NASA CR-151915

(NASA-CR-151915) A HISTORY OF THE DEEP SPACE NETWORK (National Aeronautics and Space Administration) 237 p HC A11/MF A01 CSCL 14B G3/17

N77-14188

Unclas 58935

A HISTORY OF THE DEEP SPACE NETWORK

by

William R. Corliss

May 1, 1976

238

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-151915		

4. Title and Subtitle	5. Report Date
A HISTORY OF THE DEEP SPACE NETWORK	November 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
William R. Corliss	
9. Performing Organization Name and Address	10. Work Unit No.
National Aeronautics and Space Administration Washington, D. C. 20546	11. Contract or Grant No. NASW-2728
	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, D. C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

17. Key Words (Suggested by Author(s))	18. Distribution Statement
	Unclassified - Unlimited Subject Category 17

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	240	

*For sale by the National Technical Information Service, Springfield, Virginia 22151

NOTICE

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FOREWORD

This is a history of the Deep Space Network (DSN) which is managed for NASA by the Jet Propulsion Laboratory located at Pasadena, California. It is a companion document to an earlier historical publication by the same author which dealt with the NASA communications and earth-orbital networks managed by the Goddard Space Flight Center. With publication of the DSN history, each progenitorial segment of today's worldwide NASA tracking and data acquisition network has had the story of its origin and evolution ably committed to the printed page by Mr. William R. Corliss.

In telling the story of the DSN, Mr. Corliss recaptures and summarizes the events and decisions which led to the development of this needed network capability and highlights the network's contributions to NASA's lunar and planetary exploration programs. It is hoped that each reader will gain an appreciation for the role of the dedicated people -- Government, contractor, and host country personnel -- who made the exploration of deep space possible by providing that vital link, communications. Many of you receiving this document, of course, have played roles in creating the Deep Space Network, and I hope in reading it will recall not just the problems but also the many satisfactions that were experienced along the way.

Gerald M. Truszynski
Associate Administrator for
Tracking and Data Acquisition

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PREFACE

This history of the DSN is intended to complement the histories of the MSFN, STADAN, and NASCOM published in 1974 as NASA CR-140390. Eventually, it is planned to update and combine all of these histories and present them as a unified history of NASA tracking-and-data-acquisition activities.

As in the earlier histories, I have tried to capture both the political and technological events of network design and operation since NASA was formed---and a little before. In this middle ground, historians and engineers may each find some lack of detail in their respective disciplines, but I hope I have achieved a happy balance.

William R. Corliss

Glen Arm, Maryland
May 1, 1976

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ACKNOWLEDGEMENTS

In this endeavor many people contributed generously of their time and information resources. Their help is hereby acknowledged.

Bayley, W. H. (JPL)
Belcher, A. C. (HQ)
Binkley, M. E. (HQ)
Brockett, H. R. (HQ)
Bryant, F. B. (HQ)
Fosque, H. S. (HQ)
Goldstein, R. M. (JPL)
Hall, J. R. (JPL)
Hall, R. C. (JPL)
Hamilton, T. W. (JPL)
Latham, Robert (JPL)
Mallis, R. K. (JPL)
Mudgway, D. J. (JPL)
Poore, H. (JPL)
Rapp, R. A.
Rechtin, E. (Hewlett-Packard)
Renzetti, N. A. (JPL)
Stock, R. L. (HQ)
Taylor, C. A. (HQ)
Truszynski, G. M. (HQ)
Victor, W. K. (JPL)

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Chapter 1. DSN OVERVIEW

The Deep Space Network (DSN) has been managed and operated by the Jet Propulsion Laboratory (JPL) under NASA contract ever since NASA was formed in late 1958. The tracking and data-acquisition tasks of the DSN are markedly different from those of the other NASA network, STDN. STDN, which is an amalgamation of the satellite tracking network (STADAN) and the Manned Space Flight Network (MSFN), is primarily concerned with supporting manned and unmanned Earth satellites. In contrast, the DSN deals with spacecraft that are thousands to hundreds of millions of miles away. The radio signals from these distant craft are many orders of magnitude weaker than those from nearby satellites. Distance also makes precise radio location more difficult; and accurate trajectory data are vital to deep space navigation in the vicinities of the other planets of the solar system. In addition to tracking spacecraft and acquiring data from them, the DSN is required to transmit many thousands of commands to control the sophisticated planetary probes and interplanetary monitoring stations. To meet these demanding requirements, the DSN has been compelled to be in the forefront of technology. The fact that the DSN has met or exceeded the demands of flight projects illustrates that it has done its job very well indeed.

The very excellence of the DSN's radio "ears" has been an unexpected boon to radio astronomy. The big, high-precision parabolic antennas in the United States, Australia, and Spain attract radio astronomers who generate many more requests for antenna time than the DSN can possibly fill. Thus, the DSN has made a significant contribution to ground-based radio science which is above and beyond the unique accomplishments of the Mariners, the Surveyors, the Pioneers, the Vikings, and other deep-space vehicles.

The concept of a special network to support spacecraft beyond Earth orbit is scarcely two decades old. Even in the mid-1950s it was "blue-sky", to use the terminology of those days, to contemplate even lunar probes. No one dreamt seriously of spacecraft cruising past the moons of Jupiter, photographing Mercury's surface, or landing on Mars. The forward-looking technology of the DSN has contributed to making these more ambitious ventures possible.

Chapter 2. PRE-NASA TRACKING DEVELOPMENTS AT JPL

Missile Testing and Lunar Probes

Several technical accomplishments that are cornerstones of the present DSN evolved while JPL was working under the auspices of the U.S. Army. To understand the impetus that spawned the crucial phaselock loop, the low-noise-temperature receivers, and the basic plans for a deep space tracking and data acquisition network, the aerospace political environment of the 1940s and 1950s must be recapitulated briefly at this point.

Although the German V-2 had failed to turn the tide during World War II, its technical success made it obvious to military planners that long range rockets had an important place in future warfare. In 1944, even before hostilities ceased, GALCIT [1] was developing the Private-Corporal-Sergeant series of surface-to-surface ballistic missiles under U.S. Army contract. The WAC Corporal sounding rocket was also first tested in 1945. [2] The testing and deployment of the Sergeant missile ran well into the 1950s and, while the Sergeant was not a deep space probe, the radio guidance ideas developed during its evolution fed directly into DSN technology.

The pace of missile development picked up rapidly in the early 1950s when it seemed that the Russians not only had nuclear weapons but were also building big rockets for delivering them across intercontinental distances.

JPL was introduced to the Earth satellite business during Project Orbiter, [3] the DOD-sponsored plan to launch an American satellite using an ABMA Redstone booster and JPL upper stages. Orbiter was ostensibly shelved when the Navy's Project Vanguard was chosen as the official U.S. satellite program for the International Geophysical Year (IGY). Orbiter did not die, however, and when Vanguard faltered, ABMA and JPL were quickly able to launch Explorer 1. To track Explorer 1, JPL had built the Microlock network of doppler-telemetry stations in the late 1950s. In this manner, JPL acquired its first taste of network development and operation.

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[1] GALCIT (Guggenheim Aeronautical Laboratory, California Institute of Technology) was JPL's immediate predecessor. It was founded in 1936 by Theodore von Karman.

[2] William R. Corliss, NASA Sounding Rockets, 1958-1968, A Historical Summary, (Washington: NASA SP-4401, 1971) p. 9.

[3] R. Cargill Hall, "Early U.S. Satellite Proposals," Technology and Culture, IV (Fall 1963), pp. 410-434.

Completing the JPL historical sequence leading from small missiles to deep space vehicles were the lunar probes Pioneer 3 and 4.[4] These probes went well beyond the practical range of Microlock and Minitrack, the two extant U.S. satellite tracking networks. The ARPA (Advanced Research Projects Agency)[5] which funded the Pioneer Program, recognized that a new kind of tracking network would be needed for space vehicles that went far beyond the Earth. In fact, ARPA Order No. 1 provided for the establishment of a three-station deep-space network designed by JPL. Called the ARPA Network or World Network, it was the direct forerunner of today's DSN, although it was not completed under ARPA auspices.

Significant Technical Developments

Before JPL was transferred from the Army to NASA in 1958, military programs had already sparked many technical developments crucial to the later DSN. Some of the more important of these are reviewed below.

The Phase-Lock Loop. The phase-lock loop is essentially a way to maximize the efficiency of a communication system through the use of *a priori* knowledge. To illustrate, knowledge of the transmitter frequency of a deep space probe makes communication with it much easier. The concept of the phase lock loop is much more involved than this, but it also employs *a priori* information. The interested reader is referred to two key papers by JPL personnel for details.[6] The use of a phase lock loop as a narrow band tracking filter was first suggested by Lehan and Parks of JPL in early 1952[7] for use in the Corporal missile program. In 1953, Rechtin and Victor developed a phase lock loop as a narrow bandwidth tracking filter with optimum performance over a wide range of signal-to-noise ratios. In simple terms, the phase lock loop provided a very efficient method of detecting and following narrow-band radio-frequency signals from a distant spacecraft despite the presence of inescapable wideband noise from the cosmos, the Earth itself, and the communication equipment. The phase lock

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[4] Pioneers 1, 2 and 5 were Air Force lunar probes. JPL was not involved directly.

[5] Founded by DOD on February 7, 1958, in response to President Eisenhower's declaration that the United States would have a space program.

[6] R. M. Jaffe and E. Rechtin, "Design and Performance of Phase Lock Circuits Capable of Near Optimum Performance Over a Wide Range of Input Signal and Noise Levels," *IRE Transactions*, IT-4 (March 1955), pp. 66-76. H. L. Richter, Jr., et al, "Microlock; A Minimum-Weight Radio Instrumentation System for a Satellite," *Jet Propulsion*, XXVIII (August 1958), pp. 532-540.

[7] Anonymous, "A History of the Deep Space Network to 1 January 1969" **(Pasadena: JPL 890-9, January 15, 1971) p. 5-2.**

loop, though not conceived for deep space operations, turned out to be nearly ideal for such applications.

The first space program manifestation of JPL's phase-lock-loop concept was the already-mentioned Microlock doppler tracking and data acquisition system, which was initially developed primarily for ABMA's Jupiter-C Reentry Test Vehicle (RTV) shots. Microlock's most important application was on the Army's Explorer 1 flight, where it successfully tracked the first American satellite. (Figure 2-1)

Microlock's approach to tracking was primarily recovering doppler velocity data and in this respect differed from the Navy's Minitrack tracking network set up all over the world to track the Vanguard IGY satellites. When NASA inherited both Microlock and Minitrack in 1958, it retained the latter and dismantled the few Microlock stations that had been established. The phase lock loop, which was not a part of Minitrack, was retained however and applied to all subsequent JPL spacecraft as well as Apollo and some missions not managed directly by JPL. The phase lock loop innovation was and still is a vital contribution to the U.S. space program.

CODORAC and S-Band Precursors. In addition to the phase-lock-loop feature just described, JPL's basic tracking and data acquisition technology includes two other important characteristics: (1) the regeneration by the spacecraft of the carrier received from the Earth and its subsequent multiplication by an integral fraction and transmission back to Earth; and (2) the melding of the tracking data and telemetry onto a single spacecraft carrier. Both of these characteristics were part of a radio guidance system that JPL designed in 1954 as an alternate guidance system for the Sergeant missile. One version of the JPL Sergeant guidance system was to be a combination radio-inertial type operating in the X-band around 10,000 MHz. The Doppler radio equipment supplied range and velocity information; the inertial portion provided on-board acceleration data. Another version under development was the all-inertial guidance system. Ultimately, the Sergeant used an all-inertial guidance system, but the concept of combining tracking information and telemetry on the same carrier was carried over to the present Unified S-band system used in the DSN.

The JPL guidance system for Jupiter incorporated a specific version of the technical advances described above in a system named CODORAC (Coded Doppler, Ranging, and Command). CODORAC possessed antijamming features as befitted its military application.[8] Many of the CODORAC tracking and command system were incorporated on the Rangers and later JPL spacecraft. CODORAC operated in the X-band---a frequency realm now being explored by the present DSN for operational use. A prototype built at White Sands (Figure 2-2) included a 4-ft antenna mounted on a Nike pedestal. This

[8]Jet Propulsion Laboratory, "Annotated History of CODORAC," (Pasadena; JPL Report 20-120) August 4, 1958.

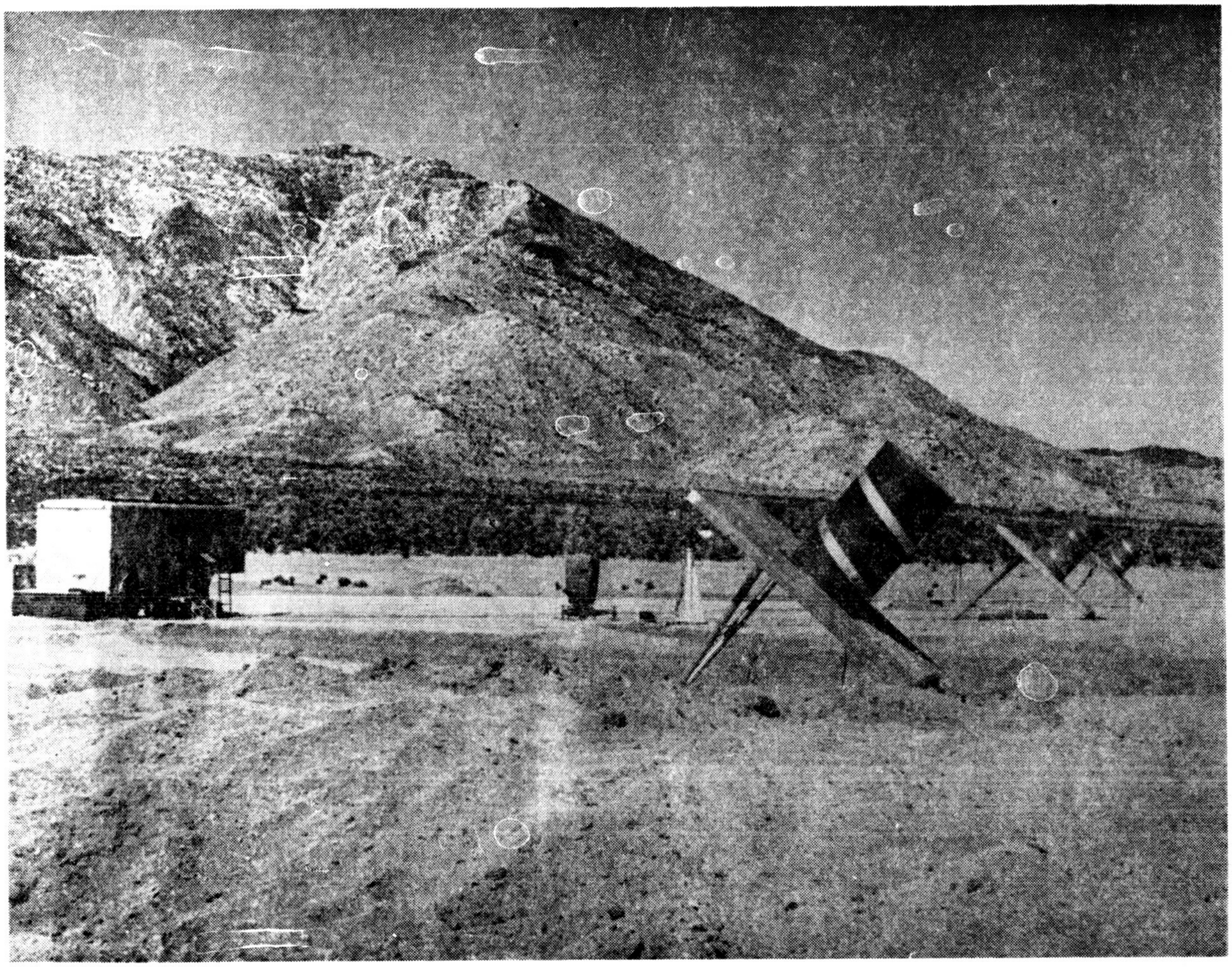

Figure 2-1. Microlock interferometer station at Earthquake Valley.

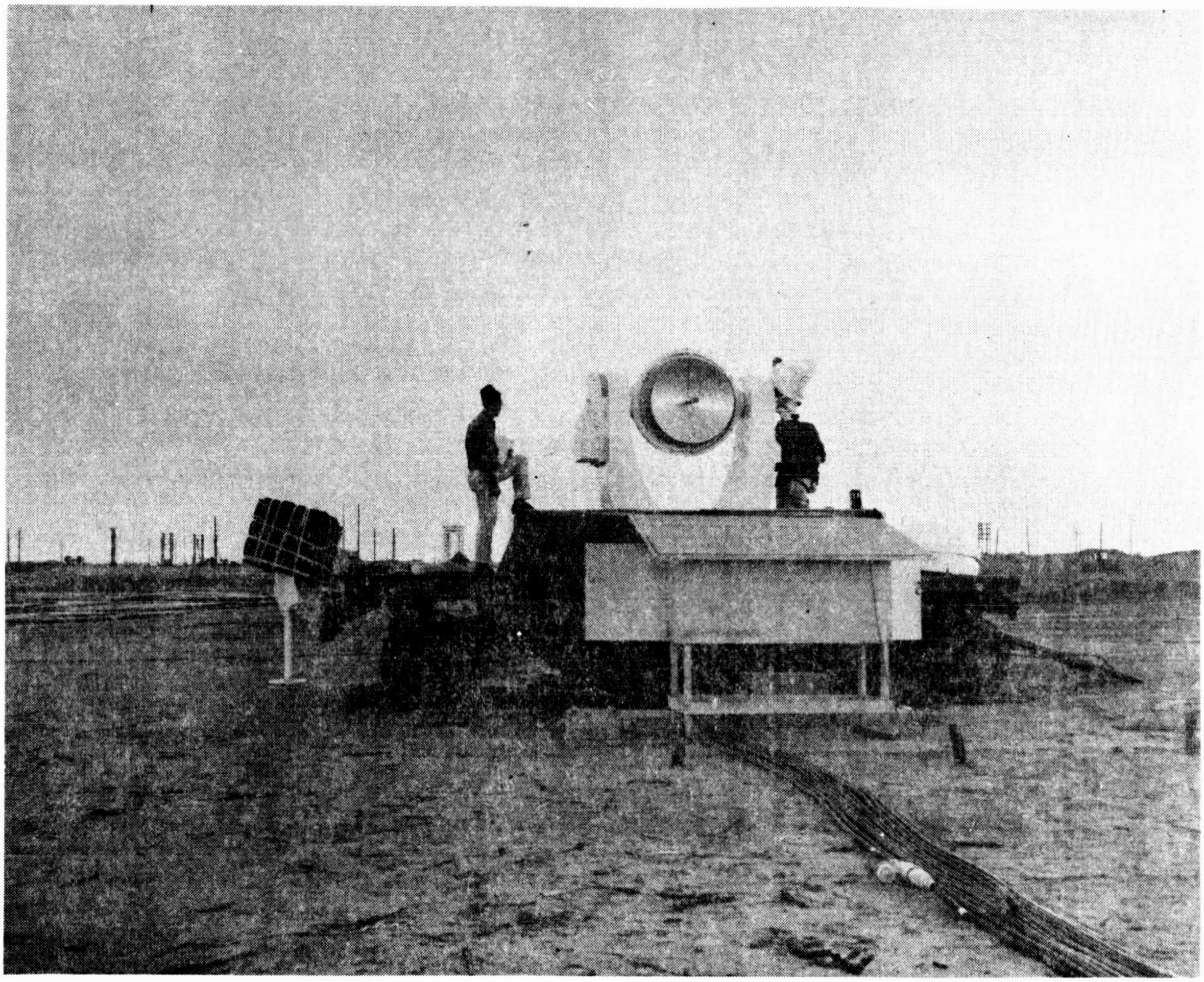

Figure 2-2. The CODORAC antenna.

equipment never saw operational use with Jupiter, but the pedestal was later used in the DSN's Mobile Tracking Station (MTS).

Low-Noise Receivers. One of the great technical challenges of deep space communication is receiving signals from a severely weight-limited spacecraft millions of miles away. The weight limitation forces spacecraft designers to minimize the radiated power from the craft's transmitter. The communication burden is therefore placed upon the ground systems which must recover an extremely weak signal nearly overwhelmed by noise. Two of the several ways to improve the signal-to-noise ratio are by radically narrowing the receiver bandwidth and reducing the amount of noise generated in or entering the terrestrial receiver.

In 1958, when faced with the task of communicating with Lunar probes, JPL was already working on bandwidth reduction using the phase-lock principle. The problem of low-noise receivers had been under attack for several years. JPL's Walter Higa was working on parametric amplifiers as early as 1935 and in 1956 published an internal memo entitled "Theory of a Low-Noise Amplifier." Despite these accomplishments, it was realized that neither the parametric amplifier nor the maser amplifiers could be made operational before the first Pioneer lunar probes. Nevertheless, this early research has paid off handsomely, because over the years the system noise temperature of DSN receiving systems has been reduced from 1500°K in 1958 to less than 20°K at zenith today.

Of course, the noise problem can also be relieved by improving the power output and efficiency of the spacecraft transmitter. Today, this is accomplished through the use of travelling wave tube (TWT) transmitters on the spacecraft. In 1958, though, TWTs were still in the development stage and spacecraft designers had to contend with a low-power, somewhat inefficient gridded vacuum tube.

Ground Communication and Control. The early missile communication and control systems were crude indeed compared with today's world-wide, wide-band, real-time networks linking tracking stations with centralized control facilities. It is hard to imagine a modern space project depending upon 60 word-per-minute teletype circuits, analog telemetry, and mechanical desk calculators; yet, such was standard equipment through most of the 1950s.

The keys to the modern transformation of data handling were several:

1. The advent in the mid 1950s of reliable, solid-state, digital processing equipment, including large, general-purpose computers.

2. The replacement of low-capacity teletype links with high-capacity, wide-band microwave links as well as better land lines and undersea cables.

3. The development of digital techniques that permitted one to transmit all kinds of information, including TV and voice, all in digital form.

JPL was in the vanguard of this revolution of information processing. One of its major accomplishments was the construction of the first digital tracking system in 1955 for the Sergeant's Doppler ranging system.

JPL also promoted the use of PCM (pulse code modulation) systems long before they became standard in space technology. (Of all the common modulation schemes PCM is most compatible with digital techniques and computers.) Originally, the emphasis was on both FSK (Frequency Shift Keying) and PSK (Phase Shift Keying), but in the early 1960s, PSK assumed prominence because it offered a 3-db performance improvement.

In November 1958, JPL completed its first communication network connecting its tracking sites with a central computing and communication center at Pasadena. This center was the forerunner of today's SFOF (Space Flight Operations Facility). First established in January 1956, the center was also employed during the Explorer-1 flight in January 1958. Communication in those days was simply a temporary patchwork of telephone and teletype lines from the Microlock stations to Pasadena. (Figure 2-3) The Explorer-1 control room was just as primitive, consisting of the communication terminal, timing equipment, office furniture, and hand calculators for data processing and orbit computations.

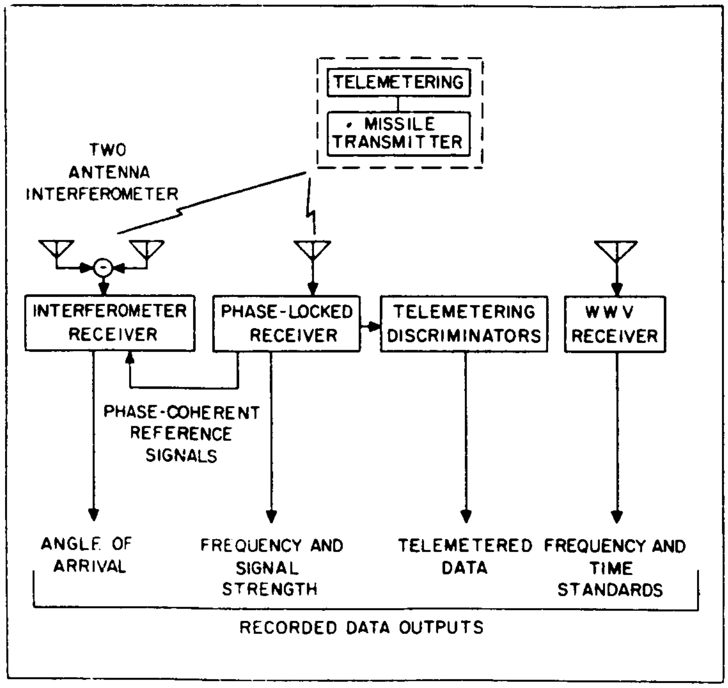

Figure 2-3. Block diagram of Microlock system.

Choice of Radio Frequency. Ever higher transmission frequencies have been one of the more notable trends in the evolution of the DSN. Generally, the higher the frequency, the less the crowding of the radio spectrum and the less the interference from natural and man-made noise. Although JPL realized this and had already acquired substantial experience with the higher frequencies in its Army missile work where weight was not critical, it was forced to use 108 MHz for Explorer 1 and Microlock because of the international agreement regarding IGY satellite transmissions. [9] Within a few months of Explorer 1, however, JPL had moved into the L-band (around 960 MHz) for the Pioneer lunar probes. This was the first of the major quantum steps upward in frequency. JPL realized that S-band frequencies near 2300 MHz had many advantages and was pushing this technology as fast as it could.

Geodesy, Timing, and Frequency Standards. Modern precision tracking of spacecraft depends upon accurate time synchronization of all network stations as well as the availability of precise geodetic coordinates for station locations. Although these factors represent a significant facet of DSN history, their real importance was appreciated by only a few in the 1950s. The importance of Explorer 1, after all, was the simple fact that the United States had finally orbited a satellite and, to a lesser extent, in the scientific data returned. Precise knowledge of Explorer's orbital parameters was secondary. Consequently, tracking station locations were considered to be determined accurately enough by conventional surveying techniques. The requirement for time synchronization was satisfied by the transmissions of WWV (the government station broadcasting time signals). The Microlock network had no atomic or other precise frequency standards.

Radiometric Tracking Theory. When the Space Age began, radiometric tracking theory was being formulated by the astronomers, who customarily measure the angles of their targets rather than distances and radial velocities, as the DSN now does. The orbital calculations for artificial satellites were not far different from those commonly made for our natural satellite, the Moon. The Minitrack satellite tracking network was based on interferometry, which measured the angles the astronomers were used to. The military used Doppler tracking extensively on its missiles, as the Germans had with the V-2s, and this work was applied to the early Explorer satellites using Microlock doppler data. However, the early Explorer satellites as well as Pioneers 3 and 4 employed only one-way doppler tracking; that is, only one radio-frequency link was established between the spacecraft and ground station---usually the flight-to-ground link---and oscillator drifts could not be separated from spacecraft velocity changes. Beginning with the Ranger program, two-way doppler tracking was introduced to eliminate this problem. Space probes, it turns out, are quite different from Earth satellites in terms

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[9]The 108-MHz frequency was state-of-the-art for light-weight, solid-state technology at this time. Note that the Soviet Sputniks violated this agreement by going to lower frequencies.

of radiometric tracking. Once a probe is in deep space, it scarcely moves against the background of fixed stars; and angle tracking is therefore of little practical use. The significance of this short aside is that, in 1958, the modern theory of the radiometric tracking of deep space probes was not understood at all. It was not until 1965, in fact, that today's radiometric tracking techniques were fully appreciated and applied in the DSN.

The Early JPL Networks

Before becoming part of NASA's space effort on December 1, 1958, JPL had helped establish two tracking and data acquisition networks; (1) Microlock, and (2) the deep space network used for the Pioneer-3 and -4 flights, which was called TRACE (Tracking and Communication Extraterrestrial). Under ARPA's direction, it had also looked at the future of deep space flight and, in consequence, had also proposed a worldwide tracking network that eventually became NASA's DSN. The proposed worldwide network, vintage 1958, was variously called the "ARPA Network" or the "World Network." Because networks, with their requirements for time synchronization, precise geodetic location, and ground system standards, require a fundamentally different technical approach than isolated tracking stations, both will be discussed here as being similar species.

Microlock and TRACE were designed for missiles and space probes, respectively, but they employed similar techniques. Microlock, like its contemporary Minitrack, did use radio interferometry in addition to doppler tracking but the interferometry was not intrinsic to the Microlock concept, which was telemetry plus doppler tracking. TRACE depended upon angle and Doppler tracking. Microlock, despite its original missile orientation, ultimately saw service not only on the early Explorer launches but also, to a very limited extent, on the early phases of the Pioneer flights. Neither Microlock nor TRACE survive intact today; the only remnant of TRACE is the old Goldstone DSN Pioneer dish, but Goldstone is the hub of the modern DSN. In actuality Microlock was a dead-end offshoot of CODORAC technology; and it was the CODORAC line that led directly to TRACE.

The Microlock Network

The most important part of the Microlock ground station was the phase-locked receiver which detected the spacecraft's transmitter signal and provided for the automatic tracking of the Doppler shift as the spacecraft passed over the station. The phase-locked receiver sent a phase-coherent reference signal to an interferometer receiver which permitted correlation detection of the signal received from the elements of the interferometer. This arrangement was very similar to that devised by the radio astronomers.

The helical Microlock ground antennas were usually arrayed linearly for rocket launch tracking and in a five-element cross (Figure 2-4) for satellite tracking. The two-dimensional 90° cross, of course, resulted in more

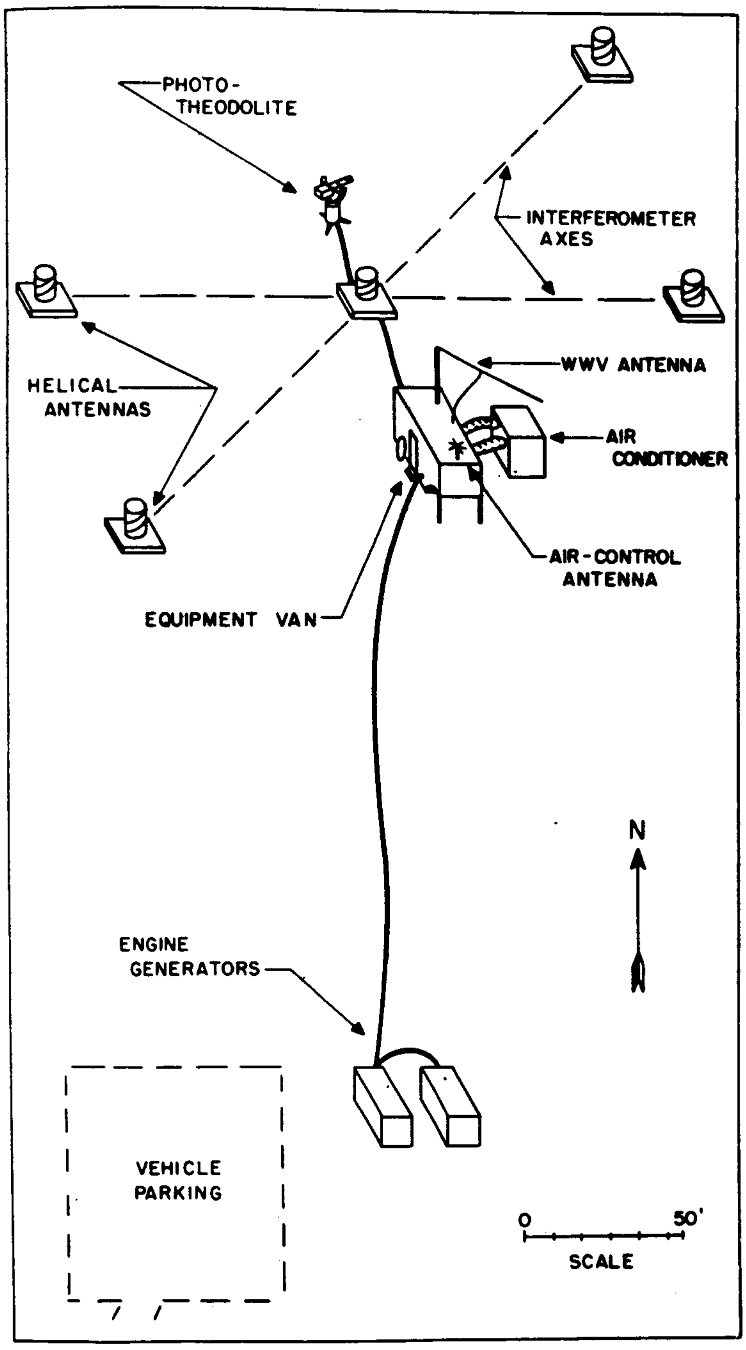

Figure 2-4. Arrangement of Microlock ground station.

tracking information than the simple linear array. (Minitrack interferometer elements were also placed in a cross array.) A typical Microlock tracking site used for satellite tracking is shown in Figure 2-5. A 25-foot equipment van, similar to those used by furniture movers, housed all of the necessary electronics, recorders, timing equipment, consoles, etc. These stations were easily transportable from one site to another, giving Microlock the flexibility needed for a variety of missile applications, its primary purpose for being.

The initial deployment of Microlock was keyed to the Jupiter missile and its reentry test vehicle (RTV) program. The first operational stations were placed at Cape Canaveral and on Grand Turk for the RTV flight in September 1966. In late 1958, four Microlock stations were set up for Explorer at the Cape, Earthquake Valley, California, the University of Malaysia, Singapore, and University College, Idaban, Nigeria. Communication of spacecraft telemetry and tracking data from these overseas sites was often rather primitive. Teletype facilities were usually nearby but it was sometimes necessary to press native runners into service between the Microlock hut and the local telegraph office. The station in California was of the interferometric cross type; that at Cape Canaveral consisted of a linear array of antennas. All overseas Microlock stations used a single helical antenna and provided telemetry and doppler data only.

The Air Force decided to use Microlock for its Pioneer lunar probe flights. As mentioned earlier, however, the Microlock stations were designed at the IGY frequency of 108 MHz, whereas the Pioneers would be transmitting at about 960 MHz. Consequently, some of the Microlock stations were converted to the higher frequency. The Air Force, for example, converted its Microlock station at Jodrell Bank, England, to the higher frequency and monitored signals from Pioneer flights with it. Other Microlock sites listened to Pioneer transmission on an informal basis.

Microlock could track anything passing overhead as long as it carried a suitable transmitter. Thus, Microlock was able to track Vanguard and other Explorer-class satellites that were launched after the Army Explorer program terminated. Limited use of Microlock was also made during the Army and Air Force Pioneer programs with stations that had been converted to 960 MHz. Minitrack, however, became the official NASA satellite tracking system, and all Microlock sites were deactivated soon after JPL was acquired by NASA.

Microlock Operations. Microlock was associated primarily with firings of the Jupiter-C, which had upper stages designed by JPL. The first Jupiter-Cs carried reentry test vehicles. At high altitudes, the upper stage fired a test vehicle into the atmosphere at high velocities to test heat shields at ICBM reentry velocities. Three reentry test vehicle flights of the Jupiter-C occurred on September 26, 1956, May 15, 1957, and August 8, 1957. (The last two flights employed no downrange Microlock stations, just the one at the Cape.)

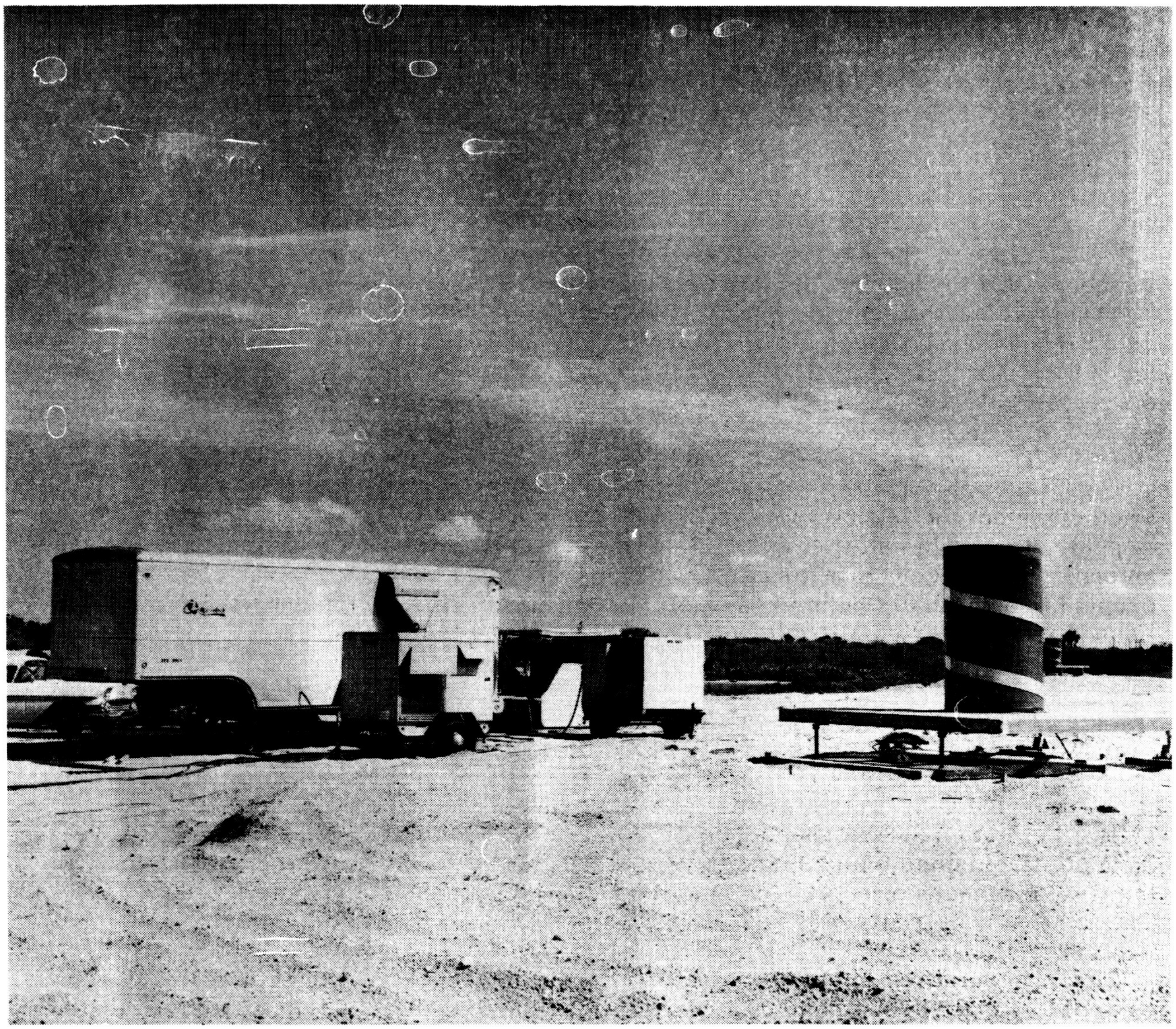

Figure 2-5. Microlock helical antenna with supporting ground equipment.

The five Army Explorer launches took place on January 31, 1958, March 5, 1958, March 26, 1958, July 26, 1958, and August 24, 1958. The second and fifth flights were failures, but the other three put spacecraft into Earth orbit where they were successfully tracked by both Microlock and Minitrack.

TRACE

TRACE, the first operational deep space network, was not worldwide in scope. All three TRACE stations (Goldstone, Cape Canaveral, and Mayaquez, Puerto Rico) were in the Western Hemisphere and could not provide 24-hour surveillance of the spacecraft. This was of course recognized, and ARPA purchased the other two 26-m antennas needed for continuous coverage, but they could not be installed in time for Pioneers 3 and 4.

The two purposes of the TRACE station at the Cape were: (1) to provide preflight checkout of the spacecraft radio equipment, and (2) to determine whether or not the launch was successful on the basis of telemetry and one-way Doppler data. This station was a simplified version of the Goldstone 26-m antenna station, consisting only of a narrow-band, phase-lock receiver channel coupled to a manually pointed paraboloidal antenna. This equipment was housed in a converted Microlock trailer located near the Pioneer-3 launch pad.

During the 6 to 8 hours after the launch of a Pioneer, while the spacecraft was gaining altitude and could not yet be seen from Goldstone, all tracking and data acquisition was relegated to a TRACE station located in Puerto Rico. (Figure 2-6) This station was a fully mobile model of the Goldstone station but with a 3.3-m paraboloid on a Nike Az-El pedestal rather than 26-meter Goldstone type. Since the probe was still close to the Earth during the first few hours of flight, the smaller antenna had adequate sensitivity. This station acquired Az-El angle data, one-way Doppler, and telemetry.

To build the Puerto Rico station, JPL engineers took the old CODORAC Nike pedestal out of mothballs and replaced the small X-band antenna with the 3.3-m dish.[10] The receiver likewise consisted of existing CODORAC components. These components were assembled into the station receiving system by the Collins Radio Company. JPL took over an abandoned Air Force radar site near Mayaguez and placed the antenna under a radome atop a two-story building. Looking beyond Pioneer a bit, it is interesting to note that much of the Puerto Rico equipment again saw service in South Africa as part of the Mobile Tracking Station (MTS) that was situated near Johannesburg for several years.

The third station in TRACE, Goldstone, is the hub of DSN operations as well as network research and development. A longer dissertation is in order here.

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[10] R. K. Mallis and Robert Latham, personal interview, July 28, 1975.

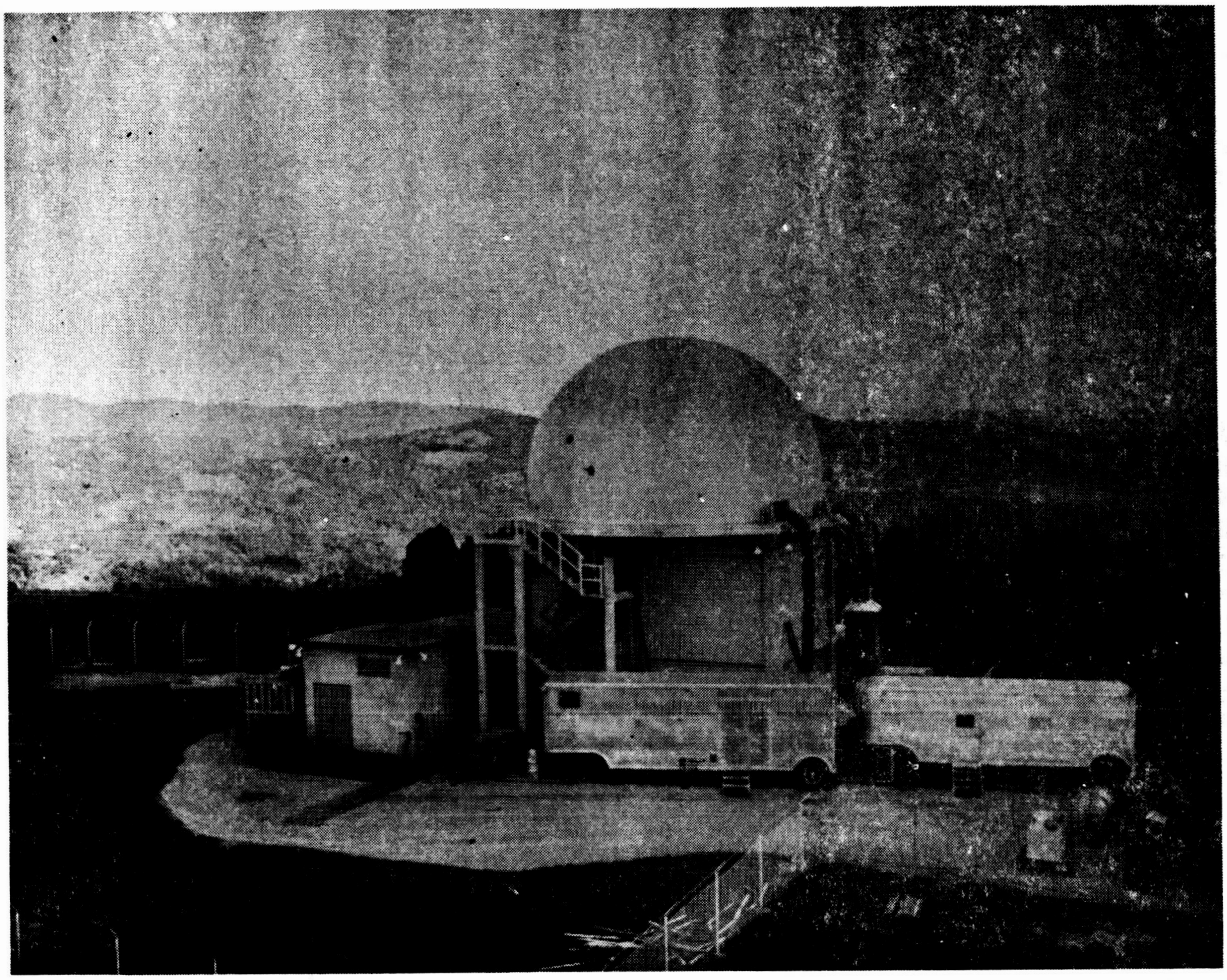

Figure 2-6. The Puerto Rico station.

Building the Goldstone Station

Goldstone is the direct result of the ARPA decision in the spring of 1958 to launch several lunar probes by the end of 1958. [11] The Army was instructed to launch two of these spacecraft using its Juno-II launch vehicle, which had been developed at ABMA. The Army naturally turned to its long-time contractor, JPL, for the payloads and the tracking and data acquisition facilities in its portion of the newly founded Pioneer Program. [12]

The flight paths of the lunar probes required, at the very least, a tracking station at the Cape during the launch phase, another in the vicinity of Puerto Rico for the near-Earth phase as the spacecraft appears to move in a retrograde path climbing away from Earth, and one deep space station to track the probe on its way to the Moon. [13] The third station could have been placed almost anywhere in the United States, but it made sense to locate it in the radio quiet of the California desert where it was within relatively easy reach of JPL personnel.

JPL had only about eight months to select a site, build an antenna, and set up the requisite communication circuits. There was little time for detailed site surveys. Fortunately, the Army owned considerable property in the Mojave Desert, and it was easy to find adequate space for a tracking station. The chosen site was a natural bowl, rimmed by hills, at Goldstone Dry Lake on the Army's Fort Irwin military reservation. It was in this general area that GALCIT had conducted Army rocket tests years before and the region was therefore not unknown to JPL personnel. The site was approximately 40 miles from Barstow, California, and only 100 air miles from Los Angeles. The ring of hills around the site helped shield it from man-made radio noise---an essential feature for receiving the very weak radio signals from the Moon, 240,000 miles away.

The key piece of equipment required at Goldstone was a large paraboloidal antenna for tracking and data acquisition. Communication with lunar probes, from the standpoint of signal strength, had to be via a very-narrow-beam antenna located on Earth. The narrower the antenna beam, the more sensitive the antenna is to signals from a spacecraft caught in the beam. With just a few months of time available, JPL had to take two crucial steps:

1. Find an already designed, very large paraboloidal antenna that could be erected quickly.

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11 William D. Merrick, et al, "Deep Space Communication," (Pasadena: JPL TR 34-10, 1960) p. 1.

12 Note that the Air Force was also requested to launch Pioneer lunar probes with its Thor-Able rockets.

13 Three deep-space stations roughly 120° apart in longitude are needed for complete 24-hour tracking, but there was obviously no time to negotiate and construct overseas sites for Pioneer.

2. Increase communication frequencies to several times the 108 MHz selected for Microlock. The low Microlock frequencies were suitable for nearby Earth satellites but not deep space communication because of the excessive noise at the lower frequencies. From the standpoint of antenna design, the higher the frequency, the narrower the antenna beam, for an antenna of fixed diameter.

Taking the frequency question first, frequency could not be raised arbitrarily. The most important restriction here was the lack of reliable components at higher frequencies, for both spacecraft and ground use. Using techniques developed during its Army missile work, JPL quickly produced spacecraft transmitters and ground-based receiving equipment that could operate reliably at 960.05 MHz, the frequency finally selected for the Pioneer Program.

The frequency of 960 MHz was well suited to the paraboloidal antennas being constructed for radio astronomy, a scientific discipline that had expanded apace during the 1950s. In fact, the demand for large antennas as research instruments was so strong that the Blaw-Knox Company had a 26-m (85-ft) diameter, polar-mounted radio-astronomy antenna that could be built within six months at a fixed price. This was a most fortunate development. Without such an antenna, the Pioneer communication problem would have been insurmountable as the spacecraft left the Earth far behind.

To illustrate how good the luck was, the antenna being considered for Goldstone had been under development for more than five years. Work had started at the Naval Research Laboratory, but assists had come from the Carnegie Institute, Associated Universities, and the Blaw-Knox Company. Of course, the antenna was designed for radio astronomy and not the precision tracking of spacecraft. It had a sidereal drive and no capacity for automatic tracking and the provision of angular pointing data. Here again, JPL's considerable experience in radio guidance came to the rescue. Based on its confidence in JPL, ARPA decided to purchase three of the 26-m dishes; one for Goldstone and the other two for overseas tracking sites that were going to be established eventually. It was a calculated risk on ARPA's part, for even though the antenna design was complete, none had yet been built. With its stipulated launch schedule, ARPA had little choice.

JPL moved ahead with the design modifications. First, a closed-loop, continuous tracking device had to be installed. This was to keep the spacecraft always in the pencil-like beam of the antenna. A second modification was the provision of an electrical feed capable of receiving the signal for the angle-tracking receiver and servo control system. Pointing angles had to be digitized so that they could be teletyped to a waiting computer in Pasadena for trajectory computations. Finally, the antenna had to be "ruggedized" to operate continuously for many hours under high desert winds and temperatures.

Construction began at Goldstone in June of 1958. (Figure 2-7) Antenna assembly commenced August 16. By early December, both the antenna and ground support facilities were complete. Pioneer 3 was launched December 6, 1958.

Figure 2-7. The Pioneer antenna at Goldstone in 1959.

The ARPA or World Network

Before NASA was created, ARPA was planning to expand TRACE into a truly worldwide network for the exploration of deep space. Indeed, plans for the World Network were well under way when NASA came along in late 1958. JPL had already completed a proposal for the new network.[14] The two overseas stations were proposed for Luzon, the Philippines, and Nigeria, Africa, based solely for optimum coverage. ARPA approved this plan as part of its Order No. 1.

In July 1958, however, Donald Quarles, from DOD, questioned the utility of the proposed network sites in terms of maximum utility to all U. S. space programs. JPL was asked to review station placement in this light. The resultant study[15] indicated that better orbital coverage for all planned U. S. space missions would be possible if the Nigerian site were moved north to southern Portugal or Spain, and the Philippine site south to south central Australia. In particular, the coverage of orbits of inclination 34° to 51° would be much improved. Future manned flights were obviously much on the minds of the mission planners at this stage. Interestingly enough, major DSN stations are now located precisely where this report suggested. ARPA never had the opportunity to completely deploy its deep space network because NASA arrived on the scene just before the launch of Pioneer 3. NASA ultimately acquired and installed the remaining ARPA-procured equipment.

JPL Moves to NASA

President Eisenhower's Executive Order 10783 officially established NASA on October 1, 1958. JPL's transfer from the Army came almost immediately, on December 3, 1958, with Executive Order 10783 as the authorizing vehicle. The Army held onto the von Braun team at ABMA until July 1, 1960.[16]

The formation of NASA did not constitute a break in the nation's space program, it was primarily a transfer of authority and funding. Instead of an Army contract, JPL now worked under a NASA contract. Thus, NASA inherited JPL's experienced personnel, its facilities (including Goldstone), as well as JPL's vision of a worldwide tracking network for deep space probes. NASA's plans for JPL were in keeping with this vision, and the concept of the World Net survived the political upheavals of 1958 intact.

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[14] Jet Propulsion Laboratory, "Description of World Network for Radio Tracking of Space Vehicles, (Pasadena: JPL Publication No. 135, July 1, 1958).

[15] Jet Propulsion Laboratory, "The ARPA Network," (Pasadena: JPL TM 39-9, 1958). (This report was never found in declassified form. It is frequently referenced in other source material!)

[16] Robert L. Rosholt, "An Administrative History of NASA, 1958-1963," (Washington: NASA SP-4101, 1966).

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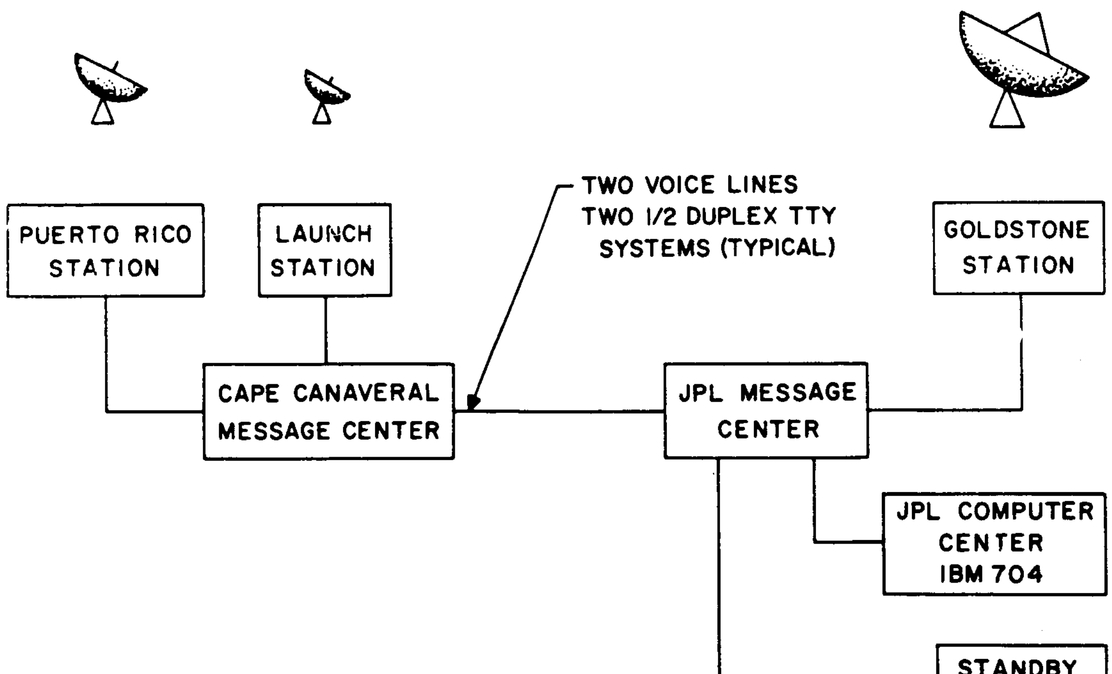
During the Pioneer flights, the feed for the 26-m paraboloid was of the simultaneous lobing type, using four circularly polarized turnstile radiators. The calculated maximum range at which the 200-mw Pioneer signal could be heard (i.e., unity signal-to-noise ratio) was approximately 1.8×10^6 km. (Figure 3-1) (It will be most interesting to compare the above performance figures with those attained by the DSN at later stages of development.)



STATION CAPABILITIES

STATION	RANGE CAPABILITY (FOR 200 mw)	FUNCTIONS
LAUNCH	10^5 km	TELEMETRY, DOPPLER
PUERTO RICO	1.6×10^5 km	TELEMETRY, DOPPLER ANGLES 0.1 - 1° ACCURACY
GOLDSTONE	1.8×10^6 km	TELEMETRY, DOPPLER ANGLES .01 - .1 ACCURACY

Figure 3-1. Capabilities of tracking network for Pioneers 3 and 4.

The ground communication circuits (Figure 3-2) consisted of fulltime voice and 60 word-per-minute teletype links. For most stations it was possible to establish trunk tie-lines with administrative exchanges already existing in the areas. Contact with the Puerto Rico station was through a submarine cable along the AMR.

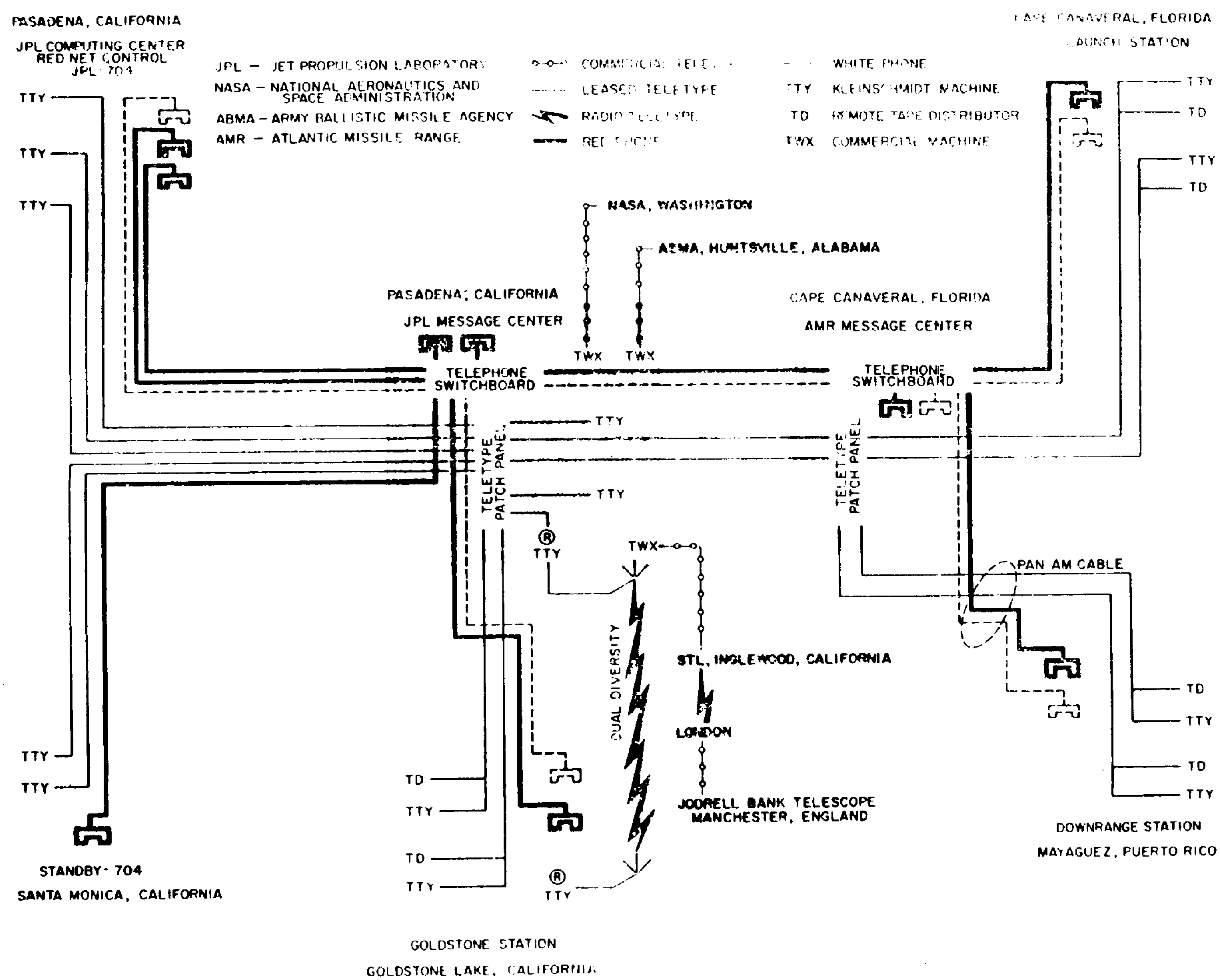


Figure 3-2. The ground communications system during Pioneers 3 and 4.

Trajectory computation was consumated by means of an IBM 704 at JPL with a back-up computer in Santa Monica. (Figure 3-3) The paper of Eimer et al referenced above contains a long section on Pioneer trajectory analysis. The most interesting feature of the approach is the heavy reliance on angle data---(which are no longer used in the DSN at all) because of the lack of confidence in one-way Doppler due to possible drift of the spacecraft oscillator frequency. Even so, Eimer et al estimate that the position of Pioneer 4 in the vicinity of the Moon was known to within about 100 km.

Pioneer 3 was launched on December 6, 1958, but it only reached an altitude of 63,500 miles before it fell back to Earth, impacting somewhere in central Africa. The total flight lasted approximately 24 hours. The Puerto Rico station tracked it for 14 hours (out and back) and Goldstone 10 hours. Puerto Rico was able to maintain telemetry contact out to at least 40,000 miles, while Goldstone with its much bigger antenna had no trouble acquiring telemetry during the entire period the Pioneer was above its horizon. The telemetry received at Puerto Rico had high scientific value because it recorded two passes through the then mysterious Van Allen belts. In actuality, the Puerto Rico station had tracked Pioneer 3 as far as it could and had then shut down. Station personnel were celebrating the first successful lunar probe flight when news arrived that the spacecraft was falling back to Earth. The party ended quickly as personnel left to fire up the station again.

Three months later, on March 3, 1959, Pioneer 4 departed Cape Canaveral and became the first U. S. spacecraft to leave the Earth's gravitational field. Early tracking and telemetry were similar to Pioneer 3. After the 100,000-mile mark, however, a departure from the nominal launch trajectory caused the spacecraft to dip below Puerto Rico's eastern horizon for 30 minutes. No tracking data and telemetry could be obtained during this period. Subsequently, Puerto Rico re-acquired the probe. The first Goldstone acquisition occurred 6.5 hours after launch when it was 60,000 miles from Earth. For about 15 minutes, the three TRACE stations plus Jodrell Bank tracked Pioneer 4 simultaneously, providing a four-way fix on its position. The first three passes over Goldstone (March 3, 4, and 5) lasted about 10 hours each. The final Goldstone acquisition was on March 6 at a range of almost 400,000 miles. At about 435,000 miles, the signal was lost as the probe's batteries ran down. At the time the signal was lost the quality of the telemetry and tracking data was still high. With a bigger battery on the spacecraft, TRACE could have tracked Pioneer 4 much farther.

An interesting sidelight on the Pioneer-4 record involves the 6-m dish at GE's Schenectady facility. Its receiver was fitted with a parametric amplifier whereas Goldstone was not. The parametric amplifier is a low-noise device and potentially could have given the GE tracking station an advantage over the larger Goldstone antenna. In any event, S. K. Brown of GE claimed that it received Pioneer 4 transmission from greater distances than JPL.[2]

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[2]E. C. Buckley, Memo for files, March 12, 1959.

Figure 3-3. The computing center at JPL during the Pioneer-3 and -4 flights.

JPL's Pioneer antenna at Goldstone also tracked Pioneer 5, an Air Force-built spacecraft taken over by NASA. Originally intended as a Venus fly by, weight limitations forced the Air Force to settle for deep space exploration. Launched on March 11, 1960 and transmitting at 378 MHz, the official tracking stations following the flight were located at the Cape, on Hawaii, at Singapore, and at Millstone Hill, Massachusetts. JPL, however, by modifying its receivers at Goldstone, was able to track Pioneer 5 on an informal basis. On April 1 and 2, 1960, Goldstone successfully tracked and recorded signals from Pioneer 5, which was then at a distance of 2.9 million miles.

Project Echo

Project Echo began in early 1959 at the Langley Research Center. The objective was the evaluation of large, balloon-type satellites as passive communication satellites. To do this NASA planned to orbit a 100-foot-diameter inflatable metallic balloon at about 1000 miles altitude and bounce signals off it from East coast to West coast. JPL's Goldstone station was an obvious choice for the West Coast terminal. The Bell Telephone Laboratories were brought into the program to provide the East Coast site. (Figure 3-4)

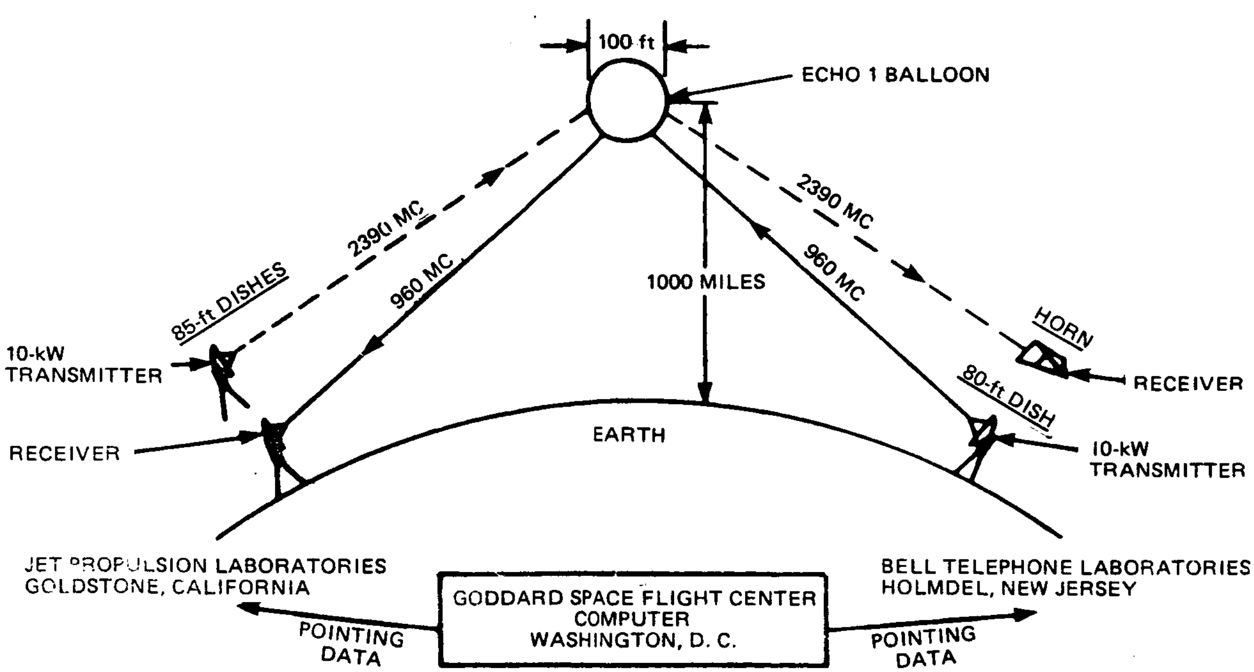

Figure 3-4. Sketch of JPL-Bell Labs Echo-1 experiment.

The plan called for setting up separate links at 960 MHz (east to west) and 2390 MHz (west to east). Bell Labs had a 19-m parabolic dish at its Holmdel facility in New Jersey for transmissions and wanted to use a 20-by-20 foot horn antenna to receive JPL's transmissions at 2390 MHz. While JPL had the 26-m Pioneer dish at Goldstone for receiving Bell Labs' 960-MHz signal after it bounced off the Echo satellite, it needed a second antenna for transmissions at 2390 MHz.[3]

JPL built its Goldstone Echo antenna, the site's second 26-m dish, with funds provided by Leonard Jaffe's Communications Satellite Program at NASA Headquarters. Construction commenced at Goldstone in July of 1959 and was completed by December. It became operational in April 1960. The new dish differed from the Pioneer antenna in its high speed, Az-El (azimuth-elevation) drive, which was more suitable for tracking satellites than the astronomy-oriented equatorial drive. The Echo site also included a 10 kilowatt transmitter operating at 2390 MHz, which represented the state of the art in 1960.

The JPL antennas were not employed for tracking the Echo satellites, just for transmitting and receiving. The Echos carried Minitrack beacons, and the Minitrack tracking stations relayed tracking information to Goddard Space Flight Center in Greenbelt, Maryland. Goddard, in turn, supplied via teletype local pointing angles in the coordinate systems required by the four different antennas involved. Because the Pioneer and Echo sites at Goldstone were 7 miles apart, a computer operating in real time was needed to correct these pointing angles for parallax.[4]

Each JPL antenna had mounted upon it a telescope with a TV remote monitor for optical tracking of the balloon satellites, which were big enough to be seen easily with the naked eye. Provisions were also made for radar tracking of the Echos in the S-Band from the Echo antenna, but this did not prove necessary during the experiements.

The signal power reflected into the ground antennas by the metallized spheres was expected to be very small. Therefore, an effort was made to reduce noise temperature. JPL installed parametric amplifiers at both antennas. They had been under development at JPL for several years, and Echo saw their first operational use by JPL. Bell Labs used a liquid-helium-cooled, solid-state maser at Holmdel, which reduced its noise temperature down to $24^{o}K$[5], which was considerably lower than JPL could manage with

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[3]JPL was most interested in experimenting at these frequencies, which are in the so-called S-Band, for they were deemed highly desirable for future deep space work.

[4]William C. Jakes, Jr., and Walter K. Victor, "Tracking Echo I at Bell Telephone Laboratories and Jet Propulsion Laboratories," in Space Research II, H. C. van de Hulst et al, eds., (Amsterdam: North-Holland Publishing Co., 1961) pp. 206-214.

[5]John R. Pierce, "Practical Problems of Satellite Communication," Astronautics, vol. V (May 1961) pp. 34-35, 90, 92, 94.

parametric amplifiers (about 150^{o}K). Thus, the Echo Project, which superficially seemed a diversion from deep space tracking and data acquisition, was a proving ground for several new developments.

Echo 1 was launched on August 12, 1960, and Echo 2 on January 25, 1964. Both inflated successfully in 1000-mile orbits. Echo 1 was 100 feet in diameter, Echo 2 somewhat larger at 135 feet. Several communication "firsts" resulted from the Echo 1 flight.[6] Within two hours of the launch, a recording of President Eisenhower's voice was transmitted from the West Coast to the East Coast. This experiment was more significant than planned because solar disturbances had seriously curtailed long distance ground communications at this time. Facsimile signals were transmitted later. Many other experiments of importance to long distance communications followed.

The actual tracking of Echo 1 proved more difficult than expected when pointing angle predictions turned out to be inaccurate. The problem was not with Minitrack but rather with the large orbital perturbations of the satellite caused by density changes of the atmosphere. The Echo balloons, being of large cross section and light in weight, were affected much more than other satellites in orbit.

Following the completion of the Echo-1 experiments, the Echo antenna was taken over by the Office of Tracking and Data Acquisition at NASA Headquarters. The entire antenna was moved in 1961 to a new area at Goldstone called the Venus site, where it was hereafter relegated to research and testing. (Figure 3-5) The Echo site subsequently received another 26-m antenna with a standard DSN-type equatorial drive.[7]

Radio Science at Goldstone; 1959-1961

Radar experiments with the Echo 26-m antenna and the Echo satellite demonstrated that JPL was developing a valuable astronomical tool out on the desert at Goldstone. Various experiments involving "Moon bounces" of radio signals confirmed this. The first major JPL success at interplanetary radar came on March 10, 1961, when good radar returns were obtained from the planet Venus.[8] These echoes were the first indisputable radar echoes from this planet. MIT scientists had claimed radar contact with Venus in late 1958

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[6]Leonard Jaffe, "Project Echo Results," Astronautics, Vol. V (May 1961), pp. 32-33, 80.

[7]H. R. Brockett, personal interview, February 25, 1975.

[8]W. K. Victor and R. Stevens, "The 1961 JPL Venus Radar Experiment," in Space Research III, Wolfgang Priester, ed., (Amsterdam: North-Holland Publishing Co., 1963) pp. 886-890.

