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Technical Memorandum 33-800

Final Engineering Report for Goldstone Operations Support Radar

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PASADENA, CALIFORNIA

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PREFACE

The work described in this report was performed by the DSN Systems Engineering Office of the Jet Propulsion Laboratory.

This is a final engineering report on the implementation of a radar capability at the Deep Space Communications Center at Goldstone, California. The project described in the report was undertaken at the request of NASA, who desired a minimum-cost capability to deal with the inadvertent entrance of aircraft into the air space over the Goldstone stations during the tracking of deep space spacecraft to minimize their interference with tracking operations. The operating capability had to deal with situations wherein aircraft would be subject to the high-power radio transmissions from these stations as well as the interruptions in communications from the spacecraft to the Earth stations, causing loss of information which these very costly NASA missions are designed to obtain. This initial (Phase 1) operating capability was transferred to operational status as of July 1, 1976.

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ACKNOWLEDGMENT

The information required to document the Goldstone Operations Support Radar implementation task is the total result of the efforts contributed by many different organizations and individuals over a period of 4 years, from 1972 to 1976. It is, therefore, impossible to list each individual by name or organization. However, it is acknowledged that participation of the Technical Staff of the Tracking and Data Acquisition Organization of the Jet Propulsion Laboratory, Pasadena, California; the Federal Aviation Agency; the United States Air Force; the Spaceflight Tracking and Data Network, operated by the Goddard Space Flight Center, Greenbelt, Maryland; the United States Army; United States Corps of Engineers; and Bendix Field Engineering Corporation, Columbia, Maryland, all contributed toward the successful completion of this task.

Assigned NASA Headquarters personnel were responsible for interproject, intra-NASA, and interagency coordination; allocation and reprogramming of major resources; establishment of task objectives and guidelines; and overall technical direction and guidance. The Goldstone Operations Support Radar Task responsibilities were assigned to M. E. Binkley of the Office of Tracking and Data Acquisition (OTDA) under the direction of G. M. Truszynski, Associate Administrator, and N. Pozinsky, Deputy Associate Administrator, OTDA.

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ABSTRACT

The Tracking and Data Acquisition Office at the Jet Propulsion Laboratory committed to the National Aeronautics and Space Administration Office of Tracking and Data Acquisition the earliest possible operational capability date for the Goldstone Operations Support Radar program.* The Deep Space Network requested to undertake the planning, engineering, and installation, as required. The type of radar selected to meet the requirements was an AN/FPS-18.

A project was established for the procurement and refurbishment of surplus equipment, assembly on site, and demonstration, as well as coordination with a separate architect and engineering company on related facilities planning and with the facility construction contractor.

The implementation, testing, demonstration, operation, maintenance and evaluation of the equipment are discussed.

*The Goldstone Operations Support Radar provides protection to intruding aircraft from possible exposure to the several narrow beams of nonionizing radiation that exist during periods of high-power transmission from the Goldstone Deep Space Communications Complex. The Federal Aviation Agency has the commitment of the National Aeronautics and Space Administration to provide an independent search radar capability at Goldstone to assist in the safe operation of high-power transmissions.

I. INTRODUCTION

The National Aeronautics and Space Administration (NASA) requested the Federal Aviation Administration (FAA) in March 1972 to establish a formal airspace restricted zone in the proximity of the Goldstone Deep Space Communications Complex (GDSCC). A document was prepared as supporting material to that initial request. The primary concern was the minimization of flight personnel risk which could result from exposure to high-power radiation in the antenna near-field of NASA deep space and Earth satellite communications systems.

The material contained in this document, Goldstone Airspace Utilization, is summarized below. Included are a description of the GDSCC, scheduling methodology, and mission plans for both Earth orbit and deep space missions. The technical description includes a discussion of electromagnetic interference (EMI) factors, typical airspace usage, and deep space receiving and transmitting systems.

In the past, coordination of airspace usage has been informal and minimal, consistent with the development nature of high-power transmitter testing, and has been effected through agreements with local NASA and Department of Defense (DOD) facilities. However, with the increasing flux of commercial air traffic in the GDSCC area, and the potential impact of the proposed Palmdale International Airport, together with the operational use of high-power transmitters at GDSCC, it is felt that there should be a formal procedure for effective joint airspace utilization as well as the establishment of a restricted zone.

A. GDSCC DESCRIPTION

The Goldstone Complex includes tracking stations for two separate NASA networks, the Deep Space Network (DSN), operated by the Jet Propulsion Laboratory, Pasadena, California, and the Space Tracking and Data Network (STDN), operated by the Goddard Space Flight Center, Greenbelt, Maryland.

1. The Deep Space Network

The DSN tracking capability consists of three major tracking station sites located at approximately 120-deg intervals of longitude on the Earth's surface in order to provide continuous 24-h spacecraft coverage. These sites are in Australia, Spain, and Goldstone, California. Each site has several tracking facilities, which are used to track and communicate with unmanned scientific spacecraft in deep space and for scientific measurements of planets and propagation media. There are two 26-m and one 64-m global networks in the DSN. They are characterized by use of extremely sensitive (-180 dBm) receiving equipment, high-power (+86 dBm) continuous wave (CW) transmitting equipment, and large-diameter, very-narrow-beamwidth (0.04 deg), high-gain (70 dBi) antennas operating in the 2- and 8-GHz regions. A typical DSN mission requires coverage of about 8 to 14 h per pass once per day at GDSCC. Deep space mission spacecraft rise in the east and set in the west in the same manner as celestial objects.

2. The Space Tracking and Data Network

The STDN is also a world-wide network and supports Earth orbiter scientific and manned missions and lunar manned missions. There are 24 STDN stations located around the Earth, and a major station in that network is located at Goldstone. The stations are characterized by use of sensitive receivers, medium-power continuous wave transmitters, and either medium-diameter antennas or arrays. This equipment operates in the 0.13-, 0.4-, and 2-GHz regions. A typical STDN mission (excluding Apollo lunar support) requires coverage of about 15 min per pass several times per day. Orbits covered are both polar and equatorial.

3. The Goldstone Site

Goldstone was selected as a tracking station site by NASA in the late 1950s. The selection was based on the following criteria:

(1) Low radio frequency (RF) noise and natural shielding

(2) Freedom from aircraft and other mobile radio interference

(3) Mild natural environment

(4) Within $\pm 40°$ latitude

(5) Well controlled access for safety from effects of high-power RF radiation environment

(6) Suitable local support for ground communications, utilities, transportation, and housing

The capital investment at the GDSCC is about 80 million dollars. The cost per spacecraft mission varies from about 30 million to 700 million dollars. Personnel employed at GDSCC total about 600. The complex is located in the central Mojave Desert within the boundaries of Fort Irwin, California, on land obtained via long-term lease from DOD. Figure 1 shows a map of the Goldstone area. Figure 2 shows typical GDSCC installations.

B. GENERAL GDSCC MISSIONS AND ACTIVITIES

The Goldstone Complex supports all NASA manned and unmanned United States deep space and Earth orbital scientific missions. The ground stations are used to acquire scientific, Earth resource, and radiometric data from and to transmit commands to the spacecraft. Several DSN stations at Goldstone support planetary radar and radio science activities and the development of new tracking station technology. A time-synchronization transmitter is also located at Goldstone for transferring precision timing information to overseas stations via lunar reflection.

The deep space program missions include near planet and outer planet opportunities. Mission lifetimes are from 4 months to well over 6 years and require daily tracking. The tracking load averages between two and three 10-h tracking passes per day by DSN stations at Goldstone (see Fig. 3).

Earth orbital missions supported by the STDN through 1982 have 1- to 3-year average lifetimes and require daily tracking when in view. The tracking load averages between four and ten 15-min passes per day by Goldstone STDN stations. Synchronous satellites such as the ATS are also supported. These require extended tracking periods up to 24 h per day.

Planetary radar opportunities occur at planetary conjunctions and vary from every 3 months for Mercury to every 27 months for Mars. Conjunction coverage is from 2 weeks to several months. The radar opportunities require high-power transmitters, large antennas, and very sensitive receivers. Scientific investigations of radio sources such as quasars and pulsars are conducted at Goldstone either separately or in conjunction with simultaneous observation at either global locations. The high-power lunar reflection time synchronization system is operated frequently during common lunar view periods with an overseas DSN site for about 1 h at moonrise and set.

Overseas DSN and STDN stations also support similar spacecraft activities.

C. SUPPORT SCHEDULING

1. DSN Support Schedule Characteristics

The tracking coverage provided for deep space missions, the planets, and other celestial bodies is primarily a function of the sidereal rate of the Earth with daily view phasing dependent on the right ascension of the object relative to the Earth's orbital position. The daily tracking periods are long--8 to 14 h--and vary only a small amount from day to day. Space missions between the Earth and the Sun, including inner planet missions, will always have view periods centered during the daylight hours. Missions placed on trajectories outward from the Earth, away from the Sun, such as outer planet missions, will always have view periods that cycle slowly over a period of 1 to 2 years through the 24-h day.

2. Deep Space Mission Support Activities

Mission support generally requires continuous or near-continuous tracking, utilizing three stations spaced at approximately 120° around the Earth. Each of these stations is required to track approximately 9 h per day on an assigned mission. An average of two to three tracking passes per day are required at GDSCC to support the 1976-1982 mission set (see Fig. 3).

Planetary observations and other radio science and development activities are generally scheduled on a 2- or 3-day per week basis. Because of the nature of this type of activity and the special support required, these tracks are usually scheduled at Goldstone rather than at overseas stations. All tracking support requires a low-noise receiving system. High-power transmitters are usually required for most missions but only during the long-range and near-encounter phases. In addition, all active planetary radar observations will also require high power.

The Goldstone Complex also supports radio science observations of celestial objects such as quasars and pulsars, but this represents a very small portion of network activity and rarely involves the use of the high- or low-power transmitters except as part of a spacecraft mission science experiment.

3. Lunar Time Synchronization

In addition to the above view period requirements, the network also conducts a time synchronization activity between Goldstone and the overseas stations. This requires the reflection of a high-power timing signal from Goldstone, off the Moon, to a receiving station overseas or at Goldstone. This activity is conducted several days a month and is scheduled to occur during the first 30 deg after lunar rise and the last 30 deg before lunar set at Goldstone. Since these view periods are tied to lunar view periods, they cycle through the 24-h day every 28 days.

4. Current Local Airspace Use Coordination

All transmitter radiation in excess of 20 kW is presently coordinated with the Air Force Flight Test Center at Edwards Air Force Base (AFB). Weekly schedules of pointing angles, times, and power levels are provided to the Edwards operations organization along with any real-time changes to these schedules. Edwards uses this information in their operations planning and to advise any aircraft entering the airspace under their control what areas are currently restricted in accordance with Air Force radiation regulations.

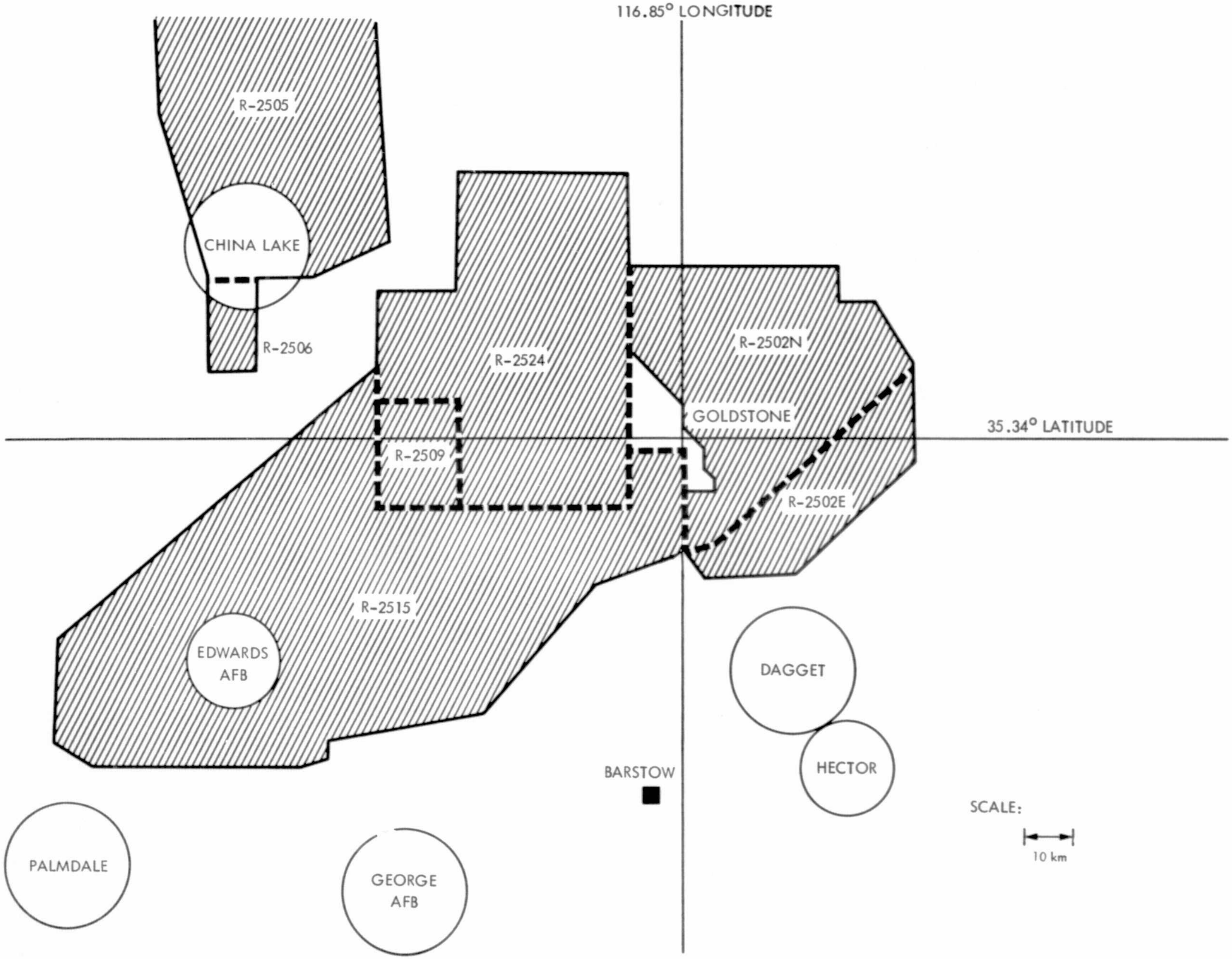

Fig. 1. Map of Goldstone area

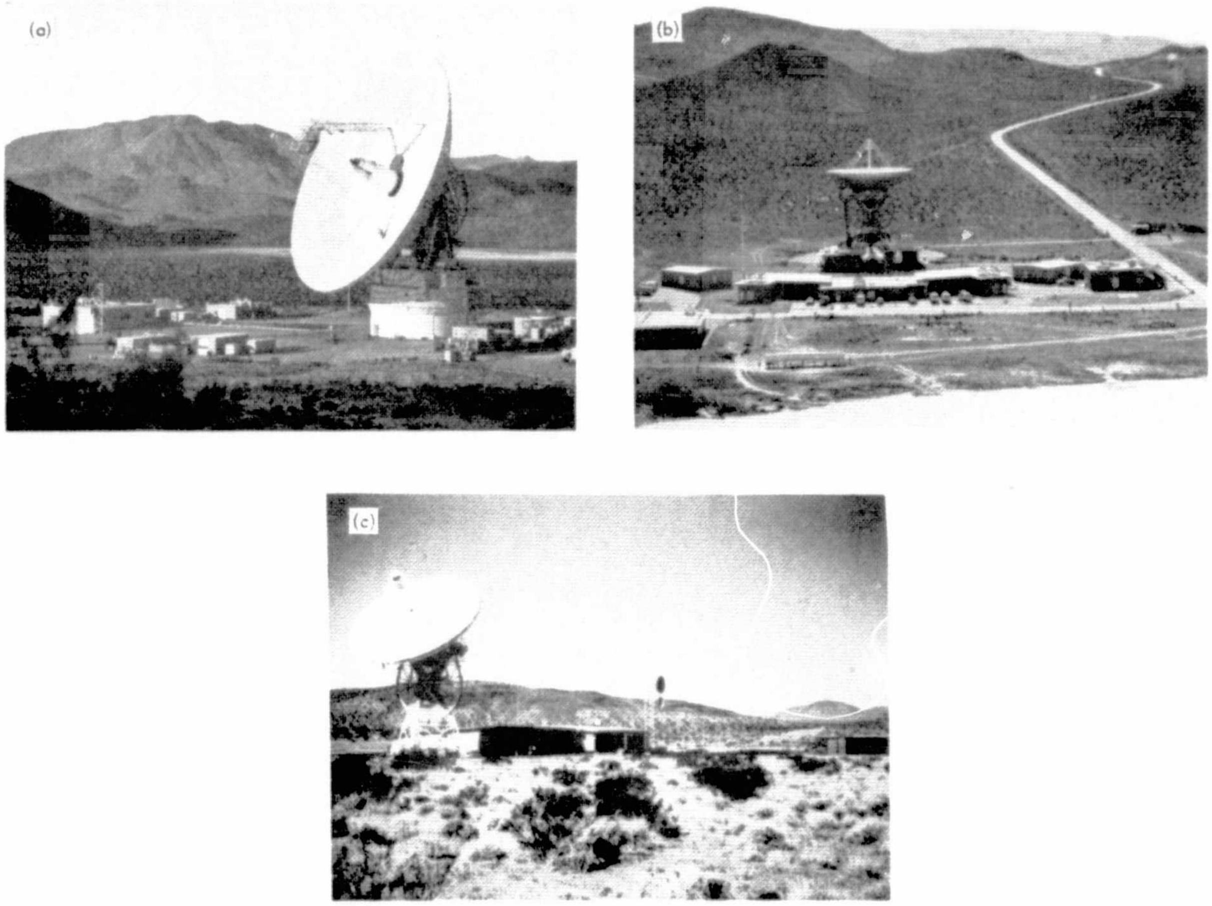

Fig. 2. Typical GDSCC installation: (a) 64-m antenna, DSN Station 14, (b) 26-m antenna, DSN Station 11, (c) 26-m antenna, Apollo site

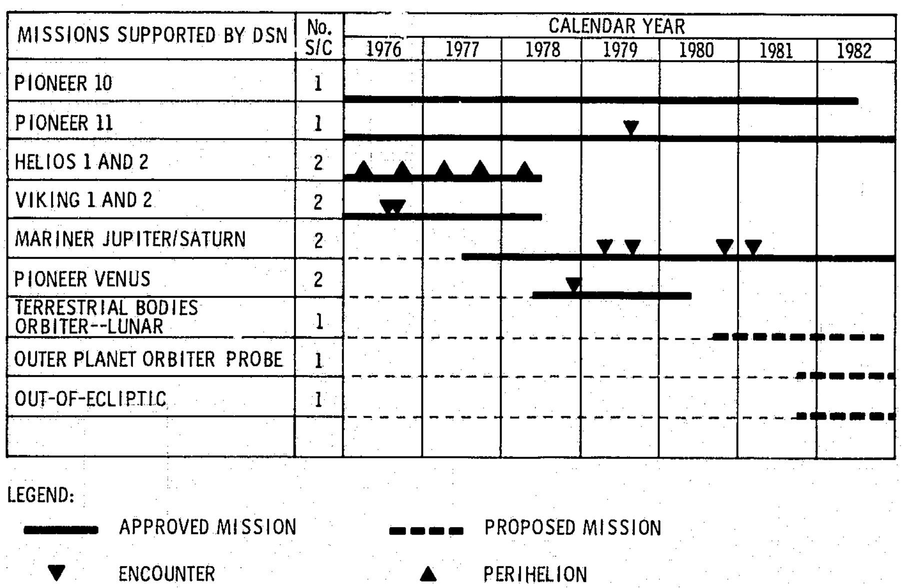

Fig. 3. DSN 5-year plan relative to OTDA mission model

II. TECHNICAL DESCRIPTION

This section provides technical descriptions of the locations and antenna pointing angles of the GDSCC tracking stations, the potential EMI factors involved, and the high-sensitivity transmitting and receiving systems used by these stations.

A. GDSCC STATION LOCATIONS AND ANTENNA POINTING ANGLES

1. Station Locations and Program Support

Following are brief descriptions of the six tracking stations located at Goldstone and the programs they currently support:

(1) DSN Station 11 (Pioneer). Incorporates a fully steerable 26-m-diameter antenna. The station is used for tracking of unmanned scientific spacecraft in deep space and is a backup tracking station for the Apollo program.

(2) DSN Station 12 (Echo). Incorporates a fully steerable 26-m-diameter antenna. The station is used for tracking unmanned scientific spacecraft in deep space.

(3) DSN Station 13 (Venus). Incorporates one 9- and one 26-m-diameter fully steerable antenna. The 9-m antenna is used for distribution, via lunar reflection, of time synchronization signals to overseas DSN stations. The 26-m antenna is used for (a) DSN tracking station technology development, (b) planetary radar studies, and (c) radio science studies.

(4) DSN Station 14 (Mars). Incorporates a fully steerable 64-m-diameter antenna. It is used for (a) tracking of unmanned scientific spacecraft in deep space, (b) DSN tracking station technology development, (c) planetary radar, (d) radio science, and (e) high-rate video reception for the Apollo program.

(5) Apollo Tracking Station. Incorporates a 26-m fully steerable antenna. It is a primary Apollo program tracking station for lunar distances.

(6) STDN Station MIN 3. Incorporates a 125 × 125 m fixed array antenna, several fully steerable helix arrays, and fully steerable 10-m-diameter antennas for scientific Earth satellite tracking. (At this writing, the station has been deactivated.)

2. Typical Pointing Angles of Goldstone Antennas

a. Lunar and Planetary Missions. Almost all of the targets tracked by the DSN antennas at Goldstone lie in the ecliptic plane. Thus, the antennas are typically pointed in the area between plus and minus 30 deg declination.

Low-elevation constraints due to the local land mask or structural limits result in an east and west elevation limit of 6 deg. A more restrictive elevation limit of 10 deg is used for the high-power transmitters, where automatic interlocks inhibit transmission below this value.

Two pointing angle patterns are illustrated in Figs. 4 and 5, one with the 6-deg elevation limit, the second with the 10-deg elevation limit. Each figure shows where the intersections of the antenna ray path would pass through various altitudes if the antenna were at the above-mentioned limits and pointed within the enclosed areas shown. Representative geometry is shown in the small inset in the top right corner of each figure. The intersections found were then projected vertically downward and plotted to scale on a map of the area. Flight radio aid locations and local reference points were plotted to scale using U.S. Government Flight Information Publications as the source of location for the navigational aids and current flight paths in the area.

Infrequently, it is necessary to point the antenna outside the above constraints. When planetary radar observations are made of some of the asteroids, some of the pointing angles will fall outside the 30-deg declination limits.

b. Earth Satellite Missions. Earth satellite pointing directions from Goldstone can occur anywhere in the hemisphere. They are from west to east or north to south, depending on use of equatorial or polar orbits. Synchronous Earth satellite tracking requires fixed pointing.

B. EMI FACTORS

The potential for electromagnetic interference always exists when two or more users of the radio frequency spectrum share a common propagation volume. The EMI potential, both to and from the GDSCC, can be either high or low for a variety of reasons. A strong potential exists, both to and from the Complex, due to the high-sensitivity receiving and high-power transmitting facilities installed there. Conversely, the EMI potential is reduced since antenna locations are selected to make use of natural topography to minimize unwanted reception from other ground-based sources and from aircraft near the horizon. Additionally, in order to realize the performance required for deep space communications, both transmit and receive beams at Goldstone are extraordinarily narrow. One study already completed indicates that the probability of the main beam of a Goldstone antenna interfering with other ground or airborne receivers is low, based primarily on the narrow beamwidths and frequency allocation used and on the low harmonic output of operational 400-kW transmitters.

On the other hand, there is a high potential for EMI through antenna sidelobes radiating either to or from GDSCC. Goldstone high-sensitivity receivers are most vulnerable to EMI from sidelobes generated by airborne sources where natural topography offers no protection from a line-of-sight interference from overhead. Conversely, airborne equipment can suffer EMI from sidelobes produced by the high-power transmitters at Goldstone. With respect to gain, power, and receiver noise temperature, the mutual interference levels are about equal. However, Goldstone presently operates at four widely separated frequency bands which are generally higher than the bands at which airborne high-power equipment operates. Thus, the EMI potential to Goldstone ground equipment (considering direct, harmonic, spurious mixing and other mechanisms) is higher than to airborne equipment.

The problem thus reduces to one of EMI between two services: one airborne, characterized as functioning with near-omnidirectional antennas radiating at multiple frequencies, and the other ground-based, functioning with very narrow beams. The air-to-ground interference potential is high; the ground-to-air potential is lower but must be considered nevertheless.

As described in quantitative detail elsewhere in this report, the Goldstone transmitting function is the only potential problem of significance to other agencies and services, and in particular to the airborne services. Beginning on the ground, studies based on present standards, field measurements, and experience show that these systems pose no untoward problem to personnel in the immediate vicinity of the antennas provided certain simple restrictions are observed. Proceeding up the transmission path, it should be recognized that while the transmitter powers are high, most GDSCC antennas possess a complementary large area, leading to moderate power densities (power per unit area) within the beams. Since the antennas are large as measured in wavelengths, the beams function in a parallel or tubular fashion to a range of a few kilometers. Thus, a proper characterization of these stations for the transmit function would include moderate CW microwave power densities within a narrow beam which is effective to distances significantly greater than ordinary ground-based radars.

Although a number of arguments may be made concerning the probable limited time airborne equipment or personnel would spend within such a beam, it is also true that some aircraft operate at slow speeds, or even hover. Under such unlikely conditions, these beams could present a risk. No standards for nonionizing radiation tolerance of aircraft exist. The present state of knowledge concerning this factor can be expected to remain relatively unchanged for at least several years.

In summary, a high-probability air-to-ground EMI problem exists; the solution necessitates large separation distances, natural shielding, and ultimately more stringent EMI specifications for avionics equipment. A second low-probability but potential problem concerns ground-to-air high power flux density, which is seen as a possible biological risk as well as a risk to susceptible airborne electronics.

C. HIGH-SENSITIVITY RECEIVING SYSTEMS

1. Receiver Description

The communications link with planetary space probes used in the Deep Space Network utilizes one carrier for both tracking and communications functions. A typical system block diagram is shown in Fig. 6. Up- and downlink spectra are shown in Fig. 7. Tracking information is obtained from the measurement of carrier frequency shifts due to Doppler effects and from the round-trip time measurement of a coded ranging signal which is phase modulated on the carrier. Information is phase modulated on the uplink carrier signal for transmitting the ranging code and for commands to control the space probe. Spacecraft information is phase modulated on the downlink carrier signal for ranging and telemetry purposes.

High-sensitivity receivers used in the space communications link are characterized by low noise temperatures, high stability, and both wide- and narrow-bandwidth reception. Low noise temperature is obtained with carefully designed antenna feeds and maser amplifiers. Narrow-bandwidth receivers for tracking the large Doppler frequency shifts of planetary probes utilize phase-lock techniques. Such receivers are capable of tracking radio frequency carrier signals at signal-to-noise ratios (SNRs) of 10 dB or less in a 12-Hz loop noise bandwidth. At a system noise temperature of 25 K, this SNR is equivalent to a receiver input signal level of -164 dBm. It is also equivalent to a received signal RF power flux of approximately 2.5×10^{-24} mW/cm^2 at the surface of the antenna primary reflector. Future receiver designs incorporating lower system temperatures and narrower bandwidths will increase receiver sensitivities by another 10 dB.

2. Interference Criteria

The spacecraft communication system is a phase-sensitive system. The receiver loop utilizes a phase servo, and data information is contained in the phase of the carrier as phase modulation. Any external interference with the phase of the carrier or the SNR of the data channel could result in either the degradation or loss of data. There are several forms this interference might take.

a. CW Signal Interference

(1) Receiver Capture. A CW interfering signal swept through the receiver passband would cause the phase loop of the receiver to release the signal and lock to the interfering signal if R, the ratio of the two signals, satisfies the relation

$$R > \frac{2D}{W_n^2}$$

where D is the sweep rate in rad/s^2 and W_n is the loop natural frequency in rad/s.

At strong signal levels, an interfering CW signal 10 dB above the received signal sweeping through the receiver passband at 100 Hz/s would cause the receiver to lose the signal and lock to the interfering signal. At lower sweep rates, the required level of interfering signal is proportionately lower, until at a signal-to-interfering-signal ratio of approximately one, the interfering signal will no longer capture the receiver, even though the sweep rate of the interfering signal is zero. A unity interfering signal-to-signal ratio at the minimum usable signal level of -164.0 dBm would then establish the maximum allowable signal level of -164.0 dBm for this effect.

(2) Carrier Degradation. In addition to the problem of receiver capture, an interfering CW signal will induce phase modulation on the received signal when the frequency separation between the two signals is comparable or less than the phase-locked loop (PLL) bandwidth. An acceptable phase modulation with about 10-deg amplitude will occur when the interference-to-carrier power ratio is -15.0 dB. Hence, the power in a CW interfering signal which may fall near the receiver frequency should be less than -179.0 dBm for maximum acceptable degradation.

(3) Telemetry Degradation. An uncoded phase-shift-keyed (PSK) telemetry channel operating at a ST/N_0 of 5.0 dB would be degraded about 1.0 dB by a CW interfering signal that is 15.0 dB below the telemetry channel power at the telemetry demodulator input. Referencing this to the input of the receiver, the interference signal must be in the telemetry sideband spectrum and be of a magnitude in excess of -176.0 dBm.

b. Noise Interference. In addition to CW interfering signals, any wideband signal or noise spectrum that would, in effect, degrade the signal-to-noise ratio of the receiver would affect both the phase servo loop and the data channels. In this case, the spectral density of the interfering signal must be at least 5 dB below the spectral density of the receiver noise in order not to degrade the receiver more than 1 dB. With a system noise temperature of 25 K, the receiver noise spectral density is -185 dBm/Hz and the maximum allowable interference spectral density must be no greater than -190 dBm/Hz. This is comparable to the interference level standards for noise established by the Consultative Committee for International Radio (CCIR) as an international agreement.

c. Maser Susceptibility to Interference. Mixing of signals with the maser pump at the idler frequency can cause interference in the receiver passband. Signals must be above -90 dBm to be significant; hence interfering aircraft avionics would have to be in the high-gain antenna beam to produce such levels. Candidate signal frequencies (GHz) for S-band receiver interference are:

$$10.37 \pm 0.08$$

$$14.87 \pm 0.18$$

$$7.435 \pm 0.09$$

$$5.185 \pm 0.04$$

The critical types of receiver interference are summarized in Table 1.

D. HIGH-POWER TRANSMITTING SYSTEMS

1. Transmitter Description

As a general practice, only that power level necessary for reliable tracking and communications in a specific application is used. Power output on all transmitters is variable. The Goldstone Complex has several different types of transmitters ranging in power from 10 to 400 kW. The transmitters of interest are the 100-kW X-band, the 100-kW S-band, the 400-kW X-band, and the 400-kW S-band transmitters.

The 64-m antenna at the Goldstone Mars site contains an operational 400-kW CW S-band transmitter for spacecraft coverage, and a 400-kW CW X-band radar transmitter for radar mapping of planets, planetary satellites, and asteroids. The 9-m antenna at the Venus site used for interstation time synchronization contains a 100-kW X-band CW transmitter. The 26-m antenna at the Venus site has both a 100-kW and a 400-kW S-band transmitter for development and planetary radar activities. (See Table 2 for a listing of GDSCC high-power transmitter characteristics.)

The transmitters are used in a CW mode; therefore, the peak power is equal to the average power. Commands, data, and ranging codes are phase modulated on the exciter at a low frequency, then multiplied to the operational frequency. The transmitters are phase modulated at rates from 100 Hz to over 1 MHz with both sine- and square-wave phase modulation. The modulation generates typical wideband spectra about the carrier which are amplified within the passband of the transmitter (see Fig. 7).

The harmonic output of all operational S-band transmitters is at least 80 dB below the carrier. High-power harmonic filters are used in the outputs of the transmitters to attain this attenuation. The resulting harmonic power is on the order of 1 mW or less at any frequency.

2. Power Density as a Function of Distance

The station locations and uses within the Goldstone Complex have been described in Section I. This subsection discusses each of the microwave transmitting configurations in terms of transmitted power density (power per unit area) as a function of distance from the antenna. Five system types are examined; four of these are currently installed at Goldstone, while one is planned for overseas installations.

Figure 8 shows the power density vs range for positive-toleranced systems. Positive-toleranced means that each parameter affecting power density has been taken as high as is toleranced; ordinarily, each system would function at approximately 80% of the values given in Fig. 8. It is considered prudent to accept the positive tolerances in this way, possibly in matters dealing with health and safety. All powers used in Fig. 8 are CW.

These systems are quite varied in power density and range. Briefly, the power density scale is dependent on power and antenna area, while the range scale is a function of diameter and wavelength. The varied character is due to the spread in antenna diameters (9 to 64 m), power (20 to 400 kW), and wavelengths (approximately 13 to 3.5 cm).

A partial experimental verification of the data given in Fig. 8 has been made. Several additional comments, however, are applicable. Each function shown in Fig. 8 may be divided into three zones: a constant power density zone, an oscillatory zone, and a diverging beam zone.

Independent studies of the antenna illuminations used, based on well known feedhorn gains (in decibels above isotropic), and scattering patterns of the cassegrain subreflectors, based on vector diffraction theory, yield results within 1 dB of the values given for the constant zone. Measurements on the reflector surfaces further support this zone, as obtained for two of the five cases shown. One of the systems (DSS 14, 64-m antenna, 400-kW radar) was further verified at a range of approximately 0.9 km.

The diverging beam zone is also considered accurate to better than 1 dB, based on the standard $1/R^2$ power density vs range function and the verified far-field gains of these sytems, which in general are well known ($\pm$0.4 to $\pm$0.6 dB).

The remaining zone of oscillations is not as accurately known. The oscillation magnitude and positions of maxima and minima depend on details of the reflector illumination function. The results given in Fig. 8 are calculated for a simple $(1 - \rho^2)$ tapered illumination. To the extent that the Goldstone stations depart from this mathematically simple function, the oscillatory zone is in error. This is not expected to be an effect larger than 2 dB. It is unnecessary, for other reasons, to be greatly concerned with details of this zone in any event.

