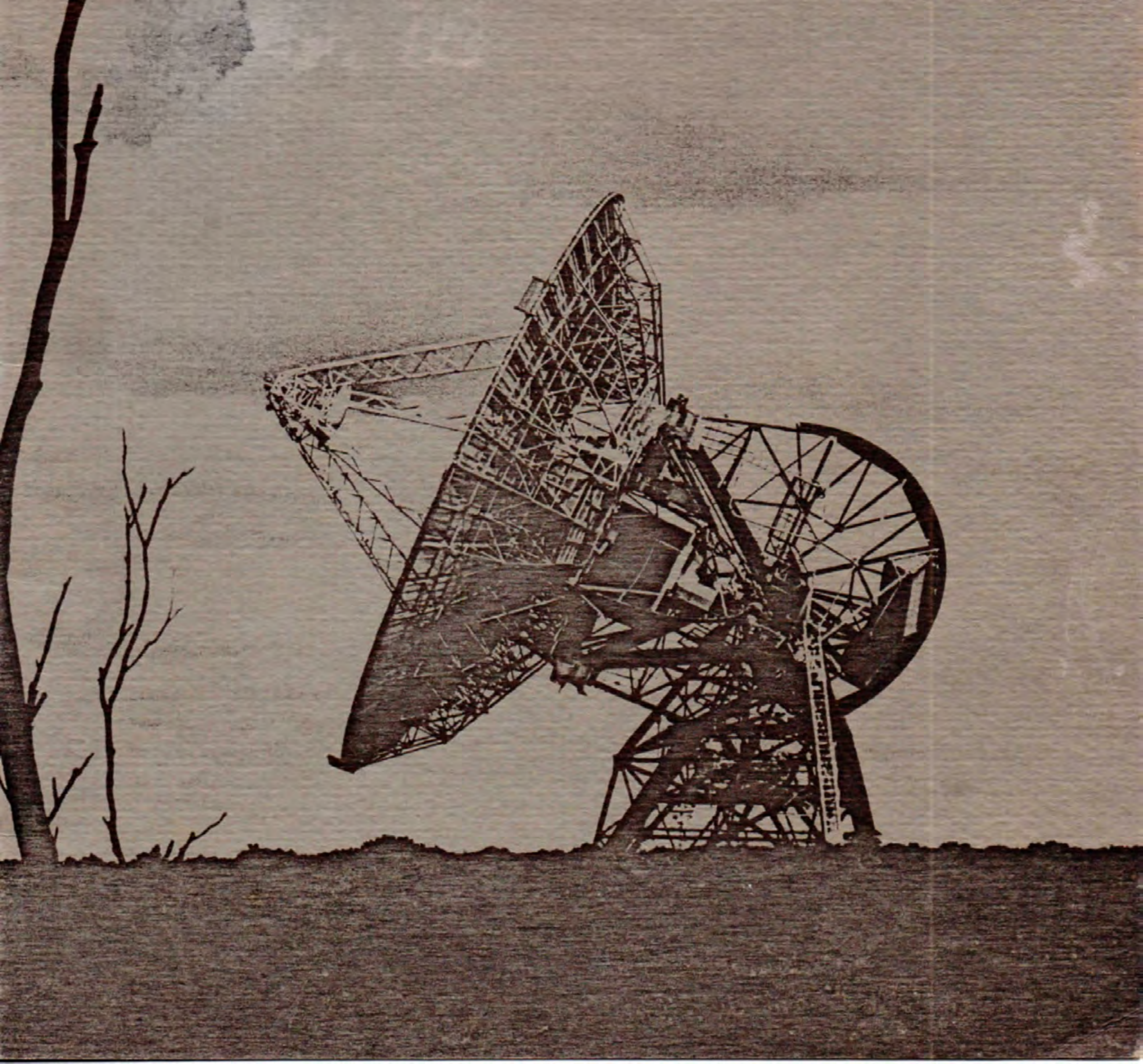
Woomera Deep Space Station



The Woomera Deep Space Station

is operated and maintained by the

Australian Department of Supply

for the

National Aeronautics and Space Administration.

The Deep Space Network

One of several world-wide data acquisition networks established by the National Aeronautics and Space Administration's Office of Tracking and Data Acquisition, the Deep Space Network (DSN) operates under the system management and technical direction of the Jet Propulsion Laboratory (JPL). It is designed for two-way communications with unmanned spacecraft at distances of more than 16,000 kilometers (10,000 miles) from Earth. The main elements of the DSN are the deep space stations based around the world; the Space Flight Operations Facility at JPL in Pasadena, California, U.S.A., which is the command and control center; and the Ground Communications Facility, which connects all parts of the DSN by telephone, teletype, and high-speed data lines.

The deep space stations are situated approximately 120 degrees apart in longitude so that the spacecraft, as Earth turns on its axis, is always in the field of view of at least one of the ground antennas. The station locations are at Woomera and Tidbinbilla, Australia; Goldstone, California, U.S.A.; Johannesburg, Republic of South Africa; and Madrid, Spain. Support facilities include a spacecraft monitoring station at Cape Kennedy, Florida, U.S.A. The stations in the U.S.A. are staffed by JPL and subcontractor personnel; the overseas stations are staffed and operated by government agencies, or their subcontractors, of the respective countries.

In addition to the Deep Space Network, the National Aeronautics and Space Administration operates other spacecraft tracking facilities, including the Spaceflight Tracking and Data Network, which comprises two formerly separate networks: the Satellite Tracking and Data Acquisition Network and the Manned Space Flight Network.

Opposite: The Mariner Venus-Mercury 1973 mission spacecraft (top left); the Viking spacecraft for the 1975 Mars mission (bottom); and the spacecraft trajectory for the Grand Tour mission (top right).

In the past, the DSN has supported the *Ranger*, *Surveyor*, and *Lunar Orbiter* lunar missions, the *Mariner*-class missions to Venus in 1962 and 1967, the *Mariner*-class Mars flyby missions in 1964 and 1969, and the continuing series for *Pioneer* spacecraft. It has also supplemented the Manned Space Flight Network for the *Apollo* lunar flights.

Missions to be supported in the decade 1970–1980 will include the *Mariner* Mars 1971 orbital mission, the *Mariner* Venus-Mercury 1973 mission, and the *Viking* Mars mission in 1975.