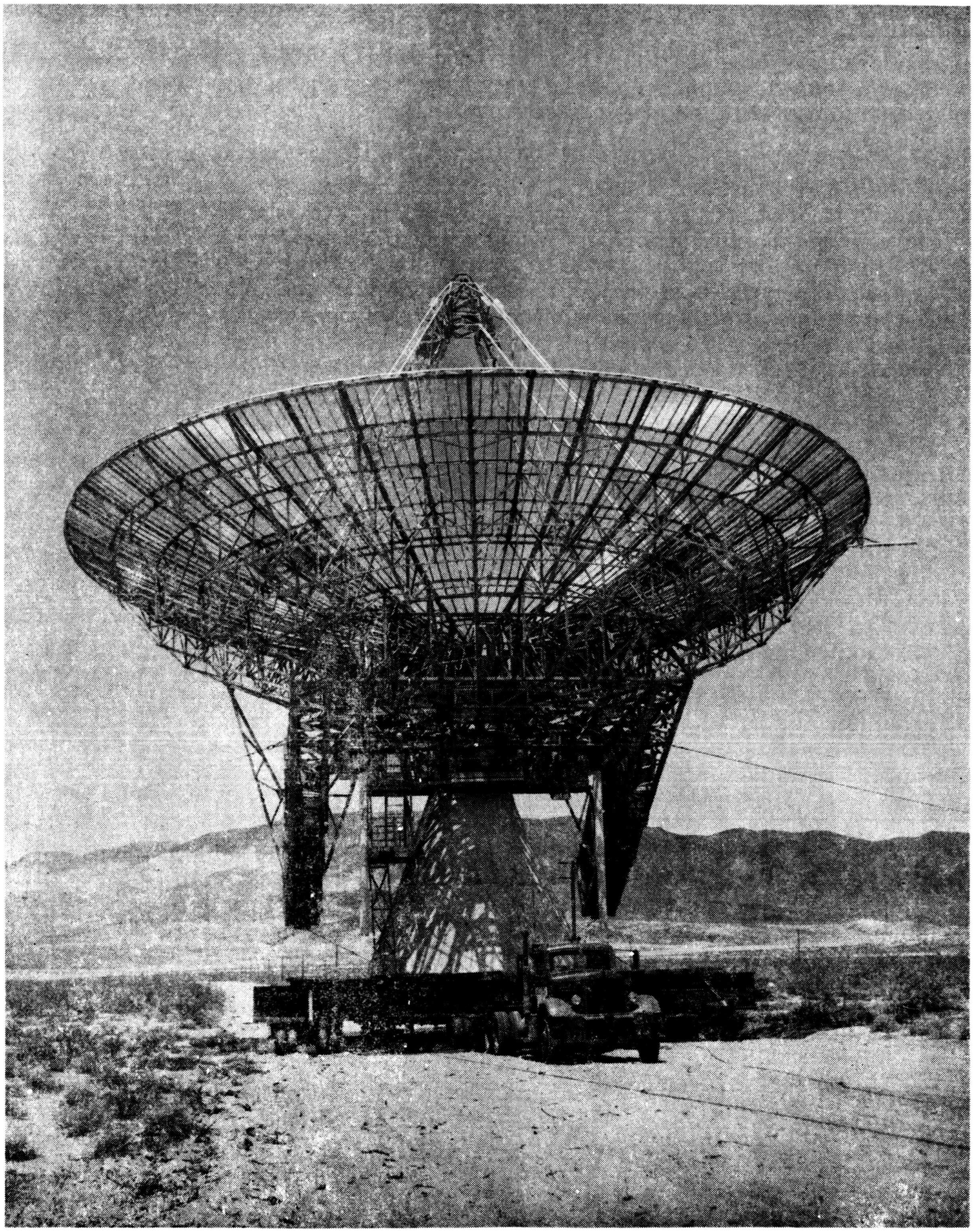

Figure 3-5. Moving the Echo antenna to its new site at Goldstone.

with their Millstone Hill antenna, but their claim had not withstood careful scrutiny.[9] In fact, another MIT attempt at the next close approach of Venus in 1959 was also unsuccessful.

During the 1961 Venus experiment, the Echo antenna transmitted a 13-kw continuous-wave signal at the planet, while the Pioneer antenna listened with a newly added cavity maser followed by a parametric amplifier receiver (64°K noise temperature). This radar was operated in a two-way, phase-coherent mode. Over 200 hours of good data were obtained while Venus was between 50 and 75 million miles from Earth.

A scientific result that was also of immense practical importance was the radio determination of the Astronomical Unit (A. U.) as 149, 598, 500± 500 km, an improvement in accuracy of nearly two orders of magnitude. If the old optical value of the A. U. had been used in Mariner-2 trajectory computations, its flyby of Venus might have been at a much greater distance with an attendant loss of scientific data.

On the scientific side, analysis of the radar returns suggested that the rotation of Venus was very slow and perhaps "locked" in a 225-day resonance, but the case was considered rather weak for this conclusion.

These first small experiments in radar astronomy whetted the appetites of astronomers. Tracking deep space probes, it developed, required ground instrumentation that was nearly ideal for sophisticated experiments in interplanetary radio science.

The DSN Takes Shape

The Army Explorers and early Pioneers had been rushed into hardware more in response to Russian and interservice rivalries than as parts of a long-term, carefully planned national effort in space exploration. With NASA assuming responsibility for all non-military space activities and with the international Space Race in full swing, ambitious plans were the order of the day. Most of the major space programs of the 1960s had their genesis in the 1959-1961 period: Apollo, Ranger, Mariner, Surveyor, Lunar Orbiter, and so on. It was also time to move ahead and build a deep space network that could track and communicate with probes at planetary distances on a continuous basis. The intermittent lunar capability patched together for Pioneers 3 and 4 was completely inadequate in the light of future NASA objectives.

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[9] R. M. Goldstein, personal interview, April 15, 1975. Also R. Price et al, "Radar Echoes from Venus," Science, vol. CXXIX (March 20, 1959) pp. 751-753,

At first there were three major actors in the tracking and data acquisition theater:

- NASA Headquarters. During the 1959-1961 period, the responsibility for NASA-wide tracking and data acquisition was being centralized under Edmond C. Buckley, who had moved from Langley to Washington in 1958 for this very purpose. Initially, Buckley was Assistant Director for Space Flight Operations and responsible directly to Abe Silverstein, who headed the Office of Space Flight Development. (Figure 3-6)

- JPL. Here, development of deep space capabilities in tracking and data acquisition were under the leadership of Eberhardt Rechtin, who had been appointed Chief of the Telecommunications Division (Division 33) in 1958. (Figure 3-7) As the DSIF (Deep Space Instrumentation Facility), as the embryonic DSN was then called, became more and more significant in JPL's plans and budgets, Rechtin was appointed Program Director of the DSIF on May 9, 1960, in addition to his Division 33 assignment.[10] The DSN did not become an official Program Office until 1963, but it interfaced with NASA Headquarters as if it were long before that date.[11]

- ARPA, where there were serious thoughts about the military potentialities of cislunar space and the Moon itself. ARPA wanted its own lunar tracking and data acquisition capabilities.

Saga of the ARPA Antennas. The pressure of the requirements of the Ranger, Surveyor, and Mariner missions then taking shape on NASA's planning boards added more momentum for the completion of what ARPA had called the World Net before NASA took over. To complete the World Net, NASA needed two more sites with 26-m dishes roughly 120° of longitude apart. ARPA had already purchased three such dishes, one of which now belonged to NASA at Goldstone. The other two were awaiting shipment overseas.

On January 10, 1959, NASA and ARPA representatives sat down to coordinate their network plans.[12] They decided to jointly build a network of five deep space stations with 26-m dishes as follows:

NASA-Operated	ARPA Operated
Goldstone	Spain
South Africa	Japan
Australia	

[10] R. Cargill Hall, "Ranger History," unpublished, Chapter 7.

[11] William Bayley, personal interview, April 19, 1975.

[12] H. R. Brockett, personal interview, February 25, 1975.

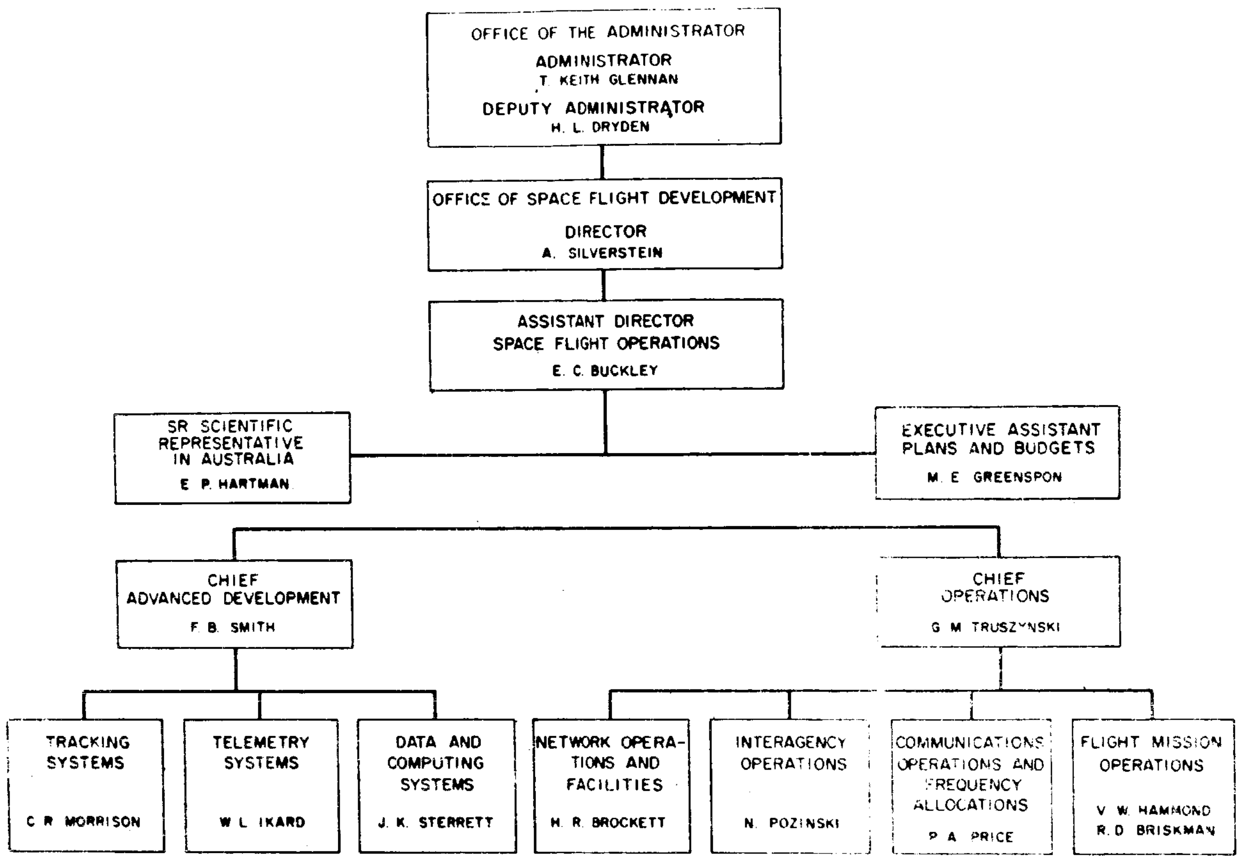

Figure 3-6. NASA Office of Space Flight Operations, 1959 to November 1961, showing tracking and data-acquisition group.

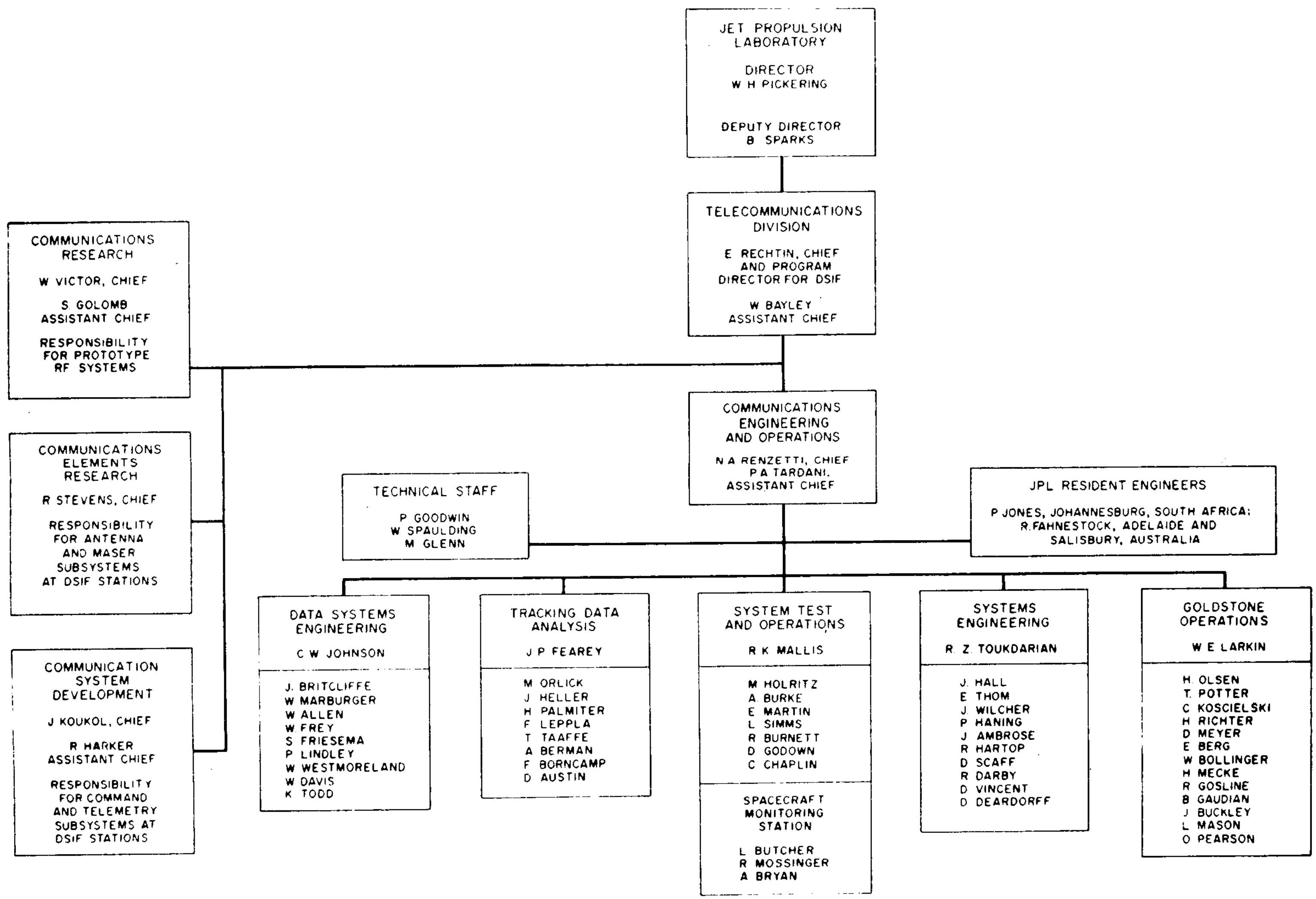

Figure 3-7. DSN organization for Rangers 1 through 5.

Each agency would get one of the antennas ARPA had already purchased. NASA decided to place its new dish in Australia; ARPA earmarked its dish for Spain. With these guidelines, a joint NASA-ARPA site survey team took off to locate likely sites.[13]

The military's plans for a separate deep space network soon faded. The 26-m antenna ARPA had hoped to install in Spain became excess baggage, something ARPA no longer really needed. Glennan, the NASA Administrator, wrote to McElroy, Secretary of Defense, asking if NASA could have the excess dish. A purchase agreement whereby NASA transferred $1.3 million to DOD was worked out. NASA eventually erected this antenna in Johannesburg, where some modifications in its base were required due to the different latitude. In this rather involved way, NASA obtained its first subnet of three 26-m antennas from ARPA. (The Echo antenna, NASA's other 26-m dish at Goldstone, was purchased much later directly from the manufacturer.)

Overseas Negotiations and Site Construction.

NASA's foreign DSN sites are few in number in comparison to those needed for manned space flight and satellite operations. The DSN stations, however, were subjected to the same guidelines in the area of international relations. First, NASA wished to convince host countries that its tracking and data acquisition stations were good for the country concerned. To this end, foreign nationals were to be used to the maximum feasible extent in building and operating the stations, even at the cost of extensive training programs. NASA facilities, therefore, would upgrade a country's technical base and in consequence be welcome additions. Edmond Buckley, at NASA Headquarters, was the principal architect of this policy as well as the following guideline: NASA in its negotiations with foreign countries should stress the nonmilitary features of its tracking and data acquisition facilities. One reason for this was the strong aversion of many countries for American military activities. Secondly, a nonmilitary network, with sites based on this principle, would be less likely to be gobbled up by expanding DOD networks, which often coveted NASA's tracking assignments.

The first overseas DSN station was located at Woomera, in the state of South Australia, approximately 110° west of Goldstone's longitude. The site recommended by the NASA-ARPA survey was already a missile and rocket test center operated by the Australian Weapons Research Establishment. Furthermore, the United States had already gained Australia's agreement to build tracking facilities here during the IGY. Australia had, in fact, erected and had manned a Navy Minitrack station and installed a Smithsonian Baker-Nunn tracking camera. In addition, the language was English and the Australians had developed considerable technical know-how. There was also thought to be a good supply of technical manpower in the area due to the nearby rocket activities.

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[13]H. L. Richter et al, "ARPA-NASA Overseas Tracking Site Survey," February 1959.

A spot called Island Lagoon, 14 miles southeast of Woomera, had been recommended for the antenna. (A dry lake nearby with an "island" in the middle was the source of the name.) Construction began in March 1960 and was complete by September. The Blaw-Knox Company, under a JPL contract, assembled and erected the antenna which was, as mentioned earlier, one of those obtained from ARPA. (Figure 3-8) Collins Radio supplied the electronics equipment.

The third and last element in the DSN's first 26-m subnet had to be roughly in the longitude band including Spain and South Africa for continuous deep space coverage. Spain was first choice but was abandoned when ARPA insisted on locating the antenna on land already leased rather than a remote location. (ARPA wanted to avoid renegotiating existing treaties.) South Africa, however, held many advantages, such as being in the track of spacecraft ascending from a Cape Canaveral launch. It also had a friendly government anxious to help with the station. Technical talent was also available and the language was familiar. There is really no mystery why the NASA-ARPA site survey team chose South Africa, but an inkling of trouble far in the future did make its way into a 1960 memo to Buckley:

> Currently it is planned to proceed with the installation of a Space Probe Station in the Union of South Africa despite the recent racial disturbances.[14]

If there were any doubts of a political nature, a second quotation from the same memo swept them aside:

> In support of the Ranger program, the choice of a new site for the 85 foot dish will probably make the operational date of the third Space Probe Station slip.[15]

Thus it was that negotiations proceeded with South Africa. A preliminary contract had been issued in April 1960 so that the South Africa Council for Scientific and Industrial Research (CSIR) could begin planning the station. The final bilateral agreement between the two governments was concluded in September 1960.

The chosen site was near Hartebeestpoort Dam about 40 miles north of Johannesburg on farmland purchased by the South African government for a radio research center. As with Woomera, NASA already had Minitrack and Baker-Nunn stations in the area. Under the pressure of Ranger, station construction began in January 1961 and was complete by July 1961, in time for the first Ranger tests. (Figure 3-9) The World Net had been completed but it was now called the DSIF.

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[14]Robert D. Briskman, "Union of South Africa Space Probe Station," memo to Assistant Director, Space Flight Operations, May 9, 1960.

[15]Ibid.

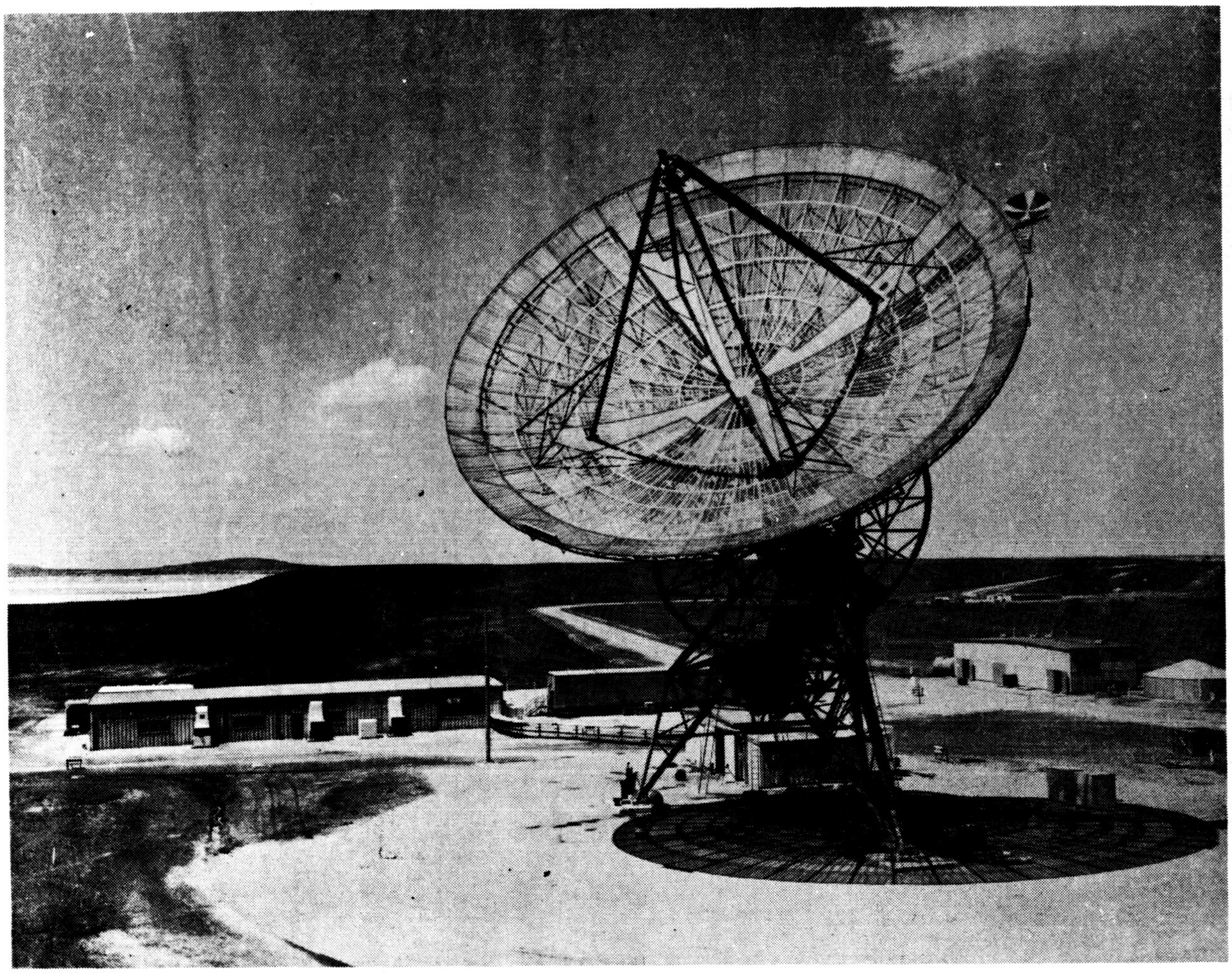

Figure 3-8. The 26-m paraboloid at Woomera.

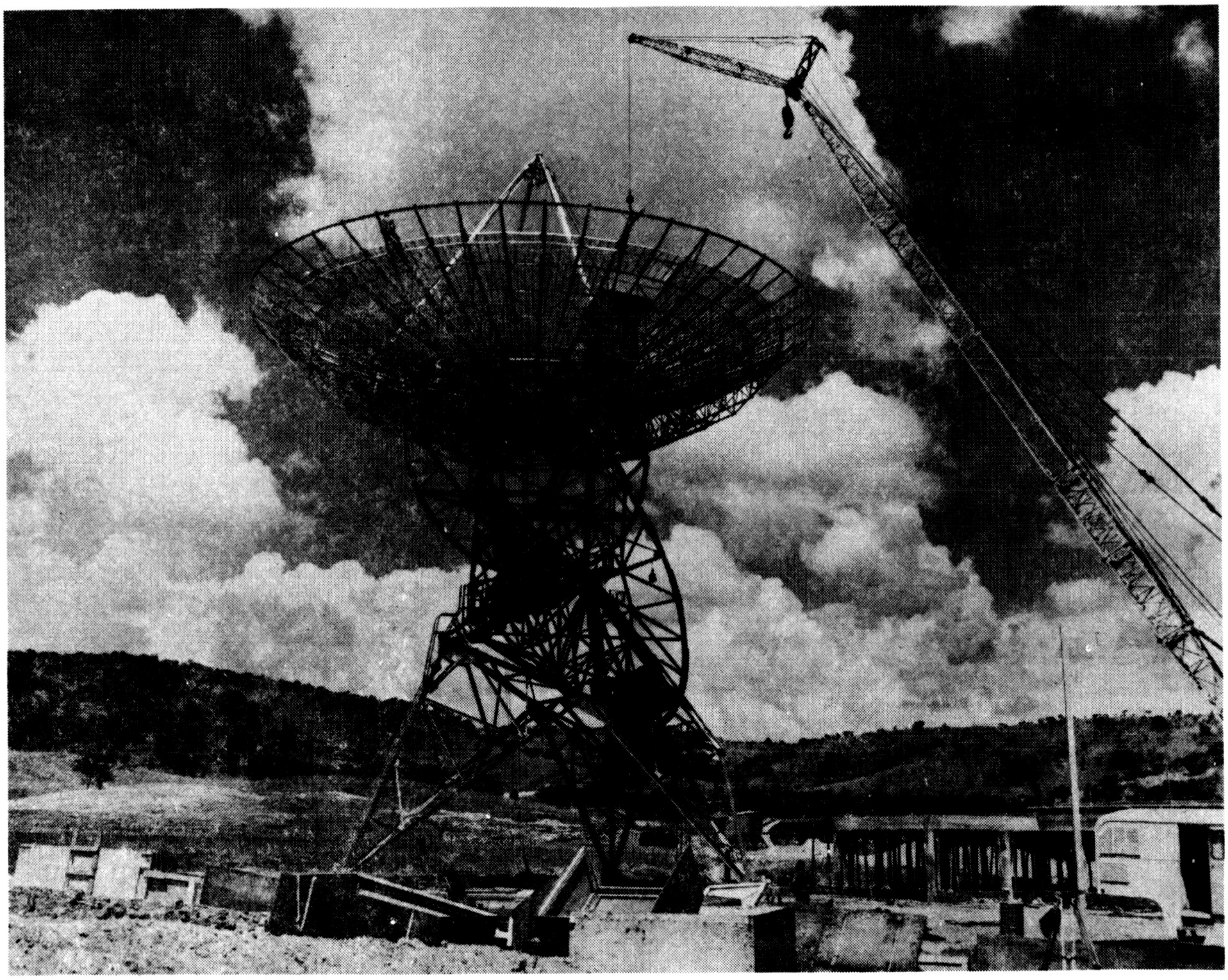

Figure 3-9. The Johannesburg DSN station.

<u>The AAS (Advanced Antenna System)</u>. As NASA's plans for space exploration matured in 1959, unmanned missions to the planets quickly moved from the category of "ridiculous and impossible" to "feasible and politically desirable." In this environment, it became increasingly obvious that the 26-m paraboloids being built for Pioneer and Echo were going to be too small for future tracking and data acquisition requirements. The attenuation of the inverse square law at planetary distances could be overcome either by more powerful transmitters on the spacecraft or more sensitive receivers back on Earth. The payload restrictions on planetary probes placed the burden squarely on the terrestrial terminal. Primarily this meant bigger antennas and lower noise temperatures. But how big could steerable antennas be built and at what costs? To answer such questions JPL inaugurated its AAS program in 1959.

A long lead time was required because several concepts had to be explored in depth. Several large antenna projects in radio astronomy had run into serious engineering problems; viz., the Navy's Sugar Grove antenna; and NASA and JPL did not want to join this unselect group. One of the first efforts to focus national technical talent on the problem took place on November 6, 1959, when NASA Headquarters sponsored a conference on big antennas.[16] Experts responsible for several large antenna projects in radio astronomy reported on their work and commented on NASA's problem. Three basic kinds of antennas were built or were being built:

1. Steerable paraboloids (like the 26-m dishes but much larger, as exemplified by the Navy's 182-m monster at Sugar Grove)

2. Fixed paraboloids with movable feeds (like the Arecibo dish)

3. Fields of small, separate, steerable antennas.

Although the engineering challenges were great, NASA and JPL decided to stay with the steerable paraboloids. The general thinking at this time was to aim for a dish with several times the area of the 26-m antennas. A steerable paraboloid of this size capable of continuous operation in all but the most extreme weather conditions was felt to be within the state of the art.

To obtain some hard engineering numbers, JPL briefed industry on the AAS on September 29 and 30, 1960, asking for proposals for feasibility studies. Seventeen proposals were received and from these JPL selected four contractor teams:

- -Blaw-Knox, Dalmo-Victor, and Alpha Corporation
- -Hughes Aircraft and Consolidated Western Steel
- -North American (Columbus)
- -Westinghouse

16Wallace L. Ikard, "Conference on Large Aperture Antennas for Deep Space Communications," Memo for Space Flight Operations Files, November 23, 1959.

The general conclusions derived from the four 4-month studies were that the concept of a steerable paraboloid 200-250 feet in diameter was indeed feasible and that the most critical parts of the design were the mounting system, the instrumentation, and the servomechanism drive. JPL then selected Blaw-Knox to prepare a detailed feasibility study and preliminary design of a 70-m antenna.[17] The $250,000 study was scheduled for completion by July 1962 so that construction contracts could be let for an operational date (at Goldstone) of January 1, 1965. Thus, the first steps were taken toward the present DSN subnet of 64-m antennas.

Ground Communication and Computing. During its support of the Pioneer 3 and 4 flights, TRACE had relied upon teletype circuits to feed tracking data and telemetry back to JPL. (Figure 3-1) The ground communication network at this time was divided into two separate nets: A Red Net consisting of all teletype lines and a single voice link; and a White Net made up of one voice circuit connecting the three tracking stations with a monitoring capacity at two message centers and with the Computing Center at JPL. The general purpose of the White Net was coordination and troubleshooting. The combination of the Red and White nets was adequate for primitive space probes but not for the high-data-rate spacecraft being planned, particularly Surveyor and Lunar Orbiter.

JPL set down three principles to guide the development of a higher performance ground communication system, to be called the GCS (Ground Communications System):

1. There must be enough flexibility to meet widely varying mission requirements.

2. High reliability is essential and should be obtained through maintenance, backup circuits and equipment, and good operational planning.

3. Provisions must be built in for accommodating new circuits and new tracking stations.

In 1961, the ground communications system was being readied for the support of Ranger. At this point in time, each tracking station was tied to JPL by two teletype circuits and one voice circuit. The JPL terminal was called the Pasadena Communications Center. To expedite the flow of incoming data to the mission control personnel, an operations control room was set up at the Communications Center. A window separated the communications personnel from the controllers, and messages between the two groups were passed through a slot in the window. The controllers monitored their own voice circuits. When a communications man was needed, a wave or shout got his attention. Later, this situation was remedied by an intercom. The Communications Center had

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17NASA, "Feasibility Study for a Deep Space Tracking Antenna," NASA Headquarters News Release 61-191, August 25, 1961.

a manual patching capability whereby any teletype machine in the Communications Center could be linked to any long distance line and long distance lines could be connected to teletype machines in the Computing Center. Teletype tapes were subsequently converted into punched cards which were fed directly into the IBM 709 computer.[18] During this early stage in DSN development, JPL controlled all of the DSN communication lines. NASA, however, was evaluating the costs involved of maintaining separate communication networks for each of its three tracking networks, with an eye to pooling circuits in a common system.

The techniques described above for handling telemetry and tracking data seem quite crude by modern standards, however, it was during this period that JPL and other NASA centers were developing the capability to feed telemetry data directly into the computer, bypassing the preparation of teletype tapes and punched cards.

Noise Temperature Reduction. Although JPL was developing considerable expertise in low-noise parametric amplifiers and masers, it had not yet reached the stage where it could employ these devices for the Pioneer lunar probes. This was unfortunate because two "competitors" did: General Electric at Schenectady and the Air Force at Jodrell Bank, where a parametric amplifier built by Thompson-Ramo-Wooldridge (TRW) was employed.

A 960-MHz L-Band parametric amplifier was, however, introduced by JPL during the Echo experiments, but this was not the same device later used throughout the network. The Echo up-converter paramp had gain-stability problems and was discarded for a single-port type.[19] To provide a stable temperature environment, Peltier cooling was introduced. In fact, the paramps introduced into the DSN in January 1962 represented the first large-scale applications of Peltier temperature stabilization in such equipment.

In parallel with the parametric amplifier work, Walter Higa's group at JPL had switched its development efforts from ammonia masers to solid-state ruby masers when Bell Labs successfully demonstrated such devices. By 1960, the JPL group had L-Band cavity ruby masers operating in open-cycle dewars. These masers were used operationally in low-noise receivers at Goldstone for Mariner 2. The principal JPL contributions in this work were in the field of cryogenics and in converting laboratory versions of solid-state masers to highly-reliable, field-tested equipment—a vital requirement for a DSN station.

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[18] JPL, "A History of the Deep Space Network to 1 January 1969," (Pasadena, JPL 890-9, September 1, 1970) p. 2-24.

[19] J. R. Hall, personal interview, July 28, 1975.

Chapter 4. THE EARLY RANGERS

The Rangers, like the early Pioneers, were lunar probes with the objective of crossing the quarter million miles separating Earth and Moon and impacting the lunar surface. In 1961, merely hitting the Moon with terrestrial hardware would have been accomplishment enough, but the Rangers were also designed to carry instruments for studying space physics in transit, taking pictures of the lunar surface before impact, and analyzing the lunar environment from a landed instrument package.[1]

The Rangers took several significant steps forward from Pioneer-3 and -4 technology. In fact, in retrospect, the program may have been too ambitious in terms of the number of advances envisaged. First, the spacecraft itself was to be fully stabilized in attitude, keeping a high-gain antenna pointed at Earth and solar-cell panels aimed at the Sun. In contrast, the Pioneers had been simple, spin-stabilized spacecraft, maintaining their spatial orientation like a rifle bullet. Complete attitude stabilization was a technical challenge in the early 1960s. The second major technical advance attempted was the landing of an instrument capsule on the lunar surface by means of a retrorocket.

Originally, five Rangers were planned. The first two were to be test beds that would be injected into elliptical orbits around the Earth. These were to check out the engineering of the attitude control, solar power, and communication subsystems. Rangers 3 through 5, the Block II Rangers, each consisted of the spacecraft "bus" plus the ejectable capsule with its retrorocket. On their way to the Moon, these spacecraft were to make measurements of cislunar space and, as the Moon loomed large before impact, take vidicon pictures of its surface. Just before impact, the capsule would be ejected; it would orient itself, fire its retrorocket according to preprogrammed instructions, and ease down to the lunar surface. Once on the surface, the capsule would right itself and transmit data on local radioactivity and moonquakes.[2]

The first five Ranger shots were plagued by launch vehicle and spacecraft failures. It became apparent that additional Rangers would be needed to obtain the close-up knowledge of the Moon's surface required for the Apollo program. Consequently, on August 29, 1961, NASA added a third block of four Rangers to be launched in 1963.[3] A fourth block of five more was announced on October 15, 1962, making a total of 14. The last five, however, were cancelled on December 13, 1963, for reasons of economy. The single-minded goal

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[1]For considerably more detail on the Ranger Program origins, perturbations, and conclusions, see: R. Cargill Hall, "Lunar Impact: History of Project Ranger," unpublished.

[2]N. A. Renzetti, and B. J. Ostermier, "Communications with Lunar Probes" (Pasadena: JPL TR 32-148, August 23, 1961).

[3]Official NASA Flight Schedule.

of the Block-III Rangers was not science but the return of detailed vidicon pictures of the lunar surface prior to impact. The Block-III Rangers were geared primarily to the engineering needs of Apollo.[4] Removed from the payload were the instrumented capsule and its retrorocket. The political pressure for Ranger successes during 1964 was most intense.

Another cornerstone in America's Moon program was the Surveyor soft lander, which was aimed at providing information on lunar surface properties for the upcoming Apollo manned landings. The Surveyor flights did not begin until 1966, but the testing of the launch vehicle, the new Atlas-Centaur, began well before that in 1962. The DSN was called upon to support some of the Atlas-Centaur test flights from 1962 through 1966, a period overlapping the Rangers. The DSN activities during these tests will be discussed later in this chapter.

The Mariner-1 and -2 launches directed toward Venus and those of Mariners 3 and 4 toward Mars also came during the Ranger period. These flights, however, were interplanetary in nature and required substantially different DSN support. Mariner 4 was in fact the first S-Band mission supported by the DSN. Therefore, they deserve chapters of their own.

Prolog to Ranger

Rather unexpectedly in the early 1960s, the tracking and data acquisition function was assuming more and more importance in NASA's budget and, consequently, in its organizational structure. Space flight turned out to be not all launch rockets and spacecraft, it depended very heavily upon ground facilities for testing, launching, and, of course, tracking and communication. The early literature of space flight does not foresee these developments at all. Management practicalities, however, soon forced NASA to recognize the importance of tracking and data acquisition by placing this function on a par with space science, manned space flight, etc. On November 1, 1961, the new Office of Tracking and Data Acquisition (OTDA) was created at NASA Headquarters. Edmond C. Buckley, who had been in charge of Space Flight Operations under Abe Silverstein (Figure 3-6) was named Director of the new Office. (Figure 4-1) In effect, the entire tracking and data acquisition function was elevated a notch in the NASA Headquarters hierarchy. It remained in this position until 1966 when the Director of the Office of Tracking and Data Acquisition[5] was appointed Associate Administrator, indicating another step upward in the NASA Headquarters hierarchy.

At JPL, as the Ranger Program got underway, DSN management still resided in Division 33 (Telecommunications) under Eberhardt Rechtin. (Figure 3-6) The growing importance of tracking and data acquisition had been recognized in 1960 when Rechtin was given the additional title of DSIF

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[4]R. Cargill Hall, "Lunar Impact: A History of Project Ranger," unpublished.

[5]Gerald M. Truszynski at this time.

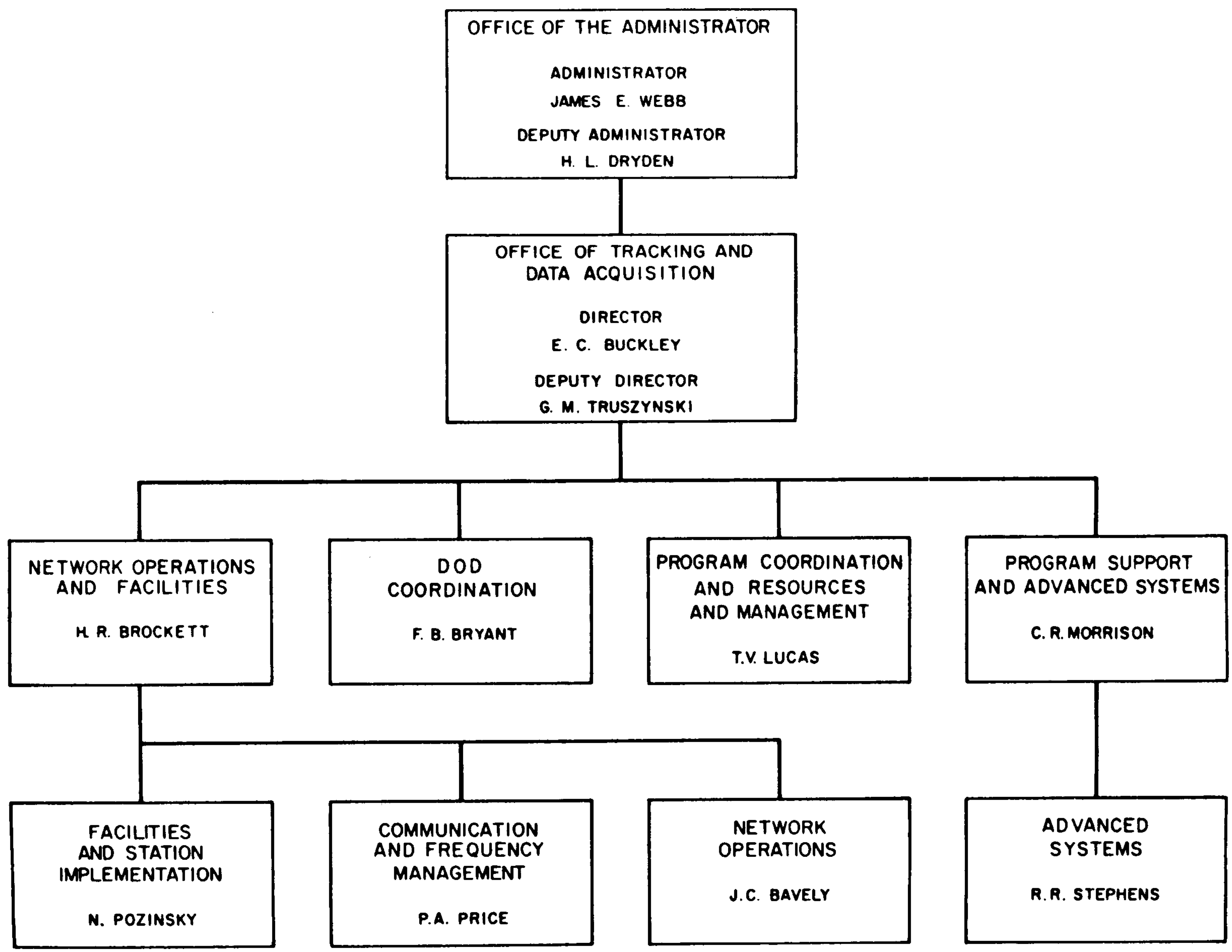

Figure 4-1. NASA organization for the Office of Tracking and Data Acquisition in 1963.

Program Director, but the function still remained immersed in JPL's traditional functional organization structure. Finally, on October 2, 1963, Rechtin was named Assistant Laboratory Director for Tracking and Data Acquisition.[6] (Figure 4-2) On the day before Christmas 1963, the DSN itself was officially established[7], although it had been termed such for several years. The "official" DSN incorporated the DSIF (the tracking sites specifically), the interstation communications (now called the Ground Communications Facility), and the mission-independent portions of the Space Flight Operations Facility (SFOF). (Figure 4-3) The purpose of the consolidation was the more efficient support of the several new off-Lab projects the DSN was being called upon to support, such as Atlas-Centaur (Lewis Research Center), Lunar Orbiter (Langley Research Center), a new Pioneer series (Ames Research Center), and Apollo. Dr. N. A. Renzetti was named DSN Manager. Before this change, Renzetti had been Chief of Communications Engineering and Operations. Basically, the JPL reorganization paralleled that which had occurred at NASA Headquarters two years earlier.

A most important responsibility of the DSN Manager was and still is the development of an integrated plan for the support of missions in conjunction with the Mission Manager, wherever he might be in the NASA and JPL organizations. But before detailed support plans could be discussed, mission planners had to have some measure of DSN capabilities in order to prepare conceptual designs of their spacecraft and missions. It has been the custom of DSN management to prepare periodically comprehensive summaries of DSN capabilities—snapshots, as it were—in a series of documents given wide distribution.[8]

The next step in matching mission requirements with DSN capabilities consisted of informal meetings between DSN and mission engineers. During most of the 1960s, the DSN provided additional flexibility through the addition of "mission-dependent" equipment at its stations and the SFOF. These special equipments performed functions not built into the DSN at that time, such as the provision of special commands or unique recording apparatus. Every program had its special equipment and own personnel to operate it at DSN stations during this period, and this proved awkward and inefficient for all the flexibility it provided.

Ranger, being an in-house JPL project, did not involve as many interfaces with other organizations as did Atlas-Centaur. It was during the Atlas-Centaur Program that the first NASA tracking panel was created to replace informal discussions of requirements and capabilities with a better organized forum. Tracking and data acquisition panels were soon set up for other

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[6] W. H. Pickering, JPL Interoffice Memo 200.

[7] W. H. Pickering, Interoffice Memo 218, December 24, 1963.

[8] A typical example: E. Rechtin, "System Capabilities and Development Schedule of the Deep Space Instrumentation Facility, 1963-1967," (Pasadena: JPL TM 33-83, March 2, 1962). Other examples may be found in the Bibliography.

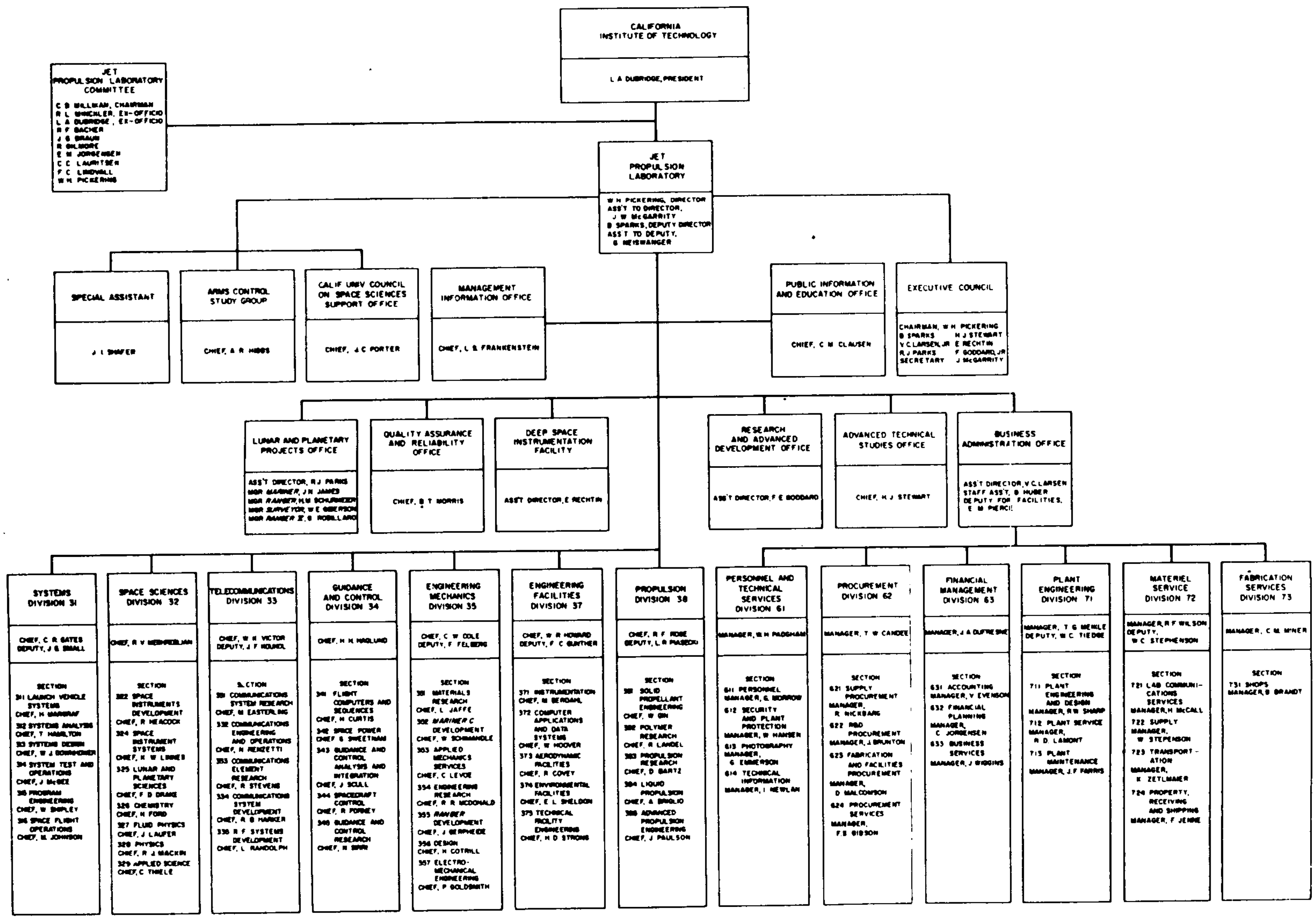

Figure 4-2. JPL organization structure after establishment of DSN project office.

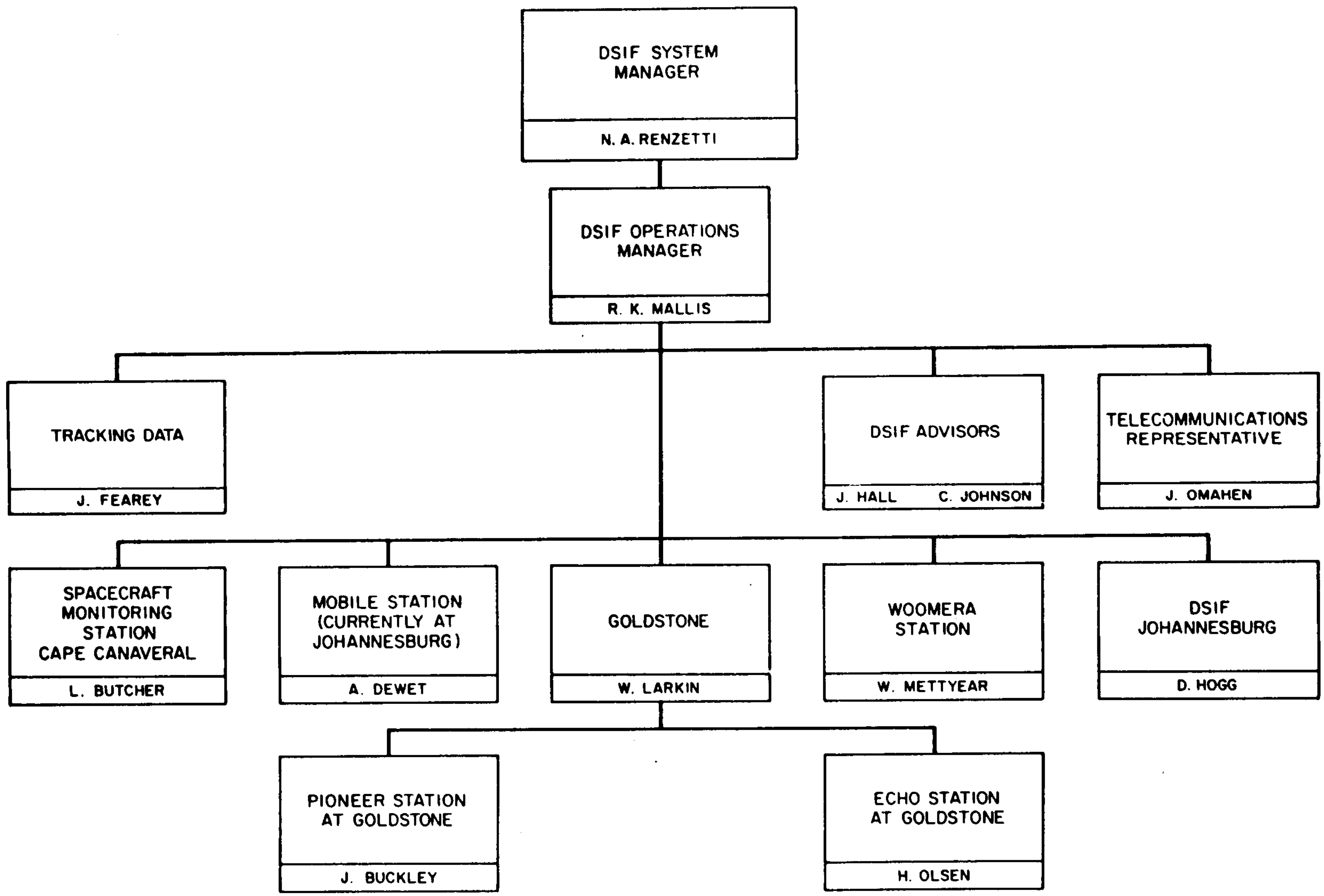

Figure 4-3. DSIF organization for Ranger Project.

missions, enabling support problems to be ironed out in a more definitive way. Minutes were kept of these meetings and some of the disadvantages of informality thus eliminated. Later, the negotiation of requirements and support became even more formal when the SIRD (Support Instrumentation Requirements Document) and its response the NASA Support Plan became the order of the day.

The DSN at the Beginning of Ranger

The Ranger flights spanned nearly four years. During this period, the DSN evolved steadily. Although the Rangers were L-Band missions (960 MHz), S-Band technology was being rushed into hardware for Apollo and Mariner planetary missions. Several other technical improvements were in the works, too, but the DSN had to retain some degree of uniformity relative to the fixed Ranger spacecraft. Insofar as the Ranger spacecraft were concerned, the major DSN change was a reduction from 1500°K to 200°K in noise temperature between Rangers 2 and 3---a result achieved through the introduction of parametric amplifiers at all sites. In November 1961, the noise temperature at Goldstone was reduced further to 50°K when an L-Band maser was installed. This, of course had no effect on spacecraft design but did improve the ability of Goldstone to receive faint signals.

Tables 4-1 through 4-2 define DSN capabilities during Rangers 1 through 5.

Table 4-3 indicates the presence of an MTS (Mobile Tracking Station) at Johannesburg. Basically, the MTS was the same equipment employed at Puerto Rico during Pioneer. In 1959, the Puerto Rico station had been fitted with a 25-watt transmitter and moved to Goldstone for checkout and then to South Africa. There it was emplaced on a hill near the Johannesburg 26-m dish to help it acquire spacecraft coming down the Atlantic Missile Range. (Figure 4-4) The narrow beam of the 26-m dish, its relatively slow tracking velocities, and the hills surrounding it made an acquisition aid, such as the MTS, desirable.

In the configuration described in Tables 4-1 through 4-3, the DSN was expected to provide the following:

1. Tracking data---two angles, either hour angle and declination or azimuth and elevation plus one-or two-way Doppler.

2. Commands---transmissions to the spacecraft required for mid-course and terminal maneuvers, changes in telemetry mode, antenna switching on the spacecraft, and other functions.

3. Telemetry data---from both the spacecraft and the instrumented capsule on the Moon's surface.

Details of the DSN configuration and its performance will emerge in the subsequent description of Ranger operations.

Table 4-1. DSIF ANTENNA PARAMETERS

Station	Antenna type	Reflector size, ft	Tracking rate, deg/sec		Antenna gain, db		Antenna ellipticity, db		Excess noise temp. °K
			Elevation or hour angle	Azimuth or declination	Receiving	Transmitting	Receiving	Transmitting	
Goldstone	Az-El[a]	85	2.0	2.0	$44.5^{b} \pm 0.6$	$41.7^{c} \pm 0.8$	1.4 ± 0.1	3.0 ± 0.1	$43^{d}\ {}^{+0}_{-15}$
Goldstone	HA-Dec[e]	85	0.7	0.7	$45.5^{f} \pm 0.6$	$41.7^{c} \pm 0.8$	1.0^{g}	3.0 ± 0.1	$43^{d}\ {}^{+0}_{-15}$
Goldstone	HA-Dec	85	0.7	0.7	$45.5^{f} \pm 0.5$	--	1.0^{g}	--	15 ± 5
Woomera	HA-Dec	85	0.7	0.7	$44.5^{b} \pm 0.6$	--	1.4 ± 0.1	--	$43^{d}\ {}^{+0}_{-15}$
Johannesburg	HA-Dec	85	0.7	0.7	$44.5^{b} \pm 0.6$	$41.7^{c} \pm 0.8$	0.6 ± 0.2	3.0 ± 0.1	$43^{d}\ {}^{+0}_{-15}$
MTS	Az-El	10	10.0	10.0	$22.8^{b} \pm 0.5$	$23.3^{f} \pm 0.5$	0.6 ± 0.2	2.7 ± 0.5	$100^{d} \pm 50$

[a] Ranger missions 1-4 only.

[b] Gain for matched polarization includes bridge loss.

[c] Sum channel of tracking antenna used for transmitter feed. Gain shown is for matched polarization right-hand circular. Does not include ellipticity but includes bridge loss.

[d] Antenna temperature is for 960-MHz tracking feed except for Goldstone Cassegrain. Sky temperature of 0°K is assumed.

[e] Ranger 5 mission only.

[f] Circularly polarized Cassegrain listening feed. Gain figures are estimated and are for matched polarization.

[g] Estimated.

[h] Gain includes sum channel bridge loss and is for linear isotropic source. Tolerance includes possible variations due to ellipticity and measurement errors. Matched polarization will increase gain figure by 3 db. Sum channel of tracking antenna used for transmitter feed. Gain includes sum channel bridge loss and is for linear isotropic source.

Table 4-2. DSIF RECEIVER PARAMETERS

Item	Goldstone Az-El	Goldstone HA-Dec	Woomera	Johannesburg	MTS
Nominal frequency, MHz[a]	960.05 ± 0.03	960.05 ± 0.03	960.05 ± 0.03	960.05 ± 0.03	960.05 ± 0.03
Receiver noise figure, db, f = Te/T + 1	1.8[b] ± 0.2	0.5[b] ± 0.2	1.8[b] ± 0.2	1.8[b] ± 0.2	6.3 ± 0.5
Receiver transmission line loss, db	0.3[d] ± 0.2	0.1 ± 0.05	0.3 ± 0.2	0.3 ± 0.2	0.80[d] ± 0.2
Receiver diplexer, db	0.4 ± 0.2			0.4[e] ± 0.2	
Loop noise bandwidth at threshold, cps	20 ± 4 (60 ± 10)	29 ± 4 (60 ± 10)	20 ± 4 (60 ± 10)	20 ± 4 (60 ± 10)	20 ± 4 (60 ± 10)
Threshold, dbm, 20 cps $2BW_{LO}$	-162 ± 1.5	-162 ± 1.5	-162 ± 1.5	-162 ± 1.5	-155 ± 1.5
Maximum input signal level, dbm	-65	-65	-65	-65	-45
Residual phase modulation crystal oscillator phase jitter contribution	less than 3 deg[f] pp	less than 3 deg[f] pp	less than 3 deg[f] pp	less than 3 deg[f] pp	less than 3 deg[f] pp

[a] 960.05 MHz is basic two-way received frequency. 960.15 MHz and 960.25 MHz are one-way capsule listening frequencies.

[b] 220 ± 30°K is the estimated system noise temperature for the parametric receiver system. 75 ± 10°K is the measured system noise temperature for the maser system.

[c] Measured at 30 MHz. The MTS figure was measured with noise injected at the diplexer.

[d] Consists of 0.30 db from hybrid bridge to diplexer; 0.3 db for diplexer; 0.1 db from diplexer to front end. 0.1 db is included for mismatch losses.

[e] Estimated figure for Ranger 4 and 5 missions only.

[f] For input signal level of -60 dbm with 150-Hz noise bandwidth.

Table 4-3. DSIF STATION CAPABILITIES

Station	Receive	Transmit	Command	Two-way doppler
MTS	X	X		X
Pioneer	X	X[a]	X[a]	X[b]
Echo	X	X	X	X
Woomera	X	X[c]		
Johannesburg	X	X[d]	X[d]	X[d]

[a] A 25-w transmitter available for command capability only during Ranger missions 1 and 2.

[b] Precision pseudo-two-way doppler only (0.35 m/sec accuracy).

[c] A 50-w transmitter for two-way doppler during Ranger 5.

[d] Two-way doppler and command transmitter capability for Ranger missions 4 and 5.

NOTE: In addition to the above capabilities, all stations had angle tracking and readout, one-way doppler measurement and readout, and received signal strength measurement capabilities.

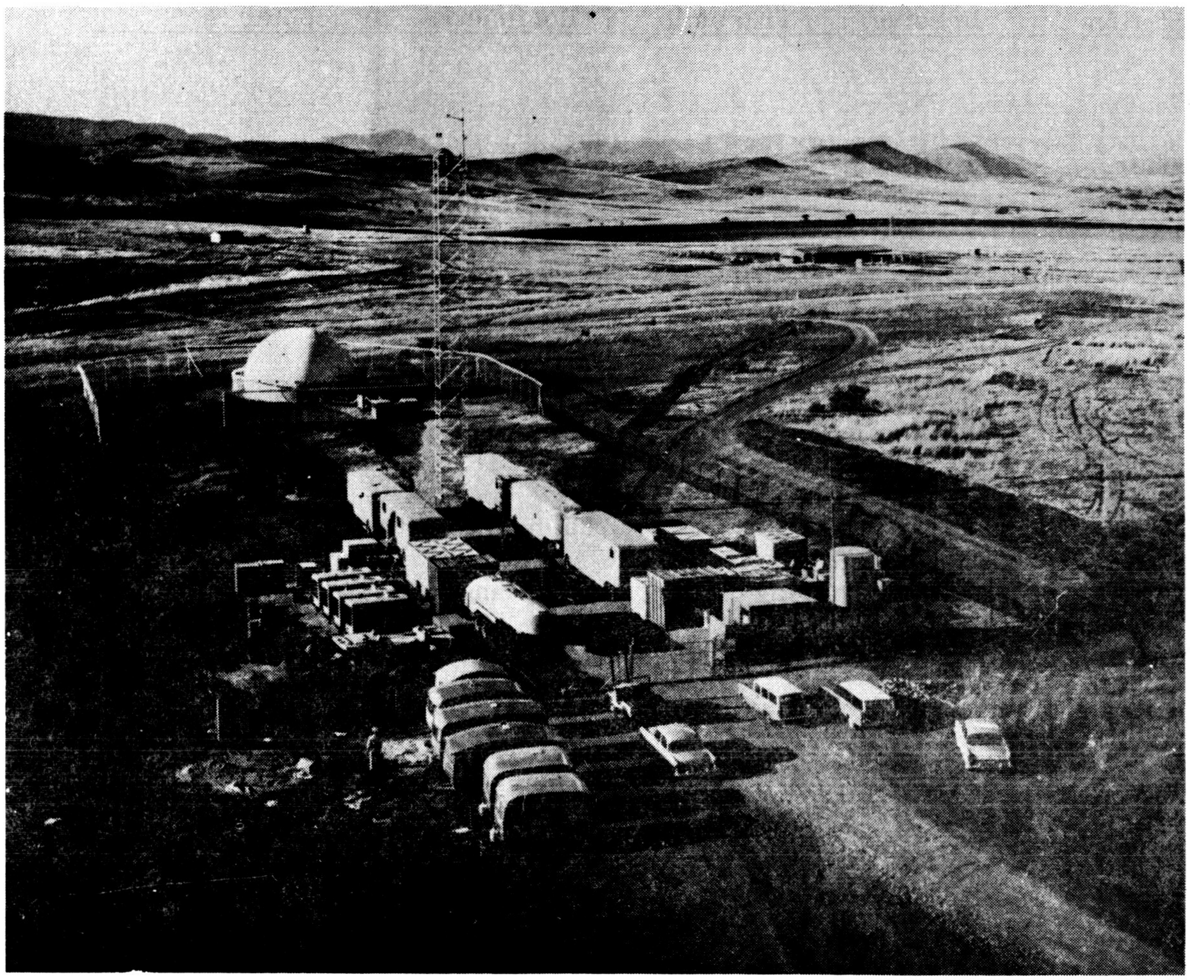

Figure 4-4. Photograph of the Mobile Tracking Station (MTS) located at Johannesburg.

Ranger Tracking and Data Acquisition

Ranger 1. The Ranger-1 mission had the following objectives:

1. To test the basic elements of the spacecraft and DSN

2. To evaluate the performance of and gain experience with the Atlas-Agena launch vehicle.

3. To test spacecraft scientific instrumentation and, on a non-interference basis, measure scientific phenomena along the flight path.

The Ranger spacecraft was simplified for the two test flights in that the landing capsule and its retrorocket were left off. Similarly, the mission itself was much less complex in the sense that there were no midcourse and terminal maneuvers. The flight plan consisted of the launch from Cape Canaveral followed by the injection of the spacecraft-plus-Agena into a 115-mile parking orbit. A second burn of the Agena would next inject the spacecraft into a highly elliptical orbit (788,000 x 4000 miles). Following separation from the Agena stage, the Ranger solar panels would be deployed and spacecraft power system turned on. The attitude-control system would be turned on next so that the spacecraft could turn on its roll axis and acquire the Earth with its optical sensors. The objective was to have the spacecraft coasting with its roll axis pointed at the Sun and its high-gain antenna aimed at the Earth.

In addition to the standard DSN equipment (Tables 4-1 and 4-2), the following mission-dependent equipment was installed for Ranger 1:

- Scientific data teletype converter (all stations)
- Engineering telemetry digital decommutator (Goldstone, Woomera, Johannesburg, and the MTS)
- Precision Doppler system (Goldstone)
- Command coder (Goldstone)

The communications network for Ranger 1 (also Rangers 2 and 3) is shown in Figure 4-5. Note that the teletype and voice links were primarily for tracking and administrative data. Scientific data and engineering telemetry were recorded on tape in these days and shipped back to JPL for processing.

In mid-June of 1961, tests began at DSN stations preparatory to the Ranger flights. Typical of these were star-tracking exercises and tracking-and-data-acquisition tests involving aircraft. The entire DSN was exercised using simulated tracking and telemetry data mailed to each station and then transmitted back to JPL according to a schedule similar to that for a nominal flight.

The actual launch of Ranger 1 took place on August 23, 1961. Due to an Agena malfunction, the spacecraft was injected into a near-Earth orbit

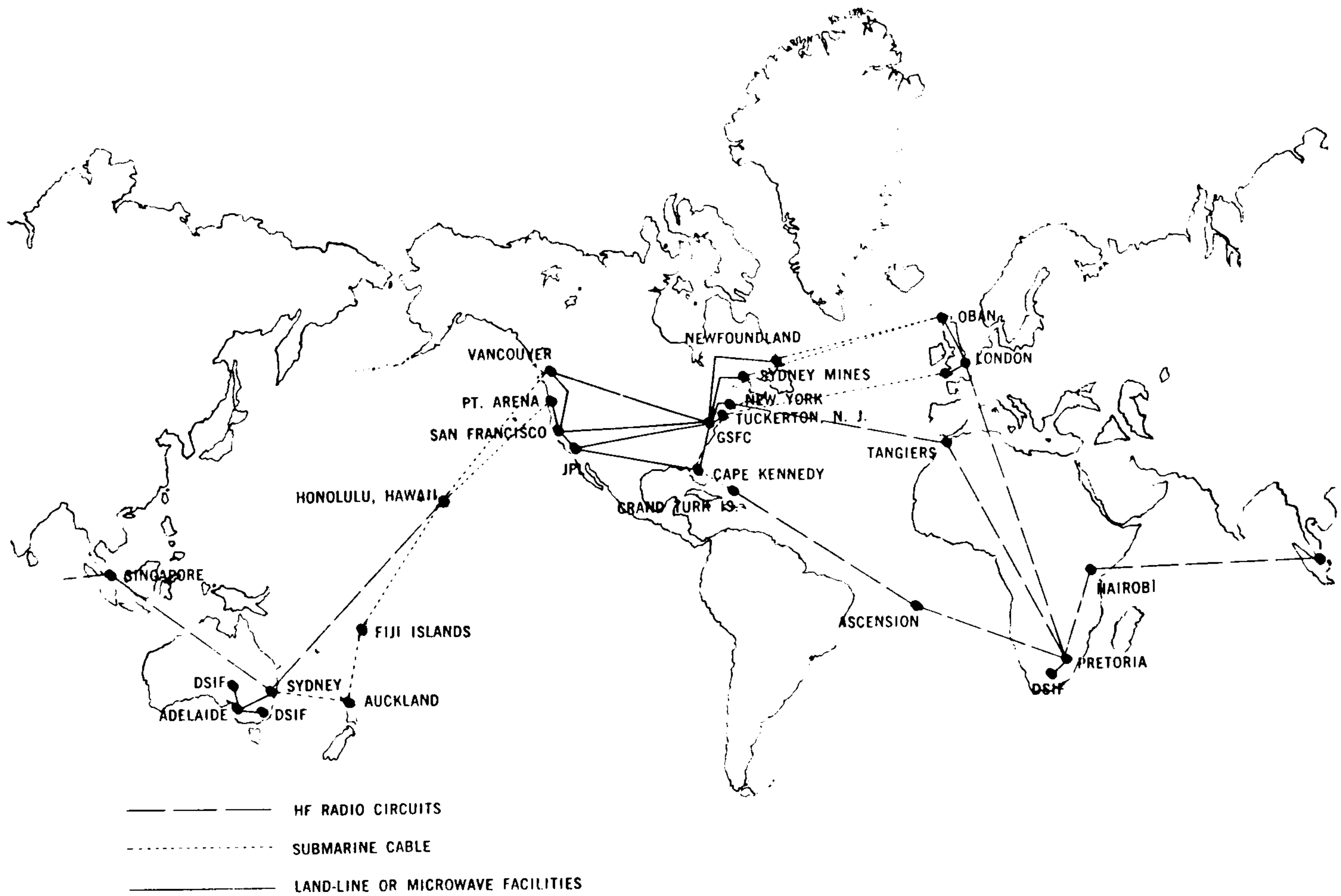

Figure 4-5. Major ground-communication links during the Ranger Program

rather than the planned highly elliptical orbit. After 100 orbits, the spacecraft reentered the Earth's atmosphere on August 30.

The nonstandard orbit attained resulted in tracking rates too rapid for the DSN's polar-mounted 26-m dishes. Consequently, the tracking burden fell to the Goldstone Echo antenna (an AZ-El type) and the similar, but smaller AZ-El antenna at the MTS located at Johannesburg. (See Table 4-1) Despite the spacecraft's high angular speed, the polar-mounted antenna did track it occasionally and did record some telemetry data. The telemetry data confirmed that Ranger 1 was working satisfactorily. Even though the mission was unsuccessful, the DSN did acquire considerable tracking experience and was able to test its procedures for operating a worldwide network for the first time.

Ranger 2. The flight plan for the second Ranger was essentially identical to that for Ranger 1. The configuration of the DSN was likewise identical except for the addition of a mission-dependent teletype converter at Johannesburg. Network tests prior to the launch also paralleled those preceeding Ranger 1.

On November 18, 1961, the Atlas-Agena placed the spacecraft into a 147 x 97 mile parking orbit---a satisfactory result. However, the Agena second burn did not occur when the time came for the injection into a highly elliptic orbit. In addition, the Atlantic Missile Range (AMR) telemetry records indicated that the Agena was rolling at an excessive rate. During the second pass over the Cape, telemetry confirmed that the Ranger had separated from the Agena. This fact had been suspected when the spacecraft's signal was acquired by the MTS as it came over the horizon at Johannesburg. The spacecraft's angular motion was so rapid that it must still have been in its parking orbit. The MTS did acquire some data, but none of the other stations was able to do much with the fast-moving spacecraft. After its fifth orbit, even the MTS could not acquire it. The spacecraft reentered the next day, November 19. The DSN was not designed to track fast-moving spacecraft in Earth orbit; consequently few data were acquired under these very difficult conditions.

Ranger 3. Ranger 3 was scheduled for lunar impact. The spacecraft and mission were both more complex than their two predecessors. The scientific and engineering goals were:

1. To obtain close-up photographs of the lunar surface

2. To collect gamma-ray data between Earth and Moon and in the vicinity of the Moon

3. To acquire seismic data from the hard-landed capsule

4. To gain experience with midcourse and terminal maneuvers

5. To test spacecraft technology

The spacecraft carried the instrumented capsule and its retrorocket on this flight, as well as a protective thermal shroud that had to be ejected at the conclusion of the first Agena burn. The mission design was similar to that of the first two Rangers except that instead of injecting the Ranger into an elliptical Earth orbit, the second Agena burn would send it out on a lunar transfer orbit. The deployment of spacecraft appendages and acquisition of Earth and Sun were similar. The midcourse correction maneuver was a new requirement, one which had to work if lunar impact was to be attained. Here, the spacecraft had to relinquish its lock on Earth and Sun, supply the thrust specified by command from Earth, and then reacquire Earth and Sun. When approaching the Moon, the spacecraft upon receipt of terrestrial commands had to point the vidicon camera at the Moon and orient the capsule for ejection, maintaining, of course, lock on Earth with the high-gain antenna. The retro-rocket included to slow down the instrumented package would be fired automatically upon signal from the spacecraft radar altimeter. Obviously, Ranger 3 was a most ambitious enterprise in terms of the technology of the day.

No major changes were made in the configuration of the DSN for this mission, although some additional mission-dependent equipment was added. Prominent among these additions were acquisition aids. An L-Band acquisition aid installed at Johannesburg, consisting of a quad-helical array, provided for the automatic acquisition of a spacecraft by the 26-m antenna when acquired by the broad-beam acquisition aid.[9] This experiment was also to supply design data for an S-Band acquisition aid that would be needed when the DSN switched over to S-Band in the future. Another acquisition aid was added at Woomera to accommodate the wide variety of trajectories possible with Ranger 3. Some vidicon experiment equipment was added in a rented trailer at Goldstone for this and later Rangers. The ground communications network remained unchanged for Ranger 3, except that a new link had to be connected to a backup computer at Space Technology Laboratories, replacing the one at Rand Corporation.

The launch of Ranger 3 occurred on January 26, 1962, and once more troubles cropped up. A failure of the Atlas ground-based guidance system resulted in a tardy liftoff, an error that could not be corrected by modifying the Atlas sustainer burn. The two programmed Agena burns followed, but they were not able to compensate for the excess velocity accumulated at launch. The spacecraft midcourse maneuver was likewise inadequate. As a result, Ranger 3 arrived at the Moon 14 hours ahead of schedule and passed in front of it, missing it by 22,862 miles.

An interesting facet of this story transpired when it was recognized that no conceivable midcourse maneuver could produce a lunar impact. The next thought was to acquire some good vidicon pictures of the Moon as the spacecraft sped in front of it. The midcourse maneuver was planned with this in mind. The command was duly sent and properly executed. The direction

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[9] This eliminated the need for the MTS, which was decommissioned at the conclusion of the Ranger Program.

of the trajectory change, however, was opposite from that expected. It developed that a command sign convention was ambiguous and had been interpreted differently by the spacecraft and attitude-control people. Even if the spacecraft had been on target, this error might well have caused mission failure. Thus a serious error was discovered and some positive good extracted from a failure. To end the tale of Ranger 3, commands were sent to the spacecraft as it neared the Moon to point the vidicon at its target. At this point, something happened to the attitude-control system, the spacecraft began tumbling and was lost.

The DSN had no trouble in acquiring Ranger 3, even though the AMR was not able to supply downrange tracking data due to ground-equipment failures. Personnel at the operations center in Pasadena generated acquisition information using the known launch time and assuming a nominal trajectory.

