THE DEEP SPACE INSTRUMENTATION FACILITY (DSIF)

When the Mariner Era opened in 1961, the network, then known as the Deep Space Instrumentation Facility (DSIF), consisted of three stations—one at Goldstone, California; another at Woomera, Australia, in the desert 320 kilometers north of Adelaide; and a third near Johannesburg, South Africa. In addition to its 26-m diameter dish antenna, each station had receive and transmit capabilities at a frequency of 960 MHz (L-band), and could process and record telemetry data at low data rates from the JPL-designed space probes. Telephone and teletype circuits linked each site to a simple control and coordination center at JPL. These circuits were carried between continents via undersea cable, and by land line, or in the case of Johannesburg, by a high-frequency radio link, to their ultimate destination.

At that time, the loose organizational structure of JPL allowed for a great deal of interaction between the technical groups responsible for the spacecraft and its operation, and the groups responsible for the development, implementation, and operation of the DSIF. This was of prime importance in the area of telecommunications, where it was essential that the spacecraft radio system was designed to be compatible with the radio systems installed at the tracking stations. While the spacecraft and tracking station design groups each focused on their individual design issues, important questions of “telecommunication compatibility” were responded to, informally, by the engineers involved. It was a carryover from earlier times, when the spacecraft radio and DSIF radio systems had been designed and built in the same technical division at JPL. This situation soon changed, however, and the question of telecommunications compatibility, with all its ramifications, became a major concern at JPL as the NASA space program gathered momentum.

Mission Operations was another factor that dominated the planning processes for early deep space missions. Determining and controlling the flight path of a spacecraft, displaying and analyzing the engineering and scientific data received from it, selecting and issuing commands to the spacecraft, and coordinating the activities of the worldwide stations of the DSIF and the communications links connecting them to JPL, are all part of Mission Operations. This specialized activity is conducted in a central location called the Flight Operations Control Center.

As early as 1960, JPL had completed studies for a facility that could handle mission operations not only for the forthcoming Ranger mission, but also for all future space missions. Plans called for a Space Flight Operations Facility consisting of the equipment, computer programs, and groups of technical and operations personnel that would carry out these and all other functions required to fly the Ranger missions. The facility would

Figure 2-4. Network Operations Control Center (NOCC) at JPL, 1969. Refurbished many times since then, and organized in several different ways to meet the expanding needs of the DSN, the NOCC continued to perform that vital function through 1997.

be located in a single building at JPL, and the same teams would work each of the missions to ensure continuity of experience and expertise.

In the short time available before the first Ranger launch, a temporary facility was established next to the existing computer room. Blackboards and pinboards to post current flight status lined the walls, desks, phones, calculating machines, and teletype machines stood wherever space permitted. Later, a few console displays were added for closed circuit television display of printouts from the large mainframe IBM 7040 computers in the adjacent computer room. A large static display board showed the status of the DSIF stations and the communications links between them.

When it became obvious that the makeshift facility would be inadequate even for missions in the immediate future, planning and funding for the much larger permanent facility was accelerated. Designed specifically for spaceflight operations, the Space Flight Operations Facility (SFOF) was completed and began supporting flight missions in 1964. A separate control center for directing the expanded operational functions of the Network occupied a large portion of the new SFOF as shown in Figure 2-4.

The Facility (DSIF) Becomes the Network (DSN)

In a memo to senior staff dated 24 December 1963, the Director of JPL, William H. Pickering, redefined the responsibilities of the DSIF to include "all mission-independent portions of the Space Flight Operations Facility," in addition to the existing responsibility for the tracking stations, the communications system linking them to JPL. The combined organizational structure was named the Deep Space Network (DSN) and would be directed by Eberhardt Rechtin, with the functional title of assistant laboratory director for tracking and data acquisition.

L-band to S-band

At this time also, a most significant engineering change was being made in the DSN. It concerned the change to a higher operating frequency for the uplinks and downlinks. Mainly as a matter of convenience and expediency, the original receivers and transmitters in the DSN had been designed in 1957 and 1958 to operate at a frequency of 960 MHz. In telecommunications terminology, 960 MHz lies within a narrow band of frequencies identified as L-band. The Ranger spacecraft radio system had to match that frequency to be compatible so that it too operated at L-band. However, there are significant advantages to the uplink and downlink performance to be had from operating at a much higher frequency of 2,200 MHz, or S-band.

By 1963, the availability of new radio frequency amplifiers and transmitters, which would operate well at S-band, allowed the DSN to take advantage of the better uplink and downlink performance at the higher frequencies. With an eye to the requirements of future missions, the DSN set about converting all the tracking stations from L-band to S-band. But where would that leave the Ranger program about to restart its lunar flights, and how would it affect the recently approved Mariner missions to Mars?