3. Near-Field Safe Distance

Exposure to high-power nonionizing electromagnetic radiation is a potential risk to both personnel and equipment located in an aircraft, and each must be considered in establishing an aircraft's safe operating distance from the radiation source.

The amount of risk to either human beings or equipment depends upon the source frequency, length of exposure, and average power density (power per unit area) at the point of exposure.

In consideration of the risk to personnel, the energy absorbed by body tissue is 20 to 100% of the incident nonionizing electromagnetic radiation for the frequencies in the 1- to 3-GHz region. As a point of reference, the normal heat generated by the body is equivalent to 5 mW/cm^2; but only when the exposure level approaches 100 mW/cm^2 does the body temperature rise. Certain organs of the body are, however, more susceptible than others to the effects of nonionizing electromagnetic radiation because of poorer blood circulation, size, and location and are of greater concern than body temperature rise.

Establishing standards for acceptable biological exposure to nonionizing electromagnetic radiation is still a nebulous issue, and tests in the United States are continuing. Most reported injuries have occurred when the exposure level has exceeded 100 mW/cm^2. Levels exceeding 100 mW/cm^2 are considered to be highly dangerous, and levels exceeding 10 mW/cm^2 are considered dangerous. The generally accepted standard for the maximum nonionizing electromagnetic radiation for human exposure in the United States is 10 mW/cm^2 (about twice the body heat generation). This standard has been accepted by such organizations as the U.S. Standards Institute, U.S. Air Force (USAF), U.S. Army Surgeon General's Office, U.S. Navy, and the British Royal Air Force.

Heating effects of nonionizing electromagnetic radiation can also be destructive to equipment and property. Inductive heating of solid materials such as metal in the form of wire, chips, steel wool, etc., may result in the ignition of flammable vapor-air mixtures. Ignition of flammable vapor-air mixtures may also be caused by electrical arcing due to nonionizing electromagnetic radiation from chance resonant or energy focusing conditions. The accepted standard for nonionizing electromagnetic radiation for fuel vapor by the USAF is 500 mW/cm^2.

Thermal damage may be suffered by electronic components. For instance, a 1-m-diameter parabolic antenna used by an aircraft weather radar or a Doppler navigation system (and oriented under worst conditions) could concentrate on the order of 300 W of energy at antenna focus in a field of 10 mW/cm^2. Electronic components connected to the antenna might also suffer permanent damage (dependent upon their electrical response at the exposure frequency and upon their thermal capability). The specific effects are difficult to predict and would necessarily be the subject for specific tests. Various FAA requirements control acceptance tests for electronic equipment used in civil aircraft for susceptibility to conducted and radiated RF energy. These tests do not cover the frequencies of interest here, and they are not for specific aircraft installations (i.e., they do not consider the shielding effect provided by the airframe). No accepted standard for this type of interference has been located.

Electroexplosive devices (EEDs) are also susceptible to ignition by nonionizing electromagnetic radiation. Although EED susceptibility may be minimized by design, consideration must be given to earlier designs still in use. The accepted standard by the USAF for nonionizing electromagnetic radiation of EEDs is presently established as 1 mW/cm^2 but is under review.

The above standards may be converted to safe operating distances by using Fig. 8. The zone centered at GDSCC shown in Fig. 9 contains flux densities greater than 10 mW/cm^2 and has a potentially higher risk.

Table 1. Critical types of receiver interference

Interference type	Level
CW signal interference	
Receiver capture	-164 dBm
Carrier degradation	-179 dBm
Telemetry degradation	-176 dBm
Noise or wideband spectrum	-190 dBm/Hz
Within maser idler bands	-90 dBm

Table 2. High-power transmitter characteristics

DSN station	Frequency used, MHz	Bandwidth, MHz	CW power, kW
13	7149.9 ±1	15	100
13	2115 ±5, 2390 ±5	15	100
13	2115 ±5, 2390 ±5	25	400
14	2115 ±5, 2390 ±5	25	400
14	8495 ±5	25	400

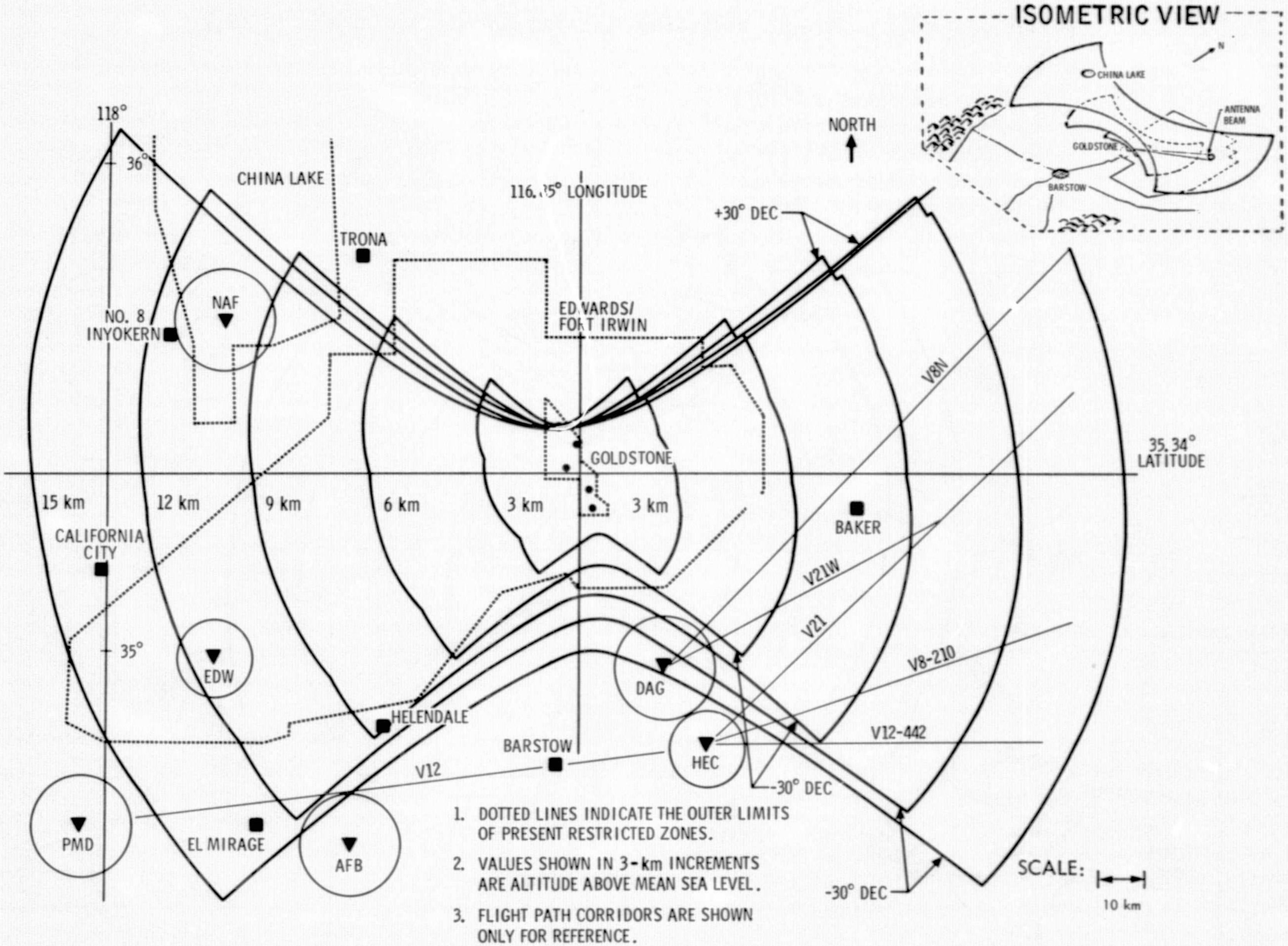

Fig. 4. Goldstone antenna pointing envelopes (6-deg minimum elevation)

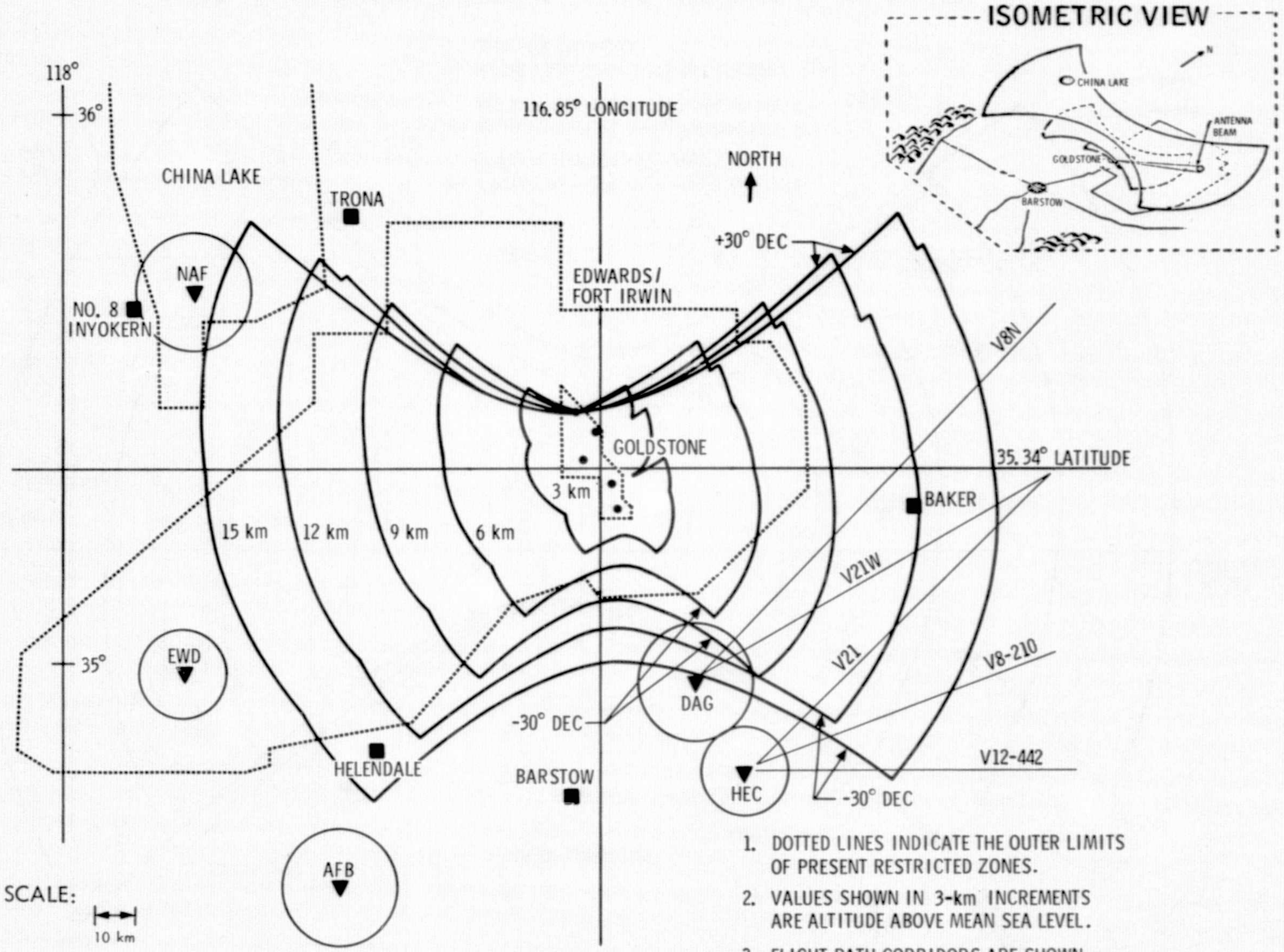

Fig. 5. Goldstone antenna pointing envelopes (10-deg minimum elevation)

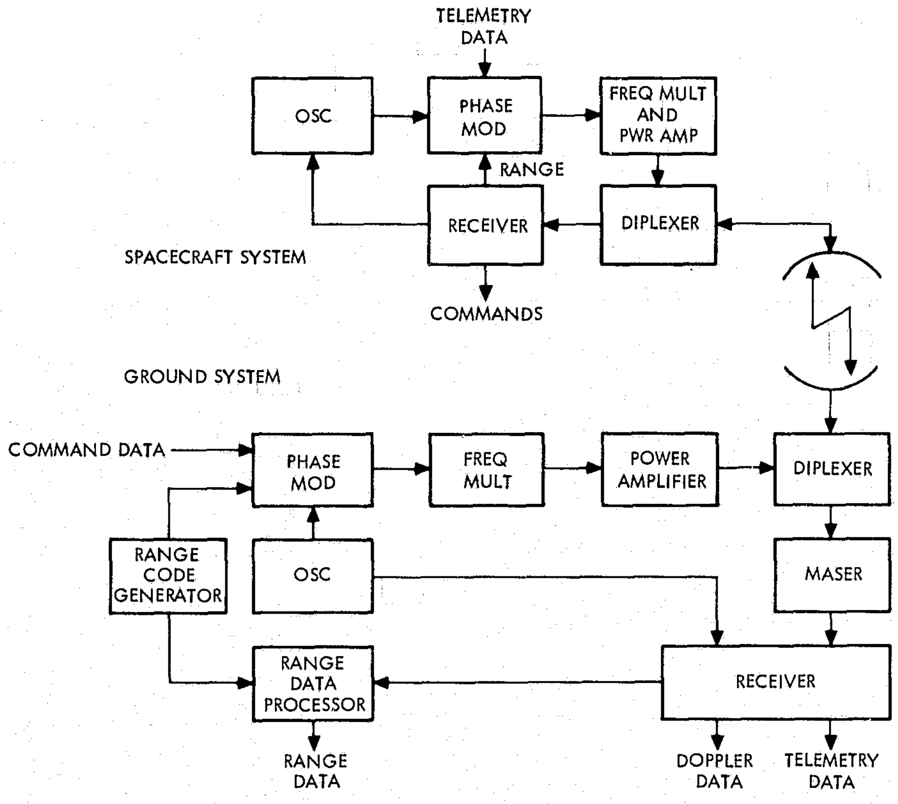

Fig. 6. GDSCC system block diagram

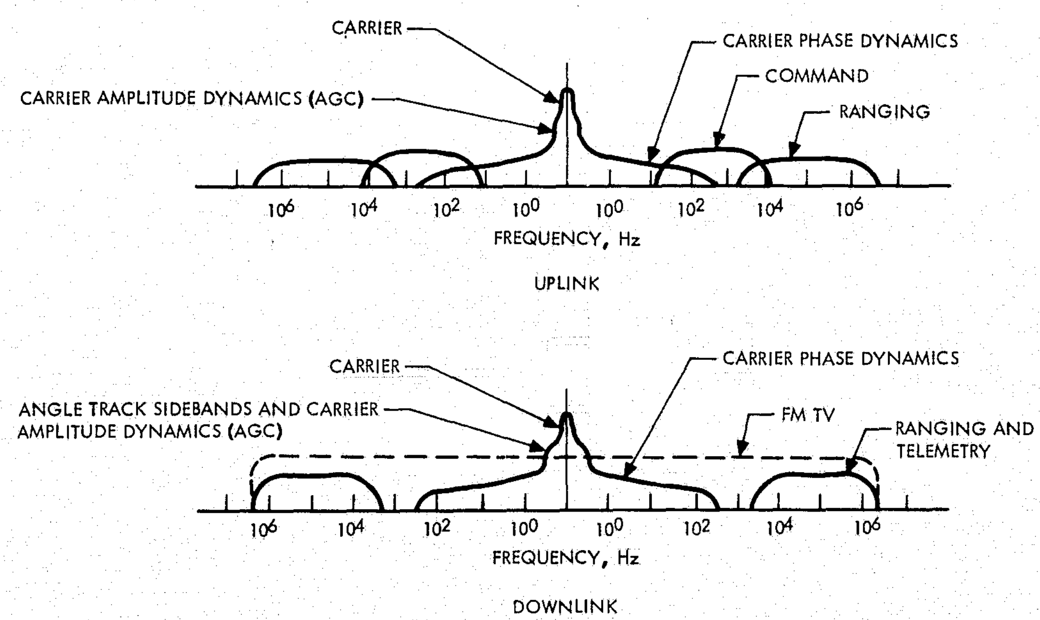

Fig. 7. Typical up- and downlink spectra

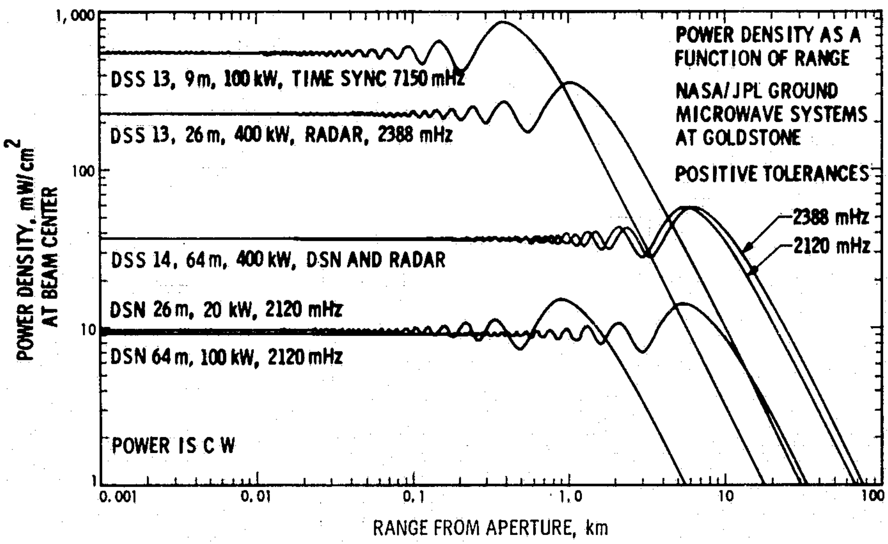

Fig. 8. Power density vs range of present GDSCC transmitter/antenna systems

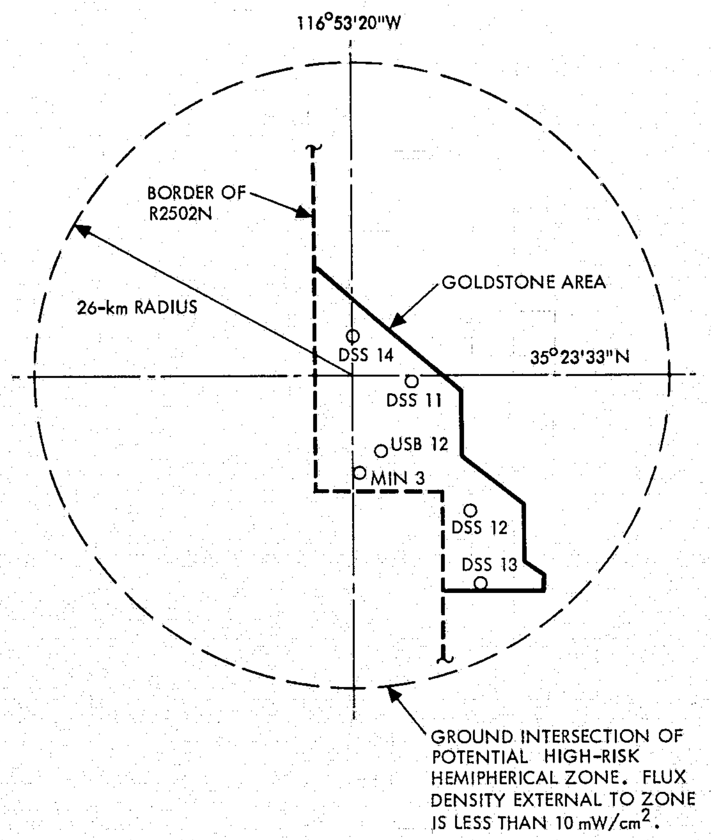

Fig. 9. Potentially high-risk zone at GDSCC

III. PROJECT PLANNING

The OTDA guidelines required an early capability with minimum implementation and operational cost. Government excess equipment would be utilized as much as possible.

An initial planning effort involved preparation of a Statement of Work for a definition phase contract to explore concepts and develop budgetary estimates. Because of resource limitations at JPL and the desire to obtain external expertise, the approach was to contract for a phased, turnkey implementation. However, the selection of a project manager with prior radar experience allowed the initial definition phase to be done in-house and the balance of the project to be contracted. The in-house effort eliminated the need for two separate sequential procurement actions and so provided for earlier project completion.

The preliminary statistics of May 1974 are shown in Table 3. The result of the preliminary planning was the implementation schedule shown in Fig. 10.

Table 3. Preliminary functional requirements and budgetary considerations

NASA task	Implement independent aircraft surveillance capability at Goldstone. Assure safe high-power transmission. Keep implementation and operational costs to a minimum. Assign planning, engineering, and installation to DSN.
Functional requirements (preliminary)	Provide radar surveillance capability of 90 - 110 km range. Minimize adverse interference with other Goldstone stations. Seek initial capability with dual equipment as operational backup. Provide surveillance for all critical transmission periods. Maintain appropriate logs.
Engineering guidelines	Provide supplementary engineering via a new-task-type contract to supplement technical division engineering support. Employ same contractor to provide for implementation. Use maximum JPL manpower of 1 manyear/ year Use existing Government-furnished equipment or surplus hardware. Improve system to reduce operator and maintenance cost (evolutionary). Assume continuously restricted airspace over Goldstone; do not periodically relinquish same.

Table 3 (contd)

Engineering guidelines (contd)	Assume prime target to be a small, slow-moving, low-altitude general aviation craft under visual flight rules. Make installed system self-sufficient, requiring no coverage or support from adjacent agencies (Air Force, FAA, Navy, etc.). Situate eventual radar site near existing roads and utilities. Purchase most items as surplus rather than assuming availability and applicability of Government-furnished equipment and material.
Major operational considerations (preliminary)	Consider automation; alert probability is very small and human operator may falter at critical time. Do not communicate directly with airspace intruder. Give appropriate warning to transmitting station to take necessary procedural action. Several procedural actions will be required to cover various operational modes or project-related events.
Maintenance and operations (M&O) guidelines (preliminary)	Existing M&O contract provides maintenance and operation: Operator coverage -- 24 h/day, 7 days/week. Electronic maintenance -- 8 h/day, 5 days/week. Mechanical maintenance -- 8 h/day, 1 day/week. Annual escalation -- 6% for labor. Sustaining spares -- to be determined.

Table 3 (contd)

Unresolved matters	Initial operational date. Target life for system. Future interface with Palmdale International. Operational use of remote surveillance video from Palmdale FAA as backup. One radar may not provide coverage and also meet noninterference level requirement. Surveillance radar yields only range and azimuth. Altitude is ambiguous.
Budgetary assumptions	The installed radar system is self-sufficient and does not require any coverage or support from adjacent agencies. All equipment is to be purchased from industry. (Application of Government-furnished equipment will require separate study to verify it as an alternate approach.) An off-Lab contractor is to be selected for providing the necessary systems support. Maintenance and operations support for the operational phase is not included in the estimate. The radar site is not too far removed from existing roads and utilities. An optional second system to ensure coverage.

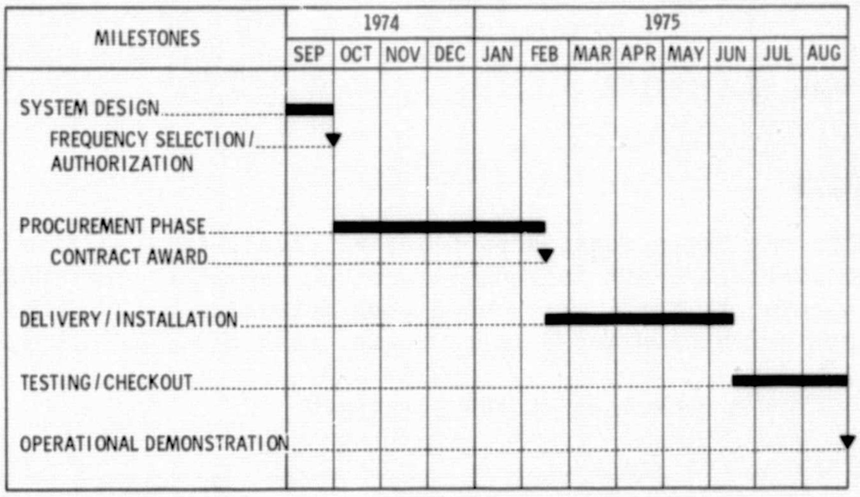

Fig. 10. OSR preliminary implementation schedule

IV. TECHNICAL REQUIREMENTS

During the months of June through September 1974, the functional requirements for the Goldstone OSR installation at GDSCC* were consolidated from NASA Headquarters and FAA requirements. The requirements sought to establish a viable system providing for the detection of aircraft intruding into the restricted airspace adjacent to and including the Goldstone Complex. Operations support scheduling and appropriate procedural action definition were associated requirements.

As constrained by funding limitations, the requirements were intended to make use of surplus or Government-furnished equipment. Furthermore, the requirements were used by all implementing organizations as the sole source for the design of appropriate hardware and software, for the development of budgetary estimates, and for the establishment of an implementation test and transfer schedule for the Goldstone OSR.

A. FUNCTIONAL DESCRIPTION

1. Definition

The Goldstone Operations Support Radar installation provides the means for detecting airborne craft intruding into the airspace over GSDCC and for providing a warning to the Complex when such detection occurs (see Fig. 11). These functions are accomplished in three informal areas of activity:

(1) Airspace surveillance and detection

(2) Information transfer

(3) Dissemination of warning (Phases 1 and 2); automatic initiation of transmitter shutdown (Phase 3)**

Airspace surveillance and detection consists of those functions necessary to search for and detect airborne intruders. Information transfer consists of a communications link between the remote surveillance radar site and the central controlling facility. Dissemination of warning consists of providing warnings to the transmitting stations. The dissemination of warnings may be replaced by an automatic transmitter shutdown capability at a later date.

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*For purposes of this document, the GDSCC also comprises on-site Spaceflight Tracking and Data Network stations under the control of the Goddard Space Flight Center (GSFC).

**The three phases of operational capability are discussed in Section IV-A4.

2. Criteria

The following assumptions form the functional basis of the Goldstone Operations Support Radar installation:

(1) Pencil beams of the 64-m antennas at 400 kW of transmitting power have a field intensity in excess of 10 MW/cm^2 to a range of approximately 26 km at S-band.

(2) The lower pointing limit of radiation at high power levels is 10 deg above the horizon.

(3) Stations are limited in operation to ±30 deg of declination (east-west bowtie) (see Figs. 4 and 5).

(4) The critical volume of beam coverage is totally within the restricted area shown on survey maps (see Fig. 9).

(5) Primary targets are general aviation flying under visual flight rule (VFR) conditions (below 5500 m).

(6) All aircraft under instrument flight rule (IFR) conditions (above 5500 m) are under FAA surveillance and control, and will avoid restricted areas.

(7) Intruder aircraft operate above the surrounding terrain and below a 5500-m ceiling.

(8) Below 1200 m, aircraft are more likely to fly into land obstructions than into a transmitter pencil beam. Under normal conditions, a very low-flying aircraft can approach undetected but also is not exposed to the elevated transmitter beams. (For example, JPL aircraft approaching Goldstone Lake airfield and landing at 900 m are not exposed to the transmitter beams.)

(9) The mountainous terrain of the Goldstone area forms natural boundary walls (~1500 m) at about 50-km range.

(10) Aircraft fly in corridors about 50 km away from stations.

(11) Detection beyond 50 km is permissible, but alert initiation at this distance is premature and would cause a high alert rate.

(12) Transmitter beams radiate at higher than 10-deg elevation angles for the greater part of a typical 12-h pass. A typical sidereal rate is 15 deg/h. (Much like the rays of the Sun or Moon, the transmitter beams are positioned at higher elevations except at the rise and set times of the day.)

(13) The first mechanization (Phase 1 implementation) calls for detection of an intruder and for providing an alert warning of the intruder's approach by telephone.

(14) Any emergency situation known by the FAA is called into the Goldstone Complex via telephone.

(15) No radio contact is made with an intruding aircraft from the Goldstone Complex; FAA-Palmdale, however, may be alerted to provide ground-to-air direction of the aircraft.

(16) Airspace is always restricted, never open to general aviation.

(17) Support radar operates on a scheduled basis except for downtime (failure, maintenance), scanning out the volume, and detecting aircraft flying into the area.

(18) Pilots are made aware, by previous instruction, of the Goldstone Complex restricted area.

3. Key Characteristics

The Goldstone Operations Support Radar installation implements independent aircraft surveillance radar capability at GDSCC to ensure minimum interaction with the Goldstone stations. Following are its key characteristics:

(1) Capability for protection of intruders from 10-mW/cm^2 or greater field intensity radiation exposure.

(2) Capability for radar surveillance to a maximum range of 93 km.

(3) Capability to present minimum adverse spurious or harmonic interference to stations of the Goldstone Complex.

(4) Capability for providing reliable surveillance during all critical mission periods of the Goldstone Complex.

(5) Assumption that the prime target is a small, slow-moving, low-altitude, general aircraft under visual flight rules.

(6) Assumption that the airspace over Goldstone is continually restricted; that this restriction is never periodically relinquished.

(7) Emphasis on keeping implementation and operational costs to a minimum.

(8) Emphasis on using existing Government-furnished equipment or excess hardware wherever possible.

(9) Emphasis on use of long life equipment.

(10) Capability with adequate redundance to ensure radar surveillance for critical operational periods of the GDSCC stations.

(11) Installation of the surveillance system as close as possible to existing roads and utilities.

(12) Installation of a self-sufficient system that does not require coverage or support from adjacent agencies such as the FAA, U.S. Air Force, or U.S. Navy.

(13) Minimal system downtime for maintenance.

(14) Maintenance of appropriate logs of significant events.

(15) Provision for evolutionary improvement in reducing operator and maintenance cost.

(16) Provision for appropriate warning to be given to GDSCC stations so that necessary procedural action may be taken.

(17) Establishment of several procedural actions to cover various operational modes or project-related events.

(18) Provision for using existing M&O contract to provide

Operator coverage --24 h/day, 7 days/week

Electronic maintenance -- 8 h/day, 1 day/week

Mechanical maintenance -- 8 h/day, 1 day/week

4. Implementation Phases

The Goldstone Operations Support Radar installation will be implemented in three phases:

Phase 1, Initial Manual Mode:	Establishment of initial capability to provide required coverage and gain experience
Phase 2, Upgraded Manual Mode:	Supplement to Phase 1, through improved equipment performance
Phase 3, Automated Mode:	Improvement of system efficiency; reduction of operator expense

Phase 1 will be effected as soon as practicable to provide coverage and gain experience. No dates have been set for the implementation of Phases 2 and 3.

The following items characterize Phase 1 operation:

(1) Use of a single surveillance radar to set off a warning of approaching craft.

(2) Surveillance radar yields only range and azimuth (a two-dimensional description). Altitude is ambiguous.

(3) Use of remote surveillance data from FAA-Palmdale as an optional backup.

(4) Use of other auxiliary or backup techniques to augment basic capability.

(5) Development of future interface with Palmdale International Airport. (Future aircraft departures for the East may additionally fly just north as well as just south of the Goldstone Complex).

(6) Determination of radar target position relative to several transmitter beams may be beyond the capability of the operator.

(7) A low-cost automatic alarm may be required because a human observer may falter at a critical time.

(8) Lack of communications with aircraft places entire burden of reacting on the stations.

B. FUNCTIONAL AND PERFORMANCE REQUIREMENTS

This section defines the general functional requirements, remote radar site selection requirements, and performance requirements of the Goldstone Operations Support Radar installation. Figures 12, 13, and 14 describe requirements, functions, and data flow.

1. General Functional Requirements

a. Radar Equipment Selection Requirements. A choice of radar equipment is available from the following broad classifications:

(1) Surveillance radar

(2) Airport surveillance radar

(3) Search radar

(4) Acquisition radar

(5) Airport traffic control radar

(6) Gap filler radar

Each of these classifications is similar in hardware, capability, and function, although specific applications may vary. Such radar equipment is packaged for ground, shipboard, airborne, and transportable environments.

Frequency bands L, S, C, and X are utilized, and a wide tuning range is possible. However, for the Goldstone Operations Support Radar installation, a spot frequency in a crowded spectrum is required because of the geographic location. Furthermore, the chosen installation must have a minimum adverse effect on the many highly sensitive tracking stations colocated in the Goldstone Complex.

The following requirements are pertinent to the selection of appropriate radar and its associated equipment:

(1) Within the constraints of cost, availability, and schedule, equipment may be of a hybrid configuration; a quality antenna (high-low beam), quality transmitter (klystron), and quality receiver (solid-state) shall be considered.

(2) Radar frequency selection shall be made per the FAA Regional Office requirements prior to procurement.

(3) Microwave system frequency allocation per the FAA Regional Office requirements shall be made prior to procurement.

(4) Radar set shall be capable of dual use. System shall be used dual "hot" (second unit warmed up and operable) for critical events, dual "cold" at other times to conserve energy and extend service life.

(5) Three-dimensional radar shall not be a requirement, although some elevation resolution is desirable. (This is the reason for the mandatory tilted beam and desirable high-low beam requirements of Table 4).

(6) Voice communications with aircraft for normal operation shall not be required.

(7) Interrogation of airborne transponders shall not be a requirement. (Such action is strictly forbidden by the FAA.)

b. Hardware and Software Requirements. As listed in broad categories, the following are the hardware requirements of the subsystem.

(1) Remote unattended radar set

(2) Remote site facility

(3) Microwave radar relay between sites

(4) Control console

(5) Control display

(6) Towers

(7) Cables

(8) Spares

(9) Special test equipment

(10) Transportation packaging

(11) Installation kits

(12) Environmental control equipment

(13) Record-keeping equipment

(14) Maintenance equipment (electronic and mechanical)

(15) Intruder aircraft audible alert warning

(16) Automatic data processor (future)

The Software requirements are as follows:

(1) Target -- definition

(2) Beam(s) -- definition

(3) Emergency -- modes (Phase 1, Phase 2, manual)

(4) Processor program (Phase 3, automatic)

A detailed list of radar set requirements is presented in Table 4.

2. Remote Radar Site Selection Requirements

The following are required for the selection of the remote radar set installation:

(1) Provide maximum average separation distance from Deep Space Stations (DSSs) to provide space-loss isolation between stations.

(2) Take advantage of existing DSS masking for maximum isolation. Locate site above the placement of windmills and towers to minimize interference to radar.

(3) Provide maximum height above terrain for good coverage.

(4) Minimize horizon mask.*

(5) Ensure that there is no line of sight to any station in Complex.

