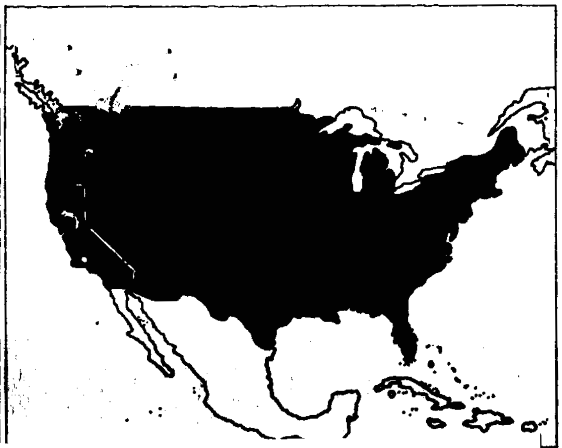
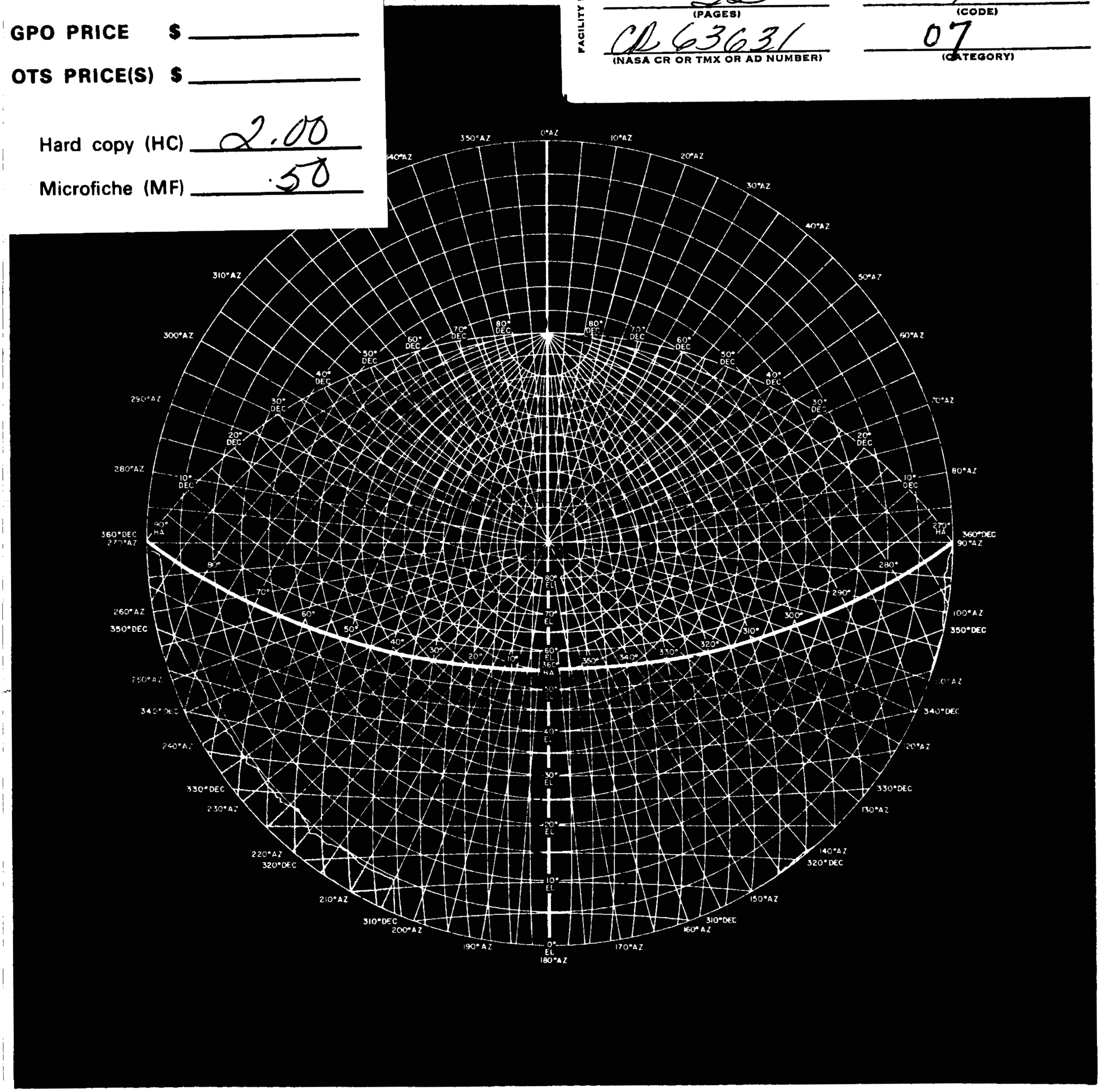


DSIF: GOLDSTONE



FRONT COVER: *A stereographic projection of the local coordinates used at the Goldstone Echo Station to define antenna-pointing angles for locating the spacecraft.*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JPL TECHNICAL MEMORANDUM No. 33-205

DSIF: GOLDSTONE

JET PROPULSION LABORATORY / CALIFORNIA INSTITUTE OF TECHNOLOGY

Foreword

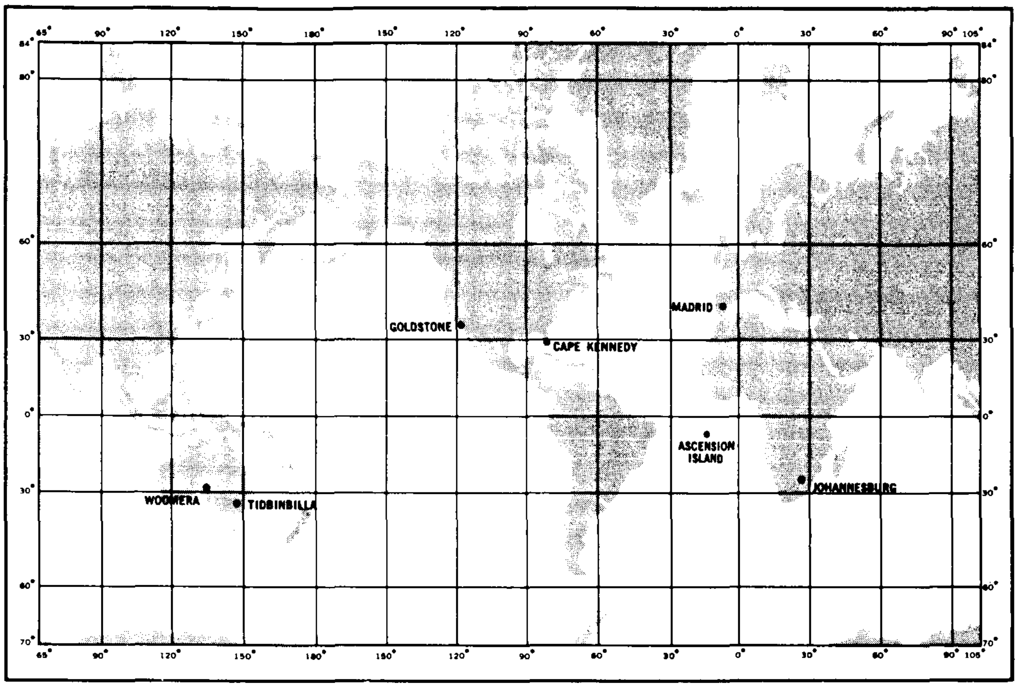
An essential part of every National Aeronautics and Space Administration (NASA) space flight project is the communications system which returns data from the spacecraft to its home base and transmits instructions from Earth to the spacecraft. The Jet Propulsion Laboratory (JPL) pioneered the development of many of the critical elements of communications systems designed to function over the vast distance involved in cislunar and interplanetary missions. In 1958 the Laboratory first established a three-station network of receiving stations to gather the data from the first U.S. Earth-orbiter *Explorer I.* Since that time, the network has developed into the Deep Space Network (DSN) specifically designed to communicate with space probes traveling to the Moon and beyond.

The DSN has many outstanding accomplishments to its credit. Included among these are radar observations of several planets, tracking the *Mariner* mission to Venus, and receiving the television photographs from *Ranger.* The capabilities of the Network are continuously being improved in order to keep up with the demands of the more complex deep space missions undertaken by NASA.

This Technical Memorandum is one of a series which describes the facilities and functions of the various major elements of the Deep Space Network.

W. H. Pickering
Director, Jet Propulsion Laboratory

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration



DSIF stations circle the globe at intervals of 120 degrees in longitude to maintain continuous coverage of the spacecraft.

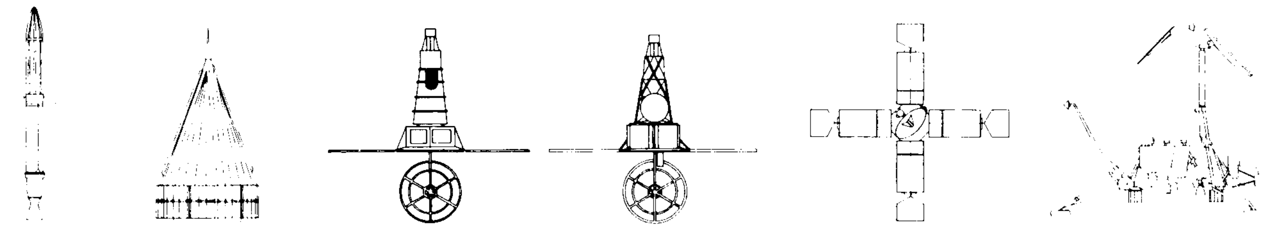
The Deep Space Network

The Deep Space Network is a facility of the NASA Office of Tracking and Data Acquisition, under the system management and technical direction of the Jet Propulsion Laboratory. The main elements of the DSN are the Deep Space Instrumentation Facility (DSIF), with space communication and tracking stations based around the world; the Space Flight Operations Facility (SFOF) at JPL in Pasadena, the command and control center; and the Ground Communication System, which connects all parts of the DSN by telephone and radio-teletype.

The Deep Space Network is to be distinguished from other NASA networks such as the Scientific Satellite Network, which tracks Earth-orbiting scientific and communication satellites, and the Manned Space Flight Network, which tracks the manned spacecraft of the *Gemini* and *Apollo* programs. The DSN is the NASA facility for two-way communications with unmanned space vehicles traveling 10,000 miles from Earth, and beyond, into the great distances of interplanetary travel.

The DSIF stations are situated approximately 120 degrees apart in longitude so that the spacecraft is always within the field of view of at least one of the ground antennas. The primary station is at Goldstone, California. The other stations are at Johannesburg, Republic of South Africa; Woomera and Tidbinbilla, Australia; Madrid, Spain; and Ascension Island, South Atlantic Ocean. Support facilities include a spacecraft monitoring station at Cape Kennedy, Florida. JPL operates the U.S. stations and the Ascension Island station; the overseas stations are staffed and operated by government agencies of their respective countries, with the assistance of U.S. support personnel.

The impact of U.S. space ventures is felt throughout the world, but most profoundly by those nations who actively participate with the United States in DSIF operations. They share in the trials and triumphs, as well as in the burden of spacecraft tracking, communication, and command that falls on the ground stations.



EXPLORER PIONEER RANGER MARINER II MARINER IV SURVEYOR

Mission Support

In preparation for increasingly accelerated U.S. activities in space, the Deep Space Network has developed the capability of controlling operations of as many as four spacecraft in flight at the same time, and advanced communication techniques that make the prospect of probes to planets as far out as Jupiter within the realm of possibility.

The DSN supports the following space exploration projects for which JPL is responsible:

Ranger. A series of TV-picture-taking missions to different areas of the Moon to collect preliminary information for scientific studies of possible landing sites for the NASA manned lunar program.

Surveyor. A soft-landing of instrumented craft on the Moon capable of performing operations to contribute new scientific knowledge about the lunar surface and to make final tests in support of the *Apollo* program.