The solution devised by DSN engineers was to install S-band to L-band conversion equipment at the stations in parallel with the older L-band equipment. This would accommodate the remaining four Rangers and the first two Mariner missions to Venus on L-band. It could also provide for the later Mariner missions to Mars and the proposed Surveyor missions, both of which would use the more efficient S-band uplinks and downlinks. The L/S-band converter would remain in place until the end of the L-band missions, by which time a new, fully S-band system would be in place. The L/S-band converters would then be removed and the conversion to the more efficient S-band operation would be complete. All missions from then on would be on S-band. Of all the improvements in the early years of the DSN, the move to S-band was probably the most significant.

Improvements for the Mariner Mars Missions

The Mariner 1964 Mars missions were the first in which the DSN would use the newly implemented L/S-band capability to adapt the spacecraft S-band downlink to suit the existing DSN L-band receivers. The capability to send commands to the spacecraft would be provided by 10-kW transmitters recently installed at Goldstone-Pioneer, Johannesburg, and Woomera stations.

In addition to the uplink/downlink improvements accruing from the change to S-band, significant improvements to navigation accuracy were expected from the introduction of atomic clocks throughout the DSN to replace the less stable crystal controlled oscillators. These rubidium frequency standards improved the quality of the radio Doppler data provided to the spacecraft navigators by the DSN stations, enabling them in turn to improve the trajectory determination process necessary to deliver the spacecraft to a small aim point in the vicinity of Mars.

Improvements in the NASA ground communications system (NASCOM), which connected the far-flung stations of the DSN to the Flight Control Center at JPL, had already taken place. Teletype links, voice, and high speed data circuits using a worldwide network of microwave links, and undersea cables and radio circuits were connected to a central communications center at the NASA Goddard Space Flight Center in Greenbelt, Maryland. From there the circuits could be distributed to JPL and other NASA Centers scattered throughout USA, as required. The DSN could call on NASCOM to bring up the communications necessary to support a particular mission whenever needed. When the mission was completed, the circuits were turned back to NASCOM to be used for some other NASA space mission, maybe at a different NASA Center.

By the end of 1964, the primitive Flight Operations Control Center used for the first Ranger missions had been superseded by the newly completed Space Flight Operations Facility (SFOF). In a dual string computer arrangement, new IBM 7094 computers performed the data processing for the *Mariner 3* and *4* missions to Mars, while the Ranger processing was still carried out on a later version of the original 7040 machines. This arrangement minimized the need for changes to the existing Ranger software.

In the spacious facilities of the new SFOF building, a large high ceiling room in the middle of the first floor housed the new Mission Control Center. An attractive entrance lobby with reception desk and space-related displays occupied the front of the building, while offices and conference rooms for the various teams of flight project personnel surrounded a DSN Control Room on the other three sides. In the huge basement below the Control Room, engineers in the DSN Communications Terminal monitored, coordinated, and routed the flow of voices and data between the stations, the DSN Controllers above them, and the data processing computers on the second and third floors of the SFOF. An elaborate internal communications system enabled all the users of the SFOF to access and direct data to and from sources and destinations as their duties and authority required during the mission. The Facility was designed to run 24 hours a day, and incorporated a generator-driven "uninterruptible power supply" that would supply primary power if the commercial power failed for any reason. During critical parts of a mission, the generators would be turned on anyway to ensure that the SFOF would not suffer any kind of a "glitch" while critical mission operations were in progress. The muffled roar of the JPL generators always informed the quiet neighborhood that something important was going on at the Lab.

Over the course of thirty years, 1964 to 1994, the management responsibility for the large data processing facilities in the SFOF passed back and forth several times between the DSN and the Flight Project offices at JPL, depending on the current "financial climate" at NASA Headquarters.

However, responsibility for the two DSN control functions, Network Control and Ground Communications Control, always remained in the hands of the DSN. The consolidation of these vital functions, together with expansion of the Network itself, benefited from a continuum of long-term planning and management. As a result, the DSN was perceived from time to time to have a "monolithic structure" by other organizations within the JPL and, indeed, even by NASA Headquarters. Good relations with NASA were essential to the well-being of continued JPL involvement in the planetary space program. Nowhere was this recognized more acutely than in the Tracking and Data Acquisition Office at JPL, where the encouragement of frequent and open channels of communication between DSN personnel and NASA on DSN-related matters did much to improve working relationships and dispel the "monolithic" image of the DSN in those years. With the beginning of the S-band missions and the advent of the SFOF containing the DSN Network and Communications Control Centers, as well as the Mission Operations Control Center and its data processing facilities, the DSN began to assume the form, and much of the substance, of the modern DSN.

The Need for a Second Network

To support the more sophisticated missions of the 1965 to 1968 period, the DSN recognized the need to expand and improve its communications, mission, and network control capabilities. The two major lunar missions nearing launch readiness, Lunar Orbiter and Surveyor, would pave the way for the start of the Apollo program and would transmit data streams at thousands of data bits per second rather than the tens or hundreds of bits per second received from the Mariners and Rangers. The increased complexity of the spacecraft would require expanded and faster monitor, control, and display facilities.

