kHz to 2 MHz
		P.J. Kellogg	University of Minnesota	
		R.R. Weber	Goddard Space Flight Center Greenbelt, Md.	
6	Cosmic Ray Experiment	H. Kunow*	University of Kiel	Energy measurements on solar and galactic particles
		G. Green		
		R. Muller		
		G. Wibberenz		
7	Cosmic Ray Experiment	J.H. Trainor*	Goddard Space Flight Center	Flow and energy measurements on solar and galactic particles; measurement of solar X-ray emission
		K. McCracken		
		F.B. McDonald	University of New Hampshire	
		B.J. Teegarden	SCIRO, Melbourne, Australia	
E.C. Roelof				

Table 1 (contd)

No.	Experiment	Investigators	Affiliation	Scientific objective
8	Electron Count Experiment	E. Keppler* B. Wilken G. Umlauf D. Williams	Max Planck Institute Lindau/Harz ESSA, Boulder, Colorado	Counting of solar electrons
9	Zodiacal Light Photometer	C. Leinhardt* E. Pitz H. Link	Landessternwarte Heidelberg	Wavelength observation and polarization measurement of zodiacal light
10	Micrometeoroid Analyzer	E. Grun* P. Gammel J. Kissel	Max Planck Institute, Heidelberg	Mass and energy measurement of interplanetary dust particles
11	Celestial Mechanics Experiment	W. Kundt* O. Bohringer H. Ovenhausen J. Peyn W.G. Melbourne J.D. Anderson	University of Hamburg Jet Propulsion Laboratory, Pasadena, California	Verify relativity theories
12	Faraday Rotation Experiment	H. Volland* M. Bird G.S. Levy	University of Bonn, Radio Astronomy Institute Jet Propulsion Laboratory, Pasadena, California	Investigate electron and magnetic composition of the solar corona and solar wind

a. Experiment No. 1, Plasma Detector. This experiment, designed to observe low-energy particles, consists of three essentially independent sensor systems:

- (1) A quarter-sphere electrostatic analyzer is used to separate single energy per unit charge bands of protons and alpha particles. The total energy per unit charge range for this measurement is to be between 231 V and 16 kV.
- (2) A half-sphere electrostatic analyzer in connection with a current detector is to serve as a second device for observation of protons and heavier particles.
- (3) Another half-sphere electrostatic analyzer is for the observation of electrons.

From these measurements nearly all important parameters of the solar wind can be derived: e.g., flux density, bulk velocity, temperature, anisotropy of the temperature, energy flux, conducted heat, and composition of the positive component. For most of these parameters, typical temporal changes of 1 minute are to be observed, but time resolution for changes in flux density are to be as high as 1/10 s. Because of this high degree of time resolution, not only the average behavior of the solar wind but also irregularities, plasma waves, microinstabilities, and shockfronts may possibly be observed in detail.

b. Experiment No. 2, Flux-Gate Magnetometer (Germany). A three-axes flux-gate magnetometer was designed to measure vector components of the magnetic field in the range $(H) \leq 102.4$ gamma in steps of 0.4 gamma and up to $(H) \leq 409.6$ gamma in steps of 1.2 gamma. The normal mode measurement proposes one vector measurement per 2 seconds. It is switchable up to 8 measurements per second, enabling the quasistatic component of the interplanetary magnetic field and its irregularities to be investigated at a relatively high degree of time resolution.

c. Experiment No. 3, Flux-Gate Magnetometer (U.S.). Another three-axes flux-gate magnetometer was designed to work in the magnetic field ranges of ± 25 gamma (± 0.1 gamma), ± 75 gamma (± 0.3 gamma), and ± 225 gamma (± 0.9 gamma) with the respective step width. The experiment is adapted to varying bit rates in order to allow for a high degree of time resolution when high telemetry capacity is available and for averaging the data of several samplings when the bit rate is low. Even at a very low telemetry bit rate, valuable information may be obtained, since averages and variances are computed on board the spacecraft. This concept allows for nearly continuous information to be obtained.

d. Experiment No. 4, Search-Coil Magnetometer. This three-axes experiment measures magnetic field fluctuations in the frequency range between 5 Hz to 3 kHz. In one axis (parallel to the spin axis of the spacecraft), spectral resolution is achieved. The spectral frequency range contains the expected electron gyro frequency for the most probable field strengths (up to about 110 gamma).

The experiment is to provide data on magnetic field fluctuations when continuous telemetry transmissions are possible. However, when the spacecraft is far from the Earth, the low telemetry data rates available may make the study of short-term transient phenomena impossible in a real-time mode. Therefore, to make such studies possible, the data from this and other selected experiments are to be put into the spacecraft's memory at a high data rate for subsequent transmission to Earth at a lower rate. Onboard logic is used to select the data to be stored.

e. Experiment No. 5, Solar Wind Plasma and Radio Wave Experiment.

This experiment observes electrostatic and electromagnetic wave phenomena over the frequency range from 10 Hz to 2 MHz. In the solar wind, a wide variety of electromagnetic and electrostatic wave phenomena can be expected in the frequency range from a few tens of Hz to tens of MHz. These phenomena include Type III radio noise and associated longitudinal electrostatic waves down to the solar wind plasma frequency (about 20 kHz at 0.3 AU), intense (30 mV/m) electrostatic waves of the type observed by the Pioneer 8 spacecraft, electrostatic waves associated with interplanetary shock waves and solar particles emissions, and whistler-mode instabilities related to anisotropic solar wind electron distributions.

f. Experiment No. 6, Cosmic Ray (Germany).

This experiment, consisting of a semiconductor counter, a scintillator, and a quartz-Cerenkov-counter enclosed by an anticoincidence cylinder, permits investigation of protons and heavier particles in the desired energy range, with the aim of gathering information about the particle flow, energy, and direction as a function of the distance from the Sun. Solar particles as well as galactic particles are of interest. Measurements obtained are to be correlated not only to the other onboard experiment results but also to measurements made by Earth-bound satellites in order to obtain information about the propagation mechanism of the particles.

g. Experiment No. 7, Cosmic Ray (U.S.).

This experiment consists of three particle telescopes for the entire energy range of 0.1 to about 800 MeV for protons and heavier particles and of 0.05 to 5 MeV for electrons. Additionally, an X-ray counter monitors the solar X-ray emissions. The three telescopes employ solid-state detectors. The telescopes and the X-ray counter are mounted on the spacecraft so that each has a field of view into the ecliptic plane. Solar particles as well as galactic particles are of interest. Their propagation mechanism and their spectra as a function of solar distance and solar activity are to be studied. It is of special scientific value that correlations to the solar X-ray flow are planned.

It is proposed to correlate this experiment with results of the other onboard experiments and with near-Earth particle measurements in order to deduce the spatial and temporal structure of solar and interplanetary events and to develop a capability to interpret quiet-time fluxes by comparison with these near-Earth measurements.

h. Experiment No. 8, Electron Detector.

In this experiment, electron particles are energy-selected by two permanent magnets and counted by semiconductor detectors. Protons, which might disturb the measurement, are deflected and counted separately, since their flow may be even higher than that of electrons. The counting of electrons at intensities from one electron/cm²-s up to 10⁴ electrons/cm²-s steradian angle is possible. The pointing direction is within the ecliptic plane with an aperture angle of about 20 deg. The time resolution is on the order of a few minutes.

i. Experiment No. 9, Zodiacal Light Photometer.

This experiment consists of three photometers looking at angles of about 15, 30, and 90 deg from the ecliptic, respectively. The photometers will observe the zodiacal light in white light and in the wavelength bands at 5500 and 4000 Å and measure its polarization. From these observations information is obtained about the spatial distribution of interplanetary dust and the size and nature of the dust particles.

With some oversimplification perhaps, it may be stated that the zodiacal light intensity is related to the particle number density, its polarization to the material, and its color to the size of the interplanetary dust particles. The spatial distribution and the material of interplanetary dust are of interest for ascertaining its origin and dynamics.

The Zodiacal Light Experiment provides a completely new and very promising type of scientific information about interplanetary dust and its variation with distance from the Sun.

j. Experiment No. 10, Micrometeoroid Counter and Analyzer. A dust particle hitting a target with high velocity (several km/s) will be vaporized by its kinetic energy and partially ionized. The ionized plasma cloud can be separated by appropriately charged electrodes into its negative part (electrons) and its positive part (ions).

From the electrical impulse heights, the mass and the energy of the dust particles are determined. A time-of-flight mass spectrometer used in connection with the above target will allow the small ion cloud to be analyzed. Thus, investigation of the chemical composition of the dust particles will become possible.

The threshold for the detection of a particle is about 10^{-15} g. Mass and energy determination are possible for particles larger than about 10^{-14} g. For particles larger than some 10^{-13} g, a mass spectrum may be gathered. The aim of the experiment is to verify present interplanetary dust composition distribution theories.

k. Experiment No. 11, Celestial Mechanics Experiment. This experiment makes use of the unique Helios orbit to accomplish the following objectives:

- (1) Determine the dynamic oblateness of the Sun.
- (2) Test the theory of general relativity with respect to both orbital and signal propagation effects.
- (3) Use the radiometric data in programs designed to improve the ephemerides of the inner planets.
- (4) Determine the mass of the planet Mercury.
- (5) Determine the Earth-Moon mass ratio.
- (6) Measure the integrated electron density between the spacecraft and tracking station.

l. Experiment No. 12, Faraday Rotation. This experiment will investigate the composition of linearly polarized electromagnetic waves that have traversed the solar corona and interplanetary medium and undergone a rotation of their polarization angle due to the presence of electrons and magnetic fields in their path to Earth. The amount of Faraday rotation is a function of the line integral of the product of electron density and magnetic field, and as such provides an independent technique for ascertaining these parameters. Faraday rotation measurements containing both spatial and temporal effects are used in conjunction with other Helios experiments and Earth-based solar observations.

II. PROJECT AND MISSION OVERVIEW

A. SPACECRAFT DESCRIPTION

1. General Configuration

The Helios spacecraft is a spool-shaped, spin-stabilized-type spacecraft (Fig. 1), the conical surfaces of the main spacecraft body being covered with a mixture of solar cells and second (front) surface mirrors (SSM). The mixture ratio is approximately 50% each, the conical angle being fixed such that the incident solar radiation is reflected away from the spacecraft body following the spacecraft's initial postseparation maneuver. A subsequent attitude maneuver orients the spacecraft spin axis toward the pole of the ecliptic in such a manner as to maintain this thermal relationship. The center cylindrical portion of the main spacecraft body contains most of the spacecraft systems and components. The cylindrical surface contains no solar cells but is made highly reflective to solar energy. In contrast, the interior surfaces of the main body of the spacecraft (as viewed along the spin axis) are black in order that they may become efficient radiators for internal spacecraft heat, which is dumped into cold space. Thermal balance is maintained by adjustable radial louvers mounted on the inside top surface (antenna mast end) of the cylindrical portion of the spacecraft body.

Attached to this basic structure are several appendages. Mounted radially to the central cylindrical structure are four experiment booms which are deployed after spacecraft separation from the launch vehicle. Two of these booms are for the magnetometer experiments; the other two form a high-frequency (HF) dipole antenna for an onboard solar plasma/radio wave experiment and are not intended for communications to or from the spacecraft. Before spacecraft separation from the launch vehicle, the combination last stage and spacecraft are "spun up" to a rotational speed of approximately 90 rpm. Following spacecraft separation and completion of a postseparation maneuver, the four booms are commanded into an extended position, reducing the spacecraft spin-rate to approximately 60 rpm.⁴ The booms remain in this extended position for the remainder of the mission.

Inside the bottom cylindrical skirt of the spacecraft main body is a truncated, conical adapter section which symmetrically mounts the spacecraft to the last stage of the launch vehicle. Because this adapter had to be centered on the spacecraft spin axis, the right circular polarization (RCP) horn element of the spacecraft S-band low-gain antenna (LGA) had to be offset approximately 6 wavelengths from the spin axis. This introduced an asymmetrical spacecraft spin modulation upon the uplink and downlink omniantenna signals (see paragraph 2-a below). The bottom spacecraft skirt also shields some of the onboard experiment sensors (e.g., the zodiacal light photometer,

⁴ Boom extension may reduce the spacecraft spin-rate to under 60 rpm, which would necessitate a small spin-up maneuver. For operational convenience, this latter spin-up maneuver may be deferred until after completion of the final attitude maneuver.

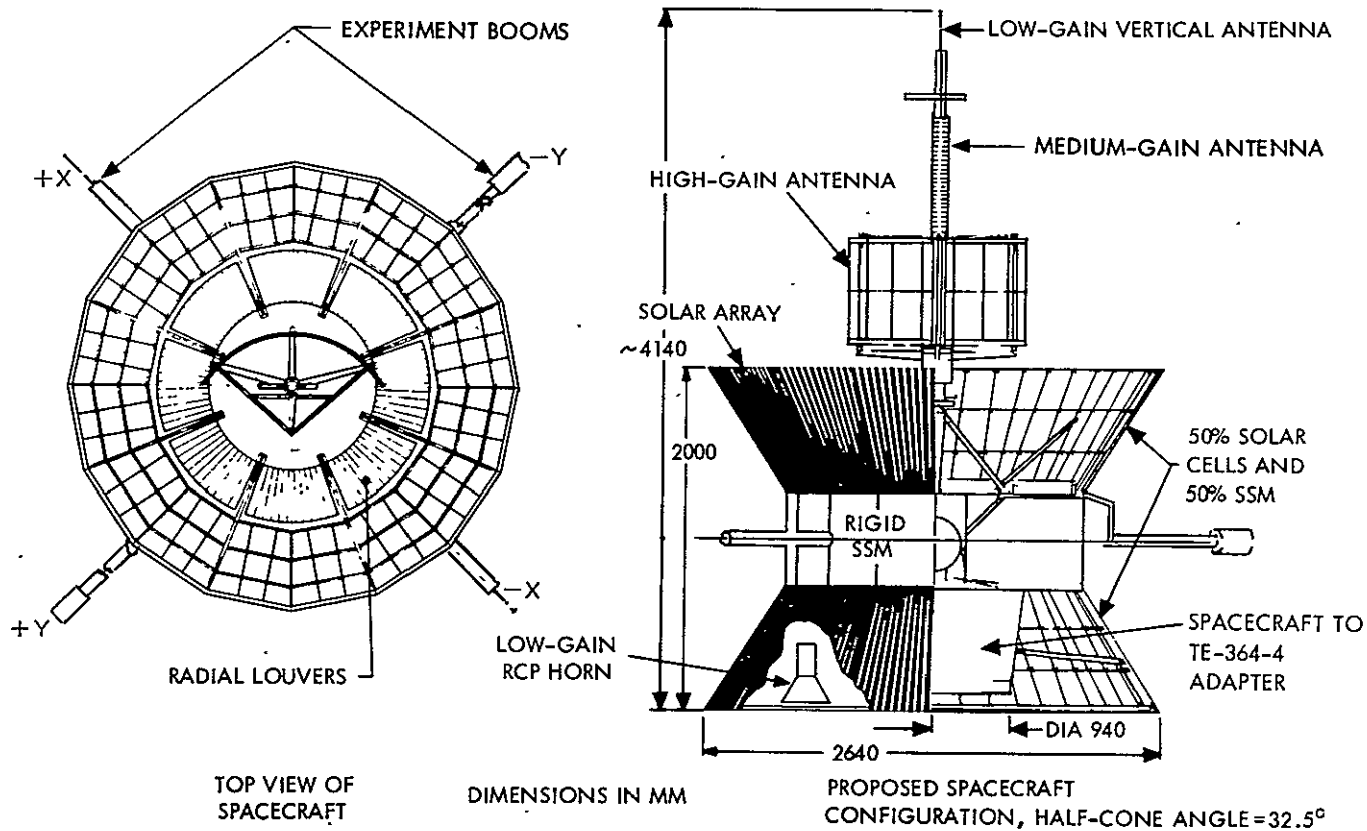


Fig. 1. Helios spacecraft

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whose optical system prevented the LGA horn antenna from being mounted within the conical spacecraft/launch vehicle adapter section).

Protruding above the top skirt of the main spacecraft body is the S-band, multiantenna assembly. On top of this mast is the dipole element of the LGA. This dipole is linearly polarized with the E vector parallel to the spin axis. For convenience, Project refers to this polarization as linear vertical (L-V), since that is the E-vector orientation when the spacecraft rests on top of the launch vehicle. Below the dipole and lying in the center portion of the antenna system mast is the medium-gain antenna (MGA). The MGA also produces a L-V pattern, i.e., E-vector parallel to the spin axis. At the bottom of the antenna system mast is the spacecraft high-gain antenna (HGA), which employs a mechanically de-spun, cylindrical paraboloid reflector and flat-plate Cassegrainian subreflector, both of which rotate about a fixed L-V feed system mounted on the mast. The combination produces an elliptical "spot" beam 5.5 deg wide and 14 deg high. The parabolic and Cassegrainian reflector surfaces are formed by a series of closely spaced fine wires parallel to the spin axis (L-V), which make the surface very transparent to thermal energy, yet form an rf reflector.

The HGA is de-spun to exactly cancel the spacecraft spin rate; however, there is a commandable adjustment in the de-spin phase, so that the spot beam can be directed toward Earth following completion of the attitude maneuver. The final attitude maneuver orients the LGA horn antenna element toward the pole of the ecliptic, thereby forcing subsequent communications with the spacecraft to be via one or more of these mast-mounted antenna elements.

2. Telecommunications System

The telecommunications subsystem provides an S-band communications capability between the spacecraft and the U.S. Deep Space Network (DSN), or the German 100-meter telemetry receiver antenna, to well beyond the maximum Earth-spacecraft range of 2.0 AU. Commands to the spacecraft from Earth are transmitted via the uplink, while experiment and spacecraft status data are contained on the downlink. Both links are required in order for the DSN to generate doppler and ranging data for precise determination of the spacecraft trajectory.

The design includes three antenna systems: high-gain (23 dB), medium-gain (7 dB), and low-gain (0 dB). The high-gain antenna (HGA) features a subreflector to increase the system gain by 2 dB over that of a simple parabolic cylinder reflector of the same size. Transmission to Earth may be accomplished over any of the three antennas at three selectable power levels: 0.5, 10, and 20 watts. The combination of the high-gain antenna and the 20-W power amplifier results in a maximum downlink data rate of 2048 bits per second to the German 100-m antenna receiving station from a distance greater than 2.0 AU.

As shown in Fig. 2, the low-gain antenna (LGA) is hard-wired to Receiver 2 and the MGA is hard-wired to Receiver 1. Both of these receivers are active at all times, with Receiver 2 having the stronger received signal prior to completion of the attitude maneuver and Receiver 1 having the stronger received signal following completion of the attitude maneuver. Figure 2 also denotes that the Helios spacecraft radio system has two transmitter chains. However, only one transmitter chain is active at a given time,

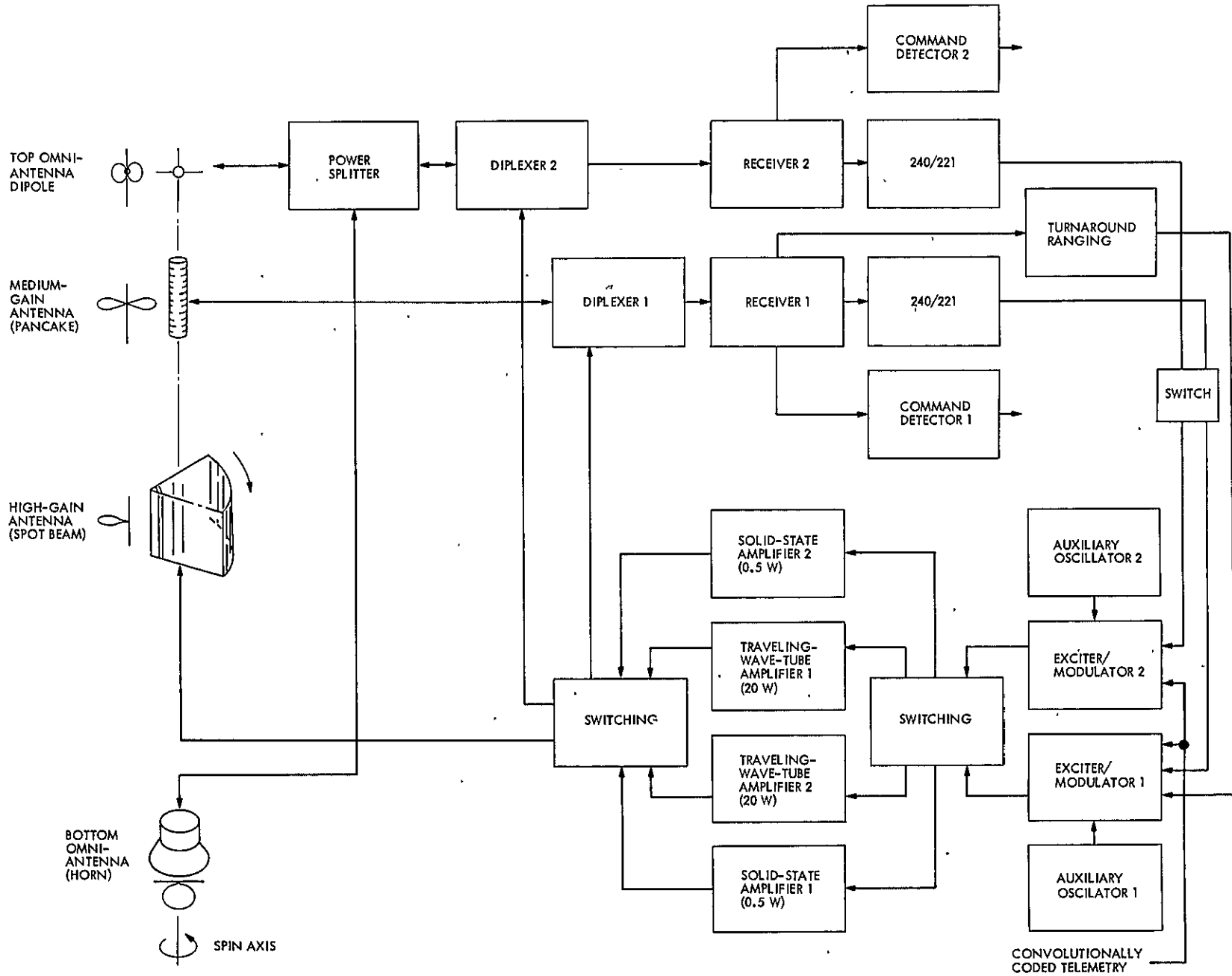


Fig. 2. Helios spacecraft radio system

with its output switchable to any of the three antenna systems (LGA, MGA, or HGA). The switching combination is flexible in that the spacecraft can receive and transmit via the same or different antenna.⁵ However, for turnaround ranging, only Receiver 1 and Exciter/Modulator 1 may be employed.

a. Spacecraft Antennas.

(1) Low-Gain Antenna (LGA). The LGA dipole and horn antenna elements are permanently combined (wired) via a 1:4 power splitter (Fig. 2) to form a quasicircular, omnidirectional antenna pattern. However, these two antenna elements create an interferometer (interference region) where their patterns overlap. Further, because the horn antenna is offset approximately six wavelengths from the spin axis (Fig. 3), the interferometer region is asymmetrical with respect to the spacecraft body. This asymmetrical interferometry pattern, at about 30 deg to the spin axis, results from the summation of the horn and dipole-radiated signals of similar polarization. As the spacecraft spins about its axis, a resulting amplitude and phase modulation is imparted to the RF signals, which can significantly affect both uplink and downlink communications (especially telemetry and command when the spacecraft is oriented such that communications must be conducted through the interferometer region). In the normal Helios Mission, the interferometer region is traversed twice: first, during the launch, near-Earth, and the postseparation maneuver phase; and second, during the attitude maneuver phase. The first situation presents less of a problem since the spacecraft trajectory will automatically produce a change in spacecraft aspect angle (with respect to the DSN Deep Space Stations), which in time will provide communications via the main lobe of the RCP horn antenna. Such is not the case for the attitude maneuver, which requires a series of successful command entries into the spacecraft in order to transcend the interferometer region. For the latter case, the Helios Project requires the DSN to employ a linear horizontal (L-H) antenna polarization at its supporting Deep Space Stations during the first 30 to 45 deg of the attitude orientation maneuver and linear vertical (L-V) polarization for the remainder of the maneuver. The utilization of L-H polarization by the DSS permits tracking of the horizontal component with the RCP horn antenna beam (albeit with a 3-dB loss), while at the same time significantly reducing the interferometer effect between the horn and dipole antenna elements through quadrature polarization. However, this quadrature (cross) polarization does not completely eliminate amplitude variations because the two antenna elements are asymmetrical. In addition, and perhaps more important to the foregoing amplitude effects, the offset horn antenna generates a phase and frequency deviation about the normal carrier frequency where the frequency shift can reach almost 30 Hz at a 1.0-Hz (60-rpm) spin rate, since the horn antenna traverses approximately 12 wavelengths per revolution in a sinusoidal manner. However, this doppler modulation, when used in conjunction with the spacecraft's sun sensor, provides Project with valuable information as to whether the initiation of the attitude orientation maneuver has caused the spacecraft to start precessing toward the north vs south ecliptic pole.

⁶Except that the HGA is used only for downlink transmission.

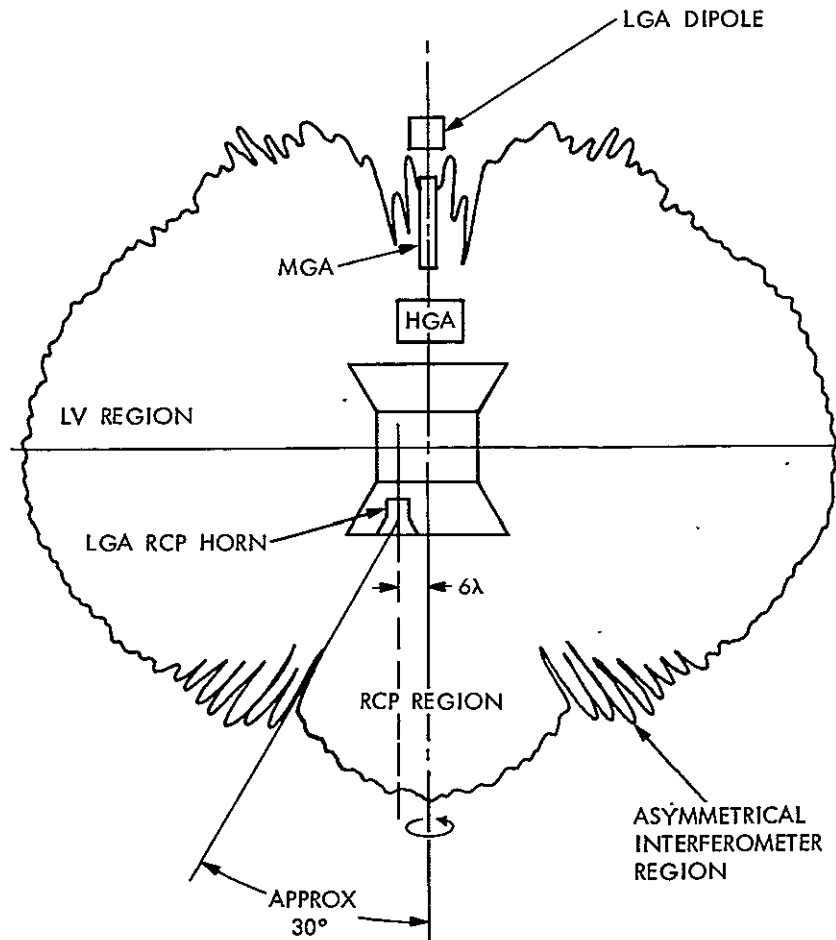


Fig. 3. Simplified pattern Helios low-gain antenna (LGA)

(2) Medium-Gain Antenna (MGA). The medium-gain antenna consists of a series of slot radiators stacked on the mast beneath the omniantenna but above the high-gain antenna. This antenna produces a linearly polarized, pancakelike pattern which, following the above-mentioned maneuver, directs its maximum radiation in all directions within the plane of the ecliptic (where Earth lies) while minimizing its radiation toward the poles of the ecliptic. It is approximately 15 deg wide in the direction perpendicular to the ecliptic and has a downlink gain of 8 dB. It is the prior knowledge of this pattern that enables the final positioning of the spacecraft spin axis toward the pole of the ecliptic. The medium-gain antenna is connected through a second diplexer to the second radio system transponder aboard the spacecraft. However, the transmitter portion of the second transponder is shared between the medium-gain antenna and the high-gain antenna described below.

(3) High Gain Antenna (HGA). The Helios spacecraft high-gain antenna is a cylindrical, parabolic-shaped reflector that is mechanically de-spun to counter the spacecraft body spin-rate of 60 rpm. The de-spin angular velocity is adjusted to exactly countermatch the spacecraft body's spin velocity in order to achieve a fixed beam direction in space. The direction that the spot-beam points is also within the plane of the ecliptic but is phase-angle-adjusted with respect to the pulses received from the onboard sun sensor that clocks the rotational speed of the spacecraft. Since the angle between the Sun and the Earth changes as the spacecraft traverses its elliptical heliocentric orbit, the phase angle for the high-gain antenna must be updated by Earth command during the mission. The high-gain antenna beam is again linearly polarized with a beamwidth of 5-1/2 deg within the plane of the ecliptic and 14 deg normal to the plane of the ecliptic. The downlink gain of this antenna is 23 dB. It is used to transmit high-rate telemetry from the spacecraft to the Earth and operates in conjunction with the spacecraft receiving on the medium-gain antenna, using a second transponder. Since the second transponder contains a turnaround ranging loop, it is possible to employ the DSN planetary ranging system in conjunction with the spacecraft medium-gain antenna system. However, at perihelion distances and beyond, the spacecraft radio system configuration will be such that it will receive ranging signals via the medium-gain antenna and return them to Earth via the high-gain antenna.

b. Receiver. Since the spacecraft receivers have fixed dynamic characteristics, both the uplink transmitted power level and its frequency must be carefully adjusted to provide optimum command reception at the spacecraft. Conversely, the DSN must optimize downlink performance to obtain reliable spacecraft telemetry reception concurrently with the doppler spin-modulation data. Each of the Helios spacecraft receivers is configured as shown in the top half of Fig. 4.

The most unusual feature of the Helios transponder (receiver/transmitter combination) is its method of transferring from noncoherent to coherent operation. In the absence of an uplink carrier signal (for any cause), the spacecraft receiver AGC causes the spacecraft transmitter to switch to the onboard very stable oscillator (VSO), which is more or less standard practice among flight projects. However, to reinstate two-way coherent operation, a command (or series of commands) must be sent to the spacecraft. These commands must specify which spacecraft receiver, in conjunction with which transmitter chain, is to be configured into the coherent mode. This "command into coherency" feature, while unusual, is actually advantageous

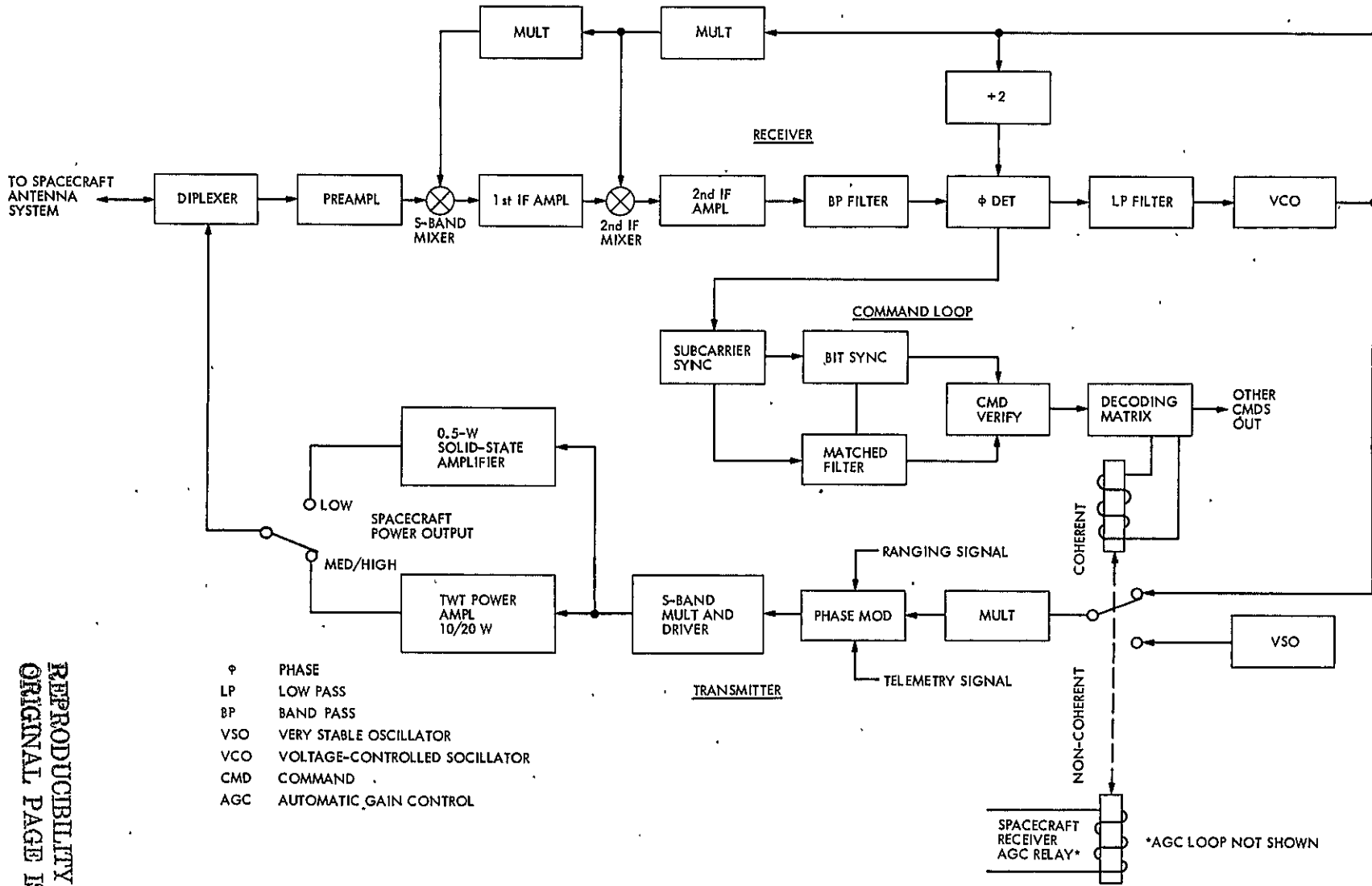


Fig. 4. Simplified diagram of Helios spacecraft transponder coherency mode control (only one channel shown)

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during certain portions of the mission. For example, it helps to reduce the interruption time of the downlink telemetry when the spacecraft attitude is transcending the interferometer region of the LGA by keeping the downlink carrier frequency constant (VSO frequency), regardless of whether or not the uplink is in lock. This feature also permits uplink command lock to be maintained at a stable level while the downlink is interrupted for cold switching of the spacecraft transmitter power levels and/or antennas. In the latter case, the downlink always reestablishes itself on the VSO frequency, regardless of the uplink frequency doppler shift. Advantages are also accrued at maximum spacecraft range from Earth, where near threshold conditions on the uplink signal may introduce noise or jitter into the downlink signal frequency. It is anticipated that two-way spacecraft-coherent and two-way spacecraft-noncoherent doppler data will be obtained during the Helios Mission; and as a consequence the DSN tracking data messages are required to indicate in the data block formats which doppler data type is being forwarded to the JPL Mission Control and Computing Center (MCCC). By mutual agreement between Project and the DSN, all spacecraft noncoherent mode doppler data are "flagged" as one-way doppler in the DSS data stream.

Both spacecraft receivers operate on the same uplink carrier frequency, which for the first Helios spacecraft is Channel 21B. Therefore, providing there is sufficient uplink signal margin, both receivers are locked to the uplink signal. While this provides a desired redundancy for reliability reasons, it also makes it incumbent upon the Project Mission Operations personnel to select their desired channel prior to commanding the specific spacecraft configuration for coherent mode operation. To avoid competition over commands, the two receivers have separate command subcarrier frequencies (448 and 512 Hz), plus different verification symbols within the command word for each channel.

c. Transmitter. The transmitter portion of the Helios spacecraft transponder is depicted in the lower half of Fig. 4, which applies to each of the redundant transmitter chains depicted in Fig. 2 (except for the turnaround ranging channel). Separate VSOs and exciter/modulators are incorporated for redundant reliability. Each transmitter chain has a choice of a low-power (approx 0.5 W) output or a medium/high-power output (10/20 W) utilizing a traveling wave tube amplifier (TWT). For further redundancy, two TWTs are employed, either of which may be connected to either exciter/modulator chain. The antenna switching matrix permits the low-power (0.5 W) amplifiers to be connected to the LGA only; otherwise, any combination of exciter/modulator and TWT amplifier may be transmitted via any of the three spacecraft antenna systems.

Modulated onto the downlink carrier is a single-channel telemetry subcarrier and (if so commanded) a turnaround ranging signal. The telemetry subcarrier frequency is 32,768 Hz, which is PCM/PSK/PM modulated onto the downlink carrier. A commutated mixture of science and engineering telemetry data is processed by the spacecraft Data Handling Equipment (DHE), as shown in Fig. 5. The telemetry data may be uncoded or convolutionally encoded by commanded option, and may be sent in real-time or as a replay of data stored in the spacecraft memory. The latter includes science "shock" data which are read into spacecraft memory at a very high rate (e.g., up to 16 kbps) and later replayed at standard spacecraft real-time downlink telemetry bit rates. Spacecraft time is generated by the crystal oscillator shown

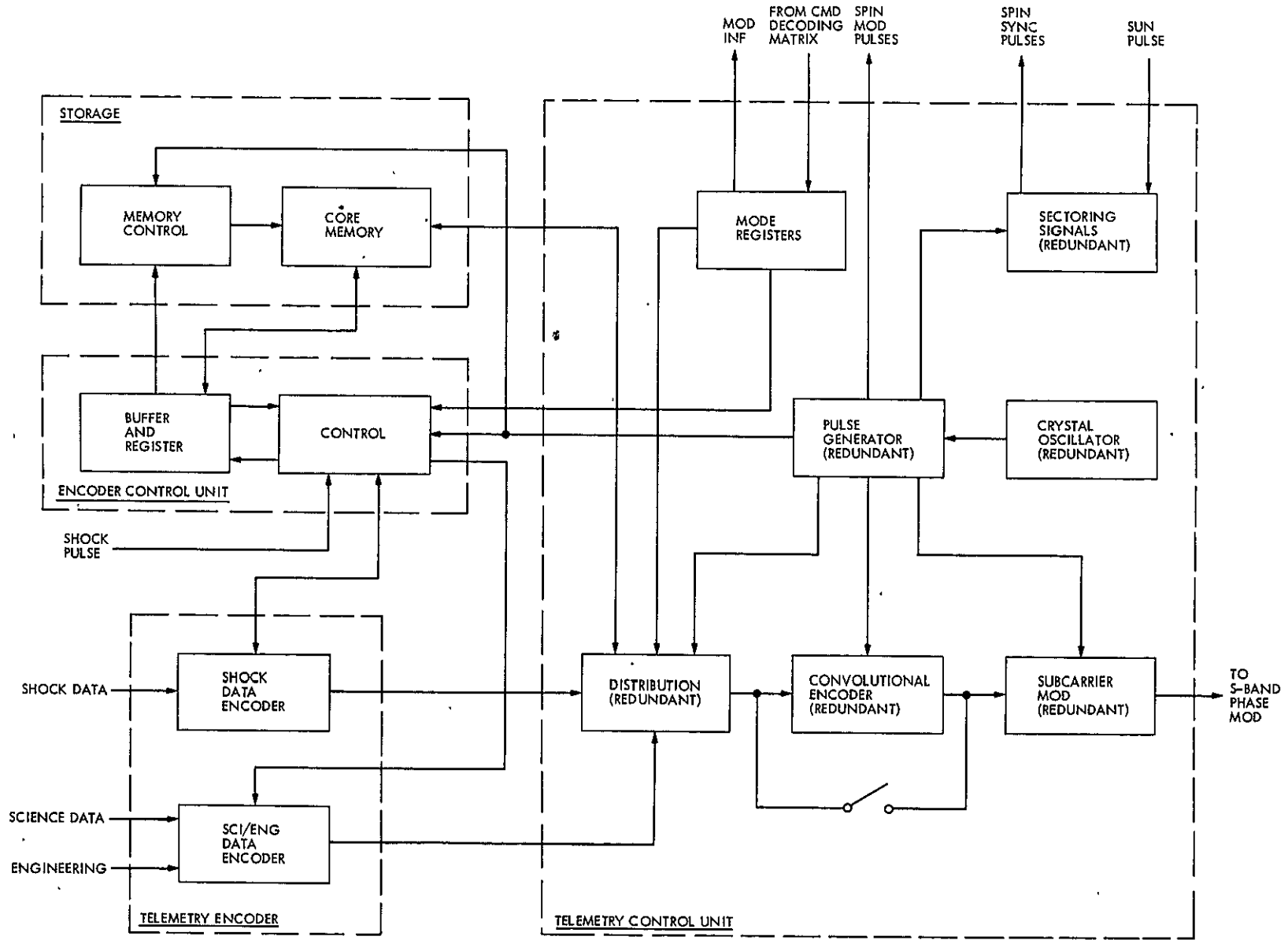


Fig. 5. Functional block diagram of Helios spacecraft telemetry subsystem

at the middle right-hand edge of Fig. 5. In addition, this oscillator provides the timing signals for all spacecraft digital operations.

3. Attitude Control

The Helios cold-gas attitude control subsystem establishes and maintains the spin rate and attitude of the spacecraft, controls the pointing of the high-gain antenna, and provides Sun reference pulses to the experiments.

Orientation of the spacecraft after separation from the third stage is performed in two steps. The first step, referred to as the Step I Maneuver, consists of turning the spin axis in the ecliptic plane until it is perpendicular to the spacecraft-Sun line, so that the solar array receives maximum illumination as soon as possible. During the second step, referred to as the Step II Maneuver, the spin axis is rotated about the spacecraft-Sun line until the spin axis is also perpendicular to the ecliptic plane, thus placing the spacecraft in its final orientation for both the science objectives and communications with Earth.

For HGA orientation, a brushless dc motor drives the antenna reflector in a direction opposite the spin of the spacecraft, so that it remains stationary with respect to the spacecraft-Earth line, at a pointing angle that can be changed by command to direct its beam toward the Earth.

4. Electrical Power

The electrical power subsystem performs five major functions for the spacecraft: power generation, energy storage, electrical bus regulation and filtering, voltage conversion, and failure detection and control. Also included is a primary battery which supplies 50 W of load power from 5 min prior to launch until the solar array becomes illuminated and assumes the load. Separation, antenna unlock, and magnetometer boom release squibs are fired by the primary battery, which is backed up by a secondary battery for the squib-activated functions. Output from the solar array exhibits a wide range of voltage fluctuation (approximately 2 to 1) because of the variance in irradiation and thermal conditions encountered during the mission.

A regulated electrical bus approach was selected for the power subsystem which will yield high overall spacecraft system reliability through circuit simplicity, lower component power dissipation, and more predictable electrical interface characteristics. Since individual power consumers need not preregulate their input voltage, the flight equipment hardware is smaller, lighter, and easier to test.

Regulation is provided at 28 Vdc (± 2 V). The solar array bus is filtered in order to maintain the very low spin ripple requirements imposed by the experiments. Voltage conversion supplies 6 and -16 Vdc to the spacecraft loads. Internal automatic, commandable control and failure management circuits continuously monitor subsystem operation so that a failure in the power subsystem will not jeopardize successful mission operation.

B. THE LAUNCH VEHICLE

The launch vehicle proposed by NASA to the Helios Mission Definition Group in 1969 was the Atlas SLV-3C/Centaur/TE-364-4. In April 1970, at the second Helios Joint Working Group Meeting, NASA informed the Helios Project that because of budget restrictions and stretchout of the Viking Project, there was a possibility of a Titan III/Centaur/TE-364-4 launch vehicle being available for the Helios Project which would be capable of providing the spacecraft with a reduced perihelion distance, thus providing experimenters an opportunity to enhance their scientific data return. However, spacecraft and mission design continued to be based on use of the Atlas launch vehicle until September 1971, when NASA officially notified the Helios Project that the Titan III/Centaur launch vehicle would be used for the Helios Project. The following is a general description of the Helios launch vehicle.

1. Titan IIIE

The Titan IIIE booster vehicle consists of two five-segmented solid rocket motors (Stage 0) and the Titan first- and second-stage liquid propellant core sections (Stages I and II) as shown in Fig. 6. Each solid rocket motor produces an initial thrust of 5,337,600 newtons (1.2 million lb). The regressive burning characteristics of the solid-propellant segments permit thrust to taper to approximately 371,945 kg (0.82 million lb) over a period of 105 seconds. Burning time for each solid rocket motor is about 2 minutes.

Each solid rocket motor is also equipped with separate command destruct and Inadvertent Separation Destruction Systems. The command destruct system functions on an abort order from Range Safety via command receivers in Stage I.

2. Centaur

The Centaur D-IT system provides guidance for Titan, with the stabilization function performed by Titan. The Centaur D-IT astrionic system integrates hardware functions into airborne computer software. The digital computer unit (DCU) is an advanced, high-speed computer with a 16,384-word random access memory. From the DCU, discrete commands are provided to the sequence control unit. Engine commands go to the servo-inverter unit through six digital-to-analog converters in the DCU.

The inertial reference unit, which is part of the inertial measurement group, contains a four-gimbal, all-attitude-stable platform. Three gyros stabilize this platform, on which are mounted three pulse-rebalanced accelerometers. A prism and window allow for optical azimuth alignment prior to launch. Resolvers on the platform gimbals transform inertial vectors into vehicle coordinates. These vectors are computed in the DCU. A crystal oscillator, which is the primary timing reference for DCU and 400-Hz inverters, is also contained in the inertial reference unit. Flight trajectory is controlled by the inertial measurement group and DCU utilizing the vehicle main engines for thrust vector control.

The central controller unit for the Centaur pulse code modulation (PCM) telemetry system is housed in the same package as the DCU and shares

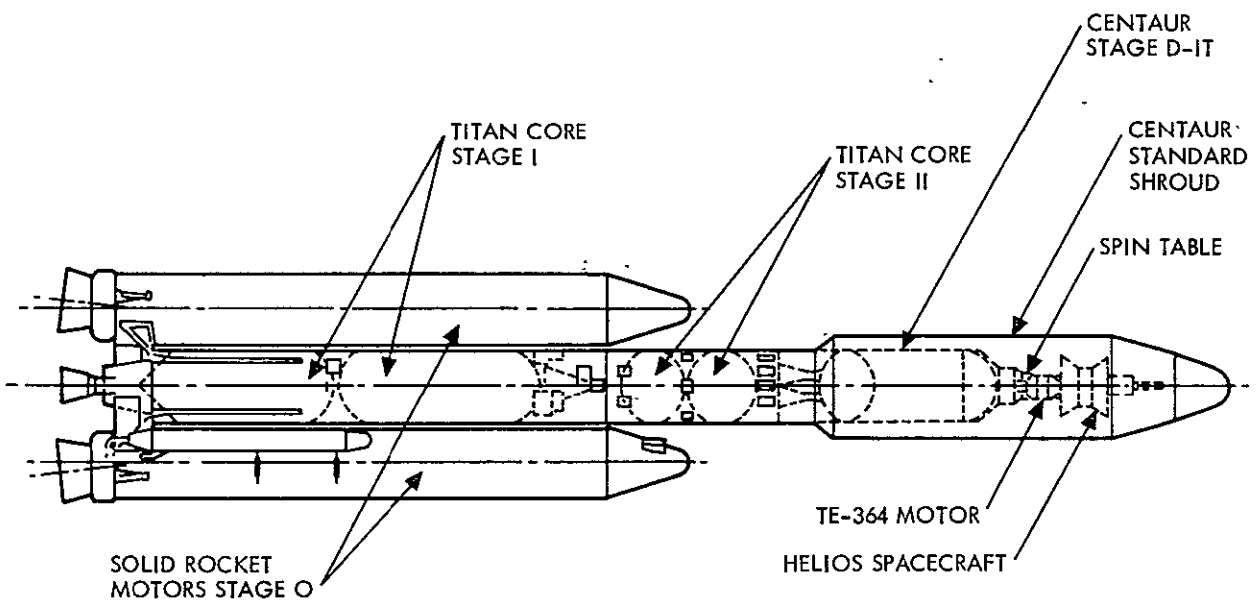


Fig. 6. Helios launch vehicle configuration

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the DCU memory. The PCM formatting is controlled completely by software. System capacity is 267,000 bps. The central controller unit services two remote multiplexer units.

Primary vehicle thrust is provided by two engines with a combined thrust of 133,440 newtons (30,000 lb) and a minimum specific impulse of 439 s. The liquid hydrogen and liquid oxygen propellants are delivered to the main engine turbopumps by means of boost pumps located at the propellant tank outlets. The multiburn vehicle coast phase control is provided by eight attitude control engines and four propellant settling engines. These engines and the propellant boost pumps use hydrogen peroxide as a monopropellant which is supplied by two positive expulsion (bladder) storage bottles. The supply system includes redundancies for improved reliability.

3. TE-364-4

The TE-364-4 (also referred to as the fourth stage or the Delta stage) major assemblies consist of a spin table, TE-M-364-4 solid propellant rocket motor, batteries, telemetry system, radar transponder, destruct system, motor separation clamp, payload attach fitting, and a spacecraft separation clamp. Interface is between the Centaur mission-peculiar cylindrical adapter and the spin table's lower (nonrotating) conical adapter.

The spin table assembly includes a four-segment petal adapter mounted on a bearing attached to the nonrotating conical adapter. During spinup, eight spin rockets mounted on the spin table are ignited, the two redundant motor separation clamp explosive bolt assemblies are initiated, and centrifugal force swings the adapter segments back on their hinges to free the Delta stage, the payload attach fitting, and the Helios spacecraft.

The TE-364-4 solid rocket motor provides an average thrust of 66,275 newtons (14,900 lb) during its burn time of about 44 seconds.