During the *Mariner* Mars 1971 mission, a *Mariner*-class spacecraft will orbit the planet Mars and take high resolution TV pictures and scientific measurements over approximately 70% of the planet's surface. Particular emphasis will be placed on selected areas so that time-variable features may be studied.

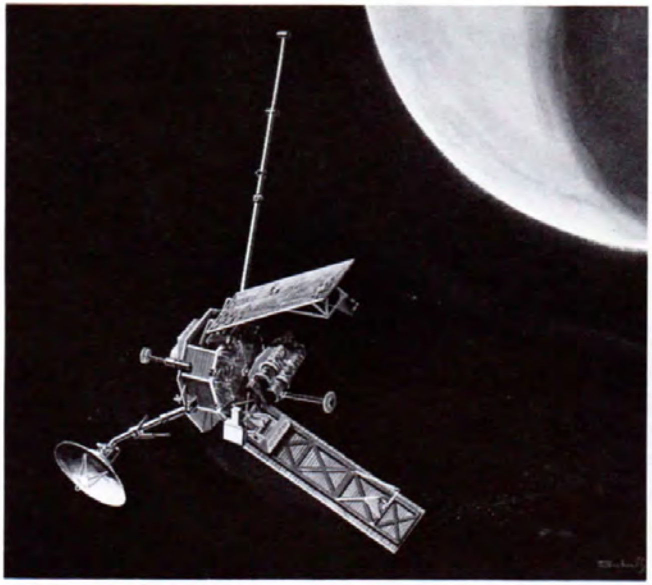
The *Mariner* Venus-Mercury 1973 Project is the first dual-planet mission to be supported by the DSN. The single spacecraft will conduct further exploratory investigations of the planet Venus, examining its environment, atmosphere surface and body characteristics during a flyby pass at a distance of about 5,300 kilometers (3,300 miles). The planetary alignment in early 1974 will permit the planet's gravitational field to accelerate the spacecraft by about 16,000 kilometers per hour (10,000 miles per hour) toward the planet Mercury, arriving there some seven weeks later. During the Mercury flyby, at a distance of approximately 1,000 kilometers (625 miles), the spacecraft will again obtain environmental and atmospheric data—the first from this planet.

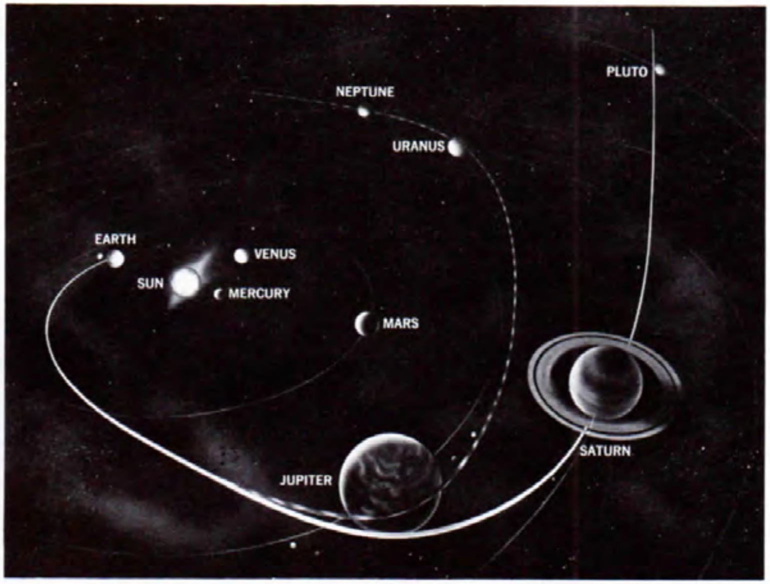
The *Viking* mission to Mars in 1975 will require the extra participation of a complete subnet of the three 64-meter (210-foot) diameter antennas situated in California, Spain, and Australia, and an overall systems ability to simultaneously command and track three separate spacecraft. The *Viking* mission calls for the launch of two composite spacecraft, each consisting of an orbiter and a lander section. After arrival at Mars, each orbiter will separate from its lander and continue a planetary mapping mission while the lander component descends to the surface. Thereafter, the landers will perform scientific observations in a manner similar to the *Surveyor* lunar missions in 1966 through 1968.

Also supported in this decade will be the Helios Solar Probe mission, a joint undertaking by NASA and the West German Ministry for Education and Science. The probe will orbit the sun at a distance of about 48 million kilometers (30 million miles).

Later in the decade, a rare alignment of all five outer planets (Jupiter, Saturn, Uranus, Neptune, and Pluto) will make possible a "Grand Tour" multiple flyby mission in which the spacecraft utilizes the gravitational field and orbital velocity of one planet as an accelerating force to travel to the next in a relatively short time. Even so, such a mission would take from seven and one-half to nine and one-half years to accomplish, and poses unprecedented problems in space communications.

The impact of space explorations is felt throughout the world, but most profoundly by those nations who actively participate in the DSN operations. They share in the jubilation and pleasure, the trials and disappointments of the various missions through an immediate association with the ground stations of the Network.