First acquisition was at the MTS and then, one minute later, at the Johannesburg 26-m paraboloid station. Woomera and then Goldstone acquired Ranger 3 as it began its long flight to the Moon. By the time Ranger 3 was acquired by Goldstone, it had become obvious that the trajectory was such that the spacecraft not only would not hit the Moon but would not fly past it during a Goldstone tracking period. Since only Goldstone had video equipment, this seemed to preclude the receipt of photographs of the lunar surface.

It was at this point that the decision was made to use a midcourse maneuver to alter the trajectory so that Ranger 3 flew past the Moon during a Goldstone view period. As mentioned above, the correction was in the wrong direction. The subsequent failure of the spacecraft attitude-control system during the terminal maneuver created serious tracking and data acquisition problems for the DSN. To try and regain control of the spacecraft, the transmitter power at Goldstone was increased from 200 w to 7 kw. Over 200 commands were sent to the spacecraft without any apparent effect. At the end of the Goldstone tracking period on January 31, the Echo station ceased its Ranger-3 support activities. The DSN had tracked Ranger 3 out to 560,000 miles.

Generally, telemetry reception at the DSN stations was very good except, of course, when Ranger 3 began tumbling near the Moon. A signal strength problem was detected at Goldstone, when there was an 8- to -10 db difference between the Pioneer and Echo stations. Investigation indicated that this was likely due to a combination of three things: incorrect cable calibration, inadequate procedures in setting parametric amplifier gain, and the use of a transponder with incorrect dial calibration.

Several equipment failures occurred at various spots around the network, but these were either corrected in time or replaced with a backup system so that DSN performance was not seriously impaired. For example, the Goldstone Pioneer station's parametric amplifier failed, but a new unit was substituted in time to resume tracking during the next period. The Woomera engineering telemetry encoder failed on January 27, but a substitute scheme of recording data was rushed into action.

Ranger 4. The mission objectives here were identical to those of Ranger 3. Similarly, the DSN, including the ground communications, were essentially unchanged.

In early April 1962, preparations began on the DSN for the upcoming flight. These included the usual maintenance, checkout, star tracks, boresight vs. polarization tests, and the extensive schedule of adjustments and calibrations required by a machine as complicated as the DSN.

Ranger 4 left the launch pad at Cape Canaveral April 23, 1962. AMR equipment and the DSN Launch Station successfully tracked the spacecraft down along the range. During this portion of the flight, telemetry signals confirmed that the spacecraft was operating normally. At launch plus 460 sec., the Launch Station lost the spacecraft signal as Ranger 4 headed toward Johannesburg. About 17 min. later, the MTS, still stationed at Johannesburg, picked up the Ranger-4 signals. It was immediately evident that something had happened while the spacecraft was out of touch over the Atlantic. One telemetry channel was lost and so was modulation on others. The signal level was also varying wildly. Worse yet, commands to the spacecraft to switch over to the high gain antenna were unsuccessful. Thus, no further engineering or scientific telemetry could be gathered.

The DSN was able to track the Ranger-4 transponder signal until the batteries ran down 10-1/2 hours after launch. (Obviously, the solar panels could not be errected and oriented toward the Sun with the command system out.) The signal from the instrumented capsule aboard the spacecraft could still be heard, however, and the network was able to follow it until two minutes before the craft passed behind the Moon April 26.

The United States subsequently claimed that the spacecraft impacted on the far side of the Moon, but the Russians claimed that it did not. Goldstone Doppler data, which was necessarily one-way Doppler data due to the transponder loss, was sufficient to prove that impact had indeed taken place.[10]

Ranger 5. The Ranger-5 spacecraft duplicated Rangers 3 and 4; the assigned mission was likewise the same. While the same DSN stations supported Ranger 5, some important changes had transpired in the areas of ground communications and computing.

Rangers 1 through 4 had shown a need for improvements in communications switching. Switching cords had been in use at the Pasadena Communications Center, and they had proven slow and error-prone. The early Ranger flights had also demonstrated the need for better communications control. Consequently, before the Ranger-5 launch, the JPL Communications Center was reconfigured. A separate Communications Control Room was built and push-button switching was installed, eliminating the troublesome cords.

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[10]T. W. Hamilton, personal interview, April 15, 1975.

Another change was the introduction of wooden prototype television consoles of the type planned for the SFOF (Space Flight Operations Facility) being constructed at JPL.

Ranger 5 brought another problem: the simultaneous support of more than one spacecraft (Mariner 2 in this instance). The three-day Ranger flights had seriously fatigued DSN personnel. With the months-long flight to Venus coming up as well as multiple missions, changes had to be made. One response to the problem was the appointment of a full-time communications operation supervisor in mid-1962.

Another significant change accomplished prior to Ranger 5 was the computerization of a great deal more mission data handling. During the early Ranger flights, each station recorded the telemetry received on tapes which were then mailed back to JPL. The delays involved were unacceptable. An attempt to process scientific telemetry at the stations was made during Ranger 1 and 2. This involved demodulation, decommutation, conversion from binary to octal, and the transmission back to JPL in nonreal time via teletype. However, realtime data were wanted, particularly engineering data relative to the health of the spacecraft. Therefore, JPL installed a dual computer setup involving the newly acquired IBM 7090 and a PDP-1 computer. The PDP-1 was attached directly to the teletype lines, generating decommutated scientific and engineering telemetry on tapes. (Its core was split to handle Ranger 5 and Mariner 2 simultaneously.) The reels of tape were hand-carried to the 7090 for processing. Tracking data came in on a separate teletype line, were punched on paper tape, and converted into IBM cards for the 7090. This approach worked very well.

With these changes, the DSN was ready for Ranger 5[11] although it was already tracking Mariner 2 which had been launched toward Venus on August 27, 1962. This fifth craft in the series was launched October 18, 1962. The boost phase appeared normal up through the loss of lock by the Launch Station 458 sec. into the flight. Both firings of the Agena also appeared satisfactory. Approximately 31 minutes after launch, the MTS at Johannesburg acquired Ranger 5. The Johannesburg 26-m antenna followed suit almost immediately. About 46 minutes after launch, the spacecraft was picked up at Woomera. Half an hour later, the mission started to go badly. Telemetry showed that the solar panels had opened properly but that they were not generating the power they should. Due to the limited life of the spacecraft battery, JPL's Spacecraft Data Analysis Team recommended that the midcourse maneuver be tried ahead of schedule. The commands were sent but it was too late because the maneuver could not be completed due to the dead batteries.

Following the unsuccessful attempt at a midcourse, the DSN occasionally picked up the spacecraft transponder signal. As with Ranger 4 more

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[11]Note that the tracking stations were referred to collectively as the DSIF (Deep Space Instrumentation Facility). When the term DSN is applied here, it means the DSIF plus ground communications and data processing and display.

success was had with tracking the transmitter signal from the instrumented package. On October 21, Ranger 5 was occulted by the Moon after hurtling 450 miles above its surface. The spacecraft signal reappeared quickly as Ranger 5 went into a heliocentric orbit with a 366-day period. On October 30, the capsule signal disappeared and the DSN broke off tracking.

The DSN had performed well, as it had during the preceding four Ranger flights. It would be more than a year before the DSN would again see Ranger spacecraft, and it would be these flights that would finally bring success to the program.

Legacy of the First Five Rangers. The first Rangers were the first spacecraft to be tracked by the new worldwide network. The excellent performance record of the DSN proved that the concept of an internationally managed network was sound. From the technical point of view, the value of continuous communication between spacecraft and network stations was amply demonstrated in terms of spacecraft control, collection of scientific data, and the conservation of spacecraft weight by shifting the communication burden to ground stations. The Ranger experience also initiated some shifts in emphasis in network design:

1. Engineering data should be relayed back to JPL in near real-time.

2. Preflight checkouts should be more frequent and more comprehensive.

3. Spacecraft signal acquisition early in flight should be expedited by acquisition antennas and flight-path predictions.

4. Semiautomatic monitoring of DSN station performance should be increased.

5. SFOF performance should likewise be monitored more carefully.

6. Failure-free network operation is impossible, but failures can be made inconsequential by good engineering.

The Atlas-Centaur

The Atlas-Centaur launch vehicle was a vital element in NASA's launch-vehicle program. With a high energy upper stage (liquid hydrogen), Atlas Centaur was scheduled to propel the Surveyor soft landers to the Moon. Because the DSN supported most of the Atlas-Centaur test flights, this program is a logical part of the network history.

The Centaur Project originated in 1958 at ARPA, with the Air Force undertaking the actual development. On July 1, 1959, however, program responsibility was transferred to NASA. Within NASA, development responsibility was first assigned to the Marshall Space flight Center. The first launch, which took place on May 8, 1962, was a failure, with the vehicle being destroyed by the Range Safety Officer after 55 seconds of flight. Thus, time-wise, the Atlas-Centaur overlapped the Block-II Rangers and belongs logically in this chapter, even though the DSN did not happen to support the first test flight. If the Atlas-Centaur Program had proceeded according to plan, there would indeed be some DSN-supported flights for this Chapter. The Program, however, underwent a long reappraisal after the first failure, and was reassigned to the Lewis Research Center. With all the delays that ensued, the second test launch did not come to pass until November 27, 1963, which puts it well after Mariner 2 and into the next chapter. In the history of a technical enterprise as massive and complex as the DSN, chapter boundaries are bound to be imperfect.

Concurrent Technical Developments

Operational efficiency demanded that the DSN remain relatively static during the early Ranger flights; the network was in a sense the captive of the spacecraft program. In the background, however, several elements of tracking and data acquisition technology were maturing. In 1961 and 1962, the DSN was striving for:

1. Greater sensitivity and lower noise temperatures to permit the network to handle the more distant planetary missions planned for the future.

2. Greater ground transmitter power to command these spacecraft.

3. More accurate tracking technology.

4. Higher capacity, worldwide ground communication circuits operating in near real time.

5. More computerization of data processing and display.

6. Higher operating frequencies.

L-S Band Conversion. NASA and JPL engineers had long recognized the fact that the L-Band frequencies (about 960 MHz) used for Ranger and the first Mariners was an awkward place to be. Not only was cosmic noise relatively high (Figure 4-6) but manmade noise was also considerable. Furthermore, NASA was using the L-Band on a temporary, noninterference basis. The L-Band was not among the frequency bands set aside for space research by the 1959 Geneva International Telecommunications Union agreement. Rather, JPL was operating at the lower edge of a TACAN band and was in danger of being pushed out by airline (FAA) and military transmitters.

NASA studies had shown that the region between 1,000 and 10,000 looked good for deep space work, with the upper limit being set by the

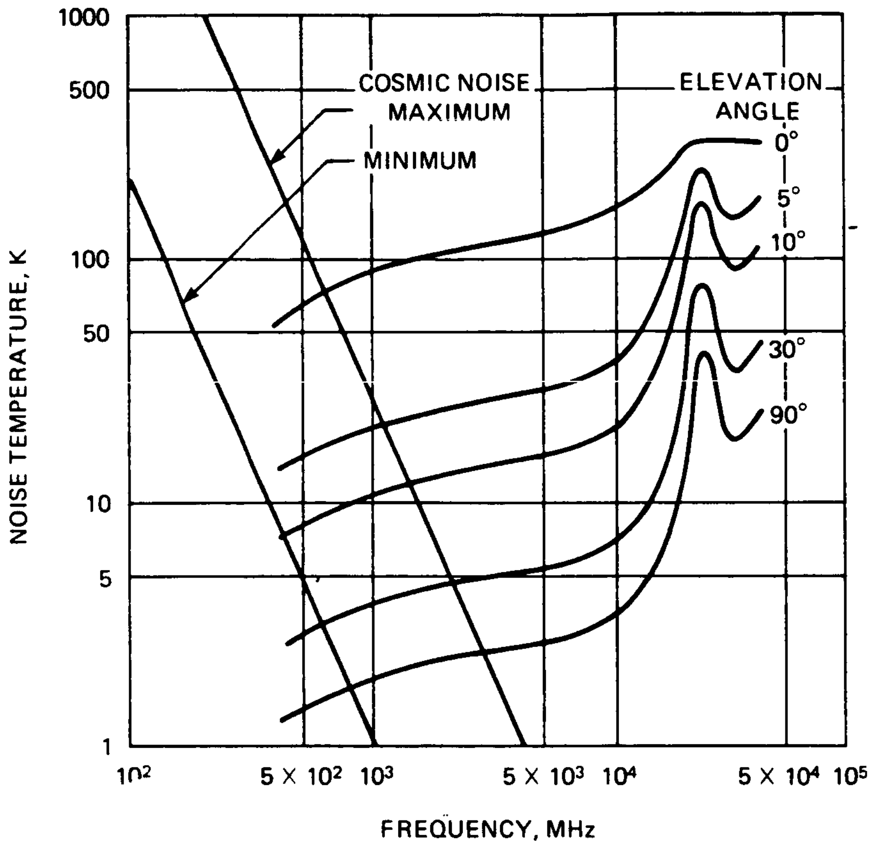

Figure 4-6. Typical radio noise temperatures.

absorption of water vapor in the atmosphere. One of several moves in the direction of higher frequencies came early in 1960 when JPL was encouraged to develop the technology necessary to operate the network at higher frequencies.[12] In mid-1962 Rechtin, in view of improvements in S-Band components, recommended that the whole DSN be switched over to the higher frequencies. By late 1962, preliminary designs had been completed and work on conversion began in earnest. JPL's goal was to fully convert the DSN with the two 1964 Mariner flights to Mars (Mariners 3 and 4). By the summer of 1963, an S-Band maser for the ground stations was available as were the antenna cone, the feed, and subreflector. The problem now hampering the band change was the stretched-out Ranger flights scheduled into early 1965. Then, too, Mariner 2, already out in space, was an L-Band spacecraft that might have an active life of a year or more. Some sort of dual-frequency system had to be worked out whereby both L-Band and S-Band spacecraft could be supported

[12] W. L. Ikard, "Frequencies for Deep Space Communications," Memorandum for Assistant Director, Space Flight Operations, May 13, 1960. Actually, JPL would have liked to operate the Rangers in the S-Band (2300 MHz) but no reliable travelling wave tubes or masers were at hand.

at the same time. Only then could there be an orderly shift to S-Band. This L/S Conversion Project, as it was called, came into being during 1963 and is described in Chapter 6.

Frequency Standards and Doppler Accuracy. The accuracy of Doppler measurements is strongly affected by the natural drift of the frequency standards employed at the DSN stations. The Rangers inaugurated the use of crystal-controlled oscillators. But even with these relatively stable time-keepers, frequency drift during the round-trip signal time to the Moon and back was enough to cause large navigational errors. As soon as this situation was recognized, Rechtin, at JPL, ordered a crash program to install temperature-controlled oscillators.[13] Even so, it was recognized that with a Mariner in the vicinity of Venus, much greater stability would be required due to the much longer round-trip signal times. The atomic oscillator seemed to be the answer, and JPL began plans to install such frequency standards for the 1962 Mariner flights.

To give the reader some idea of the magnitude of improvement occasioned by the new frequency standards, the precision crystal oscillator used for Ranger 1 improved Doppler accuracies from tens of meters per second to tens of millimeters per second, a thousand-fold improvement. The rubidium-vapor frequency standard installed at Goldstone in 1962 for the Mariners had a frequency stability of 1×10^{-11} and improved Doppler accuracy from 50 to 5 millimeters per second.

Building the SFOF. The control center employed during the early Ranger operations was makeshift, and its shortcomings stimulated thoughts about a more permanent and comprehensive solution to the problem of mission control. In February 1961, Pickèring at JPL formed a committee to assess the future mission requirements and recommend a more effective way to present data being received from the DSN to mission controllers. The committee recommended an entirely new building, later called the SFOF (Space Flight Operations Facility). NASA headquarters approved the construction of the new building on July 21, 1961.[14] As noted earlier in this chapter, various ideas potentially applicable to the planned SFOF were tried out during Ranger operations.

DSN at Mid-Ranger. As 1962 drew to a close, the DSN was in a state of transition. Several new technologies were clamoring to be incorporated in the network, but the L-Band projects still underway prevented any wholesale changes. Mariner 2 had been successfully launched and was on its way to a rendezvous with Venus (see next chapter) but, with the exception of this spacecraft, 1963 presented the DSN with a lull in operations. Here was an opportunity to push ahead with the expansion and improvement of the DSN.

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[13] T. W. Hamilton, personal interview, April 15, 1975.

[14] T. Cargill Hall, "Lunar Impact: History of Project Ranger" unpublished, Chapter 7.

Chapter 5. THE L-BAND NETWORK---CONTINUED

With the launch of Mariner 2 in August 1962, the DSN began tracking its first truly interplanetary spacecraft. The distances involved in tracking and data acquisition were multiplied more than a hundred times over the Earth-Moon distance. The DSN met the new challenge mainly through increasing transmitter power (200 w to 10 kw), uplink and reduction of the system noise temperature (200°K to about 50°K at Goldstone only) on the downlink. The interplanetary flights were, of course, measured in months rather than days, as in the case of Ranger. The way in which the DSN operated had to be modified for long-term tracking and, in addition, the impact of concurrent missions---the Mariners, the remaining Rangers, and the Atlas-Centaur flights.

The Mariner Mission

When NASA's first planetary programs were laid out in 1960, NASA hoped to take advantage of the 1962 launch windows to send probes to both Venus and Mars. These were the so-called P-37 and P-38 missions. Mariner A was slated for Venus and Mariner B for Mars; both were to employ the new Centaur upper stage. But the Centaur schedule had slipped badly, as indicated in the preceeding chapter, and by August 1961 it was generally agreed that Centaur would not be ready for the 1962 planetary probe launches. Yet, it was deemed very important politically for the U. S. to demonstrate its growing space capabilities, vis-a-vis the Russian's, by launching interplanetary payloads in 1962---the next launch windows in 1964 were considered much too far away.

JPL offered a solution in a letter to NASA Headquarters on August 28, 1961. [1] JPL proposed a Venus mission using the Atlas-Agena used for Ranger and a hybrid (and much smaller) spacecraft based on the Ranger and Mariner-A designs. The new vehicle was termed Mariner R (the "R" stood for Ranger). Two of them were to be launched, R-1 and R-2. The time between the new project go-ahead and launch was less than a year. NASA Headquarters bought the idea.

Project organizations were formed quickly at JPL and NASA Headquarters as well as at the Marshall Space Flight Center (responsible for the launch vehicle), the Department of Defense, and various contractors. Within JPL, the organization of the tracking and data acquisition function remained essentially the same as it had been for Ranger. With such an

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[1] Jet Propulsion Laboratory; "Mariner-Venus 1962, Final Project Report," (Washington: NASA SP-59, 1965) p. 11.

urgent project, frequent meetings of management and various coordination panels were essential. Division 33 personnel attended the weekly internal JPL project meetings and played key roles in the various boards, working groups, panels, etc., and in particular the Tracking, Communication, In-Flight Measurements and Telemetry Panel. [2]

The function of the DSN during Mariner flights was to obtain angular and Doppler measurements to fix spacecraft trajectory, receive telemetry, and dispatch commands to the spacecraft. The DSN was originally assigned to work the Mariner spacecraft continuously during the critical periods of the flights: launch through midcourse maneuver plus two days and 24 hours before and after encounter with Venus. At other times, coverage was supposed to be 10 hours per day. It was stipulated that the DSN be prepared to provide full coverage in engineering and/or scientific emergencies upon 6-12 hour notice. The possibility of competition for DSN services during upcoming Ranger shots was recognized, but the problem was left for resolution when it occurred.

The Mariner-2 DSN Configuration

No one entertained any thought of radically changing the DSN for the new crash project. Indeed, it had to remain fairly static for Rangers 5 through 9, and for that matter Mariner R drew so much technology from Ranger that DSN antennas really saw the new Mariners as much more distant Rangers. The DSN stations active during Mariner 2 were as follows:

DSIF 0	Launch Station, Cape Canaveral
DSIF 1	MTS (Mobile Tracking Station), near Johannesburg
DSIF 2	Pioneer station, Goldstone
DSIF 3	Echo station, Goldstone
DSIF 4	Woomera
DSIF 5	Johannesburg

The new numbers assigned to each station were ephemeral, for a new set of two-digit numbers would soon replace them. (See Chapter 6)

The Launch Station located at the Cape near Launch Complex 12, was essentially the old Ranger Launch Station, but it was now christened the SMS (Spacecraft Monitoring Station). It possessed a 6-ft. dish antenna plus various support equipment for checking out and following the launch of the spacecraft. The MTS during Mariner 2 was located one mile east of the Johannesburg DSN station. As during Ranger, the MTS was used primarily as an acquisition aid and for tracking and data acquisition during the critical injection phase of the deep space missions. This mission phase transpired over Johannesburg but at such high angular velocities that the big 26-m dish

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[2] N. A. Renzetti, "Tracking and Data Acquisition Support for the Mariner Venus 1962 Mission," (Pasadena: JPL TM-33-212, July 1, 1965) p. 23.

could not follow the spacecraft well. Goldstone-Echo and Johannesburg were equipped with the new 10-kw transmitters for long-distance command of the Mariners. (Table 5-1) During Mariner 2, Johannesburg and Woomera had low-noise parametric amplifiers providing system noise temperatures of about 200°K. Maser amplifiers had been installed only at the two Goldstone stations, yielding system noise temperatures of about 50°K. These masers gave Goldstone an unparalleled capability to hear faint spacecraft signals amidst background noise.

As usual with a launch from the Cape, downrange DOD stations contributed early tracking data to JPL. On Mariner 2, AMR stations on Antigua and Ascension sent real-time data that helped establish the characteristics of the parking orbit. In addition, a new FPS-16 instrumentation radar at Pretoria tracked the Agena after the second burnout.

Mariner was the first mission in which a new DSN Net Control facility functioned as an integral part of the Space Flight Operations Center (SFOC). The purpose of Net Control was to inform the operations manager of the status of each DSN station and, in turn relay messages concerning changes in plans to DSN stations. The new SFOF building was not completed when Mariner 2 was launched, and JPL facilities supporting the flight were dispersed around the Lab. The Central Computing Facility, which reduced the tracking and telemetry data so that command decisions could be made, was located in Buildings 125 and 202. The SFOC was in 125, but the Communications Center was in 190.

As with Ranger, the primary communications links were teletype and voice lines and augmented by airmail for the bulk transmission of scientific data and engineering telemetry. Teletype and voice circuits, shown in Figure 5-1, relayed only the most critical tracking data, commands, acquisition information, and administrative data in real time between DSN stations and the SFOC. The scientific and engineering telemetry was first encoded for teletype transmission and was then sent to JPL in near-real time. The overall makeup of Mariner ground communications necessarily resembled those for the first five Ranger flights.

Summarizing, the major changes over Ranger made in the DSN to support Mariner were the more powerful transmitters at Goldstone and Johannesburg and the Goldstone maser amplifiers.

The Mariner-1 and Mariner-2 Flights; DSN Support

Mariner R carried scientific instruments to make in situ measurements of interplanetary space on its way to Venus. During the encounter phase, its instruments would also measure radiation in the vicinity of Venus, estimate its magnetic field, and analyze its atmosphere with microwave and infrared radiometers. The major maneuvers of the spacecraft following the launch and erection of the probe's appendages were the midcourse maneuver (which aimed it more precisely at Venus) and encounter (which entailed

Table 5-1. DSN CAPABILITIES FOR MARINER 2

Station	Antenna size, ft.	Maximum angular rate deg/sec	Antenna gain (960 MHz), db		Receiver noise figure db	Transmitter power, w	Command capability	Data transmission		Recorded telemetry	Air mail time to JPL, days
			Track	Listen				Angles, doppler	Telemetry		
Mobile Tracking	10 (Az-El)	10	22.2	--	6.3	25	No	Real-time	None	Yes	7
Goldstone Pioneer	85 (HA-Dec)	0.7 (both axes)	43.5	45.5	0.6		No	Real-time (doppler only)	Real-time	Yes	1
Goldstone Echo	85 (HA-Dec)	0.7 (both axes)	43.5	46.0	NA	200/ 10 kw	Yes	NA	NA	Yes	1
Woomera	85 (HA-Dec)	0.7 (both axes)	43.5	46.0	1.8	50	No	Real-time	Near real-time	Yes	7
Johannesburg	85 (HA-Dec)	0.7 (both axes)	43.5	46.0	1.8	200/ 10 kw	Yes	Real-time	Near real-time	Yes	7

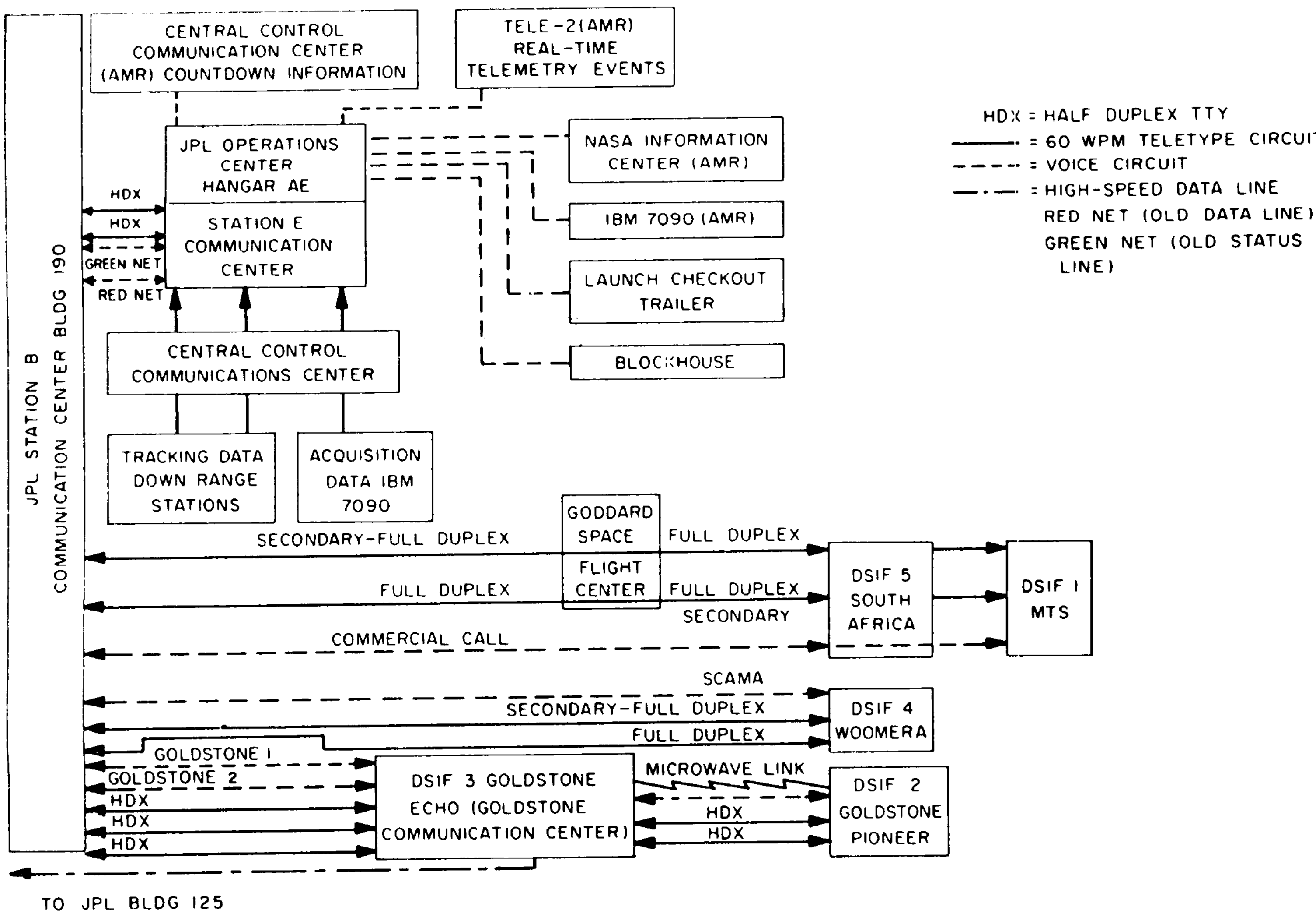

Figure 5-1. Ground communications during Mariner-2 flight.

pointing the pertinent scientific instruments at the planet so that they could scan it). The latter maneuver had to be directed by commands sent from Earth, then about 36 million miles away. The data taken during encounter then had to be sent across the same distance by the spacecraft's 3-w transmitter at the very slow rate of 8.33 bits/sec.

The Mariner spacecraft were shipped to the Cape the first week of June 1962. By mid-July, all seemed in readiness for the planned pair of launches. DSIF Network Integration tests began on July 16 and, by the 19th, the DSN was ready. The first launch attempt, however, was postponed when difficulties cropped up during the countdown. With AMR facilities and the DSN Launch Station tracking it, Mariner 1 lifted off on July 22, 1962. It only advanced a few minutes into its flight plan when the Range Safety Officer had to destroy it. There had been a defective signal from the Atlas booster and the omission of a single symbol from the computer program of the ground-based guidance system.

Mariner 2, however, was favored with success. There was a short launch postponement while the defects of the Mariner-1 flight were remedied, but on August 27 the Atlas-Agena put Mariner 2 into a 115-mile parking orbit. The DSN Launch Station along with AMR equipment followed the spacecraft until it was lost over the horizon and passed on to downrange AMR stations. The spacecraft-plus-Agena coasted in the parking orbit until 24 minutes after launch when the Agena injected the spacecraft into the transfer orbit to Venus. (Figures 5-2 and 5-3) The MTS acquired Mariner 2 approximately 28 minutes after launch; Johannesburg followed 3 minutes later.

As Mariner 2 headed out into interplanetary space, the DSN's 26-m dishes began to feed precision tracking data back to JPL. Calculations indicated that the craft's uncorrected course would miss Venus by 233,000 miles---too much for the experiments planned at encounter but still within the capacity of the onboard propulsion system to correct. On September 9, nine days after launch, punched tapes containing the midcourse maneuver commands were fed into an encoder at Goldstone. The maneuver, which required 3.75 hours to complete, was executed while Mariner 2 was 1.5 million miles from Earth.

The midcourse maneuver was successful. DSN tracking data acquired over the next few days established that the new miss distance would be about 40,000 miles.

Mariner 2 was now falling in toward the Sun. Ninety-one days after launch, Mariner 2 was 22.5 million miles from Earth, setting a new DSN communications record. As Venus and the Sun drew closer and closer, spacecraft problems began to mount as the temperatures on board climbed and equipment overheated. The biggest loss was the spacecraft's capability to begin encounter operations. Happily, a backup scheme had been devised, and the required command was transmitted from Goldstone on December 14 across the 36 million miles now separating the spacecraft from Earth. The backup plan worked and the instruments began scanning Venus. Altogether, Mariner 2 sent back 11 million data points.

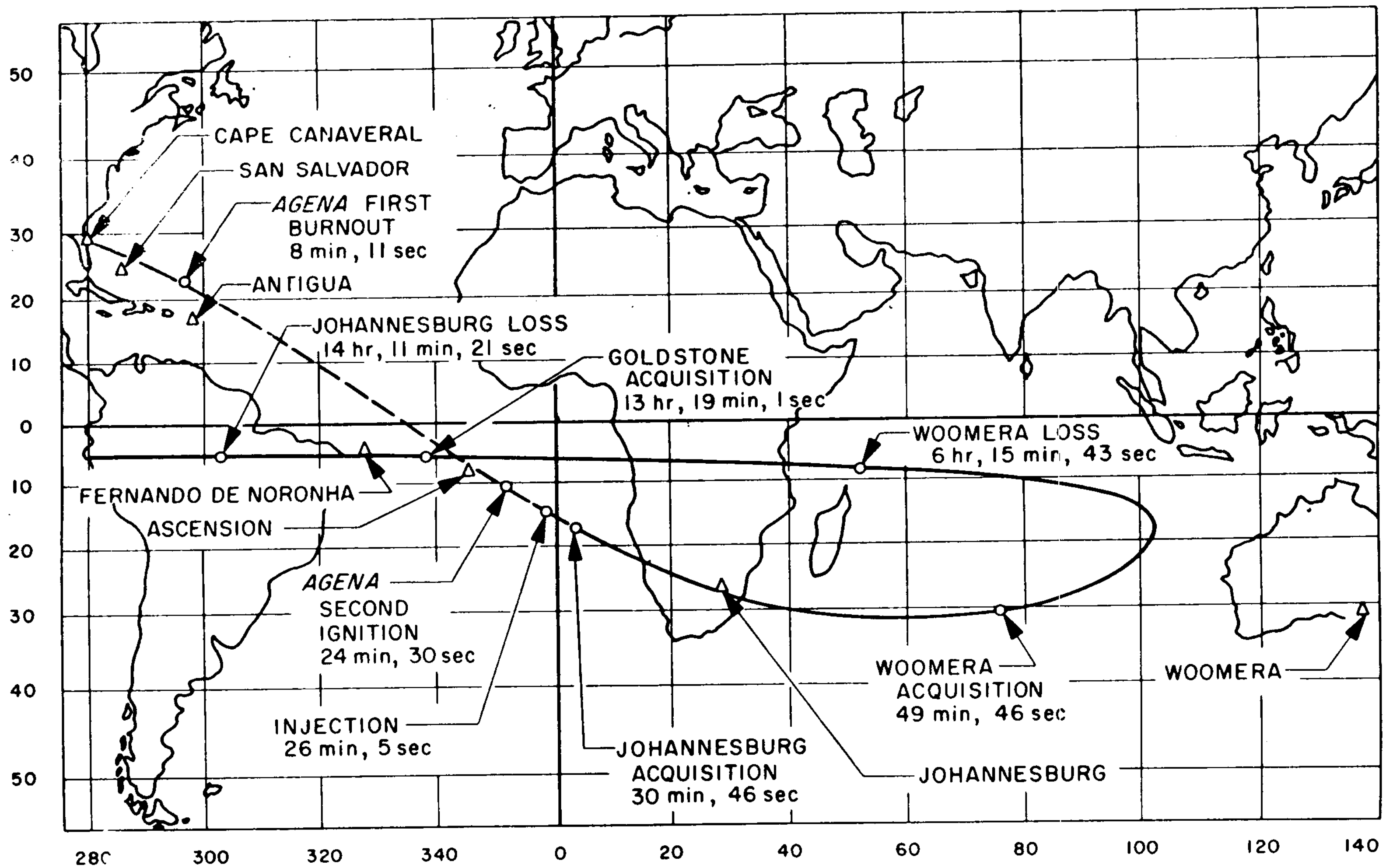

Figure 5-2. Mariner-2 Earth track.

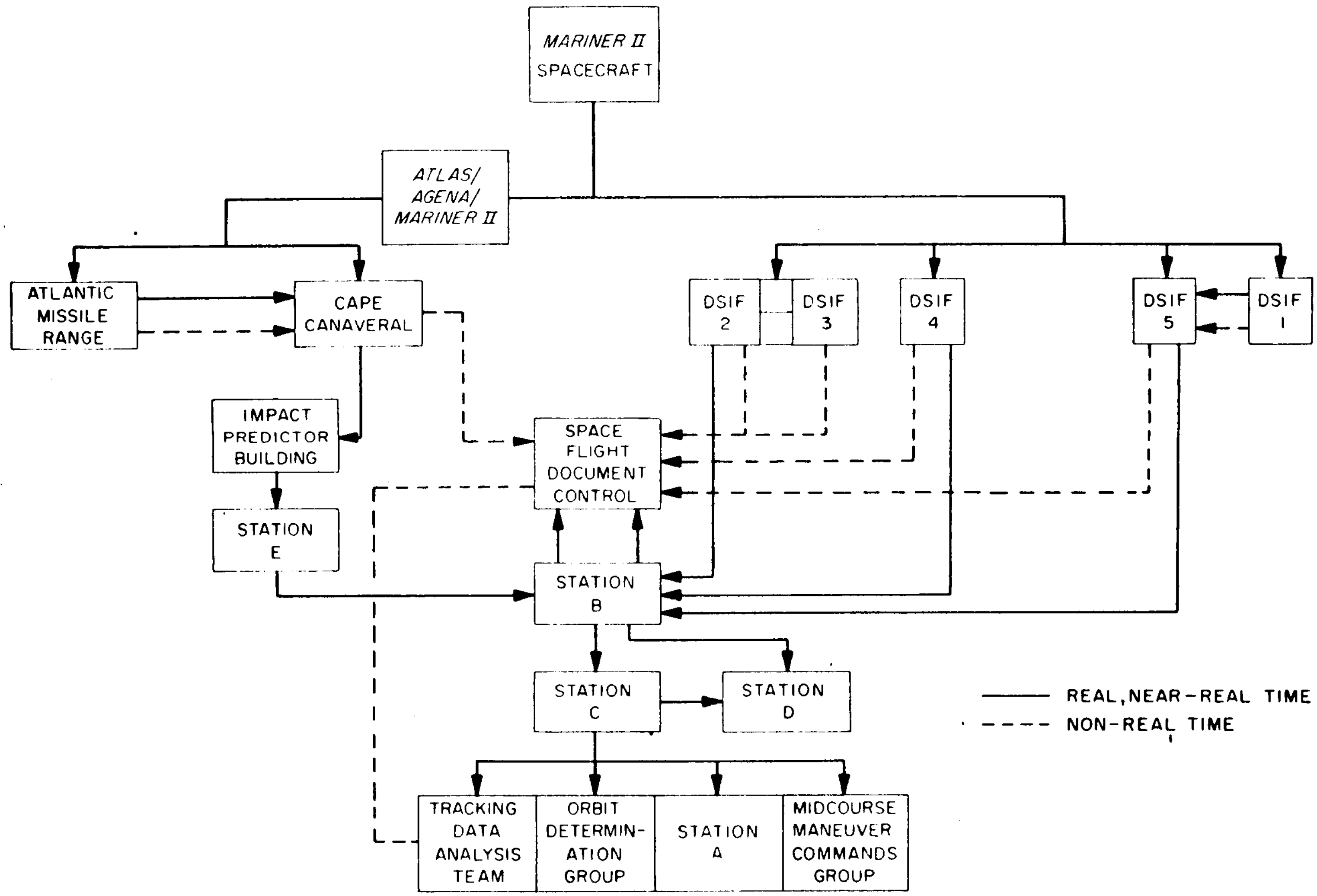

Figure 5-3. Tracking data flow during Mariner-2 flight.

After encounter, Mariner 2 went into orbit around the Sun. On January 2, 1963, when 54 million miles from Earth, signals from Mariner 2 ceased.

The DSN had been scheduled for continuous tracking during the more critical phases of the Mariner-2 mission only. However, on September 16, 21 days after launch, it was put on full-time tracking for the remainder of the mission. During this period the DSN logged more than 3000 hours of uninterrupted support of the mission. Considering the complexity of the DSN and its supporting communications and control equipment, this was a remarkable record. Despite this achievement, post-mission study of DSN support revealed several areas needing improvement:

1. The parametric amplifiers, one of the newest subsystems, caused problems at all stations. With its life expectancy of only 1000 hours, failures were inevitable during the 3000-hour mission. In addition to the intrinsic instability and low reliability of the device, DSN personnel were not trained adequately in its operation and maintenance.

2. The recorders built by the Consolidated Electrodynamics Corporation and installed throughout the network failed repeatedly. The manufacturer subsequently beefed-up the design.

3. Mission-unique equipment was frequently unreliable and required excessive maintenance. Spare parts and documentation were also wanting. It should be noted once again, that this problem plagued the DSN until it developed a multimission capability in the late 1960s.

4. Throughout the mission, operator errors indicated that personnel training was insufficient. Every station encountered operator errors and, as a result, lost data.

Such post-mission introspection has been the habit of the DSN and has contributed greatly toward its ever-increasing ability to support a variety of missions in the farther reaches of the solar system.

Block-III Ranger Operations

The last four Rangers were launched over a period of 14 months, beginning January 30, 1964, and ending March 21, 1965. From the political viewpoint, these missions had to demonstrate some success. The reputation of JPL was on the line following the poor showing of the first five Rangers. Mariner 2's successes had been most welcome and had shown that the basic launch-vehicle and spacecraft technologies were not wanting, but Ranger still had to succeed in its own right. The pall deepened when Ranger 6 continued the list of failures. But when Rangers 7 through 9 were spectacular successes, the gloom dissipated almost instantly. This section, then, finally brings the happy ending to the Ranger story.

The DSN had performed well throughout Rangers 1 through 5. Its configuration (Tables 4-1 and 4-2) remained unchanged for the Block-III spacecraft except for the installation of an L-Band maser and special video equipment at Goldstone Echo. The network was, as previously noted, in the process of switching over to S-Band and, if it were not for the stretchout of Ranger, the L-Band equipment would have been taken out of service in 1962. In fact, the Ranger flights marked the end of what was to be called later the "Mark I" DSN, a term essentially synonymous with "L-Band network." The new S-Band or Mark II network was basically in place by mid-1964 and actually supported Mariners 3 and 4, the first S-Band missions, before the final Ranger flight.

Ranger 6. The sole scientific objective of the Block-III Rangers was the securing of close-up television pictures of the Moon's surface to aid the design of the Surveyor and Apollo missions. Despite the payload simplification, the mission was rather challenging for those days. After a brief sojourn in a parking orbit, a second Agena burn would send the spacecraft off toward the Moon. The attitude control system then had to orient the spacecraft so that the solar panels pointed toward the Sun and the high-gain antenna was directed at Earth. The midcourse and terminal maneuvers described for the Block-II Rangers were basically the same for the Block-III spacecraft, except that there was no instrumented capsule to be ejected during the terminal phase.

The DSN began checkout and preparation for the mission during early October 1963. The major tests evaluated network-spacecraft compatibility, network integration, and operational readiness. The launch went smoothly with liftoff the afternoon of January 30, 1964. The Spacecraft Monitoring Station (DSIF 71)[3] at the Cape remained in radio contact for about 8 minutes. During this time, however, the SMS reported that the TV cameras apparently turned on for about one minute three minutes after launch. Johannesburg accordingly was instructed to send up a turn-off command in the event the cameras were on when it acquired the spacecraft. Acquisition at Johannesburg did not take place for more than a half hour after launch. At that time there were no indications that the cameras were on. Woomera confirmed this a few minutes later.

The mission progressed smoothly through the preliminary attitude maneuvers. On January 31, Goldstone initiated the midcourse maneuver. Tracking data following this event showed that the flight was on target for lunar impact and that no further corrections would be needed. On February 2, 19 minutes before impact, TV channel A automatically began to warm up; Channel B went into the warm-up mode 4 minutes later. At impact minus 10 minutes, telemetry should have shown that both of these channels were at full power. Pictures should also be arriving at Goldstone. Neither occurred. Commands were sent to try and force the channels into the full-power mode but to no avail. Impact occurred in the Sea of Tranquility without any pictures being sent.

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[3] Note the new numbering system.

The DSN performed well throughout the mission. It was the DSN, in fact, that provided the only clue as to the cause of the failure of Ranger 6---the apparent momentary turnon of the TV cameras just after launch. One surmise was that the turnon had been triggered accidently and the resultant electrical arcing had damaged the equipment. No conclusive diagnosis was presented by the Ranger-6 review board, although several changes in TV system design and spacecraft testing were recommended.

Ranger 7. Six months later, after in-depth reviews of Ranger 6 and some changes of the spacecraft TV subsystem, another Ranger attempt was made. On July 28, 1964, with DSIF 71 in two-way lock, Ranger 7 was launched successfully. Thirty seconds later, the station lost lock, this was quickly reestablished but unfortunately on a sideband. DSIF 71 telemetry quality was thus poor. Ranger 7 continued without further incident to its parking orbit. The MTS (DSIF 59) at Johannesburg first acquired the spacecraft 30 minutes after launch. The Johannesburg 26-m dish acquired it 1.5 min. later. Both stations had difficulty in establishing a good two-way lock with the spacecraft which was still low and moving fast. Woomera acquired Ranger 7 roughly 49 minutes after launch and achieved the first good two-way lock. This mission proceeded smoothly all the way to lunar impact on July 31, 1964, in the Sea of Clouds about 10 miles from the aiming point. Some 4300 high-resolution photos of the lunar surface were radioed back, some showing objects less than 3 feet in size. Ranger had finally succeeded.

Ranger 8. Almost seven months elapsed between Rangers 7 and 8. The DSN L-Band configuration was retained in the form described in Tables 4-1 and 4-2. The launch of Ranger 8 took place on February 17, 1965 and all maneuvers were performed perfectly. Early tracking data indicated a course that would miss the Moon by 1136 miles. A midcourse maneuver was therefore commanded at 17 hours into the flight. A terminal course correction was not needed. Impact occurred in the Sea of Tranquility 15 miles from the target, 64 hours 53 minutes following liftoff. A total of 7137 pictures were obtained on this flight.

Ranger 9. Ranger 9's launch date was March 21, 1965, a date that had to be met because of the requirements of the lunar launch window and the pressure of the upcoming Gemini GT-3 launch. Liftoff did occur on schedule and all maneuvers were carried out successfully. In fact, the Agena second burn put the spacecraft on a course that would have missed its lunar target, the crater Alphonsus, by only 400 miles. At 38.5 hours into the flight, a small midcourse maneuver corrected the trajectory. Impact took place on March 24, 1965, a split second after the last of 5814 pictures were sent back to Earth. The Ranger Program had been completed and, after much concern, the results turned out to be of immense value scientifically and to those preparing for Surveyor and Apollo.

Some More Ranger Lessons. Just as the first Rangers had taught the DSN several lessons (Chapter 4), so did the Block-III Rangers.

The first involved the lack of diversity in the ground communication links provided by the common carriers. A potentially catastrophic event occurred during the Ranger-8 mission, when 9 out of the 14 circuits leading to JPL were lost. Communications with Johannesburg and the Cape were almost wiped out. It developed that someone near Los Angeles had severed a coaxial cable while digging. All the lost circuits were in that single cable. Fortunately, the interruption occurred in a noncritical phase and the circuits were restored in time for the midcourse maneuver. Under pressure from NASCOM, the common carriers moved to provide the diversity essential to space operations---manned space flight in particular.

A strange inconsistency was discovered in 1965 when the tracking data from Rangers 7 and 8 were used to try and determine the precise positions of DSN stations. No matter how carefully corrections were made a 40-m difference in longitude remained---small but intolerable for precise tracking calculations. An astronomically trained newcomer at JPL finally found the reason---between Rangers 7 and 8 there had been a 100 millisecond change in the universal time reference.

One other potentially catastrophic event occurred on Ranger 9, when DSN transmitters failed during the final half hour before lunar impact. At Goldstone Echo, for example, the transmitter kicked off 10 minutes before impact and the two-way radio lock was lost. Quick investigation revealed an unsoldered wire. No TV pictures were lost, however, because the telemetry received was not dependent on the ground transmitter. The value of thorough training of personnel was underscored in these emergencies. Such experiences during Ranger demonstrated that missions can often be saved if redundancy and flexibility are built into the system and if personnel are resourceful and imaginative.

Atlas-Centaur L-Band Support

The Atlas-Centaur test flights, like the Ranger series, stretched out for several years---4-1/2 years in the case of the Atlas-Centaur. These launch vehicle tests were more flexible than Ranger flights in that the Centaur tracking aids and transmitters could be modified to fit the evolving DSN; there was usually payload to spare. Thus, we find the early Atlas-Centaur shots worked by the L-Band DSN, later flights involved the L-S Band Conversion equipment, and the last vehicles in the series utilized full S-Band support. Only the second and third Atlas-Centaur flights fit the criteria of this chapter; that is, full L-Band support.

Atlas-Centaur 2. The purpose of this flight was to test the launch vehicle and all its subsystems. The 960-MHz beacon mounted in the Centaur upper stage provided a good target for exercising the DSN. The network configuration was basically the same as that during Mariner 2. Table 5-2 gives the tracking

Table 5-2. DSN CAPABILITIES FOR AC-2 AND AC-3

Station	Antenna									
	Type	Reflector size, ft.	Feed	Gain receiving dB	Ellipticity receiving dB	Excess noise temperature °K	Angles & one-way doppler real time	Maximum angle tracking rate deg/sec.	Angular resolution deg.	RMS angular error deg.
Echo DSS 12	HA/Dec	85	Horn	44.5±0.6	0.5 ±0.1	15 ± 8	Yes	0.7	0.2	0.5
Woomera DSS 41			Tracking		2.7±0.1	43 ± 10				
Johannesburg DSS 51					2.7 ±0.1	43 ± 10				
MTS DSS 59	Az/El	10		23.3±0.5	0.6±0.3	100 ± 20		20.0	0.04	0.10
Spacecraft monitoring DSS 71	Az/El	6	Dipole	20.5±0.3	0.4 ±0.3	--	No	Manual	--	--

Station	Receiver						Telemetry	
	Frequency, nominal, MHz	Configuration	System noise temperature with diplexer, °K	Loop noise bandwidths, Hz	Threshold at 20 Hz $2B_{LO}$ dBmW	Input signal level maximum dBmW	Channel 4 discriminator	Tape recorders, 1/2-in.
Echo DSS 12	960.05 ±0.03	With paramp	221^{+11}_{-30}	60±10, 20±4	-165 ±1.5	-65	Yes	FR-107, FR-607
Woomera DSS 41					-162 ±1.5			CEC-5-752
Johannesburg DSS 51					-162 ±1.5			CEC-5-752
MTS DSS 59		W/O paramp	1132^{+73}_{-75}		-155 ±1.5	-45		FR-107
Spacecraft monitoring DSS 71		W/O paramp	1132^{+73}_{-75}		-155 ±1.5	-45		FR-607

and data-acquisition parameters for each station.[4] The Ground Communications System (GCS) was essentially the same as that used for Mariner 2 (Figure 5-1), as were the arrangements for Net Control at JPL.

The Atlas-Centaur launch occurred on November 27, 1963, from Cape Canaveral. The Centaur upper stage was successfully injected into Earth orbit. The MTS and Johannesburg acquired the Centaur with no difficulty. Woomera also acquired the Centaur but noted a subsequent loss of signal. Neither of the Goldstone 26-m dishes were able to pick up the spacecraft. At this time, the Goldstone antennas were operating in a slave mode using a computer-prepared drive tape made from AMR tracking data. Second attempts were also unsuccessful. The difficulty was apparently due to the loss of the beacon on the Centaur. Four hours after launch the DSN ceased looking for the vehicle.

Atlas-Centaur 3. The AC-3 launch was another orbital flight of this launch vehicle built for the launch of Surveyor and other deep space missions. The DSN support plan differed little from that of the second Atlas-Centaur flight. The major change was the support of the SFOF at Pasadena, which in the seven months since AC-2 had reached operational status. (See Chapter 6 for SFOF details.)

After several delays, the launch took place on June 30, 1964. Approximately 19 minutes later, the Atlas-Centaur impacted downrange, the victim of a hydraulic pump failure and consequent short Centaur burn. Forty minutes after liftoff the DSN was secured.

The fourth Atlas-Centaur launch occurred on December 11, 1964, but the DSN did not participate at all in this flight. The remaining Atlas-Centaur flights will be described in Chapter 6.

Radio Science

Superficially, it might seem that JPL's planetary radar work was just a happy offshoot of its tracking and data acquisition mission. To a surprising degree, however, the requirements for radar contact with the planets and spacecraft data acquisition and command are very similar, to wit:

- High efficiency/low noise antenna feed
- Very low noise amplifiers
- Very high power transmitters
- Signal processing technology
- Ranging systems design

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[4] Note that the DSN stations are now numbered by a new double-digit system, which replaces the single-digit scheme described in the Mariner-2 section. The Goldstone Pioneer station, which is not listed in Table 5-2, is DSS-11. The letter prefixes DSS (Deep Space Station) and DSIF (Deep Space Instrumentation Facility) are used interchangeably. Today, DSS designations are used exclusively.

As a matter of fact, much JPL technology in the above categories was first tested in planetary radar experiments. Not only does radio science constitute a leading edge of technology but its scientific results in the radar mapping of planetary surfaces and the refining of astronomical constants have contributed much to NASA's planetary exploration program.

Most of the JPL developments in this new science occurred at the Goldstone Venus site. Some of the new capabilities added during the time period (the L-Band era) covered by this and the preceding chapter were:

1961	9-kw transmitter, noise temperature of 64^{o}K (first use of maser)
1962	12.5-kw transmitter
1963	100-kw transmitter
1964	35^{o}K noise temperature.

It is important to note that these radar experiments were conducted at about 2400 MHz, in the S-Band, the segment of the electromagnetic spectrum where the whole DSN was soon to locate.

Using the 100-kw transmitter, JPL scientists were able to refine their previous measurements of the rotation of Venus about its axis. The period of rotation reported by Goldstein and Carpenter in 1963 was 240 days retrograde; that is, Venus according to radar measurements rotated on its axis in a direction opposite from that of Earth.[5] Later, in 1964, the same group first detected two bright spots (called alpha and beta) on the surface of the cloud-covered planet.[6] Much more surface detail was to be revealed in later experiments.

Mars was first detected by radar in early 1963.[7] The studies reported by Goldstein indicated that both smooth and rough surfaces were present.[8]

Ranging farther out into space, statistically significant echoes from Jupiter and Mercury were detected in 1963. Within a few years, half of the entire solar system had been probed by Goldstone radar.

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[5]R. M. Goldstein and R. L. Carpenter, "Rotation of Venus: Period Estimated from Radar Measurement," Science, Vol. CXXXIX (March 8, 1963) pp. 910-911.

[6]R. L. Carpenter, "Study of Venus by cw Radar," Astronomical Journal, Vol. LXXI (March 1966) pp. 142-152.

[7]Jet Propulsion Laboratory, "Space Programs Summary No. 37-20, Volume III," (Pasadena: JPL SPS 37-20, March 31, 1963) p. 38.

[8]R. M. Goldstein, "Mars: Radar Observations," Science, Vol. CL (December 24, 1965) pp. 1715-1717.

A Second 26-m Network

The first DSN 26-m network (or subnet, as it is often called) consisted of the stations at Goldstone, Johannesburg, and Woomera. This network was quite adequate for the Rangers and early Mariners; in fact, the missions of 1962-1964 punctuated long periods of nothingness. On the near horizon, however, were Surveyor, Lunar Orbiter, and more Mariner shots. These were not brief missions, such as the Rangers had been, but months in duration with several spacecraft likely to be active simultaneously. To provide adequate coverate for these overlapping missions, a second set of three 26-m dishes, approximately 120^{o} apart in longitude, was deemed necessary.

Tidbinbilla. One antenna for a second subnet was already operational: the Echo site at Goldstone. From the logistics standpoint, it was tempting to locate the two other 26-m stations near Woomera and Johannesburg. Woomera, however, was presenting staffing problems. Good technicians were hard to get in this bleak, distant region, and those who were willing to go were usually snapped up by the Australian missile facilities located there. Looking for a radio-quiet spot in the same longitude sector but with the amenities of civilization close by, NASA finally selected an area in the Tidbinbilla Valley, 10 air miles from Canberra, the country's capital city. The NASA site survey of August 1962 had homed in on the Canberra region as a good location for a DSN station. In keeping with NASA plans to co-locate tracking stations from its three networks (DSN, STADAN, and MSFN), a substantial piece of land was required to preclude interference of co-located equipment. An excellent spot was found southwest of Canberra in the sheep and cattle grazing lands of the Tidbinbilla Valley. In March 1963, NASA and Australia agreed to a lease of 150 acres to accommodate a DSN 26-m antenna and other NASA tracking equipment. (Figure 5-4)

NASA wanted to have the station operational in time for the next pair of Mariners scheduled for late 1964. By November 1963, the power building had been completed and other construction well under way, but the station was not fully operational until March 1965. It missed the launch of Mariner 4 but was in the network at the time of the Mars flyby in July 1965.

Robledo. While the Johannesburg station was particularly useful because the injection of spacecraft into lunar and interplanetary trajectories frequently took place in view of Johannesburg's equipment, an alternate site in southern Europe was considered more desirable from the standpoint of overall coverage and the question of long-term tenure in South Africa. In addition, a station at the lower latitudes would be more useful to the Apollo program which the DSN was committed to support in a backup role. Reflecting back to 1958, ARPA had anticipated placing one of its 26-m tracking stations in this region before NASA assumed the responsibility of deep space exploration. NASA surveyed the area, including Italy and Sardinia, finally choosing Spain for reasons associated with the fact that Italy was somewhat too far to the east for a good overlap of Goldstone coverage.

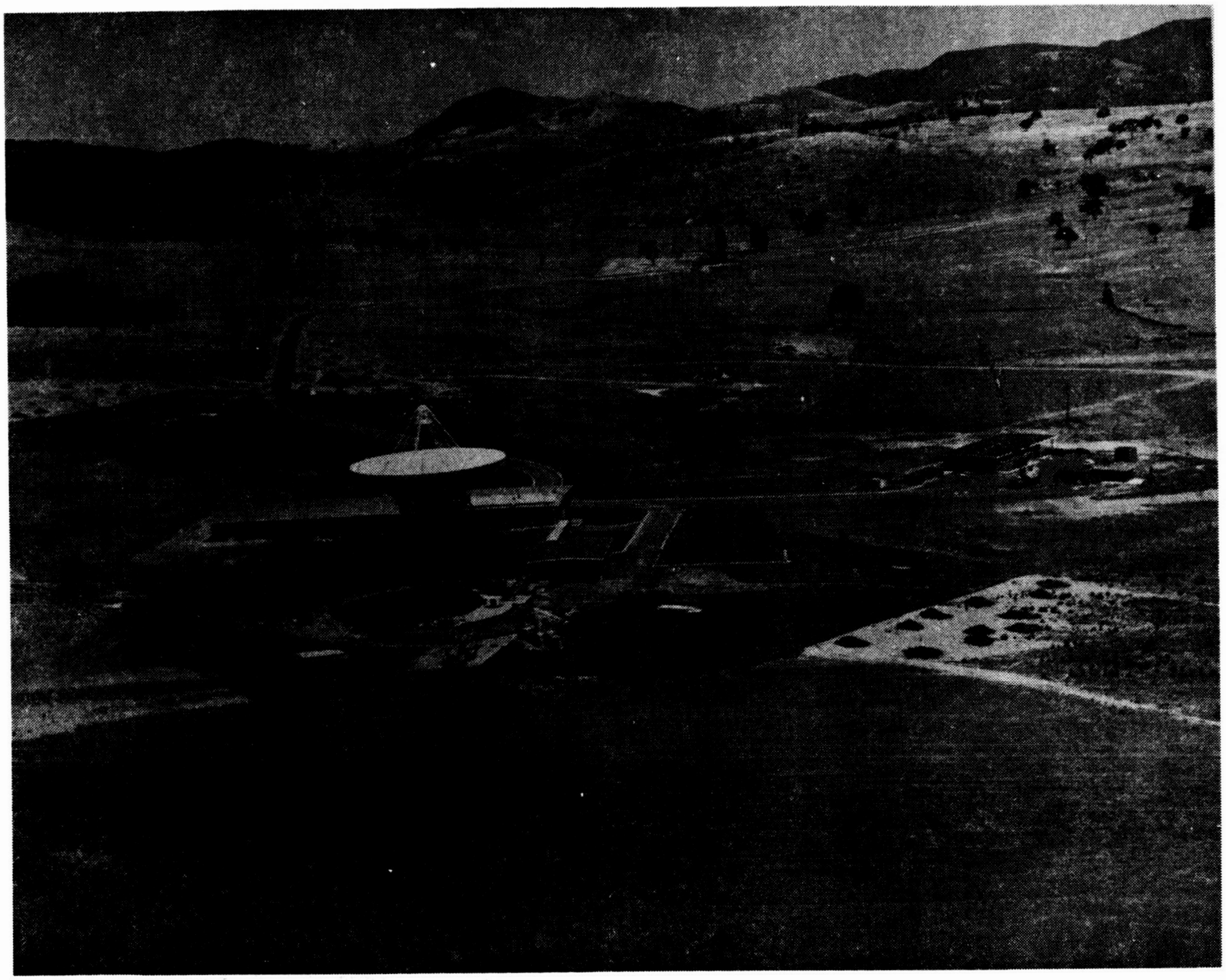

Figure 5-4. Tidbinbilla, Australia. The DSN 26-m dish.

When it became apparent that a new 26-m station in the neighboorhood of Italy had its drawbacks, the NASA site survey was enlarged to include Spain. In early 1963, four suitable sites[9] had been identified: Sevilla, Toledo, Malaga, and Madrid. Becaurse of its nearness to a large city, the Robledo de Chavela site 40 miles west of Madrid was finally chosen. In January 1964, the United States and Spain announced an agreement to establish the Robledo DSN station. On February 3, 1964, Edmond C. Buckley asked the Navy's Bureau of Yards and Docks to begin the design and construction of the new station.[10] In the early part of 1965, the antenna and electronic equipment were installed, and the site became operational July 1, 1965. Robledo supported the 1964 Mariner 4 mission to Mars as a backup to Johannesburg. (Figure 5-5)

Ascension Island. Another new site under consideration in late 1963 was Ascension Island midway between Africa and South America and 5000 miles southeast of Cape Canaveral. The need dictating a new tracking and data acquisition station in this part of the world was that of earlier acquisition and command of the new Surveyor spacecraft; there was too much of a gap between the Cape's Spacecraft Monitoring Station and Johannesburg even though the AMR stations filled in some of the blank spots. The problem concerned the direct-ascent mode for the Surveyor launch in which the parking orbit was bypassed and translunar injection occurred before Johannesburg acquisition. (Some Surveyor flights did use parking orbits.)

Goddard Space Flight Center also wanted a site on Ascension for its Manned Space Flight Network for Apollo support. NASA decided to integrate these facilities and requested permission from the United Kingdom to build such a facility. The British agreed, and a NASA site selection team visited the island in April 1964. JPL's facility was to be located at a spot with the rather desolate-sounding name of Dévil's Ashpit. NASA assigned the task of designing and construction of the Ascension facility to the Navy's Bureau of Yards and Docks.

Station construction began in January 1965 and was completed in March 1966, with full operational status being assumed a month later. Since the primary function of the Ascension station was early acquisition while the spacecraft was still close to Earth, a relatively small antenna was adequate. Goddard MSFN was installing a 9.2-m (30-foot) Unified S-Band antenna for Apollo, and the DSN followed suit. (Figure 5-6) This gave both networks backup antennas in a critical spot. Although the antenna sizes were identical, the DSN's had a polar mount while Goddard's was Az-El which was more suitable for satellite work. The same kind of redundancy was provided for

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[9]During the site selection phase, NASA was aided by the Spanish Institut Nacional de Tecnica Aeroespacial (INTA).

[10]Jet Propulsion Laboratory, "A History of the Deep Space Network to 1 January 1969," (Pasadena: JPL 890-9, January 15, 1971) p. 2-18.

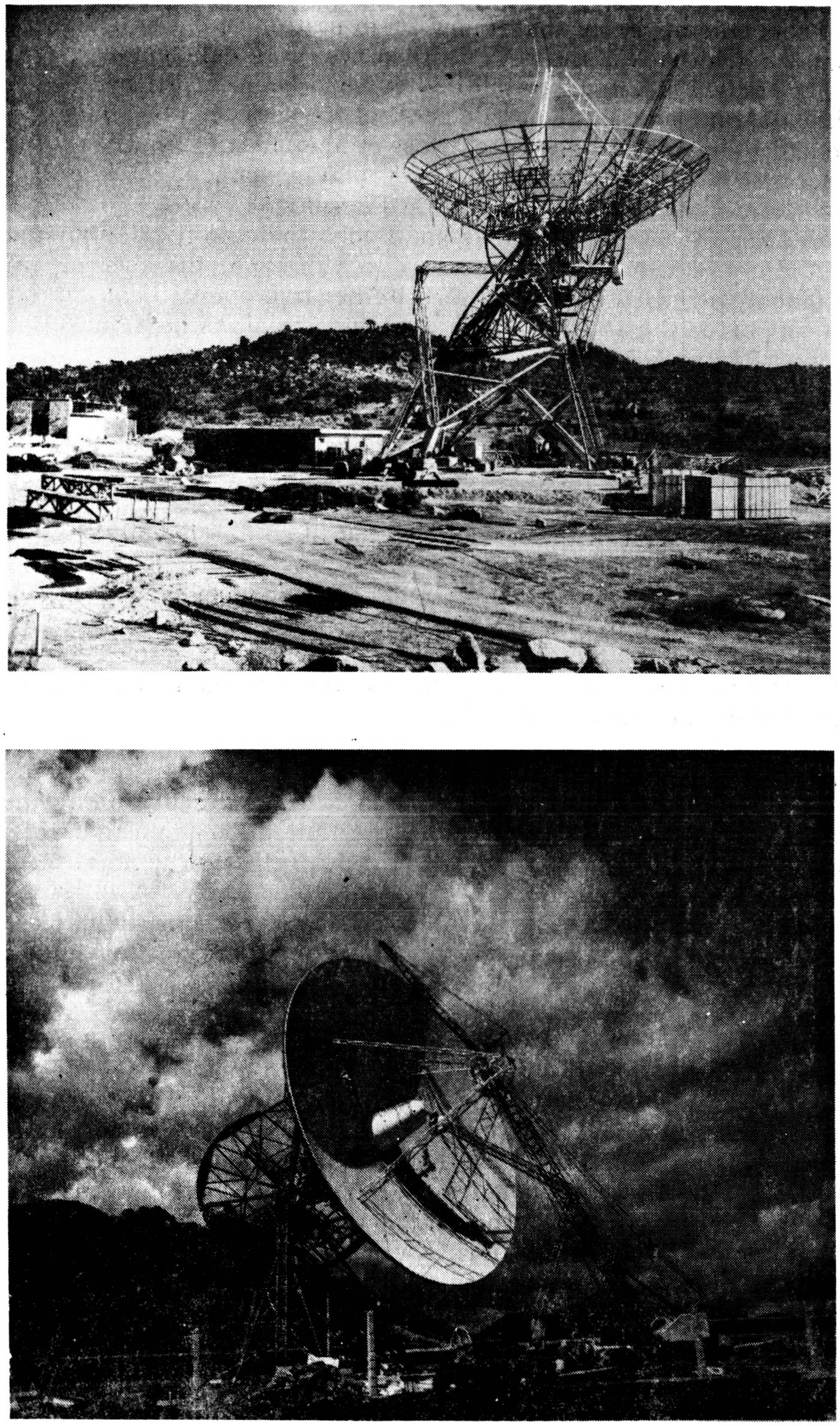

Figure 5-5. The Robledo 26-m antenna under construction.

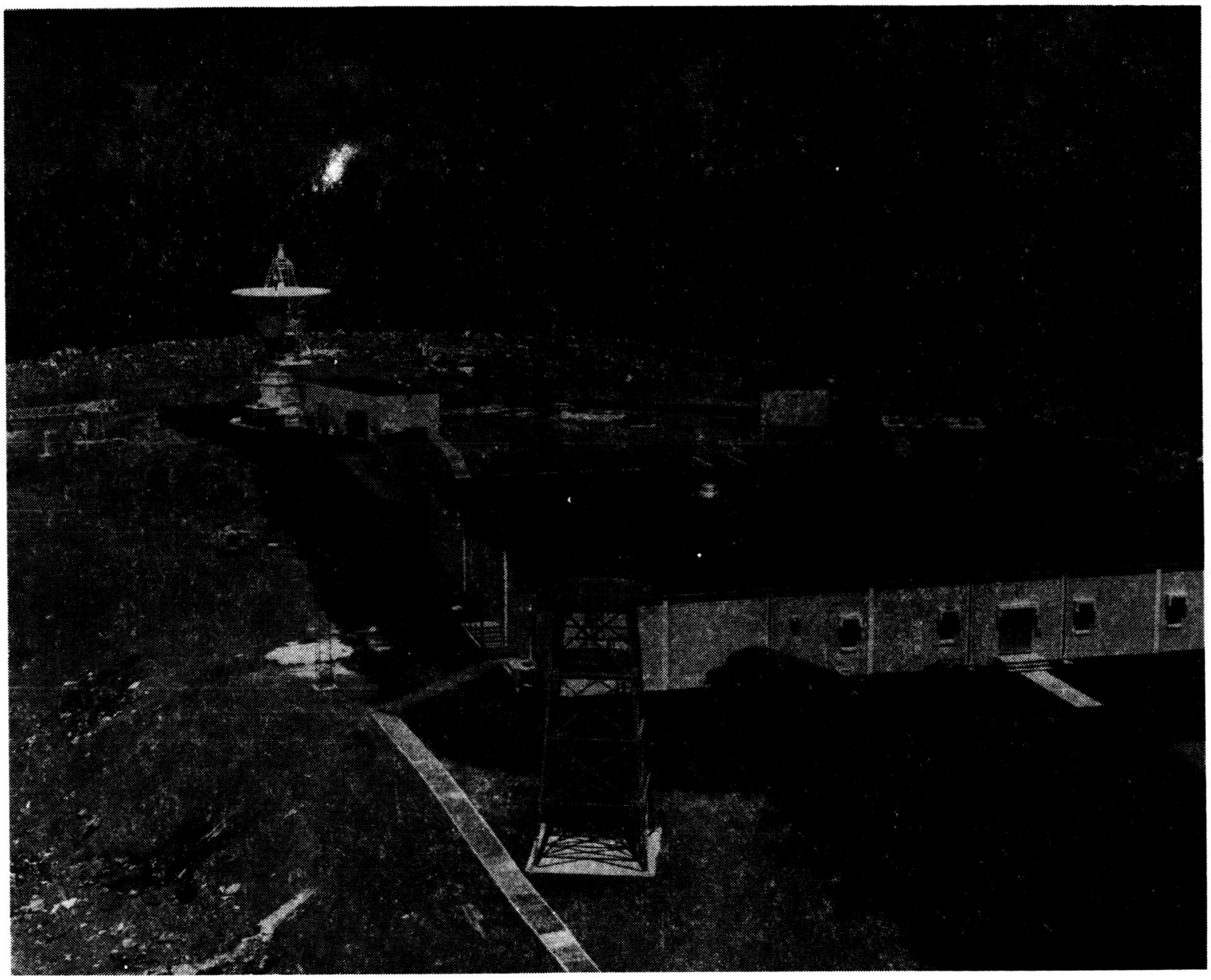

Figure 5-6. The 9.2-m DSN antenna on Ascension.

Apollo when duplicate 26-m MSFN paraboloids were co-located with similar DSN antennas in Spain and Australia.

A Permanent Spacecraft Monitoring Station. The Launch Station, DSIF 71, or Spacecraft Monitoring Station at Cape Kennedy, was originally established to support Explorer and then was enlarged for Pioneer and Ranger. It was meant to be temporary and was duly housed in trailers. Its role in the DSN was to support prelaunch testing with the spacecraft on the pad, during launch and in flight as long as it was in sight. Thus, DSS-71 was not a tracking station and boasted only a hand-pointed 4-foot paraboloid. It had no command capability. Nevertheless, it was vital to ascertain before launch that the spacecraft communication subsystem was compatible with the DSN and vice versa. With missions much more complex than Ranger coming along, it was logical to make the Cape facility a permanent one.

In line with this thinking, plans for a permanent station began to be drawn up in late 1962. It would be an S-Band station in direct support of Surveyor, Lunar Orbiter, and the other lunar and deep space vehicles being planned. The remaining Ranger L-Band missions would be handled by the temporary equipment in the trailers, which would then be phased out. One early thought was to locate the new station at the Kennedy Space Center on NASA land, but JPL studies in late 1962 rejected this due to the distance, the presence of large bodies of water, and the interference of buildings. The site finally selected was in the marshy land only a mile in back of the launch pads used for NASA space launches. The Air Force approved the site in June of 1964 and construction started in October that year. The station was built by the Corps of Engineers under the direction of NASA's Kennedy Space Center. Construction was completed in April 1965, and the permanent Spacecraft Monitoring Station was operational a month later. (Figure 5-7) The new building was not only constructed of solid concrete but was air-conditioned---both welcome changes from the "temporary" trailers that had been occupied for almost 7 years. On the roof are mounted two hand-pointed 4-ft. antennas.

Meanwhile, Back at Goldstone. The $250,000 feasibility study of a 70-m antenna had been completed by Blaw-Knox in mid-1962. This was the Phase One in this the first of NASA's "phased" projects.[11] In December of 1962, NASA issued the second request for Advanced Antenna System (AAS) proposals, this time for Phase Two, actual construction. The responses were received December 21, 1962. Bidding were these four firms: McKiernan-Tierny Corporation (a division of Litton Systems), North American Aviation Corporation, The Rohr Corporation, and a team headed by Dalmo Victor Company. On January 25, 1963, NASA and JPL announced the selection of

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[11] Very roughly, the three stages were: (1) competitive design studies; (2) design selection and completion of the first antenna; and (3) construction of additional antennas.

