Mojave Base Station Implementation

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A 12.2 meter (40 ft.) diameter X–Y mount antenna has been reconditioned for use by the Crustal Dynamics Project as a fixed base station. System capabilities and characteristics are presented, as well as key performance parameters for subsystems. The implementation is complete and transfer to National Geodetic Survey/National Oceanic and Atmospheric Administration (NGS/NOAA) is under way.

I. Introduction

Since the late 1960's, NASA has been using space technology to develop new methods for making geodetic measurements over large areas with high precision, high mobility, and minimum observation time. One of these technologies is microwave Very Long Baseline Interferometry (VLBI), which uses extragalactic radio sources (quasars) as measurement reference points (Ref. 1).

VLBI is used by NASA's Deep Space Network in the navigation of interplanetary spacecraft (Ref. 2). Its application to mobile geodetic systems is being accomplished with the collaboration of the radio astronomy community.

A VLBI geodetic system consists of a pair of radio telescopes at separate locations. Quasars emit large amounts of intense microwave radiation. The two stations simultaneously receive and record these random quasar signals, which arrive slightly sooner at one of the antennas, depending on which station is closer to the radio wave front. By using ultraprecise atomic clocks, it is possible to measure the slight difference in the signal arrival times. The time difference and the pointing angles of the two antennas are used geometrically to determine the baseline distance between the two stations (Ref. 3).

If one of the stations is mobile, it can be positioned on the opposite side of an earthquake fault from a fixed station, and measurements can be made over a period of time. Such measurements can determine changes in the baseline in all three dimensions (longitude, latitude, and elevation) with subdecimeter precision (Ref. 4).

The Mojave Base Station is the newest fixed station to join the network of fixed and mobile antennas. The 12.2 meter X–Y mount antenna was built in 1962 to support the Relay I communication satellite. The facility, operated by the Goddard Space Flight Center (GSFC), along with 7 other X–Y type meter antennas located around the globe, formed the Data Acquisition Facility Network. These stations were a prototype of modern satellite "earth stations." In 1976, after program completion, the station was placed in standby status by GSFC.

As early as 1978, JPL recognized the need for a dedicated VLBI base station facility at Goldstone. The Venus station had served as the original base station, but many other commitments of the station caused serious schedule conflicts with the Crustal Dynamics Project (CDP) requirements. An agreement was reached within NASA which provided for transfer of the 12.2 meter antenna and the 12,000 square foot control building to the CDP.

II. System Requirements

A study team of JPL and GSFC engineers was formed to establish system requirements. See Table 1 for key system requirements. See Fig. 1 for a Mojave Base Station detail block diagram.

III. Implementation Plan

The Bendix Field Engineering Corporation (BFEC) of Columbia, MD, was contracted to plan and carry out the rehabilitation of the antenna and the control building. A detailed study was completed in December 1980 which called for sandblasting and painting the antenna and modifying and repainting a portion of the control building. The antenna work included stripping old cables and equipment from the antenna and removing the hydraulic subsystem which was no longer required. The antenna RF cassegrain housing was also removed.

The design of the antenna dish surface does not allow for alignment of the surface tolerance, but the surface accuracy was measured at ±0.020 inches RMS as set by the original manufacturer.

Antenna bearings and gears were inspected and lubricated. The orthogonality of the X and Y axes was checked. The alignment of the X axis, parallel to the North–South meridian, was found to be in error by 30 arc minutes. It was determined that this error could be accommodated by the antenna pointing software. Therefore, no attempt was made to realign the X axis.

Implementation of antenna electronic equipment began in November 1982 and continued into the Spring of 1983.

The Receiver RF feed focus assembly was installed, the antenna electric drive servo motors and electronics were installed and the antenna position encoder assemblies were installed along with antenna position limit hardware. All associated cables were installed on the antenna and between the antenna and control room.

After completion of rehabilitation of the control building in December 1982, the installation of electronic equipment racks began. The antenna controller, Hydrogen Maser frequency standard, Mark III data acquisition terminal, and Hewlett-Packard 1000 computer were installed and cabled.

IV. Control Building Rehabilitation

The main control building, M-8, on the Mojave Site was selected as the building to house the electronic equipment for the VLBI system. The building had been vacant or used for storage since 1976, when it was last used to support the ATS-6 satellite. Aside from dirt which had collected over the ensuing 6 years, the building was in good condition. The fire protection system had been maintained regularly, the air-conditioning was operable and plumbing was functional.