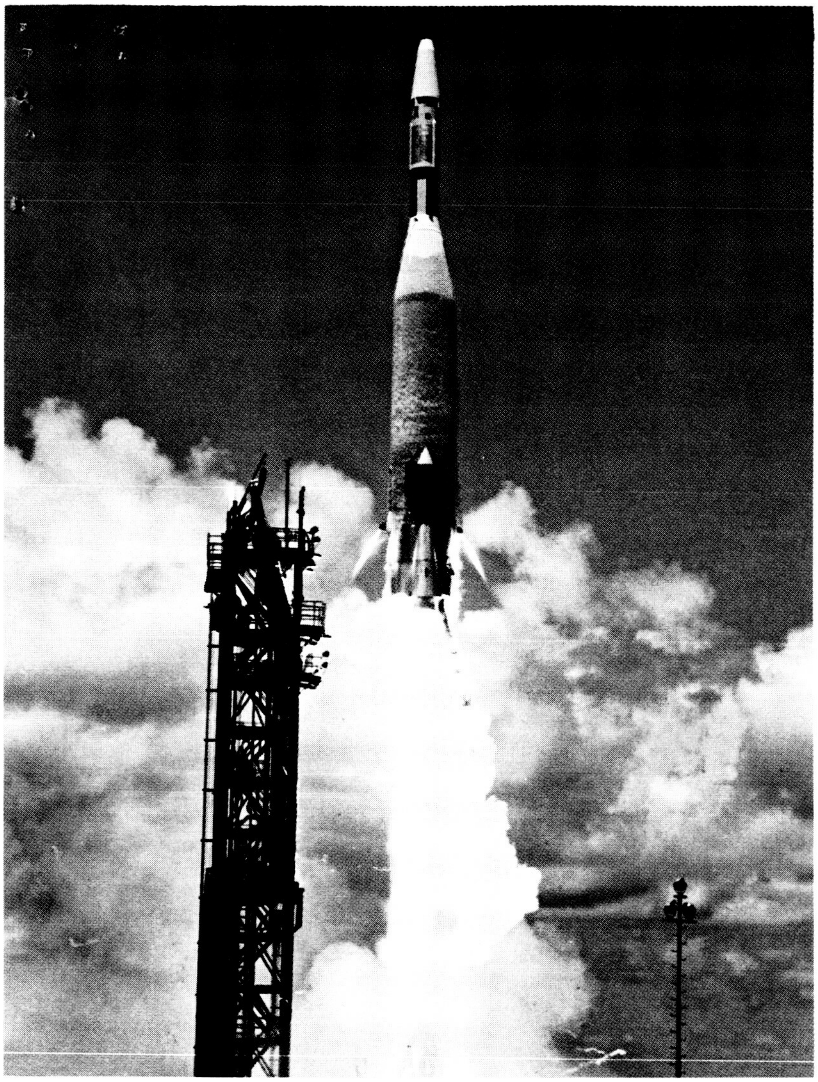
Mariner. A flyby mission to Mars during the 1964–1965 Mars opportunity to take TV pictures of the planet's surface, make radiation and magnetic fields and particles experiments, and provide basic knowledge of spacecraft performance in long-duration flights to interplanetary distances.

The DSN also supports the following missions for which the NASA agency identified with each is responsible:

Lunar Orbiter (Langley Research Center). A photographic mission to take TV pictures of the lunar surface from a satellite spacecraft.

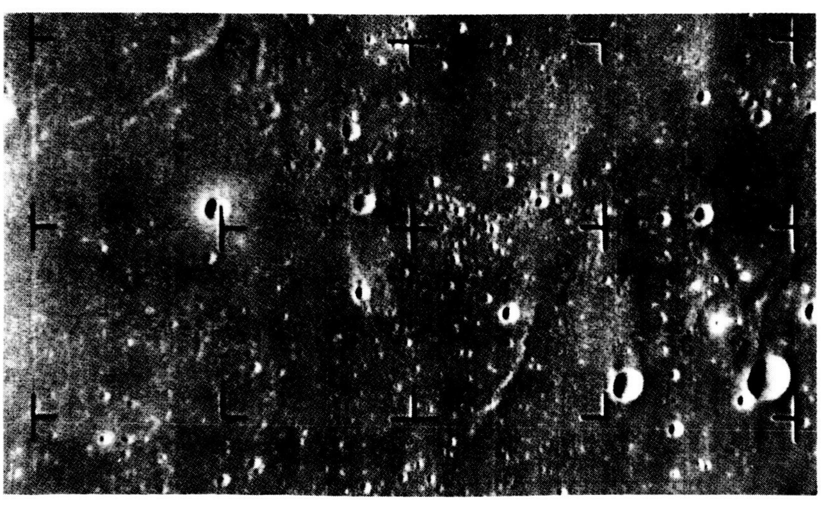
Pioneer (Ames Research Center). A new series of *Pioneer* probes designed to penetrate deep into our solar system to learn more about the nature of solar flares and other deep space phenomena.

Apollo (Manned Spacecraft Center). The manned spacecraft mission that will put men on the Moon.



Ranger VII, atop an Atlas-Agena rocket, is launched from Cape Kennedy on its historic TV-picture-taking mission to the Moon.

Control room at Goldstone awaits the first TV signals from Ranger VII.



Photograph of lunar surface, recorded by Ranger VII cameras at an altitude of 85 miles, shows craters as small as 500 feet in diameter.

FACING: *Nestled in natural bowl-shaped terrain in the Mojave Desert, the Goldstone Space Communication Station is shielded from man-made noise that would interfere with the sensitive antennas.*

RIGHT: *Goldstone administration building at Echo Station.*

Goldstone Space Communications Station

When NASA assigned responsibility to the Jet Propulsion Laboratory for the unmanned exploration of the Moon and planets in our solar system, the problems implicit in the assignment were awesome. Aside from designing and building the spacecraft itself, JPL had to solve many problems in extending knowledge in the arts of telecommunications and tracking. While research in sophisticated techniques of space age telecommunications had been going on as early as 1954, little experience existed in dealing with the practical problems of following a spacecraft traveling 10,000 miles or more from Earth, maintaining communication contact, and capturing radio waves generated from the far reaches of space. What the problem amounted to was designing and building a space broadcasting and receiving station here on planet Earth.

After the Space Act of 1958 accelerated U.S. plans and programs for space exploration, JPL engineers started work on the first station of what is now known as the Deep Space Instrumentation Facility. In deciding where to build the station, two important stipulations had to be considered: The location had to be far from man-made electrical and commercial radio and television interference such as would occur near metropolitan centers. It would also be desirable to have a natural bowl-shaped terrain to provide further shielding from interference.

A suitable site was found in the heart of the Mojave Desert in California, located about 45 miles from the town of Barstow on land that belongs to Fort Irwin. Through NASA leasing arrangements with the U.S. Army, the Jet Propulsion Laboratory has use of a 68-square-mile plot for the Goldstone facility, named for nearby Goldstone Dry Lake. Goldstone today consists of four separate stations—Pioneer, Echo, Venus, and Mars, named for the projects in which they first participated. Each station has its own antenna and tracking system; the Mars station has one of the world's most advanced antenna systems, which is capable of reaching not only to the planet Mars but to the edge of our solar system.

The original Goldstone station, Pioneer, was ready in time to track the *Pioneer III* mission in December 1958. Since then, Goldstone has contributed to such notable U.S. deep space achievements as *Pioneer IV*, the first U.S. probe to reach Earth-escape velocity and the first to be successfully tracked beyond the Moon; *Pioneer V*, tracked out to over 3 million miles; and Project *Echo*, the first experiment in using passive communication satellites. Goldstone radioed commands to *Mariner II*, the 1962 mission to Venus that established a number of historic milestones in space flight: the first successful mid-course maneuver of a spacecraft directed from Earth; the first successful scan of another planet; and the first successful data transmission at a distance of more than 54 million miles. And it was at Goldstone that the TV signals from the *Ranger VII* mission were received and recorded that gave the world its first close-up photographic coverage of the Moon's surface—the first step toward landing men on the Moon.

FACING: *Map shows location of the four antenna stations at Goldstone clustered in a 68-square-mile desert area accessible by main highway from Barstow, California. Nearby Goldstone Dry Lake serves as a landing strip for light aircraft. A few miles distant is the NASA Scientific Satellite Network for Earth satellites.*

Goldstone is a self-sufficient facility, with its own roads and its own power and telephone systems, and is equipped to conduct its own maintenance and repairs. A highway from Barstow provides motor vehicle access to the station complex. Nearby Goldstone Dry Lake is used as an airstrip for light aircraft that provide daily JPL shuttle service from Burbank to Goldstone.

The permanent buildings at the station are predominantly constructed of cement block and concrete — materials suited to the temperature and local conditions of the California high-desert area. These buildings, which contain the personnel facilities, offices, laboratories, and operations control rooms, are all air-conditioned. Prefabricated metal buildings used for heavy mechanical equipment, generators, and transportation facilities are gradually being replaced by concrete structures.

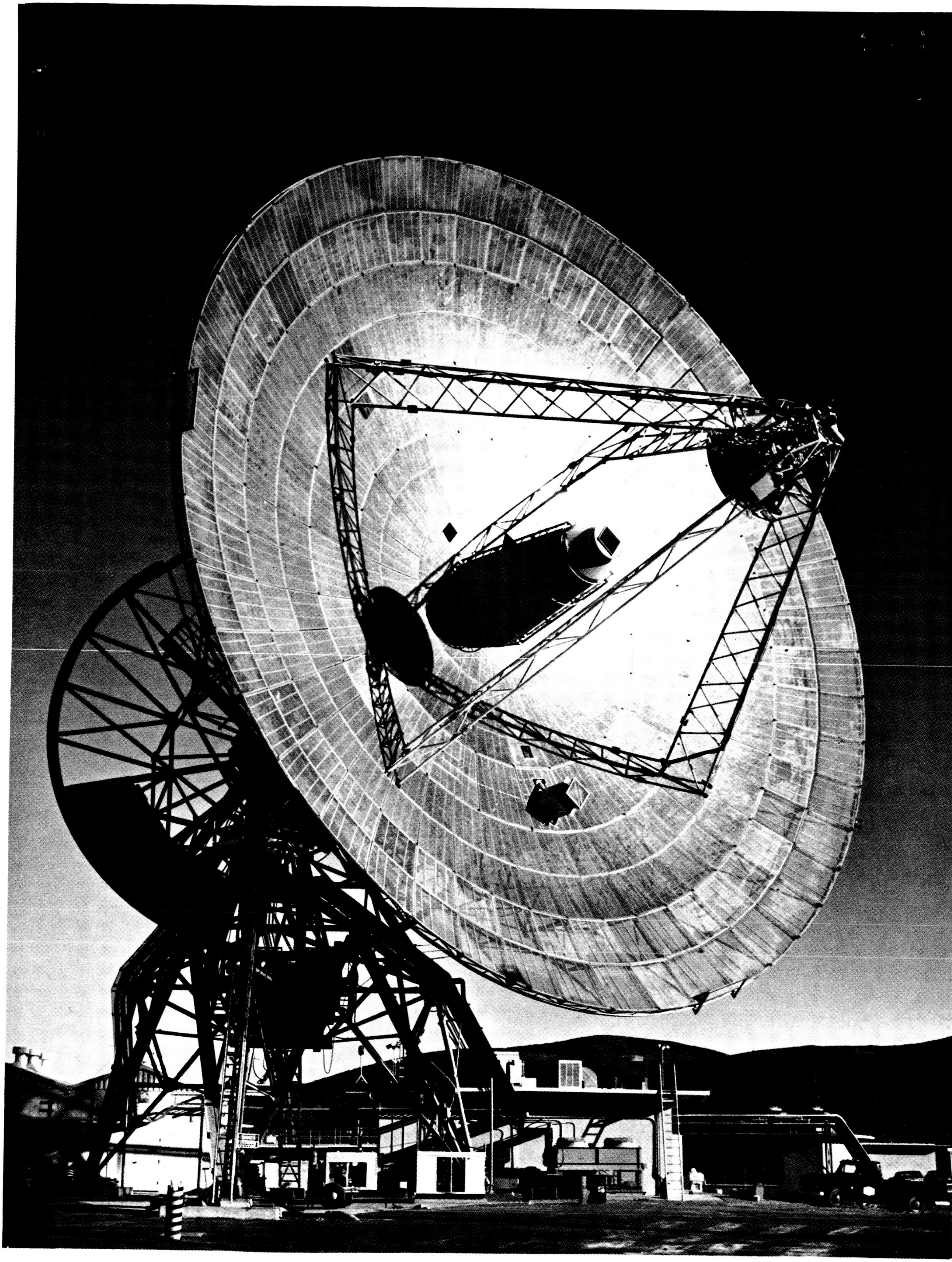
Goldstone is operated by the Jet Propulsion Laboratory, assisted by subcontractors from private industry who provide the technical staff and maintenance personnel to operate the tracking facilities up to seven days a week as required.