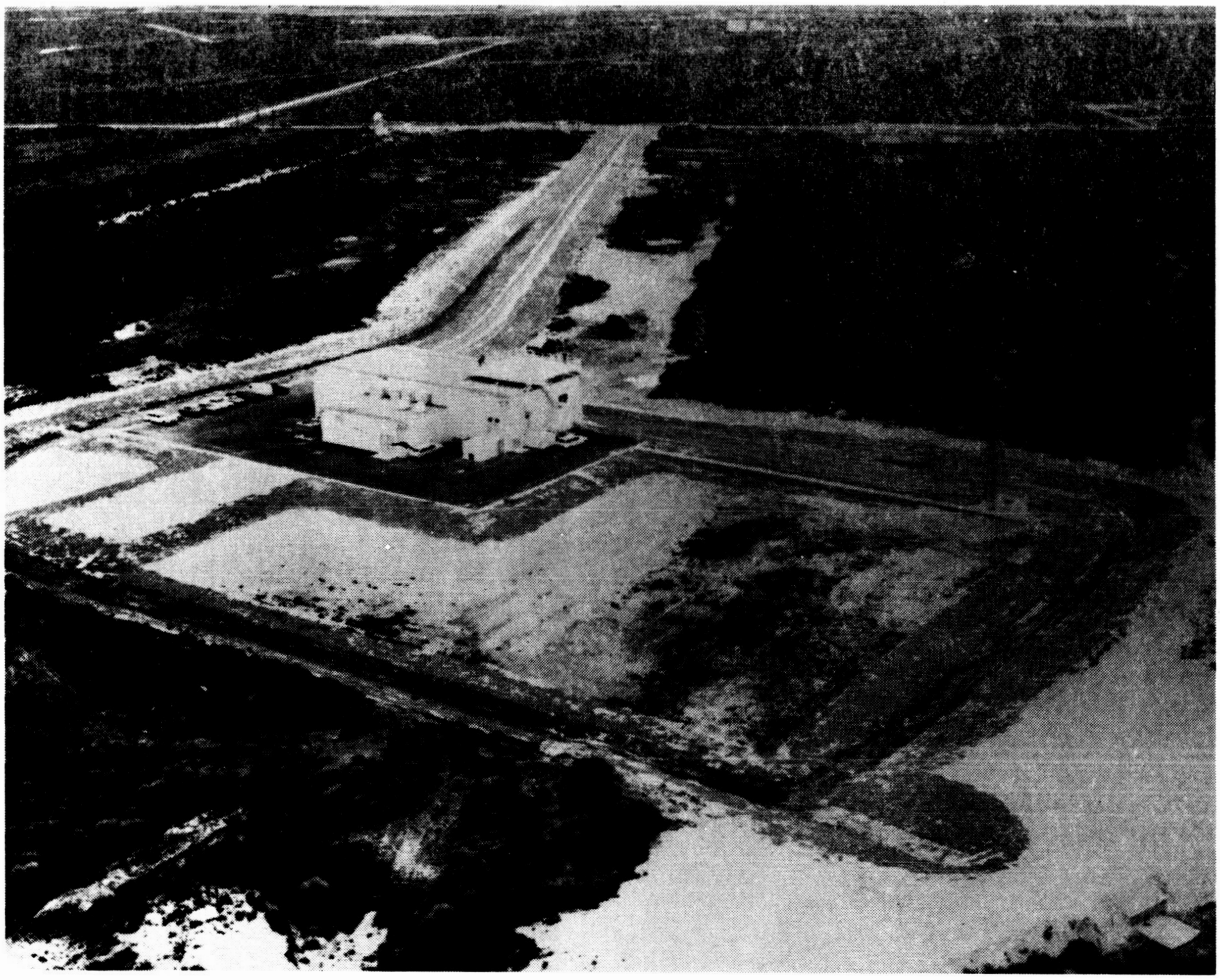

Figure 5-7. The DSN Launch Station at Cape Canaveral.

Rohr Corporation to build the big antenna at Goldstone. The value of the contract was for roughly $12 million and called for antenna completion in 36 months after contract execution (June 20, 1963); that is, mid-1966. Construction actually began at Goldstone (Figures 5-8 and 5-9) in October 1963 at the new Goldstone Mars site, so named because the antenna was originally intended to support NASA's Mariner mission to Mars which actually flew in 1964, long before the 64-m antenna became operational. [12] An interesting aside concerns the final choice of 64-m (210 ft.) for the size of the Mars antenna. This was just the size of the Australian radio astronomy paraboloid at Parkes. NASA/JPL had received a lot of help from the Australian designers and had frequently answered critics who questioned the feasibility of big antennas by pointing at the Parkes dish as a successful example. In short, NASA/JPL did not wish to appear to be in competition with the cooperative Australians by building a bigger antenna. [13]

An End to the Lull

The 1962-1964 period was one of low activity, for NASA's deep space program had not yet matured---spacecraft were on the drawing boards but not in flight. The DSN used this hiatus to select and build new stations and prepare for the Surveyors, Mariners, Lunar Orbiters, and Pioneers scheduled for 1964-1967. The dividing line in technology separating this era from the next is the change to S-Band. All of the imminent new spacecraft programs had been designed for S-Band; the L-Band Rangers were the last of a nearly extinct species.

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[12] NASA News Release 63-13, January 25, 1963. Also JPL, The NASA/JPL 64-Meter-Diameter Antenna at Goldstone, California, (Pasadena: JPL TM-33-671 July 15, 1974).

[13] Robertson Stevens, personal interview, July 28, 1975.

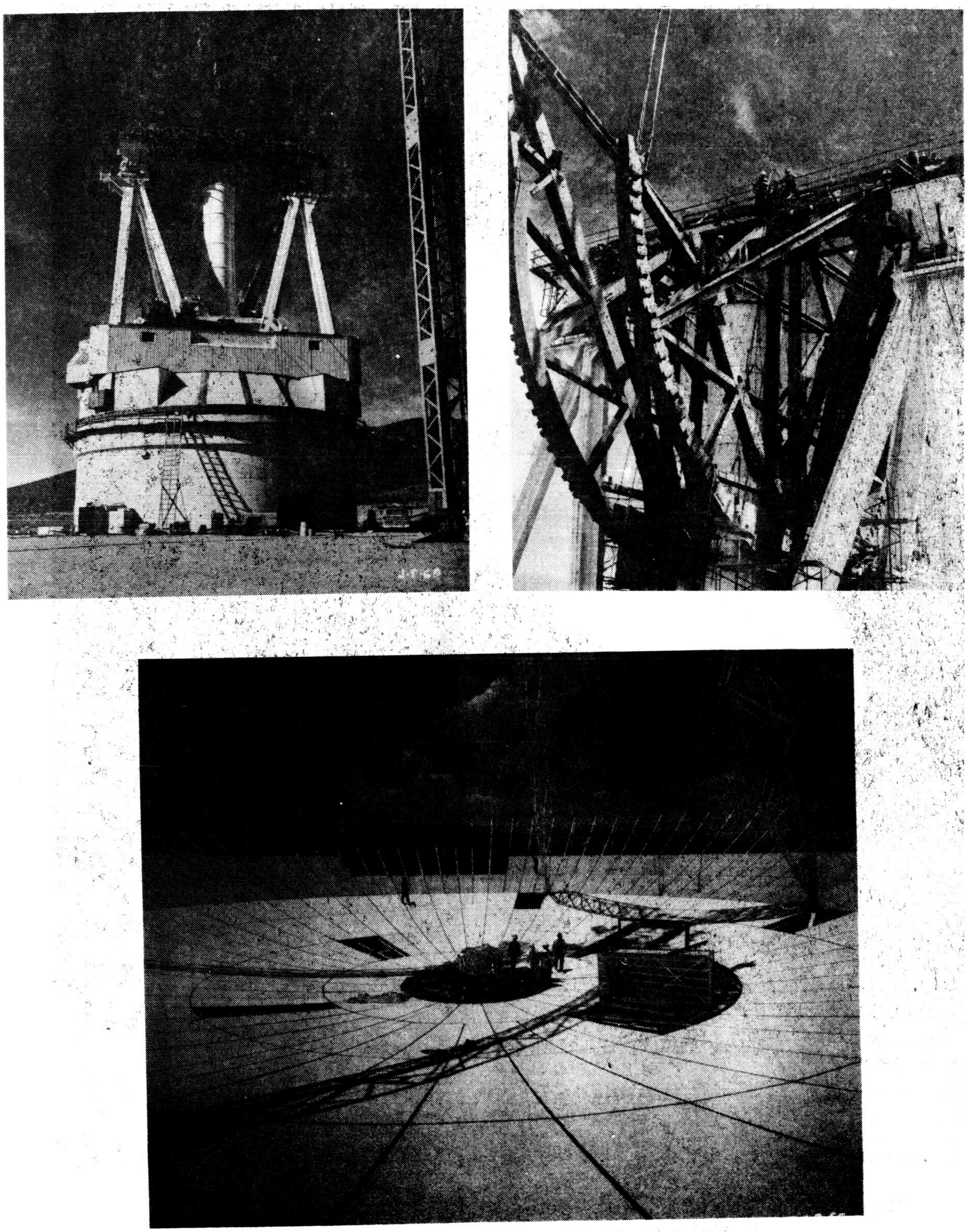

Figure 5-8. Some views during the construction of the 64-m antenna at Goldstone.

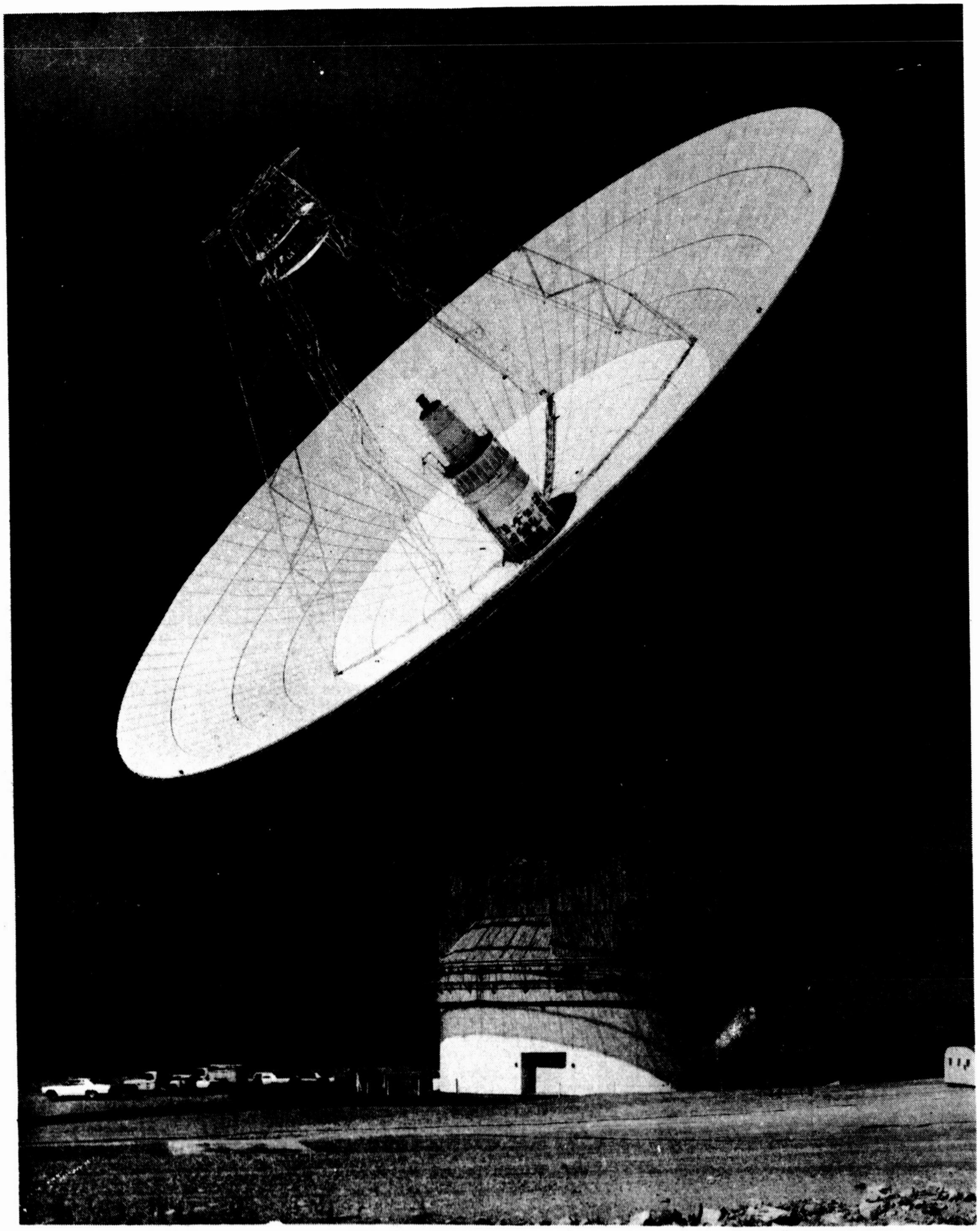

Figure 5-9. The 64-m Mars antenna at Goldstone at time of initial operations.

Chapter 6. THE MOVE TO S-BAND

The history of the DSN is really a history of stepwise increases in capability. There have been many of these, some small and some large; changes in antenna size, noise-temperature reductions, communication capacity increases, and the like. The switch to S-Band, however, was perhaps the most significant because it not only affected a large fraction of the ground equipment supporting deep space missions but the spacecraft as well. The usual time from spacecraft mission approval to flight is several years, so that the move to S-Band, which began in the early 1960s, could not be consumated until late 1964 when the first S-Band spacecraft, Mariners 3 and 4, were launched. However, vital L-Band missions persisted until the spring of 1965 when the final Ranger was dispatched to the Moon. This technological transition, when the DSN was hybridized, is of critical interest here.

The L/S Conversion Project

Taking up the thread of the story from Chapter 4, the L/S Conversion Project was designed to permit the DSN to work both L-Band and S-Band spacecraft until the time when all missions operated in the S-Band in 1965. The technical breakthrough making the Project feasible came when JPL engineers created a "synthesizer" driven by a rubidium-vapor oscillator which made S-Band frequencies compatible with L-Band data-handling equipment. Each hybridized station would, therefore, consist of both an L-Band and an L/S receiver, both feeding the unaltered L-Band system. While this equipment was supporting current missions, the new S-Band equipment could be installed alongside without interference. The switch between S-Band and L-Band operation did pose one time-consuming difficulty however: the L-Band turnstile feed had to be replaced by the S-Band hyperbola subreflector in the 26-m dish. This was a manual operation performed at the focal point of the dish---a most inconvenient location.

A prototype L/S unit was tested at Goldstone's Pioneer station. With minor modifications, it was shipped to Woomera, where it was operational in August 1964. Johannesburg was quickly converted and was ready for L/S mission support in September 1964. Goldstone Pioneer, the third station in the L/S triad had both L-Band and prototype S-Band equipment, as indicated in Table 6-1. (The split between L-Band and S-Band missions is shown in Table 6-2.) By the end of the summer of 1964, the DSN was ready for the first S-Band missions, Mariners 3 and 4, scheduled for November 1964.

With hybridization complete, the task at hand was the conversion of network stations to full S-Band. Tidbinbilla was the first full S-Band station, never having had any L-Band equipment. It began supporting Mariner 4 in March 1965, four months after launch. With the last Ranger flight completed in March 1965, the L-Band stations were converted to full S-Band at the times noted in Table 6-1.

Table 6-1. DSN CONVERSION FROM L-BAND TO S-BAND OPERATION BY STATION AND DATE

Station (DSS #) / Year	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Pioneer (11)	L 12/58	L	L	L	L	L	L&S 9/64	L&S	S	S
Echo (12)			L 4/60	L	L	L	L	S 6/65	S	S
Mars (14)									S 5/66	S
Woomera (41)			L 11/60	L	L	L	L/S 8/64	S 12/65	S	S
Tidbinbilla (42)								S 3/65	S	S
Johannesburg (51)				L 7/61	L	L	L/S 9/64	L/S	L/S	S 3/67
Mobile Station	L	L	L	L	L	L	L			
Robledo (61)								S 6/65	S	S
Cebreros (62)									S 5/66	S
Spacecraft Monitor (71)				L	L	L	L	S 5/65	S	S
Ascension (72)									S 2/66	

Table 6-2. DSN CONVERSION FROM L-BAND TO S-BAND BY MISSION AND YEAR

	Year	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
L-Band Missions		PN 3*	PN 4	PN 5	RA 1 RA 2	RA 3 RA 4 RA 5 MA 1 MA 2		RA 6 RA 7	RA 8 RA 9		
S-Band Missions								MA 3 MA 4	PN 6	PN 7 SU 1 SU 2 LO 1 LO 2	MA 5 SU 6 PN 8 LO 3 SU 3 LO 4 SU 4 LO 5 SU 5

* PN Pioneer
RA Ranger
MA Mariner
SU Surveyor
LO Lunar Orbiter

An interesting operational problem asserted itself as the S-Band equipment began to track actual spacecraft. Because of the much smaller wavelengths at S-Band frequencies, the antenna beams were much narrower than they had been at L-Band. A whole new group of acquisition techniques had to be worked out. Goldstone took the lead and promulgated its experience to the other stations. This was done successfully and, by the end of 1965, the S-Band transformation was complete.

Other Network Improvements

By the time Mariner 4 was launched, 10-kw transmitters had been distributed throughout the network. This was essential if stations other than Goldstone [1] were to be able to command distant probes.

The most significant improvement from the standpoint of navigation was the introduction throughout the DSN of rubidium clocks to replace the less stable crystal-controlled oscillators. With atomic clocks, all stations could obtain the precision, two-way Doppler measurements that were essential to guiding the spacecraft to the very small aiming point in the vicinity of Mars.

Preparations for More Sophisticated Missions

The new missions of the 1965-1967 period, particularly Lunar Orbiter and Surveyor, forced the DSN to expand its communication and control capabilities. The data streams coming back from the spacecraft would be broader (thousands of bits per second rather than tens or hundreds) and the spacecraft themselves would be considerably more complex, requiring advanced display and control equipment at JPL. In addition, more and more missions began to overlap; gone were the days of a few short missions well-separated in time. In the 1964-1967 period the Lunar Program paving the way for Apollo and further deep space exploration brought the day of many long-lived spacecraft in space simultaneously.

The New SFOF. The centralization of all mission control and computing functions into a single area was JPL's answer to the control problems engendered by the new overlapping mission mix. The Space Flight Operations Facility (SFOF) building at Pasadena (Figure 6-1) was completed in October 1963. The first Block-I IBM 7094 computers were installed immediately. As mentioned in Chapter 5, a dual-computer arrangement had been pioneered

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[1] The Goldstone Venus site had an experimental 100-kw transmitter which was normally employed for planetary radar. In the event that a spacecraft's directional antenna lost touch with the Earth, the 100-kw transmitter could supply commands that could probably be picked up by the omnidirectional antenna mounted on most spacecraft.

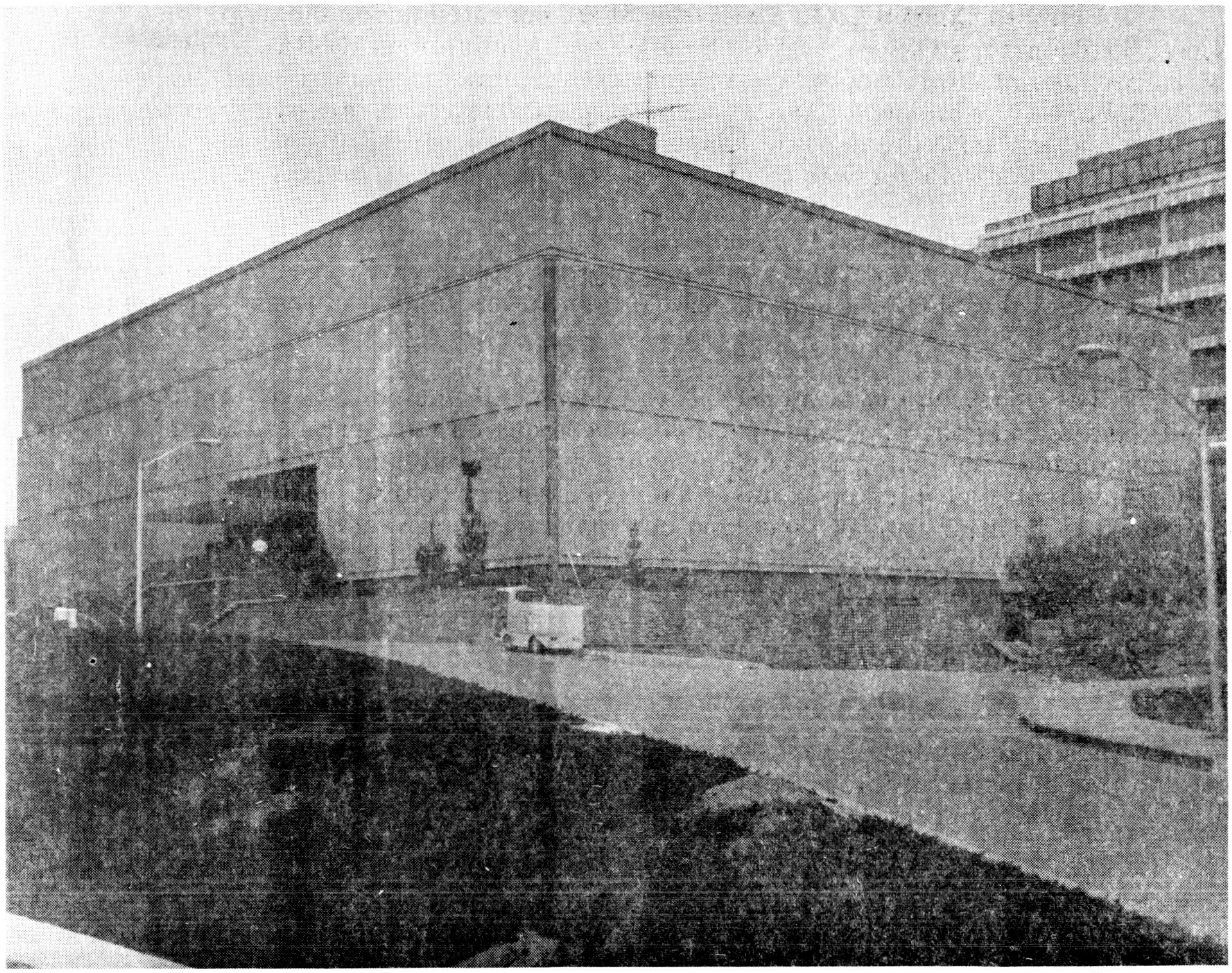

Figure 6-1. The SFOF building at Pasadena.

during Ranger for data processing with good success. This experience was applied during SFOF design in late 1962 and early 1963. The initial SFOF consisted of an IBM 7040 connected to an SFOF teletype line and a 1301 disk storage file connected to the IBM 7094. With this arrangement, the 7040 could be used to print out data in the several user areas of the SFOF and the 7094 could process data in non-real time. This arrangement, however, ran into problems and the 7040 was replaced by a 7044 computer just before the launch of Mariner 4. Mariner 4 was the first flight project to be supported by the new SFOF combination of real-time and nonreal-time computing.

The Ranger Program did not wish to convert at its late stage to a new data processing concept, creating in effect a situation analogous to the L/S Conversion Project, where new techniques and equipment could not displace established hardware in midstream. Thus, during part of 1964 and 1965, JPL operated two data processing systems.

Prior to December 1, 1964, the SFOF operated under the aegis of NASA Headquarters Office of Space Science and Applications (OSSA). However, because of the intimate relationship between mission control and the DSN, Robert C. Seamans, NASA's Associate Administrator, asked Edmond C. Buckley and his OTDA to assume responsibility for the SFOF.[2] Almost a decade later this transfer was to be repeated in the opposite direction.

Even though the SFOF is no longer a part of the DSN, it was a DSN element between 1964 and 1972. To be complete, this history should encompass this portion of the SFOF story and a more formal description of the SFOF seems in order.

The construction of the SFOF was begun with the philosophy that the timely and sound control of any space venture required the centralization of communication terminals, the rapid processing of mission data, and the near real-time display of mission status. This concept, of course, had already been used in military surveillance and command systems, such as that directed by the Air Force's NORAD. It made sense for deep space missions, too, and the four-level SFOF building at Pasadena was the result.

The equipment in the SFOF building was organized into five systems, as follows:

1. The Communications System for internal and external transmission of information. This obviously interfaced with the DSN Ground Communication System (GCS).

2. The Data Processing System for the recording and computer conversion of data. (Figure 6-2)

3. The Display and Control System for the internal distribution of data and its display to mission controllers. (Figure 6-3)

4. The Spacecraft Television Data System for refining and interpreting TV data from space missions.

5. The Support System for emergency power, facility maintenance and personnel needs.

The DSN was naturally considered a functional part of every space mission and, for this reason, the SFOF also boasted a DSN Control Room. (Figure 6-4) From this vantage point, the worldwide status of the network could be ascertained instantly and used to make and carry out mission decisions. In essence, the SFOF was a centralized, multimission control center. This approach certainly improved the effectiveness of mission control as long as the actual mission control centers resided at the SFOF. As we shall see, however, other NASA centers wanted to control their spacecraft from their own facilities.

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[2]Maurice E. Binkley, personal interview, February 18, 1975.

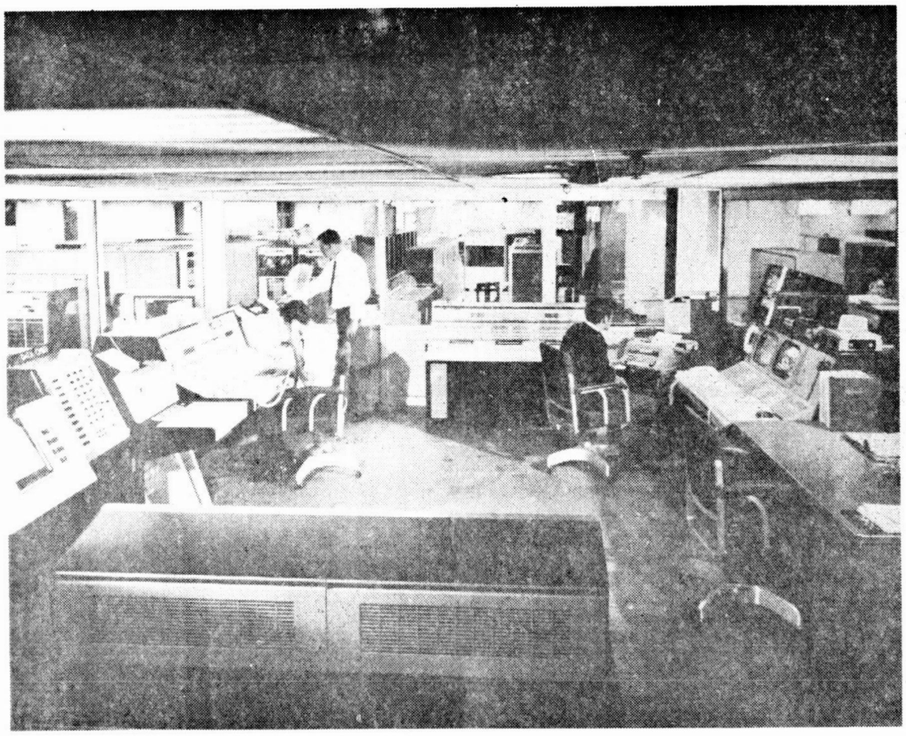

Figure 6-2. SFOF data processing control room circa 1966.

Figure 6-3. The SFOF mission control room circa 1965.

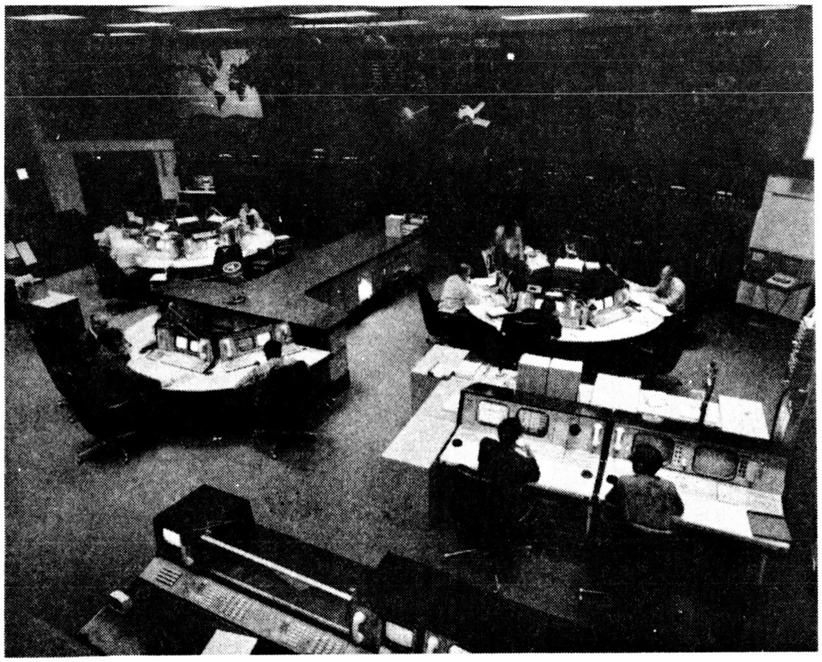

Figure 6-4. The DSN Control Room in the SFOF circa 1965.

Ground Communications. As data traffic between DSN stations and Pasadena increased, NASA added more communications links. During 1963, a third teletype link was installed between JPL and the DSN stations. There was also one voice line already in existence. Late in 1963, a broadband microwave relay was set up between Goldstone-Echo and JPL in Pasadena. This link, capable of carrying television, was operational in 1964.

It was also in 1964 that Goddard Space Flight Center introduced computer switching into NASCOM (NASA Communications) which had provided all DSN long lines since 1961. This sped up the switching of teletype lines but the technique differed markedly from that in use in DSN line switching. Mariners 3 and 4, soon to be launched, were committed to the old methods. So the DSN was bypassed temporarily.

Tactical intercoms were distributed to most DSN stations in 1964. With these equipments, conference loops could be established within a station; in addition, the long distance lines connecting the stations with the SFOF could be brought into the conference. Both Australia and South Africa initially objected to the connection of the tactical intercom with government-provided communication lines for security reasons. Eventually these objections were overcome and tactical intercoms were installed at Johannesburg and the Australian stations.

The SFOF ushered in a new era of communications control. Closed circuit TV was used for area surveillance, the distribution of teletype data, and for relaying display data from one building to another. With the new voice system, the same headset could be switched to the telephone, the intercom, or voice conference net by pushing buttons. Speakers and microphones could also be switched with great flexibility. In the SFOF basement, a semiautomatic pushbutton system switched teletype circuits. Teletype data was now fed directly into the computers without a need to punch cards first. These new capabilities first came into use during the Mariner 4 mission. [3]

The addition of new DSN stations at Tidbinbilla, Robledo, and Cape Canaveral made it obvious that the SFOF's teletype switching capabilities should be improved in the mid-1960s. JPL consequently designed and installed a communications processor similar to that used by Goddard for NASCOM.

The greatest pressure on ground communications, however, was from the need for handling higher and higher bit rates. The conventional teletype circuits in use during the early 1960s could handle less than 100 bits/sec. Surveyor, in contrast, would send back up to 4400 bits/sec. Even more demanding were the television cameras on Surveyor and Lunar Orbiter. The latter requirement was met by building a wideband 6-MHz microwave channel between Goldstone and Pasadena during 1965. This meant that only Goldstone could send television pictures back to the SFOF in real time. For the other DSN stations, JPL designed equipment that would send up to 1200 bits/sec over voice circuits and, from Goldstone, up to 4400 bits/sec over special circuits. [4]

The communication and data handling facilities are never as "romantic" as the big DSN antennas, but it should be recorded here that the antennas are wasted if the information they intercept from outer space cannot be sent back and made intelligible to the people who need it, when they need it.

Handling the Off-Lab Projects

In the mid-1960s the first significant off-Lab projects reached operational status: Lunar Orbiter, the Interplanetary Pioneers, and Apollo were managed by other NASA centers. The Surveyor Project was managed by JPL but the spacecraft was built by Hughes. The informality of the early spacecraft programs was shattered. The Surveyor mission operations team consisted of personnel from both JPL and Hughes. No longer did everyone know everyone else, his strengths and weaknesses, and no longer were all functions concentrated in a small geographical area. The inevitable

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[3] Jet Propulsion Laboratory, "A History of the Deep Space Network to 1 January 1969, (Pasadena: JPL 890-9, September 1, 1970) pp. 2-28 to 2-36.

[4] See the circuit diagrams accompanying most mission descriptions in JPL's "Tracking and Data Acquisition Summaries" for detailed circuit configurations.

consequence was a large increase in documentation, particularly interface documents defining requirements and responsibilities. The memos and meetings that hithertofore solved interface problems were now replaced by the SIRD (Support Instrumentation Requirements Document) and its response the NSP (NASA Support Plan). The use of the SIRD was dictated by NASA Management Instruction 2310. Behind the formal documentation, however, were the tracking panels where the support plans were thrashed out beforehand.[5] With so many missions reaching fruition at nearly the same time, schedule conflicts were bound to occur in the area of DSN support. Occasionally, these had to be resolved by negotiation at the OTDA/OSSA level between Edmond C. Buckley and Homer Newell. The organization charts corresponding to these interfaces usually changed from mission to mission and where historically significant are reproduced in the sections which describe the missions.

Mariners 3 and 4

The Mars launch window occurs every 25 months and opened in late 1964, and NASA scientists considered it highly desirable to send an instrumented probe on a flyby mission of the planet, especially since this period was at the sunspot minimum. JPL and other NASA centers submitted proposals to NASA Headquarters, and in early November of 1962, the JPL proposal was selected. The choice of JPL was not surprising because of the experience it had accumulated with Mariner 2 and the availability of experienced personnel. The Mariner-Mars 1964 Project, as it was called officially, originally consisted of three launches. Budgetary strictures, however, cut the number of launches to two. The launch vehicle was to be the Atlas-Agena, for the Atlas-Centaur was still not ready for operational use.

As indicated above, interfaces were becoming more important as NASA activities expanded and brought in more and more organizations. Mariner Mars 1964 was an on-Lab project, but important interfaces with NASA Headquarters and Lewis Research Center did exist. (See Figures 6-5 and 6-6) Also, during the launch and near-Earth phase of flight, JPL would interact with the Air Force ETR (Eastern Test Range) organization and Goddard Space Flight Center, which would provide some of its MSFN tracking facilities.

Tracking and Data Acquisition Requirements. The mission phases were: launch, parking orbit (near-Earth phase), cruise, midcourse maneuver, cruise, and Mars encounter. The DSN was not involved with the tracking of the launch vehicle but did receive telemetry from the spacecraft via the launch vehicle during this phase.

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[5] F. Bryant, personal interview, April 7, 1975.

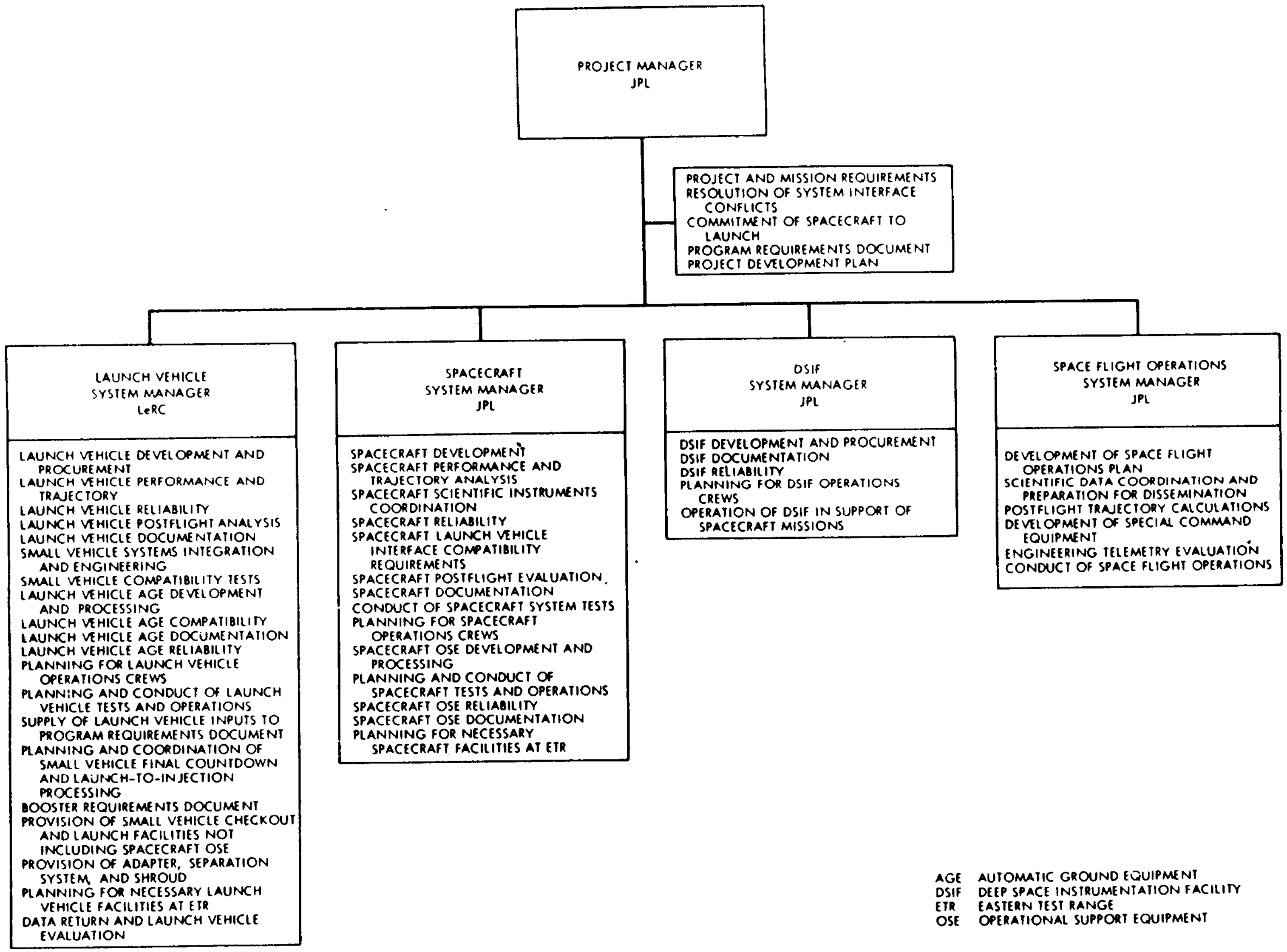

Figure 6-5. Mariner Mars 1964 project assignments.

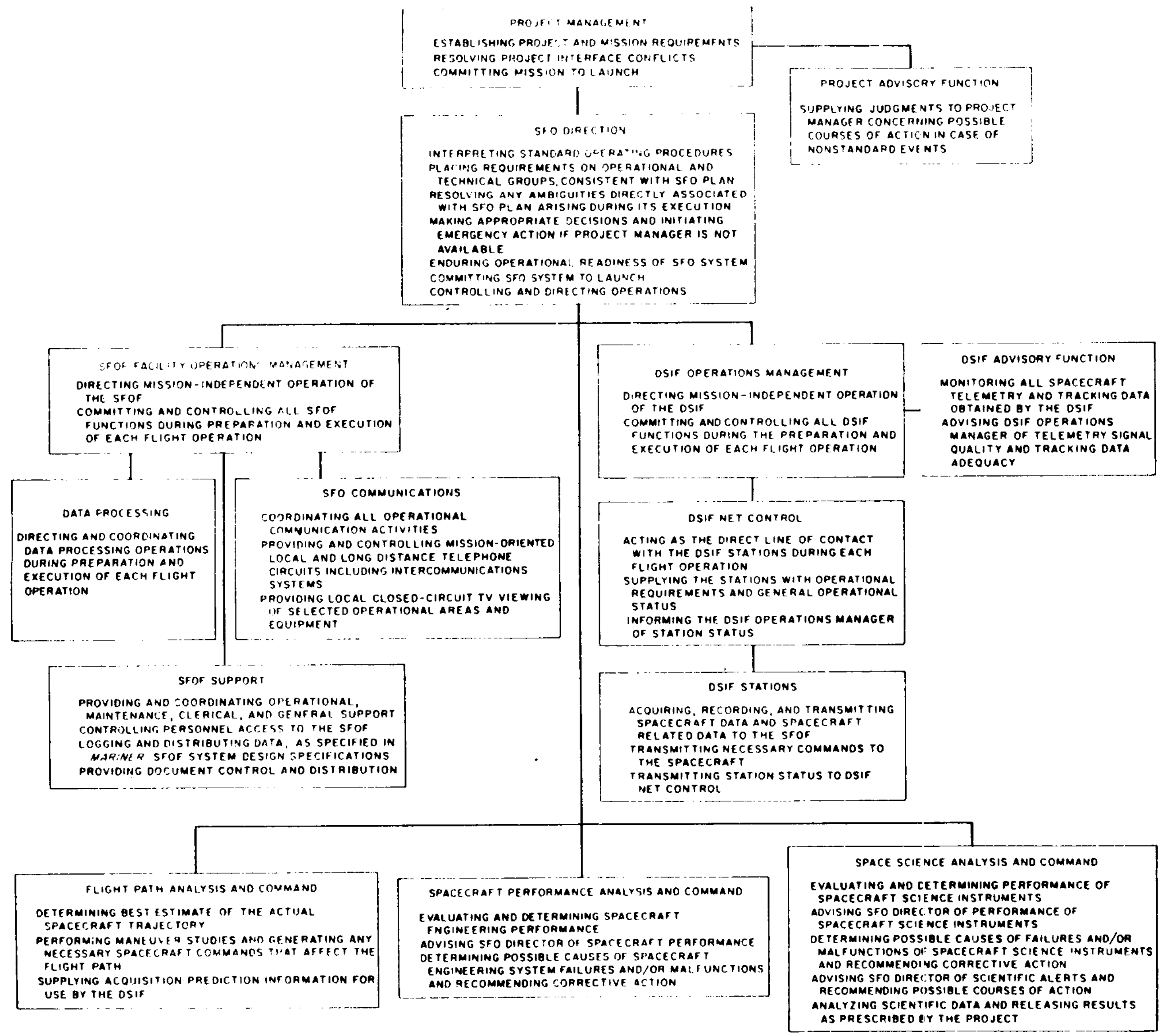

Figure 6–6. Mariner Mars 1964 overall organization structure.

For the flights of Mariners 3 and 4, NASA established three classes of tracking and data acquisition requirements reflecting decreasing priorities:

Class I	Mandatory requirements. These requirements concerned the minimum essential primary needs for a successful mission.
Class II	Requirements needed to meet all mission objectives.
Class III	Requirements defining the "ultimate" in support.[6]

In future years, tracking requirements would be further refined into a system of priorities so that decisions could be made concerning which among many spacecraft should be supported under most foreseeable conditions.

During the launch phase the ETR was to provide acquisition data for the waiting DSN stations downrange. Once the spacecraft was acquired by the DSN, ETR responsibilities ended. The critical maneuvers from the navigation standpoint were the injection into a good parking orbit, subsequent injection into a Mars trajectory, and the midcourse maneuver. On this mission the DSN was committed to round-the-clock coverage plus the provision of backup facilities during the vital midcourse maneuver and encounter events. The schedule of prime and backup sites is shown in Figure 6-7. It was, of course, the availability of stations in the second 26-m subnet that permitted this insurance of mission backup. Since bad weather, power outages, and equipment failures during a few crucial hours of flight could lose a multimillion-dollar mission, DSN redundancy was a valuable asset. With astronaut's lives at stake in Apollo, the DSN was adding MSFN "wings" to its stations to back up the flights to the Moon. (See MSFN History)

DSN Configuration. Except for the 100-kw transmitter at the Goldstone Venus station, all of the 26-m sites had essentially the same capabilities, as described in Table 6-3. Pioneer, Echo, Tidbinbilla, and Robledo, when activated in 1965, were full S-Band, while Pioneer-Echo, Woomera, and Johannesburg (See Table 6-1) had the L/S equipment enabling them to handle the remaining Ranger shots. All had at least 10-kw command capability, and parametric amplifiers were standard, yielding noise temperature of about 60°K. A glance at Table 6-3 shows that the five main DSN stations were remarkably alike. This similarity helped assure that the data received from each would be compatible and, of course, it also meant that the spacecraft would be "seeing" basically the same equipment regardless of which station was working it.

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[6] N. A. Renzetti, "Tracking and Data Acquisition Report: Mariner Mars 1964 Mission, Volume I. Near-Earth Trajectory Phase," (Pasadena: JPL TM 33-239, January 1, 1965) p. 11.

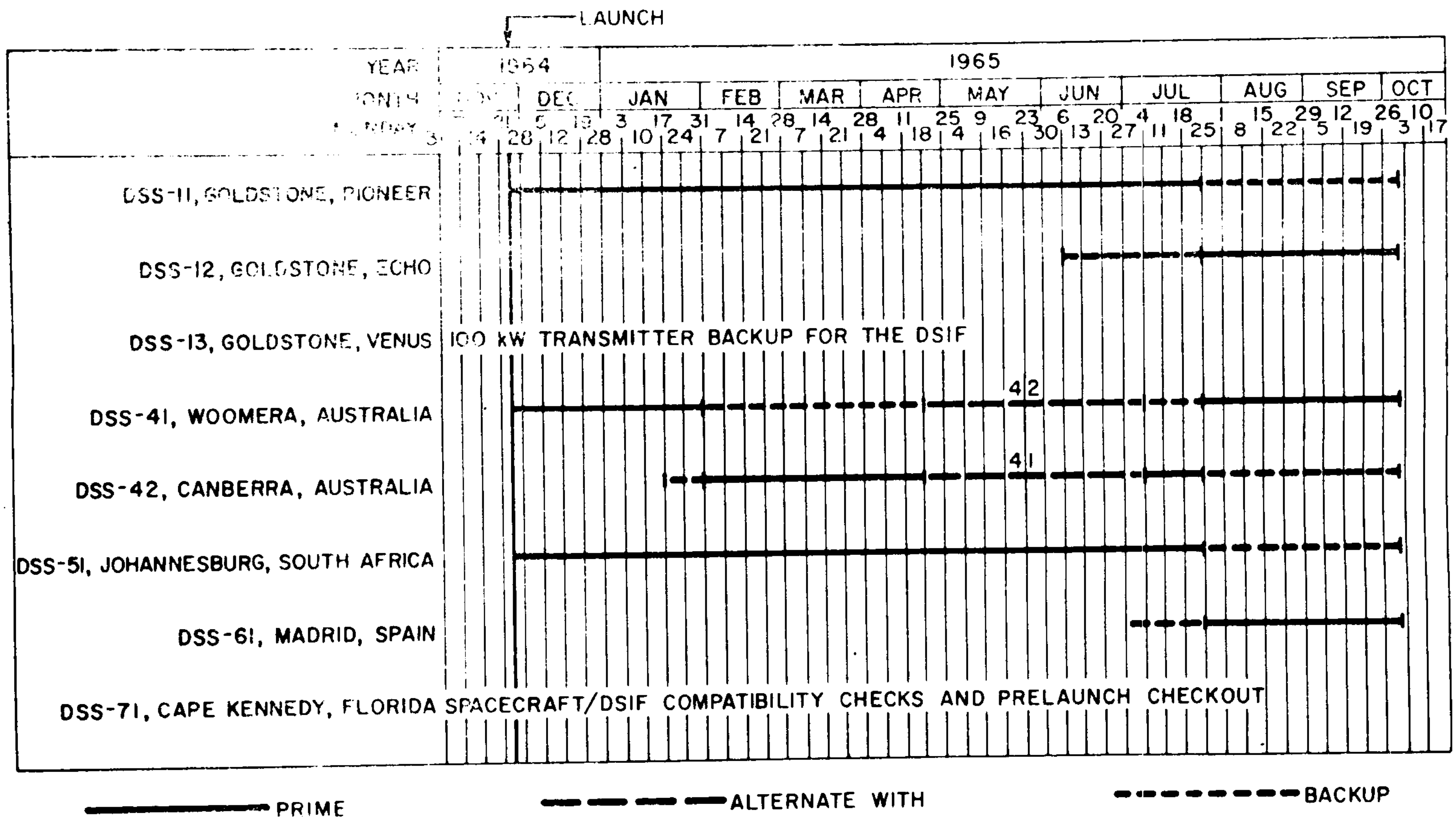


Figure 6-7. Schedule of prime and alternate DSN stations for Mariner-4 flight.

Table 6-3. DSIF STATION CAPABILITIES FOR MARINER-4 MISSION

Characteristics	Pioneer (DSN 11)	Venus (DSN 13)	Woomera (DSN 41) L- to S-band conversion kit[a]	Tidbinbilla (DSN 42)	Johannesburg (DSN 51) L- to S-band conversion kit
Receiver capability	Two	None	One	Two	One
Antenna	85-ft parabolic	85-ft parabolic	85-ft parabolic	85-ft parabolic	85-ft parabolic
Mount	Polar (HA-dec)	Equatorial (az-el)	Polar (HA-dec)	Polar (HA-dec)	Polar (HA-dec)
Maximum angular rate (both axes)	0.7 deg/s	1 deg/s	0.7 deg/s	0.7 deg/s	0.7 deg/s
Antenna gain					
Receiving	53.0 db ± 1	--	53.0 db ± 1	53.0 db ± 1	53.0 db ± 1
Transmitting	51.0 db ± 1	53.0 db ± 0.5	51.0 db ± 1	51.0 db ± 1	51.0 db ± 1
Antenna beamwidth	0.4 deg	0.4 deg	0.4 deg	0.4 deg	0.4 deg
Typical system temperature	60 k	--	60 k	60 k	60 k
Transmitter power	10 kW	100 kW	10 kW	10 kW	10 kW
Data transmission (TTY)					
Angles	Real time	None	Real time	Real time	Real time
Doppler	Real time	None[b]	Real time	Real time	Real time
Ranging (to 800,000 kms)	Real time	None	None	Real time	
Telemetry	Real & near-real time	None	Real & near-real time	Real & near-real time	Real & near-real time
Demodulated telemetry	Dual channel	None	Single channel	Dual channel	Single channel
Command capability	Yes	Yes	Yes	Yes	Yes
Data-pack air shipment time to JPL	1 day	1 day	7 days	6 days	5 days

[a]Capability difference between L- to S-band conversion kit stations and GSDS S-band stations:

a. No ranging
b. Doppler format
c. Single receiver

[b]Coherent two-way doppler when operating at 100 kW with Pioneer station.

The Ground Communication System for Mariner (called the Ground Communication Facility or GCF on later missions) comprised four different kinds of communications links:

- Teletype links operating at 60 words/min. These were leased circuits connected to switching centers at Goddard, London, and Canberra. The major terminal was the SFOF at Pasadena where a semi-automatic teletype switching system was in operation. (See Figure 6-8)
- Voice circuits. A worldwide network was pieced together from microwave links, cables, HF radio, and hardwire circuits. NASCOM's switching center at Goddard, comprising SCAMA (Station Conferencing and Monitoring Arrangement) was used.
- High-speed data circuits consisting of multiplexed microwave and voice channels.
- Wideband (video) circuits. This capability existed only between Goldstone's communication center and the SFOF in Pasadena at this point in time.

It should be pointed out that the mix of capabilities and the circuits providing them varied during the mission, being scheduled as required by the mission.

SFOF Role. All of these communication circuits converged on the SFOF, which was required to support the following mission operations:

1. Determine the spacecraft trajectory and correct it when necessary

2. Receive, record, and interpret spacecraft telemetry data in order to assess the "health" of the spacecraft so that corrective commands could be sent

3. Calculate spacecraft position and attitude (especially the orientation of scientific instruments) and correct where necessary

4. Maintain sufficient communication between the SFOF and DSN stations to obtain telemetry data from two Mariner spacecraft and tracking data from one spacecraft---from each DSN station having both spacecraft in view.

5. Control the DSN stations and the Ground Communications System.

The operational organization within the SFOF during Mariner is summarized in Figure 6-6. Note how DSN personnel, which included SFOF Operations Management and DSIF Operations Management, worked with the management of Space Flight Operations. The FPAC, SPAC, and SSAC teams defined at the bottom of Figure 6-6 were the critical project groups making the day-to-day (or minute-to-minute) decisions. The facilities within the SFOF tieing all these people together were the SFOF teletype subsystem, the

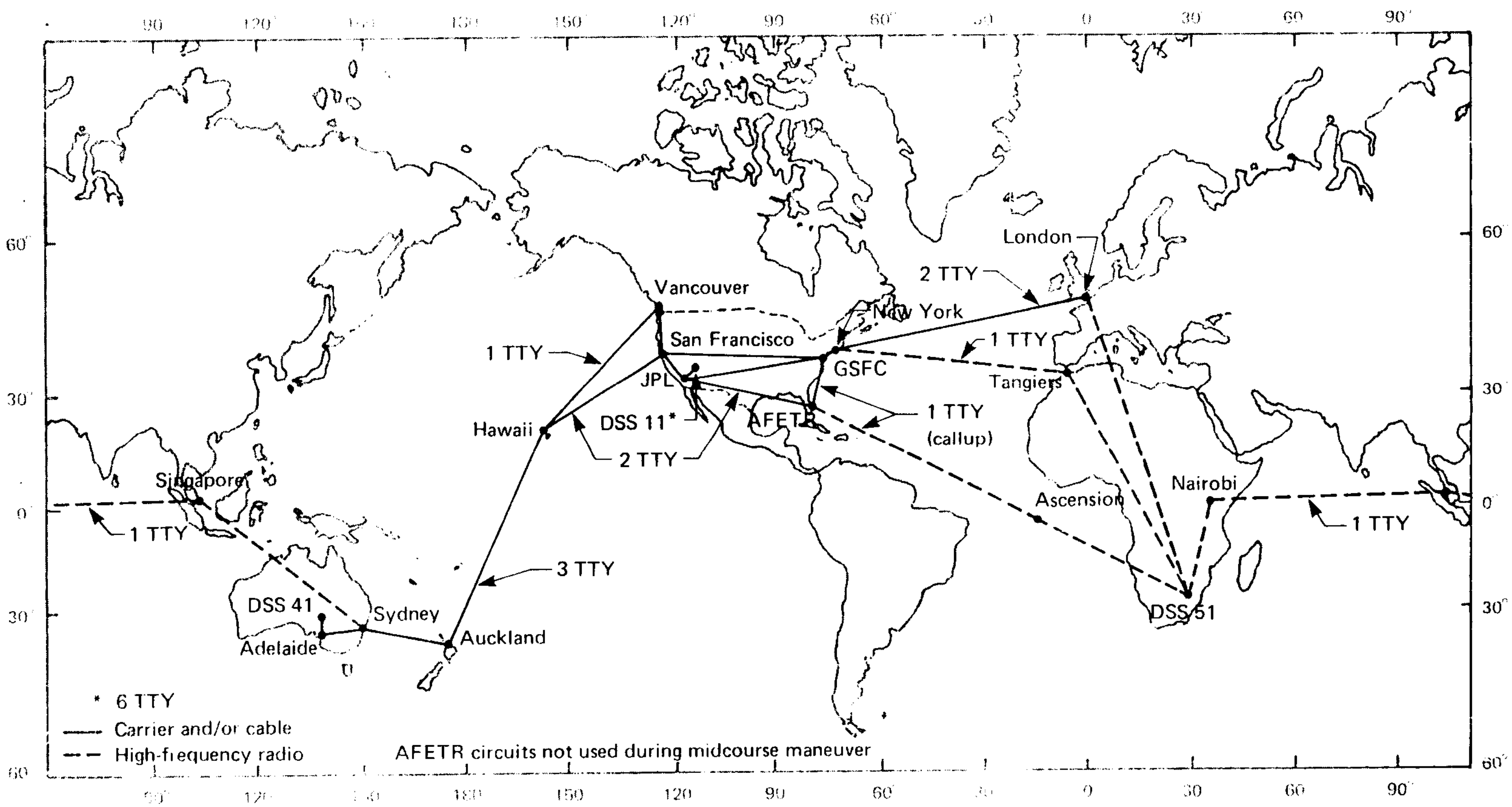


Figure 6-8. GCF teletype lines during Mariner 4.

voice subsystem, and the closed-circuit television subsystem. As the reader may have gathered already, the SFOF, in a new, barely finished building, had expanded greatly in terms of facilities and personnel. The simple control room of the Pioneer days with a few racks of equipment, a desk or two, and a console had been transformed into several different areas in a large building. Only the Operations Area is shown here. (Figures 6-9 and 6-10) This was the focal point of the SFOF during a mission. It contained the now-familiar status board and other displays deemed essential to making mission decisions.

The SFOF was and is a large data-handling machine. Data arrive from the tracking stations (Figure 6-11), are processed within the SFOF, and the information is distributed to the DSN and Project Operations and science groups. Commands, data, and mission control information are sent to DSN stations.

Since the SFOF blossomed into maturity preparatory to Mariners 3 and 4, it has been accorded some extra space at this point in the history.

Mariner-3 Flight. Mariner C, later called Mariner 3, was launched successfully from Complex 13 at Cape Kennedy on November 5, 1964. A 100 nautical mile parking orbit was attained. Downrange Air Force stations acquired the spacecraft as did Johannesburg and Woomera in turn. Trouble did not show up until two hours after launch, when the JPL SPAC group noted that the spacecraft was still operating on battery power rather than its solar panels. It was quickly discovered that the spacecraft was not attitude-stabilized, suggesting that the shroud enclosing the spacecraft had not been jettisoned. Maneuvers designed to shake the shroud loose were commanded but to no avail. As the battery power ran out, spacecraft signals became weaker and were lost altogether the next morning.

Mariner-4 Flight. The Mariner-4 attempt was made on November 28, 1964. In addition to all the radars, cameras, and optical tracking equipment at the Cape, there were nine down-range land-based radar stations plus three instrumentation ships supplying radiometric data and telemetry during the near-Earth phase. Some of these were DOD-supplied, others were borrowed from the NASA MSFN. The ascent trajectory (Figure 6-12) was such that the spacecraft was below the Johannesburg horizon, although a one-way lock was achieved for 3 seconds. Woomera was the first DSN station to acquire Mariner 4 from a practical standpoint. It confirmed that the shroud had been ejected and that the spacecraft was on solar power. The Mariner-3 problem had been corrected. As Mariner 4 doubled back across Africa (the Earth was actually rotating beneath it) it was now high enough for Johannesburg to acquire it. Goldstone Pioneer picked up Mariner 4 some 16 hours 20 minutes after launch. On November 30, a command from Pioneer caused the spacecraft to acquire the reference star Canopus, and Mariner 4 entered the first portion of its cruise phase.

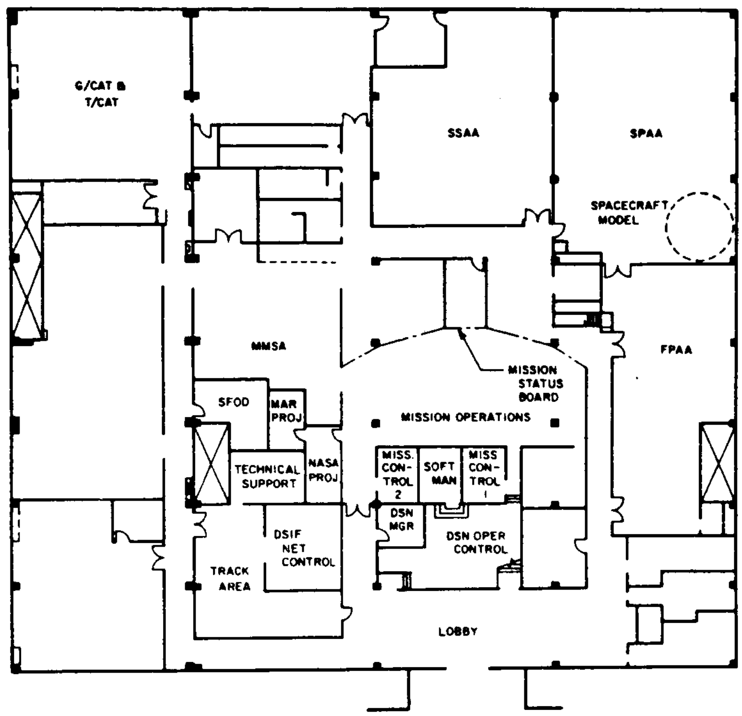


Figure 6-9. SFOF overall arrangement during Mariner 4. See also Figure 6-10.

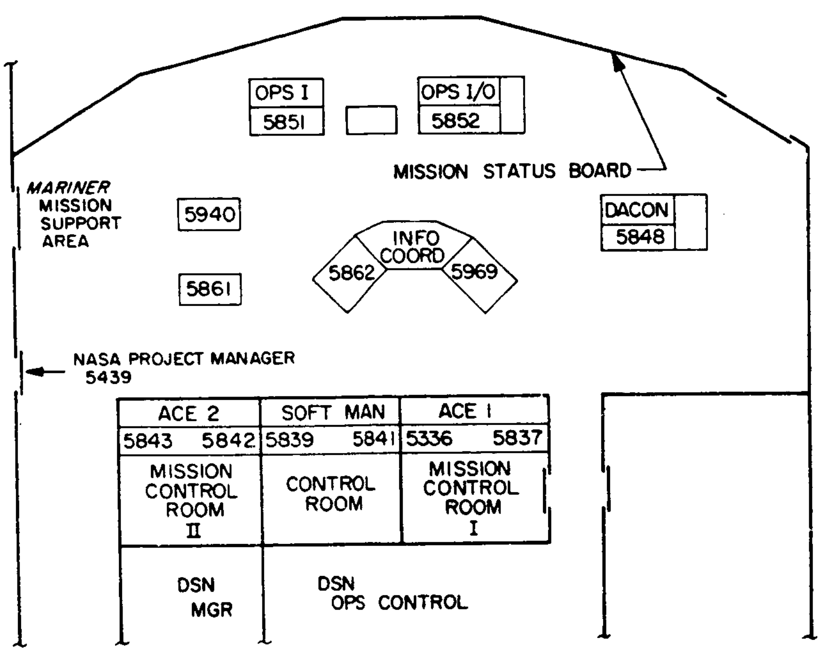


Figure 6-10. SFOF Operations Area during Mariner 4.

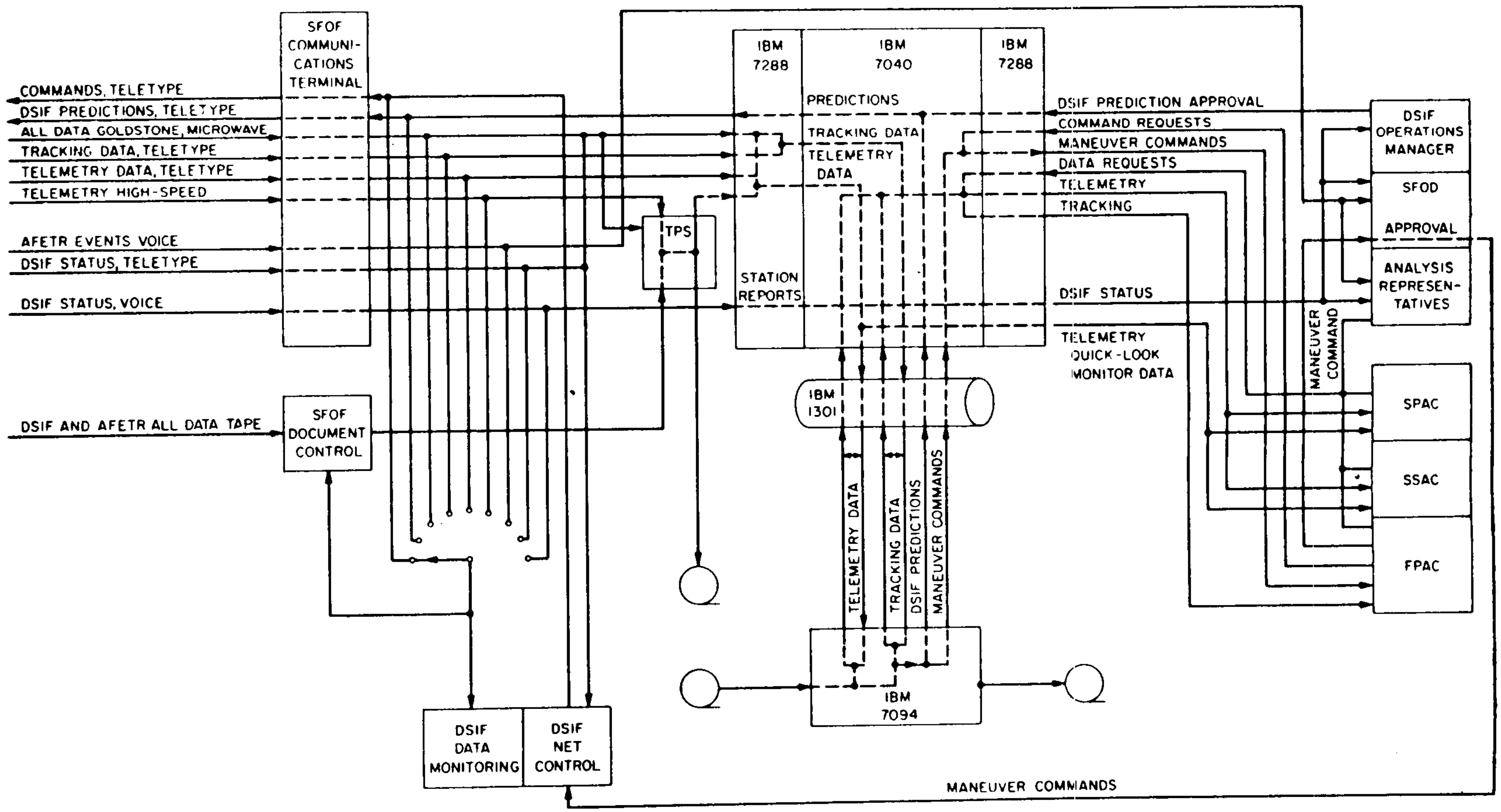
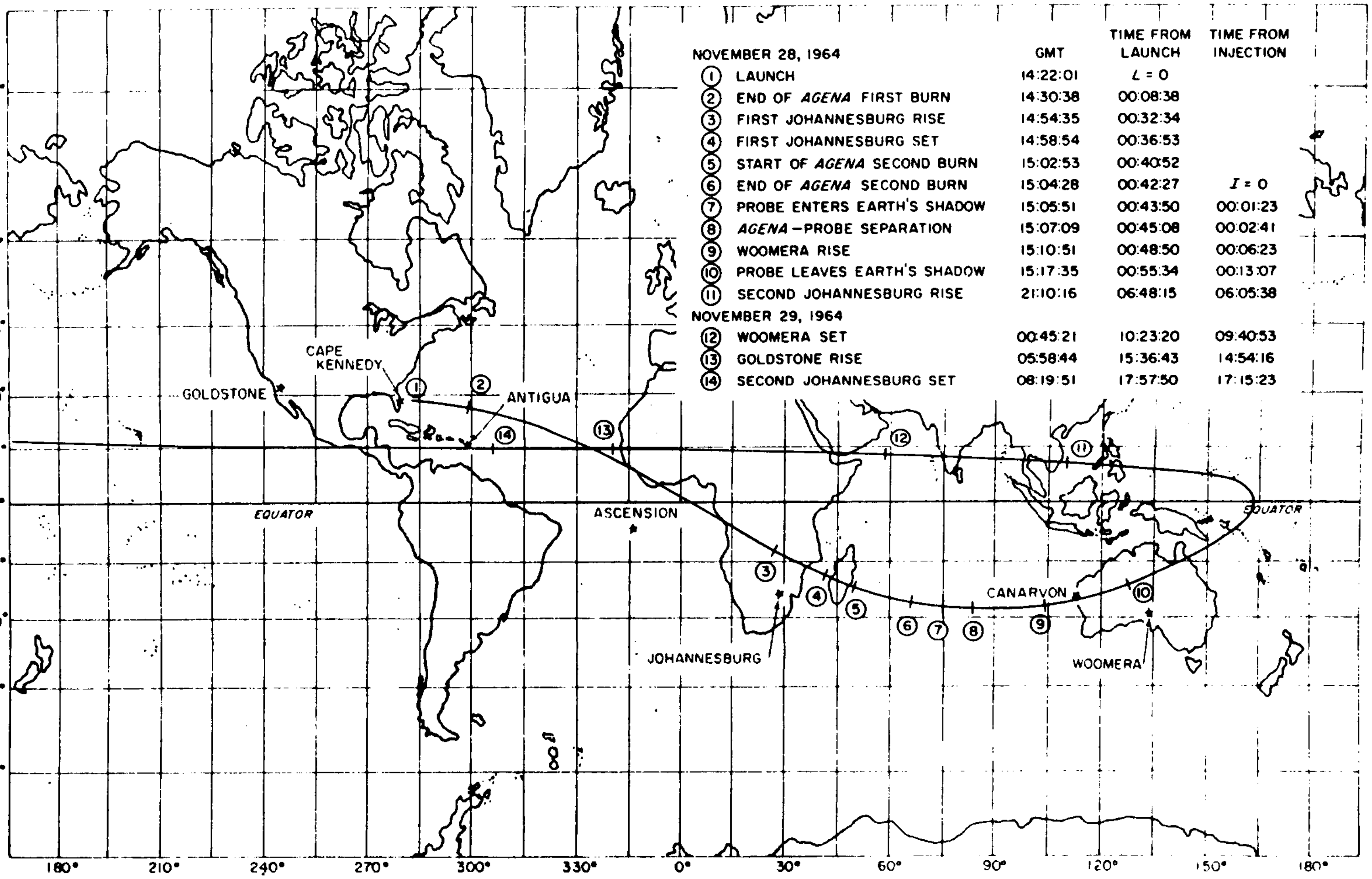


Figure 6-11. Mariner-4 mission; SFOF data flow.



NOVEMBER 28, 1964	GMT	TIME FROM LAUNCH	TIME FROM INJECTION
(1) LAUNCH	14:22:01	$L = 0$	
(2) END OF *AGENA* FIRST BURN	14:30:38	00:08:38	
(3) FIRST JOHANNESBURG RISE	14:54:35	00:32:34	
(4) FIRST JOHANNESBURG SET	14:58:54	00:36:53	
(5) START OF *AGENA* SECOND BURN	15:02:53	00:40:52	
(6) END OF *AGENA* SECOND BURN	15:04:28	00:42:27	$I = 0$
(7) PROBE ENTERS EARTH'S SHADOW	15:05:51	00:43:50	00:01:23
(8) *AGENA*—PROBE SEPARATION	15:07:09	00:45:08	00:02:41
(9) WOOMERA RISE	15:10:51	00:48:50	00:06:23
(10) PROBE LEAVES EARTH'S SHADOW	15:17:35	00:55:34	00:13:07
(11) SECOND JOHANNESBURG RISE	21:10:16	06:48:15	06:05:38
NOVEMBER 29, 1964			
(12) WOOMERA SET	00:45:21	10:23:20	09:40:53
(13) GOLDSTONE RISE	05:58:44	15:36:43	14:54:16
(14) SECOND JOHANNESBURG SET	08:19:51	17:57:50	17:15:23

Figure 6–12. Earth track of Mariner-4 spacecraft.

The uncorrected trajectory of Mariner 4 would have missed Mars by about 150,000 miles. During pass 6 over the Pioneer station on December 4, the first attempt at a midcourse maneuver was made. During this attempt, Mariner 4 lost its lock on the reference star Canopus, and the maneuver was terminated prematurely. Canopus was reacquired when the Pioneer station transmitted the appropriate commands. On the next pass over Pioneer (December 5), the midcourse maneuver was consumated successfully. (During this event, Mariner 4 was tracked by Woomera while Pioneer was sending commands.) The 20-second burn by the spacecraft motor reduced the Mars miss distance to a little over 6000 miles. (Figure 6-13)

It is important to note here that critical maneuvers, such as the Mariner-4 midcourse maneuver, can normally be commanded from several DSN stations. In the above instance, both Woomera and Johannesburg had this capability. Usually, however, a station in the Goldstone complex is selected for the critical control tasks because of the proximity of the SFOF and reservoir of trained DSN and project personnel should problems arise. In addition, the communication links between Goldstone and the SFOF in Pasadena are shorter and more reliable than those to other stations.

On December 13, in preparation for long distance communication during cruise, the Pioneer station commanded the Mariner 4 to switch over from its cavity amplifier to its travelling-wave-tube amplifier. This transition increased the signal levels available to DSN receivers. Later, as Mariner 4 receded from Earth, it became increasingly difficult for the DSN to receive data at the initial rate of 33-1/3 bits/sec, despite the change in amplifiers. This problem was inevitable and planned for; on January 3, 1965, 6.16 million miles from Earth, the spacecraft automatically switched to the 8-1/3 bits/sec rate. Next, at a distance of 26.9 million miles, on March 5, the spacecraft switched from its low-gain to high-gain antenna. Since these changes were absolutely vital to mission success, they were commanded automatically by the spacecraft timing equipment so that the spacecraft would not be lost completely should contact (and command capability) be broken inadvertantly with the DSN. The logic being that a "lost" spacecraft may be recovered more readily if it can increase its "visibility" to the DSN through internal, preprogrammed actions.