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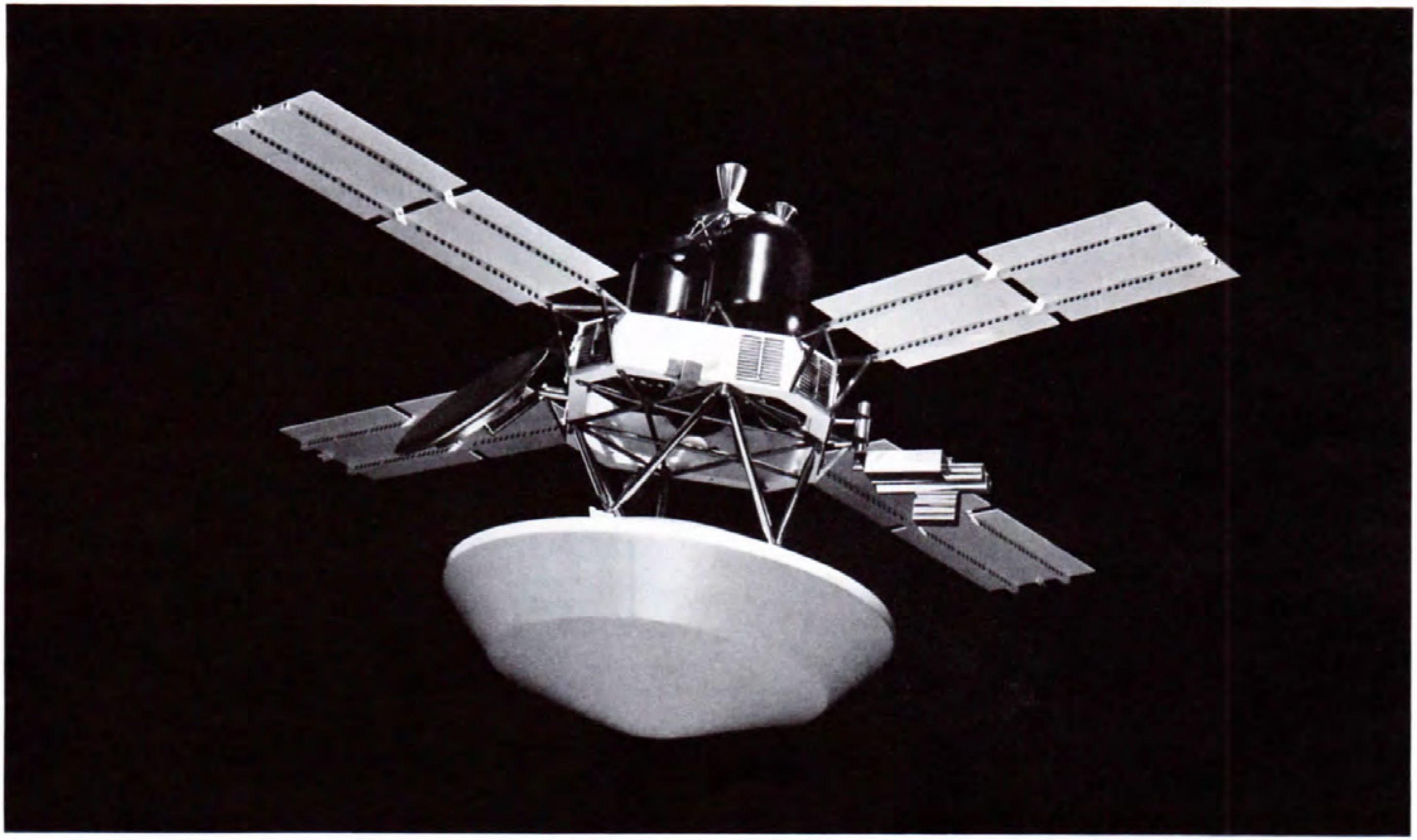
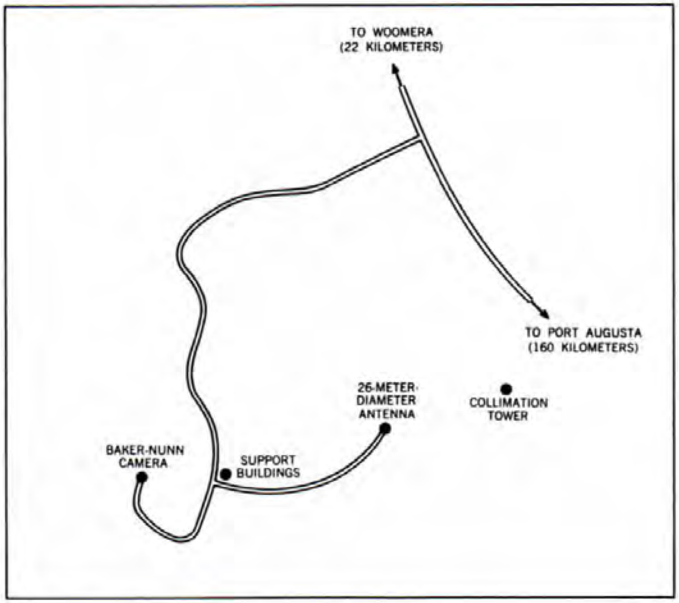


Opposite: The 26-meter-diameter parabolic antenna.

The Woomera Deep Space Station (location shown above) includes the major facilities below.

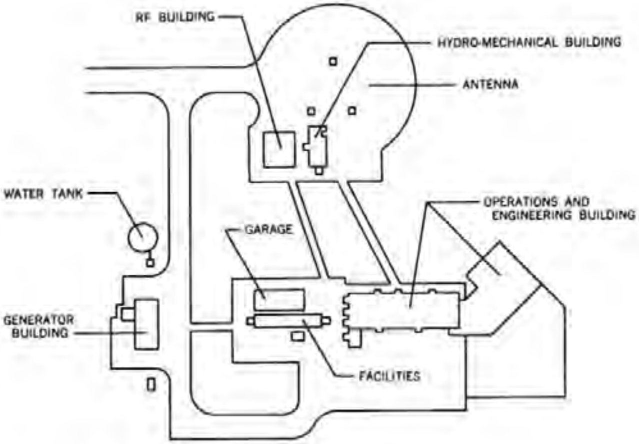


Woomera Deep Space Station

Construction of the Woomera Deep Space Station was commenced in 1960, following a cooperative agreement between the Australian and United States Governments to establish and operate deep space stations in Australia. The design and construction of the buildings were accomplished by the Commonwealth Department of Works on behalf of the Department of Supply. Basic requirements and design criteria for the station were developed in conjunction with the Jet Propulsion Laboratory. The Department of Supply, through its American Projects Branch and private contractors, is responsible for the operation and maintenance of the deep space stations at Woomera and Tidbinbilla.

Each deep space station is equipped with a polar mounted 26-meter (85-foot) diameter parabolic antenna and associated equipment for communicating with spacecraft millions of kilometers from Earth. The tracking stations must be located away from man-made electrical and commercial radio and television interference, and it is desirable that they be in natural bowl-shaped terrain to provide further shielding from interference.