Modifications to the air-conditioning were contracted to a local vendor. Air ducts to unused areas were blocked and a bypass was installed to reduce the air flow through the system. These changes were made to reduce energy usage. The system was balanced and tested: temperature varies ±3 degrees F over a 24 hour period. The electric power distribution system was modified to meet the system requirements. Power meters were added to monitor the utility, technical and antenna buses. All rehabilitation work was completed by February 1983 and the building was occupied at that time.

V. Electronic Equipment

The electronic equipment for the VLBI system was provided by GSFC. Several commercial vendors and Haystack Radio Observatory were responsible for the fabrication of various subsystems. The equipment was installed by a team of JPL, contractor, and GSFC personnel.

A. Microwave and Receiver

The Microwave and Receiver Assemblies, along with the phase calibration equipment, are located in a single housing and mounted on the Quadripod Structure of the antenna parabolic dish. The Monitor and Control Assembly monitors microwave and receiver functions and controls operation. Key characteristics of the Microwave and Receiver Assembly are shown in Table 2.

B. Data Acquisition Terminal

The Mark III VLBI Data Acquisition Terminal (DAT) is an integrated computer-controlled electronics/recording system which takes a broadband analog I.F. signal, converts selected frequency windows to video (baseband), separately clips, samples and formats each video signal, and records the resulting time-tagged Mark III serial data streams in parallel on magnetic tape. The DAT includes the control computer and necessary communication systems for complete computer control. Phase and cable calibration, data storage, tape read after write and reference frequency distribution facilities are included in the DAT. See Reference 5 for a detailed explanation of the Mark III DAT.

C. Frequency and Timing

A Hydrogen Maser frequency standard and clock assembly have been manufactured by the Applied Physics Laboratory of Johns Hopkins University in Baltimore, Maryland. The maser, Serial No. NR-7, embodies the latest technology. Frequency stability requirements are $<1 \times 10^{-14}$ parts for time periods >1 minute up to 1 day (24 hours).[1] The temperature environment of the unit is required to be stable within ±3 degrees F. Measurement of the clock offset to a known standard such as NBS is accomplished by the Goldstone Mobile timing standard. The Hydrogen Maser subsystem supplies 5 MHz and 1 pps signals to other subsystems.

D. Monitor and Control

The Monitor and Control Subsystem (MCS) consists of the HP-1000 computer and software. The RS-232 and IEEE-488 communications interfaces provide a central control point for station operation and the display of all station status and alarm messages. The monitor and control subsystem performs the following functions:

(1) Provides a central control point for the station

(2) Provides schedule input via floppy disk

(3) Prepares the ancillary data record

(4) Provides operator input–output and command via CRT terminal

(5) Generates antenna pointing commands

(6) Monitors subsystem performance

E. Water Vapor Radiometer

The Water Vapor Radiometer provides the sky apparent brightness temperature, which is used to calibrate delays due to water vapor content along the ray path from the radio source to the receiver. A thorough discussion of Water Vapor Radiometer requirements is provided in Reference 4.

F. Antenna Pointing Control and Drive

The antenna pointing subsystem is comprised of several units mounted in various locations throughout the antenna structure and control room.

[1]Chiu, M., personal communication, January 1983.

1. Antenna Control Unit (ACU). The central assembly of the subsystem is the ACU which houses all the electronics to generate motor drive commands in all modes of operation. Motor commands are produced by the ACU as a result of input commands from the front panel rate controls (manual mode), the internal tracking routines (tracking mode), or the position commands (position designate and manual modes). The closed loop output of the ACU is a low voltage analog signal proportional to the antenna position error for each axis. The X and Y axis motor controllers provide the interface between the command output of the antenna control unit and the high current requirements of the antenna drive electric motors.

2. Antenna interlocks. Antenna protection and personnel safety are accomplished by the use of travel limiting switches and safety interlocks located at critical positions throughout the antenna.

3. Angular Position Unit (APU). The angular position of the antenna is reported by the use of optical position encoder–transducers mounted on each axis and an interface–decoder within the ACU. The transducer outputs Gray code which the ACU converts into binary digits. The binary position information is used in all tracking modes.

Table 3 provides key characteristics of the Antenna Control Subsystem.

G. Meteorology Data

The Meteorology Data Subsystem (MDS) provides data which aids in the analysis of VLBI data. The atmospheric conditions at a VLBI station present a source of error in measurements which can be removed in final data processing.

Functions of the Meteorology Data Subsystem are to:

(1) Measure outside air temperature.

(2) Measure atmospheric pressure.

(3) Measure relative humidity.

(4) Record meteorology parameters on the MCS.

Table 4 presents the key characteristics of the MDS.