The base of the attach fitting is attached to the forward support ring of the TE-364-4 motor. The Helios spacecraft is fastened to the attach fitting by means of a V-band clamp. Four separation springs are utilized, each exerting a force of approximately 59 kg (130 lb) on the spacecraft in the mated configuration.

C. MISSION PLAN

The objective of the Helios Mission was to place a solar orbiting spacecraft in a highly elliptical orbit to achieve a perihelion distance of approximately 0.25 to 0.30 AU⁶ and an aphelion distance of 1.0 AU.⁷ Such a heliocentric orbit would bring the spacecraft closer to the Sun than any previous deep space effort. As a result, the Helios Project required new technology both onboard the spacecraft and, to a lesser extent, within the supporting

⁶The final targeted perihelion distance was 0.31 AU for the first Helios spacecraft.

⁷The aphelion distance of 1.0 is automatically achieved since the spacecraft is launched from Earth.

deep space communications stations. One example of the former is the thermal design of the spacecraft, which must withstand 10.4 solar constants of incident radiation from the Sun at a perihelion distance of 0.31 AU. Examples of new ground technology are (1) radio metric tracking of a spacecraft whose radial velocities from Earth can exceed 1 MHz of radio frequency two-way doppler shift and (2) long-duration tracking of a spacecraft in close proximity to the Sun.

It was planned that the first Helios spacecraft would employ a trajectory that would reach its orbital perihelion point in approximately 95 Earth days (Fig. 7) and return to aphelion (Earth's orbital radius of 1.0 AU) approximately 190 days after launch. In the meantime, the Earth would have progressed through approximately one-half of its yearly orbit, so that by the time the spacecraft returned to its aphelion, the spacecraft and the Earth would be separated by the diameter of the Earth's orbit (2.0 AU).

For scientific reasons, it was desired that the trajectory lie as close as possible within the plane of the ecliptic. Since the spacecraft would not have midcourse correction capability, the final declination of the trajectory was dependent upon launch vehicle performance capabilities, as would the actual perihelion distance achieved by the spacecraft.

1. Prelaunch and Launch Phase (Mission Phase I)

The Helios prelaunch and launch phase activities utilized the NASA and Air Force Eastern Test Range (AFETR) facilities at Cape Canaveral, Florida. The prelaunch Flight Model/DSN Compatibility Tests and the normal prelaunch Mission Operational Readiness Tests (MORT) required support from the STDN (MIL 71) station at Merritt Island, in both the STDN and DSN configurations.

Encapsulation and mating of the spacecraft to the launch vehicle were conducted. The spacecraft and launch vehicle combination then proceeded to Pad 41 (Fig. 8), where the Flight Model/DSN Compatibility tests and the MORT were conducted, supported by STDN (MIL 71). STDN (MIL 71) provided support through to launch on December 10, 1974 and to the time the spacecraft reached the tracking horizon of STDN (MIL 71).

Following the postlaunch loss-of-signal (LOS), STDN (MIL 71) acted as a Helios telemetry processing station for the Near-Earth Phase Network (NEPN), receiving data from downrange STDN/AFETR stations which it decoded and processed in DSN format for transmission via the NASA Communications Network (NASCOM) to the Mission Control and Computing Center (MCCC) at JPL.

2. Near-Earth Phase (Mission Phase I)

The Helios Project had originally planned to launch the first Helios spacecraft on a direct-ascent trajectory in September 1974. However, the partial success/failure of the Titan-Centaur proof-test flight (TC-1) in February 1974 resulted in a NASA decision in May 1974 to fly the first Helios spacecraft on a parking-orbit trajectory. From a Tracking and Data System viewpoint, the change to a parking-orbit launch trajectory had its greatest impact on the plan for the near-Earth phase support (i.e., number of supporting stations) and to a lesser extent on the DSN, which had to switch its initial acquisition from its Madrid facilities to the Australian facilities (see Fig. 9).

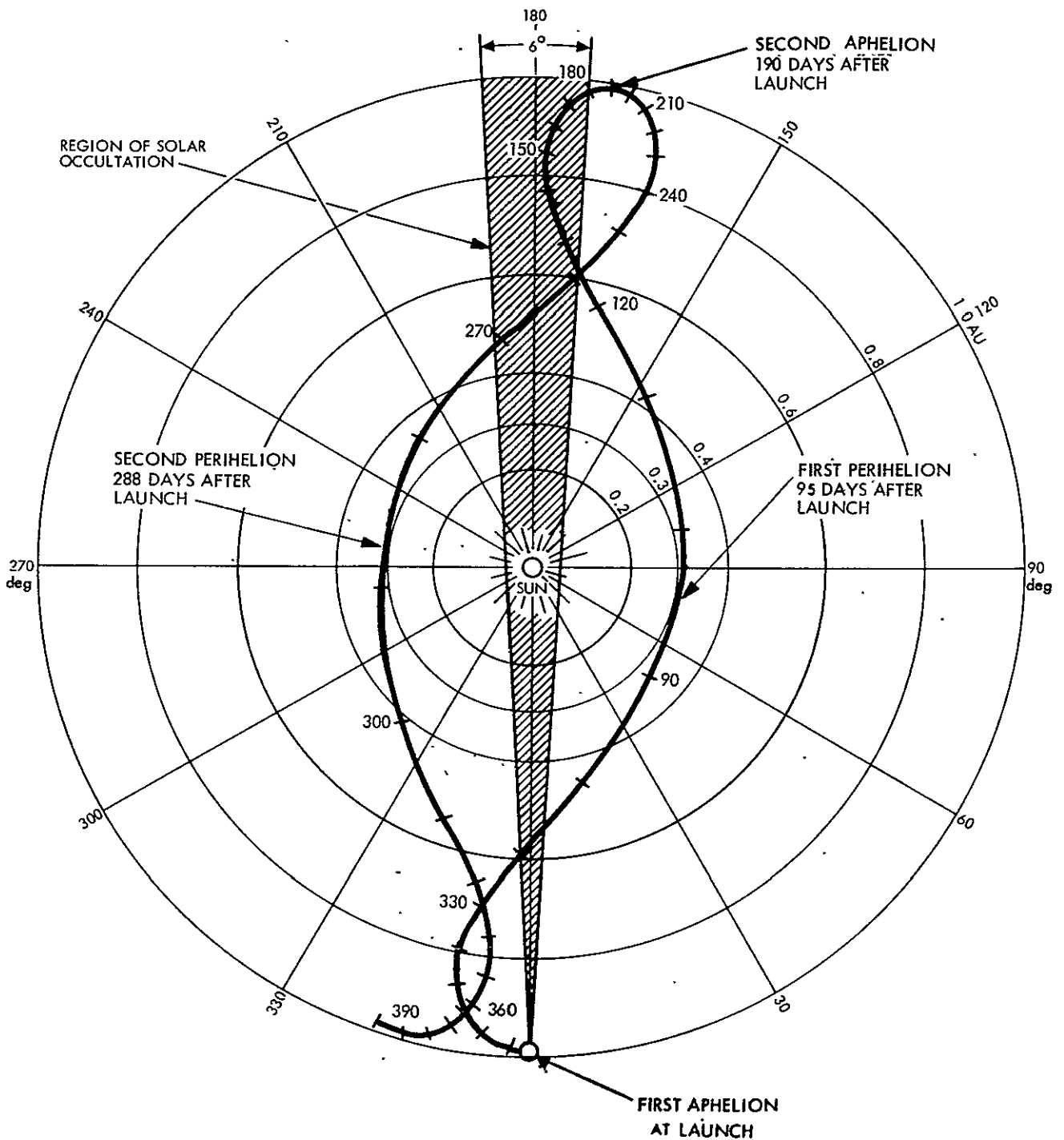


Fig. 7. Planned Helios mission trajectory (0.31 AU perihelion)

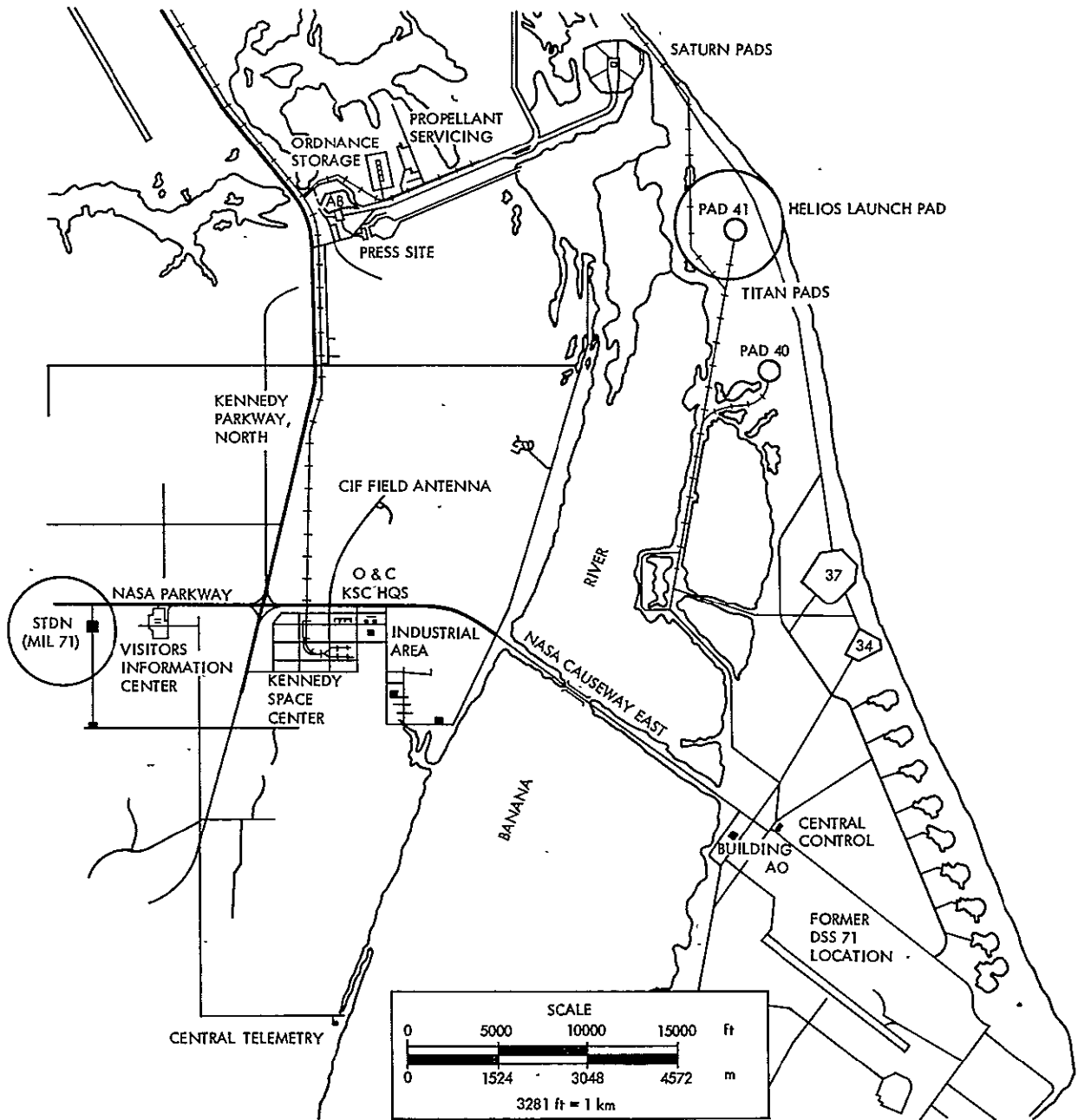


Fig. 8. STDN (MIL 71) support for Helios prelaunch and launch activities

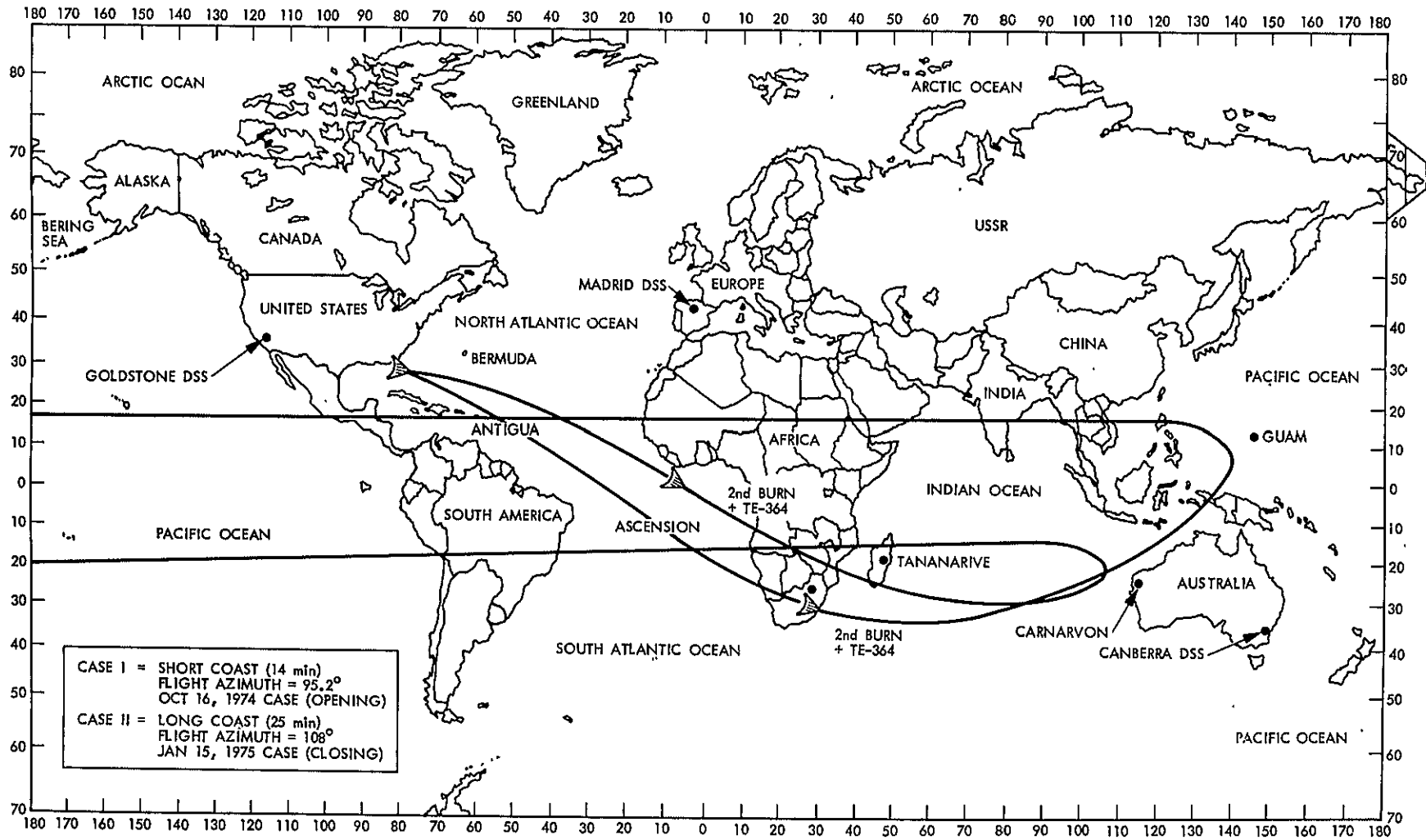


Fig. 9. Typical Helios parking orbit launch trajectories

While the specific parameters associated with a parking-orbit launch did change slightly with the actual launch date, the following discussion of a typically planned Helios parking-orbit trajectory is considered representative. The first effect of a parking-orbit trajectory upon the mission design was to change from a daytime to a nighttime launch. Figure 10 shows that in order to maintain the Helios outgoing trajectory asymptote at approximately 1800 hours Local Meridian Time, it was necessary to advance the launch time to the early morning hours of the day. Second, injection occurs at a lower altitude above the surface of the Earth than was previously planned for the direct-ascent (daylight) launch mode. The coast portion of the parking-orbit mission was planned to occur at 168 kilometers (91 nmi), with subsequent injection (following Centaur second burn) occurring at 537 km (290 nmi) altitude, as opposed to the direct-ascent trajectory, which had a perigee altitude of 925 km (500 nmi). Another aspect of the parking-orbit trajectory was that the coast period would start 2204 km (1190 nmi) down range at the Centaur's first main engine cutoff (MECO-1). The duration of the parking-orbit coast period would vary not only throughout the daily launch window but also from day to day throughout the launch opportunity. Typical cases are shown in Fig. 9. In either case, typical spacecraft velocities were 7803 m/s (25,600 ft/s) at the start of the parking-orbit coast, and 14,326 m/s (47,000 ft/s) at injection (TE-364-4 burnout). Spacecraft separation would occur at 593 km (320 nmi) altitude for a typical parking-orbit mode as opposed to 925 km (500 nmi) using the direct-ascent mode.

The foregoing parking-orbit mode sequence was expected to last approximately one hour and would be a very critical period for the Near-Earth Phase Network (NEPN). Besides processing launch vehicle/spacecraft telemetry to obtain launch sequence (mark) events, the NEPN would have to obtain and process AFETR/STDN radar metric data and process it through the AFETR Real-Time Computing Facility (RTCF) to generate station predicts for the downrange NEPN stations as well as for the DSN initial acquisition station. Since the latter would be difficult to process prior to spacecraft rise at Canberra, the Australia stations would have to be provided with preflight nominal DSN predicts as a backup. In either event, the NEPN-generated radar metric data would be used in conjunction with DSN radio metric data for the Project's first post injection spacecraft orbit determination.

3. Initial DSN Acquisition (Mission Phase I)

The rapid and successful initial acquisition of the Helios spacecraft by the DSN is a time-critical event even for a nominal launch, since the DSN provides the first opportunity for commanding the spacecraft subsequent to launch. Top priority is the initiation of the first orientation maneuver, which may require a backup command. Also, many other commands have to be entered into the spacecraft as soon as possible after initial DSN acquisition.

The DSN initial acquisition becomes even more time-critical if the Helios spacecraft experiences a nonstandard trajectory injection. It will be extremely critical if a "blind" acquisition is involved. A blind acquisition becomes necessary if a spacecraft overload protection circuit inadvertently shuts off the downlink carrier, which is a distinct possibility during the launch phase. In such an event, commands must be successfully entered into the spacecraft in order to reestablish the downlink, a situation that can become extremely difficult if there is little or no a priori information regarding the condition of the spacecraft. At the same time, the success

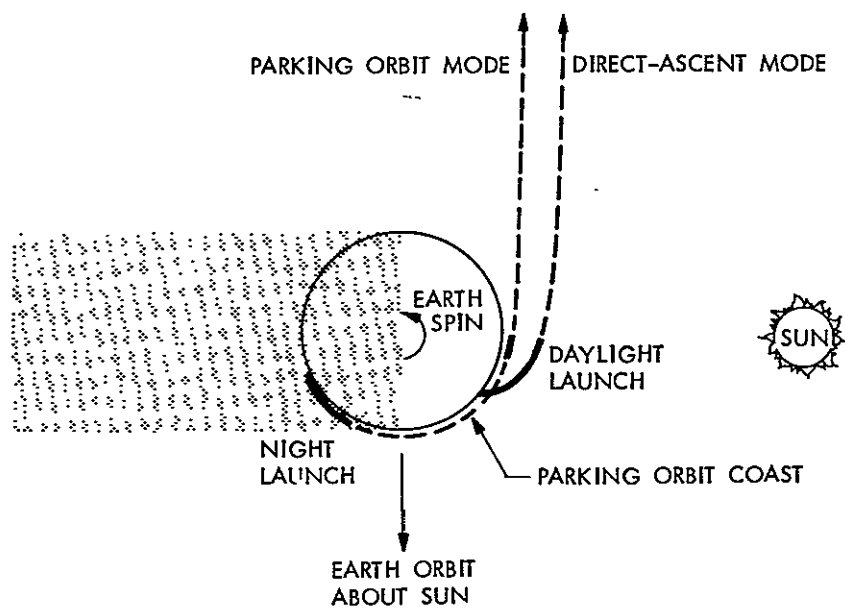


Fig. 10. Night launch vs day launch (viewed from above Earth's north pole)

or failure of a mission depends upon the DSN's ability to reestablish communications with the spacecraft. While on occasion the DSN has faced this problem with other flight projects, Helios is unique in that the spacecraft is launched in the coded telemetry mode. This means that additional steps (time delays) must be taken at the acquiring DSN station before successfully decoded spacecraft telemetry can be sent to the Mission Control and Computing Center (MCCC) for analysis of spacecraft condition.

The time criticality of the initial DSN acquisition is further magnified by the fact that the uncertainty in the true trajectory of the spacecraft becomes larger with increasing time after injection (due to injection uncertainties), together with the fact that the spacecraft is operating on its internal battery until the Step I maneuver can be initiated. Therefore, all of the foregoing factors required that the DSN successfully complete its initial acquisition of the Helios spacecraft within 1 to 2 hours after launch, with 1 hour being the nominal case. To assist the DSN station(s) in minimizing the time for initial acquisition, a listing of the spacecraft's outgoing asymptote declinations for various days throughout the Helios launch opportunity was provided (Table 2). The declination of spacecraft rise at Canberra approaches this outgoing asymptote declination as time from injection increases, which is the converse of the aforementioned injection uncertainties.

4. Step I and II Maneuvers (Mission Phase I)

The next most critical Helios Mission phase, with respect to DSN activities, is the time period encompassing the Step I and II maneuvers and their subsequent events. This criticality ranks second to DSN initial acquisition only because DSN acquisition is a prerequisite to the accomplishment of the mission events associated with these maneuvers. The nominal time period for these maneuvers (and subsequent events) occurs between spacecraft injection and the end of the first Goldstone pass, or at the latest, the end of the third Goldstone pass. Thus, in a general sense, the first 24 to 72 hours following launch represents perhaps the most critical time period with respect to mission success or failure, with both DSN and Project sharing responsibility for the outcome. For convenience, this critical time period was divided into its two major subdivisions: (1) events associated with the Step I maneuver and (2) events associated with the Step II maneuver.

a. Step I Maneuver. The Step I Maneuver occurs automatically or by command to orient the spacecraft solar panels to be fully illuminated by the Sun in order to relieve the load on the spacecraft batteries. During this maneuver, the spacecraft spin axis remains basically in the plane of the ecliptic. Following completion of the Step I maneuver, the spacecraft attitude remains fixed while the Helios Mission Operations Team commands boom extension and then evaluates the condition of the various onboard systems, using spacecraft telemetry. Following this, selected scientific experiments aboard the spacecraft are activated in the near-Earth science mode. The near-Earth science phase is complete by the time the spacecraft reaches lunar distance from the Earth. At this time, the science instruments are deactivated and the spacecraft is readied for the second orientation maneuver (Step II).

b. Step II Maneuver. During the Step II Maneuver, the spin axis is commanded to precess in a direction that will orient it to the pole of

Table 2. Helios parking orbit
outgoing asymptote declination

Launch date	Declination, deg ^a
Dec. 8, 1974	- 5.09
Dec. 11, 1974	- 3.94
Dec. 13, 1974	- 3.16
Dec. 16, 1974	- 2.00
Dec. 19, 1975	- 0.85
Dec. 22, 1975	- 0.03
Dec. 24, 1975	1.06
Dec. 27, 1974	2.19
Dec. 29, 1974	2.95
Jan. 1, 1975	4.00
Jan. 4, 1975	5.19
Jan. 6, 1975	5.94
Jan. 9, 1975	7.07
Jan. 12, 1975	8.18
Jan. 14, 1975	8.92
Jan. 17, 1975	9.99
Jan. 20, 1975	11.03
Jan. 23, 1975	12.03
Jan. 26, 1975	13.02
Jan. 29, 1975	13.97
Jan. 31, 1975	14.59

^aDeclination given is that of the outgoing trajectory asymptote for the opening of the daily launch window.

the ecliptic. As this is done, the medium-gain antenna's pancakelike pattern slowly begins to intercept the Earth. At this time, the spacecraft is commanded to operate with transponder 2 in the duplex mode via the medium-gain antenna. Using the received signal strength at a ground receiving station as an indicator, the spacecraft is commanded to continue precessing its spin axis until the pancake antenna pattern causes a maximum signal strength indication to be achieved on Earth. The maximum is determined by causing the spacecraft to precess beyond its optimum orientation and then return to the optimum position, at which time the spin axis will be oriented toward the pole of the ecliptic. Following completion of the Step II maneuver, the de-spin velocity and phase angle of the high-gain antenna are adjusted by command to direct the spot beam toward Earth. Since the spinning spacecraft is self-stabilized (gyroscopically) in this position (unless unexpectedly perturbed), no further orientation maneuvers should be necessary. All 10 onboard scientific instruments are then activated and commanded to return data via the high-gain antenna at the maximum information rate.

At the completion of the Step II maneuver, the spacecraft is in its "cruise" orientation, an attitude position and configuration it is expected to retain through the lifetime of the mission.

5. First Perihelion (Mission Phase II)

The Helios spacecraft reaches its first perihelion approximately 95 days after launch. The 25-day period surrounding perihelion, (-12, +13) days for Telemetry; (-0, +25) days for Faraday Rotation; (-0, +90) days for Celestial Mechanics, encompasses the region of highest scientific interest since the spacecraft is traversing a heretofore unexplored region of inner solar system space. Therefore, the primary emphasis is upon the return of science telemetry, both in total quantity and in accuracy (extremely low bit error rate), coupled with the accumulation of ground-based science data for the Celestial Mechanics and Faraday Rotation Experiments. Achievement of such a large science data return requires optimum performance on the part of both the spacecraft and the total ground data system (GDS). The spacecraft downlink will be commanded to employ high power and transmit via the high-gain antenna (HGA) to maximize the telemetry return, while the uplink will be received via the spacecraft MGA pancake-pattern antenna in order to provide planetary ranging capability for the Celestial Mechanics Experiment. In the event of a failure of the mechanically de-spun HGA, reasonable quantities of science telemetry could still be obtained via the spacecraft MGA pancake-pattern antenna. In either event, the L-V polarization of both of these antennas will permit data to be obtained for the Faraday Rotation Experiment. For the ground data system portion, considerable coverage is planned by the DSN 64-m stations and the German 100-m receiving station. Since the latter is expected to provide daily coverage from the zero longitude area, the DSN committed 14 passes per week from the DSN 64-m stations at Goldstone and Australia. The German receiving station is not capable of providing either doppler or planetary ranging data, but is capable of providing Faraday rotation data. Therefore, with the exception of a possible gap between stations, the Helios ground data system plan anticipated full Helios coverage by large-aperture antennas during the scientifically important perihelion passage of the Helios spacecraft.

6. Occultation (Mission Phase II/III)

As noted in Fig. 7, the perihelion passage region merges into the region of the first solar occultation. The entry into the first solar occultation is considered part of the Helios Primary Mission (i.e., Mission Phase II). Therefore, the same ground data system resources are committed as for the first perihelion passage. In addition to the science telemetry data obtained near first solar occultation, the radio metric data obtained between perihelion and first solar occultation are particularly important for the Celestial Mechanics and Faraday Rotation Experiments.

The Helios Primary Mission (Phase II) concludes upon spacecraft entry into the first solar occultation blackout. However, the exact Sun-Earth-probe angle at which occultation occurs is unpredictable. Further, the Helios trajectory is unique in that the spacecraft experiences multiple solar occultations (between perihelion passages), all of which occur well within the first year after spacecraft launch. Therefore, the 180 days following entrance into first solar occultation (initial portion of Mission Phase III) represents a time period of extreme interest to the ground-based

experimenters (Celestial Mechanics and Faraday Rotation). Use of the DSN 64-m stations at Goldstone and Australia is committed for the solar occultation period, but only on a negotiated-schedule basis with other users.

The communications blackout associated with these solar occultations can vary from a few days to several weeks, depending upon the final trajectory, launch day and blackout of interest. Spacecraft emergence from solar blackout is a time of uncertainty for both the Helios Project and for the DSN. This uncertainty is due to a lack of scientific knowledge regarding the characteristics of the solar corona and to unknown risks since the spacecraft may have been unattended for a considerable period of time. The former uncertainty can be accommodated by routine DSN "spot checks" to determine if the spacecraft signal has reappeared at its predicted celestial location. However, as time goes on without DSN reacquisition of the downlink signal, suspicion arises regarding the condition of the spacecraft. The latter requires more sophisticated techniques by both the DSN and the Project to experimentally attempt to reestablish downlink communications, and, if necessary, even to send blind commands to the spacecraft in the hope of reactivating a usable downlink transmission mode.

7. Extended Mission (Mission Phase III)

Although by international agreement Helios Mission Phase III starts at the spacecraft's first entrance into solar occultation, one can consider that the Helios Extended Mission truly starts with the spacecraft's second perihelion passage, because the period between first and second perihelion is required by the Celestial Mechanics and Faraday Rotation Experiments. It can be reasonably anticipated that the Helios Project will request continued support from the DSN 64-m antenna stations (as well as from the German 100-m receiving station) through second perihelion, with the understanding that any scheduled support would be on a negotiated basis with other flight projects/users of these facilities. Therefore, the 64-m DSN support requirements for second perihelion can be expected to be the same as for the first perihelion passage.

Following the second perihelion passage, the Helios spacecraft returns to the vicinity of Earth for approximately one-half year (Fig. 7). During this period it can be expected that only intermittent coverage would be required to insure the continued satisfactory operation of the spacecraft. Following this, the spacecraft makes its third perihelion passage, which again has high scientific interest. At the conclusion of the latter, the spacecraft will have reached its design lifetime of 18 months in solar orbit.

D. TELECOMMUNICATIONS LINK DESIGN

The Helios telecommunications link provides six different spacecraft telemetry modes which can be transmitted at 10 separate bit/symbol rates, in communication with either the 26- or 64-m antenna stations within the Deep Space Network or with the West German 100-m antenna receiving station at Effelsberg. Since the number of such combinations far exceeded that needed to accomplish mission objectives, the Helios Project Office chose to restrict nominal mission design to the 21 combinations listed in Table 3. While this does not imply that other combinations cannot be used under abnormal or emergency conditions, these 21 preselected telecommunications links will provide ample flexibility to accomplish mission objectives while

Table 3. Required Helios communication links.

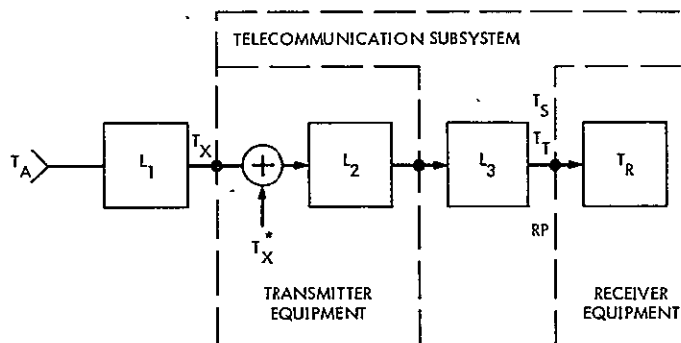
Link number	Ground station	Spacecraft antenna	Maximum range, AU	Channel bit rate, bps	Command capability	Ranging capability
1	26 m	Low	0.1	64	Yes	---
2	26 m	High	0.4	2048	Yes	---
3	26 m	High	1.3	128	Yes	---
4	26 m	High	1.6	64	Yes	---
5	26 m	High	2.0	8	Yes	---
6	64 m	High	0.4	2048	Yes	Yes
7	64 m	High	1.3	128	Yes	Yes
8	64 m	High	1.6	64	Yes	Yes
9	64 m	High	2.0	8	Yes	Yes
10	100 m	High	1.6	2048	Yes	---
11	64 m	Low	2.0	---	Yes	---
12	26 m	Medium	0.1	2048	Yes	---
13	26 m	Medium	0.3	128	Yes	---
14	26 m	Medium	0.4	64	Yes	---
15	26 m	Medium	0.8	8	Yes	---
16	64 m	Medium	2.0	8	Yes	---
17	100 m	Medium	0.3	2048	Yes	---
18	100 m	Medium	1.3	128	Yes	---
19	100 m	Medium	1.5	64	Yes	---
20	100 m	Medium	2.0	8	Yes	---
21	64 m	High	1.0	4096	Yes	---
22	Near Earth			64	Yes	---

at the same time not impose undue constraints upon the spacecraft from a thermal, electrical power, or attitude control system viewpoint.

The performance of any telecommunications link is obviously dependent upon the amount of power transmitted, the gain of the transmitting and receiving antennas, the distance (i.e., loss) between the transmitter and receiver, and, of course, the information bandwidth to be transmitted. In addition, there are losses internal to the transmitter and receivers themselves. Many of these parameters are usually either preestablished or represent the desired solution from an analytical calculation of telecommunications link performance. For instance, the transmitter/receiver losses associated with the DSN stations are well known from prior experience. In contrast, the losses associated with the spacecraft transmitter/receiver are not usually known accurately until at least a working model of the spacecraft has been fabricated. To compensate, an early analytical model of the spacecraft together with stringent specifications concerning its telecommunications design performance is needed prior to the actual fabrication of spacecraft hardware. These are developed to insure that the actual spacecraft design can be made to meet its mission objectives. The analytic model used for the Helios telecommunication subsystem losses is depicted in Fig. 11. The values used in computing these losses for the various links depicted in Table 3 were taken from the Project Office's specifications to the spacecraft prime contractor and, as such, represented the best data available at that time.

1. Uplink Considerations

The DSN was requested to provide continuous coverage to the Helios spacecraft from initial acquisition through completion of the primary mission (i.e., first solar occultation). The spacecraft design goal was for this coverage to be provided by the DSN 26-m stations, with occasional coverage being provided by the DSN 64-m stations for mission enhancement purposes. For the 0.31 AU Helios trajectory, first solar occultation would occur at a range of 1.6 AU from Earth (Fig. 7). If the mission was nominal, the spacecraft would be oriented such that after the first DSN Goldstone pass its medium-gain antenna pattern would be directed toward Earth from that time onward through perihelion and solar occultations to the end of the spacecraft lifetime. If such were the case, the uplink performance from the DSN to the spacecraft would be as depicted in Fig. 12. If not, the uplink signal would have to be received by the spacecraft low-gain (omni) antenna whose performance is depicted in Fig. 13. In the latter case, the transmission of commands via the 26-m links would become somewhat questionable at a range of 1.6 AU. However, two alternatives were possible: (1) transmit the command via a 26-m station that had 20-kW power output capability, or (2) transmit the commands via the DSN 64-m station. Since either of these represents a reasonable alternative solution to a situation that would only occur during a nonstandard mission, the performance of the link between a DSN 26-m antenna and the spacecraft low-gain antenna at a 1.6 AU range from Earth was not considered a serious problem at the time. In contrast, the performance of the uplink for a standard mission, as shown in Figure 12, appeared comfortably adequate to meet all primary objective missions.



$$T_S = T_R + T_0 \frac{L_3 - 1}{L_3} + T_0 \frac{L_2 - 1}{L_2 L_3} + \frac{T_X^*}{L_2 L_3} + T_0 \frac{L_1 - 1}{L_1 L_2 L_3} + \frac{T_A}{L_1 L_2 L_3}$$

- L_1 LOSSES (>1) OF ANTENNA CABLING
- L_2 LOSSES (>1) OF DIPLEXER
- L_3 LOSSES (>1) OF CONNECTION CABLING BETWEEN TRANSMITTER AND RECEIVER EQUIPMENT
- RP REFERENCE POINT
- T_A ANTENNA NOISE TEMPERATURE
- T_R RECEIVER EQUIPMENT NOISE TEMPERATURE
- T_S SYSTEM NOISE TEMPERATURE
- T_T TELECOMMUNICATION SUBSYSTEM NOISE TEMPERATURE
- T_X TRANSMITTER EQUIPMENT NOISE TEMPERATURE
- T_X^* NOISE FROM TRANSMITTER POWER STAGES AFTER NOTCH FILTERS

Fig. 11. Helios spacecraft analytical model

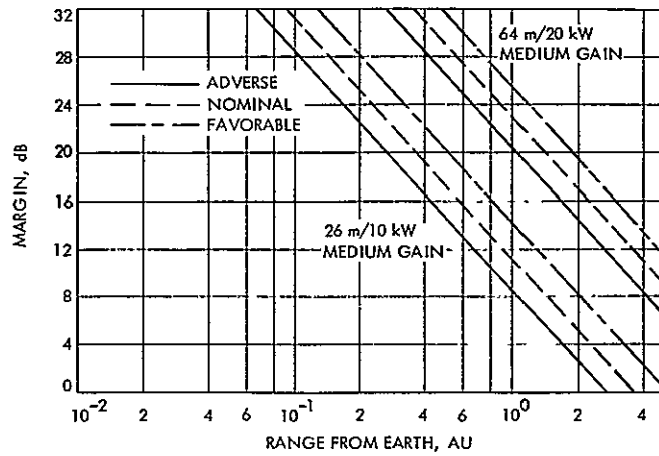


Fig. 12. Predicted Helios spacecraft medium-gain antenna uplink performance margin

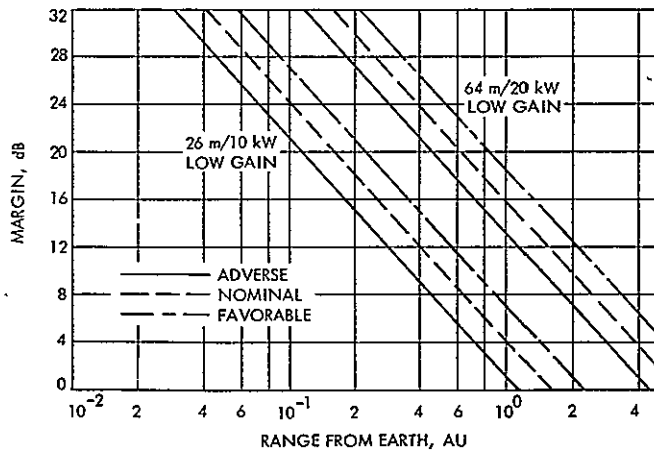


Fig. 13. Predicted Helios spacecraft low-gain antenna uplink performance margin

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2. Downlink Power Modes

As mentioned, the Helios spacecraft has several downlink power output levels that can be chosen via ground command. In addition, the spacecraft telecommunications system has redundant channels for generating the downlink signal in order to provide reliability through redundancy. These are shown in Fig. 14. Obviously, the circuit losses associated with these various paths would differ, even for the same nominal power output level. However, the exact value of these losses had to await the construction of actual spacecraft hardware. For the purposes of this discussion, it will be assumed that the path loss for any given spacecraft power output level is the same regardless of which channel is in use at a particular time.

3. Downlink Performance

The Helios downlink contains spacecraft telemetry and, upon occasion, a turnaround ranging signal. Since the latter is used infrequently (see Table 3), it will be discussed separately. A reasonable measure of the performance of the telemetry portion of the downlink is the maximum information bit rate that can be transmitted over a given distance from the spacecraft to Earth. Since the bit rate from the spacecraft can only be changed in steps of a factor of 2, a plot of the maximum bit rate vs spacecraft distance from Earth will appear to be a stair-step drawing. Further, multiple stair steps can be drawn depicting the adverse, nominal, and favorable tolerances associated with the individual entries within the telecommunications link analysis calculations.

a. Telemetry Performance to a 26-m Station. An April 1971 prediction of the Helios downlink telemetry performance⁸ to a DSN 26-m station is shown in Figs. 15 and 16. Figure 15 depicts the link via the spacecraft medium-gain antenna; Fig. 16 depicts the link via the spacecraft high-gain antenna. Both figures are for the spacecraft high-power (i.e., 20-W) mode; however, a conversion factor is provided for the medium-power (i.e., 10-W) mode. From these figures it can be seen that if the spacecraft's de-spun high-gain antenna is working properly and the spacecraft is capable of transmitting in its high-power mode, bit rates of 256 bps should be possible out to 1.6 AU from Earth. However, if either the medium-gain antenna or the medium-power mode has to be used, the telemetry performance from perihelion (i.e., 1.0 AU) would be marginal.

b. Telemetry Performance to 64-m Station. The predicted Helios telemetry performance at perihelion (1.0 AU) and again at first solar occultation (1.6 AU) improves considerably with the use of a DSN 64-m station, as can be seen from Figs. 17 and 18. For a completely standard mission, it is theoretically possible to receive 4096-bps telemetry from perihelion and 2048 bps up to first solar occultation (Fig. 18). However, if a failure

⁸The April 1971 link performance estimates were employed to ascertain that the Helios spacecraft radio system specifications were adequate to achieve the mission objectives. As the equipment completed fabrication and underwent testing, the telecommunication link design predictions were updated to permit the development of an actual mission sequence for the flight spacecraft.

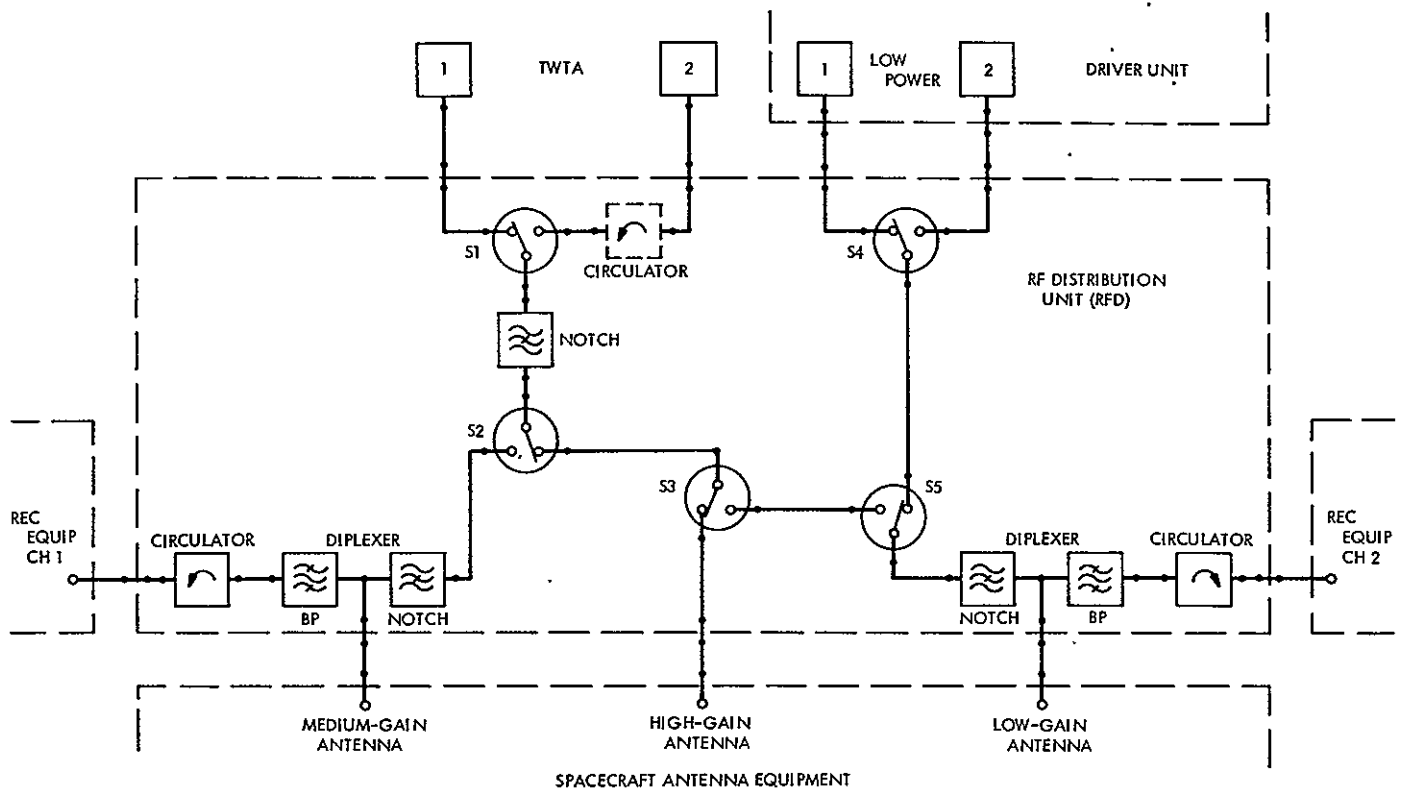


Fig. 14. Helios RF signal distribution block diagram

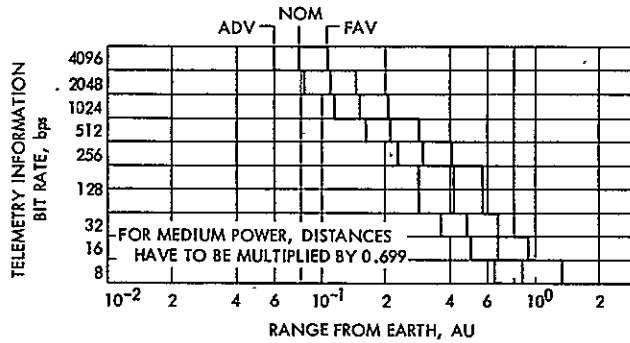


Fig. 15. Helios spacecraft medium-gain antenna (high-power mode) downlink to 26-m antenna

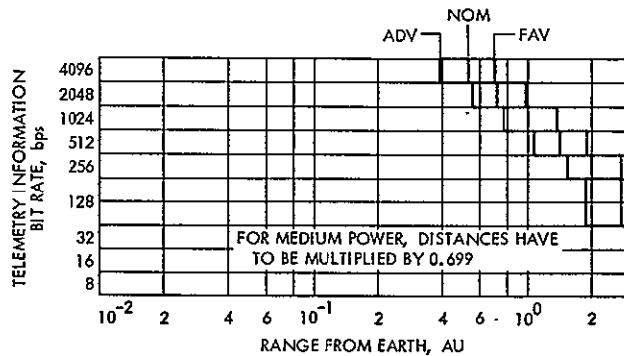


Fig. 16. Helios spacecraft high-gain antenna (high-power mode) downlink to 26-m antenna

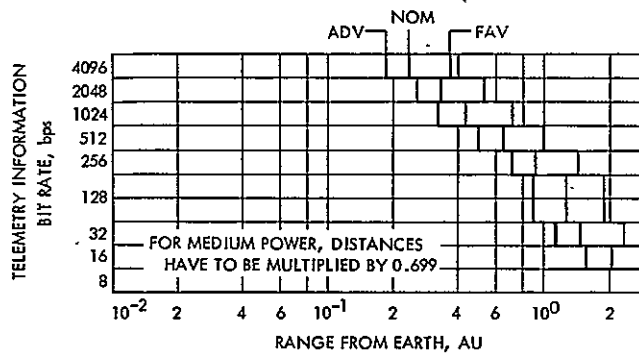


Fig. 17. Helios spacecraft medium-gain antenna (high-power mode) downlink to 64-m antenna

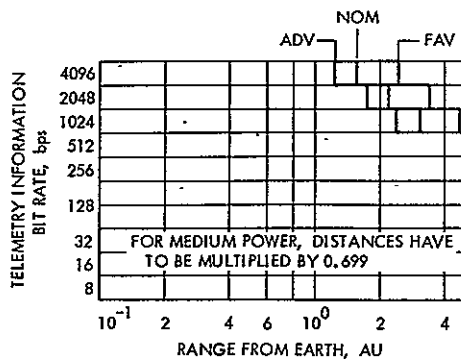


Fig. 18. Helios spacecraft high-gain antenna (high-power mode) downlink to 64-m antenna

occurs in the spacecraft high-gain antenna, these telemetry bit rates would be reduced to 32 bps at perihelion and 16 bps at first solar occultation for the case of adverse tolerance (Fig. 17).

c. Telemetry Performance to 100-m Antenna. A representative case of the predicted Helios telemetry performance to the West German 100-m antenna located at Effelsberg is shown in Fig. 19. Since this is for the spacecraft medium-gain antenna case, the maximum bit rates at perihelion and first solar occultation are 256 and 32 bps, respectively.

d. Ranging Performance. The DSN Planetary Ranging System in a 64-m station will be used around each solar occultation of the Helios spacecraft to provide data for the Celestial Mechanics Experiment. The uplink range code will be transmitted by the 64-m stations to the spacecraft medium-gain antenna and then to the transponder in the turnaround ranging mode for retransmission back via the spacecraft high-gain antenna to the originating 64-m station, where the received code will be correlated with the transmitted code. The principal criterion for the performance of the ranging loop is the time required for the 64-m stations to acquire and correlate the received code with the transmitted code. The predicted time, which is in addition to the round-trip light-time for the RF signal to travel from the station to the spacecraft and return to the station, is plotted in Fig. 20. Of particular interest is the region between 1.0 and 2.0 AU from Earth, since the Helios solar occultation occurs between 1.6 and 2.0 AU from Earth. Under the most favorable conditions, this acquisition time is between 1 and 2 min, while under the most adverse conditions the acquisition time can be in the region of 40 to 80 min. Nonetheless, range code acquisition times of one hour will still permit several unique range measurements to be made during any one 64-m antenna station's available view period for the Helios spacecraft. Therefore, the predicted performance of the ranging loop appears to satisfy mission requirements.

4. Conclusions

From the foregoing, one may conclude that the Helios radio system design can meet its mission objectives via these telecommunications links, providing, of course, that the detailed radio system specifications are met and that the spacecraft flies a nominal mission. However, to achieve certain objectives, support is required from the DSN 64-m and/or Effelsberg 100-m antennas when the range exceeds 1 AU, i.e., beyond perihelion. The greatest uncertainty in achieving mission objectives lies in the assumption of a "nominal mission." For instance, an unexpected failure of the mechanically de-spun high-gain antenna could significantly reduce the amount of telemetry (data rate) and/or ranging data (Celestial Mechanics Experiment) that can be obtained at perihelion (1 AU) and beyond. Nonetheless, a meaningful mission can be accomplished using only the spacecraft medium-gain antenna system, which is practically free of such potential mechanical failures.