For the first time, the DSN began to find that the simultaneous presence of several spacecraft on missions to different destinations created new problems in network and mission control. The vexing problem of DSN "antenna scheduling" began to arise as several spacecraft began to demand tracking coverage from the single DSN antenna available at each longitude. The difficulty of assigning priority among competing spacecraft whose view periods overlapped at a particular antenna site was to prove intractable for many years. The problem was exacerbated by competition between flight projects from NASA Centers other than JPL, each of which felt entitled to equal consideration, for the limited DSN resources. The DSN was placed in the impossible situation of arbitrating the claims for priority consideration. The regular "Network Scheduling" meetings conducted by the DSN often resulted in the establishment of priorities that were determined more by the dominant personalities in the group than by the real needs of the projects.

With all of these imminent new requirements in mind, NASA decided to embark on a program to construct a second network of DSN stations. Arguments as to where the stations were to be located were complicated not only by technical considerations, but by political and international considerations.

There were already two stations at Goldstone, one at the Pioneer site and a second at the Echo site. Eventually, NASA decided to build two new stations, one at Robledo, about 65 kilometers west of Madrid, Spain, and the other at Tidbinbilla, about 16 kilometers from Canberra, Australia.

NASA looked to the Spanish Navy's Bureau of Yards and Docks to design and construct the Robledo station. For its new facilities in Australia, NASA dealt with the Australian Government Department of Supply through its representative, Robert A. Leslie.

As an Australian foreign national, Robert A. Leslie played a major role in shaping the relationship between NASA-JPL and the Australian government, on whose good offices NASA depended for support of its several tracking stations in that country. With family origins in the state of Victoria, Australia, and an honors degree in electrical engineering from the University of Melbourne (1947), Leslie had worked on radio controlled pilotless aircraft for the military in both England and Australia for fifteen years before he encountered NASA. He was a high-ranking officer with the Australian Public (Civil) Service (an affiliation that he retained throughout his career) when, in 1963, he became the Australian government's representative for NASA's new deep space tracking facility being built at Tidbinbilla, near Canberra in southeastern Australia.

As might be expected, the success of a NASA venture in a foreign country depended to a large extent on the personalities of the people who were directly involved on each side of the international interface. The foundation for the success of what later became the Canberra Deep Space Communications Complex (CDSCC) was, in no small part, due to Bob Leslie's personal ability to "get along" with people at all levels. In representing the Australian side of negotiations between NASA and JPL, Bob Leslie was firm but gracious, capable, and friendly. His unassuming "paternal" manner endeared him alike to counterparts at NASA, his colleagues at JPL, and his staff in Australia.

Along with a few key Australian technical staff members, Leslie spent a year at Goldstone assembling and testing the electronic equipment that would subsequently be reassembled at Tidbinbilla to complete the first 26-meter tracking station (DSS 42) at the new site. He was the first director of the new Complex when it began service in the Network in 1965. It was there that he established the procedures and protocols on which all future DSN operational interactions between JPL and the Australian stations would be based.

A few years later, in 1969, Leslie left the "hands-on" environment of the deep space tracking station to head the Australian Space Office, a branch of the Australian Government that, under various names and government administrations, would guide future expansion and consolidation of all NASA facilities in Australia. In that capacity, his charm, experience, and wisdom served the DSN well.

Leslie's build was stocky and solid, his appearance craggy, his attitude "laid back." Cheerful, sociable, easy to talk to, and blessed with a good sense of humor, he was held in high regard by everyone he met, Australian or American. Tennis was his sport, fishing his hobby, and "do-it-yourself" home building his passion. In his younger days, he actually excavated the ground with shovel and wheelbarrow and single-handedly built the family swimming pool at his home in Canberra. Many a JPL engineer enjoyed a poolside barbecue at the Leslie home in the course of a technical visit to the station.

Robert Leslie retired in 1983 and died in Canberra, Australia, in 1996.

By mid-1965, the two new stations were completed and declared operational. The DSN then had two stations in Australia, (Woomera and Tidbinbilla), one in Spain, and one in South Africa. In addition, a permanent spacecraft monitoring station had been built at Cape Canaveral to replace the temporary facility with its hand-steered tracking antenna. Impressive as this growth was, still greater changes were in progress.