A site fitting these requirements was found at Island Lagoon, about 22.5 kilometers (14 miles) southeast of the village of Woomera in the central, arid part of the state of South Australia. Known to the DSN as Deep Space Station 41, it is situated near the shores of the normally dry Island Lagoon salt lake in an area set aside by the Australian Government for space research. It has its own access roads, and its own maintenance and repair facilities. The Australian Postmaster-General's Department provides telephone and telegraphic facilities, and all power consumed on



Site plan of the Woomera 26-meter-diameter antenna with associated facilities.

the site is generated at the station. Water is obtained, as for the Woomera village generally, from a branch line of the Morgan-Whyalla pipeline from the River Murray over a distance of about 560 kilometers (350 miles). The technical staff and support personnel required for the operation of the Woomera Station are supplied by an Australian contracting company.

The major facilities at the station are the:

- Operations and Engineering Building. This structure houses the majority of the tracking, telemetry, and communications equipment, as well as space for the operations control room, and offices.
- Generator Building. This structure houses power-generating and -switching equipment.
- 26-Meter (85-Foot) Diameter S-Band Antenna and Antenna Support Building. The building contains several workshops and the hydromechanical equipment used to rotate the antenna.
- Collimation Tower and associated Collimation Equipment Building. Used for station calibration and testing purposes, these structures are located on a hill about 1.4 kilometers (0.8 miles) from the main antenna.
- 1.22-Meter (4-Foot) Diameter X-Band Antenna. This antenna is situated near the operations control room and is used to receive time synchronization signals from Goldstone, California.
- Administration Center. This center contains offices, a canteen and store, and a calibration and repair facility.
- Baker-Nunn Camera. Used for astrophysical research, this equipment is housed in a small building atop a hill 1.6 kilometers (1 mile) from the DSN buildings.

For DSN operations, the Woomera Deep Space Station performs functions in support of six Network systems. Each of these systems is designed for a specific task:

- Tracking System — Generates, transmits, and processes radio metric data to continuously update the known velocity and position of spacecraft; provides the prediction information necessary for continued contact with spacecraft.
- Telemetry System — Receives and conditions science and engineering data from spacecraft for transmission to Mission Control in the JPL Space Flight Operations Facility.

- Command System — Processes and transmits spacecraft commands originating at Mission Control in the JPL Space Flight Operations Facility.
- Monitor System — Provides the means to report on the performance of deep space station instruments; reports on the quality of transmitted and received data.
- Operations Control System — Provides the procedures, personnel, and analysis necessary for support of space flight operations.
- Simulation System — Generates and utilizes simulated data to prepare for the successful support of space flight operations.

The station's antenna operates in the radio-frequency channels allocated to the DSN. Until the completion of the *Ranger* series, these channels were located in the 890 to 960 megahertz frequency spectrum known as L-band. Present equipment operates in the S-band, transmitting to the spacecraft on 2110 to 2120 megahertz and receiving information from the spacecraft on 2290 to 2300 megahertz.

The 26-meter-diameter antenna (below), with the operations and engineering building and, on the horizon, the collimation tower.

Opposite: The village of Woomera.

Woomera Village

In 1948 the Commonwealth Government, in conjunction with the British Government, established in remote areas of South Australia and Western Australia a long-range rocket-research facility. The village of Woomera was built to provide accommodation for personnel and their families engaged in building and operating this range. Since its establishment, Woomera has grown to a thriving modern community with a population nearing 5,000. In recent years the population has grown with the addition of personnel manning the DSN station at Island Lagoon.

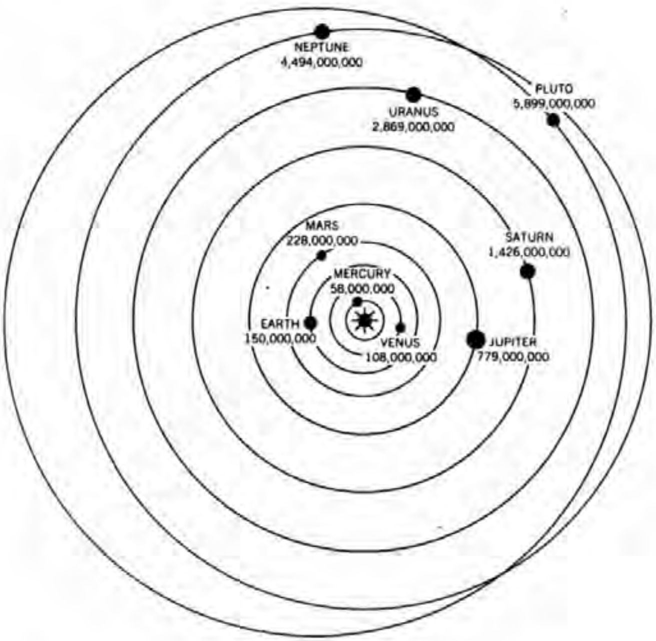
The village is situated about 480 kilometers (300 miles) northwest of Adelaide in semidesert country that is used almost exclusively for sheep grazing on large pastoral holdings. The average rainfall in the area is about 17.7 centimeters (7 inches) per year. Average daytime maximum temperatures range from 95°F (35°C) in January to 63°F (17°C) in July. Traffic avenues skirt the residential streets, and large park and public areas are within walking distance of all homes.

Public buildings at Woomera include an extensive community store and specialty shops, a hospital, a modern theatre, Protestant and Roman Catholic churches, schools, kindergartens, police and fire stations, a civic center building, and a post office. Accommodation for single persons and visitors is provided in four bachelor's quarters and a women's hostel.

Excellent facilities exist in Woomera for active recreation. The village has several tennis and squash courts, a bowling green, and a unique 18-hole golf course. Two Olympic-size swimming pools are located near the town's center and facilities also exist for basketball, cricket, football, and gliding. Baden-Powell Hall serves as a center for Scouting and related youth activities, and the village has recently acquired a youth center to supplement the Hall.

The village is administered by an Area Administrator, appointed by the Department of Supply. He is assisted by the Woomera Board, which is composed of elected residents, departmental appointees, and a permanent secretary.

Transport to and from Woomera is available by rail, road, and air. Rail service is provided by diesel railcars operating three times a week between Woomera and Port Pirie, where connection is made to Adelaide; the trip takes about eight and one-half hours. The road from Woomera to Port Augusta, a distance of 184 kilometers (115 miles), is partly graded sand and gravel and is sometimes impassable in wet weather. From Port Augusta south to Adelaide, about 320 kilometers (200 miles), the road is paved and always usable. The Department of Supply operates a regular weekday air service between Adelaide and Woomera. Advance arrangements must be made by visitors before they may enter Woomera.