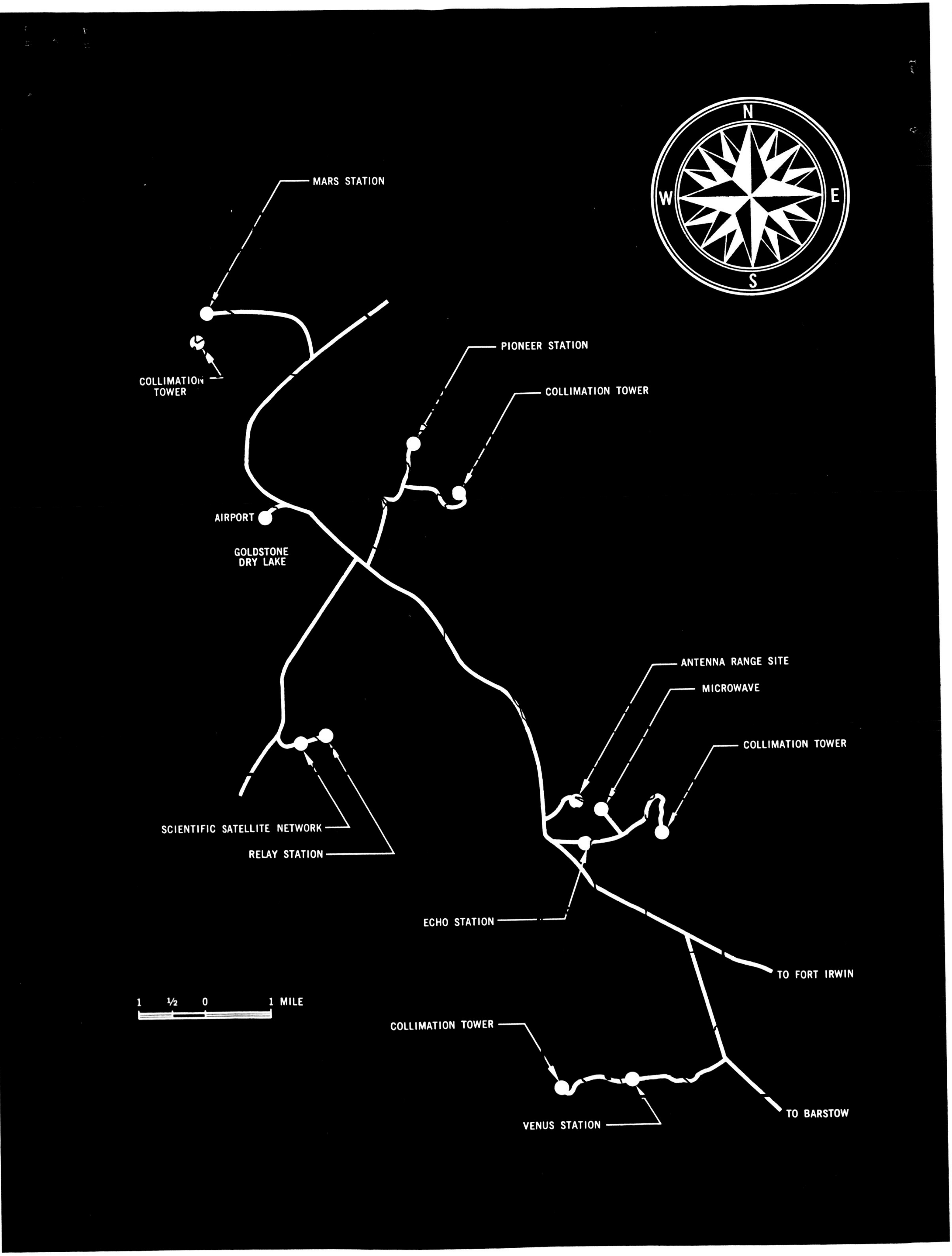
In DSIF operations, Goldstone performs the functions of *tracking*—locating the spacecraft, measuring its distance, velocity, and position, and following its course; *data acquisition*—gathering information from the spacecraft; and *command*—sending instructions from the ground that guide the spacecraft in its flight to the target, tell the spacecraft when to perform required operations and when to turn on the instruments for performing the scientific experiments of the mission.

Goldstone is also the research and development center to extend the communication range and increase data-acquisition capabilities of the DSIF. It is the proving ground for advances in DSIF techniques, and prototypes of all new equipment are thoroughly tested at Goldstone before being duplicated for installation at overseas stations. Such equipment is called Goldstone Duplicate Standard (GSDS). The aim of GSDS is standardization of the major part of all DSIF equipment to ensure uniform high performance throughout the net, reduce the cost of spares, and establish standards of training, maintenance, checkout, and countdown procedures. Prior to shipment overseas, GSDS equipment is normally field-tested at Goldstone. Personnel at Goldstone also serve as consultants and troubleshooters for the DSIF network.

Each space flight project requires equipment and accommodations unique to that project, dependent upon the type of command system to be used and the type of telemetry system the spacecraft will carry. Sometimes this may just mean a rearrangement of station equipment. When tailor-made equipment is required by a project, it is supplied to the station by the responsible project organization, and arrangements are made in advance for the equipment to be integrated with the normal complement of station equipment.

Recently, for technical reasons, the DSIF received approval to operate at a higher radio-frequency range. The changeover required major modification of equipment and procedures at all stations. The new frequency band, called the S-band, ranges from 2110 to 2120 Mc (million cycles per second) for transmission of commands from Earth to the spacecraft, and from 2290 to 2300 Mc for receiving signals from the spacecraft. The formerly allocated frequencies, called the L-band, were 890 Mc for Earth-to-spacecraft transmission and 960 Mc for spacecraft-to-Earth transmission.

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MICROWAVE
COLLIMATION TOWER
SCIENTIFIC SATELLITE NETWORK
RELAY STATION
ECHO STATION
TO FORT IRWIN
1 ½ 0 1 MILE
COLLIMATION TOWER
VENUS STATION
TO BARSTOW

FACING: *With the aid of antennas designed to detect the faintest of radio signals, man can listen to messages relayed from space.*

Reaching Into Deep Space

The only truly practical means known today of communicating with spacecraft at deep space distances is the same basic technology that brings radio and television into our homes — radiation of electromagnetic waves through space. The difference lies in the magnitude of the problem of how to overcome the great loss of energy of a signal that occurs because of the tremendous distances it must travel.

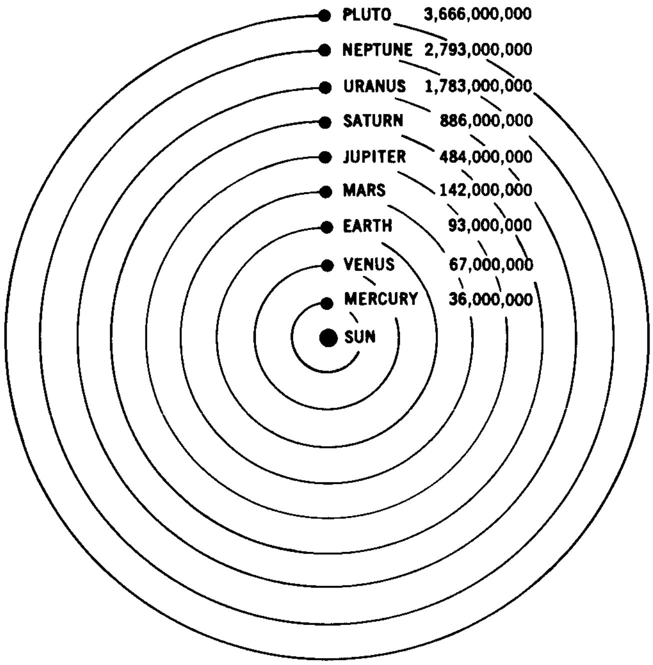
In the brief span of DSIF history, spectacular progress has been made in the evolution of antenna, receiver, and transmitter capabilities, which is fast approaching the technical and theoretical limits for communication within our solar system. Present technology is capable of meeting requirements for tracking, command, and data acquisition at distances ranging up to hundreds of millions of miles from Earth. Sophisticated communications techniques have developed so rapidly that by 1966 the DSIF capability, measured in quantity of information transmitted per unit of time, will have increased more than a thousand times over that of the pre-1960 capability.

To overcome space losses, the DSIF uses antennas designed for high gain, or very high concentration of received signal power, and powerful transmitters that send out a very strong signal. Standard DSIF ground transmitters operate at power levels of 10 kilowatts (10,000 watts); Goldstone at present has an advanced capability of transmitting at 100 kilowatts. A spacecraft transmitter, on the other hand, is very limited in power because of size and weight restrictions. Very early spacecraft (*Pioneer III*) used power outputs as small as 0.2 watt; the *Ranger VII* spacecraft used two 60-watt transmitters to send back to Earth the images recorded by the six television cameras. Continuing development will increase transmitter outputs for probes contemplated for exploratory missions to the edge of the solar system.

The well-known doppler principle has long been used in determining the relative speed with which a celestial body or star and the 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.

The doppler principle has been adapted for use in determining spacecraft velocity. Early spacecraft used

FACING: *Photographs show evolution of JPL-designed antennas — from the early systems with a tracking range of 3000 miles from Earth to the present-day giant antenna that is capable of communicating with spacecraft traveling to the edge of our solar system.*



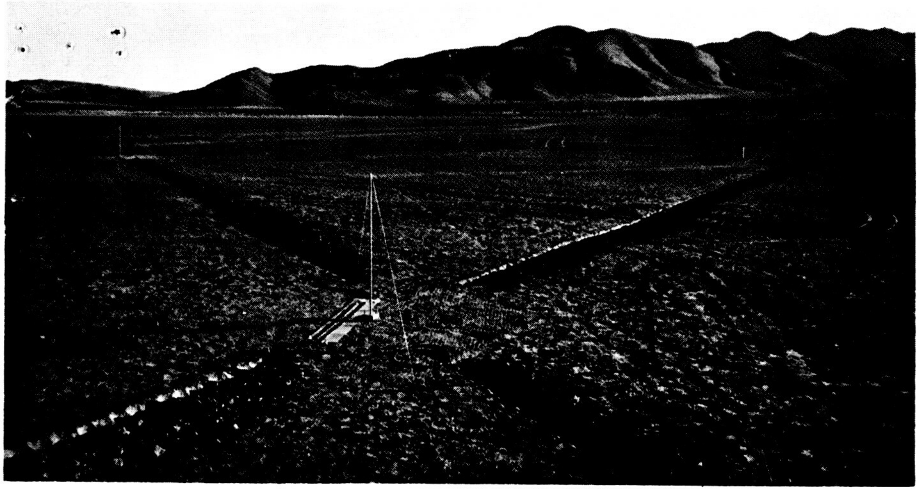
COMMUNICATION WITHIN OUR SOLAR SYSTEM INVOLVES TREMENDOUS DISTANCES. SHOWN ABOVE ARE DISTANCES OF THE PLANETS FROM THE SUN IN MILES.

one-way doppler—that is, measuring the difference between the frequency of a signal transmitted from the spacecraft and the frequency as it is received on the ground, which is proportional to the radial velocity between the Earth and the spacecraft. Because of inexact knowledge of the transmitted frequency, the accuracy of the measurement of spacecraft velocity using one-way doppler is limited to about 90 feet per second. Two-way doppler developed for the DSIF has increased this accuracy to better than one inch per second. In two-way doppler, a signal is transmitted from the ground to a turn-around transponder (receiver–transmitter) on the spacecraft, where it is converted to a new frequency in an exact ratio with the ground frequency, and then retransmitted to the ground. Since the frequency of the signal sent from the ground can be determined with great precision, the resulting doppler information and velocity calculations are very accurate. By two-way doppler calculations alone the position of a spacecraft at a distance of several million miles can be determined within 20 to 50 miles. A JPL-developed electronic ranging system uses an automatic coded signal in conjunction with doppler information to provide range measurements with an accuracy better than 45 feet at lunar and planetary ranges.