Larger Antennas Are Needed

Consistent with the JPL vision for missions to more distant planets, and more powerful communications links to support them, the DSN had long recognized a need for larger antennas, that is, larger than the existing 26-m antennas. Studies had shown that a diameter of 64 meters was about the maximum practical limit to an antenna which would have sufficient stability and structural integrity for DSN purposes. Interest in building a giant new antenna of that size, employing radical new design and construction techniques, became a reality as early as 1962 at NASA and JPL. Feasibility study contracts for an advanced antenna had already been issued to numerous U.S. corporations and, finally in January 1963, the Rohr Corporation was selected to build the antenna at a suitable site a few miles from the existing Echo and Pioneer locations at Goldstone. Since the advanced antenna was originally intended to support the first missions to Mars, the site was appropriately called "the Mars site."

Design work began immediately (1963), and procurement and fabrication of steel components started a year later. Roads, concrete foundations, alidade structure, and diesel generator buildings were completed in 1964, followed by the control room and elevation bearings. The supporting framework for the antenna panels followed next, and by mid-1966, the 64-meter Mars Antenna was ready for service. Although the first signals from Mars—transmitted by *Mariner 4*—were detected in March 1966, a great deal of performance testing, personnel training, and calibration remained to be completed before the Mars antenna was considered a fully operational addition to the DSN.

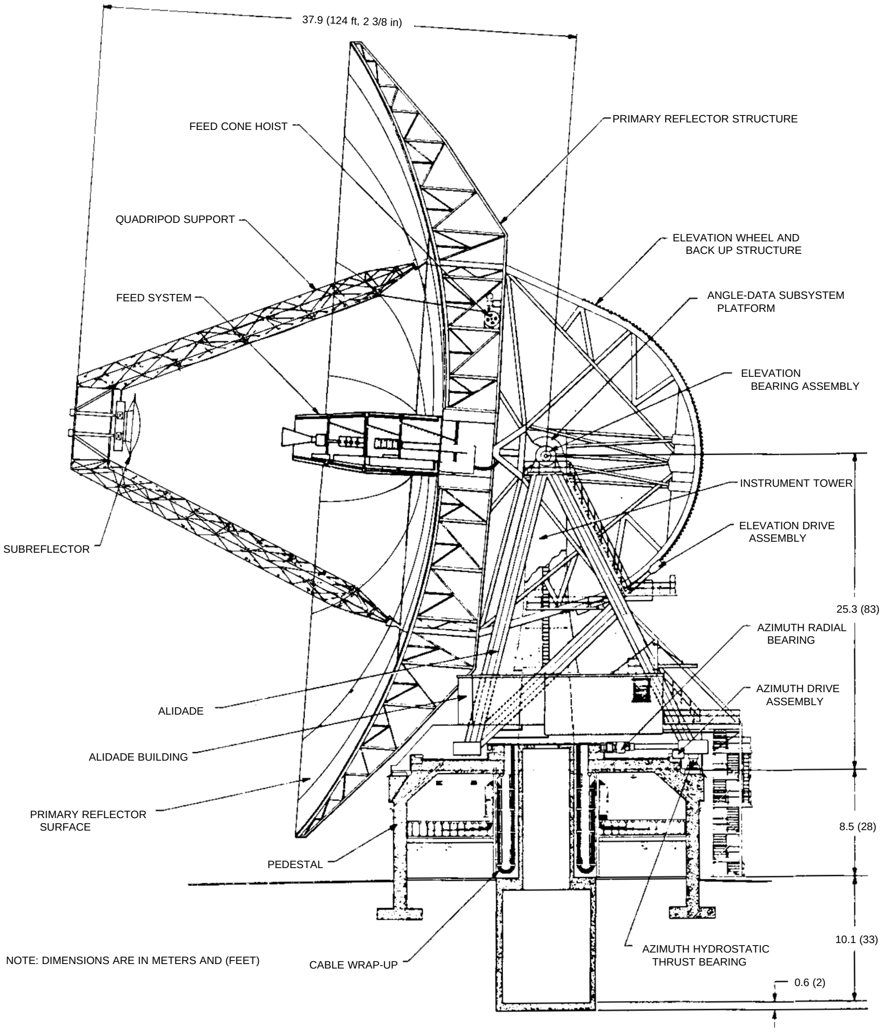


Figure 2-5. Side elevation of the 64-meter azimuth-elevation antenna at Goldstone, 1966.

Figure 2-6. The 64-meter antenna at Goldstone, 1966. The pickup truck parked to the right side of the pedestal gives an impression of the immense size of the antenna.

Designed to remain operating in wind speeds as high as 80 km per hour, the Mars antenna was constructed of massive steel beams, which, together with its pedestal, weighed about 33 million kilograms. At wind speeds exceeding 80 km per hour, the antenna was stowed in a fixed position to protect it from permanent damage. In that position it could withstand hurricane force winds. The dish, and its azimuth-elevation mounting atop the pedestal, weighed nearly 13 million kg. The structure rotated in azimuth on three flat bearing surfaces that floated on a pressurized film of oil, about the thickness of a sheet of paper. The reflecting area of the dish surface was 3,850 square meters. It could be pointed to a given position in space with an accuracy of 0.006 degree. The major structural components and dimensions of the 64-m antenna are evident in the side elevation shown in Figure 2-5.