Another conclusion that can be drawn is that the telecommunications link performance is dependent upon having proper spacecraft attitude orientation. For instance, an attitude control system failure that would preclude the spacecraft's medium gain antenna pattern from impinging upon Earth (or doing so only intermittently) would also preclude the high-gain antenna from being directed toward Earth. Such a situation would force the use of the spacecraft's omnidirectional antenna system, which would greatly

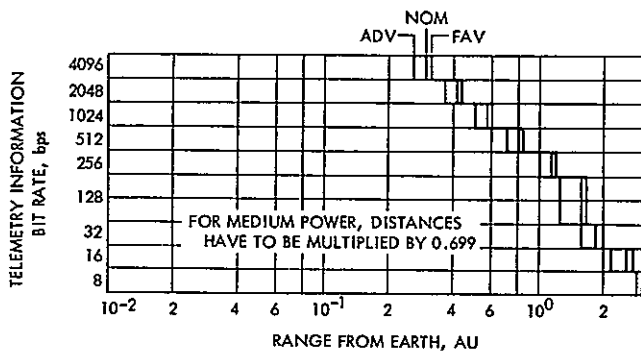


Fig. 19. Helios spacecraft medium-gain antenna (high-power mode) downlink to 100-m antenna

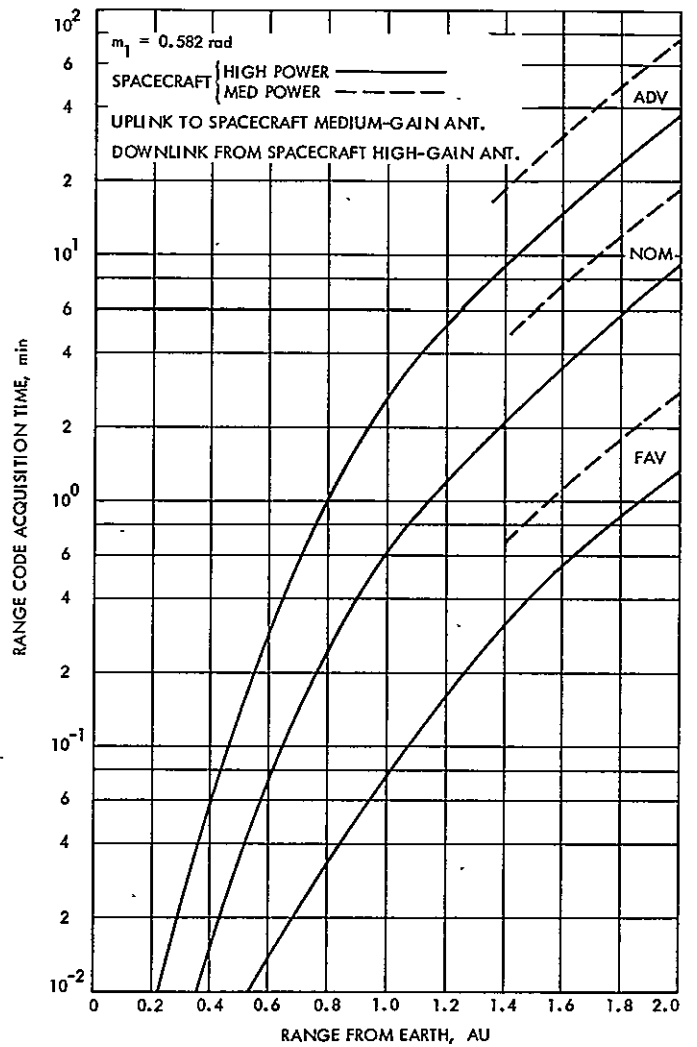


Fig. 20. Predicted 64-m/20-kW continuous spectrum ranging system performance

reduce the maximum distance from Earth that one could communicate with the spacecraft, even at the lowest data rates. However, even in such a situation, some telemetry data should still be received at perihelion or even from first solar occultation, using the 64- and 100-m ground antennas.

The foregoing two examples are considered the most serious sources of potential failure in the telecommunications link design, because most of the electronics in the spacecraft radio system has been redundantly designed.

In summary, one may conclude that, barring a catastrophic failure in the spacecraft attitude control system, the predicted Helios telecommunications link design provides ample optional modes for a meaningful mission.

III. PROJECT MANAGEMENT

A. GENERAL

The publication of the Helios Mission Definition Report in April 1969 was followed by a "Memorandum of Understanding" between NASA Administrator Thomas Paine and German Science Minister Gerhard Stoltenberg in June 1969 and by joint statements by President Nixon and Chancellor Kiesinger of West Germany in August 1969. These documents ratified the activities to date and established the basis for future relationships between the two countries. The Project would be managed jointly by both countries, with each co-manager being responsible for those elements assigned to his country. The West German Project Manager was assigned the responsibility for the design, development, and fabrication of the spacecraft, plus the overall mission design and operation. The U.S. Project Manager was assigned the responsibility for the launch vehicle, launch facilities, and the tracking and data systems. Of the onboard experiments, seven of the 10 were to be of German origin and three of U.S. origin. The integration of all 10 experiments into the spacecraft, however, would be the responsibility of the West Germans. Each country would be responsible for providing the funding necessary to accomplish its portion of the project. Coordination was achieved by holding semiannual meetings. These meetings, known as Helios Joint Working Group Meetings (HJWGM) were held alternately between the two countries. The first HJWGM was held in September 1969 in Bonn, West Germany. The tenth HJWGM, the last prior to the launch of the first Helios spacecraft, was held at JPL in May 1974.

B. INTERNATIONAL MANAGEMENT

In addition to the scientific objectives, it was important to develop a broad governmental-educational-industrial technological base within the Federal Republic of Germany to conduct space research. Therefore, the West German participation in the Helios Project was not solely restricted to the development of the spacecraft and the mission design, but also included the development of German tracking facilities, a German control center, and a full mission operations organization to conduct the mission. In addition, the international agreement provided for the cross-training of a significant number of West German specialists at various NASA installations in order to learn U.S. techniques pertaining to space exploration. These factors, together with the international character of the project, account for the "committee-like" structure of the Helios Project Management Organization shown in Fig. 21.

The upper lefthand quadrant of Fig. 21 depicts the familiar NASA flight project organizational structure wherein NASA Headquarters assigns the project management responsibility to one of its field centers, with functional support in specific areas being provided by other NASA field centers. The significant difference here is that only some of the elements comprising a total flight project are represented. The missing elements appear on the West German side of the interface in the upper-right-hand quadrant, along with some new elements due to the factors mentioned above. The West German Helios Project management is seen to parallel and complement the U.S. Helios Project organization so that, in total, the top half of Fig. 21 represents the formal

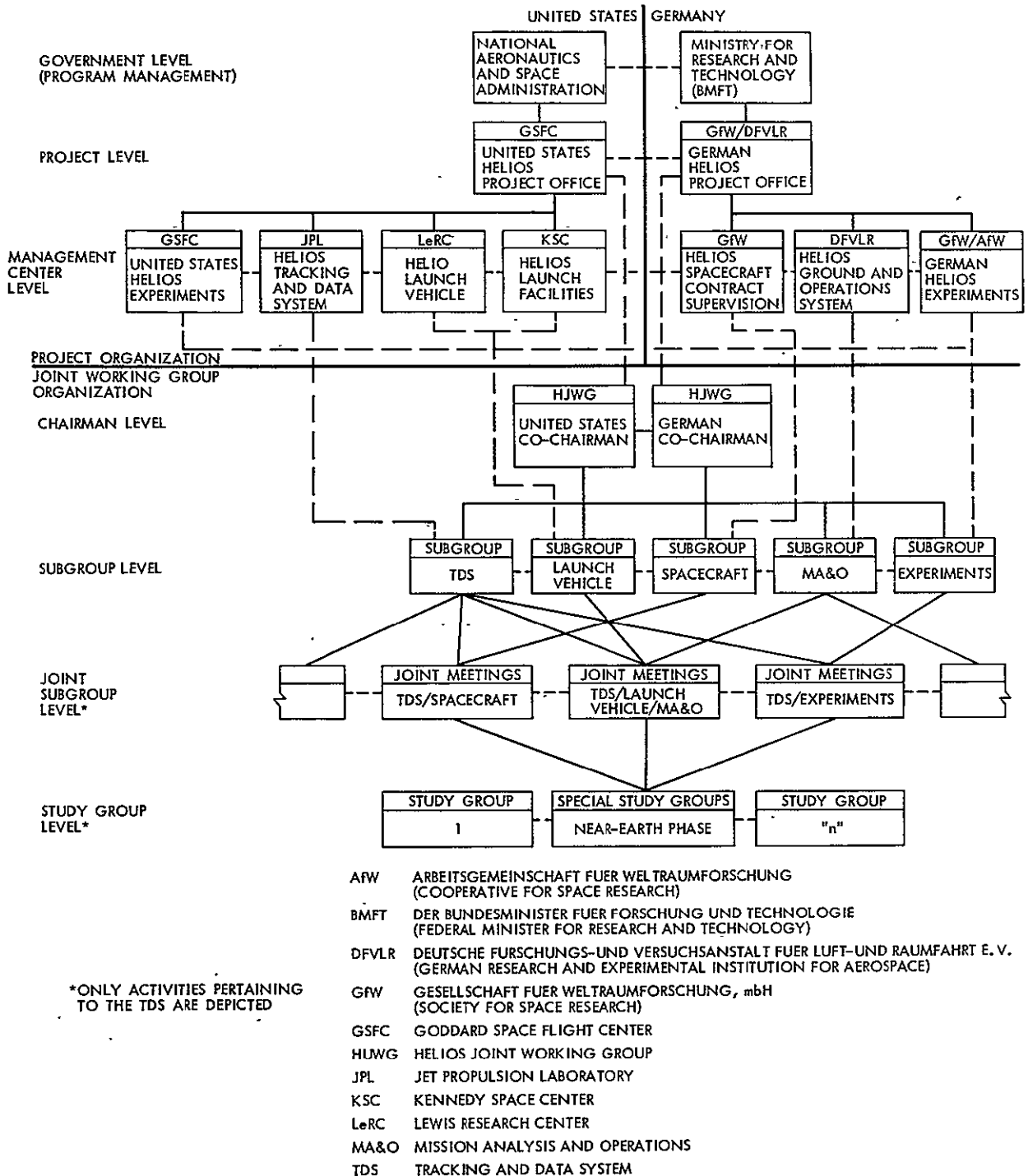


Fig. 21. International management organization

international project organization for Project Helios. An important advantage of this formal structure is that it provides a clear and distinct division of responsibility between the two countries in the administration, technical supervision, and financial management of the Helios Program.

The technical coordination of the two-country effort is accomplished via the Helios Joint Working Group (HJWG) activities. The Helios Joint Working Group organizational structure is depicted in the bottom half of Fig. 21. In accordance with the international agreement, the Joint Working Group Meetings were co-chaired by the U.S. and West German Helios Project managers, respectively. Reporting to them are the chairmen of the various technical subgroups that support the project. These subgroup chairmen are the same individuals who have been assigned the equivalent functional responsibility in the formal project organization depicted in the top half of Fig. 21. However, the subgroup panel membership within each of these technical subgroups is fairly evenly divided between the U.S. and West German representatives in order to achieve internationally optimum solutions to problems facing the Project. During the semiannual Helios Joint Working Group sessions, these subgroups met both individually to resolve problems within their own areas of specialization and jointly to resolve problems associated with the interface between the areas of technical responsibility. When necessary, the activities of the subgroups were augmented by special task or study groups assigned to investigate in detail a particular aspect of the program. A successful example of the latter was the establishment during the third HJWG session in October 1970 of a special study group to develop a typical near-Earth phase sequence of events (SOE) following launch in order to determine that the spacecraft design as contemplated would fulfill all operational constraints upon the mission. This study group was chaired by the Mission Analysis and Operations Subgroup, and its membership was comprised of representatives from each of the other subgroups.

The technical decisions (such as the above example) reached under the auspices of the Helios Joint Working Group Meetings are reviewed by the co-chairmen. Upon their approval, these decisions are routed via the respective project office to the formal organization (top portion of Fig. 21) for implementation. In the case of decisions affecting the U.S. Tracking and Data System (TDS), these were routed to JPL as the cognizant NASA field center for Helios TDS management. The NASA TDS function for Helios has two major subdivisions: (1) support from the near-Earth phase facilities called the Near-Earth Phase Network (NEPN), and (2) support from DSN. The near-Earth phase facilities have TDS responsibility from launch up to that portion of the trajectory wherein the DSN has continuous visibility of the spacecraft, at which time the DSN assumes responsibility for the TDS function.

Because of the many operational interfaces, the DSN was given representative membership in the TDS and MA&O Subgroups (center portion of the lower half of Fig. 21). In addition, the DSN was assigned the responsibility for training over 15 West German specialists.⁹ These factors explain why

⁹Further discussion provided in Section IV-A.

the DSN's support to the Helios Project was slightly more complicated organizationally than the support provided to a typical U.S. flight project.

1. International Data Flow

The Helios international data flow is depicted in Fig. 22. In this diagram, the U.S. responsibilities lie basically to the left, while the German responsibilities lie to the right with the interface region lying between the dashed lines.

Within the U.S. responsibilities, the DSN is responsible both for compatibility testing and for data acquisition during the deep space phase. In addition, the DSN provides the use of a part of the joint DSN/STDN facility at Merritt Island, Florida, to process and format Helios telemetry obtained by the near-Earth phase stations. The MCCC processes all spacecraft data received by both the DSN and NEPN to generate the Master Data Record (MDR) computer tapes which are prepared in duplicate and forwarded to the respective country's data centers. The MCCC also provides the Helios Mission Support Area (MSA) for Mission Phase I.

The German data flow responsibilities follow a similar structure. During time periods when the German stations are tracking, their data flow is direct to the German Space Operations Center (GSOC), where MDR tapes are prepared for that time interval. These German MDR tapes are also made in duplicate and forwarded to the same Data Centers for conversion into the individual Experimenter Data Record (EDR) computer tapes. However, for both convenience and economy, all of the German Control Center functions were combined within one facility, as shown by the dotted box in the right-hand portion of Fig. 22.

2. JPL/Helios Funding and Management Organizational Structure

The U.S. portion of the Helios Ground Data System shown in Fig. 22 is composed of both NASA and AFETR elements. Those elements within the cognizance of JPL are depicted in the lower portion of Fig. 23, which also depicts the division of funding and organizational responsibility between the Office of Tracking and Data Acquisition (OTDA) and the Office of Space Sciences (OSS) at NASA Headquarters. It is important to note that the funding for Helios support at JPL has three separate and distinct routes, each of which requires separate financial reporting of expenditures. However, with respect to the DSN, both the funding and the organizational responsibility follow conventional lines.

3. DSN/German Network Interfaces

The primary responsibility for data acquisition during the Helios (primary) mission rests with the NASA TDS organization, but during mission Phase II, tracking facilities within West Germany are utilized in conjunction with the DSN. Utilization of these German facilities is provided in a mission-independent manner; i.e., cross support is negotiated and conducted on a network-to-network basis. Therefore, the network interface is operationally independent of the DSN/Project data interface. The physical interface between the two networks is provided by administrative teletype messages and voice circuit coordination.

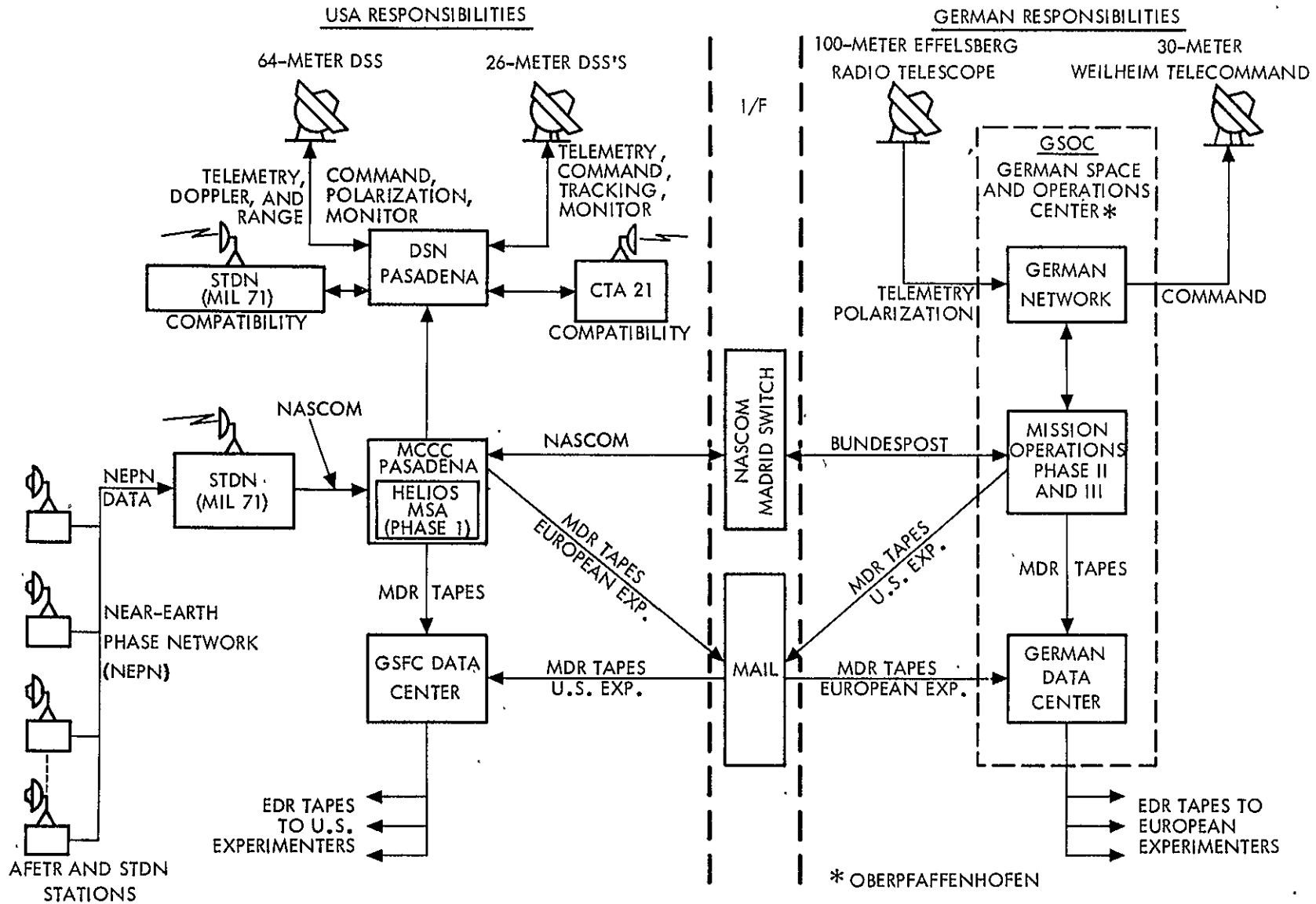


Fig. 22. Helios international data flow

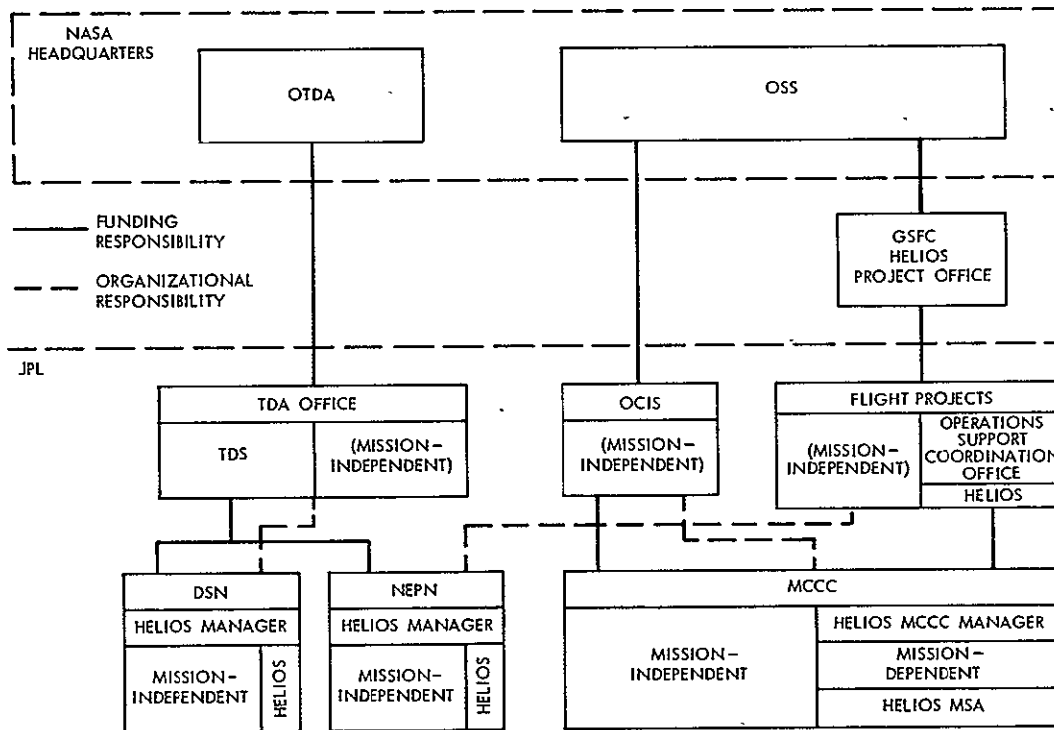


Fig. 23. JPL/Helios funding and management organization structure

4. German Network Cross-Support

During mission Phases II and III, the German Network stations at Effelsberg (near Bonn) and Weilheim (near Munich) are to provide extensive Helios support from the 0 deg longitude region. However, owing to their extreme northerly latitude and local land mask conditions, the German Network stations may not be able to provide continuous coverage in conjunction with the DSN stations in Australia and Goldstone, which could necessitate some "fill in" coverage from the Madrid Deep Space Stations on the days that the German Network is assigned tracking responsibility. Regardless of whether or not this "fill in" coverage happens to be scheduled on a particular day, cross support by the German Network requires careful coordination during all handovers, etc. In addition, there are normal administrative requirements, such as scheduling, which require near-continuous network-to-network operational interfaces. Agreements regarding this network-to-network interface were negotiated during the Helios Joint Working Group meetings. At the request of the Project, these internetwork management plans and operational procedures, though jointly prepared, appear as part of the Helios Ground and Operations System (HGOS) Management Plan.

C. TDS MANAGEMENT

The Tracking and Data System (TDS) provides support to Helios for all tracking and data acquisition (TDA) activities required to meet mission objectives. The tracking and data function is defined as the acquisition and transmission of information to/from the spacecraft that enables the determination of space vehicle position, velocity, direction, system and subsystem performance, and experiment measurements, all with respect to a common time base.

The TDS actually is an operationally unified collection of TDA resources. The required resources are provided by organizations under the Department of Defense (DOD), Goddard Space Flight Center (GSFC), Kennedy Space Center (KSC) and JPL, referred to collectively as the TDA Support Agencies.

Five major organizations provide facilities and support for the TDS, with JPL designated as the TDA Support Center for the Helios mission and thereby responsible for overall achievement of the TDA objectives and functions.

1. TDS Elements

a. Air Force Eastern Test Range (AFETR). A network system of fixed tracking stations, special ships, and Advanced Range Instrumentation Aircraft (ARIA) is maintained and managed for DOD by AFETR. This system and the Spaceflight Tracking and Data Network (STDN) managed by GSFC complement each other to give flight projects the near-Earth phase coverage for the tracking and data acquisition function.

The AFETR Tracking Network has the capability to either skin-track (surface reflection) or beacon-track launch vehicles with radar stations to generate metric data for vehicle flight path determination. This network also has the capability to receive the various launch vehicle and spacecraft telemetry RF transmissions and, when necessary, to command midflight destruction of wayward launch vehicles.

The telemetry and metric data are transmitted to the Cape Canaveral Air Force Station and the Kennedy Space Center for appropriate processing and/or retransmission to the Launch Control Center or the Mission Operations Center. In addition to the NETDS support, the AFETR manages the test range facilities, supports the launches with Range Safety Control, and provides many technical and administrative services for Launch Preparations and Operations.

The AFETR is organized and functionally implemented through the major tracking and receiving sites located at the Cape Canaveral Air Force Station (CCAFS), Grand Bahama Island, Grand Turk Island, Antigua Island, and Ascension Island. Several Advanced Range Instrumented Aircraft (ARIA) are available for telemetry tracking also. Technical resources such as the Real-Time Computer System for processing radio metric tracking data are located at the CCAFS; the administrative headquarters are located at Patrick Air Force Base (PAFB), Cocoa Beach, Florida. AFETR supports these sites with an extensive submarine cable and microwave RF link communications network system. The airborne tracking stations (ARIA) are hangared at PAFB; range tracking ships are serviced at Port Canaveral.

Project support required from the AFETR agency is coordinated by the JPL/ETR field station organization which interfaces with the AFETR via the NASA Test Support Office, a KSC organization located at Merritt Island, Florida.

b. Spaceflight Tracking and Data Network. The Spaceflight Tracking and Data Network (STDN) is a worldwide complex managed by GSFC to provide communications with both manned and unmanned spacecraft. The prime functions are tracking for flight path determination, receiving telemetry RF transmissions, and implementing and instrumenting RF link ranging. For manned spacecraft, voice and video links are also provided.

The STDN is operationally controlled from GSFC (Greenbelt, Maryland) and is organized and functionally implemented through the tracking and receiving sites located at Merritt Island (Florida), Ascension Island, Santiago (Chile), Bermuda Island, Johannesburg (Republic of South Africa), Grand Canary Island, Engineering Training Center (Maryland), stations at Goldstone (California), Guam Island, Hawaii, Madrid (Spain), Ororral Valley (Australia), Quito (Ecuador), Rosman (North Carolina), Tananarive (Malagasay Republic), Fairbanks (Alaska), and Winkfield (England). A central computing facility (at GSFC) provides the computational capability required for STDN operations and analysis. The NASA Communications Network (NASCOM), also managed by the GSFC, provides the worldwide communications for all NASA tracking networks, including the DSN.

Real-time operational control and scheduling of the network is provided by the Network Operations Control Center (NOCC) located at GSFC. GSFC assigns a Network Operations Manager (NOM) for each Project.

Project support requirements are coordinated for JPL by the Near-Earth TDS Coordinator from the JPL/ETR field station.

c. NASA Communications Network. The NASA Communications (NASCOM) global network provides operational communication lines and facilities to carry mission-related information for the conduct of NASA's technical missions,

programs, and projects. The NASCOM network interconnects such facilities as NASA's foreign and domestic tracking, telemetry, and command control stations; launch areas; test sites; mission and network control centers; and in some cases, experiments or principal investigator locations. NASCOM includes all communications circuitry and communications-associated equipment to all sites and stations up to the point of interface with station equipment.

The NASCOM network is organized and functionally implemented through the following key systems:

- (1) The Voice System, known as the switching, conferencing, and monitoring arrangement (SCAMA), provides the service of high-quality local and long distance voice circuits.
- (2) The Teletype System, augmented with computerized automatic switching (discussed below), provides for the preparation, transmission, routing and handling of message and data traffic exchanged between facilities served by direct access to the teletype system.
- (3) The High-Speed/Wideband Data System provides for relaying command, tracking, and telemetry data for spacecraft missions from remote tracking sites to mission control centers.
- (4) The Switching Computer System provides for routing of teletype traffic from any incoming line to any outgoing line in real-time; for all network stations it provides a capability for immediately recalling traffic and for monitoring, intercepting, journal accounting, and procedure controlling traffic.

d. Kennedy Space Center. The Kennedy Space Center (KSC) has several facilities which provide the following support to the NE-TDS:

- (1) Central Instrumentation Facility (CIF). The CIF provides the tracking and processing of the launch vehicle telemetry data links as well as processing data received from downrange stations.
- (2) Building AE, Cape Canaveral Air Force Station. Building AE, the Vehicle Telemetry Laboratory, is jointly operated by KSC and Unmanned Launch Operations (ULO) personnel to process and display the launch vehicle telemetry data for the entire Near-Earth Phase Network. In addition, communications, mark event readouts, and other operational support of similar nature are also provided.

e. Deep Space Network. The Deep Space Network, operated for NASA by JPL, provides support in the areas of tracking, telemetry, and command transmission for unmanned deep space projects. This support is provided by the DSN through three component facilities: (1) Deep Space Stations, (2) the Ground Communications Facility (GCF), which uses NASCOM facilities, and (3) the Network Operations Control Center. Data and information flow within six basic DSN systems: telemetry, tracking, command, monitor, test

and training (simulation), and operations control, all of which are part of the DSN Mark III System.

2. TDS Management

Normally, the Director of the TDA Support Center designates a TDS Manager to be responsible for the TDA function. As such, he acts as the interface between the Project and the TDS support agencies to match requirements with the capabilities of the support agencies in order to establish a compatible integrated system of TDA resources.

The TDS Manager reviews the NASA Support Instrumentation Requirements Document (SIRD), which in the case of Helios was prepared jointly by the German and GSFC Helios Project Managers and then approved by both the German Ministry and NASA Headquarters: both the Office of Space Sciences and the Office of Tracking and Data Acquisition. After receipt of the SIRD, it is the TDS Manager's function to insure that all project requirements are identified and assigned to one of the supporting DOD and NASA organizations. This action initiates the preparation of a NASA Support Plan (NSP) and the DOD Program Support Plan (PSP). Upon completion, the TDS Manager reviews the NSP and DOD PSP to identify any conflicts, duplications, or possible omissions. By signing and publishing the NSP, he certifies that all support planning was properly located and complete. The TDS Manager is accountable both to the NASA Project Manager to which he was assigned (e.g., Helios) and to the Assistant Laboratory Director for TDA at JPL.

3. TDS Support Configuration

Because of changing flight profiles, spacecraft performance characteristics and varying capabilities with the TDS support elements, major changes are required in the TDS configuration as the spacecraft proceeds from the near-Earth phase to the deep space phase of flight. Tracking and Data System preflight planning and flight operations support are oriented to coincide with these two phases. Therefore, the TDS Manager appoints network managers who establish the system configurations for the near-Earth phase and for the deep space phase respectively.

a. Near-Earth Phase. The near-Earth phase begins with the launch countdown and ends when the spacecraft is in continuous view of the DSN stations. Normally, resources from at least three support agencies comprise the configuration for the near-Earth phase: Data acquisition is provided by the AFETR land stations, ships, and aircraft, and by STDN stations in the near-Earth zone of operations; the data are forwarded via NASCOM facilities. In addition, KSC, a NASA field installation, manages certain instrumentation facilities available for TDA support. The type of support required from each of these elements is arranged through appropriate existing documentation. The KSC also serves as the NASA single point-of-contact with the AFETR; i.e., support required from AFETR is contracted through the KSC.

For Helios near-Earth phase, the TDS made available resources from AFETR, KSC, STDN, and the NASA Communications System.

b. Deep Space Phase. The deep space phase begins when the DSN achieves continuous view of the spacecraft and continues until the end of

mission. Normally, only one facility at each of the three DSN longitudes is required at a time to support data acquisition and processing requirements during this phase. The NASCOM and GCF resources are employed for data transmission.

D. JPL/TDA REORGANIZATION

At the seventh HJWGM in 1972, the TDS Manager announced that NASA Headquarters had redefined the responsibilities of the Office of Space Sciences (OSS) and the Office of Tracking and Data Acquisition (OTDA) and as a result there had been a reorganization within the JPL/TDA management structure and the DSN.

Prior to this reorganization the DSN had been a highly efficient independent organization composed of three elements:

- (1) A global network of 26- and 64-m-diameter antenna deep space stations.
- (2) A Space Flight Operations Facility (SFOF) at JPL which was the computerized nerve center from which all DSN-supported flight projects were controlled.
- (3) A Ground Communications Facility (GCF) which, in connection with NASCOM, provided the communications link between the Deep Space Stations and the SFOF.

Since January 1, 1964, the network, in addition to the Deep Space Stations and the GCF, had also included the Mission Control and Computing Facility and had provided the equipment in the mission support areas for the conduct of mission operations. The latter facilities were housed in a building at JPL known as the Space Flight Operations Facility (SFOF). The interface change was to accommodate a hardware interface between the network operations control functions and the mission control and computing functions. This resulted in another JPL division being assigned cognizance of the large general-purpose digital computers in the SFOF, which were used for network data processing as well as mission data processing. It also assumed cognizance of all of the equipment in the flight operations facility for display and communications necessary for the conduct of mission operations. As a result of this new division of responsibility, the DSN has undertaken the development of hardware and computer software necessary to do its network operations control and monitor functions in separate computers. This latter activity is known as the Network Control System implementation. A characteristic of the new interface is that the DSN now provides direct data flow to and from its stations (via appropriate ground communications equipment) to the appropriate Mission Operations Center, while performing the Network Operations Control function in an "off-line" mode. Therefore, metric data and science and engineering telemetry from the stations flow directly to the flight project. In the reverse direction the DSN accepts command data from the flight project and directly routes it into the ground communications equipment for transmission to the station and thence to the spacecraft in standardized format.

A description of the three reorganized DSN systems follows:

1. DSN Tracking System

The DSN Tracking System generates precision radio metric data consisting of doppler, range, differenced range vs integrated doppler (DRVID), and angles together with associated data, i.e., status, reference frequencies, data mode, DSS configuration, and GMT. The radio metric data are formatted and transmitted by the GCF High Speed Data subsystem (HSD) to the Helios Project and the Network Operations Control Center (NOCC). Validation of the Tracking System consists of computation and display of pseudo residuals¹⁰, status, mode, and configuration data. During the organizational transition phases these computations and displays are provided by the MCCC to the NOCC. However, when fully implemented the NOCC will have this capability internally.

Predictions required for DSS acquisition of the spacecraft are generated from Project-supplied station-centered (phi factors) spacecraft ephemeris and frequency information computer tapes.

These tracking predictions, consisting of antenna pointing angles, expected range, doppler, uplink frequency, events, and subcarrier frequencies, are generated in the NOCC from a Project-supplied computer tape containing the appropriate polynomials (phi factors). After generation, they are transmitted from the NOCC to each DSS via the GCF High Speed Data subsystem (HSD). At the station, predictions are received by the Digital Instrumentation Subsystem (DIS), where a page print is made for the operations personnel, a paper tape of angles is punched for the Antenna Pointing Subsystem (APS), and a magnetic tape is written for real-time system data validation. During the actual spacecraft track, radio metric data, generated at each DSS, are transmitted to the MCCC for Project use and to the NOCC for system validation.

Radio metric data comprise time-varying range, angles, doppler, DRVID, plus exciter reference frequencies, GMT, configuration, mode, and status. At each station, the radio metric data are sampled by the Tracking Data Handling subsystem (TDH), and transferred to the DIS for formatting and transmitting via the GCF High Speed Data (HSD) circuits. An original data record (ODR) of the radio metric data is generated on magnetic tape for non-real-time recall.

2. DSN Telemetry System

The DSN Telemetry System provides the capability for telemetry data acquisition, decoding, formatting, and transmission to the Mission Control

¹⁰The term "residuals" refers to the computed difference between the theoretically predicted position of a spacecraft along the trajectory and the actual observed position. It is a very powerful mathematical tool for establishing a precise spacecraft trajectory, but is done "after the fact." "Pseudo residuals" are real-time computations based on the predicted trajectory rather than a post-facto corrected trajectory. Being real-time, they quickly disclose any erroneous observed data.

and Computing Center (MCCC), along with independent NOCC validation of the telemetry data. Telemetry data received from the Helios spacecraft are processed and provided to the Helios Project in the form of serial data and digital records streams through the facilities of the DSN.

The Telemetry and Command Data Handling Subsystem (TCD) at each DSS is configured for Helios by a Telemetry and Command Processor (TCP) by inserting the specified software program and by appropriate keyboard typing by the station operations personnel to accept either convolutional coded or uncoded telemetry data.

Telemetry data recall is provided by an Automatic Total Recall Subsystem (ATRS) at each DSS immediately following each station's tracking pass. Any detected data outages selected by the MCCC are extracted from the station's telemetry Digital Original Data Record (DODR) by the ATRS for transmittal to the MCCC, where they are merged with prior received data to enable production of a Helios Master Data Record (MDR).

An analog recording is also made and replay capability is available at each DSN station. The analog recording is performed by the Pre/Post Detection Recording Subsystem from inputs received from the Receiver Exciter Subsystem (10 MHz from receiver and bit-stream telemetry waveform from the Subcarrier Demodulator Assembly). The bit-stream analog recording tapes are used by the stations as backup to the digital ODR.

3. DSN Command System

The DSN Command System provides a highly reliable means of transmitting commands to the Helios spacecraft. Its prime operational mode is characterized by automatic operation of the DSS Command Subsystem via high-speed data (HSD) circuits with control from the MCCC and the NOCC. Backup command capability is provided to allow manual control and entry of command data at the DSS.

The operation of the DSN Command System can be described by defining two periods of operation: a configuration and test period and the actual spacecraft tracking period.

a. Configuration and Test Period. Approximately 30 min prior to spacecraft acquisition by the DSS, all DSN facilities are made available to and are under the cognizance of Network Operations personnel in the Network Operations Control Area (NOCA). From this time until just prior to acquisition, Network Operations personnel perform a DSN interfacility readiness test.

b. During Flight Support Period. Just prior to acquisition, the system is made available to the Project. The Project is capable of loading commands and controlling the Idle 1, Idle 2 and Active modes of the TCD (described below). However, during critical or special command sequences, as required by the Project, the DSN Command System can be scheduled such that commands can be loaded prior to acquisition.

Commands are generated at the MCCC, placed in HSD blocks, and transmitted to the station's telemetry and command processor (TCP). The TCP

command stack provides storage of four HSD blocks of command data. These four blocks (stack modules) consist of up to six command elements each. Each command element can have up to 71 bits of command data and, at the Project's option, the command element can be timed or nontimed. The top command element in the first stack module is eligible for transmission to the spacecraft. Nontimed commands are transmitted immediately after eligibility. Timed commands are transmitted after eligibility and at the time specified in the HSD block. At the time of transmission of the command element, the TCP establishes the proper mode and configuration of the Command Modulator Assembly (CMA). The command will be transferred to the CMA for immediate transmission.

During the process of Project commanding, the NOCC receives all HSD messages being generated by the TCP. DSN Command System verification, alarm diagnosis, and displays to Network Operations personnel are accomplished at the NOCC. In the event of a failure or anomaly in the DSN Command System, Network Operations personnel coordinate the failure isolation and troubleshooting required. Depending on the degree of failure, command transmission may be terminated. A switch to a backup HSD circuit requires recertification of communication with the TCP. A reload/reinitialization of the TCP software, or a switch to the backup TCD, requires retransmission of command standards and limits and configuration data to the TCP from the NOCC.

The capability exists to enter and/or control command transmission via a manual input/output (I/O) device at the TCP. In addition to automatic command operation, a manual buffer exists in the TCP which holds six command elements of up to 71 bits each. This manual buffer is preloaded with contingency commands obtained via HSD messages from the MCCC. In the event of a MCCC or HSS failure, control of this buffer is accomplished via the I/O device at the TCP. Commands can be loaded and/or transmitted under voice control from the Project. Selective transmission of the contingency commands can be accomplished in accordance with Project instructions.

During a time-critical command sequence, in which a hot-standby TCD is scheduled for support, all command loading is accomplished via HSD from the MCCC. Optional methods of loading the hot-standby TCD exist. Nontimed commands can be loaded and the TCP-CMA placed in a mode (Idle 1) so that transmission cannot occur; or optionally the backup command sequence can be sent to the hot-standby immediately after a failure in the prime TCD.

If the emergency commands are loaded in the manual buffer via HSD circuits, the time to initiate transmission is less than 1 min from notification by the Project. If emergency commands are loaded into the TCP via the manual I/O device, the time to initiate command transmission is 5 min for the first command and 2 min for each subsequent command.

IV. TDS PLANNING

A. JPL/GERMAN TRAINEE PROGRAM

As part of the international agreement between the United States and Germany, NASA agreed to train selected West German technical personnel for a period of one year each at either the Goddard Space Flight Center or JPL. In January 1969 the TDA office at JPL began the task of defining the technical training areas, specific work assignments, and the necessary trainee experience requirements for the residence training program at JPL and concluded with the publishing of a DSN/Helios Project Trainee Plan in August 1969. This document established that technical training would be given in the following areas:

- (1) Telecommunications System Design.
- (2) Telecommunications Compatibility Testing.
- (3) Multiple-Mission Telemetry and Command System Design (Data Systems).
- (4) Spacecraft Radio Subsystem Design.
- (5) Mission Operations.
- (6) Real-Time Data Processing.
- (7) Orbit Determination.

It was decided that the best method of training would be to assign each trainee to an on-going flight project such as Pioneer 10 and 11 and Mariner-Mars '71 for "on-the-job" training under the direction of a cognizant JPL engineer. This approach represented a unique opportunity to become familiar with the DSN systems that would be used to support the Helios Project as well as an actual mission operations.

In September 1969 an initial group of four German engineers arrived at JPL to begin their year residency. To assist them in performing their task assignments the DSN Manager for the Helios Project made arrangements for the trainees to draw necessary material and supplies from the JPL supply stores.

By the time the training program came to an end in September 1972, 15 West German engineers had completed their one-year residence training at JPL while another four had completed an abbreviated training period of from one to three months. The DSN trainee program was very successful, with most of its "graduates" assuming positions of high responsibility upon their return to West Germany. In addition, it generated an air of comradeship among both the U.S. and German participants in this program. This was especially noticeable during the Helios Joint Working Group meetings and was an element in the strong team spirit that developed within the Helios Project.

B. TELEMETRY-RELATED DEVELOPMENTS

1. Single-Channel vs Two-Channel Subcarrier for Telemetry Data

During the second Helios Joint Working Group Meeting in April 1970, the Helios Project Office gave a presentation on the then current design of the spacecraft telemetry system, the estimated link capability, system losses, and their evaluation of the single-channel vs two-channel telemetry system tradeoffs. In order to make a decision by June 1970 as to whether a single- or two-channel telemetry system would be incorporated into the spacecraft, the Project Office requested that the DSN provide information as to DSN capabilities, costs associated with single- vs two-channel systems, expected data rates as a function of various mission phases, etc. In compliance with this request the DSN provided the Helios Project personnel with updated copies of the "DSN/Flight Project Interface Design Handbook" and "TDS Estimated Capabilities for the Helios Missions." During discussions on this subject the DSN pointed out that, on the basis of successful past projects, the costs of Mission Operations would be less using a two-channel system. For a single-channel system the computer and manpower costs required to separate the engineering data for real-time transmission would be very expensive over the lifetime of the spacecraft. Even though the telecommunications baseline (recommended during the German Solar Probe Conference at GSFC in July 1968) called for a two-channel convolutionally coded telemetry system capable of handling 8 to 32 bps of engineering data on one channel and 16 to 2048 bps of science data on the second channel, the Helios Project Office seemed to favor a single-channel system containing combined engineering and science data, as it was more economical in its use of downlink S-band power.

In June 1970 the TDS Manager received from the Project Office a comparison study of the single- vs two-channel telemetry systems for Helios in which the pertinent parameters and criteria of an integrated spacecraft/ground telemetry system were presented in an itemized comparison as shown in Table 4. The results were evenly divided.

In August 1970 the Project announced that a single-channel telemetry system had been selected because it provided a small advantage in telecommunications link performance; also, from the standpoint of Master Data Records (MDR) and Experimenter Data Records (EDR) generation, the single-channel system was preferred as it was expected/assumed that each experimenter would also request some engineering data along with the science data on his EDR. In addition, it was felt that it would be more efficient to use a MDR as the input to the EDR generation program which would have science and engineering data in the same file and on a common time base. It was also felt that the MDR format could be produced more easily from a single-channel system rather than from a two-channel system.

2. Experiments Interface

During the 5th HJWGM (October 20-27, 1971) the TDS subgroup discussed how the telemetry, command, tracking, data, etc., processed by the U.S. and German Tracking Networks were to be compiled, forwarded to the GSFC and GSOC space data centers, subsequently collated into separate data files, possible mathematical computation performed, and then formatted and placed into an individual log for each experimenter. This had been an open matter for

Table 4. Comparison of one- vs two-channel telemetry systems

Item	One- channel	Two- channel
Intermodulation loss (efficiency at low data rates)	+	
Additional ground equipment	+	
Complexity of onboard multiplier and modulator	+	
Design, implementation, and testing required	+	
Effect of modulation index tolerance	+	
Frame synchronization for real-time decommutation of engineering data at ground station		+
Constraints on frame structure (with variable format)		+
Coupling of engineering and science data rates (with variable data rates)		+
Coupling of engineering and science bit error rates		+

*Item "in favor" for particular system.

several Joint Working Group meetings. However, a logical solution was achieved at the fifth Joint Working Group Meeting: each experimenter who had an instrument onboard the spacecraft would receive two types of computer magnetic tapes, one containing all of his experiment data plus command information and those spacecraft engineering (housekeeping) telemetered parameters he specified, the other containing the spacecraft trajectory data and its position relative to the Sun, Earth, and other bodies in the solar system. In addition, the TDS subgroup agreed upon a standard format for placing the data onto magnetic tapes. The Experimenter Data Records (EDR) concept and structure was presented to the Experiments Subgroup for approval. Since the experimenters found no objection, the TDS subgroup proceeded to implement the EDR system.

With respect to the two ground-based experiments, it was officially announced at the fifth Helios Joint Working Group Meeting that an experiment on celestial mechanics had received both U.S. and German headquarters approval. This experiment, identified as Experiment 11, would utilize both doppler and range data from Helios to further refine our knowledge of the properties

and constants of the solar system and provide another test of Einstein's general relativity theory. A proposal was also presented to perform an additional ground-based experiment to measure the Faraday rotation of the polarization of the received Helios spacecraft signal as it passed through the Sun's corona during the solar occultation portions of the Helios trajectory. This experiment, identified as Experiment 12, would provide additional information about the characteristics and properties of the Sun's corona.

The major interface between the TDS Subgroup and the Experimenters Subgroup was in the content, structure, and detailed definition of the EDRs to be delivered by the Helios Ground Data System (GDS) to each experimenter. In gross terms, this interface is defined in the Project Support Instrumentation Requirements Document (SIRD) and in the responses provided by the NASA Support Plan (NSP), the Mission Control and Computing Center Support Plan (MSP), and the German Support Plan. However, these documents do not define the detailed structure of these EDRs. Further, many of the specifications that do appear in the SIRD and its supporting documents are the direct result of experimenters' requirements. It is a truism to say that experimenters and Ground Data System personnel live and think in different worlds. A good example of this truism is given in the following, which in itself justified the need for continued TDS/Experimenter Subgroup discussions during the HJWG meetings.

a. Telemetry Master Data Record/Experiment Data Record Completeness Criteria. The Helios Project specified that the Telemetry Experiment Data Record (EDR) was to have a bit error rate (BER) no greater than 10^{-5} . This was a very stringent specification and was one of the reasons the Helios Project selected convolutional coding for its telemetry. However, coding alone would not achieve a BER that low; each telemetry mode had to contain additional signal margin in its telecommunications link analysis. Further, a BER specification could not apply to lost telemetry frames (e.g., signal dropouts), so additional completeness criteria were needed. All of these subjects had been repeatedly discussed during previous HJWG meetings; however, there were misunderstandings by the respective parties due to language differences. During the seventh HJWG meeting, at least one area of misunderstanding was finally described in words understood by both subgroups. It related to both the BER and the completeness criteria.

In the transmission of telemetry data from the DSN stations to the Mission Control and Computing Center (MCCC) (where the data are logged onto the Master Data Record), telephone-type voice/data circuits known as high-speed data lines (HSDLs) are used. These circuits are subject to bursts of noise which in turn obliterate small blocks or chunks of the data being transmitted over the circuit. These noise bursts are random in the sense that they can occur at any time in an unpredictable manner. Prior to the seventh HJWG meeting, the experimenters had interpreted the word "random" to mean that the noise was more or less uniform: i.e., that it would affect all data bits being transmitted over the circuit more or less uniformly. Because some experimenters' data would be subcommutated within the Helios telemetry frame, those experimenters in particular were alarmed at the discovery that a given HSDL noise burst could obliterate their entire data word. Further, this data word might not be repeated by another measurement until the next main frame (one Helios main frame is composed of 72 regular 1152 bit Helios frames). The experimenters' concern was even further aggravated by the reali-

zation that the mere act of repeating the data transmission from the station would not guarantee that another noise burst would not occur to again affect the data. Unfortunately, this situation could occur in the practical world with the Helios Ground Data System averaging less than 10^{-5} BER and had met a 95-98% completeness criteria. Obviously, the experimenters were not prepared to make an on-the-spot evaluation of the impact of this realization. Nonetheless, it was at least opportune that this realization occurred some 20 months prior to launch, as opposed to after launch, as it had in the case of at least one prior flight project.

Fortunately, there was a solution to this dilemma: the real need for a 10^{-5} BER was in the content of the EDR, not in the "real-time" data fleetingly displayed at an operator's console (which could probably tolerate a 10^{-3} BER, or worse). Since the originally received data were preserved on (ODR) records at the station, the data obliterated by the high-speed data line noise and/or gaps could be resurrected from the station ODRs at the conclusion of the daily track.

This realization resulted in a new definition of MDR/EDR completeness criteria (Table 5) being established during a subsequent HJWG technical splinter session. The major participants were the experimenter for the most severely impacted experiment (No. 6) and TDS subgroup members who had considerable prior flight project MDR/EDR experience. The level of understanding developed during this splinter session enabled agreement to be reached for criteria that were both practical and satisfying to Helios mission objectives.