During the long 6-month's cruise to Mars, the DSN carried out many tests and exercises to prepare it for the all-important encounter phase of the mission. For example, encounter tests were run back on Earth using the proof-test spacecraft model as a signal source simulating the actual Mariner 4. Various backup-mode tests and alternate-encounter-mode tests were conducted to prepare for possible anomalies at encounter.

The DSN provided nearly continuous coverage for Mariner 4 during cruise. The notable exceptions occurred when various stations were temporarily released. By early July, as encounter neared, Woomera, Johannesburg, and Pioneer were once again all tracking Mariner 4. In addition, Tidbinbilla and Robledo had joined the network and the Goldstone Echo station had been diverted to the Mariner-4 mission.

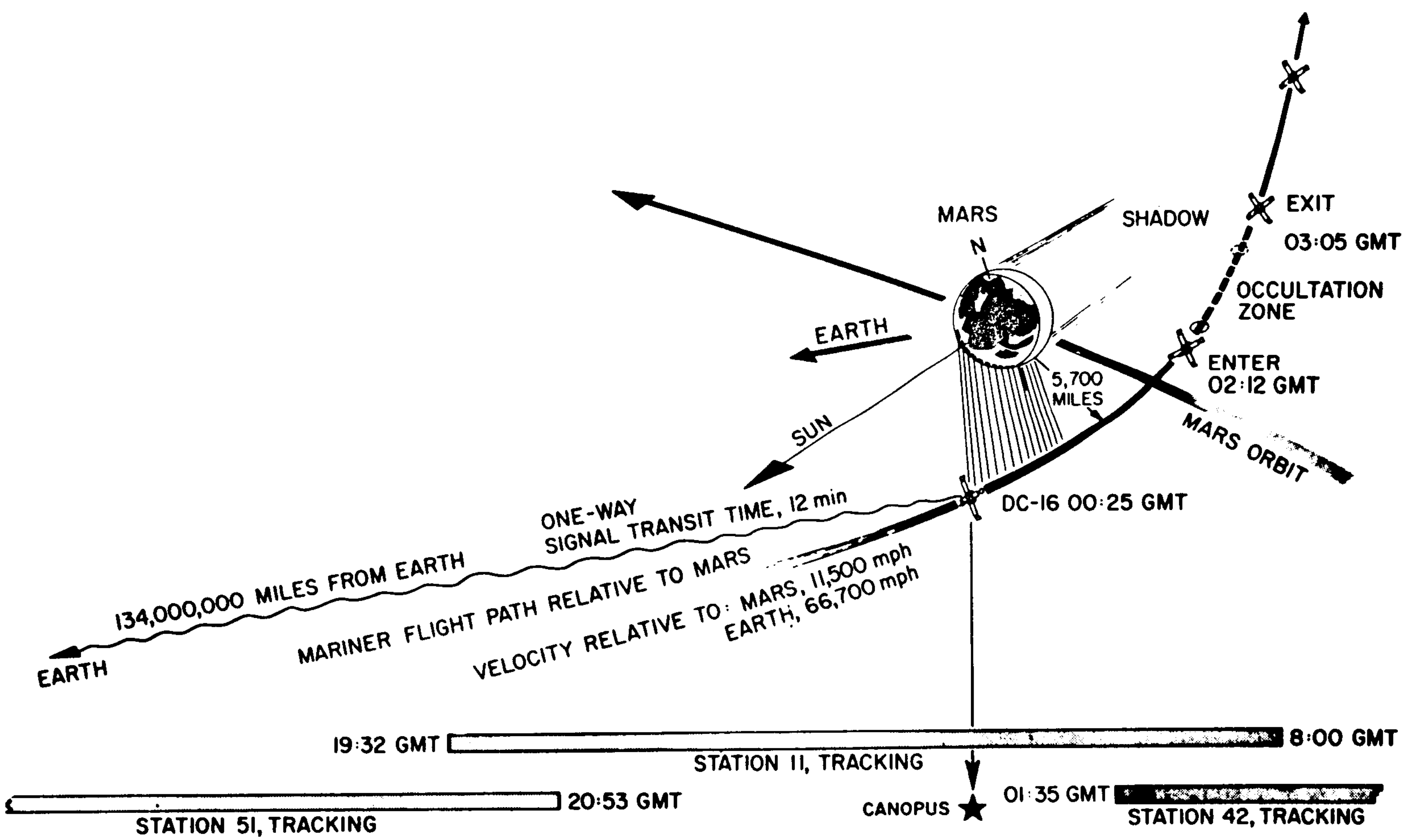


Figure 6-13. Mariner-4 plan for Mars encounter.

On July 14, 1965, the 228th day of the mission, commands from Johannesburg began preparing the spacecraft for encounter; i.e., turning on the scientific instruments and tape recorder, etc. When Johannesburg handed Mariner 4 over to the Pioneer station at Goldstone later in the day, the Pioneer station completed the command sequence. These commands would eventually have been executed automatically by the spacecraft itself, but the excellent quality of Earth-spacecraft communications permitted mission controllers to preempt the automatic command feature.

Mariner-4 cameras acquired Mars and took a series of pictures over a period of 25 minutes, 12 seconds, storing the data on the spacecraft tape recorder. Before picture playback could begin, Mariner 4 passed behind Mars, resulting in a loss of signal for about 53 minutes. After reacquisition, Mariner 4 began sending back picture data and the information acquired by the other instruments. The first picture playback sequence, at the low 8-1/3 bits/sec rate, lasted from July 15 through July 25. A second readout followed and was completed August 3. Following the second playback, Mariner 4 resumed sending cruise engineering and science data.

Various DSN stations continued tracking Mariner 4 until October 1, 1965. when the Goldstone Venus station inadvertently transmitted a command to the spacecraft to switch to the low-gain antenna. Thus, Mariner 4 was temporarily lost some 2-1/2 months after encounter.

Scientifically, the mission was a great success, giving scientists their first close-up views of the Martian surface.

DSN support throughout the mission was excellent. There were, of course. many small problems with equipment and administrative procedures that keep cropping up. These were eventually solved, usually on the spot by innovative personnel. Two problems are singled out here because they reflect upon the general technological progress of the DSN. First, the decision to employ travelling wave masers in the network appeared premature from a review of the many operational difficulties encountered. Too much time had to be spent in repairing and coaxing of equipment. Second, the high frequency ground radio communication link with Johannesburg suffered many outages, emphasizing the desirability of a cable circuit to South Africa.

All in all. the nominal Mariner-4 mission from launch to encounter, was as successful on the ground as it was in outer space. In fact, Mariner 4 was not lost forever, because with special techniques plus the availability of the new Mars 64-m antenna at Goldstone the Mariner-4 signal was picked up again. This "extended coverage" of Mariner 4, described in more detail in the next chapter, contributed valuable radio science data to solar-system researchers.

The Interplanetary Pioneers

The Interplanetary Pioneers comprised a new series of deep-space vehicles that posed several new kinds of problems for the DSN. Despite the

Pioneer name, these new spacecraft bore little resemblance to the preceding Pioneers launched by the Army and Air Force in 1958 and 1959. Rather than short-lived lunar probes, like Pioneers 1 through 4, the Interplanetary Pioneers were conceived as deep-space monitoring stations plying orbits around the Sun between Venus and Mars with lifetimes of perhaps one year each.

One problem that unexpectedly cropped up with the new Pioneers involved their great tenacity for life. Instead of giving up the ghost after one year, they kept radioing back scientific data for many years, creating the need for extended DSN support far beyond that originally planned. The new Pioneers were managed by NASA's Ames Research Center at Mountain View, California, and thus became the first important "off-Lab" project requiring significant DSN support. Furthermore, Ames wanted a data terminal and control facility at Mountain View. This was a new situation for the DSN, which had intended that all control facilities reside in the SFOF. Finally, the maximum ranges of the new Pioneers would be about 2 A. U., a distance considerably greater than the capabilities of the 26-m dishes in the 1965 DSN. Only the 64-m Mars antenna under construction at Goldstone could hope to track the Pioneers across the solar system. The sizeable scientific contributions of the Interplanetary Pioneers constitute ample proof that these challenges were met.

The history of the Interplanetary Pioneers began in 1960 when a small team at Ames began studying solar probes.[7] Unfortunately, NASA Headquarters was more interested in spacecraft to monitor interplanetary "weather." With the assistance of Space Technology Laboratories Ames adapted its concept of a small, simple, long-lived spacecraft to this monitoring mission which was the only one "saleable" at the time. On July 30, 1964, NASA Headquarters approved the Pioneer Project, and Ames began preparing for a 1965 launch.

Compared to JPL's Mariners and Rangers, the Pioneer spacecraft were small indeed, varying from 137 to 148 pounds each. Five were built altogether (2 in Block I, 3 in Block II), but only the first four were launched successfully (Pioneers 6 through 9). The plan was to place some in solar orbit between Earth and Venus and others between Earth and Mars. Such small spacecraft, however, could not afford the Earth-pointed parabolic antennas of the Rangers and Mariners and three-dimensional attitude control. The unique Pioneer engineering approach involved spin-stabilizing the spacecraft in solar orbit and using a mast-type antenna that concentrated the spacecraft radio transmissions into a thin disk. By maneuvering the spacecraft attitude through the DSN, the designers hoped to keep the Earth located within that disk. Clearly, the DSN had a new kind of target, and one that was managed and controlled elsewhere.

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[7] William R. Corliss, "The Interplanetary Pioneers, Volume I: Summary," (Washington: NASA SP-278, 1972) p. 2.

As of this writing, some of the Interplanetary Pioneers have been operating out in space for more than a full decade. Understandably, the requirements for Pioneer tracking and data acquisition changed considerably through the years in the context of competing missions, spacecraft emergencies, the number of DSN stations in operation, special astronomical events (conjunctions, etc.), and our improving knowledge of the interplanetary milieu. It is impossible to document even a fraction of these voluminous requirements here. Instead, Table 6-4 is offered to illustrate the most important types of Pioneer operations requiring DSN participation. Note that the Pioneers required two different types of orientation maneuvers; one shortly after launch and another to establish optimum radio contact before the cruise phase. Tables 6-5, 6-6, and 6-7 provide additional insights into the growing complexities of scheduling the tracking of the many probes out in deep space. The data in the tables are, of course, only typical and keep changing week by week.

The basic tracking and data acquisition support for the Interplanetary Pioneers was the task of the DSN's 26-m paraboloids. The 64-m antenna at Goldstone's Mars site (DSS-14) did not become operational until almost six months after the launch of Pioneer 6 which occurred in December 1965. However, as various Pioneers forged beyond the detection capabilities of the 26-m dishes, DSS 14 and various other antennas in the 64-m subnet that was eventually built worked them when required. (See Chapter 7.) On occasion, the 26-m antennas of the MSFN also tracked various of these interplanetary weather stations. During the first decade, many conjunctions, passages behind the Sun (occultations), and other astronomical events have permitted a host of unique radio science experiments. By pooling the capabilities of DSN and MSFN, scientific coverage of these unusual situations has been very productive.

During the years the DSN introduced several modifications aimed at increasing its ability to pick up the faint signals from the distant Pioneers with its 26-m antennas. Included have been improved masers, more efficient microwave equipment, linear antenna polarizers, 3-Hz carrier tracking loops, advanced demodulation hardware, and (for Pioneer 9 only) special decoding software for experimental convolutional coding devices. Over the years the 26-m antenna threshold range of detection for Pioneers has been increased from 0.4 to 1.5 A. U. These improvements have, of course, benefited other missions too.

As was common during this period of DSN development, stations were burdened with special mission-dependent equipment. In the case of Pioneer, this apparatus was designed to provide telemetry data processing in real time. Called GOE (Ground Operational Equipment), these racks consisted of a command encoder, a computer buffer, bit synchronizer, and various test equipment. The Pioneer Project supplied this GOE, but the DSN stations had to find room for it, operate it, and maintain it.

Pioneer 6. The first of the Interplanetary Pioneers was launched on December 16, 1965, from Cape Canaveral aboard a Delta rocket. Twenty

Table 6-4. CRITICAL PIONEER MISSION OPERATIONS INVOLVING THE DSN

Operation	Orbit phase	Operation period	Purpose
1. Separation from third stage	58.5 sec after third-stage burnout		Separate spacecraft from spent third-stage; Mission Control: JPL/SFOF
2. Orient spacecraft spin axis normal to the spacecraft-Sun line (Type-I orientation maneuver)	Automatically initiated at separation from third stage	Nominally 0-10 min	Orient spacecraft for maximum solar energy to provide spacecraft power utilizing the on-board solar array; Mission Control: JPL/SFOF
3. Initial acquisition by DSN	Acquisition of downlink telemetry before launch plus one hour	Approximately 15 min	Acquire spacecraft during transfer to heliocentric orbit and assess spacecraft health; Mission Control: JPL/SFOF
4. Spacecraft data-mode changes and experiment turnon	Commanded from ground after uplink lock and assessment of spacecraft health and orbit	Approximately 6 hr after acquisition	Prepare spacecraft for scientific data collection; Mission Control: JPL/SFOF
5. Orient spacecraft spin axis normal to plane of ecliptic (Type-II orientation maneuver)	Commanded from DSS 12 with other DSS stations as alternates within several days of launch	One complete DSS pass. Takes approximately 8-10 hr	Establish final reference orientation of spacecraft spin axis; Mission Control: DSS-12 (Goldstone); except for partial Type-II orientation maneuver for Pioneer 6 made from Johannesburg
6. Cruise phase (nominal mission)	Begins upon injection into heliocentric orbit and upon completion of experiment turnon and Type-II orientation maneuver	Continuous tracking coverage for first month after launch; two tracking missions coverage per day through nominal lifetime; dependent on schedule conflicts, and with high-priority DSN intent should be to provide continuous coverage	Collect scientific data; major coverage provided by DSS containing Pioneer GOE for assessment and analysis of real-time science and engineering data; Mission Control: Ames Research Center

Operation	Orbit phase	Operation period	Purpose
7. Cruise phase (extended mission)	Begins upon completion of cruise phase of nominal mission	One tracking mission coverage per day; tracking missions to be provided by the DSN 210-ft antenna at Goldstone. Cal.; extended mission to continue until spacecraft cannot provide useful science data or when spacecraft is beyond DSN capability	Collect scientific data: Mission Control: Ames Research Center
8. Solar-flare coverage phase	Begins when Mission Operations Manager requests coverage for reported Class-II-Bright or above solar flare during cruise phase	Nominal mission: continuous coverage for 30 to 50 hr; extended mission: within capability of 210-ft antenna system net to provide coverage over a 50-hr period	Collect maximum scientific data in spacecraft vicinity during high solar activity
9. Geomagnetospheric tail analysis (Pioneers 7. 8. and E)	Nominal period of analysis established prior to launch. actual required coverage period provided upon analysis of the resultant trajectory	Continuous coverage from syzygy-minus-5-days to syzygy-plus-15 days	Define boundaries and characteristics of the geomagnetospheric tail
10. Lunar occultation	The probability of a lunar occultation indicated from analysis of the nominal trajectory; definite times established upon detailed analysis of resultant trajectory; simultaneous view periods from Stanford University and Goldstone necessary	Continuous coverage from entrance minus 10 hr to exit plus 10 hr	Provide lunar occultation analysis utilizing the Stanford University on-board instrument in conjunction with the Stanford 150-ft tracking system and DSS 12 and DSS 14 at Goldstone. Cal.: coverage also required from other stations (Australia. Spain. or South Africa) if period occurs during overlap view with Goldstone and Stanford University

Operation	Orbit phase	Operation period	Purpose
11. Superior conjunction or analysis of Sun's corona during solar occultation (Pioneers 6, 7, 8, 9, and E)	Part of the extended mission and to be fixed to a given period upon analysis of resultant heliocentric orbit	Continuous coverage within the capabilities of the 210-ft antenna beginning one month prior to and ending one month following solar occultation	Provide analysis of Sun's corona characteristics during superior conjunction
12. Reorientation maneuvers during cruise phase	As determined by the Mission Operations Manager	During a complete tracking pass at DSS 12 Goldstone	Possibility of Mission Control's being moved to DSS 12 during this maneuver; to provide spacecraft spin axis orientation as determined by the Mission Operations Manager
13. Spacecraft anomalies	As determined by the Mission Operations Manager	Continuous coverage until anomaly has been corrected or it has been decided that it cannot be corrected, as determined by the Mission Operations Manager.	Possibility of Mission Control being moved to JPL/SFOF or remaining at NASA/ARC as determined by the Mission Operations Manager

Table 6-5. GENERAL PIONEER TRACKING REQUIREMENTS AS OF MARCH 1969[a]

Pioneer	Nominal mission
6	DSS 14 daily coverage 4–8 hr/day; absolute minimum, DSS 14 daily coverage 3 hr/day
7	DSS 14 daily coverage; 4–8 hr/day; absolute minimum, DSS 14 daily coverage 3 hr/day
8	DSS 12, 42, 51, 62 and DSS 11, 42, 61; continuous coverage; absolute minimum, DSS 12, 42, 51, 62 and DSS 11, 41, 61, two tracking missions/day for a total of 16 hr/day
9	DSS 12, 42, 51, 62; continuous coverage; absolute minimum, DSS 12, 42, 51, 62 and DSS 11, 41, 61 and MSFN; two tracking missions/day for a total of 16 hr/day, with 1 hour overlap
E	DSS 12, 42, 51, 62; continuous coverage; absolute minimum, DSS 12, 42, 51, 62 and DSS 11, 41, 61 and MSFN; two tracking missions/day for a total of 16 hr/day

[a]These requirements vary with time, of course. This table is illustrative only.

Table 6-6. TYPICAL TRACKING REQUIREMENTS FOR A PIONEER FLIGHT

Time/distance coverage	Data required	Data presentation
Class-I requirement A. Launch-vehicle second-stage engine cutoff (SECO) to SECO-plus-60 sec B. Launch-vehicle third-stage burnout to third-stage spacecraft separation (minimum of 60 sec of data if available) Class-II requirement A. SECO to SECO plus 180 sec B. Ascension (ETR Station 12) rise to Ascension set.	Time, azimuth, elevation, range Data points per sec: 1/10 minimum, 1/6 desired, 1/3 maximum	The data to be converted for presentation in NRT by teletype to the SFOF as follows: (a) Decimal raw-data format (b) Orbital elements and injection conditions of parking orbit (c) Orbital elements and injection conditions of transfer orbit assuming nominal third-stage burn (d) Orbital elements and injection conditions of transfer orbit based on actual third-stage burn
Class-III requirement SECO to third-stage ignition; third-stage spinup to third-stage burnout; DSS tracking coverage sufficient to define the free-flight orbit	Acceleration	Voice link and/or single-sideband data link in NRT; initially launch plus approximately 2 hr, and as required to meet accuracy requirements

Table 6-7. PIONEER TELEMETRY DATA-ACQUISITION REQUIREMENTS

Channel				
No.	Frequency	No. of segments	Data rates	Recording interval and accuracy
6A 7A	2292.037037 MHz 2292.407407 MHz	Transmitted in a 7-binary-bit data word on a 2048-Hz square wave, which is bi-phase-modulated with a time-multiplexed PCM bit train, using a non-return-to zero-mark format. Telemetry data are formatted into 32-word main frames.	512, 256, 64, 16, and 8 bps selectable by ground command; when the convolutional coder is operating, a parity bit will be transmitted with each data bit; this will have the effect of doubling the transmitted bit rate to obtain the same data rates noted above	Telemetry data are received, demodulated, synchronized, recorded and transmitted to an on-site SDS-920 computer. The computer decommutates and formats the telemetry data and outputs a portion of this data on teletype to the Ames Mission Operations Center. The aforementioned takes place at stations having Pioneer GOE during a tracking mission. At stations not having GOE, the output of the ground receiver is recorded during a tracking mission. During non-coverage tracking periods the telemetry data will be stored on-board for later readout. This mode is selectable by ground command.

minutes after launch, control was transferred from the SFOF to Johannesburg, where the Type-II orientation was handled. (The Type-I orientation maneuver is automatic and normally requires no DSN participation.) Although some minor problems were experienced in terms of late locks onto the spacecraft signal, the mission generally went according to plan. On January 18, JPL's SFOF shared control with the Ames Pioneer control station for the first time. By February 23, the transfer of all control functions had been completed. As the spacecraft-to-Earth distance increased the bit error rate also increased. To reduce this error rate, the first reduction of bit rate (from 256 to 64 bits/sec) was commanded on March 17. Such changes in bit rate occurred frequently as distance and other conditions changed. Type-I and Type-II orientations were also commanded to confirm and improve spacecraft attitude. At the end of the nominal 6-month mission on June 13, 1966, Pioneer 6 was still a healthy spacecraft, and the mission was correspondingly extended. Many years later Pioneer 6 was still sending back scientific data. With the 64-m antennas the DSN was able to track this spacecraft continuously. (See Chapter 7.)

Pioneer 7. The launch and DSN acquisition of Pioneer 7 took place August 17, 1966. Tracking from launch to cruise phase was excellent; the spacecraft was operating beautifully. On August 31, however, the spacecraft travelling wave tube began operating erratically and the spare was switched in by command. This spacecraft was also operating well at the end of its nominal mission and like Pioneer 6, required the DSN to plan for an extended mission. By November 28, 1969, the inward Pioneer 6 and outward Pioneer 7 were aligned so that both were tracking simultaneously in a "radial-spiral" radio science experiment.

Pioneer 8. This spacecraft was the first from Block II. It was launched without incident on December 13, 1967. The trajectory was such that tracking rates at Johannesburg were excessive and Woomera was therefore designated the initial acquisition station. The Earth-escape hyperbola for Pioneer 8 was less energetic than planned and the resultant solar orbit was consequently less eccentric and more inclined than desired. Spacecraft performance, however, has been excellent.

Pioneer 9. Liftoff occurred on November 8, 1968. Twenty-six minutes later, Johannesburg reported a momentary signal, but this was 10 minutes after predicted acquisition. Furthermore, the signal was 16 db too low. Two-way lock was finally achieved 44 minutes after launch. Receiver signal levels later rose to normal levels, and the mission then countinued according to plan. This spacecraft carried a Convolutional Coder Unit (CCU) which provided, in effect, a 3 db gain over the previously launched Pioneers. This "coding gain" was measured experimentally and was so effective that the CCU idea was subsequently applied to other NASA spacecraft.

Pioneer E. This flight, the fifth and last of the Interplanetary Pioneers, began August 27, 1969, and was a launch failure.

The Remaining Atlas-Centaur Test Flights

In 1965, both the Atlas-Centaur and Surveyor (the first spacecraft designated to use the Atlas-Centaur) were both still far behind schedule. Pressure on both programs was extreme.

The DSN had participated in the test flights of AC-2 and AC-3 in 1964 (see Chapter 5), but did not have the resources to aid the AC-4 flight. L-band beacons had been placed aboard flights AC-2 and AC-3 to facilitate DSN tracking. By the time the AC-5 flight was scheduled, the DSN had convrted to S-band operation with the exception of the L/S equipment retained at a few stations for the final Ranger flight. Thus, the last four Atlas-Centaur test flights, AC-5, AC-6, AC-8, and AC-9 flew with S-band beacons. [8]

Flights AC-5 and AC-6 carried Surveyor dynamic models on direct-ascent, variable-launch-azimuth trajectories that were targeted to impact the Moon. It was for such direct-ascent flights that NASA was installing facilities on Ascension Island. The AC-5 and AC-6 launches were to demonstrate that the Atlas-Centaur could be launched on time and possessed an adequate guidance system for the first Surveyor flight, now just a few months away. Operational procedures to be used for this all-important Surveyor shot were to be tested out on these flights. A midcourse maneuver was also to be simulated.

The AC-8 and AC-9 flights, in contrast, were to be launched into parking orbits and employ second burns to inject Surveyor mass models into simulated lunar transfer orbits. Several of the actual Surveyor flights did use this parking-orbit mode, and this pair of test flights was planned to demonstrate that the Atlas-Centaur was ready for such missions. During these flights, the DSN was to provide two-way angle and Doppler tracking of the S-band beacons on the mass models, as well as space vectors, orbital elements, injection conditions, midcourse correction requirements, and similar data.

The AC-5 Flight. This launch took place March 2, 1965, less than three weeks before Ranger 9. The DSN assigned Goldstone Pioneer, Johannesburg, and Woomera [9] to the AC-5 flight, but they were not needed because the Atlas booster engines shut down after the booster had risen only a few feet off the launch pad. The vehicle dropped back onto the launch pad, exploded, and burned.

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[8] AC-7 was used for the launch of Surveyor 2. See Chapter 7.

[9] The Ascension Island station was not operational until April 1966 and could not support AC-5 and AC-6.

The AC-6 Flight. The AC-6 was much more successful. It was launched August 11, 1965---the first vehicle to use Complex 36B at the Cape. The DSN configuration was identical to that for AC-5 except that Echo replaced Pioneer at Goldstone. The Launch Station (DSS 71), although not formally committed to the flight, did participate in the countdown and maintained one-way lock until 200 seconds after liftoff. The flight trajectory was normal and the model spacecraft was successfully injected into a simulated lunar transfer trajectory. The DSN tracked AC-6 without incident until a little over 16 hours after liftoff, when the beacon signal dropped abruptly to zero. At the time, three stations (DSS 11, 12, and 42) had contact with the spacecraft. The signal could not be reacquired by any DSN station. The beacon battery, designed for 20 hours of operation, may have been drained prematurely.

The AC-8 Flight. During the last two Atlas-Centaur test flights, the DSN was committed to tracking the S-band beacons for 40 hours (the new battery life). Longer beacon lifetimes were required because these two flights were to be injected first into parking orbits. Goldstone Pioneer, Tidbinbilla, and Johannesburg were designated as prime for AC-8. The station on Ascension was now complete and the AC-9 flight was used for training purposes. Training exercises were also carried out at the Launch Station and Robledo.

After three aborted launch attempts, AC-8 finally left its launch pad on April 8, 1966. The injection into the parking orbit occurred according to plan, but the second burn was unsuccessful so that a lunar transfer orbit was not achieved. The DSN tracked AC-8 for 26 hours until the signal ceased. The flight was far from expectations, but the DSN performed well. Apparently, AC-8 was tumbling in space, and there were numerous losses of signal. The Ascension station (DSS 72), with its high tracking rate 30-foot antenna was actually able to follow the orbiting spacecraft better than the slower 26-m dishes which were not designed to work fast-moving, Earth-orbiting satellites.

The AC-9 Flight. The flight objectives were essentially those of AC-8. The prime DSN stations were Goldstone Pioneer, Woomera, Johannesburg, and the Launch Station at the Cape. A successful launch occurred on October 26, 1966---on the second attempt. This time the flight went well, and the proper parking orbit and simulated lunar transfer orbit were achieved. The second burn of AC-9 signaled the first successful restart in space of a rocket engine employing cryogenic fuel (liquid hydrogen). Tracking services by the DSN more than fulfilled the requirements. Although the launch vehicle performance was not letter-perfect, the Atlas-Centaur demonstrated that it could inject a Surveyor vehicle into a parking orbit from which it could be sent to the Moon. By this time, however, the first two Surveyors had been launched in the direct-ascent mode. (See Chapter 7.)

Tracking Theory and Accuracy

One of the great and generally unappreciated accomplishments of the DSN is its exceedingly fine measurement of Earth-spacecraft distances and, in consequence, the distances to the other planets and sundry astronomical objects in the solar system. Astronomers with telescopes can measure planetary distances only to within thousands of miles, but with a cooperating space probe the DSN can refine planetary distance measurements to less than a meter. The fact is that the DSN-spacecraft combination has applied a new kind of radio ruler to the solar system and, in doing so, has revolutionized our knowledge of its dimensions. In addition to simple refinements, unexpected discoveries, such as that of the lunar mascons, have been made through analysis of slight dimensional perturbations. The story related below has two parts: (1) advances in radiometric theory; and (2) the tracking down and elimination of the many tiny sources of error in the measurement system.

Radiometric Theory. Until about 1965, radiometric theory had been patterned as an astronomer would think; that is, it relied upon antenna pointing angles plus the Doppler and range measurements made through the cooperation of the spacecraft transponder. Thus were acquired the six measurements needed to deduce the three positional and three velocity values that constitute an unequivocal determination of any spacecraft's spatial coordinates and motion. Measurements of this kind were made in the early days of the DSN and did provide the navigational accuracies expected of them. There were better ways of measuring the six variables needed for space navigation, but it was not until 1965 that the way to much higher accuracy was fully realized.

The most direct navigation system would measure the three position and three velocity components directly, but this is clearly impossible to do from Earth with a space probe millions of miles away. The next best thing is the measurement of variables very closely related to position and velocity. The DSN range and Doppler measurements meet this criterion, but the antenna pointing angles do not. The secret to the precision tracking of deep space vehicles depends upon measuring range and Doppler repeatedly as the aspect or relative geometry of Earth tracking stations and the space probe vary. In the case of lunar probes, the rapidly changing aspect of the probe with respect to the Earth provides enough different data points in a conveniently short period of time to create this desired "multi-aspect" condition. This is also true when the space probe is in a fast-changing orbit around the Moon or planet. Much of the DSN's most critical tracking comes when probes are in interplanetary transfer orbits and move very slowly against the background of fixed stars. Range and Doppler measurements would vary too slowly here if it were not for one factor: the rotation of the Earth of its axis. Because of the Earth's rotation, we need not wait many months while the probe travels a large portion of its orbit around the sun; rather, the diurnal motion of the Earth modulates the Doppler range-rate measurement in the manner shown in Figure 6-14. From the modulation, the requisite probe coordinates can be ascertained with high accuracy. Without going into the mathematical details, three of the necessary variables can be determined from a single pass of Doppler tracking. The variables actually measured are range-rate, modulation amplitude, and the time the modulation curve crosses the ordinate (a phase measurement). A day or two later, the probe position has changed enough so that when the same measurements are made and then combined with direct range determinations, they comprise sufficient information to yield all six needed coordinates with very high precision. (Figure 6-15)

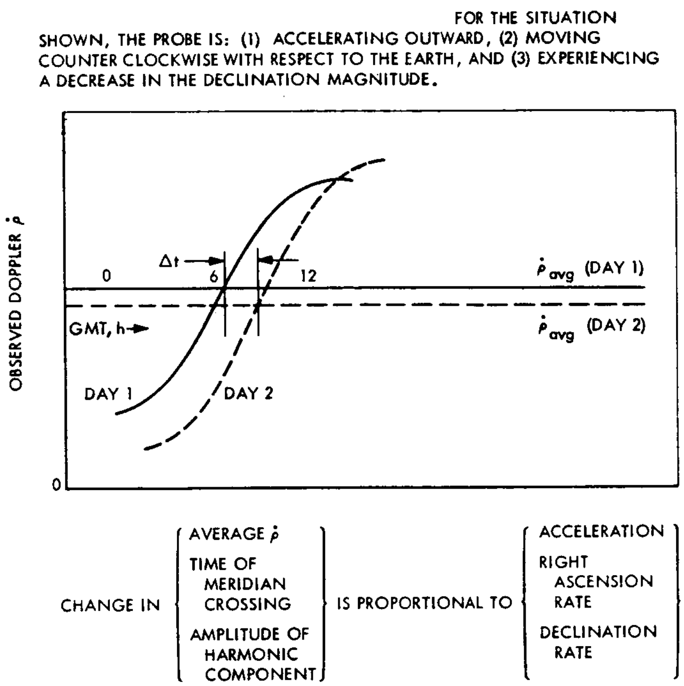

Figure 6-14. Doppler signature on two successive days.

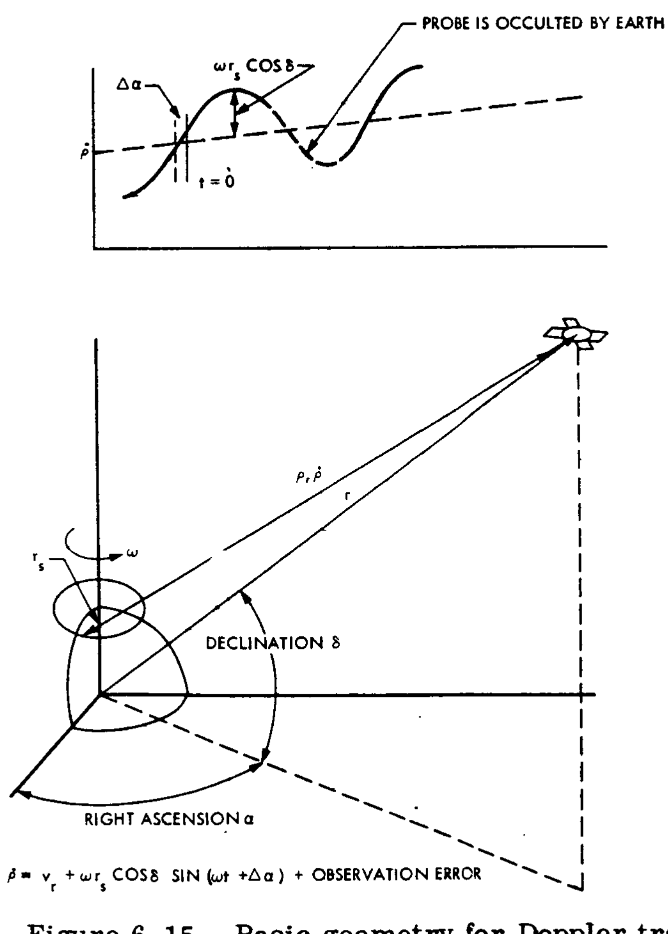

Figure 6-15. Basic geometry for Doppler tracking.

In the early 1960s, no one foresaw this rather elegant but direct method of gaining the coordinates of a distant space probe. Everyone seemed confined by the set ways of the astronomers.

The DSN Inherent Accuracy Project. Following the above revolution in radiometric methodology, JPL engineers and scientists tackled the host of factors that degraded the accuracy of tracking measurements. Among the most important sources of error were:

- Knowledge of DSN station location
- The effect on radio propagation of charged particles between the tracking station and the tracked spacecraft
- The spacecraft transponder
- The Doppler count accuracy
- The frequency standards and time synchronization methods
- The tropospheric model used to correct for air moisture, etc.

To track down these error sources, in a systematic fashion, Eberhardt Rechtin formed the DSN Inherent Accuracy Project in 1965.[10] The goals of the project were two in number:

1. To determine and verify the inherent accuracy of the DSN as a radio navigation instrument for lunar and planetary missions.

2. To formulate designs and plans for refining this accuracy to its practical limits.

Initially only two JPL divisions were involved in the project but it soon became apparent that some of the important sources of error were outside the tracking system per se. Consequently, in December 1968 a more widely based program, the JPL Navigation Program, was set up to control such extra-DSN factors as:

- Transponder accuracy
- Supplemental use of on-board navigation equipment
- Control and/or measurement of nongravitational forces (solar radiation pressure, etc.)
- Navigation software and mathematical techniques

As work progressed on both programs, not only were the practical results impressive, but the scientific value of the effort was unexpectedly high. Some of the more important improvements came when the DSN converted to S-band,

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[10]Progress reports on the Inherent Accuracy Project may be found in most JPL Space Programs Summaries since 1966. In particular, see: Jet Propulsion Laboratory, "Space Programs Summary," Vol. III. The Deep Space Network (Pasadena: SPS 37-43, January 31, 1967) p. 3.

and it is appropriate to review some of these initial results here. Additional progress will be reported in the chapters that follow.

The basic approach of the DSN Inherent Accuracy Project was to construct a "model" of what was expected to happen in terms of tracking on new flight programs using the best available theories and data. Naturally, when the actual measurements of the spacecraft trajectories were made, theory and practice did not coincide exactly. The differences between actual and predicted data are termed "residuals," and they betray the existence of error sources somewhere. The theoretical goal, of course, is to reduce them all to zero (an impossible task of course). Actually, the residuals have great scientific and engineering value, just as bankbook errors help find and correct problems.

Doppler count accuracy was improved materially by the conversion from L-band to S-band, as illustrated in Figure 6-16. Not only did the shorter wavelengths afford greater resolution in Doppler counting, but the effects of charged particles and the troposphere were also reduced. The X-2 and X-8 improvements indicated in Figure 6-16 came about through specific improvements in the way in which the electronic systems counted the Doppler variations. The Doppler resolver, introduced into the DSN in early 1967 permitted the resolution of Doppler shift to within one-hundredth of a cycle, which at S-band wavelengths corresponds to less than one millimeter.

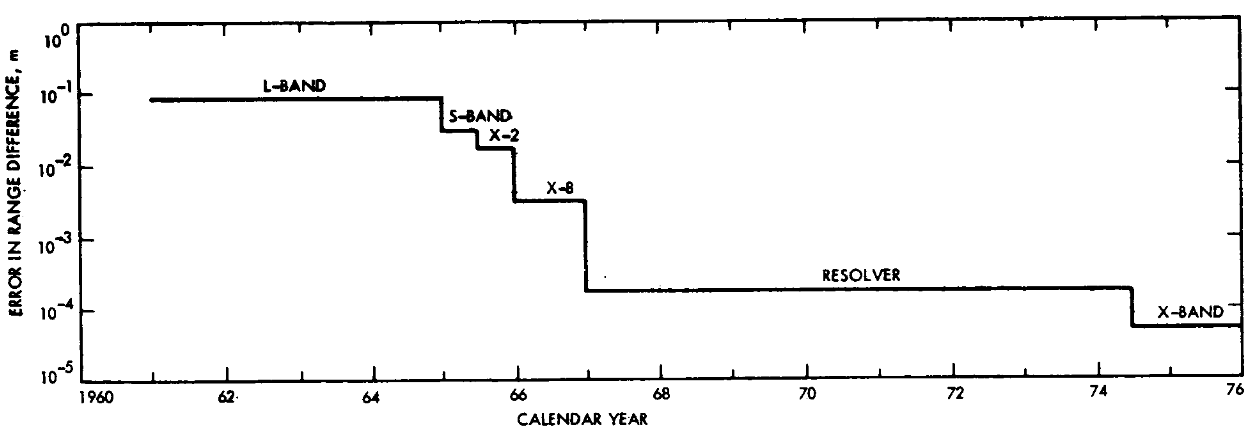

Figure 6-16. Improvements in integrated Doppler resolution.

One example of such detective work involved the analysis of Ranger Doppler residuals. As the spacecraft distance from Earth increased or as sample spacing decreased, the residuals displayed high fluctuations. These changes were eventually attributed to instabilities in the reference oscillators at the DSN stations---the rubidium-vapor frequency standards in this instance. Gradually, the rubidium-vapor oscillators were improved. The key to this discovery was the variation of the residuals during some change in the tracking operation; the increasing distance from Earth in this case. These variations in residuals which are made noticeable by some physical changes are termed "signatures."

The signatures of errors due to tropospheric refraction were created by tracking the spacecraft first at low and then at high angles. Not surprisingly, the tropospheric signatures varied from station to station. The initial tropospheric model used for correcting Doppler measurements was applied at stations all over the world. (Figure 6-17) By constructing a separate model for each station, taking local conditions into account, residuals were later reduced still further.

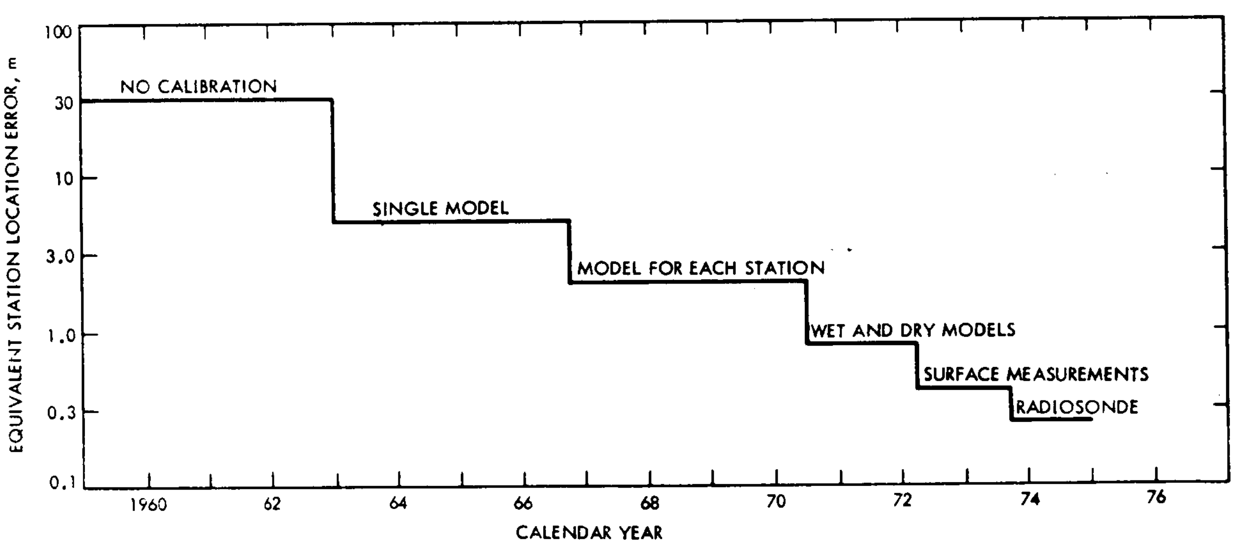

Figure 6-17. How tropospheric calibration has improved with time.

Another kind of residual arises when spacecraft missions are later "reflown" by computer. During actual flight, it is assumed that the locations of the DSN stations are known precisely and the spacecraft coordinates are unknown. On the reflown missions, the reverse is assumed: the spacecraft trajectory is taken as exact and station positions are solved for. These calculated locations vary as the spacecraft moves away from Earth. By analyzing these variations errors in station longitudes due to polar motion, errors in universal time, and other factors can be ascertained. Figure 6-18 indicates the historical improvements in station longitude uncertainty.

The DSN's Doppler and range measurements are made from the Earth's rotating surface and this surface does not rotate in a perfectly regular manner. Therefore, it is vital that all tracking measurements be tagged with accurate times. Station clocks must be extremely accurate and they must be synchronized precisely with one another. Unfortunately, station clock synchronization by reference to WWV signals, although adequate for ocean craft, is completely unsuitable for spacecraft. A significant improvement was made in DSN synchronization as a result of an error in universal time discovered during the Ranger Program. (See p. 73.) Timing polynomials correcting UTC (Universal Time Coordinated) to UTI (Universal Time Inertial) were made on a crash basis during the flight of Mariner 4 in 1965. The improvement is detailed in Figure 6-19. Further improvements in synchronization will be reported in later chapters.

The first corrections made in the DSN scheme of things as a result of the Inherent Accuracy Project generally produced the greatest improvements, as demonstrated in Figures 6-15 through 6-18. This work, however, has been continued diligently, resulting in slower but cummulatively impressive progress.

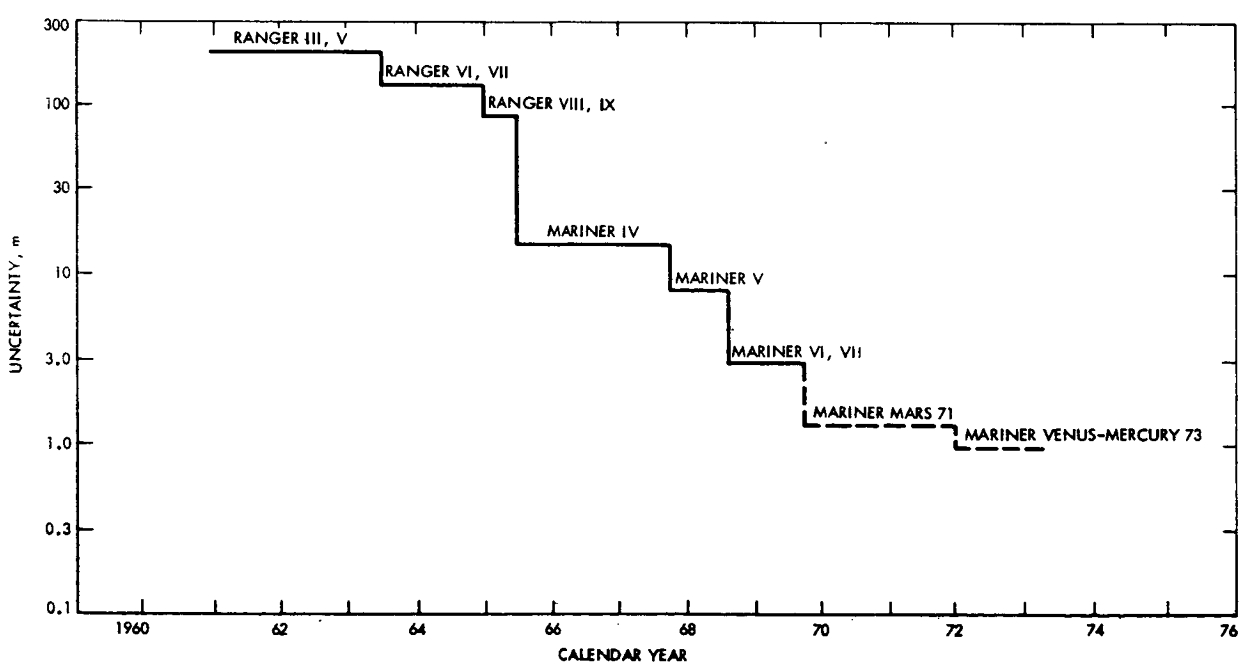

Figure 6-18. Reductions in DSN station longitude uncertainty.

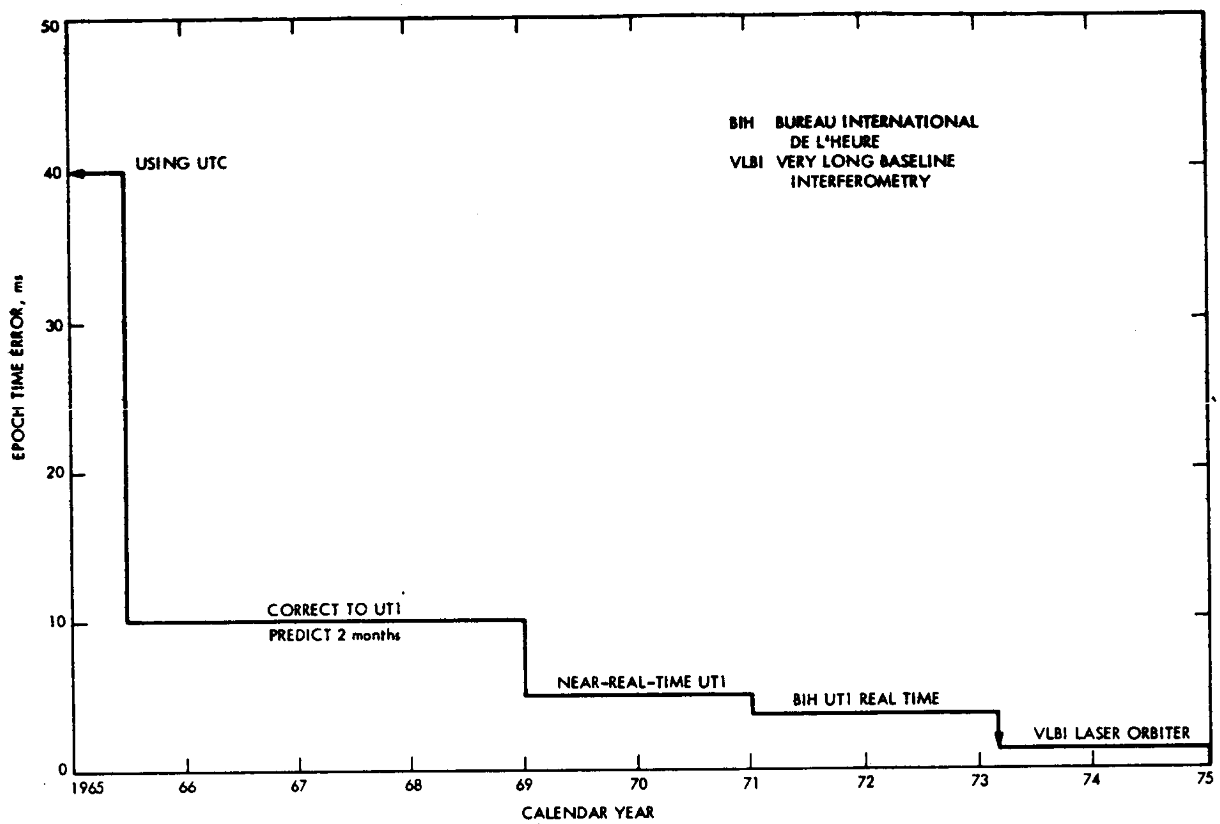

Figure 6-19. Improvements in DSN timing as a function of calendar time.

Chapter 7. GOLDSTONE-MARS BECOMES OPERATIONAL

A New Era Begins

On March 16, 1966, the big 64-m antenna at Goldstone received its first signals from Mariner 4. The signals had travelled across the solar system from the spacecraft which was about to be occulted by the Sun. It was fitting that the first spacecraft tracked by this antenna was a Mars probe because the Mars site antenna was originally planned for tracking and communicating with Martian probes. As history has proven, however, the value of this big paraboloid transcends any specific mission and has, in fact, opened up much of the solar system to exploration by unmanned probes. In addition, the Mars antenna has many times repaid its debt to radio astronomy, the source of many of its design ideas, by operating as a high precision radio telescope.

The step-increase in DSN performance afforded by the Mars antenna was applied within a few weeks of its inauguration to the first Surveyor flights, yielding much stronger signals for terrestrial processing than possible with the 26-m dishes that had been originally assigned to these missions. The Apollo flights benefited, too, because live TV from the Moon was now possible. The small Interplanetary Pioneers, which soon swept out of range of the 26-m subnets could now be followed all the way around the solar system. The 64-m antenna at Goldstone was so valuable an asset to space flight that pressure soon grew to build a three-station subnet of 64-m antennas---an eventuality long planned for by the DSN but not achieved until the 1970s. The other big dishes finally built in Australia and Spain are a subject of Chapter 8. In this chapter, the emphasis is on Goldstone-Mars and the evolution of the DSN through the remainder of the decade of the 1960s.

Completion of the Mars 64-m Antenna

In previous chapters, the story of the Mars antenna, or AAS (Advanced Antenna System), was taken through January 25, 1963, when NASA announced that the Rohr Corporation of Chula Vista, California, had been selected to prepare the detailed design for the antenna and construct it at Goldstone. Rohr engineers immediately began to complete the detailed design and make a thorough error analysis of the major parts. In January 1964, the JPL AAS Project Team (Figure 7-1) formally approved the design, and Rohr began procurement and fabrication. During the preceding year, under a separate contract, the road system at Goldstone had been extended 5 miles to the new site preparatory to building the antenna foundation. In early 1964, concrete was poured at the site for the antenna pedestal and optical instrument tower.

In April 1964, a Data System Development Plan[1] for the Mars site was

[1]Jet Propulsion Laboratory, "Data System Development Plan, Advanced Antenna System for the Deep Space Instrumentation Facility," (Pasadena: April 7, 1964).

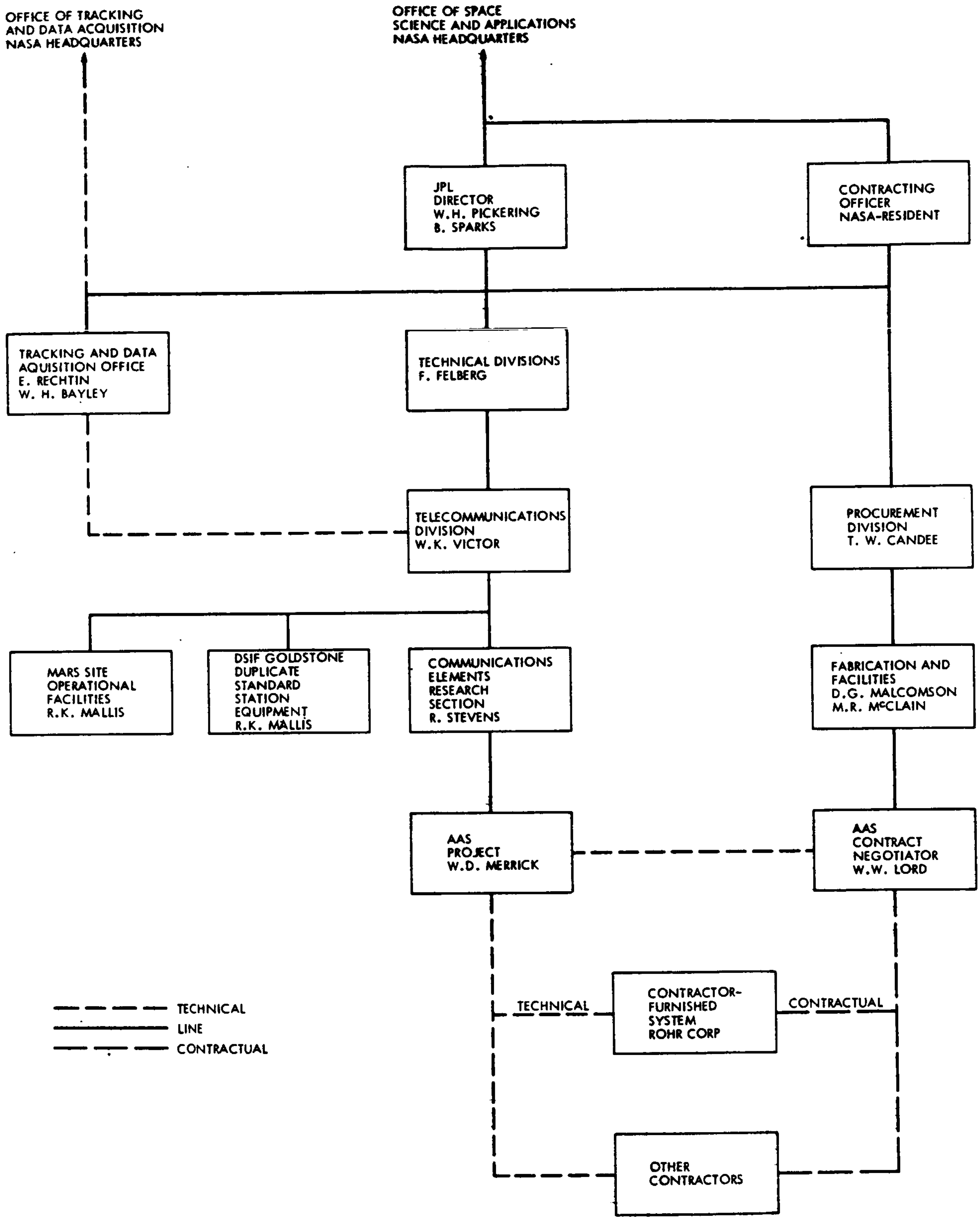

Figure 7-1. The project organization for the 64-m Mars antenna.

issued. This included not only the antenna proper but all of the electronics equipment necessary for an operational station. By this time, fabrication of the steel antenna components had begun. By June 1964. the concrete foundations were complete. The diesel generator building was completed in September and the pump house and cooling tower in November.

The 2-million-pound steel alidade was assembled at Goldstone in late 1964, and in December a trial rotation was made on the hydrostatic bearing. Elevation bearings and tipping parts were erected next. By April 1965, the second-floor control room had been completed sufficiently so that JPL could begin installing the radio and data-handling equipment. Gear wheels and bearings were installed next. When, in July 1965, the reflector panels went into place, a casual observer would have thought the antenna construction finished. There was, however, much work remaining inside.

Then, in August 1965, a major accident occurred. An error in the setting of the pressure control system for the hydrostatic bearing led to the grounding and damaging of a portion of the hydrostatic bearing. Fortunately, the antenna had been designed with such a possibility in mind, and it was possible to jack up the alidade and reflector and repair the bearing. After this disturbing episode, the final equipment was installed, tests made, and a paint job applied. The antenna had been completed well within the budget and on schedule---a not-common event in the aerospace business.

Although the first signals (from Mariner 4) were detected at Mars on March 16, 1966, formal dedication did not come until April 29, 1966. Even with the dedication, finishing touches remained, particularly in the areas of personnel training and performance testing.

General Description of the Mars Dish. The Mars 64-m paraboloid is not the largest radio antenna in the world but it does possess some unique properties in comparison with antennas designed specifically for radio astronomy. First, it is a more rigid structure than the usual radio astronomy antenna. This feature derives in part from rugged design and the presence of two concentric structures. The more flimsy radio astronomy antennas commonly shut down operations when the wind becomes strong enough to distort the antenna structure. The radio stars will still be there tomorrow, and little is lost by suspending operations. DSN antennas, in contrast, cannot afford this luxury and must be ready for crucial mission events regardless of terrestrial weather conditions. The DSN 64-m antennas are rigid and precise enough to be effective at 15 GHz, which is unusual for antennas of this size. A second unique feature of the DSN 64-m dishes is their fast slew rates---something unnecessary in radio astronomy in which essentially all target motion is caused by the Earth's rotation.

The Mars dish and its close relatives later erected in Australia and Spain employ Cassegrain microwave optics. The 64-m, high precision, paraboloidal surfaces have a focal-length-to-diameter ratio of 0.42 (Figure 7-2). At the normal DSN S-band operating frequencies (around 2.3 GHz), the

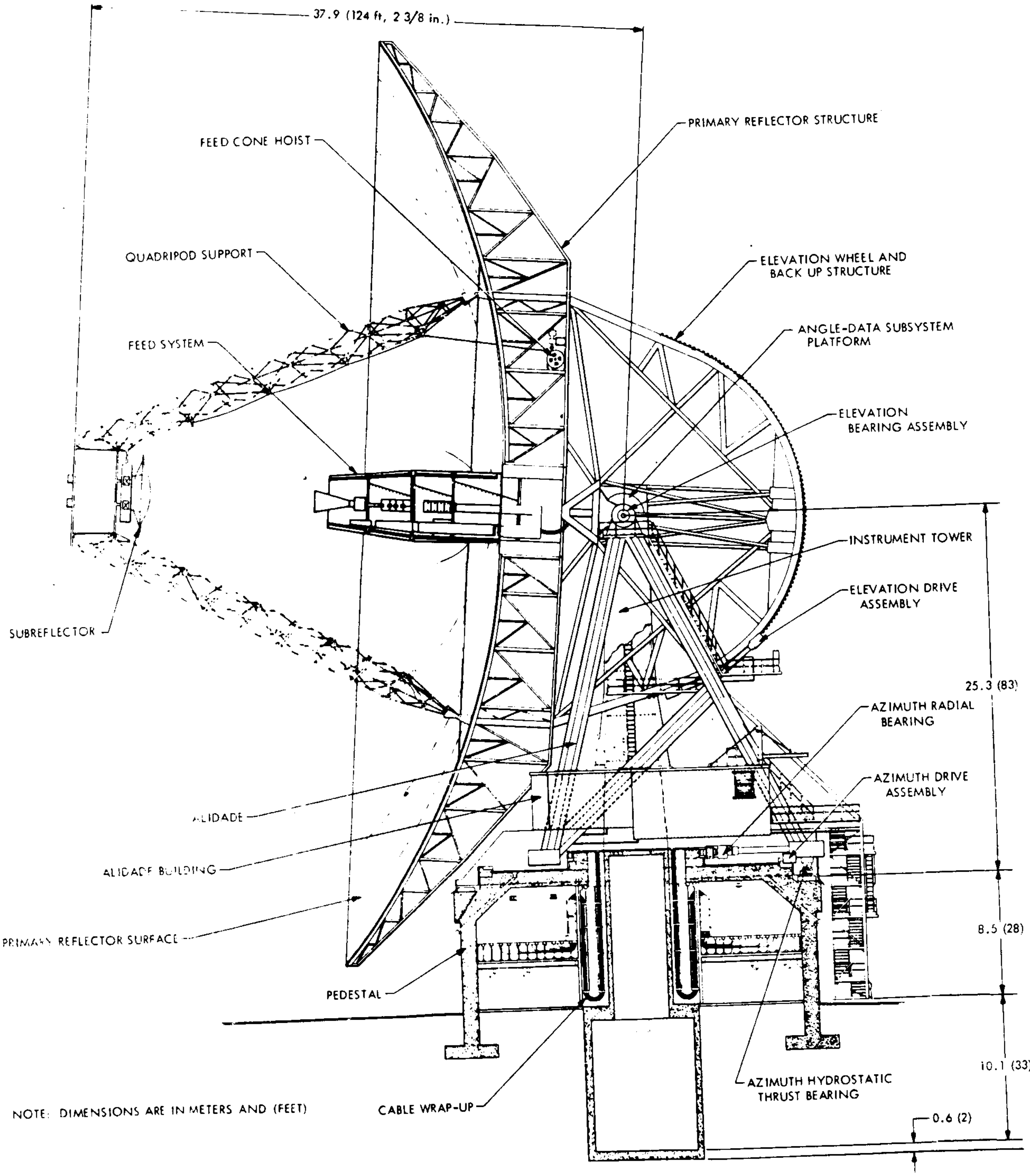

Figure 7-2. Major components of the 64-m antenna.

half-power beam width is only 0.14 degree. The corresponding gain is 61.4 db, and the total receiving system noise temperature can be as low as 16°K. The antenna mount can rotate ± 270° in azimuth; the normal elevation range is 6 to 89°. Including the pedestal weight, the Mars antenna weighs about 15 million pounds. The steerable weight above the azimuth axis is about 5 million pounds.

Even though there are larger dishes available, the Mars antenna is always busy working the many spacecraft in deep space which are beyond reach with smaller antennas. It also performs tasks for radio astronomers who appreciate its high precision and sophisticated electronic support.

During the period covered in this chapter, the Mars antenna experienced a serious mechanical failure that shut it down from March 10 to April 28, 1967. Anomalies in the hydrostatic thrust bearing caused short interruptions in tracking. The problem was solved by reshimming the bearing. During the repair operation, it was possible to use the antenna for limited periods; i.e., the terminal phase of Surveyor 3.

Concurrent DSN Improvements

The completion of the Goldstone Mars 64-m antenna represented the major advance in DSN capability of this period, but it was only one in a series of stepwise increases in all pertinent areas of technology and management. The more important of these developments occurring during the middle 1960s are described below.

Spacecraft Ranging. The capabilities of DSN ranging systems divides naturally into two classes: lunar and planetary. The physical situation is characterized by increase of more than a factor of one hundred in distance from one class to the other. It has been customary to call the two important lunar ranging systems Mark I and Mark IA.[2] Although designed for lunar use, these sytems successfully tracked Mariner 5 to ten times the Moon's distance, as a later section in this chapter will relate. The two major planetary ranging systems are named according to their designers; "Tau", for R. C. Tausworth, and "Mu", for W. L. Martin. The main technical differences between the lunar and planetary classes of ranging systems is in the method of range coding and receiver code detection. The Mark I and Mark IA lunar systems were first employed on the Lunar Orbiter and Surveyor missions from late 1966 through 1967. The Tau planetary system saw its first use on Mariner 5, 1967-1968, and an improved, more stable Tau system was used for Mariners 6 and 7, 1969-1971, which are covered in the next chapter. The Mu ranging system came still later with the extended missions of Mariners 6 and 7.

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[2]It is important not to confuse the "Mark I ranging system" with the Mark I DSN" described in such documents as "Deep Space Network Data System Development Plan; Mark III Project" (Pasadena: JPL 803-1, Rev. A, March 15, 1974).

This digression on terminology may seem rather dull, but it illustrates the tendency of technical specialists to consider the network revolutionized whenever a major improvement is consummated in their area. It would, in fact, be much easier to divide this history down into chapters if the DSN actually had evolved all at once in quantum jumps. But the DSN did not suddenly change from a lunar to a planetary network, or a low-bit-rate network to a high-bit-rate network, or a network burdened with mission-dependent equipment to a multimission network. The DSN is always being upgraded; some of the steps are small, some others are big.

Time Synchronization. For accurate ranging at lunar distances, clocks at DSN stations had to be synchronized to within 50 microseconds (the Lunar Orbiter requirement). In the early DSN, clocks had been synchronized via high frequency radio signals, but at best the accuracies were a few milliseconds. Later, the very low frequency signals from WWV provided some improvement, but not nearly enough for lunar ranging. Ground-wave propagation uncertainties were too high, and some DSN stations could not receive WWV reliably. Something better was needed for Lunar Orbiter.

Transportable cesium time standards from the National Bureau of Standards were first proposed because they promised to synchronize stations to within 5 microseconds. This was an expensive operation, however, and one which would have to be repeated at least on a monthly basis by a clock-carrying team shuttling between stations. A second, more convenient concept used the DSN ranging system and the Lunar Orbiter spacecraft itself. In essence, one station could send a signal to Lunar Orbiter, which would be acknowledged by the spacecraft transponder, permitting all stations with Lunar Orbiter in view to set their clocks upon receipt of the signal from Lunar Orbiter. In this way, station clocks could be synchronized to within 20 microseconds during the Lunar Orbiter program.

Still later, during 1966, a Moon-bounce synchronization scheme was devised. In this, the Goldstone Venus station was established as the master timekeeper.[3] It bounced X-band signals off the Moon to other DSN stations with the Moon in view. By 1968 this technique had demonstrated that it could set clocks to within 5 microseconds and was subsequently adopted throughout the entire DSN.

High-Rate and Multimission Telemetry. By 1967, the future applications of the DSN required two important changes in the way the network/spacecraft combinations handled telemetry:

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[3]Technical details may be found in DSN progress reports; viz., Jet Propulsion Laboratory, "The Deep Space Network," Vol. III (Pasadena: SPS 37-43, SPS 37-45, SPS 37-53, 1966-1968).

1. Future mission, such as the Mariner Mars 1969 camera-mapping missions, would demand much higher bit rates than those used on early planetary flights.

2. Something had to be done about all the mission-dependent equipment installed at DSN stations. This "queer gear" compromised overall network reliability and complicated operations considerably.

The "multimission" approach began to assume more and more importance at this point in time, and a little digression is in order. Prior to 1967, spacecraft transmitted over a wide range of subcarrier frequencies and data rates with various types of modulation. Each flight project decided what it wanted in the way of data and provided whatever special equipment was necessary to demodulate or otherwise process the telemetry to its taste at each DSN station. With more and more spacecraft having longer and longer lifetimes, this diversity and extra equipment were becoming intolerable. The adoption of the PCM-PM-PM type of modulation by most flight projects provided means by which NASA deep space telemetry systems could be standardized or, equivalently, made "multimission."

NASA Headquarters initiated and pushed the multimission concept strongly because of its cost effectiveness and, most importantly, because it would substantially upgrade network reliability and performance. OTDA found it rather easy to convince the flight projects to this way of thinking, particularly since the mission-dependent ground equipment, which was funded by the flight projects and would be completely eliminated in a multimission network. [4]

The Multimission Telemetry (MMT) system consisted of a flexible subcarrier receiver tunable from 20 kHz to 1.5 MHz. [5] Almost any conceivable flight project could design its data system within its capabilities. To change from one spacecraft to another, a DSN station would only have to change its computer program and reset some receiver parameters. There would be no necessity to start up and bring into operation a great variety of different mission-dependent equipments. This was the basic multimission concept, and it was applied first to telemetry.

On April 4, 1967, JPL established the High Rate Telemetry (HRT) Project aimed at meeting the Mariner Mars 1969 telemetry requirement of 16,200 bits/sec and in the process, advancing the multimission cause. A whole new approach was required because a design review of the Mariner 1969 project held in November 1966 had established that simple modifications of previous Mariner telemetry systems would be completely inadequate for Mariner 1969. [6] (It was

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[4]Personal interview, Gerald Truszynski, September 9, 1975.

[5]Note that to be completely "multimission" the command system would have to be modified in a similar way. In terms of hardware, this conversion was not begun until 1969. Thus, the DSN did not go "multimission" all at once.

[6]Jet Propulsion Laboratory, "The Deep Space Network," Vol. III (Pasadena: JPL SPS 37-48, November 30, 1967) pp. 83-130.

primarily the Mariner 1969 TV requirement that led to the very high data rates.)

In the end, the telemetry system that evolved was a modification of those used on Mariners 4 and 5, but there were substantial differences. For example, the data were block-coded, there was no synchronization channel, and the detection process was more efficient. By July of 1967, the basic engineering design of the system had been completed. A prototype was installed at JPL in early 1968 to test compatibility. During the first half of 1968, equipment was installed and checked out at several DSN stations. The first step had been taken toward true multimission capability.

Ground Communication. It follows that when the spacecraft-to-DSN data stream is expanded, the ground communication lines must be also, if real-time data are desired back at the SFOF. Consequently, in 1967, ground communications were upgraded in two ways: (1) a computer-based teletype communications switcher, called the Communications Processor, was put into operational use; and (2) the high-speed data stream was upgraded to 2400 bits/sec. The latter improvement was made specifically for Mariner 5, not Mariner 1969.

A 1967 snapshot of the steadily evolving ground communications system is available in one of the DSN progress reports.[7] The circuits pertinent to the DSN are shown in Figure 7-3. Actually, the DSN circuits shown are only a portion of those maintained by NASCOM, NASA's own communication system. Besides the high-speed data links, other circuits are provided for teletype traffic, the tactical intercom system, and intersite microwave communication.

SFOF Developments. The SFOF likewise had to keep up with the ever-increasing requirements for higher data rates, especially with reference to the Mariner 1969 mission on the horizon.

The major change in the SFOF data processing system was dictated by the new high-speed data link and the NASCOM Communications Processor. As of September 1, 1967, the data-processing system consisted of three computer strings (Figure 7-4) each with an IBM 7044 computer drum, followed by an IBM 7094II computer. A disk memory in each string was shared by the two computers in that string. The IBM 7044 was the input/output processor of the SFOF computer system. The IBM 7094II, which followed in each string, was the primary processing element for such complex analyses as orbit determination, tracking data editing, generation of predictions for spacecraft acquisition, and calculation of midcourse maneuvers.[8] All in all, this was a relatively impressive data processing system for 1967.

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[7] Jet Propulsion Laboratory, "The Deep Space Network," Vol. III, (Pasadena: JPL SPS 37-48, November 30, 1967) pp. 169-173.

[8] For a more complete description, see: Jet Propulsion Laboratory, "The Deep Space Network," Vol. III (Pasadena: JPL SPS 37-46, July 31, 1967) pp. 164-172.

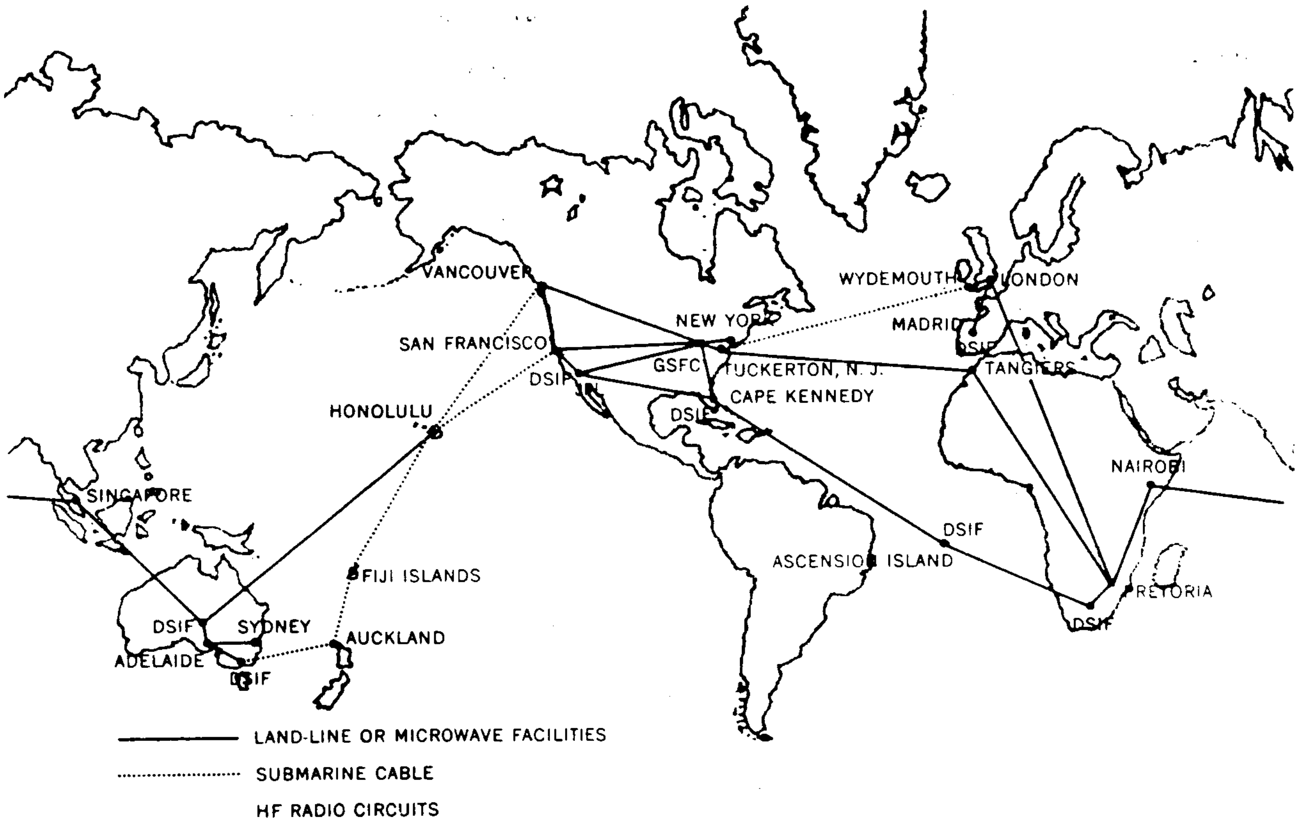

Figure 7-3. Major DSN communications links circa 1967.