In a single, major step forward, the Mars antenna provided the DSN with more than six times the transmitting power and receiving sensitivity of the 26-meter antennas, and more than doubled their tracking range. This was a significant new capability indeed. But, important as it was, it was only one in a series of stepwise improvements that took place in the DSN in the mid-1960s. A photograph of the new 64-meter antenna at Goldstone, taken soon after its completion in mid-1966, is shown in Figure 2-6.

Most of the credit for the conceptual design of the Goldstone 64-m antenna, the first of its kind ever built for tracking planetary spacecraft, went to a brilliant electrical engineer who had come to JPL originally in 1951 to work on missile tracking systems during the Corporal and Sergeant tests at White Sands. His name was William D. Merrick. In 1958, it was Bill Merrick who masterminded the design and construction of the first two 26-m antennas at Goldstone before taking up the job of project manager for the Advanced Antenna System. The "Hard Core" Design Team that Merrick formed to carry out the complex design and analysis task for the new 64-m antenna contained the best engineering talent in the fields of servos, microwaves, mechanical, optical, structural, civil, electrical, and hydraulic engineering, stress analysis and contract management that could be found at JPL or elsewhere.

He managed his "Hard Core" team, and the contractors who eventually built the antenna, in a somewhat unorthodox manner, but the on-time, in-budget and to-specification end result demonstrated the efficacy of his management style.

Although he insisted on high standards of performance from his people, his propensity for practical jokes and his sense of humor endeared him to those who worked on his team. Those who needed to direct or limit his activities found him difficult. He thought of himself as a person who got things done regardless of obstacles such as budget constraints, administrative orders, or alternative opinions that stood in his path. He could always find a way around them.

When the Goldstone 64-m antenna was completed in 1966, it was regarded by many who appreciated the effort that he put into it as a testament to Bill Merrick. After the 64-m antennas in Spain and Australia were completed, Merrick moved from the "hands-on" engineering, at which he excelled, to a staff position which offered little challenge for his special talents.

Bill Merrick retired from JPL in 1984 to take up a position in industry, and died at his home in Ventura, California, in 1997.

Incremental Improvements in the Network

Important as it was, the new 64-m antenna at Goldstone was only one of many improvements in technology and management that were added to the Network in the mid-1960s. Like the 64-m antenna, each change represented an incremental increase in the overall capability and performance of the Network. As Corliss put it, "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 multi-mission network. The DSN was always being upgraded, some of the steps were small, some of the others were big." Although there were many changes in many areas, some small, some large, among the most important at this time was the improvement in the DSN ranging system.

The technique of measuring the range (distance) from a reference point on Earth, to a spacecraft at lunar distance, to an accuracy of a few centimeters was one thing. To do the same thing for a spacecraft at planetary distance required a significant new technique for measurement of range. A Lunar Ranging system, known as the Mark I, was already in place in the mid-1960s. Although it was designed for the lunar missions, it had successfully tracked *Mariner 5* out to nearly ten times the distance of the Moon.

Planetary ranging, however, would require a hundredfold increase in capability. This could be achieved with new and more complex range codes transmitted to the spacecraft on the uplink, and new methods of detecting and decoding the range code retransmitted from the spacecraft on the downlink. More precise methods for calibrating the system, and for measuring time, would also be required. Two planetary ranging systems were developed in this period, one by Robert C. Tausworthe, the other by Warren L. Martin. The two systems were aptly named the "Tau" and the "Mu." In Tausworthe's design, the time delay between a pseudo-random code transmitted on the uplink and returned on the downlink was used to measure the range of the spacecraft. Martin's design used a sequential binary code, assisted by a Doppler rate-aided function to carry out the decoding, for range measurement. This design also automatically produced a type of data called DRVID, for Differenced Range versus Integrated Doppler, which allowed the range data to be corrected for the effects of charged particles along the path between spacecraft and tracking station. Together these improvements extended the performance of the Mu system to the point where high-precision ranging measurements were possible out to a range of 2.6 AU.

The Mark I, and a later Mark IA version, was used for the Lunar Orbiter and Surveyor missions in 1966 and 1967. The Tau planetary ranging system saw its first operational use on *Mariner 5* in 1967 and 1968, and an improved and more stable version of the Tau system was used from 1969 to 1971 for *Mariners 6* and *7*. Later still, the Mu ranging system appeared in the Network and was used for relativity experiments on the extended missions of *Mariners 6* and *7* in 1970.