(6) Locate site within Goldstone Complex near utilities (power, roads, communications, etc.).

*At an elevation below 1500 m, the chances of an aircraft hitting a mountain are greater than of flying into the transmitter beam.

3. Phase 1 Performance Requirements

a. General. A critical volume is established over the Goldstone Complex, and a single radar shall be used to determine the approach of aircraft to this near-hemispherical airspace. A zone beyond the nominal 26-km hemisphere shall be used to establish an alert condition to warn the operator of a pending problem. Based on known data relative to operating transmitters, locations, power levels, pointing angles, and beam characteristics, the operator shall relate these to the intruder's flight path for a manual intrusion alarm decision to procedurally control safe transmission conditions.

Note that Phase 1 equipment provides early initial capability as compared to Phase 2, which will upgrade the capability based on operational experience.

b. Microwave Radar Relay. The microwave radar relay (MRR) shall provide two-way communication for voice and one-way communication for radar information in the microwave band. It shall be capable of transmitting voice, radar carrier status, radar azimuth, radar trigger, radar range marks, and three target display video signals. The MRR shall consist of a transmitting terminal and receiving terminal (see Figs. 13 and 14).

The MRR shall be capable of two-way voice and unilateral radar communication between the remote, unattended radar site and the operator-located site. When fully operating, four RF channels shall provide the necessary communications:

(1) Channel 1 shall transmit the radar azimuth, trigger, Video 1, and the channel status signals.

(2) Channel 2 shall transmit the radar, Video 2, Video 3, range marks, and the channel status signals.

(3) Channel 3 shall be a spare; however, it shall transmit a channel status signal.

(4) Channel 4 shall transmit the voice and channel status signals.

The voice intelligence is transmitted, from the radar site, on Channel 1 or Channel 3. Channel numbers are not to be interpreted as signifying frequency designation.

c. Radar Set. The radar set shall detect low-flying aircraft. It shall consist of high-performance, medium-range S-band equipment adaptable to air traffic control.

The radar set shall be installed at an unattended site. This site shall be visited only once a week by maintenance personnel. Emphasis throughout the design shall be on reliability and ease of maintainability.

Among the required features of the radar set are:

(1) Use of a klystron final amplifier

(2) Dual-channel operation

(3) Automatic channel changeover and fault-sensing circuits

(4) Provision for remoting of radar data by either wideband or narrowband equipment

(5) Excellent moving target indication (MTI) performance

The authorized spot frequency for radar operation shall be 2835 ±5 MHz.

d. Other Requirements. The following is a listing of selections and provisions to be made during the development of the surveillance radar system:

(1) Select an appropriate area for equipment shelters on chosen site. (Consider the effect of the selection on an early operational date.)

(2) Provide for shelter pads.

(3) Select the antenna tower. (Although available towers may be 20 m in height, consider a much shorter tower -- 6 to 9 m -- to help meet an early operational date.)

(4) Provide for appropriate footings for the antenna tower.

(5) Provide for appropriate electrical power input:

(a) Determine whether transmission lines are to be above ground or buried.

(b) Determine whether there is to be a substation.

(c) Calculate equipment loads and provide for appropriate current and voltage.

(6) Provide for an appropriate hard-line telephone link.

(7) Establish requirements and provide for appropriate air conditioning, if required.

(8) Provide for appropriate grounding of all equipment.

(9) Select safety lights and provide for aircraft warning indicators on the antenna tower.

(10) Obtain appropriate control room space in the DSN Ground Communications Facility area to accommodate operational site requirements.

(11) Establish a microwave link with consideration of the following:

(a) Number of channels

(b) Bandwidth

(c) Frequency

(d) Orientation

(e) Link path

(f) Towers

C. INTERFACES

This section describes the interface requirements and responsibilities of the four organizations involved with the development and operation of the Goldstone Operations Support Radar installation: the DSN Engineering Section (332), DSN Systems Engineering Organization (430), DSN Facility Operations Section (422), and the contractor. The information interface was via written interchange and published documentation. Interface requirements were as shown in Table 5.

1. Operational Interfaces, Phases 1 and 2

Various communications links are required between the Goldstone Operations Support Radar installation and the various Deep Space Stations of the Complex. Similarly, links are required between the radar and external agencies. Channels shall be established to communicate with the neighboring Edwards, China Lake, Mercury, Navy, and Energy Research and Development Administration installations. The FAA Regional Office shall be informed when the installation becomes operational.

Phase 1 and 2 operational interface details are to be determined at a later date.

2. Electromagnetic Interfaces

a. Background. The Deep Space Network is operational at S-band; however, developmental activity also involves X- and K-bands. Power levels are generally increasing, and other new activity relating to energy collection and transmission have been introduced into the environment.

b. Requirements.

(1) The Goldstone Operations Support Radar installation shall produce a minimum of interference with other surveillance radars located 90 to 165 km away. (There are currently no known problems with these external radars.)

(2) To decrease the possibility of interference, bandpass filtering shall be used to further reduce spurious low-side signals to at least -100 dB, from dc to 2400 MHz. High-side harmonics shall be additionally reduced to at least -50 dB below nominal transmitter harmonic output.

(3) To minimize the possibility of false alarms, the Goldstone Operations Support Radar installation shall incorporate provisions to reject interference from other radars.

3. Power Interfaces

The following power interface requirements are pertinent to the Goldstone Operations Support Radar installation:

(1) Primary power of the Goldstone Complex shall be used.

(2) Backup power shall not be an initial requirement. (It is desirable to have an auxiliary power source; in the event the transmitting station(s) goes on standby power, the radar can continue to support operations should primary power be interrupted.)

(3) Mobile power shall not be part of Phase 1 design.

4. Facility Interfaces

The Goldstone Operations Support Radar installation shall have minimum impact on Goldstone Complex requirements, including its environment (towers, footings, roads, etc.). Figure 15 illustrates the facility installation.

The OSR shall interface with Section 332 in the following facility design areas:

(1) Facility planning (preliminary)

(2) Site selection

(3) Cost estimates for new facility

(4) Interface with NASA as required

(5) Interface with A&E personnel

(6) Scheduling

D. OPERATIONAL CONSIDERATIONS

1. Maintainability

Goldstone Operations Support Radar maintenance shall be aided by the provision of built-in diagnostics to detect and isolate failures to the drawer level. Maintenance activity shall feature ease of access to the failed drawer and ready availability of a compatible replacement. No station-level maintenance action shall require the services of more than two on-site trained operators to restore the subsystem functions to normal operation within the allowable 15-min period.

Vertical, single-layer chassis, mounted in cabinets accessible from the front and rear, shall be used for most units. These can be serviced without removal of the unit from the cabinet. Heavier items shall be easily accessible. Operation of the standby or disabled channel into a dummy load shall permit preventive and corrective maintenance without interruption to service.

Redundant failed subsystem equipment that cannot ordinarily or easily be removed for repair shall be designed so that all possible functional failures may be detected, diagnosed, and repaired within an elapsed time not exceeding 6 h. Not more than two trained repairmen, using only general test equipment, shall be employed for this service.

When corrective maintenance action is performed according to required procedures, the failed data path recovery time shall not exceed 15 min.

2. Spares

Initial sparing for the Goldstone Operations Support Radar installation shall be consistent with needs determined by predicted failure rates and functional requirements of the equipment.

3. Operability

Goldstone Operations Support Radar equipment shall require the minimum number of controls and associated displays that are optimally related and consistent with the operator's need to select and monitor major equipment functions. No set of operating conditions shall require the service of more than one trained operator to operate the equipment or any part of it during manual control operations.

4. Reliability

When operating as the complete Goldstone Operations Support Radar installation, each channel shall achieve at least 600 h of normal operation without functional failure. Normal operation is defined as ready time during which the equipment is energized and available for use plus operating time when the equipment is being used to support mission requirements.

High reliability shall be stressed insofar as possible with the use of existing surplus equipment. To enhance reliability, the standby radar and equipment channel shall automatically switch into operation in the event a failure occurs in the operating channel. Fault-sensing circuits shall record the reason for the changeover to expedite maintenance.

5. Quality Assurance

Equipment shall be reviewed by a JPL Quality Assurance (QA) representative at the time of the contractor's procurement inspection. Upon completion of factory rework and prior to shipment, the JPL QA representative shall make an inspection and prepare a report. Contractor workmanship standards shall be reviewed and approved at the time of contracting. Upon installation at the field sites, a JPL QA representative shall make an inspection and prepare a report. New work, such as cable fabrication, shall be in accordance with applicable JPL specifications.

6. Documentation

The following are types of documentation required to record the design, development, fabrication, implementation, and transfer of the Goldstone Operations Support Radar installation to Operations:

(1) DSN subsystem detailed requirements

(2) Detailed interface specifications

(3) Hardware detail specification

(4) Hardware test plan

(5) Software definition

(6) Software specification

(7) Acceptance test plan

(8) Operational documentation

(9) Maintenance documentation (manuals)

(10) Transfer agreement

(11) Maintenance support plan

7. Safety

The operation, testing, and maintenance of any item of equipment within the Goldstone Operations Support Radar installation or of the equipment operating collectively as a unit shall not require the implementation of any special or temporary safety measures by DSN personnel.

8. Economy

The Operations Support Radar installation shall be designed and constructed to minimize the cost of operation, including energy consumption, based on a 10-year life-cycle cost analysis.

Table 4. Detailed requirements for radar set

Radar	Mandatory	Desirable	No requirement
Early operational capability	X		
Dual configuration	X		
Minimal cost factor	X		
Minimal operator duties	X		
Unattended radar set	X		
High reliability and low maintenance	X		
Dual "hot" option		X	
Automatic switchover		X	
Use of available Government surplus equipment	X		
Klystron amplifier		X	
Moving target indication		X	
Low spurious output	X		
Low harmonic output	X		
60-Hz power	X		
Remote operation and display	X		
Radome			X
Antenna tilt (mechanical)	X		
High and low beams		X	
Voice communication with aircraft			X
Range (90 km, 2 m^2)	X		
Azimuth ($\pm$1 deg)	X		
Height (1200 m)		X	
Airport surveillance radar		X	
S-band operation	X		
Range blanking		X	
Spares availability	X		
Test equipment	X		
5-year projected service life	X		
10-year projected service life		X	
Medium-power transmitter:	X		
500 kW (per FAA)		X	
Less than 1 MW (per FAA)	X		
Readouts	X		
Digital readouts		X	

Table 5. Interface responsibilities

Organization	Function
JPL Section 332[a]	Facility planning Facility design (preliminary) Interface with architectural and engineering (A&E) personnel Interface with cognizant engineer
JPL Organization 430	Programmatic control Systems effort direction Functional requirements Design requirements
JPL Section 422	Operations-related support Design Implementation Maintenance and operations
Contractor	Installation and test System engineering studies Detail design Fabrication support Documentation Training

[a]Refer also to Section IV-E.

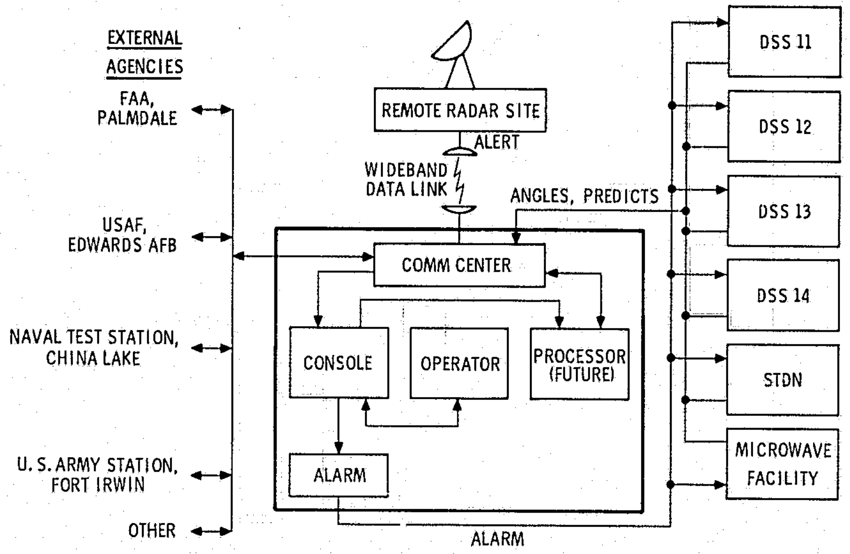


Fig. 11. OSR radar interfaces

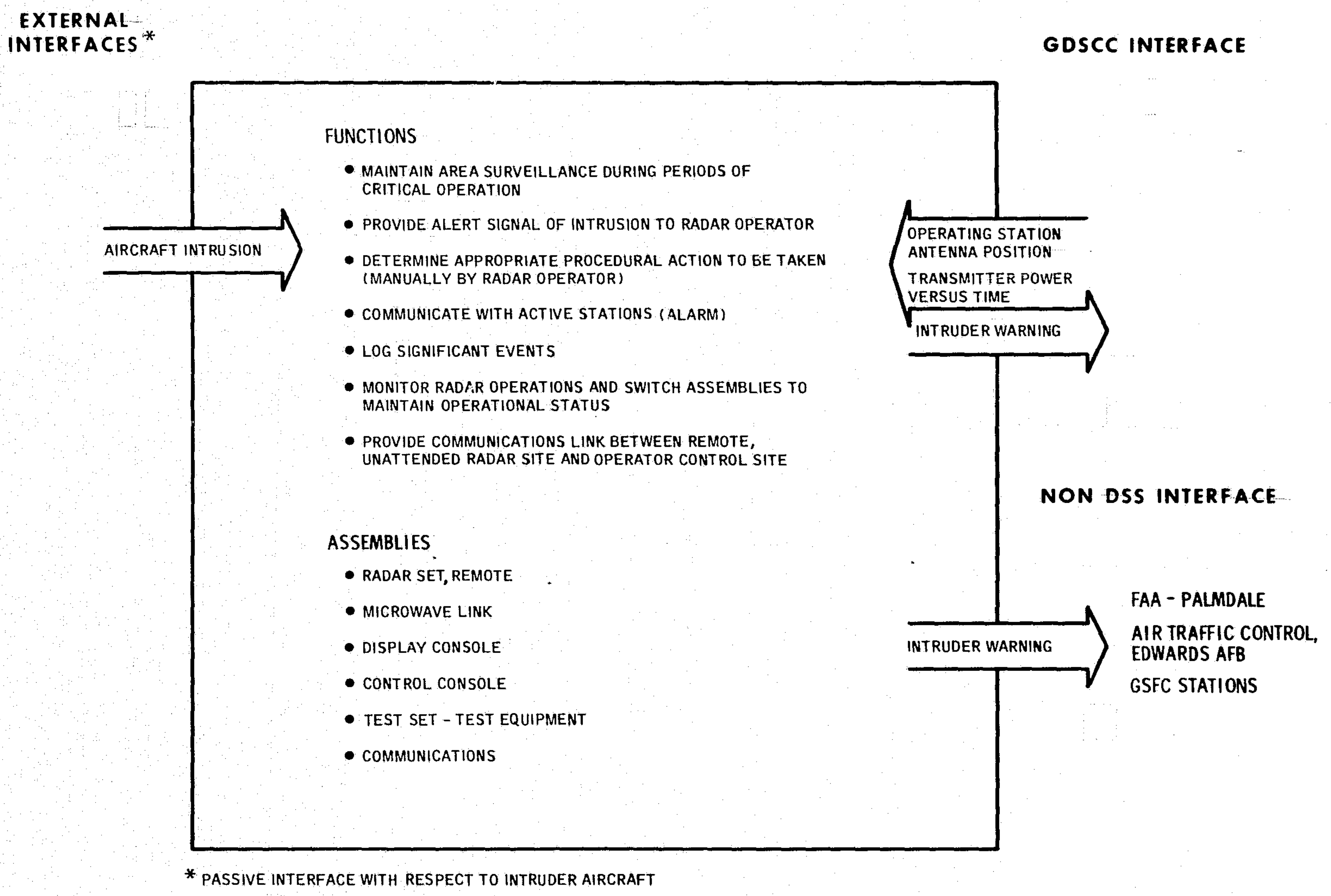


Fig. 12. OSR radar functional requirements (Phase 1)

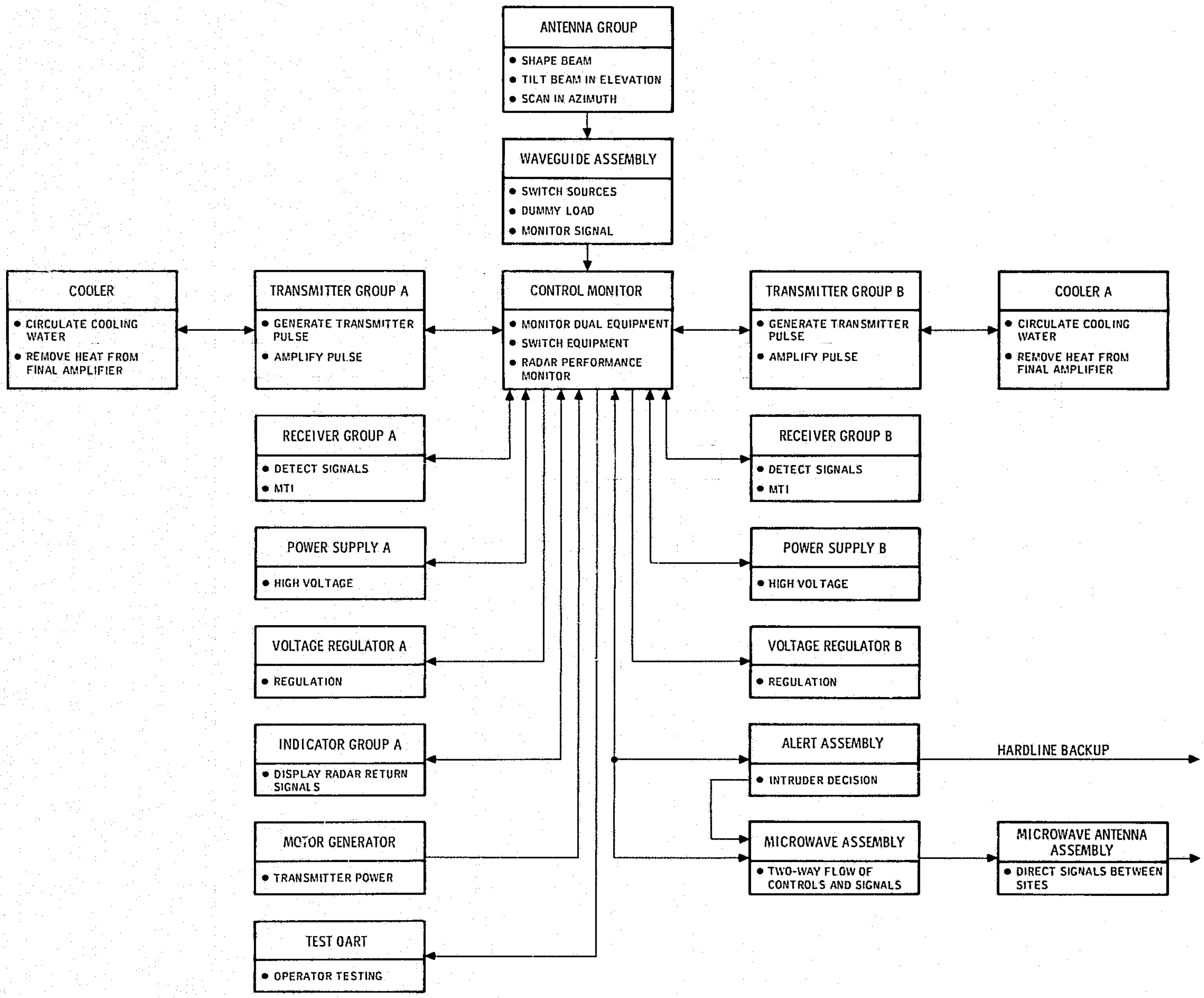


Fig. 13. OSR functions and data flow, remote radar site

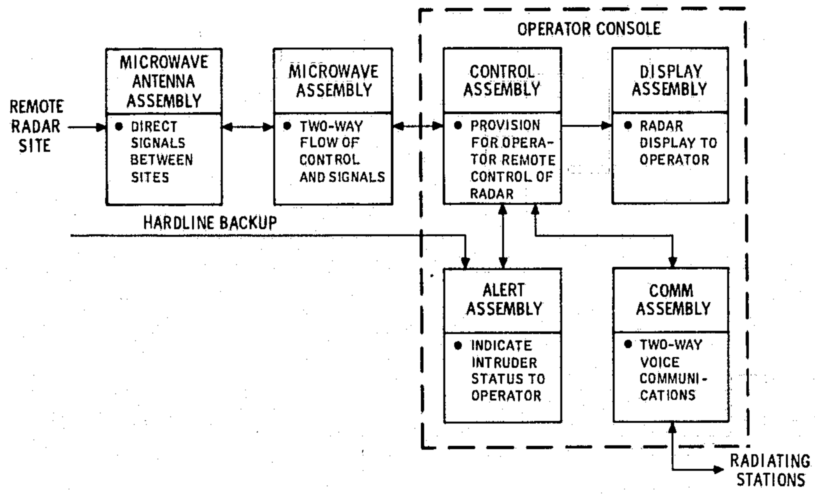


Fig. 14. OSR functions and data flow, operational site assembly

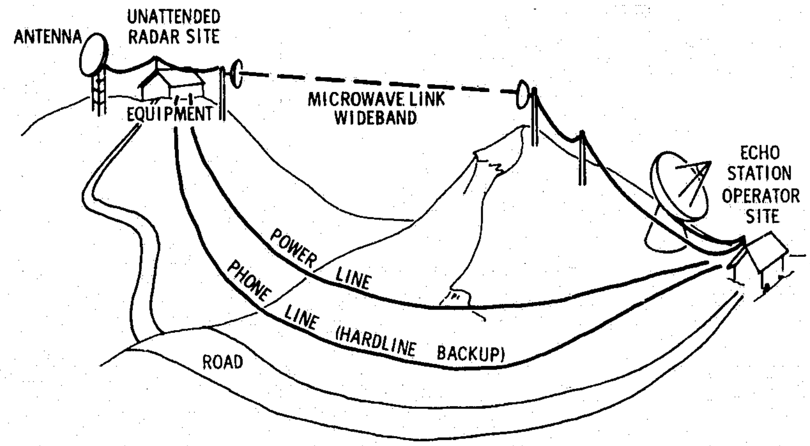


Fig. 15. OSR preliminary installation

V. RADAR SELECTION

Preliminary study by the Jet Propulsion Laboratory indicated that the radar set capable of meeting the performance objectives and availability at low cost was the AN/FPS-18. A more detailed analysis of the requirements by the successful contractor might result in alternate mechanizations and configurations. Such alternatives which met the aggregated requirements would be considered if they provided the intended performance within comparable costs and met the schedule.

A. RADAR TRADEOFF FACTORS

In considering the various possibilities for the radar sensor, the contractor had an option of either using S-band radars designed for attended operation and adding the fault-sensing circuitry and channel changeover functions or selecting a surplus radar initially designed for unattended operation. Examples of radars which could meet the detection requirements but would require extensive modifications are the AN/CPN-18, the NIKE HERCULES acquisition radar, and the AN/CPS-6B. The AN/CPN-18 has several attractive features, including a shelter and video remoting assembly. The AN/CPS-6B has height-finding capability but is a very old design and, in the contractor's opinion, is incapable of meeting the reliability requirements. To the best of their knowledge, only two radars had been designed for unattended operation: the AN/FPS-14 and AN/FPS-18. The AN/FPS-14 design was an adaptation of the FAA ASR-3 radar. From first-hand knowledge of the efforts required to modify a radar system for unattended operation, they concluded that the only practical approach was to use either the AN/FPS-14 or AN/FPS-18 as the sensor for the JPL system.

The FPS-14 is a magnetron system employing a 5586 magnetron, as does the CPS-6B and CPN-18. As a magnetron system, it is a simpler radar than the FPS-18 with its klystron. With some modifications to improve the noise figure of the system, the FPS-14 would meet the 90-km detection range criteria and the reliability requirements for the system. The FPS-14 and FPS-18 antennas have identical performance despite some variation in mechanical construction.

Several factors led to the selection of the FPS-18 as the best radar for the JPL application. Because it is capable of radiating a higher power than the FPS-14, the resulting improvement in signal-to-noise ratio offers a significant advantage in making it possible to set the false alarm level higher while still achieving the desired coverage. Additionally, one of the prime system concerns is spurious radiation and the attendant possibilities of interference with the Goldstone communication equipments. The klystron amplifier in the FPS-18 has a much cleaner spectrum than the FPS-14 magnetron with less problem in reducing the out-of-band radiation to the specified levels.

Based on the foregoing factors, the contractor proposed use of the FPS-18 radar as the basis for the Goldstone Surveillance Radar subsystems.

B. RADAR SET AN/FPS-18

Radar set AN/FPS-18, shown in Fig. 16, is a fixed, high-power, air-search radar system designed to provide reliable operation under severe conditions and continuous duty. It is primarily designed as a gap filler radar set for use with the early warning radar net, and, in addition, possesses operating characteristics and features which make it suitable for general surveillance service. Under normal conditions, aircraft of the single-engine fighter type, such as the F-86, can be detected at a range of 60 km at an elevation up to 5200 m from 1/2 to 30 deg above the horizontal throughout 360 deg of azimuth. Targets detected by the radar set are displayed in plan position indicator (PPI) fashion on the indicating equipment supplied. This radar set is designed for unattended automatic operation. When so operated, data on the moving targets in the area are sent to a remote point by the slowed-down video equipment over telephone lines. However, this equipment is not supplied as a part of the radar set.

Radar set AN/FPS-18 is so designed that, when it is continuously operated, no adjustment is necessary to retain the performance provided within the tactical operating area of the radar set for a minimum period of 1 week. Identical dual-channel transmitting and receiving equipment is provided, one channel serving as a standby. Both channels are automatically operated, and if the radiating channel should fail, the nonradiating or standby channel is automatically interchanged with the defective channel. Thus, in the event of a radiating channel failure, the radar system is inoperative for a very short time. Provision is also made to keep the remote operating station informed of the status of the equipment, and circuits are provided so that several functions of the equipment (including channel change) can be controlled from the remote operating site. The radar performance (RP) monitor continuously checks the receiver noise figure and the level of the transmitted power and reports malfunctions to the remote operating site through the remote control equipment.

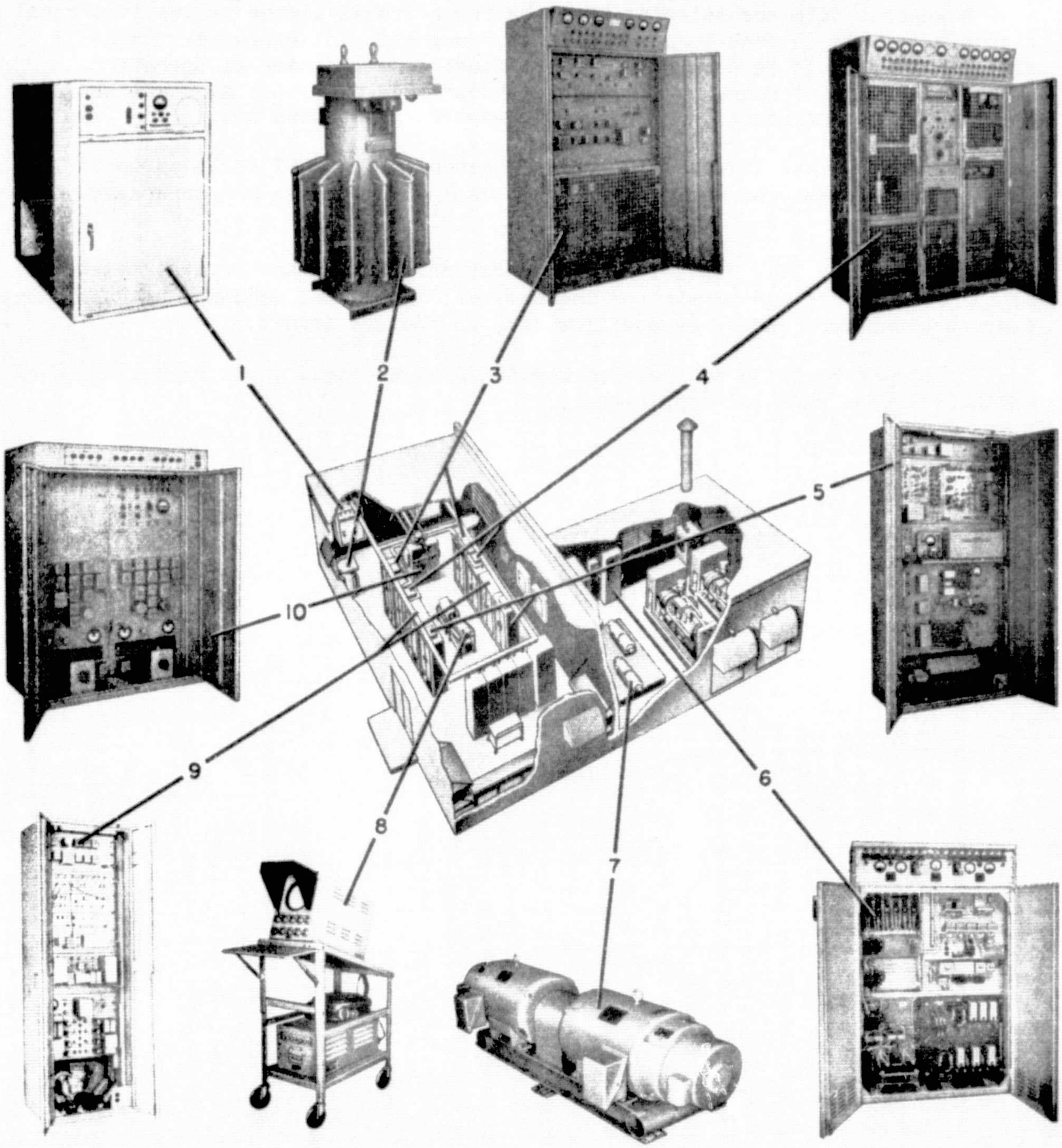
Radar set AN/FPS-18 provides information on targets present in the surrounding area out to a maximum range of 90 km. The antenna scans the area at a nominal rotational speed of 5.33 rpm with a beam of microwave energy which is 1.4 deg wide and approximates a 30-deg cosecant-squared pattern in the vertical plane. One-microsecond pulses of S-band microwave energy (2700-2900 Mc) are produced by the continuously coherent klystron transmitter 1200 times per second, with a peak pulse power of 1 MW. Energy reflected from targets present in the scanned area is gathered by the reflector, which directs the energy to the feedhorn and other propagation components also utilized by the transmitted pulse. Either vertical or circular polarization of the radiated energy can be selected, either by means of a switch on the control cabinet or from the remote operating site. Under normal conditions, vertical polarization is desirable, since the effective range of the radar set is greater; but when it is raining, circular polarization can be used to reduce the effects of rain on the returned signal and thereby make visible many targets that would be otherwise obscured by returns from raindrops.

The microwave target echoes are amplified and detected simultaneously in two separate and distinctly different receiving equipments. The normal video receiving equipment provides a video output which corresponds to all of the reflected energy picked up by the antenna. The moving target indication (MTI) video receiving equipment provides a video output which contains returns from moving targets only, the returns from fixed targets having been removed. The MTI video is fed to the video remoting equipment. Either the normal video, MTI video, or the output of the video remoting equipment can be displayed in PPI fashion on the 18-cm cathode-ray tube indicator. Sweep lengths of 20 and 90 km are available with range marks for both the MTI and normal presentations. The indicator sweep is synchronized with the rotating antenna by a 1:1 synchro system.

A summary of the key performance parameters of the radar is presented in Table 6. As mentioned in previous sections, the radar frequency is authorized for 2835 ±5 MHz, and the peak power level is to be reduced to a level between 1 MW and 500 kW.

Table 6. Key radar performance parameters

Frequency	2700-2900 MHz
Peak power output	1 MW
RF power source	V 87-B klystron
Pulse width	1 μs
Pulse repetition rate	1200 pps
Horizontal beamwidth	1.4 deg
Vertical beam coverage	0-30 deg csc^2 shape
Receiver bandwidth	1.0 to 1.5 MHz
IF frequency	30 MHz
Video output	Normal or MTI
Indicator	18 cm
Indicator ranges	0-20 km; 4-km range marks 0-90 km; 20-km range marks
Duty cycle	0.0012
Average power output	1200 W
Receiver noise figure	8 to 10 dB
Antenna rotation rate	5.33 rpm
Antenna vertical tilt angles	-6 to +6 deg
Polarization	Vertical or circular (selectable)
Power	120/208 vac, 60 Hz, 3-phase 4-wire, 60 kW maximum



1 WATER COOLER
2 INDUCTION REGULATOR
3 HIGH VOLTAGE POWER SUPPLY ASSEMBLY
4 HIGH POWER GROUP
5 RECEIVER GROUP
6 ROTARY REGULATOR CONTROL CABINET
7 ROTARY REGULATOR
8 INDICATOR GROUP
9 RP MONITOR GROUP
10 CONTROL ASSEMBLY

Fig. 16. Interior equipment (AN/FPS-18)

VI. SITE SELECTION

A general site was selected based on the criteria listed in the functional requirements and on consideration of electromagnetic interference. Specific site location would be determined by the final consideration of operational facility and interference requirements. Radar site selection also allowed for the future introduction of large wind-driven generators within the Complex.

The single site location is between Sections 14 and 15 of Township 14 North, Range 1 East, as shown on the U.S. Geological Survey Map presented in Fig. 17.

The selected site was initially a location external to the area covered by the established use permit for the Complex. By formal request, the additional four sections were added, by modification, to the use permit.

Construction could not proceed nor funds be advanced until formal approval of the selected site was completed.