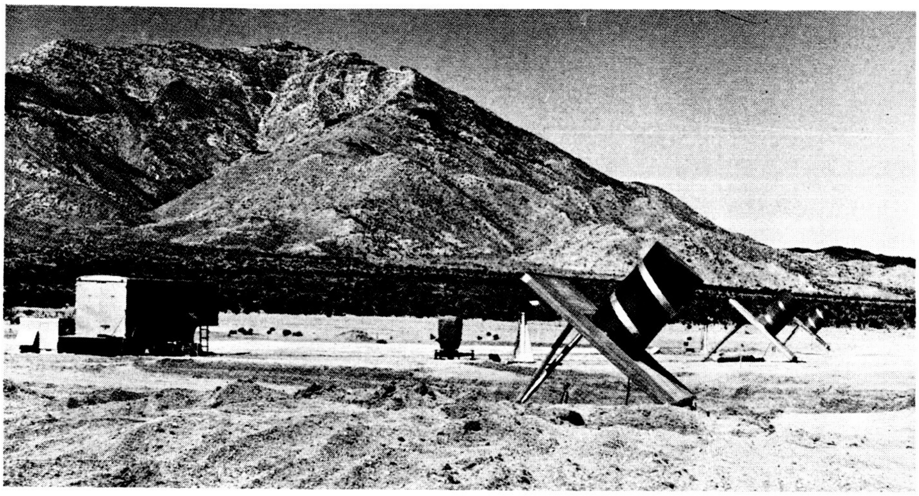
Because of the doppler shift and other effects, the frequency of the signal received on the ground from the spacecraft varies widely, which means that receiver tuning must be continually changed. Both spacecraft and DSIF ground receivers use a phase-lock method of signal detection, which maintains an automatic frequency control and keeps the receiver locked in tune with the received frequency.

Receiver performance is measured by the ability to pick up the weak signal from the spacecraft transmitter and separate it from surrounding noises (static) originating not only in the Earth's atmosphere, but from lunar, solar and galactic sources. DSIF receivers have a very low threshold—the point at which the receiver can no longer detect the signal, just as in human hearing, the lower limit at which the ear no longer responds to a sound is the threshold of hearing. 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, radio receiver sensitivity is affected by internal electronic noise in the system itself. To help overcome this problem, advanced methods of ultra-low-noise signal amplification have been developed. DSIF 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 a very low temperature and operates with a "pumped-in" source of microwave energy to augment the strength of the incoming signal without generating much internal system noise.

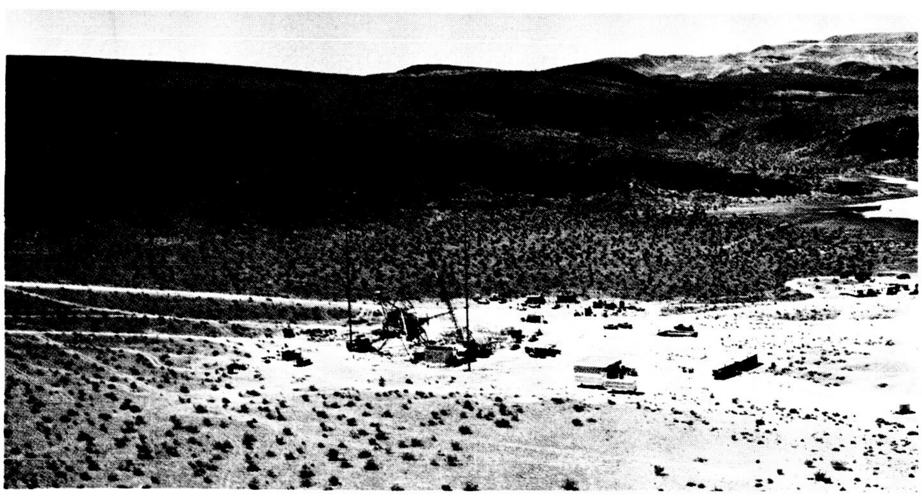
The basic components of the antenna systems in the DSIF are essentially the same, although auxiliary equipment may vary depending upon the special requirements for scheduled missions. The following is a description of the antenna system installed at Goldstone for operation at S-band frequencies. The complete system comprises thousands of different elements which must work perfectly under precision requirements.



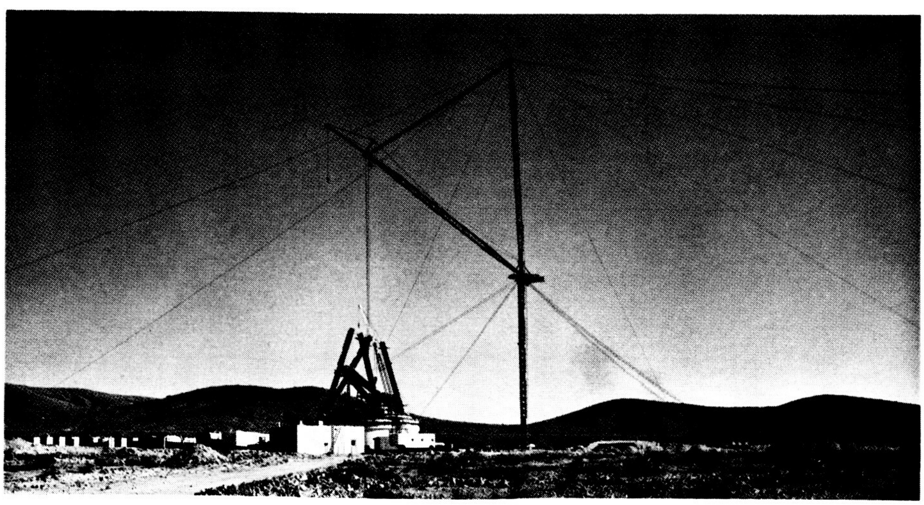
1956: Microlock interferometer



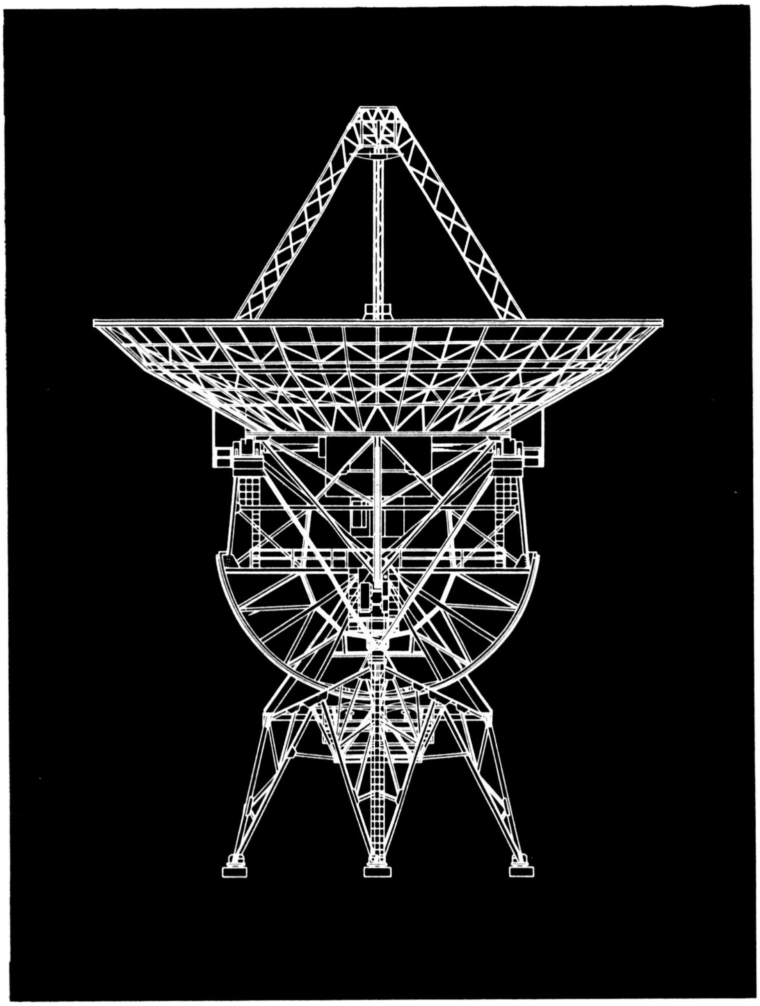
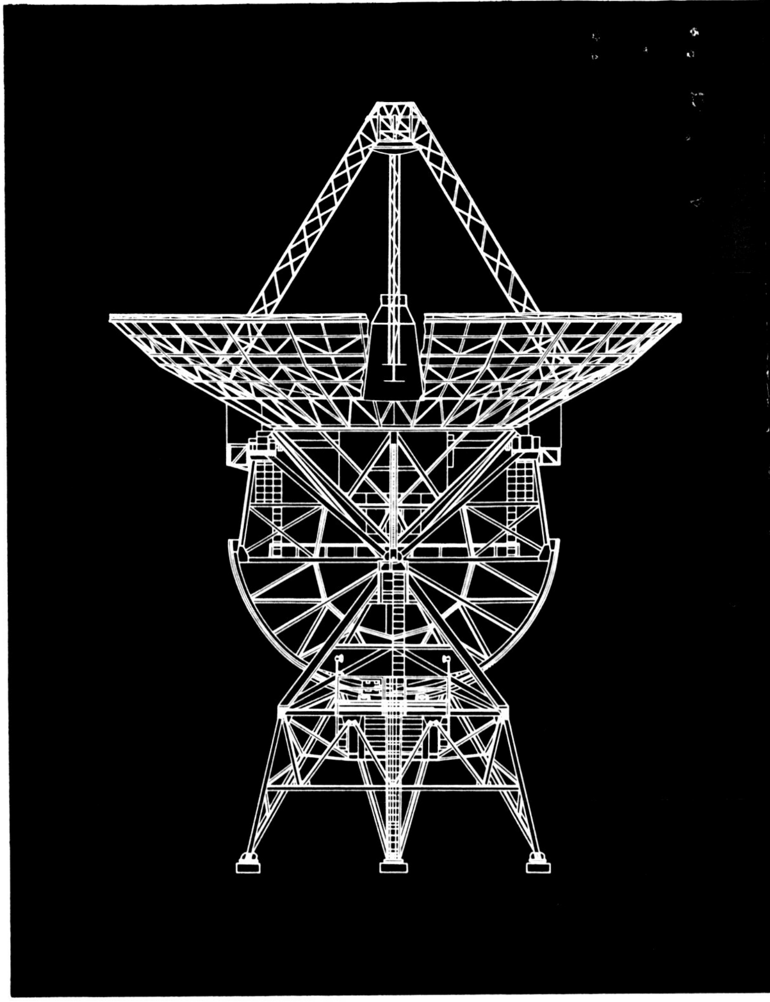
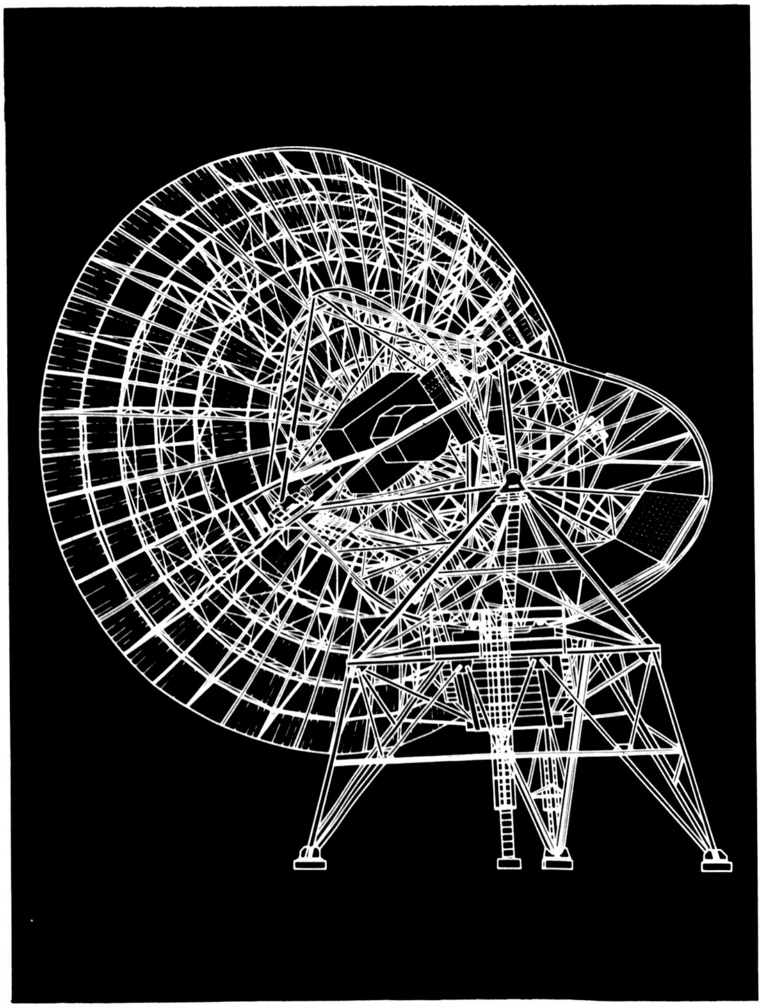
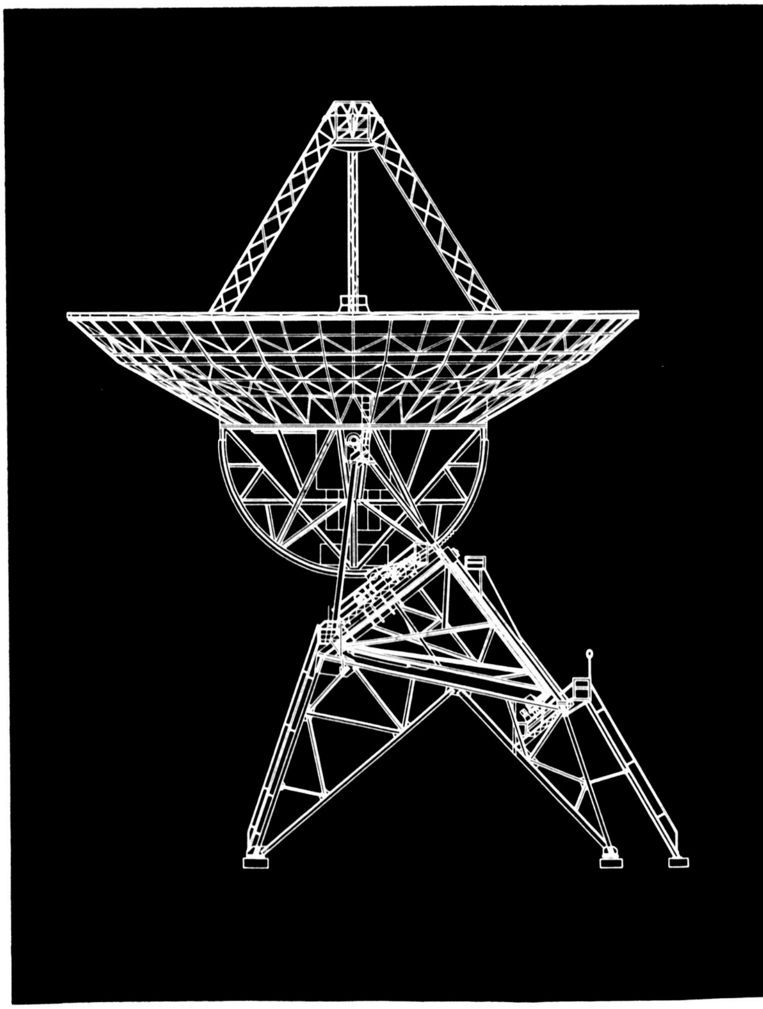
1957: Array of fixed helical antennas