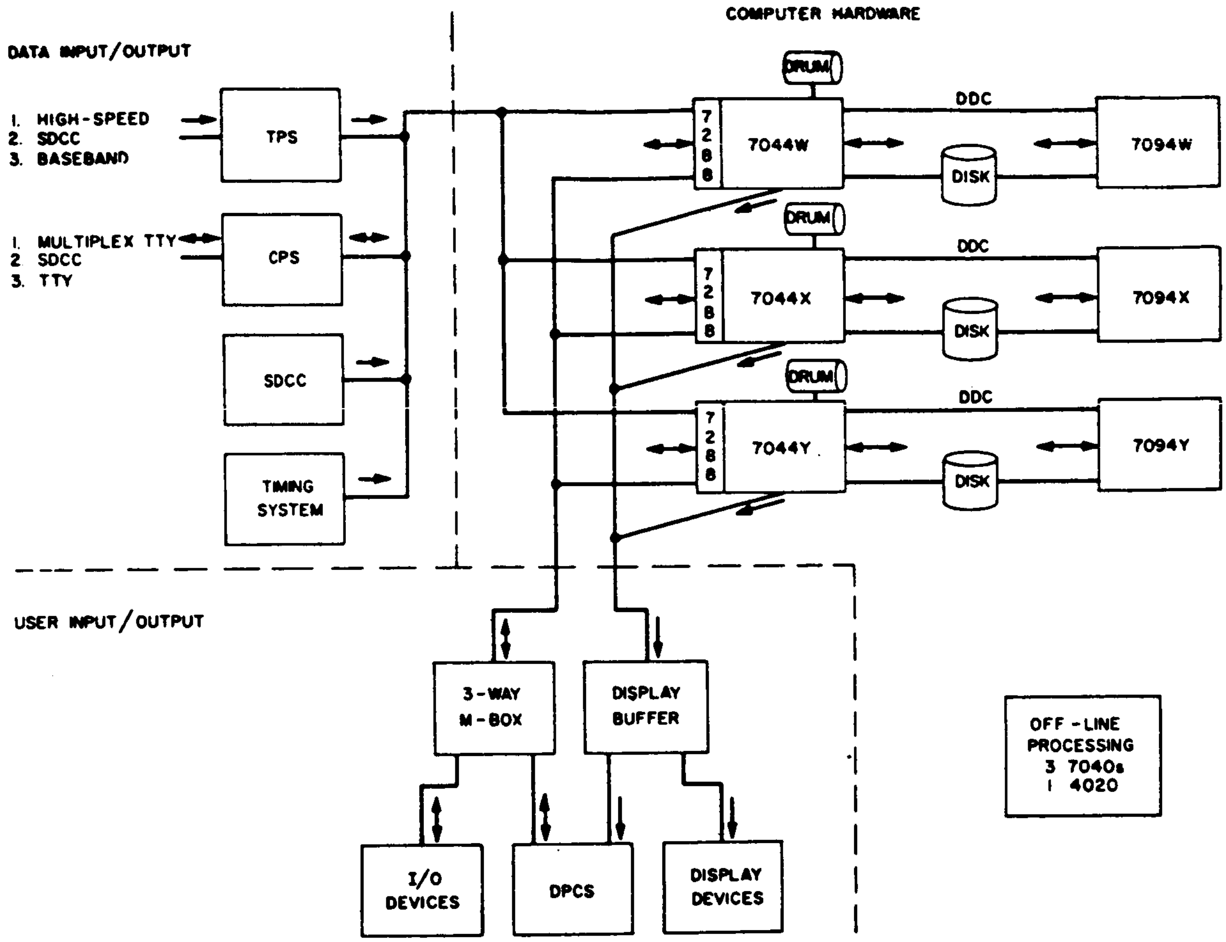

Figure 7-4. The SFOF data processing system circa 1967.

During 1968, the Mariner 1969 requirements also initiated improvements in the IBM 7044-7094 software system to:

-Improve input/output control
-Develop limited multiprogramming capability
-Simplify output formatting

In addition, a new Display Buffer Operating System was developed at the SFOF which collected and displayed DSN Monitor data and established computer-based operations control functions.

DSN Management and Scheduling. With the high-priority Apollo building up plus the many new off-Lab projects, NASA and JPL had to evolve an efficient way of coordinating all pertinent organizations. Looking only at the facet of mission support involving tracking and data acquisition, we find that by 1968 a rather complex set of interfaces had evolved between DSN and project personnel.

Responsibility for tracking and data acquisition for a mission was, as it had been since 1963, assigned to the JPL Office of Tracking and Data Acquisition. When a new flight mission was approved, this Office would appoint a TDS Manager to work with the JPL technical staff at the Cape and to coordinate the support of the Air Force facilities, the MSFN, NASCOM, and those elements of the DSN needed for near-Earth support. In addition, the JPL Office of Tracking and Data Acquisition would assign a DSN Manager and a DSN Project Engineer, who would put together a design team for the planning and operational phases of the mission at hand. A most interesting portion of Figure 7-5 consists of a "DSN Interface Team" which dealt with the mission-dependent aspects of the hardware and software. As mentioned earlier, an important objective of both NASA and JPL was to reduce the task of the DSN Interface Team to zero. Surveyor and other missions during the late 1960s did have some mission-dependent equipment, but it was being designed out of new missions as quickly as possible.

By 1968, the process of designing mission operations had become formalized, as shown in Figure 7-6. The basic input consisted of the Project Development Plan (PDP), now a strict requirement within NASA, plus the mission plan and requirements, which in the case of the DSN were formulated in the now-standard Support Instrumentation Requirements Document (SIRD) and the Project Requirements Document (PRD). The SIRD went to the DSN while the PRD levied requirements on the Department of Defense. As indicated in Figure 7-6, the DSN responded to the SIRD with its NASA Support Plan (NSP). The MSFN, NASCOM, and Department of Defense also responded with equivalent documents. The infrastructure of documentation was most impressive and a far cry from the back-of-the envelope days a decade before. Space had become a multibillion dollar activity and managerial controls had to be imposed to insure each project of sufficient DSN support.

Merely scheduling DSN support was becoming a major task of DSN management. To cope with this problem, a DSN scheduling system was established in 1966 to coordinate available facilities.[9] Not only did the

[9]Jet Propulsion Laboratory, "The Deep Space Network," Vol. III, (Pasadena: JPL SPS 37-45, May 31, 1967) pp. 93-101.

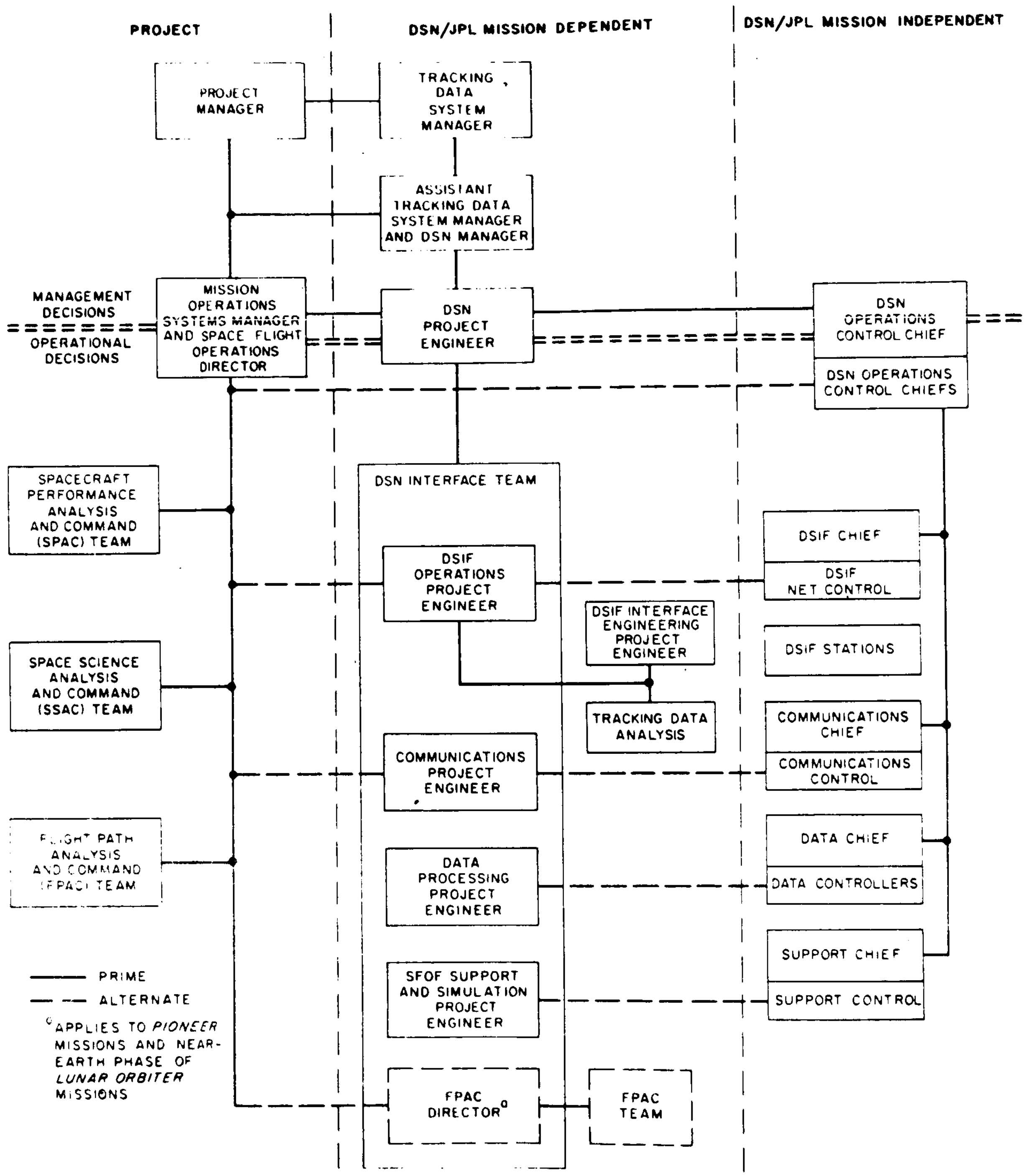

Figure 7-5. Typical functional organization for DSN mission support operations.

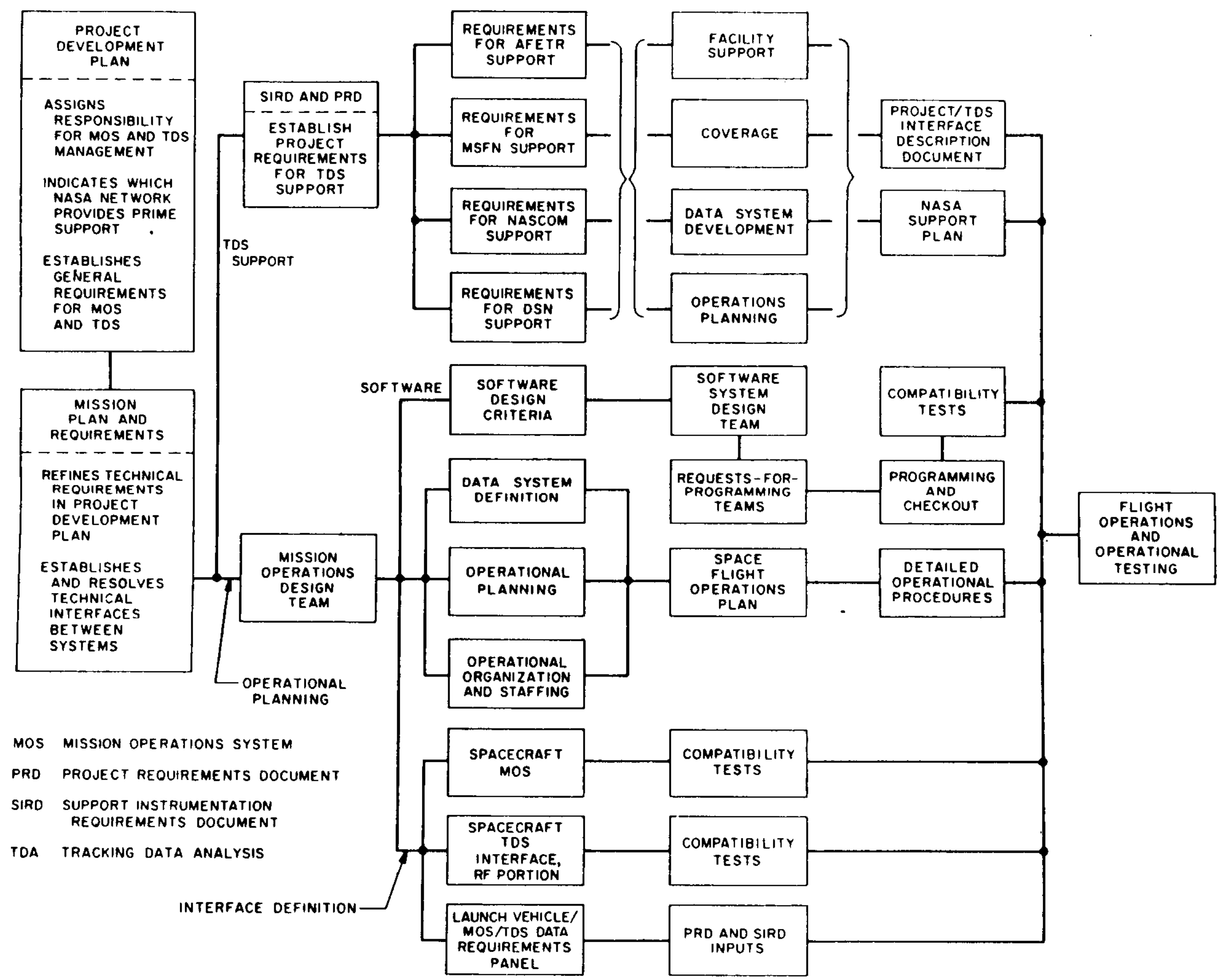

Figure 7–6. NASA mission design with special reference to the tracking and data acquisition function.

burgeoning NASA flight schedule complicate matters, but some DSN stations had mission-dependent equipment and others did not. All stations had varying maintenance and repair tasks that had to be factored into an overall scheme.

The general approach in the late 1960s was to schedule the DSN at three levels:

1. A 16-month loading schedule, issued monthly, and aimed at preventing overloading.

2. A 12-week utilization schedule, also issued monthly, and a finer look at the schedule.

3. A 7-day operational schedule, issued weekly. (This was actually 14 days long, with the first 7 days considered firm.)

The flow chart for the 16-month loading schedule is given in Figure 7-7. Computer support was provided to help cope with the many, often-conflicting requests; but two special kinds of displays helped planners visualize the overall picture: the DSN Slide Rule (Figure 7-8) and a large-scale display matrix (Figure 7-9). Adding to the general complexity was the multi-level priority system and the fact that a spacecraft emergency could preempt DSN support despite the most careful and thorough planning.

Mission Support 1966-1968

The NASA lunar exploration program absorbed the bulk of DSN support capability during the 1966-1968 period. Surveyor, Lunar Orbiter, and, of course, the backup support provided the first Apollo flights combined to utilize the DSN almost fully. The lunar program at this time consisted of short-lived missions, a few days long, and the DSN was able to divert some of the support necessary for the Mariner 5 shot to Venus and also accord some support for Pioneers 6-9 which kept on operating long after the ends of their nominal missions. Mariner 4 was also picked up again and became another example of an "extended mission." As the following mission details will reveal, the new 64-m Mars antenna was called upon to support almost all of these missions, although not always as a prime station. The DSN during this period was not yet a multimission network even though it was supporting many missions simultaneously. The DSN stations were still crowded with mission-dependent equipment, and this situation was the very antithesis of multimission philosophy.

The Surveyor Lunar Landers

The Surveyor Program had its origin in the late 1950s at JPL where a comprehensive lunar program was being sketched out. Apollo was not a high priority program at this moment in history, and the Surveyor lunar landers, complemented by Lunar Orbiters circling overhead, were primarily scientific in nature. NASA Headquarters approved Surveyor in the spring of 1960, preceding President Kennedy's call for a manned lunar landing. After Apollo

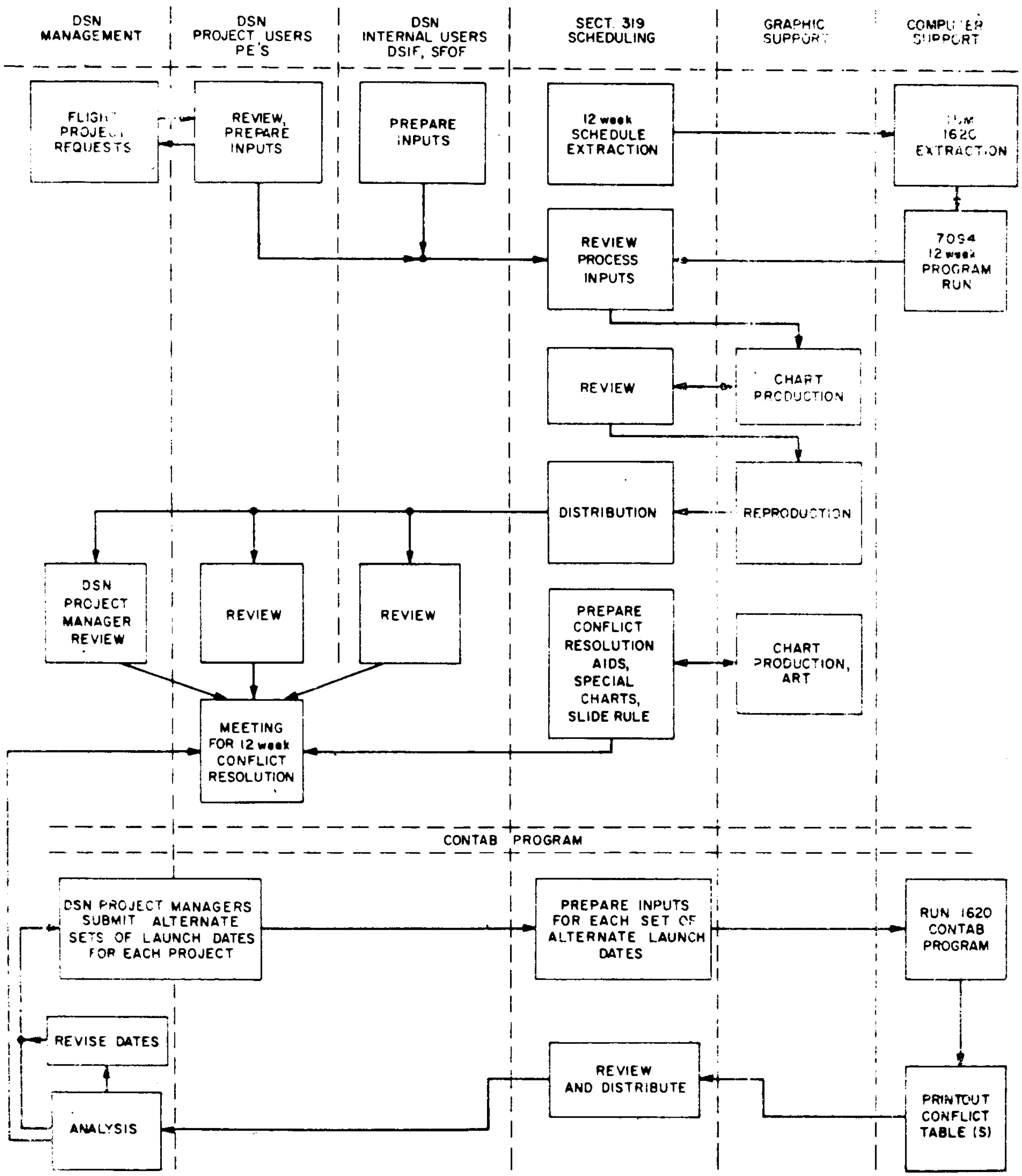

Figure 7-7. Flow chart for DSN 16-month loading schedule process.

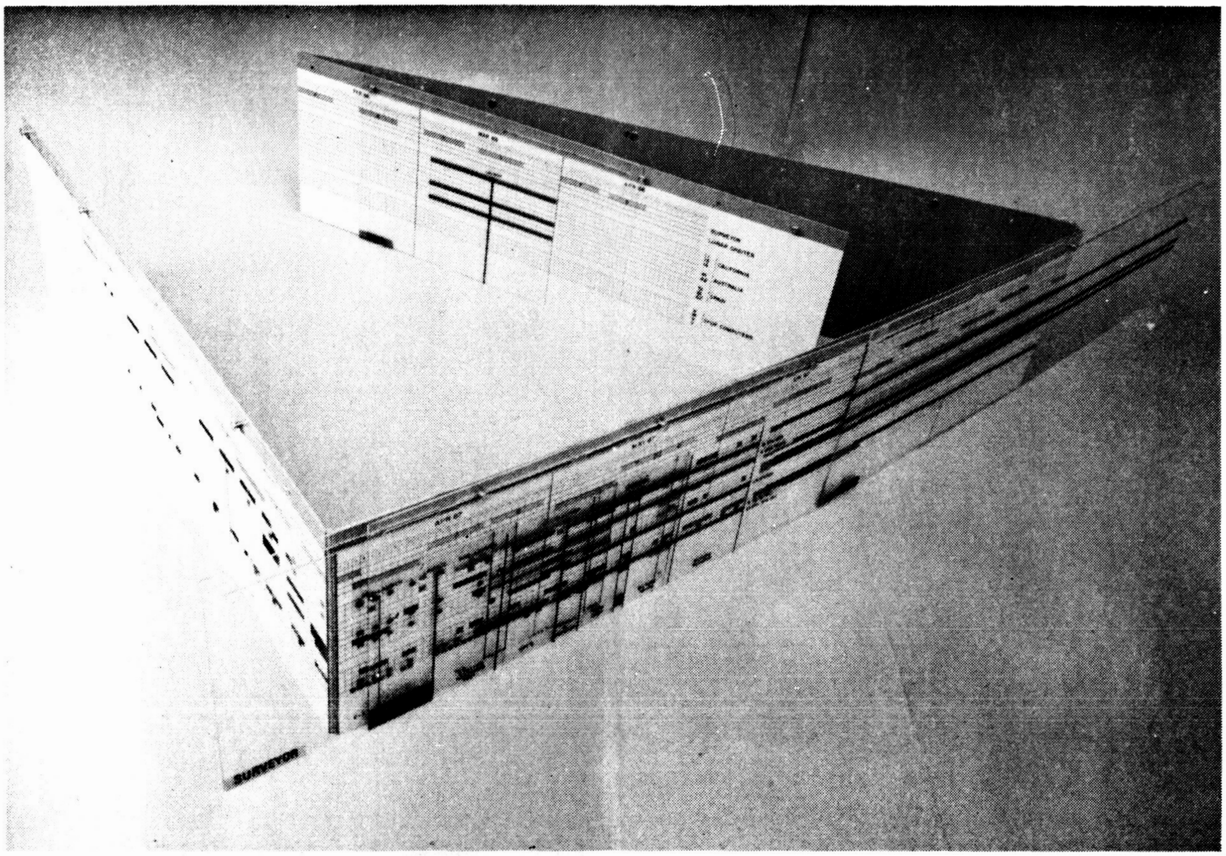

Figure 7-8. The DSN slide rule.

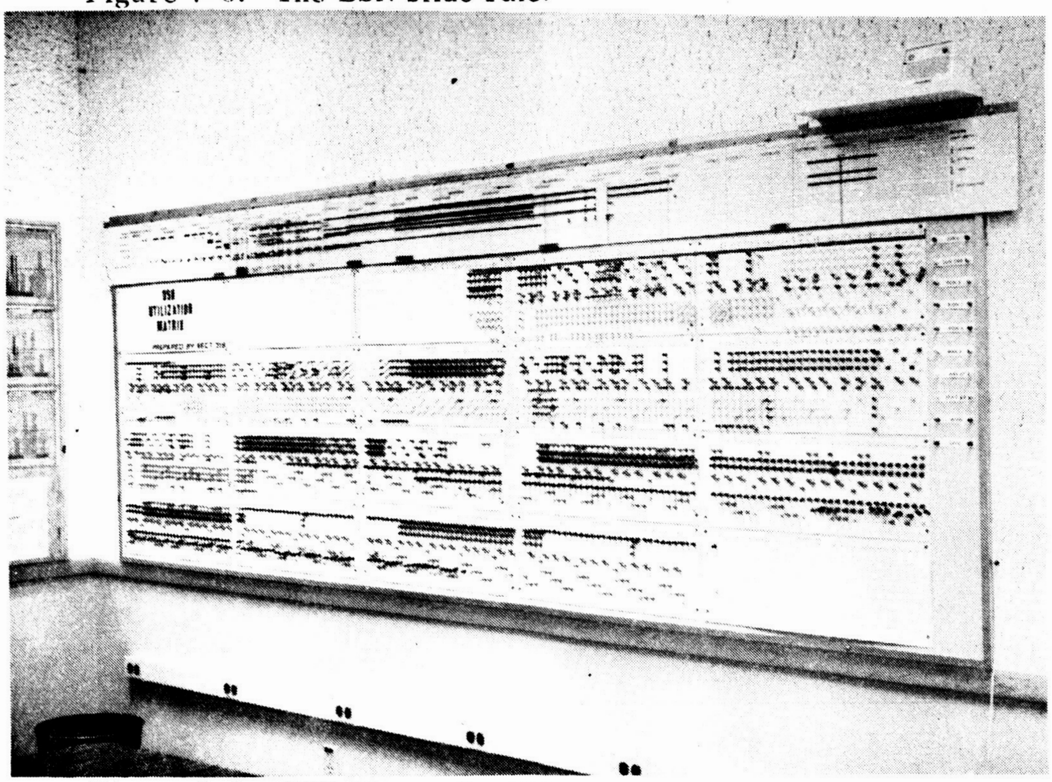

Figure 7-9. DSN 16-month ultilization forecast board.

became a national goal, the objectives of Surveyor were aimed more at determining whether man could land safely on the Moon rather than lunar science per se.

JPL managed Surveyor for NASA and, on March 1, 1961, contracted with Hughes Aircraft Company to design and build the spacecraft. All started well, but by the end of 1963, both Surveyor and its launch vehicle, the Atlas-Centaur, were plagued by slipped schedules and cost overruns. At the insistence of NASA Headquarters, JPL altered its management approach and assigned more personnel to the program. None of the technical or managerial problems involved the DSN.

Surveyor introduced several new requirements for the DSN and these significantly influenced the network's development. Most important, video data had to be received, processed, and then displayed for operational decision-making. Goldstone, for example, would feed up to 4400 bits/sec into the SFOF, and overseas stations would contribute up to 1100 bits/sec. (Figure 7-10) For the SFOF this meant high-speed, real-time data processing. Surveyor pre-launch testing required the real-time simulation of spacecraft maneuvers and handling of high-speed telemetry data. In terms of flight operations, some of the Surveyors used the direct-ascent mode (no parking orbit) and therefore had recourse to the new DSN Ascension facilities. [10] It is interesting to note that Surveyor was originally intended to be the first S-band mission for the DSN but that the schedule slippages gave the honor to Mariner 4. Surveyor did, however, provide the DSN with another "first." The spacecraft had few automatic features and was highly dependent upon centralized control and the real-time issuance of commands by the SFOF. This high degree of terrestrial control was feasible only if high reliability communications could be guaranteed by NASCOM. The first use of a synchronous communication satellite for DSN traffic assured mission planners that the requisite reliability was there. (Tables 7-1, 7-2 and 7-3)

The prime DSN stations for the seven Surveyor missions were:

DSS 51	Johannesburg
DSS 61	Robledo
DSS 42	Tidbinbilla
DSS 11	Goldstone Pioneer

Additional support was provided on Surveyor 1 by DSS 71 (Cape Canaveral), DSS 12 (Goldstone Echo) for command backup, and DSS 14 (Goldstone Mars) for receiver backup only. (Table 7-4) The 64-m Mars antenna had been operational only a few weeks when it was called upon to support Surveyor 1. Although not a prime station, the much higher gain of the Mars 64-m dish was useful during the trajectory correction of Surveyor 1 and especially in detecting (with good signal-to-noise ratios) the telemetry from the Surveyor-1 touchdown experiments, which were needed by Apollo engineers to ascertain the character of

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[10]The DSN Ascension station was actually built mainly to fulfill Surveyor requirements.

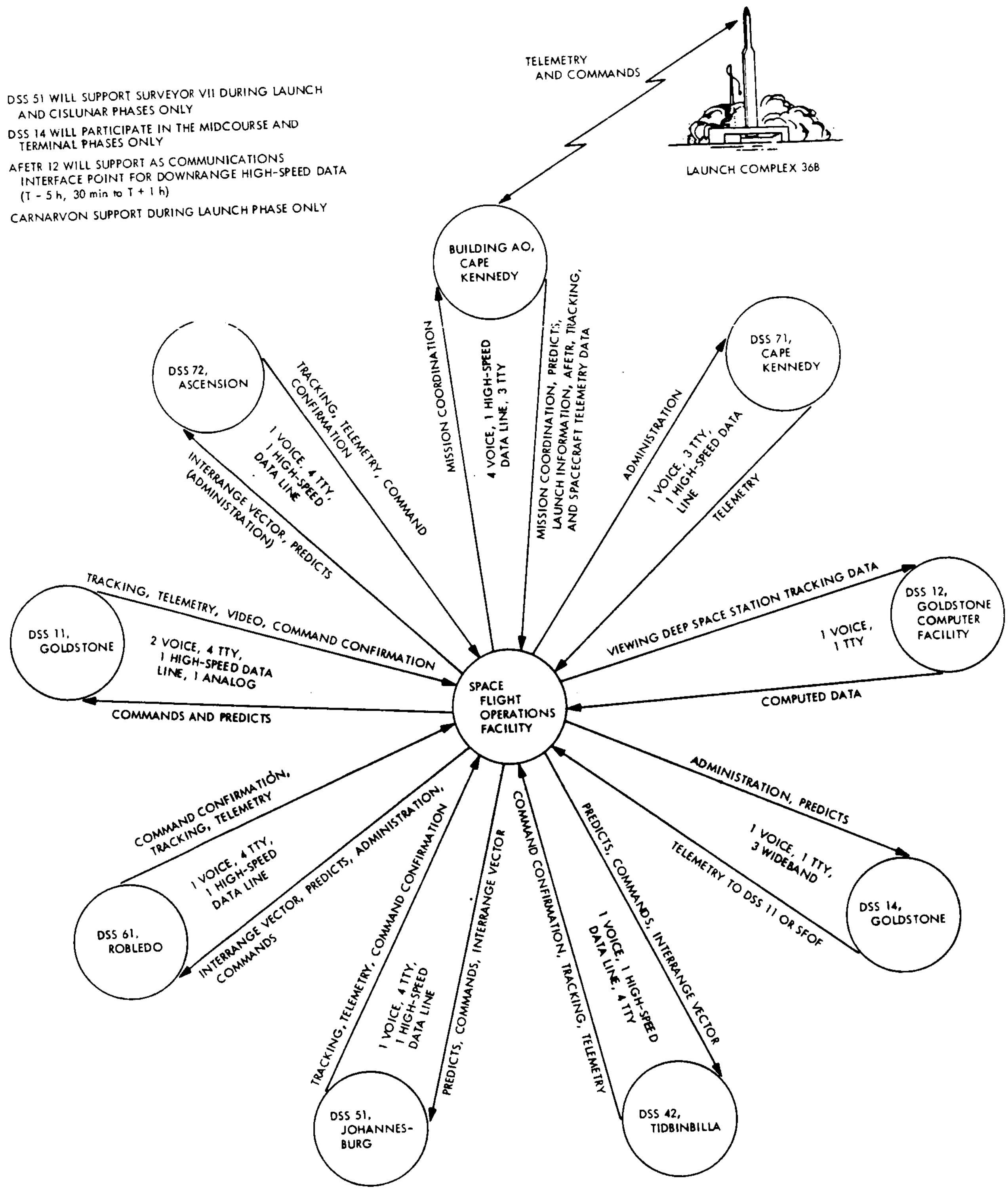

Figure 7-10. GCF configuration for a typical Surveyor mission.

Table 7-1. SURVEYOR DEEP-SPACE PHASE TRACKING REQUIREMENTS

	Coverage and Sampling Rate	Data Required	Data Presentation
1.	Track spacecraft from separation to first midcourse at 1-min sample rate (from initial DSIF acquisition to launch plus one hour, sample rate is 1 sample per 10 seconds).	Doppler (2 way and 3 way) Angles	a) Teletype page print and teletype tape. b) Magnetic tape (FR 1400)
2.	Track spacecraft from first midcourse to touchdown at 1 min sample rate.	Doppler (2 way and 3 way)	Same as above
3.	Track spacecraft from touchdown to end of mission at 1 min sample rate at 1 hr after 10^{o} elev., 1 hr centered around max. elev. and 1 hr prior to 10^{o} elev. at station set for DSS 11, 42, 51, and 61.	Doppler (2 way and 3 way) Angle	Same as above
4.	Track spacecraft during midcourse maneuver and terminal maneuver executions at 1-sec sample rate and transmit data at 10-sec sample rate.	Doppler (2 way and 3 way or 1 way)	Same as above a) Inflight b) Post Flight

Table 7-2. SURVEYOR DEEP-SPACE TELEMETRY REQUIREMENTS

SCO Frequency (kHz)	Data Rate bps)	Recording Interval From	To	Special Note
3.9	550	Prelaunch	DSIF Acquisition	Special purpose telemetry processing equipment is supplied by the Surv. Proj. Office. This equipment is called the Command & Data Handling Console
70	2200	Remainder of Mission		
33	4400			
7.35	1100			
5.4	550			
3.9	550			
960	137.5			
560	17.2			

Table 7-3. SURVEYOR DEEP-SPACE PHASE COMMAND REQUIREMENTS

Coverage	Special Note
It is required that commands can be sent to the spacecraft at any time from acquisition by the DSIF to the end of the mission during times that the spacecraft is visible from the DSIF stations, DSS 11, 42, 51, 61, and 72.	The command signal that modulates the DSIF transmitter (the modulated subcarrier) is generated by the Command and Data Handling Console (CDC) subsystem, which is provided by the Surveyor Project Office.

Table 7-4. DSIF TELEMETRY COVERAGE REQUIREMENTS FOR SURVEYOR-1 MISSION

Phase	DSIF coverage
Transit	24-h/Earth day
If landing is achieved	
(1) First lunar day and night	24-h/Earth day
(2) Second lunar day[a]	(a) 24-h/Earth day for first 3 Earth days (b) 24-h/Earth day for last 2 Earth days (c) One 10-h pass/Earth day between (a) and (b) above
(3) Succeeding lunar days and nights[a]	(a) 24-h/Earth day for first 3 Earth days (b) 24-h/Earth day for last 2 Earth days (c) One 10-h pass/Earth day between (a) and (b) above
If no landing is achieved	(a) 24-h/Earth day for not more than 3 Earth Days after encounter (b) 8-h/Earth day for additional 10 Earth days

[a]24-h/Earth day coverage regulated whenever valuable data can be provided by spacecraft instruments.

the lunar surface. Robledo and Ascension were used for training purposes only during Surveyor 1, although they did produce usable data.

The above DSN stations, of course, supported the deep-space phases of the Surveyor missions. The launch phase required the facilities of the Air Force Eastern Test Range. During the near-Earth phase, when the big DSN antennas were virtually useless, the Manned Space Flight Network (MSFN) contributed support from its stations at Bermuda, Grand Canary, Carnarvon, and Kano.[11]

Surveyor-1 Flight. Surveyor 1 was intended to be mainly an engineering flight; that is, its primary objectives were the exercise of the spacecraft, the launch vehicle, and other systems. Lunar science was listed only as a "tertiary" objective! After all the serious problems with the development of spacecraft and the Atlas-Centaur, it was a welcome surprise for the DSN to follow the spacecraft to a successful soft landing on the Moon's Sea of Storms.

Launch occurred on May 30, 1966. The direct-ascent mode was employed. (Figure 7-11) Spacecraft separation proceeded normally and a midcourse maneuver was commanded on May 31. On June 1, as the lunar surface drew near, the spacecraft was oriented so that the retrorocket would slow its descent. The retro engine separated according to plan about 30,000 feet above the Moon. The spacecraft's vernier engines continued to burn and eased Surveyor 1 gently down to the surface some 63 hours and 36 minutes after launch. The landing was so gentle that Goldstone Pioneer retained its lock on the signal the whole time. NASA's first active spacecraft on the Moon was situated only about 9 miles from the aiming point. It was on a firm surface and not submerged in a sea of dust as some had predicted. And it was working perfectly.

About 35 minutes after touchdown picture-taking began. The spacecraft had landed on a smooth mare plain studded with craters of all sizes. Over 10,000 pictures were returned by the end of the first lunar day. At the close of the second lunar day and the end of the nominal mission (July 14, 1966), over 13,000 pictures had been taken and the spacecraft had responded to 108 commands. On subsequent lunar days, additional data were acquired beyond the planned scope of the nominal mission. From the spacecraft standpoint, Surveyor 1 was a great success.

All tracking and data acquisition requirements were met by DOD, the MSFN, and the DSN. However, numerous problems did arise at many stations. To illustrate, at Goldstone, the key Pioneer station lost about an hour of data during the first pass from a high noise figure. During the second pass, an

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[11] Detailed descriptions of Surveyor tracking and data acquisition requirements and the support contributed by all participating stations can be found in: N. A. Renzetti, "Tracking and Data System Support for Surveyor, Missions I and II," Vols. I and II (Pasadena: JPL TM 33-301, July 15, 1969).

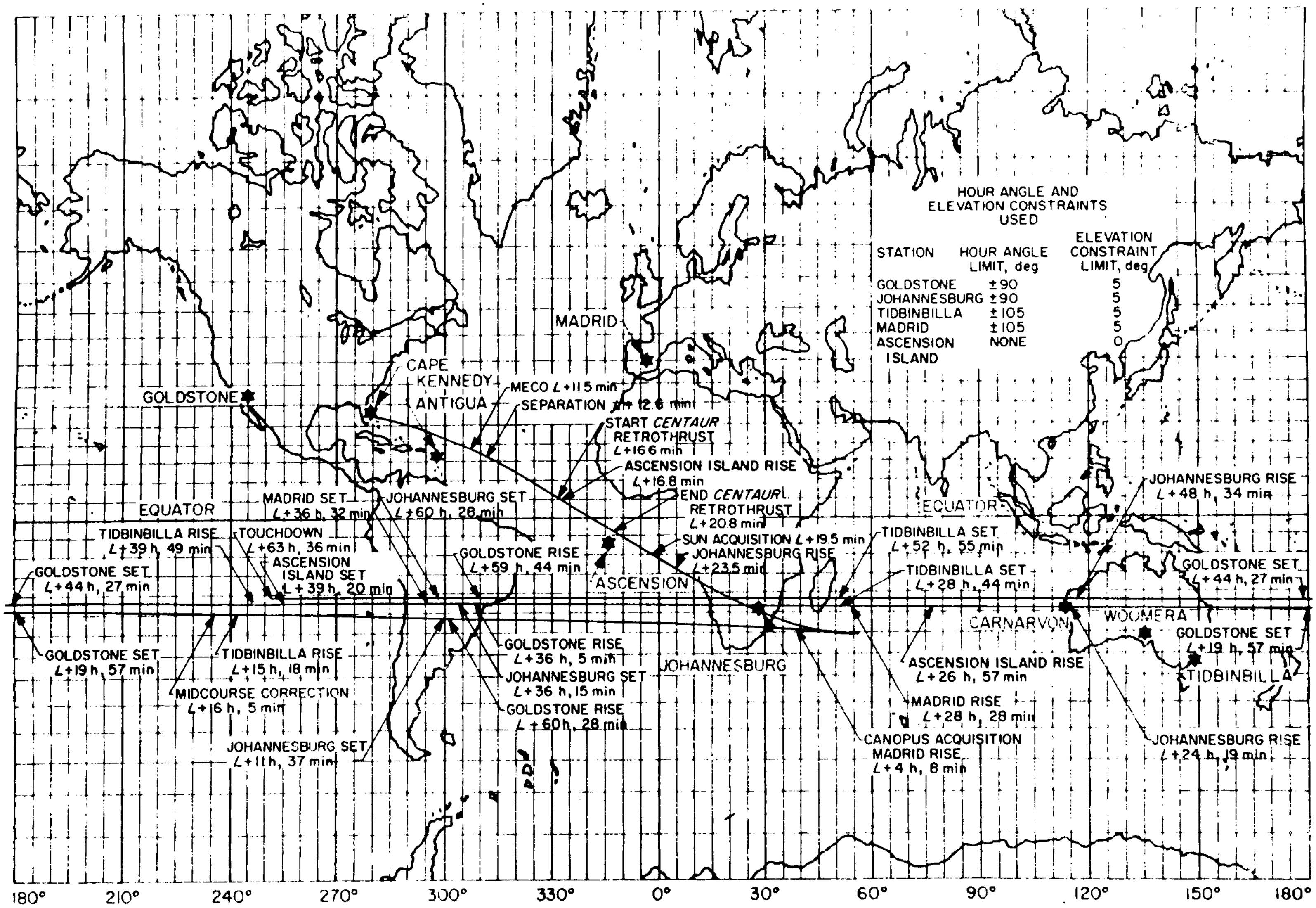

Figure 7-11. The Surveyor-1 Earth track.

equipment malfunction voided Doppler data for the entire pass. In contrast, other DSN stations, such as Tidbinbilla, performed almost perfectly. On the average, the DSN met its commitments.[12]

Surveyor 2. The mission objectives for the second Surveyor flight differed little from these of the first flight. The results, however. were not nearly as happy. The direct-ascent mode was also employed for Surveyor 2. The tracking and data acquisition requirements changed little between missions. Prime stations were again Goldstone Pioneer, Tidbinbilla, and Johannesburg. The Launch Station at Cape Canaveral was, of course, needed for launch and checkout, and Ascension was assigned to first-pass coverage only.[13] Robledo was to be involved only for training purposes. Equipment was being installed at the Mars station, and it was scheduled for emergency use only on this flight.

After several launch-vehicle holds, Surveyor 2 left the pad on September 20, 1966, on its direct-ascent trajectory. The Atlas-Centaur appeared to perform well, with all key events occurring on time. Some 11 minutes after launch, the Centaur stage injected Surveyor into a trajectory that would have missed the planned lunar landing point by only 88 miles. Soon, fears arose that the spacecraft had not separated properly. The basis for the fears came from Trinidad tracking reports and the intermittent tracking data from Pretoria and Ascension. Subsequent gyro telemetry indicated that the fears were groundless, and Surveyor 2 proceeded on toward midcourse maneuver.

On September 22, 1966, after the spacecraft responded properly to attitude-control commands, the signal was sent to fire the midcourse maneuver engine. At this time, DSN telemetry showed that Surveyor 2's attitude had become unstable; i.e., it was tumbling in space. Emergency action was commanded to regain attitude control of the spacecraft from DSN 42 (Tidbinbilla). All DSN stations participating during this critical period had trouble maintaining lock due to the tumbling of the spacecraft. Analysis of the telemetry data pointed toward a stuck valve in one of the vernier engines. Apparently this engine had not fired, and the thrust imbalance caused the tumbling. Commands were then sent from Goldstone Pioneer to pulse fire the other engines to try and shake loose the stuck valve. These attempts failed. Tidbinbilla's turn came next; one of the commands it sent was to fire the main retro engine, which should have imparted a 10-g load to the stuck valve. After this firing, though, all spacecraft signals ceased. The DSN searched several hours for Surveyor-2 signals without success. The mission was terminated.

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[12]For a summary of tracking and data acquisition support for all Surveyor missions see: Jet Propulsion Laboratory, "A Review of Tracking and Data Acquisition Support for Surveyors A-G" (Pasadena: JPL 602-84, April 1, 1968).

[13]Note that Ascension was equipped with a paramplifier instead of a maser. The higher noise temperature combined with the smaller antenna made it necessary to reduce the spacecraft telemetry data rate to 17.2 bits/sec while over Ascension.

Surveyor 3. This flight was the first to use the parking-orbit mode. Its scientific objectives were expanded beyond those of the preceding Surveyors by the addition of a surface sampler that required manipulatory commands from Earth. During these runs with the sampler, the spacecraft's camera provided visual feedback.

The DSN configuration of prime stations changed for this flight because Johannesburg was in the process of checking out and becoming familiar with its new S-band equipment. Consequently, Goldstone Pioneer, Tidbinbilla, and Robledo were designated as prime, while Johannesburg supported the mission on a best-efforts basis. As usual, the Launch Station contributed during the prelaunch and launch phases. Ascension was employed early in the flight as the spacecraft passed overhead after launch and also for one pass after touchdown. Goldstone Echo was placed in backup status for telemetry recording. The Mars station was not used at all because of mechanical work being done on the antenna bearings.

Launch of Surveyor 3 occurred on April 17, 1967, from Complex 36B at the Cape. The powered-flight phase proceeded according to plan, and the spacecraft was injected into a 167-km parking orbit for 22 minutes. Then the Centaur was restarted to put Surveyor 3 into a trans-lunar trajectory. The midcourse and terminal maneuvers went well. The spacecraft soft-landed in a medium-sized crater near the eastern shore of Oceanus Procellarum, 2.8 km from the aiming point. The landing was rather rough because the landing radars were apparently confused by reflections from large rocks in the landing area and the spacecraft automatically switched to inertial guidance for the touchdown. Due to the change in guidance systems, the vernier engines did not switch off just prior to landing as planned. The spacecraft therefore "bounced" until a command sent via the DSN shut the engines off on the third touchdown.

During the first lunar day, terminating May 3, 1967, Surveyor 3 took 6315 pictures and accumulated more than 18 hours of surface-sampler operation. During lunar operations, the DSN had to send more than 10,000 commands, many in connection with motions of the surface sampler. Surveyor 3 did not operate beyond the first lunar day.

Surveyor 4. Surveyor 4 was the last of the three missions making use of the direct-ascent mode. Mission objectives were essentially the same as those of Surveyor 3. The prime DSN stations were again Pioneer, Tidbinbilla, and Robledo. Johannesburg, however, was made prime during the transit phase due to its better geographical position. The Launch Station and Ascension participated, as usual, during the early mission phases. DSN 14, the Mars station at Goldstone, was brought in during the midcourse and terminal phases for backup telemetry reception and command.

Surveyor 4 was launched July 14, 1967, and all powered flight events were nominal; that is, they transpired according to plan. But during the terminal phase of the mission, just prior to touchdown, during the last 2 seconds of retrorocket burn, the spacecraft signal disappeared. At this moment, the DSN had three antennas (Pioneer, Echo, and Mars) with a total of five receivers following the touchdown. The loss of signal was simultaneous everywhere, providing proof that no ground systems had failed. The DSN stations around the world were requested to send turn-on commands, which they did, but to no avail. The mission had somehow failed during the last few seconds of flight.

Surveyor 5. Each succeeding Surveyor mission brought additional scientific requirements which, in turn, taxed network capabilities more. During Surveyor 5, the following new experiments were planned: a vernier-engine erosion experiment, an alpha-scattering experiment, a touchdown-dynamics experiment, and surface reflectivity experiments. All these were in addition to the usual TV-exploration objectives. The surface sampler that required so much network support on Surveyor 3 was omitted from the Surveyor-5 payload.

The prime DSN stations were again Goldstone Pioneer, Tidbinbilla, and Robledo. Johannesburg, Ascension, and the Launch Station played their transitory Surveyor roles. At Goldstone, the Mars and Echo sites were in backup status during the terminal phase of the mission.

Surveyor 5 was injected into its parking orbit on September 8, 1967, by the Atlas-Centaur launch vehicle. After 6.7 minutes of orbital coast, the Centaur restarted and placed the spacecraft in a lunar transfer trajectory so precise that it would have impacted only 46 km from target without midcourse maneuver was commanded and seemed to go normally.

At this point, the spacecraft began to lose helium pressure at an alarming rate. A valve activated during the midcourse maneuver had apparently not reseated properly. The vernier engines were fired five times in unsuccessful attempts to reseat the valve properly. It seemed that a normal soft landing would be impossible.

During the 47 hours left until lunar impact, the Mission Operations Team, consisting of JPL and Hughes Aircraft personnel, worked out a new, shorter, terminal-descent profile that could be attained with the low residual helium pressure remaining in the vernier-engine propellant tanks. Through the DSN, commands were sent to Surveyor to manually override the programmed descent sequence to maximize the chances for success. The retrorocket was permitted to fire until the spacecraft was a mere 1300 m above the surface and the vernier engine firing phase was shortened from its nominal 135 seconds to about 62 seconds. The emergency strategem worked, and Surveyor 5 made a good landing in Mare Tranquillitatis on September 11.

During the first lunar day, which ended September 24, Surveyor 5 took over 18,000 pictures. The vernier engines were fired to determine their effects upon the Moon's surface. The alpha-scattering experiment was also deployed to perform compositional analyses of the surface. The spacecraft survived the first lunar night and was reactivated by a command on October 15, 1967. Additional pictures and scientific telemetry were obtained during this second lunar day. The spacecraft was turned off for the final time on November 1, during the second lunar night.

The DSIF, SFOF, and GCF worked well during the entire period. One problem that kept cropping up after touchdown consisted of communication outages due to the overloading of the Goddard Communications Processor that handled communications for all three NASA networks. The occurrence of these outages was not surprising considering the increased traffic on NASCOM lines from JPL and other NASA centers.

Surveyor 6. The scientific objectives of this flight were unchanged from Surveyor 5 except for the addition of a "translation" experiment involving the rocket-assisted movement of the spacecraft. Tracking and Data acquisition support by the DSN was modified only slightly, in particular through the withdrawal of Ascension support, which was not needed because the parking orbit mode was employed. The Mars 64-m antenna was also assigned to supply special support during the translation experiment where its high gain would greatly improve the signal-to-noise ratio.

The launch of Surveyor 6 was from Complex 36A on November 7, 1967. The midcourse maneuver was commanded on November 8, and the spacecraft landed flawlessly on September 10, in Sinus Medii, a heavily cratered mare area. Over 30,000 pictures were radioed back during the first lunar day. On November 17, the vernier engines were commanded to fire for 2.5 seconds. This impulse moved the spacecraft laterally about 8 feet. During this novel experiment, strain-gauge measurements were picked up by Goldstone Mars to determine better the character of the lunar surface for Apollo engineers. The cameras recorded the effects of the rocket blast and, in their translated position, provided stereoscopic data of the lunar landscape. On November 26, lunar night descended and DSN Surveyor operations ceased until December 14, 1967, when the spacecraft was reactivated for a short period.

DSN support was excellent. Over 170,000 commands were sent to Surveyor 6, illustrating that mission controllers were appreciating the great value of continuous real-time control. The increased gain of the Mars antenna was also found to be highly useful, as evidenced by the added use of this instrument during critical maneuvers and experiments.

Surveyor 7. This Surveyor spacecraft carried a surface sampler as well as the alpha-scattering experiment. There were also the usual photographic and touchdown dynamics experimental objectives. The previous Surveyor successes had made it possible to risk this final flight on a landing in the much more rugged lunar highlands. The good landing spots were much smaller and the target radius had to be reduced from the previous 30 km to 10 km. This necessitated the scheduling of two midcourse maneuvers rather than one. The DSN configuration for Surveyor 7 differed little from that for Surveyor 6.

Surveyor 7 was launched on January 7, 1968. It was injected into a parking orbit with no serious problems. The injection into the translunar orbit went well, as did the first midcourse maneuver. The launch vehicle and spacecraft performed so well that the anticipated second midcourse maneuver was not needed. The spacecraft set itself down on January 10 within 1-1/2 miles of the aiming point. It rested about 18 miles north of the rim of the crater Tycho. The flight was not without problems, though, because spacecraft temperatures were unexpectedly high. The DSN had hoped to reactivate Surveyors 5 and 6 during this period of time, but the spacecraft temperatures had to be monitored almost continuously, preempting the activation attempts.

Scientific operations on the lunar surface proceeded normally until the alpha-scattering experiment failed to deploy properly. The surface sampler, however, utilizing commands sent via the DSN, was able to dislodge the instrument and save the experiment. Later, the sampler picked up the instrument and moved it to two other locations for further analysis of the lunar soil. Thus, the advantages of real-time control and manipulatory capability were amply demonstrated.

On its own, the sampler dug trenches, fractured a rock, and performed other manipulations of great value to the Apollo Program. The first lunar day ended on January 25, 1968, but Surveyor 7 was kept operating for 15 hours after sunset. It took additional star and Earth pictures. Operations commenced again on February 12 and continued until February 21. Over 150,000 commands had been sent before the spacecraft was turned off for the final time.

<u>DSN Performance through the Surveyor Program</u>. Table 7-5 illustrates the high reliability of the DSN throughout the entire Surveyor effort. In part, this record was attributed to the high degree of built-in redundancy. All down times were small fractions of the total, and the missions were not compromised at any time. Only a few problems of second-order importance were uncovered:

- Unexplained delays in data transmission
- Lack of backup equipment and personnel training applicable to non-standard events
- Some poor quality real-time and non real-time data
- Doubt over some hardware and software management interfaces
- Delineation of responsibility for operation and maintenance of mission-dependent equipment
- Adequate documentation of agreements between project and DSN personnel on level of support
- Lack of definition of ultimate responsibility for communications support in some areas.

By the time the Surveyor-7 mission rolled around, most of these problems had been cleared up.

Table 7-5. SURVEYOR MISSION SUPPORT PERFORMANCE EVALUATION[a]

	Surveyor Flight						
Tracking	1	2	3	4	5	6	7
Total Time (hr)	599	86	611	125	657	650	631
Down Time (hr)	25.1	0.6	5.4	1.3	1.2	3.3	6.0
Commands							
Sent Correctly	86,177	1,542	57,107	1,232	104,906	164,867	138,060
Sent Incorrectly	1	1	2	Nil	5	36	1
Down Time	Nil	Nil	0.5	Nil	1.5	Nil	Nil
Video							
Pictures Rec'd	12,088	Nil	10,031	Nil	25,750	45,519	20,993
Pictures Lost	Nil	Nil	Nil	Nil	98	34	5
Down Time	Nil	Nil	Nil	Nil	0.75	6.0	6.2
Telemetry							
Total Time (hr)	599	86	611	123	624	634	605
Down Time (hr)	19.4	Nil	0.2	Nil	6.4	Nil	0.2

[a]First Lunar Days for 1, 3, 5, 6, and 7.

The Lunar Orbiter Program

In 1958 and 1959, when JPL was trying to synthesize a comprehensive lunar program, an orbital lunar mapping spacecraft was conceived to help prepare the way for manned lunar landings and for lunar science as well. During the very early 1960s, JPL engineers viewed the orbiter as an adjunct to Surveyor, using similar spacecraft technology. The project was in fact called Surveyor Orbiter. Meanwhile, NASA Headquarters was becoming increasingly concerned that JPL was overburdened with Ranger, Surveyor, and Mariner. The decision was made to assign the orbiter effort to Langley Research Center to relieve JPL. On August 30, 1963, the Project Approval Document was signed, and the Lunar Orbiter Program officially began. Its primary purpose was to search for and survey landing sites for the Apollo Project. On May 8, 1964, Langley signed a contract with Boeing to build five Lunar Orbiter spacecraft.

In contrast to Surveyor photography, in which a vidicon camera fed back pictures via telemetry in real time, Lunar Orbiter possessed rather complex photographic equipment that exposed and developed photographs onboard that were later scanned onboard (in non real-time) after the fashion of terrestrial facsimile equipment. With this approach, very high resolution (5 m) pictures could be taken and then transmitted back to Earth at a rate compatible with DSN telemetry bandwidths.

Lunar Orbiter flights ran concurrently with those of Surveyor and Mariner 5 (see later discussion in this chapter.) The overlapping missions, most of them lunar, and in the same region of the celestial sphere, taxed DSN support capabilities. In addition to these missions, Mariner 4 and Pioneers 6 through 9 were still alive and transmitting useful data. Precise scheduling of the DSN plus the cooperation of the several projects involved made this data acquisition program a very fruitful one in terms of space science.

Like Surveyor, Lunar Orbiter provided several firsts for the DSN. A new "turn-around" ranging transponder provides the following·

- Extremely precise ranging data that resulted in corrections to the lunar ephemeris.
- Analysis of the radiometric data led to the discovery of the lunar mascons. These high mass concentrations pulled the Orbiters slight but detectable distances off their nominal orbits.
- DSN stations tracking the same Orbiter could synchronize their clocks to a much higher degree of precision.

The complexity of the Lunar Orbiters and the launch of five of them within the space of a single year resulted in these new "situations" for the DSN:

- The presence of up to three operating Lunar Orbiters in view of the same DSN antennas at any one moment and the simultaneous reception of their signals
- The DSN's first experience with real-time continuous support of spacecraft (over a lengthy 30-day encounter period) with complex operational routines of tracking and data acquisition

-The Lunar Orbiter software system was the most complex supported by the DSN as of 1966. [14]

The Lunar Orbiters were launched by the Atlas-Agena launch vehicle. Like most of the Surveyors, these spacecraft went first into a parking orbit from which they were injected into translunar trajectories. These phases of the flight were by now routine for personnel on the Air Force's Eastern Test Range (ETR) and at the various stations in the MSFN, which provided the primary tracking and data acquisition support from launch through DSN acquisition. During the early moments of flight, the DSN role involved only the Launch Station and the SFOF. The latter was responsible for computing and displaying essential launch and spacecraft data in the Lunar Orbiter Mission Control Area.

The DSN coverage required after acquisition is indicated in Table 7-6. During the photographic phase of the mission, the requirements naturally centered upon taking good pictures and sending them back to Earth. Two deviations from standard DSN operations were required during the phase:

1. Because the FM video transmission technique employed by Lunar Orbiter did not provide a coherent RF carrier, the DSN antennas could not track the spacecraft signals automatically. Instead, a computer provided pointing data which it calculated from orbital data.

2. Special Project-supplied ground reconstruction equipment (GRE) had to be installed at each prime DSN station to produce photographs from the telemetry data. A photographic darkroom was part of each set of mission-dependent equipment. Pictures taken at Goldstone had to be sent back to the SFOF in real time by a 6-MHz microwave link. Overseas, video tapes and photos were sent back by mail. The Lunar Orbiter Project supplied its own personnel to perform this task and operate the mission-dependent equipment as well.

Following the completion of the photographic phase, the Lunar Orbiters were tracked with high precision in what was termed the "selenodetic phase." This was particularly important during the first flight because mission planners wanted to understand the Moon's gravitational field better so that they could decide how low they could safely orbit the spacecraft and still collect data for Apollo use.

When the Lunar Orbiters finished their photographic selenodetic phases, the Project required that each live spacecraft be accorded at least 14 passes per week. Many engineering and scientific experiments were consumated during these extended missions, including coding experiments and

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[14]Hall, J. R., "Tracking and Data System Support for Lunar Orbiter," (Pasadena: JPL TM 33-450, April 15, 1970) pp. 4-5.

Table 7-6. DEEP-SPACE COVERAGE REQUIREMENTS

Interval	Required Coverage
Launch to initial lunar injection	31 h/day, average over 4 days
Injection to completion of photo mission	24 to 31 h/day, as required by Project
Completion of photo mission plus 30 days (selenodetic phase)	Three consecutive orbits, or 11 h, whichever is less, with one orbit or 3.5 h overlapping, whichever is less, every other day
From end of selenodetic phase plus 10 months	Two consecutive orbits or 7 h, whichever is less, every third day with one orbit or 3.5 h, whichever is less, overlapping coverage each track period

bistatic radar mapping of the lunar surface. Extremely important to NASA's lunar effort was the performance validation and "sighting in" of MSFN stations using Lunar Orbiters. Later, these same MSFN stations would track and communicate with manned Apollo spacecraft orbiting the Moon in similar orbits.

The fact that the Lunar Orbiter and Surveyor flights transpired during a period of rapid DSN evolution posed several difficulties. In the engineering area, DSN configuration "freezes" had to be imposed on Lunar Orbiter hardware and software from just before flight, when the DSN was all checked out and in operational readiness, until the critical phases of the mission were complete. If changes were permitted during this period, no matter how well thought out they were, the risk was high that some overlooked detail could degrade mission performance. A second problem area concerned the management of the Lunar Orbiter-DSN interface during a time when the DSN was undergoing significant modification and upgrading. A flurry of confusion occurred when the contents of a JPL planning document containing configuration estimates that did not materialize was mistakenly written into a Boeing Company contract as an established design interface. Many hours were spent straightening out this misunderstanding. This problem eventually led to a thorough and comprehensive interface control procedure.

The facilities supporting the Lunar Orbiter flights began with the Air Force and MSFN stations which provided the metric and telemetry data during the launch and near-Earth phases. The prime DSN stations assigned to the first Lunar Orbiter flights were Woomera, Robledo, and Goldstone Echo. The DSN's Launch Station provided prelaunch checkout services and early tracking telemetry. Other DSN stations, although not formally committed to the mission, did track the spacecraft. For the final three launches, Cerebros was substituted for Robledo due to preparations for Apollo underway at Robledo. The DSN GCF (Ground Communication Facility) was upgraded with the addition of high-speed data lines between Goldstone and the SFOF. At the SFOF itself were located Mission Control plus the mission-dependent GRE (Ground Reconstruction Equipment) that created the facsimile pictures from the video data coming in over the high-speed data link from Goldstone.

Lunar Orbiter 1. The first Lunar Orbiter flight was scheduled for July 1966 but problems with spacecraft performance forced a delay until August 10, 1966. Launch, parking orbit, and translunar injection phases went according to plan. Johannesburg was the first DSN station (it was not "prime") to acquire Lunar Orbiter 1, but it had trouble maintaining lock due to the target's high angular velocity during this part of its flight. Woomera, the first prime station, acquired the spacecraft 47 minutes after launch. The first of two midcourse maneuvers occurred on August 11 and was so accurate that a planned second maneuver was not required. After 92 hours of translunar flight, Lunar Orbiter 1 was injected into a high orbit for analysis of the Moon's gravitational field. (Note that all preceding NASA lunar flights had been scheduled for impacts or soft landings. By August 18, NASA mission controllers committed the spacecraft to a close-in photographic mission that lasted until August 29.

DSN operations continued until October 29, 1966, when the spacecraft was commanded to impact on the lunar surface to avoid interference with the second Lunar Orbiter planned for November. A total of 207 photographic passes (both medium and high resolution) pictures were taken and successfully sent back to Earth. The medium-resolution pictures were good but the high resolution ones were smeared. All DSN support requirements were met. Minor problems occurred with computer hardware and with scheduling computer time for the DSN, the Lunar Orbiter Project, and other active projects.

Lunar Orbiter 2. This spacecraft in the series was assigned to photograph a northern latitude band on the Moon, whereas Lunar Orbiter 1 had concentrated on a southern band. As secondary objectives, Lunar Orbiter 2 was to once again assess the lunar gravitational field and make radiation and micrometeoroid measurements.

Launch took place from Complex 13, Cape Canaveral, on November 6, 1966. The progress along the ETR was according to plan. In addition the DSN Launch Station tracked the spacecraft manually for over 3 minutes, although it was not required to provide radiometric data or launch telemetry. From its parking orbit, the spacecraft was injected into its translunar trajectory 20 minutes after launch. Johannesburg, the first prime station, then acquired the spacecraft. A single midcourse maneuver and lunar-orbit injection were executed at the proper times. After 33 orbits, at an altitude of 196 km, Lunar Orbiter 2 was maneuvered to its photographic orbit (49.7-km periselene). Lunar photography was carried out between November 18 and 26. Readout of the photographs progressed routinely for the next 11 days until, on December 7, the travelling-wave-tube amplifier on the spacecraft failed. During its active period, 211 out of 212 sets of medium- and high-resolution photos were taken and returned. The mission was considered very successful. Despite repeated attempts, the transmitter of Lunar Orbiter 2 could not be revived. The spacecraft could, however, still receive commands and, on October 11, 1967, almost a year after launch, its orbit was modified so that it would crash into the Moon.

Lunar Orbiter 3. The two preceding Lunar Orbiters had found 12 likely sites for Apollo landings. This third mission was designed to reexamine these sites and verify their characteristics rather than search for new landing areas. Otherwise the mission plan was similar: first launch, parking orbit, translunar flight, high-orbit photography, and finally terminating with low-orbit photography. These flight phases were executed routinely and the mission was normal in all respects with all planned photography accomplished. The final photo readout was nearly completed when the film advance failed. In all, 211 sets of photos had been recovered.

Lunar Orbiter 4. This was another mission aimed at broad, systematic mapping of the lunar surface for the purpose of Apollo landing site selection. Lunar Orbiter-4 objectives also included gravitational-field mapping, radiation and micrometeoroid measurements, and serving as an MSFN tracking target. The

DSN configuration of prime stations on this mission was identical to that for Lunar Orbiter 3, with Cerebros again substituting for Robledo.

On May 4, 1967, from Complex 13, an Atlas-Agena launch vehicle successfully placed Lunar Orbiter 4 into a 100-mile parking orbit. A relatively large midcourse maneuver impulse was required due to deviations from the ideal launch trajectory. It was properly executed 18 hours and 20 minutes after launch. Nearing the Moon, Lunar Orbiter 4 was injected into a high, nearly polar orbit with a periselenium of 2706 km. Photography from this orbit commenced May 11. Prior to this, on May 9, an eclipse of the Sun gave Cebreros a rare opportunity to track and communicate with the spacecraft as the Moon crossed the Sun's disk. The system noise rose more than 20 db, but the mission was not compromised.

Lunar Orbiter 4 did not operate as perfectly as its three predecessors. The anomalies were mostly with the photographic system. Failure of the camera thermal door was the most serious event. This and lesser difficulties required more real-time involvement of the DSN than had been planned. Techniques to circumvent the problems were worked out by Project and DSN personnel and, in the end, the mission produced many high quality pictures. Since Lunar Orbiters 2 and 3 were still operating during the critical periods of Lunar Orbiter 4's mission, the DSN had to develop methods to preclude locking onto the signals from these other spacecraft. Final readout of the accumulated photos took place on June 1, 1967.

Lunar Orbiter 5. The four previous spacecraft in the series had achieved the most important objectives with respect to Apollo site selection. Lunar Orbiter 5, therefore, was able to devote time to photographing sites of scientific interest, particularly those on the far side of the Moon. This goal made it mandatory that the launch occur on the first day of the launch windows. On this day, August 1, 1967, equipment failures delayed the launch for most of the 231-minute daily window. With the assurance that the first prime DSN station, Woomera, could acquire the spacecraft on a nominal trajectory without the usual ETR trajectory data, the Mission Director decided to go ahead with the launch despite the possible loss of metric data. The launch did go according to plan, and Woomera acquired the spacecraft with no trouble. The Launch Station, Ascension, and Johannesburg also acquired the spacecraft easily. Translunar injection, the midcourse maneuver, and lunar-orbit injection experienced no problems. Photography began in a high orbit. After four circuits, the spacecraft was put into a low orbit, where picture-taking continued. By August 27, all possible pictures (212 in total) had been taken and read out, and the extended mission began.

Management Problems Encountered During Lunar Orbiter. The Lunar Orbiter program was not managed by JPL (as was the concurrent Surveyor), and some management difficulties surfaced during this intense program (five launches in less than one year):

- There was a lack of definitive documentation describing DSN interfaces with the Lunar Orbiter Project; viz., the interface with SFOF software.
- The SIRD and NSP documents, which stated requirements levied on the DSN and the DSN response respectively, proved adequate for matching facility (hardware) support but were not effective in providing timely support for the Lunar Orbiter's ever-changing requirements, particularly in the multiple-mission environment.
- It was particularly difficult to schedule Lunar Orbiter passes in the multimission situation with mission-dependent equipment at only the three prime DSN stations. (Again the advantage of a truly multimission network became apparent.) Overall efficiency was also degraded by the fact that the Lunar Orbiter project had to supply its own personnel to operate the mission-dependent equipment at the three prime sites. In a multimission network, this would have been unnecessary.

Despite these problems, the DSN met the tracking and data acquisition requirements of Lunar Orbiter very successfully, with very few lost pictures and data. All in all, Lunar Orbiter was one of NASA's most successful spacecraft programs.

The Second Mission to Venus: Mariner 5

During 1965, budgetary restrictions caused NASA to delay the first Voyager flight to Mars from 1971 to 1973. This action left several planetary firing windows open---a poor situation for a country trying to prove its space supremacy. To fill some of these windows, two new Mariners were assigned to the 1969 Mars opportunity and one (Mariner 5) to the 1967 Venus window. Mariner 5 was simply a spacecraft left over from the 1964 Mariner shots to Mars. This spacecraft was rebuilt and reinstrumented by JPL and made ready for a launch in June of 1967 by an Atlas-Agena launch vehicle.

The primary scientific objective of Mariner 5 was furthering the exploration of the dense, optically opaque Venusian atmosphere begun by Mariner 2. The Mariner-4 instruments, such as the camera, could be built for the spare Mars spacecraft but could not be used for Venus. Photometers, radiometers, plasma probes, and other instruments were used instead. Scientifically, however, the similarity of Mariner 4 and Mariner 5 telecommunication systems made it attractive to track and communicate with both spacecraft simultaneously (Mariner 4 was now in its "extended" mission) and thus study the properties of interplanetary space from three well-separated vantage points (two spacecraft plus the Earth).