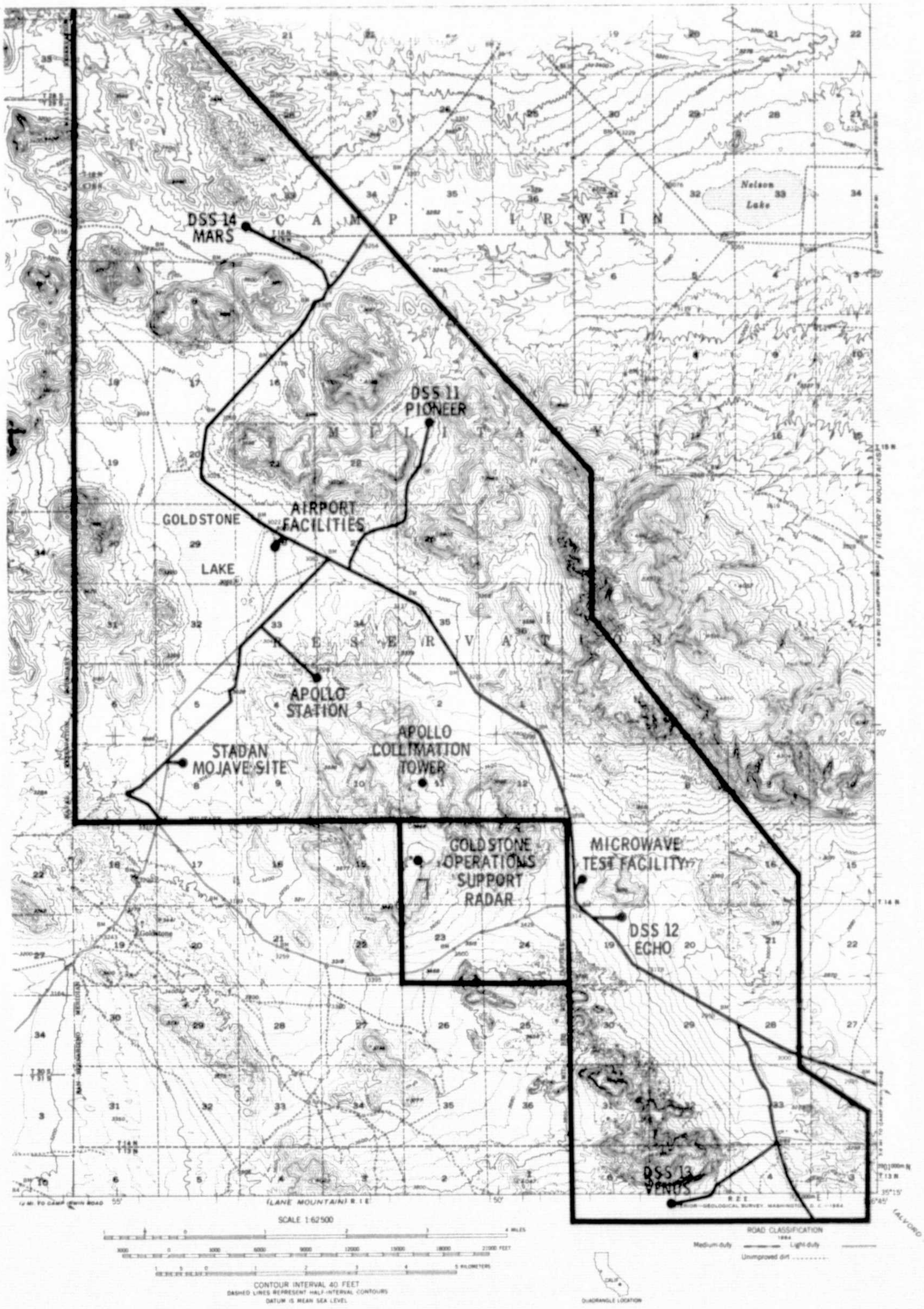


Fig. 17. GDSCC general layout

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VII. FREQUENCY SELECTION

Government procurement regulations require an approved frequency allocation prior to authorization of any transmitter procurement. This requirement made it imperative to emphasize the early resolution of the selected radar equipment, frequency band of operation, electromagnetic compatibility analysis, site location, and spectrum coordination with other agencies.

In attempting to meet the many other functional requirements, the use of the AN/FPS-18 became the prime choice. The band available was 2700-2900 Mhz. On July 18, 1974, the JPL frequency manager requested a spot frequency within the band from the Regional Frequency Office. Subsequently, the frequency of 2835 ± 5 Mhz was found to be locally available, and formal application was made for its use on August 9, 1974.

On October 7, 1974, notification was received that the JPL application was approved. This also meant that procurement could proceed.

VIII. PROCUREMENT PLAN

Preliminary study by JPL indicated that a radar set capable of meeting the performance objectives and available at low cost was the AN/FPS-18. However, detailed analysis of the requirements might result in alternate mechanizations and configurations. Such alternatives which met the aggregated requirements would be considered if they provided the intended performance within comparable costs and met the schedule.

Functionally, it was required that the radar be unattended and remotely located. Furthermore, because of the extended periods of radar coverage and the assumed low rate of intrusion, the operator or observer would be on call from his other duties. The alert mechanization would be designed so as to indicate the intrusion into a critical airspace and alert the operator to observe his display and to make a decision.

Communications distance between the remote radar site and the operator site would be approximately 6 km, line of sight. The use of cables over difficult terrain is an expensive alternative. Since surplus equipment was available to provide the multiple channels for remotely controlling and monitoring the candidate radar equipment, the preliminary design would consider such microwave equipment. However, because of the low frequency of intrusion, a mechanization of sending video data over a slower channel was also feasible for this application. Close analysis of techniques, cost, reliability, and needs would justify alternate mechanization based on other equipment.

Two sites were involved; hence, control and display would exist at the remote radar site primarily for subsystem maintenance, whereas the control room control and display would be for operator use. The radar site items are part of the original equipment (AN/FPS-18); however, the control room equipment involved additional items to be defined and supplied.

Radar site selection, radar type selection, and use of additional interference suppression devices such as microwave filters were to be coordinated to minimize any off-frequency interference by the OSR.

Government procurement regulations required frequency authorization prior to any procurement action. For this procurement, authorization of a spot frequency in the S-band was obtained. (The frequency of 2835 ± 5 MHz is allocated for use at the intended radar site in the Goldstone Complex.)

The TDA Office at JPL had committed to OTDA the earliest possible operational capability date for the Goldstone Operations Support Radar. Operational demonstration was scheduled for November 15, 1975, and transfer to operational status between January 1 and June 1, 1976.

The original procurement plan was to have a single contractor provide a turnkey effort. Subsequently, OTDA required that a permanent building be provided with the use of construction of facility funds. In order to still meet the original operational schedule, it was necessary to start the facility effort earlier and under separate procurement. The separate contracts would require an interface and associated coordination.

Negotiations were completed on March 12, 1975, with the architectural and engineering design contractor, Burns & Roe. Contract execution took place on March 20, 1975.

The A&E contractor was supplied with detailed information on the proposed surveillance radar installation in order to design the facilities, such as buildings, foundations, electrical power, roads, communications, environmental control, and site improvements.

The above design information was converted into drawings and specifications for submission to construction contractors to bid the facility work.

Finally, the facility construction work was completed in timely fashion to permit installation and final implementation by November 15, 1975.

Figures 18-21 show the detail plans and schedules developed for the coordination of the two separate but related procurements.

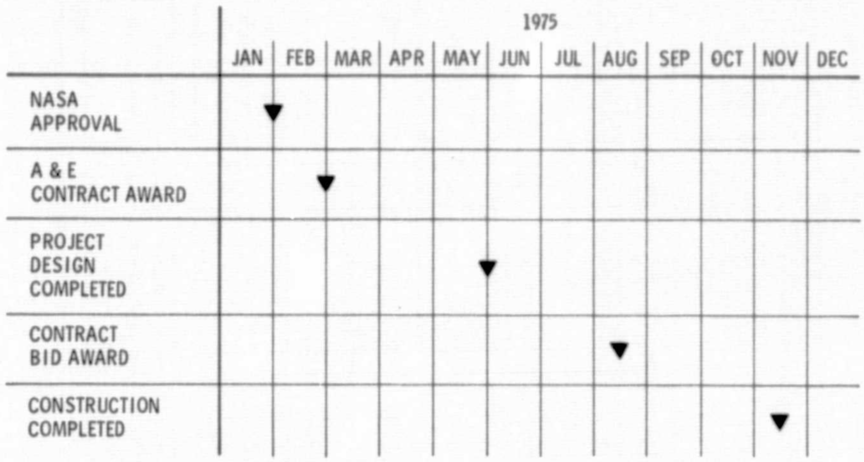

Fig. 18. OSR facilities support project schedule

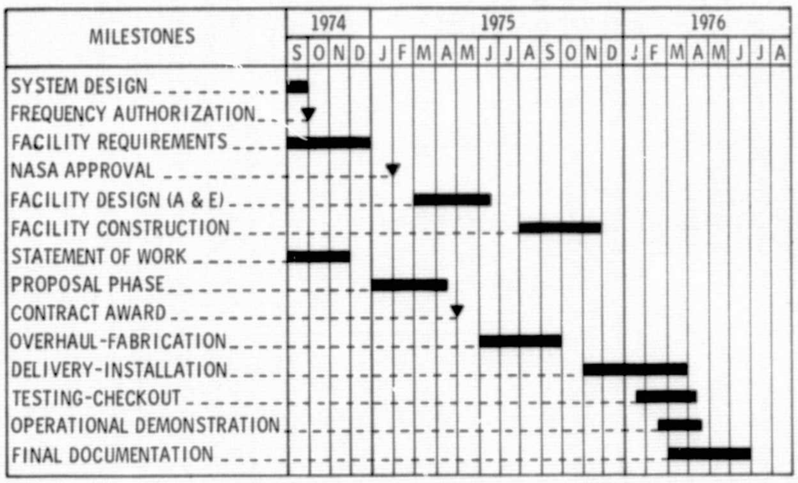

Fig. 19. OSR implementation schedule

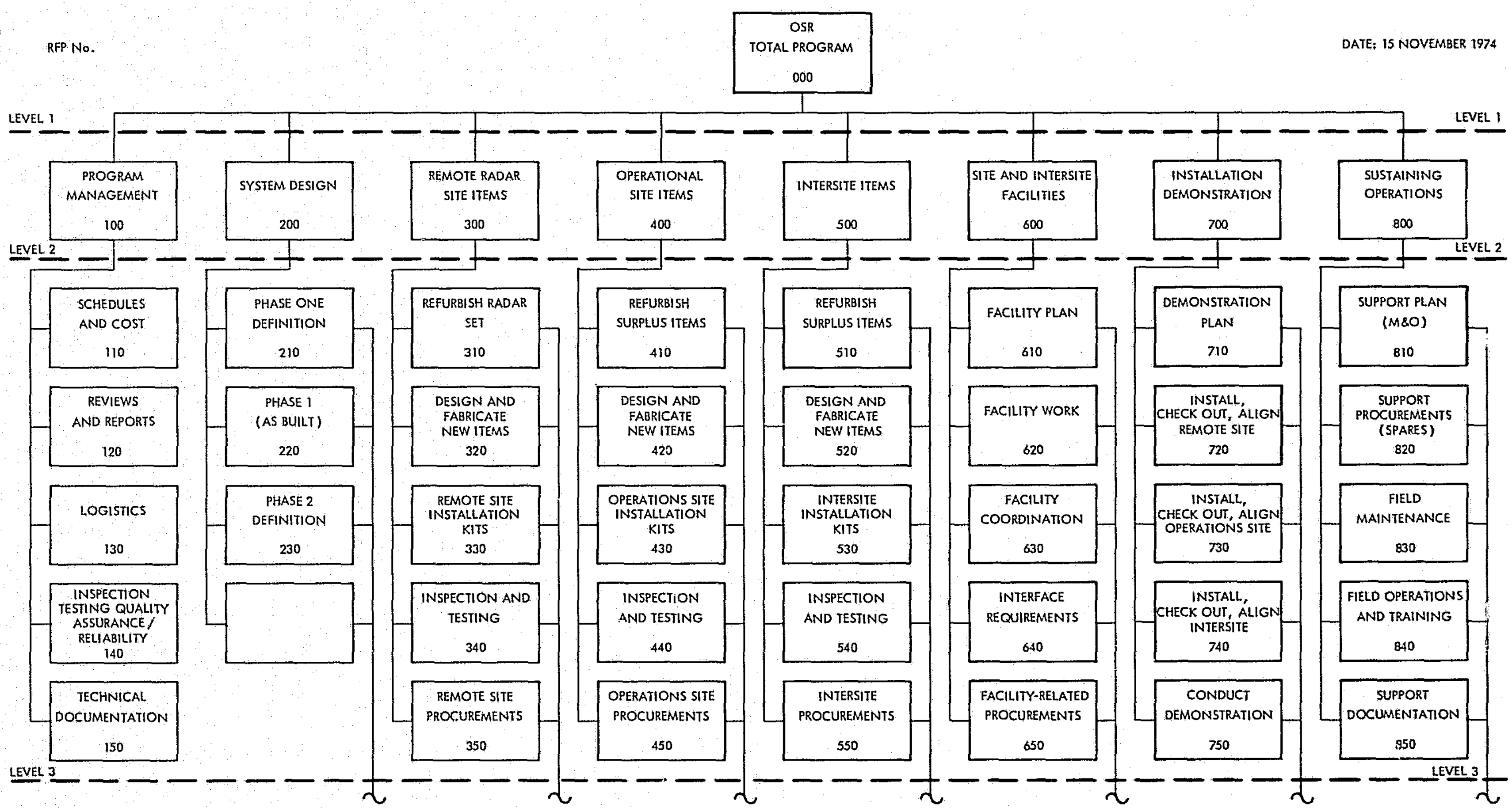

Fig. 20. OSR summary work breakdown structure

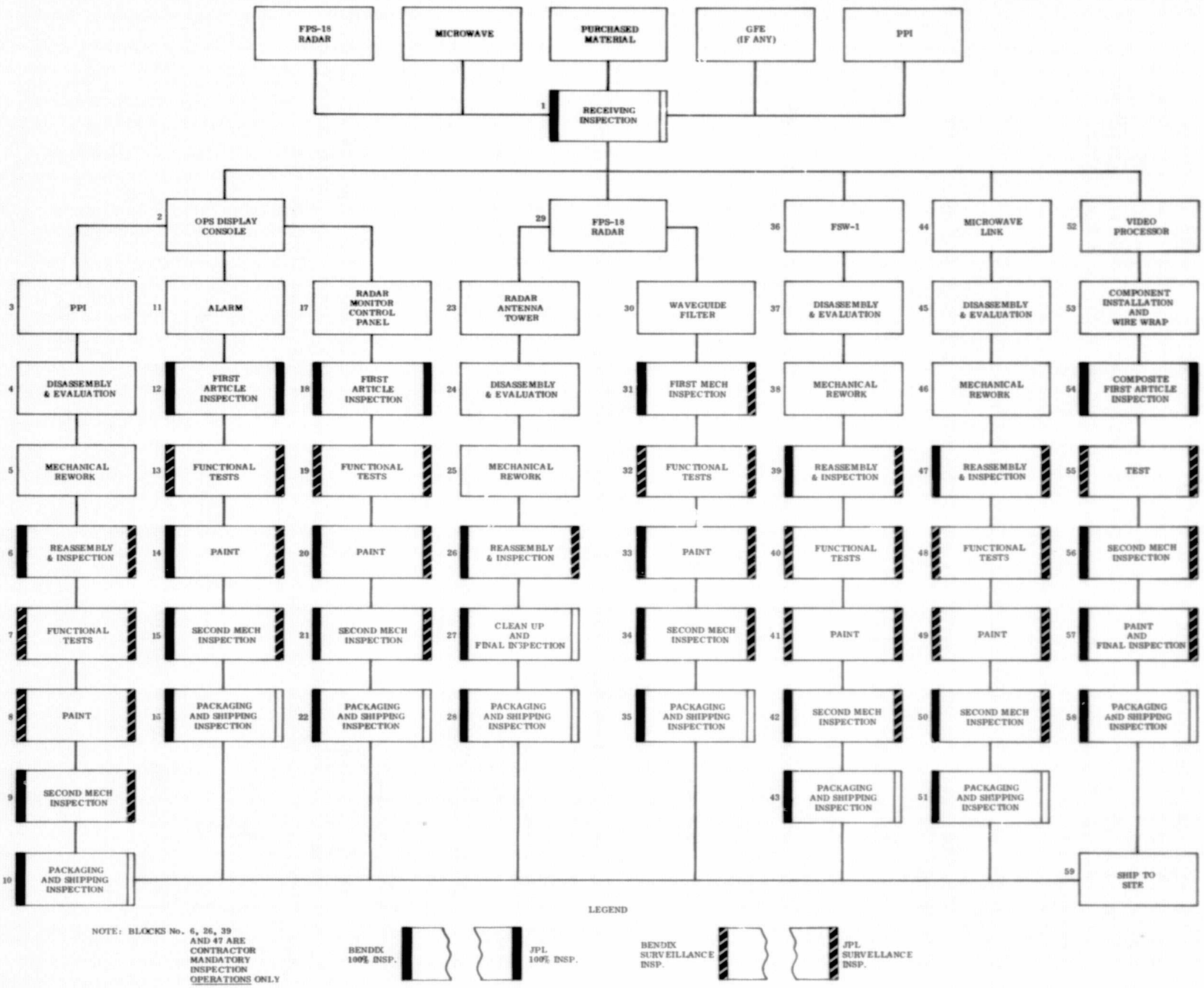

Fig. 21. OSR inspection flowchart

IX. FACILITY PLANNING

Preliminary analyses were performed at JPL relative to site selection and facility planning. Because of a manpower shortage, a Statement of Work was prepared by December 1974 for the services of an architectural and engineering firm to provide detailed design criteria. The work was performed over a period of several months from March to May of 1975, and the details are shown below.

A. SCOPE OF WORK FOR ARCHITECTURAL AND ENGINEERING SERVICES

The A&E task was to determine, prepare, and/or provide design of the following:

(1) Radar site selection

(2) Vehicular access road

(3) Site selection and routing for the microwave radar relay system

(4) Site power service and routing for same

(5) Telephone wire communications

(6) Civil site work

(7) Design drawings, technical specifications, and calculations and cost estimates

(8) Documentation

B. DETAIL DEFINITION OF SCOPE OF WORK ITEMS

1. Radar Site Selection

The A&E company was to investigate the area designated for the installation to determine the best possible location for the radar unit. This site selection was to consider, but not be limited to, the following general criteria:

(1) Radar siting

(2) Minimum interference with existing facilities

(3) Antenna tower height

(4) Minimum land mass screening of tracking

(5) Use of existing masking of other installations

(6) Avoidance of line of sight to any station at the Goldstone site

2. Vehicular Access Road

A road was to be provided for access to the site.

3. Requirements for Site Selection and Routing for the Microwave Radar Relay System

(1) Communication of the radar system data and voice communication were to be provided between the radar site and the Echo site by microwave.

(2) Depending on the site selection made, routing of the microwave radar relay system was to be made for direct line of sight communications and/or such additional reflectors as might be required.

(3) Selection of the microwave radar relay system was to be made by JPL for this installation.

(4) Installation of the radar unit and the microwave radar relay system was to be made by others.

4. Power Service

(1) The A&E company was to investigate the existing power grid at Goldstone to determine the best routing and system of power service to the radar installation.

(2) At that time, loading not to exceed 100 kW was to be utilized for design criteria. Upon final radar unit selection by JPL, downward revision of the electrical criteria was to be made.

(3) Routing and installation of the power service to the radar site was to be accomplished on a noninterference basis with existing facilities at the Goldstone Complex.

5. Telephone Wire Communications

Design of extension of the present telephone system from the Apollo second collimation tower site was to be provided.

6. Civil Site Work

Depending on the final selection of the type of radar unit and microwave unit by JPL, the A&E company was to provide the design of facilities for equipment installation as selected by JPL.

7. Documentation

Design drawings, technical specifications, calculations and cost estimates were to be prepared.

C. SCHEDULES AND SUBMISSIONS

1. First submission

The first submission (30% complete), consisting of five copies of the drawings, rough draft of the specification, preliminary cost estimate, and project schedule was to be transmitted to JPL for review. The time for completion was 30 days after the notice to proceed. The time for JPL review was 5 calendar days after JPL receives notice. The review was to be held at the A&E facility.

2. Second submission

The second submission (60% complete), consisting of five copies of the drawings, draft of the specifications, cost estimate, and revised project schedule was to be transmitted to JPL for review. JPL-annotated prints and comments on the first submission would be returned to JPL with this submission. The time for completion was 30 calendar days after A&E receipt of JPL review comments on the first submission. The time for JPL review was 5 calendar days after JPL received notice. The review was to be held at the A&E facility.

3. Third submission

The third submission (100% complete) was to consist of five copies of the fully developed drawings showing all plans, details, and sections and two copies of the specifications, cost estimate, and schedule. JPL-annotated prints and comments on the second submission were to be returned to JPL with this submission. The time for preparation was 20 calendar days after A&E receipt of JPL review comments on the first submission. The time for JPL review was 5 calendar days after JPL received submitted material in Pasadena. The final calculations were to be included in the third submission.

4. Final submission

Upon completion of the bid package, JPL was to be furnished the following documents:

(1) Five complete sets of original drawings signed and approved by the A&E firm

(2) Five copies of the computations and design rationale, soil studies, etc.

(3) Five copies of the contract specifications

(4) Five copies of the cost estimate

The time for completion was 7 days after receipt of JPL comments on the third submission.

D. AS-BUILT DRAWINGS

Within 60 days after completion of the construction contract, the A&E company was to incorporate into the original tracings all revisions and additions made during construction, or prepare new reproducible drawings as required. As-built reproducible drawings (or revised as-built original tracings) were to be sent to the cognizant JPL representative 60 days after completion of the construction contract.

E. DOCUMENTATION

1. General

a. Preliminary Documentation. Preliminary maintenance and operation manuals were to be completed 30 days prior to the time of building or facility occupancy and two sets sent to JPL. In addition, provision was to be made for station needs. Manuals were to cover only those elements which were not JPL-furnished.

b. Final Documentation. This documentation was to consist of

(1) Final construction specifications and drawings, together with amendments (on separate sheets but not incorporated into either specifications or drawings).

(2) User as-built, certified facility drawings.

(3) Final maintenance and operation manuals.

(4) User as-built, certified, reproducible facility drawings.

Six sets each of items 1 and 2, nine sets of item 3, and one set of item 4 were to be sent to JPL. In addition, provision was to be made for station needs.

All final documentation was to be completed within 180 days of occupancy of the facility.

c. Purpose and Level of Contents. The documentation was to be suitable for use by technical personnel, skilled in their respective disciplines. The level of descriptive material and the style of presentation were to be such that the documentation could be readily understood by such personnel.

d. Preparation of Documentation. It was recommended that preparation and accumulation of required documentation be accomplished under the direct supervision of the JPL cognizant engineer.

2. Submittals

When the final documentation was completed to a 20% level, representatives of the A&E office were to discuss the work accomplished with a JPL representative to ensure that all facets of the above scope were being developed in a satisfactory manner. The time for preparation to the 20% level after completion of construction and receipt of notice to proceed was to be 30 days.

When the entire documentation was completed, the A&E office was to submit to JPL nine copies of the manuals prepared in the specified format and bound in loose-leaf books.

The time for submission was to be 150 days after discussion of the 20% stage with JPL.

X. SYSTEM DESCRIPTION

A. OVERALL SYSTEM

The Goldstone Operational Support Radar system is a composite system made up basically of four subsystems. These subsystems are an AN/FPS-18 S-band radar system, an FSW-1 control monitor, an MRR-4 microwave system, and a specially designed radar video processor and target processor/alarm display system. As mentioned, these subsystems are combined to make up the total system. Following is a brief description of the system.

The AN/FPS-18 search radar is a dual-channel, medium-power, unattended, two-dimensional radar system which is capable of being controlled and monitored from a remote location utilizing the AN/FSW-1. The dual-channel capability allows for one channel to be operational, with the second channel available should the operational channel fail, thus allowing continued coverage during a critical period and/or during maintenance. The output tube is a klystron, whose frequency is a stable 2835 MHz and which passes through a waveguide harmonic filter and a spurious filter prior to transmitting through a polarizer and feedhorn to a screen reflector at 1200 pulses per second. During the receive period (listening), reflected signals are fed through a preamplifier to a normal receiver and a moving target indicator receiver. Video outputs of these receivers are fed to (1) a video processor, (2) a microwave radar link, and (3) a maintenance scope and performance monitor.

The video feed to the video processor is digitized and sent to the Echo site via telephone lines and microwave link.

Video feed to the maintenance scope allows viewing of the raw video at the radar site. Video fed to the performance monitor is processed along with other discrete parameters, and the system status is relayed to the remote site (Echo) via the FSW-1 control system. In addition to displaying system status, the FSW-1 has the capability of controlling the radar system from full power shutdown to altering transmitter power output.

As previously mentioned, the video processor accepts raw radar video and processes it to a digitized state and format. This is transmitted via telephone lines to the Echo site, where it is received by the target alarm assembly. The video processor output can also be sent to the Echo site via the microwave radar relay link in case of landline failure. (Originally, the microwave radar relay was the prime transmission link.)

The digitized video received by the target alarm system is further processed; some of the processing is controlled by the operator. Included in the processor are four gates which are operator-variable in range start and stop and azimuth start and stop. These gates can be utilized to sound an acoustic or visual alarm when a target is inside the gate, or to squelch an alarm if desired, or any combination of the above. The target alarm also examines the video processor signals and determines which signals represent active targets and which ones represent fixed or erroneous targets. Targets from the target alarm are fed to the video display.

The video display unit receives video from both the microwave system and the target alarm unit. The operator may select videos from either source or may display videos from both sources simultaneously. Videos available from the microwave system are

(1) Normal video.

(2) Moving target video (MTI).

(3) Range gated video (MTI/normal).

(4) Video processor digitized video.

The target alarm sends fully processed video to the indicator unit.

The system presents both azimuth and range information. Raw video is capable of being displayed out to a 90-km radius, while digital information can be displayed out to 120 km. A "maintenance PPI" is located at the radar site and displays both normal and MTI video.

Ancillary equipments utilized by the system consists of three 15-kV regulators, which may be utilized should the input line voltage at the radar site become erratic.

The microwave link utilizes a 6-m tower to accommodate two passive reflectors. These are required because the radar site is masked from the Echo site.

A block diagram of the OSR system design is presented in Fig. 22.

1. System Specifications

(1) Power requirements

(a) Radar site -- 120/208 Vac, three-phase, four-wire, 70 kVA

(b) Passive site -- none

(c) Operations site -- 120 Vac, single-phase, 3.2 kVA

(2) Frequency allocations

(a) Radar -- 2835 MHz

(b) Microwave -- 7160, 7240, and 7700 MHz

(3) Housing requirements

(a) Radar -- 16 × 12 m building with air ventilation

(b) Passive site -- none

(c) Operations -- 1 × 4 m floor space

(4) Coverage

(a) Raw video -- 90 km

(b) Digitized video -- 120 km

(5) Temperature range

(a) Radar -- -23.3°C (-10°F) to +54°C (+129.2°F)

(b) Passive site -- -23.3°C (-10°F) to +54°C (+129.2°F)

(c) Operation site -- +12.7°C (55°F) to +48.8°C (+120°F)

2. Summary

Table 7 summarizes the functions of the OSR system equipment. Equipment layout drawings are shown in Figs. 23 and 24.

B. SUBSYSTEM

1. AN/FPS-18 Radar System

The AN/FPS-18 radar system is a dual-channel, S-band, medium-range radar capable of unmanned operation. A complete description of the system is available in Technical Orders 31P6-2FPS18-1 and 2. A brief synopsis of the system is given here. Certain deletions were made on the Goldstone system to make it more adaptable to its operational commitments, notably:

(1) The FST-1 remoting equipments were replaced with a solid-state radar video processor (see Section X-B4).

(2) The rotary regulators were removed from the system to conserve space and energy. Substituted in their place are three single-phase, 15-kW, solid-state regulators. These regulators were installed with the system in the event that erratic power fluctuations were encountered on the complex and are primarily for use in emergency operation. During normal operation, the regulators are bypassed.

The AN/FPS-18 radar system utilizes a VA-87 klystron as a power amplifier. The receiving system consists of a normal receiver and a moving target indicator receiver. In addition, each channel has a radar performance monitor (RPM) which monitors parameters of both the receiver system and the transmitter. The antenna is a cosecant-squared type, located on an 8.5-m steel tower, and rotates at a speed of 5.33 rpm. A spurious filter and a harmonic filter are installed in the antenna waveguide run to insure that no radio frequency interference (RFI) radiation is emitted that would interfere with tracking and command operations of other systems.

The radar is a simplex system and has no capability of diplex operation. Either channel is capable of operating into the antenna via a waveguide switch. The opposite channel is connected to a dummy load through the other side of the waveguide switch. Both transmitters may be operated simultaneously, one into the antenna (active) and the other into the dummy load (standby). This allows for repair, test, and evaluation of one channel while the system maintains normal operation.

A maintenance plan position indicator is provided at the radar site. This indicator is cart-mounted and is cabled in a manner to allow it to be moved. The moveability of the indicator is convenient for troubleshooting of the radar system and saves valuable time during maintenance.

All videos, triggers, and monitor and control circuits from both channels are fed to a single control cabinet. Here the signals are distributed to the radar video processor, FSW-1 control monitors, microwave link, and the maintenance PPI scope. Incoming control signals from the FSW-1 are also fed to this cabinet for distribution.

The system covers the band of 2700-2900 MHz, utilizing two transmitter klystron tubes. A VA-87B klystron is used for the 2700-2800 MHz band and a VA-87C for the 2800-2900 MHz band.

Depending on the band of interest, either a VA-87B or a VA-87C tube is installed. The Goldstone OSR system is authorized the frequency of 2835 MHz and has a VA-87C klystron installed in the transmitter of each channel.

During normal operation of the system, one channel is active, transmitting through the antenna, with the other channel having preheat applied and the transmitter down. Should a failure occur in the active channel, it will attempt to reset itself three times. Should it fail to reset due to a major malfunction, the system will automatically transfer to the standby channel, connecting its transmitter to the antenna and applying high voltage to the channel. At the same time, it will shut down the malfunctioning channel.

During a maintenance period, a switch in the control cabinet may be set to prevent the automatic changeover. This is a safety feature to prevent high voltage being applied by anyone other than the maintenance personnel.

The system may be operated with one channel active and one channel completely down. It may also be operated with one channel transmitting into the antenna and one channel operating into the dummy load.

To start the system or either channel from an off position to a transmit condition requires a minimum of 20 min, during which time the channel or system is heating up. At the end of the 20-min period, the system will come up and transmit. However, if the ambient temperature is below +15°C (50° F), the transmitter operation may be erratic for a period of time (up to 1 h) because of the warmup requirement of critical components.

The system was designed to operate 24 h a day, 7 days a week, in an unmanned condition, with a weekly maintenance period. It will operate in the temperature range of -29°C (-20.2°F) to +54°C (+129.2°F). FPS-18 specifications are presented in Table 8.

2. <u>AN/FSW-1 Control Monitor Set</u>

Remote control of the AN/FPS-18 radar is accomplished by the AN/FSW-1 control monitor set, which enables the radar to operate unattended. The FSW-1 system provides control of the FPS-18 and monitoring of certain essential functions from the operations site.

The system is actually a militarized version of standard remote-control equipment, known commercially as "supervisory control" and often used in electric power systems for remote control of unmanned substations. A complete description, with schematics and parts breakdown, may be found in Technical Orders 31S1-2FSW-1-1, 2, 3, and 4.

The prime C-2062/FSW-2 unit at the operations site transmits an audio tone of 425 Hz to the C-2063 remote unit. The C-2062 also has a receiver capable of handling an audio signal of 1785 Hz. The remote cabinet transmits a signal of 1785 Hz and receives the 425-Hz signal from the operations building. These frequencies were chosen to minimize the possibility of interference from the harmonics of the power supplies and other sources.

Both of the FSW-1 cabinets (prime and remote) transmit audio signals continuously; intelligence is transmitted between the stations by sending groups of pulses, each pulse effecting a momentary interruption of the tone. This pulse coding method is similar to that used in the conventional dial telephone system.

The coding system was designed to provide a high degree of security and reliability. The possibilities of an incorrect operation at the remote site or a false indication in the operations room because of channel noise or interference are practically eliminated. Although interference may be severe enough to prevent operation of the control monitor set entirely, it will not, in itself, normally cause the radar to operate incorrectly. The transmitter output and receiver sensitivity are such that this combination can operate over a link having an attenuation as high as 35 dB.

The operations room C-2062 cabinet has 20 select-operate switches, each of which has an associated pair of red and green control indicating lamps located above it. The green lamp, when lit, indicates that the remote unit relay controlled by that selector switch is in the open position. The switches are arranged in two rows of 10 each. Operation of the select-operate switch causes a coded pulse group to be sent from the operations room to the remote site C-2063 cabinet, where it is decoded and applied to a relay which performs the desired function. The position of the relay is sent back, as a coded pulse group, to the operations room cabinet, which decodes the group and lights the proper indicating lamp. The operate-select switches are labeled to indicate the functions they perform in the operation of the FPS-18 radar.

There are also 30 supervisory indicating lamps on the C-2062 operations room cabinet that are available to monitor essential functions at the radar site. The supervisory lamps are located above the control switches and their associated pilot lights, in two rows of 15 each. The lighting or extinguishing of any supervisory lamp will indicate some change in operating condition at the remote site. In general, these lamps are off when the monitored devices are operating normally; illumination of a lamp would indicate that the device is no longer operating properly. The lamps are labeled to indicate the function of the components at the radar site that they monitor.

Ten of the supervisory lamps are also tied into an alarm buzzer and alarm lamp circuit. These may be assigned to critical functions to provide a positive indication of trouble at the radar site. The buzzer, if actuated, will continue to sound until receipt of the alarm is acknowledged by pressing the alarm reset pushbutton (located at the lower right of the cabinet).

A complete control operation requires approximately 2 to 3 s. A complete monitor operation requires approximately 1-1/2 to 2-1/2 s.

To simplify maintenance, certain auxiliary functions are incorporated in the FSW-1. A "scan" pushbutton on the operations room cabinet, when depressed, causes the equipment to run through a complete monitoring cycle to confirm all lamp indications.

Likewise, the lamp test pushbutton on this cabinet energizes all unenergized supervisory indicator lamps, thereby providing a check on burned-out lamps.

In the event that audio tone signals are lost in either direction, the abnormal condition will be indicated by the channel failure lamp located near the top of the C-2062 control cabinet.

The 20 selector switches on the front of the prime cabinet control the operational functions at the remote site by means of two different types of relays: a momentary type and a latching type. The first type provides momentary operation, while the latching type mechanically locks itself in an operating position, thereby establishing a continuous operation until reset. Not more than one select-operate switch may be actuated at any one time.