Great distances are involved in communicating within the solar system. Numbers on the diagram above show the distances of the planets from the Sun, in kilometers.

Reaching Into Deep Space

Transmission and reception of intelligence over interplanetary distances would seem to call for new, exotic systems. While experimental investigations may reveal other techniques, at present the only practical means of communicating with spacecraft is through the same basic technology that brings radio and television into our homes—the generation and control of electromagnetic radiation (radio waves) through space. The magnitude of difficulty encountered with radio communication at planetary distances, however, is substantially greater than point-to-point radio communication on Earth. Allowances must be made for the great loss of energy suffered by a signal moving through the tremendous distances that it must travel.

In the brief span of DSN history, spectacular progress has been made in the evolution of antenna, receiver, and transmitter capabilities. Such progress is fast approaching the technical and theoretical limits of communication within our solar system. Present technology is capable of meeting requirements for tracking, commanding, and data acquisition at distances ranging up to hundreds of millions of kilometers from Earth. Sophisticated communications techniques have developed rapidly to meet this need. The DSN capability, measured in quantity of information per unit time, has increased from eight data bits per second in 1962 to more than 16,000 data bits per second in 1971.

To overcome space losses, the DSN uses antennas designed for high gain (or very high concentration of received signal power), radio amplifiers of extremely low-noise design and powerful transmitters that radiate very strong signals. Standard DSN ground transmitters operate at power levels of up to 10 kilowatts (10,000

The 1.22-meter-diameter X-band antenna, shown with a portion of the 26-meter-diameter antenna in the background.

watts). A spacecraft transmitter, on the other hand, is limited in power because of size and weight restrictions. Very early spacecraft (such as *Pioneer 3*) used power outputs as small as 0.2 watt; the *Mariner* 1971 spacecraft uses two redundant 20-watt high-power amplifiers. Continuing development will increase transmitter outputs for probes contemplated for exploratory missions to the edge of the solar system.

Further recent advances in digital communication techniques have resulted in the implementation of a block-coded binary telemetry system for *Mariner* 1971 and convolutionally coded for *Pioneer*. With this system, the probability of correctly interpreting the information received at a deep space station is greatly increased over that with the conventional uncoded system. Technically, in block-coded telemetry, each data bit is represented by a number of redundant symbols.

In the decade of the seventies, the problem of orbit determination for distant spacecraft will assume great importance. The success of missions planned for this period will depend, to a large extent, on the capability of precisely determining the orbital parameters of a spacecraft using radio metric data obtained from the deep space stations. Fundamental to this problem is the need for extremely accurate and synchronized time. To satisfy this need, a precision Clock Synchronization Moon Bounce System has been installed throughout the Network. The system uses a computer-controlled transmitter at Deep Space Station 13 at Goldstone, California, to send timing signals to the remote deep space stations around the world by way of an X-band coded carrier. This carrier is reflected from the surface of the moon and received at the remote station by a 1.22-meter (4-foot) diameter parabolic antenna. The system achieves a synchronization between each deep space station and the DSN master clock to within 20 microseconds. Between the world's most accurate clocks at the National Bureau of Standards and the Deep Space Network master clock, an accuracy of less than 5 microseconds has been achieved.

The well-known doppler principle has been adapted for use in determining spacecraft velocity. The principle has long been used in determining the relative speed with which a celestial body or star and Earth are approaching or receding from each other (the radial velocity). The doppler shift is the apparent change in frequency of a signal reflected from or emitted by a moving object as the object moves toward or away from the observer—much as a train whistle is high in pitch as the train approaches, then lower in pitch as it passes.

Velocities of early spacecraft were determined by one-way doppler—that is, by measuring the difference between the frequency of a signal transmitted from the spacecraft and the frequency as it is received on the ground. The difference is proportional to the radial velocity between Earth and the spacecraft. Because of the inexact knowledge of the transmitted frequency, the accuracy of the one-way doppler measurement of spacecraft velocity is limited to about 27 meters (90 feet) per second.

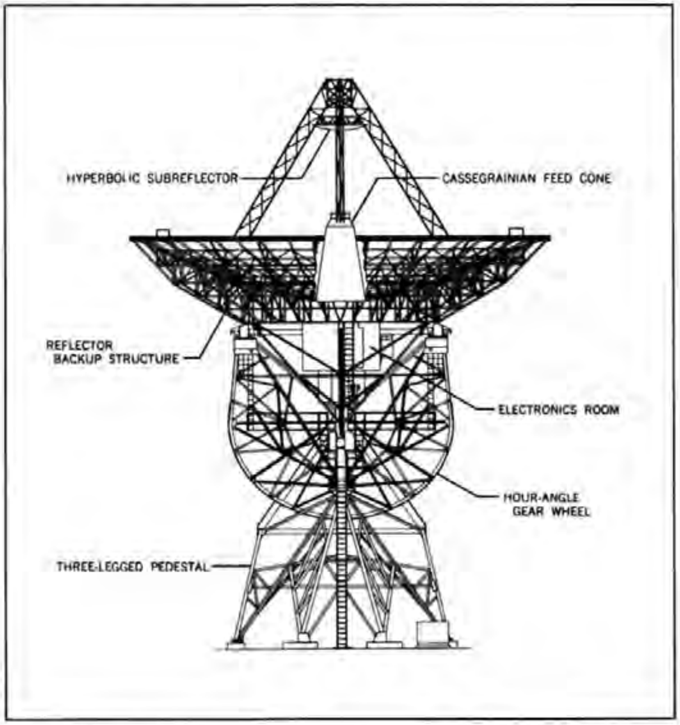
However, a two-way doppler system, developed for the DSN, has increased the velocity measurement accuracy to better than 1 millimeter (1/250 inch) per second. In two-way doppler, a signal is transmitted from the ground station to a turnaround transponder (receiver-transmitter) on the spacecraft where it is converted to a new frequency as an exact ratio of the ground frequency. The new frequency is then retransmitted to Earth. Since the frequency of the signal sent from the ground station can be determined with great accuracy, the resulting doppler information and velocity calculations are very precise. Through two-way doppler calculations alone, the position of a spacecraft near a planet several hundred million kilometers from Earth can be determined within 32 to 80 kilometers (20 to 50 miles).