Mariner 5 was a JPL-managed project, and the interfaces were much simpler (Figure 7-12) than they were for the concurrent Surveyor and Lunar Orbiter programs. Interfaces still existed, though, between JPL, the MSFN, and the Air Force's Eastern Test Range. The last two organizations contributed tracking and data acquisition support, as usual, during the launch and

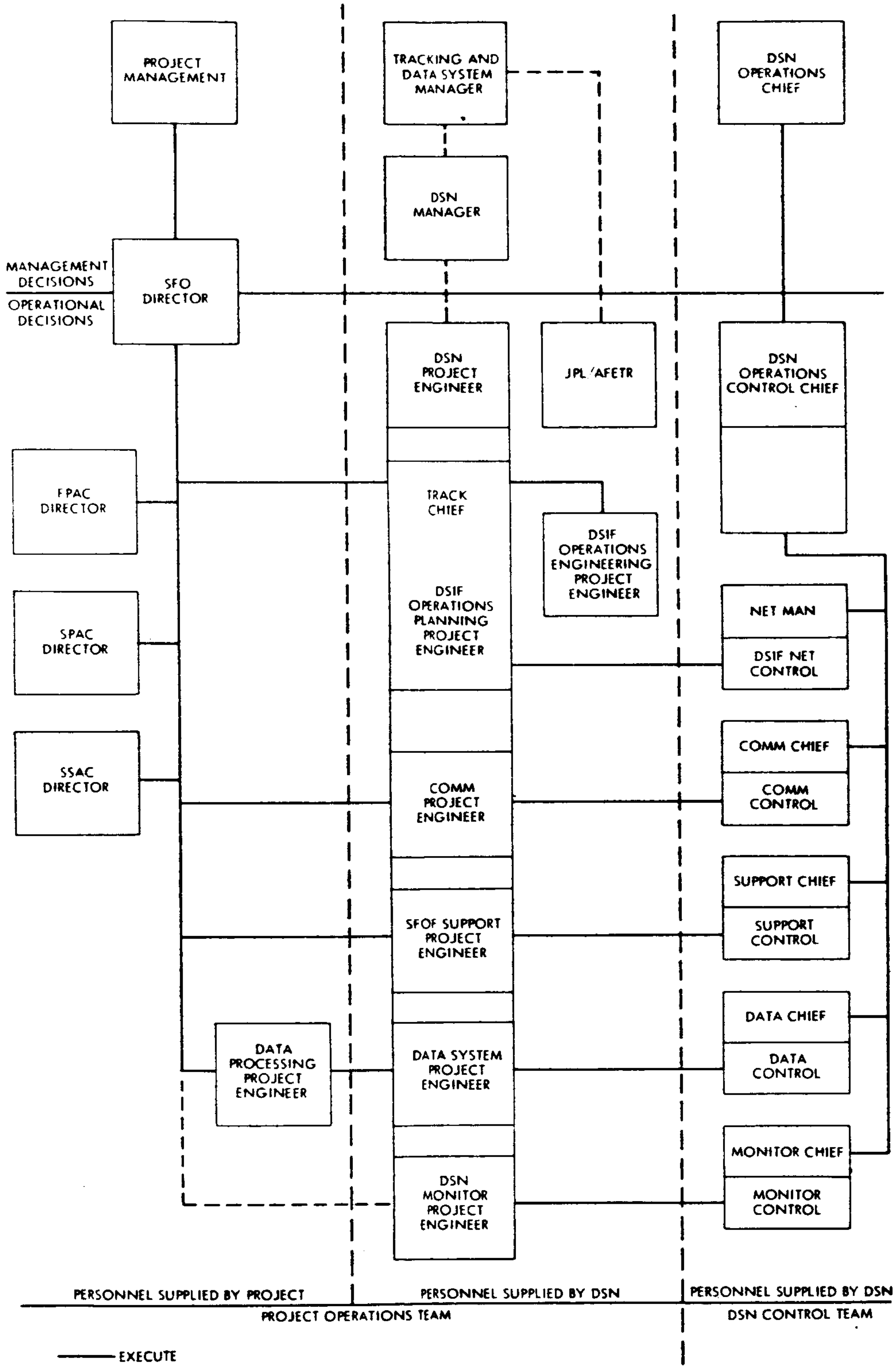

Figure 7-12. Relation between Mariner-5 flight project and DSN.

near-Earth phases of the mission. (Table 7-7) The actual tracking and data acquisition requirements for this mission are rather involved due to the competition of other missions and the desire to integrate the support of both Mariner 4 and Mariner 5 for simultaneous measurements in deep space. The lengthy tables detailing the specific requirements may be found in the JPL summary of DSN support for the Mariner 5 mission.[15]

The deep-space phase of the Mariner-5 flight plan commenced with DSN acquisition and continued as the three prime stations (Woomera, Goldstone Pioneer, and Robledo) passed the spacecraft from one to the other. After midcourse maneuver, however, the joint Mariner 4/Mariner 5 experiments complicated matters. After midcourse-maneuver-plus-two-days, the DSN plan was to dispense with the "prime station" concept and meet the joint mission requirements with whatever pattern of 26-m stations it could put together. (Table 7-8) The overall support objectives were:

1. Four 8-hour passes per day

2. Station pre- and post-track checkout time of 9 hours during critical phases and 4 hours during noncritical phases of the mission

3. Appropriate longitudinal separation between stations to provide continuous coverage when required.

It was understood, though, that three station networks would not always be available due to the pressure of other missions and that pairs of stations would sometimes have to suffice. Figure 7-13 further illustrates the DSN approach. Note that the two 26-m subnets are being employed as separate entities.

Mariner 5 was the first spacecraft to employ a redesigned 7044 computer system in the SFOF. This system successfully processed data from Mariner 4 and Mariner 5 simultaneously. Another Mariner-5 first was its use of a newly installed Communications Processor (CP) in the SFOF, which computer-switched teletype messages throughout the DSN. (Goddard had previously used a CP in directing NASCOM traffic.)

The Mariner-5 Flight. Launch took place on June 14, 1967, from Cape Canaveral. Mariner 5 was injected into a parking orbit and then into a trajectory toward Venus. The DSN lunar ranging system (Mark I type) followed the spacecraft to a distance of 10 million kilometers, making Mariner 5 the first spacecraft to be ranged beyond lunar distances. Forty days after launch, (July 24), the command was sent to decrease the data rate from 33-1/3 to 8-1/3 bits/sec. On October 1, the spacecraft transmitter was switched to its high-gain antenna and the new Mark IA experimental planetary ranging system was tested and prepared for

[15]N. A. Renzetti, "Tracking and Data System Support for the Mariner Venus 67 Mission," Vol. I (Pasadena: JPL TM 33-385, September 1, 1969) pp. 23-24.

Table 7-7. MARINER-5 SUPPORTING FACILITIES

Agency	Station and Location
AFETR	Station 1. Cape Kennedy/Patrick AFB (CKAFS)
	Station 3. Grand Bahama Island (GBI)
	Station 7. Grand Turk Island (GTK)
	Station 91. Antigua Island (ANT)
	Station 12. Ascension Island (ASC)
	Station 13. Pretoria, South Africa (PRE)
	RIS Twin Falls, South Atlantic
	RIS Coastal Crusader, South Atlantic
MSFN	Bermuda Island station (BDA)
	MSFN/USB site, Ascension Island (ASC)
	Tananarive site, Malagasy (TAN)
	Carnarvon site, Australia (CRO)
	Goddard Space Flight Center (GSFC)
NASCOM	Worldwide facilities of NASCOM provided communications between supporting agencies
JPL/AFETR	Building AO, Cape Kennedy
DSN	SCS 71, Cape Kennedy
	DSS 72, Ascension Island
	DSS 51, Johannesburg
	SFOF, Pasadena

Table 7-8. DSN CAPABILITIES DURING MARINER 5

Capability[a]	OSCS Pioneer OSDS S-band	OSCS Echo OSDS S-band	OSCS Mars	Woomera OSDS S-band	Tidbinbilla OSDS S-band	Johannesburg OSDS S-band	Robledo OSDS S-band	OSDS S-band
Station	DSS 11	DSS 12	DSS 14	DSS 41	DSS 42	DSS 51	DSS 61	DSS 62
Receiver capability	2	2	2	2	2	1	2	
Antenna	26-m	26-m	64-m	26-m	26-m	26-m	26-m	
Mount	Polar (HA-dec)	Polar (HA-dec)	Az-El	Polar (Ha-dec)	Polar (HA-dec)	Polar HA-dec)	Polar (HA-dec)	
Maximum angular rate (deg/sec)	0.7	0.7	0.5	0.7	0.7	0.7	0.7	
Antenna gain, db Receiving	53.0 ± 1 -0.5	53.0 ± 1 -0.5	~61.0	53.0 ± 1 -0.5	53.0 ± 1 -0.5	53.0 ± 1 -0.5	53.0 ± 1 -0.5	
Transmitting	51.0 ± 1	51.0 ± 1	~59.0	51.0 ± 1	51.0 ± 1	51.0 ± 1	51.0 ± 1	
Antenna beamwidth, deg	~0.4	~0.4	0.1	~0.4	~0.4	~0.4	~0.4	
Typical system temperature, ^{o}K	55 ± 10	55 ± 10	--	55 ± 10	55 ± 10	55 ± 10	56 ± 10	
Transmitter power, kW	10	10	20	10	10	10	10	
Data transmission (TTY)								
Angles	Real time	Real time	Real time	Real time	Real time	Real time	Real time	
Doppler	Real time	Real time	Real time	Real time	Real time	Real time	Real time	
Ranging (to 800,000 km)	Real time	Real time	Real time	Real time	Real time	N/A	Real time	
TLM	Real and near-real time	Real and near-real time	Real and near-real time	Real and near-real time	Real and near-real time	Real and near-real time	Real and near-real time	
Demodulated TLM	Dual channel	Dual channel	Dual channel	Dual channel	Dual channel		Dual channel	
Command capability	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Data pack air shipment time to JPL	1 day	1 day	1 day	2 wk	2 wk	2 wk	10 days	10 days

[a]The following stations have acquisition aid: DSS 11, DSS 41, DSS 42, and DSS 51.

Figure 7-13. DSN coverage for Mariner-5 cruise period.

use during the forthcoming encounter with Venus. DSN coverage during the cruise phase is shown in Figure 7-14. The encounter sequence was started on October 18, 1967, 15 hours prior to the encounter. The closest approach was 3946 km on October 19. On this same day, the spacecraft was occulted by Venus for about 21 min. giving radio astronomers an opportunity to observe the effect of the planet's atmosphere upon the spacecraft's transmitter signals. An experiment in bistatic radio astronomy was also carried out. The Goldstone Mars facility was prime during the encounter.

The DSN continued to track Mariner 5 on an intermittent basis until it passed out of radio range at about 160 million km. Before contact was lost on November 21, a series of five commands was sent to place the spacecraft in a "long-term-cruise" condition. Contact was reestablished on October 14. 1968. one year later, but the signal was weak and displaced by 30 kHz in frequency. Attempts at contact had been underway since July 22, when the Mars station theoretically should have picked up Mariner 5, but the weak signal and frequency offset precluded success. Telemetry reception and command capabilities could not be resurrected despite many attempts to clear the anomaly. Consequently, on November 5, the mission was declared at an end.

During the Mariner-5 cruise and encounter phases some significant problems occurred in the DSN-spacecraft system:[16]

- Large gaps in real-time data and frequent degradation of operations resulted from unfavorable high-frequency propagation conditions between Pretoria and London.
- More data were lost because the DSN ground system could not hold data for the short periods while the communications processor (CP) was starting, interchanging, and updating computers.
- Failure of a teletype tone keyer knocked out DSS-14/SFOF teletype communications during the encounter.
- Two separate anomalies connected with the R&D planetary ranging system reduced its effectiveness during encounter.

The Reacquisition and Extended Mission of Mariner 4

During June 1965, plans were developed at JPL to reacquire Mariner 4. The extended mission was to consist of two more phases. During phase II, Mariner 4 would be used alone to conduct long-range communication experiments with the Mars 64-m antenna. Also, various scientific experiments, such as the determination of the effect of the solar corona on Mariner-4 transmission were to be carried out. Phase III would comprise the joint experiments with Mariner 5 described above.

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[16]N. A. Renzetti, "Tracking and Data System Support for the Mariner Venus 67 Mission," Vol. II (Pasadena: JPL TM 33-385, September 1, 1969) pp. 19-25.

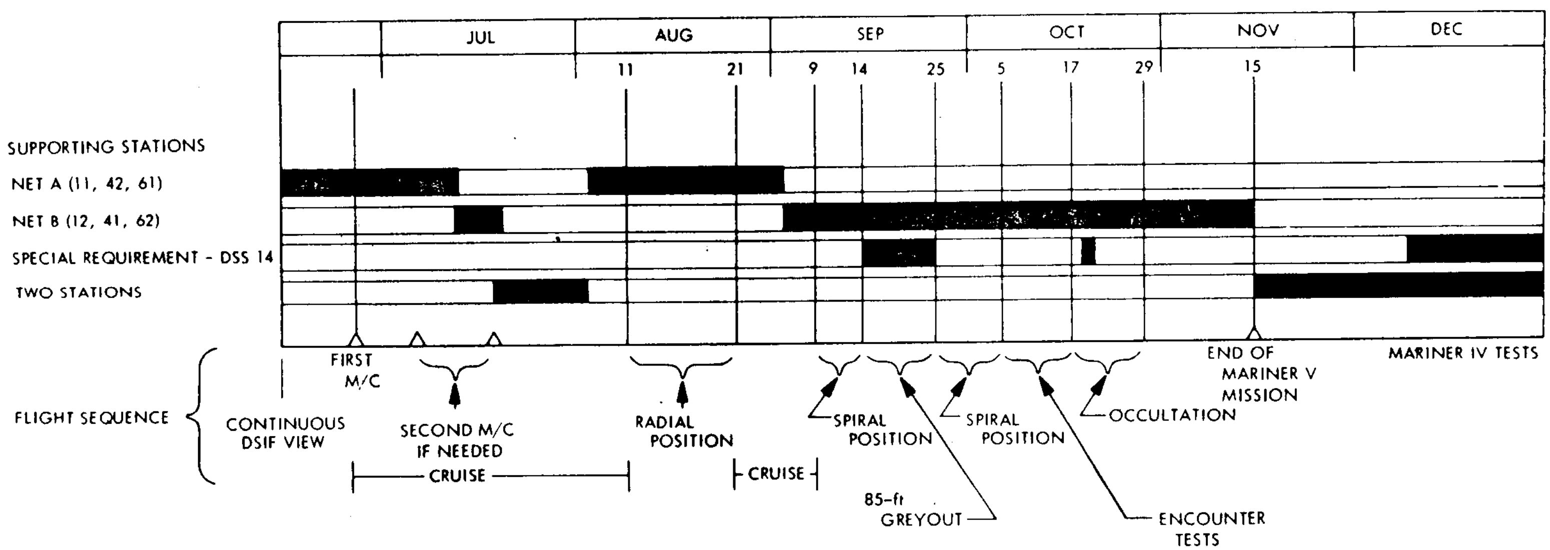

Figure 7-14. Tracking and data-acquisition plan for the Mariner-5 mission to Venus.

Two DSN stations, Venus and Mars, both at Goldstone, were assigned to Phase II.[17] A 100-kw transmitter was installed at the Venus site to provide command capability under emergency conditions. It should be emphasized this extended mission had lower priority than the lunar programs progressing simultaneously. In addition, the DSN was also committed to the Pioneer spacecraft which were turning out to be challenging long-distance targets. The agreement between NASA and JPL left it that the DSN would search for Mariner-4's signal "at times opportune to its own activities."[18] During the five-month period beginning November 1, 1965, the Venus site picked up and unequivocally identified the spacecraft's very weak signal. From March 18 to October 18, 1966, the Mars station was calibrated and checked out using the Mariner-4 signal. (Actually the Mars site was not yet complete, but the antenna contractor permitted these tests.) The Mars 64-m dish was the listening station between March 18 and April 12 when Mariner 4 was occulted by the Sun. The Venus station acted as the transmitting site during the occultation experiment.

From October 18, 1966, until June 1, 1967, the DSN made 27 tracks of Mariner 4. DSS 14 (Mars) continued to use the Mariner-4 signal to check out equipment and train its crew. On the May 8 pass, spacecraft telemetry revealed that, for some unknown reasons, the spacecraft had switched from its travelling-wave-tube amplifier to its cavity-maser amplifier. It was surmised that a large power transient within the spacecraft had caused the switch. The change, unfortunately, caused a severe reduction in transmitter signal strength and, in consequence, the signal received on Earth.

Phase III of the extended mission began officially on June 1, 1967. On October 6, Robledo successfully sent a series of 23 commands to Mariner 4 which switched it to its high-gain antenna and pointed that antenna at the Earth. The DSN next carried out some engineering tests. After nearly three years in space, upon command from DSS 14, Mariner 4 performed a midcourse maneuver. It then played back one of the pictures taken during its encounter with Mars. Amazingly, there was no degradation in quality. Then, to everyone's surprise, a command to Mariner 4 to turn on the supposedly defunct travelling-wave tube succeeded. By December 8, however, the spacecraft's supply of attitude-control gas had been exhausted. DSS 14 (Mars) continued to work Mariner 4 but with diminishing success. On December 20, the Mariner Project decided to end the lengthy (1119 passes) mission of Mariner 4.

The Pioneer Program: Extended Missions

The expected lifetimes of the four successfully launched Interplanetary Pioneers were 6-to-8 months each. Instead of failing at their appointed times, these remarkable spacecraft kept on transmitting data back to Earth

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[17] N. A. Renzetti, "Tracking and Data Acquisition Report: Mariner Mars 1964 Mission. Volume III. Extended Mission," (Pasadena: JPL TM 33-239, December 1, 1968).

[18] Ibid, p. 23

from their orbits between Mars and Venus. Their unpredicted longevities provided scientists with much more data about interplanetary space than they had expected, but it has also kept the DSN busy tracking and acquiring data from them. Brief synopses of the Pioneer-6 extended mission follows.

Pioneer 6. The distance of Pioneer 6 during the extended mission relegated the tracking task to the 64-m antenna at Goldstone Mars.[19] During the first year (July 1966 to July 1967), Pioneer 6 was engaged in watching for solar-flare activity, particularly large flares that might compromise the lunar programs. A radar-bounce experiment with Mercury was performed on June 25, 1967. Solar-flare monitoring continued into the second year of extended mission. In August 1968, a Type-II orientation maneuver was carried out satisfactorily despite the loss in late 1967 of the craft's high-gain antenna. Part of this signal loss was recovered when a new cone (an ultracone) was installed in the 64-m antenna. During this second year, Pioneer 6 reached a point 293 million kilometers from Earth, setting a new distance record. The DSN tracked Pioneer 6 for a total of 1107 hours during this year. The third year of the extended mission encompassed a solar occultation experiment in November 1968. DSN support during this period was compromised by the use of the Mars antenna (the only one tracking Pioneer 6) for the higher priority Apollo flights. Repairs to the antenna's main bearing also took time away from Pioneer 6.

DSN Support to Project Apollo

Although the MSFN provided the bulk of the Tracking and Data acquisition support for the Apollo flights, the DSN contributed much in terms of technology and facility support. The JPL/DSN role in Apollo is discussed in detail in a companion volume of this history. The reader is referred to it for this important segment of the DSN history.[20]

Radio Science

The DSN precision ranging system greatly improved our knowledge of the positions of the Moon and planets and, in consequence, their ephemerides. For example, the flight of Mariner 5 determined the orbit of Venus to within 15 m; the Lunar Orbiters pinned down the Moon's orbit to the same degree of accuracy. It was the precise tracking of the Lunar Orbiters that led to the discovery of the lunar mascons (mass concentrations) that seem to exist

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[19] N. A. Renzetti, "Tracking and Data System Support for the Pioneer Project. Pioneer VI. Extended Mission: July 1, 1966-July 1, 1969," Vol. V, (Pasadena: JPL TM 33-426, February 1, 1971).

[20] William R. Corliss, "Histories of the Space Tracking and Data Acquisition Network (STADAN), The Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM)," (Washington: NASA CR-140390, June 1974).

beneath the Moon's surface. Two JPL scientists reported anomalies in DSN tracking data in 1968 and interpreted the orbital perturbations in terms of inhomogeneities in the lunar crust.[21]

Data on the Sun's corona and plasma emissions were obtained when Mariner 4 and Pioneer 6 passed behind the Sun, in April 1966 and November 1968, respectively. In the first instance, the predicted spectral broadening of the signal caused by the corona was observed: Pioneer 6's linearly polarized signal permitted Faraday rotation measurements of the solar plasma.

The Lunar Orbiters also participated in bistatic radar measurements of the Moon. In these experiments, high power signals were aimed at the Moon from Goldstone. Goldstone receivers could then detect direct reflections from the lunar surface as well as Lunar Orbiter signals recording receipt of the direct beam. The interference patterns that resulted were used to draw radar maps of several areas near the Moon's limb.

When DSN antennas could be spared during this busy period, they were engaged in planetary radar experiments. Radar observations of the asteroid Icarus were made in mid-June of 1968.[22] They indicated that the radius of Icarus is between 0.3 and 0.6 km and that it had a period of rotation between 1.5 and 3.3 hours.

The Next Step Forward

The addition of the 64-m Mars antenna to the DSN marked a natural beginning for this chapter. However, during virtually every mission described, the DSN experienced problems with mission-dependent equipment. This equipment degraded the network's effectiveness as mentioned at several points in this chapter. Some small improvements had been made in the direction of a mission-independent network during this period, but they were not enough. A forceful, comprehensive technical revolution was required.

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[21] P. M. Muller and W. L. Sjogren, "Mascons: Lunar Mass Concentrations," Vol. II, (Pasadena: JPL SPS 37-53) September 30, 1968, pp. 10-16. See also: Science, Vol. CLXI (August 16, 1968) pp. 681-684.

[22] R. M. Goldstein, "Radar Observations of Icarus," Science, Vol. CLXII (November 22, 1968) pp. 903-904.

Chapter 8. BUILDING THE MULTIMISSION NETWORK

With the completion of the Surveyor and Lunar Orbiter programs in early 1968, the DSN in effect turned its antennas outward toward the planets. The manned Apollo effort was in full swing and the DSN played an important support role there. At the R&D level it was pushing ahead rapidly with its conversion to a multimission network. The period 1968-1974 brought into operational status a multimission command system, a multimission network control system, and a new spectrum of equipment designed to eliminate the mission-dependent, project-supplied gear that had plagued the DSN for so long. Improvements in precision tracking continued and deep-space communication distance records were broken repeatedly during this period. Nevertheless, the dominant theme of this period was conversion to a multimission network.

Due in part to budgetary pressures, deep space missions declined in number during the 1968-1974 period, but they also became more complex and departed for more distant and more difficult targets. In response, the DSN also went through a period of consolidation to fewer but better-instrumented stations. Several stations of marginal utility were closed, but in the same period Spain and Australia received their 64-m dishes, completing the 64-m subnet that had long been a goal of DSN management. The DSN was being readied for the more ambitious exploration of the solar system, with flybys of Venus, Mercury, Jupiter, and Saturn, and Mars landers.

The Multimission Concept

Many references have been made in the preceding chapters to the desirability of standardizing equipment in the DSN and at the same time expurgating mission- or project-dependent equipment. In essence, the multimission concept means asking flight projects to design to a specific telemetry/command interface while restraining their natural impulses to introduce highly specialized apparatus at DSN stations. Such special equipment is often very effective in accomplishing narrow project objectives but, as DSN experience has proved, it can seriously reduce the overall efficiency of DSN operations, particularly in terms of reliability, cost of operations (extra personnel), general clutter, cost of spares, and the cost of familiarization. Since the DSN multimission interface places an extra design burden on the flight projects, it is only fair that the DSN make multimission interfaces as versatile, efficient, and convenient as possible. This is exactly what was done, as the following descriptions of the various technological and management facets of the multimission DSN will prove.

The DSN did not become multimission all at once. The development of multimission telemetry equipment began in the mid-1960s and was proven out on Mariner Mars 1969. The command system and network control system were next reworked. The conversion to multimission capability, in fact, reached into every corner of the DSN. When the Mariner Mars 1969 Spacecraft (Mariners 6 and 7) were launched, the DSN was ready to demonstrate the first of its multimission hardware. The telemetry system debut was successful and, when Mariner 1971 and Pioneer 10 were ready for flight, the entire DSN had converted to the multimission configuration. [1]

Total conversion to multimission operations, however, is an unattainable ideal. True, new flight projects did not move bulky equipment and extra personnel into DSN stations, but almost every one of them had "special requirements" that entailed some nonstandard change in the DSN---just for that mission. The 1975 Viking flights, for example, were immensely complicated missions with requirements that the standard DSN interface could not satisfy completely. Viking required many engineering changes to the standard DSN multimission configuration and the shipping of many modification "kits" to DSN stations. [2] Thus, the multimission concept is not an all-or-nothing property of a tracking-and-data acquisition network; rather, it is a design philosophy that works well in practice for both network and project. Exceptions are permitted, but they should be few and superficial.

DSN Technology Advances

Multimission Telemetry. The Multimission Telemetry System (MMTS) and High Rate Telemetry (HRT) project were introduced in Chapter 7 in connection with JPL's first hardware efforts in the direction of multimission capability. NASA and JPL wanted to demonstrate the new telemetry system on Mariner Mars 1969. As originally planned, the two new Mariner spacecraft were to take many more pictures of Mars than Mariner 4 and store them on analog tape. This tape was then to be played at reduced speed through an analog-to-digital converter and rerecorded on another tape. Finally, this digital tape was to be played through the spacecraft transmitter at a still lower rate (270 bits/sec) and picked up by the DSN. The reliability of the double taping process naturally came into question. JPL engineers wondered whether they could possibly transmit back the pictures at the rate of the analog tape recorder (16,200 bits/sec), eliminating one of the tape recorders. [3] The desired bit rate was roughly 2000 times that of Mariner 4, but computations showed that with the 64-m Mars antenna, higher spacecraft power, and certain other changes, it could be done. The HRT project was born of these considerations. Therefore, Mariner Mars 1969 tested out not only multimission telemetry but very-high-rate telemetry.

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[1] N. A. Renzetti, personal interview, April 14, 1975.

[2] D. Mudgway, personal interview, April 16, 1975.

[3] R. C. Tausworthe, et al, "A High-Rate Telemetry System for the Mariner Mars 1969 Mission," (Pasadena: JPL TM 32-1354, April 1, 1969).

The special high-data-rate requirement of Mariner Mars 1969 forced the DSN to incorporate higher telemetry rates sooner than it might otherwise have done. It was also hoped that MMTS with HRT incorporated would satisfy the requirements of the new Pioneers (10 and 11), Viking, Helios, Mariner Venus-Mercury 1973, and other missions on the horizon.[4]

During the actual flights of Mariner 6 and 7 in 1969, both the MMTS and HRT facets of telemetry transmission achieved high success. The HRT (16,000 bits/sec) playbacks of the pictures were so good that the slow (270 bits/sec) playback via the 26-m antennas became unnecessary. MMTS was also used for supporting the Interplanetary Pioneers during their extended-mission cruise phases.

A similar situation occurred when the Mariner Mars 1971 Project levied requirements for additional, higher-capacity telemetry channels.[5] The DSN Telemetry System, as it was now called in JPL reports, once again had to expand its capacity accordingly, as did the GCF and SFOF. In this light, multimission capability does not mean a static capability but rather the ability to handle new missions with a minimum of change in the DSN and with the introduction of as little mission-dependent equipment as possible.

This evolutionary aspect of the multimission approach is epitomized by the DSN Telemetry System, perhaps because the flight projects always want higher data rates than are planned when the project is initiated. Telemetry system evolution continued after the Mariner Mars 1971 flights, but as telemetry system capabilities expanded, so did the number of projects the DSN could handle in true multimission fashion. The point here is that sometimes flight projects stimulated DSN developments and vice versa.

In the early 1970s, the DSN was moving toward what was termed a "Mark III" plateau of support capability. The missions to be supported comprised Pioneers 6-11, Mariner Venus/Mercury, Helios, and Viking. Once again, however, DSN engineers conceived a step-by-step development, with each succeeding step making the network less and less mission-dependent.[6] Between the Mark III-73 and Mark III-74 network models, for example, the DSN developed the capability to handle convolutionally coded transmissions from both Pioneer and Helios spacecraft.

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[4]Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-58) p. 3.

[5]Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-61, January 31, 1970) pp. 121-122.

[6]Jet Propulsion Laboratory, "The Deep Space Network," (Pasadena: Progress Report 42-23, October 15, 1974) pp. 5-7.

Multimission Command of Spacecraft. The DSN Multiple-Mission Command System (MMCS) lagged the multimission DSN Telemetry System by two to three years, mainly because the spacecraft command function did not involve nearly as much communication traffic and ground equipment. Even in 1969, each DSN station was burdened with a different command system for each flight project. Each system had its own configuration, procedures (many of them manual), and equipment. The command process was needlessly long and complicated and, worse yet, different for each project. (Figure 8-1)

Commands originated in the SFOF Mission Control Center using mission-dependent programs. No less than five separate and distinct methods existed for the transmission of commands to the DSN station working the target spacecraft. (Figure 8-1) In one method, the IBM 7044 computer in the SFOF would take command data from disk memory or IBM cards and format it for teletype transmission to DSN stations. Another scheme was simply to relay the command verbally over voice circuits. At each transfer point, the command data had to be checked and verified manually because an erroneous command could abort a mission. Finally, if all went well, the DSN station would radio the proper command to the spacecraft. The system worked, but it was cumbersome and the antithesis of multimission philosophy.

Like the multimission DSN Telemetry System, the MMCS development proceeded stepwise. The mission targeted for the first demonstration was Mariner Mars 1971. [7] The objectives of the MMCS specifically stated that no mission-dependent equipment would be required at any DSN station for any mission. The system was to be as automatic as possible with no special operator being required at any station. All actions necessary for the transmission of a command would reside in the SFOF at Pasadena. (Figure 8-2) The all-important function of command verification would be accomplished by the DSN station (Figure 8-3) which would return the received command to the SFOF bit-by-bit to confirm that it had been received correctly. Only then would the command be "enabled" and sent to the spacecraft. The GCF high-speed data lines were to be the primary mode of command ground transmission with voice-circuit backup. The new command system was tagged Mark III-71. It was installed throughout the network by November 1970 and supported the flights of Mariners 6 and 7.

The new command capability did not satisfy mission requirements for long. Viking in particular forced a redesign of the MMCS beginning in September 1972. [8] The Telemetry and Command Processor installed at DSN stations had reached the limits of its capacity in both command-processing time and storage capacity. (Viking required not only much higher command rates (8 rather than 1 symbols/sec) but also the simultaneous execution of

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[7]Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-56, March 31, 1969) pp. 3-7.

[8]Jet Propulsion Laboratory, "The Deep Space Network," Vol. XIII (Pasadena: JPL TR 32-1526, February 15, 1973) pp. 203-208.

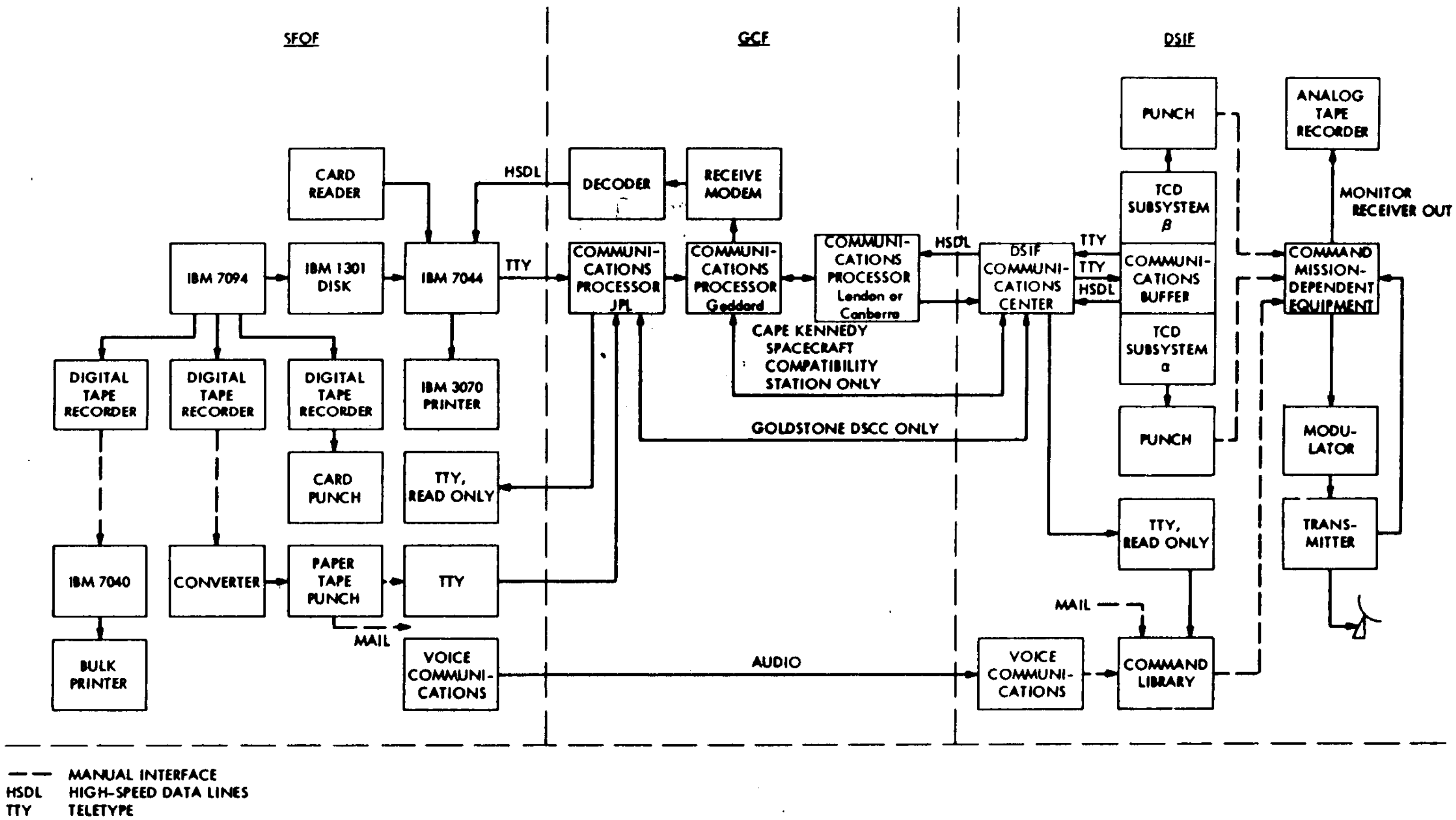

Figure 8-1. DSN command system from SFOF to DSN station circa 1968.

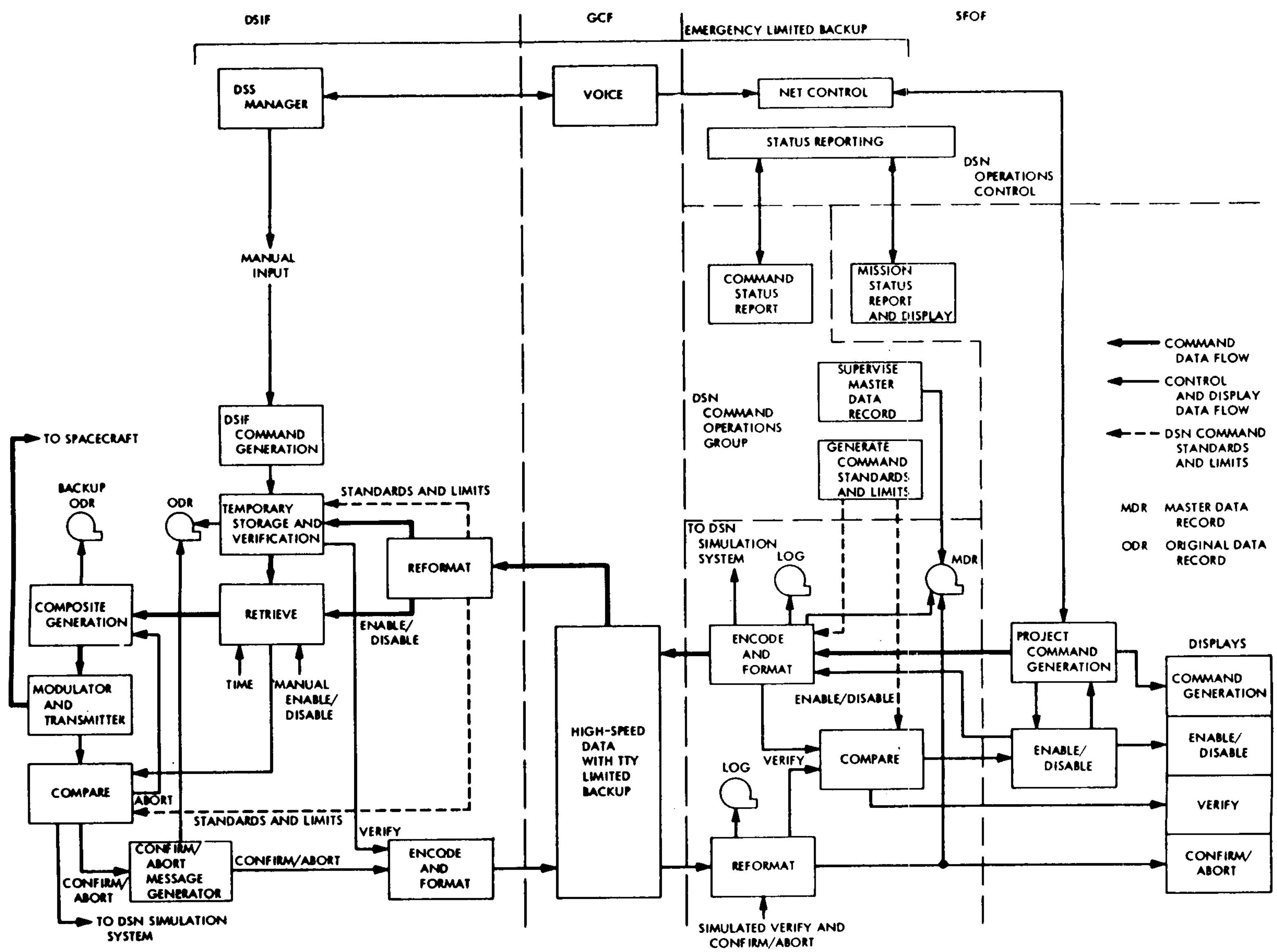

Figure 8-2. DSN command system functional diagram circa 1969.

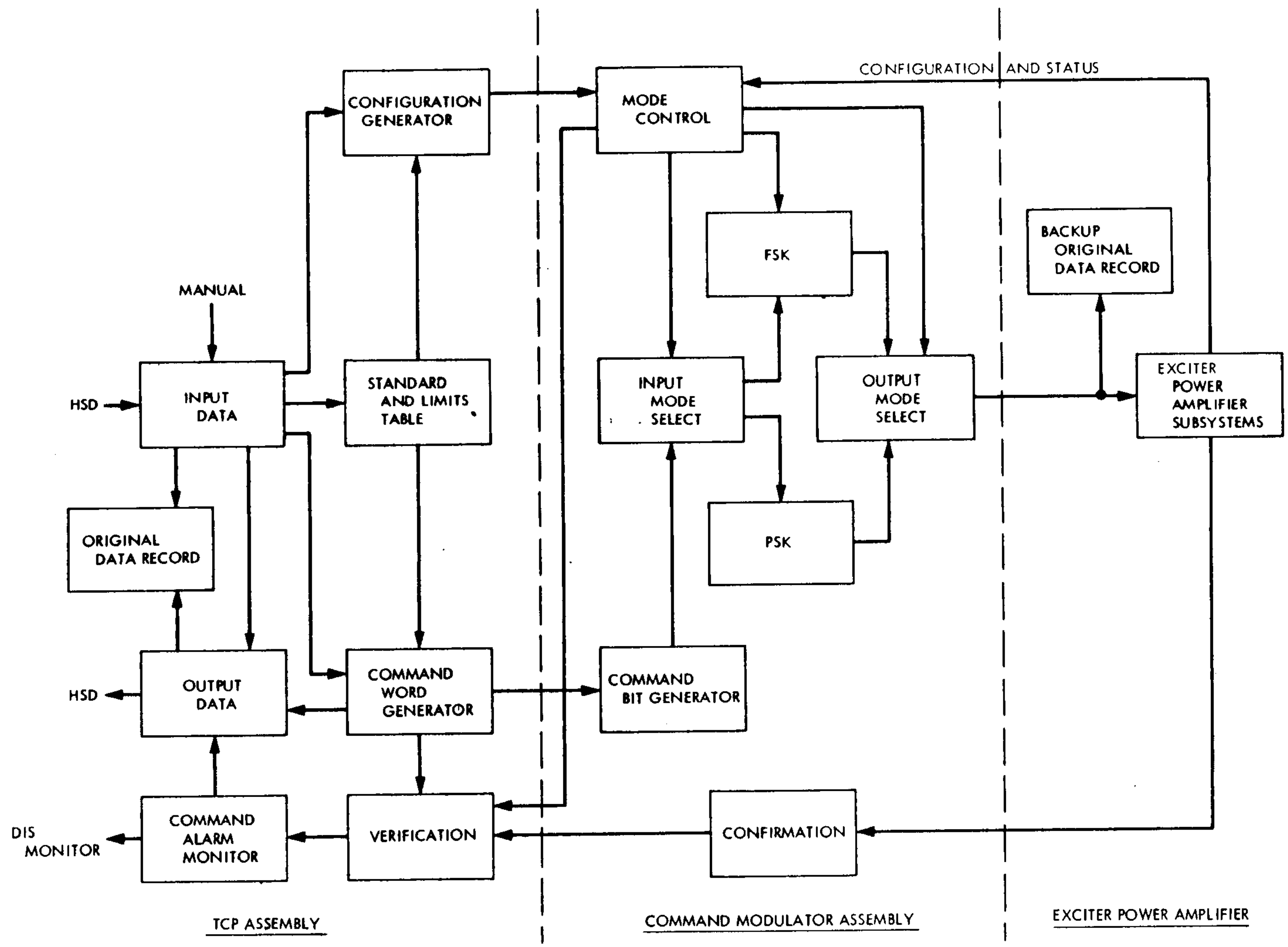

Figure 8-3. Block diagram of the station portion of the DSN multimission command system circa 1969.

command and telemetry functions. The bottleneck was the Telemetry and Command Processor and it was here that the redesign focussed. The problem was not so much in the hardware as in the timing constraints caused by the Mark III-71 software. This software was redesigned and, along with other lesser system changes, combined to make the Mark III-74 Command System, which has supported Helios, Viking, and the immortal Pioneers.

DSN Monitor and Control. With the advent of high-capacity data circuits, the DSN stations became less and less isolated. In fact, it became possible to view the DSN as one, vast, electronically integrated machine. Rather than measure and control the performance of each station individually, advancing technology made it possible to centralize the monitor and control functions. (Figure 8-4)

Basically, the DSN Monitor and Control System detected and reported on the status of the DSN facilities. The various systems within DSN stations (the DSIF), the GCF, and the SFOF are all monitored as to their operational status, performance level, and configuration. [9] Such information collected

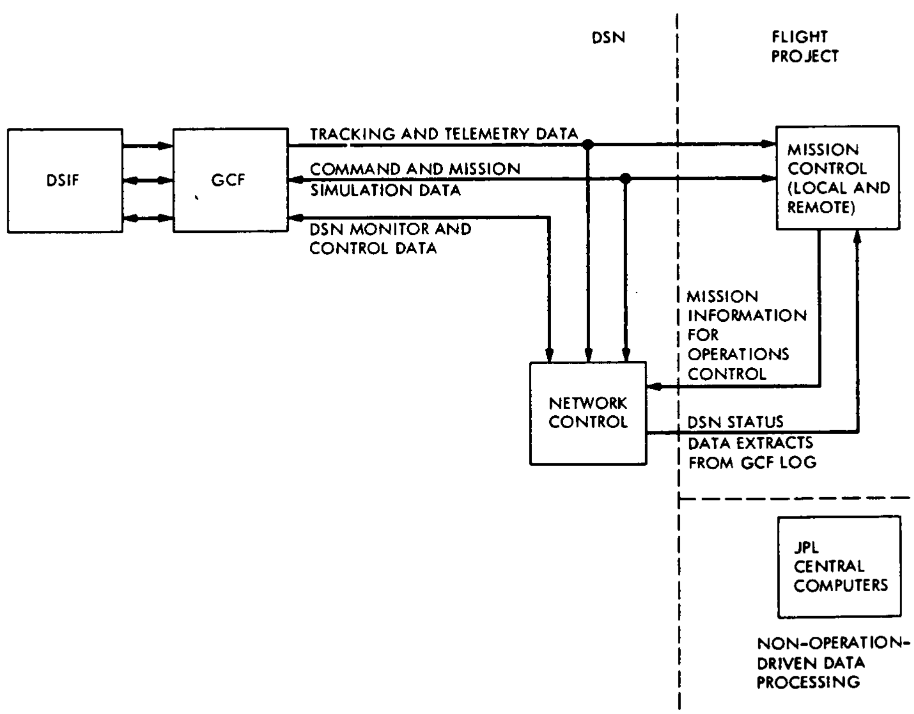

Figure 8-4. DSN Control System functional characteristics.

[9] Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-65, September 30, 1970) pp. 6-13.

and displayed in the DSN Operations Control Center enabled the DSN Operations Team to make network-wide decisions quickly and effectively. The Monitor and Control System also created a permanent record of DSN parameters as a history of DSN performance and record for later analysis. Obviously, the monitoring of the DSN had to be in parallel with project data; that is, its operation (or its failure) could not compromise the normal DSN telemetry, tracking, and command functions.

During the early 1970s, the sophistication of the DSN Monitoring and Control System grew incrementally and became multimission in character.[10] Since the system by design had to have zero effect on the usual DSN tracking, command, and telemetry functions, the only interface with flight projects was in the displays showing network status. Therefore, making the Monitor and Control System multimission in nature involved presenting an interface via standard GCF/NASCOM data formats. This was the major objective of the Mark-III DSN.

The DSN Tracking System. The trajectory of Mariner 5 took it beyond the tracking capabilities of the Mark-IA system, and the new Tau ranging system (See Chapter 7) was applied. It was successful in tracking Mariner 5 to about 0.5 A.U., which included Venus encounter. For the Mariner Mars 1969 mission (described later in the chapter), an improved Tau ranging system followed Mariners 6 and 7 well beyond the Mars encounter to a distance of about 0.8 A.U. This tracking system is diagrammed in Figure 8-5. The data obtained by the system consists of:

1. Doppler and digital resolver data, which are derived by comparing the received signal with a reference signal---usually obtained from the DSN transmitter signal.

2. Antenna pointing angle data from the antenna shaft encoders.

3. Ranging data derived from the round-trip transmission time.[11]

The Tau system worked well for Mars and Venus encounters but more distant NASA missions were soon to be forthcoming.

Mariners 6 and 7, in fact, soon swept beyond the ranging capabilities of the improved Tau system. Fortunately, the longer-distance Mu ranging system was ready in time for the Mariner Mars 1969 Extended Mission. The Mu ranging system differed from the Tau system in its use of a different kind of coding (sequential binary instead of pseudorandom coding) and RF Doppler

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[10] Jet Propulsion Laboratory, "The Deep Space Network," Vol. XI (Pasadena: JPL TR 32-1526, October 15, 1972) pp. 5-11.

[11] Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-51, May 31, 1968) pp. 3-10.

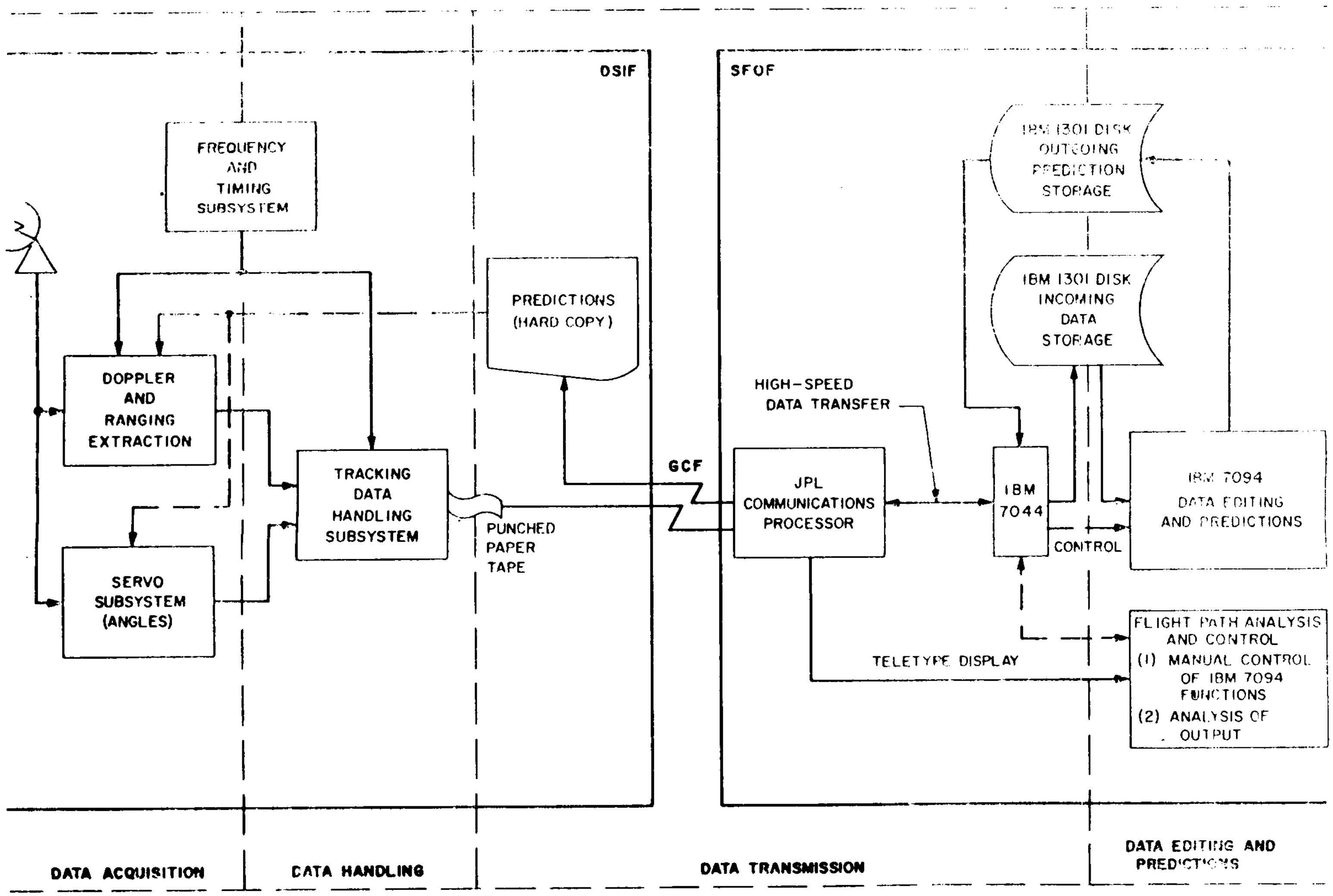

Figure 8-5. The DSN tracking system circa 1968-1969.

rate-aiding for range decoding. The high-speed digital logic of the Mu system made an extremely stable ranging system. Since the round trip times for radio signals from a spacecraft 1 A. U. distant run about 16 minutes, this added stability is vital to accuracy at great ranges. The Mu system has ranged spacecraft beyond 2.6 A. U.---distances involving round trip travel times of close to an hour. The Mu system also produced DRVID data automatically. (See next section.)

For missions beyond 1972, the "Mark-III" era, the DSN tracking system was upgraded in several ways:[12]

- Improved Doppler quality at greater distances
- Real-time reporting of tracking system status
- Increased use of software to improve flexibility
- Use of high-speed data lines for tracking data and predicts

Generally, the most important changes for the Mark-III network were increased automation (many functions used to be manual or at best semi-automatic) and faster generation and distribution of more detailed provision of tracking and status information.

Charged Particle Calibration. The presence of electrically charged particles in the space traversed by lunar and interplanetary radio signals has always been a nagging source of error in spacecraft ranging measurements. One way to correct for the retarding effect on signal transmission is to estimate the total quantity of charged particles per unit area between DSN station and spacecraft. The error can then be computed from radio propagation formulas.

Several techniques for charged particle calibration of DSN ranging systems have been attempted. One of the first approaches involved making Faraday rotation measurements of the signals from synchronous Earth satellites. The amount of Faraday rotation could be related to the total quantity of charged particles (mostly electrons) between the satellite and DSN station. This made possible ranging corrections for the first and last 22,000 miles of the round-trip ranging signals. This was useful because a large fraction of the perturbing of charged particles resided near the Earth. (Figure 8-6)

Between 1968 and 1975, the most important calibration system was called DRVID, for Differenced Range Versus Integrated Doppler. Technically, the method utilized the fact that charged particles affected group and phase velocities of the signal in different ways.[13] DRVID is a "dispersive Doppler" technique and, though demonstrated on Mariners 6 through 9, is not consisered the best approach to charged particle correction.

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[12] Jet Propulsion Laboratory, "The Deep Space Network," Vol. II, (Pasadena: JPL SPS 37-59, September 30, 1969) pp. 3-6.

[13] H. Fosque, personal interview, February 18, 1975.

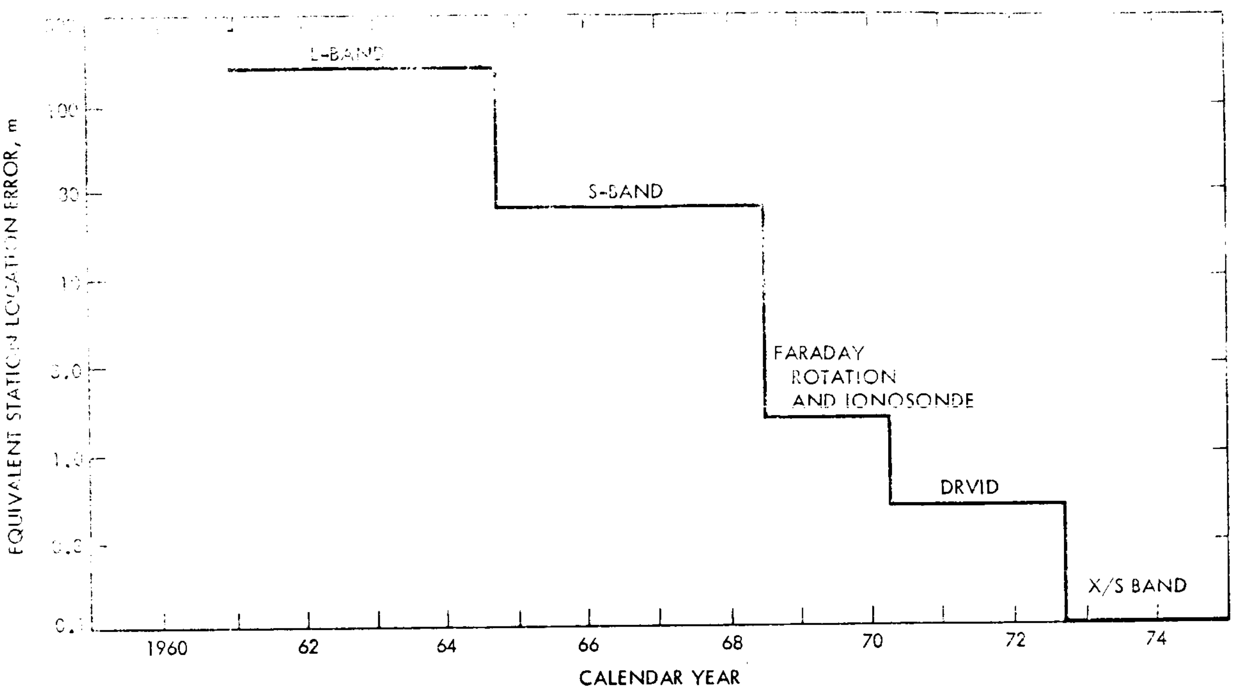

Figure 8-6. Improvements due to charged-particle calibration.

With the advent of X-band experiments at 3.5-cm wavelength on Mariner 10, an opportunity existed to calibrate the ranging system in a different way. Since Mariner 10 also carried a standard S-band transmitter radiating at 13-cm wavelength, the differential effect of charged particles on the different wavelengths could be measured, leading to better estimates of the charged particle content of the space traversed by the signal. On the Mariner-10 flight, the X/S-band correction technique reduced the ranging error by about 80%.[14] The 1975 Vikings will also carry X-band and S-band transmitters to permit DSN engineers to further evaluate this method of charged particle correction.

The DSN Simulation System. All NASA tracking and data acquisition networks have relied on simulation to check out the networks prior to a mission and for training operating personnel. As the DSN evolved, the simulation function became more and more formalized and, in the latter half of the 1960s, was accorded the status of a full-scale DSN "system." Like most other DSN systems, the Simulation System has been upgraded several times, particularly in connection with the Mark-III DSN of the 1970s.

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[14] Jet Propulsion Laboratory, "Annual Report, 1973-1974," (Pasadena: 1974) pp. 14-15.

The basic purpose of the DSN Simulation System is the creation of a realistic operational environment for DSN operators. To do this it inserts streams of typical and atypical tracking and telemetry data into the DSN at appropriate rates and times. To DSN operators, these data streams are indistinguishable from those emanating from an actual space mission.

In the late 1960s through Mariner Mars 1969, the heart of the system was the Simulation Data Conversion Center (SDCC) at Pasadena, which had an ASI 6050 computer, special consoles for controlling simulation data, teletype equipment, and tape recorders. Each DSN station had an FR 1200 tape recorder for playing simulation tapes and inserting their data into the telemetry stream.

In the post-Mariner-1969 era, when the Mark-III network was being ushered in, the DSN Simulation System was also improved. A Simulation Center was created at JPL and "simulation conversion assemblies" were installed at all DSN stations.[15] Figure 8-7 is a function block diagram of the upgraded system. The trends exemplified in the Mark-III Simulation System were:

- The ability to simulate a multimission environment
- Real-time generation and control of simulation data
- Minimization of simulation hardware outside the JPL-located DSN Simulation Center
- Some capability to simulate all DSN functions simultaneously.

The DSN Simulation System was obviously getting more and more realistic.

Antenna Cone Development. The cone-shaped container for microwave devices located between the vertex and the focal point of a DSN paraboloid has long been a primary target for research and development. Low noise and interchaneability have been the most important criteria used in developing new cones. (The history of JPL work on paramplifiers and masers has been reported in previous chapters.) During the period covered by this chapter, two significant advances were made in cone design. Most pertinent in terms of the multimission environment was the tricone or multicone, a concept that was pioneered in the late 1960s on the 64-m subnet. The tricone solved an awkward problem at DSN stations: it took considerable time (on the order of 24 hours) to replace an antenna cone when a change in spacecraft targets demanded it. Station effectiveness was compromised, especially when many different spacecraft had to be tracked on a tight schedule. The solution, the so-called tricone, was simply three cones mounted on one base. (Figure 8-8) By tilting the antenna subreflector remotely via an electrical motor, the microwave beam can be directed toward any one of the three cones. The tricone enabled a DSN station to switch signals between cones in less than a minute and greatly increased operating efficiency.

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[15] Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-61, January 31, 1970) pp. 3-7.

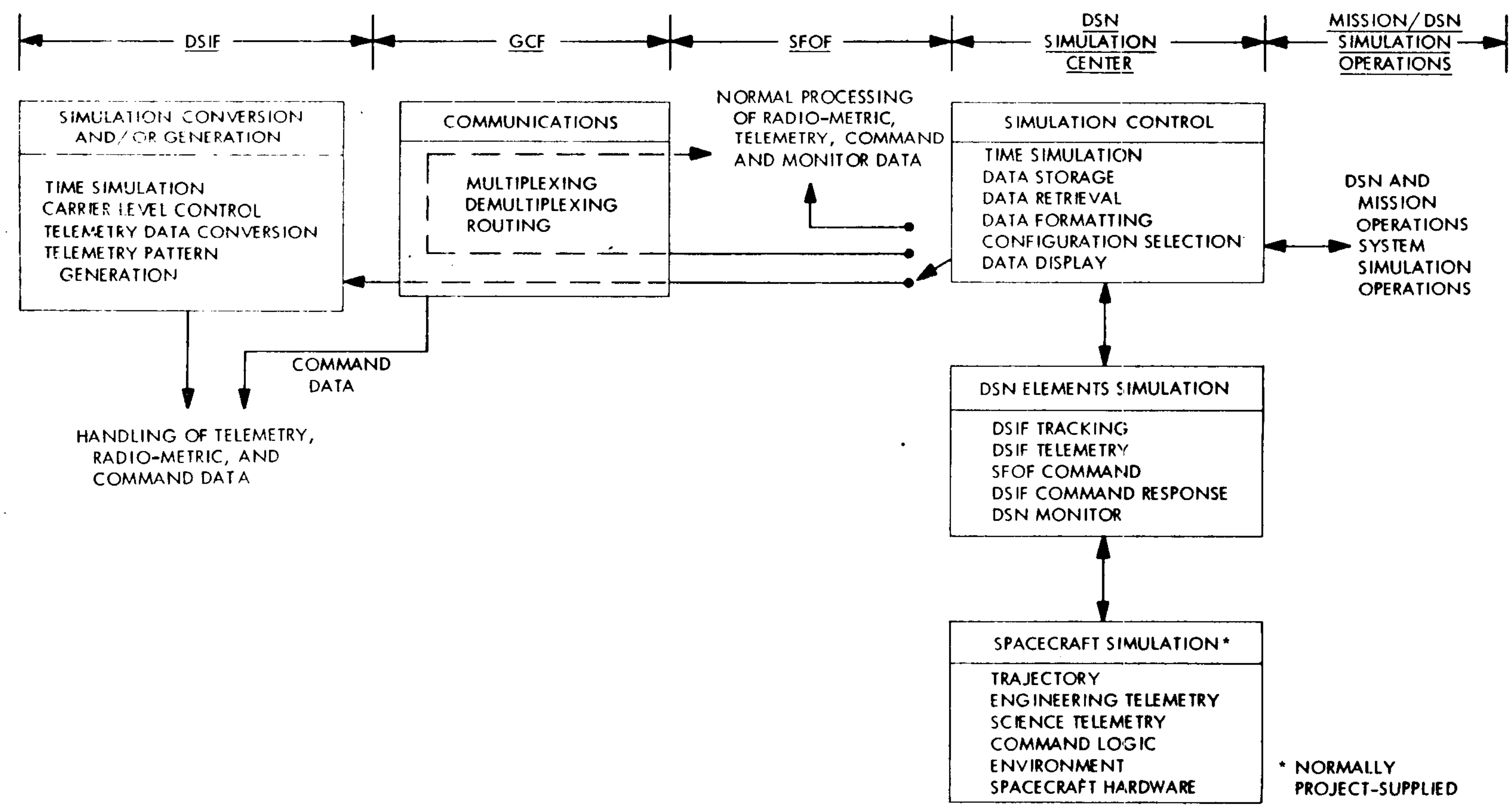

Figure 8-7. DSN Simulation System functional diagram circa 1969.

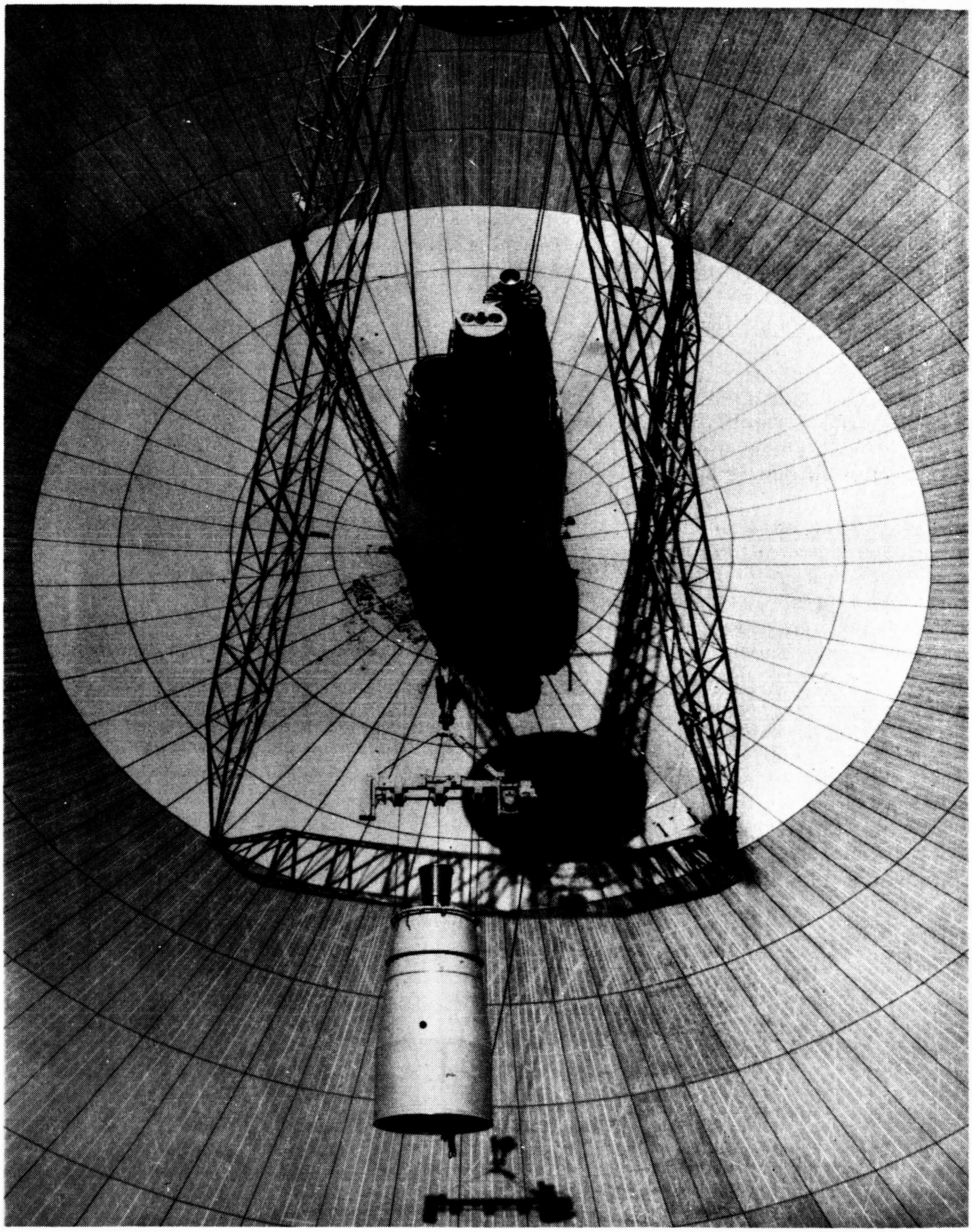

Figure 8-8. Hoisting one of the cones into place on a tricone assembly.

The ultra-low-noise feed cone or "ultra cone" represented a stepwise reduction in total system operating temperature.[16] The ultra cone possessed a maser amplifier (See Chapter 5) which was cooled by a closed-cycle refrigeration system. It was in fact the ultra cone that made it possible for the Goldstone Venus station to serve as an effective backup station for the much larger Mars antenna during the Mariner-5 encounter with Venus. The ultra cone reduced the system noise temperature to about 16°K which helped to partially close the gap in signal-to-noise ratio between the two antennas. The ultra cone was later added to the 64-m antennas and, on the Mariner-10 flight, reduced system noise temperatures from 18.5 to 12.4°K which made the high data transmission rate of 117 kilobits/sec from Mercury possible.

Expanding GCF Capabilities

Lest it become a data bottleneck, the DSN Ground Communication Facility (GCF) had to increase its ability to transmit large volumes of data with high reliability. The last big expansion in capacity had been in response to the Surveyor requirement for 4400 bits/sec, as manifested in the High Speed Data (HSD) system of that era.

A 1971-1972 snapshot of GCF capability reveals the transmission capabilities shown in Figure 8-9. Four kinds of capability are manifest: voice, high-speed-data, teletype, and wideband (50,000 bits/sec). The HSD circuits carry 4800 bits/sec, substantially the same as during the Surveyor period. Most DSN stations possess one voice, one HSD, and four teletype circuits back to the SFOF.[17] These are usually provided by NASCOM. Wideband links exist only between the SFOF and Goldstone Mars (DSS 14), and two areas at the Cape (the Compatability Test Area (CTA-21) and Hangar AO). The Cape circuits were added specifically for Mariner Mars 1971. Also shown in the figure are lines from the SFOF to Ames Research Center (for Pioneer) and the Laboratory for Atmospheric and Space Physics (LASP). Special lines such as these were proliferating during this period and not all are shown.

The 50,000-bits/sec wideband circuits were the major addition above the Surveyor capabilities. Mariner Mars 1971 stimulated their installation with its 16,000-bits/sec requirement. The voice, teletype (still 100 words/min), and HSD capabilities remained about the same. The 1973-1974 upgrading, in contrast, was more far-reaching. The new missions (Mariner Venus-Mercury 1973, Helios, and Viking) demanded additional circuits almost everywhere. Mariner Venus, for example, had a data rate of 117,000 bits/sec at encounter.

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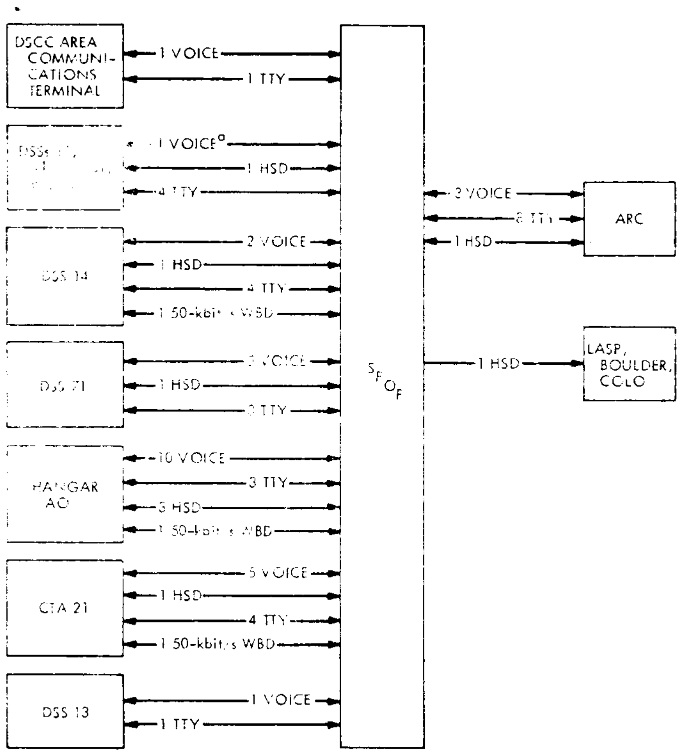
[16] Gerald S. Levy, et al, "The Ultra Cone: An Ultra-Low-Noise Space Communication Ground Radio Frequency System," IEEE Transactions, MMT-16 (September 1968) pp. 596-602.

[17] Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena JPL SPS 37-66, November 30, 1970) pp. 99-105.



a DSSs 41 AND 42 WILL SHARE A SINGLE VOICE CIRCUIT DURING NON-CRITICAL PERIODS.

DSSs 51, 61 AND 62 WILL SHARE A SINGLE VOICE CIRCUIT DURING NON-CRITICAL PERIODS.

Figure 8-9. GCF principal transmission circuits 1971-1972.

A major enhancement of GCF capabilities came when wideband circuits were provided to the Spanish and Australian stations (DSSs 42, 43, 61, and 63). These circuits each had a capacity of 28,500 bits/sec. For the Mariner Venus 1973 encounter, the link between Goldstone Mars (DSS 14) and the SFOF in Pasadena was upgraded to 230,000 bits/sec but only for the short period required.[18] HSD service was also improved in several minor ways. The teletype system, which was little used with the coming of the HSD and wideband circuits, was actually reduced in capacity. Instead of the typical four lines to each station, one sufficed now.

SFOF Improvements

By the mid-1960s it was clear that the SFOF built to support Surveyor, Lunar Orbiter, and the early deep-space Mariners and Pioneers was not going to suffice for the 1970s. The data streams from Mariner Venus 1973 and

[18] Jet Propulsion Laboratory, "The Deep Space Network," Vol. XI (Pasadena: JPL TR 32-1526, October 15, 1972) pp. 124-127.

Viking would overwhelm the SFOF's data-handling ability. This realization instigated the creation of an Advanced Data Systems Project within JPL's Systems Division. This Project was charged with recommending a conceptual design for a third-generation SFOF to be operational in 1972. The new SFOF would be the counterpart of the Mark-III systems being formulated in other parts of the DSN. A "pilot" system analogous to the Venus R&D antenna site at Goldstone, to be called the Scientific Computing Facility, was also proposed to iron out development problems. [19]

Foremost among the problems posed by the missions of the 1970s were the questionable reliabilities of men and machines in the light of greatly increased mission durations and complexities of operations. The human and machine error rates experienced with the second-generation SFOF equipment were considered unacceptable for the advanced missions. A second class of problems that had to be solved originated with the increasing demands made for the simultaneous use of fixed resources; i.e., the overlapping requirements for the same SFOF computers.

Four different approaches were proposed for alleviating these problems: [20]

1. Upgrade onboard spacecraft computers to relieve taxed ground systems

2. Add redundancy to the human system

3. Increase the speed of information transmission and control more carefully the dispersal of information to operators

4. Automate a much greater portion of the monitoring, analysis, and decision making.

The Mark-III SFOF that finally emerged in hardware form provided the following capabilities over and above those available from the Mark-II SFOF:

- Outbound transmission of data via high-speed lines (See Figure 8-10)
- Reception of wideband data
- Processing and display of high-rate telemetry data
- Incorporation of multichannel digital television
- Redesign of the physical plant to accommodate additional DSN users.

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[19] Jet Propulsion Laboratory, "The Deep Space Network," Vol. II (Pasadena: JPL SPS 37-49, January 31, 1968) pp. 140-145.

[20] Jet Propulsion Laboratory, "The Deep Space Program," Vol. II (Pasadena: JPL SPS 37-65, September 30, 1970) pp. 126-131.