For the accurate ranging required by the Lunar Orbiter mission, the electronic clocks at the various tracking stations had to be synchronized to within 50 microseconds of the master clock at Goldstone. In the early days, the DSIF had to rely on radio signals from WWV for station time-keeping purposes. The most accurate measurement at the time was in milliseconds rather than microseconds. Later, transportable cesium atomic clocks from the National Bureau of Standards offered improved accuracy for station time synchronization. However, this method proved to be too expensive and inconvenient for operational use. A more operationally convenient method of time synchronization using the spacecraft itself was eventually implemented for Lunar Orbiter and improved the accuracy to 20 microseconds.

As usual though, the DSN was looking for something better. It showed up in 1966 as the "Moon-bounce Time Sync" scheme. This depended upon the propagation delay of a precision timed X-band signal which was transmitted from the Goldstone Venus station to each of the overseas stations during their mutual lunar-view periods. The Goldstone Venus station acted as master timekeeper and timing signals reached the desired stations via the Moon. By 1968, the DSN was setting its clocks to an accuracy of 5 microseconds using this technique, which had been adopted for operational use throughout the Network.[8]

Driven by the rapidly increasing data rates being transmitted by the new spacecraft coming into the DSN, the capability of the ground communications system had to be expanded to permit the tracking stations to return data to JPL as rapidly as possible. More stations needed more operational voice and teletype traffic to control them. Consequently, in 1967, a new computer-based teletype communications switcher was installed in the Com Center in the SFOF and the high-speed data circuits were upgraded to carry 2,400 bits per second.

The SFOF, too, felt the pressure to keep up with the ever-increasing requirements for higher data rates on the uplinks and downlinks for the new missions. The SFOF data processing capability was expanded to three computer strings, each comprising an IBM 7044 and large disk memory for input/output processor functions, followed by an IBM 7094. The 7094 was used as the primary processor for the complex calculations related to orbit determination; it generated antenna pointing and receiver tuning predictions used for initial acquisition, calculated the parameters needed for spacecraft maneuvers, and manipulated the spacecraft tracking data generated by the DSN stations. In addition, a special system was developed to display monitor and performance data for the DSN station controllers.

Flight Project Requirements Become Formalized

By 1967, the interactions between the DSN and new flight projects needing DSN support had become very formalized. No longer were all the missions managed by JPL, where loose interdepartmental agreements would suffice to commit funds and resources to meet a specific JPL objective. Now, other NASA Centers were responsible for the spacecraft and its scientific payload, and the function of JPL was to provide the tracking and data acquisition support using the resources of the DSN. Even within the JPL institution, the changing management organization at NASA Headquarters was reflected in entirely separate funding channels for the flight project and the DSN organizations. This situation resulted in a very formal process for the presentation of flight project requirements to the DSN, and the acceptance (or rejection) of these requirements by the DSN.

NASA Headquarters insisted that these negotiations be set out in detail in two formal documents, the Support Instrumentation Requirements Document (SIRD) for the flight projects, and the NASA Support Plan (NSP) for the DSN. Before any flight project could begin to effectively design its mission, it not only had to have a signed SIRD from one office of NASA Headquarters but a signed NSP from another. With these in hand, a newly approved flight project could truly begin. In the years ahead, the relationship between the DSN and all flight projects would always be a reflection, for better or for worse, of the SIRD/NSP negotiations.

Finally, the DSN was beginning to use computer assistance to resolve mounting conflicts for station time, not only for spacecraft tracking purposes but also for station maintenance, implementation of new hardware and software, and testing time. Also, the stations were becoming much more complex, and consequently required more time for calibration, configuration and check-out prior to the start of each tracking pass. In addition, the flight projects were becoming less tolerant of station outages which depleted their hard won tracking time allocation. The persistent issue of tracking time allocations would never go away; it was ameliorated somewhat as techniques to manage it improved, but it never went away.

This was the state of the DSN when, within a very short period it found itself dealing with more spacecraft than any of its people could have imagined a few short years earlier.

The DSN Becomes a Multimission Network

Referring to this period in the history of the DSN, William Corliss wrote, "The NASA lunar exploration program absorbed the bulk of the DSN support capability during the 1966-1968 period. Surveyor, Lunar Orbiter, and the backup support provided to 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. The new 64-meter 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, although it was supporting many missions simultaneously. The DSN stations were still crowded with mission-dependent equipment and this situation was the very antithesis of a multimission philosophy."

These and other issues related to the general problem of data return from deep space are discussed by Hall, Linnes, Mudgway, Siegmeth, and Thatcher[9] and an excellent description of the growth of the DSN from inception through 1969 is given by Renzetti et al.[10]

To simplify the increasing problem and cost of accommodating the many different kinds of special telemetry and command processing equipment appearing at the tracking stations to support the various missions, the DSN developed a "multi-mission" philosophy.

Instead of each flight project bringing its own equipment (and people to operate it) to the stations, the DSN would provide a generic set of equipment capable of operating over a wide range of parameters at each station. Future projects would have to design their uplinks and downlinks to fall within the capability of the equipment provided by the DSN. That way, all flight projects could use the same set of ground support equipment, and operations costs and complexity could be reduced. With some modification, this concept has been preserved to the present time.