Selector switches which operate remote components that require only momentary control have only two positions: "up" (to actuate) and "neutral." They are spring-returned. The duration of the operation is controlled by manually holding the switch in the operating position. Releasing the switch allows it to return to its neutral position, thereby de-energizing the relay it is controlling and stopping the operation.

The selector switches that control continuous operation of remote components have three positions: "up" (to operate), "neutral," and "down" (to reset). Each of these switches has its individual set of red* and green lamps to indicate the status of remote equipment operation.

As previously stated, the 30 supervisory lamps are arranged in two rows of 15 each. These lamps receive information from relays in the remote unit concerning operating conditions at the remote site. The contacts of these relays may be normally closed or normally open, depending on the nature of their operation and use.

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*Certain switches have amber instead of red pilot lamps.

When any one of the lamps associated with the alarm-type supervisory positions comes on, the alarm lamp located near the top of the door on the prime cabinet lights, and the alarm buzzer sounds continuously to call the condition to the attention of the radar operator. Depressing the alarm reset pushbutton at the lower right of the cabinet will extinguish the alarm lamp and silence the buzzer.

Depressing the "scan" pushbutton on the C-2062 control cabinet initiates a complete scanning cycle, whereby all monitoring relays in the remote C-2063 cabinet are initially de-energized. The equipment then proceeds to report the status of each of the 50 positions. As each position reports, its monitoring relay energizes. These relays continue to energize -- one at a time -- until the operational functions of all 50 of the monitoring relays have been completed. As each operation is scanned, its monitoring relay locks itself.

As the remote unit scans each position, it will change the associated lamp indication, if necessary, to make it agree with the actual status of the contact being monitored at the remote cabinet. When all 50 of the monitoring relays have been restored to the energized position, the equipment stops.

If the prime unit is not in operation, or if signals are not getting through, the remote unit will attempt to start the scanning cycle itself once every minute. As soon as it receives signals from the prime unit, it will proceed with the normal scanning cycle.

3. MRR-4 Microwave System

The MRR-4 microwave radar relay system is a wideband intersite link that permits remoting of the raw video from the FPS-18 radar set. The MRR-4 transmits the video pulse outputs and synchro information from the radar site to the Echo Station. In addition, it provides channels from two-way voice communications between the radar site and the Echo site. A full description, including schematics and parts breakdown, may be found in Technical Orders 31R5-4-8-1.

The MRR-4 configuration consists of a WM4N01 transmitting terminal and a WM4N02 receiving terminal. Because of the terrain and the radar tower location, a passive repeater is required as part of the path. The passive repeater consists of two 15-cm ellipsoidal reflectors positioned back to back on a 6-m tower. The antennas at the radar site and the Echo site are 2-m parabolic reflectors. The calculated path loss is -49 dBm (see Fig. 25).

Because of space limitations, the WM4N02 receiving terminal was modified to reduce the number of equipment racks from three to two. This was accomplished by removing one receiver, its power supply, and the maintenance scope.

As configured, the OSR microwave system has two transmitters at the radar site and one transmitter at the Echo site. Channel and frequency assignments are as follows:

Radar site

Channel 1, 7160 MHz

Trigger
Synchro data
Normal video
Voice communications

Channel 2, 7240 MHz

MTI video
Processor video
Azimuth change pulses and north mark

Echo site

Channel 3, 7700 MHz

Voice communications

Each of the channels has an alarm signal which is set at a predetermined level. If the received signal drops below this level, the alarm will light, alerting the operator to a malfunction or marginal condition.

Certain built-in test equipment is located at the transmitter site (radar site): an oscilloscope, a video, trigger, and marks simulator, and an antenna position simulator.

The MRR-4 accepts input signals from the radar system in the form of video, triggers, marks, and servo information. These inputs modulate RF oscillators which make up FM subcarriers. The subcarriers, in turn, are combined into a composite signal for transmission. In addition to the radar information, a 3-MHz FM subcarrier and, in the case of the order wire, a 5-MHz FM subcarrier are combined with the other information. This information is intercepted at the Echo receiver, where the subcarriers are stripped from the composite signal and reconstructed. The resulting information is then fed to the target processor for display. The MRR-4 specifications are presented in Table 9.

4. Radar Video Processor

The radar video processor accepts the normal and MTI video outputs from the radar and, using beam splitting techniques, extracts the range and azimuth of each target. Each video input is applied to a separate video quantizer/pulse-width discriminator module. The quantizer thresholds the video and places the threshold video into discrete 115-m range cells. The threshold is variable over the range of 1 to 12%.

The pulse-width discriminator examines the pulse width (in range) of each target return and generates a gate if the pulse width exceeds a preset value (adjustable from 0.4 to 6.1 μs). Target detection and beamsplitting are effectively performed by using a linear integration technique. Each range cell contains a 6-bit binary counter, which is incremented if a target return is present and decremented if no target return is present. Two comparators are used to establish leading edge and trailing edge (in azimuth) detection points. Leading edge detection is normally set to approximately half of the number of radar returns in an antenna azimuth beamwidth, whereas the trailing edge is set to approximately two-thirds the value of the leading edge. The leading edge detection is used to activate the azimuth processor module; the trailing edge detection is used to indicate that target processing is complete. Logic circuitry in the video processor module prevents a trailing edge detection unless a leading edge has been previously declared. In addition, successive range cells are inhibited if the previous range cell is processing a target return, thereby eliminating redundant reports on the same radar target when the target return extends over more than one range cell.

When the leading edge of the target has been declared, an 8-bit counter is enabled and is incremented for each azimuth change pulse (ACP). This ACP counter is located on the azimuth processor module and, by use of the memory module, provides an 8-bit ACP counter for each range cell. An ACP is equal to 0.087 deg (1/4096 of 360 deg). When the target trailing edge is declared, the content of the 8-bit ACP counter is divided by two, and the result is subtracted from a 12-bit azimuth counter which contains the position of the target.

The target azimuth (12 bits), target range (10 bits), and target azimuth run length (6 most significant bits of ACP counter) are transferred to a first-in first-out (FIFO) register when a target trailing edge is declared. The FIFO acts as a buffer between the high-speed processor and the slow-speed asynchronous transmitter used for data transmission. The FIFO can store up to 64 targets.

Data transmission between the radar video processor and target processor/alarm is by way of an asynchronous transmitter/receiver. The target azimuth, range, and azimuth run length data (28 bits) are transmitted as 4-bit characters. Each character consists of a start bit, 8 data bits, 1 parity bit, and 1 stop bit. The most significant bit of the first three data characters is a "0," whereas the most significant bit of the fourth character is a "1."

Supporting elements of the video processor include a range clock generator which provides all timing reference, a synchro-to-digital converter, a simulated target generator, and a digital monitor. The simulated target generator is capable of generating fixed and moving targets and is used to check out the overall target alarm and tracking functions.

The radar data processor is physically contained in a rack-mountable chassis 53 × 13 × 13 cm and will mount in a standard 48-cm rack. The unit is self-contained, with its own power supply and cooling. It was mounted in the radar building in one of the microwave racks.

The unit consists of 15 wire wrap cards and associated connectors and contains spare slots for further expansion. Access for board removal is on the left side of the unit.

The input and output specifications presented in Table 10 are applicable to the radar video processor.

5. Target Processor/Alarm Display System

The target processor/alarm display system accepts data from the radar video processor via phone lines and further refines them for presentation on the X-Y display. In addition, the processor has the capability of setting up selective gates and producing alarms when a target enters one of these gates.

The target processor may also accept raw video, digitized video, triggers, ACPs, north mark, and synchro data from the microwave link. This capability is utilized as a backup mode.

The input target data from the video processor are received by an asynchronous receiver module which strips the parity, start, and stop from the received character and applies the 8-bit data to an input buffer register. The buffer reassembles the data into 12-bit azimuth, 10-bit range, and 6-bit run length elements.

The azimuth and range data (polar coordinates) are converted to X, Y (rectangular) coordinates utilizing a sin/cos lookup table, a binary multiplier, and quadrant selector logic.

The binary azimuth and range data are also converted to binary coded decimal format for use by the alarm display and the azimuth/range alarm gate logic. Thumbwheel controls on the target alarm processor front panel provide for selection of up to four gated areas. These gated areas may be used for either selective alarm gating or blanking input data. Gated areas are formed by selecting radial azimuth lines and concentric range circles to yield toroidal segments.

The run length data are compared against a front panel control run length selector. Targets which exceed this selection are not processed. This eliminates such phenomena as moving storm clouds as massive targets.

The processing of current radar target data as received by the data input subsystem consists of sequentially reading the previous scan target data stored in memory and subtracting these data from the current target data. The data in memory are divided into two types of targets: (1) track targets and (2) nontrack targets. Track target data consist of the previous target position plus a velocity vector, which provide direction and speed of the target. Addition of these two components provides an estimated position, which is subtracted from the current position. The result of the subtraction yields a differential velocity vector.

Nontrack data consist of previous position data only, and when subtracted from current target data, they yield a velocity vector. The result of the subtraction is then compared against a single and a set of programmable velocity limits.

The target processor will sequentially scan memory for active target data from the previous scan until one of the following conditions is met:

(1) Track-up -- Occurs when comparing current target position with a track target and the differential velocity is less than the differential velocity limit.

(2) Fixed target -- Occurs when comparing current target position against a previous nontrack target position and the differential velocity is less than the fixed target limits.

(3) Track initiate -- Occurs when comparing a current target position against a previous nontrack target position and the differential velocity is greater than the lower velocity limit and less than the high velocity limit.

(4) Noncorrelated target -- Occurs when none of the above conditions prevail and when all active targets in memory have been compared.

The target comparison is performed by the target comparison subsystem consisting of two sets of adders and two sets of comparators, one for the X and one for the Y components of the target data. A velocity selector circuitry is provided which automatically selects the velocity limits, depending on whether a track or nontrack is being compared. Previous target data are obtained from a 1024 × 63 bit memory.

The memory is divided into two equal groups, one for track target and the other for nontrack target. The track portion of the memory is further subdivided into 64 subgroups, each containing eight elements. The net result of this grouping provides the capability of handling up to 64 tracks, with each track containing up to eight scans of data, and 512 nontrack targets.

Once each scan, the data in the memory are updated so as to eliminate old data and move active data to the upper portion of the memory, leaving the higher address for new data. This memory update cycle (MUC) is controlled by the north mark data word received from the radar. During the MUC, the following actions take place:

(1) Track portion of memory

  (a) Push target data into the next-higher address element of the track subgroup; i.e., data in the highest address of the subgroup will be lost and data in location 0 will be moved to location 1.

  (b) Provide an estimated position for target if no radar update has been received during the completed scan.

  (c) Eliminate all track data if target position has been estimated for three consecutive scans.

  (d) Move higher address track subgroup to lowest available subgroups.

(2) Nontrack portion of memory

  (a) Eliminate any target data that are two scans old.

  (b) Move higher address active data to lowest available memory location.

a. <u>Display Subsystem Description</u>. The display subsystem provides for the visual display of real-time radar data (PPI mode) and target random access processor data [Random Access Plan Position Indicator (RAPPI) mode]. For the PPI mode, the display subsystem contains a free-running oscillator operating at approximately 2.2 times the radar pulse repetition rate. The oscillator in turn may be synchronized by the radar trigger when receiving radar data via the radar microwave link. The following types of signals can be selected for viewing in the PPI mode of operation of the X-Y display:

(1) Processor-generator signals

(a) Range marks -- 3- and 15-km marks for 50-km range, 6- and 30-km marks for 100-km range.

(b) Alarm gate -- a signal outlining the boundaries of each of the four alarm/blank gates.

(c) Azimuth strobe -- a strobe indicating position of north.

(2) Radar data

(a) Normal video

(b) MTI video

(c) Range gates normal/MTI video

(d) Video processor video

Antenna rotation data for PPI operation are normally obtained from the azimuth change pulses generated by the radar video processor and are synchronized with the radar trigger. These pulses provide rotational data as well as range synchronization. A pulse occurring once each scan is used to synchronize the ACP counter with north.

An alternate mode of operation is available which uses the synchro data from the radar antenna. This mode is used only when the radar video processor is operative.

The RAPPI mode of the X-Y display is operative during the dead time of the PPI sweep. It provides a random access display of the target procesor memory data. Track targets are displayed as targets with vectors. As up to eight scans of data may be present for a track, the result is that track data are displayed as a series of up to eight successive target returns, indicating the direction of the track. Nontrack targets are displayed as individual dots on the display.

The display control panel provides for selection of the information to be displayed on the X-Y display. For RAPPI display, it is possible to select the following types of targets:

(1) Track targets

(a) Alarm only
(b) All tracks

(2) Nontrack targets

(a) Fixed targets
(b) Noncorrelated targets
(c) Fixed and noncorrelated targets

Any combination of the above targets displayed during the RAPPI mode are normally of a higher intensity than those produced in the PPI mode because of the refresh rate of the RAPPI mode. Data displayed in PPI mode are refreshed once per antenna rotation (approximately 12 s), whereas RAPPI data are refreshed at a rate of 12 to 40 times per second.

b. Target Processor/Alarm Display Specifications. The target processor/alarm display input/output specifications are presented in Table 11.

C. OPERATING PROCEDURES

Under normal conditions, the OSR system is operated with one radar channel transmitting and the standby channel in the preheat condition. The MRR-4 microwave system operates with two transmitters transmitting to the Echo site. The video processor and the target alarm system are operational, sending digitized video to the display system. The display (PPI) displays MTI video via the microwave link and digitized video from the target processor. The alarm gates of the target alarm system are set to alarm only when targets enter the area to be protected.

When the operator at the Echo site hears an alarm, he goes to the display unit and observes the intruder. At his discretion, he may turn off the raw MTI video to clean up the display and track the intruding aircraft. The operator then contacts the site(s) threatened by the intruder giving range, azimuth, and apparent course. (The apparent course can be detected by the digitized video, which maintains seven scans of data on the display.) The operational authorities at JPL or the Goldstone Complex then determine the course of action to be followed.

The OSR system is designed for continuous operation, 24 h per day. When the system is operated in this manner, it is recommended that a channel change be accomplished every 24 h. This can be done at the Echo site utilizing the FSW-1 monitor-control system. To change channels, the operator depresses switch 1, labeled Radar-Channel Transfer.

During the periods of operation, it is conceivable that a channel may develop a fault. If this occurs on the operating channel, it will automatically attempt to reset itself. If, after three attempts, the channel fails to reset itself, then the system automatically changes to the standby channel if it is available. If the standby channel is not available, the radar automatically shuts down the high voltage.

If there is an automatic shutdown, the operator should attempt to reactivate the system. To do this, he depresses switch 3, labeled Radar-Fault Shutdown Reset. If the system again fails to return to normal operation and the standby channel preheat has been on for at least 20 min, the operator depresses switch 1, Radar-Channel Transfer. If the system still fails to activate, then it will be necessary to call radar maintenance.

Table 7. OSR system equipment functions

Equipment item	Function
Radar set AN/FPS-18	Detect in range and azimuth airborne objects equal to or greater than light aircraft at ranges up to 90 km.
Control monitor AN/FSW-1	Control the operating conditions of the radar set and monitor its principal characteristics for control/display at the operating site.
Radar video processor	Convert the range and azimuth data of the radar set to coordinate data for transmission via telephone lines to the operating site.
Target processor	Accept the coordinate data from the radar video processor, display the resultant targets (intruder aircraft), and generate an alarm if the intruder aircraft enters within a gated area.
Mircrowave radio relay MRR-4	Provide the transmission path for raw radar video, quantized radar video, and emergency voice communications.
X-Y display	Provide visual display of video from the radar system and target processor.

Table 8. FPS-18 specifications

Parameter	Specification
Frequency	2835 (tunable 2800 to 2900) MHz
Peak power	1 MW
Average power	1200 W
Pulse repetition frequency (PRF)	1200 pulses/s
Duty cycle	0.0012
Pulse width	1 μs
Normal receiver sensitivity	-105 dBm
MTI receiver sensitivity	-103 dBm
IF frequency	30 MHz
Receiver bandwidth	1.0 to 1.5 MHz
Power requirements	120/208 Vac, 60 cps, 60 kVA, three-phase, four-wire
Maximum maintenance PPI range	90 km
Minimum maintenance PPI range	20 km
Antenna pattern	Cosecant squared
Antenna beamwidth, 3-dB points	1.4 deg horizontal, 30 deg vertical
Azimuth resolution	1.4 deg separation
Range resolution	1.5 times pulse width
Polarization	Selectable vertical or circular
Tilt angle	Variable -6 to +6 deg

Table 9. MRR-4 specifications

Parameter	Specification
Power output	100 mW
Frequency range	7125 to 7985 MHz
Emission type	F9
Power input	120 Vac, single phase
Radar site	10 A
Echo site	10 A
Input level requirements	
Video 1	0.75 V min; pulse width, 0.15 min
Video 2	0.60 V min; pulse width, 0.25 min
Video 3	0.50 V min; pulse width, 0.20 min
Trigger	2.5 V min; pulse width, 0.14 min
Marks	7.0 V min; pulse width, 0.25 min
Directional coupler isolation	25 ±2 dB
IF frequency	75 MHz
LO frequency	75 MHz below receiver frequency
IF bandwidth	11 to 15 mc
Operating temperature range	-29 C (-20 F) to +52 C (+126 F)

Table 10. Radar video processor specifications

Parameter	Specification
	Inputs
Power	108 to 130 Vac, single phase, 60 cps, 5 A
Trigger	10 to 50 V positive, 1200 ±30 PRF, 1 μs nominal
Synchro data	90 Vac line to line, 120 Vac, 60 cps reference
Antenna rotation	5 to 15 rpm
Video input	
Normal video	4 V max. peak into 75 Ω, SNR 2:1 to 10:1
MTI video	4 V max. peak into 75 Ω, SNR 2:1 to 10:1
Transmitter pulse width	1 ±0.2 μs
	Outputs
Trigger	Positive 15 V into 75-Ω load (PRF equals radar PRF)
ACP and north mark	Combined signal, transistor-transistor logic (TTL) compatible nominal +2 V, 8192 ACP per antenna revolution. Synced with the input PRF to occur at T_0 plus 120 km. One north mark per antenna revolution. Synced with the input PRF to occur at T_0.
Video outputs	Two isolated outputs, TTL compatible. Nominal 2 V peak into 75-Ω load. Video is an integrated MTI/norm unless otherwise selected by front panel control.
Digital outputs	1200 bits/s serial asynchronous, 44 bits (four characters per target). Characters consist of a 1 start, 8 data, 1 selectable parity, and 1 stop bit and are compatible with RS232C, data interface standard.

Table 11. Target processor/alarm display specifications

Parameter	Specification
	Inputs
Power	108 to 130 Vac, single-phase, 60 cps, 10 A
Synchro data	90 Vac line to line, 120 Vac, 60 cps reference
Trigger	Positive 15 V into 75 Ω
ACP and north mark	Combined signal, +2 V nominal, 8192 azimuth change pulses per antenna revolution
Digital data	0 dBm, 1200 bits/s serial asynchronous
Video inputs	4 V max into 75 Ω. SNR 2:1 to 10:2, three-input capability
Tape jack	Recorded video processor signal fed into target processor
	Outputs
Videos	
Normal	Unprocessed normal radar video
MTI	Unprocessed MTI radar video
Range gated	Unprocessed MIT and normal gated
Digitized	Digitized raw video from radar video processor
Azimuth strobe	Intensified strobe indicating north
Range marks	3 and 15 km for 50-km range, 6 and 30 km for 100-km range
Processed videos	
Track targets	Targets with azimuth and range changes
Fixed targets	Targets without azimuth and range changes
Non-correlated targets	Random targets or first indication of one of the above
Alarm gate	Azimuth and range outline of alarm gate
Tape jack	Real-time radar signal from video processor for recording

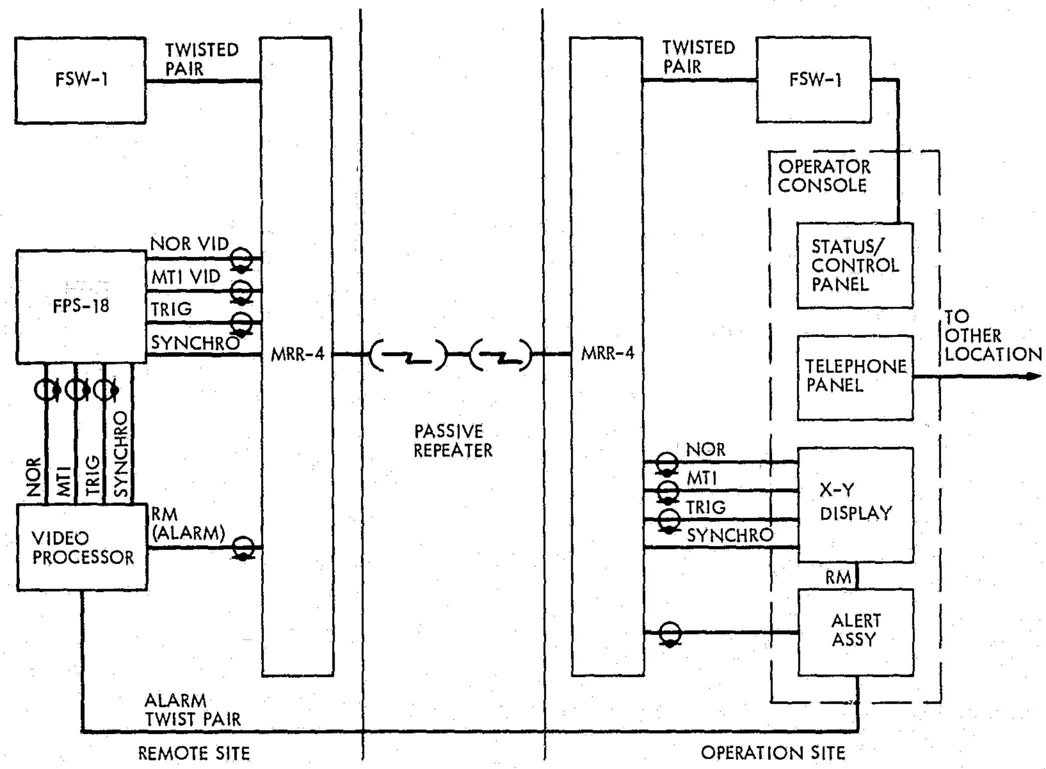


Fig. 22. OSR system block diagram

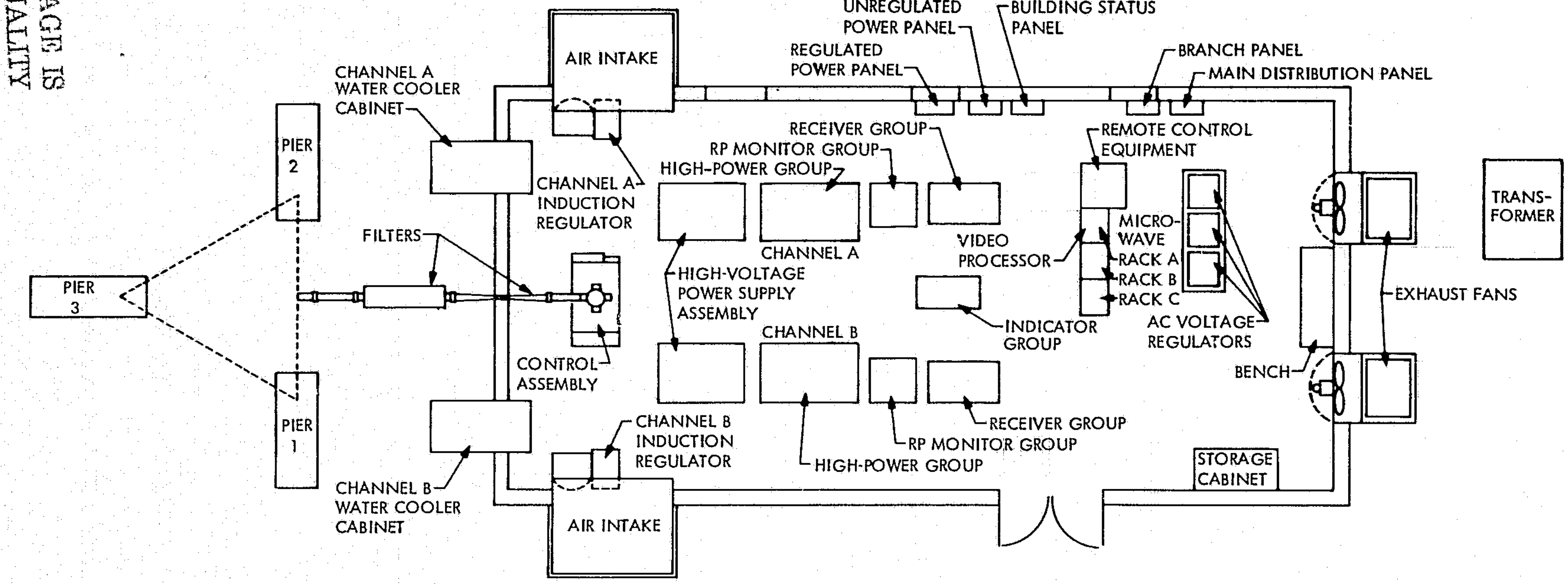
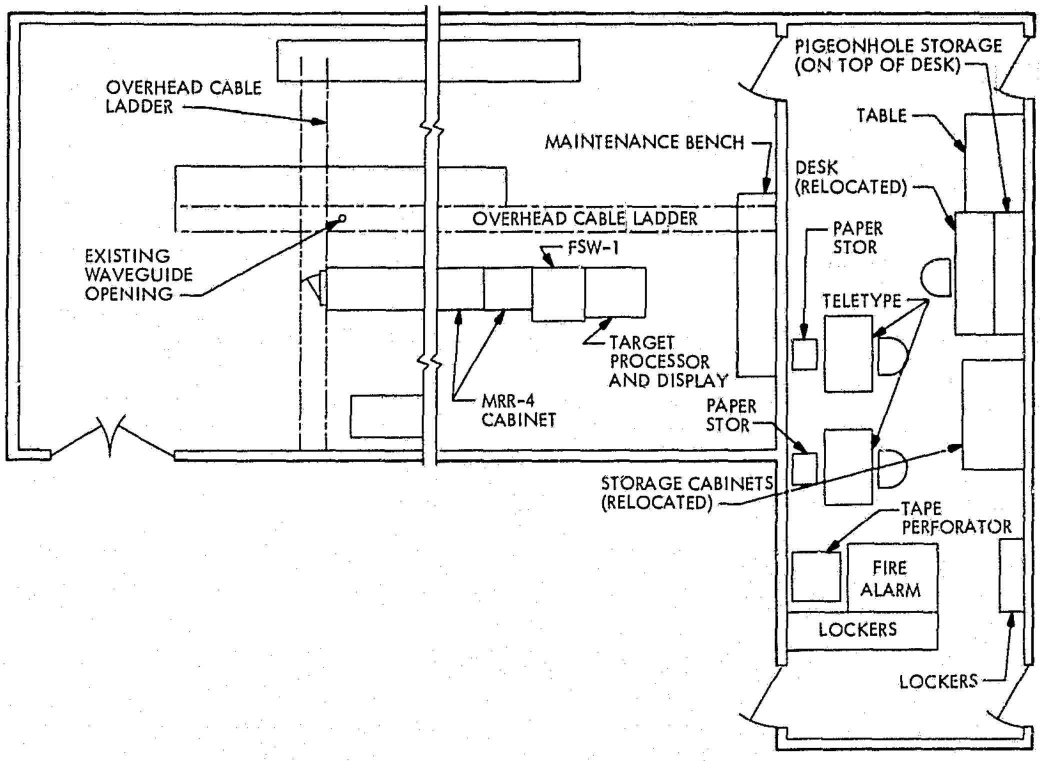


Fig. 23. Remote site equipment arrangement



ELECTRICAL REQUIREMENTS: 120 V, SINGLE-PHASE, AND 60 CYCLES

		CIRCUIT BREAKER	QTY	CONNECTED LOAD	DEMAND LOAD
MRR-4	2 OUTLET	15-A TRIP	2	20.0 A	20 A
FSW-1	1 OUTLET	15-A TRIP	1	2.5 A	2 A
TARGET PROCESSOR AND DISPLAY	1 OUTLET	15-A TRIP	1	10.0 A	10 A
				32.5 A	32 A

Fig. 24. OSR facility support plan, operations building equipment layout

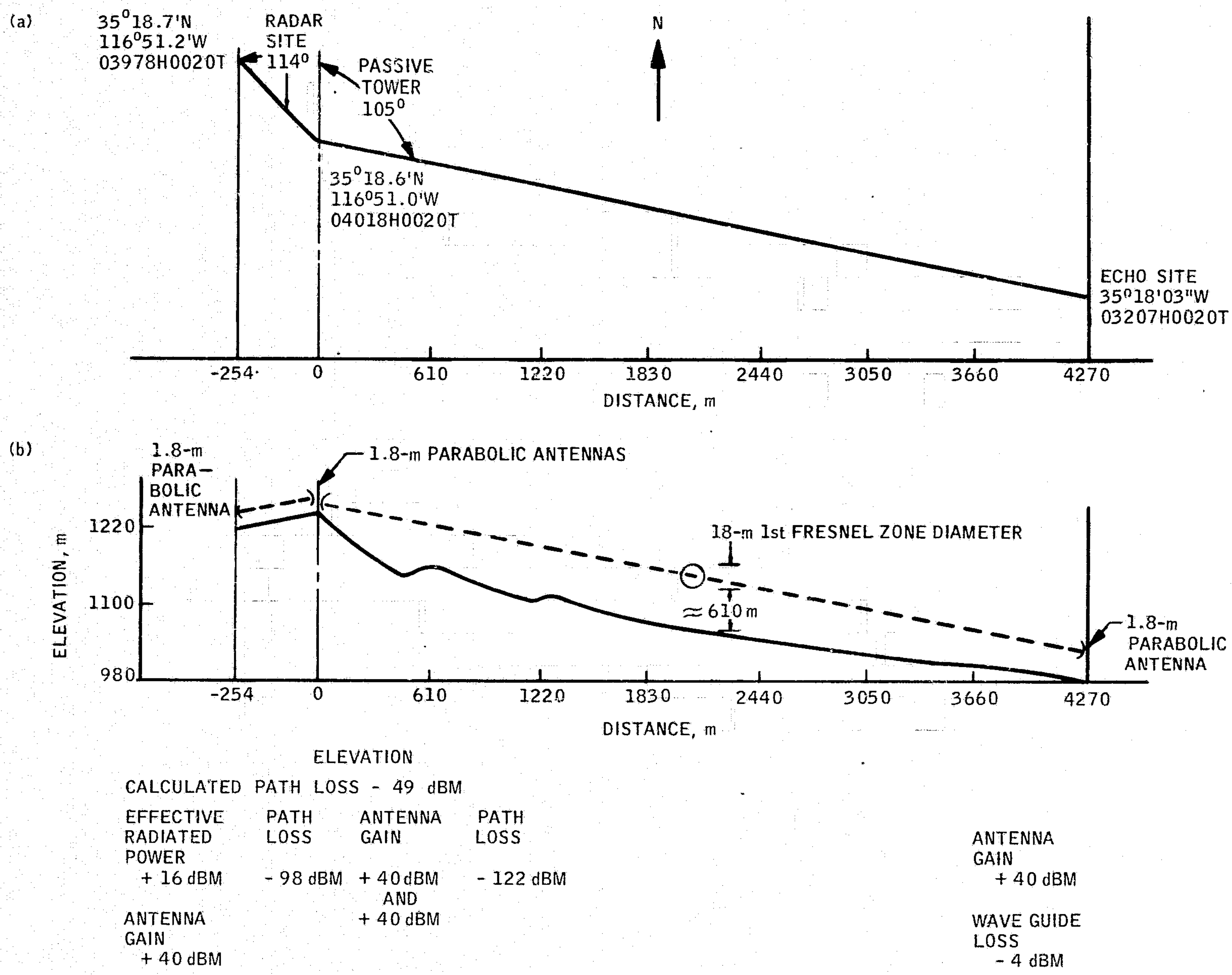


Fig. 25. OSR microwave communications path profile: (a) plan view, (b) elevation view

XI. OSR IMPLEMENTATION

JPl Contract number 954230 was awarded to Bendix Field Engineering Company on April 23, 1975, to remove an available FPS-18 radar from North Carolina, refurbish it in their Columbia, Maryland, plant, and finally to reinstall it at the Goldstone tracking station. This contract also included refurbishment of an FSW-1 remote control system for the radar and an MRR-4 microwave communication system to link the radar with its main control point at the Goldstone Complex Communications Center.

A. CONTRACTOR ACTIVITIES

Once the contract was signed, Bendix started negotiations with various surplus dealers for the acquisition of an AN/FPS-18 radar system, microwave link, and a PPI scope. After considerable negotiating, the AN/FPS-18 and the microwave link were acquired from Radio Research Laboratories of Norwalk, Connecticut. The FPS-18 system was an installed system located at Englehard, North Carolina, and had to be dismantled.

Bendix dispatched a team in mid-May to the Englehard, N.C., site to dismantle the radar and tower and ship them to the Columbia facility for refurbishment. During shipment, the antenna reflector was struck by a low-hanging tree limb and damaged. The damage was repaired during refurbishment, utilizing insurance claim monies.

Upon receipt at Columbia, the system was stripped down, cleaned, repaired, and painted. This activity was accomplished during the months of June, July, August, and most of September 1975. The schedule was delayed about 1 month for the refurbished and 3 months for the new equipment as a result of late deliveries by vendors.

Other engineering activities taking place at the same time involved the reduction of the microwave equipment for the operations building from three racks of equipment to two. Also, the removal of the rotary regulators and the FST-1 video processing equipment required wiring changes in the FPS-18. Solid-state regulators were obtained to replace the rotary regulators in case the incoming power had a tendency to fluctuate.

B. DESIGN REVIEWS AND SITE VISITATION

Prior to the design reviews, Bendix personnel made a visit to the radar site (May 7 and 8) at Goldstone for planning purposes.

The preliminary design review for the project was held at Goldstone on June 18 and 19, 1975. Items such as general system overview, program schedule, quality assurance (QA), surplus equipment refurbishment, facilities, safety, installation, new equipment design, operation, and system demonstration were discussed.

The final design review was held on September 30 and October 1, 1975. The general program overview, test plan, installation, demonstration plan,

C.2

maintenance and operation support plan, safety plan, spare parts, and test equipment were discussed.