Table 5. Helios MDR/EDR completeness criteria

Telemetry rate, bps	Minimum percent data return	Maximum data gaps per 24 hours
8	>75	24
16	>88	24
32	96	40
64	96	80
128	96	160
256	96	320
512	96	480
1024	96	960
2048	96	854

b. Data Records for Experiments 11 and 12. Helios has 10 major onboard scientific experiments plus two ground-based passive experiments. The latter are Experiments 11 (Celestial Mechanics) and 12 (Faraday Rotation), whose primary data are not contained in the Helios telemetry stream but rather from measurements taken at the DSN stations. For Experiment 11, the primary data types are doppler and planetary ranging, which are contained in the DSN Tracking System MDR. For Experiment 12, Faraday Rotation, the primary data are recordings of the polarization angle of the incoming Helios carrier signal as received by the DSN Goldstone 64-meter station. Since neither of these data types fits conveniently into the EDR format structure negotiated with the Experiments Subgroup for Experiments 1 through 10, action items were jointly assigned to these experimenters and the TDS subgroup to develop an MDR/EDR plan specific to Experiments 11 and 12 for presentation at the eighth HJWG Meeting. This was accomplished, in effect, by supplying these experimenters with the equivalent of an MDR in lieu of an EDR.

c. Use of Discrete Ranging. The Celestial Mechanics Experiment (No. 11) uses DSN doppler and range data to precisely measure the influence of the Sun's gravity upon the Helios trajectory and the propagation of its radio signal. These influences are greatest when the spacecraft is near perihelion and solar occultation, respectively. However, to completely measure the effect and to get reference points, data are also needed regarding the trajectory well before and after perihelion and occultation passage. During this total time period, the range from Earth to the spacecraft can vary anywhere from 0.6 to 2.0 AU. Therefore, a DSN Planetary Ranging System had to be employed. During the development of the Helios spacecraft, the DSN contemplated employing a "continuous spectrum" type of planetary ranging system during the Helios era. However, during the course of this development, flight projects in general expressed an interest in the DSN "discrete spectrum" planetary ranging technique, with the result that in July 1972 the DSN made a formal decision to implement both types of planetary ranging systems for operational use in the Helios era. This made it possible for Helios to use either type of planetary ranging system, the only constraint being that the project would have to select one or the other prior to the beginning of any particular DSN 64-m station pass. The significance to Helios of this decision was that the discrete spectrum Planetary Ranging System permitted either or both (1) less power to be used in the ranging sidebands, or (2) a shorter range code acquisition time (time consumed in making a ranging measurement), depending upon the project tradeoffs involved.

A planetary ranging system capability was not planned for the DSN 26-m stations. However, for scheduling convenience, it was incorporated into DSS 11 at Goldstone, California.

The Helios telemetry margins, particularly at 2.0 AU, had degraded somewhat during the evolution of the spacecraft radio system designs. As a result, use of the Continuous Spectrum Planetary Ranging System under these circumstances could be stated to have only a slight effect upon the telemetry data return at 2.0 AU. A special seventh HJWG splinter session investigated this situation in detail and recommended that the planetary ranging modulation index used by the spacecraft be changed from its prior value of 45- to 24-deg phase modulation. This new value would enhance science data return at 2.0 AU, yet still provide capability for Continuous Spectrum Planetary Ranging to a distance of 1.6 AU together with Discrete Spectrum Planetary

Ranging capability all the way to 2.0 AU. The latter situation turned out to be acceptable to the Experiment 11 representative, as well as to the 10 spacecraft experimenters who were concerned about any further degradation of their science telemetry return.

3. DSN Telemetry Performance

The Helios spacecraft employs one telemetry channel to transmit both science and engineering data back to Earth. Both data types are convolutionally encoded¹¹ and modulated onto a single 32,768-Hz telemetry subcarrier which, in turn, is phase-modulated onto the S-band downlink carrier. The combined science and engineering information data rate may be varied from 8 to 4096 bps,¹² in steps of a factor of 2. The onboard science requirements dictate that the telemetry bit error rate (BER) not exceed 10^{-5} , with a maximum frame deletion rate of 10^{-4} . To accomplish this, the telemetry is convolutionally encoded at rate 1/2, using a Massey code with a constraint length of 32.

The DSN experience in processing Pioneer 10 telemetry was of interest to Helios since the former also uses convolutionally encoded telemetry. Unfortunately, only a limited amount of Pioneer 10 data had been accumulated and analyzed with respect to DSN performance by the time of the sixth Helios Joint Working Group Meeting in April/May 1972. In addition, it was difficult to extrapolate DSN performance regarding the Pioneer 10 frame length of 384 bits (maximum) to the anticipated performance with the 1152-bit Helios frame length. Some 192-bit-frame-length Pioneer 10 data had been analyzed which showed a decoding deficiency of between 0.3 and 1.2 dB over preflight predictions. A portion of this deficiency may be attributable to certain preflight calculations which did not consider all of the error sources that exist in an actual receiving station. To reduce this discrepancy, the DSN presented an improved analytical model of DSS telemetry performance for Project use in telecommunications link analyses. In addition, the DSN agreed to provide Helios with a complete set of computer simulations regarding DSN performance with respect to Pioneer 10 telemetry and also to provide the Helios Project selected computer simulations based on the Helios telemetry frame length, prior to the seventh Helios Joint Working Group Meeting in October 1972.

In September 1972, the Helios Project Office issued an update to the Telecommunications Link Design Document. In the time available prior to the seventh HJWG Meeting, the DSN carefully reviewed each link analysis covering the multitude of operating modes permitted by the Helios spacecraft radio system. By necessity, this review concentrated upon the validation of the various DSN performance parameters assumed in the link calculations, with secondary emphasis being placed upon the techniques and/or assumptions used in conjunction with the spacecraft parameters. During the seventh HJWG Meeting, the DSN reported that its review of the Helios Telecommunications Link Design had not disclosed any errors in computation or any serious errors of omission regarding unidentified losses within the link. It was noted, however, that

¹¹An uncoded mode is available for use during the near-Earth phase.

¹²The DSN is limited to 2048-bps convolutionally coded telemetry processing in real-time.

the September 1972 revision still contained certain assumptions: i.e., design or specification values were employed for those spacecraft parameters for which actual test data were not yet available. This situation was significant because several of the Helios telecommunications links had experienced an erosion of performance margin to the point where any further decrease in performance would begin to jeopardize the accomplishment of mission objectives as they related to obtaining useable data over those links.

Related to the foregoing activity were the parameters assumed for the performance of the DSN Telemetry System while sequentially decoding the Helios convolutionally encoded telemetry. Since the Data Decoder Assembly (DDA) to be used in support of Helios was still under development by the DSN, it had been necessary to estimate its future performance. The estimates employed in the September 1972 issue of the Helios Telecommunications Link Design were based upon approximately one month of postlaunch data obtained from the Pioneer 10 convolutionally encoded telemetry. However, as mentioned above, the Pioneer 10 telemetry frame length is much shorter than the 1152 bits/frame employed for Helios. Therefore, to further refine the estimate of DSN Telemetry System performance for Helios, the DSN performed a computer simulation based upon the Pioneer 10 telemetry performance data but converted to the Helios frame length. This computer simulation was compared to theoretical analyses performed by both JPL and the Helios Project. The result was an updated performance estimate for Helios (see Fig. 24). However, more work remained in this area, as will be discussed in later sections.

4. Coded vs Uncoded Telemetry Data During Launch

During the sixth HJWG meeting, and again during the Helios telecommunications presentation on May 5, 1972, the question of Helios telemetry support during the Near-Earth Phase was discussed from several aspects. At the time, the Helios Project Office was planning to launch the spacecraft in the uncoded engineering data mode at 128 bps to safeguard critical operations during the launch phase. Because the onboard experiments would be turned off, it was possible for the engineering telemetry data stream to contain as many as 128 consecutive zeros (or ones), which would exceed the maximum of 64 consecutive zeros/ones permitted by the NEP stations or the 100 consecutive zeros/ones permitted by the DSN stations. It was pointed out that this could produce frame synchronization problems at both the Near-Earth Phase stations and at the initial DSN acquisition stations. A small Spacecraft/TDS splinter group discussed the matter during the sixth HJWG and recommended that the problem be circumvented by launching the spacecraft in a coded telemetry mode. That recommendation would require that the NEP stations install decoders or that the received coded data be transmitted via communication circuits to the DSN facility at Cape Canaveral for decoding and processing. However, at the conclusion of the May 5 Helios telecommunications presentation, the Helios Project Office indicated that, insofar as NEPN/DSN support was concerned, more information was needed on the tradeoffs of coded vs uncoded telemetry data before making a Project decision. The NEPN agreed to investigate the matter further and to present the available options through the TDA Office to the Helios Project.

Similarly, the DSN agreed to study the question of coded vs uncoded engineering telemetry data with respect to the initial DSN acquisition problem. It was both a Project and a DSN objective to minimize the time from first

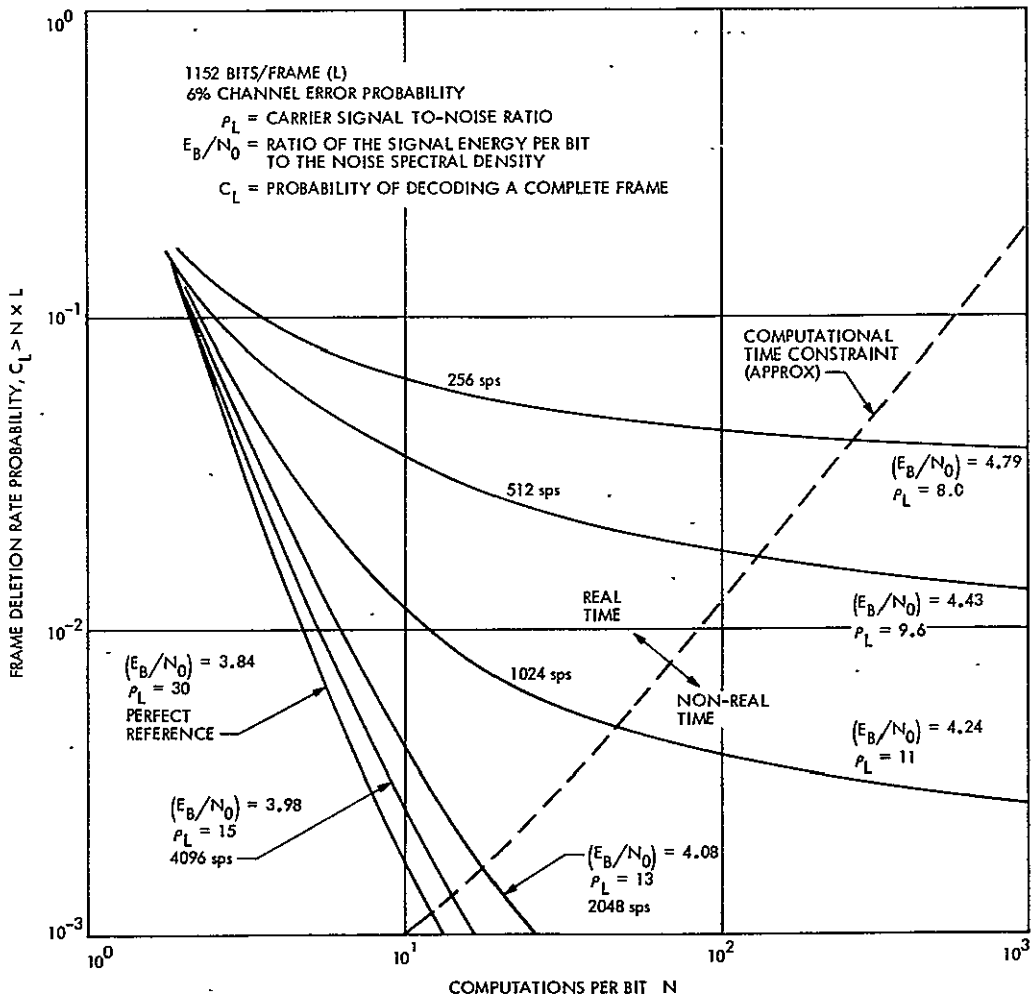


Fig. 24. DSN October 1972 estimate for Helios coded telemetry performance

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spacecraft visibility until the initial DSN station had complete acquisition: i.e., radio metric, telemetry, and command capability. The relative merits (or demerits) of coded vs uncoded data were also to include, in a quantitative manner, the impact of a series of 128 consecutive zeros or ones in the telemetry data stream.

Both the NEPN and the DSN were to provide sufficient technical data to the Helios Project Office by July 1, 1972, so that they could weigh these alternatives against a third and undesirable alternative, which was to make changes in the spacecraft design.

a. Near-Earth Phase (NEP) Study. The NEP study looked at the question from the standpoint of both STDN and AFETR station capabilities and limitations. The STDN stations at Bermuda, Grand Canary, and Ascension (ACN) could not generate 7.2-kbps HSD blocks from uncoded data when there were more than approximately 64-bit intervals without a bit transition in the data format. The limitation was in the bit synchronizer portion of the PCM decommutator which feeds the data bits to the 642B computer (that generates the HSD format).

As an alternative, the regenerated 128-bps uncoded bit stream obtained from the PSK (subcarrier) demodulator at each STDN station could be transmitted to a DSN station on a Bell 202D data modem. This would have required that the SSA in the DSN station be able to tolerate 128-bit intervals without a bit transition plus any bit jitter introduced during retransmission. The regenerated 128-bps coded bit stream could also be transmitted to a DSN station using a 202D data modem. However, since STDN and NASCOM had replaced all of their 202D data modems, this method of retransmission would have been complicated.

The STDN stations could insert coded data asynchronously into 7.2-kbps HSD blocks at either the 128- or 2048-bps rate. This method dictated the use of an SCA/DDA capability at STDN (MIL 71) to recover the coded data from the HSD blocks and decode the data. This, however, could overburden STDN (MIL 71).

The AFETR stations at Grand Bahama and Antigua could retransmit regenerated 128-bps coded or uncoded data to STDN (MIL 71) using 202D data modems. For uncoded data the SSA in STDN (MIL 71) would have to tolerate 128-bit intervals without a bit transition plus any bit jitter being introduced during retransmission.

The AFETR stations at Grand Bahama and Antigua would have required PSK demodulator plug-ins to detect the 2048-bps coded bit stream (approx \$4,800 which was not programmed) and to record the regenerated bit stream on tape.

The NEPN study concluded that it was essential that all NEP stations be able to monitor the received data to the maximum extent possible so that steps could be taken to correct any station-induced anomalies observed in the data. In particular, to sacrifice NEP subcarrier demodulation and frame synchronization was false economy. The logical extension of this concept was that coded data was undesirable before DSN acquisition because data quality could not be ascertained at the station and also that decoding the data at each station would have been an expensive but only partial solution since

it would not have solved the STDN bit synchronization problem or the AFETR 2048-bps retransmission circuit problem.

b. DSN Study. The DSN study involved the evaluation of the SSA data transition density for telemetry data in an uncoded engineering mode (Format 4). In order to evaluate the SSA, a Fortran simulation program was written. From this, the Format 4 frame was studied and the sequences of data where transitions would not occur were identified. During these sequences the loop error was set equal to zero, and it was found that there was a possibility of sequences of 32, 56, 136, and 16 bits, each separated by sequences that were assumed to have transitions that occurred with a probability of 0.5.

A phase input was generated assuming pessimistic doppler. At 2.295 GHz, the doppler shift and rate were assumed to be 10 kHz and 200 Hz/s, respectively. Timing jitter was introduced as Gaussian distributed phase. The timing jitter was generated for values of -4.3 (threshold), 0, and 10 dB. The phase input drove a difference equation representation of the SSA. The constants used were for the medium bandwidth, which gave a loop gain of 39 dB.

This parameter was of paramount importance in establishing the ability of the loop to maintain an accurate timing reference during intervals of no transitions. Also of importance was the duty factor, i.e., the number of bits with no transitions in a frame over the frame length. Each time a sequence symbol occurred without transitions, the loop had to rely on its memory to track the incoming phase. At the end of the sequence, a phase error would have been built up due mainly to inability of the second-order loop to follow the incoming doppler rate without the error information. The SSA loop required time (approximately the same time it took to create the error) to reduce the error.

For the Helios situation the loop SNR would be large and it was expected that the loop would perform well. This expectation was verified by simulation test results. The test data were generated after the loop transients were allowed to settle and phase error statistics were then gathered over 57,600 bits. The data indicated that the SSA was not significantly degraded when operating on the Helios Format 4 frame data. At threshold (-4.3 dB), the degradation was only 0.103 dB, which differed from the ideal data (50% transitions) by only 0.021 dB. At higher SNR's the difference in degradation was even less. It is interesting to observe that even with the ideal frame and a large SNR of 10 dB (approximately 50 dB loop SNR), the degradation was still -0.048 dB, which implied that most of the degradation was actually due to doppler rate.

The DSN study concluded that test results showed that the original concept of launching the Helios spacecraft in the 128-bps uncoded telemetry mode was still valid.

c. Study Results. Both the NEPN and DSN studies, performed independently, concluded with the recommendation that Helios spacecraft be launched in the uncoded telemetry mode, contrary to the opinions expressed at the sixth HJWG meeting and despite the differences in their study rationale.

The NEPN recommendation to launch Helios using 128-bps uncoded engineering telemetry was made despite the STDN station's bit synchronizer limitation of up to approximately 64-bit intervals without transition. To circumvent the bit synchronizer problem, it was suggested that the 128-bps uncoded engineering telemetry bit stream be regenerated at the STDN station and sent via NASCOM to DSS 71 using a Bell 202D data modem. However, this too had problems which required further study. Despite these problems, the 128-bps uncoded telemetry bit stream recommendation was preferred by the NEPN over the option of transmitting either coded data or data at a much higher bit rate.

The theoretical analysis of the DSN Symbol Synchronizer Assembly (SSA) was encouraging in that it indicated that sequences of up to 136 bits of logical zeros could be accommodated with very little SSA degradation insofar as the initial DSN acquisition problem was concerned. Whether or not the SSA performance would be significantly degraded by any bit jitter introduced by regenerating the 128-bps uncoded telemetry bit stream at a STDN station, then sending it via NASCOM to the SSA at DSS 71, depended upon the magnitude of that timing jitter. The actual station hardware was expected to agree with the theory to within a fraction of a dB. However, differences between theory and practice did not change the DSN recommendation to launch Helios in the uncoded telemetry mode since the SSA was serially in the data stream for either uncoded or coded telemetry, and the use of uncoded telemetry data facilitated the initial DSN acquisition since the sequential decoder was bypassed.

From the foregoing, it was concluded that the SSA could meet the Helios Class I requirement for initial DSN telemetry acquisition, and that the NEPN, in conjunction with DSS 71, could probably meet the Helios Class II telemetry requirement (perhaps with some degradation) if the spacecraft transmitted 128-bps uncoded telemetry during the launch phase. While the latter of the two conclusions was still an assumption, it had a higher probability of realization than either the coded telemetry or the higher bit rate options.

d. Final Decision. The final decision was made by the Project Office during the seventh HJWGM held in October 1972. The decision, based on the recommendations presented by mission operations and spacecraft engineers, was in favor of launching the spacecraft in the 128-bps coded telemetry mode. On December 10, 1974, the first Helios spacecraft was launched in the coded telemetry mode and as a result the NEPN support stations were required to look for synthetic frame synchronization in the engineering data stream. This was accomplished by using a sequence of ones/zeros in the coded data stream that repeated themselves because onboard experiments were off (a procedure developed and verified by the NEPN using tape recordings of spacecraft data taken prior to launch).

5. Spin Modulation

It is well known by spacecraft designers that a spin-stabilized spacecraft can alter the telecommunications link between the spacecraft and the ground receiving stations, particularly if its RF antenna placement is not coincident to the spin axis and its radiation pattern is nonsymmetrical. The Helios spacecraft is not only spin-stabilized but its low-gain antenna (LGA) system utilizes a linearly polarized (omnidirectional) antenna mounted

on top of the spacecraft that is coincident to the spin axis and a right-circular polarized (RCP) antenna horn mounted on the bottom of the spacecraft that is offset from the spin axis. This combination produces a spin modulation to the RF carrier comprised of frequency, amplitude, and phase modulation which causes a degradation to the telecommunications link. Late in 1972 the question came up as to how would this spin modulation affect the Telemetry System at the DSN stations? JPL engineers conducted an analysis of the problem as described below.

The Helios LGA, comprised of simultaneously driven top dipole and bottom horn antenna elements, produces a combined pattern envelope that is nonsymmetrical about the spacecraft spin axis (Fig. 25). The horn antenna is displaced 6λ (wavelength at the transmitted frequency) from the spin axis and combined with the linearly polarized antenna produces interferometric effects.

During DSN initial acquisition and the Step I attitude maneuver (when the spacecraft aligns its axis normal to the Sun), the signal traverses through the lower antenna interference zone. The effect to the telecommunication link varies the signal phase and signal amplitude and deviates the carrier frequency. A similar effect occurs during the Step II maneuver when the spacecraft is commanded to align its spin axis perpendicular to the ecliptic plane (radial-polar rotation).

The results of the analysis revealed that the Telemetry System was more sensitive to frequency deviation and phase variations than to amplitude variations. This was a particularly important factor since these results were also applicable to the uplink command transmission to the spacecraft, where a similar type of demodulation/detection system is employed. Briefly stated, the most severe doppler and doppler rate values occur at the carrier frequency, and RF loop circuits that tracked the signal can produce phase errors which will contribute to the overall degradation (Ref. 2).

The analysis also revealed that a low signal level margin above the RF loop design threshold value produces noticeable errors and that a signal margin of 15 dB or greater will be required to insure that the spin modulation signal variations produce negligible degradation. The performance for either the coded or uncoded telemetry mode produced comparable SNR requirement results.

In early February 1973, an extension of the study was conducted following receipt from the Helios Project¹³ of preliminary spacecraft LGA patterns measured from a Helios spacecraft mockup for the cases where right-hand circular polarization (RCP) and linear polarization were used with the recording equipment. Because the LGA patterns using linear polarization recording equipment did not indicate as severe a set of phase variations as assumed in the earlier JPL analysis, the results of the extension study revealed less pessimistic results than the first. This can be seen in Fig. 26 for the RCP case, which indicates greater amplitude and phase modulation values than in the horizontal linear case shown in Fig. 27 for aspect angles between

¹³Letter RBI-6042/73, C-264, dated February 16, 1973, by Dr. Janeff and K. Zerwes, Subject: Helios LGA Pattern Measurement.

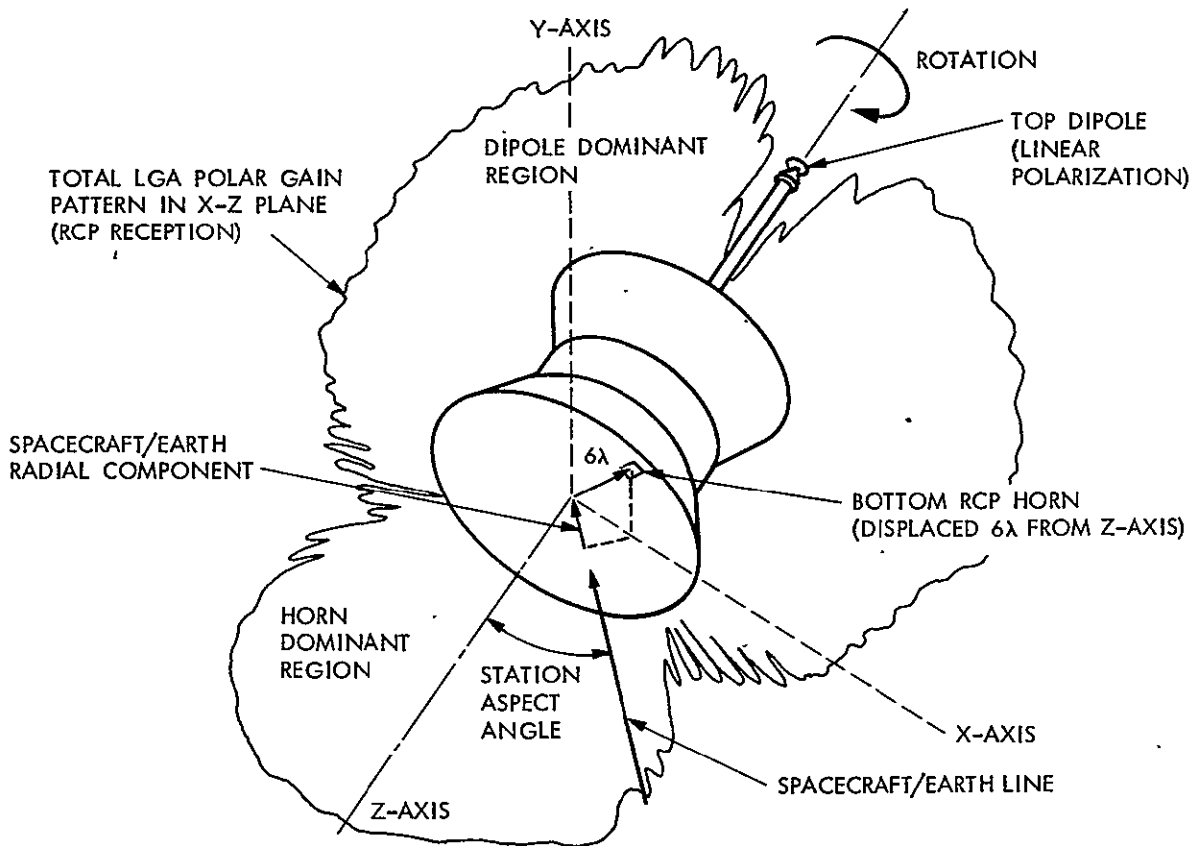


Fig. 25. Spacecraft omniantenna pattern in plan through spin axis

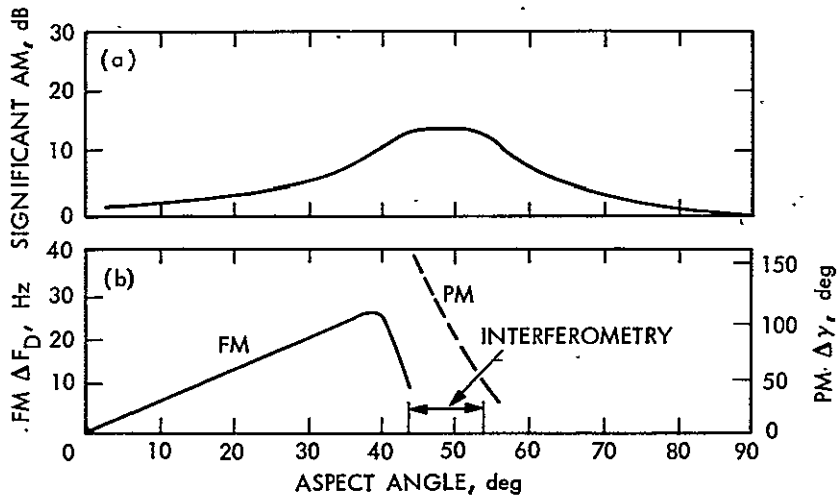


Fig. 26. Summary of spin modulation effects vs aspect angle for RCP

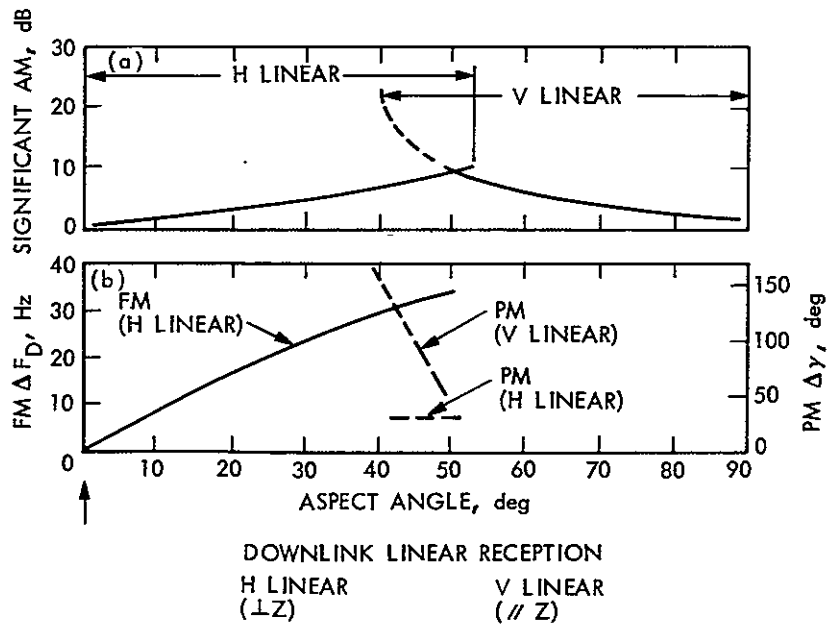


Fig. 27. Summary of spin modulation effects vs aspect angle for linear polarization

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40 and 55 deg. This is due to the rejection of the vertical linear polarized signal from the dipole antenna and the reception of only the horizontally polarized component of the horn antenna.

A further study of Figs. 26b and 27b reveals that the FM deviation remains the same for either RCP or horizontal linear polarization at the low regions of the aspect angles. However, if the signal margin above loop threshold was large enough to widen the loop bandwidth, then the doppler rate due to the FM deviation combined with the lower values of AM and PM resulted in less impact to the telecommunications link.

6. DSN Sequential Decoding Performance

During the sixth HJWG meeting in April and May 1972, the spacecraft telecommunications engineers expressed their urgent need for predicted performance data of the stations' sequential decoders for use by telecommunications link analysts in developing total system (end-to-end) performance estimates needed by the mission planners. The DSN explained that each DSS had redundant data decoders and Telemetry and Command Processors (TCP) as shown in Fig. 28 and that each telemetry channel contained assemblies which had individual losses (Fig. 29). These losses resulted in a degradation of telemetry system performance prior to the data entering the TCP. These degradations are shown in Table 6. Figure 30 shows the theoretical performance curves for Pioneer 10 at various symbol error rates in the incoming data stream. Figure 31 shows the DSS performance for the Pioneer 192-bit frame length telemetry as of April 1972.

The DSN also acknowledged that the DSS performance for Pioneer 10 was indicative but not completely relatable to the expected Helios performance because of differences in frame length, etc. The Pioneer 10 Telemetry System performance data relating to the theoretical performance of the DSN Telemetry System did not specifically predict the performance of the DSN Telemetry System as it would apply to the Helios 1152-bit frame length telemetry, etc. Toward the latter objective, the DSN agreed to generate valid estimates of the DSN performance for Helios in order to respond to the experimenters' requirements for bit error rate, frame deletion rate, etc.

Between the sixth and eighth HJWG meetings, JPL, Ames Research Center, and the DFVLR were all working in parallel to develop recommendations on how to account the DDA performance in the link calculations as realistically as possible. In September 1973, four months after the eighth HJWGM, a DSN/Helios telecommunications technical meeting was held to discuss the findings.

At ARC, performance simulation tests were carried out for the Pioneer case and compared with actual Pioneer 10/11 flight telemetry performance. The overall test results are summarized in Fig. 32 in the form of symbol error rate vs deletion rate (DLR). Using this information, the Pioneer Project was able to improve the data return.

The difference in performance margins between calculated and observed value for Pioneer 10 during a sample of passes over a 35-day time interval at DSS 43 revealed a data carrier performance of 0.2 dB (minimum) better than predicted if anomalies were discounted as being caused by a systematic error (Fig. 33). Station anomalies with respect to deletion rate, for

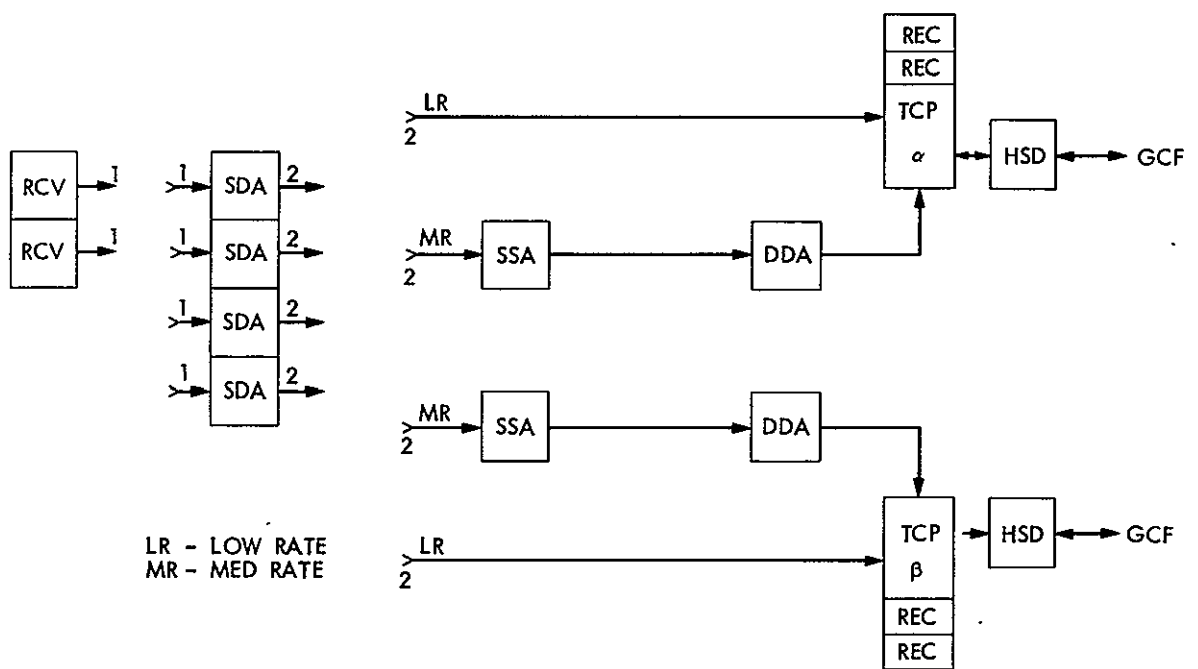


Fig. 28. DSS telemetry system (26-m station)

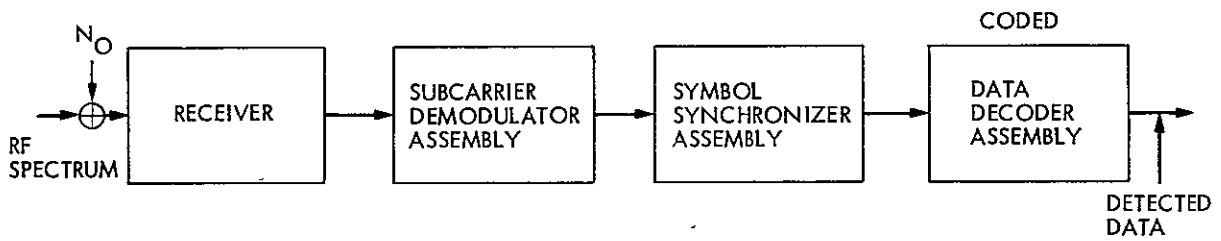


Fig. 29. DSS-telemetry system medium rate channel.
 (6-2500 bps coded or uncoded)

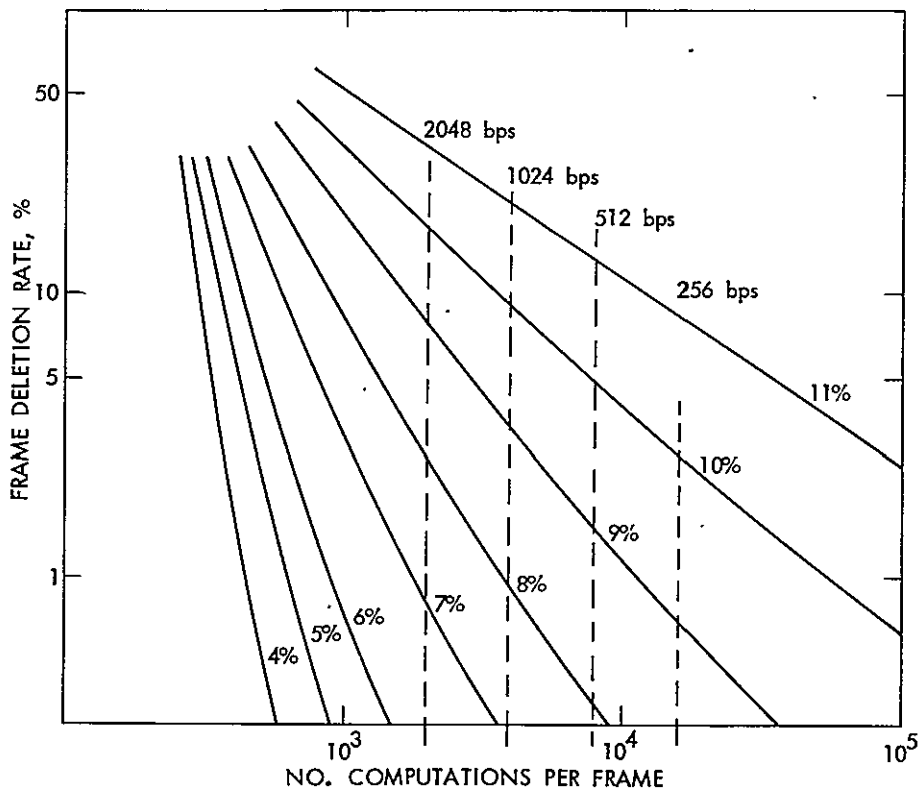


Fig. 30. Expected Pioneer performance for 192-bit frame

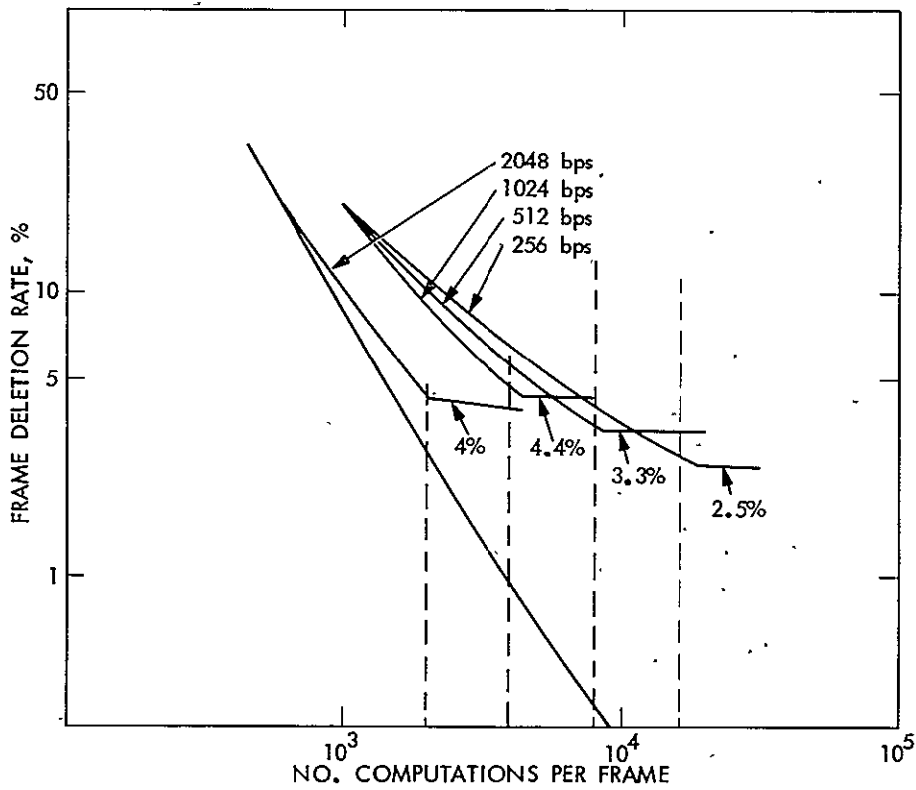


Fig. 31. Actual Pioneer performance for 192-bit frame

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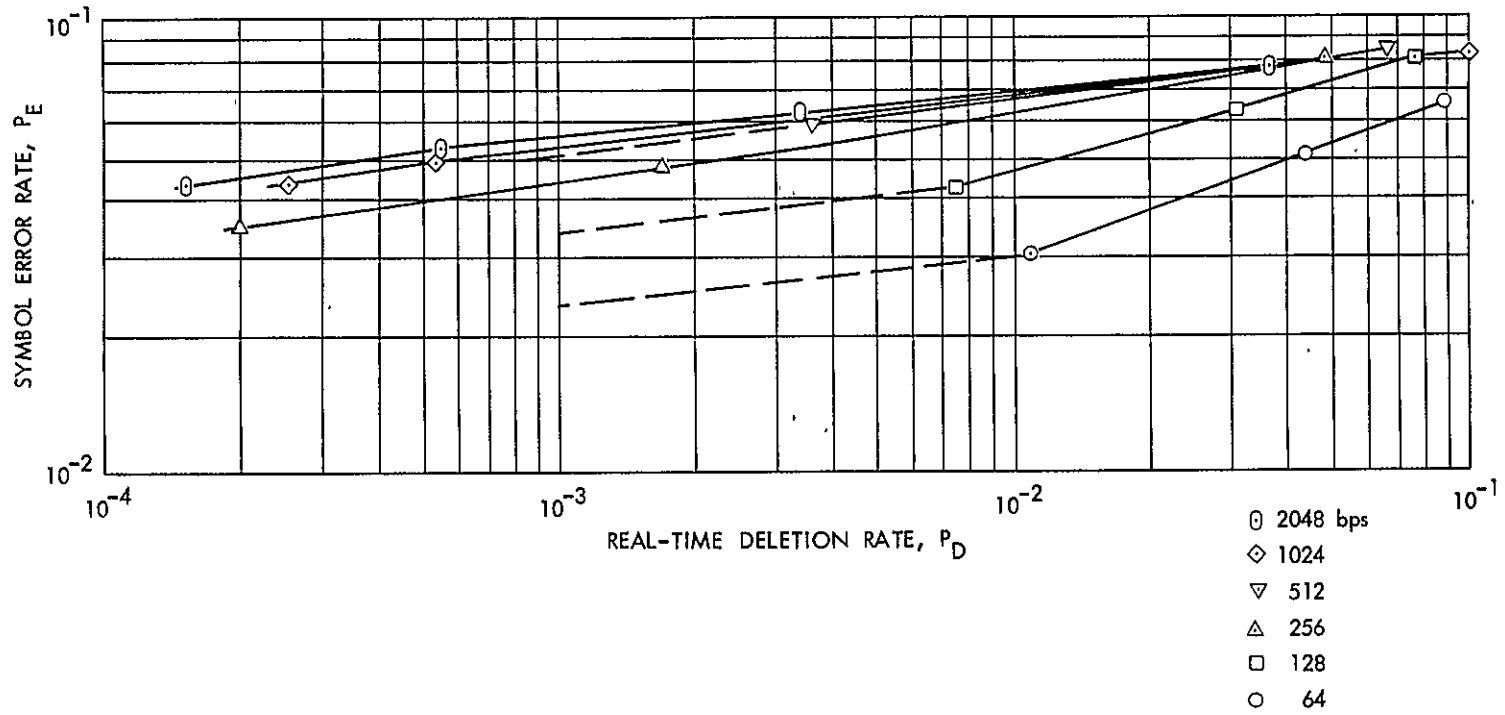


Fig. 32. RF-channel test data, Pioneer-10/11 format

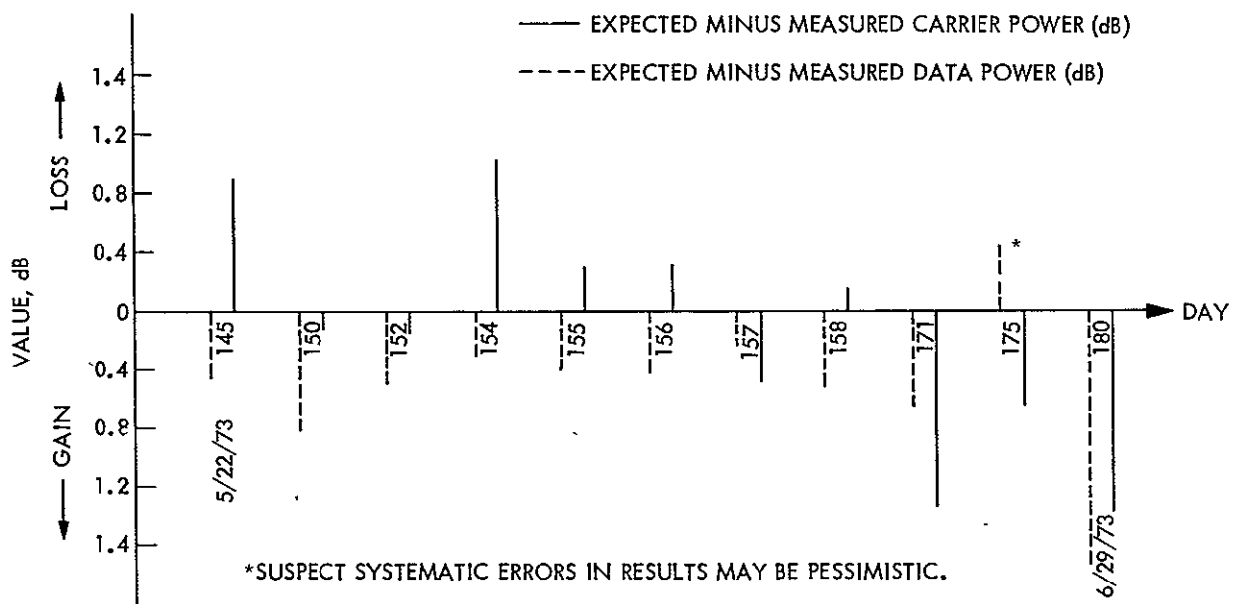


Fig. 33. Link calculations at DSS 43 for Pioneer 10

Table 6. DSS Telemetry System degradation

Symbol rate, sps	ST/N ₀ , dB	Degradation ($\alpha\beta\gamma$), dB
4096	0	0.9 ± 0.4
2048	0	1.0 ± 0.4
1024	0	1.0 ± 0.4
512	0	1.0 ± 0.5
256	4	1.0 ± 0.5
128	5	1.2 ± 0.5
64	6	1.6 ± 0.5
32	7	1.6 ± 0.5
16	9	3.2 ± 0.7

instance between telemetry strings at the same station, could occur in the DSN operation as observed by the Pioneer Project. In a typical case, the DLR deteriorated without a change in BER for one string at DSS 51, which led to an operational reduction of the bit rate. This anomaly was not present in the other string at the same station, however.

Typical Pioneer Master Data Records (MDR) contained DLR and BER data. Monitoring of these data, particularly the BER and computations curves, was implemented by the Pioneer Project to improve operations with respect to data recovery and equipment monitoring. The comparison of RF simulation with real-time test data proved the applicability of this approach.

In parallel with the ARC test effort for the Helios and Pioneer Projects, JPL continued to improve the DDA modeling. JPL's presentation indicated a close agreement with the empirical test results obtained by ARC. Also, a comparison of calculated computation distribution curves for 2048 bps with empirical data taken at DSS 71 (sample size approximately 1000 frames) indicated acceptable correlation.

The simulation employed a global statistics model for the DDA, approximating the effects of SDA and SSA by a constant loss of 0.5 dB. It was believed that the model had been developed to a point where further refinements would bring only minor improvements. It was JPL's opinion that the model was satisfactory for purposes of link design; link computations for operations planning should, however, use an empirical data basis of DLR vs BER.

In Germany, the DFVLR's modeling effort was directed toward a numerical two-parameter estimation of the model, using the same empirical test data. The parameters estimated were a correction to bit SNR and the DDA's effective integration time of the phase error (essentially representing a code memory effect). The resultant performance prediction curves, i.e., the probability of frame deletion vs total signal-to-noise ratio (Fig. 34), were compared to the corresponding curves generated by JPL. The technique allowed a close fit of the analytical/numerical modes for empirical test data. This numerical model was further employed to investigate the influence of the two-way link phase jitter. The results indicated a rather strong influence of spacecraft carrier loop SNR on the two-way link deletion (Fig. 35).

In the discussion, the suggestion was made to test the two-parameter fit for all bit rates and for the entire package of available empirical data. A variation of the code memory factor as a function of the computations per second could lead to possible further refinements.

For the purpose of updating the Helios link design document, one curve of total power-to-noise ratio, P_T/N_0 , at a deletion rate of $P_D = 10^{-4}$, for bit rates from 8 to 2048 bps were sufficient, while the family of curves of P_D as a function of P_T/N_0 for all bit-rates would be required for calculating operational links. The ensuing discussion revolved around this problem. Since the experts agreed that JPL's theoretical curves of $P_D = f(P_T/N_0)$ were basically correct in their slope but were offset by up to 1 dB relative to test data, it was suggested that they be used but shifted according to the empirical results.

It was agreed to use a smoothed and/or combined version of the experimental and model performance data for link design. This approach appeared to be the best which could be defined at the time; it could not be considered final and required confirmation and updating.

A splinter session on September 28, 1973, also addressed the question of what beneficial information should be included in the Helios MDR data quality monitoring. JPL suggested the use of actual uplink and downlink carrier AGC vs prediction and SNORE¹⁴ vs E_s/N_0 .¹⁵ The determination of E_s/N_0 required provisions in the decoder software (a la Pioneer) to compute the corrected bits and thus the symbol error probability.

After the meetings, JPL generated a revised set of DDA performance data, bit rate vs required P_T/N_0 . The data set represented true experimental data, smoothed by using the analytical model. The following tolerance components were considered necessary to be attached to the data set:

¹⁴SNORE: signal-to-noise ratio estimator, using SSA matched filter signal to obtain an estimate of E_s/N_0 .

¹⁵As obtained from the symbol error count, using the inverse complementary error of function.