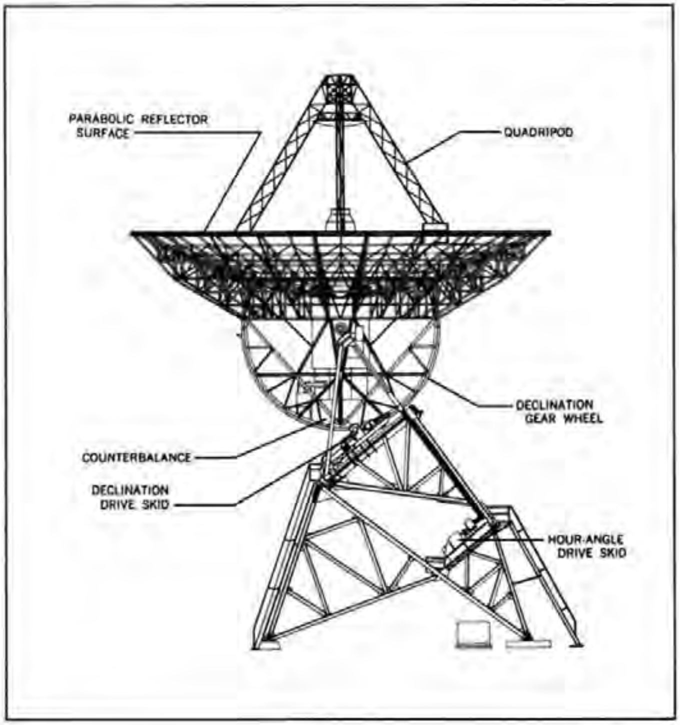
Another improvement is the JPL-developed electronic ranging system that uses an automatic coded signal in conjunction with doppler information to provide range measurements with an accuracy better than 15 meters (49 feet) at planetary distances.

Because of the doppler shift and other effects, the frequency of the signal received on the ground from the spacecraft varies widely. This means that receiver tuning must be continually changed during the reception period. All spacecraft and DSN ground receivers use a phase-lock method of signal detection to maintain an automatic frequency control, thereby ensuring that the receiver remain locked in tune with the received frequency.

DSN receivers have the ability to pick up weak signals emanating from distant spacecraft transmitters, and to separate them from surrounding electromagnetic "noises" originating, not only in Earth's atmosphere, but from lunar, solar, and galactic sources as well. Such receivers have a very low threshold. This threshold is that point at which the receiver can no longer detect the signal, just as in human hearing the threshold is the lower limit at which the ear can no longer respond to a sound. And, just as internal body sounds (such as that of blood coursing through the head) interfere with the lowest external sound discernible to the human ear, so radio receiver sensitivity is affected by internal electronic noise in the system itself. To help overcome this problem, advanced methods of ultralow-noise signal amplification have been developed. Deep space S-band receiving systems use a traveling-wave maser amplifier. The maser is basically a synthetic ruby crystal immersed in liquid helium to keep it at the very low temperature of −268.5°C (or 4.5°K) and operates with a "pumped-in" source of microwave energy to augment the strength of the incoming signal without generating significant internal system noise.

Early in this decade, a standardization program was implemented throughout the Deep Space Network and controls were introduced to ensure that similar configurations were maintained. The following pages, while describing the system installed at Woomera, also describe the standard system installed at other deep space stations.





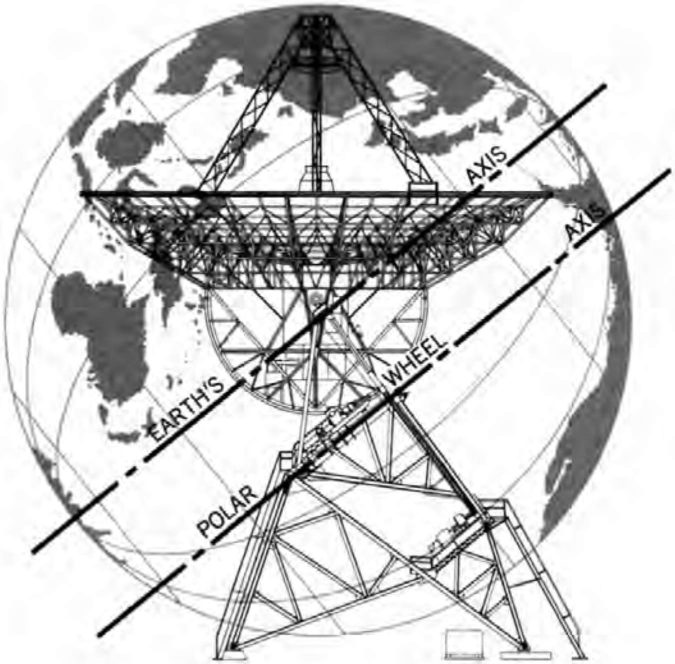
Two views of the 26-meter-diameter antenna.

The Antenna

The basic DSN antenna uses a parabolic reflector 26 meters (85 feet) in diameter. The reflector is a perforated aluminum-alloy, dish-shaped surface accurately adjusted to form a paraboloid of revolution described by the formula $X^2 + Y^2 - 48Z = 0$ (dimensions in meters).

The antenna and its supporting structure stand about 35 meters (113 feet) high and the total weight is around 272,000 kilograms (600,000 pounds). The lower part, called the pedestal, supports the large hour-angle gear wheel upon a base of three legs. The upper, smaller gear wheel (called the declination gear wheel) is carried by the hour-angle wheel and, in its turn, supports the main dish structure. Both gear wheels are accurately balanced by massive lead weights.

When a deep space probe is launched from Earth, it travels in an orbit about the sun, similar to the motions of other celestial bodies. Thus it appears to rise and set on the horizon like any other planet or star. The angular position of the spacecraft, relative to the star background, is defined by a set of imaginary circles (coordinates) very similar to the well-known Earth coordinate system of longitude and latitude. Each antenna in the DSN is oriented to a set of local coordinates, and the coordinate set is used as a reference to measure the antenna pointing angles by which the spacecraft is located. The 26-meter-diameter antennas installed at Woomera and other DSN sites use a system of polar coordinates that measure the hour angle and the declination angle of the spacecraft being tracked. Hour-angle increments represent angular direction east or west, referenced to the station's local meridian circles, and declination-angle increments represent angular direction north or south, referenced to the celestial equatorial circle.