After the surplus equipments were refurbished, they were connected up as a system in the factory and aligned and operated. The FPS-18 system was operated for a continuous 30 h after alignment and troubleshooting. The MRR-4 microwave was up for 72 h continuous run. The alignment and testing took place during the latter part of September and the month of October 1975. These satisfactory factory acceptance tests were witnessed by JPL engineering and QA personnel. JPL QA personnel also made a complete inspection of the workmanship.

C. GOLDSTONE INSTALLATION

In early November 1975, the radar tower, antenna, electronics, microwave system, and FSW-1 were shipped to Goldstone.

1. Tower Erection

The Bendix installation team arrived at Goldstone during the last week of October 1975. Erection of the top 8.5 m of the radar tower was started first. The bottom 13 m of the tower were not utilized to prevent illumination of other Goldstone stations by the radar. Several on-site modifications to the tower were required to enable it to meet Occupational Safety and Health Administration (OSHA) requirements. Examples of these modifications were to raise certain guardrails to a 107-cm height, illuminate the stairways, install kick plates on the work platform, and elongate the entry to the stairwell. JPL-furnished cranes and forklifts were utilized to assist in the erection of the tower (see Figs. 26-32).

2. FPS-18 and FSW-1 Installation

Installation of the FPS-18 and FSW-1 was started on November 18, 1975, at Goldstone. A slight delay was incurred because the beneficial occupancy date of the building was delayed. In an effort to work around this, temporary portable power was made available by JPL to provide light, heat, and to power installation tools. In spite of a 2-week break for the holiday period, the installation proceeded to the point of initial operation of both channels of the radar by January 17, 1976. Numerous aircraft were tracked in the area on January 18 and 19. By the end of January, the installation phase of the basic radar system was essentially completed, and most of the Bendix installation team departed.

During the installation phase, several modifications had to be made to the FPS-18 radar to enable it to comply with both the California electrical code and Cal OSHA requirements. Some examples of these modifications were the separation of power and signal cables into separate new ducts, installation of larger power and rack grounding wires, and the relocation of some units to allow adequate work space. (See Fig. 33 for a view of the completed radar system.)

3. MRR-4 Installation

The MRR-4 microwave link was installed as a backup to the buried telephone cable to provide a video display of the radar information at the Goldstone Complex Communications Center. This link consists of the microwave electronics in the radar building and Communications Center and a passive repeater tower at the crest of the terrain overlooking both sites. (Figure 34 presents a sketch of the configuration.) Four microwave channels are available. Three of these transmit from the radar site to the Communications Center on the frequencies of 7160, 7240, and 7320 MHz. The fourth channel transmits from the Communications Center to the radar site on 7700 MHz. (See Figs. 35-39 for views of this installation.)

Documentation in the form of technical orders, manufacturers' handbooks, and drawings was submitted with the equipment. Test equipment which was peculiar to the system was also delivered.

4. New Design Equipment

A parallel effort was started at the initiation of the contract. This was an engineering program which was tasked with developing an automatic alarm assembly and ascertaining any modifications required to the refurbished equipments. The original concept was to utilize a surplus plan position indicator for the system. As the concept developed and the requirements became clearer, it became obvious that the PPI approach would not satisfy the requirements. This conclusion was based on the following:

(1) The display unit was to be operated by a part-time operator. He would be at the display only after an alarm had alerted him of an intrusion. The persistence of a PPI scope is only about 3 to 4 s. This meant that after the operator arrived at the scope, he would have to view five to six antenna rotations to determine the course and speed. He would then have to determine whether the situation called for action. Thus, each response to an alarm would involve 2 to 3 min of operator time. Depending on air traffic in the area, this would almost dictate the use of a full-time operator.

(2) The ability to improve and automate the system was a requirement that had to be considered in the design. The PPI scope does not lend itself to automation in an economical fashion. If the Phase 1 results indicated a higher incidence of intrusion than originally envisioned, a different type of display would be required.

(3) The packaging of the alarm system and display had to be compact because of space limitation. Although certain PPI scopes are relatively small, maintaining a package of suitable size remains a problem.

After a careful evaluation considering initial cost, versatility, packaging, on-going maintenance, etc., an X-Y display was chosen. This allowed the target processor/alarm display system to be packaged into a single cabinet. While the initial cost was somewhat higher, the other factors offset this expense, and the overall cost was less than that of a PPI.

During the preliminary design review, held on June 18 and 19, 1975, the system and the X-Y display were discussed. At this time, a change in concept was presented making the landline transmission the prime mode of operation and the microwave link the backup.

As the design progressed and the operations people became more involved, it became apparent that more sophistication was required than originally conceived. Some of the factors involved were:

(1) The operator would not be radar-oriented and would be performing other critical functions.

(2) Space for the equipment and operation was limited.

(3) Increase in manning would have to be kept to a minimum.

(4) Maintenance personnel would have to perform in more than one discipline.

(5) The operator would not be the end user and would require additional aids for valid information transfer.

(6) Such items as a board test set would be required for both production and field maintenance.

(7) The light-emitting diode (LED) readout had to be increased to three to be useful to the operator. Also, the use of the X-Y display did increase some of the circuit complexity.

Vendor deliveries were a problem in the design as well as the refurbishment area, delaying the design to some degree.

After the design was complete and the hardware built, some design problems were found. These were worked out, and the new equipment was shipped on March 9, 1976, installed, and checked out (Fig. 40).

5. Video Processor/Display Installation

This portion of the installation was entirely new equipment, designed by Bendix for the purpose of digitizing the PPI information for transmission via telephone lines to the Goldstone Communications Center, where it is restored on an X-Y display for the operator. Also included are an intrusion alarm and coordinate display for targets. This equipment arrived at Goldstone in mid-March 1976, and was installed and operational during the second week of April.

6. System Testing

System testing started the week before Christmas, 1975. When the radar was brought up, a large number of aircraft were noticed within the 90-km radius of coverage. Many of these were airliners, military planes, and some civil aircraft. It was obvious that the area was penetrated more often than originally thought.

The first aircraft were tracked in the Goldstone area on January 10, 1976, and by January 17, both channels of the radar had been powered up and had successfully tracked aircraft in the area. It was observed that typically there would be about eight to ten aircraft within the 90-km range of the radar. During the month of February 1976, this traffic picked up to 30 aircraft in the radar's range as a result of a military exercise.

System alignment, preliminary testing, and "hands-on" maintenance and operation training started in mid-January 1976. Formal acceptance testing of the FPS-18, FSW-1, and the MRR-4 microwave link started in mid-March 1976 and continued through the end of April 1976. The tests included detailed checking of each subassembly as well as the total system, in accordance with test procedures written by Bendix and approved by JPL. In addition to repetitions of factory acceptance tests, these tests included flight checks of the radar during which the JPL aircraft was tracked, RFI tests in conjunction with the STDN station, and X-ray and RF radiation hazard tests. The result of the latter two tests was proof that there is no observable RFI at the STDN station and that the radar site is a safe area for personnel, even though it is designed for unattended operation. Data from these tests, as well as the factory tests, are contained in JPL internal document TD511695, Test Description, Goldstone Operational Support Radar.

During the checkout (on-site) of the radar video processor and target processor/alarm display, several modifications were made to the equipment. Some of these were required for proper operation and some for greater ease of operation.

7. Facility Interface

The radar site selected by JPL and evaluated by Bendix allowed maximum screening of the existing stations of the Complex while providing very little blockage of radar coverage of the airspace to be protected.

The building and miscellaneous requirements for the remote radar site were presented to JPL in the original proposal. This was further updated in the Facility Plan submitted to JPL, showing modifications and equipment layout at the remote site. The Facility Plan also covered the operations and intersite requirements.

Coordination was provided as required with the facility construction contractor, STDN Apollo Station, DSN Echo Station, radar equipment contractor, and various support groups at the Complex.

8. Transfer to Operations

The system was turned over to Goldstone personnel about April 4 for their evaluation. Some problems experienced with the microwave were taken care of by site personnel. As the site personnel became more familiar with the equipments, they made certain modifications for ease of operation. After the Goldstone operations people had used the system for about 60 days, a return trip was made by the design engineer to provide M&O support and to discuss system performance and possible improvements with the personnel involved.

Also at that time, personnel were able to discuss the system and any problems that had arisen with the system engineer. This further enhanced their training and operation of the system. It also provided some background for Phase 2 and Phase 3 recommendations.

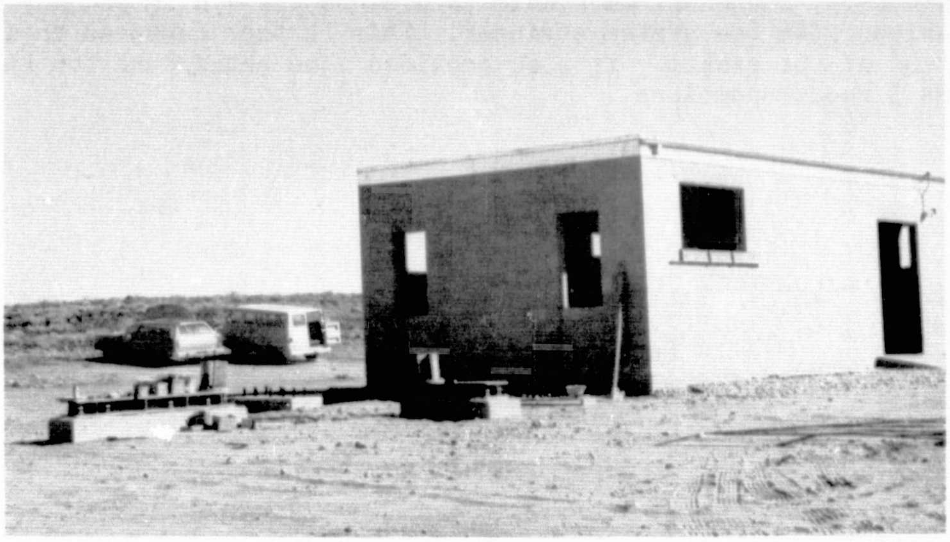


Fig. 26. Partially completed radar site facility

Fig. 27. Radar antenna tower adapter installation

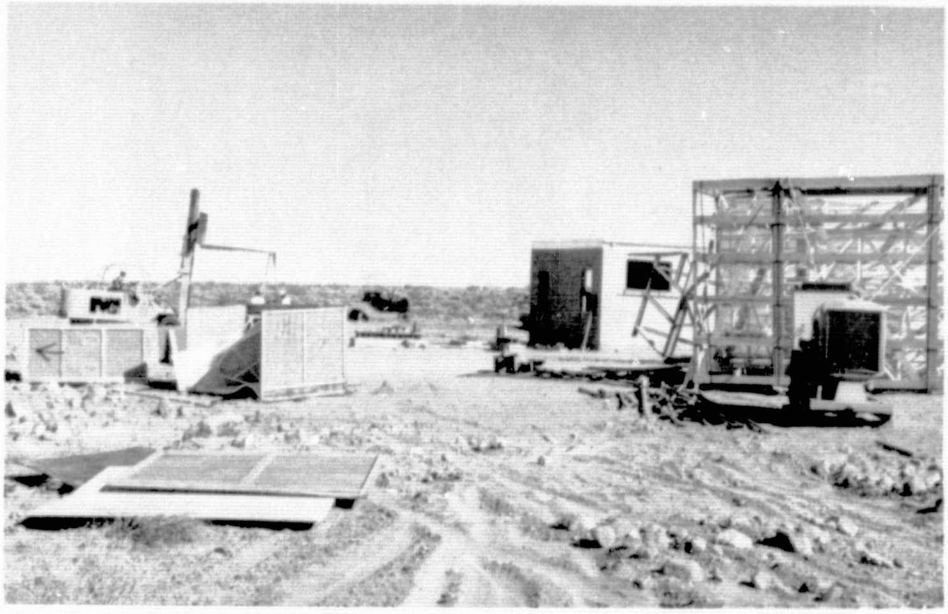


Fig. 28. Unpacking of antennas

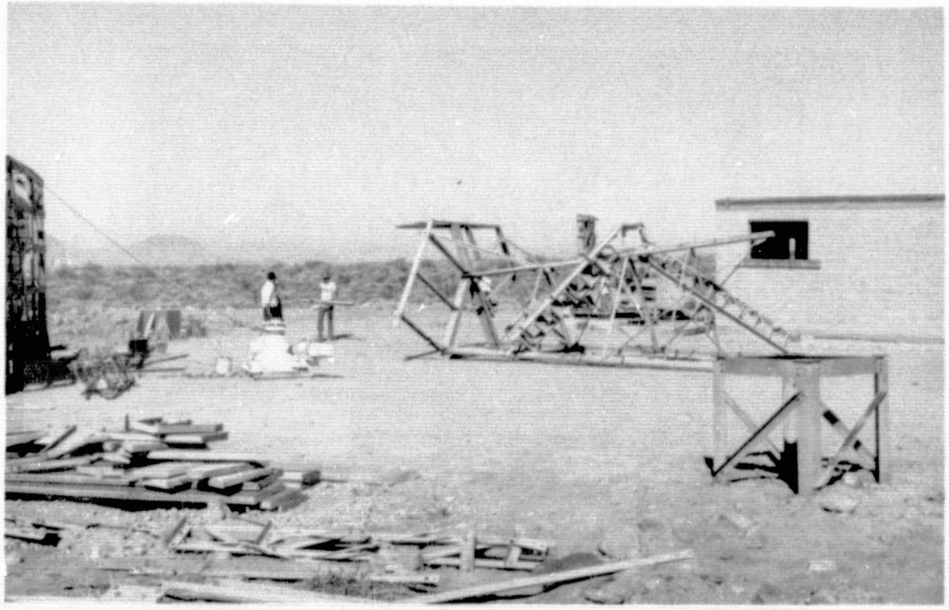


Fig. 29. Antenna tower ground assembly

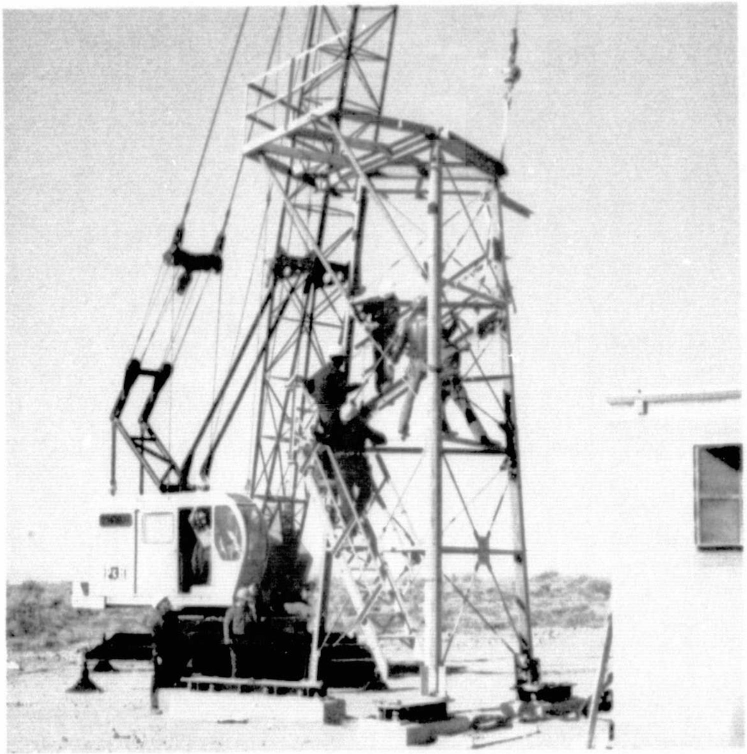


Fig. 30. Antenna tower erection

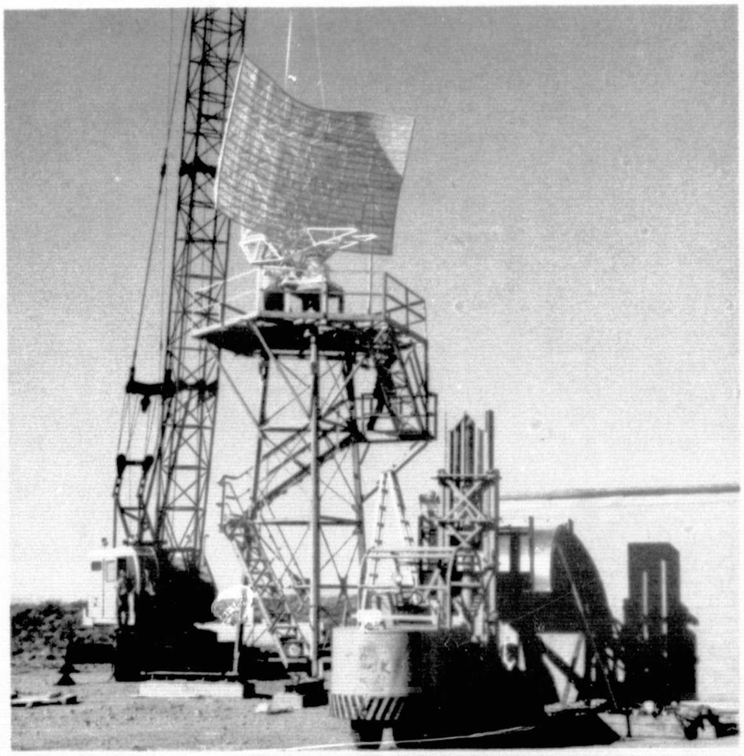


Fig. 31. Antenna installation on tower

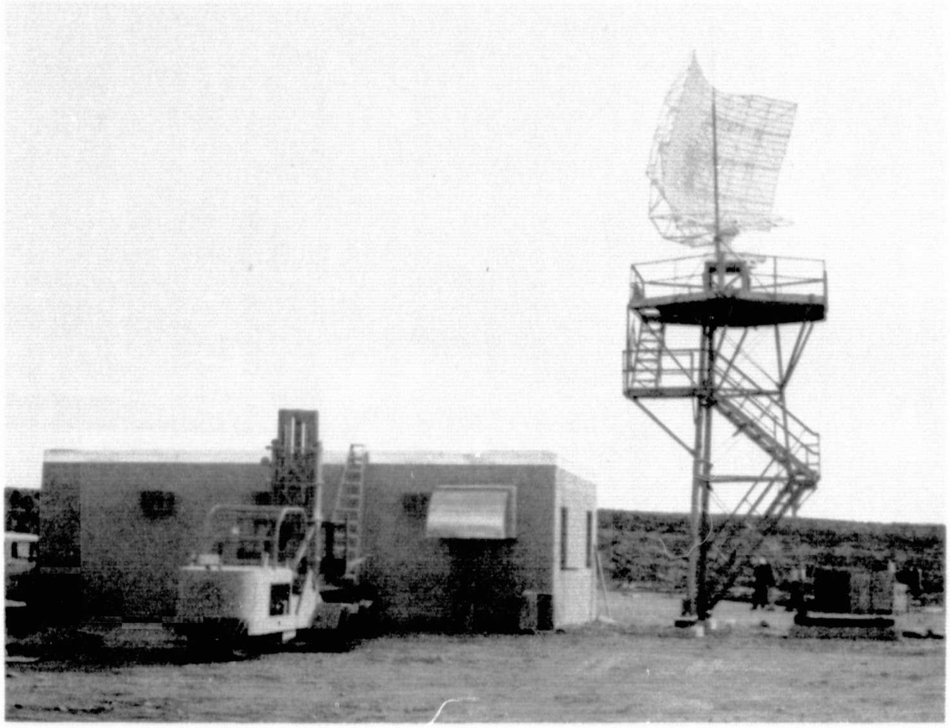


Fig. 32. Antenna installed

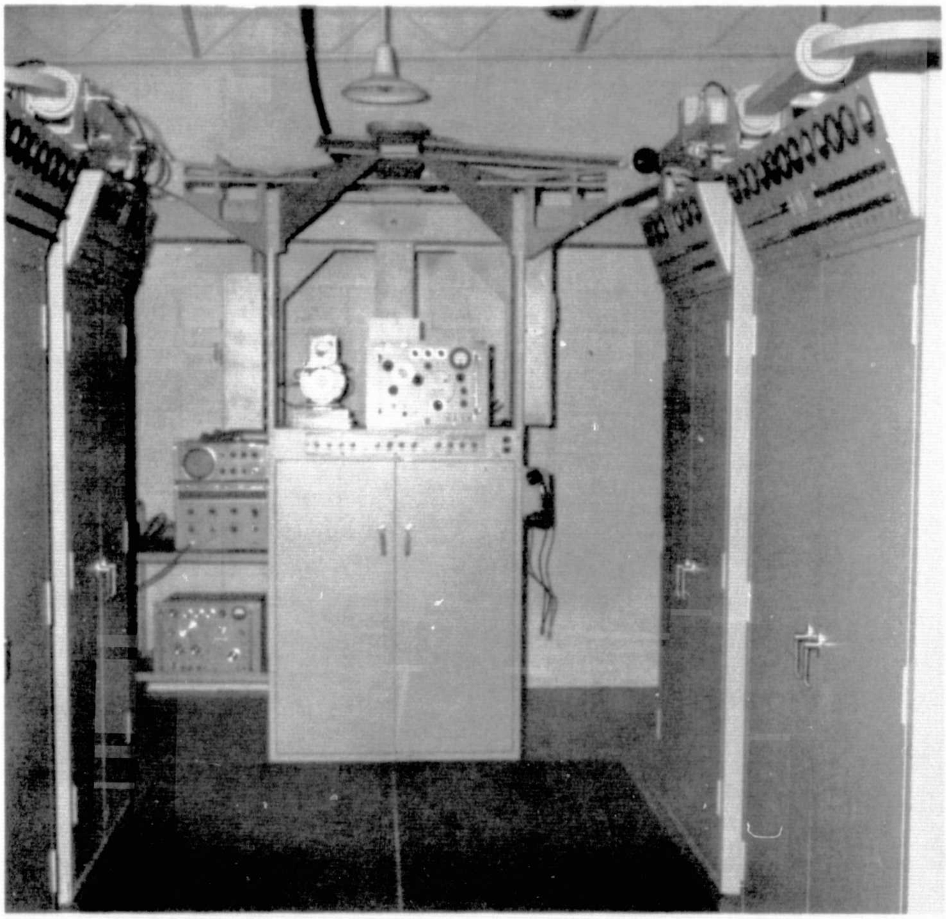


Fig. 33. Radar equipment installed

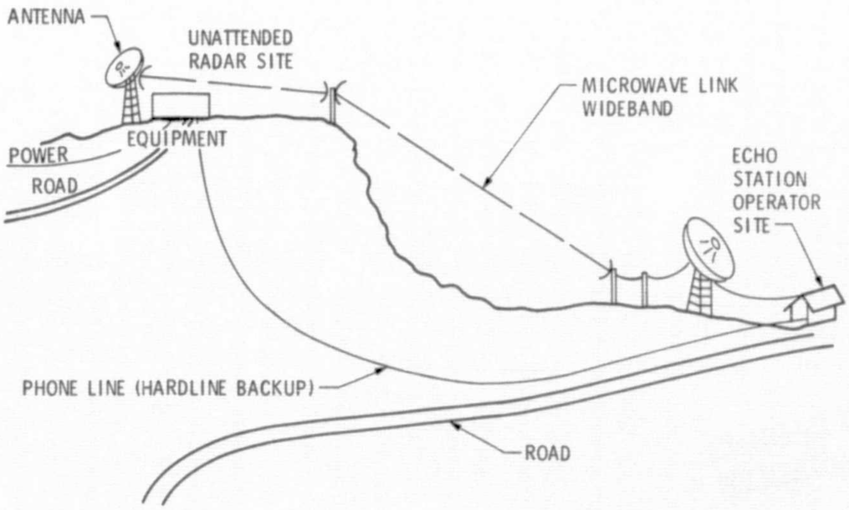


Fig. 34. OSR intersite microwave link

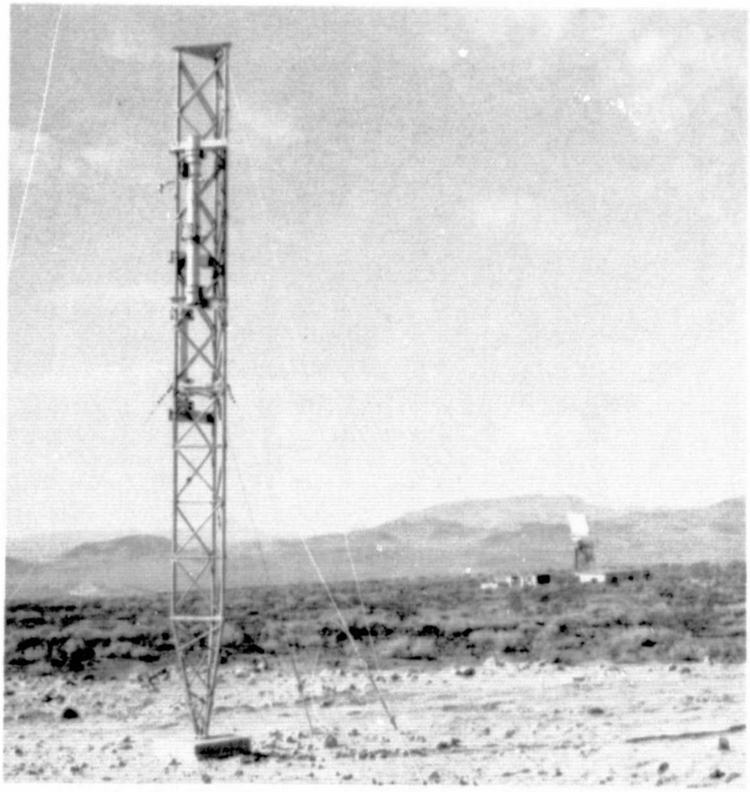


Fig. 35. Passive link tower installation

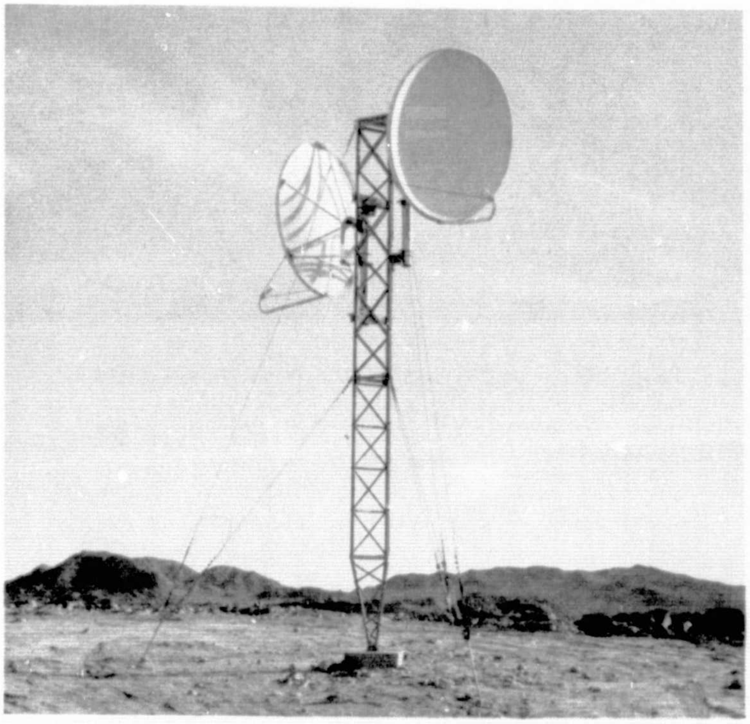


Fig. 36. Passive link completed

Fig. 37. Radar site microwave antenna

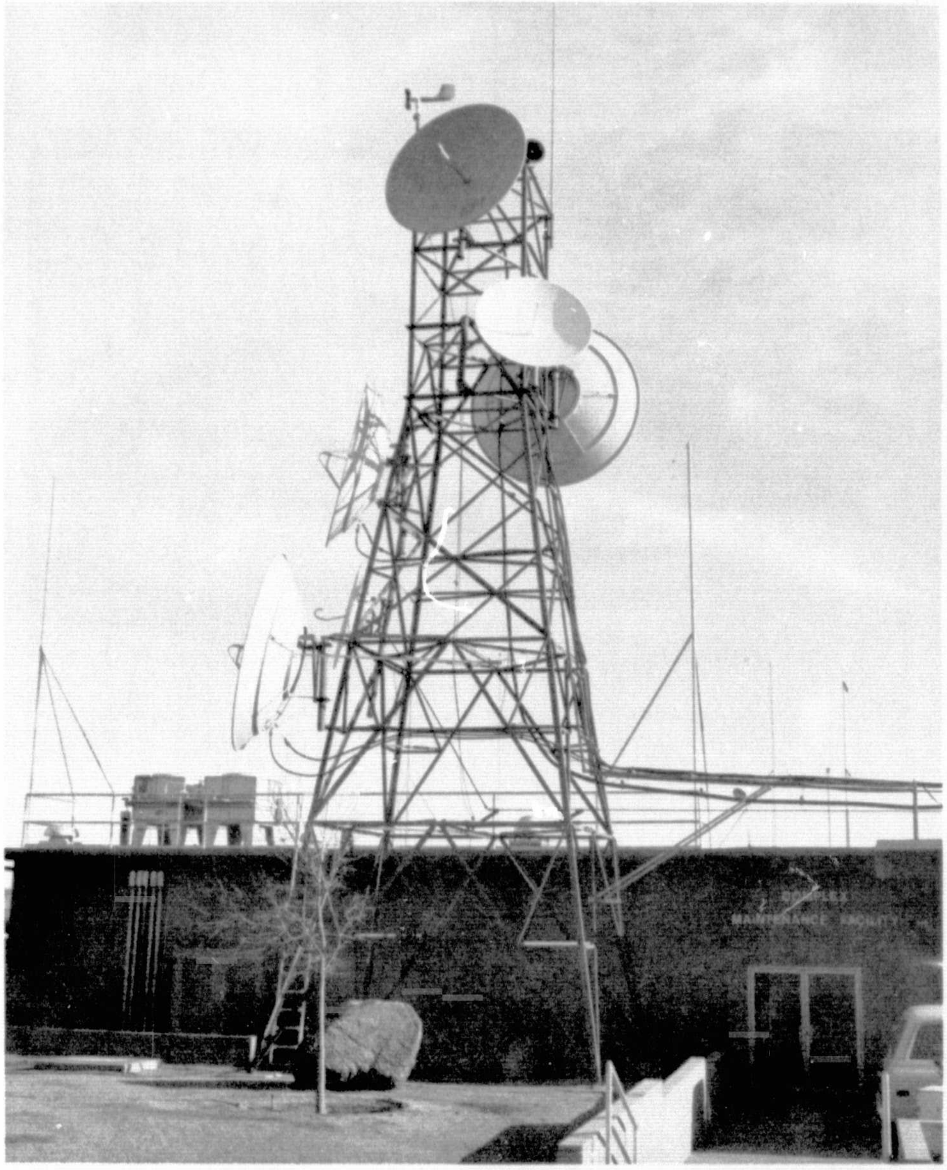


Fig. 38. Echo site microwave terminus

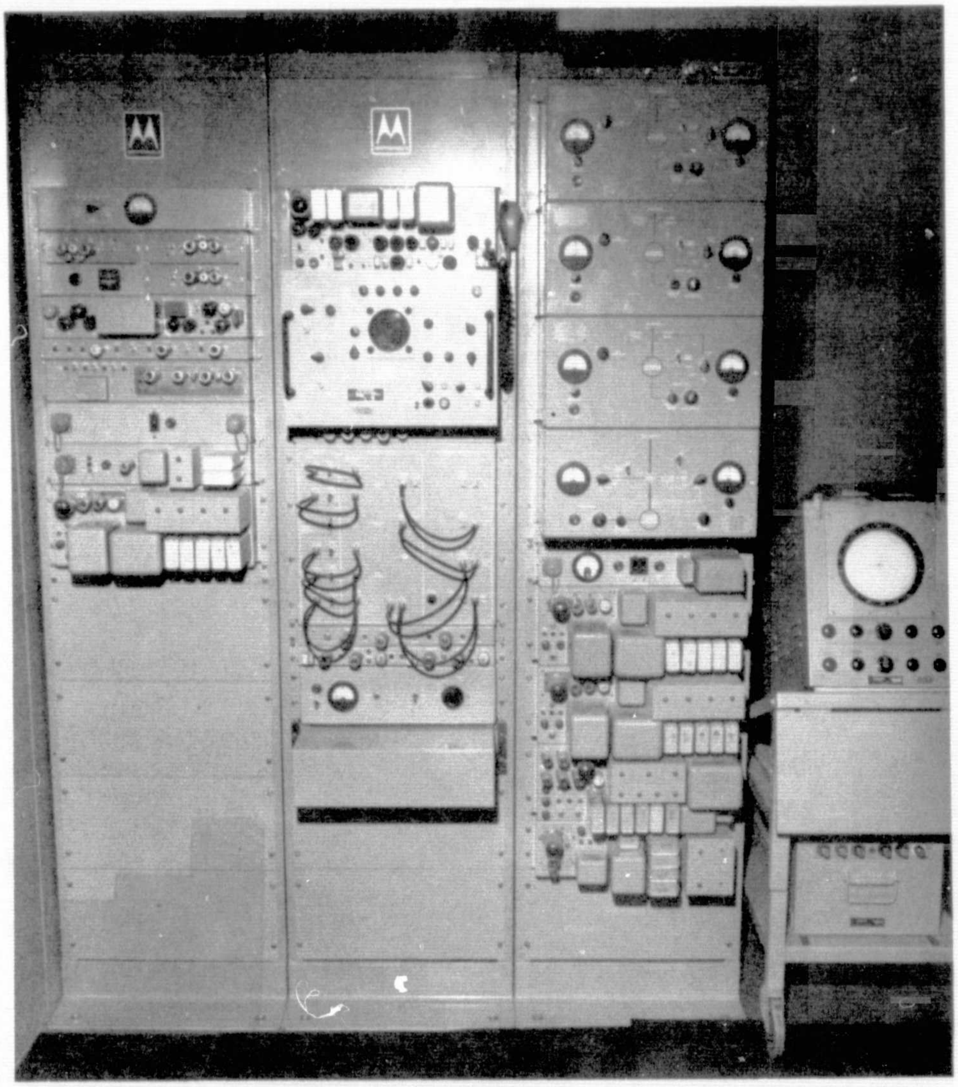


Fig. 39. Microwave equipment installed

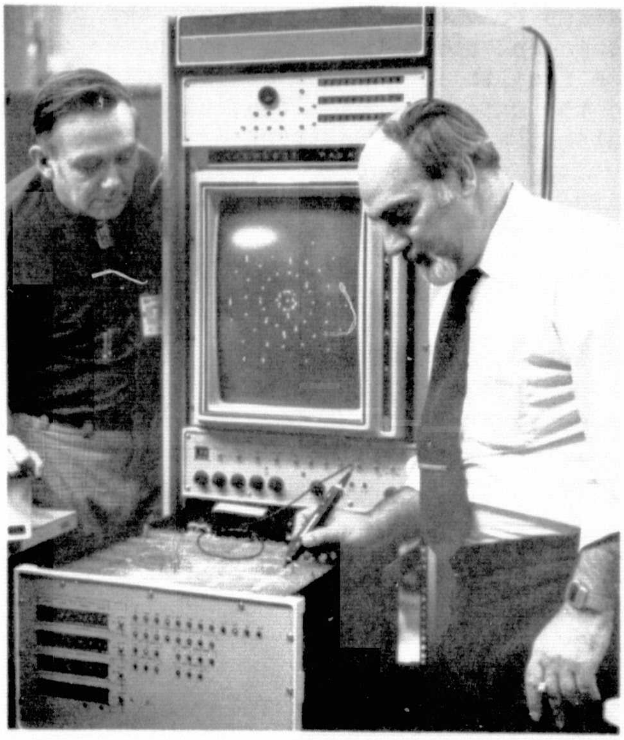


Fig. 40. X-Y display and target processor

XII. FACILITY IMPLEMENTATION

A. SUPPORTING FACILITIES

Facilities necessary to operate and maintain the radar antenna and its associated electronic and communications components were an integral part of this project. These facilities include the building; a fenced graded and graveled support area; the antenna foundation; electrical power and distribution; heating, ventilating, and air conditioning; general and emergency lighting; grounding; fire protection; and an access road. No water or sanitary facilities were provided or required.