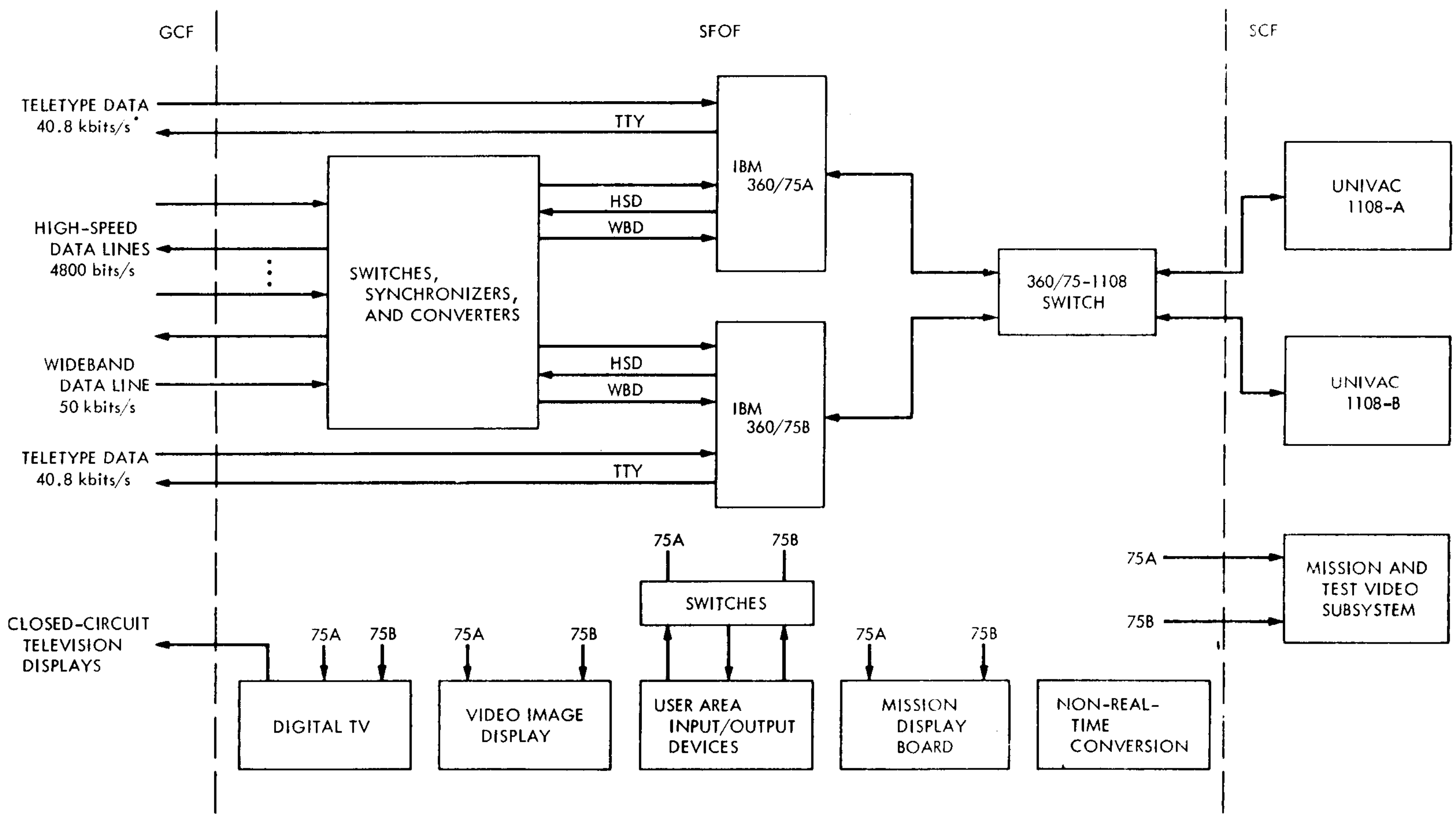

Figure 8-10. Generalized block diagram of the SFOF Mark-IIIA 1970-1972.

In addition, the proposed Scientific Computing Facility was implemented using UNIVAC 1108 computers. In the upgraded SFOF, the old IBM 7094/7044 computer strings were replaced by IBM 360/75s. (Figure 8-10)

The deep-space missions of the late 1960s and early 1970s brought with them substantial increases in the SFOF's data-processing load. Much of this data processing was strictly scientific and unrelated to DSN operations. Yet, the tracking and data acquisition function was obligated to provide for this computer time without the authority to review requirements. The flight projects were, in essence requesting and getting large blocks of computer time and were neither financially nor managerially accountable for them. It was a bad managerial situation. NASA Headquarters recognized the situation and, in October 1971, Gerald Truszynski (OTDA) and John Naugle (OSS) reviewed the problem and decided to transfer the SFOF functions from OTDA to OSS. [21] In this way, the responsibility for review and validation of requirements and the associated costs of scientific data processing would be borne by flight projects themselves. The transfer took place as of July 1, 1972. Figure 8-4 indicates the new interfaces created. The DSN was now responsible only for network control and associated data processing. Minicomputers which had adequate capacities for the modest needs of the DSN's new data handling needs were now used instead of the large number-crunching SFOF computers.

The Headquarters change of responsibility was paralleled at JPL where the SFOF was moved out of the Tracking and Data Acquisition office and placed in the newly created Office of Computing and Information Systems. This JPL office, as would be expected, reported to Headquarters through OSS rather than OTDA. [22]

Management Reviews of the Tracking and Data Acquisition Function

The increasing national investment in tracking and data acquisition facilities and operations in the early 1970s attracted the attention at three Federal levels:

- NASA top management
- The United States Congress
- The Office of Management and Budget

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[21] Jet Propulsion Laboratory, "The Deep Space Network," Vol. XI, (Pasadena: JPL TR 32-1526, October 15, 1972) pp. 5-11.

[22] Robertson Stevens, personal interview, July 28, 1975.

Reviews of NASA's tracking and data acquisition activities followed. Only the results of the first two reviews are available for public study.[23]

The first review was directed by the NASA Administrator for the purpose of determining whether:

1. Flight missions were being supported adequately
2. A reasonable balance existed between data requirements by flight projects and support costs
3. Long-term plans matched projected requirements
4. Investments should be made in new technologies that would make the tracking and data acquisition function more effective from the cost standpoint.

The review was conducted by an ad hoc Tracking and Data Acquisition Panel chaired by Dr. Gerald P. Dinneen, from MIT's Lincoln Laboratory, and staffed by six others with varied industrial and academic affiliations. The Panel served from January 4, 1972, to June 30, 1972. Since the conclusions and recommendations of the Panel strongly affect the DSN, they are reproduced below in their entireties:

> "Here is a list of our conclusions and recommendations according to the four questions stated in the introduction. Each of these is discussed in more detail in subsequent sections of this report.
>
> 1. Level of Support
>
> (a) We find that the support being provided by OTDA adequately meets the needs of the flight mission directors and principal investigators.
>
> 2. Balance of Effort
>
> (a) The Panel finds that a reasonable balance is being maintained between the data requirements and the network and data-processing costs.
>
> (b) We find that the budget for OTDA which has averaged 7.1% of NASA's total over past years is not out of place.

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[23](1) The so-called Dinneen Report: NASA, "Report of the Tracking and Data Acquisition Advisory Panel," (Washington: NASA report) July 31, 1972. Also available in: U.S. Congress, Committee on Science and Astronautics, "Review of Tracking and Data Acquisition Program," (Washington: GPO) 1974, pp. 873-901. (2) U.S. Congress, Subcommittee on Aeronautics and Space Technology, "Tracking and Data Acquisition Program," (Washington: GPO) 1974.

3. Long-Range Plans

(a) We conclude that the OTDA long-range plans are well directed to meet future mission requirements.

(b) The Panel concurs with the current plans for the development of the 15-Station Spaceflight Tracking and Data Network (STDN).

(c) We conclude that a second 64-meter subnet is necessary in the Deep Space Network (DSN) and endorse the OTDA plan.

(d) We recommend the X-band addition to the Deep Space Network.

(e) We endorse Phase 1 of the Telemetry On-line Processing System (TELOPS) plan.

(f) We note that Phase 2 of TELOPS is R&D and recommend some small-scale experiments.

(g) The Panel recommends the introduction of automation as planned and urges a continuing effort to automate OTDA functions.

(h) We recommend a vigorous system definition and technology effort for the Tracking and Data Relay Satellite System (TDRSS).

(i) We recommend that NASA expand its role in the processing reduction and analysis of imagery data.

(j) We encourage continued work on laser tracking.

4. New Technology

(a) We believe more attention should be given to trade-offs between spacecraft and ground-based developments.

(b) We feel OTDA should be encouraged to continue a modest level of research on laser communications with an eye to the far future.

(c) The DSN requirements presented to the Panel do not necessitate the construction of 128-meter ground stations for the foreseeable future; however, the Panel recommends continued technical design studies.

(d) We recommend that NASA consider a mechanism to assure attention to spacecraft improvements comparable to that given to ground equipment for T&DA functions."

Of particular note is the recommendation that a <u>second</u> subnet of 64-m antennas be added to the DSN. (The completion of the first subnet is described below; the plans for a second subnet were scrapped as NASA money became tighter.) The introduction of the X-band also was recommended and, as mentioned earlier, did occur.

The second review, this time by the House Subcommittee on Aeronautics and Space Technology, took a less technical track. One of the stimuli for the review was the controversy in Congress about the real need for the Johannesburg tracking stations in view of the South African government's apartheid policy. NASA announced in July of 1973 that it was closing the Johannesburg station (see later discussion) but the Subcommittee decided to continue with its review anyway. The review was extremely broad and dealt with the need for the networks and specific stations, the NASA relationships with DOD and NOAA, the management of the tracking and data acquisition function within NASA itself, the international aspects, and the need for the proposed Tracking and Data Relay Satellite. The hearings of the Subcommittee took place during the fall and winter of 1973-1974.

The conclusions and recommendations pertaining to the DSN focus on the introduction of X-band technology (strongly supported) and the need for a second 64-m subnet (questioned). In fact, it was specifically recommended that NASA provide Congress with a "detailed analysis of the need for an additional subnet of three 64-m antennas for the Deep Space Network" as part of the Fiscal Year 1976 Authorization Request.

It is important to note, however, that the tone and final results of each study are very favorable regarding the effective management, technological proficiency, and effective operation of all of the NASA tracking and data acquisition networks.

DSN Stations: Better But Fewer

Paralleling the trends in the other NASA networks, the DSN began a phase of station consolidation during the late 1960s. The primary pressures were changing support requirements coupled with cost-effectiveness considerations. Coupled with consolidation was a general upgrading of station capabilities. The completion of the first 64-m subnet (three approximately 120° apart stations) was the key factor, but the technical advances described earlier in this chapter were also important. Basically, the DSN of the mid-70s consisted of three terrestrial locations; California, Australia, and Spain; each boasting a well-instrumented complex consisting of at least two 26-m dishes and one 64-m antenna.

Station Closings. The DSN station on Ascension Island (DSS 72) was constructed mainly to support Surveyor flights employing the direct-ascent mode. With the completion of the Surveyor program, Ascension became superfluous. Its 9.1-m (30-ft) antenna was of the size standard in both STDN and the MSFN. Consequently, it made sense to transfer the site to one of these other networks. This was accomplished in November 1969, when Goddard Space Flight Center took over operation of the site. DSS 71, the Launch Station in back of the launch pads at the Cape, was consolidated with the STDN launch station and moved to Merritt Island in February 1974. The combined station was designated MIL-71. The basis for this change was simply cost effectiveness.

One of the earliest DSN stations, that at Woomera, Australia, became a casualty during DSN consolidation. NASA had always had trouble manning its facilities at Woomera and wished to consolidate its tracking stations elsewhere in Australia. The DSN already had Tidbinbilla, near Canberra, with its 26-m antenna. The MSFN had its Honeysuckle Creek station in the same area, also with a 26-m antenna. Furthermore, with Apollo drawing to a close, the Honeysuckle Creek station was no longer vital to the MSFN. Thus, it made sense to dismantle the Woomera DSN facility and transfer Honeysuckle Creek from the MSFN to the DSN. There would still be two DSN 26-m dishes in Australia but they would both be near Canberra and also near the Tidbinbilla site selected for the 64-m antenna. Reconfiguration of Honeysuckle Creek was complete by May 1973 when it became an operational part of the DSN. (Table 8-1)

The Johannesburg DSN 26-m dish was long deemed essential for deep-space launches coming down the ETR across southern Africa and then, as they gained altitude and the Earth rotated under them, sweeping back across Africa once more. The Australian DSN stations were often prime stations on a deep space mission although Johannesburg usually saw the spacecraft first. As the Australian stations became better instrumented and some deep-space launch trajectories moved northward, Johannesburg became less critical and it was determined that a location in Southern Europe was best from an overall viewpoint for long range support commitments.

The Mutual Stations. During the GSFC preparations for Apollo, two types of tracking networks were required; (1) a large number of 9-m stations to handle the Apollo spacecraft during earth orbit; and (2) a network of three 26-m MSFN stations to handle the translunar and lunar phases of the flights. These 26-m stations were located near the DSN complexes at Goldstone, Madrid, and Canberra. It was also decided, since the Apollo telecommunications equipment was very similar to DSN equipment, to equip one DSN station at each complex (DSS 11, 42, and 61) to provide backup capability to the MSFN 26-m stations. These were affectionately known as the "Mutual Stations." A second control room was built at each station and equipped with MSFN electronics and a microwave link to the prime Apollo MSFN sites nearby. After completion of the project, the DSN assumed cognizance of the mutual stations and a major portion of the electronics which has been put into deep-space tracking service.[24]

Completing the First 64-m Subnet

The 64-m antenna at the Mars site at Goldstone had proven to be of immense operational value to NASA's lunar and planetary programs. Unfortunately, it could only "see" a little more than one-third the celestial sphere at any one time. It could not track spacecraft continuously and its 7-db (factor-of-six) gain over the 26-m DSN antennas was sorely missed when spacecraft

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[24] Jet Propulsion Laboratory, "The Deep Space Network," Vol. VIII (Pasadena: JPL TR 32-1526, April 15, 1972) pp. 5-7.

Table 8-1. HISTORICAL SUMMARY OF DSN STATIONS

Name	DSS No.	Construction Start	Construction End	Operational	Remarks
Goldstone Pioneer	11	6-58	11-58	12-58	26-m antenna
Goldstone Echo	12	7-59	12-59	4-60	26-m antenna
Goldstone Venus	13	4-62	11-62	8-62	26-m antenna
Goldstone Mars	14	10-63	2-66	5-66	64-m antenna
Woomera	41	3-60	9-60	11-60	26-m antenna closed
Tidbinbilla, Weemala	42	7-63	10-64	3-65	26-m antenna
Tidbinbilla, Ballima	43	11-69	7-72	4-73	64-m antenna
Honeysuckle Creek	44	--	--	5-73	26-m antenna Transferred from STDN
Johannesburg	51	1-61	6-61	7-61	26-m antenna closed 6-30-74
Robledo	61	8-64	7-65	7-65	26-m antenna
Cebreros	62	1-66	12-66	1-67	26-m antenna
Robledo	63	6-70	--	9-73	64-m antenna
Launch Station	71	10-64	4-65	5-65	1.3-m antenna Moved to MILA
Ascension	72	1-65	3-66	4-66	9.1-m antenna Transferred to MSFN 1968 (now STDN)

dropped below its horizon. During Apollo, for example, the big radio astronomy antenna at Parkes, Australia, was asked to aid the MSFN in obtaining critical TV coverage of lunar operations. (See MSFN history.) With many ambitious deep-space missions, such as Viking, on the drawing board, a full subnet of three 64-m antennas equally spaced in longitude seemed essential to NASA's mission. Consequently, after a competition involving four bidders, NASA and JPL announced on June 27, 1969, the selection of Collins Radio Co. of Richardson, Texas, to build 64-m antennas in Australia and Spain. [25]

NASA had, of course, already surveyed Australia and Spain for good locations for its subnets of 26-m DSN antennas. In keeping with its policy of consolidating facilities, NASA made the decision to locate the 64-m antennas near the 26-m sites. Logistics would be simpler and support facilities, such as power supplies, could be shared. The Australian site was therefore near Canberra at a location called Ballima (also Booroomba) in the Tidbinbilla Valley. In Spain, the 64-m dish was installed near the 26-m Robledo station, which is near Madrid. [26]

Construction began first in Australia on November 3, 1969. While most of the engineering personnel were employees of Collins, the major construction effort was carried out by the Australians. Australia also furnished most of the construction materials. The main antenna structural elements, though, were fabricated in the United States and shipped to Australia. A dock strike on the West Coast during this period threatened to delay construction, but NASA utilized DOD shipping channels which were unaffected. [27] Construction was completed in July of 1972. All in all, the job went very smoothly with few technical or labor difficulties.

In Spain, construction began formally on June 18, 1970. It did not go as smoothly as it had in Australia. One of the most serious problems involved the hard granite encountered during excavation of the foundation. In addition, there was a language barrier and a difference in systems of measurement. On crucial tasks, it was found to be safer to use either all-American or all-Spanish crews to avoid misunderstandings. Collins subcontracted in Europe for all construction labor, materials, and equipment. The organizational picture was rather complicated and led to some diffusion of responsibilities. In some instances, American job practices were rejected by local workers. Safety shoes, for example, were disdained by Spaniards working on the antenna structure. The construction delays were later made up when antenna erection

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[25]NASA Release 69-98, June 27, 1969.

[26]K. P. Bartos, et al, "Implementation of the 64-Meter-Diameter Antennas at the Deep Space Stations in Australia and Spain," (Pasadena: JPL TM 33-692, January 15, 1975).

[27]Robert A. Rapp, personal interview, April 2, 1975.

went faster than scheduled. The antenna was officially dedicated on May 10, 1974.[28]

The first 64-m subnet was thus completed. But already there was discussion at JPL and NASA regarding the desirabilities of a second 64-m network and even 128-m antennas. A second 64-m antenna was proposed for Goldstone, but NASA's diminishing budgets have not permitted this valuable addition. The reason is that when new NASA missions are reviewed for possible funding, they are evaluated in terms of total mission cost. If a mission were to "require" an additional 64-m dish, the not inconsiderable costs thereof are included as part of the mission costs. It is therefore understandable that, with tight budgets, no projects "require" additional 64-m antennas, despite general agreement that the additional capability would enhance scientific data return and mission reliability, as well as provide more time for radio science. The construction of a second 64-m subnet will probably have to wait for some great new effort in space, such as a manned mission to Mars.

Similarly, a 128-m antenna would be most useful in deep-space work, but the funds for such a large undertaking are also not yet available. A cheaper method of increasing antenna aperture would be "ganging" or arraying existing antennas together; that is, connecting them electrically or by a precise timing system so that their areas are effectively added together. Experiments of this type were carried out at Goldstone in 1974. Radio astronomers have pooled geographically separated antennas for some years in long baseline interferometers.

The New Deep Space Missions

After the outstandingly successful Ranger/Lunar Orbiter/Surveyor/Apollo sequence of lunar missions, NASA's focus in deep space turned to the planets. Exploration strategy was two-pronged: (1) send the first flyby probes to planets beyond Mars and Venus; and (2) study Mars in more detail with flybys, orbiters, and unmanned landers. During the early 1970s, Mariner 10 and Pioneers 10 and 11 fulfilled the first goal, and Mariners 6 through 9 plus Viking, the second. It was no accident of course that the Mariner 6 and 7 flybys, the Mariner 8 and 9 orbiters, and the Viking landers paralleled closely the NASA lunar flyby-orbiter-lander strategy that had been so fruitful.

The DSN was ready for the much greater distances and higher data rates required. The various technical advances and new facilities just described had been begun years before the new missions left their launch pads. As usual, though, the new DSN capabilities, which had seemed perhaps unnecessarily ambitious when proposed, were quickly absorbed by mission designers.

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[28] NASA Press Release 74-119A, May 8, 1974.

Mariner Mars 1969 (Mariners 6 and 7)

Earlier probes to Venus and Mars had indicated that Mars was the most likely planet in the solar system to support life. The richly detailed and cratered surface of the planet revealed by Mariner 4 had surprised planetologists and made them anxious for more photos. Mars thus became NASA's prime planetary target. The Mariner Mars 1969 mission, therefore, concentrated on TV imaging of the planet's surface, and experiments that might aid the design of future missions particularly those looking for life. Besides the TV cameras, the two new Mariner-type spacecraft assigned to the mission carried an ultraviolet spectrometer, an infrared spectrometer, and an infrared radiometer. Of special import to the DSN was a telemetry experiment in block coding at 16,200 bits/sec, roughly a thousand times the data rates used at previous encounters with Mars. At this speed, low resolution pictures in real time could be sent from Mars.

Like all other deep-space launches, the 1969 Mariners were to be launched down the ETR from the Cape. Air Force and MSFN stations were assigned to cover the launch and near-Earth phase, which was brief because the direct-ascent mode was used. The deep-space requirements, as indicated in Table 8-2, consisted of continuous coverage during launch, trajectory correction maneuvers, and encounter, and frequent but not continuous coverage during cruise. Radio metric data were required at least every four days. Once the spacecraft got beyond the range of the Mark-IA ranging equipment at the 26-m stations, the Mars antenna was obviously a necessity.

The liftoff of Mariner 6 occurred on February 25, 1969.[29] As the spacecraft approached South Africa, the 26-m antenna at Johannesburg quickly acquired the spacecraft's signal. Early in the flight, Woomera and Goldstone Echo were committed as prime DSN stations. Four days later a midcourse maneuver was commanded from Woomera, and subsequent analysis of radiometric data showed that the maneuver was successful. Mariner 6 was aimed to encounter Mars five months later and sweep by its equatorial region at a distance of about 3200 km. (Figure 8-11)

The launch of Mariner 7 followed the Mariner-6 pattern. Liftoff was on March 27; midcourse maneuver, 12 days later. For the first time, NASA had successfully launched both of a pair of Mariner spacecraft. Both spacecraft were on target and, from the DSN standpoint, in the same portion of the sky. The DSN had to handle the two telemetry streams simultaneously as well as the Pioneers and its Apollo assignment.

Toward the end of July, both Mariners were drawing near Mars with Mariner 7 now only five days behind Mariner 6. The encounter operations for Mariner 6 began on July 28, 1969, when Cebreros sent a command to turn on the High Rate Telemetry (HRT) experiment. Of course, the only station

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[29] N. A. Renzetti, et al, "Tracking and Data System Support for the Mariner Mars 1969 Mission," Vol. I (Pasadena: JPL TM 33-474, September 1, 1971).

Table 8-2. DEEP-SPACE TRACKING AND TELEMETRY COVERAGE FOR MARINERS 6 AND 7.

Mission interval	Radiometric data required		Telemetry coverage required	Remarks
	Type	Sample rate		
First acquisition to launch + 3 h	Range doppler (two-way) angles	Continuous at 1 sample/min 1 sample/10 s	Continuous	-
Launch + 3 h to midcourse maneuver + 5 days	Range doppler	Continuous at 1 sample/15 min 1 sample/min	Continuous	Mark 1 ranging expected only to about lunar distance. Assumes R&D ranging thereafter at 64-m antenna only: one pass every 2 weeks per spacecraft desired to meet secondary objective
Cruise	Range doppler	To be specified during operations 1 sample/min	Two complete S/C commutator cycles separated by no more than 5.6 h	Metric data requirement is for one complete horizon-to-horizon pass every 4 days, separated by not more than 90 h. No single station shall be used for more than three consecutive passes. At 8 1/3 bits/s, two commutator cycles are of 112 min duration, at 33 1/2 bits/s, 28 min.
Second midcourse maneuver - 10 days to + 5 days	Range Doppler	Continuous at 1 sample/15 min 1 sample/min (1 sample/s during maneuver)	Continuous	May not be performed
Encounter (E)				
(1) E - 14 days to E - 1 day E + 1 day to E + 15 days	Range doppler	1 sample/15 min 1 sample/min	Continuous - (8 1/3 or 33 1/3 bits/s and 66 2/3 or 270 or 16,200 bits/s)	Mission design assumes three 26-m antennas and one 64-m antenna for standard operations and plans to take advantage of any additional support that may become available
(2) E - 1 day to E - 1 h Exit occultation + 1 h to E + 1 day	Range doppler	1 sample/min 1 sample/min		
(3) IRS gas jetting - 30 min to occultation Exit occultation 20 min to exit occultation + 1 h	Range doppler	1 sample/s 1 sample/s		1 sample/s data required in real time

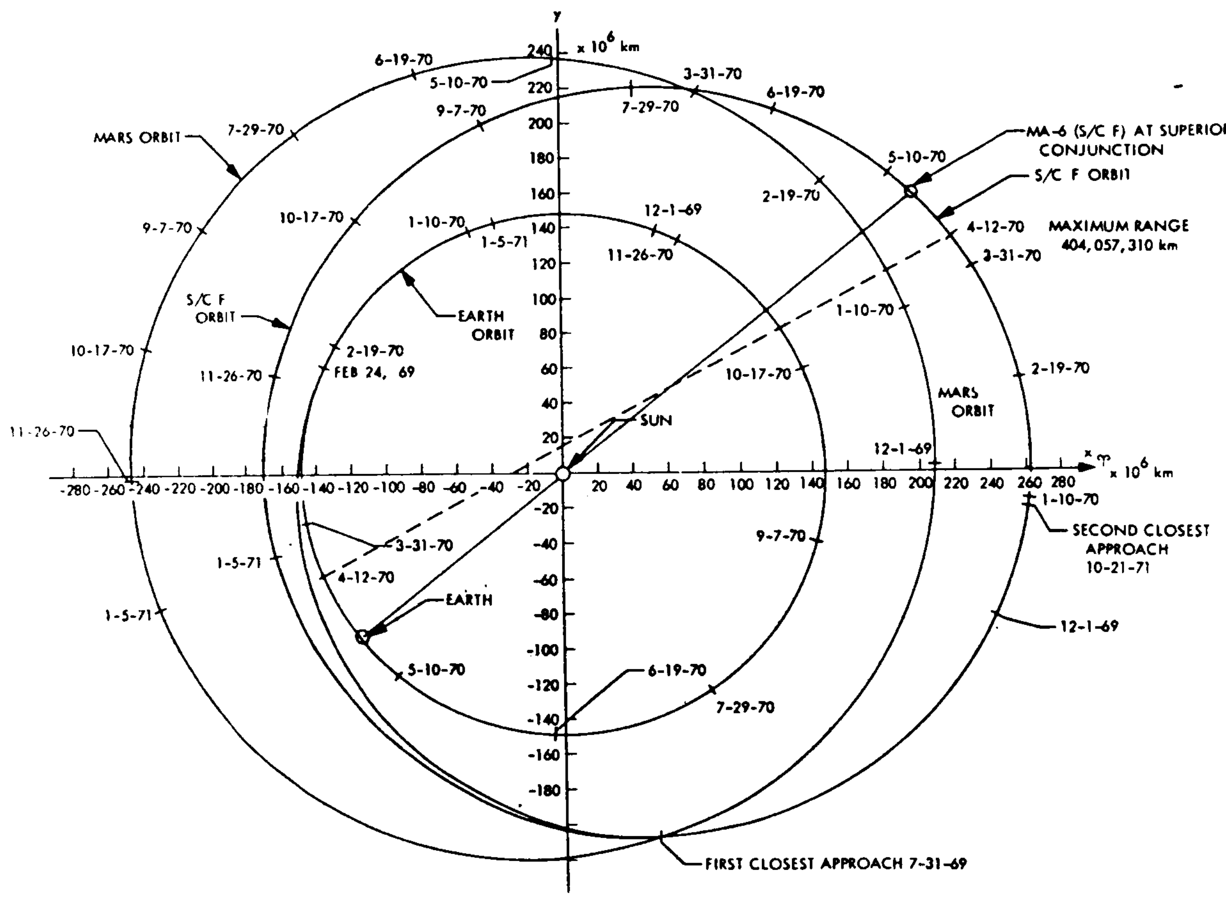

Figure 8-11. Heliocentric view of the Mariner-6 trajectory to Mars.

capable of receiving 16,200 bits/sec from the distance of Mars was the Mars antenna at Goldstone. To reserve the Mars antenna exclusively for this function, the HRT experiment was turned on by Cebreros and off by Woomera. All seemed to be going well until approximately six hours before the Mariner-6 encounter, when Johannesburg reported that the signal from Mariner 7 had disappeared. It was an emergency that came at the worst possible time. The Robledo 26-m antenna broke off from its tracking of Pioneer 8 and began to search for the lost spacecraft. When the region of Mars came into view for Goldstone, DSS 11 (Pioneer) joined the search. Cebreros passed Mariner 6 over to the Goldstone Echo station and also began looking. Mariner 7, still silent, went over the horizon for Johannesburg and Spain. It was decided to send a command to Mariner 7 to switch from the highly directional high-gain antenna to the omnidirectional low-gain antenna. The spacecraft responded and Pioneer and Tidbinbilla both began to acquire telemetry from the recovered spacecraft. Something had happened to Mariner 7, but no one knew just what.

The DSN was committed only to supporting one Mariner in a critical phase, but here was one approaching encounter and a second one with serious, unknown problems. A small, special team was set up to study the Mariner-7 problem while the main DSN effort was applied to the encounter of Mariner 6. The Mariner-6 encounter went well, and three series of pictures were taken, using both the HRT and regular telemetry systems to send them back to Earth.

Meanwhile, as in a suspense movie, Mariner 7's encounter was only hours away and no solution to the dilemma was at hand. Telemetry data indicated that the reference potentiometer for determining the position of the spacecraft scan platform was no longer on an operating telemetry channel. A plan was devised to obtain spacecraft attitude reference by turning on the TV camera and sighting in on Mars using the HRT experiment to get real-time data. This worked, thanks to the high bit rate stream available, and ground commands were able to correct spacecraft attitude and get the high-gain antenna back in operation in time for the encounter. The encounter sequence began late (on August 5) but was still considered very successful. Mariner 7 obtained good photos of the Martian southern hemisphere, including the polar cap. As for the cause of Mariner 7's perturbation, no clear-cut answer has been found. Evidently, the spacecraft experienced a sharp change in radial velocity as well as a change of attitude. The emergency did underscore the desirability of having a high-speed data channel for such crises. In addition, the HRT channel provided an alternate, much faster route for relaying the TV pictures of Mars back to Earth. All told, 202 pictures (showing 20 times the area seen by Mariner 4) were returned.

The formal end of the Mariner Mars 1969 mission was on November 1, 1969, but both spacecraft were still performing so well that the project decided on an extended mission. Scientists wished to perform relativity experiments, improve astronomical constants and make measurements of electron densities in interplanetary space and in the Sun's corona. (Superior conjunction occurred in April and May 1970.) Until an official program was formulated and approved at NASA Headquarters, the DSN supported the spacecraft on a reduced scale from Cebreros and Goldstone Mars. When the formal extension was approved in January 1970. Goldstone Echo was added to the station roster. The Mars station was temporarily taken out of service from January 25 to March 1. 1970. while a tricone was installed along with the new 400-kw transmitter.

Mariner Mars 1971 (Mariners 8 and 9)

The logical follow-on mission to Mariner Mars 1969, using the lunar program analogy. would be picture-taking orbiters around Mars. The next Mars opportunity was in the spring of 1971. and two Mariner-class spacecraft were prepared accordingly. The new Mariners drew heavily upon the technology of the 1969 mission. Instrumentation was very similar, with emphasis again on photography. The primary objectives were the search for evidence of life and the gathering of data that would aid Mars landers. After mapping as much of the surface as possible. scientists wanted more data on the density and composition of the Martian atmosphere. A 90-day orbital mission for each spacecraft was planned. These spacecraft would be the first terrestrial satellites of another planet.

The requirements levied upon the DSN for this mission were more extensive than those of the 1969 mission. due in part to the orbital injection maneuvers needed at Mars and the 90 days of orbital coverage for both spacecraft. The specific requirements were so extensive that they cannot be reproduced here.[30]

During the two years intervening between the Mars opportunities. DSN capabilities had expanded. The Multimission Telemetry System (MMTS) had been inaugurated on the 1969 flights; for the 1971 mission. the new multimission command was available. The High Rate Telemetry (HRT) system, which was experimental in 1969. was now fully operational. With it. pictures and science data could be relayed back from Mars much more rapidly. The wideband. 50.000-bits/sec link between Goldstone and JPL was ready to send the two 16.200-bits/sec data streams simultaneously. The Mars station at Goldstone was still the only 64-m station in operation, but the high-speed readouts of the Mariner tape recorders were planned only when DSS 14 had Mars in view. Another important feature of these missions to Mars was the ability of a single DSN antenna to handle two deep-space probes located within its beam width.

The 1971 flights began badly. When the first Atlas-Centaur lifted off on May 8, 1971, preliminary information on the flight of Mariner 8 looked good. Shortly after ignition, though, the Centaur stage went out of control, and Mariner 8 landed in the Atlantic just northeast of Puerto Rico.

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[30]See: R. P. Laeser, et al. "Tracking and Data System Support for the Mariner Mars 1971 Mission," Vol. I (Pasadena: JPL TM 33-523, March 15, 1972). (Four volumes in this series cover various phases of the mission.)

Mariner 9 was originally scheduled for a May 18 liftoff, but this was delayed until May 29 while the Centaur problem was under investigation. Trouble with the Centaur ground-support equipment then delayed the launch until May 30. Finally, Mariner 9 blasted off successfully on a direct-ascent trajectory which would take it to the rendesvous with Mars in the middle of November 1971. Mariner 9 had to bear the burden of the entire scientific program with the loss of Mariner 8. The Mariner Project prepared a new plan for observations by a single spacecraft, but the requirements placed on the DSN changed only in minor ways. The tracking and data acquisition task was now, of course, easier with only one spacecraft.

The first midcourse maneuver of Mariner 9 was consummated on June 4. The cruise to Mars was uneventful and, on November 14, a long, 2-hour 47-minute burn was commanded to insert Mariner 9 into orbit about Mars. The resultant orbit had a period of 12.567 hours and a periapsis of 1398 km. Mariner 9 was in good shape and ready to begin a detailed photographic survey of the Martian surface. Unhappily, most of the planet was shrouded in an immense dust storm. The cameras could see almost nothing. But the unhappiness was temporary; the very existence of the dust revealed a dynamic planet, and scientists waited anxiously for the dust to settle.

The mission plan was revised and Mariner 9 waited in orbit. In the interim, the other scientific instruments were busy and pictures of the moons Phobos and Deimos were snapped. By January 3, 1972, the dust storm had subsided enough to begin the 90-day primary mission. Then, the deluge of pictures began. They came by the thousands and led to the discovery of channels, possibly cut by water, and evidence of ice action in the polar regions. The detailed maps of the surface needed to plan the Viking landings were drawn as Mariner 9 cameras covered more and more of the planet.

The Mariner-9 spacecraft was still operating well at the end of the nominal mission on April 1, 1972. NASA used this opportunity to schedule extended operations. Second looks were taken at especially interesting areas of Mars. Beginning on April 2 and lasting through June 4, scientists were fortunate enough to observe solar occultations repeatedly as the spacecraft passed through the shadow of Mars twice a day. Prior to each passage into the cold shadow zone, the DSN commanded the spacecraft to go into a "survival mode." Despite its rigorous and longer-than-planned mission, Mariner 9 survived until October 27. Both spacecraft and the supporting ground systems had performed remarkably well. It was one of the most successful of all NASA's planetary missions.

The Jupiter Pioneers

The remarkably long lifetimes of the Interplanetary Pioneers (Pioneers 6 through 9) made the technology they employed a good choice for the long missions to the outer planets. The Pioneers were simple, rugged, and much smaller than the Mariner-class spacecraft. Unlike the Mariners, they were spin-stabilized thus avoiding the complications of three-axis attitude control. Since the trip to Jupiter required much more energy than flights to Mars and Venus and also passage through the asteroid belts and Jupiter's intense magnetic field, it was no surprise that NASA selected "third-generation" Pioneers for this mission. NASA Headquarters approved the Jupiter Pioneer program on February 8, 1969.

The Jupiter Pioneers were designed to measure the parameters of interplanetary space on their ways to Jupiter and after their encounters. To obtain knowledge of this unexplored part of the solar system and mysterious Jupiter, the spacecraft carried such instruments as a cosmic-ray telescope, plasma analyzer, magnetometer, asteroid-meteoroid detector, and an imaging polarimeter. Most of the scientific instruments were thus associated with fields-and-particles experiments. The flights were also to test equipment for future flights into this new realm. For example, radioisotopic power supplies replaced the usual solar cells because sunlight weakens greatly at Jupiter's distance. The new Pioneers had 2.75-m high-gain parabolic antennas mounted on them rather than the shorter-range mast-types used on the Interplanetary Pioneers. Thrustors were also required on the Jupiter mission to correct spacecraft trajectories. Thus the Jupiter Pioneers incorporated many technological advances over the Interplanetary Pioneers. Nevertheless, the design philosophy was much the same, and the same design team (NASA's Ames Research Center and TRW Systems) was carried over from the Interplanetary Pioneers. (Figure 8-12)

The first Jupiter Pioneer, hereafter called Pioneer 10, was launched from the Cape by an Atlas-Centaur during the Jupiter window in March 1972; the second spacecraft, Pioneer 11, was scheduled for the next Jupiter window 13 months later, in April of 1973. The launch trajectories were of the direct-ascent type, with the resources of the Air Force ETR and the MSFN tracking and acquiring data during the launches and near-Earth phases.[31]

Once the DSN acquired the Pioneers it was originally required to provide continuous telemetry support with 26-m stations until 6 months after the Jupiter encounter. The 64-m subnet was to support at least one horizon-to-horizon pass per week during the same period. The data rates possible with the big antennas were of course much higher (See Figure 8-13).[32] The tracking requirements varied with mission phase, being most critical during Jupiter encounter and the trajectory corrections. Good tracking data were especially important during and after the encounter phase because of the nonautomatic nature of the spacecraft and its lack of on-board data storage. Continuous 64-m coverage was

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[31]A. J. Siegmeth, et al, "Tracking and Data System Support for the Pioneer Project," Vol. I (Pasadena: JPL TM 33-584, April 1, 1973).

[32]Even with the 64-m antennas, the data rate during encounter would be less than 1000 bits/sec due to Jupiter's great distance from Earth (over 5 A. U.) Still, this rate was much higher than the Mariner-2 data rate from Venus in 1962 (8 1/3 bits/sec).

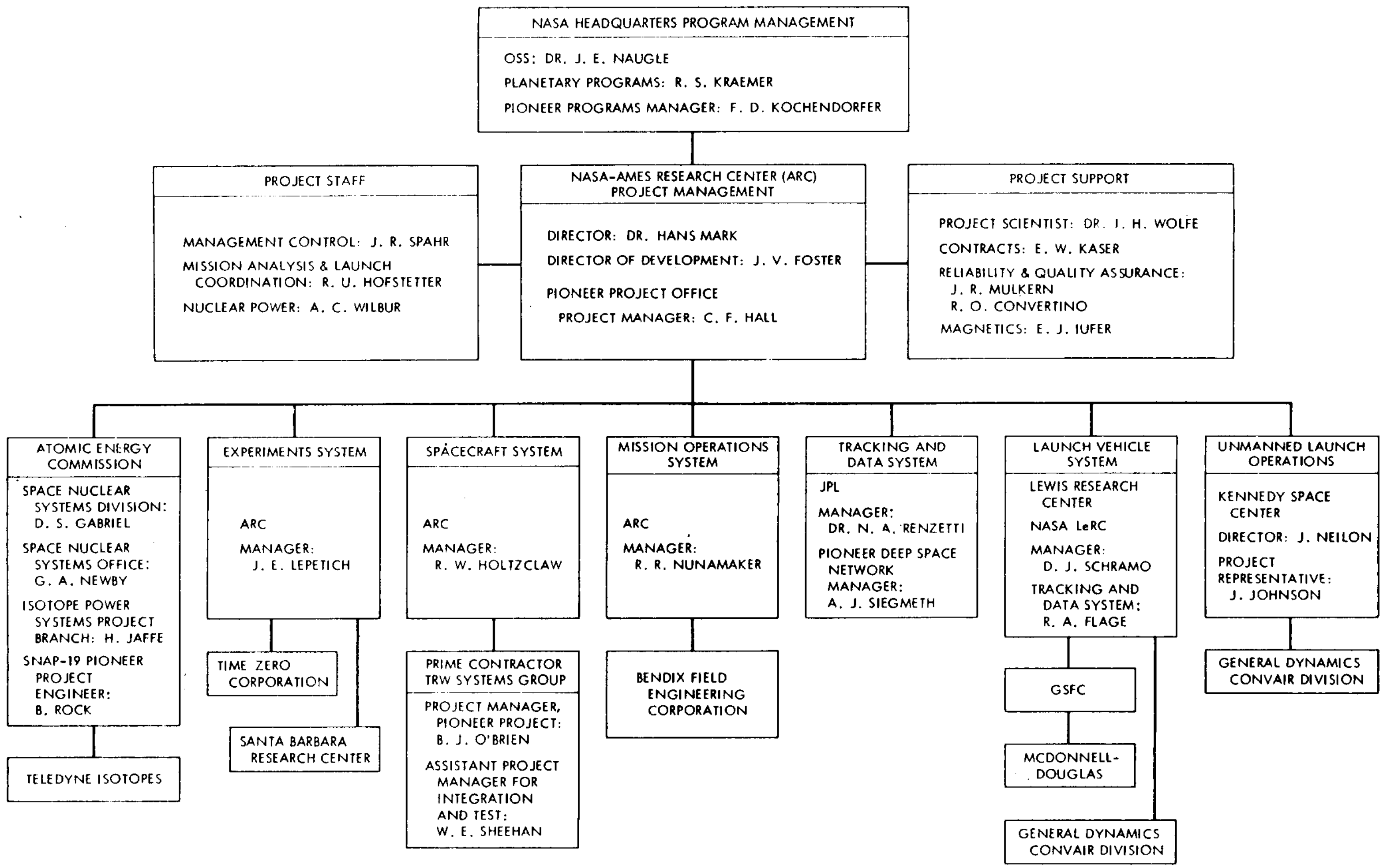

Figure 8-12. Program management team for Pioneers 10 and 11.

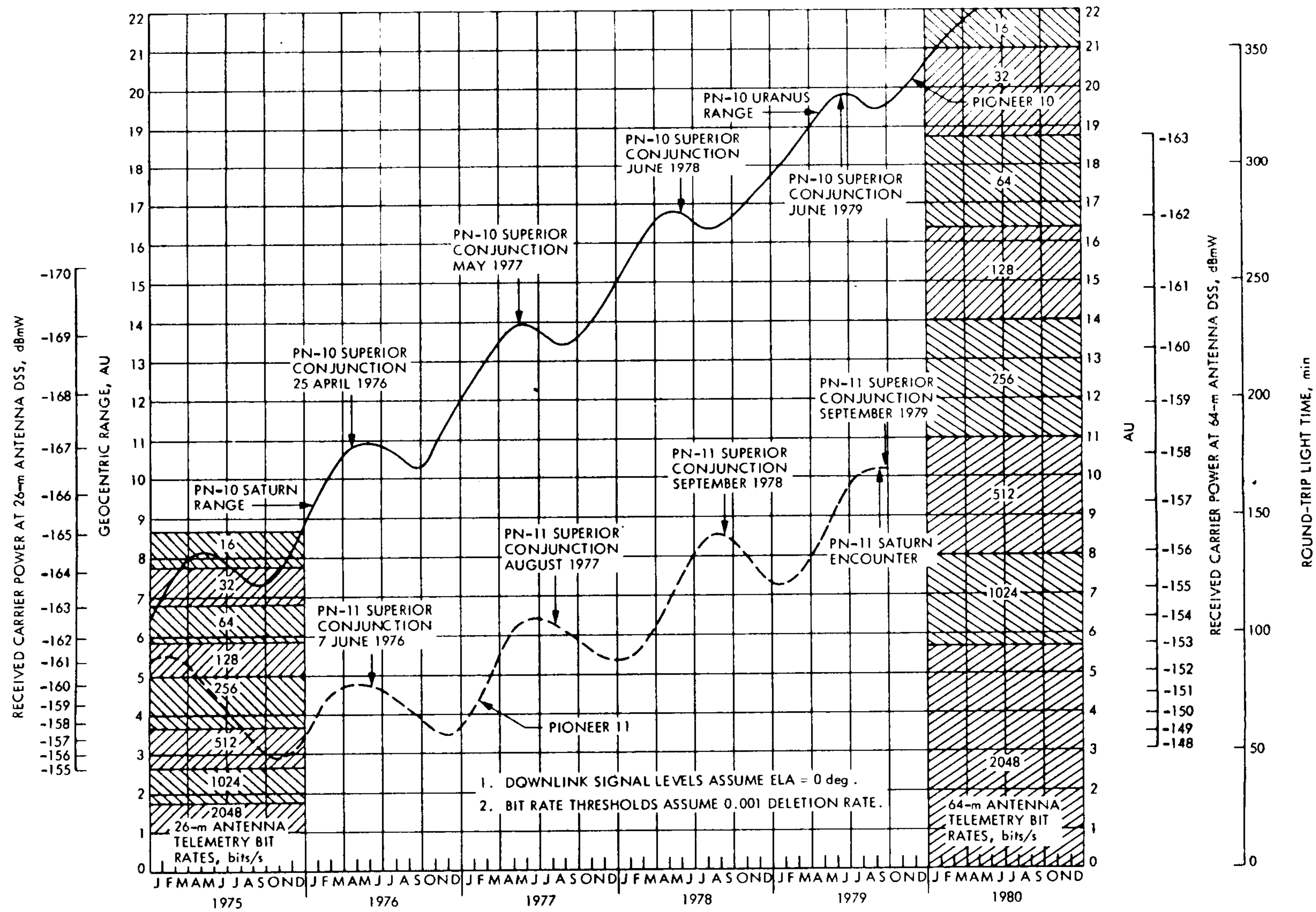

Figure 8-13. Downlink performance estimates for Pioneers 10 and 11.

required for 30 days on each side of the date of closest approach to Jupiter for the measurements of fields and particles in the vicinity of the planet. Pioneer 10 will become the first man-made object to leave the solar system, while Pioneer 11 was held in reserve for possible redirection to Saturn should the Pioneer-10 encounter be unsuccessful. With present DSN capabilities, Pioneer 10 will be tracked to about 22 A. U. (about 1980) when the limits of the telecommunication link will be reached.

Pioneer 10. After three fruitless countdowns, Pioneer 10 finally left the launch pad on March 3, 1972. The Centaur stage injected Pioneer 10 into a Jupiter-bound trajectory 16 minutes after launch. About 5 minutes after injection, the DSN acquired the spacecraft at Johannesburg. The spacecraft was oriented and its transmitter was turned on with no problems. The 26-m DSN stations provided most of the support, with some help from DSS 14, during this early flight phase. On the fourth day of flight, March 7, two midcourse maneuvers were commanded, with the object of timing the arrival of the spacecraft at Jupiter for December 4, 1973,[33] when the satellite Io would be in a position to occult Pioneer 10. The encounter of Pioneer 10 also had to be adjusted so that Goldstone Mars and the 64-m antenna still under construction near Canberra would be able to view it.

Pioneer 10 entered the asteroid belt in July of 1972 and left in the following January. Surprisingly, the meteoroid-asteroid detector aboard indicated no important changes in the flux of particles recorded. Solar occultation of the spacecraft lasted from January 11 to 21, 1973. This was a rather difficult period because the high-gain antenna had to be pointed away from the Sun but yet radio contact had to be maintained or the spacecraft would automatically switch elements in its radio system. The new high-power (400-kw) transmitter at the Mars station helped retain contact with Earth even with the spacecraft's high-gain antenna off-pointed from the Sun. Closest approach to Jupiter was reached December 4, 1973 at 2.86 Jupiter radii, 203,250 km, from the planet's center. The encounter was highly successful for science, with the instruments confirming that Jupiter was much more complex and intriguing than expected. Close-up photos of the planet were obtained and an atmosphere was detected on the satellite Io.

The DSN supported the flight with its 26-m and 64-m stations but there were serious conflicts with the overlapping Mariner 10 mission to Mercury and Venus as well as the Viking Project. The latter needed radar data on Mars obtainable only from the DSS 14 antenna. The multiplicity and complicated nature of these conflicts made them the most difficult ever encountered by the DSN. A Network Allocation Working Group had to be set up to resolve the conflicts, which in most cases could only be settled by compromising through and taking support time from one project and giving it to another. Such extensive conflicts will be more common in the future and the

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[33] The 21-month flight was several times the length of previous Mariner trips to Venus and Mars.

machinery for resolving them evolved during the Jupiter Pioneer flights has become permanent. The DSN, which used to have the luxury of assigning entire subnets to projects on an exclusive basis, had moved into a period where it would have to assign support to missions antennas by antenna and day by day and even hour by hour.

Ground communications were made more difficult by the fact that Pioneers 10 and 11 were the first deep-space projects to be controlled from outside the SFOF. (Figure 8-14) The Pioneer Mission Control Center at Ames had complete control of the spacecraft. To illustrate the redundancy built into the network, the following example is provided. An operational problem occurred on October 18, 1972, when a transatlantic submarine cable failed connecting Johannesburg to the GCF. Communications to Johannesburg were reestablished quickly over landline teletype circuits but not before the imaging polarimeter on the spacecraft had passed through Jupiter. Fortunately, commands were sent in time to avoid Sun damage to the instrument. The DSN was also able to divert the Robledo 26-m antenna to Pioneer 10 during this emergency.

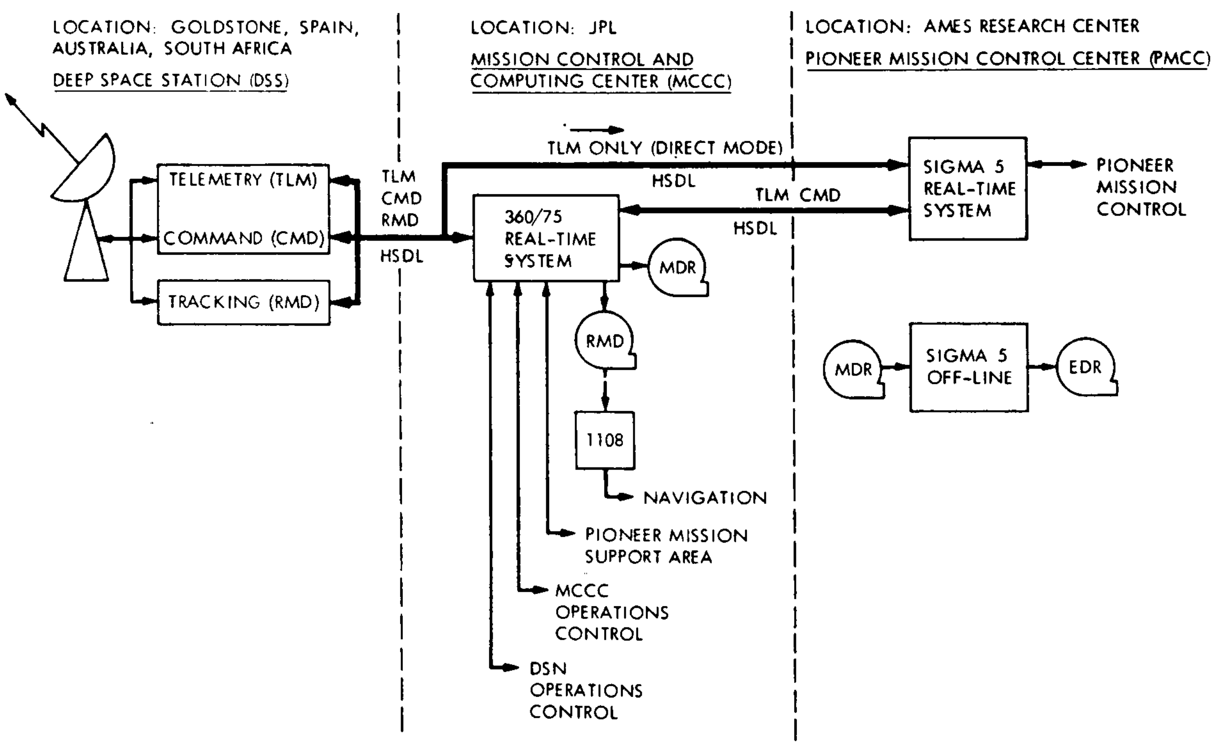

Figure 8-14. Pioneer-10 data system during Jupiter encounter. The schematic shows that telemetry bypasses SFOF and is routed directly to Ames Research Center, but the bypass mode was a backup during Pioneer-10 encounter. Ames actually operated with processed telemetry from the SFOF.

To provide a feeling for the extent of DSN support for Pioneer, eleven DSN stations supported Pioneer 10 for 21,000 hours (2000 tracks) between April 1, 1972, and January 1974. During this time, the spacecraft-to-Earth distance varied from 22 million to 890 million kilometers. During the 60-day encounter period, over 17,000 commands were sent to control the spacecraft during its intricate studies of Jupiter.

Pioneer 11. The mission of Pioneer 11 was essentially identical to that of Pioneer 10 except for the slingshot trajectory by Jupiter. Launch was on April 6, 1973. (Figure 8-15)

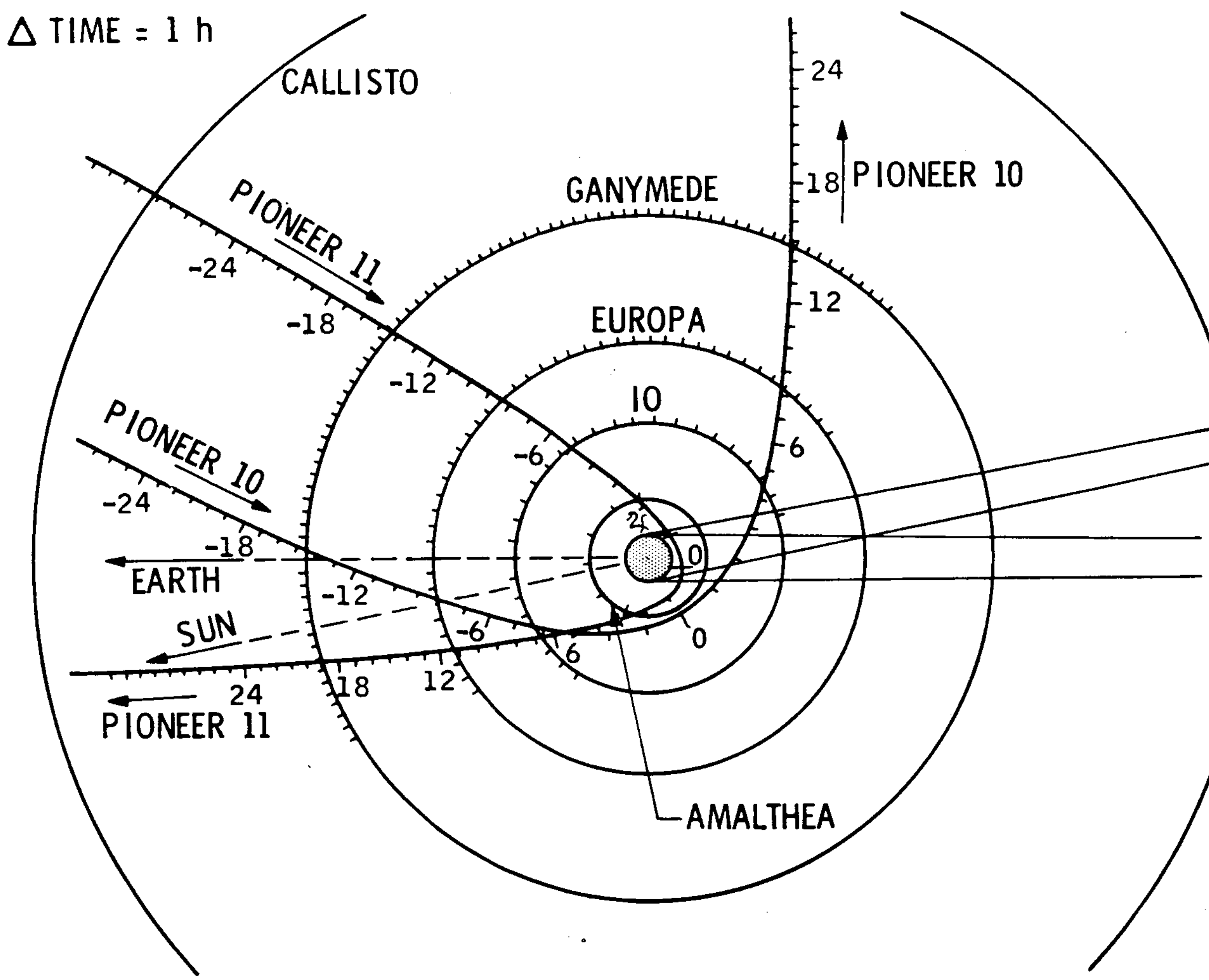

Figure 8-15. Pioneer-10 and -11 trajectories near Jupiter as seen from celestial North Pole.

DSN Contributions to Radio Science

The DSN of course has been primarily concerned with developing instrumentation appropriate to supporting deep-space missions, but in the process it has created excellent antennas and data-processing systems for radio astronomy. In 1975, the DSN 64-m antennas were the best instruments for planetary radar in the world.[34] The increases in DSN performance have been spectacular:

	Early 1960s	Mid 1970s
Transmitter power (kw)	9	400
Antenna diameter (m)	26	64
System noise temperature (^{o}K)	64	20

With such performance, the 64-m dishes are in great demand for scientific research. The experiments proposed are so many that scientists have organized a Radio Science Experiment Selection Panel to assign high priorities to the best. The total operating time that the DSN can divert from its primary spacecraft support mission runs only about 10 to 15% of the antenna time at Goldstone Mars. This does not come close to satisfying the demand generated within the radio astronomy community.

The DSN accomplishments in radio astronomy during the period encompassed by this chapter are numerous. Only a few highlights can be mentioned here. Starting at the innermost planet, in 1969 radar experiments at Goldstone Mars showed that the surface of the planet Mercury consisted of several large rough features and one very smooth area.[35] Later, in 1972, radar probes at 2.388 GHz revealed the existence of hills and valleys with relief of about 1 km. The data also suggested craters with 50-km diameters and depths of about 700 m.[36] The Mariner-10 flyby confirmed these findings.

Venus has been a radar target of special interest because while its surface cannot be seen through the optical telescope radar can penetrate its clouds. Surface features were detected early (Chapter 6) and in the 1970s, radar maps of its surface were greatly improved through better instruments and image-enhancement techniques. Figure 8-16 shows that, like the other inners planets, Venus has a heavily cratered surface.[37]

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[34] R. M. Goldstein, personal interview, April 15, 1975.

[35] R. M. Goldstein, "Mercury: Surface Features Observed During Radar Studies," Science, Vol. CLXVIII (April 24, 1970) pp. 467-469.

[36] S. Zohar and R. M. Goldstein, "Surface Features on Mercury," The Astronomical Journal, Vol. LXXIX (January 1974) pp. 85-91.

[37] H. C. Rumsey, et al, "A Radar Brightness and Altitude Image of a Portion of Venus," Icarus, Vol. XXIII (1974) pp. 1-7.

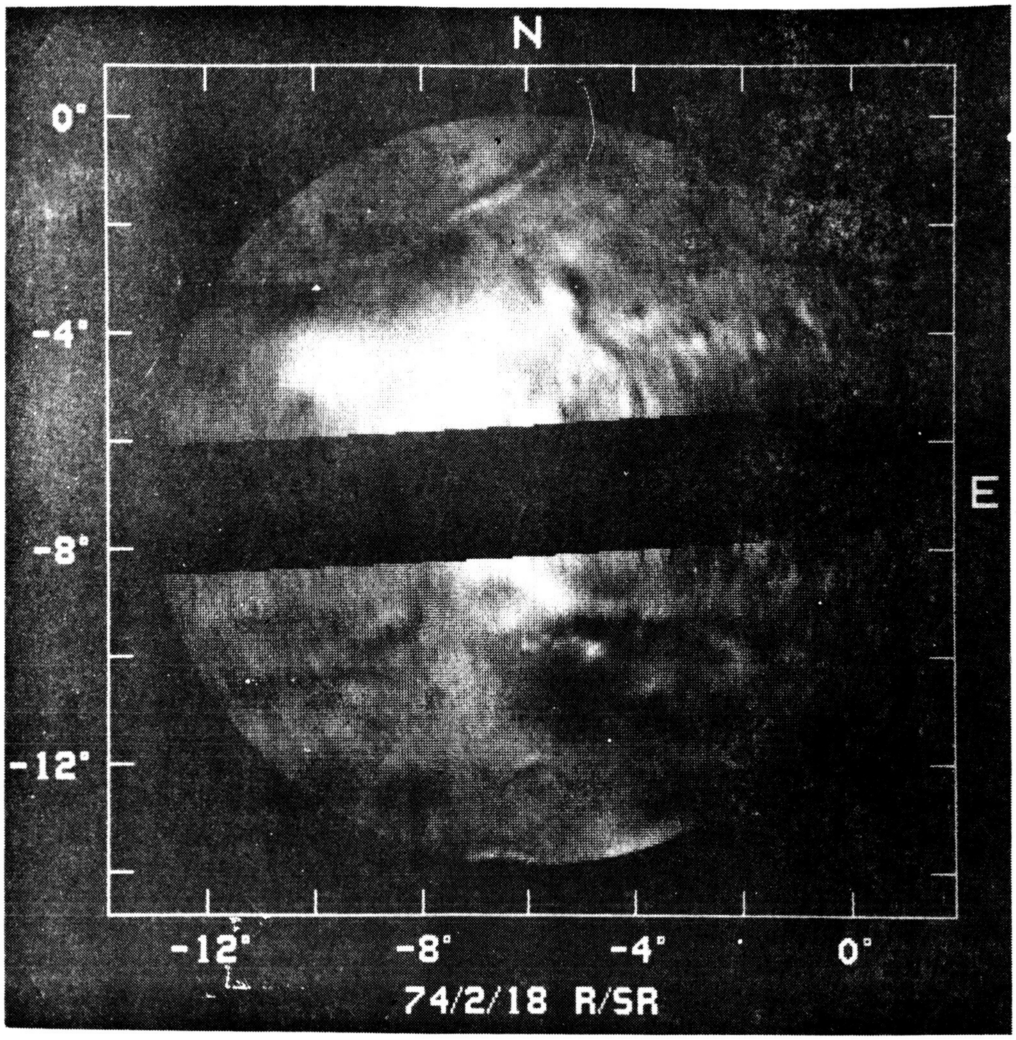

Figure 8-16. High-resolution radar brightness image of part of Venus showing the heavily cratered surface.

The Goldstone 64-m dish has also been helpful in measuring Martian topography.[38] During the 1971 opposition, for example, the surface topography was explored, and many craters in the 50-100 km-diameter range, 1-2 km deep, were seen. These data complemented the photos from Mariner 9 which did not yield accurate measures of crater depths. The Mars antenna has also been employed in searching out suitable sites for the Viking landers. Low areas are desired for maximum atmospheric braking of the landers and also because moisture may be concentrated there, increasing the likelihood of life. Radar-bright areas will be avoided because they probably consist of hard sterile rock.

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[38] G. S. Downs, "Martian Topography and Surface Properties as Seen by Radar: the 1971 Opposition," Icarus, Vol. XVIII (1973) pp. 8-21.

Farther out in the solar system, the 64-m Mars radar detected the rings of Saturn for the first time.[39] The particles that make up the rings were efficient reflectors of the 12.6-cm waves, indicating that they were probably rough objects a meter or more in diameter. Some of the radar-reflecting objects do not seem to be visible at all!

Looking outside the solar system, DSN antennas, particularly the 64-m ones, have been active in the Quasar Patrol program established in 1972. This cooperative project has actually taken the bulk of the time the Mars antenna can be diverted to radio astronomy. Another kind of cooperative project has been Very Long Baseline Interferometry (VLBI) whereby several big radio astronomy antennas work together in an interferometer array to make extremely precise measurements of distant radio objects.[40] In this manner, the DSN has contributed to the knowledge of the universe from the nearby planets to the outermost objects known.

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[39] R. M. Goldstein and G. A. Morris, "Radar Observations of the Rings of Saturn," Icarus, Vol. XX (1973) pp. 260-262.

[40] Curtis A. Knight, et al, "Quasars: Millisecond-of-Arc Structure Revealed by Very-Long-Baseline Interferometry," Science, Vol. CLXXII (April 2, 1971) pp. 52-54.

Chapter 9. DSN TRENDS

One of the hallmarks of the DSN has been its continual forward evolution and pursuit of higher performance. This property---really the collective property of the people who built the DSN---has permitted us to see close-up pictures from Mercury to Jupiter, to dig remotely into the lunar surface, and plumb the interplanetary medium. Radio astronomers, too, have found the DSN an instrument par excellence. The following points summarize the trends that have characterized the evolution of the DSN:

1. The DSN has always been a "state-of-the-art" network; it has always been on the technological frontier.

2. Through its progress in several avenues of technology, the DSN has continually increased its capacity to acquire data and track spacecraft at greater and greater distances. (Figure 9-1)

3. New technology is introduced to almost every new mission on experimental, non-interference basis, and then is implemented as an operational capability on the next mission.

4. The ever-increasing technological capability of the DSN has allowed it to respond "beyond the call of duty" on all flight programs, particularly in emergency situations.

5. Even with the rising complexities of missions and the DSN itself, the DSN has steadily improved its overall reliability. No spacecraft has ever been lost due to a communications failure.

6. The decision of NASA and JPL to establish a separate tracking-and-data-acquisition function has resulted in integrated research, development, and budget planning on a long-term basis that is independent of specific, often rather narrow flight project requirements.

7. Since 1965, there has been steady progress toward a multimission network.

8. In recent years, there has been a strong trend in the direction of of site consolidation, wherein fewer but better-instruments are able to provide better support at lower overall cost.

9. The continuing NASA policy of insisting that foreign nationals operate its overseas sites has kept the DSN relatively free of international political problems.

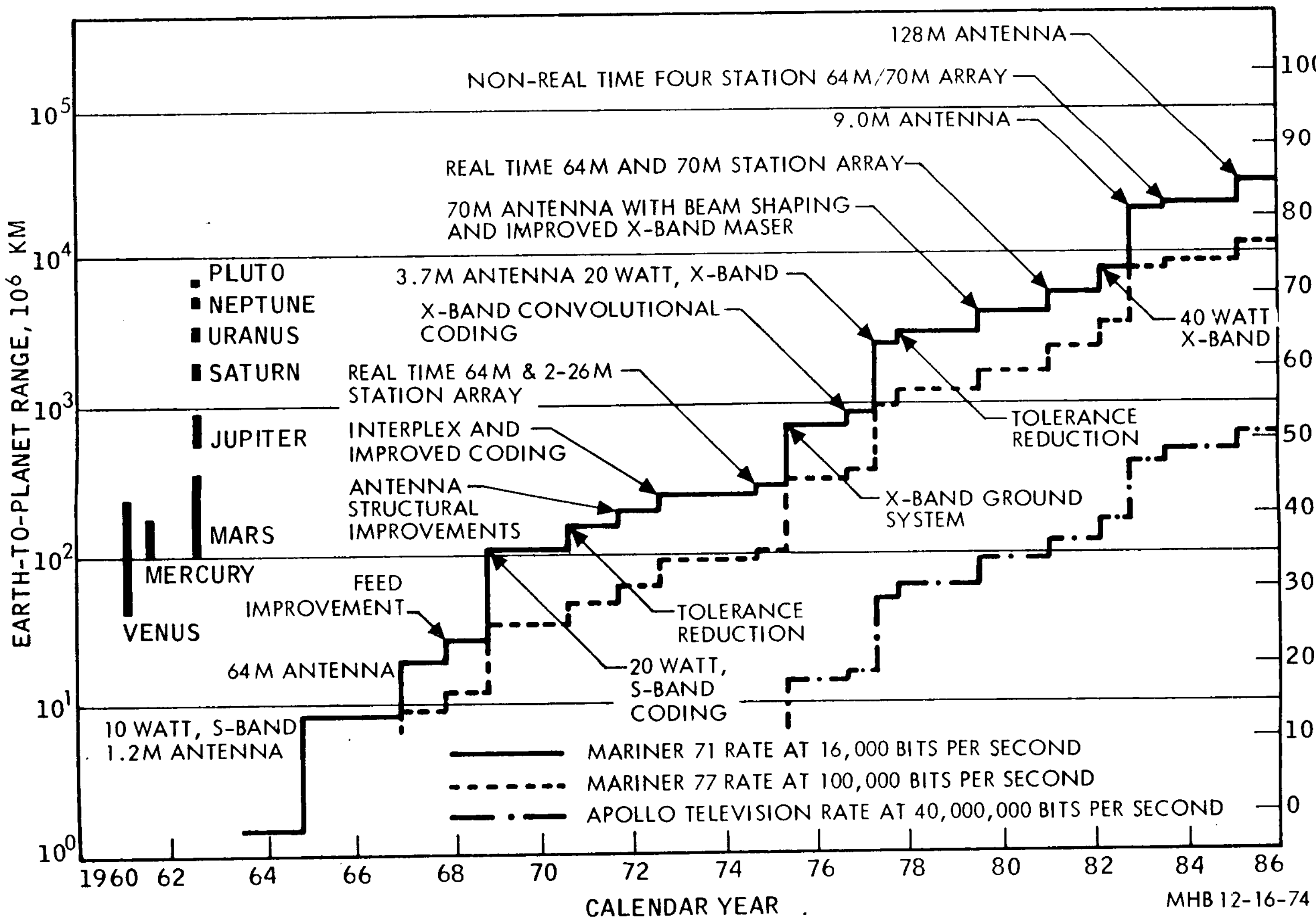

Figure 9-1. DSN downlink communication capability as a function of time.

10. Initially, the tracking-and-data-acquisition function also included the project data-processing function for deep-space missions but this responsibility was divorced from the DSN in the early 1970s to provide a simpler, more manageable interface.

11. Radio science has worked hand-in-hand with the DSN in terms of network enhancement. Developments in geodesy charged-particle calibration, and precision timing, for example, have been stimulated by the needs of both radio science and the tracking-and-data-acquisition function. Both, of course, have benefited.

12. The trend toward network automation exists in the DSN but it is evolving more slowly than in Earth satellite tracking and data acquisition. The DSN, however, was "computerized" rapidly at the station and network levels.

13. The trend toward centralization of all mission operational activities within the SFOF has been reversed in recent years as more and more off-Lab projects developed their own mission operation facilities. However, the redefinition of the roles of NASA facilities may counter this trend.

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This bibliography specifically excludes reports and papers that are almost exclusively scientific results from DSN-tracked spacecraft or DSN radio science. Emphasis is on technology.

Very detailed descriptions of DSN technological evolution and operations may be found in DSN progress reports. Three distinct series exist:

> The Space Programs Summary 37-x. The Deep Space Network is covered in either Vol. II or Vol. III. This series takes the DSN through the year 1970.
>
> JPL Technical Report 32-1526, Vols. I through XIX, covers 1971 through 1973.
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Appendix A. DEEP SPACE NETWORK (DSN) FINANCIAL SUMMARY

(Millions of Dollars)

	FY 63 & PRIOR	FY 64	FY 65	FY 66	FY 67	FY 68	FY 69	FY 70	FY 71	FY 72	FY 73	FY 74	FY 75	FY 76
OPERATIONS	20.9	12.2	19.0	25.2	34.8	37.9	32.2	34.9	37.9	38.8	32.1	33.1	35.3	38.4
CONSTRUCTION & EQUIPMENT	57.3	23.0	15.5	12.9	9.4	12.2	30.4	31.1	22.4	14.4	7.5	14.9	14.3	14.3
	78.2	35.2	34.5	38.1	44.2	50.1	62.6	66.0	60.3	53.2	39.6	48.0	49.6	52.7

Appendix B. MEMO ESTABLISHING THE DEEP SPACE NETWORK

JET PROPULSION LABORATORY

OFFICE OF THE DIRECTOR
Interoffice Memo 218
December 24, 1963

To: Senior Staff
Section Chiefs
Section Managers

From: W. H. Pickering

Subject: Establishment of the Deep Space Network

Effective immediately, the Deep Space Network is established by combining the Deep Space Instrumentation Facility, Interstation Communications, and the mission-independent portion of the Space Flight Operations Facility. Development and operation of this network is the responsibility of the Assistant Laboratory Director for Tracking and Data Acquisition by extension of the role statement for this Assistant Director (Office of the Director IOM 200, October 2, 1963).

Funding sources are unchanged for Fiscal 1964 and for the budget submitted by JPL for Fiscal 1965. However, JPL will endeavor to have OTDA and OSSA agree on a single source of funding as quickly as possible.

The interface with mission peculiar facilities and organizations will be worked out between the Assistant Laboratory Director for Tracking and Data Acquisition and the Assistant Laboratory Director for Lunar and Planetary Projects using as a guideline the definition of "mission-independent" as:

1. Required for two or more flight projects.

2. Best handled by JPL and not outside flight project organizations (ARC Pioneer, GSFC-MSFN, LeRc Centaur, etc.).

This change is made in order to accommodate efficiently the increasing number of outside flight projects for which the Jet Propulsion Laboratory has been tasked to supply tracking and data acquisition support. The change should also assist in closer integration of the previously separate facilities.

W. H. Pickering
Director

WHP:mc

U. S. Government Printing Office: 1976---735-700/3 Region 3-11