1958: The first 85-foot-diameter antenna under construction at Goldstone Pioneer Station.



1964: The advanced 210-foot-diameter antenna under construction at Goldstone Mars Station.

FACING: *Four-way view of the standard DSIF antenna showing the 85-foot-diameter dish-shaped reflector pointed at zenith and toward the horizon displays the intricate balance of its structural steel girders. Tall as a 10-story building, antenna and supporting structure weigh about 600,000 pounds.*

The Antenna

The standard DSIF antenna is a parabolic reflector, 85 feet in diameter. The reflector is a perforated metal mirror that looks like an inverted umbrella and is often called the "dish." The antenna and its supporting structure stand 10 stories high and together weigh around 600,000 pounds.

About 8,000 pounds of electronic and operating equipment are an integral part of the antenna structure. This equipment is mounted on the antenna itself and in rooms reached by ladder on the supporting structure. The supporting base is a reinforced concrete pad sunk deep into the ground. Whenever new equipment is added, counterbalancing weights must also be added to distribute stress evenly over the structure.

Driving the Antenna

The 85-foot-diameter antenna is steerable; that is, its "beam" or major radiation pattern can be readily shifted in any direction to follow the spacecraft. When a deep space probe gets out and away from the Earth, it travels in an orbit or path similar to other celestial bodies, and "rises" and "sets" on the horizon like the Sun. The predicted or actual course of a spacecraft is determined by the same methods astronomers use in locating heavenly bodies. That is, the angular position of the spacecraft relative to the star background is defined by a set of imaginary circles (coordinates) corresponding somewhat to Earth longitude and latitude. Each antenna in the DSIF is oriented to a set of local coordinates that are used to measure the antenna-pointing angles by which the spacecraft is located. The DSIF tracking antennas use a system of polar coordinates which measure the hour angle (representing angular direction referenced to a station's local meridian circle) and the declination angle (representing angular direction referenced to the celestial equatorial circle).

The gear system that moves the antenna is polar-mounted. The axis of the polar, or hour-angle gear wheel, is parallel to the polar axis of the Earth, and points precisely to the North Star. 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 gears, is mounted on an axis parallel to the Earth's equator (perpendicular to the polar axis) which enables the antenna dish to pivot up and down. These wheels can be moved either separately or together. The arrangement of the gears allows the beam of the giant reflector to be pointed in almost any direction in the sky.

The motion of the antenna is controlled by the servo system, which consists of hydraulic pumps and motors, gear reducers, and pinions that engage the antenna gear system. A separate servo system drives the polar wheel and the declination wheel. Electric-motor-driven pumps in the hydromechanical building send high-pressure hydraulic fluid through stainless steel pipes up to the driving motors on the antenna that actuate the gears. The electronic control and readout equipment for the servo system is in a separate control room. Like the driver

FACING, TOP: *Close-up view of the polar-mount gear system of the 85-foot antenna shows the large polar wheel and smaller declination wheel which are rotated to steer the antenna in the direction of the spacecraft as it moves across the sky.*

FACING, BOTTOM: *The polar-mount antenna is so-named because the axis of the main gear wheel, or polar wheel, is mounted parallel to the Earth's polar axis and points exactly to the North Star, Polaris. Axis of the declination wheel is parallel to the Earth's equator.*

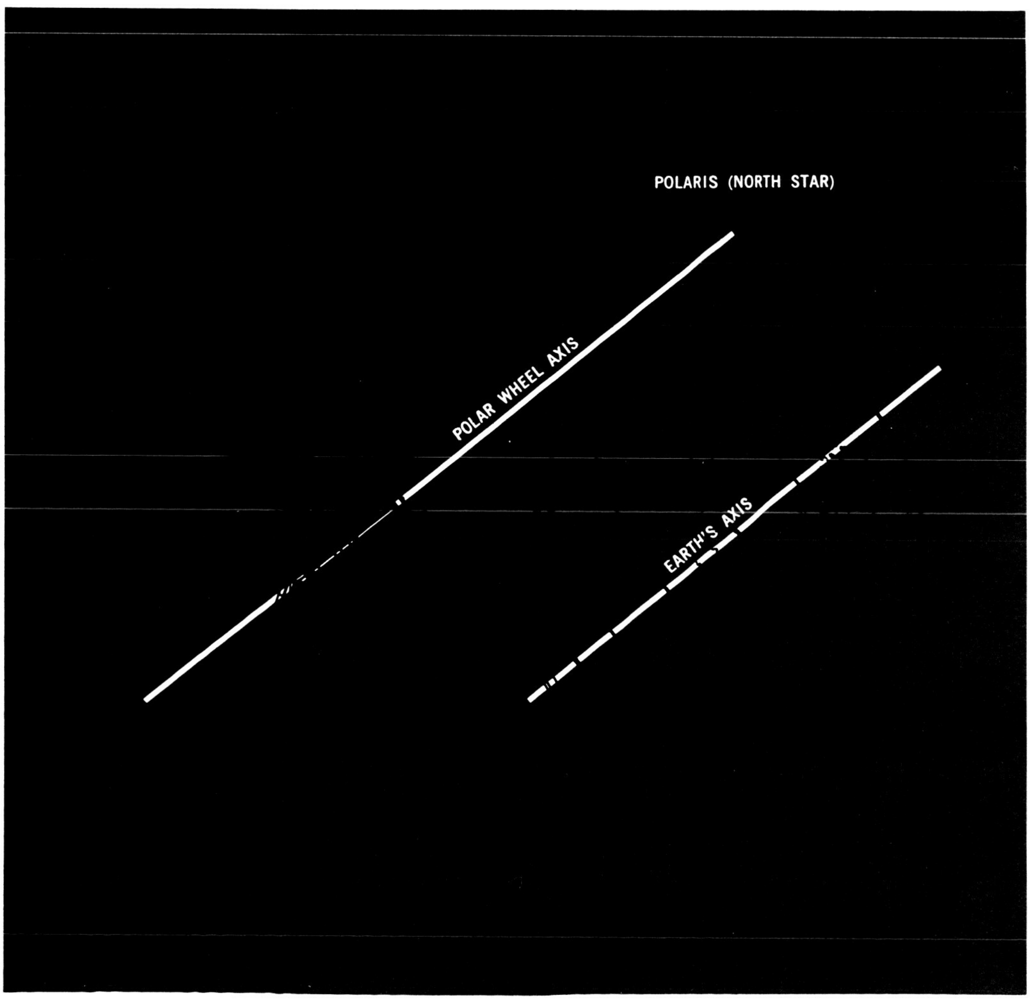
of an automobile, the operators of the servo system control and operate the equivalent elements—steering wheel, brakes, clutches, etc.—and in the same sense "drive" the antenna. They are responsible for the safety and efficiency of its operation, and the safety of personnel who might be working on the antenna.

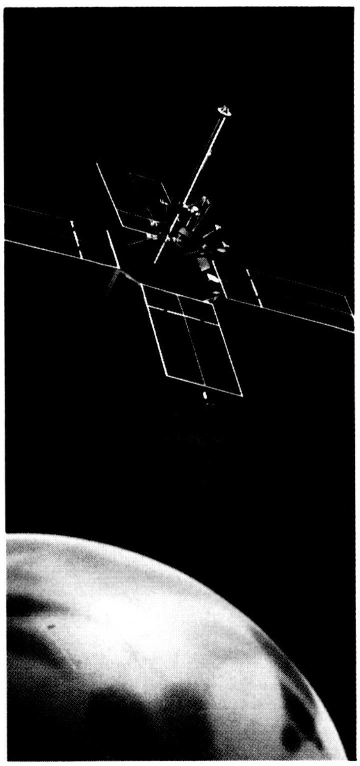
Pointing the Antenna

The antenna, like an 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 systems of the Goldstone Echo and Pioneer tracking stations normally operate in what is called a slave mode: angle information for pointing the antenna at specific times is supplied to the station by computer printout from the SFOF control center, and the computer and the antenna servo system operate together in an automatic loop to keep the antenna trained on the spacecraft. Pointing-angle information based on computer-calculated predicted trajectory data may be supplied to the station in advance of the actual launch of the spacecraft, and is then verified by actual trajectory data from early passes over the overseas DSIF sites, particularly first-acquisition data from Johannesburg or Ascension Island. Computer angle information may also be verified at Goldstone by nulling error signals from the receiver angle-tracking channels. (Error signals are voltages that tell the angle between the spacecraft and the exact center of the beam of the antenna.) With accurate information on the time and position at which the spacecraft will appear in the antenna field of view, no time is lost in locating the spacecraft.