Orientation of the polar-mounted 26-meter-diameter antenna, in which the axis of the polar gear wheel is parallel to the polar axis of the Earth.

The gear system, which moves the antenna, is polar mounted; i.e., the axis of the polar, or hour-angle gear wheel, is precisely parallel to the polar spin axis of Earth. This gear sweeps the antenna in an hour-angle path from one horizon to the other. The declination gear wheel, the smaller of the two wheels, is mounted on an axis precisely parallel to Earth's equator and accurately perpendicular to the polar axis. The axis enables the antenna dish to pivot north and south. With this axis arrangement the wheels can be moved, either separately or simultaneously, to allow the beam of the reflector to be pointed to almost any spot on the celestial sphere and remain there while Earth rotates on its spin axis.

The motion of the antenna is controlled by a servo system consisting of hydraulic pumps and motors, gear reducers and pinions that engage the antenna wheel gears. Separate servo systems drive the polar wheel and the declination wheel. Pumps in the hydro-mechanical building send high-pressure hydraulic fluid through stainless steel pipes up to the driving motors on the antenna. Electronic control equipment and antenna-positioning readout equipment are located in the control room.

Pointing the Antenna

The antenna, like the old-fashioned ear trumpet, receives most strongly the signals coming from a point directly in front of it. Therefore, it is necessary to keep the antenna pointed in the direction of the space vehicle to receive its signals. To accomplish this, the servo system of the Woomera Deep Space Station normally operates in an automatic mode. In this mode, the spacecraft signal is used to derive the angle error information to lock the antenna onto the spacecraft. Pointing angle information is calculated by sophisticated computers in the JPL Space Flight Operations Facility at Pasadena and supplied to the station in advance, thereby assisting the servo operator as he manually drives the antenna to initially acquire the space vehicle's signal. Thereafter, the antenna automatically follows the spacecraft across the sky as Earth rotates.

As the spacecraft travels further away from Earth in its trajectory around the sun, the signal received by the DSN antennas gradually diminishes. Eventually, the task of directing antenna movement must be taken over by a computer located in the deep space station control room. Pointing-angle information is fed into the station computer prior to the desired tracking time and it responds by calculating and updating the required pointing angle 50 times every second. The antenna is driven to these angles so that a smooth continuous track of the spacecraft is obtained.

Since loads carried by the antenna over a period of time can cause deformation of the antenna structure, the deformations must be known so that the true pointing angle of the antenna beam may remain constant. Testing and adjustment of the antenna alignment and operation is carried out by a series of tests, utilizing equipment housed at a collimation tower situated on a hill 1.4 kilometers (0.8 miles) from the antenna. At the collimation tower a test antenna, a transmitter-receiver unit, and an optical target, together with a television camera mounted on the main antenna, permit accurate collimation of the optical and radio-frequency boresights. The television camera package is also used from time to time to track stars over extended periods; this allows for an accurate calibration of the antenna angle sensors (encoders) and for pointing accuracy verification.

Equipment producing radio energy to simulate the spacecraft signal is mounted in the collimation tower. This equipment is used to calibrate and check the performance of the main antenna and its associated electronic systems.

Telemetry and monitoring computers in the Woomera Deep Space Station control room.

Receiving a Signal From the Spacecraft

The collecting surface of the antenna dish, 557 square meters (6,000 square feet) in area, reflects the incoming extremely weak radio signal from the distant spacecraft toward the focal point of the paraboloid, 11 meters (36 feet) above the center of the dish. Just before reaching this point, however, the signal is reflected again by a small subreflector dish formed in the shape of a hyperboloid. The subreflector focuses the signal into a feed horn located in the Cassegrainian cone in the middle of the main dish. From the feed horn to the low-noise maser amplifier, the signal is carried by only a few meters of S-band wave guide ducting; thus maximum amplification of the signal occurs before it is contaminated by the electronic noise in the rest of the receiver system.

Immediately below the Cassegrainian cone and underneath the structure of the main dish is the upper electronics room. This room houses equipment that converts the incoming S-band signal to a 50-megahertz frequency. At this frequency the signal can be passed over several hundred meters of special low-loss coaxial cable down to the receivers located in the control room. The receiver has four separate input channels, two reference channels (called sum channels) for doppler information and spacecraft telemetry, and two angle channels that carry angle-tracking signals for utilization in the antenna autotrack mode.

Receivers in the Woomera control room, with station director's console in the foreground.

Computers that process the spacecraft signal into usable information.

Translating the Signal From the Spacecraft

As each new generation of spacecraft is designed and flown, new requirements are made on the telemetry systems. The demand is always for more information from the spacecraft. To provide for this demand and to increase the data reliability under conditions of increasing difficulty, the multimission telemetry system has been implemented throughout the Deep Space Network, including the Woomera Station.

Prime telemetry signals from the spacecraft, in pulse-code modulated form, that appear on the receiver sum channel are either time- or frequency-multiplexed, or, more likely, both. That is, the composite commutated telemetry signal is carried on one or more subcarriers. For the *Mariner* series of spacecraft there are two, sometimes three, separate subcarriers—one for spacecraft engineering data and one (or two) for the scientific experimental data. This composite signal is divided into its separate component streams by subcarrier demodulator assemblies—one for each subcarrier frequency.

The subcarrier demodulator assemblies send the integrated digital serial data stream to computers in the control room that examine the serial bit stream for known groups of bits called synchronization words. Once these are detected and "locked on to," the computer can then format or arrange the remaining bits into recognizable spacecraft or scientific component values. Some of these selected spacecraft telemetry data words are displayed at the station as they are received as an aid for operations personnel in maintaining contact with the spacecraft.