B. DESIGN CRITERIA

The project description and criteria for the design of the support facilities, including supervision of the A & E, were accomplished by an electrical and civil engineer under contract to JPL for this specific task. JPL personnel were not available; however, JPL did provide overview supervision of the support facilities effort.

The site and road survey and the design and construction specification and drawings were prepared by an independent professional A & E firm selected by the JPL A & E Selection Board.

The Operations Support Radar facilities were constructed by a general engineering contractor. These facilities consist of the following:

(1) Building: A 6 × 12 m concrete block building, constructed of concrete blocks, reinforced to withstand wind and seismic loadings (see Fig. 32).

The building is lighted, furnished with ventilating fans to cool the housed electronic equipment, and has a Halon-type fire protection system. The fire protection system also sounds an alarm at the Complex central control panel, located at DSS 12, in case of fire.

The air conditioning/heating is supplied by three wall-mounted units. These units are used only for personnel comfort during brief periods of maintenance.

(2) Security: A 31 × 31 m fenced area surrounding the building and antenna is provided to prevent casual intrusion and also to provide a graveled working area.

(3) Access Road: A road approximately 1850 m long permits access for maintenance and emergency personnel. This road begins at the STDN Complex collimation tower and extends to the Operational Support Radar site. The access road is graded and graveled (Fig. 41).

(4) Power and Communication: Agreement was negotiated with STDN to splice into the high-voltage power source at the collimation

tower. An isolation, fused oil switch was installed at the splice point. Communication cable tie-in was accomplished in an existing junction box located in the collimation tower building. This provided communication direct to the Echo site communication center.

The power and communication cables were routed to the operation support building by way of a trench, running parallel to the road (Fig. 42).

Fig. 41. OSR access road

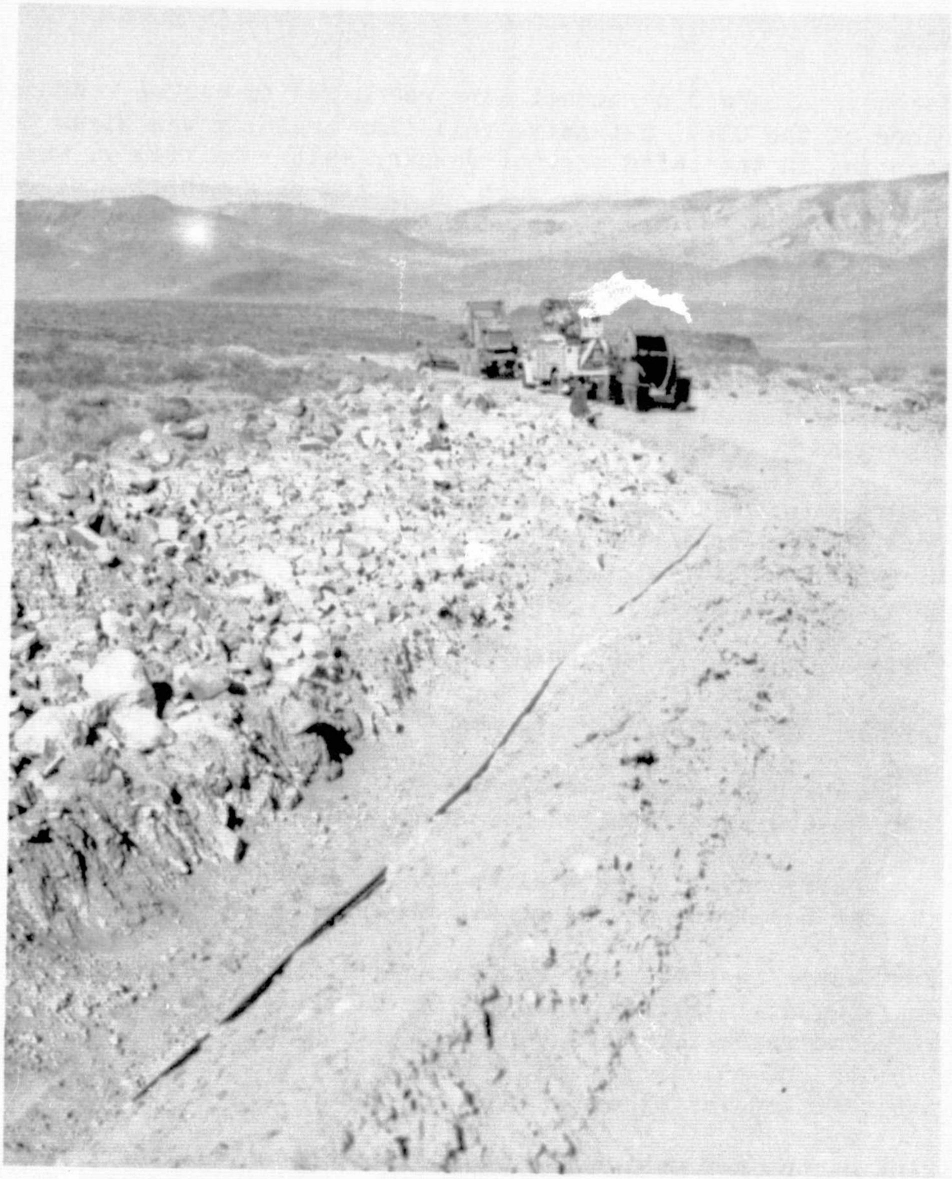


Fig. 42. Power and communication cable location

XIII. MAINTENANCE AND OPERATIONS

A. TRAINING

Two Aeronutronic-Ford personnel were recruited to assume responsibility for maintenance of the OSR. Extensive full-time training was given to these personnel starting in the third week of January 1976. Initially, this training consisted of "hands-on" experience, such as system alignment, troubleshooting faults, participation in system acceptance testing, and finally, formal classroom instruction. The classroom instruction was video-taped by the training unit at Goldstone for future instructional use. This training continued through the end of April 1976, by which time the two trainees were qualified to assume complete responsibility for maintaining the radar and its ancillary equipment. Additionally, the Goldstone Communications Center shift operators were given training in remote operation of the radar from the Communications Center and in interpretation of target displays.

A training course was presented for each discipline involved in the system. These courses consisted of both classroom and practical training. Each student was presented material especially prepared for each course, which he kept. The titles of the courses and their duration were as follows:

(1) FPS-18 for Radar Repairmen -- 2 weeks

(2) MRR-4 for Microwave Repairmen -- 1-1/2 weeks

(3) Operation for Radar Repairmen, Microwave Repairmen and Operators -- 1 week

(4) Video Processor/Target Alarm for Radar Repairmen and Microwave Repairmen -- 2 weeks

The instructor for the radar and microwave courses was a field engineer from the Bendix Fountain Valley, California, facility. He also conducted the periodic maintenance instruction. The training on the microwave equipments was waived by the operations manager, and the time originally programmed for microwave training was expended with the radar personnel.

Training on the new design equipments was conducted after installation by the design engineer from the Columbia, Maryland, facility.

B. SPARES

Spare units, boards, and components were delivered with the system for ongoing maintenance. In many instances, spares in excess of the 6-months' supply specified were delivered because of the minimum buy quantities imposed by some vendors.

The contractor also recommended that a complement of spare items be kept on site as bench stock, and a list was compiled using available consumption data and experience with similar equipments. This listing was further influenced by the operational commitments of the equipments and the availability of backup equipments. In the case of the FPS-18 radar system, there are two complete channels, either one being capable of meeting commitments for radar coverage -- in essence, one spare radar system. Since the system is not committed to 24-h, 365-day a year coverage, high-cost items with a relatively low failure rate were recommended in such cases. It should also be noted that common components such as resistors and capacitors were not listed, since most of these would be considered stock items at an electronics facility.

C. TEST EQUIPMENT

The following listing of test equipment is segregated into three parts. One part is kept at the radar station, one at the Echo site, and the third is used where required as required.

(1) Radar site

(a) HP-410 multimeter
(b) Triplett 630 multimeter
(c) HP-616A signal generator
(d) Tektronix 545 oscilloscope
(e) Tektronix 53/54C scope preamp
(f) UPM15 pulse generator
(g) HP-431 power meter
(h) TS-270 B/UP echo box
(i) HP-3469B digital voltmeter
(j) LP-313 dual-mode logic probe
(k) HP-J281A coax to waveguide adapter
(l) Assorted stick attenuators, 3, 6, 10, and 20 dB
(m) CU-507 dummy mixer
(n) Assorted coax test cables and probes

(2) Echo site

(a) HP-3469B digital voltmeter
(b) Tektronix 545 oscilloscope
(c) Tektronix 53/54C scope preamp
(d) HP-410 multimeter
(e) HP-J281A coax to waveguide adapter
(f) LP-313 dual-mode logic probe
(g) Assorted coax test cables and probes

(3) Periodic use equipments

(a) TV-7/U tube tester
(b) ME6B/U (HP-415) electronic ac voltmeter
(c) HP-608D signal generator
(d) TS 359 A/U capacity divider
(e) Weston 433 0-10 ac voltmeter
(f) Weston 931 0-10 dc voltmeter
(g) Radar-sweep 30-mHz sweep generator
(h) HP-423A crystal detector
(i) HP-620 signal generator
(j) HP-J538A wavemeter

D. CONTRACTOR SUPPORT

After the installation phase, Bendix provided ongoing support on a diminishing basis. This support consisted of a visit by the design engineer from Bendix headquarters in Columbia, Maryland.

Future service can be continued under a separate contract. Bendix maintains a facility at Fountain Valley, which has the capability to provide this emergency service.

In addition, a periodic inspection and repair as necessary (IRAN) is available from Bendix headquarters. The recommended time frame for IRAN activities is every 24 months. Also, logistic services are available at Columbia.

E. SYSTEM TRANSFER TO OPERATIONS

Transfer of the radar system and all of its ancillary equipment to Goldstone operations was accomplished on May 3, 1976. Prior to the transfer, all JPL requirements relative to configuration, documentation, conformance to technical specifications, QA workmanship requirements, OSHA requirements, personnel training, and sufficient test equipment had been met or scheduled.

Where possible, every effort was made by JPL and Bendix to utilize Government-surplus test equipment. Considerable cost savings was effected by acquiring such equipment.

XIV. ACCEPTANCE TESTING

The AN/FPS-18 and the AN/FSW-1 were surplus equipments, which required extensive refurbishment to meet the original as manufactured performance specification. The MRR-4 was surplus equipment that required a minimum of refurbishment to meet the original performance specifications. The data and target processing units were designed and manufactured specifically for this OSR requirement.

Testing was performed in accordance with the procedures outlined in the related Technical Orders, as listed in Table 12.

The test equipment required is listed in Table 13.

A. REFURBISHED RADAR EQUIPMENT

The subassemblies of radar set AN/FPS-18 were tested in accordance with the minimum performance standards of Technical Order 31P6-2FPS18-2. The results of these tests were documented on data sheets which specified the minimum acceptable performance limits.

The following FPS-18 items were tested in accordance with the minimum performance standards outlined in the related Technical Orders:

Arc detector TS-1121/FPS-18
Canceller CM-88/FPS-18
Control assembly C-2097/FPS-18
High-voltage power supply PP-1497
Indicator IP-401/FPS-18
Indicator power supply PP-1319A
Induction regulator CN-385/FPS-18
Mixer CV-442/FPS-18
MTI IF amplifier AM-1516/FPS-18
Normal IF amplifier AM-1517/FPS-18
Power supply (synchrodyne panel) PP-1567/FPS-18
Power supply PP-1567/FPS-18
Preamplifier AM-1440/FPS-18
Pulse chassis AM-1518/FPS-18
Receiver power supply PP-1565/FPS-18
RF oscillator (Coho) O-453/FPS-18
RF oscillator (STALO) O-454/FPS-18
Transmitter T-599/FPS-18
Trigger amplifier AM-1596/FPS-18
Voltage regulator CN-394/FPS-18
Voltage regulator CN-424/FPS-18
Water cooler MX-2010/FPS-18

B. INTEGRATION AND COMPATIBILITY

Radar set AN/FPS-18 was tested at the system level in accordance with the standards outlined in the related Technical Order:

Transmitter power output measurement
Standing wave ratio (SWR) measurement
Normal receiver sensitivity
MTI receiver minimum discernible signal (MDS) measurement
Cancellation ratio measurement
Subclutter visibility measurement
Radio frequency interference

The following control monitor, AN/FSW-1, subassemblies were tested in accordance with the minimum performance standard outlined in the related Technical Orders:

Prime unit C-2062/FSW-1
- Transmitter output
- Receiver sensitivity
- Power supply

Remote unit C-2063/FSW-1
- Transmitter output
- Receiver sensitivity
- Power supply

C. REFURBISHED COMMUNICATIONS EQUIPMENT

The microwave communication set, MRR-4, subassemblies were tested in accordance with the minimum performance standards outlined in the related Technical Order. However, the reconfiguration of the frames required to reduce by one the number at each location resulted in the removal of certain original configuration items such as test equipment. Essentially, the four receivers and associated transmitters were retained to provide the required four channels. These were tested at the newly assigned and authorized frequencies.

D. NEW EQUIPMENT

Minimum performance standards were not available for the data processor and target processor until some months after the refurbished equipment had been tested at the contractor's facility and shipped to and installed at Goldstone.

In-plant testing of the new processors was performed at the circuit board level, utilizing a newly developed test fixture. Assembly testing was performed by use of a simulator and tape recorder to provide radar target data. Full system testing, final adjustments, and required modifications were made only after final installation at Goldstone was completed.

A test fixture, simulator, and tape recorder were delivered with the final equipment to permit further testing in the field. These items were then supplied as M&O support equipment, along with documentation, during the training phase at Goldstone.

E. SYSTEM OPERATIONAL TEST

During the period of the operational testing of the OSR system, the entire system was subjected to the normal operating stress to reduce to a minimum any marginal parts remaining in the system. Therefore, the components of the system were operated for several hundred hours for both channel A and channel B. Readings of pertinent meters, and measurements of radiated power and receiver sensitivities were made and recorded. Several relays, switches, and vacuum tubes required replacement during this burning-in period. The performance and reliability were greatest when the system was operated in the original design mode of continuous operation. Turn-on and turn-off operation required increased maintenance.

F. NONIONIZING RADIATION SAFETY SURVEY

On January 27, 1976, a survey was made of the Goldstone Operational Support Radar site to verify safety requirements for nonionizing radiation when this unit is operating. The survey, which was extended over a wide area to ensure that no personnel risk is present, included the following:

(1) Inspections were made of the radar system and immediate area, including all high-power waveguide runs and joints, the two transmitters, and the interior and exterior of the radar building. Also, the antenna tower and platform and access routes were surveyed.

(2) The terrain surrounding the radar site was surveyed. This included the access road, the passive repeater for the microwave data link, and the top of the mesa. Also, the fence perimeter was examined fully.

(3) The collimation towers for the Space Tracking and Data Network 26- and 9-m antennas were surveyed as possible locations where personnel may receive radiation from the OSR during operation.

(4) The radiation density as a function of the OSR antenna elevation angle was measured. For this test, a fixed location was surveyed for different antenna elevation angles.

A Narda Microline® electromagnetic radiation monitor Model No. 8315A with a Narda Model 8321 broadband isotropic probe was used to conduct the survey. This unit has proven reliable, and is accepted by the various safety personnel as having the capability to quantify any nonionizing radiation levels. The antenna was, in general, "talked" onto a peak reading and left stationary for an area survey. In some cases, such as checking the fence perimeter, the antenna was allowed to rotate. Areas of personnel access or potential risk were carefully probed and the results recorded. Portable two-way radios were used to maintain communication between the field survey team and radar operators.

It was concluded that personnel exposure due to operation of the Goldstone Operational Support Radar is minimal under normal conditions. In the interest of safety, the antenna elevation is restricted to +2 deg or more, and personnel are not permitted on the antenna platform with the radar operational. Although the OSR has higher microwave power densities in its vicinity than a DSN station, these levels are not excessive and are within the JPL safe limit of 1.0 mW/cm^2.

Table 12. Test procedure sources

Technical Order No.	Title
31P6-2FPS18-1	Operation: Radar Set AN/FPS-18
31P6-2FPS18-2	Service: Radar Set AN/FPS-18
31P6-2FPS18-7	Standard Installation Instructions: Radar Set AN/FPS-18
31S1-2FSW-1	Operating Instructions: Control Monitor Set AN/FSW-1
31S1-2FSW-2	Service Instructions: Control Monitor Set AN/FSW-1
31R5-4-8-1	Instructions and Parts Breakdown: Microwave Radar Relay System MRR-4

Table 13. Test equipment

Quantity	Item	Model
1	Oscilloscope	Tektronix 545
1	Preamplifier	Tektronix 53/54C
1	Signal generator	HP-616A
1	Signal generator	HP-608E
1	Volt-ohm-milliammeter	Triplett 630-A
1	Vacuum tube voltmeter	HP-410B
1	Pulse generator	UPM-15
1	Echo box	TS-270 B/UP
1	Coupler, signal generator	CU-507/FPS-14
1	Dummy mixer	Bendix AT64884
1	Termination, 100 Ω	
1	RF detector	Telonic XD-3
1	Coaxial attenuator, variable, 75 Ω	
1	Power meter	HP-430C
1	Thermistor mount	HP-477B
1	Attenuator, coaxial, 3, 6, 10, and 20 dB	
1	Digital voltmeter	HP-3469B
1 each	Frequency meter	HP-536A
1 each	Frequency meter	HP-537A
1 each	Coaxial termination (50 Ω)	HP-908A
3 each	Adapter, waveguide to coax	HP-J281A

XV. OSR DEMONSTRATION PLAN

A. FLIGHT TEST

The objective of the demonstration plan was to verify that the OSR will detect, relay, and display the position of an intruder aircraft at a central location and both visually and audibly alert the OSR operator to the fact that an intrusion has taken place.

The method of verifying that the OSR met the above objective was to check each of the individual equipment items for its pertinent operating characteristics and capabilities and to demonstrate that the items were compatible with each other. The equipment items and their functions in the OSR system are presented in Table 14.

Each item was once again tested to the same standards and procedures discussed in section XIV. Additional system, flight, safety, interference and communications checks completed the demonstration plan. Some of these tests are detailed in Table 15.

B. FPS-18 RADIO FREQUENCY INTERFERENCE TEST

On October 25 and 27, the FPS-18 system was monitored for spurious and harmonic emission. The radar system was radiated through the feedhorn. An antenna was placed 15 m from the FPS-18 feedhorn and connected to a spectrum analyzer. Frequencies from 1 to 9.8 GHz were checked, with no spurious frequencies being found. The second and third harmonics were found and measured.

The test was run in two parts using the same location and equipments. The power being radiated from the FPS-18 was monitored to maintain a constant level. It initially appeared as if a large amount of spurious emission was present. However, by using a notch filter on the analyzer to eliminate the radar fundamental, it was found that no spurious signals were present. What had been seen initially were harmonics of the spectrum analyzer mixer circuit. Without the additional radar filters, the harmonics detected were 51 and 79 dB, respectively, down from the fundamental frequency.

With the radar filters in, the following test results were obtained. The band from 1 to 9.8 GHz was once again checked, and no spurious signals were found. The harmonics were apparently below the sensitivity of the analyzer (-98 dBm). An NF-105 was next used; the second harmonic was less than -100 dBm and third harmonic less than -105 dBm, which is the noise level limit of the NF-105. The additional filters were demonstrated to significantly reduce harmonic and spurious emission.

C. PROCEDURE

The JPL aircraft flew a heading of 70 deg (true), at an altitude of 1500 m, until it was over the Goldstone radar station. After reaching the radar location, it turned to a heading of 90 deg (true) and flew east at the same altitude for 120 kilometers. The altitude was then increased to

3000 m, and the aircraft flew a heading of 270 deg (true) until it was again over the radar station, where it turned to a heading of 250 deg (true) and flew back to the starting point. There it decreased the altitude by 900 m and repeated the original flight path at 2100 m.

The above flight patterns enabled the operating personnel to evaluate the performance of the radar set against the nose and tail aspects of a small, reciprocating engine aircraft.

Upon completion of these flight paths, the aircraft returned to a point 37 km east of the Goldstone radar station and proceeded to orbit CW about the station at an altitude of 1800 m until it was at an azimuth of 250 deg (true) from the radar station.

D. RECORDING

The recorder entered the following information on the flight test data sheet for each run flown by the test aircraft:

(1) Aircraft type

(2) Air speed to be maintained

(3) Wind direction and velocity

(4) Radar antenna tilt angle

(5) RF power output as measured by maintenance personnel (noting channel being used)

(6) Receiver sensitivity (MDS)

(7) Date of test flight

(8) Recorder's name

(9) Run number

(10) Course heading

(11) Altitude

(12) Scan data. For each scan, a hit or miss was recorded for both the processed video and the raw (MTI) video. A 1 indicated a hit and a 0 a miss. Every fifth scan, and at the initial and terminal scans, the range and azimuth of the target were entered as indicated by the target processor's range and azimuth readout indicators. If a given run exceeded 100 scans, additional sheets were used as required.

(13) The alarm gates of the target processor were adjusted for a length of 120 km with a width of 10 deg. This resulted in the alarm sounding continuously during the run unless there were more than

three consecutive misses, at which point the alarm ceased. For each scan without alarm, a dot was entered after the hit or miss indication in the processed video column (e.g., hit with no alarm = 1·, miss with no alarm = 0·).

Table 14. OSR system equipment

Equipment item	Function
Radar set AN/FPS-18	Detect in range and azimuth airborne objects equal to or greater than light aircraft at ranges up to 90 km.
Control-monitor AN/FSW-1	Control the operating conditions of the radar set and monitor its principal characteristics for control/display at the operating site.
Radar video processor	Convert the range and azimuth data of the radar set to coordinate data for transmission via telephone lines to the operating site.
Target processor	Accept the coordinate data from the radar video processor, display the resultant targets (intruder aircraft), and generate an alarm if an intruder aircraft enters within a gated area.
Microwave radio relay MRR-4	Provide the transmission path for raw radar video, quantized radar video, and emergency voice communications.

Table 15. OSR flight tests

Equipment	Test conditions
Radar set AN/FPS-18	Power output not less than 500 kW
	Receiver sensitivity - 103 dBm
Video processor display	Both processed and raw (MTI) videos selected
	Intruder alarms (2) set to 117 km long and 10 deg wide
	One intruder alarm centered on an azimuth of 250 deg and the second alarm on an azimuth of 90 deg
Flight parameters	
Starting point	4 km north of Edwards, California
Altitudes	1500, 2100, and 3000 m above sea level
Radials	070, 250, 90, and 270 deg, all true headings
Terminating point	120 km due east of the radar site at Goldstone
Air speed	333 km per hour

XVI. OPERATING PROCEDURES

A. NORMAL OPERATION

Under critical conditions, the OSR system is operated with one radar channel transmitting and the standby channel in the preheat condition. The MRR-4 microwave system operates with two transmitters transmitting to the Echo site. The video processor and the target alarm system are operational, sending digitized video to the display system. The display is displaying MTI video via the microwave link and digitized video from the target processor. The alarm gates of the target alarm system are set to alarm only when targets enter the area to be protected.

When the operator at the Echo site hears an alarm, he goes to the display unit and observes the intruder. He may turn off the raw MTI video to clean up the display and track the intruding aircraft. The operator then provides the station site(s), the intruder's range, azimuth, and apparent course. (The apparent course can be detected by the digitized video track, which maintains seven scans of data on the display.) The operational authorities at JPL or the Goldstone Complex then determine the course of action to be followed.

The operator enters all pertinent data on the operator log sheet, which includes a graphic display for plotting targets. Each operator signs the log sheet each time he comes on shift and enters all intrusions that occur. He also enters any malfunctions and abnormalities observed as they occur on the system (radar, microwave, video processor/target alarm, display and FSW-1).

At periodic intervals, the radar operational channel is changed, and a check is run on the system to determine that it is functioning properly. A minimum discernible signal is injected to determine sensitivity. The FSW-1 is observed to determine that the power level and other parameters are within operating standards.

The alarm gates are determined by the proper operational authorities and are set in by the OSR operator or the radar maintenance personnel. The operator views the display periodically to ensure the presence of digitized target alarm video.

B. EMERGENCY OPERATION

Since in normal operation, the system operates without a full-time operator, loss of only raw radar video is considered a maintenance emergency and not an operational emergency. Only loss of digitized alarm video is classified as an operational emergency.

If digitized alarm video is lost during a critical period, the operator must man the display continuously during that period. This is necessary because no audible alarm sounds if an intruder enters the area to be protected. The operator views the display and manually detects intruders.

Upon a loss of the target alarm video, the operator advises the systems engineer, who instructs the personnel involved to take appropriate maintenance action.

C. OPTIONAL OPERATION FOR EQUIPMENTS

To conserve energy, alternative modes of operating the equipment are possible but not necessarily recommended. Utilization of these optional modes would increase maintenance of the system.

(1) The system could be turned off and operated only when required by operations. This condition would result in maximum energy conservation but would also require maximum maintenance. The operator would turn on the radar system at the FSW-1, placing one channel in preheat. After the warmup period, the operator would turn on the antenna and one radar transmitter, again using the FSW-1. He would then determine whether the target alarm was operational by placing an alarm gate over a target of opportunity. If the target alarm is operational, it is not necessary to turn on the microwave equipment. In this mode, there would be no automatic switchover of radar channels in the event of failure.

(2) Another mode of operation would be with one radar channel in preheat and the other channel shut down. During the required operational period, the antenna and high voltage could be activated by the FSW-1. This would result in less energy conservation but would increase the reliability of one channel of the radar system, placing lower maintenance requirements on the system. As in the previous mode, there would be no automatic channel change.

(3) A third mode of operation (and one that would provide a reasonable compromise) would be to leave both channels of the radar in the preheat condition and the antenna turned off. During an operational requirement, the antenna would be turned on along with the high voltage on one channel. This mode allows automatic channel change and would keep equipment maintenance at a reasonable level.

D. NORMAL TURN-ON/SHUTDOWN PROCEDURE

This procedure assumes that maintenance has configured the system for normal operation and the microwave and radar video processor have been left on.

1. <u>Turn-on (Using FSW-1 Controls)</u>

(1) Energize switch 7 radar power. The green indicator lamp will illuminate.

(2) Energize switch 2 radar-standby channel preheat. The green indicator lamp will illuminate.

(3) Energize switch 11 antenna rotation. Again the green indicator lamp will illuminate.

(4) Check indicator lamps associated with polarization switch 12 to determine whether desired polarization has been selected. Green indicates vertical and red circular polarization.

(5) After 20 min have elapsed, check monitor lamps 21 and 26. One of these should be extinguished.

(6) Apply power to the target processor/alarm display cabinet by turning on the circuit breaker in the right rear top of the cabinet.

2. Shutdown (Using FSW-1 Controls)

(1) Using switch 2, turn on the radar-standby channel preheat and note that the green lamp extinguishes and the red lamp illuminates.

(2) After 15 s, energize switch 1 and initiate a channel change.

(3) Using switch 11, shut off the antenna rotation.

(4) Turn off the target processor/alarm display utilizing the circuit breaker in the right rear of the cabinet.

(5) After 5 min have elapsed, shut off the total power by using switch 7 (radar power); the red indicator lamp will illuminate.

E. OPERATOR CONTROLS

In addition to the previously mentioned FSW-1 controls, the following controls located on the target processor/alarm display cabinet are for operator and/or operational control.

There are three basic groupings of functional controls. One set of controls, used for the display presentation, is located adjacent to the display tube on the right-hand side. One of these adjustments is the intensity control, which is brought out on a knob and adjusts the brightness of the display. This is used as the operator control. All other controls are screwdriver-adjust and are considered maintenance adjustments.

Directly below the display is a panel which contains the majority of the controls used by the operator. These control the functions or video presented on the display and are listed below in sequence from left to right. The letters in Fig. 43 correspond to those on the list.

a. Range gate control -- determines the range covered by the MTI when range gated video is utilized. It controls the gate in 1.6- and 13-km increments.

b. Radar video -- selects the type of radar video (MTI range gate or normal) to be presented on the display.

c. Processor video -- presents the digitized video that is being sent from the radar video processor on the display.

d. Range marks -- turns the range marks on or off.

e. Azimuth strobe -- turns the azimuth strobe on or off.

f. Alarm gate switches -- a series of four switches (one for each alarm gate) which, when in the ON position, outline the gated area for the designated alarm/blank gate.

g. Video -- applies target processor video to the display and is used in conjunction with switches h, i, j, and k.

h. TRK ALM (track alarm) -- displays only targets in the alarm gate when in the TRK ALM position or all targets when in the ALL position.

i. TRK-BOTH-NONTRK -- determines whether only moving targets (TRK), nonmoving targets (NONTRK), or both will be displayed.

j. BOTH-FT-NCT -- determines whether fixed targets (FT), noncorrelated targets (NCT), or both will be displayed.

k. Range switch -- sets the display for either a 60- or a 120-km presentation.

l. NORM VID GAIN -- controls the gain of the normal video presentation.

m. MTI VID GAIN -- controls the gain of the MTI video presentation.

n. PROC VIDEO GAIN -- controls the gain of the radar video processor digitized video.

o. RANGE MARK GAIN -- controls the intensity of the range marks on the display.

p. AZ STROBE GAIN -- controls the intensity of the azimuth strobe on the display.

q. ALARM/BLK GAIN -- controls the intensity of the gate outline.

r. RAPPI VIDEO GAIN -- controls the intensity of the target processor video. (RAPPI videos are the ones on controls h, i, j, and k).

In addition to the controls, there are two light-emitting diode (LED) indicators to show alarms and microwave status. These are lit when there is an alarm or when the microwave is active.

Located above the X-Y display unit are three LED readouts and associated switching. The only switch that is considered an operator control is the switch used to silence the alarm after the operator has gone to the display. Once a target has cleared the gate and there are no other targets in the gate area, the switch should be reset. There is a fail-safe circuit that resets the alarm after all targets have cleared the gate area; however, the operator makes a manual reset.

The LED readouts are operator aids that sequentially display target 1, then targets 2, 3, etc. Each target is assigned a track number of three digits, which are the first three digits of the readout. The next digits give the range, and the final digits the azimuth. As the antenna sweeps, tracks are produced in the alarm gates. These tracks sequentially appear on one of the LED readouts. On subsequent commutations, the same track reappears on the same LED display, with its original track number and any updated range and azimuth information.

The LEDs are also used for maintenance purposes. Only readouts two and three are used for maintenance, and the remaining switches on this panel are associated with the maintenance functions.

On the drawer panel below the display are four rows of switches for each gate. Associated with these rows of switches and on the right side of them is a three-pole switch. This switch turns on the gate for either alarm or blank. There is one switch per gate.

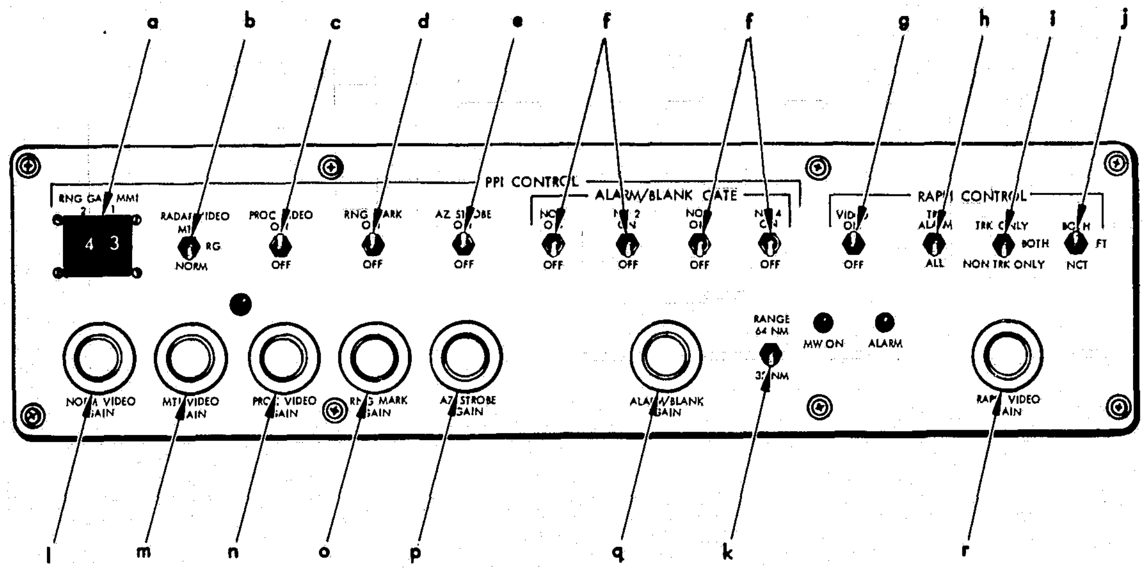


Fig. 43. PPI and RAPPI control panel

XVII. EVALUATION

A. OBJECTIVES OF EVALUATION PERIOD

1. Determination of Intrusion Model

One of the prime unanswered aspects of the problem of overflying aircraft at GDSCC is the quantity and characteristics of aircraft involved. To answer this question, an evaluation period of 90 days was planned during which the radar would be operated in such a way as to collect a wide variety of sample data. These samples would be obtained during all times of day, days of the week, and weekends. Because of manning, budgetary, energy conservation, and maintenance considerations, the equipment was planned to be operated 8 h per day. The resulting data would allow the reconstruction of the equivalent of 3 weeks of continuous coverage. The plan also provided for determining the frequency of aircraft penetration.