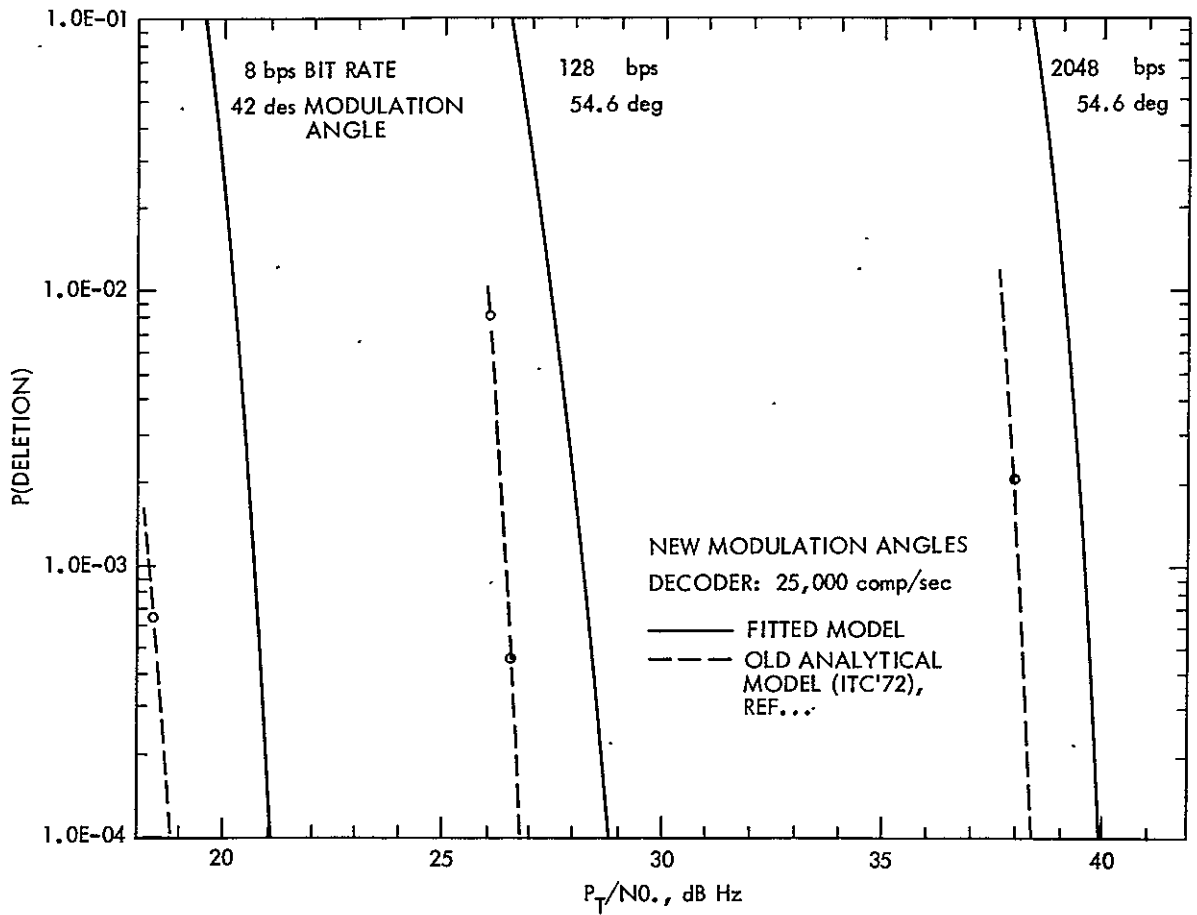


Fig. 34. Overall station performance

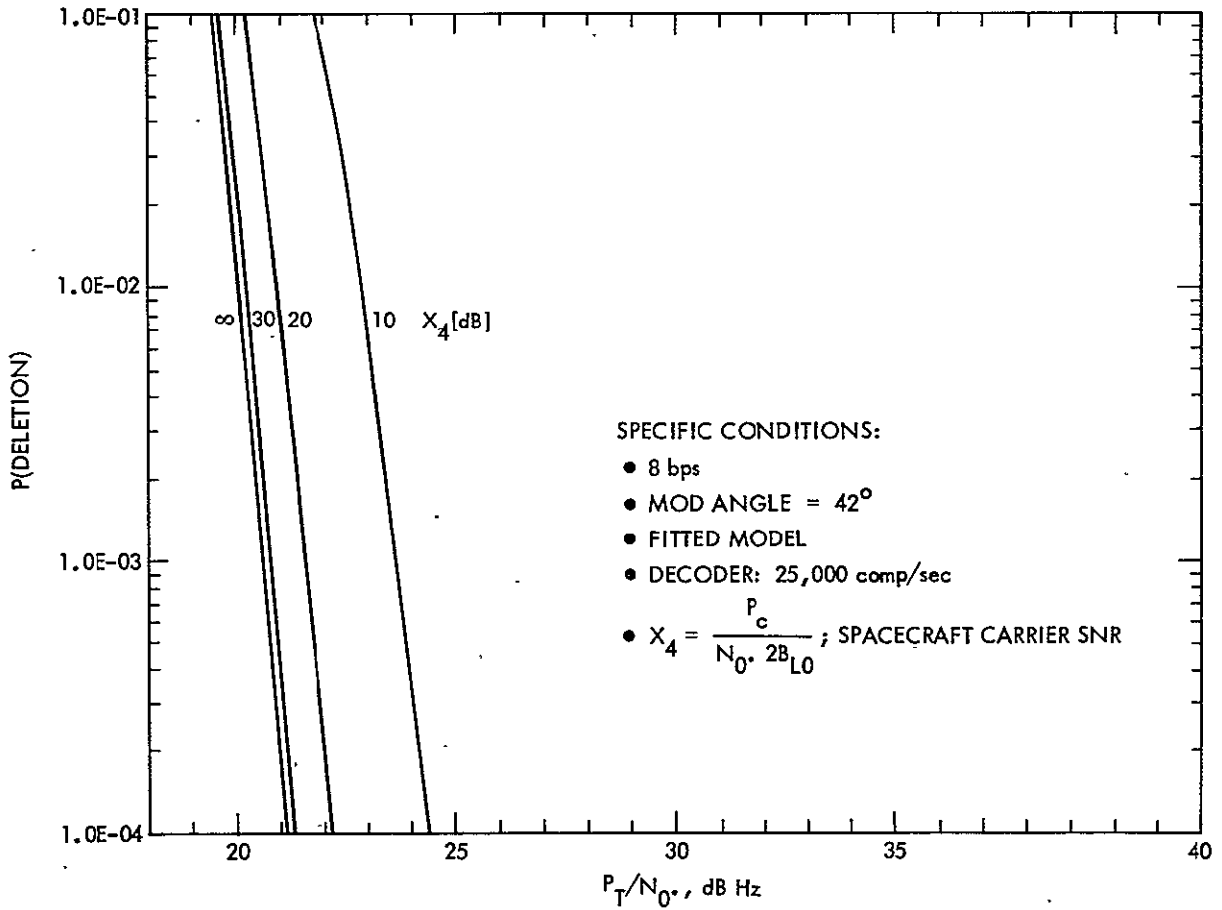


Fig. 35. $P(D)$ vs P_T/N_0 , overall station performance, influence of two-way link

C-2

Modulation angle setting	± 0.3 dB
Y-factor setting	± 0.4 dB
Extrapolation of curves to 10^{-4} (limited sample size)	0.7 ... 0.3 dB for 8 ... 2048 bps

For station-to-station variation, a 0.5-dB tolerance was added. For link design, spacecraft modulation tolerances had to be accounted for. Nominally, the revised DDA performance estimate indicated that the effect of noisy carrier reference on P_T/N_0 at $P_D = 10^{-4}$ for 8 bps was -1.1 dB relative to DFVLR's older optimistic analytical model (a 5.6-dB improvement relative to the degradation of -6.7 dB, as discussed in the following paragraph).

7. Modulation Index Selection

In April 1973, the Helios Project requested the help of the DSN in the selection of the low bit rate telemetry modulation index because of problems they were having in the spacecraft telemetry link design due to the lack of information pertaining to the DSN Data Decoder Assembly (DDA) low-bit-rate performance characteristics.

At the eighth HJWGM, May 7-11, 1973, the DSN presented the results of the JPL modeling study on the effects of downlink modulation index on DDA performance. The tradeoff was the allocation of power between the carrier and subcarrier. The optimum modulation index was predicted to lie between 30 and 35 deg for the lower bit rates. The model was admittedly somewhat pessimistic at the lower bit rates because it assumed a uniform noise distribution.

Generally, if the DDA decoded a frame, the bit error rate was insignificant. For example, a frame deletion rate (FDR) of 10^{-4} yielded at least a BER of 10^{-6} or better. For low bit rates, when the total power-to-noise ratio fell to the vicinity of 20 dB, the total data return was greater using uncoded data because the BER (though perhaps significant) was smaller than the frame deletion rate. It was therefore acknowledged that the FDR rather than the BER is the controlling factor for convolutionally encoded telemetry.

The results of the Helios Project modeling study agreed quite closely with the independently derived JPL data (Pioneer 10 extrapolations). For example: using a modulation index of 32 deg the Project model agreed with the JPL total power-to-noise ratio predictions within 0.5 dB for a 10^{-4} frame deletion rate. The Project also agreed with JPL in that, below a certain SNR threshold, it could be advantageous to go uncoded.

Neither study included the effects of solar spectrum broadening, but that was of secondary importance because that phenomenon would only be experienced when the spacecraft was at or near solar occultation. What was significant was that the two new models (Project and DSN) were 1 and 7 dB, respectively, more pessimistic than the model previously employed in the telecommunications link analysis. Further, the 6-dB spread between the two models represented too severe a penalty to impose upon the link uncertainty. This presented a quandary since it was felt that sufficient statistical data could not be obtained from Pioneer 10 prior to the fall of 1973; yet the transponder's

modulation index had to be established by early summer 1973 in order for the spacecraft to meet its manufacturing schedule. The quandary was solved via a three-way effort involving Project telecommunications personnel, convolutional coding experts from NASA's Ames Research Center (managers of the Pioneer 10 Project) and the DSN. Using a special test procedure developed by the Ames personnel, the DSS 11 station at Goldstone was operated around the clock (with team members filling in during the nonstaffed station hours) to obtain magnetic tape recordings of station performance using a simulated coded data stream. These recordings were flown via courier aircraft to the Ames Research Center at Sunnyvale, California, where they were played into a laboratory computer which was uniquely programmed to simultaneously simulate the DSN decoder while analyzing its own performance. Recordings covering various received signal-to-noise ratios and telemetry bit rates were thus analyzed, then plotted graphically. Gradually, sufficient statistical data were obtained so that a composite and greatly refined model of the telemetry decoding performance could be achieved. The composite model predicted decoding losses in the neighborhood of 2 dB with an uncertainty about 0.5 dB, based on single-station performance. Using the composite model's performance estimates, the Helios Project on July 31, 1973, selected transponder modulation indices of 42 and 54.6 deg for the low and high telemetry bit rates, respectively, and the manufacture of the spacecraft proceeded. The question of how much uncertainty remained in the composite model due to variations between DSN stations was deferred to later in-flight Helios experience, plus whatever information yield was obtained from a DSN parallel test, using frequency/bit-rate scaling techniques.

C. TRACKING-RELATED DEVELOPMENTS

1. Near-Earth Phase Study Group

During the planning and early design stages of any new flight project, it is important to investigate a few typical spacecraft trajectories to ascertain whether or not the spacecraft design, mission objectives, and the necessary TDS support can be molded into a viable total concept. Toward this end, a special Helios Near-Earth Phase Study Group was formed during the Third Helios Joint Working Group Meeting in Bonn, West Germany, in October 1970.

The need for a thorough near-Earth and first DSN acquisition study involving all mission systems had not been recognized early enough by other Projects in the past, with the result that last-minute changes in the spacecraft, launch vehicle, mission operations or TDS procedures were necessary in a number of instances. For example, it was pointed out that because of the first-acquisition delay constraints and limited spacecraft battery life, one of the Surveyor spacecraft had to be modified just before launch to include a sequencer to automatically acquire the Sun after injection. In another case, the Pioneer VI spacecraft had to be modified to turn on the power amplifier after injection because of a marginal received signal level constraint.

The pending acquisition problem for Helios was particularly critical because of a very high injection velocity, a wide range of launch azimuths, and an unguided third stage. The need for such a study was particularly urgent in order to mitigate unacceptable performance discoveries just prior to launch.

In preparation for the Near-Earth Phase Study Group Meeting (which occurred the week following the third JWGM), the JPL/ETR organization developed a set of Near-Earth Phase station coverage data for each of the tentative Helios trajectories provided by the NASA Lewis Research Center. These data, together with information provided by the Helios experimenters, provided a better knowledge of the spacecraft and launch vehicle performance characteristics, and a refined knowledge of the Helios Program mission objectives permitted the Near-Earth Phase Study Group to develop a tentative mission sequence from launch through completion of the spacecraft's orientation maneuvers. In developing their recommendations for the near-Earth sequence of mission events, the study group considered both direct-ascent and parking-orbit trajectories. The study group concluded that the parking-orbit trajectory provided only a moderate increase in launch window opportunities over that provided by the direct-ascent trajectory, while at the same time presenting a more difficult tracking and data acquisition problem because of the lack of sufficient tracking facilities in the South Atlantic and Indian Oceans. Therefore, the Helios Project Office accepted the study group's recommendation that for planning purposes the nominal Helios mission design should be based upon a direct-ascent trajectory, a target perihelion of 0.25 AU,¹⁶ and a launch date of July 1974¹⁷ - but with the Project Office restriction that the spacecraft itself be designed to be compatible with a parking-orbit trajectory in case the latter became necessary at a later date.¹⁸

Once the foregoing decision was made, the Lewis Research Center produced a formal set of Helios direct-ascent launch trajectories covering both the Titan/Centaur and Atlas/Centaur launch vehicle combinations. Subsequently, the JPL/ETR organization developed tracking and telemetry station coverage data for these upgraded trajectories. This material was used during the second meeting of the Near-Earth Phase Study Group to establish a formal mission sequence for the Near-Earth Phase of the Helios mission.

Following the fourth Helios Joint Working Group Meeting, the second meeting of the Near-Earth Phase Study Group was conducted at the Goddard Space Flight Center during May 5-7, 1971. The principal objective of this latter meeting was to establish whether or not a viable near-Earth sequence of events could be established which would permit the activation of selected science instruments aboard the spacecraft in time to make magneto-pause measurements in the region from 13 Earth radii to lunar distance. To accomplish this, the study group selected one typical trajectory (e.g., a 60-deg launch azimuth using a Titan/Centaur launch vehicle) and the latest available information generated by the study group membership together with information received during the fourth Helios Joint Working Group Meeting. The study group succeeded in generating a sequence of events for the selected Near-

¹⁶In July 1974 the U.S. and German Project Managers selected 0.31 AU as the final targeting perihelion for the first Helios spacecraft.

¹⁷After several changes, the opening launch date was set in September 1974 for December 8, 1974.

¹⁸Partial success/failure of first Titan-Centaur proof test flight in February 1974 resulted in a NASA decision in April 1974 to launch a Helios spacecraft on a parking-orbit trajectory.

Earth Phase Mission Profile. Included in the list of constraints used by the study group was the DSN acquisition procedure. This constraint, together with the need for the Mission Operations Team to carefully monitor and possibly send override commands to the spacecraft during boom deployment, delayed the planned initiation of the two-way coherent transponder mode of operation until spacecraft separation plus 70 min. This in turn delayed somewhat the DSN's ability to generate an early spacecraft trajectory for the purpose of computing station predicts and for use by the Mission Operations Team during the Step II maneuver. The impact of such a delayed start in the two-way, coherent mode of operation was not considered serious provided AFETR radar metric data were available from the C-band transponder aboard the TE-364-4 third stage.

2. Solar Occultation (Communications Blackout Period)

The planned Helios trajectory was such that the spacecraft would be occulted by the Sun several times. These occultations would create a radio signal "blackout." The blackout region or angle as viewed from Earth is larger than that dictated by the physical size of the Sun, because the solar corona distorts the radio signal in such a manner as to make it more difficult to receive. In addition, the temperature of the Sun causes an increase in radio system noise as an antenna looks closer and closer toward the Sun. The combination of these two effects increases both the apparent blackout angle and the amount of time the spacecraft must endure without communications from Earth. Because of the latter, it was highly desirable that the Project and the experimenters be able to accurately predict this blackout angle.

In September 1970 the DSN received from the Helios Project a report¹⁹ on blackout periods, giving the time (days after launch) that the Helios spacecraft would enter a blackout period and the number of days the period would last. In preparing these calculations a launch date of July 1, 1974 had been used for the first Helios spacecraft along with target perihelions of 0.25 and 0.30 AU. The durations of the blackout periods corresponded to a critical Sun-Earth-spacecraft angle of 1 deg.

In reviewing the report on blackout periods the DSN noted that the blackout data were in substantial agreement with the findings of a DSN preliminary analysis made in July 1970. To assist the Project in understanding the Sun's influence on various communication modes - e.g., signal blackouts occurring at different times for telemetry, command, ranging, and carrier - the DSN Manager provided copies of two reports concerning the DSN's solar occultation experience with the Pioneer 6 (Ref. 3) and the Mariner 6 and 7 (Ref. 4) spacecraft.

Several weeks later a Critical Concept Review meeting was held in Munich, West Germany, at which the Project gave a presentation on Helios blackout region calculations as a function of Sun-Earth-spacecraft angle (0 to 5 deg) for a nominal launch date of July 1, 1974. In addition, the Project also

¹⁹Blackout Periods for Helios A and B, Project (GfW) Document TN 70/20, September 1970, Dr. Hiller.

distributed copies of a report²⁰ on blackout periods for a Helios spacecraft on a 0.25 AU trajectory. In both cases the reports indicated that the spacecraft would never be in a blackout period during the perihelion passage. The predicted time and duration of blackout periods differed only slightly.

The subject of solar occultation remained dormant until the sixth Helios JWGM in April/May 1972. In a TDS/Spacecraft Joint Subgroup meeting the subject of the behavior of telecommunications channels when a spacecraft enters occultation was brought up by the Project. During the discussion it was pointed out by the TDS Manager that there had been no organized, systematic analysis of all the data that the NASA missions had accumulated over the years, nor was there a funded NASA task to carry out the work. There was, however, some data available from an early JPL solar probe study (Ref. 5) that provided a plausible mathematical model for the solar corona effects upon communication channels, which the Project might find helpful. The Project decided to use the JPL study data to develop an assumed model for the telecommunications link performance vs angle from the Sun.

In February 1973 the TDS Manager and the German Project Office received copies of a Helios Blackout Study (Ref. 6) from the GSFC Helios Project Office. This study was conducted to define the times and durations during which the Helios spacecraft could be expected to move in a defined region of heliocentric space. This region of interest is conical in shape, having an apex angle of 3 deg, and having its generating axis coincide with the Earth-Sun line.

For purposes of determining the time of intercept with the conical boundary, and the periods during which the spacecraft occupied the region inside a cone, a computer program was developed and exercised.

In order to ascertain the information desired, the spacecraft was presumed to begin its motion, along its flight path, at a "near-Earth" position. This initial position was acquired using the analytical definitions set down in the Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac, 1961. For the purposes of this estimation the spacecraft was set to move in the ecliptic plane, under the singular attraction of the Sun. However, the modeling included a planetary ephemeris; thus realistic positioning of the Earth and the inner planets (Venus and Mercury) was maintained throughout the calculations.

Within the computer program per se, a subroutine was used to define the time at which the spacecraft intercepted the blackout cone's boundary. In this regard rather precise information was gathered concerning the position of the spacecraft, its state of motion, etc. In view of the definition for its conical region, the spacecraft's trajectory was described relative to the Earth-Sun line in addition to this representation in heliocentric, inertial space. Also, with these trajectories passing "through" the orbits of Mercury and Venus, a description of the spacecraft's relative position, with respect to these inner planets, was presented in the output of the computer program.

²⁰Blackout Periods for Helios 0.25 AU Mission, Launch Date: 1 July 1974, Project (GfW) Document TN 70/23, dated October 1, 1970, Dr. Hiller.

For this study the spacecraft trajectories were designed to have two specific perihelion passage distances: namely, 0.275 and 0.30 AU, as prescribed. Also, for this preliminary estimate of "blackout" periods, launch dates ranging from July 15 through December 15, 1974, were used.

A case of particular interest was one that had its launch on September 18, 1974, and its perihelion distance set to 0.30 AU. The trajectory data were generated for a maximum time span of 400 days. In this case study there were three periods of communications blackout, and these appeared to result in a near minimum total time spent in the conical region.

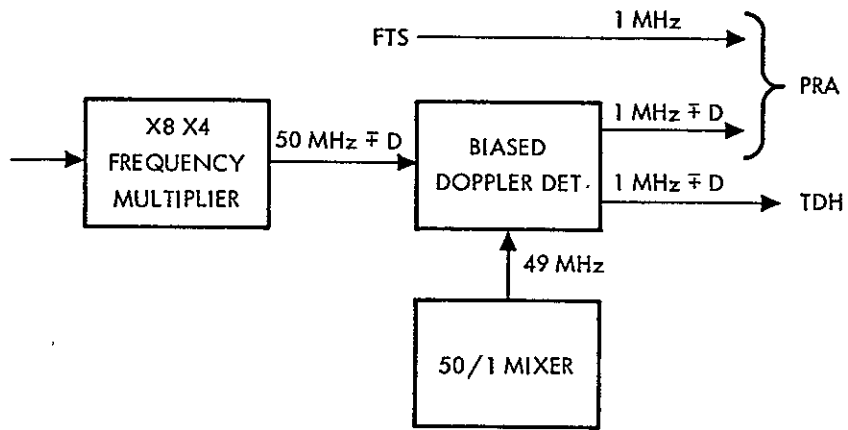
During this flight the longest time spent in blackout occurred about midway (timewise) between the first perihelion and the following aphelion, and lasted approximately $44 \frac{1}{4}$ days out of a total time of about 96+ days. For the opposite extreme, the flight path that would suffer the most due to communications blackouts would be one launched in mid-December (1974) and designated to have a perihelion passage distance of 0.275 AU. In this case nearly 24% of the total flight time (for two orbits about the Sun) would be spent inside the "blackout region"; and this percentage would increase significantly if the conical zone were widened to any appreciable degree.

As a point of interest, Helios-1 was actually launched on December 10, 1974. However, its perihelion distance of 0.31 AU produced a somewhat lower blackout percentage than predicted by the above study.

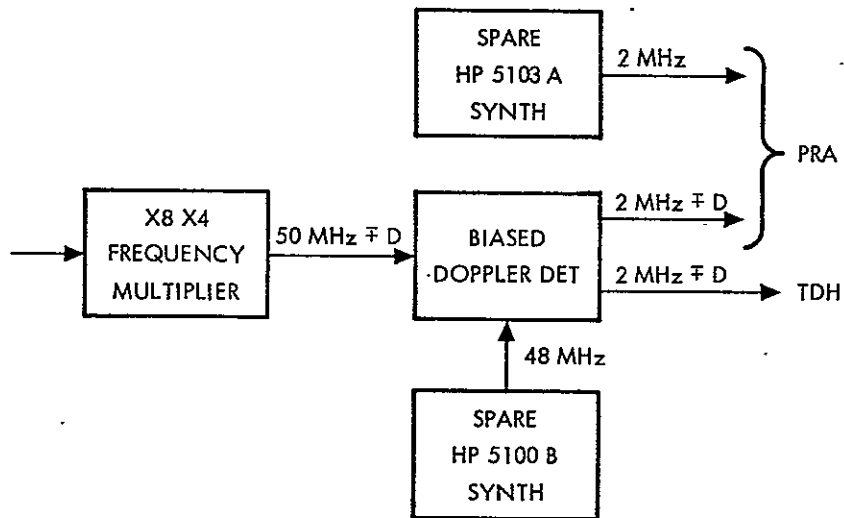
3. Two-Way Doppler Shift at Perihelion

In January 1973 a potential problem with the two-way doppler frequency shift during the planned Helios perihelion passage was brought to the attention of the DSN. Owing to the spacecraft's radial velocity from Earth when at 0.31 AU perihelion, the two-way doppler frequency shift would produce an S-band value of approximately 1.02 MHz. Because the doppler extractor in the existing DSN Block III Receiver/Exciter Subsystem²¹ could not accommodate this anticipated doppler shift, a study was made into possible solutions. By mid-February an acceptable solution had been found which called for the implementation of a temporary modification to the Receiver/Exciter Subsystem at DSS 43 to provide a 2-MHz doppler bias frequency with plus 200 kHz to minus 1200 kHz doppler range during the perihelion passage. Also, in order to permit proper data processing, a bias frequency indicator needed to be added to the Digital Instrumentation System (DIS) software for inclusion in the data blocks transmitted via HSDL to the MCCC. During Helios mission support, DSS 43 would employ a 1-MHz doppler bias frequency, with plus 1200 kHz to minus 600 kHz doppler range, until just before perihelion is reached; then the 2-MHz doppler bias frequency would be utilized to meet the Helios requirement of providing two-way doppler up to and including the second perihelion passage (Fig. 36).

²¹A Block IV Receiver/Exciter Subsystem which could handle this doppler shift was under construction for installation into the DSN 64-m stations. However, the first of these (DSS 14) would be barely ready in time for Helios-A.



(A) STANDARD 1-MHz CONFIGURATION



(B) HELIOS 2-MHz CONFIGURATION

Fig. 36. Doppler extractor modification

A similar scheme was also developed for the 26-m stations for use during the Helios second perihelion passage, when continuous support from the 64-m stations could not be assured because of other flight project needs.

4. DSN Acquisition

a. Initial DSN Acquisition. As a prelude to the discussions regarding the possible "blind acquisition" of the Helios spacecraft, it was necessary to thoroughly understand the procedures and techniques associated with a standard or nominal DSN initial acquisition of the Helios spacecraft after launch. In this regard, certain key factors were established during the proceedings of the sixth HJWG Meeting in April and May 1972; namely, the expected trajectory would have a 926-km (500-nmi) perigee altitude and would be restricted to the southern launch corridor. The combination of these two factors greatly reduced the angle and doppler tracking rates associated with the DSN initial acquisition to the point that both would be within standard DSN station capabilities. Consequently, the remaining uncertainties were associated with the interferometer region of the spacecraft low-gain antenna system and the dispersion uncertainties in the injection point due to the TE-364-4 last-stage solid-rocket motor burn. The latter had been studied in detail prior to the meeting, with the result that the estimate for a successful DSN initial acquisition was greater than 0.9 (90%) in the nominal case. Further, this probability would occur in a time period (measured in minutes) closely following spacecraft rise at the initial acquisition station, which, at that time, was DSS 51 in Johannesburg, South Africa. However, planning was underway in mid-1973 to deactivate DSS 51 in July 1974 and, if approved, would require a change in the DSN initial acquisition station from DSS 51 to DSS 62 at Cebreros, Spain, with DSS 61 at Robledo, Spain acting as backup, as well as a change from the southern launch corridor to a northern launch corridor. With the approval of the deactivation of DSS 51 and the shift in launch corridors, the DSN began making plans for the initial acquisition by DSS 62. Using the northern launch corridor the spacecraft trajectory was such that injection and separation could occur after spacecraft rise at Cebreros, and as high as 15 to 30 deg elevation angle, with angular tracking rates from 1 to 10 deg/s. However, as the spacecraft gained altitude, these rates were expected to diminish rapidly and be within the station's antenna capabilities as the spacecraft crossed the station's meridian on a near-overhead pass.

Because DSS 62 did not have an acquisition aid (ACQ Aid) antenna, the DSN made plans to remove the ACQ Aid from DSS 11 in mid-1974 and ship it to DSS 62 for installation and checkout prior to the Helios launch (see Section V-C). Then in April 1974, just prior to the tenth HJWG Meeting, NASA announced that a decision had been reached between the U.S. and the Germans that the Helios spacecraft would be launched into a parking orbit rather than on a direct ascent.

This decision had a direct impact on the DSN initial acquisition plans. First, it meant that initial acquisition would occur over Australia, and second, it would occur later after spacecraft separation than originally planned. The DSN again shifted plans and designated DSS 42, the 26-m antenna station in Weemala, Australia, as the prime DSN initial acquisition station. In addition, DSS 43, the 64-m antenna station in Ballima, Australia, was designated as the backup acquisition station. The situation remained thus until

early October 1974, when NASA Headquarters officially slipped the Helios launch date to December 8, 1974, thus creating a conflict with the Pioneer Project for the use of DSS 43 (see Section V-D.).

b. Blind Acquisition. During the sixth HJWG Meeting in April and May 1972, the question of blind acquisition of the Helios spacecraft arose when it was discovered that a power supply overload in the downlink transmitter could place the transmitter in a "silent mode," thus requiring a command signal from the DSN ground station to reinstate the downlink transmitter signal. The acuteness of this problem depended upon the mission phase. The most critical period was deemed to be after spacecraft separation from the launch vehicle and prior to initial acquisition, and, because there was no prior flight experience, the search techniques would have to depend upon the accuracy of the preflight predictions. In addition, the problem was further complicated by the necessity of having to transmit a command "idle stream" to phase lock the spacecraft receiver bit synchronizer prior to its ability to accept a command. Therefore, during the sixth HJWG Meeting, a special study team was constituted to investigate this potential problem in detail and to present the findings at the seventh HJWG Meeting. The DSN participated in this effort both prior to and during the seventh HJWG Meeting. In performing their study, the team had to make certain key assumptions: the spacecraft failure was not catastrophic; the 926-km (500-nmi) perigee altitude (lofted) trajectory would be employed; the low-gain antenna (LGA or omni) pattern nulls would not exceed 5 dB; the Near-Earth Phase Network (NEPN) could provide pointing information to the DSN based on launch vehicle tracking data; and the DSN initial acquisition station would have an acquisition aid antenna. Of the foregoing, the assumption of -5 dB antenna nulls seemed to be questionable, with the feeling that -40 dB would be a better number. While the DSN agreed to recalculate their predictions based on the -40 dB null criterion, the team concluded that the controlling factor in a successful blind acquisition was the perigee altitude. Altitudes significantly lower than 926 km (500 nmi) would both increase the time required and lower the probability of successfully entering a blind command into the spacecraft to reactivate the downlink. For evaluation purposes, the original assumptions produced the conclusion that the DSN would have a high probability (e.g., 0.9) of successfully establishing communications with the spacecraft by Launch +1 hour. The significant change with respect to a standard initial acquisition was, therefore, the time required after spacecraft rise at the initial station for two-way communication to be established.

Because of the relatively late decision to fly Helios-A on a parking orbit trajectory with initial DSN acquisition over Australia, the HJWG study group did not meet again on the blind acquisition question. However, by this time the NASA TDS organization had a reasonably good understanding of the spacecraft and mission constraints involved with the entire initial acquisition process (including blind acquisition) and so were able to develop internally the required new operational procedures needed for the parking orbit case. These new operating procedures were reviewed and accepted by the Helios Mission Operations Team upon their arrival at JPL for prelaunch activities.

D. COMMAND-RELATED DEVELOPMENTS

1. DSN Command System Redesign

The Multiple Mission Command (MMC) System that had been designed for the Mariner Mars 1971 (MM'71) mission (referred to as the DSN Mark III-71 Command System), and implemented throughout the DSN, successfully supported the MM'71, Pioneer 10, Pioneer 11, and the Mariner Venus/Mercury 1973 (MVM'73) missions. For these projects the command transmission rate was 1 bps. However, for Helios there was a requirement for a command transmission rate of 8 symbols per second, while the Viking Project had a command requirement for 4 bps. To meet these increased transmission rates the DSN Command System had to undergo extensive software program changes.

The requirements for increasing the command transmission rates from the Mark III-71 to the Mark III-74 era made it necessary to transfer some command functions from the DSS Telemetry and Command Processor (TCP) to the Mission Control and Computing Center (MCCC). Many of the TCP command software functions are driven by interrupts from the command hardware at the DSS. The frequency of these interrupts is proportional to the bit rate supported. The increase in bit rate effectively increased the frequency of these interrupts 8 times as often for Helios as for previously supported projects. In order for the DSS TCP to operate at this increased bit rate it was necessary to transfer some of the time-consuming software functions from the TCP to the MCCC. The command stack searching and manipulation functions were considered the most time-consuming and were deleted from the DSS TCP and transferred to the MCCC.

Redesign of the DSN Command System software was initiated in September 1972. On December 7, 1972, a design review was held, at which time the new design was approved for implementation in the DSN and identified as the DSN Command System Mark III-74. By December 1973 the Mark III-74 System had been phased into the DSN without disrupting operational support of ongoing projects (Pioneer 10, Pioneer 11 and MVM'73). Between September 1974 and January 1975 the ongoing projects were successfully phased over from the Mark III-71 to the Mark III-74 Command System.

a. Mark III-71 Data Flow. In the Mark III-71 Command System (Fig. 37a), the MCCC software basically provided a remote terminal capability to the TCP. Under operator control, the MCCC software generated high-speed data (HSD) blocks of command data. The data were transmitted to the DSS, where they were placed in the TCP command stack. A verification block was then returned, and the MCCC performed a bit-by-bit comparison with what was transmitted. A failure to correctly verify resulted in an automatic retransmission of the entire command block. When the Project decided to send a command, an enable block was generated, either automatically or under operator control, and transmitted to the DSS TCP. Again a verification block was returned, and the MCCC software then performed a bit-by-bit verification on the enable block. Finally, after successful transmission of the command from the DSS to the spacecraft, the TCP constructed a command confirmation HSD message which was sent to the MCCC. The MCCC software then displayed the command confirmation to the operator.

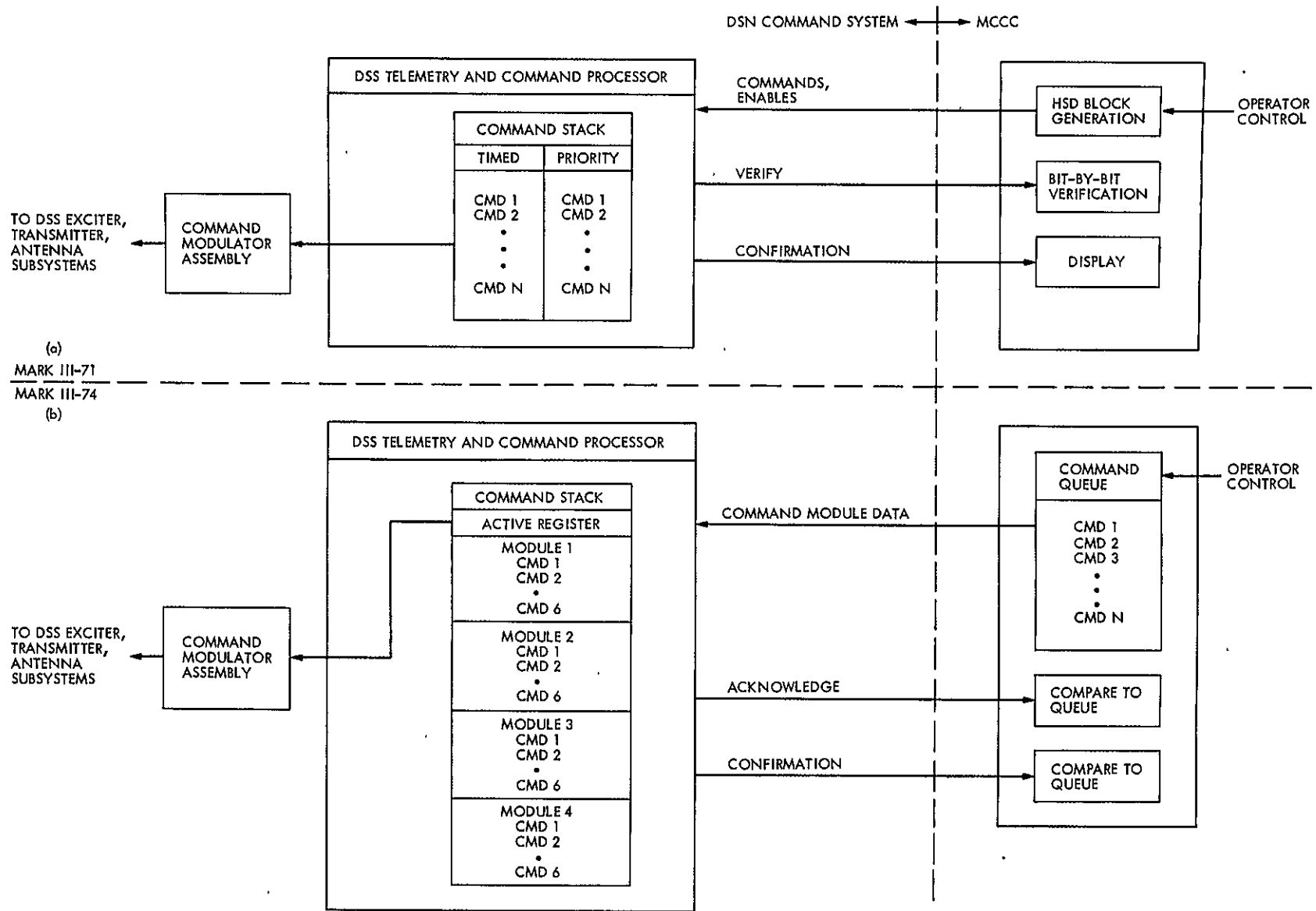


Fig. 37. Comparison of Mark III-71 and Mark III-74 command system

At the DSN stations, the TCP sorted, arranged, and searched the commands in the command stack. Upon receipt of commands from the MCCC, the TCP software sorted priority and timed commands into basically two stacks. When enable messages were received from the MCCC, the TCP software at the DSN station was required to search both stacks completely to ensure proper command enabling.

b. Mark III-74 Data Flow. In the new Mark III-74 Command System (Fig. 37b), the MCCC software provides direct control of the contents of the TCP command stack. The command operator now only controls the contents of the command queue in the MCCC computer. The MCCC software then can, via HSD messages, force the TCP stack contents to be consistent with the command queue in the MCCC. Therefore, commands are now entered into the command queue under operator control. When the operator enables commands in the queue, the commands are "eligible" for transmission to the DSS TCP. The commands are sent to the DSS TCP and placed in the TCP per direction in the HSD message. An Acknowledge message is constructed at the DSS TCP and sent to the MCCC. The data are compared against the contents of the queue. Failure to compare results in automatic retransmission to the TCP. After successful transmission of a command from the DSS to the spacecraft, a message is sent from the DSS TCP to the MCCC, where it is compared with the contents of the queue. The command is then marked "successfully confirmed" and displayed to the operator.

At the DSN stations, the TCP software is no longer required to arrange and search the TCP command stack. The MCCC software is required to keep the stack in logical order such that the TCP only has to "look" at the top command in the stack. The TCP stack is arranged into four modules and an active register. The command stack is loaded by modules via HSD block from the MCCC. The MCCC software is required to keep the stack modules updated consistent with the command queue in the MCCC. The only command eligible for transmission to the spacecraft is the top command in the number one module. Note that an enable message is no longer required from the MCCC. There are two types of commands in the Mark III-74 System: (1) timed commands and (2) nontimed commands. A nontimed command will be transmitted immediately when it occupies the top command position in the number one stack module. A timed command will be transmitted when the GMT reaches the command transmit time and the command occupies the top command position in the number one stack module. The command is transmitted to the spacecraft by "moving" it to the active register. Upon successful transmission of the command from the DSS to the spacecraft, a HSD message is constructed by the DSS TCP and sent to the MCCC for notification of confirmation.

c. Summary. The primary change to the DSN station TCP software for the Mark III-74 System was the deletion of the stack arranging and searching. This has allowed the capability for the software to perform more important functions at the higher (8 vs 1 bps) command bit rates. The same types of hardware checks provided at 1 bps for the Mark III-71 System are provided for the Helios command rate of 8 bps.

2. Command Idle Stream

The Helios spacecraft was designed with two actively redundant receiver/command detector chains (Fig. 38). The first chain was fixed-wired to the low-gain (omni) antenna system, while the second chain was fixed-wired to

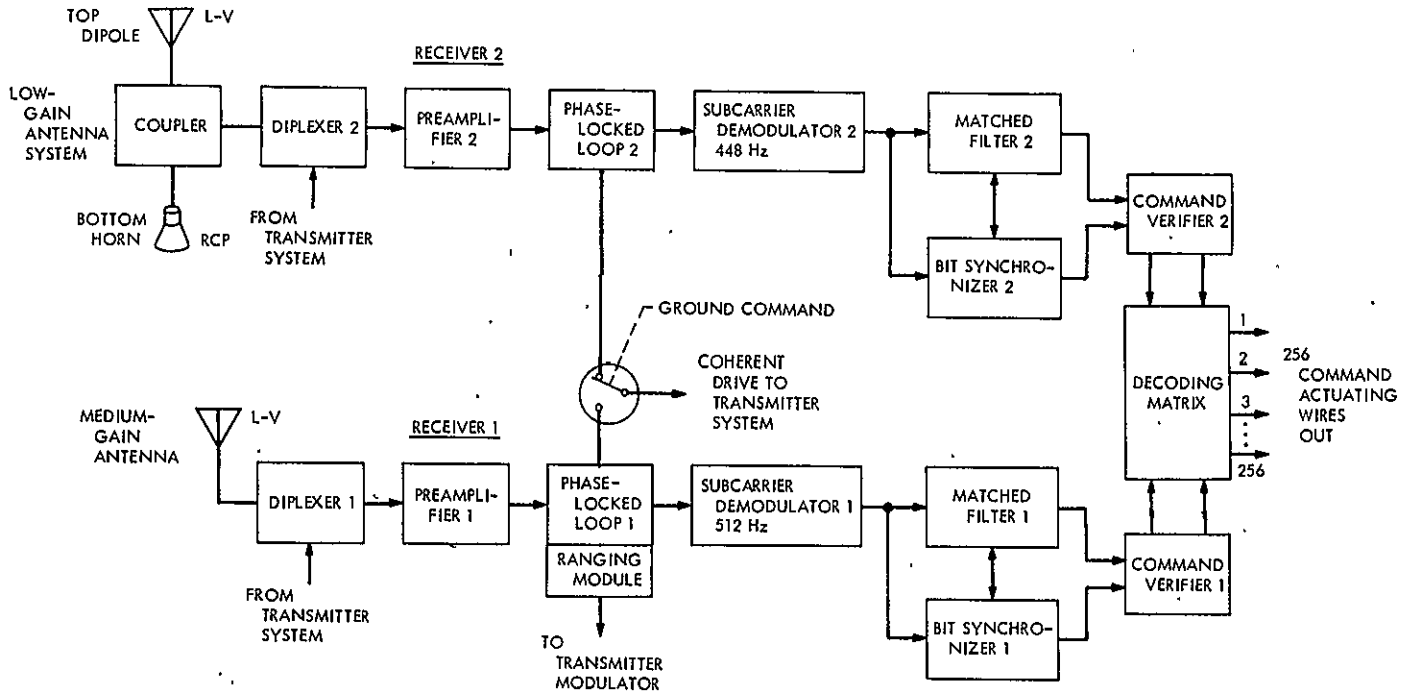


Fig. 38. Helios command detection system block diagram

the medium-gain antenna system. (As discussed previously, the spacecraft high-gain antenna provides a transmit-only function.) Since both receiver/command detector chains were to be continuously active, there were redundant means to enter commands into the spacecraft to protect against a failure in one of the chains. Since both receivers operated on the same S-band carrier frequency, means were provided whereby ground control could select the desired chain through which to enter a command.

First, there was a desired path due to the gain differential between the low- and medium-gain antennas. During the near-Earth and cislunar portions of the mission, the preferred path was via the low-gain antenna system, since the spacecraft would not have been oriented such that the medium-gain antenna pattern impinged upon Earth. However, after the Step II orientation maneuver, the situation would be reversed, with the medium-gain antenna having a 6- to 8-dB advantage over the low-gain antenna system.

Second, each receiver/command detector chain would have a separate command subcarrier frequency (448 vs 512 Hz), thereby permitting ground control to select the chain desired regardless of spacecraft orientation, even though the 8 symbols/command rate would be coherent with both subcarrier frequencies.

Third, as a further protection, each chain's command verifier had a unique address in the command word structure. This precluded commands accidentally appearing in the wrong chain from entering the decoding matrix.

The combination of the above features provided a truly redundant, fixed-wired active command system that could be operated in either the noncoherent or coherent transponder mode, while at the same time providing ample insurance against a double command entry.

The performance requirements for the Helios command system are shown in Table 7. It is interesting to note that, while the performance of the command system was dependent upon having sufficient uplink signal strength, the redundant receiver/command detector chains did not otherwise significantly contribute to achieving the requirements listed in Table 7. This was because the commands were entered through only one chain or path at a time. The redundancy did, however, provide hardware reliability. Command bit or word error reliability had to be coded into the command symbol structure itself.

Table 7. Helios command requirements

Requirement	Value
Bit error probability	$\leq 10^{-5}$
Detected word error probability	$\leq 10^{-3}$
Undetected word error probability	$\leq 10^{-10}$

a. Helios Command Code. To achieve low error probabilities, Helios commands were Manchester-coded, which translates each command bit into two symbols (the original bit followed by its complement) for transmission to the spacecraft. The coded 8 symbols/second command symbol stream was phase-shift-keyed (PSK) modulated onto one of the two (i.e., 448 or 512 Hz) command subcarrier frequencies, which was, in turn, phase-modulated onto the S-band uplink carrier. (Ranging modulation could be present or not on the S-band uplink carrier - depending upon the mission mode at the time.) Upon receipt at the spacecraft, the command signal followed one of two paths indicated in Figure 38 and was routed through the appropriate command verifier to the decoding matrix. The decoding matrix had 256 separate hard-wire outputs which were routed to the individual items to be controlled aboard the spacecraft. These 256 outputs represented the total (i.e., maximum) list of independent commands that could be sent to the Helios spacecraft.

b. Idle Sequence. Owing to both the relatively low frequency of the command subcarriers and the stringent requirements for low bit or word error probability, the spacecraft command detector loop needed a fairly narrow bandwidth. On the other hand, narrow bandwidths do not respond well to square-shaped pulses. The latter problem could be minimized if the spacecraft command detector was kept in synchronism with the incoming command symbol stream. For Helios, this was accomplished by sending an uncoded idle stream of bits/symbols to the spacecraft during the intervals between commands. The idle stream had the following pattern:

...001001001...

This idle stream, which was sent at a rate of 8 bits/symbols per second, was also coherent with the two command subcarrier frequencies - i.e., 448 or 512 Hz. It was necessary for the spacecraft to receive the idle stream for a few minutes prior to receiving a command or series of commands in order to ensure that the spacecraft bit synchronizer (Fig. 38) was in lock. However, once the bit synchronizer was in lock, the idle stream could be interrupted on either "0" or a "1" to start the actual command sequence.

c. Command Symbol Sequence. Each Helios command consisted of a sequence of 68 symbols sent at a rate of 8 symbols/s. The 68 symbols composed one command word. One command word had to be sent for every command desired to be executed. The allocation of symbols within any one command word is shown in Fig. 39. From Fig. 39 it is noted that each command word repeats the command address twice and also contains three synchronizing subwords. In addition, each command word of 68 symbols also contains flag, verification, and parity bits which are similarly repeated twice within the total command word. The flag bit symbols are used to determine if the address is to be processed by the command decoder to generate one of the 256 command outputs or if the address bit is to be delivered directly to the data handling system to prepare it for the next mode of operation. The verification bit symbols are used to determine which receiver/command detector is permitted access to the decoding matrix (see Fig. 38). The parity bit symbols are used in a conventional manner to validate the address and verification portions of the command message. The foregoing structure plus the benefits of Manchester coding was designed to fulfill the requirements set forth in Table 7.

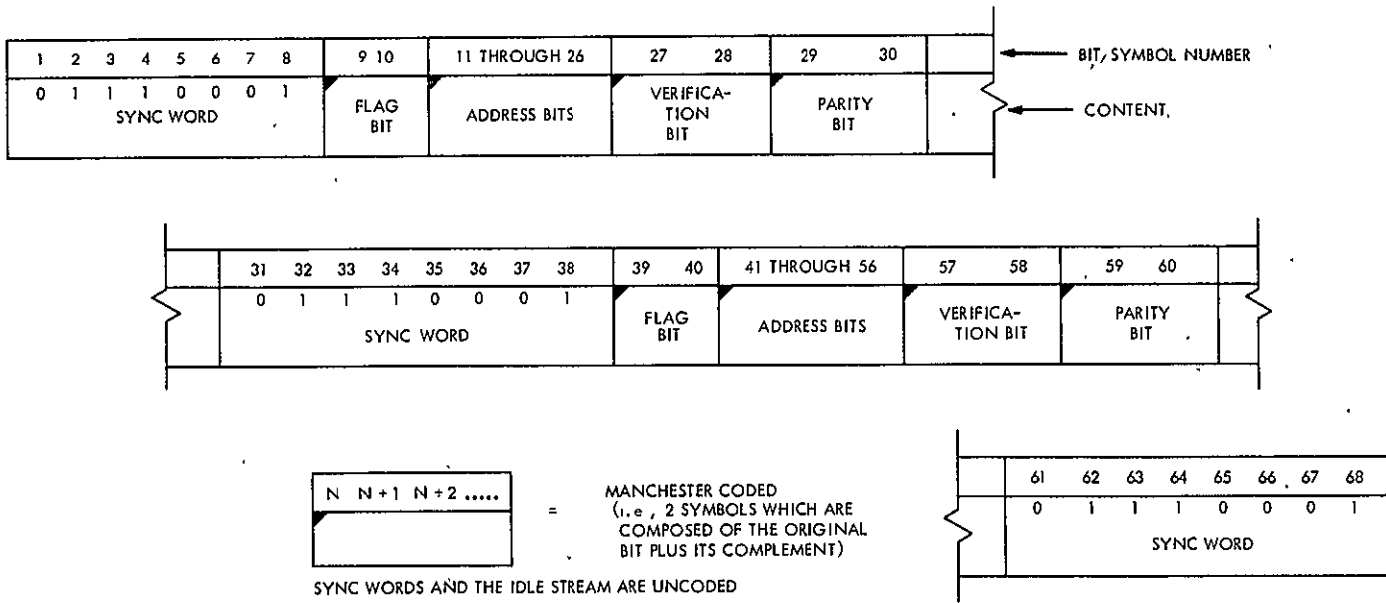


Fig. 39. Helios command bit symbol sequence

If on occasion it might be desirable to send a series or chain of commands in one sequence, i.e., without interruption, the final 8 sync bits of the preceding command in the chain could be eliminated because they duplicate the leading 8 sync bits of the next command to be sent. In other words, sync words may only be eliminated when (1) they appear immediately adjacent to one another, and (2) commands are chained together and sent without interruption. There is no spacecraft limitation regarding the number of commands in a chain; however, the high-speed data line between the MCCC and the Deep Space Stations do have a finite data block size which, for practical purposes, limits the number of commands in any one chain to approximately 10.

d. Impact on the DSN. The Helios precoded command table of 256 potential commands did not present a difficult problem to JPL. Neither did the transmission of a selected precoded command or series (up to 10) of commands from the MCCC to the DSS over the high-speed data lines present a significant problem. Upon receipt at the station, the DSS telemetry and command processor (TCP) both logs the total command message and repeats it back to JPL for verification and subsequent enabling prior to transmission. At the time of transmission (either immediate upon enabling or at a specified time) the precoded command symbols stored in the TCP are synchronously and coherently modulated onto the appropriate command subcarrier for transmission to the Helios spacecraft. To accomplish the latter requires that the station:

- (1) Derive the command subcarrier frequency, the idle stream frequency, and the timing for the command symbols themselves from one coherent source.
- (2) Receive prior instructions as to which Helios command subcarrier frequency to employ for a given command.