Its success has been largely due to the DSN policy of advanced development, in keeping the DSN capability well ahead of the flight projects' demands to use it. The DSN was able to do this by basing its long term planning on judicious forecasting of future mission requirements.

By the early part of 1968, the Lunar Orbiter and Surveyor Lander missions had been concluded. Spectacularly successful, they had returned an avalanche of lunar surface and other science data, which was assimilated into the design studies for the Apollo piloted missions.

It was not realized at the time that a DSN mission would not view the Moon again for nearly twenty-five years. In December 1992, a remarkable picture of the Moon in orbit around Earth would be captured by a spacecraft called *Galileo*, outbound on a mission to Jupiter and its satellites. By then, the DSN and the environment in which it functioned would be very different indeed.

The missions to follow over the next six years (1968–1974) would focus the DSN's attention outward to even more distant planets and to the Sun. During these years, the DSN made enormous improvements in its operational capability to meet the requirements of the new planetary missions.

New telemetry and command systems with true multimission features were added throughout the Network. Not only were these additions multimission in nature but their ability to run at higher data rates on the uplink and downlink had been increased to 16 kilobits per second for telemetry and 32 bits per second for the command link. New forms of coding the downlink data to improve the quality of the science data delivered to the flight project had also been developed.

The speed of identification and correction of problems in the Network was improved by giving station controllers better tools to monitor and control the configuration, status, and performance of remote tracking stations.

The Doppler and ranging data generated by the tracking stations and used by the flight projects for spacecraft navigation purposes was improved in accuracy and extended in range. Studies were made to better understand the disturbing effect of charged particles on the radio path between the spacecraft and the DSN antennas. Thrown off by the Sun, these particles introduce delays in the radio path and consequent inaccuracies in the navigation data. Ways of calibrating out these undesirable effects were found and put into effect.

To create a realistic operational environment to train DSN operators prior to the start of a real mission, the DSN uses a Simulation System. Electrically generated signals can be programmed to simulate a real spacecraft under a variety of flight conditions. Artificial faults can be introduced and the operations personnel can be trained in the proper reactions. With an increasing number of more complex spacecraft coming into the Network in the early 1970s, a Simulation Center was established at JPL to carry out the simulation tasks for all missions. Conversion assemblies at the stations allowed the individual stations to interact with the "SIM Center" to suit their individual training needs.

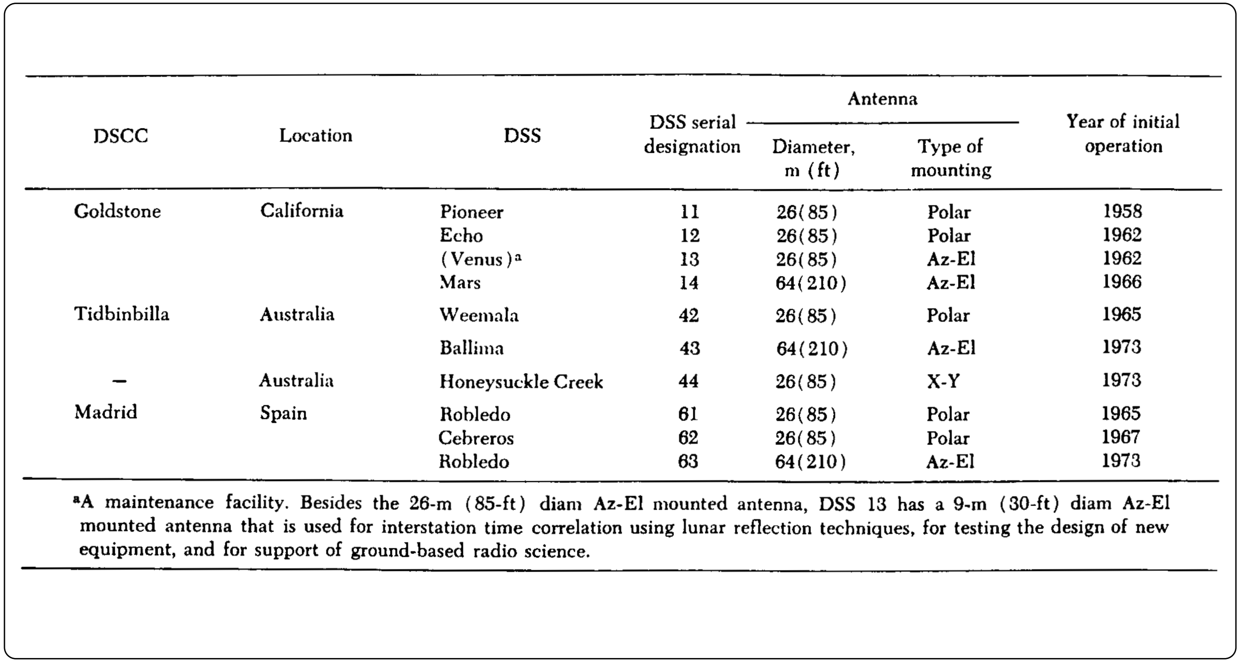
The addition of "wideband" circuits that could handle data at 50 kilobits per second between the Goldstone Mars station and the SFOF, and 28.5 kilobits per second to Spain and Australia, gave the Ground Communications Facility (GCF) as it was now called, a capability to deliver the increased volume of data from the now enhanced DSN to the SFOF. Because the existing high speed circuits, operating at 4800 bits per second, could handle much of the traffic formerly handled by teletype, the teletype services were phased out.