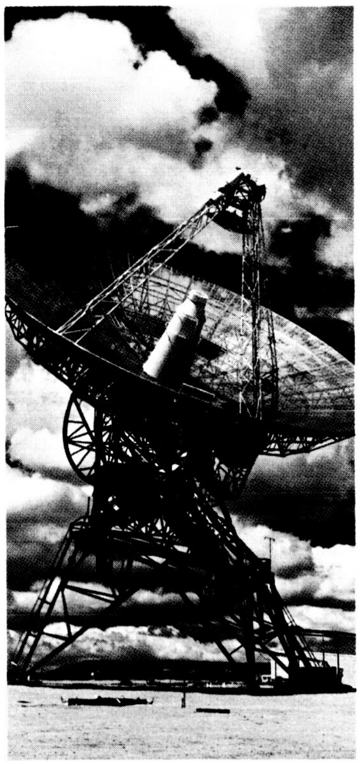
Aligning the Antenna

The gears and all parts of the antenna structure are so precisely balanced and aligned that, heavy as it is, the antenna can be rotated at rates up to 1 degree per second. Each Goldstone station has a collimation tower—located about a mile from the antenna—which is used in testing and adjusting antenna alignment and operation. A test antenna, a transmitter–receiver unit, and optical targets are mounted on the collimation tower. The tower simulates spacecraft signals for testing antenna and station operation. Visual checking of antenna boresighting (adjusting the line of sight, similar to aligning gun sights) is done in conjunction with an optical tracking package, mounted on the 85-foot antenna, which consists of a television camera, a 35-mm film boresight camera, and an optical telescope. This equipment is also used for optical tracking of luminous celestial objects such as the Moon, planets, and stars. Radio stars of known position are also tracked by the antennas to verify pointing accuracy and other performance factors.


POLARIS (NORTH STAR)
POLAR WHEEL AXIS
EARTH'S AXIS



Engineering measurements or scientific data generated by instruments aboard the spacecraft are radioed to Earth by the spacecraft transmitter.



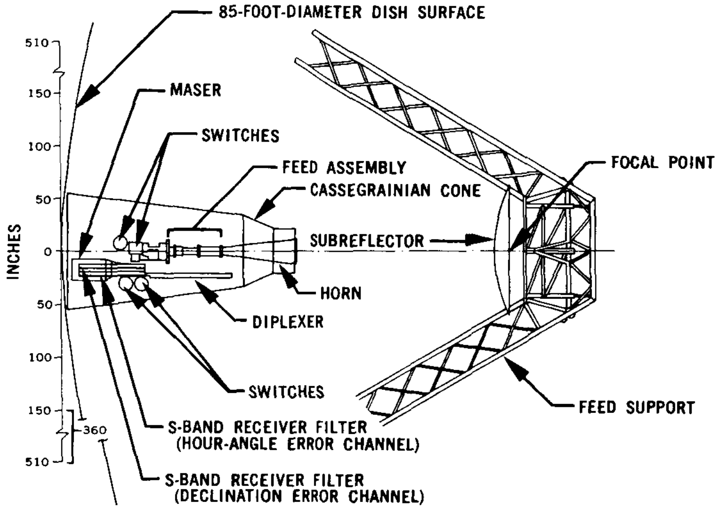
The radio signal, greatly reduced in strength because of the distance it travels, is captured by the Earth antenna.

Signal is amplified and processed through the receiving system, and information from the signal is translated and recorded on magnetic and punched paper tape.

Data gathered at Goldstone ar transmitted to the SFOF at JPL b teletype and high-speed digital dat circuits over a microwave link.

FACING, TOP: *The Cassegrainian feed cone mounted in the center of the antenna reflector is the focal point of the received signal. Radio waves bounce from the main dish to a subreflector (see sketch below) which focuses the waves into a feed horn in the cone.*

FACING, BOTTOM: *10-kilowatt transmitter gives the antenna an effective radiating power of 2.5 billion watts for sending signals into deep space.*



GEOMETRY OF THE CASSEGRAINIAN FEED SYSTEM

Sending a Command to the Spacecraft

The accuracy of the trajectory of a deep space probe is controlled by transmitting command signals that initiate roll, pitch, and yaw maneuvers, as well as propulsion, ignition, and timing sequences, which are determined by computations made from tracking data. Signals are also sent to the spacecraft to change data rates, change the type of telemetry information being transmitted, turn the transmitter on or off or change its power, reorient the spacecraft or its antennas, or even to switch antennas, receivers, and transmitters.

Sending a command to the spacecraft is somewhat the reverse process of receiving a signal. The transmitting station is equipped with a 10-kilowatt transmitter. The exciter and controls of the transmitter are in the control room; the radio-frequency power amplifier and associated equipment are mounted up on the antenna. The power level of the signal put out by the exciter is very low—on the order of a few watts. This is amplified in the power amplifier so that the signal radiated from the antenna is very strong—at least 10,000 watts. The transmitter is normally used with a diplexer, which is a device designed to allow simultaneous operation of both a transmitter and a receiver at different frequencies on a single antenna.

The commands to be sent to the spacecraft originate in the JPL SFOF control center in Pasadena. The command information is sent over the teletype link from Pasadena to the participating station at Goldstone.

Because an incorrect command could result in possible damage to the spacecraft, extreme precautions are taken to ensure accuracy. Command information from the SFOF is usually sent three separate times over the teletype links to the command station, and is also verified by voice over the telephone. Ground command and control equipment at the station includes read-write-verify equipment that carefully checks a command before it is sent and as it is being sent to the spacecraft. This special equipment reads and verifies the teletype message, transforms the command into a signal for radio transmission, and monitors the transmitted radio-frequency signal bit-by-bit. If any bit proves incorrect, transmission is automatically stopped to make correction. Very often, especially if the command is to be stored in the spacecraft memory equipment for later execution, the command as received by the spacecraft is telemetered back to the ground and checked again with the transmitted command. A special-purpose computer is used just to execute these check routines.

At the SFOF control center, information is processed by computers into usable form for analysis by scientists and engineers.

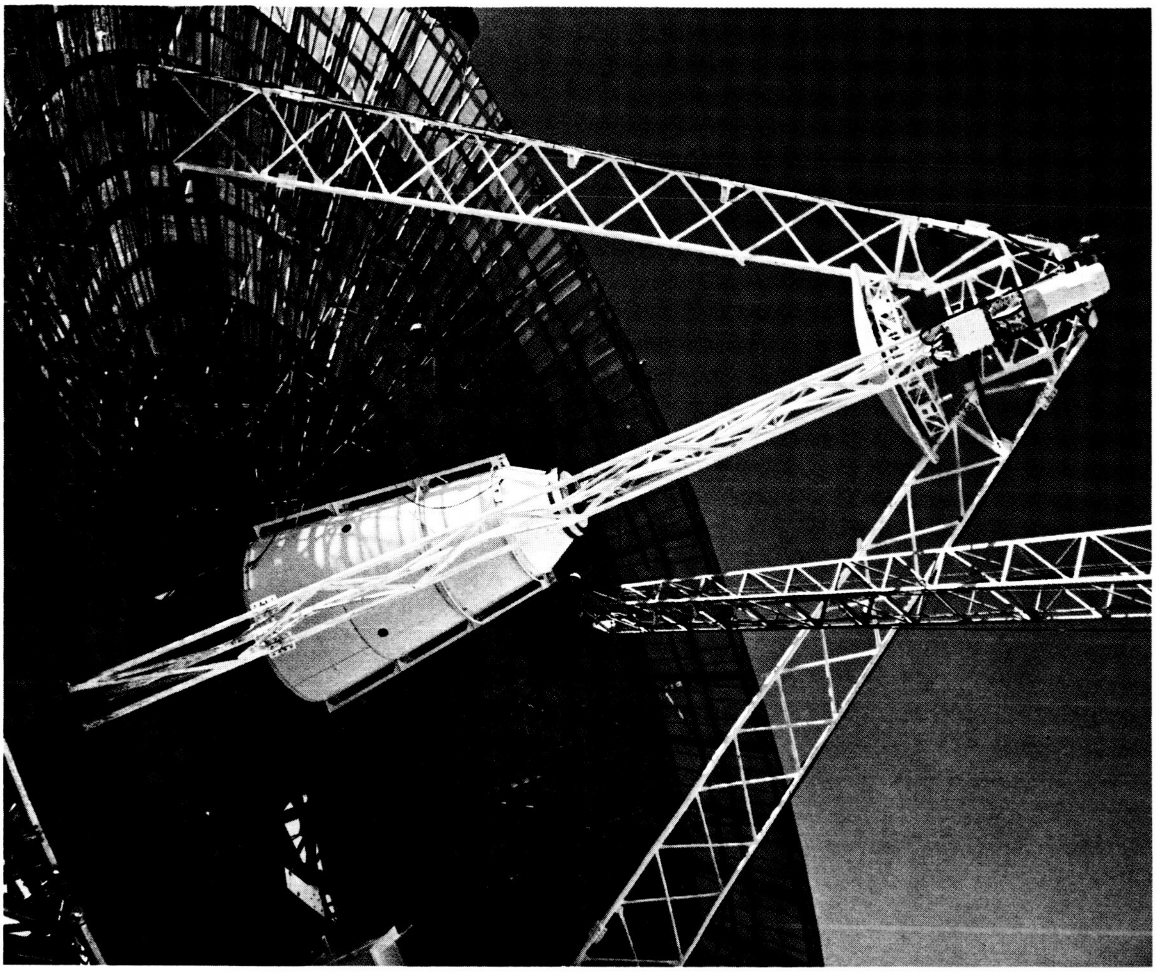
Processed data present video, tracking, engineering, and scientific telemetry in the form of time-labelled numerical printouts or graphs. All processed data are stored on magnetic tape.

Tracing a Signal Received From the Spacecraft

The reflecting surface, or dish, of the 85-foot antenna collects the radio energy which is fed into the sensitive DSIF receivers. The antenna, with an area of almost 6000 square feet, can detect signals so faint that the radio-frequency energy is calculated to be about equivalent to that radiated by a 1-watt light bulb at a distance of approximately 75 to 80 million miles.

In general, shorter radio-frequency connections between the antenna signal feed system and the receiver mean greater antenna efficiency. DSIF antennas for S-band operation have a Cassegrainian cone feed system mounted at the center, or focal point, of the reflector, which allows very short connections. This system is similar in design to that of a Cassegrainian telescope used in optical astronomy. Radio waves collected by the main dish bounce up and hit a subreflector mounted on a truss-type support that extends about 36 feet from the center of the dish. The subreflector focuses the waves into a feed horn in the Cassegrainian cone. The signal is then fed directly from the feed horn to the low-noise maser amplifier, so that maximum amplification of the weak signal occurs before it is contaminated by the electronic noise of the rest of the receiver system.

The S-band phase-lock receiver has four separate receiving channels: two reference channels (called sum channels) for doppler information, spacecraft telemetry, and TV signals; and two channels that carry angle-tracking signals for antenna pointing. The information in each of the sum channels is dispersed by distribution amplifiers in the receiver system to proper destinations in the telemetry instrumentation and data-handling systems in the control room.



FACING: *Geographic routings of land lines, submarine cables, microwave and high-frequency radio circuits in the DSN Ground Communication System*

Translating the Information From the Spacecraft

Signals processed by the receiver are sent to ground instrumentation and data-handling equipment in the control room. This includes paper-tape and magnetic-tape recorders, and ultraviolet oscillographs.

Tracking-data-handling equipment records angle measurements of antenna position, doppler frequency measurements, range measurements, and time. These data are recorded on paper tape for immediate teletype transmission to the SFOF in Pasadena for use in spacecraft orbit determination, calculation of maneuver parameters, command decisions, and prediction of arrival time at the target.

Telemetry signals from the spacecraft that come in on the receiver sum channel are either time- or frequency-multiplexed or both; that is, the signals from the various measuring instruments on the spacecraft are carried on one composite radio-frequency signal, either sequentially (time-multiplexed) or simultaneously on several subcarrier frequencies (frequency-multiplexed). This composite signal is "unscrambled" by decommutators and/or discriminators in the ground telemetry system so that each signal is identified by a channel number. Analog or digital (or both) methods of signal modulation are used for transmission of data from the spacecraft to Earth.

Analog modulation transmits engineering measurements in continuously varying electrical signals that represent measurements of voltages, temperatures, pressures, radiation intensity, etc. With coded digital modulation techniques, it is possible to increase the efficiency of data transmission from the spacecraft. Digital transmission also simplifies data handling at the ground station because digital signals can be formatted for direct inputs to computers and for teletype transmission.