Both of these requirements are met by the Mark III command system implemented into the DSN. Therefore, as long as the proper operational procedures were followed, there does not appear to be a problem for the DSN to execute the Helios commands.

E. SPACECRAFT COMPATIBILITY WITH DSN

From the start of the Helios Project it was recognized that telecommunications compatibility between the DSN and the Project would be an involved problem due to the implementation of the spacecraft telecommunications system being conducted in Germany concurrently with continuing DSN development. As a result of this awareness a compatibility program was started in November 1970 with the establishment of a design team composed of Helios and DSN representatives at the third meeting of the HJWG. The design team developed a DSN/Helios Spacecraft Telecommunications Compatibility Management Plan document to provide direction and approval of compatibility resource expenditures. This document reflected approximately 10 years of DSN experience in establishing subsystem and system level compatibility between itself and deep space projects prior to launch.

The following paragraphs describe the three phases of compatibility testing between the Helios spacecraft and the DSN, as well as some of the problems that were revealed and corrected.

1. Engineering Model Transponder

In April 1972 the first DSN/Helios compatibility tests were conducted at the former DSS 71 (Cape Canaveral Air Force Station, Florida), using an Engineering Model (EM) spacecraft transponder. Because of spacecraft scheduling constraints the EM transponder did not contain the telemetry and command data handling unit when shipped from Germany. This condition resulted in the telemetry and command modulation having to be simulated by using specially generated digital waveforms in order to measure various transponder performance parameters and did not establish a true end-to-end telecommunications compatibility test. In addition, receiver design deficiencies that had been noted during receiver verification and EM transponder integration tests conducted in Germany in 1971 were not all corrected, and therefore some problems were expected in the receiver portion of the transponder.

Because of limited time available for subsystem compatibility testing of EM transponder equipment, it was necessary to ensure that no test time was lost as a result of transportation requirements and delays. To this end, the amount of special test equipment transported between Germany and the U.S. was kept to a minimum, and maximum use was made of the former DSS 71 facilities.

Before initial subsystem compatibility testing, it was necessary to ensure that the EM transponder equipment was still in proper functional condition. Thus, a functional performance test requiring two days was carried out to verify nondegradation of main subsystem parameters.

Apart from DSS 71 and screen room facilities, the DSN furnished certain items of general laboratory test equipment as a convenience to the GfW Helios Project Office. The Helios Project Office provided a project-peculiar break-out box²² and associated equipment for subsystem compatibility testing, which included the following:

- (1) Monitoring of telemetry outputs from the transponder.
- (2) Simulation of command interfaces between the data handling equipment and the transponder.
- (3) Simulation of a load for the command detector output.
- (4) Simulation of a subcarrier and clock for input to the spacecraft transmitter.
- (5) Simulation of clock inputs to the traveling wave tube (TWT) converter.
- (6) Distribution and switching of power supplies (except where this is done within the transponder, in response to telecommands).

²²A specially designed device that permitted access to selected signals within the transponder and/or the associated cabling.

- (7) Provision of an RF mating unit for the transponder to the DSS 71 interface.
- (8) Provision for laboratory test equipment access to the EM transponder.
- (9) Provision for accepting a simulated formatted bit stream (convolutionally coded or uncoded) for modulation of the subcarrier.
- (10) Provision of certain signals to DSS 71 (such as receiver lock status signals, demodulated command bit stream).
- (11) Provision of the wiring interface with all test equipment.

The EM transponder equipment arrived at DSS 71 in April 1972 with the necessary test jigs for assembling the components in a mechanical and electrical configuration suitable for the test and with a test harness corresponding as closely as possible to that in the spacecraft.

DSN personnel prepared all mission-independent software required for compatibility testing. All mission-peculiar software requirements were provided in detail by GfW.

Testing consisted of the following:

- (1) Spacecraft transponder maximum sweep and acquisition rate.
- (2) Spacecraft transmitter S-band spectrum.
- (3) Spacecraft receiver rest frequency determination.
- (4) Spacecraft transponder carrier and subcarrier threshold.
- (5) Spacecraft transponder carrier phase jitter measurement.
- (6) Ground receiver carrier and subcarrier threshold.
- (7) Probability of ranging acquisition with and without doppler offset.
- (8) Erasure rate.
- (9) Subcarrier frequency and phase jitter.
- (10) Spacecraft receiver lock and free-running frequency determination.

As a result of these tests the following design deficiencies were noted in the EM receiver:

- (1) Drift of rest frequency.
- (2) Poor acquisition: impossible at strong signals because of pushing and probably false locks. In addition, there were problems, in certain modes, that arose when the spacecraft transmitter

was turned on. The worst effects were associated with the high-power mode.

- (3) Phase detector offset voltage increased substantially and caused shift of rest frequency and also a loop stress.
- (4) Increased threshold level.
- (5) Increased receiver noise.

These extensive tests proved that the transponder design was inadequate for the purposes of deep space telecommunications. As a result of these tests the Helios Project began an extensive transponder development program of approximately one year. During this period, JPL provided consultants in the area of transponder design and compatibility test who participated in the acceptance testing of the prototype transponder in Germany in February 1973.

2. Prototype Model Spacecraft

a. Telemetry Coding Problem. In early March 1974, during a German Space Operations Center (GSOC) Compatibility Test with the updated version of the EM spacecraft, it was discovered that the data decoder assembly (DDA) in the telemetry subsystem to be used at the German Effelsberg Station (GES) was unable to lock up on or decode the incoming telemetry data stream.

German analysis of the spacecraft-generated telemetry bit-stream by manual decoding revealed the presence of inverted frame sync pattern and data bit-stream patterns, caused by the inversion of the uncoded bit-stream before it entered the spacecraft encoder. Informed of the problem, the DSN ran a special test at its Compatibility Test Area (CTA 21) to simulate the problem and correct it using a modified sequential decoder initialization procedure. The test appeared to be successful since the station (CTA 21) was able to decode. The results of this test were forwarded to the Project on March 21, 1974, along with a request for a magnetic tape recording of actual prototype spacecraft telemetry prior to its arrival at JPL for DSN Compatibility Tests, which were scheduled for late May 1974.

In April 1974, both the requested magnetic tape recording and the Helios prototype model (PM) spacecraft arrived at JPL, the latter to undergo thermal-vacuum tests in the 25-ft space simulator, then, in mid-May, compatibility tests with the DSN's CTA 21 facility. Attempts were made to replay the telemetry tape recordings into the CTA 21 data decoder assembly (DDA). These were unsuccessful, but attributed at that time to a probable incompatibility between tape recorder machines. Attention was then focused on obtaining a "preview" telemetry compatibility test while the PM spacecraft was undergoing thermal-vacuum tests. A special microwave link was installed to relay the PM spacecraft's S-band signal to CTA 21. This preview disclosed that the inverted telemetry problem had not been solved via the prior simulation conducted in CTA 21. Time was now of the essence, because compatibility tests were to start a week hence. Proceeding on the premise that there had to be an error in the prior simulation assumptions as to how the telemetry inversion occurred within the spacecraft (there were at least six possibilities), arrangements were made to continue to transmit "live" spacecraft telemetry from the

thermal-vacuum chamber to CTA 21. Then, using those occasions when the S-band telemetry was activated for the thermal-vacuum test sequence, each of the various telemetry inversion possibilities was investigated using temporary "patches" to the software for the DDA. In due course, the correct patch was discovered and an overtime effort initiated to redesign the DDA software package prior to the start of formal compatibility testing. The latter effort was completed barely in time, so distribution of the new decoder software package to the network stations was deferred until after the completion of the PM/DSN compatibility tests, in case other difficulties appeared.

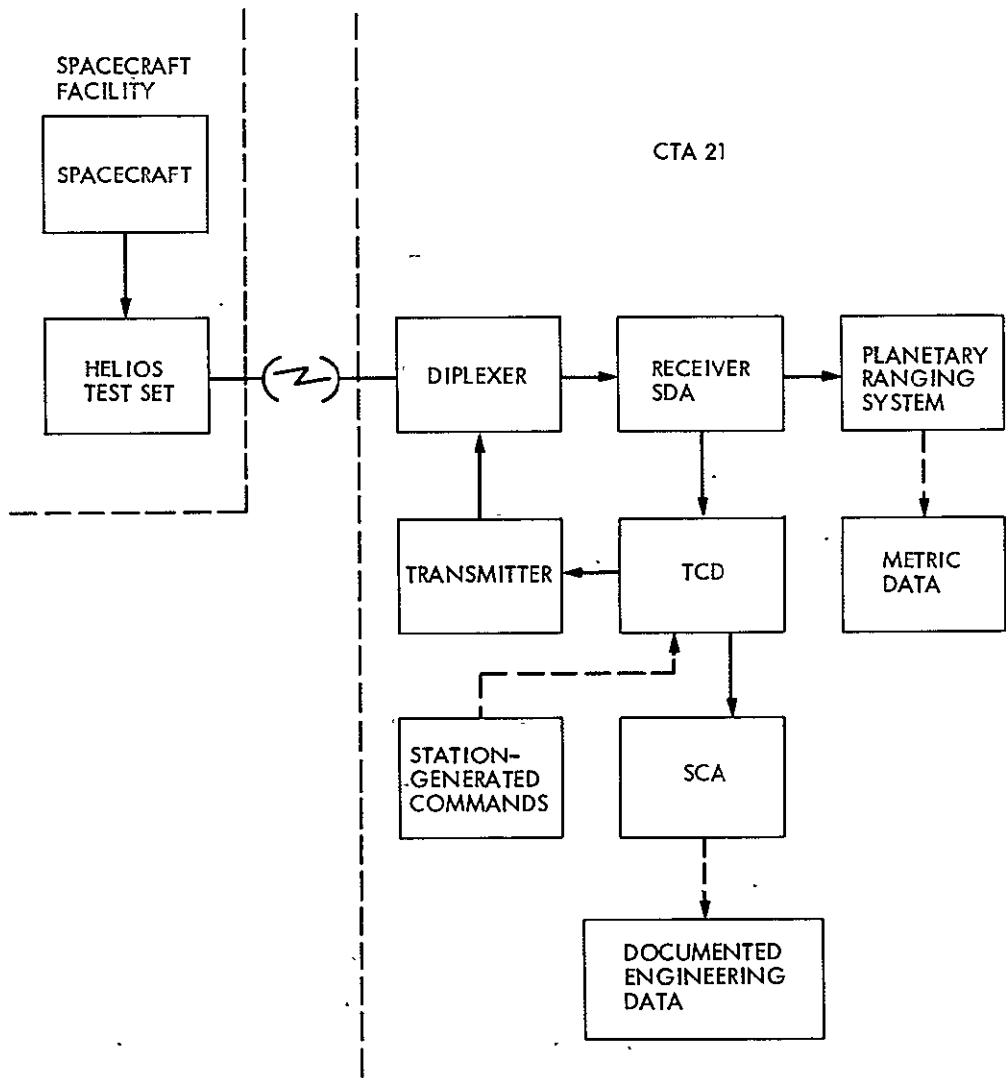
From the DSN viewpoint, an unfortunate aspect of the telemetry inversion problem was that the old DDA software package had been distributed throughout the network and the stations had completed their performance testing - all of that was now invalid and had to be repeated for the new software package. A fortunate aspect was that, armed with the answer to the inversion problem, CTA 21 was now able to successfully replay the telemetry magnetic tape recordings received earlier from Germany, and thence assist the STDN (MIL 71) facility at Cape Canaveral in successfully replaying a similar tape recording that was prepared for Near-Earth Phase Network (NEPN) testing. This latter capability was attained prior to the arrival of the PM spacecraft at Cape Canaveral, thereby avoiding potential schedule delays.

b. Prototype Model (PM) Compatibility Tests at JPL. With the telemetry coding problem resolved, the compatibility tests were conducted from May 17 to May 29, 1974. These tests were to verify the compatibility of the redesigned spacecraft telecommunications system with the DSN ground equipment. Besides verifying that the inverted telemetry problem had been solved, these tests successfully demonstrated that the earlier design problems encountered with the engineering model (EM) transponder had been also satisfactorily resolved.

During these tests, the Helios prototype spacecraft, containing flight-qualified components identical in design to the actual flight spacecraft, was located in Building 248 at JPL. Interconnection with the DSN CTA 21 facility in Building 125 was via an S-band RF link (Fig. 40) between fixed parabolic reflector antennas mounted on the rooftops of these two buildings, plus the necessary coaxial cable runs from the rooftop antennas to the respective equipments. RF connection to the prototype spacecraft was via a hard-wired coaxial coupler to the spacecraft's S-band input/output, rather than via the actual spacecraft antennas. Baseline range delay measurements were made between CTA 21 and a reference "zero-delay device" located at the above-mentioned coupler to the spacecraft.

The prototype spacecraft control consoles were located adjacent to the spacecraft in Building 248, with additional support provided by the Helios Test Set (HTS), which was situated just outside JPL Building 150, a short distance away. Intercom circuits between each of these locations provided for the necessary voice coordination during the compatibility test activities.

On May 17, the RF link was tested and the amplitude stability was measured to be 0.2 dB over a 24-h period. Formal testing started on May 18; test duration was approximately 120 h. Excellent support from the German spacecraft team and CTA 21 personnel provided a smooth and continuous flow of testing. Decommuration of spacecraft telemetry via high-speed data blocks sent from



SDA - SUBCARRIER DEMODULATOR ASSEMBLY
 TCD - TELEMETRY AND COMMAND DATA PROCESSOR
 SCA - SIMULATION CONVERSION ASSEMBLY

Fig. 40. DSN/Helios spacecraft compatibility test configuration

the Telemetry and Command Data (TCD) subsystem to the Simulation Conversion Assembly (SCA) provided real-time spacecraft operating parameters, e.g., receiver AGC and receiver SPE.

The test objectives included a successful demonstration that compatibility deficiencies previously noted in the EM telecommunications design had been satisfactorily resolved. The following are brief summaries of the PM tests results.

- (1) RF Test. The standard DSN RF tests of tracking range, rate, and acquisition under doppler conditions were very successful. In particular, very limited pushing or pulling effects were noted over a tracking range of ± 32.5 kHz in the spacecraft transponder. All RF thresholds corresponded to predicted values and were very stable.
- (2) Command Test. Station-to-spacecraft command operation performance for DSN-generated commands was successfully tested at threshold levels, for a total of 1500 commands, with and without ranging signal presence, and under simulated mission conditions (i.e., under spacecraft low-gain antenna amplitude and phase variations in the uplink).
- (3) Metric Data Tests. A series of tests were performed utilizing the Planetary Ranging Assembly (PRA) for both the continuous and discrete codes. In addition, verification of the PRA range measurements was made with Mark I-A range delay measurements. This latter effort enabled Mark I-A test data obtained during spacecraft manufacture in Germany to be substituted for additional testing at CTA 21. The acquisition times and spacecraft range delay at simulated 1.6 AU and 2.0 AU conditions were performed as well as range stability and DRVID stability tests. No interference was observed between ranging, command, and telemetry.
- (4) Telemetry Tests. The telemetry tests were designed to verify both coded and uncoded telemetry performance of the DSN with the Helios spacecraft. Uncoded telemetry performance was tested by determining the bit error rate as well as actually decommutating HSD telemetry blocks. Coded telemetry performance was verified by measuring the frame deletion rate for the 8, 256 and 2048 bps rates, as well as reviewing the HSD telemetry block integrity. Both the coded and uncoded telemetry performance met the test criteria. In addition, 128-bps uncoded tests (critical for Step II maneuver) were successfully performed.

c. Prototype Model (PM) Compatibility Verification Tests at Cape Canaveral. After completing environmental and DSN compatibility testing at JPL, Pasadena, the Helios prototype model spacecraft and its associated support equipment were transported to Cape Canaveral, Florida, where they would serve as a backup to the flight model spacecraft during launch preparations.

After unpacking and setup in Building A0 at the Cape, the condition of the PM spacecraft was checked by running a DSN Compatibility Verification

Test with the then recently relocated DSS 71 equipment within the STDN facility at Merritt Island, Florida. These tests between the PM spacecraft and STDN (MIL 71) were conducted between July 31 and August 2, 1974, and totaled 39 hours in length. The tests, while successful, did point up a few corrective actions that were necessary prior to the start of the flight (F-1) model DSN compatibility tests scheduled for the latter part of September 1974. The three most significant corrective actions are discussed below:

- (1) Communications Distance. Because of the increased distance between Building AO and the STDN (MIL 71) facility over that between Building AO and the former DSS 71 facility, there was insufficient signal level to perform a two-way-link range calibration using the ranging zero delay device. This was temporarily circumvented by employing the STDN's 9-m-diameter tracking antenna operating at 500 watts of power for the uplink to the spacecraft, while maintaining the downlink from the spacecraft into the small, fixed-orientation roof-mounted antennas normally used with the DSN equipment which was now housed in the STDN (MIL 71) facility.
- (2) Signal Level Fluctuations. The PM/DSN Compatibility Verifications Tests were the first involving a spacecraft and the newly relocated equipment STDN (MIL 71) using a microwave path over a body of water (Banana River). Signal level variations as much as 4 dB interfered with testing - most notably the command threshold tests and telemetry bit-error-rate tests at 32 and 8 bps. While a major contributor to these fluctuations was eventually traced to a faulty RF coupler (test adapter) at the spacecraft end of the link, there remained a 1 dB link fluctuation caused by the microwave path.
- (3) Threshold Measurements. The unattenuated RF signal level from the PM spacecraft (Building AO) as received via the existing small rooftop antennas at STDN (MIL 71) was -70 dBm. Pin modulators were used within the STDN (MIL 71) equipment to reduce the effective received signal level to the value specified for each particular portion of the compatibility test sequence. These pin modulators had a dynamic range of only 70 dB, thereby necessitating the use of additional (usually variable) attenuators in series with the receiver input for threshold tests. Some of the testing was impaired by RF leakage around these external attenuators and into the receiver.

Despite the foregoing initial difficulties, sufficient tests were successfully completed at the Cape to verify that both the PM spacecraft after its arrival and the recently relocated DSN equipment at STDN (MIL 71) were compatible. This verification test was a prelude to further ground data system (GDS) tests the Helios Project wished to perform, in addition to the two-day GDS testing that occurred at the conclusion of the May 1974 PM/CTA 21 compatibility tests at JPL. The GDS tests with the PM at Cape Canaveral included an end-to-end test wherein PM telemetry was decoded at STDN (MIL 71), formatted onto high-speed data lines and sent to the MCCC at JPL, Pasadena, where it was processed and rerouted via other high-speed data lines to the German Control Center (GCC) in Oberpfaffenhofen (South of Munich), where it was successfully displayed. A test of the reverse process, wherein commands

originating at Oberpfaffenhofen were to be sent through the MCCC to the PM spacecraft at the Cape was not successful due to procedural problems in Germany. However, commands originating at the MCCC were successfully executed via STDN (MIL 71) to the PM spacecraft, thereby verifying the proper operation of the DSN/MCCC portion of the command system interface. Since the MCCC interface with Germany had been previously verified, the command procedural problem that occurred during the Cape tests was not considered serious. However, the test was successfully repeated at a later date.

In addition to the preceding, the GDS tests involved the relocated DSN equipment at STDN (MIL 71) in a Near-Earth Phase Network (NEPN) compatibility/data flow test. In this latter configuration, PM telemetry data were received by the STDN-MIL 9-m antenna and fed into the STDN-MIL receivers, where it was detected and symbol-synchronized and placed onto a high-speed data line. This HSDL, routed via Goddard Space Flight Center, was one of two which fed the Automatic Selection Unit (ASU) computer in the MIL 71 portion of that STDN facility. The other HSDL was Helios telemetry received by the AFETR TEL-IV station. After data stream selection by the ASU, the data were passed into the standard DSN Telemetry System for decoding and formatting for transmission to the MCCC. This test successfully demonstrated the PM spacecraft compatibility with the NEPN, thereby achieving another important milestone in the preparation for the first Helios spacecraft launch.

3. Flight Model (F-1) Spacecraft Compatibility Tests

The Helios flight model spacecraft arrived at Cape Canaveral, Florida, on September 28, 1974, to undergo telecommunication compatibility testing after encapsulation and mating to the Titan/Centaur launch vehicle. Following encapsulation and mating, the spacecraft and launch vehicle combination were transported to Launch Complex 41 (Cape Canaveral Air Force Station), approximately 8 miles from STDN (MIL 71). With the spacecraft in a launch configuration, an S-band RF air link was utilized to establish an interface between the spacecraft and STDN (MIL 71). The spacecraft transmit/receive function was performed by connecting a test point on the spacecraft encapsulation shroud to a 1.2-m antenna mounted on the launch service tower. The compatibility testing required 8 hours and verified spacecraft maximum sweep and acquisition rate, uplink threshold, downlink threshold, ranging system acquisition time, telemetry performance, and spacecraft command performance. The following are brief descriptions of the test results:

- (1) RF Test. Throughout the test period the short-term RF link fluctuations were observed to be 1.5 dB between Launch Complex 41 and STDN (MIL 71). All phases of the RF tests were completed successfully and to the satisfaction of the DSN/Helios Project Test Team.
- (2) Telemetry Test. During the Telemetry Subtest No. 1 the short-term RF link fluctuations were observed to be 1.5 dB between Launch Complex 41 and STDN (MIL 71). However, during Subtest No. 3 the fluctuations were 7.5 dB and resulted in the Telemetry and Command Subsystem (TCD) at STDN (MIL 71) dropping lock occasionally. Because this condition had been experienced during the prototype compatibility testing conducted July and August

1974, it was an "engineering judgment" by the DSN/Helios Project Test Team that the tests were performed satisfactorily.

- (3) Command Test. During the Command Subtest No. 1 a total of 114 commands were successfully transmitted to the spacecraft. The short-term RF link fluctuations were observed to be ± 6 dB. During the Command Subtest No. 3 a total of 118 commands were successfully transmitted to the spacecraft, while the short-term RF link fluctuations were only ± 2 dB.
- (4) Metric. The ranging system acquisition time test was successfully completed with no problems being experienced.

None of the foregoing exceptions were deemed significant, and the flight spacecraft was judged compatible with the DSN and hence ready for launch from a telecommunications viewpoint.

V. TDS IMPLEMENTATION

A. GENERAL

From an overall viewpoint, there was not a large-scale implementation effort required specifically to support the Helios missions. The new equipment and/or computer software programs required by the DSN stations for Helios support were also required for support of other flight projects. Helios did influence the timing of these new implementations, however, and in some cases influenced the actual design. For historical purposes the following paragraphs describe those implementations that had to be completed in time to support the first Helios mission.

B. NEAR-EARTH PHASE NETWORK

1. Mission-Independent

a. Consolidation of DSS 71 and NASA's MILA Facility. In mid-1970, NASA/OTDA requested that JPL study the feasibility of combining its compatibility test station (referred to as DSS 71) at Cape Canaveral, Florida, with the Goddard Space Flight Center's Merritt Island Launch Area (MILA) facility, some 8 miles westward. At the direction of the TDS manager for Helios, the DSN personnel at DSS 71 began reviewing the telecommunications support requirements for the Mariner Venus/Mercury 1973, Helios, Viking, and Planetary Explorer projects at the Cape. In addition, they also had to analyze the feasibility of moving the operations equipment of DSS 71 to the MILA station and consolidating the capabilities of the two separate stations within one organization.

In February 1971, a feasibility study report was released by the DSN which pointed out two major technical considerations that had been evaluated in analyzing the consolidation: RF link performance and DSN subsystem requirements. Extensive RF link testing was conducted between both the DSN and the MILA station and various spacecraft assembly and/or test areas (Fig. 41). These tests were conducted with strong signal-to-noise ratios in a coherent two-way mode and the data analyzed in both time and frequency domains with histograms and power spectrums generated for both amplitude and phase variations. A summary of the RF link performance is provided in Table 8.

Analysis of the RF link test data indicated that the maximum phase variations were approximately two cycles at S-band frequency. The magnitude and frequency of the phase variations on all RF links were insignificant and would not affect the performance of phase-sensitive telecommunications tests with spacecraft. Analysis also indicated large amplitude variations on all RF links except the one between the MILA station and Launch Complex 41. The large variations were due to RF reflections from the surface of the Banana River and would affect the accuracy of critical telecommunications system design compatibility testing of all projects.

In order to meet its compatibility, prelaunch, and launch support commitments to the projects, the DSN required an equipment configuration at the MILA station equivalent to that of a standard DSN station. In addition, the near-Earth TDS organization required an Automatic Switching Unit (ASU) in order to support near-Earth telemetry requirements of the projects. Having

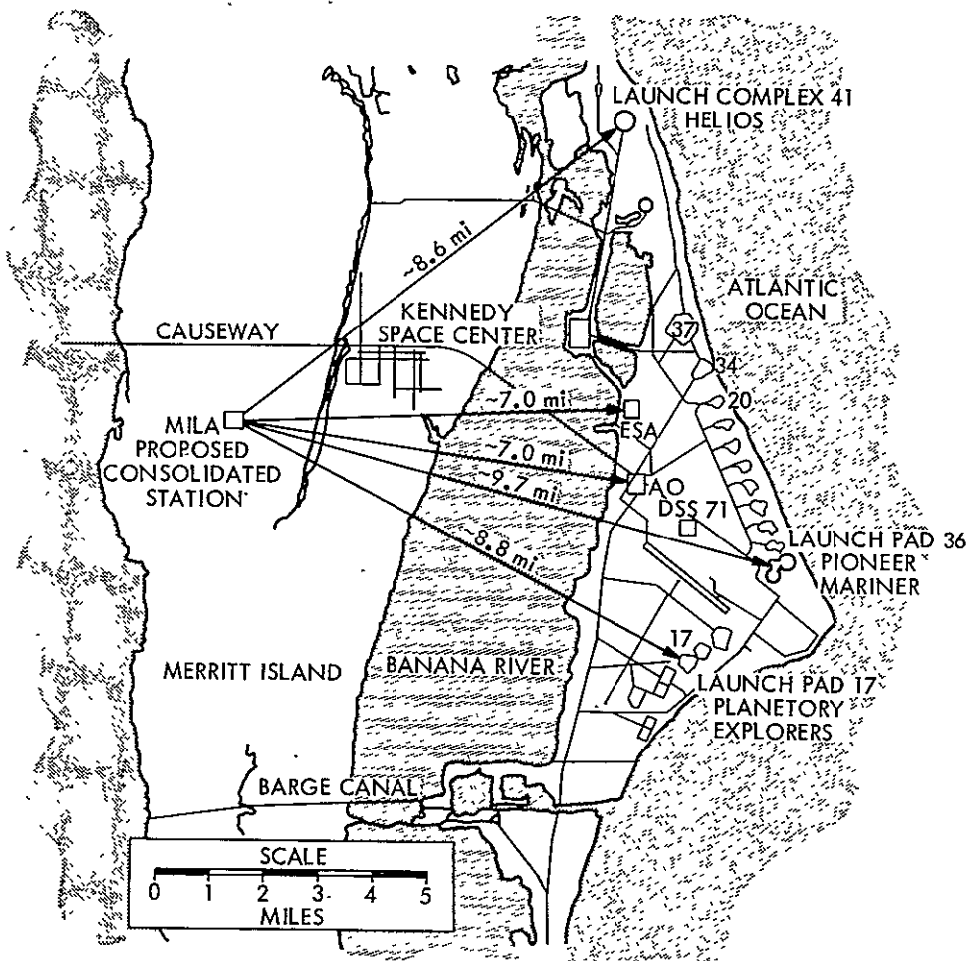


Fig. 41. RF paths from STDN (MIL 71) Merritt Island/Cape Canaveral, Florida

Table 8. RF link performance

RF link routing	Phase stability (total phase shift), deg	Amplitude stability (3 sigma), dB
DSS 71 Internal test	3.5	0.009
DSS 71 to Bldg A0	34.0	0.35
MILA to Bldg A0	57.0	1.09
DSS 71 to Launch Complex 36	68.0	0.25
MILA to Launch Complex 36	162.0	0.98
DSS 71 to Explosive Safe Area (ESA)	34.0	0.17
MILA to Explosive Safe Area (ESA)	186.0	1.95
DSS 71 to Launch Complex 41	60.0	0.36
MILA to Launch Complex 41	67.0	0.20

determined that consolidation was feasible, the next step was to develop an implementation plan and schedule acceptable to all flight projects, the GSFC, and the DSN.

Because the Pioneer Project had two launches scheduled, one in 1971 (Pioneer 10) and one in 1972 (Pioneer 11), and the Mariner Project had scheduled the launch of Mariner 10 in November 1973, it was determined that the deimplementation of DSS 71 would start following the successful launch of the Mariner 10 spacecraft in November 1973. Accordingly, an implementation plan for the MILA/DSS 71 integration was prepared and approved by representatives of GSFC and JPL in August 1973. Figure 42 shows the MILA/DSS 71 integration schedule.

On the basis of these schedules the consolidation of the two facilities was completed in time to accommodate the Helios prototype model compatibility testing in June 1974. This was followed by the release of the DSN deimplementation plan and schedule for DSS 71 (Fig. 43). In February 1974 the Director

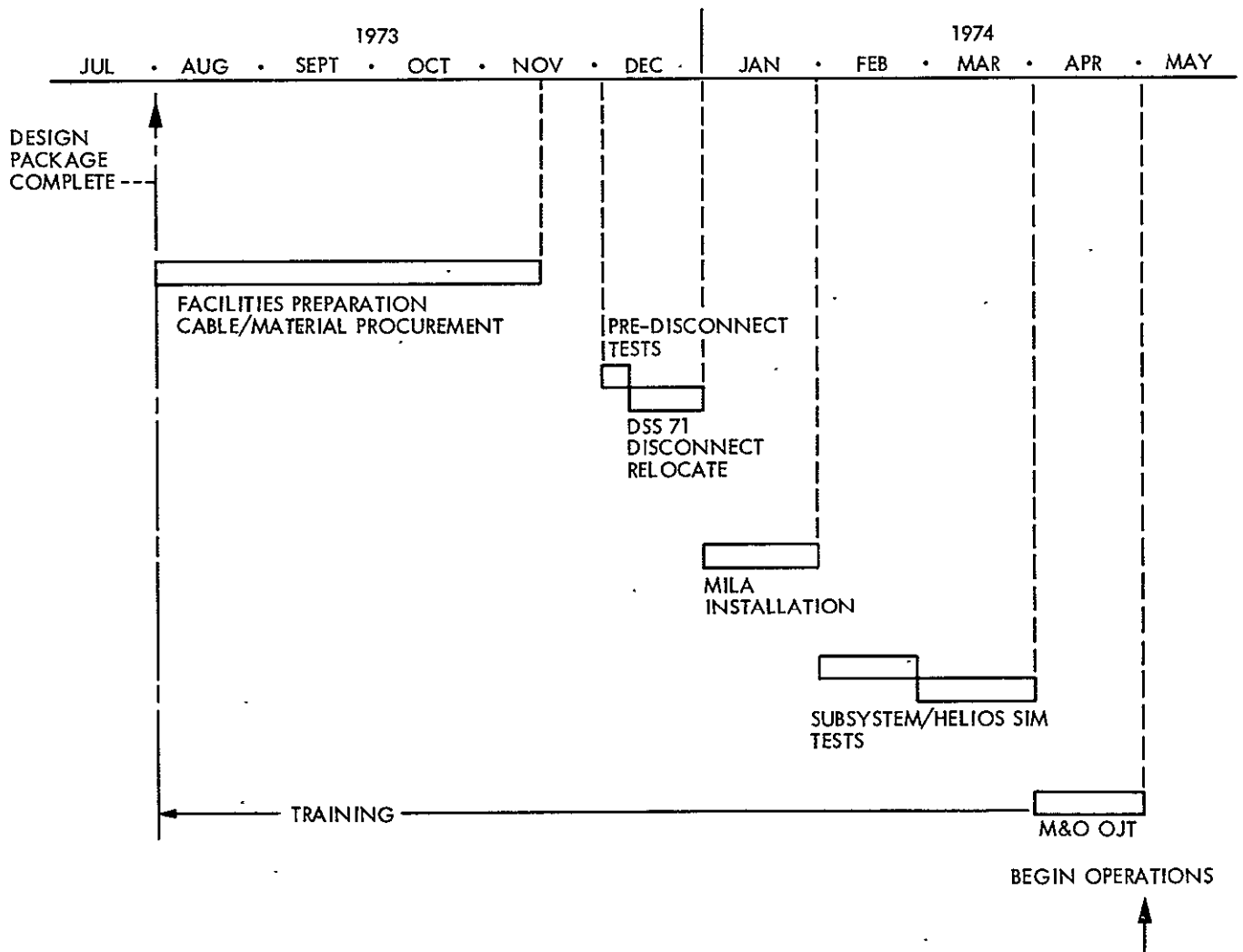
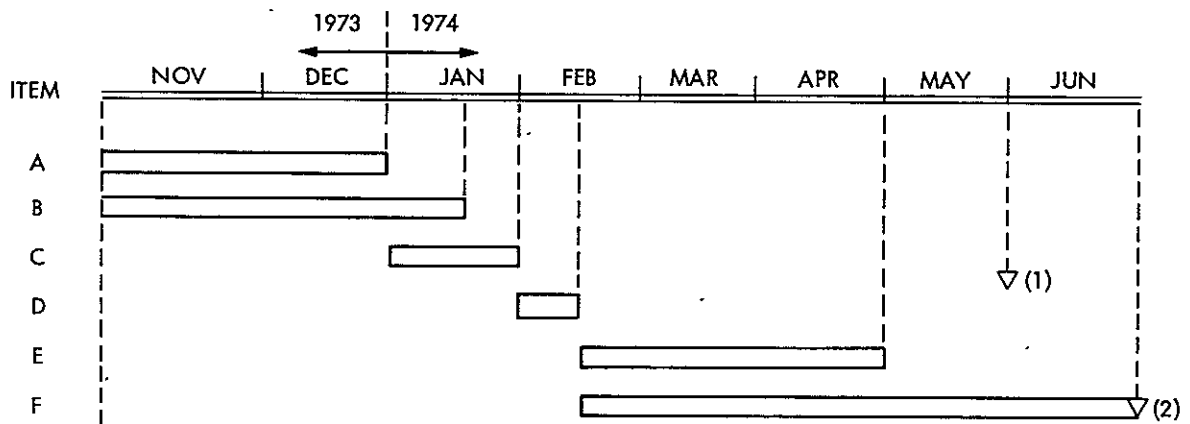


Fig. 42. MILA/DSS 71 implementation schedule



NOTE 1 - MIL-71 OPERATIONAL
 NOTE 2 - DSS-71 FACILITY DEACTIVATED

- ITEM A - HELIOS TELEMETRY PERFORMANCE TESTING
- B - STATION INVENTORY INTO MAJOR CATEGORIES
- C - PERFORMANCE TESTING (BASELINE DATA) AND TRAINING
- D - OPERATIONAL EQUIPMENT REMOVAL AND TRANSFER
- E - DISPOSITION OF REMAINING OPERATIONAL EQUIPMENT AS PER ECO'S
- F - DISPOSITION OF REMAINING SUPPORT EQUIPMENT

Fig. 43. DSS 71 deimplementation schedule

of Networks for GSFC and the JPL Assistant Laboratory Director for Tracking and Data Acquisition signed and released a Memorandum of Understanding for the support of the combined station by GSFC.

b. Implementation of Second TCD String at STDN (MIL 71). In February 1974 it became obvious that STDN (MIL 71), with only one Telemetry and Command Subsystem (TCD) string, could not meet the Helios (or Viking) launch phase requirements of observing and processing data from the downrange stations or complete the system performance tests (SPTs), which required two TCD strings for comparison type tests. Without a backup TCD a major failure in the one TCD could delay or degrade the prelaunch testing and launch support.

As DSS 51 (Johannesburg, South Africa) was being deactivated, it was decided to ship one TCD string and peripheral equipment to STDN (MIL 71) for installation and checkout prior to the Helios launch and the DSN/Viking testing. Owing to shipping problems the equipment didn't arrive until early November. However, the installation and checkout were completed by mid-November 1974.

C. DEEP SPACE NETWORK

Because the TDS supports all deep space projects, the scheduling of all phases of DSN equipment modification and testing is of the utmost importance, and changes can result in a conflict between two or more projects. From the beginning, Project Helios had to contend with the Pioneer, Mariner Venus/Mercury 1973 (MVM'73), and the Viking projects for implementation, testing, and operational time of the DSN systems and facilities. Each project had its share of problems which caused schedule changes, and these changes had an impact on the other projects. Helios was no exception, but with close coordination and careful planning, conflicts were resolved.

Helios was originally scheduled to launch in July 1974, which was about a year prior to the Viking launch. This allowed sufficient time for the implementation of the necessary DSN system changes to meet both the Helios and Viking requirements. However, the slip of the Helios launch date from July to September, then October, November, and finally December had a strong impact on the extensive modifications and additional equipment implementation schedule of the Viking Project. Further, this slip in Helios launch date also encroached upon Network preparations for the Pioneer 11 Jupiter encounter - which further complicated the scheduling problem, not only for Helios but the other two projects as well.

1. Mission-Independent

a. Polarization Tracking Capability at DSS 14. In February 1970 the DSN requested that DSS 14 be modified (Fig. 44) to provide a closed-loop polarization tracking and recording capability to support a Pioneer 9 solar Faraday rotation experiment from November 1970 to January 1971.

A temporary Engineering Change Order (70.025) affecting the Receiver/Exciter Subsystem, Microwave Subsystem, Digital Instrumentation Subsystem, servo subsystem, a coherent reference generator, and cabling was approved in June 1970, with the notation that the modification was to be removed in January 1971. However, in September 1970 a request by the experimenters

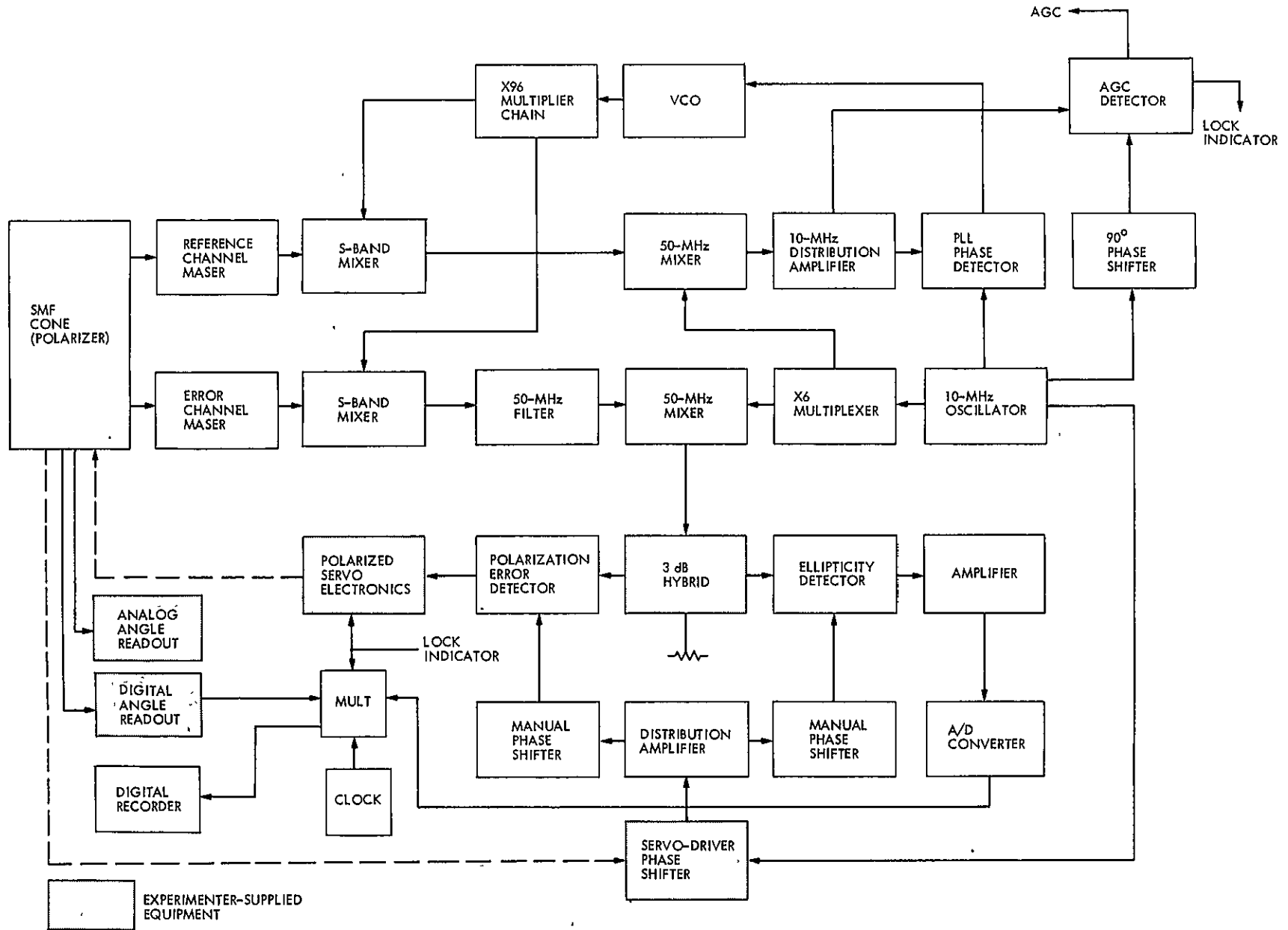


Fig. 44. Functional block diagram of the S-band receiver system as required for polarization tracking and recording

for an extension was granted until February 1971. Because of a DSN Change Control Board (CCB) policy, temporary ECOs could only be extended in one-year increments. Therefore, the two Faraday rotation experimenters kept a close watch on the expiration date of each extension granted and requested another extension. Their interest was not only in keeping the capability for polarization tracking for the Pioneer Project but for the upcoming Helios Project, which required this capability also. Through their efforts the capability for polarization tracking at DSS 14 was extended into the Helios era.

Like the Pioneer 9 spacecraft, the Helios spacecraft would employ linear polarization for its antennas - as opposed to circular polarization, which is employed on Mariner-class spacecraft. Each type of polarization has its advantages and disadvantages. One of the advantages of linear polarization is scientific in nature: Faraday rotation of radio wave signals in the presence of solar corona. The degree of rotation is a function of the number and polarity of charged particles in the corona, while the rate of change in the polarization angle is relatable to the time variances of charged particles in the corona. The Helios mission therefore offered another excellent opportunity to study the solar corona. And on behalf of such an experiment, the DSN undertook to implement automatic polarization angle tracking and recording equipment into its 64-m stations.

In January 1973 a teletype message was received from NASA/OTDA instructing the TDS manager to reduce DSN commitments wherever possible in accordance with newly issued 1973 OTDA budget guidelines. This budget reduction had an impact on the development of an Automatic Polarization Tracking Subsystem for the DSN 64-m stations so they could comply with a Project requirement for optimizing the Helios telecommunications link performance and providing Faraday rotation data for Experiment 12. The impact was a decommitment to the Helios Project of providing an automatic polarization tracking capability at the 64-m station in Australia (DSS 43). However, the DSN commitment for providing this capability at the 64-m station (DSS 14) at Goldstone, California, remained in effect because DSS 14 could perform the task through the use of special R&D equipment already at the station. Plans were then formulated to provide DSS 43 with a manually adjustable polarizer which, while not capable of obtaining Faraday rotation experiment data, would at least optimize the telecommunications link performance.

In July 1973, using fiscal 1974 funding, development began on a Manual Polarization Tracking Subsystem to be implemented and operational at DSS 43 by March 1974.

b. Linear Polarization at the 26-Meter Deep Space Stations. For the earlier Pioneer Project, the DSN developed a preset linear to circular polarization conversion assembly (sometimes called a "venetian blind" due to its appearance) for the 26-m stations to match linearly polarized RF uplink and downlink signals. The stations which supported Pioneers 6-9 had their Antenna Microwave Subsystem (UWV) modified with these assemblies.

Implementation of these polarizer assemblies proved so successful in enhancing the Pioneer telemetry data reception that in March 1972 it was decided to make the change a permanent part of the UWV for Project Helios.

These assemblies are now standard equipment at all DSN 26-m stations, except DSS 44 at Honeysuckle Creek, Australia. DSS 44 is a former Apollo/Manned Space Flight Network (forerunner of the STDN) facility and as such its antenna is an X-Y mount as opposed to the polar mount structures of the DSN 26-m stations. Because of this difference in antenna structure (i.e., motion of the axes), the venetian blind linear feed adapter is only partially usable for a tracking pass at DSS 44. Its effectiveness is limited to a few hours each side of the meridian crossing by the spacecraft.

c. Coherent Phase-Shift Keying Modification. In order to meet the Helios requirements for coherent subcarrier and command symbol frequencies, a modification was required to the Command Modulator Assembly (CMA) in each station's TCP. The original CMA design used two clocks: one each for the subcarrier frequency and symbol rate. The subcarrier frequency was generated in a frequency synthesizer referenced to the Frequency and Timing System (FTS) 5 MHz and the symbol rate was generated in a number-controlled oscillator (NCO) referenced to the FTS 1 MHz. In order to provide symbol rate synchronous with the subcarrier frequency, a circuit was employed which synchronized the bit start with the subcarrier zero crossings. Originally it was felt that this scheme would handle the PSK single-channel requirements. However, subsequent discussions with the flight command system designers uncovered a problem in the design. The frequency synthesizer was not phase-coherent with the 5-MHz FTS reference and could be in any phase with reference to the 5 MHz. However, the symbol clock was phase-coherent with the FTS reference. The outcome of this was that at any time the subcarrier phase could vary by 0 to 180 deg in phase with respect to the symbol clock. This would have the effect of inverting the data to the spacecraft.

A modification to the CMA was proposed that would cure the problem. Instead of deriving the reference for the symbol clock from the FTS 1 MHz, if the reference was derived from the subcarrier synthesizer, the ambiguity in phase would be removed. This modification would also ease the operation in that it would allow the symbol rate to follow the subcarrier frequency automatically. The proposed modification was approved and modification kits prepared, shipped, and implemented at all DSN stations.

d. Command Confirmation Modification. The exciter portion of the DSN Receiver/Exciter Subsystem contains a phase detector which allows confirmation of a command transmission to a spacecraft. However, owing to an excessive dc drift of the output of the phase detector, the confirmation of a command transmission was not reliable.

As a result of a failure report (FR) generated at DSS 14, maintenance personnel performed preliminary tests and found that the confirmation phase detector module was extremely temperature-sensitive. Additional testing indicated that by changing certain components and adding temperature compensation to the module, the dc drift could be minimized. On the basis of this information an Engineer Change Order (ECO) was generated, modification kits were prepared and shipped to all DSN stations, and implementation and testing were completed throughout the DSN by September 1974.

e. Planetary Ranging. At a post seventh Helios JWGM splinter session held on November 2-3, 1972, the DSN described the difference between the continuous spectrum and the discrete spectrum ranging systems. It was pointed

out to the Project that the principal advantages of the continuous spectrum code were that the spread of the spectrum lowered the probability of spacecraft interference and that the range reacquisition could be accomplished without waiting for the round-trip light time. For the discrete spectrum code, the principal advantages were an 18-dB more efficient detection process and the ability to produce DRVID data sooner. In addition the discrete spectrum code also had two principal disadvantages: (1) acquisition errors were less detectable than in the continuous spectrum code, and (2) nonprogrammed reacquisition of range data required round-trip light time in addition to the normal code acquisition time.

The decision as to which system to select was left to the Project. In order to meet the Project requirements for one or the other, the DSN decided to develop and install both the continuous spectrum and the discrete spectrum ranging systems at the 64-m stations, the conjoint 26- and 64-m stations (DSS 42/43 and DSS 61/63), and a Goldstone 26-m station (DSS 11). Developing and implementing both systems provided the stations with the capability of meeting either the discrete or continuous spectrum ranging code requested by the Project (on a per station pass basis) during the mission. In addition, a study was conducted in August 1973 on the feasibility of DSS 42/43 and DSS 61/63 sharing the Range Demodulator Assembly (RDA) and the Planetary Ranging Assembly (PRA) with both the 26- and 64-m antennas. The study indicated that the planetary ranging capability of the 64-m antennas could be extended to the 26-m antenna by the addition of a switching arrangement at the RDA and PRA in the equipment area of the station control building. On the basis of results of this study, an Engineering Change Order was generated and modification kits were prepared and shipped to DSS 43 and 63. Implementation and testing were completed in November 1974. The implementation of planetary ranging at DSS 11, Goldstone, required a separate procurement, which thus was completed later.

f. DSS Receiver Identification Change. In July 1974 the Mission Control and Computing Center (MCCC) engineers reported that because of a problem in the DSS monitor status high-speed data blocks from the conjoint DSS 42/43 and DSS 61/63 stations, MCCC was sending incorrect data to the German Space Operations Center. MCCC reported that the data from DSS 42 and 61 were extracted by the Remote Information Center (RIC) processor at the MCCC from information contained in the DSS monitor status and configuration high speed data blocks (HSDB) and placed in the RIC monitor blocks which are sent to GSOC. In the DSS data block (which contained positions for information on four receivers), the identification (ID) number of the receiver being used acted as the key to the MCCC as to which part of the block contained the receiver automatic gain control (AGC), static phase error, etc., to be sent to GSOC. However, in actual operation the HSDB from DSS 42 and 61 would always indicate information on Receiver Nos. 3 or 4, then insert the information in the reserved blocks for Receiver Nos. 1 and 2 of DSS 43 or 63, resulting in MCCC sending to GSOC zeros for all DSS 42 and 61 receiver-related parameters.

At a meeting in August 1974 between DSN and MCCC personnel it was decided that implementing a Viking ECO adding two additional receivers at the 64-m stations (DSS 43 and 63) and numbering them as Receivers Nos. 3 and 4, and renumbering the receivers at the 26-m stations (DSS 42 and 61) from 3 and 4 to Receivers Nos. 5 and 6, as well as modifying the TCD/DIS software to recognize the new numbering sequence would correct the DSS receiver identifications problem.