VI. System Tests

After installation of equipment and initial power-up tests, system tests were performed to verify system operation. Tests were performed in the following functional areas:

(1) Receiver–Mark III Terminal Checkout

(2) Antenna Pointing Tests

(3) S- and X-band Performance Tests

A. Receiver and Mark III Terminal

Except for initial cool-down problems with the cryogenically cooled GaAs–FET Low Noise Amplifiers, receiver tests were completed without trouble. Compatibility of the receiver unit which was fabricated at Haystack Radio Observatory and the air-cooler unit fabricated by a local vendor in Barstow, was a challenge. After minor difficulties, the unit operated and temperature tests indicated proper operation was obtained. Performance results are shown in Table 2.

B. Determination of Pointing Corrections

An antenna must be accurately pointed at quasi-stellar radio noise sources for successful VLBI experiments. Most pointing errors are caused by imperfections of the mechanical structure of the antenna and mounting of the RF feed assembly.

D. B. Shaffer[2] of Interferometrics, Inc., provided a methodology for determining pointing corrections. The procedure describes some of the considerations for good pointing determinations, contains a list of the best sources to be used for pointing observations and gives some suggested observing plans. Pointing accuracy of the 12.2 meter antenna was determined by Shaffer to be .02 degrees at X-band. Performance results are shown in Table 3.

C. S- and X-Band Performance

During June 1983 RF performance of the 12.2 meter (40 foot) antenna was determined. Aperture efficiency and system temperature were measured by tracking radio star noise sources (see Table 5). Observations were performed with two different front-end configurations: one configuration included uncooled amplifiers, while the other configuration used cooled GaAs–FET amplifiers.[3]

[2]Shaffer, D. B., personal communication, September 1983.

VII. Activities

The Mojave Base Station (MBS) began VLBI observations in support of the Crustal Dynamics Project in June of 1983 and since then has participated in each observation session with the mobile vehicle antennas. The MBS has participated in several other special observations including the first baseline measurements between the VLBI station at Kashima, Japan and the U.S.

The original NASA Crustal Dynamics Project plan called for NASA to transfer a dedicated base station to the National Geodetic Survey/NOAA Branch of the Department of Commerce. The transfer of the Mojave Base Station will take place in 1984. GSFC is responsible for the transfer, but JPL has the task of operating the facility until transfer and of assisting GSFC with the transfer. Actual station operation is performed by Bendix Field Engineering Corporation personnel.

The Mobile Vehicle (MV) stations will also be transferred to NOAA as planned beginning in 1984 with the transfer of the 5-meter MV-3 antenna and electronic trailer van. The 4-meter (MV-2) and 9-meter (MV-1) facilities will be transferred in 1985. MV 2 and 3 will be located and operated out of the Mojave Base Station. MV-1 is permanently located at Vandenberg Air Force Base.

A depot level maintenance facility has been located at the Mojave Base Station to support the MV's and to perform special engineering and testing functions.

[3]Shaffer, D. B., personal communication, August 1983.

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Table 1. Key system requirements

Simultaneous Reception Bands:	8180–8580 MHz 2235–2335 MHz
Polarization:	RCP Both Bands
Operating System Temperature:	150°K max. (X-band) 100°K max. (S-band)
System Instantaneous Bandwidth (1 dB):	400 MHz (X-band) 100 MHz (S-band)
IF Frequency:	100–500 MHz (X-band) 215–315 MHz (S-band)
Signal Cable Calibration:	Measure Delay to 10 pico sec.
Data Acquisition Terminal:	Mark III Compatible
Data Record Rate:	112 MB/s
Channels:	28
Antenna Blind Point Accuracy:	0.1 Antenna Beamwidth at X-band
Antenna Slew Rate:	1.0 degree/sec.
Frequency Standard:	Hydrogen Maser
Water Vapor Radiometer:	2 Frequencies
Meteorology:	Measure Temperature, Humidity and Barometric Pressure

Table 2. Microwave and receiver key characteristics

Input Frequencies:	X-band 8180–8580 MHz (–1 dB) S-band 2210–2350 MHz (–1 dB)
Aperture Efficiency:	⩾ .45 X-band ⩾ .47 S-band
Antenna Beamwidth:	.205 degrees, X-band .745 degrees, S-band
System Temperature: (at Zenith)	60°K X-band (Cooled FET) 72°K S-band (Cooled FET)
Intermediate Frequency: Bandwidth	X-band 400 MHz Wide at –1 dB S-band 140 MHz Wide at –1 dB
Phase Calibration Input:	–30 dB coupler

Table 3. Antenna pointing control key characteristics

Prime Mover:	Electric Drive Motors, 2.5 Horsepower, 2 Per Axis
Elevator Limits:	>80° from Zenith in all Directions
Maximum Velocity:	1.0 degrees/second Both Axes
Pointing Accuracy:	0.02 degrees Both Axes
Angle Readout:	
Accuracy	0.01 degrees Both Axes
Resolution	0.00275 degrees Both Axes