It had become obvious that the SFOF itself would not be able to cope with the demands of the future flight projects for data processing and handling. The data streams planned for the future Mariner and Viking missions to Mars would overwhelm the data-handling capability of the old IBM 7040/7044 generation of computers. An Advanced Data System study group recommended a completely new design for the new Mark III SFOF, which involved, among other things, replacing the old machines with new IBM 360/75s.

No longer an appendage to the DSN, the SFOF became an autonomous organization with full responsibility for supporting the flight missions. DSN responsibility in the SFOF was redefined to cover only Network control and the data processing necessary to carry out that function.

Openings and Closings

The tremendous improvement (a factor of six times over a 26-meter station) in uplink and downlink performance, afforded by the 64-meter antenna at Goldstone, was offset somewhat by the limitation of a single antenna at only one longitude. To provide the continuous coverage with high performance required by the new missions, similar antennas in Spain and Australia would be needed. The viability of the 64-meter design had already been established by the Mars station experience, and by June 1969, the Collins



DSCC	Location	DSS	DSS serial designation	Antenna		Year of initial operation
				Diameter, m (ft)	Type of mounting	
Goldstone	California	Pioneer	11	26(85)	Polar	1958
		Echo	12	26(85)	Polar	1962
		(Venus)[a]	13	26(85)	Az-El	1962
		Mars	14	64(210)	Az-El	1966
Tidbinbilla	Australia	Weemala	42	26(85)	Polar	1965
		Ballima	43	64(210)	Az-El	1973
–	Australia	Honeysuckle Creek	44	26(85)	X-Y	1973
Madrid	Spain	Robledo	61	26(85)	Polar	1965
		Cebreros	62	26(85)	Polar	1967
		Robledo	63	64(210)	Az-El	1973

[a] A maintenance facility. Besides the 26-m (85-ft) diam Az-El mounted antenna, DSS 13 has a 9-m (30-ft) diam Az-El mounted antenna that is used for interstation time correlation using lunar reflection techniques, for testing the design of new equipment, and for support of ground-based radio science.

Figure 2-7. Composition of the Deep Space Network, 1974.

Radio Company of Richardson, Texas, had been selected to build two more 64-meter antennas. To simplify logistics and support facilities, the new antennas would be built near the existing 26-meter sites at Canberra, Australia, and Madrid, Spain.

Construction of the Australian antenna began soon after and was completed in three years, without significant delays, in mid-1972. Electronics were installed and tested and, after a period of calibration, operator training, and performance demonstration tracking, the station reached full operational status in April 1973.

Although work on the Spanish antenna encountered some problems along the way, it followed a similar pattern and was declared operational in September 1973. By this time, a second 26-meter antenna had been added to each of the complexes at Madrid and Canberra.

The DSN now had two networks of 26-meter antennas plus a complete network of 64-meter antennas. They would be numbered so as to indicate the areas in which the antennas were located; 11 to 19 for Goldstone, 41 to 49 for Australia and 61 to 69 for Spain. Thus the DSN would consist of Deep Space Station 14 (DSS 14) at Goldstone, DSS 63 at Madrid, and DSS 43 at Canberra, plus the six 26-meter stations, which were similarly identified.

At each location, the number and types of antennas continued to increase. Larger buildings were built to house the hundreds of racks of electronic equipment required to control the antennas, and to transmit, receive, record, and process the spacecraft data before it could be fed to the NASCOM communication circuits for transmission back to JPL. Instead of a single antenna and a modest Control Room at each longitude, there were now several antennas, a Signal Processing Center, power station, cafeteria, laboratory, workshops, offices, and supporting facilities. The entire establishment had become a Deep Space Communications Complex (DSCC)—GDSCC for Goldstone, CDSCC for Canberra, and MDSCC for Madrid.

The new complexes at Canberra and Madrid now provided the support formerly given by Woomera and Johannesburg, both closed by NASA: Woomera for economic reasons, Johannesburg for diplomatic reasons. The composition of the Network as it existed in 1974 after these closings had taken place is tabulated in Figure 2-7.