By October, the Viking ECO had been implemented at both DSS 42 and 61. On October 21, 1974, during a U.S./German ground data test, proper receiver parameters were passed from DSS 42 to the MCCC at JPL and on to the GSOC via NASCOM.

2. Mission-Dependent

a. Modification of Convolutional Coder for Helios Telemetry Data.
In August 1972 it was determined that in order to meet the Helios requirement of providing telemetry simulation capability at all DSN supporting stations, the Test and Training Subsystem required a minor hardware and software modification. An ECO was generated and approved which resulted in the fabrication of a Helios patch connector assembly for the convolutional coder of the Simulation Conversion Assembly (SCA). In addition, the SCA software package (DOI-5089-TP-C) was updated to accommodate the Helios 32-bit pseudonoise tail frame synchronization in the simulated data. A trial installation and checkout was successfully conducted at the former DSS 71 facility in July 1973. Modification kits were then prepared and shipped to all DSN stations for implementation.

b. Acquisition Aid Subsystem Implementation at DSS 62. In mid-1973 the DSN informed the Helios Project that DSS 51 (Johannesburg, South Africa) would be closed in July 1974 and therefore not be available for the initial acquisition of the Helios-A spacecraft. The DSN had selected DSS 62 (Cebreros, Spain) to perform the initial acquisition task with DSS 61 (Robledo, Spain) acting as backup. The 26-m antenna at DSS 62 did not have an Acquisition Aid (ACQ Aid) Antenna Subsystem, and its 0.36 deg beamwidth was too narrow to provide the coverage at initial DSN acquisition for the then proposed direct-ascent Helios launch trajectory.

A quick check was made that revealed that there were two ACQ Aid Subsystems available for DSS 62, one installed at DSS 11 (Goldstone, California), and a spare at DSS 51. A study was then conducted as to the most cost-effective and expedient method of providing DSS 62 with a ACQ Aid Subsystem that could be installed and operational by June 1974 in order to meet the DSN test and training requirements for Helios.

The decision was made to dismantle, pack, and ship the ACQ Aid Subsystem (consisting of an S-band acquisition aid antenna, an optical acquisition aid, a 30-ft SAA collimation tower, remote controls, and cables) from DSS 11 to DSS 62. An ECO (73-104) was generated and approved in February 1973 and the task subsequently completed. However, the April 1974 NASA/BMFT decision to launch Helios-A on a parking orbit trajectory negated the need for the DSS 62 Acquisition Aid (after it was already installed and working) since DSN initial acquisition for a parking orbit mission would be over Australia.

c. Telemetry Backfeed Data. As described in Section II, the Helios spacecraft receiver/transmitter design was unique in that normal operation used the noncoherent mode (transmitted frequency derived from an onboard oscillator) with a command required to change to coherent operation with the uplink signal. Any interruption in the uplink carrier signal will cause the transmitter to switch automatically from a two-way coherent mode back to a noncoherent mode. To reinstate the two-way coherent mode, another command from the ground station is required. Without a display of spacecraft telemetry

data on-site, the ground stations had no method of monitoring spacecraft mode status, so an operational problem was created in supporting the Helios mission.

For all past missions supported by JPL, the ground stations had an on-site display of certain spacecraft telemetry parameters (SPE, AGC, Command Detector Lock Status, etc.) provided either by on-site decommutation or backfeed of MCCC decommutated data. This capability had been and still is considered a valuable aid to operations in that it provides a means of monitoring performance parameters derived directly from station outputs. On-site AGC and SPE displays were a necessary capability for spacecraft receiver best lock frequency testing throughout the MM'71 mission. Spacecraft AGC and SPE are required to locally verify successful completion of two-way acquisition and station handovers when a spacecraft is operating in the non-coherent mode and the downlink is independent of the uplink.

Because of this unique Helios receiver/transmitter design the DSN decided that it was desirable to display certain spacecraft telemetry data (command detector lock status, AGC, static phase error, etc.) at each supporting station. A series of discussions between DSN and MCCC representatives resulted in an agreement that MCCC would process the spacecraft telemetry and backfeed the needed parameters to the stations via high-speed data lines. In May 1974 modification work was begun on both DSN and MCCC software; by August 1974 backfeed data were being supplied to the stations during Operational Verification Tests (OVT). Telemetry backfeed to the DSSs was implemented by the MCCC as a Helios capability.

Following the later completion of Helios Mission Phase II, a query was made to the DSN stations as to the overall value of the backfed telemetry data. All stations reported that the backfeed of telemetry data not only improved the overall station operation but was also a great morale booster in that it gave the station personnel a feeling of involvement in the mission.

D. DSS 44 IMPLEMENTATION FOR HELIOS SUPPORT

In early October 1974 the TDS manager was informed by NASA Headquarters that the launch date for Helios-A had been officially changed from November 20 to December 8, 1974 because of a computer problem in the Centaur stage of the launch vehicle. This new launch date conflicted with the Pioneer Project as it would occur during the critical phase of the Pioneer 11 Jupiter encounter (November 26 to December 12) for which the DSN had committed full support coverage from the 64-m DSS 43. For Helios launch phase support the DSN had selected, but not committed, DSS 43 to back up DSS 42 during DSN initial acquisition.²³

However, with DSS 43 also committed and under configuration control for the Pioneer Jupiter encounter, it became essential to the TDS and DSN

²³Initial DSN acquisition changed from Spain (DSS 62) to Australia (DSS 42) as a result of the April 1974 decision to launch Helios-A on a parking orbit trajectory (see Section II-C).

management that the recently acquired 26-m STDN station at Honeysuckle Creek, Australia (designated DSS 44), be upgraded and operational as quickly as possible in order to provide the needed backup support for initial acquisition, telemetry, and command. That meant that the DSN had six weeks to complete converting the Honeysuckle station to a DSN configuration, and then complete Helios required ECO implementation, testing, and station crew training. At that time the Honeysuckle facility was in the middle of being converted to a standard DSN station configuration using system and subsystem equipment from the deactivated DSS 51. The scheduled operational date for the converted station was December 1, 1974. However, because of shipping delays and dock strikes in Australia, the operational date had slipped to mid-January 1975. As of October 31 the reconfiguration task at DSS 44 was only 50% complete.

• The acceleration of upgrading DSS 42 was dictated by a Helios Project mandatory requirement to provide a hot backup for DSS 42 and the criticality of performing the spacecraft Step I maneuver, boom and antenna deployment, spin-up, Near-Earth Phase experiment turn-on, and memory readout during the first Australian pass.

A teletype message was sent to the station manager at DSS 44 on November 4 outlining a proposed plan for providing the required capabilities in time to support the Helios launch. On November 5, a teletype message from the station manager stated that he felt confident that the station could be made ready to support Helios in accordance with the proposed plan but requested 24 hours in which to make a detailed examination of the station and systems. Of major concern was the fact the station was being asked to back up the prime initial acquisition station, but the station did not have an S-band Acquisition Aid Subsystem. In his message he stated that, originally, in the STDN configuration, there had been an ACQ Aid antenna on the 26-m antenna. It had been removed for shipment to GSFC for STDN use, but it was still on-site. The GSFC subsequently granted permission for its use to support Helios.

On November 8, a teletype message from the station manager stated that a detailed examination of the station and its status had been completed and outlined the task involved. In summary the tasks involved the following problems:

- (1) Compressing the 26-m antenna work schedule and completing it by November 17.
- (2) Locating and installing an ACQ Aid antenna and transmit filters.
- (3) Obtaining modified software to drive the Antenna Pointing System (APS).

This last item was of major concern to the DSN because the 26-m STDN antenna was an X-Y type, whereas all other DSN 26-m antennas were polar - i.e., HA-dec (hour angle-declination) type. A typical DSN 26-m HA-dec antenna is polar-oriented (tilted) and consists of a pedestal, a large hour-angle gear wheel that points the antenna dish east-west, a smaller declination gear wheel that points the antenna dish north-south, and a 26-m-diameter antenna dish. The STDN 26-m antenna acquired by the DSN was very similar to that just described, except that the large gear wheel (X-axis) is horizontal and points the antenna dish north-south, whereas the smaller gear wheel (Y-axis)

points the antenna dish east-west. In both cases, joint movement of the two axes enables the antenna to be pointed precisely at and to follow a moving spacecraft above the horizon. The problem that concerned DSS 44 was the fact that the predict coordinates by which they were to locate the spacecraft on the horizon would contain HA-dec antenna pointing angles and not X-Y angles. The DSN decided that the predict coordinates for DSS 44 would be generated with X-Y pointing angles and transmitted to the station for the initial acquisition.

On November 25, 1974, the station reported that the acquisition aid antenna installation had been completed and was ready for a final proof test, and that all essential Helios-related subsystem testing at the station had been completed. On December 4, 1974, DSS 44 was instructed via teletype message to consider itself under temporary Helios configuration control until December 12, 1974. Thanks to an extraordinary effort by the Australian crew and on-site U.S. personnel, DSS 44 was ready to support the Helios A launch.

VI. PRELAUNCH OPERATIONAL TESTS AND TRAINING

A. GENERAL

Prelaunch test and training is an essential phase of any project in that it provides the opportunity to check systems and procedures, detect problem areas, and take the necessary corrective action and retest prior to the launch date, in addition to the very essential mission sequence training that is necessary prior to any flight. The primary 26-m (DSS 12, 42, and 62) and 64-m (DSS 14 and 43) DSN support stations for Helios underwent more training tests than did the secondary 26-m support stations (DSS 11, 44, and 61). As in the past, the approach proved beneficial in establishing a high proficiency in the DSS operations personnel, Network Operations Control Team (NOCT) personnel, and other DSN operators required to support the Helios mission.

B. SYSTEM PERFORMANCE TEST/MISSION CONFIGURATION TEST

The System Performance Tests (SPT) and the Mission Configuration (system level) Tests were conducted simultaneously to conserve available testing time and were the responsibility of the System Cognizant Operations Engineer (SCOE) and the Network Operations Project Engineer (NOPE). These tests were conducted only after station hardware had been transferred to the Network Cognizant Operations Engineer (COE) and software has been received from the DSN Program Library and successfully acceptance-tested.

The objectives of these tests were to determine the performance of each station's Telemetry, Tracking, Command, and Monitor and Control System in the Helios configuration, including software and hardware integration at the system level.

1. Telemetry System Performance Tests

System Performance Tests are executed throughout the DSN whenever a modification is made to any DSN telemetry system which may affect its performance. Such is the case when new or modified software is introduced or when hardware is added. The addition of modified software (DOI-5050-OP-B) necessitated the requirement for Helios telemetry SPTs.

The Helios telemetry SPTs were executed during February and March of 1974 and demonstrated that the DSN Telemetry System was capable of supporting Ground Data System (GDS) tests using DOI-5050-OP-B TCD operational software. Unfortunately, the DOI-5050-OP-B software could not be used for mission support once it was discovered (April 1974) that the telemetry data output from the spacecraft convolutional encoder was inverted. When this discrepancy was discovered, a modified interim Model-B software package was released to CTA 21 and STDN (MIL 71) for conducting of spacecraft compatibility tests. In the meantime, the required modifications were introduced into the next vintage: the Model-C software. These changes were then validated during acceptance testing at CTA 21. The modification made to the DOI-5050 software required that new Helios telemetry SPTs be performed throughout the network following the release of DOI-5050-OP-C in July 1974.

A second factor requiring additional telemetry SPTs was the addition of a second SSA-DDA to each TCP at the 64-m stations, since this is considered to be a major implementation. The telemetry SPTs were conducted using the Helios version of the Telemetry System Performance Test. The procedure was separated into three parts: the first containing the configuration and interface tests, the second containing the performance tests, and the third containing the non-real-time test.

The test configuration (Fig. 45) and interface tests were performed on the second channel of the Telemetry and Command Data Handling (TCD) Subsystem. Although the DOI-5050-OP-B software was designed to process data through three TCD channels, the Helios Telemetry System used only Channel 2; thus SPTs were conducted only on that channel. The configuration and interface test contained a high-speed data interface test that verified the HSD blocks. These blocks were verified by inspection of the formatted block headers; the configuration and lock indicators were reformatted by the test software in the DIS for ease of interpretation. This test also contained a set of TCP-DIS monitor message verification tests which verified that the initialization, status, and calculation messages were correct as specified.

Although the AGC/dBm conversion test and the signal-to-noise ratio calculation test were separate parts of the test procedure, they were normally run as a part of the configuration and interface tests. The AGC/dBm conversion changes AGC volts to signal level in dBm. The conversion parameters were entered into the program and the accuracy of the conversion checked to see that it was within 0.5 dBm. The SNR calculation test verified the accuracy of the software SNR estimator routine. SNRs of 15, 10, and 5 dB were set up using the Y-factor method. The calculation was verified to be accurate within a tolerance of 0.3 dB. The important aspect of the configuration and interface tests was that they insured that the functional capabilities of the telemetry system existed.

The performance tests determined the capability of the telemetry system to meet the DSN support requirements. Normally these tests were executed for a given performance criteria, yet the Helios Project required a frame erasure rate of 10^{-4} in the coded mode. This erasure rate and the long (1152 bit) frame used by Helios required an inordinate amount of test time to achieve test results which would yield acceptable accuracy. Therefore, only a single coded mode test was performed which measured erasure rate (at 2048 bps). This test also yielded a computation distribution curve (Pareto distribution). The 2048-bps test plus the remaining data rates down to 8 bps measured only symbol error rate (SER) performance. The SER was used as a measure of decoder performance since it was estimated by the decoder after successful decoding of a data frame. Thus a correct SER measurement signified correct operation of the decoder. All uncoded tests were performed at a bit error rate (BER) of approximately 1×10^{-3} .

The tests were performed by setting an input SNR, using the Y-factor detector as shown in Fig. 45, which resulted in approximately the desired output error rate (BER or SER). The system degradation, from the receiver through the SSA, was predicted using models of the telemetry system which were evaluated using the Telemetry Efficiency Program. Tolerances were set by including input SNR setup errors and statistical errors due to averaging required to obtain the SER or BER estimates.

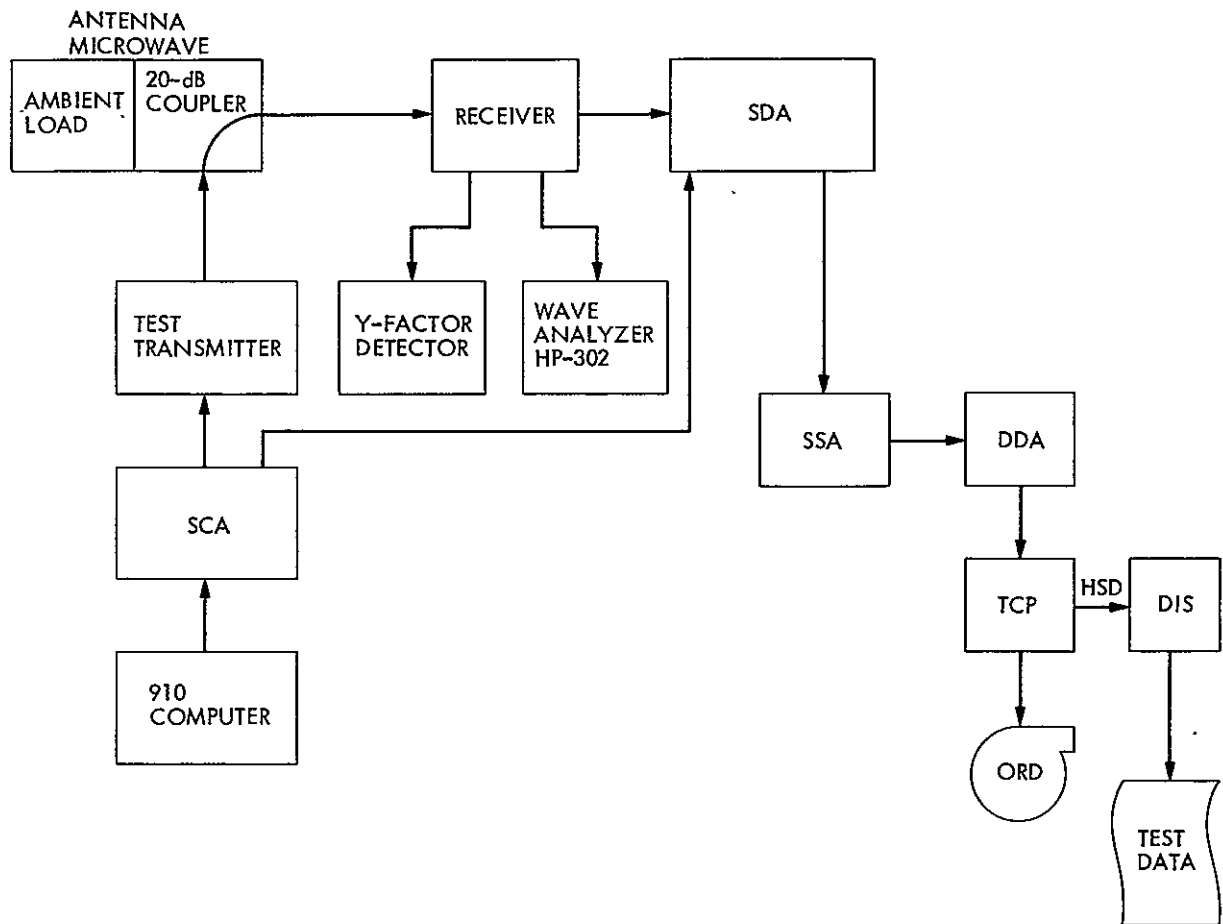


Fig. 45. Telemetry test configuration, general

It was deemed at the outset of the SPTs that execution of all tests would be redundant, particularly tests where data rates were close to one another and neither the modulation index nor mode was different. It was decided that only the highest and lowest data rates and the data rates where a modulation index change occurred (middle data rates) would be tested for both the uncoded and coded modes. Therefore, tests 1, 5, 6, and 9 of the uncoded mode, and tests 10, 14, 15, and 18 of the coded mode (Table 9) were executed during the Helios SPTs.

Table 9. Performance tests

Test	Data rate, bps	Mode	Modulation index, deg
1	2048	Uncoded	56.5
2	1024	Uncoded	56.5
3	512	Uncoded	56.5
4	256	Uncoded	56.5
5	128	Uncoded	56.5
6	64	Uncoded	42
7	32	Uncoded	42
8	16	Uncoded	42
9	8	Uncoded	42
10	2048	Coded	56.5
11	1024	Coded	56.5
12	512	Coded	56.5
13	256	Coded	56.5
14	128	Coded	56.5
15	64	Coded	42
16	32	Coded	42
17	16	Coded	42
18	8	Coded	42

Helios SPTs using the Model-B software were executed throughout the Network with the following completion dates:

<u>DSS</u>	<u>Completion Date, 1974</u>	<u>DSS</u>	<u>Completion Date, 1974</u>
11	March 18	42	March 8
12	February 26	43	March 12
14	March 14	62	March 4

All Telemetry System test results were good, with the exception of the low bit rate performance tests, where it was noted that at 8- and 16-bps rates the SNR was quite erratic and error rates were high. However, in April 1974 it was discovered that the telemetry data output from the spacecraft was inverted, resulting in an incompatibility between the spacecraft and the DSN and invalidating the results of the Model-B software package used in the SPTs. As mentioned previously, the Model-B software package was modified and validated at CTA 21 before being released as the Model-C software package (DOI-5050-OP-C) in July 1974 and rushed to the DSN stations so they could perform an SPT prior to the then scheduled October launch. Each station successfully conducted its SPT using the new Model-C software package. The results of these tests are shown in Table 10.

2. Tracking and Monitor and Control System Performance Tests

The DSN Multiple Mission Tracking System and Monitor and Control System were established together with operational systems supporting Pioneers 10 and 11 and Mariner Venus/Mercury 1973. Although these two systems were capable of supporting the Helios Project without new or modified hardware or software and were not required to undergo System Performance Tests, each system successfully passed an SPT during February 1974.

C. OPERATIONS VERIFICATION TESTS

Between March and November 1974 the DSN conducted 46 Operations Verification Tests (OVTs) with the prime and secondary Helios support stations (Table 11). In addition to the DSN stations, the following facilities were utilized:

- (1) Network Control System (NCS).
- (2) Network Operations Control Area (NOCA).
- (3) Mission Control and Computing Center (MCCC).
- (4) MCCC Simulation Center (SIMCEN).
- (5) Mission Operations Control Team (MOCT).
- (6) Ground Communications Facility (GCF).

These tests served two purposes: first to verify the compatibility of hardware, software, and operational procedures, and second, to provide the necessary operational exercises for the DSN and other personnel to demonstrate their ability to meet the Helios operational requirements.

Table 10. Helios telemetry SPT results

DSS	TCP	Test	Rate	SNR		SER/BER		Remarks	
				Experiment	Actual	Experiment	Actual		
62	1	1	2048(C)	-	-	0.074	0.004	0.077	
		2	2048(C)	-	-	0.074	0.004	0.072	
		1	2048(U)	6.8	0.3	6.46	6.8 10^{-4} 1.4 10^{-3}	1.4 10^{-3}	
		2	2048(U)	6.8	0.3	6.51	6.8 10^{-4} 1.4 10^{-4}	1.4 10^{-3}	
		1	Conf/Inter ^a	-	-	-	-	-	OK
		2	Conf/Inter ^a	-	-	-	-	-	OK
Both		ATRS II							OK
2	1	1	2048(C)	-	-	0.074	0.004	0.067	
		2	2048(C)	-	-	0.074	0.004	0.067	
		1	2048(U)	6.8	0.3	6.63	6.8 10^{-4} 1.4 10^{-3}	1.28 10^{-3}	
		2	2048(U)	6.8	0.3	6.73		1.32 10^{-3}	
		1	Conf/Inter ^a	-	-	-	-	-	OK
		2	Conf/Inter ^a	-	-	-	-	-	OK
Both		ATRS II							OK

^aConfiguration interface.

Table 10 (contd)

DSS	TCP	Test	Rate	SNR			SER/BER		Remarks	
				Experiment	Actual		Experiment	Actual		
11	1	1	2048(C)	-	-	-	0.074	0.004	0.075	
	2	1	2048(C)	-	-	-	0.074	0.004	0.079	
	1	10	2048(U)	6.8	0.3	6.59	6.8 10^{-4} 1.4 10^{-3}		9.3 10^{-4}	
	2	10	2048(U)	6.8	0.3	6.73	6.8 10^{-4} 1.4 10^{-3}		1.03 10^{-3}	
	1	Conf/Inter ^a	-	-	-	-	-	-	-	OK
	2	Conf/Inter ^a	-	-	-	-	-	-	-	OK
Both		ATRS II								OK
42	2	1	2048(C)	-	-	-	0.074	0.004	0.08	
	3	1	2048(C)	-	-	-	0.074	0.004	0.08	
	2	10	2048(U)	6.8	0.3	6.52	6.8 10^{-4} 1.4 10^{-3}		1.27 10^{-3}	
	3	10	2048(U)	6.8	0.3	6.72	6.8 10^{-4} 1.4 10^{-3}		1.15 10^{-3}	
	2	Conf/Inter ^a	-	-	-	-	-	-	-	OK
	3	Conf/Inter ^a	-	-	-	-	-	-	-	OK
Both		ATRS II								OK

^aConfiguration interface.

Table 10 (contd)

DSS	TCP	Test	Rate	SNR		SER/BER		Remarks	
				Experiment	Actual	Experiment	Actual		
43	1	1	2048(C)	-	-	0.074	0.004	0.08	
	2	1	2048(C)	-	-	0.074	0.004	0.08	
	1	10	2048(U)	6.8	0.3	6.59	6.8 10^{-4} 1.4 10^{-3}	1.28 10^{-3}	
	2	10	2048(U)	6.8	0.3	6.52	6.8 10^{-4} 1.4 10^{-3}	1.37 10^{-3}	
	1	Conf/Inter ^a	-	-	-	-	-	-	OK
	2	Conf/Inter ^a	-	-	-	-	-	-	OK
Both		ATRS II							OK
61	3	1	2048(C)	-	-	0.074	0.004	0.07	
	3	7	64(C)	-	-	0.074	0.004	0.07	
	3	10	2048(U)	6.8	0.3	6.74	6.8 10^{-4} 1.4 10^{-3}	1.2 10^{-3}	
	3	14	128(U)	6.6	0.5	6.94	6.8 10^{-4} 1.4 10^{-3}	9.15 10^{-4}	
	3	Conf/Inter ^a	-	-	-	-	-	-	OK
	3	AGC/SNR	-	-	-	-	-	-	OK
	3	ATRS II							OK

^aConfiguration interface.

Table 11. OVT summary

	DSS							STDN (MIL 71)
	12	42	62	11	61	14	43	
Number of OVTs conducted	13	6	7	1	2	6	6	5
Total OVT hours per DSS	65	30	35	5	10	30	30	25

An OVT consisted of transmitting simulated telemetry data, coded and uncoded, and at rates of 256, 512, 1024, and 2048 bps through the station equipment and via the GCF high-speed data lines to the MCCC at JPL where the data were processed and validated. Spacecraft commanding was exercised both from MCCC in the automatic mode and from the station in the manual mode.

The detailed objectives of the OVTs were to:

- (1) Demonstrate compatibility of operating procedures with Project Helios hardware and software systems.
- (2) Provide DSS, GCF, NCS, and NOCT operations personnel with training exercises relative to Project Helios support.
- (3) Verify Network capability of performance in data acquisition, data processing, commanding, and monitoring and control.
- (4) Verify that Network personnel were trained in adequate numbers to support Helios operational commitments.

Problems were encountered by each station during the tests. However, they were all of a minor nature and usually resolved before the next scheduled OVT was performed.

As noted in Table 11, DSS 12 conducted twice as many OVTs as the other stations. The additional testing was necessary because of the high attrition rate of experienced station operations personnel at DSS 12 during June and July 1974. As a result, DSS 12 requested that a second series of OVTs be conducted starting in August 1974 to provide adequate training time for the new operations personnel prior to the Helios launch.

As each station successfully completed its series of OVTs the next test phase, Performance Demonstration Tests (PDTs), would begin. The OVT objectives were met by all stations to the satisfaction of the DSN.

D. INTERNETWORK OPERATIONS VERIFICATION TESTS

Several internetwork OVTs were conducted in 1974 to verify the compatibility of hardware, software, and operational procedures and to provide operational exercises for both U.S. and German personnel to demonstrate that they were adequately trained to meet the Helios internetwork operational requirements. Testing included simulated spacecraft acquisition, internetwork two-way station transfer, spacecraft commanding, and data processing.

The first U.S./German internetwork OVT was conducted on July 29, 1974, and was supported by the following participants:

U.S.	German Network (Fig. 46)
DSN Operations	German Space Operations Center (GSOC)
MCCC Operations	German Telecommand Station (GTS)
MCCC Simulation Center (SIM CEN)	German Effelsberg Station (GES)
DSN Ground Communications Facility (GCF)	
DSS 62	

This was the first test to exercise the US/German interface in an operational environment, and while the test was not a complete success, it provided valuable experience for all participants. Several significant problems occurred which caused delays during the test resulting in the deletion of a large number of the items in the planned mission sequence of events (SOE).

The following are significant comments/anomalies regarding this test:

- (1) Three simulated internetwork spacecraft transfers were conducted during the test and were carried out with no problems. This was one of the prime objectives of the test and was completely successful.
- (2) Probably the most significant problem which disrupted this test was the extremely poor quality of the voice circuit between JPL and GSOC throughout the test. The line was plagued by 100% echo received at JPL, periodic voice oscillation (ringing) on the line, cross-talk, very low voice level received at JPL, and some periods of total line dropout. On at least three occasions during the test, the line was turned back to GCF for trouble-shooting, with the resulting report that the problem was between NASCOM Madrid Switch and Germany. No make-good circuits were available due to ongoing support to the German Project AEROS. At various



Fig. 46. German Network locations

periods the Madrid Switching Center reconfigured the Helios HSDL/voice lines for AEROS-B support without prior voice coordination.

- (3) Several computer outages at GSOC occurred during the test.
- (4) GSOC was unable to send commands across the normal interface. Commanding during the test was accomplished in the backup mode (entry to the MCCC 360/75 computers). The problem at GSOC was later determined to be caused by operator unfamiliarity with command procedures.
- (5) Some parameters in the DSN monitor data display at GSOC did not give proper indications. Also, GSOC did not receive monitor data from GTS because of nonavailability of GTS software.
- (6) No manual commanding (DSS entry) was attempted because of the poor quality of the voice circuit.
- (7) GSOC was unable to generate tracking predicts for the German stations because of nonavailability of software. The software was expected to be available by the end of September.
- (8) GES did not actively support the OVT because of loss of the HSD/voice/TTY interface to GSOC.
- (9) The procedure for backup commanding was not clearly defined.

Owing to the problems and delays encountered during this test, many of the planned sequence of events (SOE) items had to be deleted. This resulted in the operation's being placed in a backup mode, which provided valuable experience in a realistic situation that had not been planned. As the test objectives were not all met and many SOE items were not exercised, the test was scheduled to be repeated on the following day (July 31, 1974).

Late in the evening (2200 GMT) of July 31, the second internetwork OVT was begun with the same participants as on the first attempt. This OVT progressed very well, and all but two test objectives were accomplished. Internetwork commanding and backup mode commanding were both successfully executed. Both telemetry and monitor data were successfully transmitted to GSOC from the DSN. Two station transfers were smoothly executed between DSS 62 at Madrid, Spain, and GTS at Weilheim, Germany.

Although this OVT was successful, there were some problem areas. The most troublesome problem throughout the test was in the area of voice communications. In Germany, the voice line between GSOC and GES was totally unusable throughout the test, and communications had to be established over public telephone lines. Delays and very poor voice quality were experienced between DSS 62 and GSOC. This resulted in an agreement between the DSN and GSOC that whenever the DSN was tracking from its station in Goldstone, Australia, or Spain, GSOC would be patched direct to the tracking DSS.

Computer outages were also experienced at GSOC for approximately 25% of the overall test time. Owing to DSN software problems the transmission of SOEs and predicts to GSOC could not be accomplished. In addition, the

GSOC did not receive any useful monitor data from the DSN/MCCC nor did MCCC generate any Master Data Record (MDR). Because of the lack of software, GTS did not have an automatic command capability or monitor data generation capability.

Approximately three hours into the OVT, Project AEROS experienced a spacecraft emergency which preempted the test at GSOC for 45 min. While this OVT was successful in other areas, it was agreed that a third inter-network OVT should be conducted at a later date to see if the agreed upon direct voice communications patching between the tracking DSS and GSOC would improve the voice quality problem.

A third Internetwork OVT was conducted on September 17, 1974. Again the participants were the same, except that the supporting DSN station was DSS 61 instead of DSS 62. Although this OVT was over 2 hours late in starting and progressed slowly because of numerous delays (equipment, software and procedural problems), the principal test objectives were met except for the following:

- (1) The processing of orbital elements could not be performed.
- (2) The operation of the MDR interface could not be verified.

The direct voice communication patching between GSOC and the tracking DSS proved very successful and the voice quality was loud and clear. Station handovers and manual commanding were not exercised during this OVT because of equipment problems, but they were not necessary for this test since they had been successfully demonstrated during the second OVT on 31 July.

The following is a list of hardware, software, and procedural problems experienced during this OVT:

(1) Hardware

- (a) About 2 hours of test time elapsed before the CMD data transfer test could be performed. The problem was identified as a station (DSS 61) equipment problem.
- (b) A failure of DSS 61 DDA caused a delay of about 60 min during the first part of the test. The station repaired the DDA by isolating and replacing a bad circuit card.
- (c) The voice line between GSOC and JPL was out for 20 min.
- (d) Switching from coded to uncoded telemetry mode could not be performed. When switching to the uncoded mode the SCA at DSS 61 would not lock up on SIMCEN (Simulation Center) data.

(2) Software

- (a) Monitor data from DSN/MCCC did not reflect the actual system status:

Starting at 10:57 GMT until the end of the test, the Telemetry System Lock Indications remained in a static "in-lock" state, although bit rate changes which interrupt data flow were taking place.

The parameter "Transmitter Power" exceeded the valid range (i.e., 1023.3 kW instead of 10 kW).

The parameters "DDA Input Errors," "Frames on Log," and "Deletion Rate" showed zero throughout the test.

Command System Status Information ("Command System Mode," "Number of Commands Transmitted," "Number of Commands Aborted") were not consistent with project status displays (see (b) below).

- (b), Command displays at GSOC were not consistent. The NOCC command status display was generated from monitor data, while the CSFO command status display was generated from MCCC data. During the test the monitor data differed from the MCCC data. This was thought to be associated with the DSS 61 TCP-DIS computer interface problem.
- (c) Telemetry data blocks were received from MCCC at GSOC even if the DDA was out of lock or if frames had been deleted. (In both cases the sync condition code was stating full sync.) Errors within these blocks caused problems during MDR processing.

3. Procedures

- (a) User Area 25 (GSOC) was not assigned when CMD System was turned over to Project CMD Test.
- (b) The DSN Post Track Report was not provided to GSOC in a timely manner.
- (c) The use of the call sign "HEOPS" instead of "CSFO" caused some confusion, since internetwork procedures reflect the call sign "CSFO" and the DSN stations had been so trained. It was recommended by Network Operations to use the call sign "CSFO."
- (d) DSN monitor data received at GSOC contained all zeros for 2 hours. This was caused by the TCP-DIS computer interface not being established properly at DSS 61 (procedural error).
- (e) Lack of adequate project procedures caused the "COHR" (coherent mode) command to be entered into queue from GSOC before CMD MOD was turned on. After the CMD data transfer test was completed (before acquisition of signal), the CMD MOD was turned off to await AOS by the station. GSOC, not informed of this action, entered and enabled the "COHR" CMD into queue. As soon as the CMD MOD was turned on,

the CMD was sent. Internetwork procedures were revised to control this situation.

Although problems occurred during each of the three internetwork OVTs, the overall experience gained proved valuable to both the U.S. and German operations personnel. Both operational and procedural problem areas were identified during these tests and corrective measures taken. Equipment problems were referred to the Ground Data System engineers and quickly resolved.

E. PERFORMANCE DEMONSTRATION TESTS

Performance Demonstration Tests (PDT) using the Model-C TCP software were conducted in August 1974 with all Helios support stations except DSS 43. On September 8, 1974, a PDT was conducted at DSS 43. The PDTs were conducted to demonstrate that the DSN was ready to support the Mission Operations System testing. The sequence of events used for these tests included typical Helios events pertaining to telemetry and command operation. Anomalies were intentionally injected to demonstrate personnel operational readiness to meet problems with contingency actions. The response to each intentional anomaly at each station was adequate and, in most instances, excellent. The performance of ODR playback was not demonstrated due to the nonavailability of automatic total recall system (ATRS II) software. The following PDTs were conducted:

Date, 1974	Station	Results
August 15	DSS 62	Successful
August 15	STDN (MIL 71)	Unsuccessful
August 16	STDN (MIL 71)	Retest successful
August 17	DSS 42	Successful
August 17	DSS 61	Successful
August 21	DSS 12	Successful
August 21	DSS 11	Successful
August 31	DSS 14	Successful
September 8	DSS 43	Successful

Although anomalies were experienced at each DSS, they were all of a minor and nonrepeatable nature. From the results of these tests it was concluded that DSN performance in the Helios configuration had been successfully demonstrated and the transfer of the Helios operational configuration to the Network Operations Control Team (NOCT) was accomplished.

F. INITIAL ACQUISITION OVT

The Initial Acquisition OVT was designed to demonstrate the capability of DSS 42 to perform initial acquisition of the Helios spacecraft. Two tests, based on events and parameters which closely simulated those of an actual Helios acquisition, were conducted on August 26 and 30, 1974, using the standard Helios hardware and software configuration of DSS 42, NOCT, MCCC, SIMCEN, GCF, and NASCOM to simulate and exercise:

- (1) Uplink/downlink signal levels.
- (2) Spacecraft RF mode changes.
- (3) Station antenna angle slew.
- (4) Predicts and SOE transmission.
- (5) Initial acquisition procedures.
- (6) Silent and normal spacecraft acquisitions.
- (7) Sidelobe/sideband lock detection and correction.
- (8) Prime and backup stations.

Both tests were successful and provided valuable training for the station personnel in performing normal acquisition²⁴ and blind acquisition²⁵ of a spacecraft.

As a result of a procedural problem during the first test between the Network Operations Control Team and the station regarding transmitter turn-on and frequency sweep rate information, a new format was prepared for relaying this information and proved successful during the second test.

A third test was conducted on September 5 at the request of DSS 42 so that additional personnel could participate. This test, however, could not be successfully completed because of communications and equipment problems. On the basis of results of the first two successful tests the station was considered ready to perform initial acquisition in support of Helios.

²⁴Spacecraft transmitting downlink signal.

²⁵Spacecraft transmitter not operating.

G. SPECIAL STEP II MANEUVER OVT

Because the Step II maneuver was originally scheduled to take place over DSS 14 (prime 64-m station) and DSS 11 (backup 26-m station), it was necessary to conduct a special OVT to familiarize the DSN station personnel with the operational procedures and to exercise the station systems required to support the maneuver.

1. DSS 14

The first Step II maneuver OVT was conducted at DSS 14 on November 5, 1974. The procedures for changing bit rates, coded to uncoded, subcarrier frequencies, and tracking rates were performed on time and with proficiency. However, approximately halfway through the test the antenna polarizer switch failed. In addition, the test was an hour late in starting, which resulted in the allotted test time running out before the Automatic Total Recall System (ATRS) playback program (DOI-5061-OP) could be tested. These two factors resulted in the test being rescheduled for November 22.

The second test was performed on November 22. This test was a complete success, with the operating personnel performing all procedures in proper sequence and on time and all test objectives being met.

Although DSS 14 had been selected as the prime support station for the Helios Step II maneuver, the slip in the Helios launch schedule to December 8, 1974, caused a conflict with the Pioneer Project because the DSN had committed the 64-m station to support the Jupiter encounter of Pioneer 11. As a result, the DSN had to commit DSS 12 as the prime support station for the Step II maneuver.

2. DSS 12

In early November 1974 DSS 12 was committed as the prime support station for the Helios Step II maneuver for the reason stated above. The special Step II maneuver OVT was not conducted at DSS 12 because the station participated in two MOS tests conducted by the Project, which included the necessary operational procedures for performing the Step II support. These two MOS tests were conducted on November 15 and 21, 1974, and on the basis of successful performance of the station personnel and systems it was determined that it was not necessary to conduct the Step II maneuver OVT.

3. DSS 11

The first Step II Maneuver OVT was conducted at DSS 11 on November 16, 1974. Maintenance on the 26-m antenna was in progress prior to the scheduled OVT time and extended through the OVT time, thus obviating use of the antenna polarizer. The procedures for changing bit rates, coded to uncoded, subcarrier frequencies, and tracking rates were successfully performed. Playback of the ATRS program (DOI-5061-OP) was also successfully completed.

On November 24 a second Step II Maneuver OVT was conducted. Owing to equipment problems, the station was 4 hours late in starting the test, and only 2 hours remained in the scheduled OVT time. In the remaining 2 hours the station operating personnel were able to perform all procedures

in proper sequence and on time to meet the test objectives. The success of these tests was demonstrated by DSS 12 and DSS 11 during the flawless DSN performance of the actual Helios-A Step II Maneuver on December 11 and 12, 1974.

H. INTERNETWORK TRAINING TRACKS

On November 2, 1974 the first U.S./German Internetwork Training Track was conducted using the in-flight Pioneer 9 spacecraft. This exercise provided the first opportunity for both the U.S. and the German operators (at DSS 63 and the German receiving and transmitting stations) to practice internetwork spacecraft handover procedures. Six spacecraft handovers were successfully performed during this exercise and provided a high degree of confidence in both the procedure and operations personnel.

A second Internetwork Training Track using the Pioneer 9 spacecraft was conducted on November 5. During this exercise, 4 two-way handovers were successfully performed between DSS 63 and the German receiving and transmitting stations, and the overall results were very satisfactory.

There were no major hardware or software problems noted during either of these training exercises. There was an area of concern, however, during the second training exercise when it was noted that the uplink power levels were greater than had been expected between DSS 63 and the German transmitting station. At DSS 63 the uplink power level averaged approximately -121.0 dB instead of the predicted -124.1 dB. The German transmitting station averaged approximately -137.0 dB which, for a 30-m station, should have been -11.6 dB less than that predicted for the 64-m DSS 63. The source of the latter problem was traced to the GTS antenna pointing software and corrected before the next exercise.

On November 19, 1974, a third Internetwork Training Track was conducted. As the Pioneer 9 spacecraft appeared on the horizon, DSS 63 acquired the spacecraft downlink signal but failed to establish uplink acquisition on the first attempt. Successful uplink (two-way acquisition) was established 5 min later on the second attempt. The first handover from DSS 63 to the German transmitting station (GTS) was unsuccessful owing to an error in the GTS antenna pointing software. Once corrected, the second handover from DSS 63 to GTS was performed successfully.

During each of the three Pioneer 9 training tracks, one problem kept occurring, and that was the DSN monitor data received at GSOC from DSS 63 contained all zeros. This was later traced to a problem in the MCCC software that had previously been documented and was subsequently corrected.

I. ABBREVIATED DSS 44 TESTS

1. DSN Initial Acquisition

Owing to the accelerated conversion schedule of the STDN Honeysuckle Creek facility to an abbreviated DSN configuration station in time to support the Helios Operational Readiness Test (ORT) on December 5 and launch scheduled for December 8, there was not enough time to give the station personnel the normal amount of training time. As the prime function of DSS 44 was to back up DSS 42 during

the initial acquisition phase of the launch, it was decided to limit the tests and training to Initial Acquisition Operational Verification Test only.

On December 1, 1974, the first initial acquisition training test was conducted. The primary training objective was to train each crew for a nominal initial acquisition, an abnormal initial acquisition, an acquisition at DSS 42 followed by a subsequent uplink transfer to DSS 44, manual commanding, and ATRS II automatic telemetry recall. The general sequence of the Operational Verification Test followed the planned initial acquisition sequence, but was varied so that each crew would also receive the maximum degree of normal Helios operations training in conjunction with acquisition training.

The first OVT was conducted with a long list of operational constraints, but the total test sequence was accomplished and the last 1.5 hours of the test was devoted to automatic telemetry recall. Procedural unfamiliarity at both the MCCC and the station hampered this first attempt. The following constraints could not be totally resolved, but work-around solutions proved successful for all of the OVTs.

- (1) Monitor software program DOI-5046-OPC would not accept "Station 44" as a valid I.D. The DIS was initialized as "DSS 51," but HSD TLM back-feed to the DIS would not function with the TCP initialized as "DSS 44" and the DIS as "DSS 51."
- (2) The pin diode attenuators could not be remotely varied from the SCA because of a hardware interface deficiency. All testing was conducted with static AGC setting manually entered by the station.
- (3) DSS 44 was equipped with a Technical Facility Subsystem (FAC) rather than a system junction module (SJM), and many monitor parameters were invalid because of the incompatibility between the FAC and the monitor software program. The monitor system was not committed; the station supplied all the required parameters via voice.

The format for the second OVT on December 4 was changed in order to perform all of the tracking functions that were required for initial acquisition. The first part of the test was dedicated to generating and transmitting predicts to the station, following the launch profile. The station drove the antenna and generated valid tracking data. This was performed twice, and all SOE items involving the tracking system were accomplished without problems. The APS/SCA-910 was then configured for telemetry support. The nominal and anominal acquisitions were performed, followed by manual commanding. Automatic telemetry recall was not attempted. The only problems noted were low simulation signal levels at high bit rates and internal station interface monitor problems to the SMC CRT. All test objectives were met.

The third DSN Initial Acquisition OVT with DSS 44 was also conducted on December 4, 1974. Only 2 hours could be scheduled for the test because the station was involved in a Class "A" countdown for the Operation Readiness Test scheduled for December 5. Time permitted only a nominal initial acquisition case and manual commanding to be exercised. Both were performed without serious problems and the test objectives were met.

The successful completion of these three Initial Acquisition Operation Verification Tests, after the reactivation of DSS 44, served as training for the Helios Operational Readiness Test scheduled for December 5, 1974. The station's performance on all three tests was exemplary.

J. CONFIGURATION VERIFICATION TESTS

A few days before the Helios launch, and prior to the last Operations Readiness Test, DSN Configuration Verification Tests (CVTs) were planned to ensure that DSN stations were in the required Helios configuration. These tests were used to verify and freeze station configuration until after launch. Owing to the variation of the individual station performances during MOS testing, the CVTs offered the opportunity to concentrate on areas of concern. The CVT's were scheduled and coordinated by the Network Operations Project Engineer (NOPE), with the areas of concentration and conduct of the testing left to the discretion of the station directors. Time for last-minute checks and adjustments required for Helios launch support were scheduled. The successful support provided by the DSN during the first few days following launch of the Helios spacecraft confirmed that the DSN stations committed to the operational support of Helios had been well prepared, tested, and trained for their assignment.

VII. MISSION OPERATIONS

A. LAUNCH SUPPORT

1. December 8, 1974, Countdown

Preparations were commenced to launch the Helios-A spacecraft on December 8, 1974, with the opening of a 42-minute daily launch window at 07:16 GMT. During the minus count, all supporting DSN facilities began their pretrack calibration sequences. Besides STDN (MIL-71), DSS 42 and DSS 44 in Australia, DSS 62 in Madrid, and DSS 11 and DSS 12 at Goldstone were involved in this first-pass countdown procedure. At T -10 min in the countdown sequence, which was at the point of a built-in hold, a launch vehicle telemetry readout from the Centaur liquid hydrogen engine caused some concern. The T -10 min hold extended into the opening of the launch window, but the Centaur telemetry problem was not resolved. The hold continued until approximately 20 min prior to the 07:58 GMT close of the daily window on December 8, at which time it was decided by the project managers to scrub the launch attempt for that day. Shortly thereafter, the project managers made a decision to reschedule the next launch attempt for December 10, 1974, in order to avoid unfavorable weather forecast for December 9, as well as to provide time to thoroughly diagnose the problem within the Centaur stage of the launch vehicle.

2. December 10, 1974, Countdown and Launch

The Helios-A launch countdown resumed on December 10, 1974, toward a targeted opening of the 42-minute daily window at 07:11 GMT. Again, the DSN stations at all three longitudes participated in the minus count by performing their prepass calibrations and data flow tests. This time the launch vehicle proceeded through the T -10 min built-in hold and continued satisfactorily right up to the opening of daily launch window. The Helios spacecraft lifted off Pad 41 at Cape Canaveral at 07:11:01.5 GMT and into parking orbit with all subsequent launch vehicle events occurring on schedule. Early radar tracking from the ETR radar stations indicated that the launch vehicle trajectory was entirely nominal (Fig. 47). This fact, plus confirmation from the downrange telemetry stations that the Helios spacecraft transmitter signal was operating, gave confidence that a nominal initial acquisition procedure could be employed by DSS 42 upon spacecraft rise.

With this successful launch, and the subsequent verification that the spacecraft was operational, the official designation for the mission was changed from the "Helios-A" to the "Helios-1" mission.

3. Near-Earth Phase Network Coverage

The Near-Earth Phase Network (NEPN) was supported by STDN (MIL 71) during Helios prelaunch and launch activities. This support was via the RF interface to the STDN (MIL 71) antennas from spacecraft activation up to postlaunch loss-of-signal (LOS) at the STDN (MIL 71) horizon. During this time period, STDN (MIL 71) operated under the auspices of the NEPN, but provided spacecraft data flow to the MCCC using standard DSN GCF HSD block formats. Prior to launch, STDN (MIL 71) provided two-way communication with the

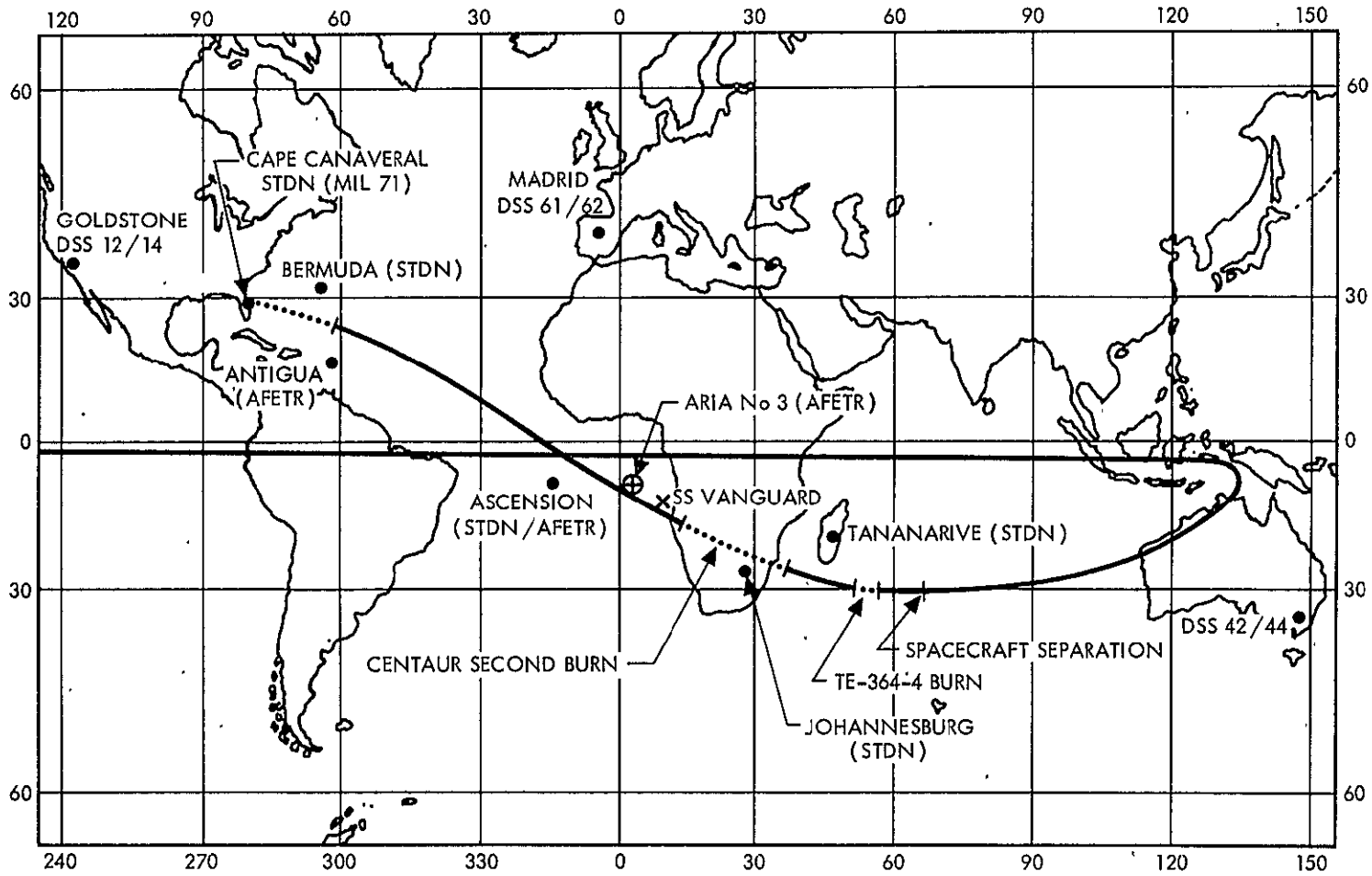


Fig. 47. Actual Helios-1 near-Earth trajectory

spacecraft (telemetry and selected commanding); but at launch and subsequently, the communications were one-way (telemetry) until LOS.