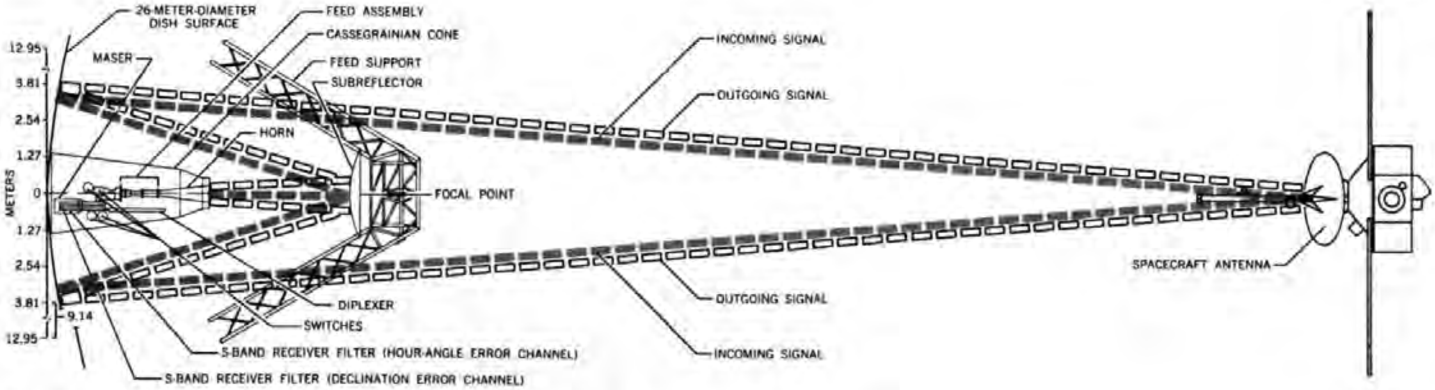
The prime, formatted data are then sent via high-speed data lines to the Network and Mission Control Centers in the JPL Space Flight Operations Facility at Pasadena,

Typical network control activities in the Space Flight Operations Facility, Pasadena, California, where formatted data are received from the deep space stations for study, analysis, and mission control.

where they are separated and distributed among engineers and experimenters for study and analysis and real-time mission control. The JPL Facility, as the nerve center for mission and DSN operations, processes data from all deep space stations in this manner. Final evaluation of the data may take months or even years.

In case the communication link between the Woomera Station and the JPL Space Flight Operations Facility fails, all data are recorded on magnetic tape recorders at least twice before leaving the station. This ensures that all vital data, transmitted from the spacecraft and recorded on Earth, are recoverable.

In addition to the telemetry system, values for antenna position, range, time, and doppler are periodically recorded. Such information, identified as radio metric data, is immediately passed on to the Space Flight Operations Facility upon generation.



The Cassegrainian feed system is the focal point for receiving and sending signals. The diagram shows how incoming and outgoing radio waves travel through the system.

Sending a Command to the Spacecraft

Changes to the trajectory of a deep space probe are implemented by transmitting command signals that initiate roll, pitch, and yaw maneuvers at predetermined times. These are followed by timed ignition and propulsion sequences. The appropriate commands to be sent to the spacecraft are determined by the computations made from radio metric data. Signals are also sent to the spacecraft to change data rates, change the type of data being transmitted, turn the spacecraft transmitter on or off (or change its power), or even switch spacecraft antennas, receivers, or transmitters.

Because an incorrect command could result in possible damage to the spacecraft or loss of critical data, extreme precautions are taken to ensure accuracy. Early missions, prior to 1971, used a variety of command methods and, consequently, the ground equipment required has varied from mission to mission. Apart from the high costs in equipment value, and in training and installation time, this approach has also limited the deep space station's flexibility. Now, however, a multimission command system is in operation that will handle all present and projected missions under almost wholly automatic control of the JPL Space Flight Operations Facility at Pasadena.

Commands are sent to the Woomera Station in digital form, via a high-speed data link, directly to a computer in the station's control room. They are checked for errors automatically upon reception and a verification message is sent back, almost immediately, to the Space Flight Operations Facility. Multiple commands, stored in the station's computer, may be transmitted at any required time. During transmission, the command "word" is again checked bit-by-bit. If an error is detected, an automatic abort sequence is initiated and the spacecraft ignores the command.

The command word output from the computer is impressed on the subcarrier in analog form and passed to an exciter where power is raised to a level of a few watts. It is then boosted to a radiated signal level of 10,000 watts by a high-power klystron situated in the upper electronics room immediately below the antenna dish.

The high-power radio signal then passes through a diplexer (a device allowing the reception and transmission of signals simultaneously), enters the S-band microwave horn, and is reflected and collimated by the Cassegrain reflector surfaces into a thin beam of radio-frequency energy that eventually illuminates the spacecraft millions of kilometers away. Receivers on board the distant spacecraft receive the radiated signal, and other spacecraft subsystems decode the command. Commands may be acted upon immediately, or stored in a small spacecraft computer for execution at some later time.

Internetwork Communications

Communications are established between the Woomera Deep Space Station and the JPL Space Flight Operations Facility at Pasadena by teletype, voice, and high-speed data links. These links are part of the world-wide National Aeronautics and Space Administration Communications Network, which is dedicated to the transmission of operational traffic. This network consists of the circuits, terminals, and switching equipment interconnecting all the DSN stations with the Network and Mission Control centers located in the Space Flight Operations Facility.

The basic complement of circuits required for all Deep Space Stations is two voice/data circuits plus four teletype circuits. All teletype traffic is transmitted at the rate of 100 words per minute and all high-speed data channels operate at the standard rate of 4800 bits per second.

All communications to and from the Deep Space Stations at Woomera and Tidbinbilla pass through the NASA Communications Network Switching Center in Canberra. The data link between Canberra and the Communications Network headquarters in the Goddard Space Flight Center at Greenbelt, Maryland, is achieved by a combination of undersea cables, when available, and communications satellites, where practicable. Between Goddard and the Space Flight Operations Facility, the data are carried by a system of microwave links. Administrative messages are transmitted by the Woomera Deep Space Station via 100 word-per-minute teletype.

The teletype medium provides the primary means of transmitting radio metric data from the deep space stations to the Space Flight Operations Facility, and for sending other operational information from the Space Flight Operations Facility to the deep space stations. Prime telemetry, monitor, and command verification data to the Space Flight Operations Facility, however, are transmitted via the high-speed data channels. The same channels are used in the reverse direction for the transmission of simulation data, predictions, and spacecraft commands.

Communications room at the Woomera Deep Space Station.

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