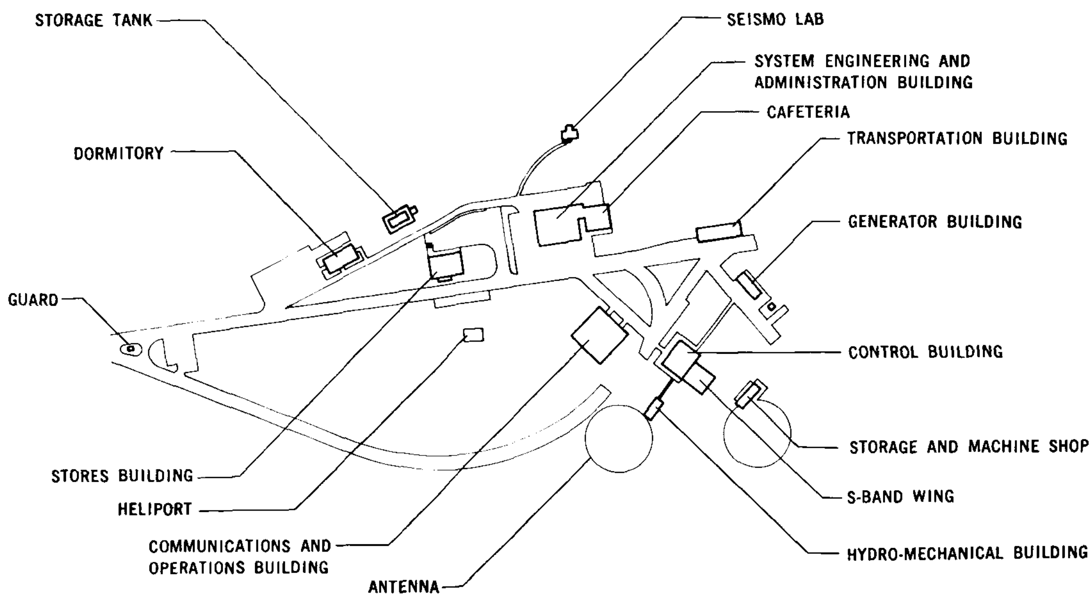
The detected unscrambled signals are recorded on magnetic tape so that complete permanent recordings of all telemetry data from the spacecraft will be available for later data processing either at the SFOF or by the NASA Center responsible for the project. Certain selected spacecraft telemetry signals are displayed at the station as they are received for the use of operating personnel in maintaining contact with the spacecraft. Digital data are exhibited on special displays; analog data are recorded on oscillograph recorders, which produce a visible pattern of electrical signals.

Because the quantities of data produced during a mission are enormous and constantly growing as space projects become more sophisticated, increasing use is being made of on-site data processing in the DSIF to relieve the burden both on communication lines to the SFOF and on the SFOF data-processing system. In the on-site data-processing system at Goldstone, which is controlled by general-purpose digital computers, some of the unscrambled spacecraft data are converted and reduced to digital format for transmission by high-speed data lines direct to the computers at the SFOF.

Video data are split off from the sum channel by the receiver and sent to special video equipment in the control room at Goldstone for processing.

FACING, TOP: *Operations headquarters during a mission is the control room, where banks of electronic consoles lining the walls contain the controls for the receiving system, the transmitter, the servo system, and the data-recording system.*

FACING, BOTTOM: *Aerial view of Echo Station.*



ECHO STATION GROUND PLAN

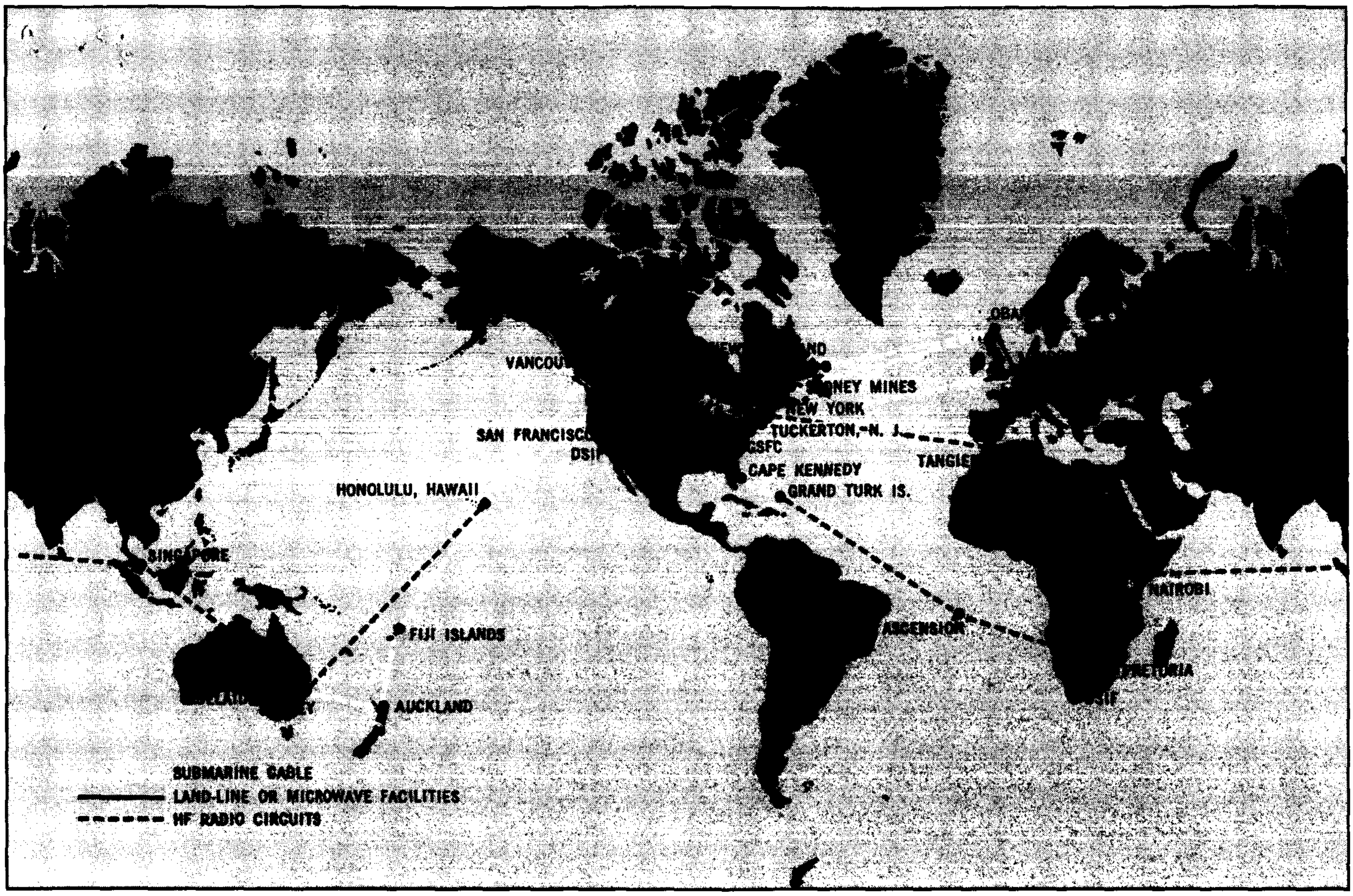
Echo Station

The Echo station is the Goldstone administration center and operations headquarters. The buildings house offices for administrative and technical personnel, a cafeteria, and a dormitory. Transportation facilities are centered here, and the communications building is the control center for Goldstone communications with the SFOF and other DSIF stations, as well as for Goldstone intersite communications.

In the control building at Echo is the Goldstone station control and monitor console from which the station manager conducts station operations during a mission. The console has special instruments that keep him informed of the status of all operating systems: the antenna, receiver, transmitter, station instrumentation, tracking data, telemetry, and command data handling, and any special equipment required for different missions. The console also has connections with the Goldstone intersite communication system, and telephone connections with JPL in Pasadena and with the DSIF overseas stations.

The 85-foot-diameter antenna at Echo is equipped for both receiving information from the spacecraft and transmitting commands to the spacecraft.

Echo transmitted the commands for the midcourse maneuver that put *Ranger VII* on target. Polaroid pictures of man's first close-up glimpse of the Moon were processed at the station, along with the magnetic tapes containing 4300 video images of the lunar surface.



In addition to processing and recording spacecraft telemetered data, each station also processes and records data generated by the ground equipment, such as received signal strength, transmitted power, condition of all station equipment, and calibration voltages. This information is processed by the digital instrumentation system, which uses general-purpose digital computers that accept and process both analog and digital signals. All ground data are recorded on digital magnetic-tape recorders, and certain selected data are recorded on punched paper tape for transmission over teletype circuits to the SFOF.

All taped information sent to JPL is labeled and identified by date, time received, station, and spacecraft number. Because time reference is a critical factor in tracking determinations, and in other DSIF functions that depend upon the timing of electronic phenomena, the time of receipt of telemetry data is recorded to an accuracy of at least one hundredth of a second. All data received during a mission are recorded on magnetic tape for a permanent record and for the use of scientists and engineers in evaluating the results of a mission. Literally hundreds and hundreds of miles of magnetic tape are used in some missions, and final evaluation takes months, and sometimes years, of study.

DSIF acquisition procedures, which include antenna pointing, receiver tuning, transmitter tuning, ranging lock, and telemetry decommutation, are so precisely timed and coordinated that it is possible to start recording data from 1 to 10 minutes after radio contact with the spacecraft is established, and to start transmitting data to the SFOF within 4 to 16 minutes.

Interstation Communications

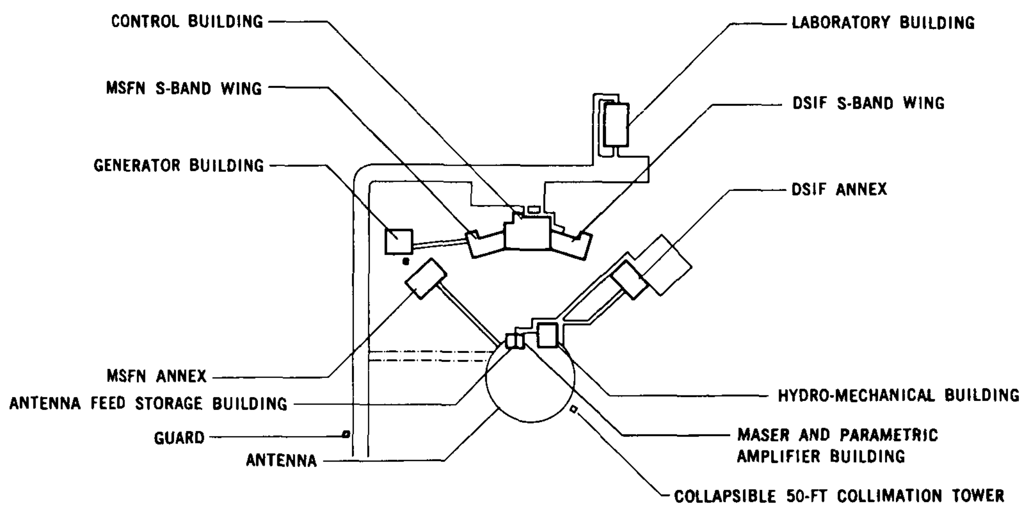
Goldstone has communication with other DSIF stations by telephone and teletype through the DSN Ground Communication network. A multiplex microwave link is used to facilitate the handling of the vast amount of data that must be transferred from Goldstone to JPL. This link carries multiple channels for voice and teletype transmission, two circuits for high-speed digital data transmission, and one video channel.

Teletype transmission is at the rate of 60 and 100 words per minute. On the high-speed data lines, Goldstone computers "talk" to computers at the JPL SFOF at the rate of 600, 1200, and 4400 bits per second (the 4400-bit rate is about equal to 8800 words per minute).

Communications at Goldstone, on-site and between stations, are handled by telephone and teletype, local paging system, and closed-circuit TV. In addition, high-speed data "hot" lines operate between the tracking stations for fast, real-time transmission of tracking information during critical periods of a mission.