In addition to the direct RF link support provided during the launch phase, STDN (MIL 71) provided the telemetry interface between the downrange NEPN stations and the MCCC by selecting the best NEPN data source (downrange station), processing (decoding) that NEPN station's received telemetry data and formatting this NEPN telemetry data into standard DSN telemetry HSD blocks for transmission to the MCCC. Except for compatibility tests, all pre- and postlaunch Helios support provided by STDN (MIL 71) was scheduled and coordinated by the NEPN manager for Project Helios. This NEPN cognizance extended from the arrival of the Helios spacecraft at the Cape until termination of NEPN support activities for Helios, i.e., when formal TDS responsibility was transferred from the NEPN to the DSN.

The Near-Earth Phase Network (NEPN) supported the launch of Helios-1 with 13 stations to receive data from the following six telemetry links and two radio metric links (Table 12).

Table 12. NEPN support

Telemetry data links		
Frequency, MHz	Modulation	From
2287.5	PCM/FM	Titan III
2202.5	PCM/FM	Centaur
2215.5	PCM/FM	Centaur
2208.5	FM/FM	Centaur
2250.5	FM/FM	TE-M-364-4
2297.6	PCM/PSK/PM	Helios spacecraft
Radio metric data link		
Double pulse spacing		
5765	6 us	Centaur
5765	9 us	TE-M-364-4

a. STDN. The STDN provided telemetry and/or radio metric data coverage from the following stations:

- (1) STDN (MIL) and STDN (MIL 71).
- (2) Bermuda Island.
- (3) Ascension Island.
- (4) U.S.S. Vanguard.
- (5) Johannesburg.
- (6) Tananarive.

Although the STDN support was good, there were a few problems which resulted in the loss of some data. MILA lost the telemetry link from the TE-364-4 sooner than expected owing to a bad vehicle antenna aspect angle. The Bermuda station radar was late in acquiring due to receiving improper acquisition data. The ship USS Vanguard, stationed off the west coast of Africa at 13.8 deg south latitude and 12 degrees east longitude, lost 27 seconds of mandatory telemetry data on frequencies 2202.5, 2215.5, and 2250.5 MHz, when the forward superstructure of the ship blocked antenna reception just prior to the Centaur's second main engine start (MES 2). This loss of data resulted when the ship started its turning maneuver a little late. Approximately 70 s of telemetry data was lost because the Johannesburg station acquired on an antenna sidelobe because of a low elevation angle and inaccurate antenna pointing data. Fortunately, this launch interval was also being covered by the ARIA No. 3 aircraft stationed at 11 degrees 52 minutes south latitude and 00 degrees 58 minutes east longitude and flying at an altitude of 30,000 ft (Fig. 47). The Tananarive station locked on a sideband frequency instead of the telemetry carrier frequency, which resulted in invalid real-time telemetry data being sent to STDN (MIL 71). In addition, the Tananarive radar acquired the TE-364-4 5765 MHz beacon near the end of the station's pass. Because the beacon signal was weak and lobing, the Tananarive station was requested to track the TE-364-4 until loss of signal. The radar data obtained from this track were used to generate a set of orbital elements for the TE-364-4 orbit. Although the Tananarive radar was also required to track the Centaur C-band beacon, the request to remain with the TE-364-4 resulted in no Centaur data being obtained.

b. AFETR. The AFETR provided telemetry and radiometric data coverage from the following stations:

- (1) Cape Canaveral.
- (2) Grand Bahama Island.
- (3) Grand Turk Island.
- (4) Antigua Island.
- (5) Ascension Island.

(6) Two ARIA aircraft.

Support from the AFETR was also very good, but there were some problems which resulted in a partial loss of data. The Grand Turk station was late in acquiring and lost approximately 30 seconds of telemetry data from all six links. At Ascension Island, the FPS-16 radar antenna initially acquired on the FPS-15 radar interrogation, resulting in invalid range data. FPS-16 radar achieved valid acquisition of the TE-364-4 C-band beacon at launch plus 1427 seconds.

Three ARIA aircraft were allotted to cover the launch phase. However, because of a mechanical problem with the telemetry antenna storage mechanism, ARIA No. 2 did not provide any coverage. As a result, approximately 117 seconds of mandatory parking orbit telemetry data that were not being covered by any other station were lost.

c. Kennedy Space Center. At KSC the Central Instrumentation Facility provided telemetry coverage of all six telemetry data links and one radiometric data link.

4. DSN Initial Acquisition

Following a perfect launch trajectory, the Helios-1 spacecraft was acquired by the Australian DSSs at 07:57:33 GMT, with DSS 42 providing the prime source of data and DSS 44 acting as a redundant backup. During this time, the spacecraft's attitude was such that its signal as received by the Australian stations was being transmitted by the dipole (top) element of the omnidirectional antenna. However, as the spacecraft gained altitude during its trajectory over Australia, the aspect angle changed such that the station reception was via the circularly polarized horn (bottom) element of the omnidirectional antenna system. The spacecraft radiation pattern boundary between the top dipole antenna and the bottom circular horn antenna element of the omniantenna system created an interference region. This was of concern to both the Project and the DSN with respect to whether successful telemetry reception could be achieved during the transition. However, during the flight, the signal degradation caused by this interference region proved to be less than had been feared. When the spacecraft trajectory had carried the aspect angle past the interference region, commands were sent by DSS 42 to initiate the Step I maneuver sequence.

B. STEP I AND STEP II MANEUVERS

1. Step I Maneuver

The Step I maneuver orients the spacecraft such that its solar panels are uniformly illuminated by the Sun, but with the spacecraft spin axis still lying essentially in the plane of the ecliptic, i.e., the plane of its injection. This maneuver was required for both electrical power and thermal control.

At the completion of the Step I maneuver, the spacecraft was still rotating at the 92.8-rev/min velocity imparted during its spin-up prior to injection. The next sequence initiated by commands sent via DSS 42 was to deploy the magnetometer booms, a process that caused the spacecraft rotational rate to decrease to less than 55 rev/min. Following the magnetometer boom

deployment, the radiowave experiment antenna booms (located at 90 deg to the magnetometer booms) were also commanded deployed. Early telemetry analysis indicated that one of the antenna booms did not deploy fully. However, the Helios Project decided to defer investigation of this possibility until the spacecraft had achieved its cruise phase configuration. With boom and antenna deployment completed, and the spacecraft spin axis still lying in the plane of the ecliptic, the next mission sequence over Australia was to turn on selected onboard science experiments in order to measure the solar wind bow wave that surrounds the Earth. This was also accomplished over Australia.

2. Step II Maneuver

Following first rise of the Helios-1 spacecraft over Goldstone on December 11, 1974, the spacecraft telemetry format was changed from science to engineering data in preparation for the Step II maneuver. At this time, the spacecraft was well past lunar distance, and the near-Earth science turn-on had been accomplished. The first series of Step II maneuver commands caused the spacecraft to yaw within the plane of the ecliptic to calibrate the thrust of the cold gas attitude control nozzles. After this was accomplished, commands were sent to pitch the spacecraft such that the antenna mast began to move toward the north pole of the ecliptic.

During the early portion of the Step II maneuver pitch commands, the spacecraft attitude was such that DSS reception was via the off-axis horn antenna out of the bottom of the spacecraft. As the pitch angle increased, so did the spin modulation on the doppler frequency increase, thereby giving an indication of spacecraft attitude in the radio metric data. The spin-modulated doppler signal was usable up to the point where the interference region was being traversed. To traverse the interference region (a feat requiring numerous commands), the Helios Project, in cooperation with the DSN, requested horizontal (ecliptic-plane) polarization at DSS 12 and vertical (perpendicular) polarization at DSS 11, with both stations supplying spacecraft telemetry via high-speed data lines to the Mission Control and Computing Center in Pasadena. This technique enabled DSS 12 to communicate with the spacecraft via the horn antenna, while DSS 11 was communicating via the spacecraft's omni-dipole antenna. The point of equal signal strength reception between DSS 11 and DSS 12 represented emergence from the interference region. Since the total degradation of the signal was not as severe as had been feared, the interference region was traversed with a telemetry margin of +10 dB at a 128-bps engineering data rate.

Following emergence from the interference region, DSS 12 switched to vertical polarization, and the spacecraft downlink was switched from the omniantenna system to the medium-gain antenna system, so the Goldstone station's received signal strength (AGC) readings would indicate the commanded traverse of the sidelobe pattern of the spacecraft medium-gain antenna and would also indicate when the peak of the main lobe of this antenna had been located. By the end of the first Goldstone pass, the spacecraft attitude was such that the medium-gain antenna pattern was very close to its peak value - indicating a nearly 90-deg orientation of the spacecraft with respect to the plane of the ecliptic.

By this time, the Helios Project's prime Mission Operations Support Team had been on duty for nearly 24 hours (since many had participated in

the prelaunch activities), so the reactivation of the onboard science instruments was deferred to the third Goldstone pass on December 12, 1974, during which time the exact center of the main lobe of the spacecraft medium-gain antenna was accurately measured and the spacecraft attitude accordingly determined. Prior to this, during second-pass activity, the spacecraft spin rate was increased to nearly 60 rev/min - though not exactly 60 rev/min per the experimenters' real-time request. With both the spacecraft spin rate and attitude in the cruise mode, the last engineering sequence of this series was to position the spacecraft high-gain antenna such that it was directed toward Earth. This was accomplished by commanding various phase adjustments to the despun velocity until the main lobe of the high-gain antenna had been determined through DSS receiver signal strength measurements. This completed the intense postlaunch Helios activity, and the mission settled down to its primary objective of achieving science return enroute to its perihelion passage of the Sun.

C. MISSION PHASE I AND II SCIENCE

1. Mission Phase I

Following the first-pass activation of the onboard scientific instruments, DSSs 42 and 44 in Australia and DSS 62 in Madrid, Spain, processed the cislunar science telemetry data desired by the Project. With a successful conclusion to the critical Step I and Step II maneuver sequences and the subsequent orientation of its high-gain antenna, the equally critical checkout of the scientific experiment packages was initiated by the flight team and project scientists. The experiment package checkout using the spacecraft high-gain antenna proceeded nominally through the first four experiments. Experiment 5 (the Plasma and Radio Wave Experiment) telemetry data contained an excessive level of noise. The experimenter requested that the spacecraft's operational antenna be switched to the medium-gain antenna to isolate the noise source. This request was honored, but on a later pass over DSS 42. After the delay caused by the Experiment 5 anomaly, final verification and configuration of the scientific experiment data package continued, using the spacecraft high-gain antenna.

With the exception of Experiment 5, the checkout and analysis of the integrity of the scientific experiments was established. At this point, Experiment 5 underwent intensive analysis. The experimenter recommended spacecraft medium-gain antenna operations, which would result in substantially lower, and therefore unacceptable, spacecraft telemetry data rates during the early phase of the mission. Thus the high-gain antenna mode was selected, at the expense of Experiment 5 data, to allow operation at a higher data rate using the 26-m Deep Space Stations.

As Mission Phase I was nearing its end in early January 1975, noise on Experiment 1 (Plasma Detectors) telemetry data was detected. Analysis of Experiment 1 telemetry data²⁶ revealed that noise generated during the high-gain antenna mode operation was also affecting its data. With Experi-

²⁶By H. Rosenbauer, Max Planck Institute.

ment 5 data being essentially worthless and an important part of Experiment 1 data being lost due to high-gain antenna operation, the consensus was to increase operations on the spacecraft medium-gain antenna by using the 64-m Deep Space Stations.

This mutual German/NASA decision was made to maximize the scientific data return of the total scientific experiment package. Medium-gain antenna operations required schedule reallocation of the 64-m stations at Goldstone and Australia, in conjunction with the 100-m German Effelsberg station, to maximize scientific data return during January and February 1975, when only DSN 26-m station support had been originally scheduled. To minimize the amount of switching between high-gain and medium-gain antenna modes, a Helios antenna switching plan was implemented for Mission Phase II.

2. Mission Phase II

This antenna switching plan, which was agreed upon by both Flight Operations and project scientists, resulted in maximum spacecraft medium-gain antenna operations by providing extended coverage by the large aperture ground antenna stations. The defined tracking schedule in this plan required 14 switching operations during the period January 30 to February 28, 1975, for a total of 28 switches between the spacecraft medium-gain and high-gain antenna modes.

The DSN 26-m stations provided support during several of the extended medium-gain antenna mode operations, but usually only provided scheduled coverage during spacecraft high-gain antenna operating modes, which enabled maximum telemetry data rate. However, the problems encountered with Experiments 1 and 5, plus a downlink signal level anomaly, caused real-time schedule changes which involved successful negotiations with other projects to secure additional 64-m coverage substantially greater than the original requirement for investigation of these problems. Multiple-mission tracking and the Helios Project data requirements necessitated schedule changes that caused the Helios Project to lose three complete passes, one over Australia and two at Goldstone.

D. MISSION PHASE I/II TRANSFER

Mission Phase I was defined as that time period wherein Mission Operations were conducted by the German Flight Operations Team, but from the JPL Mission Support Area (MSA). It encompassed prelaunch operations activities, launch, Step I and II maneuvers, and subsequent operations up to four weeks following launch - at which time mission control was transferred to the German Space Operations Center (GSOC) at Oberpfaffenhofen, West Germany. Mission Phase II was defined as that time period starting with the completion of Phase I and continuing through the spacecraft entry into first solar occultation.

On January 7, 1975, two of three German flight operations teams departed from JPL for GSOC to begin preparations for the transfer of the Helios mission control functions. In order to provide a real-time interface and problem analysis pertaining to DSN support, a DSN operations representative accompanied the German teams. The third German team remained at JPL to ensure a smooth transfer.

Mission control responsibility had been with the German flight operations teams stationed at JPL since the successful launch of the Helios-1 spacecraft on December 10, 1974, along with active participation by the German control center since the initial spacecraft acquisition over DSS 42 (Australia), the first successful track of the spacecraft by the German Effelsberg Station (GES) on December 13, 1974, and the first command transmission to the spacecraft by the German telecommand station (GTS) on 15 December 1974.

Data comparison made between the JPL and GSOC real-time computer programs showed full agreement regarding Helios flight data. GSOC also successfully recorded and processed data from the Effelsberg station while in a multimission configuration with West Germany's AEROS-B and Symphonie Projects, which were active simultaneously with Helios. Calibration and limit values were adjusted, where needed.

Based on the above results, the German mission manager concluded that the mission had progressed satisfactorily according to the GSOC plans for the transfer of mission control operations. On the morning of January 10, 1975, the U.S. and German project managers approved of the initiation of the transfer that same day and formally agreed that the Helios Mission Phase I would officially end at 1400 GMT on January 13.

As planned, the transfer of mission control responsibility from JPL to the German control center in GSOC was successfully accomplished at 1400 GMT on January 10, 1975. The continuity of normal mission operations during the transfer verified the soundness of the jointly prepared Mission Phase I/II transfer plan.

Phase I of the Helios Mission was officially terminated at 1200 GMT on January 13, 1975, with the spacecraft traveling at a speed of 8.5 km/s, at a distance of 24.3 million km from Earth (Fig. 48). On the following day, January 14, 1975, the last German flight operations team departed JPL to return to Germany to perform their operational functions at the German control center during Phase II of the Helios Mission.

E. MISSION PHASE II

1. A Change in Operational Interface

With the completion of Phase I and the beginning of Phase II on January 13, 1975, a new operational support mode was implemented. The new operational mode for Mission Phase II involved a German/JPL direct real-time voice interface between the German Network Operations Control Chief (NOCC) and the DSN Operations Chief (OPSCHIEF)/Mission Control and Computing Center Operations Controller (MCCC OPSCON). The JPL Chief of Mission Operations Support (CMOS) and the JPL Command Operator continued to support all critical Phase II operations on a shift-by-shift basis, as appropriately scheduled in advance; otherwise, support was on a call-up basis. Within 3 hours of a request by GSOC to the DSN OPSCHIEF/MCCC OPSCON, preparations for commanding in the backup mode (command initiated from JPL) would commence. This applied 24 hours a day, 7 days a week, throughout the remainder of the mission.

During all noncritical periods, including periods of commanding in the backup mode, the GSOC operational interface with JPL existed through

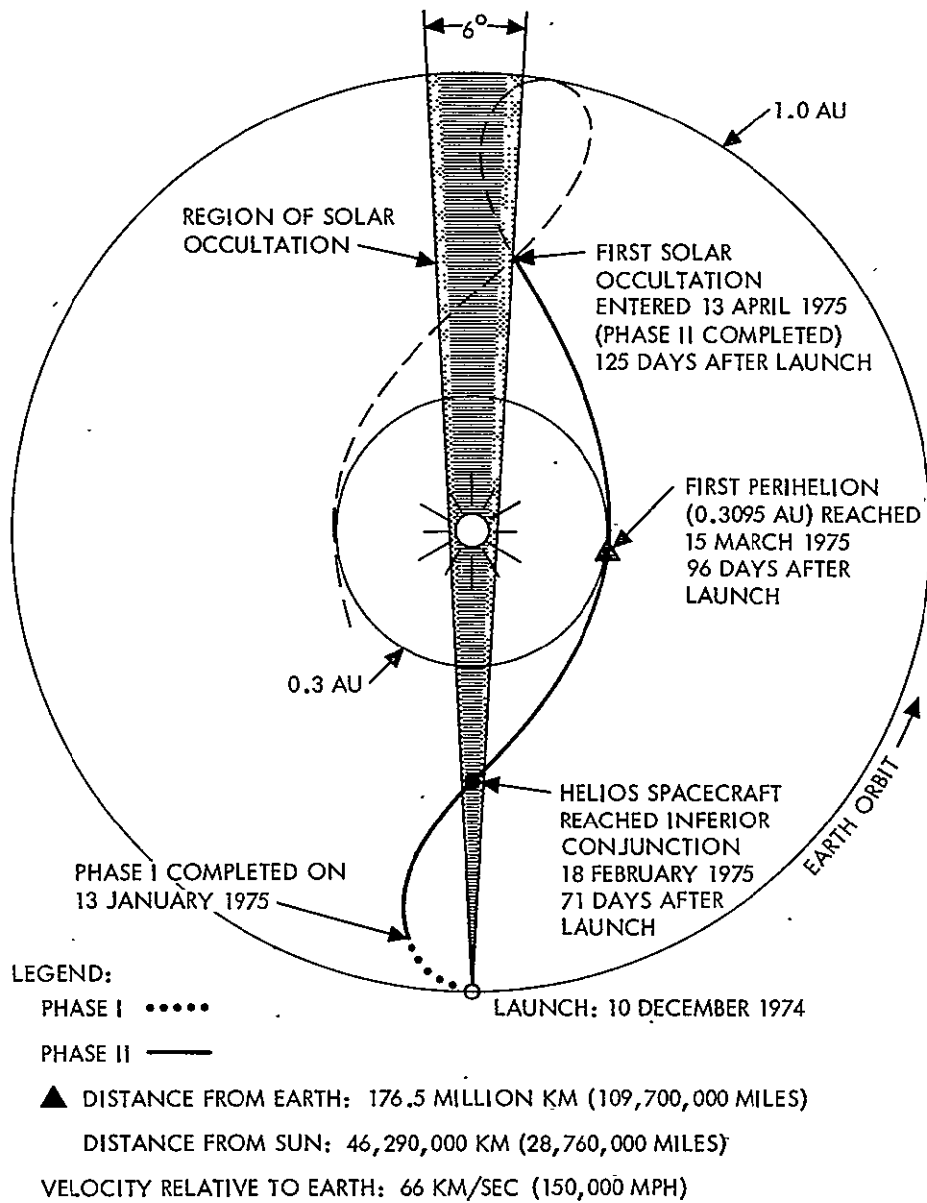


Fig. 48. Helios trajectory, mission phase I and II

the DSN OPSCHIEF and MCCC OPSCON. All MCCC-related coordination was handled by the OPSCON. DSN-related coordination (including DSN GCF) was handled by the OPSCHIEF.

A "CMOS Call-Up" was exercised on February 4, 1975, at 2025 GMT, when the German NOCC requested backup mode commanding from JPL because of an inoperative computer at the German Center. Within 10 minutes, the first of 9 backup commands had been sent and verified. Backup command support was successful and terminated at 2225 GMT, when control was once again transferred back to GSOC.

2. Helios Downlink Signal Level Variation

DSS 62 (Spain) reported on January 8, 1975, that since Helios-1 had been switched back to high-gain antenna mode on December 20, 1974, random transient phenomena had been observed on the system noise temperature chart recordings. These transients, which were noted as small, sudden changes in system temperature, could be detected in both two-way (one station) and three-way (two station) tracking configurations. This observation eliminated the possibility that the noise was being generated by the DSN station receiving equipment. Occasional variations of 1 to 2 dB in the downlink signal level had also been detected.

The variation in the received signal level was one aspect of the anomaly that was not as readily observable as was the system temperature chart recording. This was due to the sample rate of the station monitoring device, the Digital Instrumentation Subsystem (DIS), and the DSS receivers being configured in narrow AGC bandwidths. The DIS algorithm used several points to calculate the receiver AGC. With the receivers in the narrow bandwidth position, a smoothing action resulted in the observed downlink signal level fluctuations. Therefore, only the occasional large variations of 1 to 2 dB were observable.

As a result of careful observations, DSS 62 (Spain) initiated a thorough investigation of the Helios downlink signal during pass 27 on January 5, 1975. The variations in the downlink signal level were directly correlated to the transients on the system noise temperature chart recording during this test, but no definite trend or periodicity of the variations could be established.

The Helios downlink investigation was expanded by the DSN throughout the 26-m network that was supporting Helios. The analysis efforts were concentrated at DSS 12 (Goldstone). DSS 62's initial experiences were duplicated at DSS 12 on passes 32 through 35. No attempt was made to isolate the problem within the spacecraft during the DSN investigation, inasmuch as that was a Helios Project responsibility. The investigation provided detailed information on the characteristics of the shape, duration, and recovery time of the variations. This phenomenon was only observed with data associated with spacecraft high-gain antenna operation. One typical 3-1/2 hour period that was analyzed had 22 randomly occurring variations. The magnitude of the majority of these variations was 0.3 to 0.6 dB, with an average duration of approximately 5 seconds; but some had a magnitude of as much as 2 dB. The DSN provided the above information to the German Operations Team and continued to assist and provide support to GSOC in efforts to isolate and correct the variations

in downlink transmissions. (The cause of the downlink signal transients was later traced to electron emission from the spacecraft high-gain antenna feed system. Design corrections were introduced into the Helios-B flight spacecraft.)

3. Commitments, Conflicts and Compromises

In the original planning of the Helios Mission it was agreed that NASA would provide 24-hour continuous DSN support coverage during Phase II of the mission. This agreement was based on the then scheduled launch date of July 1974 and the assumption that no conflict would occur with other ongoing flight projects during Phase II. Spacecraft and launch vehicle development problems, however, caused several slips in the launch date, and each slip had an impact on other flight project requirements for DSN support coverage. In the last two months of 1974, approximately 16 meetings were held between the DSN and flight project representatives from Pioneer, Mariner Venus/Mercury 1973 and Viking to collectively compile their project requirements and to discuss possible scheduling compromises as a result of the final scheduled Helios-1 launch date.

The launch of Helios-1 on December 10, 1974, meant that first perihelion, the period of greatest scientific interest for the Helios experiments, would occur in mid-March 1975, the same time as the MVM '73 spacecraft would be making its third encounter of the planet Mercury. Faced with the problem of meeting other project requirements for DSN support, NASA informed the German Helios Project Manager on January 8, 1975, that the DSN could not provide the continuous 24-hour coverage as had been originally committed to the Helios Project and that plans were being developed whereby the DSN tracking facilities would be shared by all flight projects, with the intent of minimizing the number of Helios scientific data interruptions so that the impact on the Helios Project would be minimized.

On January 30 the German Project Manager was informed that a plan had been formalized for February and March 1975 through coordination scheduling meetings of the affected flight projects. Figure 49 shows how the DSN stations allocated support time for February. Figure 50 shows how the DSN stations allocated Helios support time for March. Although the requirements for 64-m station support exceeded the DSN capability, the joint coordination and compromises made by all three projects made it possible for the DSN to meet the most important requirements of each project.

On February 14, as the Helios spacecraft was approaching its inferior conjunction (the point in space where the spacecraft passes directly in front of the Sun, Fig. 48), commands were transmitted to Mariner 10 spacecraft to perform a trajectory correction maneuver prior to its third encounter. Analysis of the radio metric data, however, indicated that the spacecraft gyros had not functioned properly and the planned trajectory correction had not taken place. As a result, the Mariner Project made an urgent request for full and immediate DSN 64-m antenna support in order to obtain additional data to enable a decision to be made by February 18 as to whether or not another trajectory correction was necessary. A special scheduling meeting was conducted on February 15 which resulted in the reallocation of the DSN 64-m antenna usage by Helios. Helios exchanged 4 hours use of DSS 43 for 8 hours use of DSS 42 on February 17. In addition Helios agreed to share the

DEEP SPACE STATIONS	FEBRUARY, 1975																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
26-meter																												
12	H	H			H				H		H	H	H	H/M	H	H	H/M	H	H	H		H	H				H	H
42	H														H			H		H			H					
62	H																											H
														FULL COVERAGE DAILY														
64-meter																												
14			H	H						H/M			H			H/M			H			H/M	H	H/M				
43															D	H/M						H						H/M

H = FULL 8 h COVERAGE FOR HELIOS
 H/M = SHARED COVERAGE: 4 h HELIOS, 4 h MARINER
 D = DEMONSTRATION PASS AFTER MAJOR STATION RECONFIGURATION

Fig. 49. Scheduled DSN support for Helios in February 1975

DEEP SPACE STATIONS	MARCH 1975																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
26-meter																																
12																H															H ← → H	
42		H									H															H					H ← → H	
44																H																
62	H																															H
64-meter																																
14	H																															
43	H		H																													

H = FULL 8 h COVERAGE FOR HELIOS
H/P10 = SHARED COVERAGE- 4 h HELIOS, 4 h PIONEER 10
H/P11 = SHARED COVERAGE: 4 h HELIOS, 4 h PIONEER 11
M = FULL 8 h COVERAGE FOR MARINER VENUS/MERCURY 1973.

Fig. 50. Scheduled DSN support for Helios in March 1975

use of DSS 62 with Pioneer 10, although it meant removing the station's linear polarizer and a lower telemetry bit rate for Helios.

Analysis of the additional Mariner radio metric data accumulated by the 64-m antenna stations indicated a 50% probability of the spacecraft's impacting the planet Mercury. Therefore, on February 19 another special scheduling meeting was conducted at the urgent request of the Mariner Project. In order to reduce the probability of impact, the Mariner Project required additional 64-m antenna support to gather data over long continuous tracking arcs and to provide the capability for transmitting correction maneuver commands while there was still sufficient time.

As a result of this emergency the Helios Project exchanged its shared use of DSS 14 on February 24 for full use of DSS 11. Helios also exchanged its shared use of DSS 43 on February 28 for full use of DSS 42 but lost the use of DSS 62 (26-m antenna) on March 1, 1975. Because of this joint cooperation between projects, the Mariner Project was able to obtain and analyze additional data that enabled the spacecraft to be commanded to successfully perform a Sun-line maneuver resulting in a 99% probability of not impacting the planet Mercury on its third encounter.

Although the DSN coverage support was not completely as planned before launch, the Helios mission objectives were not jeopardized, and the only impact on the Helios Project was a slightly lower science telemetry data return because of 26-m station coverage instead of the planned 64-m stations.

4. Inferior Conjunction

The Helios-1 orbit, relative to the Sun-Earth line was such that the spacecraft passed in front of the Sun (inferior conjunction) and behind the Sun (superior conjunction). As the spacecraft approached the Sun-Earth line, telecommunication was disrupted in the first instance by solar-generated noise causing a grayout and in the second instance by total occultation causing a complete blackout.

The Helios-1 spacecraft entered inferior conjunction on February 17, 1975, when DSS 62 (Spain) first observed the grayout effects. On February 18, the spacecraft crossed in front of the Sun's photosphere (Fig. 34), at which time total telecommunications blackout was observed by both DSS 62 and DSS 12 (Goldstone) and no useful telemetry data obtained. DSS 62 also observed the grayout effects on February 19 as the Helios-1 spacecraft exited the region of the Sun-Earth line.

The DSN had two objectives in mind for collecting as much inferior conjunction data as possible during this period. The first was to improve the data collection procedures; the second was to compile a reliable data base from which to generate predicts on excessive system noise temperature (SNT) vs the Sun-Earth-probe (SEP) angle. Both objectives were met and the information successfully applied to Pioneers 10 and 11 as well as Helios-1 superior conjunctions in March and April 1975.

5. Perihelion Passage

Since the Helios-1 spacecraft would be traversing a heretofore unexplored region of our inner solar system, a 25-day period surrounding perihelion (March 3-27, 1975) was determined to be the region of highest scientific interest. To insure the quantity and quality of the scientific data during this perihelion passage time period, the DSN had scheduled two 64-m antenna stations (DSS 14 at Goldstone and DSS 43 in Australia)²⁷ as the prime DSN stations and the 26-m antenna stations (DSS 12 at Goldstone, DSS 42 in Australia, and DSS 62 in Spain) as backup stations.

On the morning of March 15, 1975, at 09:12:14.7 GMT, the Helios-1 spacecraft reached its closest approach to the Sun (Fig. 51), a distance of 0.3095 AU. The German 100-m antenna at Effelsberg, which was tracking Helios-1 at the time, reported that it was receiving convolutionally coded scientific data at the rate of 2048 bps from the spacecraft, that (1) the telemetry downlink signal level was -141.7 dBm, (2) the telemetry signal-to-noise ratio was 7.8 dB, (3) the solar heat intensity had reached 10.4 solar constants at the spacecraft, and (4) the performance of all spacecraft subsystems was excellent. Throughout the 25-day period surrounding the Helios perihelion, performance of the DSN Telemetry, Tracking, and Command Systems was excellent, and all DSN commitments for Helios data recovery were met.

The Helios-1 spacecraft started its perihelion passage on March 3, 1975, at a distance of 111.6 million km (69,350,000 mi) from Earth and traveling at a velocity of approximately 50.3 km/s (112,518 mph). On March 27, the spacecraft exited the perihelion passage at a distance of 202 million km (125,520,000 mi) from Earth and traveling at a velocity of approximately 74.6 km/s (166,875 mph) and on its way to its first superior conjunction (solar occultation).

The DSN 26-m stations provided 330 h of coverage; the 64-m stations provided 365 hours of coverage; and a total of 2733 commands were successfully transmitted to the Helios-1 spacecraft during the month of March. The downlink telemetry performance recorded by each DSN station during the perihelion passage is provided in Table 13.

Optimizing the performance of the stations supporting Helios during this special coverage period (DSS 12/14/42/43/44/62) was the major thrust of the DSN planning and scheduling effort. Special prepass readiness tests for each prime and backup station were conducted throughout the perihelion period. Full redundancy of station coverage was not practical during this, the major phase of the Helios-1 mission, owing to the significant requirements also placed on the DSN by the Mariner and Pioneer Projects during March 1975. The scheduling of backup stations to provide coverage was planned and did occur when the Mariner Project declared a spacecraft emergency on March 13, 1975. This required 64-m-antenna coverage to ensure that the Mariner 10 spacecraft was in a stable attitude prior to its third encounter of Mercury

²⁷The German 100-m antenna station at Effelsberg, Germany, was providing coverage from the 0° longitude region.

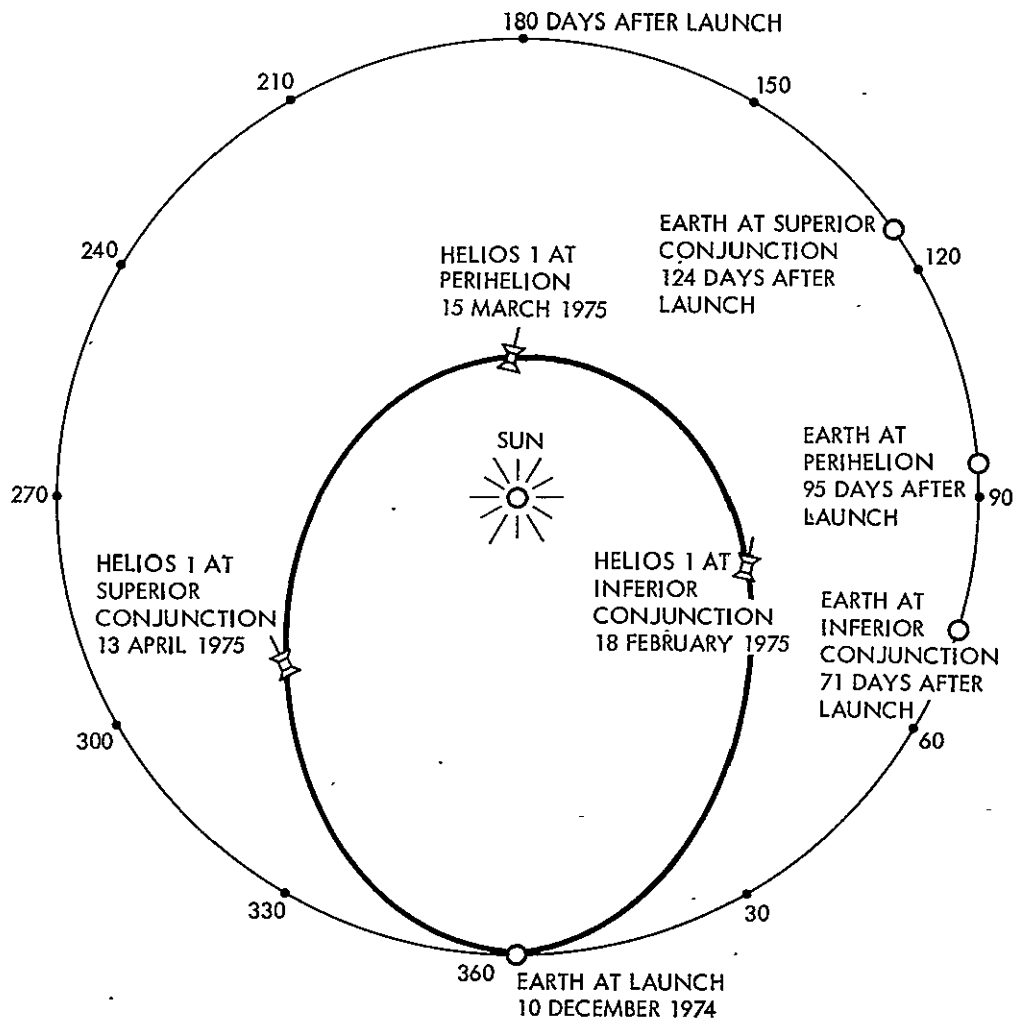


Fig. 51. Spacecraft and earth orbits around Sun

Table 13. Helios downlink telemetry performance for March 1975

Residuals	Spacecraft ANT mode	DSS				
		12	14	42	43	62
Downlink						
Number of observations	MGA		10		11	
	HGA	3	11	7	11	15
Mean, dB	MGA		-0.4		-0.3	
	HGA	1.1	0.7	0.5	0.1	0.6
Sigma, dB	MGA		0.7		0.7	
	HGA		0.4	1.0	0.6	0.6
SNR						
Number of observations	MGA		11		11	
	HGA	3	11	6	11	15
Mean, dB	MGA		0.5		0.6	
	HGA	1.3	0.8	0.8	0.2	0.7
Sigma, dB	MGA		0.5		0.5	
	HGA		0.4	0.8	0.4	0.4
SNT						
Number of observations	MGA		23			
	HGA	3	1	8	22	15
Mean, K	MGA		18.6			
	HGA	30.3	25.7	34.2	23.6	30.1
Sigma, K	MGA		0.4			
	HGA			0.5	0.5	1.0

on March 16, 1975; which was one day after Helios-1 perihelion. All perihelion commitments were met by all elements of the DSN, and the perihelion phase activities were quickly supplemented by those activities relating to the upcoming superior conjunction.

6. Superior Conjunction

As Helios-1 passed through the perihelion region and successfully fulfilled its science criteria from that region of unexplored space, new scientific objectives came into focus as it approached superior conjunction. The primary emphasis during the first Helios superior conjunction was the accumulation of science data for the Faraday rotation and celestial mechanics experiments.

Mission Phase II ended on April 13, 1975, as the spacecraft trajectory reached a Sun-Earth-probe (SEP) angle of 3 deg. On April 25, telemetry blackout occurred at all DSN 26-m stations and lasted until May 23. At the DSN 64-m stations, however, the telemetry blackout was not as severe because of the greater antenna gain factor. As a result, the telemetry blackout at the 64-m stations lasted only from May 2-15, 1975.

The Helios-1 superior conjunction had two periods of interest. The first period of interest was for the radio frequency analytical study by the DSN when Helios-1 would be within 5 deg of the SEP angle. The second was the Project period of interest. The dates of the defined period of DSN analytical and Project scientific studies, encompassing the first Helios-1 superior conjunction, were from April 7 to June 24 and April 13 to June 8, 1975, respectively. This conjunction would not result in a complete spacecraft occultation by the Sun, but the SEP angle would sweep across within 0.43 deg of the Sun's photosphere.

The period of greatest scientific interest was when Helios-1 was within 3 deg of the SEP angle. The dates and degrees of SEP angle are as follows:

SEP, deg	Entry date, 1975	Exit date, 1975
5	4/7	6/24
4	4/10	6/16
3	4/13	6/8
2	4/18	5/29
1	4/24	5/20
0	5/2	5/13

The Helios superior conjunction was highly unusual as compared to previous spacecraft, which were more nearly polar conjunctions. The unique Helios trajectory had an orbital eccentricity of 0.016 deg and offered the Helios Radio Science Team its first opportunity to measure the solar and corona effects upon the radio-frequency (RF) line, which is within the plane of the ecliptic during a superior conjunction.

The Faraday Rotation Experiment (E-12), which was one of the passive radio science experiments for Helios, exhibited an unexpected magnitude during superior conjunction. This phenomenon affected the polarization of the RF link more than had been anticipated and invalidated the DSN's polarization predicts near the station's local meridian. A special polarizer configuration and procedure were implemented at DSS 14 (Goldstone 64-m station) to permit that station's autopolarizer to track the received RF signal completely through 360 deg. This procedure, along with a polarization boresite calibration procedure, removed a potential 180-deg ambiguity in the Faraday rotation data. It is understandable then that stations not equipped with remotely controlled polarizers encountered more difficulties maintaining a correct polarizer setting. Fortunately, biases to correct the polarization predicts could be obtained from the station with an autopolarizer (DSS 14).

The Celestial Mechanics Experiment (E-11), the second passive radio science experiment, was also supported as planned with the Planetary Ranging Assembly (PRA) at DSS 14. Additionally, Celestial Mechanics was also supported by the MU II sequential ranging equipment. This equipment, classified as R&D, was designed to support the Mariner Venus/Mercury 1973 radio science experiments. The experimenter is currently attempting to correlate the PRA and MU II ranging data. Continued investigation of celestial mechanics will be supported during the next Helios-1 superior conjunction.

F. OPERATIONS SUMMARY

With the end of Mission Phase II on April 13, 1975, the Helios-1 spacecraft had successfully completed its first inferior conjunction and perihelion passage and had met its prescribed initial scientific objectives.

The DSN tracking coverage encompassing the Phase II time period between February 10 and April 14, 1975, spans two important periods of the Helios-1 scientific mission phase. The two major Helios-1 events that occurred during this time were inferior conjunction and perihelion. In addition to Helios perihelion, there were also increased Mariner 10 and Pioneer 10/11 activities that occurred simultaneously.

The DSN commitment to provide continuous tracking coverage throughout the Helios Mission Phase II was met. A total of 168 tracks had been scheduled at DSS 12, 14, 42, 43, and 62. The number of actual tracks supported during this time frame was 172. This included demonstration passes at Stations 43 and 44 and two extra tracks at Station 12. One of the extra tracks at DSS 12 was to provide backup commanding when DSS 14 incurred Command System problems. The second additional track at DSS 12 occurred when a Mariner 10 spacecraft emergency was declared. DSS 14, which was supporting Helios at the time of the emergency, was then required to support Mariner 10. DSS 12 was called up to support Helios in real-time, resulting in Helios data outage of approximately 20 min.

The long-range schedule, which had not included plans for a third Mariner 10 encounter of Mercury, had projected 64-m station coverage throughout the 25 days of perihelion coverage. The added requirement to support a third Mercury encounter would result in a loss of 64-m station coverage to the Helios perihelion coverage. When it was ascertained that there would be a third encounter, four Helios 64-m tracks were given over to Mariner, through

negotiations, to ensure a successful finale to the Mariner Project. In total, only six 64-m station tracks were lost to Mariner 10.

On March 24, 1975, Pioneer 11 had a superior conjunction, and Pioneers 10 and 11 were also in a spiral alignment at the same time. During this period, which was equally important to the Pioneer Project, several tracking passes at 64-m stations were shared. Because of the sharing of resources during March to optimize tracking coverage, the DSN was able not only to meet the Helios-1 commitments but also the highly active Mariner and Pioneer Project events of March 1975.

During Mission Phase I and II the DSN transmitted a total of 13,480 commands to the spacecraft. The total percentage of commands transmitted vs the total number of aborted commands (only 6) gives the DSN Command System an outstanding performance achievement rating of 99.99956%. The end of Mission Phase II marked the start of Mission Phase III and first superior conjunction. As the Helios-1 spacecraft continued in its orbit around the Sun the passive experiments became the prime scientific experiments. At the same time, the Phase III support requirements resulted in reduced support activities from the DSN.

VIII. CONCLUSION

In this report the authors have described the overall evolution of the Helios Project from its conception in September 1966 through to the completion of the Helios-1 Mission Phase II on April 13, 1975. The report has discussed the development of this joint U.S./German space project: scientific objectives, international management, planning, telecommunications systems developments, technical and operational interfaces, and testing, together with the activities of the JPL Tracking and Data System. Included also was a discussion of the conflicting support requirements between Helios and other flight projects and the close coordination and cooperation that resulted.

With the completion of Mission Phase II on April 13, 1975, the Helios-1 spacecraft had successfully passed through its first inferior conjunction, its first perihelion passage, and, having met all of its prescribed scientific objectives up to that point, entered its first superior conjunction. With the occurrence of superior conjunction on April 13, 1975, the Helios-1 spacecraft entered into its Mission Phase III or Extended Mission Period.

This volume (the first of three) has dealt with the development of the Helios Project through to the end of Helios-1 Mission Phase II. Volume II deals with the development of the Helios-B (second mission) requirements through to the end of its Mission Phase II. Volume III discusses the support provided by the DSN to the Project for the Mission Phase III of both the Helios-1 and Helios-B.

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GLOSSARY

ACQ AID	Acquisition Aid Subsystem (DSS Mk II)
AFC	automatic frequency control
AFETR	Air Force Eastern Test Range
AGC	automatic gain control
ARC	Ames Research Center (NASA, Moffett Field, California)
ARIA	Advanced Range Instrumentation Aircraft (DOD ETR)
ATRS	Automatic Total Recall System (computer program)
AU	astronomical unit (equal to average distance Earth to Sun 93 million miles)
BER	bit error rate
bps	bits per second
CCAFS	Cape Canaveral Air Force Station
CCB	Change Control Board
CMA	Command Modulator Assembly (DSS TCD)
CMD	Command Subsystem (NOCC, DSS)
CMD	Command System (DSN)
CMOS	Chief of Mission Operations Support
COE	Cognizant Operating Engineer
CP	circular polarization
CP	Communications Processor
CPA	Command Processor Assembly (DSS CMD)
CRT	cathode-ray tube
CVT	Configuration Verification Test
dB	decibel
dBm	decibels referred to 1 milliwatt
DCU	Digital Computer Unit

DDA . Data Decoder Assembly (DSS TCD)

DHE Data Handling Equipment

DIS Digital Instrumentation Subsystem (DSS Mk II)

DL downlink

DOD Department of Defense

DODR Digital Original Data Record

DRVID Differenced Range Versus Integrated Doppler (charged particle measurement)

DSN Deep Space Network

DSS Deep Space Station(s)

DSS 11 Pioneer Deep Space Station, Goldstone Complex, Barstow, California

DSS 12 Echo Deep Space Station, Goldstone Complex, Barstow, California

DSS 14 Mars Deep Space Station, Goldstone Complex, Barstow, California

DSS 42 Weemala Deep Space Station, Tidbinbilla Complex, Canberra, Australia

DSS 43 Ballima Deep Space Station, Tidbinbilla Complex, Canberra, Australia

DSS 44 Honeysuckle Creek Deep Space Station, Australia

DSS 61 Robledo Deep Space Station, Madrid Complex, Robledo de Chavela, Spain

DSS 62 Cebreros Deep Space Station, Madrid Complex, Cebreros, Spain

ECO Engineering Change Order

EDR Experimenter Data Record

FAC Technical Facilities Subsystem (DSS)

FM frequency modulation

FTS Frequency & Timing Subsystem (DSS)

GCF Ground Communications Facility

GDS Ground Data System

GES German Effelsberg Station (near Bonn)

GSFC Goddard Space Flight Center (Greenbelt, Maryland)

GSOC German Space Operations Center, Oberpfaffenhofen, W. Germany
 GTS German Telecommand Station, Weilheim (near Munich), W. Germany
 HA hour angle
 HA-dec hour angle-declination (type of antenna mounting)
 HF high frequency
 HGA high-gain antenna
 HJWG Helios Joint Working Group
 HSD high-speed data
 HSDB high-speed data block
 HSDL high-speed data line
 HSS High-Speed Data Subsystem
 Hz hertz (cycles per second)
 I/O computer input/output device
 ID identification
 KSC Kennedy Space Center (NASA, Merritt Island, Florida)
 LCP left (-hand) circular polarization
 LGA low-gain antenna
 LH linear horizontal
 LOS loss of signal
 LV linear vertical
 MA&O Mission Analysis and Operations
 MCCC Mission Control and Computing Center (JPL)
 MCS Monitor & Control Subsystem (NOCC, GCF)
 MDR Master Data Record
 MECO Main Engine Cutoff (Centaur Vehicle)
 MGA medium-gain antenna
 MILA Merritt Island Launch Area

REPRODUCIBILITY OF THE
 ORIGINAL PAGE IS POOR

MIL 71 Spacecraft Compatibility/Monitor Station, Merritt Island, Florida
 (within STDN MILA)

NASCOM NASA Communications Network (world-wide)

NAT Network Analysis Team

NCS Network Control System (DSN); NOCC implementation project

NEPN Near-Earth Phase Network

NOCA Network Operations Control Area (NOCC)

NOCC Network Operations Control Center (DSN, also STDN)

NOM Network Operations Manager

ODR Original Data Record

OSS Office of Space Sciences

OTDA Office of Tracking and Data Acquisition (NASA)

OVT Operational Verification Test

PCM pulse code modulation

PDS polarization diversity S-band (feed cone or maser)

PM phased modulation

PRA Planetary Ranging Assembly (DSS)

PSK phase-shift keying

RCP right (-hand) circular polarization

RCV Receiver/Exciter Subsystem (DSS)

R&D research and development

REC Recording Subsystem (DSS)

RF radio frequency

RNG Ranging Subsystem (DSS)

RTCF Real Time Computing Facility (AFETR, Cape Canaveral)

SAA S-Band Acquisition Antenna (DSS)

S-band frequency band between 1550 and 5200 MHz

SCA Simulation Conversion Assembly (DSS TCD)

SCOE	System Cognizant Operating Engineer
SDA	Subcarrier Demodulator Assembly
SER	symbol error rate
SIMCEN	Simulation Center
SNR	signal-to-noise ratio (alternate for S:N or S/N used by JPL convention)
SOE	sequence of events
SPD	S-band polarization diversity (feed cone)
sps	symbols per second
SPT	System Performance Test
SSA	Symbol Synchronizer Assembly (DSS TCD)
SSM	second surface mirror
STDN	Spaceflight Tracking and Data Network (GSFC)
STDN MILA	Spacecraft Compatibility/Monitor Station, Merritt Island, Florida
TCD	Telemetry and Command Subsystem (DSS)
TCP	Telemetry and Command Processor (DSS TCD)
TDA	tracking and data acquisition
TDH	Tracking Data Handling Subsystem (DSS Mk II)
TDP	tracking and data processor
TDS	Tracking and Data System
TLM	Telemetry System (DSN)
TRK	Tracking System (DSN)
TTS	Test & Training System (DSN)
TTY	teletype
TWT	traveling wave tube
TWT-A	traveling wave tube amplifier
UL	uplink
UWV	Antenna Microwave Subsystem (DSS)

VCO voltage-controlled oscillator
VCXO voltage-controlled crystal oscillator
VSO very stable oscillator
WB wideband
x-y x axis, y-axis (type of antenna mounting)