Table 4. Key characteristics of the Meteorology Data Subsystem

Measure:	
1. Temperature	1°C
2. Relative Humidity	5%
3. Barometric Pressure	⩽ 1 millibar
Readout Resolution	0.1 millibar
Measurement Accuracy at Sea Level	.01%

Table 5. Aperture efficiency and system temperature

	Cooled FET Tsys °K	Aperture Efficiency
S-band	72	.47
X-band	60	.45

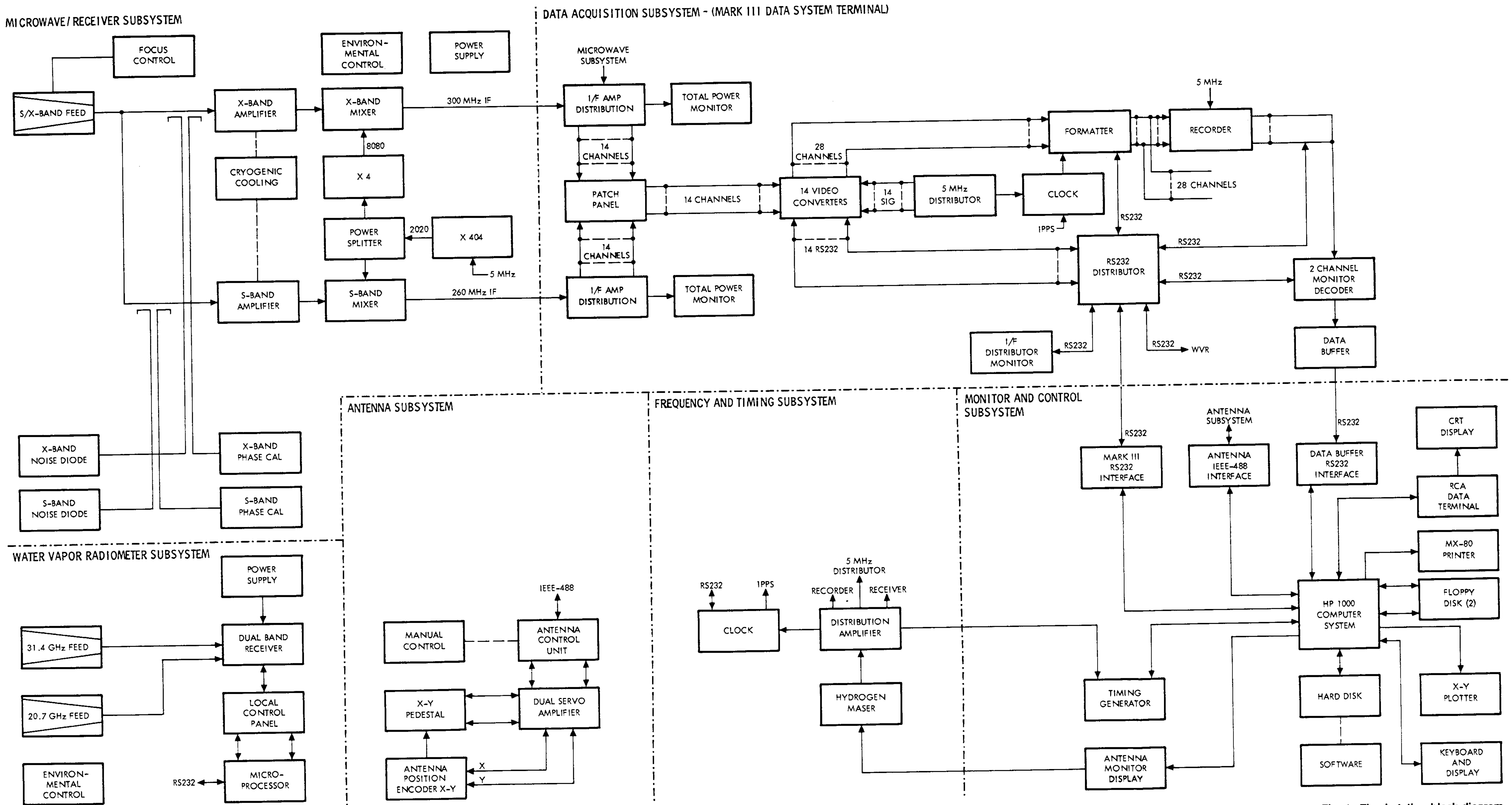

Fig. 1. Fixed station block diagram