FACING, TOP: *GSDS Cassegrainian cone, destined for shipment overseas, is lowered into place on the 85-foot-diameter antenna at Pioneer Station for test and checkout.*

FACING, BOTTOM: *Aerial view of Pioneer Station.*



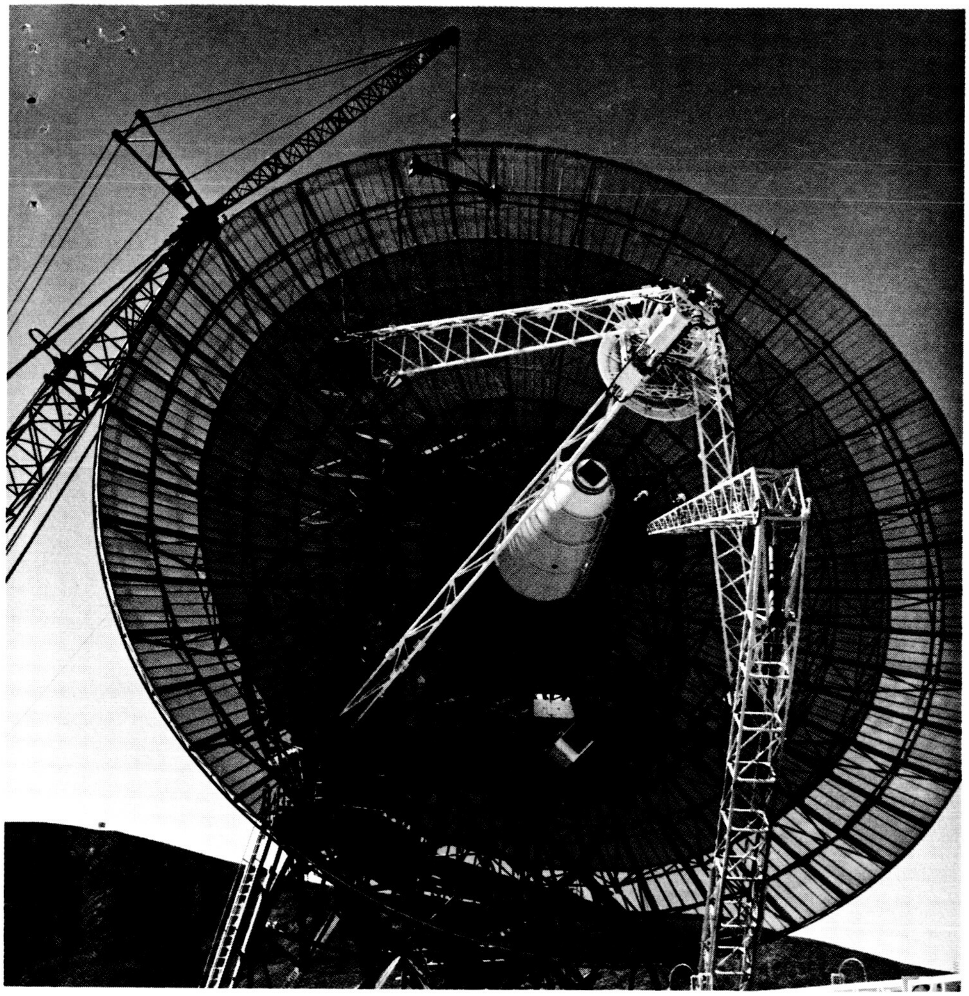
PIONEER STATION GROUND PLAN

Pioneer Station

Pioneer, the original Goldstone station, has undergone great changes since it began operation in 1958, and has participated regularly since then in DSIF tracking missions. In addition, one of its main uses has been as an advanced testing site for DSIF operations. New techniques and GSDS equipment are checked out and thoroughly tested in operation at Pioneer before acceptance for standard DSIF installation.

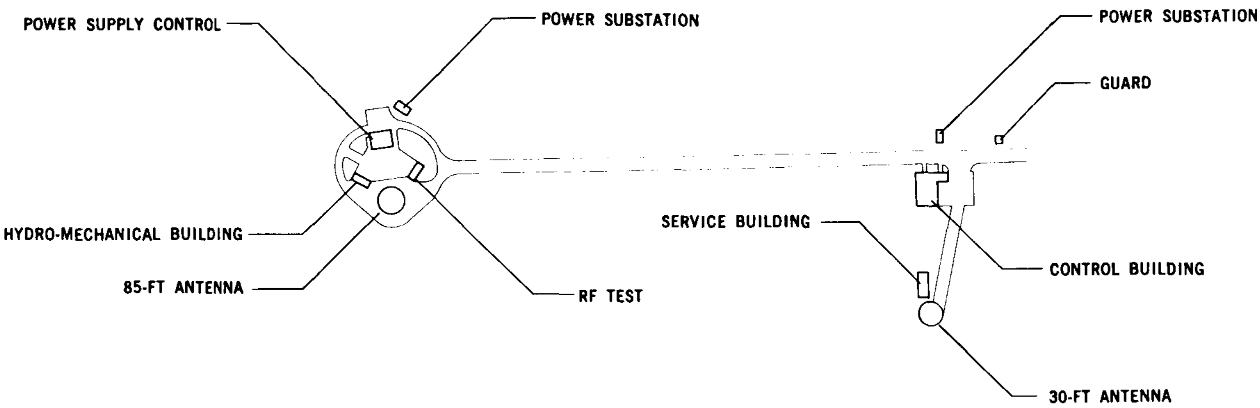
Pioneer was the first DSIF station to be changed over to S-band frequency operation. The 85-foot-diameter antenna is completely equipped in the S-band configuration, and annex buildings and wing additions to the main control building have been constructed to accommodate new S-band operating and control equipment. S-band systems for the overseas stations were first installed and checked out at Pioneer, and DSIF personnel trained there in S-band operating procedures.

Extensive station additions were also made for the ground support systems that will be used for primary control in the *Mariner* and the *Surveyor* projects. In preparation for DSIF support of the *Apollo* program, a special wing has been added to provide space for the Manned Space Flight Network equipment.



FACING, TOP: *85-foot-diameter antenna at the Venus Station, showing the azimuth–elevation mount and Cassegrainian feed cone.*

FACING, BOTTOM: *Aerial view of Venus Station, with 30-foot-diameter antenna in foreground.*



VENUS STATION GROUND PLAN

Venus Station

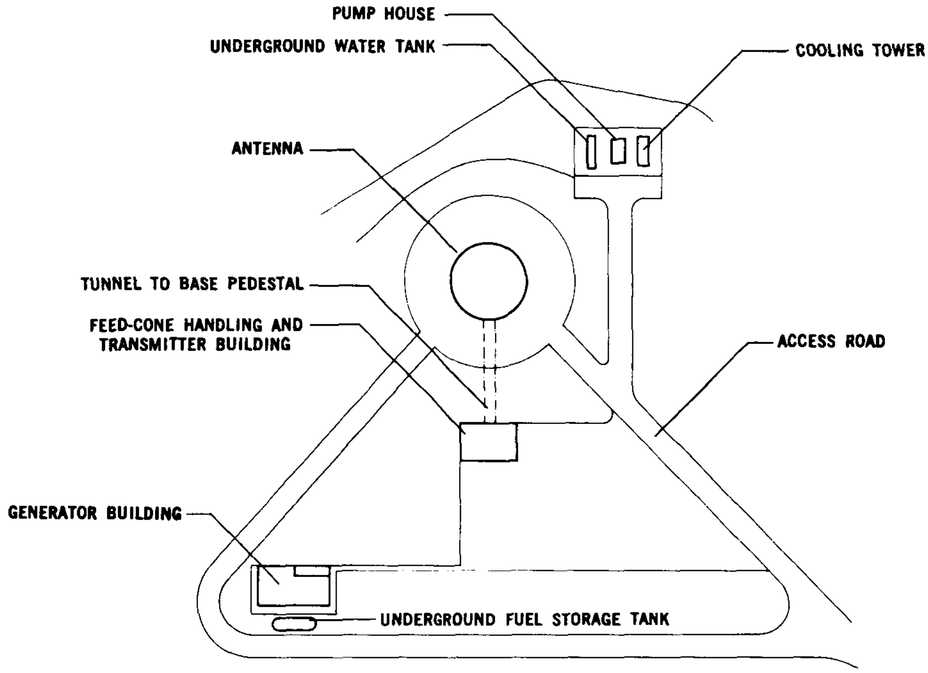
The Venus station at Goldstone is used to develop very high power radio-frequency transmitters and new systems for the DSIF. In the development of new systems it has been found useful to initiate research and development projects which can be the focal point for bringing together several technical areas in the field of deep space communications. One of these projects is a series of lunar and planetary radar experiments which uses large antennas, powerful transmitters, low-noise receivers, and signal-processing techniques similar to those used in a two-way deep space communications link. These experiments give an opportunity to observe and evaluate performance of these components in long and continuous operation for eventual use in the DSIF operations. Also useful in space communications and tracking is the science information obtained from radar measurements, such as surface characteristics of the Moon and planets, and improved determination of their motions and locations. Radar detection can penetrate the clouds of Venus, for example, where optical astronomical telescopes are limited in their "seeing" ability. Radar experiments performed at the Venus station have included beaming signals at the Moon, Venus, Mercury, Mars...and as far away as Jupiter.

The main antenna at the Venus station is an 85-foot-diameter parabolic reflector, with an azimuth-elevation mount. This mount differs from the polar mount in that the antenna is moved up and down 90 degrees in elevation between the horizon and zenith (the point directly overhead) and also pivots around the vertical axis 360 degrees starting from true north. The position angles of spacecraft location relative to this antenna are measured in azimuth and elevation coordinates, and it has a tracking rate up to 2.0 degrees per second.

The Venus antenna is used primarily in advanced engineering and development work and as a backup station for the DSIF. It uses a Cassegrainian cone feed system, a powerful 100-kilowatt transmitter, and an extremely sensitive narrow-bandwidth receiver. In the Venus radar bounce experiments, it is estimated that the received signal power from the planet Venus was so weak that at that power level it would take 100 years to lift one grain of sand a distance equal to its own height.

The Venus station also has a 30-foot-diameter reflector antenna, which is a 1/7-scale model of the 210-foot-diameter advanced antenna system being built at the new Goldstone station, Mars. The scale model is used to test design and operation of the "210" feed system.

FACING: Cutaway drawing shows the massive structure of the 210-foot-diameter Mars antenna, which weighs 20 million pounds and stands 21 stories tall. The circular pedestal that supports the antenna is a two-story building. Rising through the center is a 50-foot-high instrument tower that rests on a foundation sunk 38 feet underground.



MARS STATION GROUND PLAN

Mars Station

The Mars station at Goldstone will be operational in 1966. It is the site of the giant "space tracker" with a 210-foot-diameter parabolic reflector that can maintain spacecraft communications to a distance of two and one-half to three times the range achieved by the 85-foot antennas, thus extending the useful range of the DSIF to the edge of our solar system. It has six and one-half times more transmitting and receiving capability than the 85-foot antennas. The added capability permits either increased distance in space communications or the acquisition of more data from spacecraft at shorter ranges.

The "210" stands as tall as a 21-story building and weighs a total of around 20 million pounds. It is constructed with an azimuth–elevation mount, with special instrumentation called the precision angle-data system to read out antenna-pointing information in polar coordinates. This unit is mounted in a room supported by a tower that rises 50 feet above the ground through the center of the antenna's pedestal, and stands independent of the antenna structure. To keep the sensitive angle-data system completely free from vibration or disturbance from antenna movements, winds, etc., the tower is rigidly reinforced with steel and stands on a silo-type concrete foundation sunk 38 feet underground.

The reflector and its supporting structure, which together weigh 5 million pounds, rotate on a pressurized oil film that acts as a friction-free bearing. The antenna gear system is driven by motors with a combined maximum capacity of 1300 horsepower, mounted on the structure. The antenna is so precisely aligned and balanced that despite its vast size and weight it can be elevated from looking at the horizon to looking straight up in three minutes.

The pedestal, or supporting base, is two stories high and weighs approximately 10 million pounds. The walls are 42-inch-thick solid reinforced concrete, with concrete footings extending 13 feet underground. The first floor has rooms for heavy equipment and maintenance shops; rooms on the second floor contain the receiver, transmitter, and servo controls, and instrumentation for recording data. The "210" is equipped with a Cassegrainian feed system.