2. The OSR as an Adjunct to RFI Observation

There are other areas of concern in addition to the observation of aircraft relative to high-power transmitter beams. Aircraft are known sources of RFI, which can seriously affect the operations at GDSCC. The evaluation also undertook to determine the usability of the OSR to isolate and identify sources of interference reported by operating facilities.

3. The OSR as a Weather Detection Adjunct

The ability of the OSR to identify the impending arrival of significant weather fronts would be very beneficial to GDSCC by allowing early changeover to generator power, preparation for radical temperature changes, and high-wind protection measures to be implemented.

4. Operability, Maintainability, and Reliability

The initial design for Phase 1 of the OSR is the first step toward the development of an automated system. To reach this objective, the evaluation period provided for the accumulation of maintenance and failure data as well as human and equipment interface experience upon which to base future design changes and modifications.

5. Considerations for Future Operation of the OSR

The initial Phase 1 design of the radar system does not incorporate displays and alarms at the other operational facilities. Additionally, only limited methods and procedures for utilizing the information available from the radar were provided. There are many considerations involved in determining the most efficient and effective utilization of the installed system, including

(1) Manpower and training

(2) Energy consumption

(3) Equipment reliability

(4) Information transfer and logging

(5) Required response by transmitting facility

(6) Operability and maintainability

6. Workload Assessment and Level of Effort Required to Support Subsequent Operation

The operations plan to use the Phase 1 design of the radar stipulated that it would be utilized to detect transmitter beam line crossings and to log such activity. An objective of the evaluation period was to determine the level of effort required to support this operational task.

B. EVALUATION DATA AND EXPERIENCE

1. Density Determination

Several data collection and reduction approaches were tried to determine the frequency and density of airplane intrusion, most of which proved to be impractical or too time consuming. Since precise course and speed information was not pertinent, a sample plan was devised and validated that produced information on the number of intruders by quadrant and range.

The radar was operated for a total of 919 h, during which 748 h of valid data were recorded on magnetic tape and 504 h were reduced and correlated. This provided the equivalent of approximately 63 8-h days of observations.

The periods of radar operation for data reduction were chosen as much as possible to include samples of varying conditions, including periods of known high activity. By consolidating these data, the equivalent of 3 weeks of 24-h/day data was accumulated.

The initial data were recorded in tabular form by hour, day, sector, and range. The data were correlated and are presented in Figs. 44 to 49. Because of the large bulk of data involved, only totals and averages are displayed graphically (the tabular data and the analog recordings are available at Goldstone), and only data summaries are presented in this section.

In keeping with the nature of the collected data, Fig. 44 presents the entire evaluation period activity, summarized so that both the magnitude and dispersion of the data are readily apparent in terms of range and quadrant.

Figure 45 is a breakout of the total activity discussed above in terms of cumulative daily totals and cumulative daily averages. Because of the sampling technique utilized, it must be realized that the numbers for an indicated day do not represent one single day of 24 contiguous hours. Each day is a composite reconstruction of samples which do include each hour of the represented day. The numbers are the result of 3 complete weeks of such reconstructed days. Included in these data are a few periods of unusual activity having little influence on the overall average. These exceptions to the norm are identified and discussed below.

Figure 46 depicts average activity in the 56-km radius in terms of range and quadrant. This is the same information presented in Fig. 44 but designed to more clearly portray relative magnitude and dispersion. The consistently high activity in the SE sector is apparent at all ranges. This is the sector in which Fort Irwin is located in the 0-19 km range. The disproportionate activity in this quadrant at the 37-56 km range is attributable to commercial traffic along an FAA air route crossing that area.

Figure 47 illustrates a running comparison of average daily activity by sector. This chart not only points out the more heavily frequented quadrants but shows the cyclical variations by day of week.

Figure 48 summarizes the daily activity presented in Fig. 47 to illustrate average daily activity for the average composite week.

Figure 49 depicts the average hourly activities for the three composite weeks. The average number of aircraft in the area at any time was 18.75.

2. Experience Relative to Use as an RFI Source Detector

A method was established for investigating the capability of the OSR to assist in locating the source of RFI. The technique involved receiving RFI reports from affected stations and monitoring the radar in an attempt to correlate aircraft position with RFI. Unfortunately only three occasions of RFI presented themselves, and the RFI occurred either too briefly for observation or else when the radar was off.

3. Weather Detection Experience

Local Weather Bureau forecasts and observations were relied upon to identify opportunities for investigating the usefulness of the OSR for weather applications. This was necessary because of the lack of full-time operators and the fact that there is no alarm capability designed in the OSR which will alert personnel to a changing weather condition.

During the evaluation period, only two weather systems occurred which could be studied. It was learned that

(1) The OSR, when operating in the raw video PPI mode, produces excellent images of weather fronts and their movements to the full extent of its 100-km range.

(2) The OSR also produces easily identified electrical storm activity while operating in the digital display mode. Sudden electrical

discharges cause the generation of numerous false tracks radiating in all directions from the origin of the storm.

4. Operability, Reliability, and Maintainability

a. Operability. The design of the FPS-18 was predicated upon continuous operation and an unattended installation site. Operation is primarily by remote control, except for main power shutdown, etc.

Once the OSR is activated, the operation of the system is relatively simple and can be accomplished by personnel assigned to the communications unit, which is maintained on a 24-h per day basis.

Operation consists of monitoring the functional indicators for the system, selecting standby modes, selecting backup and redundant modes, and resetting alarms. On occasion, the system may require reactivation after a power failure.

The microwave link is capable of being operated entirely by the communications personnel and normally requires no adjustment except for channel and redundant link selection.

The equipment was operated satisfactorily in all respects by the assigned radar technicians, with monitoring provided by communications technicians.

b. Reliability. The JPL functional requirement specifies at least 600 h of normal operation for each channel without functional failure. The equipment could not be evaluated against this criterion because of energy conservation, manpower, and other constraints externally imposed on the evaluation period plan. The following information, however, was extracted from the operational logs:

(1) FPS-18: Approximately 1200 fully operational hours were accrued. Since these hours were not continuous, conventional reliability formulas are not applicable; however, it is significant that there were no more than 26 downtime failures. Of these, only two were of any considerable length.

(2) Video processor unit: There were no failures recorded on this unit.

(3) FSW-1: This unit was operated continuously and experienced 13 downtime failures.

(4) MRR-4 Microwave Link: Path alignment problems with the microwave link prevented initial operation of this unit. After resolution of the problem, the equipment was operated continuously for approximately 1200 h with only one failure.

(5) Target Processor, Alarm, and Display: This equipment was operated in excess of 600 h and experienced three failures, of which one involved downtime.

c. Maintainability. OSR specifications included the following maintainability requirements:

(1) Built-in diagnostic capability.

(2) No station-level maintenance action to require more than two trained personnel to restore operation within 15 min.

(3) Off-line maintenance of redundant channel.

(4) Heavy and nonremovable item failures to be restored in less than 6 h.

The following is a recap of failures experienced and the time required to restore them with the system:

(1) FPS-18: The 26 failures experienced required 56 manhours to correct. This establishes a mean time to restore (MTTR) of 2.15 h. In addition, 136 manhours of preventive maintenance were required.

(2) Video processor unit: No failures occurred; therefore, the MTTR for this unit is indeterminate at this time.

(3) FSW-1: This unit required a total of 44 manhours to restore the 13 failures experienced. This indicates a MTTR of 3.38 h. Thirteen hours of preventive maintenance were expended.

(4) MRR-4: The one failure experienced on this unit since May 12, 1976, required 3 h to correct, which produces a MTTR of 3.0 h.

(5) Target processor, alarm, and display: Three failures occurred, requiring the expenditure of 4 manhours, for a MTTR of 1.33 h; 7.5 manhours were expended on preventive maintenance.

During the evaluation, a total of 43 failures occurred, which consumed 104 maintenance manhours. This yields a system MTTR of 2.48 h. A total of 156.5 preventive maintenance manhours were expended.

Based on the 1200 operational hours logged on the system, and without considering redundancy factors or partial system utilization, the indicated approximate mean time between failures (MTBF) is 28.57 h. The individual subsystems had the maintenance parameters shown in Table 16.

There were no restorative actions which could be accomplished within the specified 15 min either at the FPS-18 site or at the remote operator position. Only two failures could not be restored within the specified 6 h: the FPS-18/heater thermostat, which took 6.5 h and the FSW-1/tone transmitter and receiver, which required 8.0 h.

5. Workload Experience

During the manual phase of the OSR operation, it was borne out that the assigned maintenance crew can provide the required sustaining effort to ensure that the system hardware is operable in its present configuration.

The major workload associated with the system was the monitoring and interpretation of displayed information. The system was designed to produce alarms only when radar gates were penetrated. This would have required infrequent attention by an operator.

In practice, the high density of aircraft caused the system to remain in a constant alarm condition even when operated for very short periods. This unanticipated workload could not be accomplished with the manpower provided.

The data collection required for this evaluation was possible only through magnetic recording of real-time data and a subsequent time-consuming, off-line reduction effort.

C. ASSESSMENT OF EVALUATION RESULTS

1. Pertinent Aspects of the Data

Figure 50 depicts the overall density and distribution of all aircraft having overflown the 56-km radius about Goldstone. The data represented clearly identify the distribution and dispersion of the GDSCC aircraft population. An overlay is provided which relates this activity to the facilities and known areas of high activity such as aircraft target ranges, civil airways, and military tactical areas.

The SE sector contains the greatest activity, the brunt of which falls into the 37-56 km range and is easily explained by the dense commercial traffic traveling major air routes which cross that zone.

The NE sector reflects an above average activity compared to the NW and SW sectors, and this increased activity has been identified through military channels as being associated with a bombing range (Leech Lake) located in that area. Closer examination of the traffic concentration there confirms the predominance of activity over and around the lake. The most significant aspect of these data is the gross variation between the anticipated one or two aircraft per day and the observed number ranging in the hundreds.

Analysis of weekly composite data using cumulative techniques shows that if the apparently unusual intruders of July 4 are included in the data, (see Fig. 51), the maximum variation is 7%; if July 4 data are excluded, the maximum variation is 3%. This tends to indicate that there are 6 days (Monday through Saturday) of reasonable consistency of number of intruders per day of the week and that the higher Sunday average is simply a perturbation caused by heavy holiday activity, which closer examination of sector activity confirms to have occurred in and about Fort Irwin.

Another peak activity occurred in the Fort Irwin area on a Friday. This anomaly was correlated with scheduled activities of the National Guard 49th Aviation Air Wing of the 40th Armored Division. Approximately 40 aircraft were estimated to be involved (see Fig. 52.).

A third period of high activity was noted in the composite weekly data depicted in Fig. 53 and was correlated with the arrival of the 18th Air Cavalry for maneuvers at Fort Irwin.

2. Geographic, Technical, and Operational Aspects

A basic problem in selecting the FPS-18 site involved the avoidance of interference with the GDSCC operational antennas. The same criteria which allowed minimization of this interference created a problem of considerable terrain obstruction. Many of the military aircraft using the range facilities in the area are actually engaged in missions which are designed to avoid radar detection through such techniques as very-low-altitude terrain following guidance radar systems. The probability of detecting such sophisticated targets is questionable.

The equipment, as presently located, functions in much the same manner as a gap filler, and the cosecant beam pattern is not ideally suited for long-range detection. The digital processing and display devices are not designed to provide continuous track data in the case of frequently interrupted targets when aircraft fly near masking terrain features.

GDSCC is situated within the boundaries of a restricted airspace. This restriction is established primarily so that the several military installations nearby can use the airspace for military operations. These operations have proved to be extensive.

3. Known Activities in the Area

a. Leech Lake. Activity consists of military operations from George Air Force Base (AFB). Typical missions are dive bombing and low-level gunnery runs. There are usually five or six aircraft involved at any one time.

Aircraft approach the area via Lost Lake, Owl Lake, and from east of Ft. Irwin. These approaches were chosen on the basis of previously distributed schedule information as to the GDSCC high-power transmitter operations. The aircraft approach at low altitudes to avoid the transmission elevation angles and also utilize available terrain shadowing for the same purpose.

Approximately two flights per day consisting of six aircraft each are involved. This activity takes place on a year-round basis, and the activity duration is approximately 1 to 1-1/2 h per day.

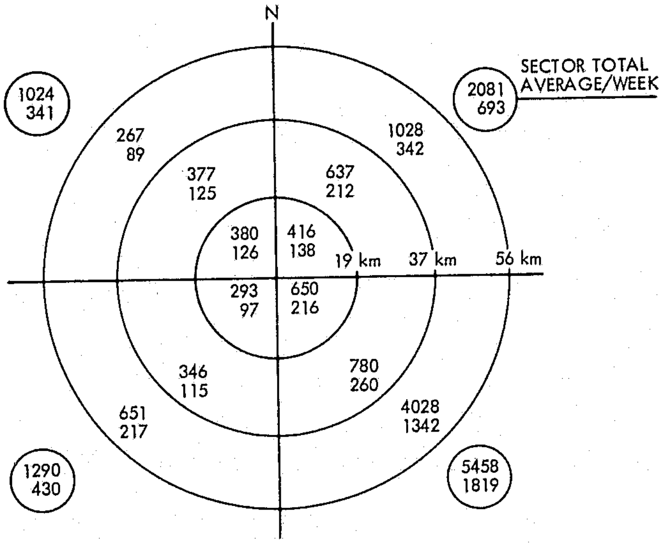
b. Cuddeback Range. George AFB also utilizes this range. Activity consists of approximately 1500 daytime missions per year and 125 nighttime missions. The missions usually consist of four aircraft.

c. Echo Range. Echo is located in the NW sector and is currently utilized infrequently by both Edwards AFB and the Naval Weapons Training Center. Information from Navy sources indicates that activity in this area will increase.

d. Fort Irwin. Army operations in this area vary widely and are not predictable; however, activity is usually associated with the weekends, during which most maneuvers are scheduled. The typical aircraft employed are scout and observation craft as well as numerous helicopters. Most of this traffic is low-level and occurs in sectors having the most severe terrain obscura.

Table 16. Maintenance data summary

Subsystem	Failures	Failure rate/hour	Restoration hours	Restoration rate/hour	MTBF	MTTR
FPS-18	26	0.02	56	0.47	21.43	2.15
Video processor	0	0	0	N/A	N/A	N/A
FSW-1	13	0.01	44	0.30	92.31	3.38
MRR-4	1	0.0008	3	0.33	1200	3.00
Target processor	3	0.0033	4	0.75	300	1.33



TOTALS AND AVERAGES/WEEK BY RANGE						
RANGE, km	NE	SE	SW	NW	TOTAL	AVG
0-19	416	650	293	380	1739	434
19-37	637	780	346	377	2140	535
37-56	1028	4028	651	267	5974	1493

Fig. 44. Summary of total and average weekly aircraft activity during 3 reconstructed weeks

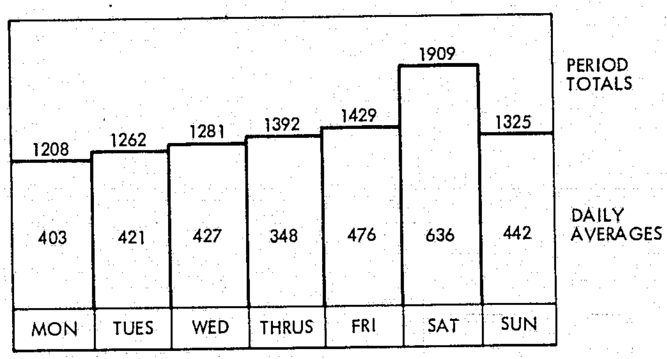


Fig. 45. Summary of total and average daily aircraft activity during 3 reconstructed weeks

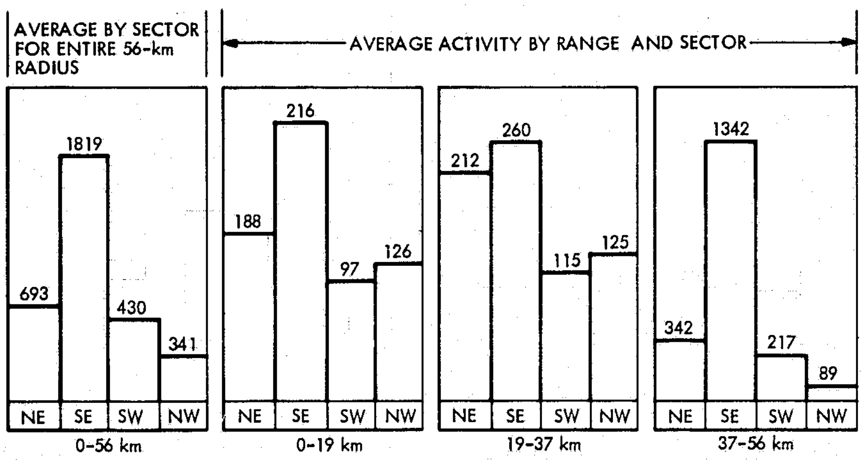


Fig. 46. Aircraft activity by sector and range during 3 reconstructed weeks

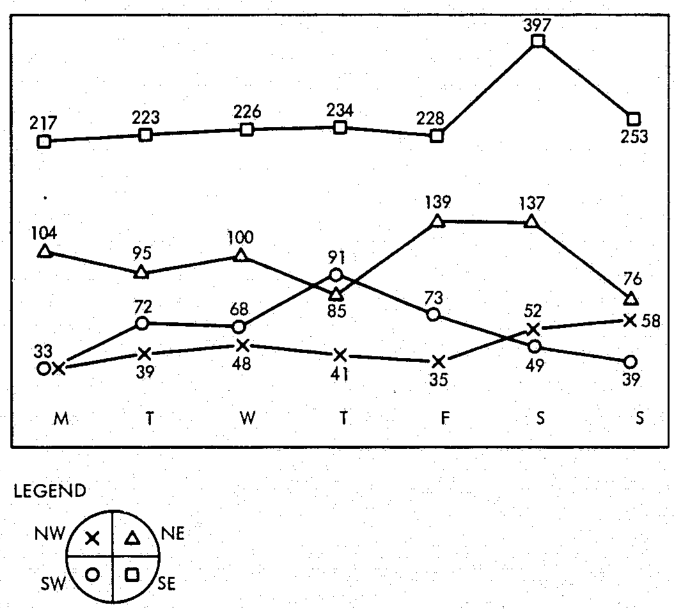


Fig. 47. Comparison of average daily aircraft activity by sector and day for average composite week

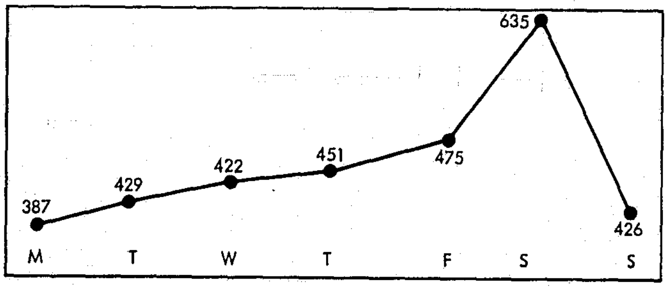


Fig. 48. Average of all sector aircraft activity for average composite week

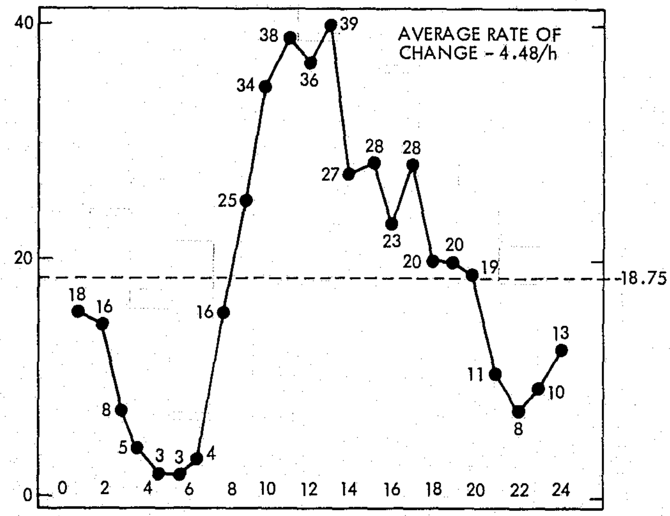


Fig. 49. Average hourly aircraft activity for 3 composite weeks

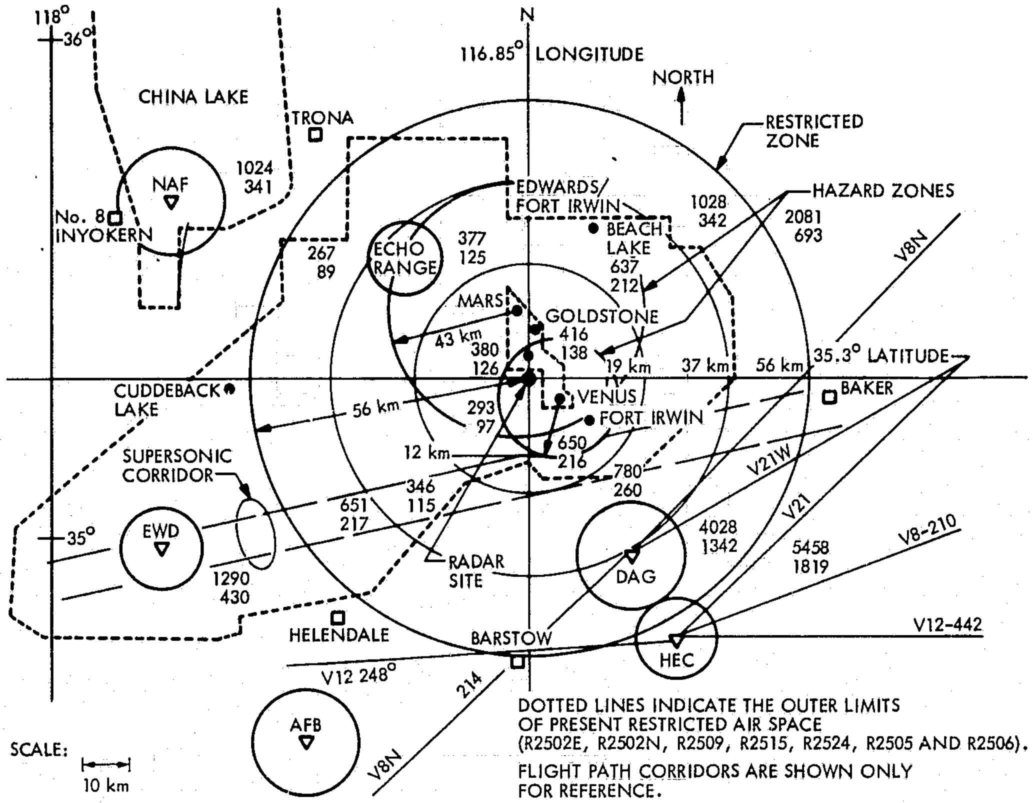


Fig. 50. Plot plan of restricted zone and facilities and sources of air traffic

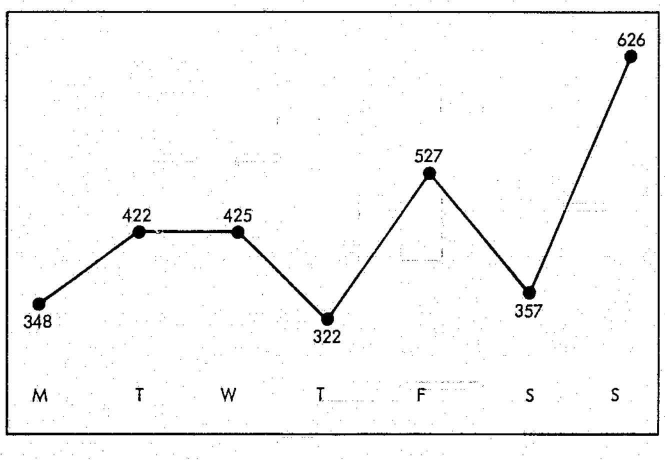


Fig. 51. Composite week, including July 4 holiday, SE sector

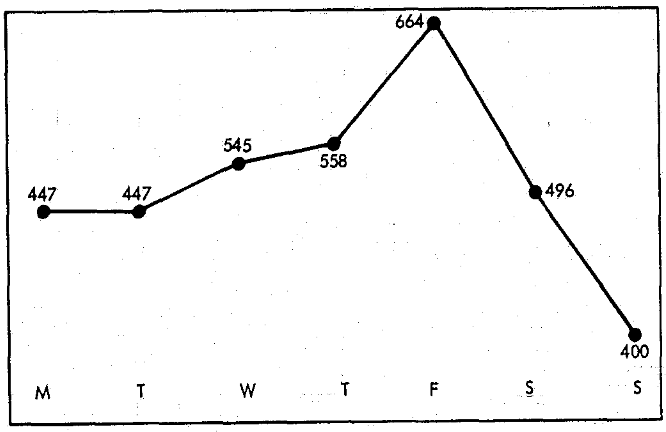


Fig. 52. Composite week, including National Guard activity at Ft. Irwin, SE sector

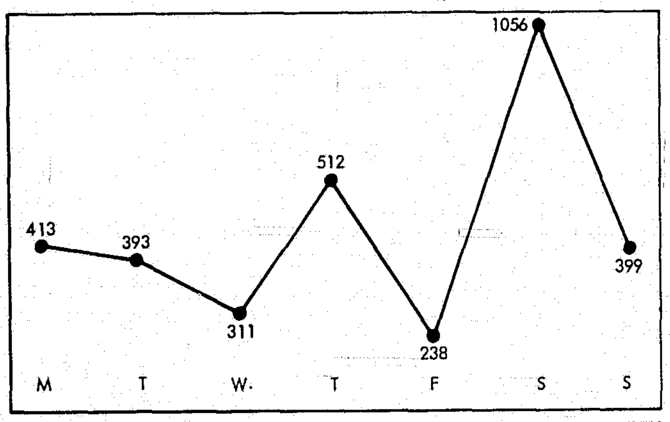


Fig. 53. Composite week, including 18th Air Cavalry maneuvers, SE sector

XVIII. CONCLUSION

The radar system and its related equipment have undergone a 90-day evaluation period by the Goldstone operations personnel. This evaluation was conducted for an 8-h period each day. Such items as system reliability, best tradeoff of range and clutter versus antenna elevation angle, potential RFI, and PPI scope areas to be blocked from the alarm system because of established airways and airports within the radar's range were studied. Additionally, an operations philosophy was developed to relate aircraft intrusions to the restricted area with high-power transmitter operations and reports of RFI to spacecraft signals.

A. PHASE 2 RECOMMENDATIONS

As the system evolved, it became clear that the Phase 1 concept was a little too primitive to meet the requirements from an operation viewpoint. Thus, the system as delivered is close to being Phase 1-1/2 to 1-3/4. There are however, certain items that should be considered for Phase 2.

1. Height Capability

Many of the large number of airline and military aircraft appearing as targets on the display are at an altitude that places them in a safe area. However, the operator has no way of determining this. He has only azimuth and range information on which to base a decision.

There is a feed and a receiver that Bendix believes could be incorporated into the FPS-18 which would provide relative height information. This modification would not present absolute but relative height in the area of ± 300 m. Preliminary calculations indicate that an aircraft flying at 15,000 m at 90 km would have a probable error of 160 m. When the consideration of the cost of a larger building, a height finder radar, and additional maintenance are added to the mission costs, it would appear that relative height would be acceptable and certainly less expensive. The height information would be taken into account by the alarm system. This would further reduce the number of alarms that require an operator's decision. The equipment required would be an additional or new feed horn, a rotary coupler receiver, and processor logic.

2. Remote Display

The information is presently fed only to the Echo site. Here a part-time operator interprets the alarm and passes the information via phone to the interested parties. No visual observation is available for the end user, and he must base his decision on a verbal description. The original design took into consideration the possible expansion and remoting of information to other units. Based on the number of intrusions presently beng observed, it appears that Phase 2 should incorporate remote displays at the user location. This would require additional X-Y displays, cabinets, and associated circuitry, as well as one alarm gate per remote which the site would set. The feed to the remote sites would be via phone lines; there would be no microwave video.

In addition, the remote displays should be modified to offset the video presentation. This means that the video displayed at the Mars station should be such that the center of the display is the Mars antenna location. (At present, the remote radar is the center of the display.) The same should be true for the Venus station and any others that may have remote displays.

3. Addition of Temporary Track Memory

The system as designed declares a track when there is a target return for two consecutive scans of the antenna. This allows a large number of false starts, particularly close in, where ground clutter breakthrough is prevalent. A temporary track memory would store this information, but it would not be shown on the track counter LEDs or alarm the system. After a preset number of consecutive radar returns are received, the information would be moved to track memory and be displayed on the LED and the alarm assembly. This would assist the operator inasmuch as he would not be getting as many false alerts and the LED readouts would more realistically indicate the number of tracks for the period. It would also help ensure that the track memory does not become overloaded, particularly during periods of inversion and/or "angel" activity. This modification requires only a logic change and no increase in memory.

4. Electronic Regulator Modification

The FPS-18 was modified to eliminate the rotary regulators because of their high power consumption. In their place are three single-phase 15-kW electronic regulators which can be utilized during periods of excessive voltage fluctuation. At present, these have to be "hard-wired" in and out of the system. They should be on a switching arrangement which allows them to be switched in and out of the system. For energy conservation, the regulators are normally not used in the system.

In addition to an arrangement for switching the units on and off line, there should also be a sensing circuit to cut off the system in case of an input line phase failure. This sensing circuit should be a two-step circuit. During the periods in which the system is operating on only the input line (regulators out of the circuit), the sensing would monitor only the input power.

During periods when the regulators are on line, the sensing circuit would monitor the output of the regulators. In case of a failure, the sensing circuit would automatically switch the regulators off line and return to sensing the input line.

5. Automatic Reset of Radar Video Processor

The radar video processor is located at the remote radar site. It is protected against overloads and surges. However, should it trip as a result of a surge or overload, it must now be reset manually. This entails sending a person to the remote site. The unit should either be modified to automatically attempt to reset itself three times, or the reset should be remoted to the operations site. This could be accomplished by circuit modification and utilization of one of the spare FSW-1 channels.

6. Light Pen

The light pen is an operator aid in the form of a hand-held unit that can be placed on the face of the display over a target being displayed. The pen, in turn, is connected to an automatic readout circuit which displays the range and azimuth of any target of interest under the pen on an alphanumeric display. That information can be held as long as the operator desires. This would ease the workload on the operator and remove more of the margin for error.

7. Automatic Recording

To aid in maintenance and operator training, the system presently has the capability of making a cassette recording of the information being displayed on the X-Y plotter. This capability should be upgraded to a more sophisticated system which would allow for longer recording periods, with time and date superimposed on the tape. (The present system has a maximum 1-h capacity per tape.) Coinciding with this, the time and date should be displayed on the X-Y display during all periods of operation, making the information available in one place for manual operations.

8. Increased Tower Height

During the Phase 1 planning, a radar site and tower height were selected. There were several restrictions placed on the siting. Basically, it had to be accessible for a road and power, and had to be masked from the tracking station. After a considerable amount of surveying by JPL personnel, the present site was obtained. With the restriction placed upon the siting of the system, the choice appears to be the best available. There is however, a large amount of screening which limits pickup of very low-flying aircraft, as is evident from the ground clutter returns. Consideration should be given to increasing the tower height. However, prior to actually increasing the tower height, a thorough study should be made to determine the exact amount of screening and its effect on the areas of interest. From this study, the tower height extension required can be determined.

An area of considerable concern was the Apollo "col tower." The concern was that illumination of the tower would affect its remote control capabilities. There are presently no data to substantiate or to disprove this concern. This is another area that would have to be studied prior to increasing the height of the tower.

B. PHASE 3 (FULL AUTOMATION)

In the future, as the population of civil aircraft and the space network increase, the system may have to be fully automated. The original design took this possibility into consideration as much as was practical. Hardware is costly, and to design without the ability to expand is not cost-effective. However, judgment must be exercised, or an overdesign situation can arise. Bendix feels that the design of the unit allows going to full automation with a reasonable amount of modification and that the equipment will not be obsolete and unusable for this phase.

Some of the items that should be considered in the full automation phase follow (assuming Phase 2 implementation).

(1) The alarm gates should be configured in a manner that would allow automatic shutdown of the high-power systems. However, shutdown should not happen without prior warning. An operator should first be alerted to allow a human decision to be made. It is conceivable that the importance of the mission, the speed of the aircraft, and its position may be such that a shutdown should be averted. The operator would have a control that would override an automatic shutdown.

(2) The X-Y display is capable of displaying alphanumerics. There is a considerable amount of area on the display where these could be displayed. Consideration should be given to displaying targets in the gate area on the screen of the display. The information could be obtained from the memory. This could be the track number, current range and azimuth, and previous range and azimuth, with up to six previous antenna scans being displayed. The information would be selectable by an alarm gate and the number of scans. Selection would be necessary during periods of heavy air traffic.

(3) The target processor has four alarm/blank gates that are utilized to place a warning zone around the site or sites of concern. At present, the gates are manually set and encompass a large area. This is necessary to provide protection in all areas to which the uplink beam could be steered, so that if the beam is steered toward the east, the area to the west is also covered by the gate. The alarm/blank gates should be integrated to the upbeam antenna system. As the uplink antenna moves, the gate would automatically shift to provide the necessary coverage. This would keep the alarm area down to a minimum size, and less operator time would be required because of a lower number of probable alerts.

(4) During critical missions, it is conceivable that program management or upper management at the Pasadena facility would require real-time information. This would become very important if a decision had to be made concerning the shutdown of the uplink transmitter during the mission. The necessary information could be presented on a remoted X-Y video display or in the form of a hard copy giving azimuth, range, and any other desirable data. The display or hard copies would be located in a central area that could be utilized by the interested parties. Transmission from Goldstone to Pasadena would be via telephone circuitry.

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